REPORT

Tonkin+Taylor

Moutere Catchment

Stream Restoration Framework

Prepared for
Tasman District Council

Prepared by
Tonkin & Taylor Ltd

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1 Introduction

Tasman District Council (TDC) engaged Tonkin & Taylor Ltd (T+T) to develop a restoration framework for the Moutere Catchment. The purpose of the restoration framework is to align river management, ecological and community objectives for stream management/enhancement. A key restoration focus is on the assessment of bed and bank stability as well as contributing to ecological function of the catchment, without compromising drainage and flood protection functions.

The scope of the restoration framework included:

- High-level classification of all waterways in the Moutere catchment, using up to ten 'stream types' that have different restoration or management requirements (Refer Section 3).
- Prioritisation of the different stream types, with the restoration of those stream types that will result in the most ecological benefit being the highest priority (Refer Table 3.1 and Section 3.9).
- Development of a decision tree to help council staff identify and guide restoration project objectives (Refer Section 4 and Appendix A).
- Development of a 'tool box' of suitable intervention and restoration options for each of the stream types (Refer Section 5 and Appendix B).
- Development of a GIS layer of the likely stream types to be used by TDC in the restoration of the waterways in the Moutere catchment.

This report was prepared in accordance with our proposal dated 16 January 2020.

1.1 Background

The Moutere Catchment is located approximately 25 km west of Nelson, extending north from the upper catchment in the Moutere hills to the Moutere inlet south of Motueka.

"Ecosystem health" of freshwater is one of four compulsory values prescribed under the National Policy Statement for Freshwater Management (NPS-FM) (2020) and therefore it is important that this value is given due consideration in stream restoration projects. Good habitat is critical to healthy stream ecosystems. Two of the other four compulsory values are also important for stream restoration and this framework, namely:

- Threatened species: "All the components of ecosystem health must be managed, as well as (if appropriate) specialised habitat or conditions needed for only part of the life cycle of the threatened species."
- Mahinga kai: "In Freshwater Management Units (FMUs) or parts of FMUs that are used for providing mahinga kai, the desired species are plentiful enough for long-term harvest and the range of desired species is present across all life stages"

The Moutere catchment may have declining river heath due to historic land-clearance, ongoing land-use practices, as well as modification of the river systems to assist drainage, prevent erosion, and provide flood protection. This has resulted in a net loss of in-stream habitat and a reduction in ecosystem health over the last 100 years.

Some of the key 'ecosystem health' concerns in the catchment are high stream temperatures, low dissolved oxygen and high levels of long green filamentous algae (James 2018). Studies have also been undertaken to understand sediment sources (Gibbs and Woodward 2018) and biodiversity loss within the wider area (North 2015). Underpinning all of this, is a fundamental change in the natural character of the waterways in the Moutere catchment.

Natural character is defined in the Tasman Resource Management Plan (2008) as:

- Landform, including natural features and patterns;
- Natural processes that create and modify landform;
- Indigenous plant and animal species present;
- Natural sounds;
- Natural water quality;
- Absence, or unobtrusiveness, of use and development;
- Expansive open space, especially where there is knowledge that undeveloped space is in public ownership; and, in particular, the sea.

This definition of natural character, and the acknowledgement that geomorphology and natural processes are a critical component of natural character, is also supported by the New Zealand Coastal Policy Statement (2010) as below:

- Recognise that natural character is not the same as natural features and landscapes or amenity values and may include matters such as:
  - **natural elements, processes and patterns;**
  - **biophysical, ecological, geological and geomorphological aspects;**
  - natural landforms such as headlands, peninsulas, cliffs, dunes, wetlands, reefs, freshwater springs and surf breaks;
  - **the natural movement of water and sediment;**
  - the natural darkness of the night sky;
  - places or areas that are wild or scenic;
  - a range of natural character from pristine to modified; and
  - experiential attributes, including the sounds and smell of the sea; and their context or setting.

With a desire for ecosystem health and natural character to be at the forefront of stream restoration in the Moutere catchment, TDC have developed a 'stream restoration framework' for the Moutere catchment based on geomorphic principles. This ensures that stream restoration projects address the whole of stream health, integrates well with river management practices and policies (TDC 2015), and provides underlying support for the community driven stream restoration projects in the area.

1.2 Objectives

The objective of this report is to provide an over-arching strategy for stream restoration and a tool-box of potential stream restoration/management actions for the Moutere Catchment.

It is intended that this document will provide the background and context to enable a holistic understanding of stream behaviour and to provide prioritised restoration activities at a catchment scale.

The following considerations were also used when developing the Moutere Restoration framework:

- To link into and build upon the knowledge gained in the development of the Tasman Natural Channel Design Guidelines using additional national and international literature as well as learnings from other recent T+T projects.
- To formulate a restoration framework that focussed on restoration actions that provide a dual benefit, namely erosion protection and habitat enhancement.

- To incorporate and build upon TDC's commitment to manage rivers holistically.
- To develop a framework that acknowledges the different stakeholders invested in river management, enhancement and use in the region and that balances these needs.
- To provide clear direction to prioritise streams for restoration in the Moutere catchment, to ensure best ecological outcomes, and best 'bang for buck'.

1.3 Limitations

The Moutere Restoration Framework is intended to be an overarching guide on how different stream types have evolved through changing conditions in the catchment. By understanding the processes underpinning a streams evolution, we can set realistic restoration objectives for the different stream types.

As this document is an overarching framework, restoration objectives, step-by-step guidance, or reach scale restoration actions have not been provided. It is intended that further work would be undertaken to develop reach or site-specific restoration plans using this document as the foundation from which to build upon.

The Moutere Restoration Framework has been developed using a qualitative approach to stream processes. This has been done to allow stream character and behaviour to be assessed at a catchment scale. It also means that the framework is relevant at a regional level where similar stream types exist.

The stream characterisation in the Moutere catchment for the Moutere Restoration Framework has been done at a high level/coarse scale using the River Environment Classification (REC) streamline data, aerial imagery and LiDAR where it was available. These data sets have been developed independently and by difference agencies, and so in some cases they don't match very well. For example, sometimes the REC streamlines do not match the topographic stream locations derived from LiDAR. This means there are often discrepancies in elevation/slope data, or the stream classification. The intention is that the stream characterisation will be ground-truthed throughout the restoration process.

2 Catchment description

The Moutere Catchment is a medium sized catchment north west of Nelson and has an area (NIWA 2017) of approximately 148 km^2. The Moutere River has up to 15 tributaries, of which only four are officially named. The Moutere River flows north for 25 km and joins the Moutere Inlet just south of Motueka (refer Figure 2.2 for catchment map).

The morphology of the Moutere catchment is characterised by a wide valley floor 'infilled' by alluvial gravels. The overall slope of the valley from the headwaters to the coast is considered reasonably 'flat' (0.6% from Upper Moutere to the coast) (Figure 2.1), and the surrounding hills of the Moutere catchment are predominantly low rolling hills, with the highest point being 369 m above sea level. Valley slopes in the rolling hills are also reasonably low, averaging around 2.5%.

The sub-catchment valleys are generally regularly-spaced, and mostly flow in a northerly direction. As with the main valley, most sub-catchment valleys are also characterised by wide valley floors, even when the valley slope increases. The exception to this, are those sub-catchments in soils derived from Separation Point Suite (SPS). SPS as a geological unit, is 'harder' than the geological units comprised of gravels, and so the hills are steeper and the valleys narrower. However, soils derived from SPS are characterised by unconsolidated sands, which lead to much more dynamic river systems. This is discussed further in Section 2.2 and Section 3.

Eight distinct stream types have been identified within the catchment. Each stream type has different formative (and maintenance) processes, provides different habitat values, and will require different restoration objectives and interventions (refer Section 3, Figure 3.1 and Table 3.1).

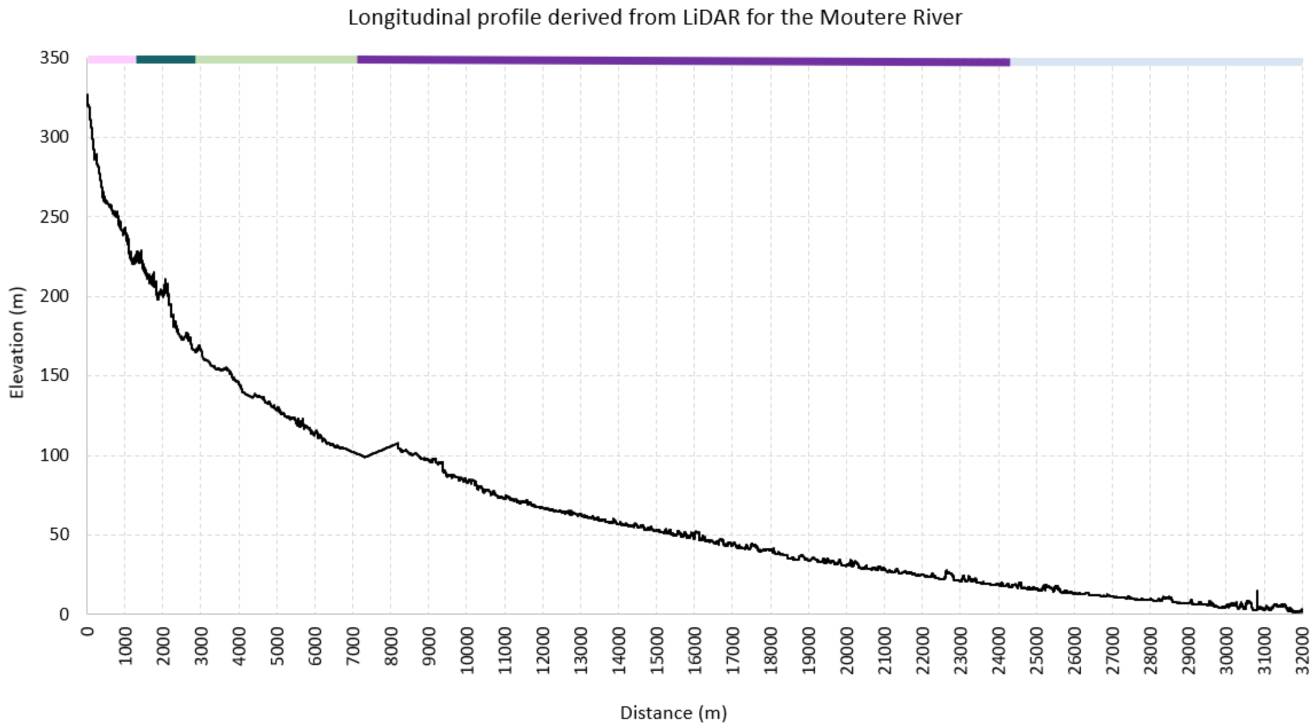


Figure 2.1: Indicative longitudinal profile of the Moutere River based off LiDAR (note some smoothing was required as the REC stream lines do not match the LiDAR stream locations). Indicative stream types are denoted by the coloured bars at the top of the graph (refer to Figure 3.1), Valley fills (light pink), confined gravel bed (dark teal), partly confined gravel bed river (light green), unconfined meandering gravel bed, (purple), artificially straightened gravel bed (light blue).

2.1 Climate and flow dynamics

The climate of the Nelson-Tasman District is considered mild with relatively consistent rainfall throughout the year. Periods of more than two weeks without rain are common in the district. The Moutere Catchment has a mean annual rainfall of 1,250 mm and an average annual temperature of 12.7 ˚C (NIWA 2016b).

Extreme rainfall events are infrequent and are generally associated with active fronts or ex-tropical cyclones. A large rainfall event in March 2005 resulted in widespread channel change in the adjacent Mouteka River catchment (Fuller *et al.* 2011), and is likely to have resulted in channel change within the Moutere River also. This event resulted in the highest rainfall recorded in the Moutere catchment (Kelling Road rain gauge) with over 165 mm recorded over a 24 hr period. This is in excess of the modelled 100 yr Annual Recurrence Interval (ARI) rain event for this rain gauge. Another extreme rainfall event in the region occurred in 2011, where an active front resulted in up to 205 mm of rainfall at Richmond and 423mm at Takaka over a 24 hour period (NIWA 2011). The heavy rainfall resulted in over 200 landslides across the region and widespread flooding. Although the 2011 event did not appear to have affected the Moutere catchment as much as it did elsewhere in the region, it provides a clear example of how extreme events affect catchment processes and river response.

The Moutere River flow statistics for this site have been taken from estimates available from NIWA (2016a) and NIWA (2017) Table 2.1.

Table 2.1: Indicative catchment flow statistics for the Moutere River at the 'Old House Rd' site (downstream of Old House Road)

Site	Mean Annual Low Flow (MALF) (m^3/s)	Mean Annual Flood (MAF) (m^3/s)	5 year ARI (m^3/s)	10 year ARI (m^3/s)	100 year ARI (m3/s)
Moutere at 'Old House Rd'	0.06	62	93	118	197

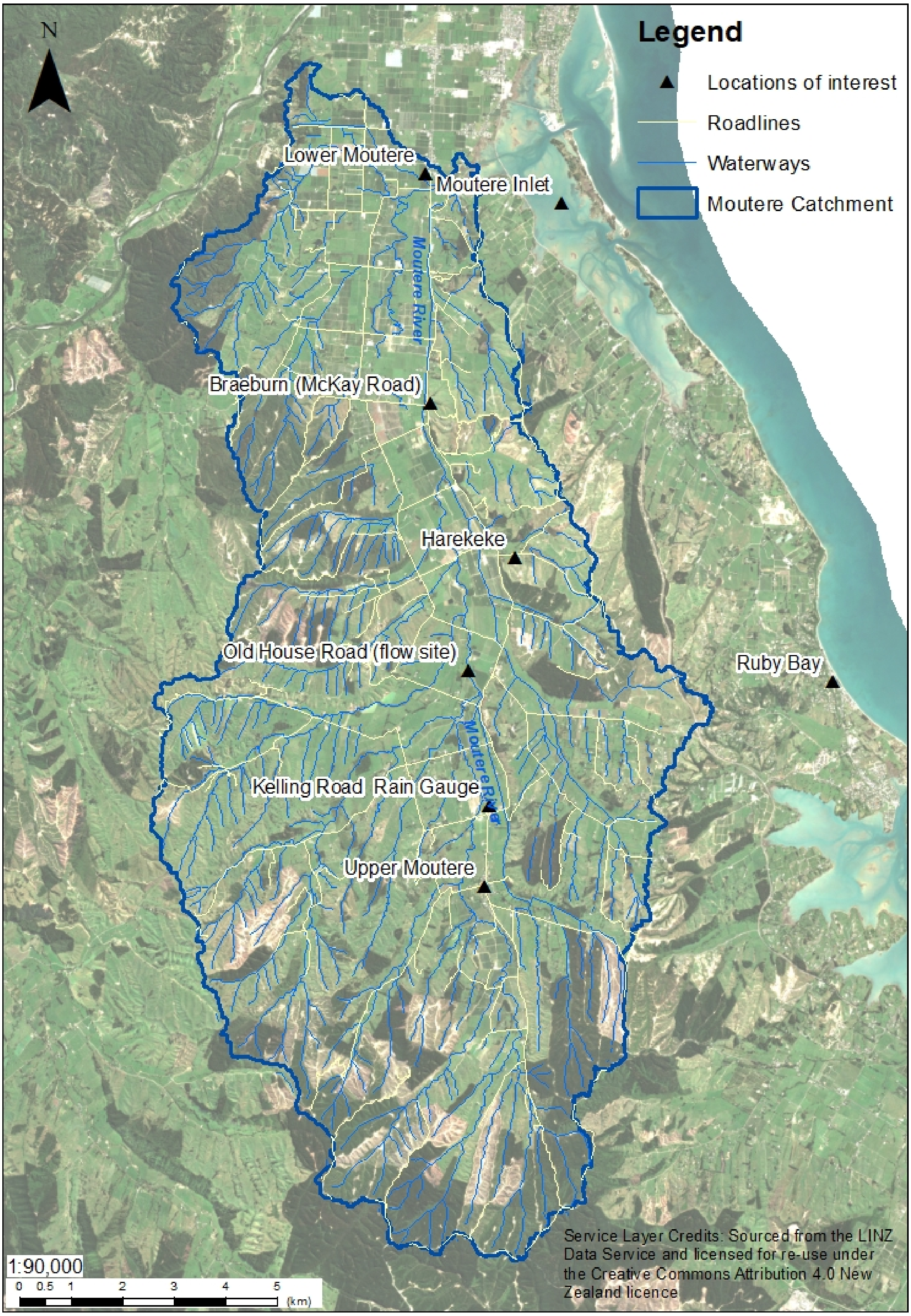


Figure 2.2: Map of the Moutere Catchment showing stream lines, and locations of interest that are discussed in this report

2.2 Geology and soil

The majority of the Moutere catchment is mapped as Moutere Gravels (Figure 2.3). This deposit comprises gravel within a clay matrix with up to boulder sized sandstone clasts. This gravel layer is deep (up to 700 m) and was formed by fluvio-glacial outwash following the rapid uplift of the Southern Alps and Spencer Mountains (North 2015). The Moutere Gravel is considered erodible and will contribute clay to bolder sized particles into the waterways.

Terraces and floodplains within the Moutere catchment are underlain by Pleistocene, Holocene and contemporary river deposits. The accumulation of these sediments has formed a series of aggradation surfaces up to 100 m above current river levels. These deposits are unconsolidated and will contribute gravels and sands to the river network.

The Cretaceous aged SPS is found in the western extent of the catchment and is significant to river character and behaviour (Figure 2.3). Though the SPS is highly indurated, it is also significantly fractured and deeply weathered (Landcare Research 2003). As a result, it is highly erodible and will contribute sand into the waterways.

Detailed regional soil maps do not yet exist for the Moutere catchment and wider area, however the soil orders have been mapped. Most of the catchments are identified as Albic ultic soils which are prone to erosion (Landcare Research 2020). However Albic Ultic soils are classified as having high clay content so these surface soils may increase the stability of the upper banks of waterways, where present.

Fluvial recent soils were mapped within the Moutere catchment and are formed in areas of high erosion and/or deposition, and contain unconsolidated materials of various size clasts (Landcare Research 2020). As such, these soils are often found close to waterways, and will contribute gravels and sands to the waterways if eroded or disturbed.

Recent gley soils are also located along some of the waterways (Landcare Research 2020). Gley soils are found in areas with a high water table and can be waterlogged all year round. Gley soils are often fine grained material and will contributes silts and organic matter to the waterways if eroded.

In the lower river catchment an area containing brown soils have been mapped, which are the most common New Zealand soil type comprising mostly of clay minerals. The same area has been geologically mapped as Late Pleistocene river deposits comprising of a clay matrix with gravels and minor sands and silts. These soils are likely to have a low erosion potential, due to the high clay content. However, if eroded, they will likely contribute clays to gravels to the waterways.

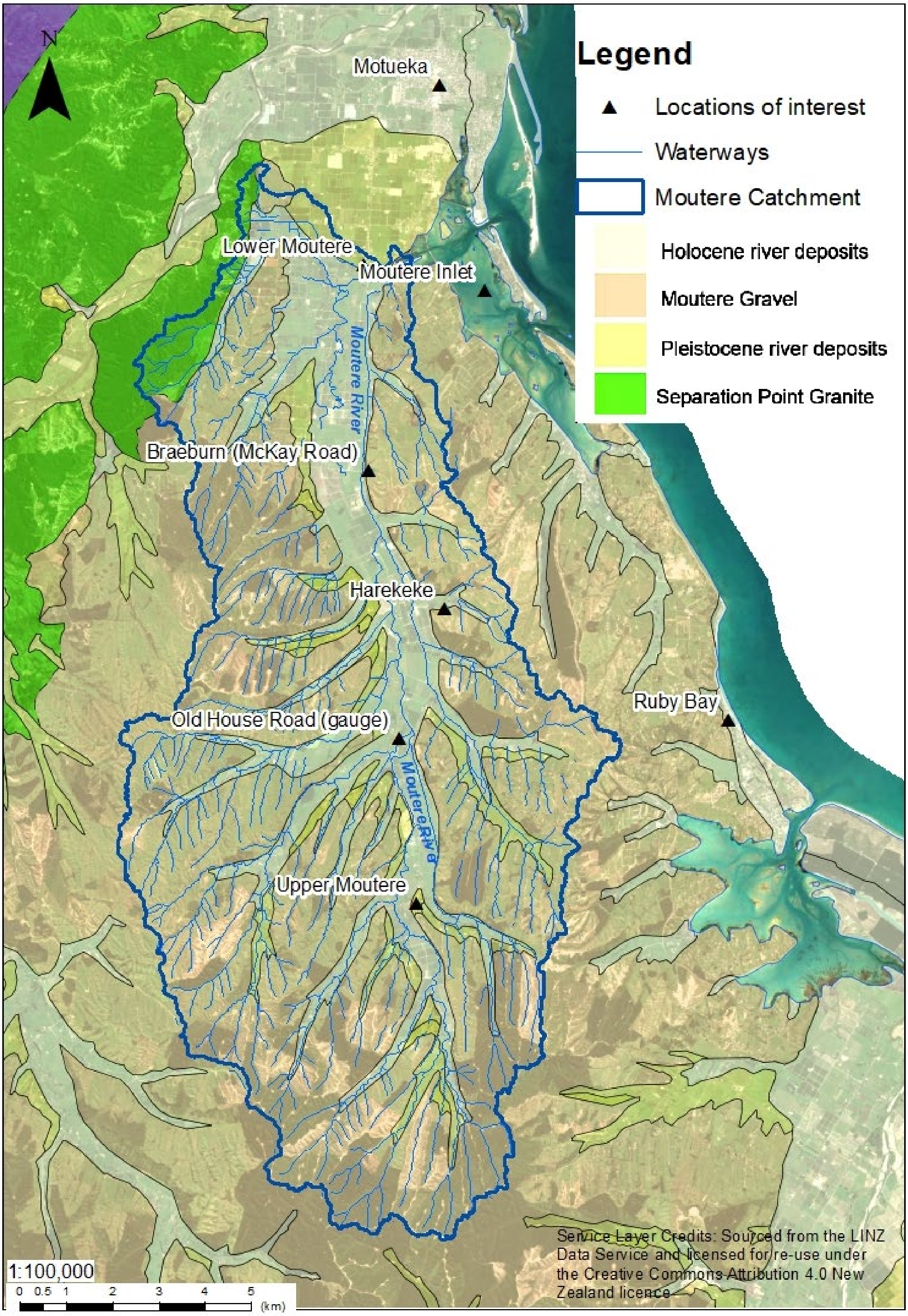


Figure 2.3: Indicative underlying geological units of the Moutere Catchment (GNS Science 2016)

2.3 Sediment regime

The critical elements in assessing a sediment regime include:

- Type of sediment in the system,
- How each type is transported (bed load versus in suspension),
- How the different sediment types interact with each other,
- The connectivity for sediment transport between reaches and from hillslopes to the stream, and
- The sediment 'zones' in the catchment, namely the erosion zone (sediment sources), transport zone, and deposition zone (sediment sinks).

It is generally well accepted that most geomorphic 'work' occurs during bank-full events, when the maximum volume of water is confined between banks. Geomorphic work refers to erosion and deposition of sediments from the effects of flow. Bank-full is often considered analogous to the Mean Annual Flood (MAF), or a 2 Year ARI flood event (Rutherfurd *et al*. 2000). This is similar to the findings of Basher *et al* (2011) in the adjoining Motueka catchment, where a small sub-catchment underlain by Moutere Gravels and covered in indigenous forest experienced most bank erosion during a small event <1 year ARI. However, Fuller *et al* (2011) identified the most channel change in one of the larger arms of the Motueka River (a wandering gravel bed river) occurred during a large flood event of more than 450 m^3/s, which is analogous to almost a 100 year ARI event for that particular study reach.

Given the discrepancies in river response of different stream types to different flows, we have presented a range of indicative flow values (as per NIWA 2016a and NIWA 2017) for each stream type (Section 3). However, for the purposes of this report, we will assume that bankfull is responsible for the most geomorphic work, and that this equates to a MAF event or a 2 year ARI.

Bed load is the sediment faction that contributes the most to geomorphic processes in gravel bed rivers (Leopold 1992, Fuller *et al* 2011). However, estimations of bed load (as opposed to suspended load) is outside of the scope of this report. Bed load entrainment is often difficult to predict, with variable sediment sizes, coarse surface armouring, imbrication, and possibly hydrostatic pressure between surface flows and sub-surface flows all playing a role in modulating bedload entrainment (Neverman *et al.* 2018; Brierley, Reid and Coleman 2011). However, for the purposes of this report, bedload entrainment has been considered to occur during a MAF event or greater.

The ability for a reach to transport bedload helps us to understand the underlying geomorphic processes in a river, the evolutionary trajectory, the recovery potential and the reaches role in the wider catchment dynamics. For example, some reaches which promote bedload deposition and storage (such as wandering gravel bed river types) may act as 'sediment sinks' restricting bedload movement into downstream reaches (Brierley, Reid and Coleman 2011). In this example, the upstream 'sediment sink' is driving the character and behaviour of the downstream reaches. As we modify these rivers, we change these sediment processes and the connectivity between reaches, so an action in a reach upstream may impact on reaches downstream. In this regard, understanding the reaches spatial and physical relationships to each other may be key to achieving the restoration objectives.

Suspended sediment loads are the portion of sediment carried in suspension and are usually restricted to the fine-grained particles (sands, silts and clays). Suspended sediments generally have a limited role in morphological processes, especially in gravel bed rivers, but play an integral role in stream health and ecological function.

Estimations of suspended sediment load are often based on a number of catchment variables, such as land cover, rainfall and catchment area. The relationship between suspended sediment concentrations/loads and discharge is often expressed as a linear one (Brierley, Reid and Coleman, 2011) and generally suspended sediment concentrations do increase with an increase in flow (Basher *et al* 2011). However, the dynamics of suspended sediment within a flow event can be extremely complex, being influenced by sediment sources, land cover, land use, coarse surface armouring and other catchment scale factors. Hicks (1990) suggests that smaller, more frequent events may be responsible for the maximum suspended sediment load production and transport in the Moutere catchment. While Basher *et al.* (2012) suggests that 70% of suspended sediment within the Manawatū River is transported at flows less than MAF.

Assessments of suspended sediment from the adjoining Motueka River catchment, suggest that geology and rainfall are the main determinants of suspended sediment yield at a catchment scale. They also demonstrated that the biggest impact on suspended sediment yields was a large (50 year ARI) rainfall event that increased sediment loads by up to 10 times and for a period of four years post event (Basher *et al.* 2011). Studies also from the Motueka catchment suggest that pine harvesting also contributes to elevated suspended sediment loads (as discussed further in Section 2.4).

The Moutere catchment displays a characteristic increase in suspended sediment loads from the headwaters to the coast (Table 2.2). A total annual suspended sediment load of 14,769 t/yr is estimated to enter the Moutere Inlet at the coast. However, this load is likely to vary spatially as well as temporally, and some sub-catchments (such as the Blackbird Valley Stream sub-catchment, and the Upper Moutere sub-catchment) are likely to contribute higher proportions of the load. Gibbs and Woodward (2018) demonstrated this variability, with their field-based estimates of suspended sediment loads higher for several sub-catchments than those modelled in NIWA (2017).

Table 2.2: Estimated suspended sediment loads for the Moutere catchment (taken from NIWA 2017)

	Head waters of the catchment	Old House Road	Moutere Inlet
Annual suspended sediment load (tonnes per year)	94	5,371	14,769

2.4 Landuse history

Pre-European colonisation, the Moutere catchment likely had a diverse vegetation assemblage across the different landforms. The valley floor of the Moutere valley was primarily a large swamp and swamp forest dominated by harakeke (*Phormium tenax*) and kahikatea (*Dacrycarpus dacrydioides*). Rautahi (*Carex geminata*), pūrei (*Carex secta*), tī kōuka (*Cordyline australis*) and mānuka (*leptospermum scoparium*) would have been locally common in these habitat (North 2015). It's also likely these freshwater wetlands would have characterised many of the upper catchment valley floors (near the headwaters).

The active edges of gravel river margins would likely have been characterised by primary successional species such as manuka (*Leptospermum scoparium*), tutu (*Coriaria arborea*), toetoe (*Cortaderia* species) and various Coprosma species.

The drier alluvial floodplain surfaces would have been dominated by lowland podocarp-broadleaf forest characterised by rimu (*Dacrydium cupressinum*), tōtara (*Podocarpus totara),* matai (*Prumnopitys taxifolia*), and kahikatea (North 2015). Broadleaf components would have included black beech (*Fuscospora solandri*) northern rata (*Metrosideros robusta*), hīnau (*Elaeocarpus* *dentatus*), miro (*Pectinopitys ferruginea*), tawa (*Beilschmiedia tawa*), and titoki (*Alectryon excelsus*) (North 2015).

The Moutere hills were likely dominated by podocarp-beech forest, particularly rimu, black beech (*Fuscospora solandri*) and hard beech (*Fuscospora truncata*)(North 2015).

Large-scale land clearance began with European settlement of the catchment in the 1840's, with most of the indigenous vegetation cleared by the early 1900's. As of 2015, only 3% of hillslope forest, 1.7% of alluvial forest and 8% of freshwater wetlands remain in the Northern Sector of the Moutere Ecological District (North 2015). A flow model developed for the Motueka River suggests that river flow in that catchment is now about 21% higher under current land use than pre-European indigenous forest cover (Fahey *et al.* 2010; Cao *et al*. 2008).

The Moutere Hills (headwaters of the catchment) were converted from orchards to exotic pine plantations following the 1930's economic depression. While this land-use is still prevalent, large-scale conversion of pine forests to pasture or rural residential properties occurred in Upper Moutere between 2007 and 2008 (Gibbs and Woodward 2018). A recent study using sediment fingerprinting suggested that harvesting of pine forests could be attributed to a dramatic increase in fine sediments in the Moutere Inlet (Gibbs and Woodward 2018). Gibbs and Woodward (2018) demonstrated that up to 87% of the fine sediment in the Moutere Inlet can be attributed to recent pine harvesting (Figure 2.4). While some sub-catchments suggested that 'bank erosion' was the primary contributor in several sub-catchments, they reasoned that this sediment may have initially come from pine harvesting activities (Gibbs and Woodward 2018).

In the adjoining Motueka catchment, studies have shown that suspended sediment yields can increase by up to 100 times post pine harvesting. But interestingly, studies in the Moutere catchment suggest that the pasture study plots had a higher annual sediment yield than pine forests, with 4 t/km^2/year under pine forest and 79 t/km^2/year under pasture (from Hicks 1990, in Basher *et al* 2011).

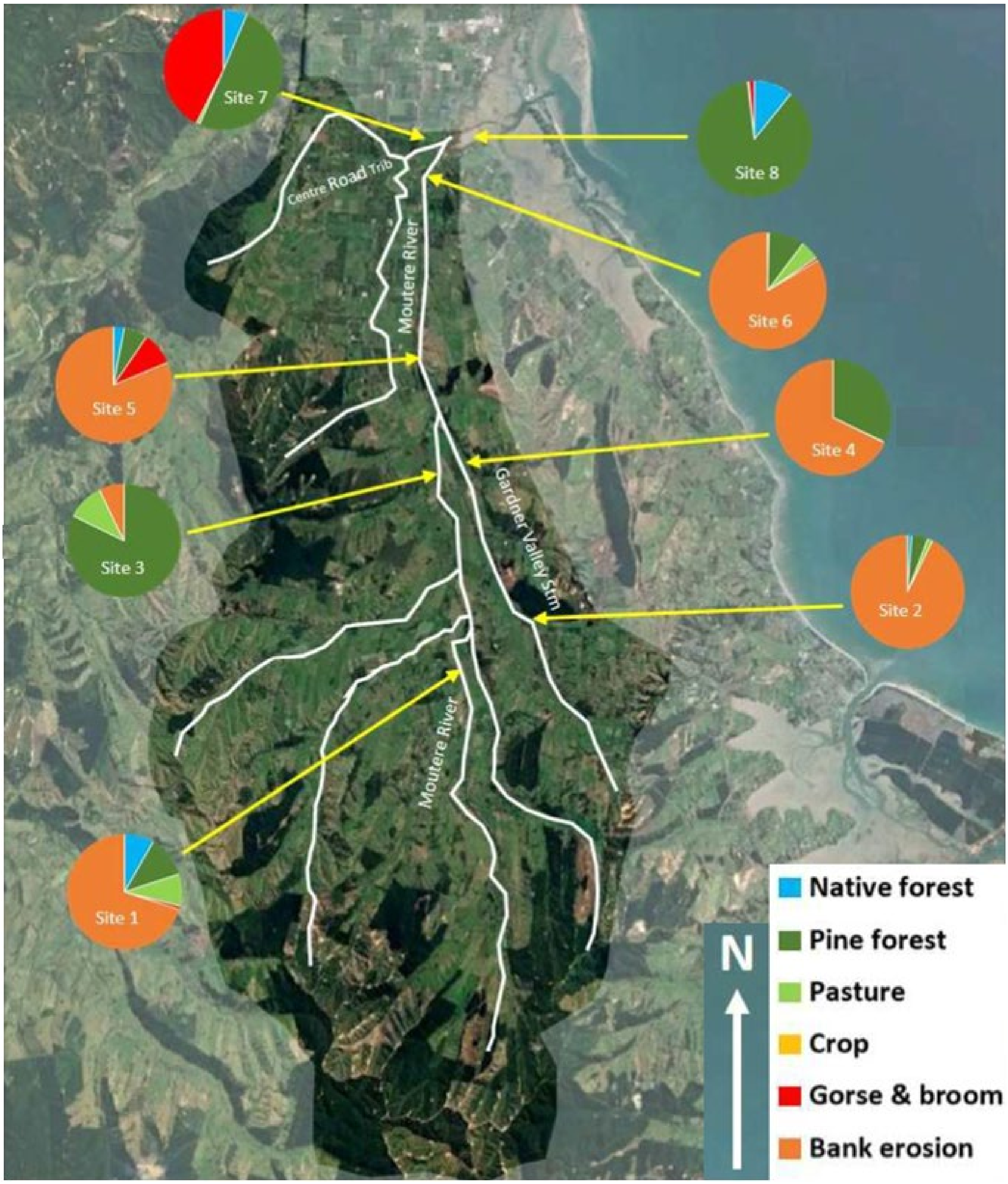


Figure 2.4: Proportional contribution of sediment from the different 'land use' sources for each of the streams identified (Modified from Gibbs and Woodward 2018)

2.5 River management history

Modification of the watercourses within the Moutere catchment has been occurring since European colonisation.

The New Zealand Company had a substantial role in the colonisation and 'westernisation' of the Moutere valley. It is believed that the modification of the river systems in the Moutere, and the draining of the floodplains, was undertaken by settlers and the New Zealand Company in the late

1800's (TDC 2015). The straightening of the lower reaches of the Moutere River may have occurred during this time.

A number of other waterways were modified following WWII in the late 1940's to assist land drainage and increase productivity of agriculture. This included many of the waterways on the main Moutere Valley floodplain (including the old Moutere channel (Blue Creek)).

In 1992, the responsibility of flood protection and river management was transferred to TDC under the Soil Conservation and River Control Act (1941). The requirements of the Act are then enacted as per the Rivers Activity Management Plan (2015), which enables TDC to:

> "carry out its statutory roles to promote soil conservation and mitigate damage caused by floods and riverbank erosion."

The requirements of the Rivers Activity Management Plan (2015) apply to specifically classified rivers (Refer to Table B-1 in the Rivers Activity Management Plan (2015)). This includes a 12 km reach of the Moutere River at the downstream end of the catchment. River works are covered by a 'global' resource consent issued in 2016 (Ref 100851). The global consent has a range of consent conditions for river works and activities. The overall intent of the consent is to ensure river works are sympathetic to, and protect or enhance, the river processes, natural character, and overall ecosystem health of the rivers the works are undertaken in.

An assessment of a small section of the Moutere River, downstream Old House Road, undertaken by T+T in 2020 estimated the degree of river change over time, and how river modification may have impacted river character and in-stream aquatic habitat. The analysis estimated an 86% reduction in active channel width, and a 43% reduction in low-flow channel width (possible wetted width) from the 1940's channel. The river had also lost a lot of its sinuosity and the channel corridor appears to have incised to such a degree that the floodplain has largely been abandoned. For a conceptualised diagram of the evolution of this stream type, see Figure 3.11.

There was also a reduction in the type, size and frequency of geomorphic units (the building blocks of in-stream habitat), being reduced to a few lateral bars (beaches) present, occasional short riffles, frequent runs and occasional pools.

The reduction in active channel width by 86% and the low-flow channel now occupying 62% of the active channel area means that there is no space for the diversity of active channel units to establish. The stream type descriptions in Section 3 provides further discussion on the changes in river character and behaviour through time, as well as an assessment of possible pre-European character.

3 Stream types

River character and behaviour is an important factor in understanding how different stream types may ‘respond’ to modification, enabling us to work ‘with’ the rivers existing processes for a more sustainable restoration outcome. It also helps us to identify typical in-stream habitat features for different stream types and what habitat features may have been lost through modification over time.

River character and behaviour has been assessed at a high level based on a modified version of the River Styles Framework (Brierley and Fryirs, 2005) following a two-day catchment site visit and desktop analysis. The River Styles Framework provides a geomorphic tool for assessing the role of landscape setting and processes on catchment scale patterns and linkages in river types. Stage One of the River Styles Framework assesses the catchment wide river character and behaviour. In this assessment, waterways in the Moutere catchment have been defined based on river character from parameters such as valley confinement, river shape (planform), sediment type, and in-stream or secondary sediment stores.

Valley setting (confinement) is important in defining river behaviour as it determines the ability for a stream to move sediment through the system, and the ability for the watercourse to move across a floodplain (Montgomery and MacDonald 2002; Buffington and Montgomery 2013; Brierley and Fryirs 2005). The valley setting can be associated to catchment position with upper catchment locations usually associated with ‘confined’ valleys, and lower-catchment locations usually associated with ‘unconfined’ valley settings. Valley confinement has been determined for the eight stream types identified in the Moutere catchment and is discussed further below.

While not a hard and fast rule, generally ‘confined’ reaches will source coarse sediment from the hillslopes and channel bed and move it through the system reasonably quickly (source zone). This is important for stream restoration, and it may require additional consideration of bed protection (such as rock riffles or rock cascades), and consideration of sediment transport mechanisms (such as suitably sized culverts or potential vertical channel space to allow for short term bed level increases). There are some exceptions to this rule, which are discussed further in Section 3.4.

Partly-confined reaches are generally associated with channels that have some ability to source sediment from the channel banks and channel bed, transport sediment through the system in high flows, and have the ability to store sediment within the channel (transport and / or deposition zone). This has implications for stream restoration, as it may require planning for areas where sediment deposition can occur (such as localised widening of the channel with access points, or deep pools), as well as some localised areas of bank protection where lateral movement of the channel may adversely impact on infrastructure.

Unconfined reaches are set within an alluvial valley and are generally associated with channels that want to move across a floodplain (through bank erosion) and are often reaches where sediment will be deposited in the channel (deposition zone). The flat terrain of these reaches (and when the planform is intact) can disconnect sediment transfer from downstream reaches, and they can therefore act as a sediment sink (Brierley, Reid and Coleman, 2011). This has implications for stream restoration, as the straightened reaches in these landforms may have become ’transport reaches’ and restoring their planform through stream lengthening, recreating meanders, or re-engaging floodplains may change the sediment dynamics throughout the catchment. Therefore, while these types of restoration options would provide great ecological and geomorphological benefits, they may compromise flood protection objectives.

Stage Two of the River Styles Framework assesses river evolution and geomorphic condition, including the capacity of each of the river types to ‘adjust’ to changes in conditions. For the purposes of the Moutere Restoration Framework, we have assessed if stream types have changed over-time, and identified how they have changed, and why they may have changed. This was done specifically to help guide restoration objectives and support the restoration of both geomorphic function and in-stream habitat provision.

A total of eight stream types have been mapped throughout the Moutere catchment. These are identified and briefly described and prioritised in Table 3.1 and their location shown on Figure 3.1. More detailed information about the reasoning for the prioritisation of the stream types is presented in Section 3.9. However, geomorphic condition of individual reaches is site specific, and the initial prioritisation has been based on a generalised assessment of recovery potential and professional judgement. Geomorphic condition of the individualised reaches can be undertaken during a site specific restoration plan.

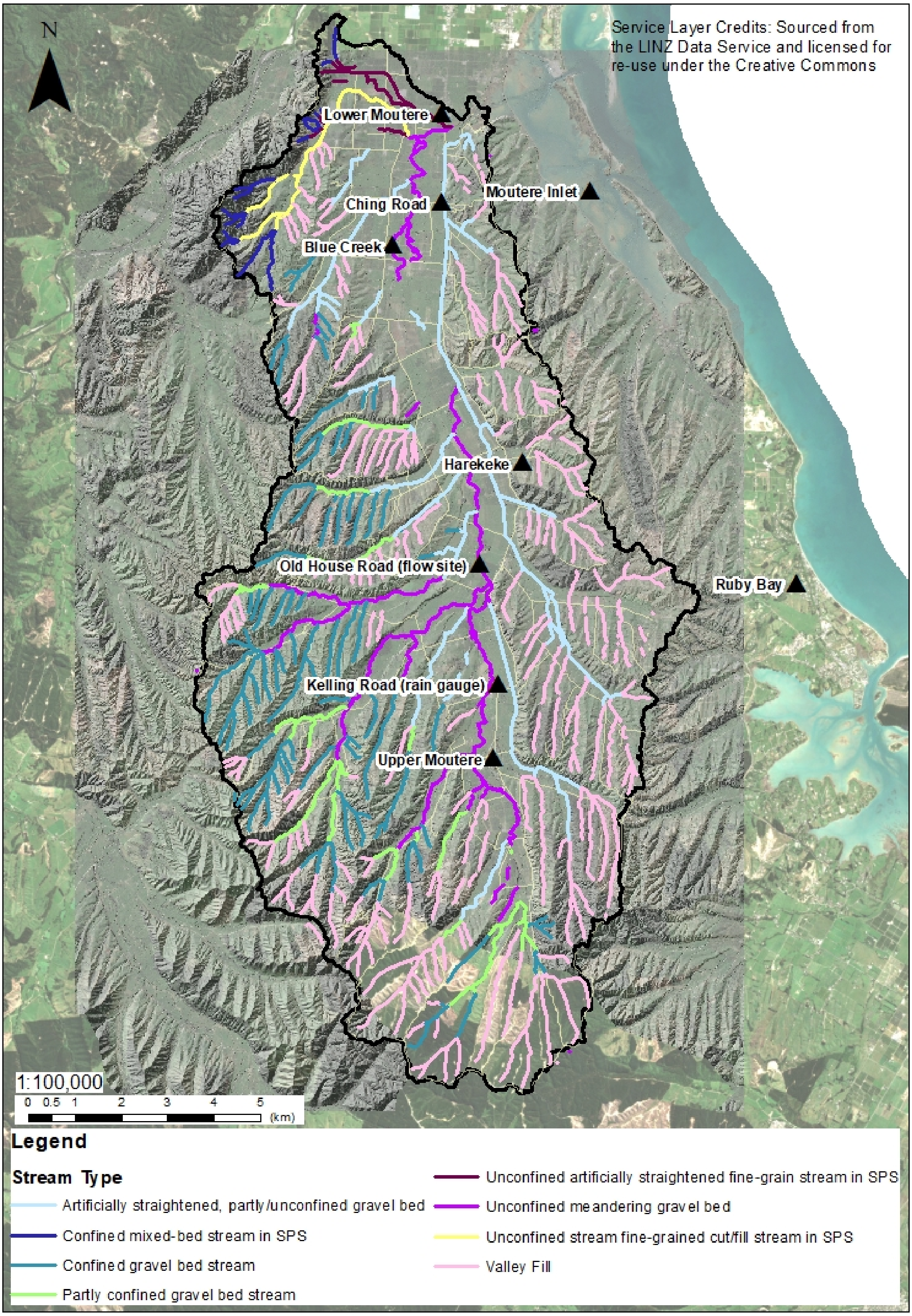


Figure 3.1: Map of the pre-classified stream types for the Moutere catchment

Table 3.1: Indicative parameters values for the eight identified stream types in the Moutere Catchment

River type	Valley setting	Thalweg	Sinuosity	Typical average valley slope (%)*	Typical valley width (m)	Dominant sediment process	Sediment type	Initial prioritisation
Artificially straightened, partly/unconfined gravel bed	Partly/ unconfined	Single	Straight	3%	200 m	Transport reach	Gravel and fines	8
Confined gravel bed stream	Confined	Single	Straight	8%	60 m	Source/ transport reach	Gravel and fines	4
Partly confined gravel bed stream	Partly confined	Single	Moderate	7%	130 m	Source/ transport reach	Gravel and fines	2
Valley fill	Confined	Discontinuous/absent	N/A	8%	50 m	Source/depositional reach	Fines	1
Unconfined meandering gravel bed	Unconfined	Single	Straight to moderate	5%	>1,000 m	Source/transport/depositional reach	Gravel and fines	3
Unconfined fine-grained cut and fill stream in SPG	Partly/ unconfined	Single	Moderate	3%	700 m	Source/transport/depositional reach	Fines (sand)	5
Unconfined artificially straightened fine-grained stream in SPG	Unconfined	Single	Straight	2%	>1,000 m	Transport reach	Fines (sand)	7
Confined mixed-bed stream in SPG	Confined	Single	Low	10%	40 m	Source/transport reach	Angular gravels	6

**NB Valley slope has been calculated from REC streamlines and LiDAR and averaged for all segments for each stream type. The REC streamlines and LiDAR do not necessarily line up well, and there may be some discrepancies.*

3.1 Artificially straightened, partly/unconfined gravel bed

Artificially straightened gravel bed rivers in partly-confined or unconfined valleys, refer to those reaches that have had the natural sinuosity reduced by human intervention (refer Figure 3.2 and Table 3.2). In the Moutere catchment, these interventions are generally historic, occurring prior to 1900.

With the degree of modification in the landscape, and the long history of river modification, it is difficult to say with certainty what river type these would have been in their original state. However, there is evidence of multiple highly sinuous channels on the floodplain which suggests these streams were either meandering gravel rivers or wandering gravel bed rivers which avulsed frequently. The straightening of these channels has led to the following changes in stream process (and as displayed in Figure 3.3):

- Decreased stream length and stream width.
- Increase in stream power resulting in an increase in sediment transport.
- Increase in bed erosion rates leading to channel incision.
- Following incision of the channel, stream banks became over-steep and prone to erosion through mass wasting.
- Loss of critical in-stream habitat such as long transverse riffles, large pools, woody debris, stable undercuts, large gravel bars, backswamps and a variety of riparian vegetation.

Artificially straightened gravel bed rivers are most likely to adjust vertically (primarily degradation), as increased stream power and increased sediment transport capacity means the bed material is able to be mobilised more often. Bank erosion is most likely to be driven by toe-scour (e.g. undercutting) and subsequent block failure, or through mass wasting processes as the banks become over steep.

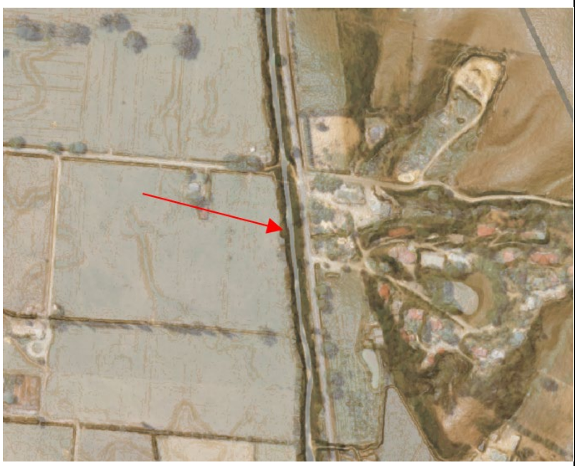
	
Artificially straightened unconfined gravel bed, with alternating lateral bars and a continuous run. Note the rock-protection at the toe of the banks. Looking downstream.	Aerial view of an artificially straightened unconfined gravel bed stream (red arrow) near Chings Road.

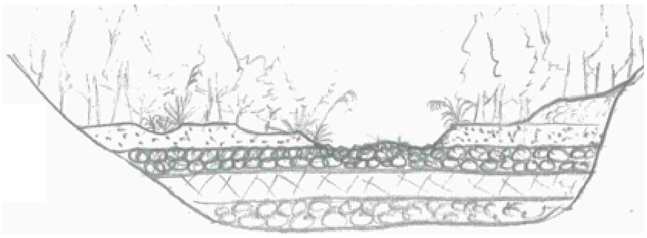
Figure 3.2: Example of an artificially straightened unconfined gravel bed river in the Moutere catchment

Table 3.2: Characteristics of the artificially straightened unconfined gravel bed river stream type

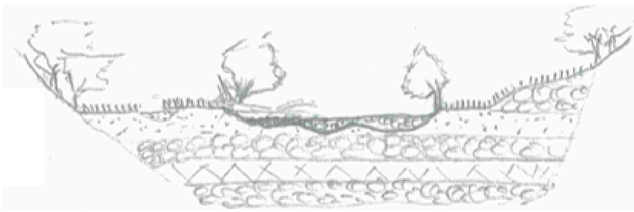
Valley setting	**Channel planform**	**Bed material**	**Channel geometry**	**Geomorphic units**
Partly or unconfined	Single, straight, incised channel. Limited floodplain engagement.	Rounded gravels and fines, some infrequent bedrock.	U-shaped channel. 10 m active channel width. Banks are near vertical and4 m high.	Riffle/runs, occasional pools.
Bar types	**Sensitivity to change**	**Floodplain features**	**Dominant erosion type**	**Flow type**
Lateral, alternating bars.	Low	Likely incised beyond active floodplain	Undercutting	Permanent
Indicative Mean Flow (m^3/s)*	**Indicative Mean Annual Flood (m^3/s)**	**Indicative 5 year ARI (m^3/s)****	**Indicative 10 year ARI (m^3/s)****	**Indicative 100 year ARI (m^3/s)****
0.09	N/A	60.6	71.2	134.8
Vegetation assemblages				
Current vegetation is mostly exotic species, dominated by willows. Historic vegetation types would have been primary successional species manuka, tutu, toetoe and karamu along the active edges, with kahikatea swamp forest on the older but frequently wetted surfaces.				

*NB – Flow statistics from https://shiny.niwa.co.nz/nzrivermaps/ and averaged over three indicative reaches

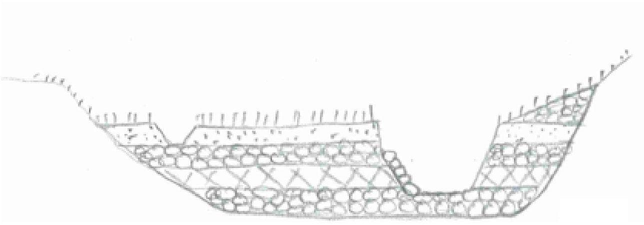
**NB – Flow statistics have been generated using the Rational Method from New Zealand River Flood Statistics (NIWA), and averaged over three indicative reaches



Pre-European
- Native kahikatea floodplain forest with extensive 'swamp' vegetation
- Shallow gravel channel with multiple channel off-cuts and back-swamps
- Mixed gravel bed (cobbles through to fines) with extensive wood loading
- Most likely a 'Wandering Gravel Bed' stream type.



Forest clearance
- Floodplain forest cleared first, riparian vegetation intact.
- Hill vegetation cleared later and often replaced with pines, but hillslopes mostly disconnected from channel
- Minor increase sediment in the channel, mainly fines
- Minor aggradation of channel
- Increased flooding across floodplain



Current
- Channel has been straightened, resulting in a decrease in stream length and an increase in velocities
- Riparian margin mostly grass/weedy vines, some willows where bank instabilities have occurred
- Designed channel trapezoidal in shape, efficient at transporting sediment
- Incision occurring
- Banks are high and steep, increased erosion potential
- Bank erosion associated with scour on bends (where present) and mass wasting processes

Figure 3.3: Conceptualised evolutionary trajectory of an artificially straightened, partly confined/unconfined gravel bed river

3.2 Confined gravel bed stream

Confined gravel bed streams most often occur in the headwaters of the smaller tributaries underlain by Moutere Gravels (refer Figure 3.4 and Table 3.3). Confined streams typically abut the valley margin more than 90% of the time (Brierley and Fryirs, 2005). However, some Confined gravel bed streams also occur on wider valley floors, but are incised beyond the active floodplain, sometimes confined between a series of terraces. This stream type is generally characterised by steep valley slopes (>8%) and narrow valleys. A conceptualised evolutionary trajectory is provided in Figure 3.5.

These streams are usually intermittent, with some of the lowland reaches possibly permanent. Remnant pools are critical habitat features of this stream type, providing refuge for fish and invertebrates during periods of low flow. As with all stream types, dense and continuous riparian vegetation is a critical element of habitat formation in this stream type, ensuring that there is:

- Enough shade to maintain these pools,
- Enough shade to maintain the temperature of the water in the pools to an acceptable level,
- Food for fish and invertebrates within the pools, and
- Coarse woody debris often responsible for creating the pools.

Confined gravel bed systems are unable to adjust laterally across the floodplain, so bank erosion is usually associated with bed level changes (e.g. incision creating over steep banks). Channel blockages (such as woody debris jams) may also create localised areas of erosion, however these isolated occurrences are considered critical to in-stream habitat often creating pools, or undercuts. These pools and undercuts are likely to have been key habitats for the At Risk – Declining Giant kōkopu *(Galaxias argenteus*), which is no longer found in the catchment.

In some reach's benches may be present. Benches act as a kind of floodplain, allowing flood flows to occupy a larger area in the channel, reducing stream powers and reducing the erosion potential. These benches are also likely to be highly valued spawning areas for some galaxiid species (such as banded kōkopu (*Galaxias fasciatus*)), especially if they are densely vegetated.

	
Confined gravel bed stream, with a pool and run sequence. Looking downstream.	Aerial view of a confined gravel bed stream (red arrow centre right), with terraces present (triple red arrow bottom left) near Deepdale Road.

Figure 3.4: Example of a confined gravel bed stream in the Moutere catchment

Table 3.3: Characteristics of a confined gravel bed stream type

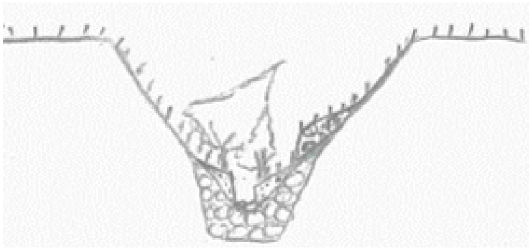
Valley setting	Channel planform	Bed material	Channel geometry	Geomorphic units
Confined (sometimes between terraces)	Single, low sinuosity channel.	Rounded gravels and fines.	Two-stage type channel up to 3 m wide active channel with steep banks 2.5 m high.	Riffle/pools, benches, occasional backwater areas.
Bar types	**Sensitivity to change**	**Floodplain features**	**Dominant erosion type**	**Flow type**
Lateral bars.	Low	Either no floodplains present, or incised beyond active floodplain. Terraces sometimes present.	Block failure.	Intermittent/permanent
Indicative Mean Flow (m^3/s)*	**Indicative Mean Annual Flood (m^3/s)**	**Indicative 5 year ARI (m^3/s)****	**Indicative 10 year ARI (m^3/s)****	**Indicative 100 year ARI (m^3/s)****
0.004	N/A	5.7	6.8	11.9
Vegetation assemblages				
Current vegetation is mostly exotic species, dominated by pines and some pastural Historic vegetation types would have been podocarp-beech forest, and possibly some lowland podocarp-broadleaf forest on the lower terraces (where present).				

*NB – Flow statistics from https://shiny.niwa.co.nz/nzrivermaps/ and averaged over three indicative reaches

**NB – Flow statistics have been generated using the Rational Method from New Zealand River Flood Statistics (NIWA), and averaged over three indicative reaches

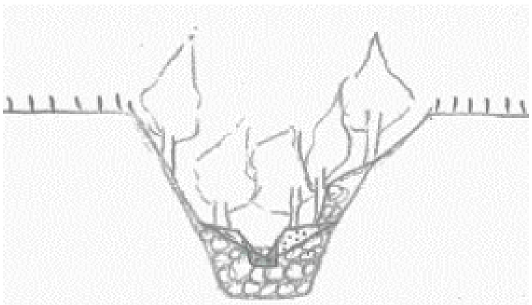
Pre-European

- Native podocarp beech forest or podocarp broadleaf forest vegetation
- Shallow gravel channel with occasional benches or inset floodplains
- Mixed gravel bed (small gravels through to fines) with extensive wood loading
- Pools forming around woody debris common features
- Streams may have been intermittent



Forest clearance

- Terraces and floodplains cleared of vegetation and converted to agricultural use
- Riparian margin possibly remained vegetated
- Temporary increase in sediment yield, especially fines
- Increase in surface run-off and stream discharge
- Some instability on surrounding hillslopes but largely disconnected from the channel
- Incision initiated, some bank instability occurs (mass wasting)



Current

- Incision has resulted in the abandonment of previous inset floodplains (now are terraces)
- Increase in fine sediment loads from surrounding land use
- Lateral deposition of mixed material forming new inset floodplains/benches
- Some infilling of pools
- Willows in the riparian margin promoting aggradation of channel

Figure 3.5: Conceptualised evolutionary trajectory for a Confined gravel bed stream

3.3 Partly confined gravel bed stream

Partly confined rivers abut the valley margin for 10-90% of the reach length (Brierley and Fryirs, 2005). This means the lateral movement of the river across the floodplain is occasionally restricted by the valley margin, but the river can adjust both laterally across the floodplain and vertically within its banks. In the Moutere catchment, the valley margin can be characterised as hillslope, or alluvial terraces. There is evidence of highly sinuous former paleochannels on both the floodplain and terrace surfaces. This suggests that these partly confined gravel beds streams may have been modified at some point in the recent past (e.g. straightened and deepened) and /or suggests a long-term incision trend. A conceptualised evolutionary trajectory for partly confined gravel bed streams is provided in Figure 3.7, and a description of typical stream characteristics in Table 3.4.

These stream types are laterally active, with evidence of meander migration in the active channel, as well as historic terrace and hillslope erosion (Figure 3.6). Bank erosion appears to be largely driven by fluvial processes, such as scour and undercutting.

Instream geomorphic units such as riffles/run sequences are common, with occasional pools and stable undercuts. Small lateral gravel bars and islands are also common. During the site visit, a gravel deposit was observed to span the channel, possibly left behind as the flood peak passed and the bed transport ceased. The stream flowed beneath this deposit (flow was not apparent on the surface of the stream bed), and appeared as surface flow on the other side. This process appeared to be natural (as opposed to occurring through river management activities), and is likely to form an important part of sediment and biological processes for this stream type.

Riparian vegetation is critical for this stream type, providing shade to the stream, maintaining refuge pools, providing food, and providing the coarse woody debris often responsible for creating the refuge pools. The refuge pools, and adjacent wetlands/paleochannels which are now mostly lost are likely to have been key habitat for giant kōkopu.

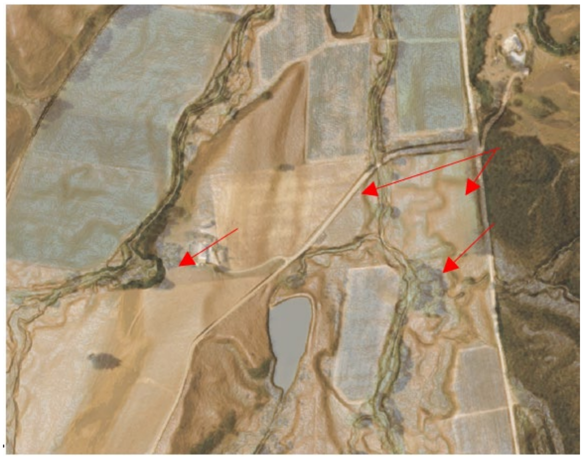
	
An example of a partly confined gravel bed stream. Note the gently sloping terrace at the top right of the photo. Looking upstream from the Deepdale Road Bridge.	Aerial view of two partly confined gravel bed streams. Note evidence of hillslope erosion (bottom left red arrow), terraces (top right double red arrow) and evidence of paleochannels (bottom right red arrow).

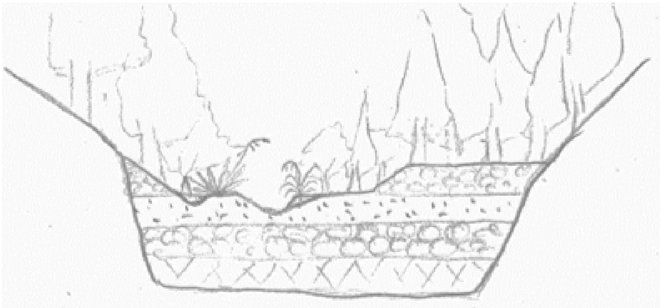
Figure 3.6: Example of partly confined gravel bed stream in the Moutere catchment

Table 3.4: Characteristics of a partly confined gravel bed stream type

Valley setting	Channel planform	Bed material	Channel geometry	Geomorphic units
Partly-confined	Moderate sinuosity	Rounded gravels and fines.	Shallow U-shaped channel up to 2 m wide active channel, with steep banks up to 1.5 m high.	Riffle/runs, occasional pools.
Bar types	**Sensitivity to change**	**Floodplain features**	**Dominant erosion type**	**Flow type**
Occasional lateral, bars.	Moderate	Evidence of highly sinuous paleo channels	Undercutting	Permanent (but patches of 'hyporheic flow' where stream bed is dry)
Indicative Mean Flow (m^3/s)*	**Indicative Mean Annual Flood (m^3/s)**	**Indicative 5 year ARI (m^3/s)****	**Indicative 10 year ARI (m^3/s)****	**Indicative 100 year ARI (m^3/s)****
0.03	N/A	32.7	38.6	60.2
Vegetation assemblages				
Current vegetation is predominantly pasture, with areas of pine forestry. Historic vegetation assemblages would have been lowland podocarp-broadleaf forest on the drier surfaces, and possibly kahikatea/harekeke swamp forest on the wetter surfaces, including paleo-channels, channel cut-offs or back channels.				

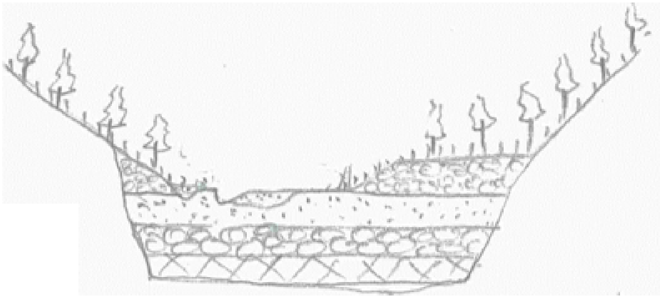
*NB – Flow statistics from https://shiny.niwa.co.nz/nzrivermaps/ and averaged over three indicative reaches

**NB – Flow statistics have been generated using the Rational Method from New Zealand River Flood Statistics (NIWA), and averaged over three indicative reaches



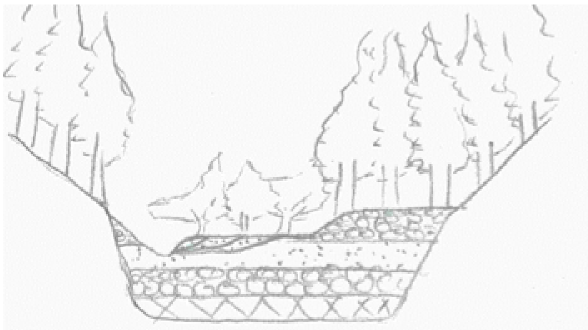
Pre-European

- Native kahikatea floodplain forest with extensive 'swamp' vegetation
- Shallow gravel channel with multiple channel off-cuts and back-swamps
- Mixed gravel bed (cobbles through to fines) with extensive wood loading



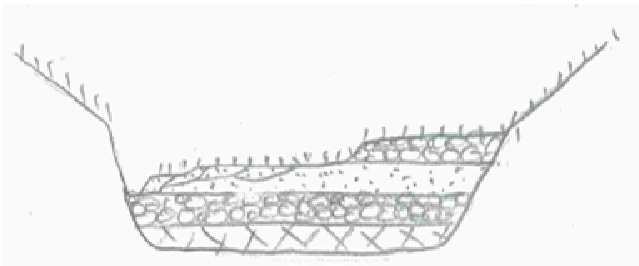
Forest clearance/pine conversion

- Forest cleared and often replanted in pines
- Temporary increase in sediment yield
- Aggradation of channel, possible avulsion
- Increased flooding of valley floor



Mature pine forest

- Sediment supply reduced as pines mature
- Flow volumes slightly increased from native forest levels
- Channel incises through previous deposits



Pine harvesting

- Flow volumes increase following harvesting
- Sediment yield increases (mainly fines)
- Incision processes accelerated
- Bank erosion widespread

Figure 3.7: Conceptualised evolutionary trajectory for a partly confined gravel bed stream

3.4 Valley fill

A valley fill river type is a valley that has filled with sediment over time and has turned into a wetland with a discontinuous/absent channel characterised by occasional pools (Figure 3.8). These stream types are sediment stores, naturally occurring sediment traps, and are critical for the maintenance of base flows and attenuation of flood flows. However, they are also highly susceptible to erosion. Lowering of downstream base levels (for example incision or deepening of the channel downstream) or changing the hydrology (such as increasing flows or reducing vegetation cover) may cause erosion of the bed of the valley fill, changing its character and behaviour (Figure 3.9).

Valley fills appear to be reasonably common in the headwaters of most small tributaries, especially on the east and south-eastern sides of the catchment. They are often associated with confined valley settings with average slopes of approximately 8%, but ranging between 1-10% (Table 3.5).

Vegetation, predominantly dense wetland vegetation are a key element for the form and function of the stream types, but also for habitat provision for fish, birds and aquatic invertebrates. An At Risk-Declining fernbird (*Bowdleria punctata*), was observed in the site shown in Figure 3.8.

The refuge pools in these systems could also have been suitable habitat for galaxiids such as banded kōkopu (*Galaxias fasciatus*) and invertebrates such as kōura (*Paranephrops planifrons*).

Given the high susceptibility for this stream type to change character and behaviour with a change in catchment conditions, and the habitat these stream types provide to a range of fauna, this stream type should be considered a high priority for restoration and protection.

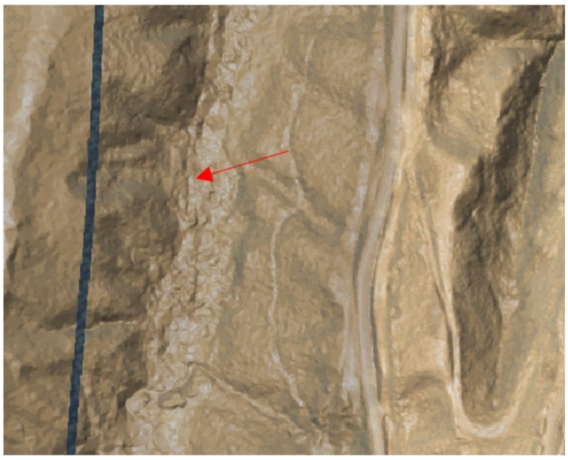
	
A valley fill with partially intact wetland vegetation, surrounded by recently harvested pine. Looking upstream towards the head of the catchment.	A topographical aerial view of the valley fill (red arrow) with the Moutere Highway running along the right side of the image.

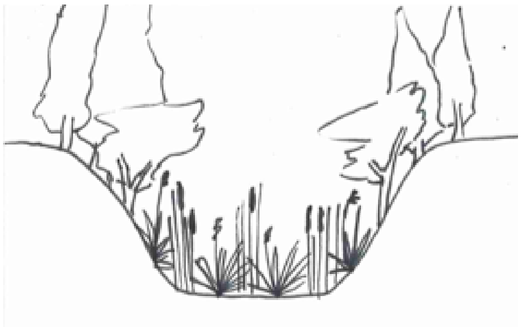
Figure 3.8: Example of a valley fill stream type

Table 3.5: Characteristics of a valley fill stream type

Valley setting	Channel planform	Bed material	Channel geometry	Geomorphic units
Unconfined	Straight, discontinuous channel, resembling a wetland.	Predominantly fine grained material with some small gravels. Lots of organic material.	Infilled channel with occasional pools.	Occasional pools.
Bar types	**Sensitivity to change**	**Floodplain features**	**Dominant erosion type**	**Flow type**
N/A	High	N/A	Incision (bed erosion)	Intermittent/ephemeral
Indicative Mean Flow (m^3/s)*	**Indicative Mean Annual Flood (m^3/s)**	**Indicative 5 year ARI (m^3/s)****	**Indicative 10 year ARI (m^3/s)****	**Indicative 100 year ARI (m^3/s)****
0.003	N/A	7.7	9.2	15.8
Vegetation assemblages				
Where the stream type remains 'intact' with a discontinuous channel, current vegetation is predominantly wetland species such as Rautahi. Where stream type is degraded (e.g. a single channel) vegetation type is a mix of wetland and exotic pasture species. Historic vegetation assemblages would have likely been kahikatea/harakeke swamp forest.				

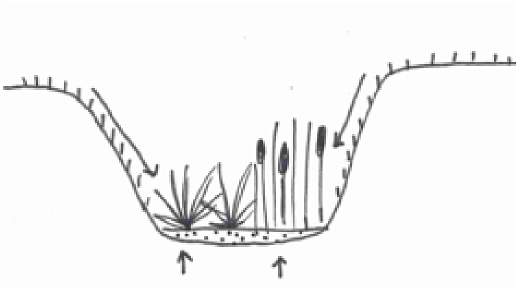
*NB – Flow statistics from https://shiny.niwa.co.nz/nzrivermaps/ and averaged over three indicative reaches

**NB – Flow statistics have been generated using the Rational Method from New Zealand River Flood Statistics (NIWA), and averaged over three indicative reaches



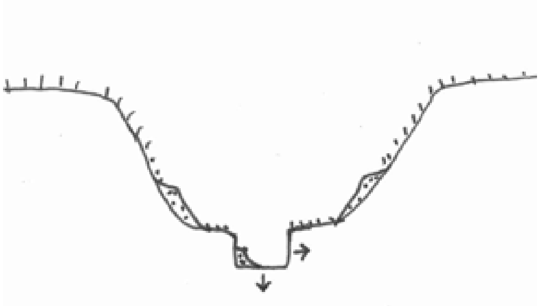
Pre-European

- Native podocarp/beech forest on the hillslopes
- No clearly defined channel on valley floor, but defined pools are common
- Swamp/wetland vegetation occupies the whole of the valley floor



Forest and flax clearance

- Forest cleared (limited to no vegetation on the hillslopes)
- Harekeke removed from valley floor but other vegetation remains intact
- Large sediment supply from hillslopes (more than the channel can transport)
- Further aggradation of valley floor



Agricultural period/Current

- Increase in discharge exceeds the increase in sediment yield (see hillslope disconnect below)
- Drainage channels dug through 'swamp'
- Channel incises, headcuts present, but incision can only go as far as the Moutere gravel armour layer
- Bank erosion may occur, generally as rotational slip/slump or mass wasting
- Hillslopes generally disconnected from channel which reduces sediment supply to stream

Figure 3.9: Conceptualised evolutionary trajectory for a valley fill stream underlain by Moutere gravels.

3.5 Unconfined meandering gravel bed

Unconfined channels are laterally active across a broad alluvial floodplain. Interaction with the valley margin is rare. Terraces are present in some places on the floodplain, suggesting a long-term degredational trend. There is also evidence of highly sinuous paleochannels on the floodplains suggesting that this river type has had a reduction in sinuosity and potentially an increase in sediment transport capacity over time (refer Figure 3.10 and Table 3.6).

An analysis of a short section of this stream type suggest that this stream type has had a change in character and behaviour in the last 100 years, and often resembled a 'wandering gravel bed' stream type. For the reach analysed, there has been an 86% reduction in average active channel width and a 43% reduction in average low-flow channel width between 1940 and 2017. The analysis also suggested that there was a substantial decrease in the sinuosity of the low-flow channel, and a loss of channel length and heterogeneity as a result (Figure 3.11).

The loss of channel width has likely had a number of flow effects, the key ecological effect likely being a loss of geomorphic diversity (such as riffles, runs and pools that provide fish habitat), extensive gravel bars which provide critical habitat for some bird species, and other effects on water quality parameters such as temperature and dissolved oxygen (DO).

In its current state as an unconfined meandering gravel bed stream, both vertical adjustment and lateral adjustment are expected processes. Vertical adjustment in this stream type can be attributed to:

- Aggradation events when channel widths are over-wide, discharge reduces, or sediment loads increase beyond a critical threshold, or
- Degradation/incision when channel widths are narrow, access to the floodplain is restricted, channel lengths are shortened, discharge is increased, or sediment loads are reduced beyond a critical threshold.

Lateral adjustment in this stream type can be attributed to:

- Point bar deposition and subsequent meander migration through bank erosion,
- Undercutting of the toe of banks resulting in bank failure,
- Mass wasting of over-steep banks as a result of incision.

Continuous floodplains on both sides of the channel increase the likelihood for these floodplains to be comprised of recent unconsolidated alluvials, increasing the erosion susceptibility of the banks. Once vegetation is removed, the channel banks and floodplain surfaces have a higher risk of lateral adjustment.

	
An example of an unconfined meandering gravel bed. Looking downstream from the Supplejack Valley Road Bridge.	Aerial view of an unconfined meandering gravel bed stream type showing incised gullies (top left red arrow), terraces (bottom left red arrow) and paleochannels (right red arrow).

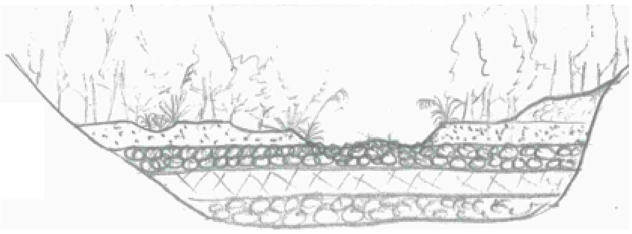
Figure 3.10: Example of unconfined meandering gravel bed stream type in the Moutere catchment

Table 3.6: Characteristics of an unconfined meandering gravel bed stream type

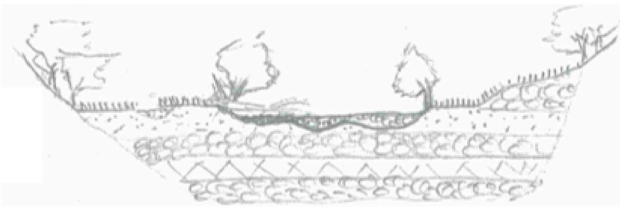
Valley setting	**Channel planform**	**Bed material**	**Channel geometry**	**Geomorphic units**
Unconfined	Straight, to moderate sinuosity, incised channel. Limited access to floodplain.	Rounded gravels and fines, some infrequent bedrock.	U-shaped channel 5 m wide, with near vertical banks 4 m high.	Riffle/runs, occasional pools.
Bar types	**Sensitivity to change**	**Floodplain features**	**Dominant erosion type**	**Flow type**
Mid-channel and lateral bars	Moderate-high	Terraces, paleochannels, incised 'gullies'	Undercutting	Permanent
Indicative Mean Flow (m^3/s)*	**Indicative Mean Annual Flood (m^3/s)**	**Indicative 5 year ARI (m^3/s)****	**Indicative 10 year ARI (m^3/s)****	**Indicative 100 year ARI (m^3/s)****
0.06		42.0	49.6	83.3
Vegetation assemblages				
Current vegetation is a mix of exotic woody species such as willow and poplar, with an abundance of exotic weedy and herbaceous species such as wild hops, calystegia and blackberry. Historic vegetation assemblages would have been primary successional species manuka, tutu, toetoe and karamu along the active edges, kahikatea/harekeke swamp forest on the wetter surfaces, including paleo-channels, channel cut-offs or back channels and lowland podocarp-broadleaf forest on the drier surfaces.				

*NB – Flow statistics from https://shiny.niwa.co.nz/nzrivermaps/ and averaged over three indicative reaches

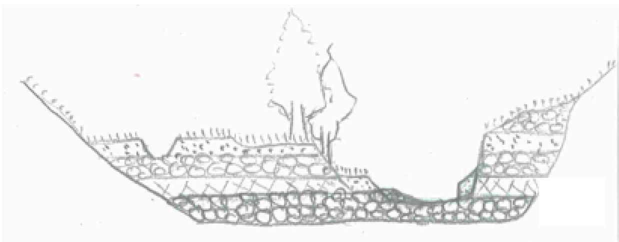
**NB – Flow statistics have been generated using the Rational Method from New Zealand River Flood Statistics (NIWA), and averaged over three indicative reaches



Pre-European
- Native kahikatea floodplain forest with extensive 'swamp' vegetation
- Shallow gravel channel with multiple channel off-cuts and back-swamps
- Mixed gravel bed (cobbles through to fines) with extensive wood loading
- Most likely a 'Wandering Gravel Bed' stream type.



Forest clearance
- Floodplain forest cleared first, riparian vegetation intact.
- Hill vegetation cleared later and often replaced with pines, but hillslopes mostly disconnected from channel
- Minor increase sediment in the channel, mainly fines
- Minor aggradation of channel
- Increased flooding across floodplain



Current
- Increase in run-off from forest clearance leading to incision
- Riparian margin contains some mature vegetation
- Flow volumes increased (limited interception)
- Channel incises and narrows.
- Bank erosion mainly associated with mass wasting

Figure 3.11: Conceptualised evolutionary trajectory for an unconfined meandering gravel bed river

3.6 Unconfined cut and fill sand bed derived from Separation Point Granite's (SPS)

SPS is a specific geological unit mostly found in the north-west corner of the catchment. SPS has a deep weathering profile and overlying soils are dominated by silt and sand that is prone to hillslope erosion, and so streams in SPS can be highly dynamic. Pulses of sediment are generated during large rainfall events or sometimes following earthquake events. Being in an unconfined setting, these stream types have a low slope (1-3%) and are prone to rapid bed aggradation and possible channel avulsion during large flood events ('fill' phase)(refer Figure 3.12 and Table 3.7).

After the flood event has past, the channel will begin to 'cut' back down through the deposited material, possibly in a new location than prior to the deposition event (avulsion). During the 'cut' period, the banks will be unstable, and will periodically erode until riparian vegetation begins to recolonise the bank surfaces (Figure 3.13). During the 'cut' phase, the channel will have reduced capacity, and may flood surrounding areas more frequently.

This stream type is likely to have had a large degree of modification, such as channel 'dredging' to reduce flood risk, or some degree of channel straightening. However, as the examples of this stream type in the Moutere catchment still maintain some degree of sinuosity, they have been treated separately to those that are effectively straight 'drainage' channels (refer Figure 3.12).

The cut and fill nature of this stream type means in-stream habitat features are often transient. This means wider landscape features become important components of this stream type, providing refuge for organisms during either phase of change. Features such as benches, Backswamps and wetlands are all elements of this stream type which have generally been lost through landscape modification.

The fine-grained nature of the alluvium generally means the banks are not stable, and dense woody vegetation is required to maintain stability long term. Woody vegetation is also critical to ensure woody debris is contributed to the channel, and woody debris/wood features are a crucial habitat component missing from many streams in New Zealand. While woody debris provides in-stream habitat, it also promotes sediment storage, and this may have implications for downstream reaches should the wood 'dam' be breached, and a wave of additional sediment is released. Sediment pulses leading to rapid bed aggradation are likely to be more frequent in catchments that are in pine forest, or pasture.

Because of this dynamism, a level of caution is advised when working with channels with these characteristics. A vegetated buffer around the stream channel is ideal to prevent any erosion response impacting on private and public assets. Riparian vegetation will also need to be considered carefully. Suites of species will need to be chosen that can 'lay flat' against flows, re-sprout or 'spring back' from being covered in sediment, and that can quickly recolonise bare surfaces. Willows, Poplars and Pines should be avoided. Willows exacerbate depositional processes and limit the degree of 'cutting' a stream can do. For unconfined sand bed streams in SPS, this can increase the risk of flooding and channel avulsion.

Incorporating wood features into the stream restoration projects in these stream types should be carefully considered and all risks documented and mitigated where possible in the reach scale restoration design. Rock features would be more resilient to channel change. However, rock armouring should also be used carefully, and the potential geomorphic impact of rock armouring assessed before being used.

Riparian planting, recreating, or enhancing bench features, and re-creating meanders in this stream type are considered positive restoration outcomes for this stream type.

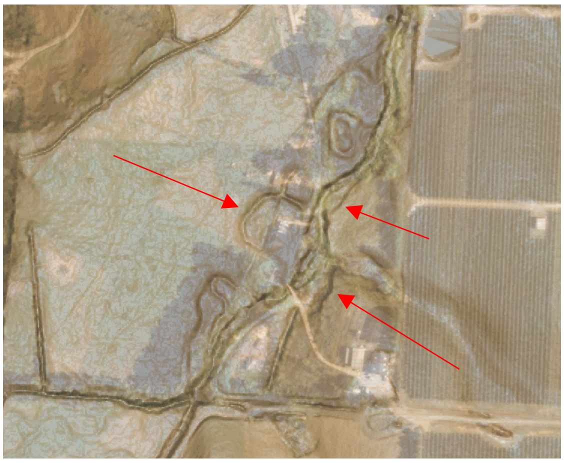
	
An example of an unconfined sand bed stream derived from Separation Point Granite, showing a 'fill' response.	An example of an unconfined sand bed stream derived from Separation Point Granite which has filled with sediment. Note the paleochannels (left red arrow), inset benches (top right red arrow), and terrace (bottom red arrow).

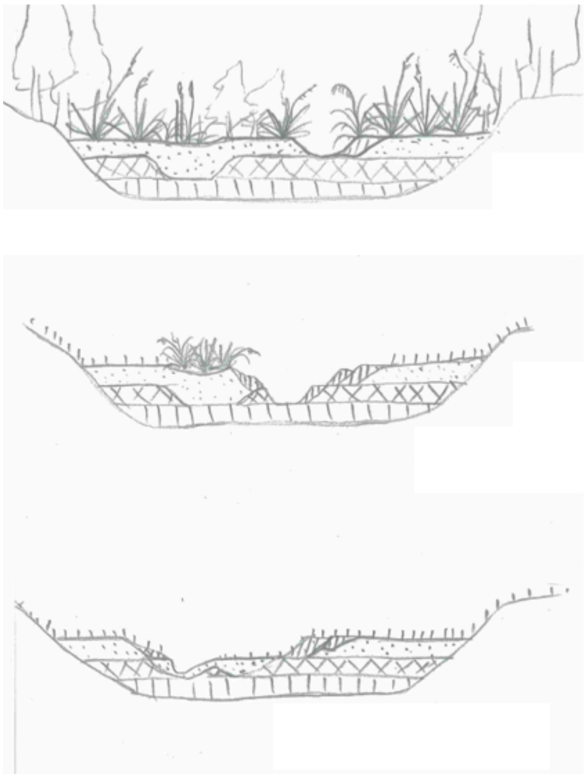
Figure 3.12: Representative examples of an unconfined cut and fill sand bed stream in separation point granites

Table 3.7: Characteristics of an unconfined cut and fill sand bed stream in SPS stream type

Valley setting	**Channel planform**	**Bed material**	**Channel geometry**	**Geomorphic units**
Unconfined	Moderate sinuosity, variable degrees of modification, varying access to floodplain.	Fine grained material, mainly sand.	Variable channel geometry: wide, infilled channel 6 m wide, with steep banks 1.5 m high; deepened U-shaped channel 1 m wide with steep banks 4 m high.	Variable units: Homogenous bed (glide); riffle/run sequences; benches, Backswamps, wetlands.
Bar types	**Sensitivity to change**	**Floodplain features**	**Dominant erosion type**	**Flow type**
N/A	High	Terraces, paleochannels.	Undercutting, mass wasting	Permanent
Indicative Mean Flow (m^3/s)*	**Indicative Mean Annual Flood (m^3/s)**	**Indicative 5 year ARI (m^3/s)****	**Indicative 10 year ARI (m^3/s)****	**Indicative 100 year ARI (m^3/s)****
0.02		24.4	29.0	49.8
Vegetation assemblages				
Current vegetation is mostly exotic species, dominated by willows. Historic vegetation types would have been primary successional species manuka, tutu, toetoe and karamu along the active edges, with kahikatea swamp forest on the older but frequently wetted surfaces.				

*NB – Flow statistics from https://shiny.niwa.co.nz/nzrivermaps/ and averaged over three indicative reaches

**NB – Flow statistics have been generated using the Rational Method from New Zealand River Flood Statistics (NIWA), and averaged over three indicative reaches



Pre-European

- Native kahikatea floodplain forest with extensive 'swamp' vegetation
- Channel mostly well defined, but some areas of channel may be wide and shallow
- Backswamps and meander cut-offs common
- Bed and banks almost entirely sand, held together by vegetation
- Geomorphic features created by vegetation and woody debris
- Extensive/significant channel change (including avulsion) occurs during reasonably frequent large events (such as 5-10yr ARI).

Forest clearance

- Forest cleared and floodplains converted to agriculture
- Increases in sediment yield from surrounding land use, and upstream reaches
- Increase in stream discharge
- Incision (cut phase) occurs through head cut erosion
- Bank erosion likely to be extensive during 'cut' phases.
- Cut and fill response of channel largely depends on event history, channel likely to aggrade (fill) during a flood event and incise (cut) in the moths/years following the event

Current

- Elevated sediment yield from pre-European condition, but increases linked to upstream sources (e.g. pine harvesting)
- Bank erosion has been extensive and material deposited in the channel (increasing local sediment loads)
- Flow volumes slightly increased from native forest levels
- Channel widening and infilling generally occurring, exacerbated by willows.
- Cut and fill phases still linked to event history.

Figure 3.13: Conceptualised evolutionary trajectory for an unconfined meandering gravel bed river

3.7 Unconfined artificially straightened fine-grained stream derived from Separation Point Granites (SPS)

Artificially straightened sand bed streams derived from SPS in an unconfined valley setting are very similar to the stream type described in Section 3.6, the main difference being these streams are straight (refer Figure 3.14 and Table 3.8). The main reason for straightening and deepening is likely to facilitate the conversion of the floodplains from 'swamps' to arable land (Figure 3.15).

The northern part of the Moutere catchment is characterised by a shared floodplain with the Moutueka River. Evidence of this shared use is still visible on the floodplain (Figure 3.14). The remnant flood channels may have been 'used' as preferential flow paths for the artificially straightened sand bed streams in the vicinity, prior to modification.

The lack of any evidence of highly sinuous paleochannels near the artificially straightened sand bed streams also suggests that these streams may have been 'discontinuous' channels flowing through a large wetland.

	
An example of an unconfined artificially straightened sand bed stream derived from Separation Point Granite. Looking upstream from Chamberlain Street Bridge. Source: Google earth.	An example of an unconfined artificially straightened sand bed stream derived from Separation Point Granite (left red arrow). Note the remnants of the Motueka River flood path (right red arrow).

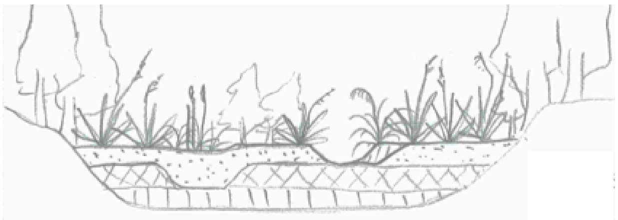
Figure 3.14: An example of an unconfined artificially straightened sand bed stream in separation point granites

Table 3.8: Characteristics of an unconfined artificially straightened sand bed stream in SPS stream type

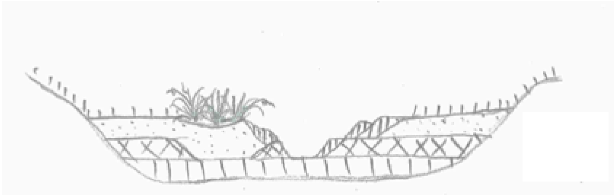
Valley setting	**Channel planform**	**Bed material**	**Channel geometry**	**Geomorphic units**
Unconfined	Straight, incised channel. Limited access to floodplain.	Fine grained material, mainly sand.	Variable channel geometry: wide, infilled channel 6 m wide, with steep banks 1.5 m high; deepened U-shaped channel 1 m wide with steep banks 4 m high.	Variable units: Homogenous bed (glide); riffle/run sequences; benches, Backswamps, wetlands.
Bar types	**Sensitivity to change**	**Floodplain features**	**Dominant erosion type**	**Flow type**
N/A	Moderate-high	Terraces, paleochannels.	Undercutting, mass wasting	Permanent
Indicative Mean Flow (m^3/s)*	**Indicative Mean Annual Flood (m^3/s)**	**Indicative 5 year ARI (m^3/s)****	**Indicative 10 year ARI (m^3/s)****	**Indicative 100 year ARI (m^3/s)****
0.01		9.0	10.7	18.3
Vegetation assemblages				
Current vegetation is mostly exotic herbaceous species. Historic vegetation types would have been primary successional species manuka, tutu, toetoe and karamu along the active edges, with kahikatea swamp forest on the older but frequently wetted surfaces.				

*NB – Flow statistics from https://shiny.niwa.co.nz/nzrivermaps/ and averaged over three indicative reaches

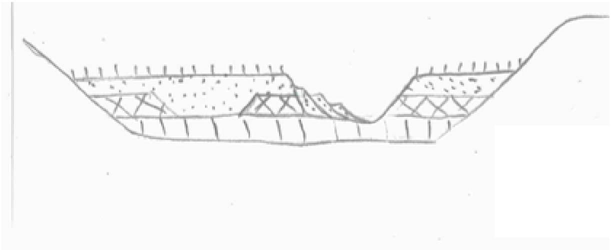
**NB – Flow statistics have been generated using the Rational Method from New Zealand River Flood Statistics (NIWA), and averaged over three indicative reaches



Pre-European
- Native kahikatea floodplain forest with extensive 'swamp' vegetation
- Channel mostly well defined, but some areas of channel may be wide and shallow
- Backswamps and meander cut-offs common
- Bed and banks almost entirely sand, held together by vegetation
- Geomorphic features created by vegetation and woody debris
- Extensive/significant channel change (including avulsion) occurs during reasonably frequent large events (such as 5-10yr ARI).



Forest clearance
- Forest cleared and floodplains converted to agriculture
- Increases in sediment yield from surrounding land use, and upstream reaches
- Increase in stream discharge
- Incision (cut phase) occurs through head cut erosion
- Bank erosion likely to be extensive during 'cut' phases.
- Cut and fill response of channel largely depends on event history, channel likely to aggrade (fill) during a flood event and incise (cut) in the moths/years following the event



Current
- Elevated sediment yield from pre-European condition, but increases linked to upstream sources (e.g. pine harvesting)
- Stream channel straightened and deepened, possibly widened resulting in slightly elevated velocities
- Flow volumes slightly increased from native forest levels
- Bank erosion mainly through rotational slip and slump
- 'Fill' phases now restricted to lateral bar development, very little risk of avulsion

Figure 3.15: Conceptualised evolutionary trajectory for an unconfined artificially straightened fine-grained river in SPS

3.8 Confined mixed-bed stream derived from Separation Point Granites (SPS)

Confined streams in SPS are in the steep upper catchment in the north western part of the Moutere catchment. No representative sites were visited during the site visit. However, it is likely that these streams are characterised by steep slopes (10%), narrow low flow channels (0.5-0.8 m), inset benches, and a mixed sediment load of boulders, cobbles, pebbles and sands (refer Figure 3.16 and Table 3.9).

These streams have small contributing catchments, but the steepness means the flow dynamic is likely to be very 'flashy' with most rainfall events generating flow.

The mixed bed load and flashy discharge regime means this stream type is highly dynamic, and dense woody vegetation is required to maintain stability long term (Figure 3.17). Pine forest, willows, or poplars are not recommended to be used as riparian vegetation for these streams, due to the large volume of wood fall associated with these species.

Woody debris is an important part of regulating stream processes in this stream type, and creating in-stream habitat such as pools. However, while wood provides in-stream habitat, it also promotes sediment storage, and this may have implications for downstream reaches should the wood 'dam' be breached, and a wave of additional sediment is released. The likelihood of this happening is high in catchments that are in pine forest due the manner in which pine is harvested and the slash left in place.

An example of a confined stream with a range of sediment sizes (mixed bed) in separation point granites.

Figure 3.16: Representative example of confined mixed bed stream in separation point granites

Table 3.9: Characteristics of a confined mixed bed stream in SPS stream type

Valley setting	Channel planform	Bed material	Channel geometry	Geomorphic units
Confined	Low sinuosity, steep gradient channels	Angular boulders, gravels and fines, some infrequent bedrock.	Unknown	Steps, pools, cascades, riffles.
Bar types	**Sensitivity to change**	**Floodplain features**	**Dominant erosion type**	**Flow type**
Unknown	Low-moderate	No floodplains	Bed erosion	Intermittent
Indicative Mean Flow (m^3/s)*	**Indicative Mean Annual Flood (m^3/s)**	**Indicative 5 year ARI (m^3/s)****	**Indicative 10 year ARI (m^3/s)****	**Indicative 100 year ARI (m^3/s)****
0.004		8.0	9.5	15.2
Vegetation assemblages				
Current vegetation assemblages are unknown, but possibly mostly exotic pine forests. Historic vegetation types would have been podocarp-beech forest, and possibly some lowland podocarp-broadleaf forest on the lower terraces (where present).				

*NB – Flow statistics from https://shiny.niwa.co.nz/nzrivermaps/ and averaged over three indicative reaches

**NB – Flow statistics have been generated using the Rational Method from New Zealand River Flood Statistics (NIWA), and averaged over three indicative reaches

Pre-European

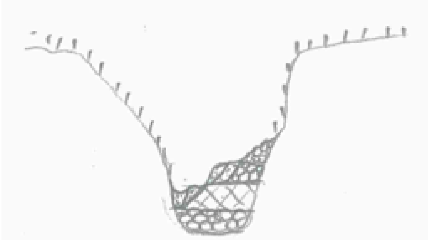
- Native podocarp beech forest vegetation
- Clearly defined channel with undercut banks held together by vegetation
- Mixed bed with a high proportion of sands, and extensive wood loading
- Occasional inset floodplains comprised of sand
- Channel change readily occurs during annual storms or greater
- Extensive/significant channel change occurs in high magnitude low frequency events

Forest clearance/pine conversion

- Forest cleared and often replanted in pines
- Temporary increase in sediment yield
- Some hillslope instability, and hillslopes highly connected to the channel
- Aggradation of channel, possible avulsion
- Increased flooding of valley floor
- Debris jams cause sediment and water build up in the channel, resulting in substantial downstream impacts when debris jam is released

Mature pine forest

- Sediment supply reduced as pines mature
- Flow volumes slightly increased from native forest levels
- Channel incises through previous deposits
- Erodible and unstable sand banks generally unvegetated and experience high rates of erosion



Pine harvesting

- Flow volumes increase following harvesting
- Sediment yield increases (mainly fines)
- Initial infilling of the channel and increase risk of flooding
- Incision follows initial channel infilling
- High risk of debris jams forming
- Possible aggradation and increased flood risk to downstream reaches

Figure 3.17: Conceptualised evolutionary trajectory for confined mixed bed river in SPS

3.9 Recovery potential and stream type prioritisation

Determining the recovery potential of the restoration reach helps to identify how much effort might be needed to 'restore' the reach back to a pre-existing condition, if it needs to be supported to function in its current state or transitioned towards a different condition. This is a key determination for the prioritisation of stream types (Hyslop *et al*. 2009).

The River Styles Framework provides a decision tree for working out the recovery potential of a reach (Figure 3.18), and therefore its priortisation. This framework relies on the determination of reach condition against an 'intact' example of the representative stream type. Geomorphic condition of a reach is site specific, and was out of scope of the Moutere Restoration framework. With streams that have been heavily modified, the determination of 'intactness' poses some challenges, as such, this framework will not be suitable for 'artificially straightened' stream types (hence priority 8, the lowest priority, in Table 3.1). In addition, very few 'intact' examples of any of the stream types were identified in the catchment.

For the purposes of the Moutere Catchment restoration framework, the condition of the restoration reach can be compared to the representative examples provided in Section 3, and using the following guiding questions:

- What are the planform characteristics of the reach, and do they match with what's expected for the stream type?
- What types of geomorphic units/habitat types are present in the reach, do they match what's expected for the stream type?
- What is the frequency of geomorphic units/habitat types in the reach, and does that match with what would be expected for an intact example of the stream type?
- What riparian vegetation is present, and does it match the 'historic' vegetation for the stream type?
- Does the reach have a floodplain, and can it access the floodplain, or has it incised away from the floodplain (and will rarely or infrequently engage the floodplain)?
- Are there any currently active drivers of change that may negatively impact on the condition of the reach now, or in the future (e.g. present in downstream of upstream reaches).

High recovery reaches, are going to provide the best value for money, needing the least amount of effort for the greatest gain. These reaches should be the highest priority for restoration and protection. As an example, valley fill stream types in headwater areas that still retain their 'valley fill' characteristics, would be considered high recovery reaches and should be targeted for restoration efforts. These have been identified as the highest priority reaches (priority 1 in Table 3.1).

Moderate recovery reaches are those that may require a little more investment in regard to time and cost, and it may take a little longer for the reach to achieve the restoration goals. The restoration of moderate recovery reaches may also have additional beneficial impacts on adjacent reaches (e.g. reduction of fine-grained sediment transported into downstream reaches) and may be critical to restore in order to achieve the restoration goals of adjacent reaches. These reaches should be prioritised second. As an example, some partly-confined meandering gravel bed stream types in pastural landscapes would likely be moderate recovery reaches. These reaches should form part of a long term restoration strategy, with those reaches downstream of already restored or intact reaches prioritised. These have been identified as priority 2 in Table 3.1.

Low recovery reaches are likely to have a significant cost associated with them, and it will likely take a long time to reach their restoration goals. Most commonly, these reaches are the most heavily modified and sit at the very downstream end of the catchments. These reaches obviously provide a critical role in both fish spawning (for some species) and fish passage. Therefore, restoration of these reaches may simply aim to improve the conditions for fish spawning and fish passage, but full scale restoration may be the low priority.

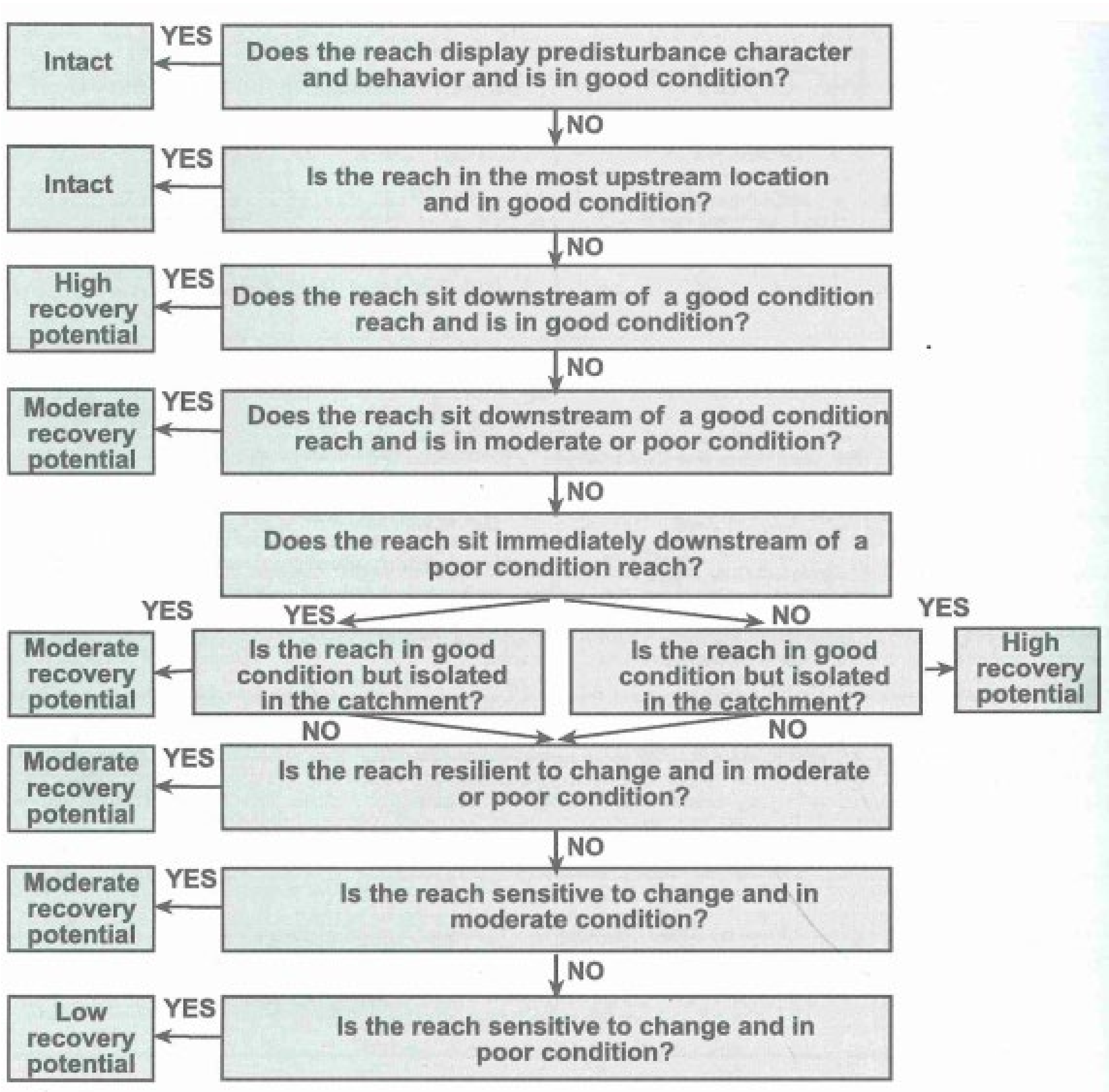


Figure 3.18: River Styles Framework decision making tree for determining recovery potential of a reach, with implications for restoration prioritisation (Taken from Brierley and Fryirs, 2005)

4 Restoration framework

The restoration framework described below has been developed using geomorphic principles, and was primarily based on two geomorphic frameworks, namely the Rosgen Geomorphic Channel Design framework (USDA 2007) and the River Styles Framework (Brierley and Fryirs 2005).

One of the key components of both geomorphic frameworks, is characterising the stream type. This enables restoration objectives to be achievable for that stream type, ensuring it works with the prevailing catchment or geomorphic conditions/processes, and is contributing to the ecosystem health of the wider stream network.

Stream characterisation has been completed, at a high level only, for the Moutere catchment (Section 3). However, once a restoration site has been identified, a more detailed site assessment will need to be undertaken to confirm the stream type (Section A1.2).

In addition to confirming the stream type, additional steps have been added to capture/identify:

- The restoration objectives (Appendix A1.1),
- The drivers of channel change (Appendix A1.3),
- What the effects of change might mean for ecosystem health (Appendix A1.4), and
- The likelihood of being able to 'restore' a stream to its pre-modified stream type i.e. its recovery potential (Section 3.9).

The recovery potential also feeds into the prioritisation of restoration (Refer to Table 3.1).

Although stream typing might underpin the restoration project, identifying the restoration goals and objectives is the number one priority for any successful stream restoration project (Appendix A1.1). A conceptualised restoration framework project flow is provided in Figure 4.1.

The Moutere restoration framework provides an over-arching strategy for stream restoration and a tool-box of potential management actions for the Moutere Catchment. As such, the restoration framework only provides high-level guidance on the first five steps in Figure 4.1. The Moutere restoration framework does not cover implementation, and reach based restoration plans should still be developed. The framework also doesn't cover restoration monitoring, however this is highly recommended as it will provide evidence for restoration success, or critical and timely feedback for changes to the restoration goals if the restoration objectives are not being met.

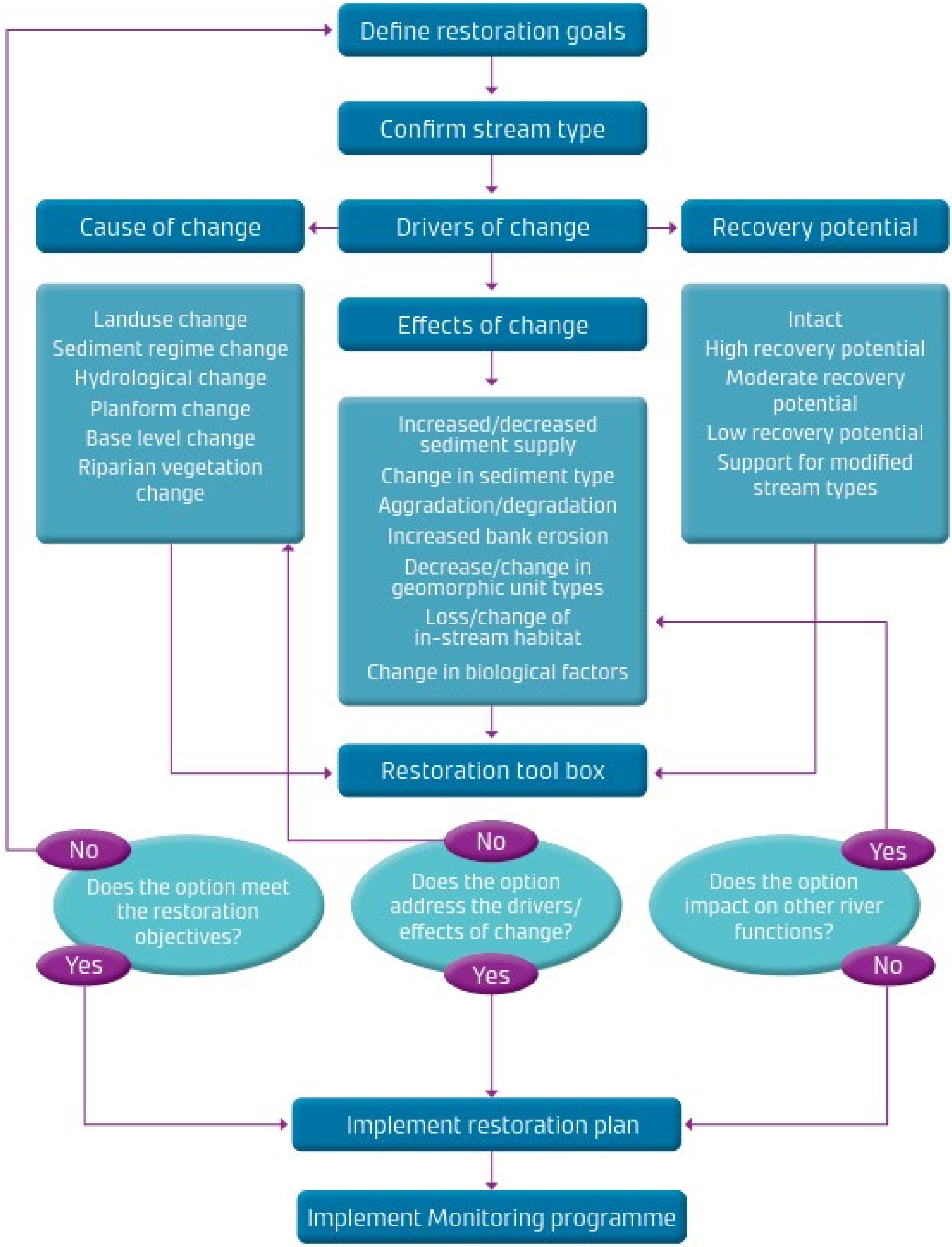


Figure 4.1: Conceptualised Stream Restoration Framework for the Moutere Catchment

5 Restoration tool-box

Once the stream type has been determined, the drivers and effects of change defined, and the recovery potential determined, then the appropriate restoration actions can be identified. As the Moutere restoration framework is based on geomorphic principles, the restoration actions are based on stream type, with only some actions suitable for some stream types (Table 5.1).

All of the restoration actions identified in Table 5.1 below have been specifically chosen for the particular stream types based on:

- The actions ability to work with the likely geomorphic processes.
- The actions ability to address the likely drivers of change.
- The likelihood of the action being sustainable in the long term (equally that the action doesn't cause issues in the future).
- The action providing ecological benefits as well as geomorphic benefits.

All actions in the 'restoration tool box' are discussed in more detail in Appendix B and have been chosen specifically for each stream type based on professional judgement, and actions have not been recommended for all stream types. Refer to the stream type descriptions in Section 3 and the action description in Appendix B for more information.

It is important to match the restoration actions to the restoration goals as well as the drivers of change to make sure that the restoration goals are achieved. If the actions suitable for the stream type does not match with the goals, then a review of the restoration goals may be required (refer to Figure 4.1.

Table 5.1: The suite of recommended restoration actions suitable for stream types within the Moutere catchment

River type			Confined			Partly confined		Unconfined			
Restoration options	**Indicative timeframe**	**Indicative costs**	**gravel bed**	**Mixed bed derived from SPS**	**Valley fill**	**Artificially straightened gravel bed**	**Meandering gravel bed**	**Meandering gravel bed**	**Cut and fill derived from SPS**	**Artificially straightened gravel bed**	**Artificially straightened fine-grained derived from SPS**
Retirement of hillslopes	Long	High	✓	✓	✓				✓*		
Channel realignment (increase sinuosity)	Short - medium	High				✓				✓*	✓
Channel widening	Short - medium	High			✓	✓	✓		✓		✓
Wetland creation	Medium - long	Medium -high			✓	✓	✓	✓	✓	✓	✓
Integrated vegetation	Short - medium	Medium-high (width and density dependent)				✓	✓	✓		✓	
Bank regrading/ stabilisation	Short	Medium				✓	✓	✓		✓	
Two-stage channels/ Constructed benches	Short	Medium				✓	✓	✓	✓	✓	✓
Rock riffles	Short - medium	Low-medium				✓	✓	✓		✓	
Weirs, cross-vanes and W-vanes	Short-medium	Low-medium				✓	✓	✓	✓	✓	✓
Rock chutes	Short - medium	Low-medium	✓	✓	✓						
Log or rock groynes	Short-medium	Low-medium				✓	✓	✓	✓*	✓*	✓*
Timber pile training fields	Short-medium	Low-medium					✓*	✓*	✓		
Floodplain engagement	Medium - long	Low-medium				✓	✓	✓	✓	✓	✓
Riparian planting	Medium - long	Low-high (width and density dependent)	✓	✓	✓	✓	✓	✓	✓	✓	✓

(*) denotes where the option may only be sometimes suitable, or caution needed when utilising the option in that stream type.

6 Recommendations/next steps

The Moutere Restoration Framework provides an overarching framework for stream restoration and prioritisation based on geomorphic principles. As it doesn't provide a step-by-step guide to stream restoration, the following recommendations have been provided to guide the next steps in the stream restoration process:

- Overlay the prioritisation of stream types as identified in Table 3.1 with social, cultural, ecological and economic priorities, existing initiatives or objectives to ensure reach scale prioritisation is holistic and inclusive.
- Create reach scale restoration plans for the top priority reaches using the restoration framework outlined in Section 4. This will need to include the ground -truthing of the stream type to ensure restoration outcomes are achievable for the chosen reach.
- While riparian vegetation is incredibly important for stream restoration, ensure that any physical works to address negative geomorphic processes/support better geomorphic function, are undertaken before planting occurs. This is to ensure that riparian planting is not destroyed through physical works.
- Some physical works may require engineering design to ensure there are no adverse effects on the reach or the wider stream processes. Engineering design may need to include some hydraulic modelling.
- The stream type GIS layer has been based on version 3 of the River Environment Classification (REC) and is therefore quite coarse. This could be updated in the future, or as the stream types are ground-truthed during the development of the reach scale restoration plans.
- Develop a holistic monitoring programme that ensures the restoration objectives are being met. This should be based in both ecology and geomorphology to ensure the true benefits of the restoration are being realised.

7 Applicability

This report has been prepared by Tonkin & Taylor Limited (T+T) for Tasman District Council (TDC) with respect to the particular brief given to us, by reference to applicable professional standards, guidelines, procedures and practices at the date of issue of this report. The purpose of this report is to provide generic guidance only. The application and interpretation of this report in specific circumstances is outside the control of T+T and is the sole responsibility of the user.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
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Senior Fluvial Geomorphologist	Project Director

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Appendix A: Restoration framework descriptions

A1.1 Define restoration goals

One of the biggest contributing factors to unsuccessful stream restoration is often attributed to poorly defined restoration goals (Rutherfurd *et al.* 2000). To be able to design a realistic restoration plan, where success can be 'measured' and 'monitored', you need to have a clearly defined goal, or set of goals. The restoration plan can then be designed around that goal.

Below are a selection of restoration goals that could be applied in the Moutere catchment. Each goal also has a selection of questions, to help decide if the goal is appropriate for the stream type:

- Increase/enhance/restore/recreate in-stream aquatic habitat.
  - What habitats have been lost in your stream over the past 100 years?
  - What can we realistically re-introduce into the stream under the current geomorphic conditions?
  - Are there any areas downstream that might be affected by proposed habitat features? e.g. small culverts that might get blocked by large woody debris.
  - Does my stream type need specific riparian vegetation to ensure geomorphic processes are maintained?
- Increase streambank stability.
  - Does my stream type have a high risk of bank erosion?
  - What type of bank erosion occurs in my stream type?
  - What habitat features could have a dual role of erosion protection and habitat provision?
  - Is bank erosion in my stream type actually caused by bed erosion?
  - Do I need to address bed erosion to help with the long-term stability of my stream?
- Improve water quality.
  - What is contributing to water quality decline?
  - Can water quality be effectively addressed in my reach, or do I need to address sources further upstream first?
- Improve base flows and reduce flood peaks.
  - Has my stream type previously had wetlands present in the catchment?
  - Has my stream type previously had Backswamps and ox-bows/paleo channels in the catchment?
  - Is there an opportunity to recreate or enhance wetlands in the upper reaches of my stream?
  - Has my stream been straightened and deepened?
  - What can I realistically do to support a more natural hydrological regime without compromising flood protection?

A1.2 Confirm stream type

To confirm the stream type, a series of observations should be undertaken on site, and compared to the indicative parameter values for each stream type (Table 3.1).

The relevant stream type characteristics tables in Section 3 should help to confirm the stream type of your reach.

The data collected to confirm the stream type can also be used in restoration monitoring to track the improvement in condition in the restoration reach over time.

A1.3 Drivers of change

While the drivers of change have been identified at a catchment scale for each of the stream types, identifying the most significant and/or what additional drivers of change are impacting your site at a local scale will also help to identify appropriate restoration actions.

It should be noted, however, that drivers of change at a catchment scale may be too difficult to address at a site-based restoration level or may not be able to be wholly mitigated, but may still be impacting the stability of your reach. If this is the case, you may need to reassess your restoration goals to ensure they are achievable for your stream type and the applicable drivers of change.

In the sub-section below, six of the most common drivers of change (USDA 2007) in the Moutere catchment have been identified and discussed. These drivers of change may occur individually, or may interact with each other initiating 'secondary drivers' of change, potentially causing cumulative or cascading effects (discussed further in Appendix A1.4). Additional information on the effects of drivers of change can also be found in the Tasman Natural Channel Design Guideline.

A1.3.1 Land use change

Land use change is often one of the major drivers of change at a catchment level, and difficult to address in a reach scale restoration plan. However, land use change may also affect change at a reach scale, especially when the change is recent. Sections 2.1, 2.3, 2.4and 2.5 identify pine forestry and pasture land uses as increasing fine grained sediment loads and have led to long term increases in discharge. Some of the secondary drivers that land use change can cause at a reach scale include:

- Sediment regime change.
- Hydrological change.
- Riparian vegetation change.

Where these secondary drivers are affecting stream stability within the restoration reach as a result of land use change, it may be more pragmatic to address the secondary drivers within the restoration plan.

A1.3.2 Sediment regime change

Sediment regime change is typically used to describe a change in the volume of sediment within a system, where a reduction in sediment may induce channel degradation, while an increase in sediment may induce channel aggradation. Sediment regime change can also be talked about in terms of a change in sediment type. This might be a change from predominantly rounded gravels forming the bed of the channel, to the bed being dominated by predominantly fine grained material. This change in sediment type can also have significant effects on habitat quality and quantity for much of our indigenous aquatic fauna.

A change in the sediment regime could be due to a range of factors, including:

- Long-term or decadal changes in climate affecting vegetation type or discharge regimes.
- Land use change (e.g. an increase in forestry, or farming).
- Bank stability (e.g. an increase in bank erosion).

- Bed level change (e.g. a flattening of the channel gradient may decrease flow velocities and reduce sediment size).
- Riparian vegetation changes (e.g. a reduction in riparian vegetation leading to increased bank erosion and surface run-off).

Several of these drivers of change can be addressed within the reach using the tool box options provided in Section 5 (e.g. riparian vegetation changes, bank stability, bed level change). Other drivers of change, such as long-term or decadal changes in sediment loads, will either need to be addressed at a catchment scale (through land use change), or will be unavoidable due to the effects of climate change and should be acknowledged in the restoration plan. Improving overall ecosystem health will improve the resilience of streams to unavoidable changes.

A1.3.3 Hydrological change

Hydrological change can again occur over different spatial and temporal scales. Changing hydrology can also, again, affect several other drivers of change and vice versa.

Some of the things that can cause hydrological change include:

- Long-term or decadal changes in climate affecting flow regimes.
- Land use change (e.g. an increase in urban areas decreasing baseflows but increasing peak flows).
- Surface water or ground water takes (linked to long term climate and land use)
- Planform change (e.g. drainage lines constructed through valley fill systems)
- Bed level change (e.g. a decrease in bed level might increase base flow if a shallow aquifer is intercepted, or a decrease in baseflow if a stream aggrades and surface water becomes hyporheic).
- Riparian vegetation changes (e.g. Willows and poplars are known to reduce base flows, and this can be more pronounced in intermittent streams).

Several of these drivers of change can be addressed within the reach using the tool box options provided in Section 5 (e.g. riparian vegetation changes, bed level change). Other drivers of change, such land use change or surface/groundwater takes may need to be addressed through council planning processes.

Long term changes in hydrology potentially associated with climate change may be unavoidable and should be acknowledged in the restoration plan. However, improving overall ecosystem health will improve the resilience of streams to these changes.

A1.3.4 Planform change

Planform change are changes in the overall shape of the reach or stream corridor, such as channel straightening. Planform change can be a natural occurrence, e.g. changes in the river following a large flood. However, in the Moutere catchment, most planform changes tend to be human induced.

Planform change can influence sediment dynamics (e.g. a change in sediment type), discharge (e.g. changes in volume contained within the channel, or velocities of flows), and base level.

Some examples of planform change include:

- Channel straightening.
- Wetland/valley fill modification (through the creation of drains).
- Meander cut-offs (can be a natural or human induced phenomenon).

- Long term changes in sediment or hydrology changing river character and behaviour (e.g. a switch from a wandering gravel bed stream type to a meandering stream type with a reduction in sediment supply).

There are small scale 'within' channel interventions than can help increase sinuosity at a meso-scale presented in the tool box options provided in Section 5. Full stream realignment has not been covered in this restoration framework, but guidance can be found for this larger scale intervention in the Tasman Natural Channel Design Guidelines. However, it must be acknowledged, that reinstating a meandering planform may change the prevailing geomorphic processes, and understanding the risks (such as a potential aggradational response leading to an increase in the occurrence of flooding) may need to be carefully considered before embarking on a such a project.

Long term changes in planform potentially associated with climate change may be unavoidable and should be acknowledged in the restoration plan. However, in the identification of this fact, the restoration plan can seek to work with the existing stream conditions to improve overall ecosystem health.

A1.3.5 Base level change

Base level is the 'imaginary' horizontal level or surface to which rivers are essentially trying to erode to (Schumm 1993). It is often sea level, but can also be reach scale factors such as a dam, weir, bedrock outcrop, or the bed level of the main stem river. Changes in bed level will likely induce a change in the geomorphic processes of a reach, most notably in terms of aggradation (when there is a base level elevation increase), or degradation (when there is a base level elevation decrease).

Things that might be associated with a base level elevation increase (promoting aggradation) include:

- Sea level rise.
- Reaches upstream of a dam/weir.
- Immediately upstream of a river level crossing (e.g. concrete ford).
- Aggradation in the main stem river (that the restoration reach feeds into).

Things that might be associated with a base level elevation decrease (promoting degradation) include:

- Reaches downstream of a dam/weir.
- Immediately downstream of a river level crossing (concrete ford).
- Removal of a weir/dam.
- Degradation in the main stem river (that the restoration reach feeds into).

Several of these drivers of change could potentially be addressed within the reach but will ultimately require buy-in from asset owners and/or stakeholders.

Some drivers of change, such as sea level rise, will be unavoidable and should be acknowledged in the restoration plan and an adaptive management approach may need to be used to suit the incremental nature of the issue.

Identifying and acknowledging changes in bed level, may also help to understand and identify possible barriers to successful restoration, and feed into the recovery potential and prioritisation framework.

A1.3.6 Riparian vegetation change

Riparian vegetation plays a critical role in geomorphic processes, as well as habitat provision and ecosystem health. While there has been a large uptake in riparian planting to improve stream health in the last decade, the nuances of 'the right vegetation in the right place' can be the determining factor in the success of the restoration project.

The TDC Natural Channel Design Guideline (specifically Sections 4.7 and 7) address some considerations in regards to riparian planting. It is also important to link your riparian planting actions to your stream restoration outcomes. For example:

- If improving stream bank stability is the objective of the restoration plan, then ensuring the types of plants selected for the restoration support bank stability is critical. For example;
  - If fluvial scour or overland run-off is driving the erosion then sedges and grasses might be the key riparian component.
  - If mass wasting and over-steep banks are driving erosion then more deep rooting species on the bank and bank margins might be the key riparian component.
- If improving water quality is the objective of the restoration plan, then ensuring the riparian plants selected for the restoration plan support water quality functions is critical. For example:
  - If nutrient run-off from surrounding land-uses occurs as 'surface flow' within the reach then sedges and grasses along the stream bank might be a key component.
  - If water quality is being degraded through a piped network directly into the stream, or coming in via tributaries, then floodplain wetlands (or stormwater wetlands) might be a key component of the restoration.
  - If dissolved oxygen is low within the reach, then planting might need to include tall trees to provide shade to the stream, and deciduous trees should be avoided (as excessive leaf fall from deciduous trees can affect dissolved oxygen levels).

A1.4 Effects of change

It may be hard to determine the driver(s) of change, and harder still to determine the effect(s) of that change. Appendix A Table 1 below provides a high-level look at the possible range of effects that might be associated with each driver of change.

This can be used to help refine the restoration goals, restoration interventions, or to help better understand and identify the possible drivers of change.

Appendix A Table 1: Summary of the potential effects of the different drivers of change

Driver of change	Effect						
	Aggradation	Degradation	Bank stability	In-stream habitat	Water quality (sediment)	Water quality (other)	Water quantity
Landuse change							
Forestry	x		x	✓/x	x	x	x
Pasture/cropping	x	x	x		x	x	x
Urbanisation		x	x	x	x	x	x
Sediment regime change							
Increased sediment load	x			x	x		
Decreased sediment load		x	x	x			

Driver of change	Effect						
	Aggradation	**Degradation**	**Bank stability**	**In-stream habitat**	**Water quality (sediment)**	**Water quality (other)**	**Water quantity**
Change in sediment type				x	✓/x		
Hydrological change							
Increase in discharge		x	x	✓/x	✓/x	✓	✓/x
Decrease in discharge	x	✓	✓	✓/x	✓	x	✓/x
Planform change							
Reduction in stream length		x	x	x	x		
Reduction in stream sinuosity		x	x	x	x		
Increase in stream cross-sectional area	✓/x	✓	✓	✓	✓/x	x	
Decrease in stream cross-sectional area		x	x	x		✓/x	
Base level change							
Decrease in base level elevation		x	x	x			
Increase in base level elevation	✓/x		✓			✓/x	
Riparian vegetation change							
Increased indigenous riparian vegetation			✓	✓	✓	✓	✓
Decreased indigenous riparian vegetation		x	x	x	x	x	x
Increased deciduous exotic vegetation	x		✓	✓/x		✓/x	✓/x
Increased exotic vegetation (willows, poplars)	x		✓	✓/x		x	x
Decreased exotic vegetation (willows, poplars)		✓/x	x	✓/x	✓/x	✓/x	✓/x
Increased grasses/sedges			✓	✓	✓	✓	

Driver of change	Effect						
	Aggradation	**Degradation**	**Bank stability**	**In-stream habitat**	**Water quality (sediment)**	**Water quality (other)**	**Water quantity**
Decreased grasses/sedges			x	x	x	x	

N.B: A X denotes a negative effect, a ✓ denotes a positive effect, a X/✓ combination reflects possible positive or negative effect.

Appendix B: Restoration tool descriptions

B1.1 Retirement of hillslopes/large buffers

Hillslope processes play a key role in the hydrological and sediment regimes in every catchment. Changes to land-use on hillslopes has been demonstrated to affect both of the these, often resulting in the degradation of stream environments.

Hughes *et al.* (2020) show that hillslopes converted from indigenous forest to pine forestry resulted in a reduction in total stormflow of 30%, with a potential reduction in low-flows of up to 25% in the Waikato. The use of some traditional exotic tree species in hillslope stabilisation (e.g. poplars) may also result in a reduction in stream flows.

Harvesting of pine forests also leads to large areas of exposed soil, which has been linked to an increase in sediment yield of between 50-75% (Basher 2013; Gibbs 2006; Gibbs and Woodward 2017, Fuller *et al.* 2013). These elevated sediment yields can persist for up to seven years post harvesting.

Hillslopes in pasture may also result in an increase in run-off and an increase in sediment with some research suggesting increased sediment yields between 50-70% compared to indigenous forest (Basher 2013; Fuller *et al.* 2013).

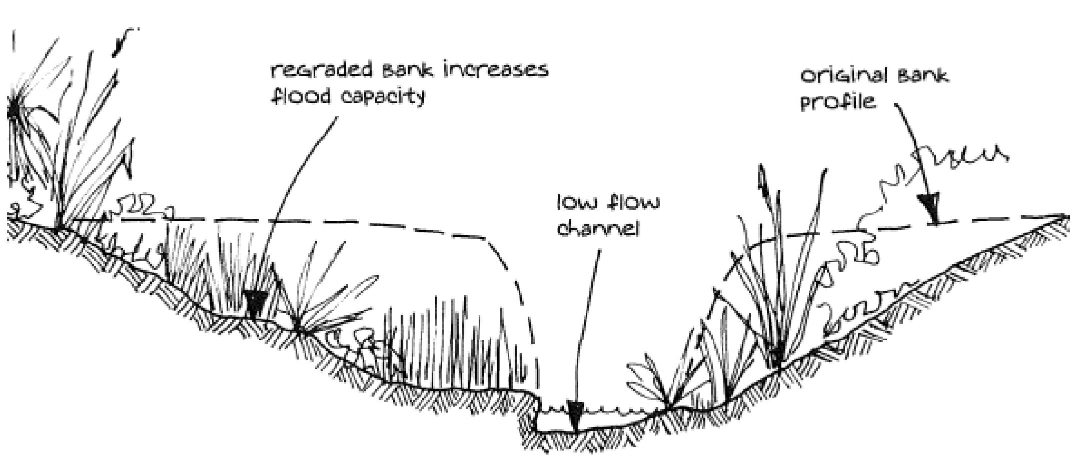
In particularly sensitive stream types (such as valley fills and streams in soils derived from SPS), the retirement of hillslopes from commercial forestry or grazing may help to increase stream restoration outcomes. If complete retirement and replanting of hillslopes is not possible, large vegetated buffers around the streams (greater than 20 m wide) may help to reduce sediment inputs into the streams and potentially help to moderate hydrological changes.

B1.2 Bank regrading/stabilisation

Bank regrading is where the bank is 'cut back' using machinery to a stable angle (Figure Appendix B.1). Vegetation on the regraded banks provide stabilisation and reduce direct bank scour. Bank regrading is suitable for overstep banks, but if fluvial erosion of the toe of the bank is the primary cause, rock armouring of the toe may also be required.

There are several options for regrading depending on the size of the bank, and the space available. If the bank height is low (<5 m) a single regrade across the whole face can be considered. If the bank is greater than 5 m, several benches can be cut into the bank, although this may require more space. Benching may also be considered in confined rivers where additional space for flood flows may help to reduce flood flow velocities and help support natural deposition processes.

Regraded banks will always require stabilisation. At minimum hydroseeding with a dwarf rye grass to help stabilise the cut face and prevent rilling is required in the short term. Once the grass is established, riparian planting can be undertaken using a combination of rhizomatous native sedges (*Carex geminata*) and woody species. If stream velocities are high or additional protection is desired, bank protection using rock, geotextile 'soil bags' or soil socks may be used in conjunction with planting.



Conceptual diagram of a stream cross section showing original stream bank, and regraded bank profile (Christchurch City Council, 2003).

Figure Appendix B.1: Example of bank regrading with vegetation suitable for all river types

B1.3 Two-stage channels/bench features

Two stage channels are stream channels constructed with a bench feature that is inundated relatively frequently (1-2 year ARI). These channels have been utilised in the U.S and Australia for the last few decades, especially in agricultural landscapes (Febria and Harding 2018).

Generally, benches are cut into the existing channel, and are vegetated to encourage fine sediment deposition (such as sands). Hydrological data for the stream reach is used to determine the height of the bench to optimise inundation and sediment capture. Bench widths are usually between 1 and 3 m, and can be either on both sides of the stream channel, or on one side only (Febria and Harding 2018; Taylor and Francis 2011).

Two-stage channels would be for reaches with a higher percentage of fine sediment load (sands). But bench features are also a way to increase nutrient processing (especially nitrates and phosphorus), and can provide a ‘floodplain’ function in narrow or incised streams.

The intent of the two-stage channel is that flood water is able to spread out over a greater area, within the channel, acting like a mini-floodplain. The lower flow velocities associated with this process encourages fine sediment deposition on the bench surface. Evidence from the US suggests a reduction in turbidity between 15 - 82% during floods, alongside reductions in nitrate runoff from pasture land, which has a knock-on effect on water quality (Febria and Harding 2018).

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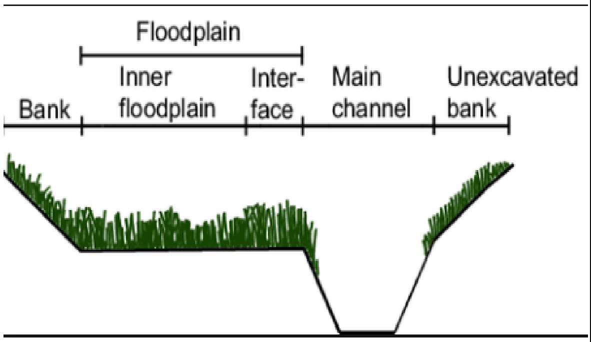
<tr><td></td><td>
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<tr><td>Example of a regraded and benched stream bank with native sedges (T+T files).</td><td>Conceptual drawing of a two-stage channel (Västilä, 2015).</td></tr>
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Figure Appendix B.2: Example of regraded banks with bench feature

B1.4 In-stream structures

Reaches that display active and on-going bed or bank instability (erosion) could be stabilised by adding in-stream structures. These structures can also provide additional in-stream habitat, providing a dual benefit of erosion protection and habitat enhancement. There are a range of structures suitable for different river types and different geomorphic processes, and identifying which structure to use in what circumstance can be difficult. For example, bank erosion can be driven by bed degradation, and as such remedial actions should focus on stabilising the bed, rather than addressing the bank erosion.

A range of instream structures are discussed below.

B1.4.1 Rock riffles

Rock riffles are ‘natural’ structures that provide bed armouring to a short ‘steep’ section of the river. They are essentially a grade control structure. Rock riffles can be constructed on the bed, at bed level, to help reduce bed erosion (Figure Appendix B.3). These features can use locally sourced rock to better represent ‘natural’ features. Rock riffles are more commonly found in partly confined and unconfined gravel or mixed bed rivers, but can also help stabilise or protect valley fill systems if incision is identified as a driver of change.

	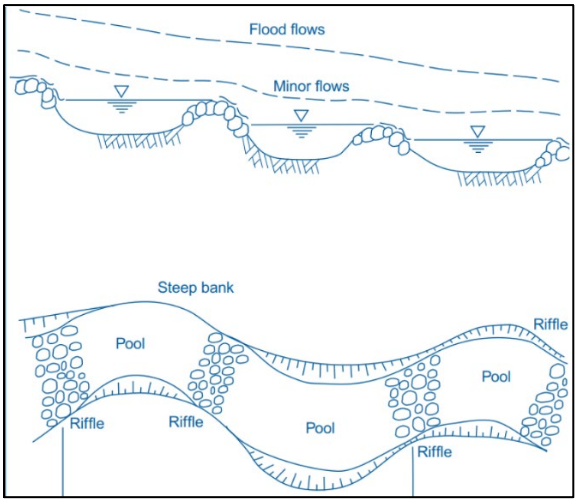
An example of a series of rock riffles fitted into a natural stream to control bed degradation (incision) Image from (Department of Environmental protection Maryland, 2018).	Plan and cross section view of riffle construction and placement in regards to meanders and flows (image from Brisbane City Council, 2003).

Figure Appendix B.3: Examples of constructed rock riffles

B1.4.2 Rock chutes

Rock chutes are drop structures that are constructed within the stream channel to mitigate bed incision in streams. Rock chutes are similar to a rock riffle, but are designed to be more robust and are specifically for instances where there may be headcuts, or where streams have been shortened (through straightening), or streams that are at high risk of erosion and may generate large pulses of sediment. Drop structures need to be permanent as they are located in the stream bed, and so need to be constructed from durable material (such as rock). Drop structures can sometimes have a dual purpose, such as a stream crossing, but if the intent is for it to control stream grade it needs to be designed for that purpose first and foremost.

Drop structures are suitable for all river types, but will require regular maintenance checks to ensure they are functioning as intended.

Rock chutes (Figure Appendix B.4) can be used to stabilise sudden streambed drops, typically 1 m to 5 m fall (Toore, 2001). Rock chutes should be designed to allow fish migration, and consideration should be given to sediment pre-loading between the rocks. Rock chutes require an underlying granular filter layer to prevent internal erosion and fines migration, and to help the larger rocks 'bed into' the stream bank.

In some instances, such as head cuts, the stream bed may require regrading to remove vertical faces. The crest of the rock chutes should be keyed into the stream bed, but sit slightly proud to prevent any reactivation of headcuts and to promote deposition. Bank armouring may also be required to prevent lateral scour.

	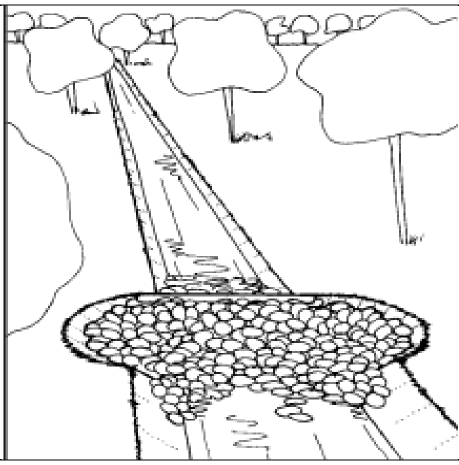
Example of a rock chute in a stream bed to control bed grade (Brisbane City Council, 2004).	Conceptual diagram of a rock chute for a head-cut / scour pool (Brisbane City Council, 2004).

Figure Appendix B.4: Examples of instream structures for areas of bed degradation

B1.4.3 Weirs, cross-vanes and W-vanes

Log and rock weirs are similar to riffles in that they create a stepped profile, but they are more often used in straight sections of stream, and sometimes in a series. Log and rock weirs create a wide shallow bed upstream of the weir which encourages deposition of sediment. Downstream of the weir, there will almost always be a scour pool to assist with the energy dissipation. Log and rock weirs can help stabilise the bed, help raise bed levels in a designated reach (if designed to do so), and can help create varied habitat in reaches with a mostly homogenous bed. Log and rock weirs are suitable in lower energy environments such as partly-confined meandering gravel bed, artificially straightened fine-grained and gravel bed rivers.

Log weirs should be constructed of a durable timber. Log weirs can either be manually anchored into the bank, or 'keyed' into the bank and bed. There are multiple methods of anchoring wood structures in stream and rivers including using ballast, piles, cabling/chaining, pining, and deadman anchors (WDFW, 2004).

There are several different types of log/rock weir configurations if scour pool formation needs to be contained or restricted. A straight weir will distribute energy evenly across the weir, and the scour pool will likely form across the entirety of the channel. These structures are more suitable to reaches that don't already have bank erosion issues. A cross-vane weir is similar to a straight weir, except the edges of the weir are angled away from the bank to discourage bed scour from occurring next to the banks. V-weirs will produce one deep scour pool in the centre of the channel. A W-weir will produce several smaller, shallower scour pools alternating across the channel.

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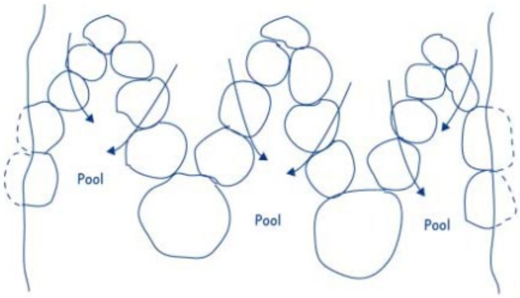
<td>
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<td>Example of a W-rock weir in a large river in America (Conejos Canyon Ranch, 2001).</td>
<td>Plan view of a W-rock weir, showing placement of rocks in regards to flow (sourced from Brisbane City Council, 2003)</td>
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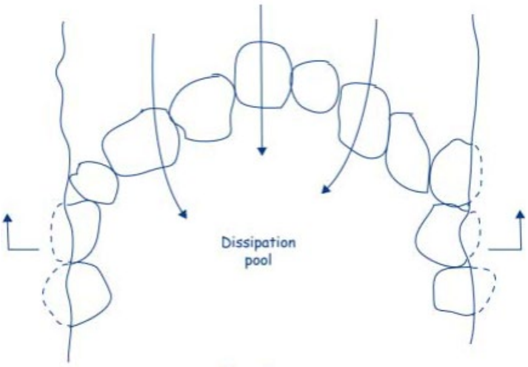
<td>
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<td>An example of a simple rock weir in a Waikato Stream, note the variety of rock sizes (WRC unpublished).</td>
<td>Plan view of a simple rock weir, showing placement of rocks in regards to flow. Large anchor stones can be used to keep the weir in place (image from Brisbane City Council, 2003).</td>
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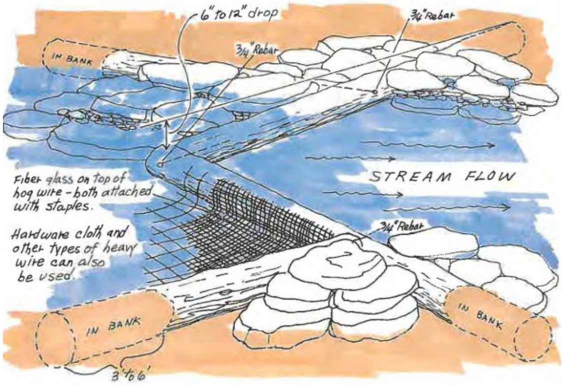
<td>
</td>
</tr>
<tr>
<td>An example of a cross-vane weir constructed from wood and anchored using a duckbill anchor (image from WRC unpublished).</td>
<td>Conceptual diagram of a log wedge dam with rock abutments (USDA 1992).</td>
</tr>
</table>

Figure Appendix B.5: Examples of weirs

B1.4.4 Log or rock groynes

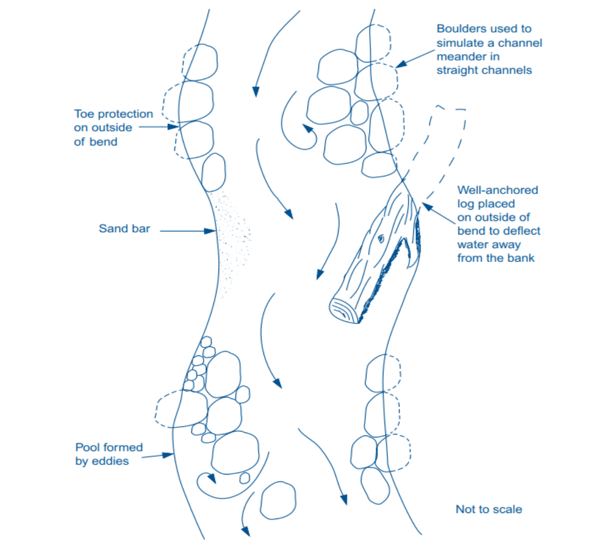
Groynes are used to help reduce flow velocities at the toe of bank, preventing bank erosion. They are only effective in streams that have a stable bed (i.e not actively incising or aggrading). They are generally installed perpendicular to the bank but can also face upstream (stream barbs) or downstream, and are always in a series. They are most commonly used on the outside of a meander bend.

Rock groynes are suitable for larger streams (e.g. greater than 5 m base width) including artificially straightened unconfined/partly confined gravel bed and confined/partly-confined meandering gravel bed stream types. While groynes could provide much needed habitat in streams (in soils derived from SPS), other options such as timber pile training fields may be more suitable in the more dynamic environment (See Section B1.4.5).

There is a risk that rock groynes may cause bank erosion on the opposite bank. This can be addressed through strategic armouring of the opposite bank, ensuring the opposite bank is well vegetated prior to installation, or reducing the length of the feature that extends into the channel.

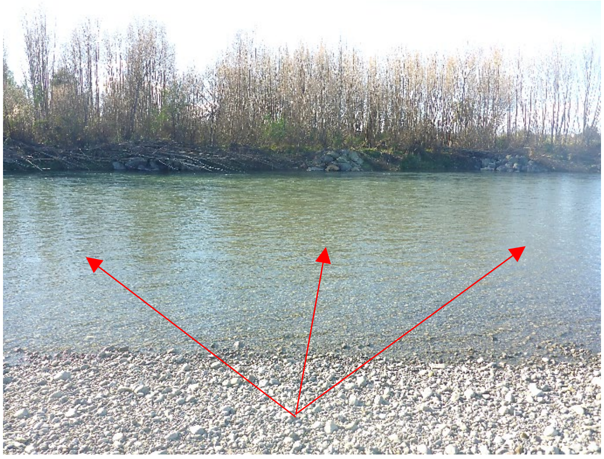
Log groynes can be constructed using felled woody material, with or without the root or crown structure attached and are suitable for small to large streams (e.g. greater than a 3 m base width). Leaving the crown attached, and placing this material into the flow will encourage more deposition where the crown is. Having the root ball extending into the channel will create a small scour pool around the root ball, and deposition on the downstream side.

Log groynes can either be manually anchored into the bank, or 'keyed' into the bank and bed. There are multiple methods of anchoring wood structures in stream and rivers including using ballast, piles, cabling/chaining, pining, and deadman anchors (WA DoF, 2004).

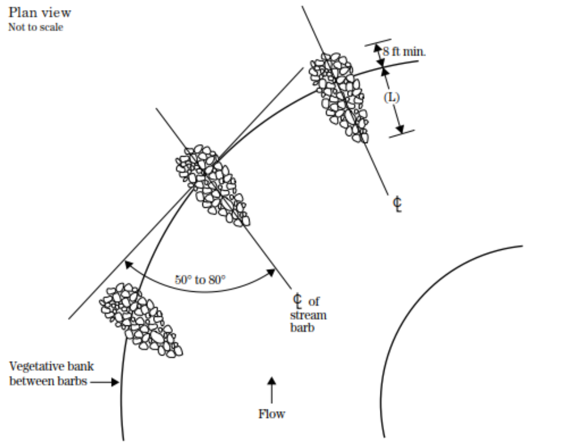


Conceptual diagram of log weirs including how to place in regards to direction of flow, and how to key into the banks (Brisbane City Council, 2003).

Example of a series of log groynes keyed into the bank and with additional boulder anchors (image from WRC unpublished.).



Examples of rock groynes in a mobile bed river in New Zealand (Authors own image)



Conceptual diagram of rock groynes showing indicative length and spacings (image from US Department of Agriculture, 1996).

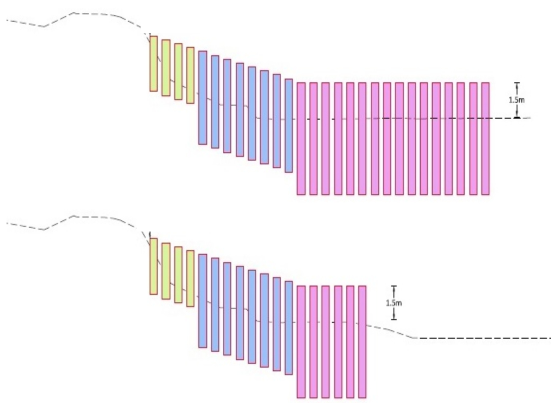
Figure Appendix B.6: Examples of instream structures to protect banks of erosion

B1.4.5 Timber pile training fields

Timber pile training fields are lines of timber poles (normally but not exclusively treated timber) driven vertically into the stream bed (Figure Appendix B.7). They are used to facilitate deposition at the toe of bank, with the long term aim of developing a vegetated bench in front of an eroding bank. Timber pile training fields are suitable for severe erosion, erosion occurring over long lengths of stream, or where bank regrading is unfeasible. They require a moderately high fine grained sediment load in order to be effective (e.g. in partly/unconfined streams in soils derived from SPS), and should be supported with indigenous riparian planting to encourage vegetation recruitment on deposited surfaces.

The layout and alignment of the timber pile training field requires engineering design, and the installation requires heavy machinery to hammer or vibrate the piles into the stream bed.

An example of a timber pile training field (red arrows) in North Queensland, 10 years post construction (image courtesy of Neilly Group Engineering).



Conceptual cross-section design of two lines of piles showing placement in relation to the stream bank, and how far they should be driven into the bed (image courtesy of Neilly Group Engineering).

Figure Appendix B.7: Example of timber pile training fields for use in incised meandering, incised confined and potentially partly confined river types

B1.5 Wetland creation

Functional wetlands have the potential to trap fine grained sediments and retain nutrients in a range of flow events, depending on how they are designed. They can potentially remove between 20 and 75% of the suspended sediment load. If designed appropriately, they may also increase flood storage, reducing downstream flooding. They are also formed a large component of the habitat in the Moutere catchment which has been lost over time.

There is the potential to create new functional 'wetlands' by utilising and enhancing previous floodplain features such as paleochannels, as well as restoring and enhancing valley fill stream types. Small offline wetlands could be utilised where there is an engageable floodplain, including the partly confined meandering gravel bed stream types All wetland features will need some careful consideration of how to prevent them from failing during large flood events, and to ensure the 'offline' wetlands are actively engaged during the intended flow size/frequency..

There are two options for offline wetlands. Firstly, the wetland could be a large bench feature (see Section B1.3 for details) that has rock armouring along the channel margin to reduce potential risks of failure. The middle of the wetland can contain deep pools with extensive planting in the surrounding areas. A second option for an offline wetland could be a wetland that is connected to the river by a channel or flowpath, but with no outlet so that water is stored in the area. There is the option of creating a high flow outlet channel at the downstream end of the wetland.

B1.6 Channel widening

Channel widening is to increase the active and exposed gravel area of the stream bed in some streams that have lost channel width due to drivers of change. Widening the active channel may decrease flood velocities, which may reduce some flood induced scour. Widening the active channel may also encourage sediment deposition in the form of gravel bars, helping to reinstate a more naturalised stream bed. In valley fill stream types which have degraded through bed incision, channel widening (with other supportive interventions) may be suitable to decrease flow velocities, increase deposition and help support the restoration of the stream back to a valley fill system.

Channel widening may not be possible in streams that have very high banks (such as artificially straightened unconfined gravel bed stream types), due to the large amount of earthworks required to undertake this.

B1.7 Channel realignment

As is evidenced in natural systems, a meandering channel increases channel length over a specified distance, effectively reducing stream power. This process encourages localised deposition, particularly within the channel, with the development of features such as point bars, as well as localised scour of the stream bed, such as on the outside of meanders. This process also helps to stabilise the bed, by reducing the channel slope thereby reducing stream velocities and potentially reducing bed erosion or incision processes. Some research suggests that lengthen the stream and increasing sinuosity may increase nutrient retention (Newcomer Johnson *et al.* 2018).

Several stream types in the Moutere catchment have been artificially straightened, and this option may help to support more natural stream processes to reduce bank and bed erosion, as well as increase habitat availability.

The best river types to undertake channel realignment and meander re-engagement, are those reaches that have had a reduction in sinuosity overtime. This includes: artificially straightened gravel bed, and artificially straightened fine-grained stream types.

B1.8 Floodplain engagement

Floodplain engagement enables flows to spread across the floodplain. This reduces the velocities of water, encourages the deposition of fine sediment, and has been shown to increase nutrient retention (particularly for nitrates and phosphorus).

Hume *et al.* (2009) suggest that re-engagement of a floodplain that equates to 1% of the total catchment area will lead to a 50% reduction in sediment loads entering the Tauranga Harbour. Based on international literature, deposition on floodplains range between 0.008 - 1 kg/m^2 and primarily targets 'fine grained sediments' (Asselman and Middelkoop 1995; Gretener and Strömquist 1987). Vegetation on the floodplain, such as grasses and sedges, increases the sedimentation rates. A review of the effectiveness of floodplains in nutrient retention and processing indicated that 60% of studies demonstrated success in increasing nutrient retention and processing by reengagement of the floodplain (Newcomer Johnson *et al.* 2018).

Floodplain re-engagement is difficult to achieve in todays society, when many floodplains are occupied and utilised by people. In partly-confined meandering gravel bed rivers, where there are small discrete floodplain pockets, floodplain reengagement could be explored. Floodplain pockets can also be 'cut into' the banks of a highly incised stream (refer to Section B1.3 and B1.5).

B1.9 Integrated vegetation

Integrated vegetation is a tool which uses willow poles to provide short term stability to stream banks, while indigenous vegetation is establishing. Willow poles can be used in a series of 'training line' along a stream bank (to stabilise the upper bank) and indigenous riparian plants planted in between the rows. The intent is for the willows to be trimmed at years 3 and 6 and then poisoned standing at year 9, which is when the indigenous vegetation would have sufficient root mass to stabilise the banks.

Including indigenous vegetation, rather than just relying solely on willows, is a better outcome for in-stream biota. Indigenous vegetation is not deciduous, and therefore will be contributing tolerable levels of organic matter into the stream for biological function (rather than large seasonal pulses which may degrade water quality). A range of indigenous riparian vegetation also provide a diverse structure to the bank, increasing bank stability from all types of flow (including overland run-off). In addition, some species of indigenous riparian vegetation have been shown to have a positive impact on nutrient loading in streams by intercepting and processing shallow nutrient transfer (such as mānuka and rautahi). Lastly, unlike willows, indigenous riparian vegetation is unlikely to become 'nuisance' vegetation which may need ongoing maintenance and management.

Integrated vegetation is suitable for all partly and unconfined stream types.

B1.10 Riparian planting

Riparian vegetation is an integral part of stream dynamics and enabling a stable and naturally functioning stream system, therefore we recommend riparian planting throughout the different river reaches. Riparian planting has the potential to stabilise banks and slow run-off. Additional benefits may include:

- Shade river water (60-70% shading from a fish-eye view).
- Provide habitat and encourage bird life.
- Enhance recreation and amenity value.
- Restore native biodiversity to stream environments.

Appropriate vegetation plays a critical role in stabilising stream banks and preventing bank erosion. Bank vegetation decreases water velocities near the bank and dampens turbulence by suppressing eddies. However, to be effective, the vegetation must extend to at least the low water level, otherwise flow will undercut the root zone.

Grasses and sedges are effective at both low and high velocities, being capable of withstanding much higher flow velocities than woody species such as trees. Plant roots also increase the shear strength of the bank soils. Rhizomatous grasses and sedges should be included in riparian planting, and a suitable grass cover-crop (such as a dwarf rye grass) used to provide bank stability and prevent rilling.

Channel vegetation can generally be divided into three categories:

- Toe of bank and bench vegetation –flexible sedges, rushes and grasses that do not impede flood conveyance, provide erosion control, can filter contaminants and sediments, and provides instream and spawning habitat.
- Mid-bank vegetation – small shrubs as well as flexible sedges, rushes, grasses and ferns that do not impede flood conveyance, provide erosion control, can filter contaminants and sediments, and provides instream and spawning habitat.
- Upper bank vegetation – a diverse range of trees, shrubs and groundcovers that provide bank stability, soil erosion control, shade, and habitat.

In smaller streams, and streams in confined reaches, woody riparian vegetation can be planted on all bank surfaces if required.

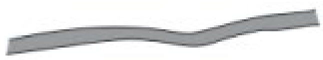
The Tasman District Council Natural Channel Design Guideline has further guidance on what to plant to achieve certain outcomes, and the Nelson Tasman Land Development Manual also has some guidance on riparian planting.

Appendix C: Glossary

Term	Sub-classifications	Meaning
Aggradation		The process of general bed raising by deposition of sediment.
Aggradation (rates)	Moderate bed aggradation	Accumulations of material at obstructions; bed tending to flat; same size material on bed as bars; evidence of minor overbank siltation.
	Extreme bed aggradation	High width/depth ratio; flat bed; channel largely blocked; overbank siltation evident; adjacent water logging, trees or vegetation in the channel.
Active channel		The width of the stream channel that is wider than the low-flow channel, narrower than the bankfull channel and carries frequent flow events (i.e. seasonal rainfall).
Avulsion		The rapid abandonment of a river channel and the formation of a new river channel.
Backswamp		A lower section of a floodplain which receives water during an overbank flood event, and is generally a depositional feature (e.g. where fine grained alluvial settles out).
Bank height		Elevation difference between bankfull water level and the channel invert.
Bankfull		The junction between the floodplain and the channel. The point is often difficult to define in the field, especially where there are benches in the channel.
Bars		An elevated area of sediment, deposited by stream flow.
Benches		Flat surfaces in a channel above the average water level but below bankfull point.
Coarse woody debris (rates)	High natural loading of wood	Essentially ideal: abundant debris from indigenous species. Site probably never de-snagged and streamside vegetation probably never cleared.
	Moderate natural loading of wood	Near ideal: numerous-moderate pieces of coarse woody debris from indigenous species. Perhaps limited coarse woody debris from exotic species present also. Limited impact of de-snagging or streamside vegetation clearing.
	Low natural loading of wood	Highly modified from ideal: few visible pieces of coarse woody debris in channel (either from indigenous or exotic species).
	No wood	No visible coarse woody debris.
	Slash	Not ideal and likely to have negative impacts on stream processes and surrounding areas: abundant debris from pine forestry areas.
Confined Stream		At least 90% of the channel abuts the valley margin (Brierley and Fryirs 2005).
Degradation (incision)		General lowering of a stream bed by erosional processes.

Term	Sub-classifications	Meaning
Degradation (rates)	Moderate bed degradation	Steep bed; absence of alluvial material; narrow low flow course; bank erosion; evidence of recent minor deepening.
	Extreme bed degradation	Low width to depth ratio; evidence of recent severe deepening; bare banks; bank erosion; possible erosion heads.
Drop structure		A drop structure is an engineered structure in a river commonly used to control the grade of a steram.
Ephemeral stream		Ephemeral means a wetland, lake, river, or reach of river that only exists or flows for a short period following heavy or persistent precipitation or snowmelt. Predominantly vegetated.
Erosion (rates)	Limited erosion	Good vegetative cover; some minor isolated erosion; no continuous damage to bank structure or vegetation, some exposed roots.
	Moderate erosion	Banks held by discontinuous vegetation; some obvious damage to bank structure and vegetation; generally stable toe, moderate exposure of roots.
	Extensive erosion	Little effective vegetation; mostly unstable toe; large numbers of exposed roots.
	Extreme erosion	Evidence of rapid unchecked erosion; no effective vegetation; unstable toe; very recent bank movement.
Farm drainage canal		An artificial stream that: Is entirely constructed for rural land drainage purposes, with no part being natural or modified stream or river; and Does not incorporate naturally occurring bodies of surface water. A farm drainage canal is usually constructed to enhance production from farm land by improving drainage.
Flood		An overflow of a large amount of water beyond a body of water's normal limits, especially over what is normally dry land.
Floodway		Part of a greenway that caters for the design flood (normally a 1% AEP event) and includes allowance for riparian vegetation within flood flow capacity.
Flood flows		Flow associated with flood events (normally a 1% AEP event).
Flowpath	Flowpath	The path that is taken by water during a rainfall event.
	Primary flowpath	The path taken by water during a rainfall event that can be accommodated within the drainage network, which may include pipes and open drains.
	Secondary flowpath	The path or paths taken by water during a rainfall event that is beyond the extent of the primary flowpath, when the capacity of the drainage network forming the primary flowpath is exceeded.
Fluvial erosion		Stream bank erosion mechanisms that specifically occur as a result of flowing water, such as undercutting, and scour.
Geomorphic unit		Features within the stream corridor (such as bars, pools etc) that reflect formative river processes, and are directly linked to a rivers character and behaviour.
Head cut		Erosional feature with an abrupt vertical drop, also known as a knickpoint, in the stream bed.

Term	Sub-classifications	Meaning
Imbrication		Where rocks deposited by fast flowing water, are pushed in one direction by the current so that they overlap each other.
Incised		A vertically contained stream. Incised streams can be associated with abandoned floodplains due to a lowering of local base level, are often characterised by high streambanks, and can occasionally be bounded by alluvial terraces.
Intermittent streams		Stream reaches that cease to flow for periods of the year because the bed is periodically above the water table. This category is defined by those stream reaches that do not meet the definition of permanent river or stream and meet at least three of the following criteria: it has natural pools; it has a well-defined channel, such that the bed and banks can be distinguished; it contains surface water more than 48 hours after a rain event which results in stream flow; rooted terrestrial vegetation is not established across the entire cross-sectional width of the channel; organic debris resulting from flood can be seen on the floodplain; or there is evidence of substrate sorting process, including scour and deposition. (as per Auckland Unitary Plan 2016)
Low flow		Low flows can be characterised in several ways; by a high exceedance percentile, such as the flow equalled or exceeded 95% (or similar) of the time, by some multiple or fraction of the mean or median flow, or by use of extreme value sampling.
Low-flow channel		The component of the channel that conveys low-flows, and provides critical aquatic habitat in periods of low flow.
Mass wasting		Stream bank erosion mechanisms that do not necessarily include 'fluvial' processes, such as slab/block failure, sloughing, rotational failure, cantilever failure, parallel slide.
Meandering channel		Single thread alluvial channel, often in an unconfined valley setting. Formed through the process of lateral accretion on the inside of bends and localised erosion on the outside of bends. Diversity of bars (specifically mid-channel bars) is often low. Sinuosity ratio is generally greater than 1.5.
Modified stream		A river or stream that may have been subject to works or modifications for a variety of purposes and is or has one or more of the following features: part of a river, stream or creek that has been channelled or diverted; part of a wetland or swamp through which water has been channelled or diverted to flow either permanently or intermittently and which connects with other naturally occurring bodies of water; a stream that has a natural headwater of either a channel or spring and generally follows the path of a historic river or stream or defined drainage channel that functions naturally by providing a connection between surface water and groundwater, and is capable of providing habitat for flora and fauna.

Term	Sub-classifications	Meaning
Partly-confined streams		10-90% of the channel abuts the valley margin (Brierley and Fryirs 2005).
Permanently flowing stream		The continually flowing reaches of any river or stream.
Planform		The shape of a river from a birds eye view.
Recovery timeframe		The time it will take for these areas to go back to a pre-defined condition.
River/stream		A continually or intermittently flowing body of fresh water; and includes a stream and modified watercourse; but does not include any artificial watercourse (including an irrigation canal, water supply race, canal for the supply of water for electricity power generation, and farm drainage canal).
Riparian vegetation		Vegetation on the banks of a river/stream (usually more broadly defined as a strip of land up to tens of metres wide along the banks of a stream).
Riparian vegetation (rates)	Continuous vegetation	Continuous vegetation is defined as cover between 80% and 100%.
	Patchy vegetation	Patchy vegetation is defined as cover between 20% and 80%.
	Sparse vegetation	Sparse vegetation is defined as cover between 0% and 20% cover.
Run		A slow moving, relatively shallow body of water with moderately low velocities and little or no surface turbulence
Sinuosity		The 'wiggliness' of channel. Often expressed as a ratio (channel length/straight line valley length).
Degree of sinuosity (adapted from Schumm 1985; Buffington and Montgomery 2013)	Straight	Sinuosity ratio: 1-1.05 
	Low sinuosity	 Sinuosity ratio: 1.06 – 1.25
	Moderate sinuosity	 Sinuosity ratio: 1.25-1.45
	Highly sinuous	 Sinuosity ratio: >1.5
Stable channel		The ability of a stream, over time, in the present climate, to transport the sediment and flows produced by its watershed in such a manner that the stream maintains its dimension, pattern and profile without either aggrading or degrading. Also called 'equilibrium'.

Term	Sub-classifications	Meaning
Thalweg		A line connecting the lowest points of successive cross-sections along the course of a river
Top of bank channel width		Channel's top width measured at the top of the bankfull channel.
Two stage channel		Two stage channels are stream channels constructed with a bench feature that is inundated relatively frequently (1-2 year ARI).
Wandering gravel bed river		Wide (but confined) active channel with often one channel but occasional bifurcations. Low-flow channel is often moderately sinuous with riffle-run sequences and a high diversity of bar types. Often referred to as a transitional form between braided and meandering stream types.
Woody debris		Dead or living trees (i.e. branch or root system) that have fallen into or are immersed (totally or partially) in a stream.
Woody debris (rates)	High natural loading of wood	Essentially ideal: abundant debris from indigenous species. Site probably never de-snagged and streamside vegetation probably never cleared.
	Moderate natural loading of wood	Near ideal: numerous-moderate pieces of coarse woody debris from indigenous species. Perhaps limited coarse woody debris from exotic species present also. Limited impact of de-snagging or streamside vegetation clearing.
	Low natural loading of wood	Highly modified from ideal: few visible pieces of coarse woody debris in channel (either from indigenous or exotic species).
	No wood	No visible coarse woody debris.
	Slash	Not ideal and likely to have negative impacts on stream processes and surrounding areas: abundant debris from pine forestry areas.
Unconfined stream		Less than 10% of the channel abuts the valley margin (Brierley and Fryirs 2005).

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