Assessment of naturally hard- and soft-bottomed rivers, Wairau Plain, Marlborough

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EXECUTIVE SUMMARY

Under Section 3.25 of the National Policy Statement for Freshwater Management 2020 (NPS-FM 2020), Marlborough District Council (MDC) is mandated to assess whether river sites are naturally hard-bottomed in locations designated for achieving targeted attribute states concerning fine sediment deposition and to consider whether it is appropriate to restore a given site to a hard-bottomed state. Currently, there is a lack of guidance and agreed-upon methodology for the council to employ in making these determinations. To assist MDC in making these determinations, a spatial baseline model is established for the natural (pre-anthropogenic) state of riverbed sediment cover in the Wairau Plain. The model uses a geological framework based upon borehole data to determine the lithological characteristics of sedimentary facies beneath the Wairau Plain (the substrates that rivers erode into), and surficial (relict) river channels are used as proxies for natural (pre-anthropogenic) sedimentary facies. These dual inputs form the basis of a spatial riverbed classification scheme where sections of rivers are classified as naturally hard-bottomed, naturally soft-bottomed or naturally transitional between a hard- and soft-bottomed state. This spatial classification provides a rapid assessment method to assist MDC in (1) determining whether sections of rivers have been severely impacted by human activities and (2) identifying sites where more detailed geological investigations are needed to determine the full extent that sites have been impacted. In addition, the use of sedimentary facies in this study provides predictive insight to the future response of riverbed sediment cover (including riverbed transition zones) to sea-level rise associated with climate change, as well as vertical land movements associated with earthquakes, to assist MDC in developing and maintaining ecological outcomes that fulfil the goals of the NPS-FM 2020 and the long-term aspirations of the local community, including iwi and industry.

RECOMMENDATIONS

Recommendation 1: A geologically based method is needed for secondary site-specific assessments to assist MDC in determining whether it is appropriate to restore anthropogenically impacted sections of rivers and, if appropriate, help the council in developing and accessing restoration options, as required under Section 3.25 of the NPS-FM 2020.

Recommendation 2: MDC should seek advice and guidance on the potential impacts of climate change and associated sea-level rise on riverbed sediment cover to assist the council in developing sustainable ecological outcomes that fulfil the goals of the NPS-FM 2020 and the long-term aspirations of the local community, including iwi and industry.

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1.0 INTRODUCTION AND PROJECT AIMS

The Wairau Plain (Figure 1.1) is of key significance to the Marlborough region, as it hosts most of the region's population and much of its economic activity. A multitude of the plain's rivers and groundwater resources are vital to the community, including iwi and industry, but the extent to which these resources have been impacted by river management interventions and consequential intensification of land use is not well understood.

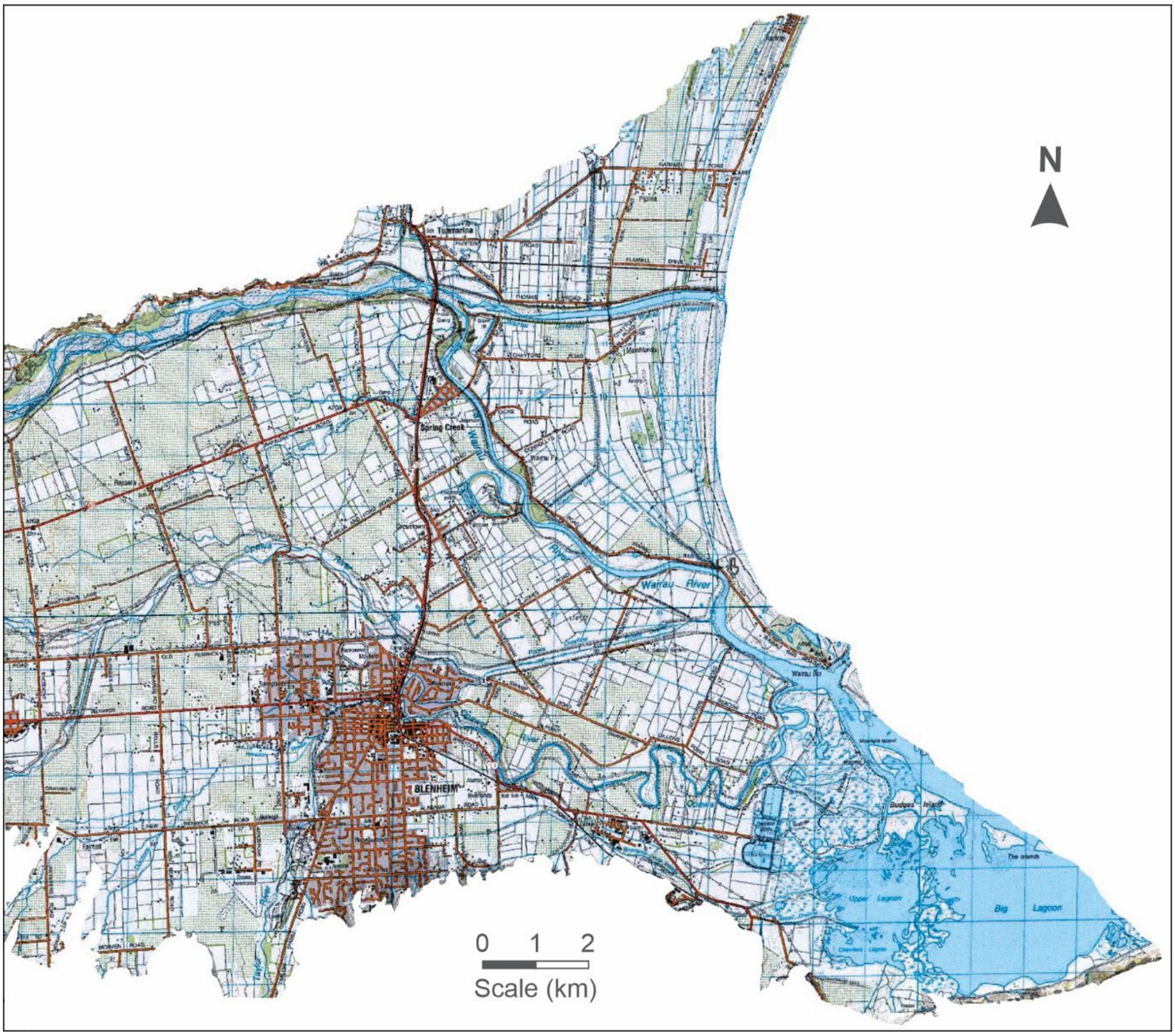

Figure 1.1 Wairau Plain study area. Topographic map showing infrastructure, urban development and important locations.

Under Section 3.25(1) of the National Policy Statement for Freshwater Management 2020 (NPS-FM 2020) (Appendix 1), Marlborough District Council (MDC) is mandated to assess whether river sites are naturally hard-bottomed at locations designated for achieving targeted attribute states concerning fine sediment deposition. Currently, there is a lack of guidance and agreed-upon methodology for MDC to employ in making this assessment. Section 3.25(2c) of the policy statement (Appendix A1) also necessitates MDC to determine whether, having regard to the relevant long-term vision, it is appropriate to restore impacted sites to a natural hard-bottomed state.

Protocols and guidelines for measuring riverbed sediment cover have been established in New Zealand (Clapcott 2015; Clapcott et al. 2011, 2020). Indirect approaches, including empirical hydrologic methods and channel morphologic measurements from digital elevation models have also been used in Canada and North America to predict riverbed grain size (Buffington et al. 2004; Gorman et al. 2011). These different approaches faithfully model the present-day state of riverbed sediment cover but not the natural (pre-anthropogenic) state of riverbed sediment cover. Consequently, a new method is developed in this study, based on geological and geomorphological inputs, to establish a spatial baseline model for the natural (pre-anthropogenic) state of riverbed sediment cover in the Wairau Plain. The aim of the baseline model is to provide MDC with a spatial framework to rapidly assess anthropogenic impacts to riverbed sediment cover and, where appropriate, assist the council in developing and implementing action plans for restoration that fulfil the goals of the NPS-FM 2020 and the long-term aspirations of the local community, including iwi and industry.

2.0 BACKGROUND

The flat, low-lying geomorphology of the Wairau Plain (Figures 1.1 and 2.1) denotes a long history of finely balanced tectonic subsidence, sediment supply and alluvial deposition, tempered by glacial–interglacial changes in sea level and vertical land movements (VLMs) associated with near- and far-field earthquakes (e.g. Brown 1981; Nicol and Van Dissen 2018; Nicol et al. 2023). This is reflected in the distribution of surficial sedimentary facies and the complex depositional architecture of Quaternary sedimentary facies beneath the Wairau Plain (Figures 2.2 and 2.3). The depositional architecture and lithological characteristics of subsurface sedimentary facies can be resolved into a three-dimensional geological framework using borehole data and the principles of sequence stratigraphy (Catuneanu 2022). The distribution and lithological characteristics of sedimentary facies can also be resolved using the principles of river geomorphology (Bravard and Petit 2009; Buffington and Montgomery 2022).

Figure 2.1 Wairau Plain and adjacent hills and valleys. Satellite image showing important locations, rivers and faults. (Base image: Google Maps.)

2.1 River Geomorphology and Sedimentary Facies

River-channel morphology is primarily a function of eroded, transported and deposited sediment, and this divides rivers with medium and low gradients into two general categories, braided and meandering rivers (Bravard and Petit 2009) and their respective braidplain and coastal floodplain sedimentary facies.

- Braided rivers have multi-threaded channels that branch and merge to create a characteristic braided pattern. Braided channels are highly dynamic, with mid-channel bars consumed and re-formed continuously, and these are typical of rivers with high coarse-grained bed loads and frequent flood flows (Charlton 2007; Buffington and Montgomery 2022).
- Meandering rivers have single-thread highly sinuous channels that form in low-gradient sections of rivers, where fine-grained sediments are eroded from the outer side of bends and deposited on the inner-side bends (Charlton 2007; Buffington and Montgomery 2022). Meandering river channels are typical of low-lying coastal floodplains and tidally influenced sections of rivers and estuaries.

On a large scale, where gradients and flows change gradually along the length of a river, the transition between braided and meandering rivers marks a critical threshold in river geomorphology where the deposition of coarse-grained sedimentary facies generally ends and the deposition of fine-grained sedimentary facies begins. The transition is also where coarse- and fine-grained sedimentary facies interfinger. Small-scale variations in riverbed morphology, such as pools, riffles and meanders, also cause perturbations in gradients and flows and riverbed sediment cover.

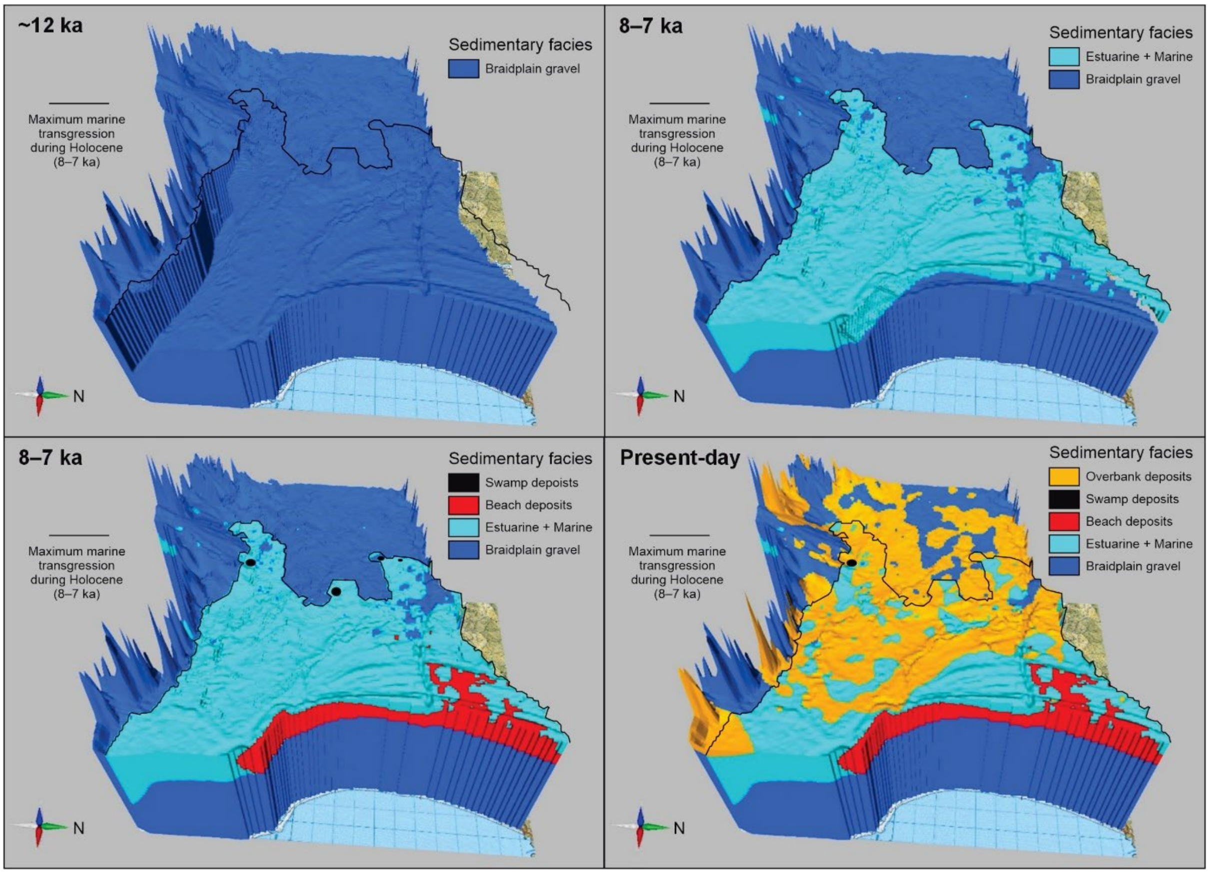

Figure 2.2 Geological block models, Wairau Plain study area. Three-dimensional geological models showing the distribution of Quaternary (Holocene and Pleistocene) sedimentary facies beneath the Wairau Plain, based upon borehole data (White et al., in prep.).

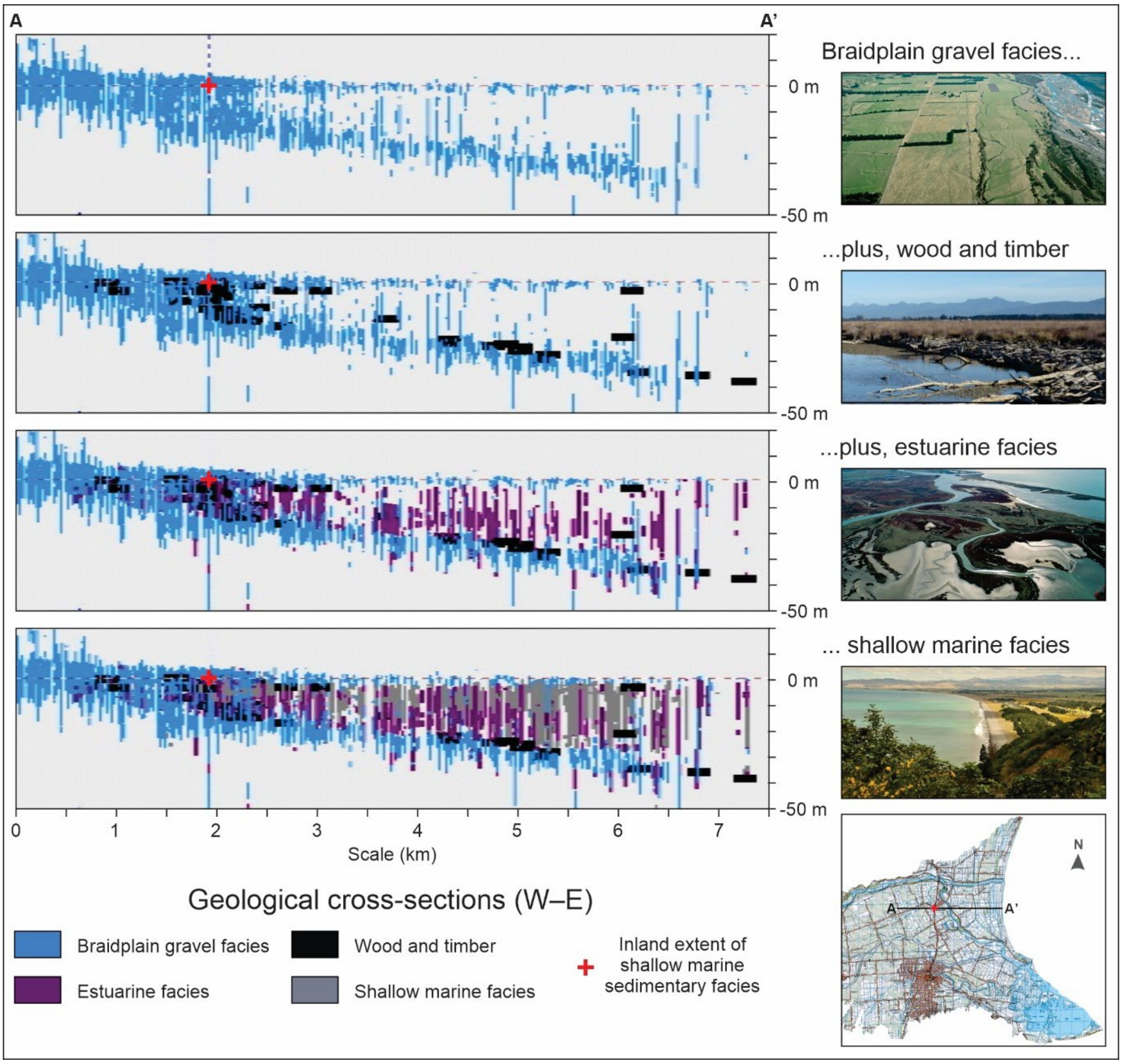

Figure 2.3 Composite geological cross-sections, lower Wairau Plain. Distribution of Holocene and Pleistocene sedimentary facies beneath the lower Wairau Plain, based upon borehole data (White et al., in prep.). Insert: Location of cross-section A–A'.

2.2 River-Management Interventions

River-management interventions in the Wairau Plain have heavily modified the flows of most rivers and streams (Calder-Steele 2024) and consequently impacted riverbed sediment cover across most of the Wairau Plain. These interventions are described in White et al. (2016) and Calder-Steele (2024), and interventions from 1848 to1983 are shown in Figure 2.4.

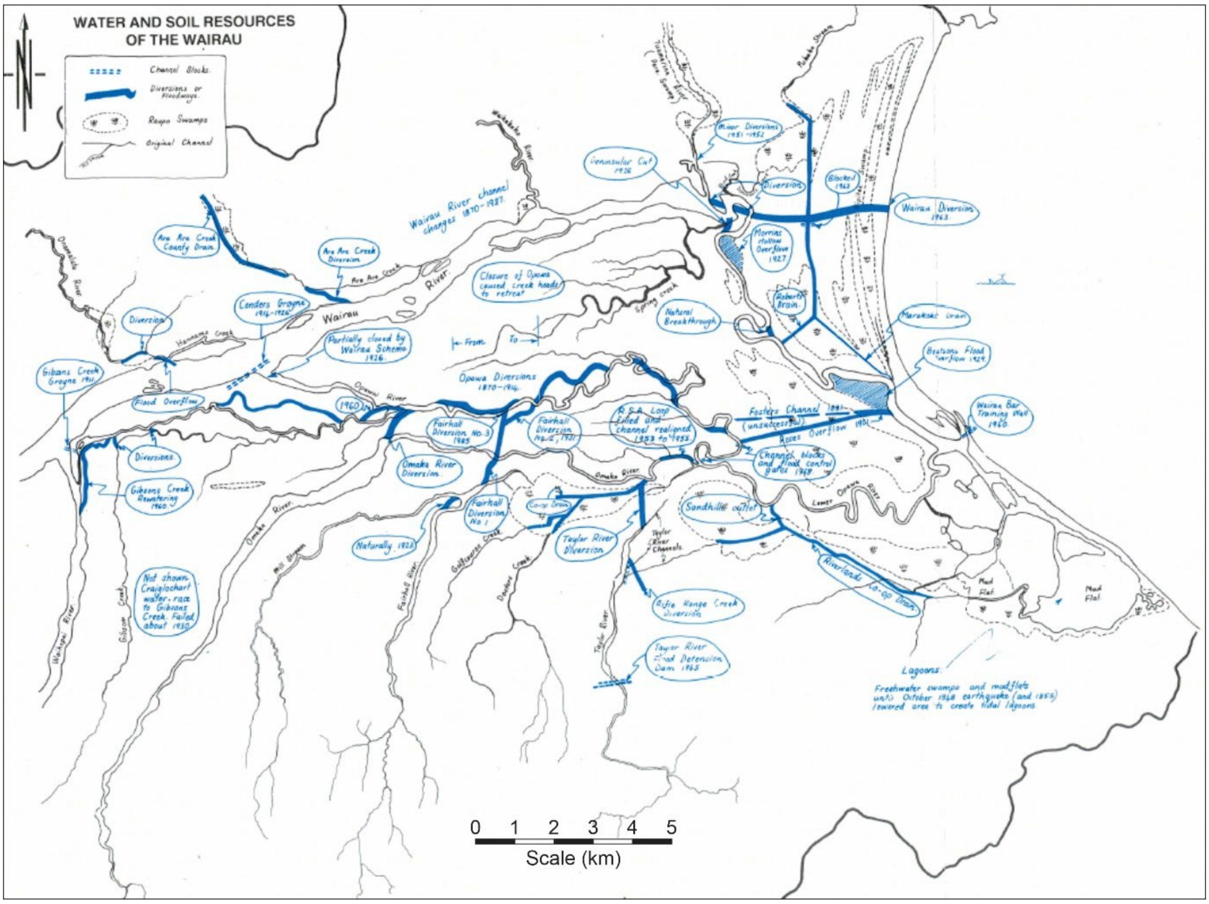

Figure 2.4 Early river-management interventions, Wairau Plain (Rae 1987).

Before the Wairau Valley Scheme (WVS) was introduced, ~6900 ha in the Wairau catchment were inadequately drained, main river channels were gradually aggrading and regular floods were disrupting communities and agricultural production (Waters 1959). That changed when the Marlborough Catchment Board was established in 1956 and the WVS was implemented in 1960–1975. The goal of the WVS was to achieve “as far as economically possible” the prevention of flooding, provision of adequate drainage and stabilisation of all river and stream channels and catchments (Waters 1959). The reduced flood risk and lower water levels that resulted from the WVS set the scene for a major intensification of land use that has transformed the Wairau Plain and contributed significantly to the economic growth and prosperity of Marlborough, while also contributing to a reduction in indigenous and endemic ecosystems.

Post-WVS improvements have upgraded the flood infrastructure to a 1-in-100-year standard, and soil conservation works in the hills and tributary interventions have reduced sediment supply to the Wairau Plain (Marlborough District Council 1994; Calder-Steele 2024).

3.0 METHODOLOGY

This study uses geological and geomorphological inputs to establish a spatial baseline model for the natural (pre-anthropogenic) state of Wairau Plain riverbed sediment cover.

Unpublished geological data from the GNS Science Groundwater Strategic Science Investment Fund (National Aquifer Mapping and Characterisation project) are used to develop a geological framework to determine the distribution and lithological characteristics of sedimentary facies beneath the Wairau Plain (the sedimentary deposits that rivers erode into). The framework is based on a digital borehole database comprised of 2899 borehole logs and 21,241 lithological descriptions (from MDC's Wells & Geology Database), and subsurface sedimentary facies are assigned using Boolean operators specific to the characteristics of surficial (relict) Holocene sedimentary facies of the Wairau Plain (White et al., in prep.).

River gradients and flow velocities were not measured at sites across the Wairau Plain; instead, surficial (relict) river channels are used as proxies for natural (pre-anthropogenic) river gradients and flows. Surficial (relict) channels are mapped and classified in this study using digital terrain models from processed high-resolution MDC airborne LiDAR (Light Detecting and Ranging) data[1] (Figure 3.1).

To efficiently address the goal of this study, a spatial assessment is made of rivers and streams across the Wairau Plain to determine whether a subset of riverbed segments are naturally soft- or hard-bottomed.

1 https://smartmaps.marlborough.govt.nz/smapviewer/?map=9590cd3c520c4f7e82cdcd5a208b8466

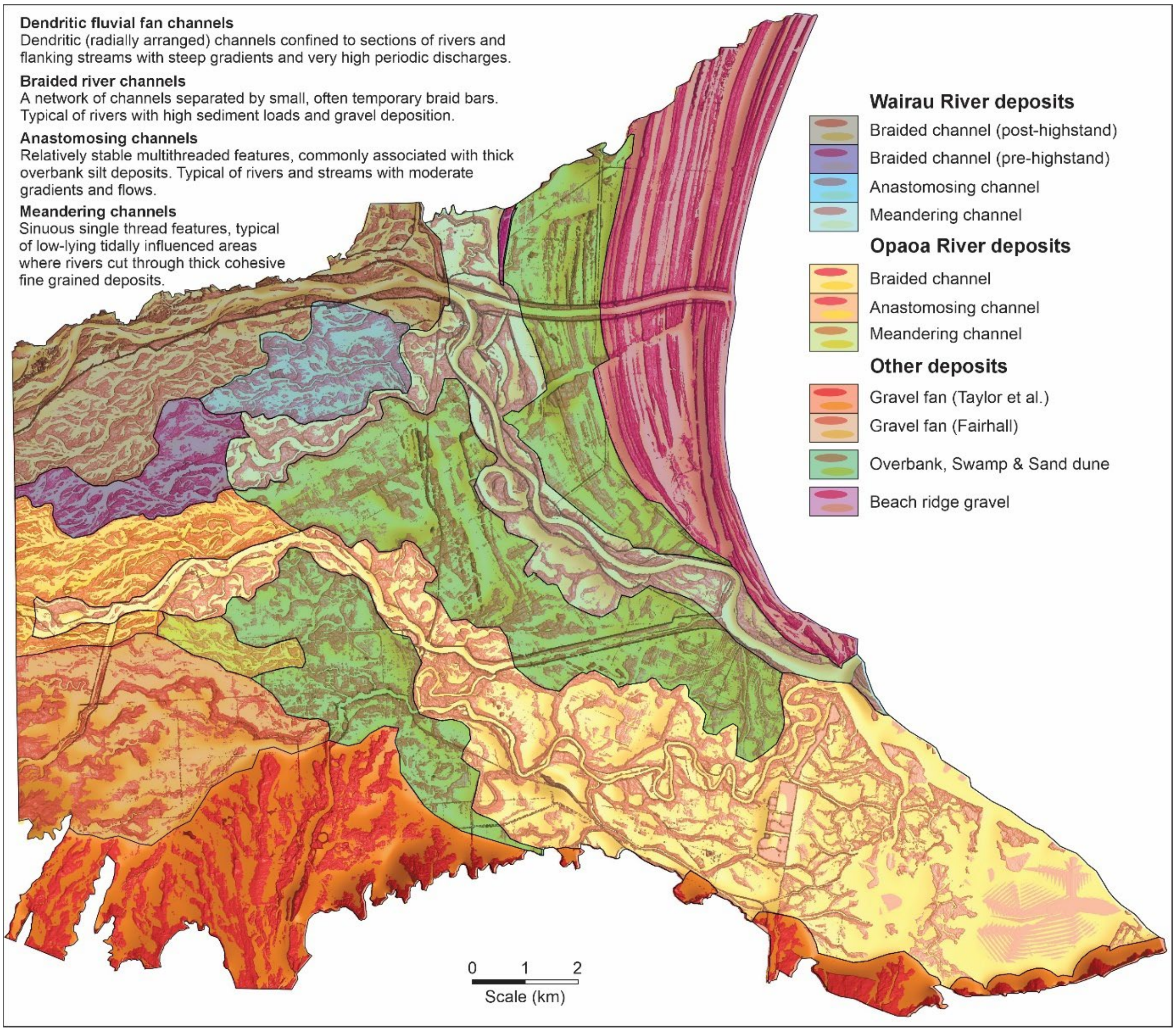

Figure 3.1 Classification of surficial (relict) river channels and associated sedimentary facies. Map of primary river-channel morphologies, based upon a digital terrain model. Dendritic (radially arranged) fluvial fan channels and coarse-grained gravel fan facies are developed along the southern flank of the Wairau Plain, braidplain channels and coarse-grained braidplain gravel facies are confined to the upper part of the plain, anastomosing channels and interfingering coarse- and fine-grained facies occur in the central part of the plain, and meandering channels and fine-grained coastal floodplain facies cover most of the flat, very low-lying, plain near the coast.

4.0 RESULTS

4.1 Surficial (Relict) River Channels and Sedimentary Facies

Under the principles of river geomorphology, the morphology of river channels is strongly linked to river gradients and flows (Bravard and Petit 2009; Buffington and Montgomery 2022). This is evident in the distribution of surficial river channels and sedimentary facies across the Wairau Plain (Figure 3.1). For example, fluvial fan channels and facies are mainly distributed along the southern flank of the plain, and coastal floodplain facies are distributed in a broad belt across much of the lower Wairau Plain. In addition, each facies and facies belt is represented by a distinctive, often unique, set of sedimentary deposits with diagnostic lithological characteristics that enable sedimentary facies to be identified in lithological descriptions from boreholes (White et al., in prep.).

The preservation of these alluvial channel features and their associated sedimentary facies indicates that they were likely formed during major unconstrained flood events when sediment erosion, entrainment and deposition was greatly enhanced and pre-existing riverbed features were over-printed by the immense volume of water and transported sediment. Most of the alluvial channels and associated facies are also likely to be relict features that pre-date early European river management interventions because interventions to reduce flood risk and improve drainage favour the preservation of pre-existing widespread alluvial features. Prior to these river interventions, during the earlier period of human occupation, unconstrained flooding was common across much of the Wairau Plain. In this respect, surficial channels and their associated facies are essentially relict features that represent the natural (pre-anthropogenic) state of river gradients and flows, as well as alluvial deposition.

The following descriptions are based on fieldwork undertaken in conjunction with this study and fieldwork related to the GNS Science National Aquifer Mapping project (Crundwell, unpublished GNS Science data).

4.1.1 Fluvial Fan Channels and Facies

Fluvial fan channels and facies have a dendritic (radially arranged) pattern and are most commonly associated with tributaries that drain catchments along the southern flank of the Wairau Plain and spill out onto the plain. The distinctive arrangement of fluvial fan channels is largely attributed to channel avulsion, where river channels are repeatedly displaced when a triggering event, commonly a flood, forces a river across a stability threshold (Slatt 2013). Fluvial fan facies along the southern flank of the Wairau Plain have relatively steep gradients (approximately 1:100 to 1:400), and relict sedimentary facies are dominated by coarse-grained variably sorted sub-angular to sub-rounded greywacke-derived gravel and minor fine-grained regolith and loess. Fluvial fan facies gravels have high connectivity between sedimentary layers (Slatt 2013) and are classified as unconfined aquifer.

4.1.2 Braided River Channels and Braidplain Facies

Braidplain channels consist of a complex network of multi-threaded (interwoven) channels separated by braid-bars. Such channels are confined to large rivers in the upper part of the Wairau Plain (Figure 2.1) that flood frequently and have moderate gradients and high sediment bed loads. The distinctive multi-threaded pattern of braided river channels is caused by channel avulsion (Slatt 2013). Relict braidplain deposits in the upper part of the Wairau Plain have gradients ranging from approximately 1:400 to 1:600, and facies are dominated by variably sorted sub-rounded to rounded greywacke-derived gravel, minor silt, rare woody material and very poorly preserved organic material (comminuted plant material and seeds). Braidplain facies are typically coarse-grained and have very little mud, and sand and gravel deposits are often laterally continuous and vertically connected (Slatt 2013). Braidplain facies gravels are classified as unconfined aquifer.

4.1.3 Anastomosing River Channels and Transitional Facies

The central part of the Wairau Plain, near Renwick and west of Spring Creek (Figure 2.1), marks a critical threshold in river geomorphology where gradients decrease from 1:600 to 1:1000 and coarse-grained sedimentary facies of the upper plain interfinger with fine-grained sedimentary facies of the lower plain. Freshwater springs are common in this area and are often developed at the heads of anastomosing channels, where fine-grained overbank deposits overlie coarse-grained aquifer gravels. Anastomosing channels are typically associated with and erode into fine-grained overbank deposits, and underlying transitional facies gravels are classified as semi-confined aquifer.

4.1.4 Meandering River Channels and Coastal Floodplain Facies

Meandering river channels and coastal floodplain facies are confined to a broad coastal belt that encompasses the flat, very low-lying, parts of the lower Wairau Plain where gradients range from approximately 1:1000 to 1:2000. Meandering river flows are usually slow-flowing, but they can also be highly dynamic during major flood events, when gravel- and sand-sized sedimentary particles are transported downstream as bed load and fine-grained suspended sediment overtops channel levees and is deposited on the adjacent floodplain (Slatt 2013). Fine-grained coastal floodplain facies are generally classified as aquiclude.

The coastal facies belt includes a variety of subfacies and sedimentary deposits.

- Thick fine-grained coastal floodplain facies are developed across much of the low-lying coastal floodplain and are commonly associated with tidally influenced sections of rivers and streams that have deep, meandering, slow-flowing, single-threaded channels. Sedimentary deposits in this facies include variably coloured (green, pink, brown and black) organic enriched mud/clay, often with well-preserved plant fragments, seeds, spores, freshwater diatoms and wood. Peat deposits are also sometimes developed in low-lying areas and depressions, and minor sand and gravel deposits accumulate in some river channels.
- Sand dune facies form a narrow belt behind the Cloudy Bay foreshore, and belts of relict sand dunes facies are developed adjacent to State Highway 1, between Tuamarina and Spring Creek, and near Riverlands school. Present-day and relict sand dune facies are predominantly comprised of light-grey, well-sorted, fine-grained, quartz-rich sand. Rare cobble- and gravel-sized ventifacts can also be present, and larger sand grains are often frosted. When bedding surfaces are present, they are often steeply inclined and cross-bedded.
- Beach and beach ridge facies are developed along Cloudy Bay foreshore, and relict beach-ridge facies are also well developed in the Rarangi area and extend inland almost to Tuamarina (Figure 4.1). These facies are linked to high-energy shoreline environments and include coarse-grained sand and gravel deposits (including ‘pea-metal’ granular and pebble gravel). Wood and mollusc shells (mostly fragmented) can also be present. Cobble- and pebble-sized beach gravels are distinctive in that clasts are often well rounded and blade-shaped.

- Organic-rich swamp and wetland facies also developed along the margins of the Wairau Plain, where blind rivers and fluvial fans discharge onto the plain, and in cut-off segments of meandering river channels.

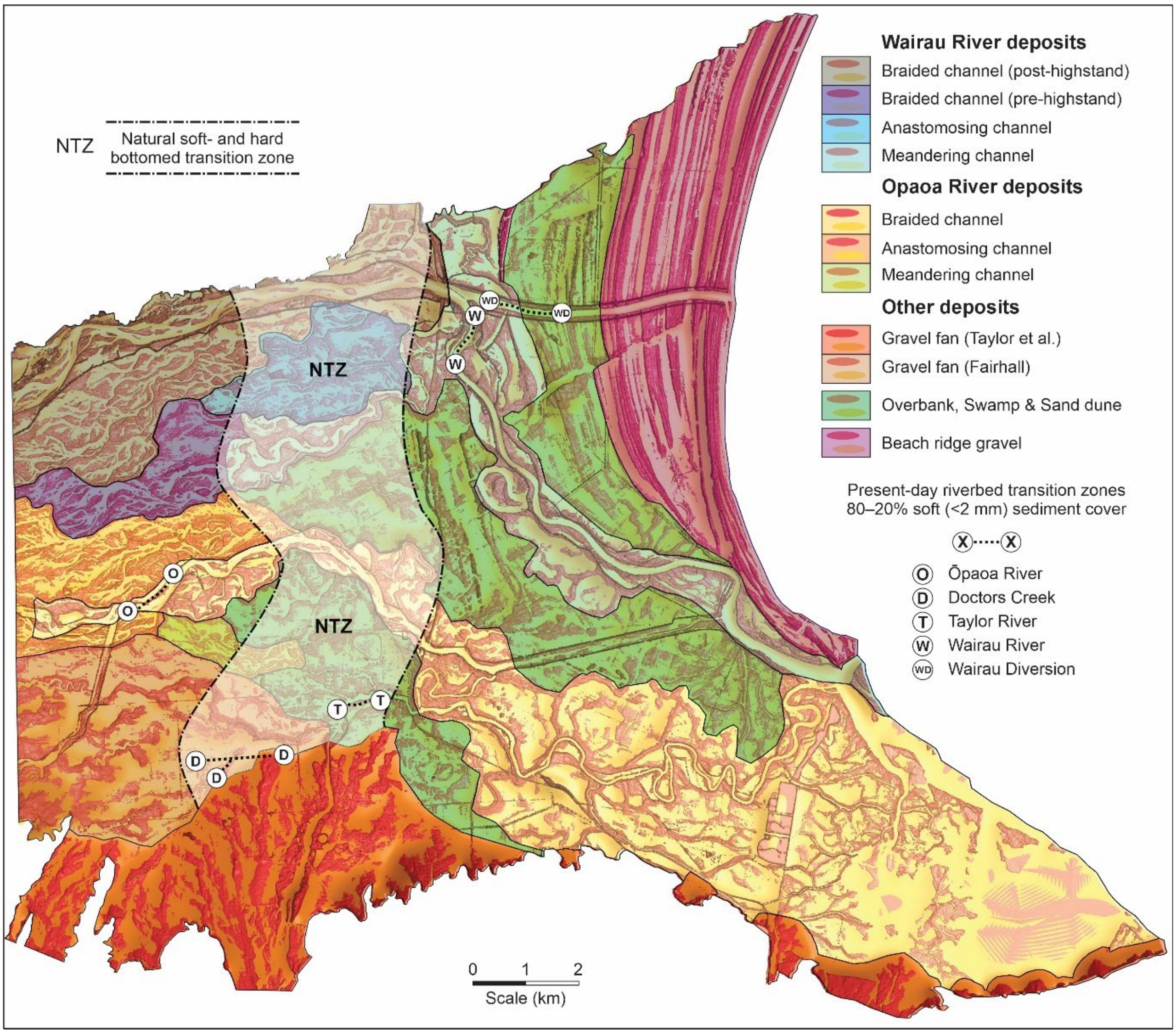

Figure 4.1 Modelled and present-day riverbed transition zones, superimposed over relict river channel and facies classification. Present-day Ōpaoa River and Wairau River transition zones where riverbed sediment covers transitions from hard- to soft-bottomed are located outside the modelled (natural) transition zone (NTZ) and classified as severely impacted. Doctors Creek and Taylor River riverbed transition zones are located in the upper and lower parts of the NTZ, respectively, and classified as less severely impacted, warranting further investigation – see discussion in Section 5.

4.1.5 Estuarine and Lagoon Facies

Estuarine, lagoon and salt marsh facies are diagnostic of low-energy, tidally influenced environments. These facies are developed near the coast, in and around the margins of lagoons and tidal tributaries of rivers and streams that discharge into the lagoons along the southwestern part of the Wairau Plain. These facies are also developed beneath the Wairau Plain (Figure 2.3). Associated sedimentary deposits are extensively bioturbated and are mostly dark-coloured and fine-grained (mud/clay and sand), with common wood, comminuted plant material and shells of brackish-water molluscs and calcareous microfossils. Minor coarse-grained gravel (pebble and sand) is also sometimes present in the channels of tributaries. Fine-grained estuarine and lagoon facies include sedimentary deposits that are generally classified as aquiclude.

4.1.6 Shallow Marine Facies

Shallow marine deposits extend offshore into Cloudy Bay, and also onshore beneath the Wairau Plain (Figure 2.3), and are mostly comprised of fine-grained sand, blue-grey mud and minor coarse-grained gravel. Shells of shallow-water molluscs and calcareous microfossils are often common, and comminuted plant material is sometimes present in small quantities. Shallow marine facies include sedimentary deposits that are generally classified as aquiclude.

4.2 Sedimentary Facies beneath the Wairau Plain

The distribution of sedimentary facies beneath the Wairau Plain (Figure 2.2) resembles the arrangement of surficial sedimentary facies (Figure 3.1). Surficial and subsurface facies are often displaced orthogonally to the coast, and displacements range from a few metres to many kilometres. For example, braidplain facies gravels older than 10,000 years are mapped below the present-day coastline, and those gravels are overlain by a wedge of marine and estuarine facies that extends at least 5.5 km inland (Figure 2.3). Braidplain gravels beneath the wedge of marine and estuarine sedimentary facies were most likely deposited during the period of sea-level rise following the Last Glacial Maximum (~19,000 years ago when global sea-level was ~120 m lower than the present-day [Grant et al. 2014]). Radiocarbon ages from borehole samples (Ota et al. 1995) indicate that the marine and estuarine sedimentary facies were deposited during the Holocene (approximately 7000–8000 years ago). That is about the time that global sea level rose rapidly during Meltwater Pulse 1C and reached a peak during the Holocene (Blanchon 2011a, 2011b; Blanchon and Shaw 1995). The distribution of these facies is consistent with the general principles of sequence stratigraphy, which state that, when sea level (the baselevel that sedimentary facies equilibrate to) rises, either from eustatic or tectonic causes, facies belts and their associated sedimentary deposits shift inland and that, when sea level falls, they shift seaward (Catuneanu 2022). Such shifts in sedimentary facies apply to the past, present and future.

4.3 Riverbed Sediment Cover

The lithological characteristics of riverbed sediment cover, including grain size, is largely determined by sediment source (the geology of river catchments), the distance that sediment is transported (abrasion and sorting), fluvial geomorphology (river gradients and flow) and the substrate that rivers erode into (Bravard and Petit 2009; Buffington and Montgomery 2022). Rivers with steeper gradients and higher flows have a greater capacity to erode and move large particles downstream and as gradients and flows decrease the capacity of rivers to erode and move particles decreases (Ritter et al. 2002). As a general rule, under natural flow regimes, grain size decreases and organic enrichment increases as rivers near the coast and river gradients and flows decrease (Koiter et al. 2013). The morphology of river channels also changes as river gradients and flows decrease (Bravard and Petit 2009; Buffington and Montgomery 2022). These changes are reflected in the distribution of present-day and relict river channels and alluvial sedimentary facies (including riverbed sediment cover) along the length of rivers in the Wairau Plain.

4.4 Spatial Model for ‘Natural’ Riverbed Sediment Cover

The distribution of surficial (relict) channel morphologies and associated alluvial sedimentary facies (Figure 3.1) closely resembles the distribution of sedimentary facies that present-day rivers erode into (Figure 2.2), and this is reflected in the spatial model for natural riverbed sediment cover in the Wairau Plain (Figure 4.1).

- Fluvial fan rivers and streams along the southern flank of the Wairau Plain are currently eroding into coarse-grained fluvial fan sedimentary facies. Because the gradients of these rivers and streams exceed the threshold for fine-grained deposition, the dominant coarse-grained lithological characteristics of relict fluvial fan facies is reflected in present-day riverbed sediment cover. Consequently, in the spatial model, all relict fluvial fan facies along the southern flank of the Wairau Plain are classified as naturally hard-bottomed (Figure 4.1).
- Braidplain rivers in the upper part of the Wairau Plain are continually eroding and re-working underlying coarse-grained braidplain sedimentary facies. Because the gradients of these rivers exceed the threshold for fine-grained deposition, riverbed sediment cover is predicted to be naturally coarse-grained. Consequently, relict braidplain facies are also classified in the spatial model as naturally hard-bottomed (Figure 4.1).
- Meandering rivers in the lower part of the Wairau Plain are slowly eroding into fine-grained coastal floodplain facies (mostly overbank silt deposits). Because the low gradients and flows of these rivers fall below the threshold for fine-grained deposition, riverbed sediment cover is predicted to be naturally fine-grained. Consequently, relict meandering river facies are classified in the spatial model as naturally soft-bottomed (Figure 4.1).
- The transition between natural coarse-grained deposition and fine-grained deposition occurs in the central part of the Wairau Plain, near Spring Creek and Renwick, where coarse-grained braidplain facies interfinger with fine-grained coastal floodplain facies. The interfingering of these facies marks a critical geomorphological threshold in the Wairau Plain where river flood flows regularly overtop river levees and fine-grained (overbank) deposits accumulate on the relatively flat-lying plain behind the levees. The thickness of the overbank flood deposits increases as rivers approach the coast and river gradients decrease, and this makes it more difficult for rivers to erode through the overbank deposits and into the underlying coarse-grained gravel deposits. Consequently, this transitional zone is classified in the spatial model as the natural transition zone between coarse-grained (hard-bottomed) and fine-grained (soft-bottomed) riverbed sediment cover (Figure 4.1). The hard- to soft-bottomed transition zone occurs in the central part of the plain where braidplain and coastal (floodplain) sedimentary facies interfinger (Figure 4.1) and river gradients transition from steeper gradients of the upper plain to much lower gradients of the lower coastal floodplain (Figure 4.2).

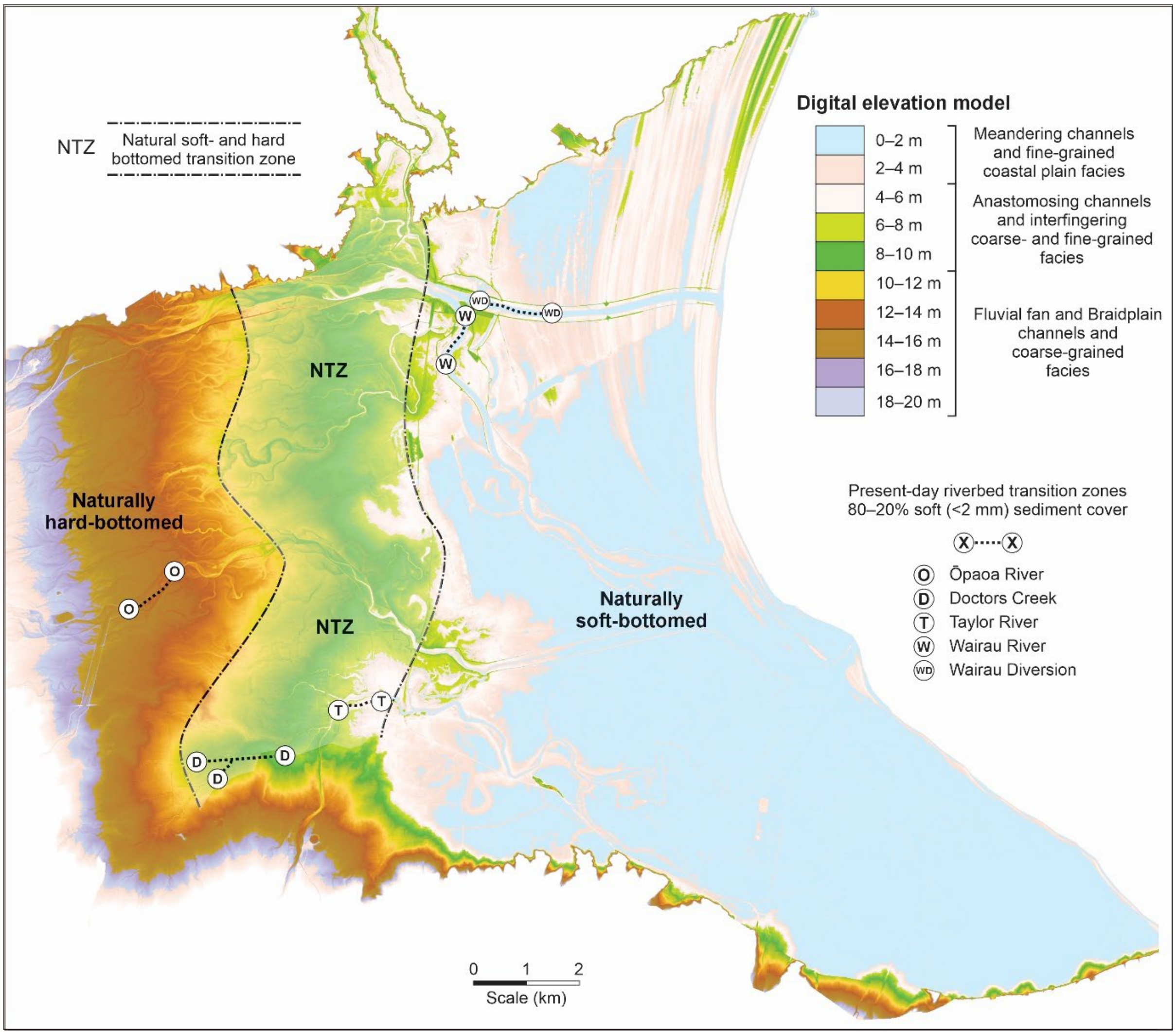

Figure 4.2 Modelled and present-day riverbed transition zones, superimposed over a digital elevation model. Relict river-channel gradients in the upper part of the Wairau Plain classified as naturally hard-bottomed range from1:400 to 1:600; gradients in the natural transition zone (NTZ) between hard- and soft-bottomed riverbed sediment cover decrease from 1:600 to 1:1000 and gradients in the lower plain classified as naturally soft-bottomed range from 1:1000 to 1:2000.

4.5 Present-Day Riverbed Transition Zones

Fieldwork conducted in conjunction with this study focused on a subset of sites with accessible riverbed transition zones. Five sites were investigated; four are located on the Wairau Plain (Ōpaoa River, Doctors Creek, Taylor River, Wairau River) and the other site, Pukaka Stream, is a small tributary on the northern side of the plain, near Rarangi (Figure 4.3). All sites have been impacted to varying degrees by river-management interventions, but the extent that each site has been impacted is unclear. Based upon the rapid habitat assessment method of Clapcott (2015), the transition zones that we refer to in this study encompass sections of rivers where the percentage of soft riverbed sediment cover (particles <2 mm diameter) ranges between 20% and 80%. The transition zones at the five sites are confined to relatively short (0.6–1.6 km long) segments of rivers (Figure 4.3).

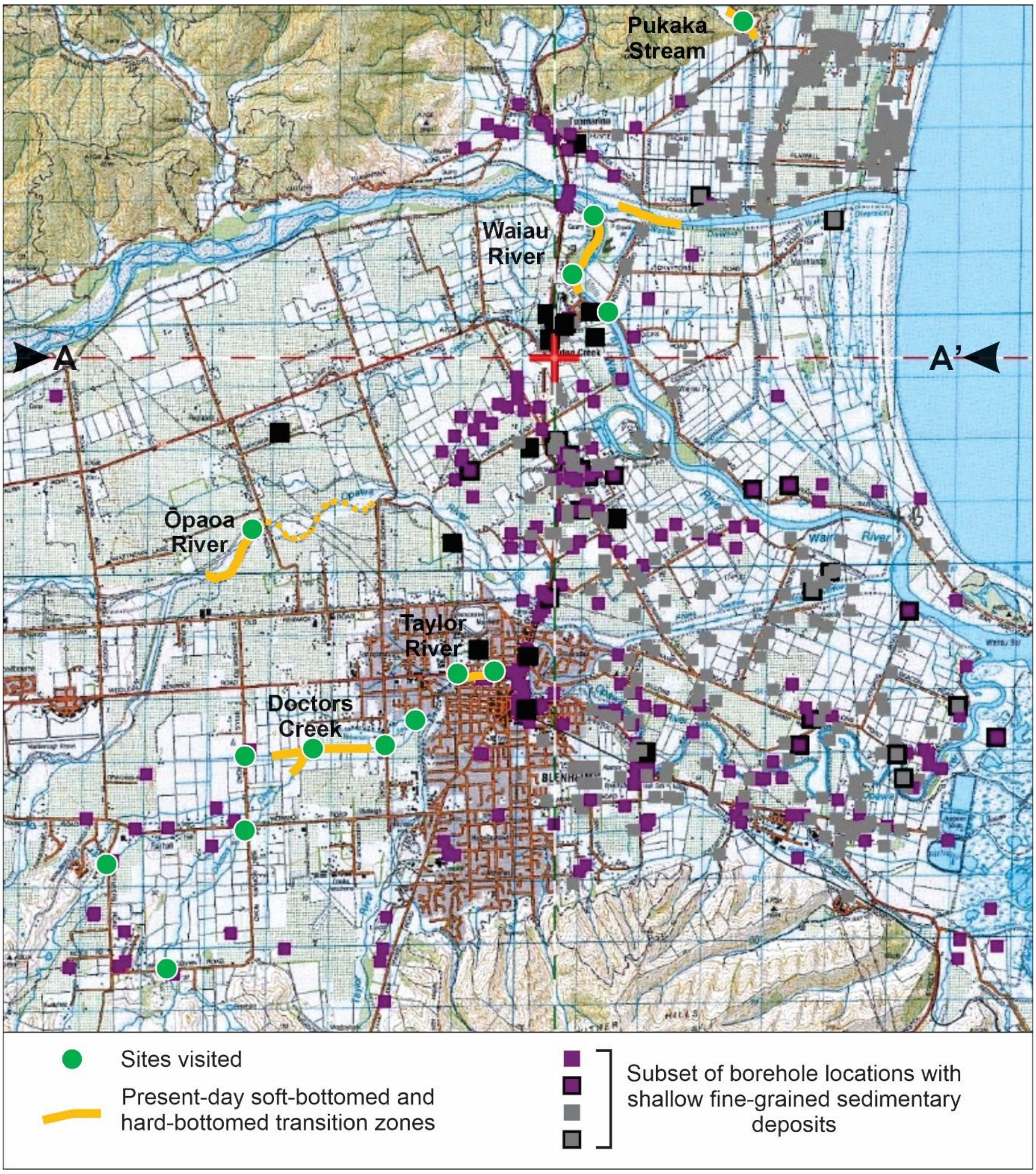

Figure 4.3 Present-day riverbed transition zones and field sites. Borehole locations with shallow fine-grained sedimentary deposits are shown by square coloured markers. A–A' is the location of the geological cross-section (see Figure 2.3).

4.5.1 Ōpaoa River Transition Zone

Ōpaoa River sources most of its water from large catchments along the southern hills flanking the Wairau Plain. Prior to major river interventions, the Ōpaoa River regularly flooded low-lying areas between Blenheim and Big Lagoon, and flooding was compounded when flood flows from the Wairau River entered the Ōpaoa River. The flood risk to Blenheim was reduced in 1901, when Roses overflow was opened to divert excess flow from the lower Ōpaoa River to the lowermost Wairau River (Figure 2.4). The flood risk was reduced further when the Wairau River Board closed the Ōpaoa Breach in 1926. When the WVS was implemented, a permanent stopbank/groyne was constructed across the breach in 1963, at Conders Bend, and new stop banks, drains and diversions were added and parts of the Ōpaoa River channel re-aligned (Figure 2.4). These interventions have effectively reduced flood flows in the Ōpaoa River by about two-thirds (Calder-Steele 2024).

The Ōpaoa River hard- to soft-bottomed transition zone is located north of Woodbourne (Figures 4.3 and 4.4) in a section of river that has been highly impacted by river-management interventions. The severe impact of these interventions is reflected in the ~4 km displacement of the transition zone from the modelled 'natural' location north of Blenheim to the present-day location north of Woodbourne.

Riverbank outcrops along the Ōpaoa River transition zone (Figure 4.5) reveal a thin upper layer of silt (<0.3 m thick), deposited on top of poorly sorted sub-rounded to rounded greywacke-derived gravel (>0.5 m thick) that is associated with the Ōpaoa River braidplain gravel facies. The silt layer has paua shell fragments that are presumed to have washed down from the Talley's Seafood processing factory (~1 km upstream), indicating that the silt deposit on top of the gravel is relatively recent.

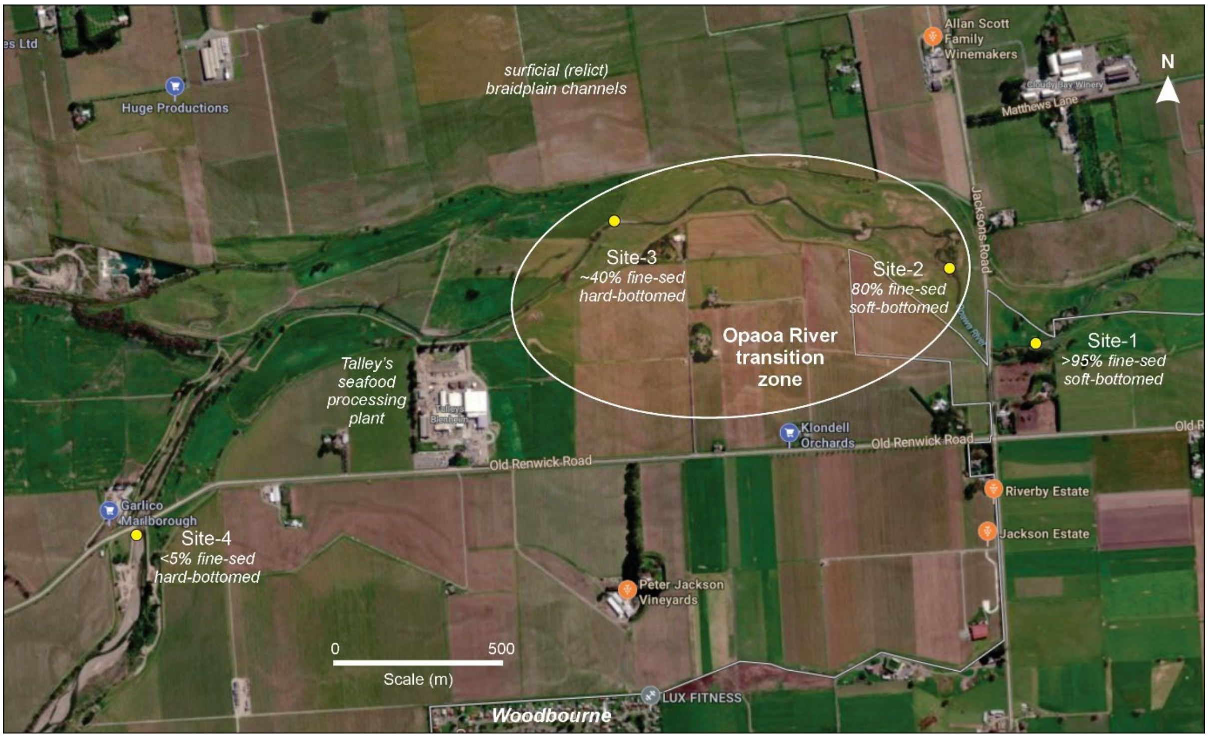

Figure 4.4 Ōpaoa River transition zone. The present-day transition between hard- and soft-bottomed riverbed sediment cover occurs north of Woodbourne, in an area where there are surficial (relict) Ōpaoa River braidplain channels. Some of the relict braidplain channels are evident north of the transition zone. (Base image: Google Maps.)

Figure 4.5 Ōpaoa River riverbank outcrop. The outcrop (Site 2, Figure 4.4) comprises a 0.3-m-thick layer of recent silt with rare paua shell fragments, overlying old Ōpaoa River braidplain gravels. (Credit: Martin Crundwell.)

4.5.2 Doctors Creek Transition Zone

Doctors Creek is a tributary of Taylor River that drains a large area of flat, swampy land that is subject to frequent overflows (Davidson 1959). Major WVS interventions in Doctors Creek include the construction of small flood detention dams in tributaries and drains discharging to Taylor River. In addition, the Fairhall River flow was removed from Doctors Creek by the Fairhall River Diversion to Ōpaoa River (Figure 2.4).

The Doctors Creek riverbed transition zone is located west of Blenheim (Figures 4.3 and 4.6), in a section of 'river' that has been modified by river management interventions. The transition zone is close to the toe of the Taylor River fan, in an area where there are surficial (relict) fluvial fan channels associated with the Fairhall River fan (Figure 4.1). The nearest riverbank outcrop, at 'Wiffen section' Site 2 (Figure 4.7), includes (from top down): silty topsoil (0.3 m), friable organic matter (0.1 m), silt and degraded peat/wood (0.3 m), silt with pebbles towards the base (1.3 m) and iron-stained gravel at the base of the section (>0.3 m). The organic matter and degraded peat in the upper part of the section indicates that the area was once a swamp, and the gravel at the base of the section is associated with the Fairhall River Fan (Figure 4.1). The depth of the Fairhall fan gravel facies at the base of the section suggests that the coarse-grained riverbed sediment cover in the upper part of the Doctors Creek transition zone, where the ground surface is higher, is associated with the Taylor River fan, and that the fine-grained sediment cover in the lower part of the Doctors Creek transition zone is likely related to flooding at the toe of the Taylor River Fan.

The present-day soft- and hard-bottomed transition zone in Doctors Creek is located within the modelled natural transition zone and is close to the boundary where riverbed sediment cover is naturally hard-bottomed. This suggests that, while there may be some anthropogenic impacts on riverbed sediment cover in Doctors Creek, they are not severe, and more detailed geological investigations are needed to determine the extent that this site has been impacted.

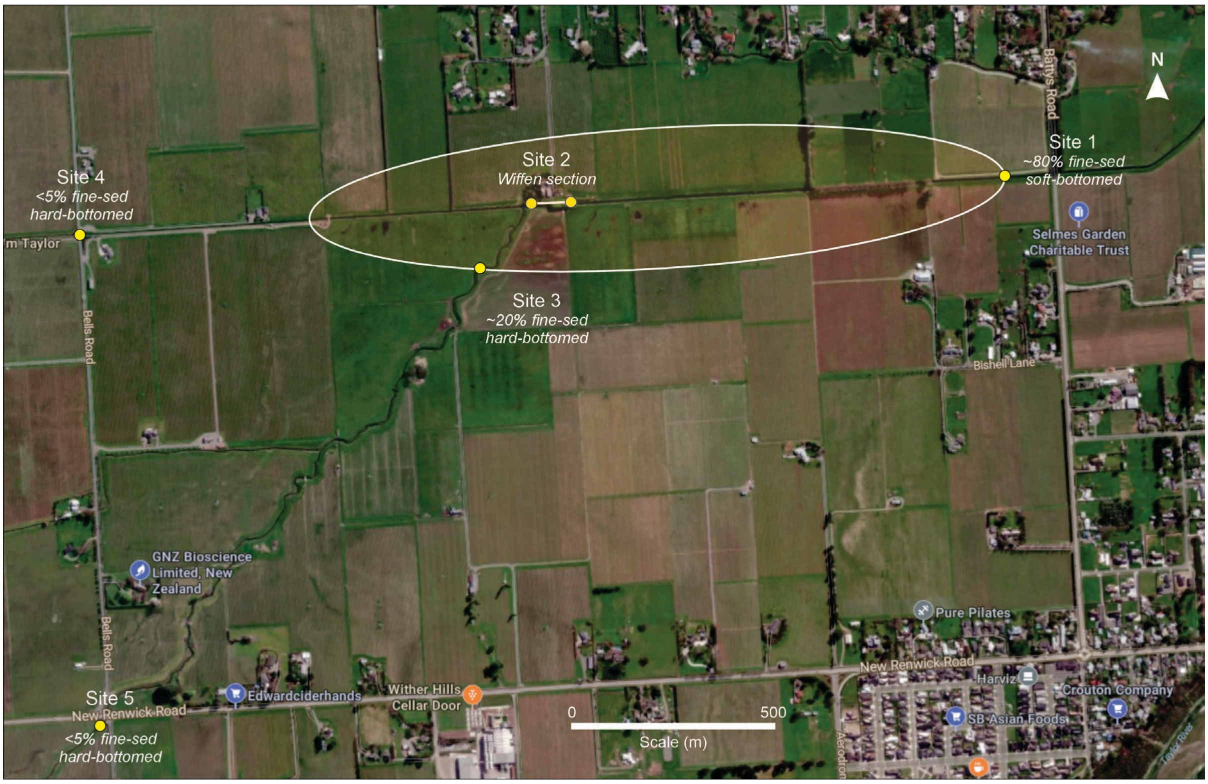

Figure 4.6 Doctors Creek transition zone. The riverbed transition zone is located west of Blenheim and occurs close to the toe of Taylor River Fan, in an area where there are surficial (relict) fluvial fan channels associated with the Fairhall River Fan. (Base image: Google Maps.)

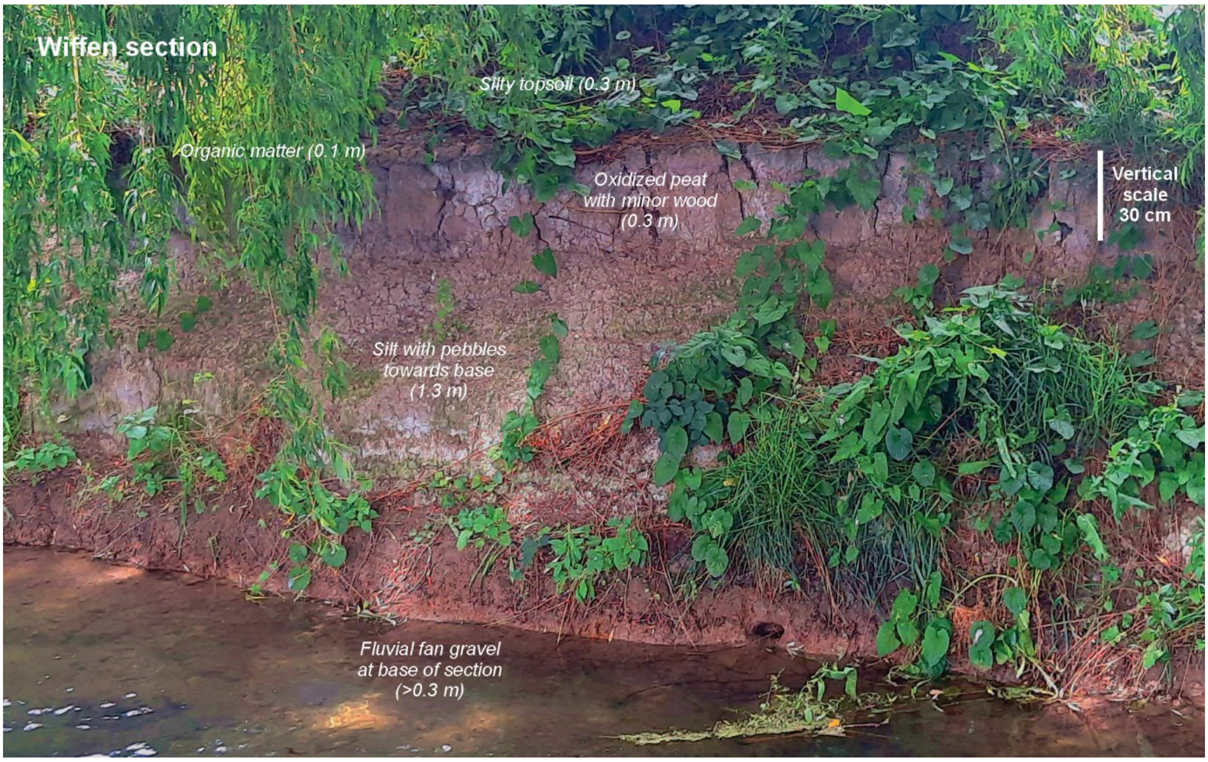

Figure 4.7 Doctors Creek, Wiffen section. Riverbank outcrop in Doctors Creek drainage channel discharging to Taylor River. Location: Site 2 in Figure 4.6. Prior to river-management interventions, this area was a poorly drained swamp. (Credit: Martin Crundwell.)

4.5.3 Taylor River Transition Zone

The earliest river-management intervention in Taylor River was in 1878, when the river was diverted to the Omaka River (Figure 2.4). The Taylor River was subsequently dammed in its upper reaches in 1965 to reduce urban flooding (Figure 2.4). Since then, stopbank heights have been increased, culverts and floodgates upgraded and pump stations installed in urban areas (Calder-Steele 2024). Most of the Taylor River flow in the upper part of the catchment is lost to groundwater recharge of the Wairau Plain, and flow is only continuous in the lower section of the river that drains the low-lying part of the catchment (Davidson 1959).

The Taylor River hard- to soft-bottomed transition zone is located near the centre of Blenheim (Figures 4.3 and 4.8) in a section of river that has been highly modified by river-management interventions. The transition zone occurs close to the toe of the Taylor River fan, in an area where the signatures of surficial (relict) channels is 'muted' by overlying fine-grained coastal floodplain deposits, including swamp deposits (Figure 4.1).

Figure 4.8 Taylor River transition zone. The riverbed transition zone is located near the centre of Blenheim and occurs close to the toe of the Taylor River Fan, in an area where the signatures of surficial (relict) channels are 'muted' by thick fine-grained coastal floodplain deposits. (Base image: Google Maps.)

The present-day soft- to hard-bottomed transition zone in Taylor River is located within the modelled natural transition zone and is close to the boundary where river sediment cover is predicted to be naturally soft-bottomed (Figure 4.1). This suggests that, while there may be some anthropogenic impacts on riverbed sediment cover, they are not severe, and more detailed geological investigations are needed to determine the extent that the site has been impacted. Heavy infestations of invasive exotic species of aquatic plants (Figure 4.9), and bankside outcrops that show a 40–50-cm-thick layer of poorly sorted muddy regolith over silty gravel (Figure 4.10), which is presumed to associated with the Ōpaoa River braidplain facies (Figure 4.1), attest to some of the impacts. River-management interventions, such as the sediment trap near Taylor River trail (Figure 4.11), also demonstrate the extent to which the natural flow of the river has been impacted.

Figure 4.9 Taylor River channel. Invasive exotic species of aquatic plants along the river channel and banks of the Taylor River. Location: between Sites 1 and 2 in Figure 4.6. (Credit: Martin Crundwell.)

Figure 4.10 Taylor River riverbank outcrop. Location: between Sites 1 and 2 in Figure 4.6. (Credit: Martin Crundwell.)

Figure 4.11 Taylor River sediment trap. Location, Site 5 in Figure 4.6. (Credit: Martin Crundwell.)

4.5.4 Wairau River Transition Zone

The Ōpaoa breach was closed in 1926 to stop Wairau River flood overflows from entering the Ōpaoa River. This increased flood flows in the Wairau River by about 50% and caused riverbed scour in the mid-section of the river. River flows were further impacted in 1963, when a permanent stopbank/groyne was constructed at Conders Bend and the Wairau Diversion was opened (Figure 2.4).

The Wairau River soft- to hard-bottomed transition zone is located immediately downstream from the Wairau Diversion, in a part of the river that has been severely impacted by river-management interventions (Figures 4.3 and 4.12). The most significant intervention has been the Wairau Diversion (Figure 4.13), which allows about half of the normal river flow and most of the flood flow to discharge directly to the sea, instead of following the meandering channel of the river and discharging to a lagoon and then sea at Wairau Bar (Christensen and Doscher 2010). The increased conveyance efficiency of the Wairau River has increased flow velocity and riverbed scour and straightened the river channel in the central part of the river between State Highway 6 and State Highway 1 and reduced peak flow velocity and increased fine-grained riverbed sediment accumulation in the lower part of the Wairau River (Christensen and Doscher 2010). The impact of these changes in river flow is evident in the ~3 km displacement between the modelled 'natural' location of the transition zone near Rapaura and the present-day location below State Highway 1 (Figure 4.1).

Figure 4.12 Wairau River transition zone. The transition zones in the Lower Wairau River and Wairau Diversion are located immediately downstream from the diversion, in an area of the coastal floodplain where there are old meander channels and surficial (relict) meandering channels. (Base image: Google Maps.)

Figure 4.13 Aerial photo of Wairau River and Wairau Diversion. In the Wairau Diversion, gravels extend ~2 km downstream from the State Highway 1 bridge, and the soft- to hard-bottomed transition zone in the lower Wairau River is immediately downstream from the gravel extraction plant – see Figure 4.11. (Credit: MDC.)

4.5.5 Pukaka Stream Transition Zone

Prior to river-management interventions, Pukaka Stream was a blind 'river' that drained hill country and terminated in a swamp (Davidson 1959). The first major river management interventions were in 1878, when drains and stopbanks were constructed to drain the swamp. Improvements to drainage were made in 1917 and, subsequently, pump stations have been installed to increase drainage efficiency.

The Pukaka Stream riverbed transition zone occurs in a narrow, confined part of the Pukaka Stream valley (Figure 2.1) and is very poorly constrained due to field accessibility issues (thick vegetation and limited road access). The first accessible site where riverbed sediment cover is classified as hard-bottomed (100% gravel) is approximately 3 km upstream from the mouth of the valley, and riverbed sediment cover in the lowermost part of the valley where the stream flows out onto the plain is comprised entirely of mud and is classified as soft-bottomed.

Auger holes in the flat lying lowermost part of the Pukaka Stream valley reveal significant lateral variations in coarse-grained sedimentary facies 0.6–3 m beneath the surface of the ground (Figures 4.14 and 4.15). The upper fine-grained silt deposits thin notably towards the mouth of the valley and out into the plain (between hole-2 and hole-3) and onlap beach gravel deposits (at hole-1) and dune sand and beach gravel deposits (at hole-3). Taking into account the distribution and thickness of the upper silt deposits and the depth that the stream in the lower part of the Pukaka Stream valley erodes, riverbed sediment cover in this area should be naturally soft-bottomed (i.e. the same state as the present-day). However, physical evidence of impacts at this site are evident near the mouth of Pukaka Stream valley, where the natural flow of the stream is severely impacted by invasive willows and aquatic plants (Figure 4.16).

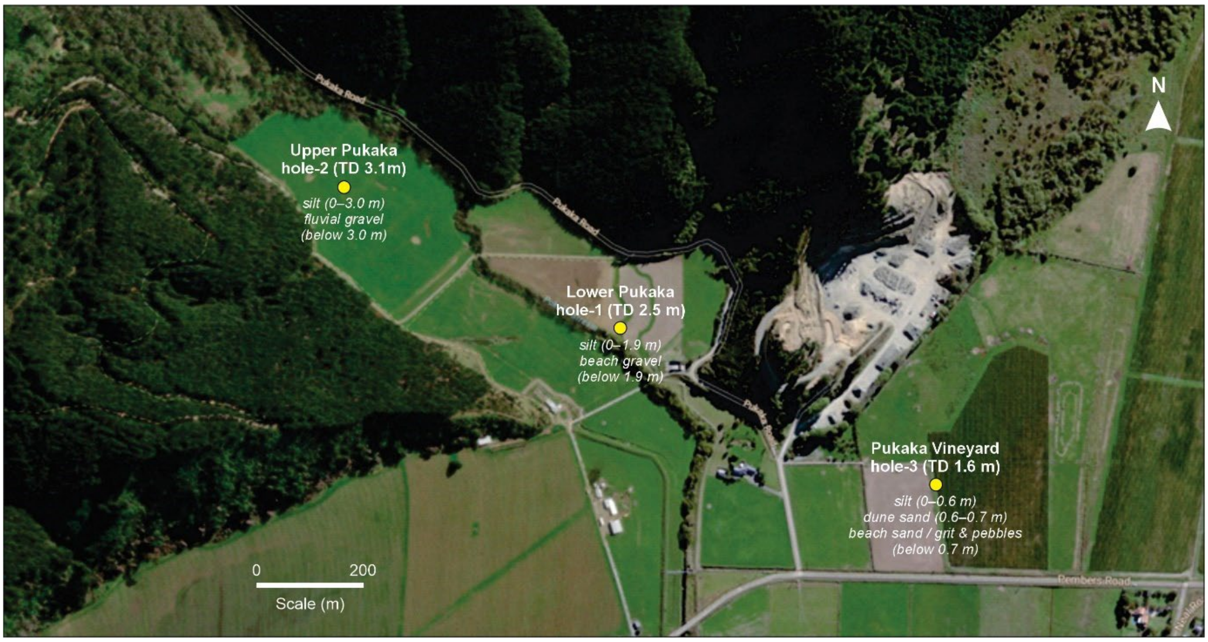

Figure 4.14 Pukaka Stream auger hole locations. (Base image: Google Maps.)

Figure 4.15 Pukaka Stream auger holes. Pukaka Stream Site 1, auger extended to 2.25 m; Site 2, auger extended to 3 m. (Credit: Paul White.)

Figure 4.16 Pukaka Stream near the mouth of Pukaka Stream valley. Invasive willows and aquatic plants have modified the natural stream flow and created a series of pools and riffles, near hole-2 (Figure 4.14). (Credit: Martin Crundwell.)

5.0 DISCUSSION

5.1 Anthropogenic Impacts on Riverbed Sediment Cover

Major river-management interventions (stopbanks, diversions, channel re-alignments, drains and pump stations) that have reduced the flood risk and improved drainage in the Wairau Plain, and the consequential intensification and diversification of land use that has resulted from these interventions, have had significant impacts on riverbed sediment cover and the plain's freshwater ecosystems and natural biodiversity. For example, reduced river flows from river-management interventions in the Ōpaoa River and tributaries of the Ōpaoa River, and the increased supply of fine-grained sediment resulting from changes in land use in catchments of the Ōpaoa River, have had a major impact on riverbed sediment cover. In addition, invasive exotic species of aquatic plants, which thrive in highly modified sections of rivers, have also reduced flow velocities in parts of these rivers to the point where entrained fine-grained sediment is deposited in river channels that would normally be hard-bottomed (Petticrew and Kalff 1991). The full extent of these impacts is evident in the ~4 km displacement of the present-day transition zone in the Ōpaoa River with respect to the modelled natural transition zone in riverbed sediment cover (Figure 4.1).

Dense infestations of exotic aquatic plants in these rivers (Figure 4.8) have also reduced the diversity of native aquatic species, and sometimes replaced them, through competition for resources and ecosystem engineering (Bunn et al. 1998). Aquatic plants have also had some positive impacts because they stabilised riverbed sediment cover and made it more resistant to erosion (Wharton et al. 2006; Heppell et al. 2009) and provided new habitats for many species.

Exotic species of trees, such as invasive willows that thrive along the banks of rivers, have also had a detrimental impact on riverbed sediment cover. For example, in the lower part of the Pukaka Stream, the roots of willows and fallen trees interrupt the natural river flow and trap entrained sediment in deep pools, where the flow velocity is much reduced (Figure 4.16).

5.2 Impacts of Sea-Level Rise and Tectonic Subsidence

The use of sedimentary facies in this study provides predictive insight to the future response of riverbed sediment cover (including riverbed transition zones) to changes in sea level (the baselevel that rivers and sedimentary facies equilibrate to). For example, under the general principles of sequence stratigraphy (Catuneanu 2022), if relative sea level rises, either from eustatic or tectonic causes, sedimentary facies (including riverbed transition zones) shift inland and, when sea level falls, they shift seaward.

The sixth synthesis report of the Intergovernmental Panel on Climate Change (IPCC), released March 2023, notes that the rate of climate change and sea-level rise is accelerating due to human activity. Under climate-change scenarios reported by the IPCC, absolute sea level is projected to rise 0.20–0.33 m by 2050, 0.38–0.90 m by 2090 and 0.60–1.67 m by 2130. Sea-level rises of this magnitude are comparable to the peak Holocene sea-level rise during Meltwater pulse 1C (7000–8000 years ago), when estuarine and shallow marine sedimentary facies shifted at least 5.5 km inland (Figure 2.3).

Long-term tectonic subsidence (negative VLM), seen from borehole and geological data, could potentially add an additional 0.4 mm/year of relative sea-level rise (0.012 m by 2050, 0.028 m by 2090 and 0.044 m by 2130) on the northern side of the of the Wairau Plain and even more on the southern side of the fault (Crundwell, unpublished GNS Science data from the National Aquifer Mapping project). The magnitude of relative sea-level rise from long-term tectonic subsidence is very small compared to sea-level rise from climate change, but it could potentially add to the inland shift in sedimentary facies.

More concerning, near- and far-field earthquakes that cause geologically instantaneous VLMs in parts of the Wairau Plain (e.g. Nicol and Van Dissen 2018) could potentially cause relative changes in sea level on the scale of millimetres to metres and contribute to significant shifts in sedimentary facies.

The NZ SeaRise[2] programme, which uses geodetic observations from interferometric Synthetic Aperture Radar (InSAR) and Global Navigation Satellite Systems (GNSS) and bases VLM estimates on a time series between 2003 and 2011 (a period of tectonic quiescence with no large earthquakes), shows VLM values that are highly variable along the Cloudy Bay foreshore, even between closely spaced stations. Such variability is unlikely to be attributed to tectonics alone and other factors must be involved, such as sediment supply. For example, the lowest VLM values (-1.8 mm/year) occur at the southern part of Cloudy Bay, where river-management interventions have starved the coast of its natural sediment supply, and the highest values of 0.5 mm/year occur at the northern part of Cloudy Bay, where the sediment supply to the coast has increased due to the increased conveyancing efficiency of the Wairau Diversion. Changes in sediment supply to the coast are almost certainly contributing to the Cloudy Bay VLM signal, but the extent to which sediment supply is masking the tectonic signal is uncertain. The impact of the tectonic signal on sedimentary facies is also uncertain. In addition, understanding sea-level-induced changes to riverbed sediment cover is also critical for any future investment plans to remediate anthropogenic-induced changes.

2 https://searise.takiwa.co/map/6245144372b819001837b900/embed

6.0 CONCLUSIONS

The spatial baseline model that is developed and presented in this study for natural (pre-anthropogenic) riverbed sediment cover in the Wairau Plain provides a simple and easy to use rapid assessment method to assist the MDC in identifying anthropogenically impacted sections of rivers and streams.

The spatial baseline model indicates that riverbed sediment cover has been impacted to different degrees across the Wairau Plain, depending on the type and extent of river-management interventions, and also the location of impacted sites. For example, the model distinguishes sites that have been severely impacted where there have been major interventions (e.g. Ōpaoa River and Wairau River) where present-day soft- to hard-bottomed transition zones are displaced significantly with respect to the modelled ‘natural’ riverbed transition zone (Figure 4.1). The model also recognises sites that have been less severely impacted (e.g. Doctors Creek and Taylor River), where the present-day transition zones in riverbed sediment cover are located within the modelled ‘natural transition zone’ (Figure 4.1) and need more detailed geological investigations to determine the full extent to which they have been altered from their natural state, and whether action plans to restore those sites is warranted. In terms of Section 3.25 of the NPS-FM 2020, this is an important first step in the assessment of impacted Wairau Plain rivers and the anthropogenic factors that have contributed to the altered state of impacted sites.

The use of sedimentary facies in this study also provide predictive insight to the future response of riverbed sediment cover (including riverbed transition zones) to changes in relative sea level (the baselevel that rivers and sedimentary facies equilibrate to) from either eustatic or tectonic causes. Such insight is important because it assists MDC in developing, accessing and implementing ‘environmentally sustainable’ investment plans to mitigate the impacts of sea-level rise associated with climate change.

7.0 RECOMMENDATIONS

The rapid assessment method that is developed and presented in this report is an important first step in the assessment of impacted Wairau Plain rivers. It also highlights the need for a geologically based method to undertake secondary, site-specific, assessments to assist MDC in determining whether it is appropriate to restore anthropogenically impacted sections of rivers and, if appropriate, help the council in developing and accessing restoration options, as required under Section 3.25 of the NPS-FM 2020.

Climate change and associated sea-level rise is likely to cause sedimentary facies (including transition zones in riverbed sediment cover) to shift inland and cause some naturally hard-bottomed sections of rivers to transform to a soft-bottomed state as the natural earth system re-adjusts to a future state of equilibrium. In addition, changes in sediment supply associated with climate change, and tectonic subsidence, must also be considered in order to determine the potential extent and rate of conversion in riverbed sediment cover during this re-adjustment. Currently, there is a lack of guidance and agreed-upon methodology for MDC to employ in determining the potential impacts of climate change and associated sea-level rise on riverbed sediment cover. This information is essential to assist the council in developing sustainable long-term ecological outcomes that will fulfil the needs of the Marlborough community and goals of the NPS-FM 2020.

8.0 ACKNOWLEDGEMENTS

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APPENDICES

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APPENDIX 1 NATIONAL POLICY STATEMENT FOR FRESHWATER MANAGEMENT

Section 3.25 – Deposited Sediment in Rivers

1. If a site to which a target attribute state for deposited fine sediment applies (see Table 16 in Appendix 2B) is soft-bottomed, the regional council must determine whether the site is naturally soft-bottomed or is naturally hard-bottomed.
2. If a regional council determines that a site that is currently soft-bottomed is naturally hard-bottomed, the council must:
   a. monitor deposited sediment at the site using the SAM2 method at least once a year (instead of at the frequency required by Table 16 in Appendix 2B); and
   b. monitor freshwater habitat in a manner suitable to the current state of the site (that is, as soft-bottomed); and
   c. determine whether, having regard to the relevant long-term vision, it is appropriate to return the site to a hard-bottomed state; and
   d. if it is appropriate to return the site to a hard-bottomed state, prepare an action plan for how to do that.

APPENDIX 2 ADOPTED WORKFLOW

1. Identify soft- to hard-bottomed transition zones in Wairau Plain rivers and streams where the percentage of soft riverbed sediment cover (particles <2 mm diameter) ranges between 80% and 20%, using the rapid habitat assessment method of Clapcott (2015).
2. Select and inspect a subset of accessible soft- to hard-bottomed transition zones and access anthropogenic factors that may be contributing to the deposition of fine-grained sediment (particles <2 mm diameter).
3. Develop a detailed geological framework for Holocene and Pleistocene sediments beneath the Wairau Plain, using borehole data (White et al., in prep.).
4. Map and classify the distribution surficial (relict) river channels using processed digital terrain models from MDC high-resolution airborne LiDAR data and use the channel morphologies as proxies for natural (pre-European) river gradients and flows.
5. Model the natural (pre-European) state of riverbed sediment cover across the Wairau Plain, using the geological framework and the mapped distribution of surficial (relict) river channel morphologies.
6. Assess anthropogenic impacts on riverbed sediment cover by comparing the locations of present-day soft- to hard-bottomed sediment transition zones and the modelled natural (pre-European) state of riverbed sediment cover.
7. Establish guidelines for use by the MDC to assess and manage anthropogenic impacts and sea-level rise impacts associated with climate change.

APPENDIX 3 GLOSSARY OF TERMS, ABBREVIATIONS AND UNITS

Alluvial – relating to or derived from alluvium (loose clay, silt, sand or gravel that has been deposited by running water in a riverbed onto a floodplain, fluvial fan or beach).

Anastomosing river channels – multiple river channels that merge into larger channels (i.e. dendritic drainage). Anastomosing channels are typically associated with and erode into fine-grained overbank deposits.

Anthropogenic – originating in human activity.

Aquiclude – a solid, impermeable, sedimentary layer (facies) or body of rock, underlying or overlying an aquifer.

Aquifer – an underground permeable sedimentary layer (facies) or fractured rock that conducts water. Commonly associated with fluvial-fan and braidplain facies.

Aquitard – a low-permeability sedimentary layer (facies) that restricts groundwater flow between aquifers. Commonly associated with coastal floodplain facies.

Avulsion – in sedimentology. A hydrological process, related to river channels that are repeatedly displaced, when a triggering event, commonly a flood, forces a river across a stability threshold. Contributes to the dendritic (radially arranged) pattern of fluvial fan channels and multi-threaded pattern of braided river channels (Slatt 2013).

Baselevel – in river geomorphology. Limit below which a river cannot erode.

Beach and beach ridge facies – present-day and relict coastal deposits associated with shorelines.

Blade shaped clasts – in sedimentology. Rounded, flat, elongate sedimentary clasts that are diagnostic of beach deposits.

Borehole data – lithological descriptions (sedimentary layers and characteristics, including grain and clast size and shape, compactness, colour, and distinctive content, such as wood and shells, etc.) recorded by drillers.

Braided river channels – complex network of multi-threaded (interwoven) channels separated by braid-bars. Typical of large rivers that flood frequently and have moderate gradients and high sediment bed loads.

Braidplain facies – present-day and relict coarse-grained sedimentary deposits associated with braided rivers. Typically coarse-grained, with very little mud, and sand and gravel deposits are often laterally continuous and vertically connected (Slatt 2013).

Calcareous microfossils – microscopic shells of protozoans (e.g. foraminifera and ostracods) and shell and skeletal fragments of larger marine organisms (e.g. molluscs and bryozoa) – diagnostic of marine sedimentary facies.

Clast roundness – in sedimentology. The degree of clast rounding, on a scale of rounded to angular, reflects the distance that clasts have been transported and/or the environment of deposition.

Clay – in sedimentology. Extremely fine sedimentary particles <0.002 mm (2 μm).

Coastal floodplain – flat, very low-lying, area near the coast, prone to flooding and marine inundation.

Coastal floodplain facies – present-day and relict fine-grained sedimentary deposits associated with a broad facies belt that encompasses very low-lying parts of a river plain that is susceptible to flooding and marine inundation.

Cobble – in sedimentology. Very coarse sedimentary rock fragments (clasts) between 64 mm and 256 mm diameter.

Comminuted plant material – plant material that has been broken and abraded into very small fragments.

Confined aquifer – an underground aquifer between layers of impermeable material that is hydraulically pressured (above atmospheric pressure), causing water to rise above the top of the aquifer when it is penetrated by a well.

Dendritic fluvial fan channels – channels that branch and form multiple channels (analogous to the branches of a tree).

Depositional architecture – the three-dimensional arrangement and geometries of sedimentary deposits within a specific geological setting, encompassing the spatial distribution of sedimentary facies, sedimentary structures and stratigraphic units.

Digital elevation model – digital elevation model (DEM). A three-dimensional representation of the ground surface, including both natural and artificial elements such as buildings and infrastructure.

Digital terrain model – a digital terrain model. A three-dimensional representation of the unaltered (natural) ground surface.

Ecosystem engineering – in ecology. The process by which species (e.g. invasive aquatic plants) create, significantly modify, maintain or destroy habitats.

Estuarine and lagoon facies – present-day and relict sedimentary deposits associated with estuaries and lagoons, influenced by a combination of marine processes (such as waves and tides) and fluvial processes (from river input).

Eustatic sea-level change – global changes in sea-level associated with changes in the volume of ice on land, or changes in the shape of the sea floor caused by plate tectonic processes.

Fluvial fan – is an accumulation of sediment that fans out from a concentrated source of sediment (i.e. from the mouth of a tributary that spills out onto a river plain).

Fluvial fan facies – present-day and relict fluvial fan deposits associated with dendritic (radially arranged) surficial channels.

Freshwater diatoms – microscopic, single-celled siliceous algal that live in freshwater (common in low-energy freshwater environments and sedimentary facies).

Geodetic observations – observations (data) acquired by remote sensing (sensors and instruments on land and sea, in the air, and in space).

Geological framework – a three-dimensional geological model based on geological observations (data) below the surface of the ground.

Gravel – in sedimentology. A loose aggregation of coarse to very coarse rock fragments, including size classes from granule (2–4 mm) to boulder (<256 mm). Udden-Wentworth scale: granular gravel (2–4 mm) and pebble gravel (4–64 mm).

Hard-bottomed – in ecology. Refers to rivers dominated by coarse-grained riverbed sediment cover (i.e. where 50% or more of the riverbed sediment cover is >2 mm [Clapcott et al. 2011]).

Holocene – the current geological epoch that began approximately 11,700 years ago. Associated with a period of warm interglacial climate.

InSAR – Interferometric Synthetic Aperture Radar. A remote sensing technique used to generate maps of surface deformation or digital elevation.

Intergovernmental Panel on Climate Change (IPCC) – an intergovernmental body of the United Nations, whose job it is to advance science knowledge about climate change caused by human activities.

IPCC climate-change scenarios – based on future emissions scenarios: very low, low, intermediate, high, very high (IPCC 2023).

ka – unit of time (kilo annum) equal to 1000 years.

Last Glacial Maximum – the most recent time during the last glacial period that ice sheets were at their greatest extent (about 18,000–24,000 years ago).

LiDAR data – 'Light Detection and Ranging' remote sensing technology that quantifies the three-dimensional structure of vegetation and underlying terrain using laser technology.

Lithological characteristics – in sedimentology. Physical properties of sedimentary deposits, including colour, composition, texture and grain size.

Loess – a clastic sedimentary accumulation (deposit) of windblown, typically silt-sized, particles.

Meandering river channels – single-thread highly sinuous river channels that form in low-gradient sections of rivers.

Meltwater pulse 1C – the most recent period of rapid post-glacial sea-level rise (about 8.2–7.6 ka) when sea-level rise is estimated to have risen 6.5 m in less than 140 years (Blanchon 2011a, 2011b; Blanchon and Shaw 1995).

Natural (pre-anthropogenic) state – natural state before human settlement.

Naturally hard-bottomed – modelled (pre-anthropogenic) hard-bottomed state of riverbed sediment cover.

Naturally soft-bottomed – modelled (pre-anthropogenic) soft-bottomed state of riverbed sediment cover.

NPS-FM 2020 – National Policy Statement for Freshwater Management 2020.

NTZ – natural transition zone. Natural (pre-anthropogenic) transition zone between hard- and soft-bottomed riverbed sediment cover.

Overbank deposit – in sedimentology. Fluvial deposit (usually fine-grained) on the floodplain of a river that has broken through or overtopped the river's levees during flood flow.

Pea-metal beach gravel – natural beach and beach-ridge gravel deposits, comprised of well-rounded granule- and pebble-sized (2–64 mm) rock fragments.

Pebble – in sedimentology. Coarse sedimentary rock fragments (clasts) between 4 mm and 64 mm.

Pools and riffles – in river geomorphology. A succession of one or more combinations of pools and riffles (gravel bars) along a stream channel in the downstream direction.

Quaternary – the current and most recent of three periods of geological time in the Cenozoic Era. It follows the Neogene Period and begins 2.58 million years ago.

Rapid habitat assessment method – rapid habitat assessment is a protocol for assessing physical habitat condition in New Zealand waterways (Clapcott 2015).

Regolith – a blanket of unconsolidated, heterogeneous superficial deposits.

River channel morphology – refers to the physical characteristics of river channels, including shape, size and behaviour.

River geomorphology – the study of the interactions between the physical shape of rivers, their water and sediment transport processes, and the landforms they create.

River levee – a natural embankment that confines normal river flows and, when breached or overtopped, causes widespread flooding.

River management interventions – human interventions, such as stopbanks, diversions, channel re-alignments, drains and pump stations that have been introduced to reduce the risk of flooding and improve drainage.

Riverbed transition zones – in this study. Sections of rivers where the percentage of soft riverbed sediment cover (particles <2 mm diameter) ranges between 20% and 80%.

Sand – in sedimentology. Fine sedimentary particles between 0.063 mm (63 μm) and 2 mm diameter.

Sand dune facies – present-day and relict sand-dune deposits associated with wind-driven accumulations of sand.

Sedimentary facies – bodies of sediment that are recognisably distinct from adjacent sediments that resulted from different depositional environments and processes.

Sedimentary facies belts – groupings of sedimentary facies and subfacies that are associated with a particular geomorphological setting (e.g. coastal facies belt).

Semi-confined aquifer – an aquifer that is overlain or underlain by a low permeability (aquitard) layer, through which leakage takes place.

Sequence stratigraphy – a branch of stratigraphy that attempts to discern and understand geological history by subdividing and linking sedimentary deposits into unconformity bounded units on a variety of scales.

Shallow marine facies – present-day and relict shallow marine deposits associated with the inner continental shelf.

Silt – in sedimentology. Very fine sedimentary particles between 0.002 mm (2 μm) and 0.063 mm (63 μm) diameter.

Soft-bottomed – in ecology. Refers to rivers dominated by fine-grained riverbed sediment cover (i.e. where more than 50% of the riverbed sediment cover is <2 mm [Clapcott 2015]).

Spatial baseline model – in this study. A simple two-dimensional model based on geological and geomorphological inputs that is used to classify sections of rivers as naturally soft-bottomed, naturally hard-bottomed or naturally transitional between a hard- and soft-bottomed state.

Surficial (relict) river channels – this study. Natural (pre-anthropogenic) alluvial landforms associated with unconstrained flood flows.

Swamp and wetland facies – present-day and relicts with organic-rich deposits.

Unconfined aquifer – an aquifer whose upper water surface (water table) is at atmospheric pressure and thus is able to rise and fall.

Ventifact – in this study. A stone that has been abraded and pitted by wind-driven sand.

VLM – vertical land movement related to tectonic subsidence and uplift, both long-term and geologically instantaneous caused by near- and far-field earthquakes.

WVS – Wairau Valley Scheme. Implemented in 1960–1975 after the Marlborough Catchment Board was established in 1956. The goal of the scheme was to achieve “as far as economically possible” the prevention of flooding, provision of adequate drainage and stabilisation of all river and stream channels and catchments (Waters 1959).

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