REPORT

Tonkin+Taylor

High Level Geomorphic Assessment

Te Karaka Flood Management Optioneering

Prepared for
Gisborne District Council

Prepared by
Tonkin & Taylor Ltd

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1 Introduction

Tonkin & Taylor Ltd (T+T) has been engaged by Gisborne District Council (GDC) for the purposes of supporting project management, analysis, optioneering design, and evaluation of potential solutions to mitigate the flood risk to Te Karaka, a township situated in Tairāwhiti. The purpose of this report is to detail a high-level geomorphic assessment for the reach of the Waipaoa River adjacent to Te Karaka township to support flood risk mitigation options.

This report has been prepared in accordance with the contract signed 17 February 2025 – Te Karaka Flood Management Optioneering.

1.1 Project objective and scope

This geomorphic assessment has been prepared to support GDC in evaluating flood risk mitigation options for the Te Karaka settlement. The assessment aims to identify geomorphic risks and tolerances associated with a shortlist of flood management strategies, and to inform the selection of preferred options.

The primary objectives of this assessment are to:

- Characterise the existing geomorphology of the Waipaoa River and its catchment near Te Karaka.
- Conduct a high-level literature review covering:
  - Catchment and river evolution.
  - Large-scale landscape processes influencing river morphology and behaviour.
  - Broad geomorphic trends.
- Review existing data on mean bed levels and river cross-sections.
- Incorporate expert insights provided by Dr. Ian Fuller.

The shortlisted flood management options have been modelled using an existing, calibrated hydraulic model developed by DHI. T+T have provided detailed design options and cost estimates based on model outputs. The geomorphic assessment findings will be integrated into the Multi Criteria Analysis (MCA) to support the identification of a preferred option or combination of options.

This report presents an overview of the Waipaoa River catchment and its geomorphic characteristics, evaluates the behaviour of the river system, summarises hydraulic modelling outputs, assesses geomorphic risks and tolerances for flood management options, and identifies areas for further investigation.

1.2 Background

Te Karaka is a small settlement located approximately 25 km north-west from Gisborne. The Waipaoa River forms a loop around the Te Karaka township. The Waipaoa River originates from the eastern slopes of the Raukūmara Range, with a catchment area of approximately 2,208 km^2.

Prior to Cyclone Gabrielle in 2023, Te Karaka relied on 4.5 km of stopbanks along the Waipaoa River for flood protection. These stopbanks, however, were not designed to handle extreme weather events of Cyclone Gabrielle's scale, with the design event (Cyclone Bola peak river flow + 25%) showing that the entire township is subject to a significant flood hazard (from stopbanks overtopping). The low-lying geography of Te Karaka increases the flood risk, making even moderate floods a threat to homes, infrastructure, and livelihoods.

The aftermath of Cyclone Gabrielle required extensive cleanup efforts, with significant government and community support. Many homes and buildings were uninhabitable due to flood damage, resulting in displaced families. Cyclone Gabrielle is the costliest cyclone on record in the Southern Hemisphere, with total damages estimated at $14.5 billion.

To mitigate future flood risks, the government has approved a budget of $13.2 million to enhance flood protection for Te Karaka. This funding is part of a broader flood resilience strategy that includes infrastructure improvements and reassessments of flood management systems. GDC has previously collaborated with DHI to model various options, and T+T has utilised this information, along with insights from a site visit on 12 February 2025 and their flood management expertise, in the optioneering process.

2 Catchment overview

2.1 Topography

The Waipaoa River catchment covers approximately 2,208 km^2 and is located within the forearc region of the Hikurangi Margin - a tectonically active zone where the Pacific Plate subducts beneath the Indo-Australian Plate at a rate of 5–6 cm per year (Wallace et al., 2004). This active tectonic setting generates uplift rates up to 4 mm y^{-1} in the headwaters of the Waipaoa River (Litchfield and Berryman, 2006). Despite the active tectonics, the catchment exhibits relatively modest relief, with a maximum elevation of 1,213 m above sea level and only 16% of the area exceeds 300 m elevation (Kuehl et al., 2016). The terrain is predominantly steep, with 86% of the catchment comprising slopes greater than 20°, particularly in the mid- to lower catchment where more coherent Miocene-Pliocene lithologies dominate (Kuehl et al., 2016).

2.2 Geology

The headwaters of the Waipaoa catchment, comprising approximately 8% of the total area, are underlain by highly deformed Cretaceous-age shale and mudstone of the East Coast Allochthon (Mazengarb and Speden, 2000). The remainder of the catchment is predominantly underlain by Miocene-Pliocene mudstones and sandstones. Around Te Karaka township, valley floor sediments consist of gravels, sands, and silts, while surrounding hillslopes feature a mix of mudstone, sandstone, siltstone, and tuff. Isolated pockets of mudstone interbedded with tuff, ignimbrite, paleosols, gravel, and sand are also present (Figure 2.2).

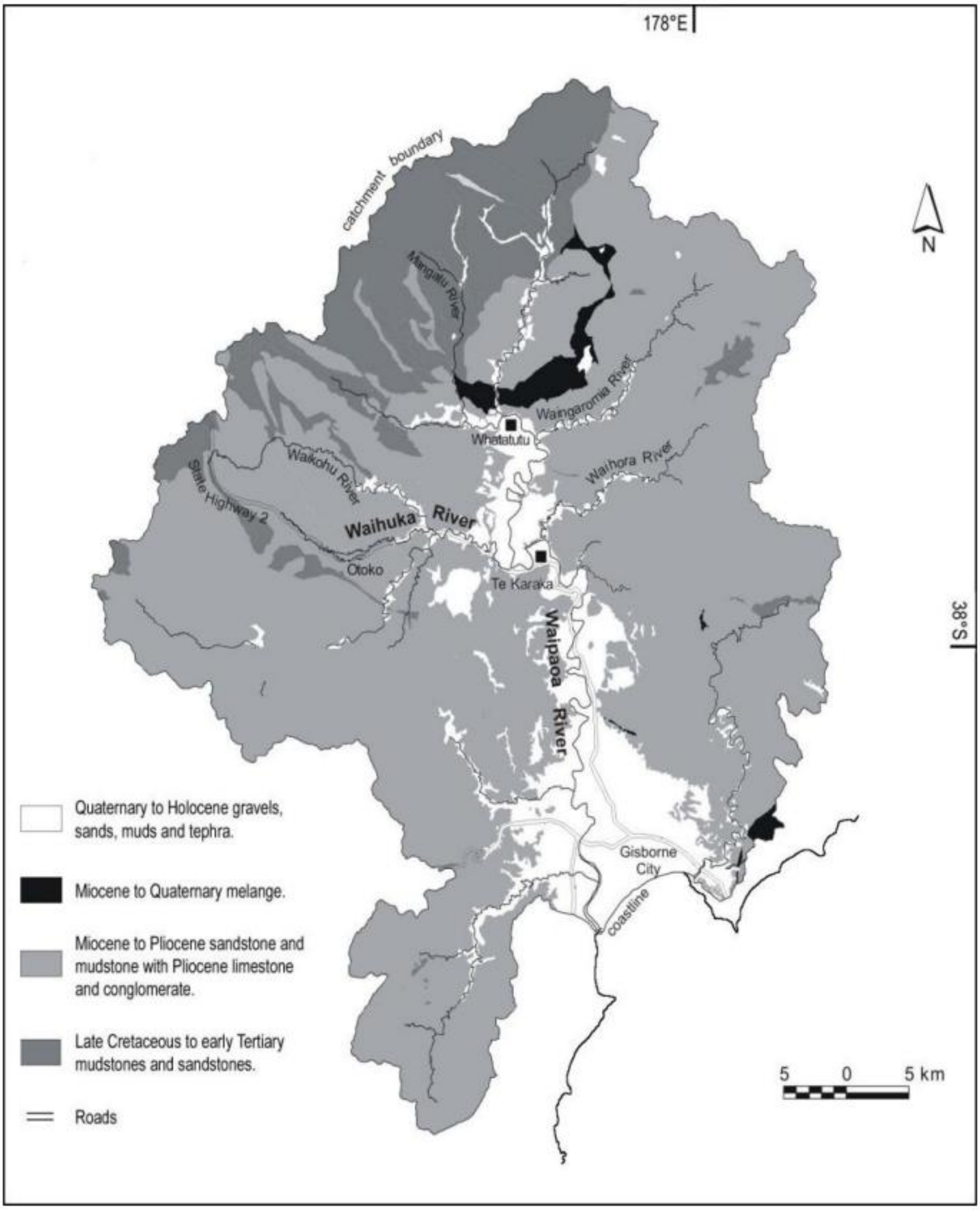

Figure 2.1: Distribution of lithologies within Waipaoa catchment. Sourced from Landcare (2011). Location of Te Karaka shown mid-catchment.

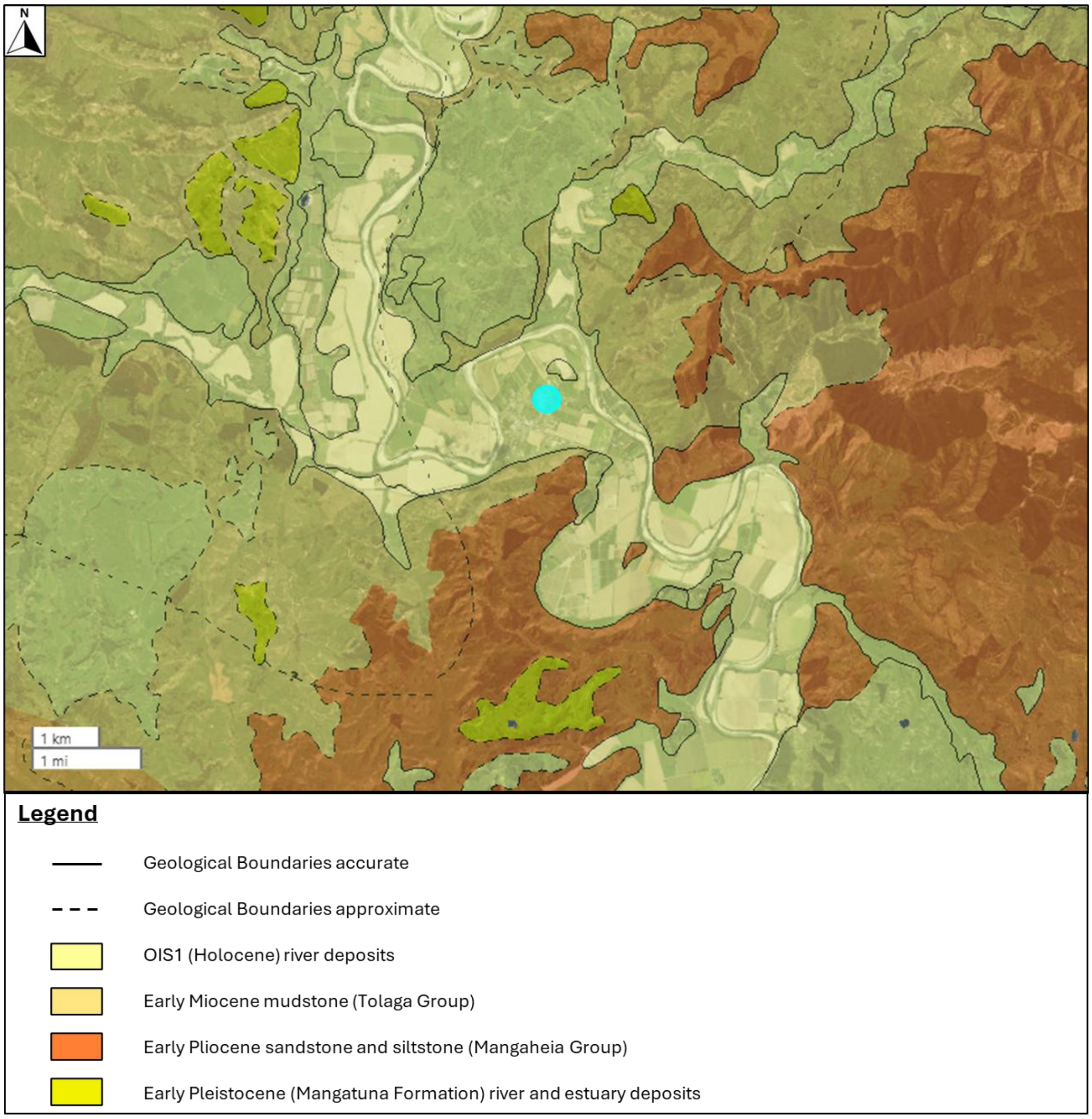

Figure 2.2: Distribution of lithologies within the vicinity of Te Karaka Township (blue dot). Sourced from Heron (2018).

2.3 Climate and hydrology

The Waipaoa catchment experiences a warm, temperate climate characterized by warm, moist summers and cool, wet winters. Rainfall increases inland, with mean annual precipitation ranging from approximately 1,200 mm at Tairāwhiti/Gisborne City to around 2,500 mm in the upper catchment (Hessell, 1980). The region's climate is strongly influenced by the El Niño–Southern Oscillation (ENSO), with La Niña phases typically bringing intense rainfall events and El Niño phases associated with prolonged droughts. Summer tropical cyclones, such as Cyclones Hale and Gabrielle in 2023 and Cyclone Bola in 1988, have also contributed to accelerated erosion.

Sediment yield in the Waipaoa catchment is largely driven by the cumulative impact of frequent, low-magnitude storm events. Approximately 75% of landslide-derived sediment is generated during storms with recurrence intervals of less than 27 years (Reid and Page, 2003), underscoring the significance of gully erosion processes (Marden et al., 2018). Statistically, there is a 29% annual probability of a major event, with a greater than 99% likelihood of one occurring within any

10-year period (Kelliher et al., 1995). These climatic and hydrological dynamics contribute to high erosion rates and substantial sediment transport (Water and Soil Directorate 1987).

The hydrology of the Waipaoa catchment is highly variable. The mean annual flood (MAF) is 1,477.17 m^3/s, with a recorded peak flow of 5,272.67 m^3/s and a mean flow of 33.59 m^3/s. This variability highlights the potential for short-duration, high-magnitude flood events capable of driving significant geomorphic change (Figure 2.3).

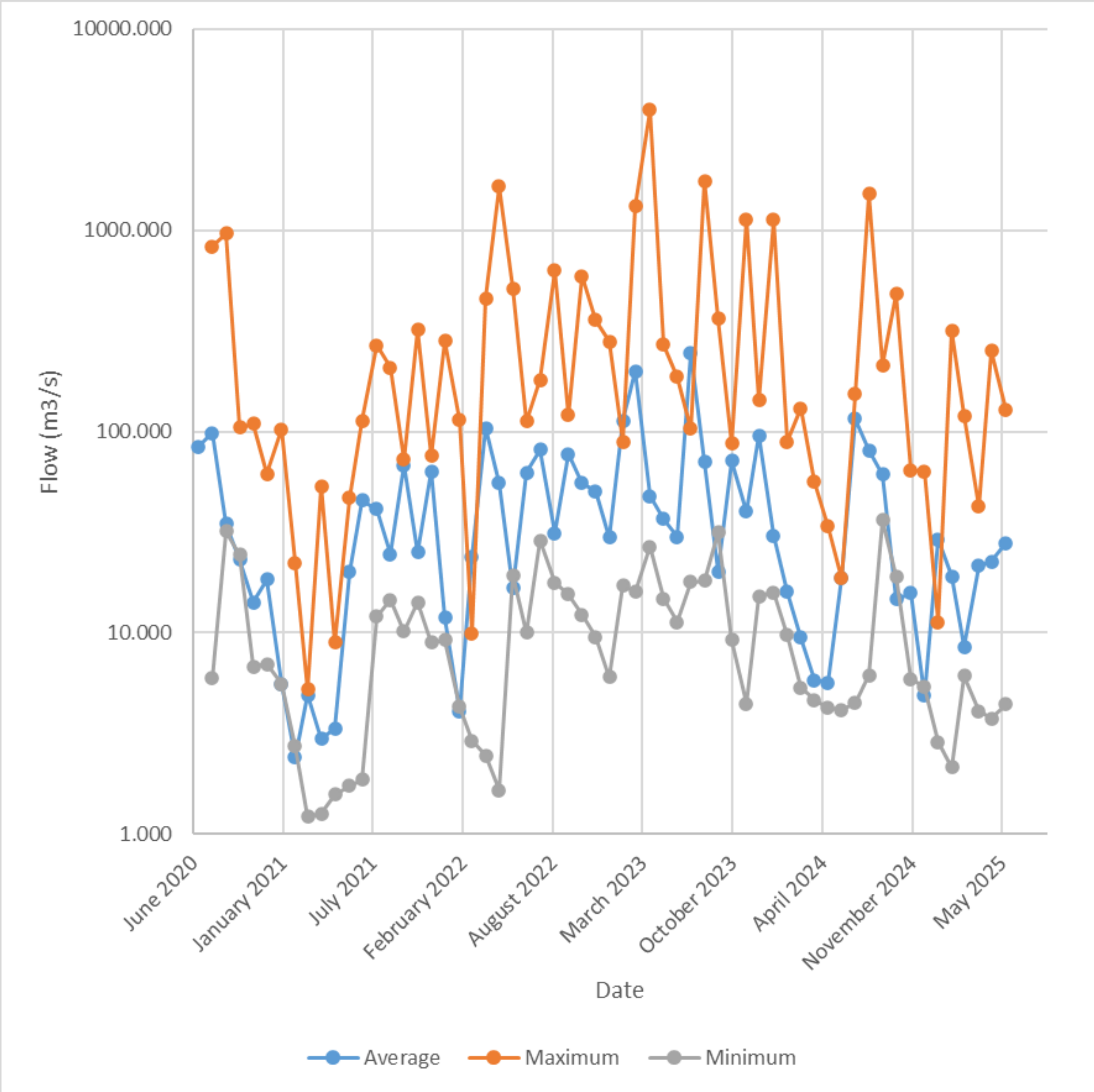

Figure 2.3: Summary of flow data for the Waipaoa River at Kanakanaia (June 2020 - May 2025)[1].

[1] Gisborne District Council. Te kōeketanga awa - River levels. Retrieved from https://www.gdc.govt.nz/environment/maps-and-data/river-levels

2.4 Land cover

Land cover is a fundamental control of river form and function, contributing to sediment yields, catchment run-off and morphological diversity (Baillie, 2001). In larger catchments, vegetation may be a secondary influence, but still affects sediment yields (Basher, 2013). River processes and their riparian vegetation are also implicitly interlinked, with river processes modified by vegetation, but equally, the vegetation itself can be modified by the river. This interlinked process is currently known as fluvial biogeomorphology (Corenblit et al., 2007; Gurnell & Bertoldi 2024).

The clearance of indigenous forest from the Waipaoa catchment by European colonists has reversed late-Holocene incisional trends in the mid- and upper catchment, exposing highly-erosion-prone terrain throughout the catchment (Fuller et al., in prep). Deforestation of the lower catchment occurred as early as 700 years ago with arrival of Polynesian (Māori) settlers. Deforestation continued into the headwater reaches following European settlement (Pullar 1962; McGlone et al. 1994; McGlone & Wilmshurst, 1999 and Wilmshurst et al. 2008). Much of the lowland had been deforested by 1875 (Murton 1968), and by the late 1920s 97.5 % of the old-growth native forests had been destroyed (Gomez et al. 1999). The magnitude of erosion since European forest clearance in the late nineteenth and early twentieth century exceeds that of any other part of New Zealand (Phillips and Marden 2004).

Although deforestation continues today, it occurs at a reduced rate compared to the 19th and early 20th centuries. Current land cover patterns (Table 2.1) show cyclical changes in exotic forestry, often inversely correlated with indigenous forest cover[2]. Similar trends are observed between exotic grasslands and native shrublands (e.g., mānuka and kānuka). These cycles of forest clearance and conversion to grassland reduce the landscape's buffering capacity, increasing sediment generation from exposed soils (Marden, 2022).

2.5 Sediment regime

River behaviour in the Waipaoa catchment is strongly influenced by catchment-scale boundary conditions such as topography, valley morphology, and slope—factors largely governed by regional geology (Section 2.2), as well as land cover. The underlying lithology and presence / absence of forest cover determines terrain erodibility, which in turn controls sediment supply and the spatial and temporal patterns of river channel change.

With removal of indigenous forest cover, runoff from the Waipaoa catchment has incised into uplifted, jointed, and clay-rich marine sedimentary rocks that are highly susceptible to mass movement, gullying, and chemical weathering (Mazengarb & Speden, 2000; Pearce et al., 1981). These highly erodible geologies contribute to significant sediment production and transport. Estimated suspended sediment yield is approximately 15 million tonnes per year (Hicks & Shankar, 2003), with a total of 14.08 ± 2.1 km^3 of sediment generated since the Last Glacial Maximum (Marden et al., 2014). Such high levels of erosion are also shown through estimated peak basin-averaged erosion rates of 14 mm yr^{-1} (Marden et al., 2014b).

The Waipaoa is in a state of dynamic instability and highly sensitive to changes in sediment production (Phillips and Gomez, 2007). Modelling suggests the Waipaoa was and still is a highly sensitive system with results suggesting that suspended sediment discharge increased by 140% after Polynesian arrival, 350% after European colonisation and 660% after headwater deforestation (Kettner et al., 2007). These trends demonstrate a high degree of sediment delivery and conveyance through the system. Coarser material has been stored in valley floors that have aggraded by up to 100 mm yr^{-1} following deforestation (Gomez and Rosser, 2018). In the upper catchment single

[2] Manaaki Whenua – Landcare Research. LCDB v5.0 - Land Cover Database version 5.0, Mainland, New Zealand. Retrieved 10 April 2025. Retrieved from LCDB v5.0 - Land Cover Database version 5.0, Mainland, New Zealand | LRIS Portal.

Table 2.1: Summary of landcover change (ha) between 1996 and 2018.

Landcover	2018 Change	2012 Change	2008 Change	2001 Change	Minimum change	Maximum change
Broadleaved Indigenous Hardwoods	-48.32	23.61	108.76	-3.11	-48.32	108.76
Deciduous Hardwoods	24.36	-43.11	34.10	205.90	-43.11	205.90
Exotic Forest	-3799.39	559.36	3007.57	5497.86	-3799.39	5497.86
Fernland	-66.49	-63.38	15.33	164.92	-66.49	164.92
Forest - Harvested	5340.82	148.18	-1193.03	-1049.99	-1193.03	5340.82
Gorse and/or Broom	-17.83	-19.47	204.64	47.08	-19.47	204.64
Herbaceous Freshwater Vegetation	-5.13	0.00	0.00	-46.24	-46.24	0.00
High Producing Exotic Grassland	-1721.93	-361.15	-2602.73	-4889.75	-4889.75	-361.15
Indigenous Forest	-11.09	0.00	-6.77	2.31	-11.09	2.31
Landslide	1.99	2.58	-16.16	-10.90	-16.16	2.58
Low Producing Grassland	421.12	-352.19	-315.41	-673.18	-673.18	421.12
Manuka and/or Kanuka	-129.14	103.93	551.72	580.67	-129.14	580.67
Orchard, Vineyard or Other Perennial Crop	6.41	-0.25	237.39	134.57	-0.25	237.39
Short-rotation Cropland	-10.69	-1.10	-26.68	35.89	-26.68	35.89

Note: The following landcover types were excluded from the table as they had less than 15 Ha of change throughout the data periods (Built-up Area (Settlement), Urban Parkland/Open Space, Tall Tussock Grassland, River, Transport Infrastructure, Surface Mine or Dump, Matagouri or Grey Scrub, Gravel or Rock, Mixed Exotic Shrubland and Lake and Pond).

thread rivers have been replaced by bedload-dominated braided channels. The material forming this bedload is very weak, which means it breaks down very readily and as a result the lower Waipaoa, which was once clear flowing and cobbly (pre-European clearance) is now muddy and fines-dominated (see Section 3).

In response to naturally high erosion rates, ongoing catchment management efforts have focused on revegetation of erosion-prone areas to reduce slope-derived sediment inputs and protect critical infrastructure. While afforestation in the upper catchment is expected to reduce valley floor aggradation, it will also generate channel incision in upper reaches as sediment supplied to the channel is reduced. In turn, this incision becomes a significant sediment source, perpetuating aggradation downstream. Accordingly, the lower catchment valley floor in the vicinity of Te Karaka is likely to continue experiencing aggradation due to this persistently high sediment throughput. Modelling by Gomez et al. (2009) suggested that the lower Waipaoa River could continue to aggrade by as much as 0.31 m in the 2030s and 0.85 m in the 2080s.

2.6 Summary

The boundary condition changes outlined in this section underscore how land use transformation and climatic variability have amplified the geomorphic responses of an already highly erodible landscape. These compounded influences have significantly increased off-slope sediment delivery across the catchment, resulting in sustained sediment overloading of the Waipaoa River system throughout the 20th and 21st centuries, which will continue for decades to come (Gomez et al., 2009).

As climate change progresses and primary industries—such as silviculture, horticulture, and agriculture—continue to expand within the catchment, these pressures are expected to intensify. Consequently, the river’s character and behaviour will continue to evolve in response to shifting sediment regimes and hydrological patterns. Flood management strategies for Te Karaka must therefore be adaptive and developed in alignment with anticipated geomorphic changes to ensure long-term resilience and effectiveness.

3 River condition

River character and behaviour are key to understanding how the river may respond to river channel modification including the options considered in this report. Understanding past behaviour can help inform future river trajectories and potential management decisions to mitigate risks arising from these modifications. River character and behaviour in the Waipaoa at Te Karaka has been assessed at a high level, based on existing literature and measured bed levels.

3.1 General principles

As illustrated in Figure 3.1, catchment morphology plays a critical role in determining river behaviour and sediment dynamics. In the upper catchment, valleys are typically confined, limiting the river's capacity for lateral adjustment and sediment storage. These confined reaches are efficient sediment transport zones, where coarse material sourced from hillslopes and the channel bed is rapidly conveyed downstream.

Moving downstream, valley confinement reduces and the river transitions into partly confined reaches. These areas offer greater potential for both lateral and vertical channel adjustment, as well as increased sediment storage. In the lower catchment, the river often flows through unconfined, broad alluvial valleys. Here, the channel becomes more mobile, adjusting its position across the floodplain through processes such as bank erosion and point bar deposition. These unconfined reaches frequently act as sediment sinks, where net deposition occurs. When the floodplain remains intact, these zones can effectively decouple sediment transfer to downstream reaches (Brierley, Reid & Coleman, 2011).

However, anthropogenic modifications—such as stopbanks, urban development, and other engineered flood management interventions—can impose artificial confinement, particularly in lower catchment areas. These modifications alter natural sediment dynamics and channel behaviour, often reducing the system's capacity to store or dissipate sediment and flood energy.

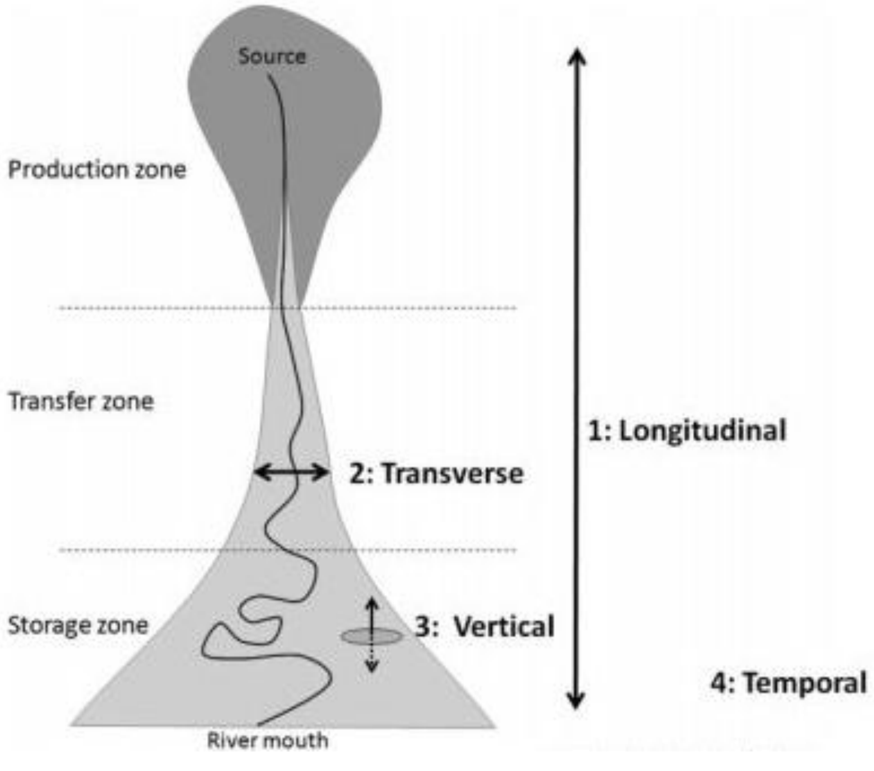

Figure 3.1: Typical longitudinal confinement of a river (Corenblit et al., 2015)

3.2 Waipaoa (pre-)historic river condition

During the Last Glacial Maximum the valley floors of the Waipaoa catchment aggraded in response to enhanced sediment delivery from a tree-less, landscape during cold climate episodes up to ~18 ka (Marden et al., 2008). A warm, moist postglacial period resulted in return of forest, reducing sediment supply and increasing stream power, triggering widespread incision (Gomez and Livingston, 2012). Incision undercut hillslopes not buffered by river terraces, resulting in significant slope adjustment (Bilderback et al., 2015), particularly via earthflow basal incorporation. This process of incision and slope readjustment was more or less complete by ~4 ka BP (Marden et al., 2014a). It is estimated that up to 120 m of incision occurred in the headwaters and 55 m of incision occurred in the middle reaches of the Waipaoa. Longitudinal connectivity effectively conveyed this incision-derived sediment to the Poverty Bay floodplain, which aggraded, storing 9.9 Mt of the ~41 Mt of sediment generated by postglacial fluvial incision (Marden et al., 2014a) infilling a shallow estuary and forming today's Poverty Bay Flats. The residence time of alluvium in the Waipaoa, based on the surface area of the entire suite of Late Pleistocene and Holocene river terraces is ~4400 yr, with a half-life of 310 yr (Phillips et al., 2007). Patterns of changing incision and aggradation respond to changes in connectivity between landscape compartments that reflect the spatial controls of geology and temporal controls of climate driving both lateral (slope-channel) and longitudinal (headwaters-lower river) sediment conveyance.

European settlement on the East Cape prompted large-scale forest clearance for pastoral farming, settlement and later timber trade (Coombes, 2000). The development of primary industries has meant the catchment has experienced transformative changes as a result of changing hydrologic cycles and land cover. Early settlers shaped the landscape to meet their needs as result sediment loads into the river system were increased as sediment was liberated from the deforested hillslopes. The rivers changed from single-thread, clear-flowing cobble-bedded rivers, to multi-thread, sediment-laden, rapidly aggrading channels with matrix-rich gravelly beds (Gomez et al., 2001). It is estimated that the upper river has aggraded by up to 20 m over the last century (Marden, 2011). The lower Waipaoa River, once gravel-bedded and laterally active, has become fixed between cohesive, silty banks and floodplain sedimentation is dominated by rapid vertical accretion (Gomez et al., 1998). Channel dimensions in the lower Waipaoa have accommodated increased fine sediment supply by a reduction in bank full width and cross-section area, leading to channel contraction (Gomez et al., 2007). The high suspended load is derived in part from the rapid breakdown of gravel-sized clasts of highly erodible shales and mudstones supplied from hillslope erosion in the upper catchment (Gomez et al., 2001), as well as the direct supply of fine sediment from gullies (Hicks et al., 2000). Reduced channel capacity and floodplain accretion in the lower Waipaoa compromises the Waipaoa Flood Control Scheme. The high rates of erosion and sediment conveyance within the Waipaoa catchment have been a catchment management issue since the mid twentieth century (Marden, 2012).

3.3 Current Waipaoa River condition

The Waipaoa River is a prime example of an 'Anthropocene river', i.e. one that has undergone a pronounced regime shift in response to anthropogenic forcing (DeBoer et al., 2020), and as such demonstrates a system where human activity has had an overwhelming impact (Fuller et al., 2015, Downs and Piégay, 2019). The scale of this impact reflects not only land-use change, but also the sensitivity of the catchment and connectivity between various parts of the catchment.

The supply of sediment to the system has not ceased in the twenty first century with Fuller et al. (2023) summarising the Waipaoa catchment as a "Globally significant example of an overloaded channel with exceedingly high sediment flux that is prone to profound, rapid and recurrent geomorphic adjustment, reflected in marked transition from rapidly aggrading bedload to aggrading suspended load dominated river along its length".

The catchment has a high connectivity from the mountains to the sea with hillslope erosion such as gully mass movement complexes and landslips inducing rapid fan and valley floor aggradation. As sediment stores are deposited along various points of the rivers course, subsequent higher flow events lead to recurrent reworking of fans and bed materials with dynamic and unpredictable geomorphologies ensuing. It has been noted that decadal aggradation rates may have diminished, but sediment flux remains exceedingly high, highlighting the concept that the sediment is spending less time in residence at a given location and instead is reworked to accommodate the next flow (Phillips and Gomez, 2007).

Fuller et al. (in prep.) have completed an assessment of morphological budgeting using differencing between the 2005 and 2019 LiDAR Digital Elevation Models (DEMs) to show sediment dynamics within the catchment. The assessment suggests that 2.3 million m^3 of sediment was removed from the upper Waipaoa. Conversely, only 0.86 million m^3 was deposited at various points in the downstream reaches, creating a net deficit in the sediment budget of 1.4 million m^3, this sediment was exported downstream and lost to the system. Such numbers highlight how large quantities of sediment is mobilized and transported throughout the system, whilst the sediment is not retained in the long term the short-term effects are large in magnitude and short term in duration. This creates a unique river management scenario where solutions are expected to accommodate for such phenomena, including progressive channel aggradation in light of such large sediment volumes being conveyed, and forecast bed level changes up to 0.85 m in the lower Waipaoa as modelled by Gomez et al. (2009).

Subsequent sub sections detail our recent analysis of DEMs[3] to characterise the current river condition and river response to the 2023 cyclone events (Cyclone Gabrielle and Cyclone Hale) in the vicinity of Te Karaka, building upon the assessment carried out by Fuller et al. (in prep) to further understand how the river has responded to recent weather events and sediment supply.

3.3.1 Cross section comparison

Ten cross sections were analysed to assess how the Waipaoa River channel and adjacent sediment stores have adjusted over time. These cross sections, provided by GDC and spanning from 1951 to 2000, are compiled in Appendix A. Overall, the majority of cross sections (excluding XS35) indicate that the general channel form has remained relatively stable, with only minor fluctuations in width and depth. These variations are likely attributable to sediment reworking in response to episodic weather events. The relatively limited changes to cross-section form over time are consistent with observations made at McPhail's bend by Gomez et al. (1998; 2007), who noted that the fine-grained cohesive banks limited the capacity for lateral adjustment and served to fix the river in place. In other words, bend migration is unlikely.

Cross section XS35 generally follows the same trend; however, the 1981 survey shows a notable deviation, with the active channel appearing to have avulsed approximately 250 metres to the true left. It is unclear whether this shift reflects a genuine geomorphic response to a flood event or a potential survey error, such as incorrect horizontal referencing. The consistency in cross-sectional shape across other epochs suggests the latter—a systematic survey error.

Survey coverage of areas adjacent to the active channel was inconsistent, with variations in both survey interval and horizontal extent. This inconsistency limits the ability to confidently assess long-term changes in adjacent sediment stores. However, where comparisons are possible across selected epochs, the trends align with those observed within the channel, showing alternating periods of erosion and deposition.

[3] (2018, March 2023 and September 2023).

3.3.2 Geomorphic Change Detection

The Geomorphic Change Detection (GCD) software is open source, publicly available software for the detection of surface raising and lowering between successive surfaces and includes the quantification of error in this change detection (Wheaton et al., 2010, Bailey et al., 2020). GCD allows improved sediment budgeting based on propagation of vertical uncertainty in repeat elevation surveys. It also allows for the quantification of volumes of surface raising (aggradation/deposition) and lowering (erosion/mass movement) within areas of interest and intercomparison between different epochs of change and areas of interest.

To account for uncertainty in the elevation data, a minimum level of detection (LoD) of 0.2 metres has been applied. This threshold is based on the estimated vertical uncertainty of the digital elevation models (DEMs) used in the analysis. Applying this LoD helps to filter out noise and minimise the influence of significant vertical discrepancies, particularly when one dataset exhibits greater vertical error than the other. However, it is important to note that this approach does not fully capture compounded vertical errors that may arise from both datasets in repeat elevation surveys.

GCD analysis of the Waipaoa River used the following DEMS:

- 2018/2020[4].
- March 2023[5].
- September 2023[6].

The use of the three DEMs allows the analysis to capture the impact of Cyclone Gabrielle and Cyclone Hale on river sediment stores (2018/2020 to March 2023) and the subsequent reworking of the sediment deposited during the Cyclone Gabrielle and Cyclone Hale events as the system reestablished an equilibrium (March 2023 to September 2023). The following two sections provide a summary of the results for the GCD analysis.

3.3.2.1 2018/2020 to March 2023

In the period between 2018/2020 and March 2023, the active channel underwent large scale deposition with areas of erosion less apparent and smaller in spatial extent. Figure 3.2 show the prevalence of deposition (blue) in the active channel.

Significant deposition occurred along the true right of the active channel throughout much of the reach, including the adjacent floodplain between the active channel and stopbank. This is likely due to large volumes of sediment deposited during recent cyclone events, which have remained largely unmobilised at the time of LiDAR data capture. These deposits are situated in low-energy zones—such as overbank or out-of-channel areas.

[4] Land Information New Zealand. Gisborne LiDAR 1m DEM (2018-2020). Retrieved from https://data.linz.govt.nz/layer/105614-gisborne-lidar-1m-dem-2018-2020/.
[5] Land Information New Zealand. Gisborne and Hawke's Bay - Cyclone Gabrielle River Flood LiDAR 1m DEM (2023) Retrieved from https://data.linz.govt.nz/layer/114544-gisborne-and-hawkes-bay-cyclone-gabrielle-river-flood-lidar-1m-dem-2023/.
[6] Land Information New Zealand. Gisborne LiDAR 1m DEM (2023). Retrieved from https://data.linz.govt.nz/layer/115847-gisborne-lidar-1m-dem-2023/.

On the wider valley floor, Figure 3.3 shows larger zones of apparent surface lowering to the east and west of Te Karaka; however, these are likely to be largely attributable to horticultural activities (e.g., crop removal), as indicated by their uniform shape and location within known horticultural land use areas. Changes in elevation around the township itself should not be interpreted as evidence of geomorphic processes. However, upstream on the true left some surface lowering could be attributable to flood scour, but this is difficult to resolve due to the use of this area by agriculture.

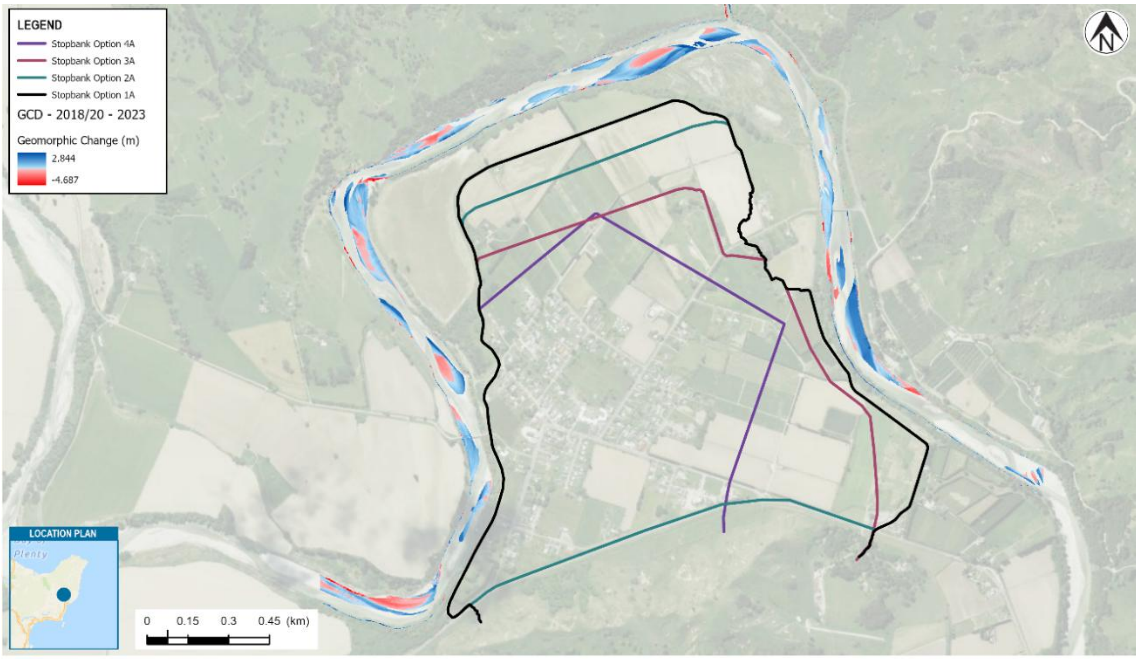

Figure 3.2: Summary of surface changes in the active channel between 2018/2020 and March 2023. Red denotes erosion surface lowering and blue denotes deposition/surface raising. Flow is from left to right.

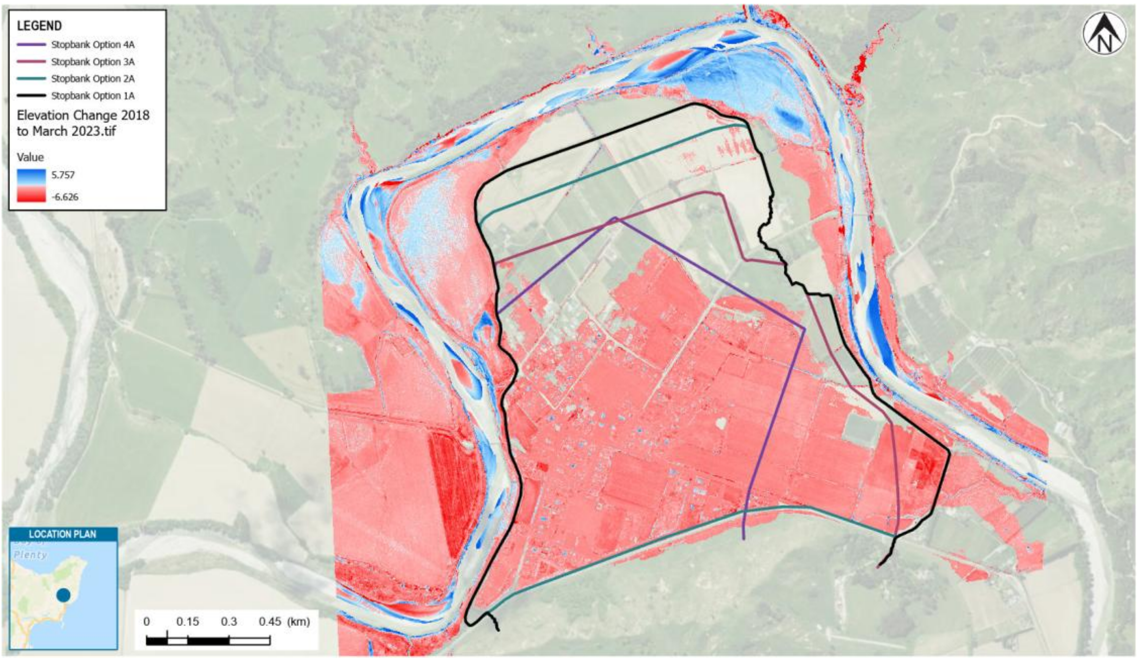

Figure 3.3: Summary of surface changes on the valley bottom between 2018/2020 and March 2023. Red denotes erosion surface lowering and blue denotes deposition/surface raising. Flow is from left to right.

3.3.2.2 March 2023 to September 2023

Between March and September 2023, the reach experienced significant geomorphic change, primarily driven by the reworking of sediment deposited during Cyclones Hale and Gabrielle. As shown in Figure 3.4, the reach exhibits a mosaic of erosion (red), and deposition (blue).

In the upstream portion of the reach, the true left of the active channel displays linear erosion patterns, likely resulting from high flows being directed along the channel margin and reworking sediment deposited in the previous epoch (Figure 3.4 and Figure 3.5). In contrast, the downstream half of the reach shows alternating zones of erosion and deposition, closely aligned with bar features visible in aerial imagery. The true right of the channel, particularly in the northwest and northeast corners of the reach, experienced notable deposition. This is attributed to the availability of accommodation space and reduced flow velocities in areas of flow expansion.

South of Te Karaka, patterns of erosion and deposition become less distinct, suggesting that sediment reworking is concentrated immediately north of the township or that sediment is being transported through this section and deposited further downstream. These spatial trends are further influenced by valley confinement, which increases toward the downstream end of the reach. This reduced confinement limits accommodation space, likely resulting in shorter sediment residence times compared to the more expansive upstream areas.

Figure 3.5 shows a large area of surface lowering (red) to the true left of the river upstream of Te Karaka, this is likely attributable to agricultural activities rather than geomorphic processes.

Beyond the stopbanks, in the vicinity of Te Karaka, larger zones of apparent deposition were observed; however, these are likely attributable to horticultural activities (e.g., crop growth), as indicated by their uniform shape and location within known horticultural land use areas. Changes in elevation around the township should not be interpreted as evidence of geomorphic processes.

The floodplain adjacent to the channel along the inside of the bend at Te Karaka has mostly been characterised by further deposition (Figure 3.5).

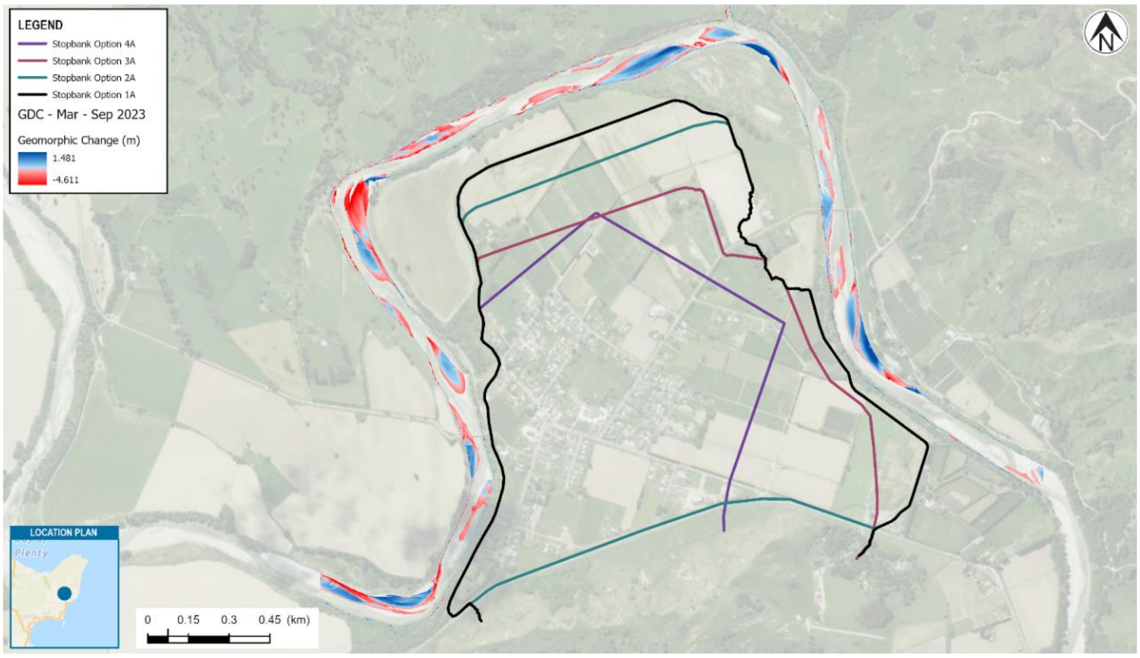

Figure 3.4: Summary of surface changes in the active channel between March 2023 and September 2023. Red denotes erosion/mass movement and blue denotes deposition/aggradation.

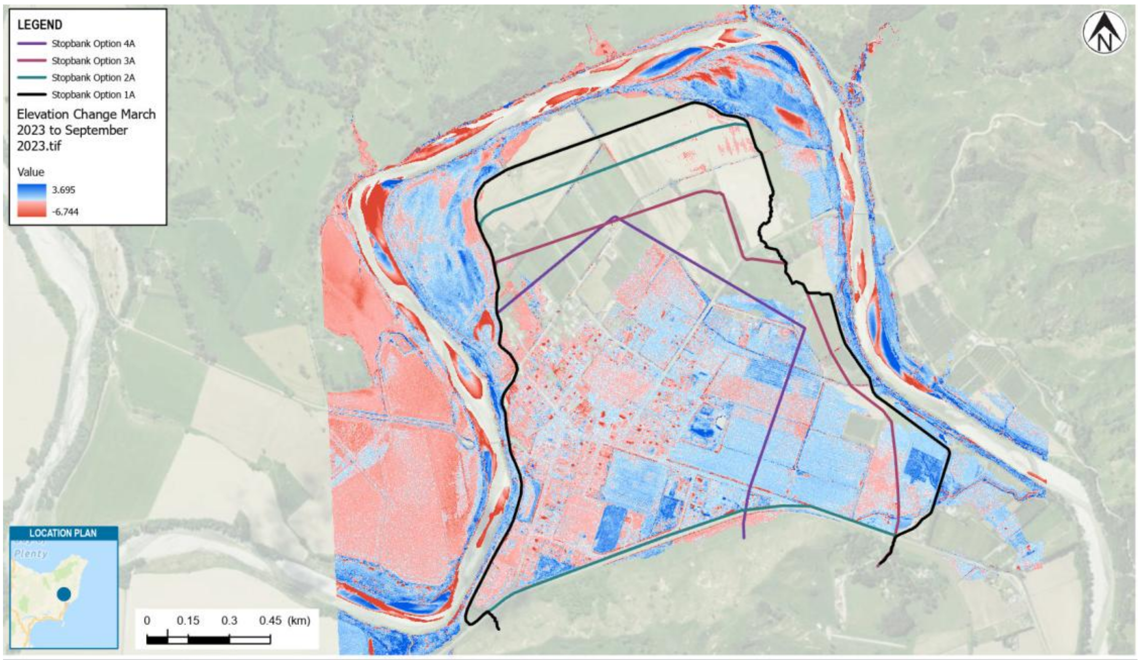

Figure 3.5: Summary of surface changes on the valley bottom between March 2023 and September 2023. Red denotes erosion/mass movement and blue denotes deposition/aggradation.

3.3.3 Summary

The Waipaoa River near Te Karaka has been artificially confined on the true right bank (stopbanks) and is naturally confined by valley margins on the true left bank. This confinement, together with the nature of sediment lining the channel limits the river's capacity for lateral migration, despite the river's inherent (historic) tendency to adjust its bed and banks in response to sediment load and flow variability.

Instead of freely adjusting, the river temporarily stores sediment—primarily sourced from upstream—within the channel and adjacent floodplain. This sediment is then episodically reworked, leading to alternating phases of erosion and deposition. Over the two analysed epochs, within the constraints of existing flood management infrastructure, this dynamic is evident. Material is mobilised and redistributed to accommodate fluctuations in sediment load and discharge. Volume changes associated with these processes are presented in Appendix B.

Between 2018 and March 2023 the predominance of deposition in both the channel and adjacent valley floor is clear with approximately 0.5 m of raising in the active channel. This raising is likely associated with sediment conveyed by the floods associated with Cyclones Gabrielle and Hale in particular and provides insight into how the sediment loading from severe weather events in the Waipaoa increases the risk of stopbank overtopping by reducing channel flood capacity. With the ongoing sediment supply from the catchment to this reach, and increasing likelihood of further severe weather events, this epoch highlights the challenge faced by flood management optioneering. Repeated sediment deposition must be expected.

In the epoch spanning March 2023 to September 2023, the immediate short-term response of the river to the increased sediment loading during the previous epoch (2018 to March 2023) was evident, with approximately 0.3 m of lowering in the active channel. Areas of the valley bottom adjacent to the channel on the true right showed ongoing deposition (Figure 3.5). During this period of lower flow conditions, more representative of mean flows in the catchment, the river reworked the deposited sediment in the channel and lower-elevation floodplain and transferred it

downstream. The net effect of this sediment reworking was the general lowering of the dry surfaces in the channel, potentially re-instating previous capacity of the stop banks, although ongoing deposition adjacent to the stopbanks on the true right may have offset this change.

It should be noted that in both epochs reported, geomorphic change was only detectable from dry surfaces within the active channel. LiDAR does not penetrate the water column, so the response of the wetted channel and extent of aggradation and reworking of the bed is unknown. Further work should be undertaken to quantify the adjustment of the wetted channel using bathymetric surveys.

4 Shortlist assessment

The shortlist of flood management options was proposed by T+T in the options assessment report[7]. The options were selected on the basis that Option 1 and Option 6 represented the two extremes of enclosed area (of flood risk reduction); Option 5 was the highest scoring of the remaining options and Option 3 represented a different concept whose benefits are worth exploring further. Option 1 is also important to keep under consideration for now, as it best represents the status quo. A summary of the shortlist options is given in Table 4.1 below.

Following the selection of the shortlist, the flood management options were sent to DHI Modellers to model how the options would perform in a flood event. As directed by GDC, all options are to have a level of service of a 5,625 m^3/s flood, corresponding to Cyclone Bola + 25% event, with 600 mm of stopbank freeboard. This is the design standard for the Waipaoa River scheme.

Table 4.1: Long list options for Te Karaka

ID	Long list option
1	Upgrade existing stopbanks
1A	Upgrade existing stopbanks with 1m of aggradation in the active channel
2	Retreat northern stopbank 160 m plus State Highway Spillway.
2A	Retreat northern stopbank 160 m plus State Highway Spillway with 1m of aggradation in the active channel
3	Retreat northern stopbank by 300 – 315 m, with retreat of the eastern stopbank to within 10 m of the edge of wastewater treatment pond
3A	Retreat northern stopbank by 300 – 315 m, with retreat of the eastern stopbank to within 10 m of the edge of wastewater treatment pond with 1m of aggradation in the active channel
4	Complete stopbank retreat to the smallest area of protection
4A	Complete stopbank retreat to the smallest area of protection with 1m of aggradation in the active channel

4.1 Summary of modelling of the options

The following section summarises the hydraulic modelling results produced by DHI for selected flood management options, with a focus on assessing their influence on flow dynamics, sediment transport potential, and geomorphic response within the Te Karaka reach. Refer to the Hydraulic Modelling Memo for more information on the models[8].

Model outputs were analysed for Options 1A and 4A only, as these represent the maximum and minimum extents of stop bank construction proposed within the shortlisted options, thereby capturing the full range of potential geomorphic responses.

[7] T+T, April 2025. Te Karaka Flood Management Optioneering – Options Assessment.

[8] T+T, 16 April 2025. Modelling Brief for Short-list Options – Te Karaka Flood Management Optioneering

4.1.1 Rationale for comparison of modelling results

The summary of results presented below is based on Options 1A and 4A, which represent the worst-case scenarios for each respective option—assuming up to 1 metre of channel aggradation. As such, the risks identified under these scenarios are intended to inform planning for events involving significant sediment accumulation within the active channel. which is realistic considering the sediment trends discussed above, as well as the geomorphic change detected in the active channel following Cyclone Gabrielle. Given the ongoing geomorphic trajectory of the Waipaoa catchment—including the reworking of substantial sediment stores in the upper catchment and continued slope-derived sediment input (Fuller et al., in prep.)—aggradation in the lower valley, including the Te Karaka area, is expected to persist into the foreseeable future (Gomez et al., 2009).

To compare modelled outputs with observed river conditions, polygons were generated from the GCD elevation change dataset spanning 2018/2020 to March 2023 (refer to Section 3.3.2.2 and Figure 4.1). Areas of elevation gain were classified as deposition zones, while areas of elevation loss were classified as erosion zones. Polygons exceeding 300 m² were considered significant and used to identify general patterns of geomorphic change. It should be noted that this approach provides a high-level overview and does not capture smaller-scale erosion or deposition features.

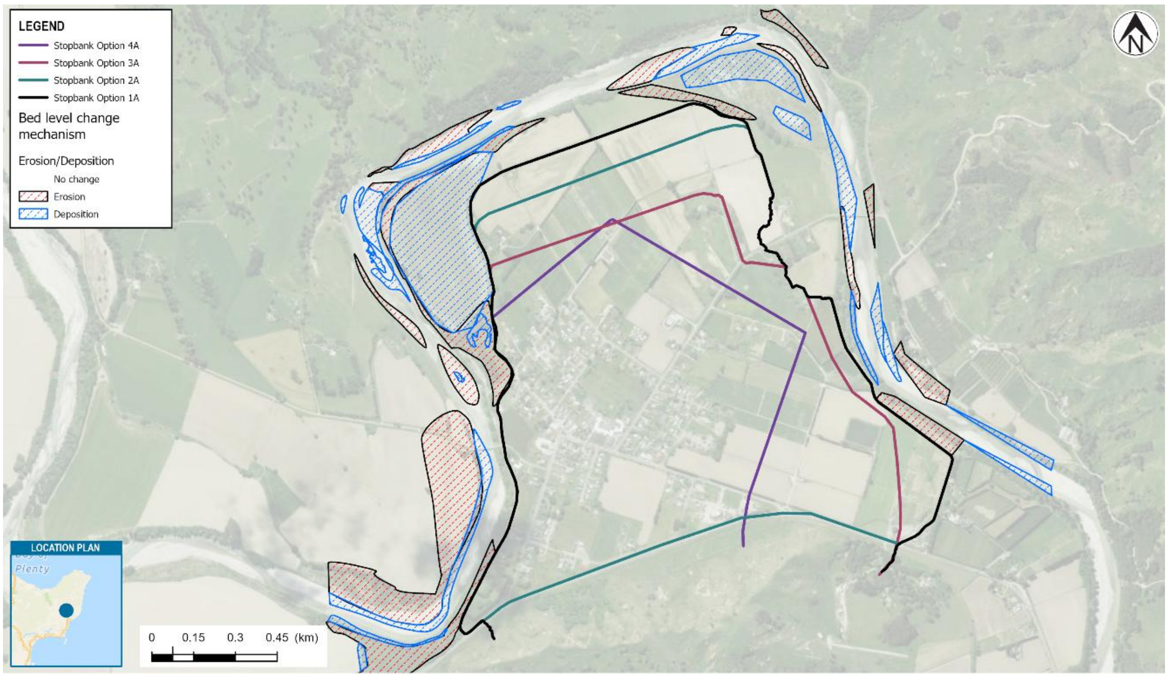

Figure 4.1: Delineated areas of erosion and deposition denoted from GCD results. Blue represents zones of deposition, and red represents zones of erosion.

Overlaying these polygons onto the modelled outputs allows for a spatial comparison of observed and predicted sediment dynamics. This comparison highlights how each option may influence sediment movement, particularly in relation to flow velocity and shear stress. It also enables identification of areas where erosion or deposition may be exacerbated or mitigated under different management scenarios.

Water level and depth were not included in this assessment, as these parameters are addressed in the broader flood optioneering report. Moreover, water depth is not a primary driver of geomorphic change or sediment transport and was therefore excluded from the geomorphic risk analysis.

4.1.2 Option 1A

4.1.2.1 Velocity

Figure 4.2 presents the modelled velocities for Option 1A, illustrating areas of high and low flow energy within the reach under the proposed maximum stopbank extent scenario. The difference is shown relative to the existing condition.

Modelled absolute velocities

Difference in modelled velocity between existing condition and modelled condition

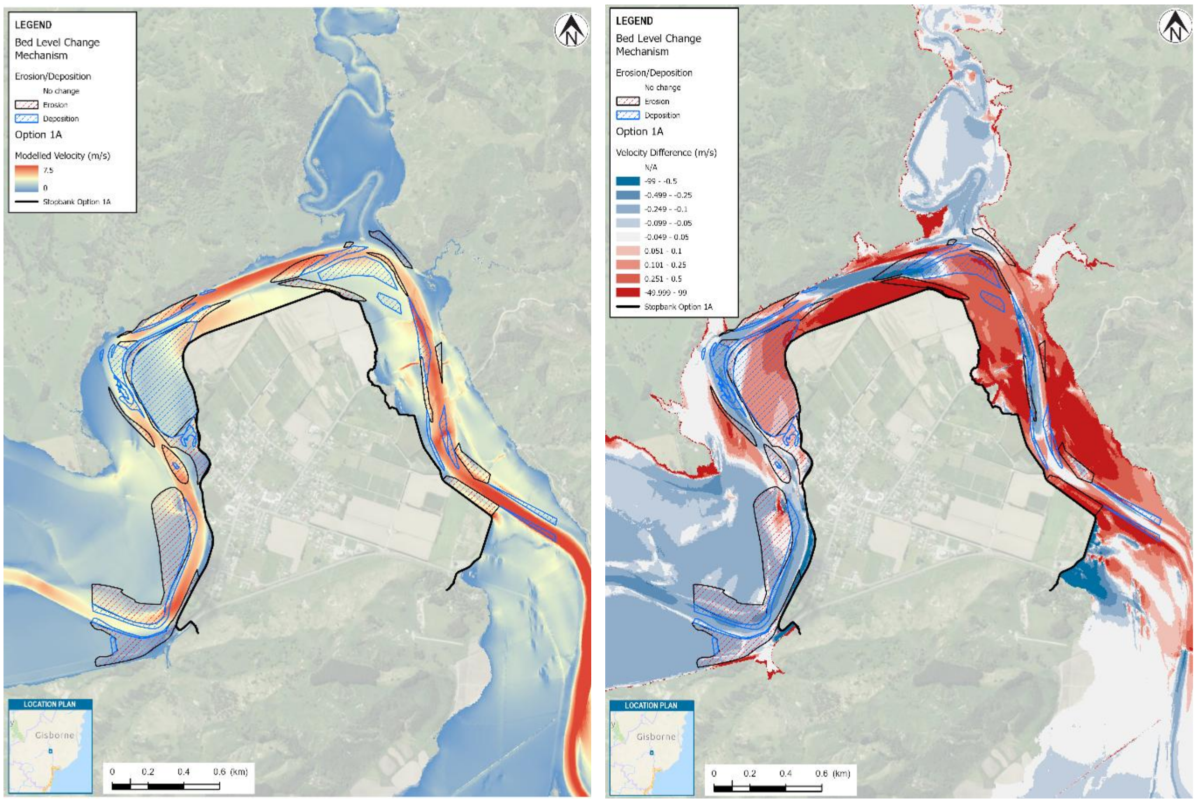

Figure 4.2: Summary of modelled velocities in Option 1A

Modelled velocities for Option 1A remain highest in the active channel relative to other model results, with a small area of elevated velocity on the point bar/floodplain pocket to the north of Te Karaka. Some local adjustment in response to flow stage and sediment supply is expected.

Velocity changes in Option 1A show an increase in velocities north of Te Karaka and downstream, however the areas of highest velocity change are the areas on the floodplain pockets to the north and east of Te Karaka (~0.25-1.4 m/s), the change in velocity will likely be high enough to create increased sediment mobilisation in the red areas in Figure 4.2, as such, sediment transport is expected to be greater in the vicinity of Te Karaka, with the possibility of sufficient velocity for floodplain scour or erosion here. The floodplain area and valley margins immediately north of Te Karaka are likely to undergo the highest degree of change in option 1A as the areas of velocity increase also coincide with areas of erosion previously identified in the GCD analysis (refer Section 3.3.2). Downstream the patterns of velocity change, erosion and deposition are inverted. Downstream of Te Karaka areas of known erosion align with areas of low velocity and areas of known deposition align with areas of high velocity. This pattern reinforces the dynamic nature of the river system which is noted to go through cycles of sediment transport and deposition in response to high flow events and sediment pulses. Note the cyclone epoch shows widespread deposition in the active channel – where velocities in the channel are higher, this may facilitate sediment transport and could limit deposition in these areas. Higher velocities during Cyclone Bola at McPhails Bend farther downstream limited floodplain accretion in that event (Gomez et al., 1998). However, at the entrance to the Te Karaka bend a zone of flow expansion on the true right does not significantly elevate velocity, suggesting that deposition is likely to continue in this area.

The modelling indicates that there is likely a change in river behaviour in the areas north and east of Te Karaka and as such risks remain from the baseline scenario and are exacerbated in some areas by the increase in velocities.

4.1.2.2 Shear stress

Figure 4.3 presents the modelled shear stresses for Option 1A, within the reach under the proposed maximum stopbank extent scenario. The difference is shown relative to the existing condition.

Modelled absolute shear stresses

Difference in modelled shear stress between existing condition and modelled condition

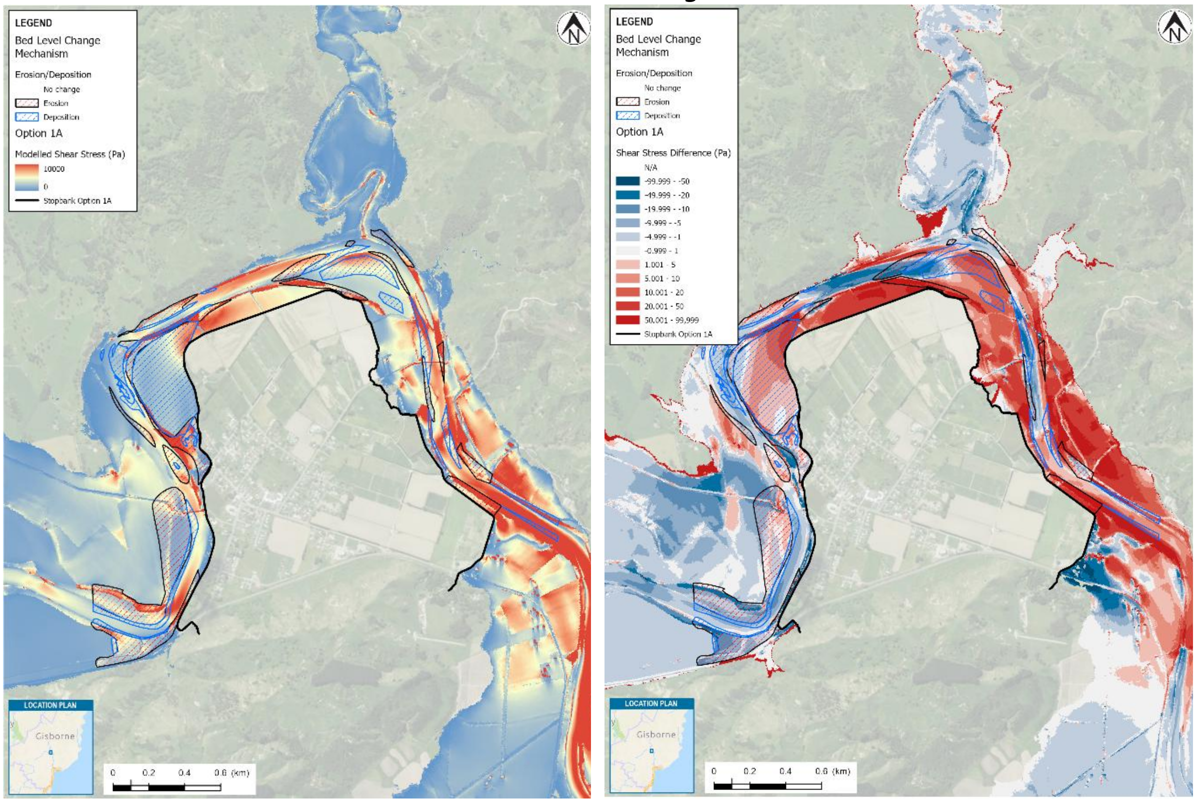

Figure 4.3: Summary of modelled shear stress in Option 1A

Absolute shear stress in option 1A remain highest in the active channel, the margins of the active channel and where the river bends and flows go over the bank full extent and across floodplain pockets. The spatial distribution of shear stress is more closely tied to channel planform. The areas of deposition previously noted appear to coincide with increased shear stress, however this may be a result of the wholesale bed raising and therefore instream sediment stores have not provided a buffering effect. Some local adjustment in response to flow stage and sediment supply is expected.

Shear stress increases in option 1A based on the modelling were up to 600 N/m^2, indicating that there is the potential that increased sediment transport and likely erosion will occur in the red areas in Figure 4.3, as such, erosion is expected to be greater in the vicinity of Te Karaka. The active channel margins east of Te Karaka are likely to undergo the highest degree of change in option 1A as the areas of shear stress increase coincide with linear areas of deposition previously identified in the GCD analysis (refer Section 3.3.2) therefore the shift from deposition to erosion will be most noticeable. This pattern reflects the dynamic nature of the river system. Changes in shear stress do not appear to be as significant as velocity. At the entrance to the Te Karaka bend a zone of flow expansion on the true right does not significantly elevate shear stress, suggesting that deposition is likely to continue in this area, aligning with the velocity results here.

4.1.3 Option 4A

4.1.3.1 Velocity

Figure 4.4 presents the modelled velocities for Option 4A, illustrating areas of high and low flow energy within the reach under the proposed minimum stopbank extent scenario.

Modelled absolute velocities

Differences in modelled velocity between existing condition and modelled condition

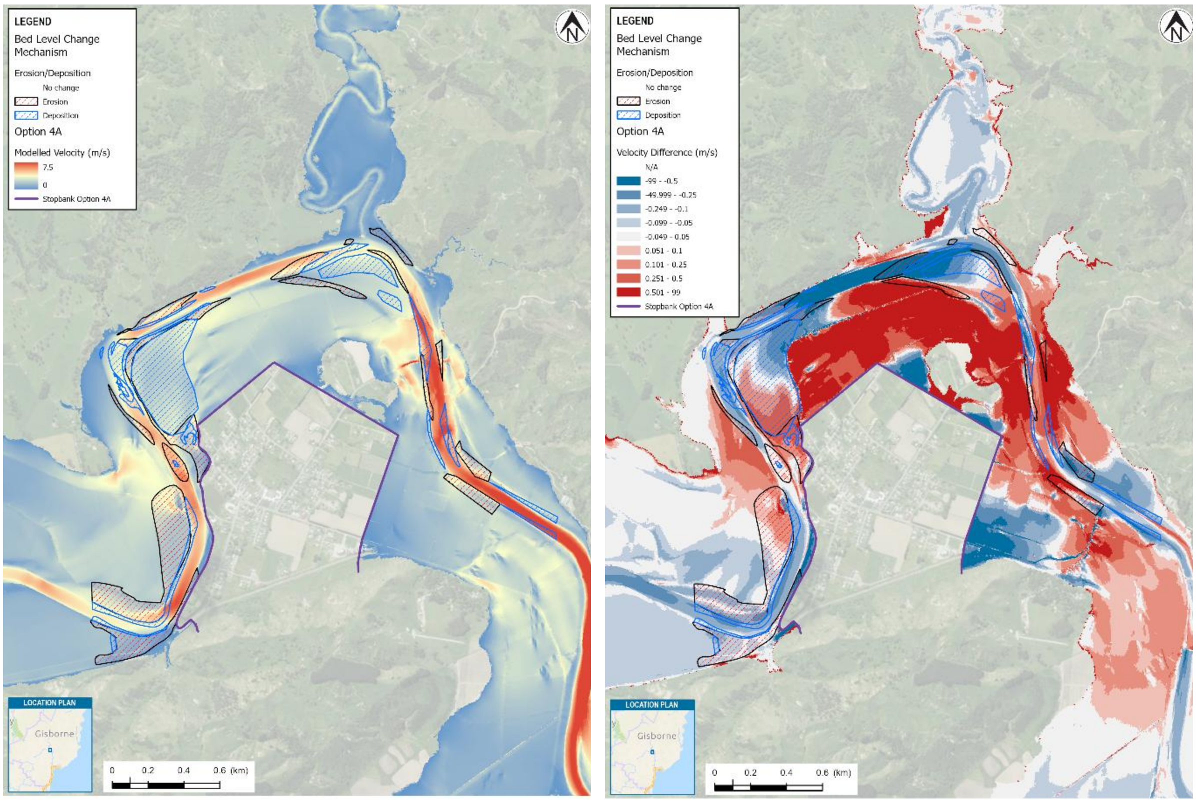

Figure 4.4: Summary of modelled velocities in Option 4A

Modelled absolute velocities in option 4A remain highest in the active channel with elevated velocities on the straighter reaches to the west, north and east of Te Karaka. Downstream absolute velocities remain high, highlighting the likelihood that sediment that is mobilized near Te Karaka will be transported downstream beyond the township. The area that was previously contained within the existing stop bank (north of Te Karaka) would become inundated and have moderate velocities.

Comparing the baseline velocities and the velocities under the Option 4A scenario indicates a decrease in velocities north of Te Karaka in the active channel area whilst an increase in velocities immediately adjacent to the revised stop bank location as the area has been inundated where previously it was behind the stopbank.

As the flood flows would spread over a larger area in in this option it is unlikely that areas identified as erosional on the GCD outputs would increase. The depositional regime of the reaches around Te Karaka is however expected to increase as velocities in the area north of the revised stop bank location are unlikely to keep sediment entrained and therefore deposition indicated by the large blue polygons to the east of Te Karaka is likely to extend along the northern floodplain. Expanded flow in the widened channel is therefore likely to result in sediment deposition in this area.

4.1.3.2 Shear stress

Figure 4.5 presents the modelled shear stresses for Option 4A, within the reach under the proposed maximum stopbank extent scenario.

Modelled absolute shear stresses

Difference in modelled shear stress between existing condition and modelled condition

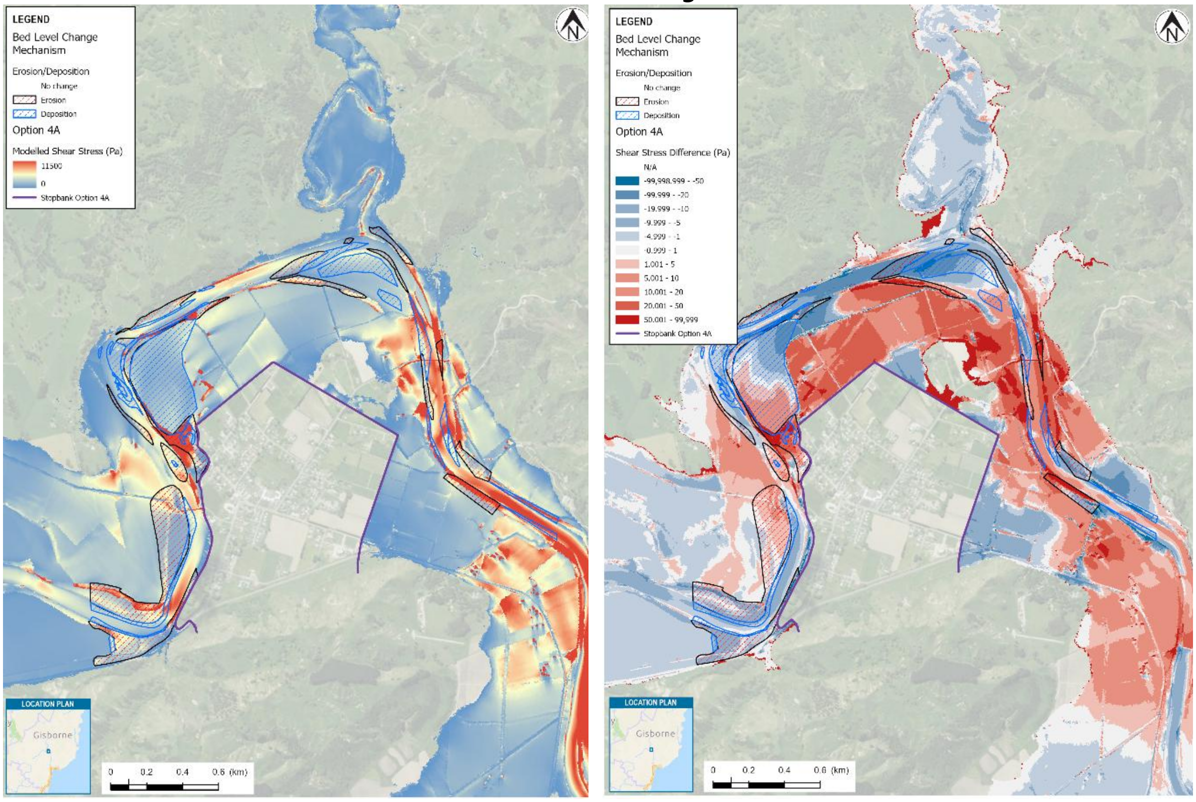

Figure 4.5: Summary of modelled shear stress in Option 4A

The modelling of absolute shear stress in option 4A highlights that shear stress is greatest at the margins of the active channel and in some bends. Higher shear stress is also noticeable at the start and end of the bend near the new stopbank. The areas of deposition previously noted appear to lie in zones with increased shear stress, however this may be a result of the wholesale bed raising and therefore instream sediment stores have not provided a buffering effect. Some local adjustment in response to flow stage and sediment supply is expected. In comparison with Option 1A the shear stress immediately north of the stop bank is not noticeably elevated, likely a result of the larger accommodation space afforded by Option 4A.

Shear stress increases of up to 250 N/m^2 were modelled in option 4A, indicating an increased erosion potential in these red areas in Figure 4.5. As such, the active channel and valley margins east of Te Karaka are likely to undergo the highest degree of change in option 4A as these areas of higher shear stress coincide with areas of erosion previously identified in the GCD analysis (refer Section 3.3.2). Generally, lower shear stress in the area north of Te Karaka and at the entrance to the bend where stopbanks are widened is likely to facilitate sediment deposition.

The modelling indicates that there is likely to be localised change in river behaviour in the areas downstream of Te Karaka.

4.1.4 Summary

Option 1A retained high velocities within the active channel and exhibited a notable increase in flow velocities along the northern and eastern boundaries near Te Karaka. These elevated velocities suggest a heightened potential for erosion in these areas, although some localised moderation may occur. Overall, the prevailing trend under Option 1A appears likely to be erosional in the channel and some areas of the floodplain where erosion (lowering or scour) was observed following Cyclone Gabrielle. However, at the entrance to the Te Karaka bend, lower velocities are likely to encourage deposition of sediment on the floodplain.

In contrast, Option 4A maintained active channel velocities but in allowing a greater spread of floodwaters across a widened area of floodplain generated lower velocities out of channel, which will likely increase sediment deposition, particularly north of Te Karaka. Deposition is also expected to intensify at the entrance to the bend in the northwest corner of the existing stopbank, potentially expanding across the adjacent floodplain.

The use of Digital Elevation Models of Difference (DoDs) in this study help identify broad spatial patterns of erosion and deposition (across dry surfaces), which can then inform long-term morphological changes and maintenance requirements to preserve service capacity. Potentially significant deposition is anticipated within the expanded channel zones where stopbanks have been set back.

The modelling results and GCD analysis underscore the river system’s dynamic nature, characterised by cyclical patterns of sediment transport and deposition in response to high-flow events and sediment pulses.

5 Geomorphic risks and tolerances

Overall, there are recurring erosion and deposition trends, which have inherent risks, these are summarised below:

- For Option 1, there is a potential erosion risk to the stopbanks, depending on their construction and the associated flow velocities capable of mobilising sediment.
- The inside bend north of Te Karaka is likely to experience increased deposition. The extent of this deposition depends on the set back of the constructed stopbanks.
- As the stopbank alignment shifts southward, velocities and shear stress in the active channel north of Te Karaka decrease, likely leading to increased deposition within the channel.
- Areas already showing signs of deposition, combined with reduced velocities, are at risk of exacerbated sediment accumulation.
- Where velocities are reduced and deposition is already occurring, further sediment build-up is likely.
- Although the cohesive nature of the Waipaoa Riverbanks reduces the likelihood of avulsion or new channel formation, such events could potentially still occur during extreme flood events due to high velocities in the active channel
- Some scour may occur in newly liberated areas of widened floodplain, but these generally show a tendency toward deposition, because velocities have been reduced.
- Immediately following a storm, aggradation may be significantly higher than expected. If two events occur in close succession, the risk of increased deposition (in flow expansion zones) or erosion (within the channel) is elevated.
- Without detailed knowledge of the sediment composition, it is difficult to predict whether observed velocities will result in erosion or deposition. The channel's response during flood events depends on stream power, flood duration, and sediment load—all of which are inherently variable and difficult to forecast.
- Channel aggradation is expected to continue, limiting the channel's capacity to convey floodwaters. While providing more space for floodwaters may promote sediment deposition in expanded flow zones, this geomorphic response must be anticipated and managed.
- Given the geomorphic trends in the Waipaoa system, maintaining effective flood protection for Te Karaka poses significant long-term challenges. The lowest-risk strategy may ultimately be a managed retreat from this part of the valley floor.

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7 Applicability

This report has been prepared for the exclusive use of our client Gisborne District Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

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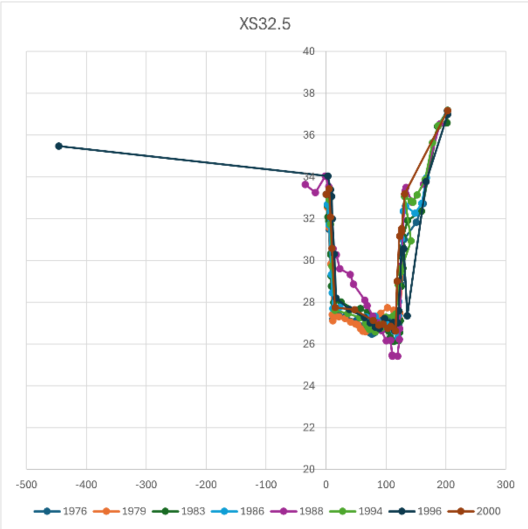
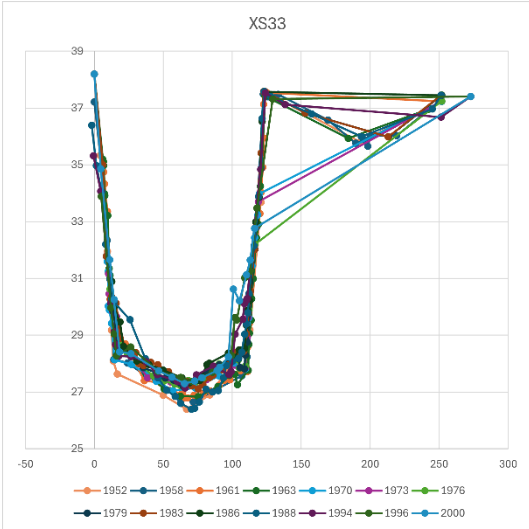
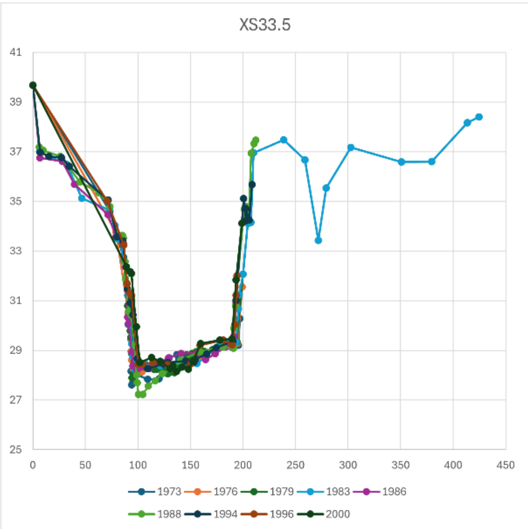
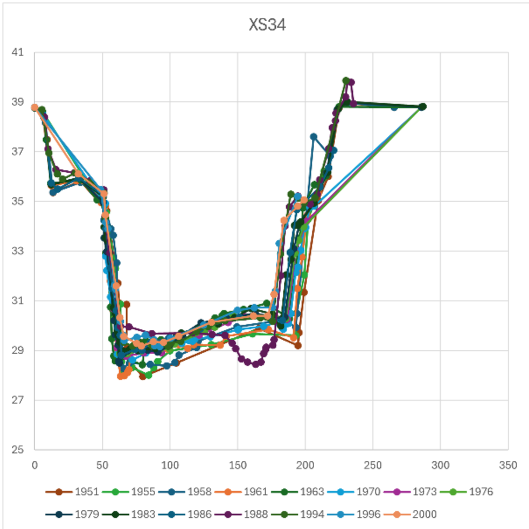
Appendix A Cross Section Comparisons

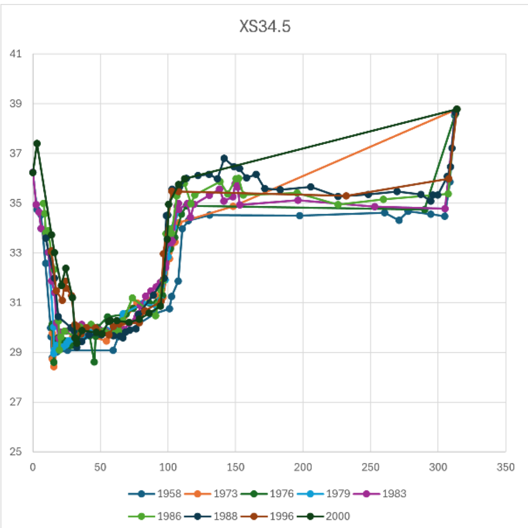
Table Appendix A.1: Summary of cross section data in the vicinity of Te Karaka

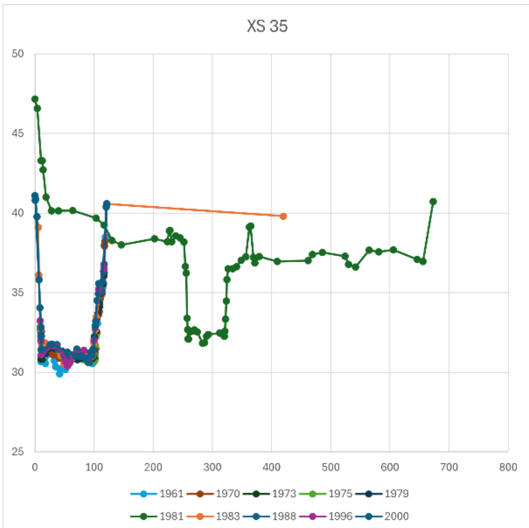


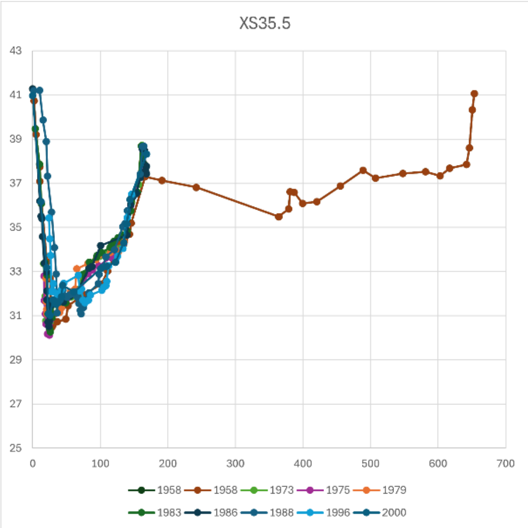








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37
35
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31
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600
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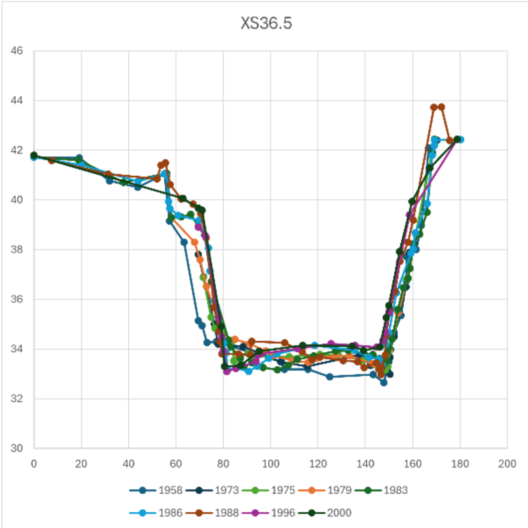
1958
1973
1975
1979
1983
1986
1988
1996
2000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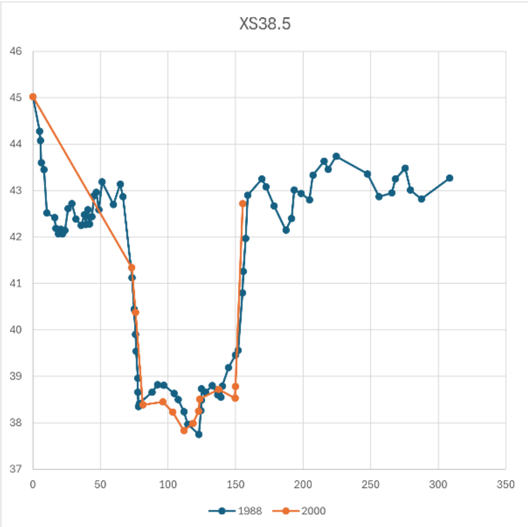
180
200
1958
1973
1975
1979
1983
1986
1988
1996
2000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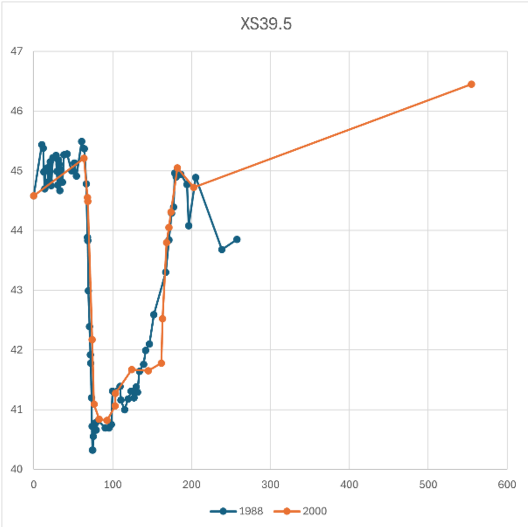
2000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43
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41
40
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100
200
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400
500
600
1988
2000

Appendix B GCD Output Comparisons

B1 Active channel change in area

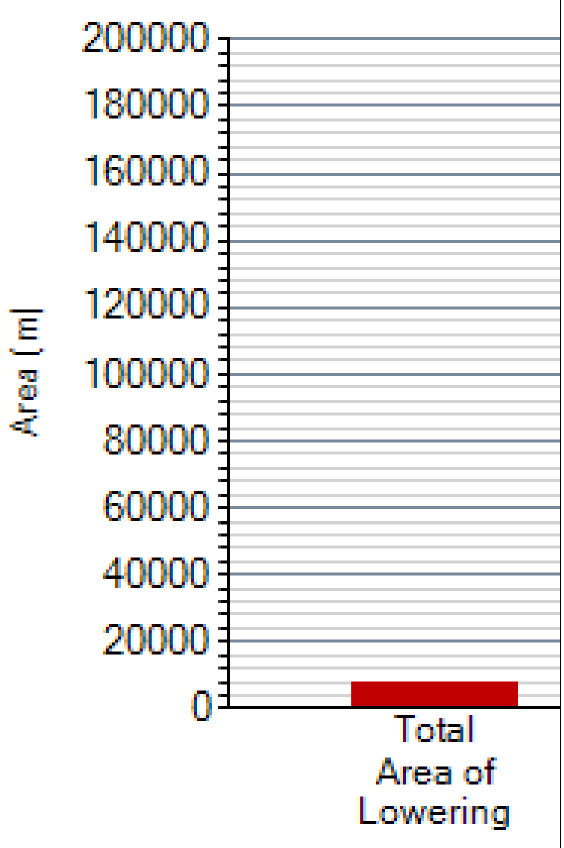

Figure Appendix B.1: Histogram showing the relative areas subject to lowering and raising of the active channel within the vicinity of Te Karaka between 2018 -March 2023.

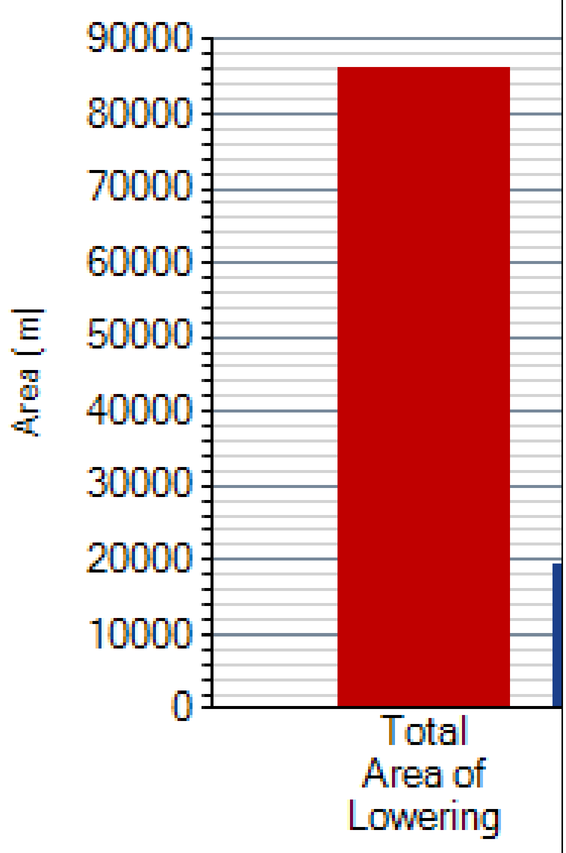

Figure Appendix B.2: Histogram showing the relative areas subject to lowering and raising of the active channel within the vicinity of Te Karaka between March 2023 – September 2023

B2 Active channel change in depth

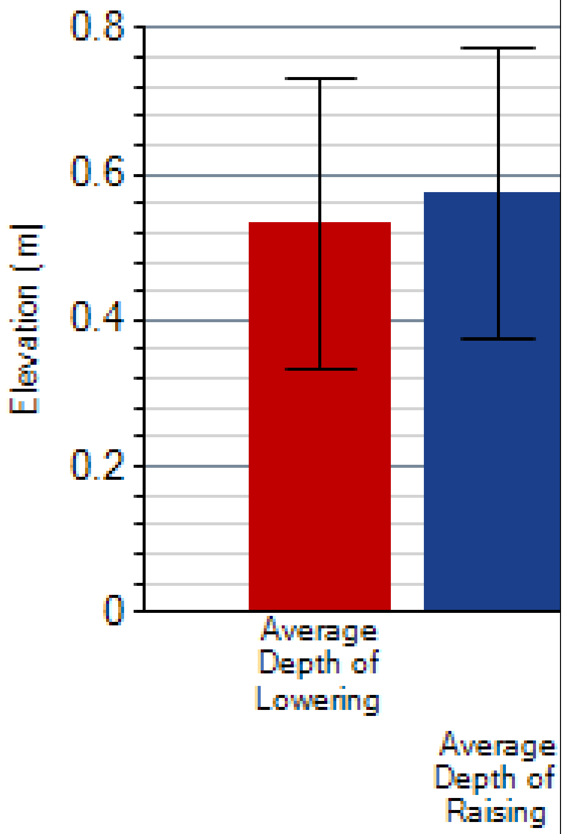	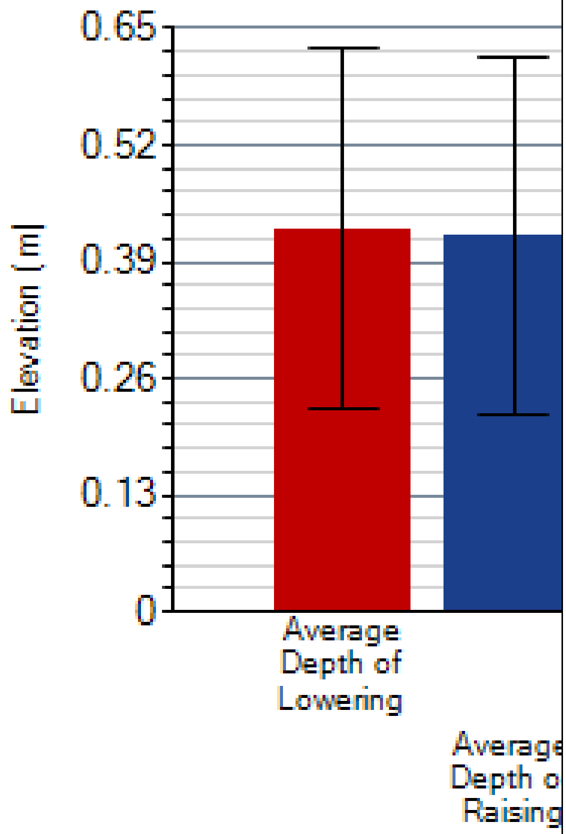
Figure Appendix B.3: Histogram showing the relative changes in elevation (depth) of the active channel within the vicinity of Te Karaka between 2018 -March 2023	Figure Appendix B.4: Histogram showing the relative changes in elevation (depth) of the active channel within the vicinity of Te Karaka March 2023 – September 2023

B3 Active channel change in volume

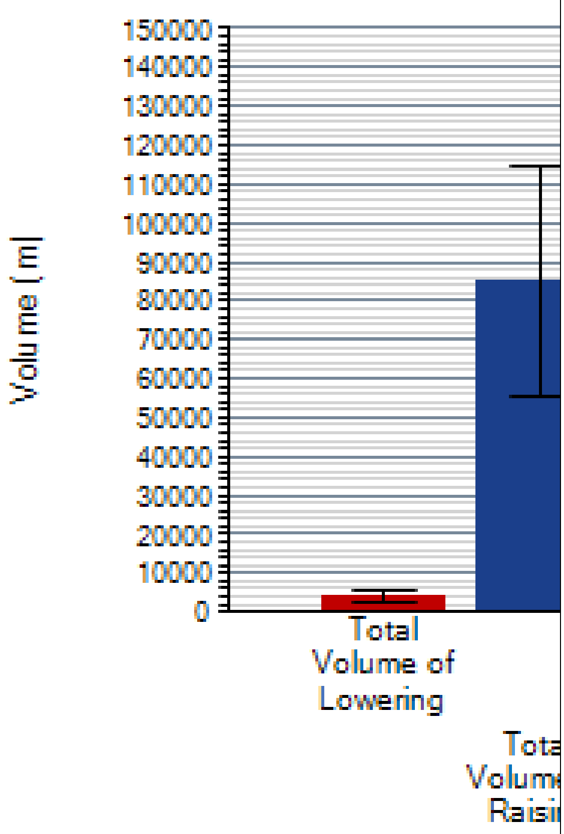	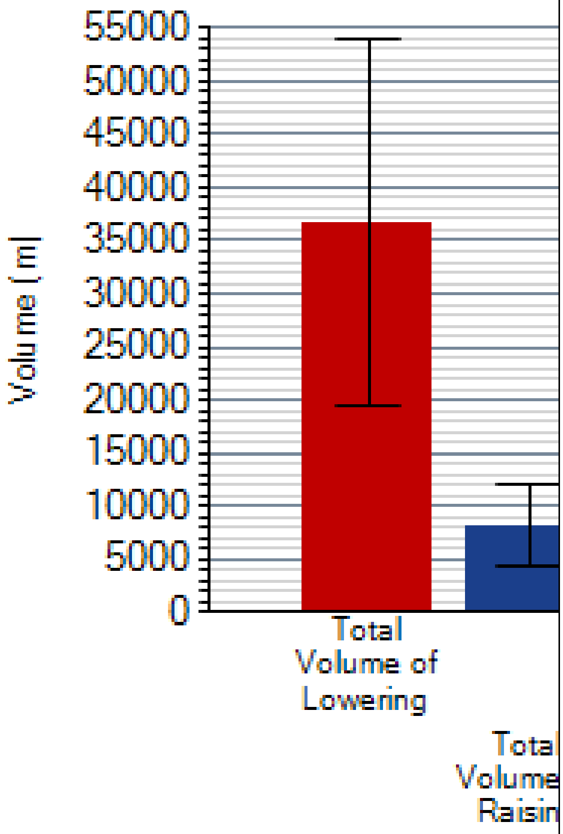
Figure Appendix B.5: Histogram showing the relative changes in volume of the active channel within the vicinity of Te Karaka between 2018 -March 2023	*Figure Appendix B.6: Histogram showing the relative changes in volume of the active channel within the vicinity of Te Karaka between March 2023 – September 2023*

B4 Valley bottom change in area

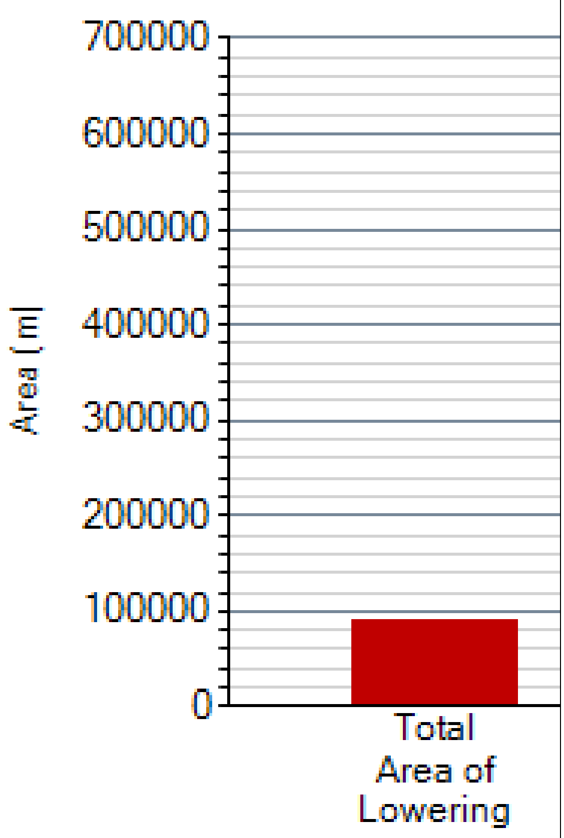	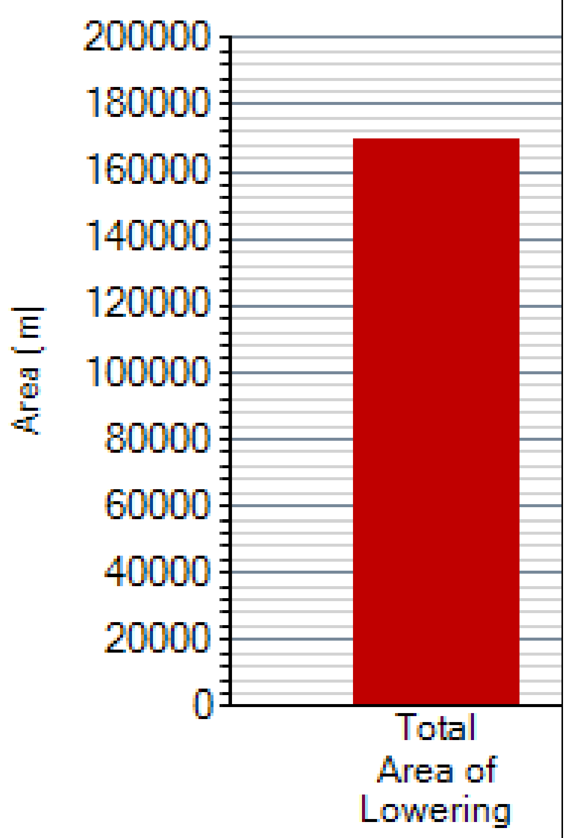
Figure Appendix B.7: Histogram showing the relative areas subject to lowering and raising of the valley bottom within the vicinity of Te Karaka between 2018 -March 2023.	*Figure Appendix B.8: Histogram showing the relative areas subject to lowering and raising of the valley bottom within the vicinity of Te Karaka between March 2023 – September 2023*

B5 Valley bottom change in depth

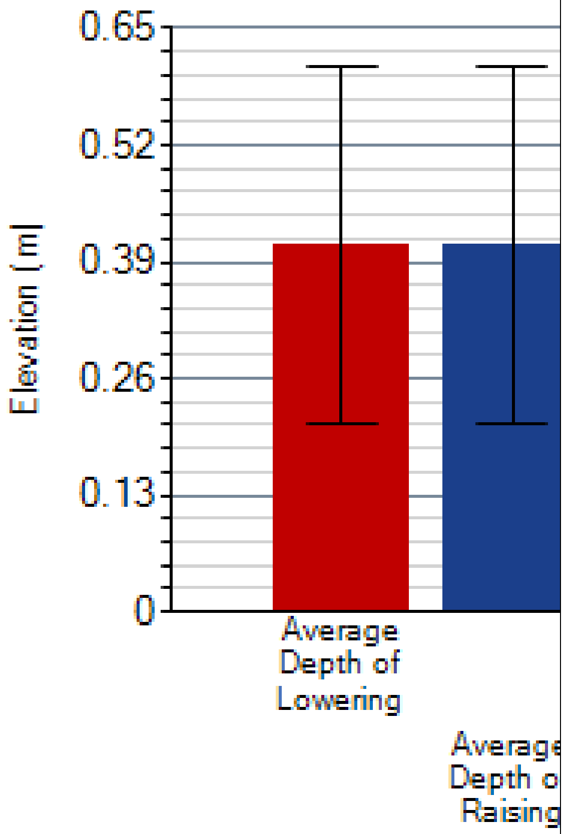

Figure Appendix B.9: Histogram showing the relative changes in elevation (depth) of the valley bottom within the vicinity of Te Karaka between 2018 -March 2023

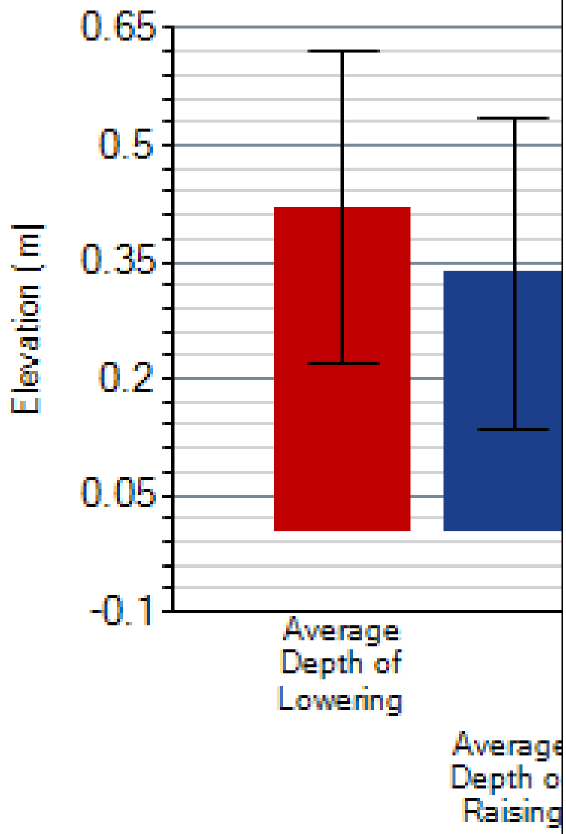

Figure Appendix B.10: Histogram showing the relative changes in elevation (depth) of the valley bottom within the vicinity of Te Karaka March 2023 – September 2023

B6 Valley bottom change in volume

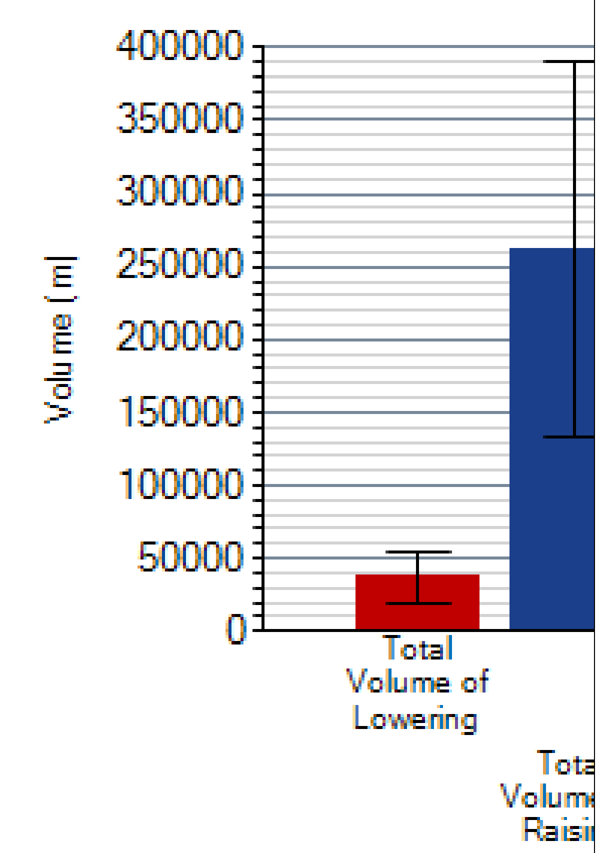

Figure Appendix B.11: Histogram showing the relative changes in volume of the valley bottom within the vicinity of Te Karaka between 2018 - March 2023

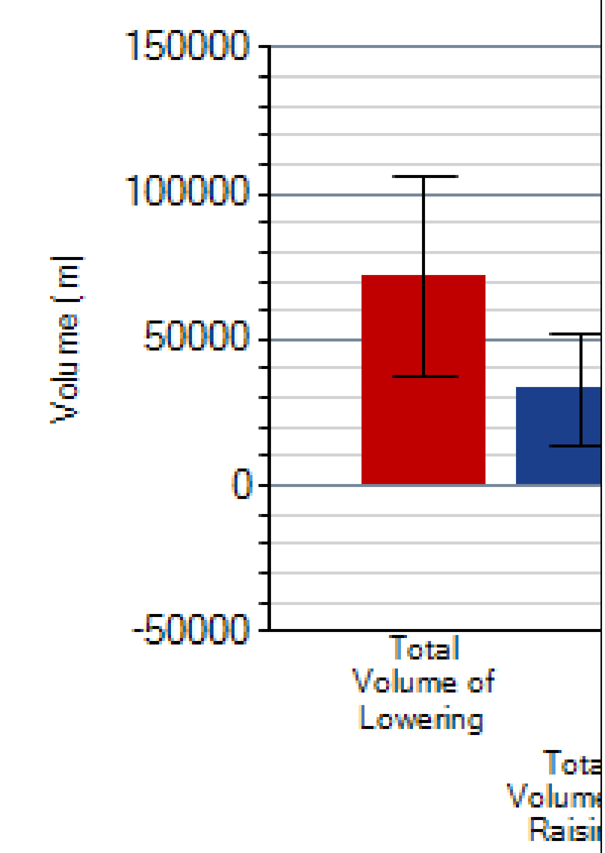

Figure Appendix B.12: Histogram showing the relative changes in volume of the valley bottom within the vicinity of Te Karaka between March 2023 – September 2023

B7 Summary tables of GCD

Table 7.2: Summary of surface changes on the valley bottom between 2018/2020 and March 2023.

Area	Erosion or deposition	Sum of volume change (m3)	Average change of surface thickness (m)	Average of area of change (m2)
Active Channel	Lowering	-4,000	-0.49	8,000
	Raising	85,000	0.63	148,000
Valley Bottom	Lowering	-37,000	-0.41	91,000
	Raising	263,000	0.41	642,000

Table 7.3: Summary of surface changes on the valley bottom between March 2023 and September 2023.

Area	Erosion or deposition	Sum of volume change (m3)	Average change of surface thickness (m)	Average of area of change (m2)
Active Channel	Lowering	-37,000	-0.38	86,000
	Raising	8,000	0.47	19,000
Valley Bottom	Lowering	-71,000	-0.42	170,000
	Raising	33,000	0.34	98,000

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