Rangitikei River Channel Change & Morphological Budgeting

February 2023

horizons
REGIONAL COUNCIL

Prepared for:

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February 2023
Report No. 2023/EXT/1808
ISBN 978-199-106127-0

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Report for Horizons Regional Council

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Executive Summary

1. Mapping of river geomorphology using supplied rectified aerial photography in the 1950s and 2021

The earliest available photography providing complete coverage extending from the Rangitikei River mouth to (and including) the Kawhatau River was mapped to assess the composition of the active river channel corridor in the 1950s and 2021. Shapefiles of the active channel, wetted channel, unvegetated bars, lightly and densely vegetated bars are provided electronically. These features provide a broad overview of river geomorphology in the active channel of the Rangitikei and Kawhatau Rivers. Change in these features is assessed using NCI:

2. Assessment of Natural Character Index (NCI) to characterise change over time in river characteristics

Change in river characteristics between the 1950s and 2021 was assessed using an NCI approach, which provides a ratio of the parameter assessed in 2021 compared with the feature in the 1950s. Rather than provide a 'whole river' assessment, analysis was divided into three segments: Kawhatau, upper Rangitikei (from confluence with Kawhatau to upstream limit of the river scheme), lower Rangitikei (~62 km of the river management scheme extending to the river mouth).

3. Morphological budget of exposed riverine sediments (sub-aerial bars) derived from DEM of difference using 2017 and 2021 LiDAR datasets supplied

Assessment of the LiDAR datasets supplied revealed that the 2017 DEM was systematically 0.42 m higher than the 2021 DEM reflecting the different vertical datums used in processing these datasets: 2017 being in Wellington 1953 vertical datum, 2021 being in NZVD2016. The 2017 DEM was adjusted to avoid incorporating this systematic bias in morphological budgeting analysis. Morphological budgeting used Geomorphic Change Detection software (Wheaton et al., 2010) within ArcGIS to derive volumes of raising (deposition) and lowering (erosion) of sub-aerial bars along the entire length of river flown by LiDAR (~62 km). Subaqueous surfaces cannot be reliably detected using standard LiDAR. Change detection was thresholded at 0.2 m, set as the minimum level of detection.

Thresholded volumes of change indicated a net volume of change equating to -242, 310 m^3, derived from the total volume of surface raising (deposition) approximating 2,090,010 m^3 ± 594,276 m^3 less the total volume of surface lowering (erosion) approximating 2,332,230 m^3 ± 368,241 m^3.

4. Historic morphological budget of the active river channel derived from river cross section data supplied

Cross-section (XS) data supplied fortwo contiguous reaches of the Rangitikei River (lower 62 km) and four discrete reaches of the Kawhatau River (and two tributaries) were analysed using an approach designed by Conley (2023). Because not all cross-sections were surveyed in all field campaigns, surveys selected for analysis optimise spatiotemporal resolution over the period of record (1975-2021 for Rangitikei sections and 1997-2019 for Kawhatau sections). Areal change between sequential survey years (epoch) was determined by geometric intersection for each cross-section. Volume was derived by averaging areal changes from two adjacent cross-sections and multiplying by the distance between. Considerable spatial and temporal variability were observed within- and between individual cross-sections. Along profile trends varied by epoch as well with some patterns across reaches. Reaches 1 and 4 of the Kawhatau both exhibit >20,000 m^3 of cumulative net-erosion upstream-to-downstream for the 2001-2015 epoch. Cumulative fluctuation for the lower (river-kms 1-32) Rangitikei reach mostly falls within a +/- $1x10^6$ band, with the lowest ~20 kms appearing generally depositional, but having localised areas of high-magnitude erosion for some epochs. The upper portion (river-kms 33-62) of the Rangitikei River shows considerable spatiotemporal variability, with the highest magnitude cumulative change operating within a +/- $3x10^6$ range for the 2009-2017 (gain) and 1998-2009 (loss), respectively.

5. Recommendations for gravel extraction based on morphological budget and analysis of river geomorphology, including a comparison with and assessment of One Plan allocable volumes.

Morphological budgeting using GCD indicates a net loss in sediment storage of 242,310 m^3 in the lower Rangitikei between 2017 and 2021 from dry bar surfaces. This is a conservative estimate and there is a large error associated with this volume. Nevertheless, this result would indicate that gravel extraction in the reach does not match supply. Results from longer-term analysis using cross-sections indicate considerable variability in both space and time. In light of both a high degree of spatiotemporal variability indicated by the cross-section budgets, and the cumulative losses indicated in the GCD analysis, a conservative approach to allocation of gravel volumes is recommended given the sensitivities of these morphological budgets in both the Rangitikei and Kawhatau Rivers.

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1. Introduction

1.1 Overall Aim

In reviewing management of the Rangitikei, Horizons Regional Council has sought information on the adjustments to channel planform and character during the period of management scheme intervention from the 1950s to present day in order to understand the potential impacts intervention has had on river form. In particular, understanding the impacts of gravel extraction, which has formed part of strategic management over this period, is key to informing future approaches to managing the river. Morphological budgeting approaches using cross-section data and LiDAR DEMs are used to provide initial insight to the gravel budget of the Rangitikei over multi-decadal, low spatial resolution and sub-decadal, high spatial resolution scales respectively.

1.2 Channel morphology

This report provides an assessment of changes in channel morphology using rectified aerial photography from the 1950s and 2021 to provide an insight into long-term (over 60 years) adjustment of river characteristics. Long-term assessments of river characteristics of this nature are valuable because they compare the (largely) pre-intervention state of the river with the post-intervention state. Comparison is quantified using a Natural Character Index (NC), which provides a simple, but effective and objective means of identifying the extent of change in a given characteristic (e.g. area of bars) between the dates of observation. No, or little, change in a parameter is evidenced in an NCI of, or approximately, 1.0. The extent of change in key river characteristics, notably active channel area and bar areas is presented to illustrate the extent of change in channel morphology of the Rangitikei between the 1950s and 2021. NCI assessment provides a broad spatial and temporal context in which to assess the gravel budget of the Rangitikei using available cross-section data between 1975 and 2021.

1.3 Morphological budgeting

Morphological budgeting in principle provides a lower-bound estimation of gravel storage between survey events (Ashmore & Church, 1998). Change in storage (erosion and deposition) occurring between survey events is undetected. Compensating scour-and fill is also undetectable. Volumes associated with any morphological budget should be considered as conservative estimations of change. The combination of LiDAR and channel cross-sections provides a good opportunity for an holistic assessment of the gravel budget in the lower Rangitikei for the respective time periods available.

1.3.1 Channel cross-sections 1975-2021

Cross-section analyses provide a potentially useful means of assessing elevation changes across the width of the active channel. Using an end-over-area method a volume of gravel can be estimated between surveys and sections in time and space. Cross-section data have the advantage of extended coverage in space and time, although each section is a snapshot of the riverbed and change in storage between surveyed sections is unaccounted for. However, the multi-decadal length of these records does allow detection of large-scale, long-term trends in a gravel budget, since movement of a river's bedload is intermittent and takes place only when competence thresholds are exceeded (during higher flows). Over multiple decades, changes in sediment flux should be detectable using cross-section data.

1.3.2 LiDAR derived DEMs 2017-2021

Comparatively high-resolution three-dimensional change in river morphology can be assessed by comparing digital elevation models (DEMs) of the channel. DEMs derived from LiDAR surveys flown in 2017 and 2021 are compared using geomorphic change detection (GCD), which derives a conservative estimation of volumetric change between the two surfaces. Lowering reflects erosion (removal of material), raising reflects deposition.

1.4 Site Context

The location and character of the Rangitikei being investigated needs to preface this report because channel morphology, river behaviour and sediment transport reflect controls exerted by channel confinement and stream power. The sediment conveyor is conceptualised in Figure 1.1. Gravel in a river bed is primarily sourced from:

i. Original generation from the source, or production zone, i.e. the catchment headwaters. In the Rangitikei this refers primarily to the greywacke-dominated axial ranges (Ruahine and Kaimanawa Ranges), as well as volcanic sources in the Central Plateau.
ii. Reworked alluvial deposits that have been originally sourced from the production zone, but temporarily stored in river terrace and floodplain deposits in the transfer zone (Figure 1). Significant reworking of these deposits is to be expected in response to lateral channel adjustments.

The sediment conveyor in the transfer zone is not smooth, but jerky, which means gravel is conveyed often as a series of pulses, bedwaves, or slugs (Nicholas et al., 1995). Through the transfer zone, gravel supply may be highly variable, depending upon lateral channel changes and reworking of adjacent floodplain and terrace deposits. The nature of this transfer zone is such that the river has sufficient energy (slope and discharge) to convey sediment through these reaches and that on the whole, these transfer reaches will alternate between aggradation and degradation, depending upon the jerkiness of the conveyor, reflecting gravel flux and supply both from upstream and lateral reworking of alluvial deposits.

In the depositional zone, stream energy may drop below gravel transport thresholds and the river may lack sufficient power to transport the coarsest fraction of its bedload (gravel) due largely to channel gradient change. Flattening of the channel slope reduces stream energy and gravel is often deposited. In the Rangitikei this depositional zone can be considered as being beyond the limit of confining terraces towards the coast, where the river becomes unconfined. However, the river maintains a relatively steep profile for all but the final ~5 km of its course (Figure 1.2), which means it retains gravel transport capacity and has a high degree of power through much of this short (~18 km) unconfined segment (cf. Figure 1.2).

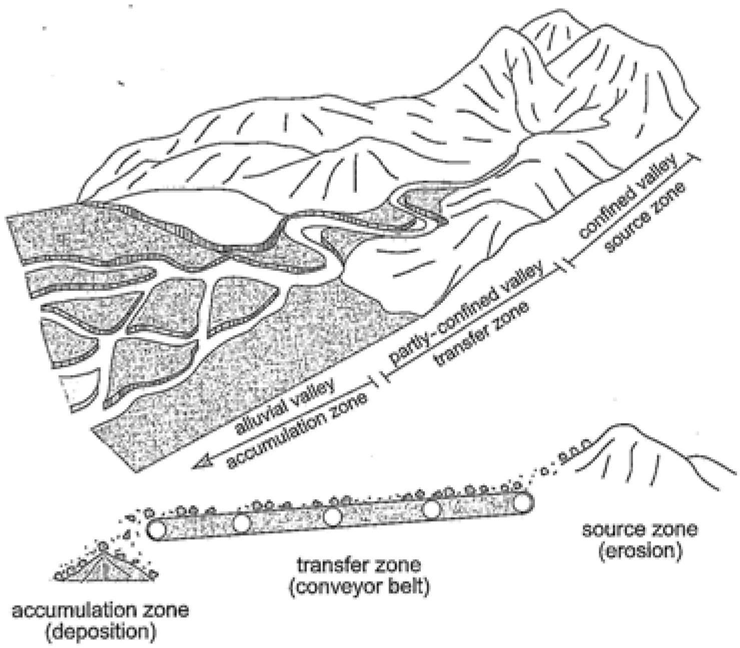


Figure 1.1 The catchment sediment conveyor conceptualised (after Brierley & Fryirs, 2005).

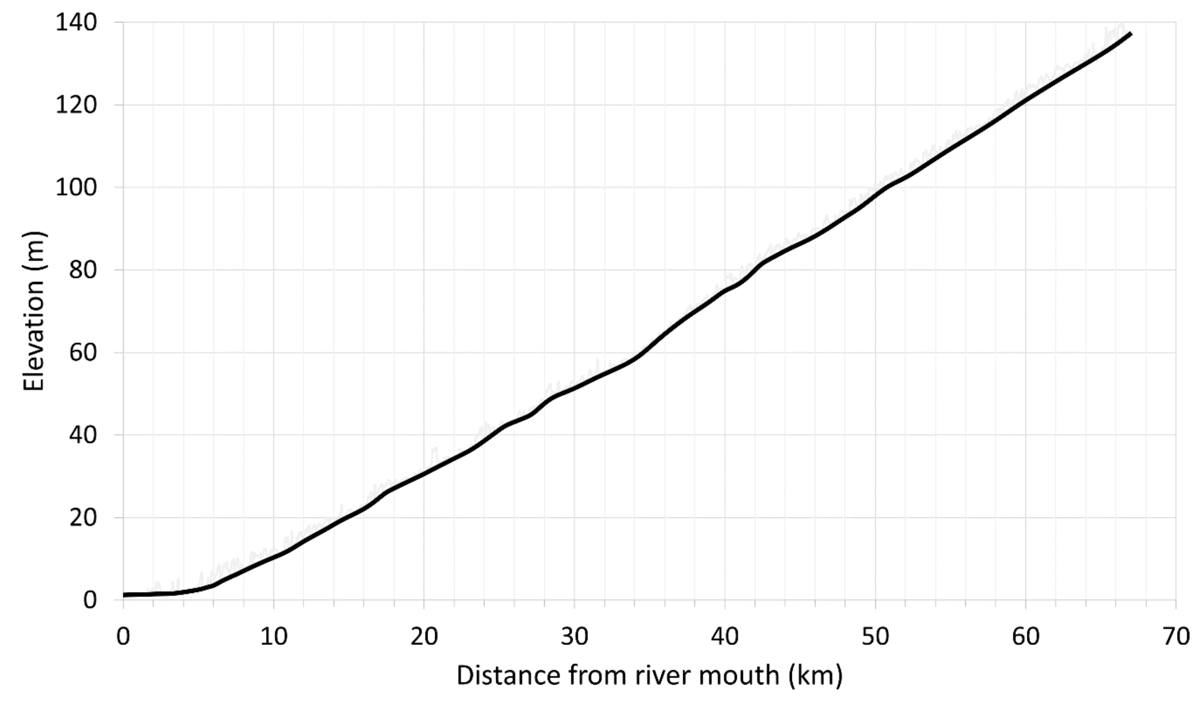


Figure 1.2 Lower Rangitikei long profile, interpolated from 2017 LiDAR-derived DEM following the centreline of the active channel. A consistently steep profile is maintained through all but the final ~5 km of river length towards the coast. The river can be considered as being unconfined downstream from ~18 km

1.5 Reaches defined

Rather than undertake a single assessment of channel morphology for the entire length of channel from the Kawhatau to Rangitikei river mouth, this study divides that length into three reaches (Figure 1.3) based on reach characteristics and history. Morphological budgeting in the Rangitikei is limited to reach 3 due to availability of data.

1. Kawhatau, being distinct from the principal Rangitikei River and a significant supplier of bed calibre material to the Rangitikei, given its proximity to the Ruahine Ranges. The upstream limit in the Kawhatau extends to the Pourangaki River confluence, which is also the upstream gravel extraction site in the Kawhatau. The Kawhatau is incised and confined between strath terraces for the entirety of this length, with a narrow valley floor.
2. Upper Rangitikei from its confluence with the Kawhatau to the upstream extent of the Rangitikei management scheme at ~62 km (in the vicinity of Rewa), which has not been subject to the degree of engineering intervention in the lower reach and could be construed as displaying a natural range of channel adjustments and characteristics, notwithstanding gravel extraction that may have occurred along its length. The Rangitikei in this reach is also incised and confined to partly-confined by strath and alluvial terraces, but the valley floor widens and the river has a greater capacity for adjustment than the Kawhatau.
3. Lower Rangitikei along entire length of managed scheme (lower ~62 km), which has been the focus of significant engineering and gravel extraction. This reach is also the focus of morphological budgeting in the Rangitikei using GCD between 2017 and 2021 LiDAR-derived active channel DEMs and historic cross-section. The river is partly-confined by terraces for most of this length, but becomes unconfined ~18 km from the river mouth.

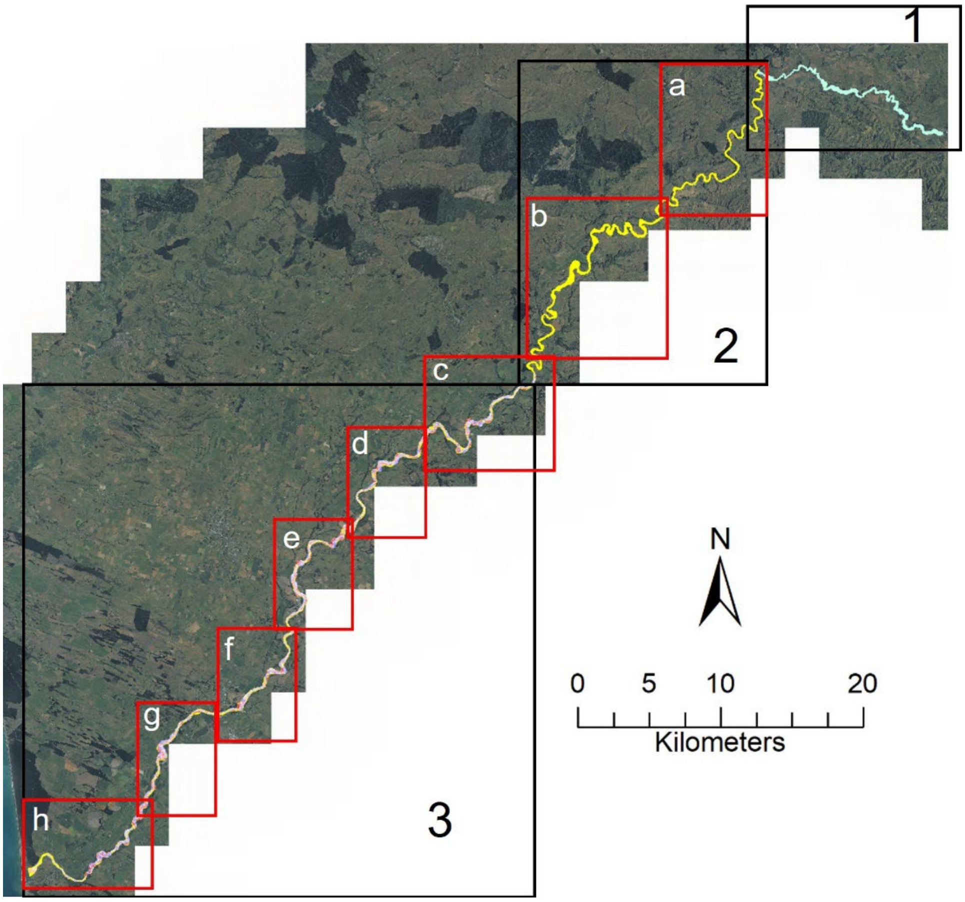


Figure 1.3 Reaches of interest defined – 1: Kawhatau, 2: upper Rangitikei, 3: lower Rangitikei, which is also the reach where geomorphic change detection has been used to provide a morphological budget based on differencing between DEMs derived from the 2017 and 2021 LiDAR datasets. Rangitikei cross-section analysis is also focused in reach 3. Red boxes a-h are keyed with Rangitikei channel morphology maps in Figures 2.2-2.9

2. Channel morphology

2.1 Mapped and measured parameters

Parameters mapped from the Kawhatau to Rangitikei River mouth are listed below. These features are provided as shape files for use in ArcGIS. Interpretive mapping used the most recently acquired aerial imagery of 2021. For comparison and assessment of change in characteristics over time, rectified aerial imagery from the 1950s was used. No single imagery date covered the entire length of interest, so the lower Rangitikei (reach 3) was mapped using imagery acquired in 1958, while the upper Rangitikei (reach 2) and Kawhatau (reach 1) were mapped using 1952 imagery. Both dates precede significant river engineering in the Rangitikei and it is reasonable to assume are a fair reflection of the composition of the river corridor in this decade.

- **Active channel area:** zone of river corridor interpreted as being actively or recently actively reworked by the river channel and comprising the wetted channel and bars. The active channel excludes areas of mature forest and cultivated land that may otherwise be located in the river corridor.
- **Wetted channel area:** area of active channel mapped as wet at the time of aerial photography, includes side-channels, backwaters and braids. The spatial extent of the wetted channel is dependent on flow discharge at the time of photography and if available flows at time of aerial photo acquisition should be reported. Large-scale aerial photography as used in this work was captured at the end of the summer season during low flows, providing some consistency and allowing a reasonable comparison of wetted channel to be made: flows were not obviously high in available imagery (1952, 1958, 2021).
- **Unvegetated bar area:** area within the active channel devoid of vegetation, constitutes most recently active portion of the river corridor swept clear of vegetation by repeated inundation during higher (flood) flows. Being depositional features, likely the focus of active bedload accretion, although flood scour can also lower sections of bars where flow is concentrated in chute channels across the bar surface that subsequently dry-up.
- **Lightly vegetated bar area:** area within the active channel with initial vegetation colonisation or sparse vegetation growth. Interpretation based on the presence of vegetation, but with bare sediment remaining visible. Vegetating bars are indicative of this part of the river corridor becoming less active (or may reflect an extended period since the last flood flow which swept the bar surface). These features likely become the focus of finer sediment accretion as sands and silts become trapped by vegetation stems. However, lightly vegetated bars are also readily remobilised and worked over during larger flood flows because stem density and vegetation cover is insufficient to prevent sediment entrainment and mobilisation.
- **Densely vegetated bar area:** area within the active channel that has become completely vegetated by grass or shrubby vegetation (not trees), but not cultivated and not forested. No bare sediment is visible on these surfaces. These fully vegetated bars are floodplain in the making and represent the least active part of the active channel. They have the potential to become reworked in a sufficiently large flood and likely are inundated from time to time.
- **Wetted channel length:** total length of wetted channels, including side-channels and braids. This parameter can be used in conjunction with the braid channel index (see below) and by itself can be used to assess the degree of channel complexity in a reach and how this might change: e.g. increased length indicates increased complexity (more channels), whilst reduction is indicative of channel rationalisation.
- **Midline channel length:** the length of the primary (widest) channel. This parameter is also used to calculated the braid channel ratio and can be used in lieu of sinuosity (increasing

midline length indicates a longer pathway such as may occur with bend development. Similarly, reduced midline length indicates a straightening within a reach.

- **Braid channel ratio:** river morphology was characterised using a **braid channel ratio** because the Rangitikei has historically had several braided reaches separated by locally divided, wandering reaches. The braid channel ratio is defined by Friend & Sinha (1993) as, 'the total of the mid-channel lengths of all the channels in a reach divided by the length of the midline of the widest channel'. Sinuosity was not assessed because the river channel was multi-threaded (braided or wandering) for much of its length in the 1950s, which means sinuosity is not a meaningful metric to apply.

2.2 Channel morphology maps

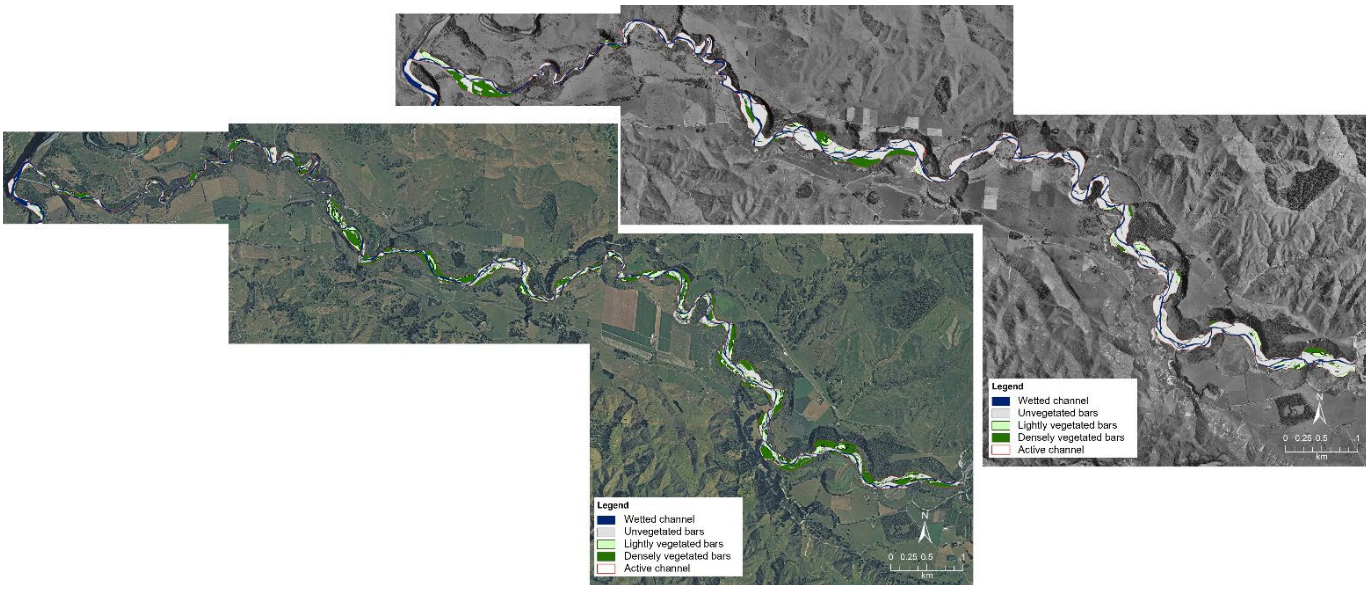


Figure 2.1 Kawhatau river morphology, 1952 (B&W) and 2021 (colour)

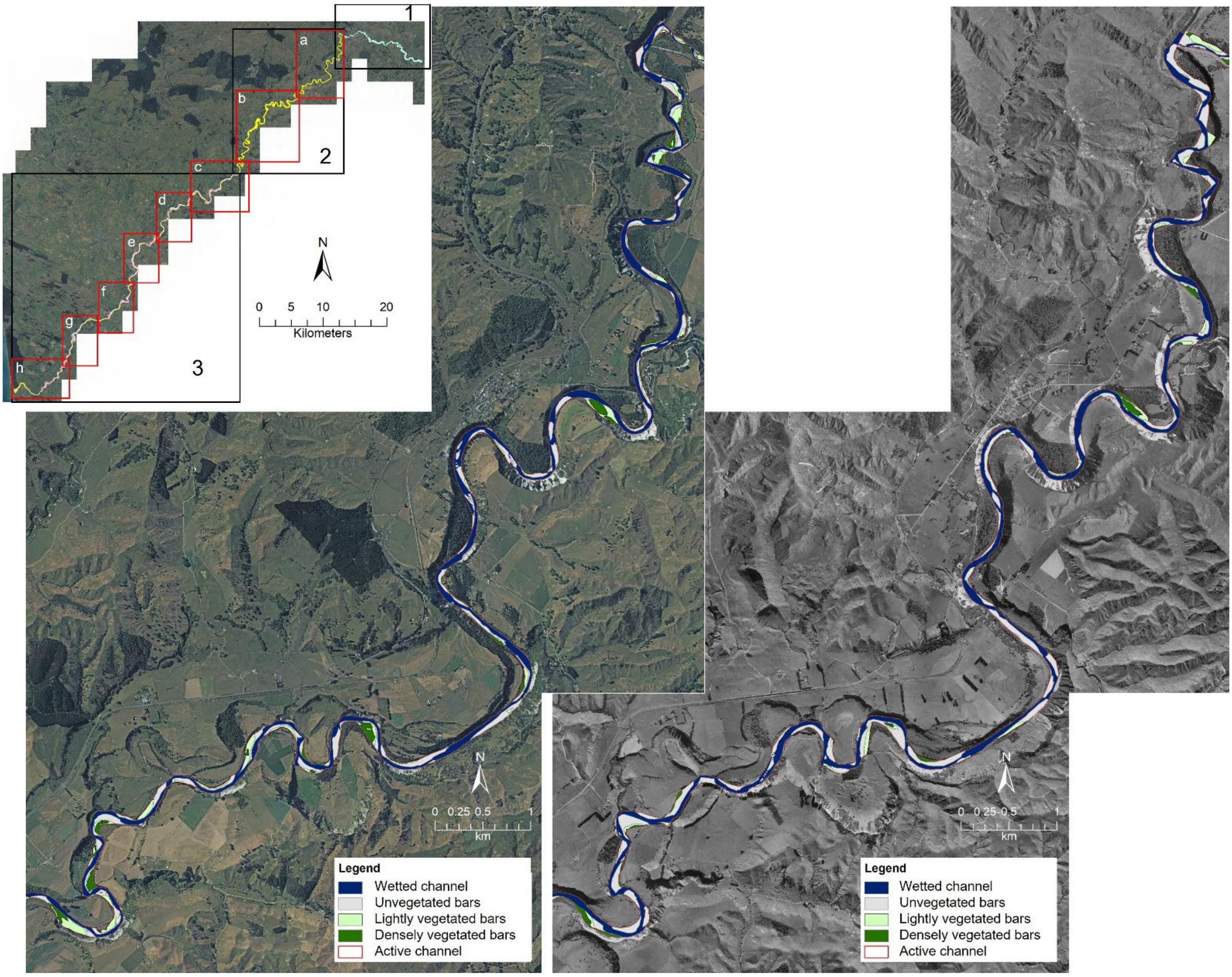


Figure 2.2 Upper Rangitikei (a) river morphology, 1952 (B&W) and 2021 (colour). Inset (cf. Figure 1.3) shows location for Figures 2.2-2.9.

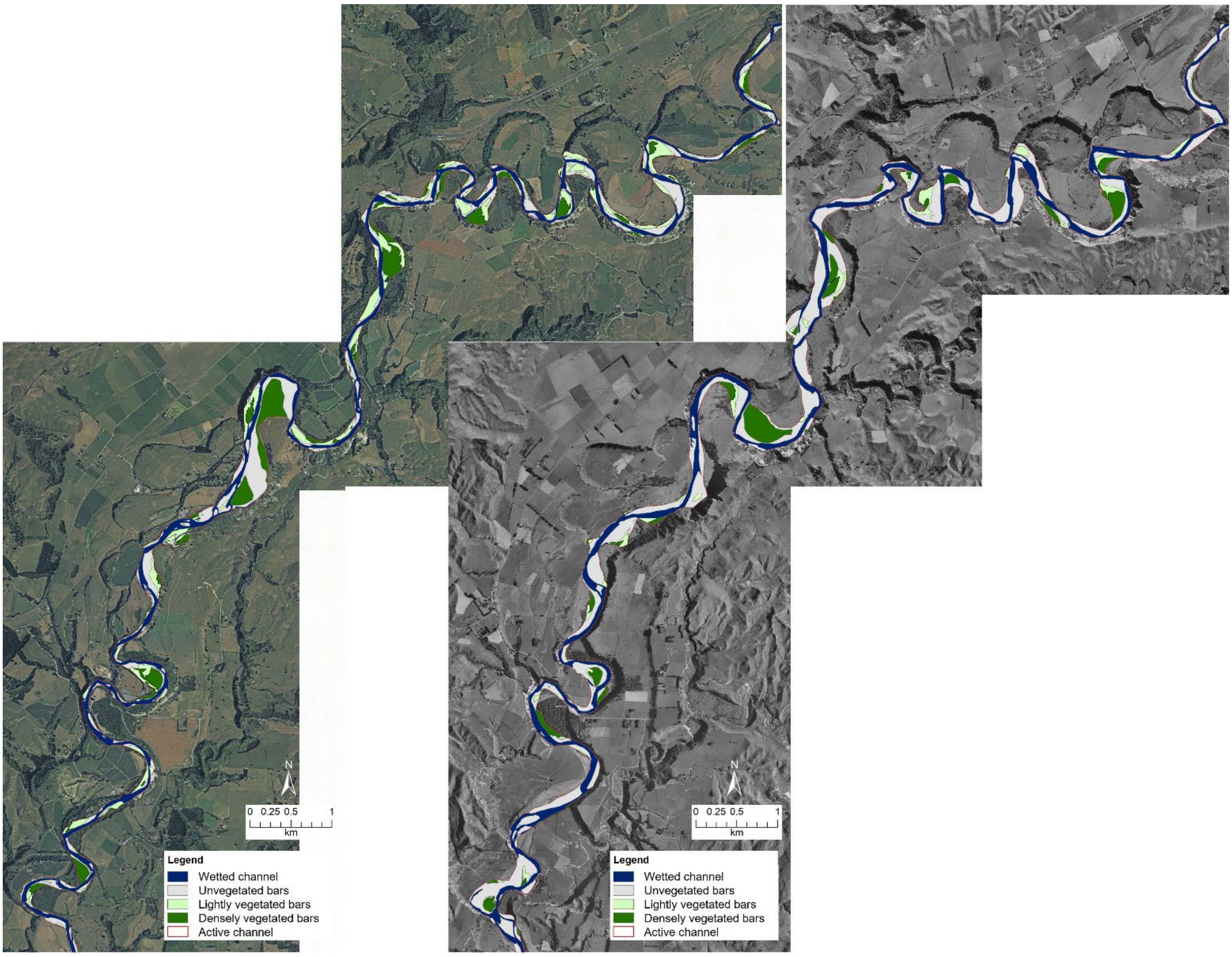


Figure 2.3 Upper Rangitikei (b) river morphology, 1952 (B&W) and 2021 (colour).

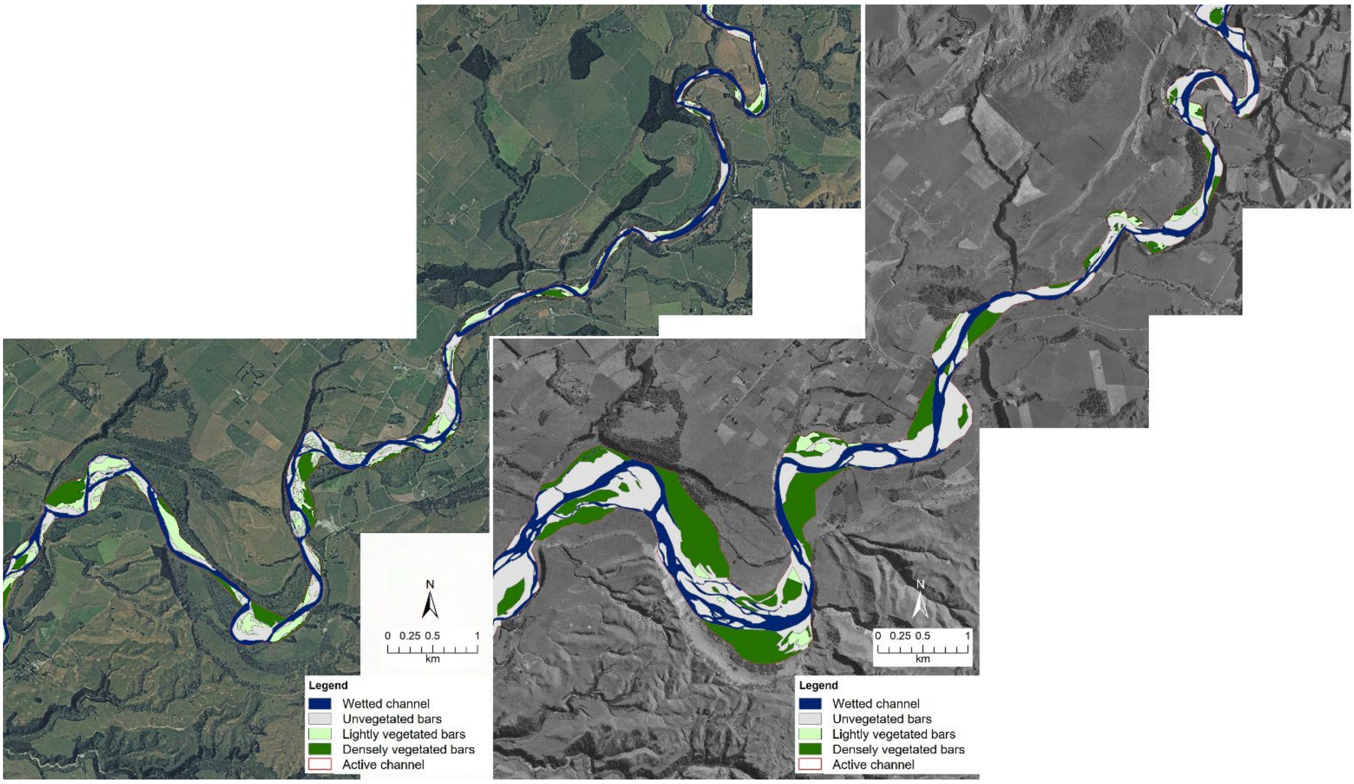


Figure 2.4 Lower Rangitikei (c) river morphology, 1958 (B&W) and 2021 (colour).

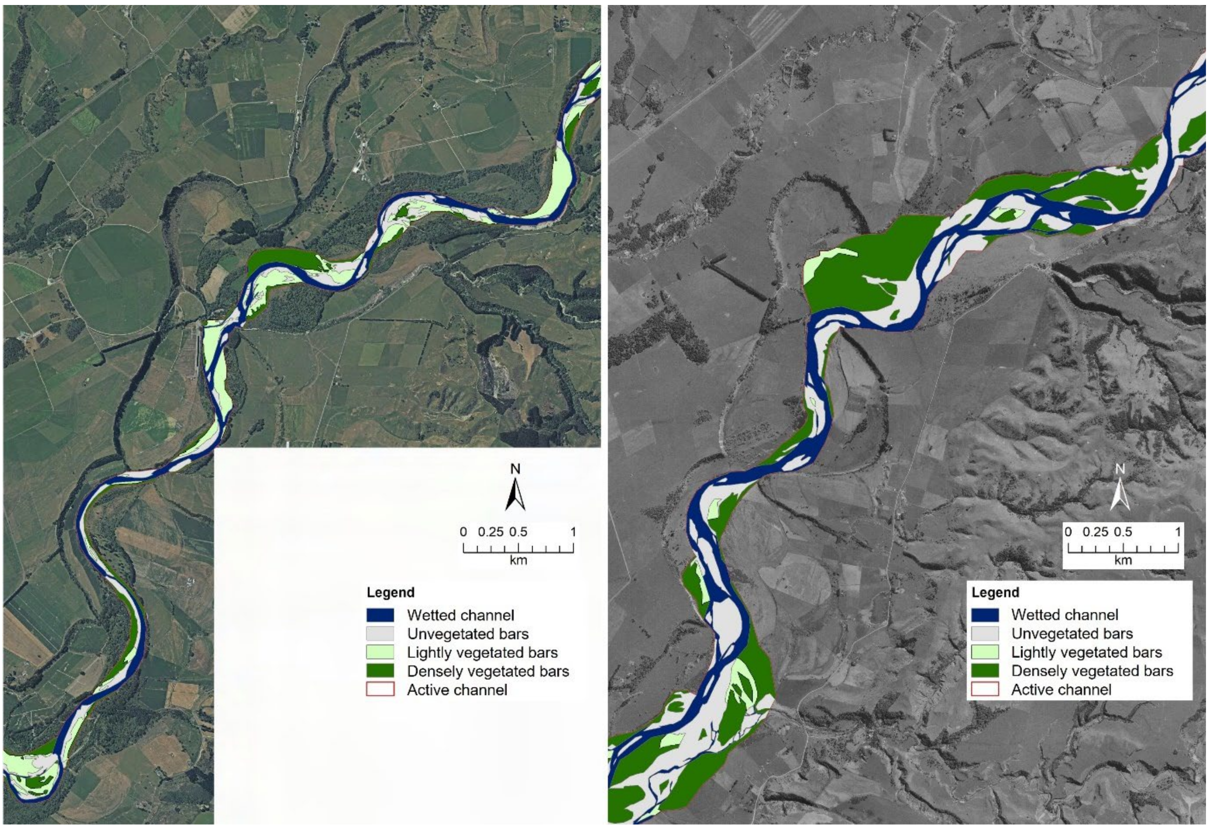


Figure 2.5 Lower Rangitikei (d) river morphology, 1958 (B&W) and 2021 (colour).

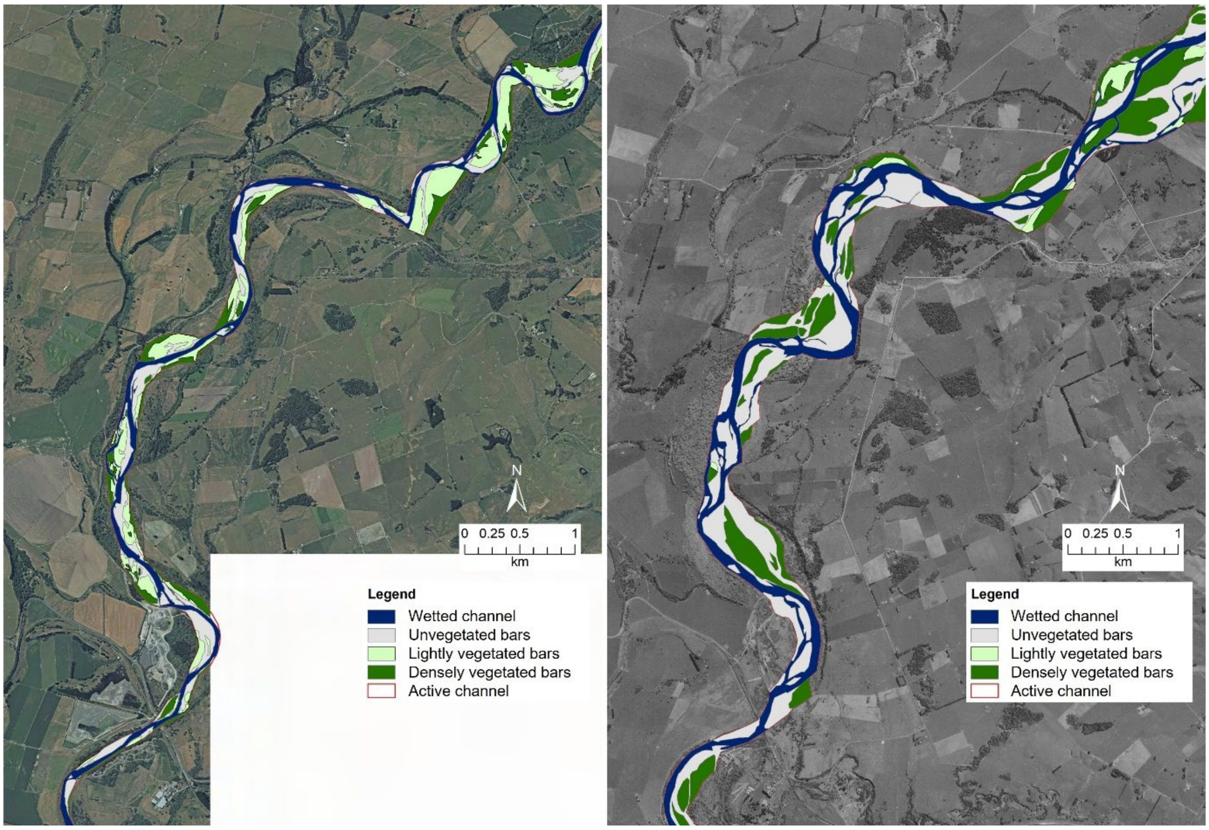


Figure 2.6 Lower Rangitikei (e) river morphology, 1958 (B&W) and 2021 (colour)

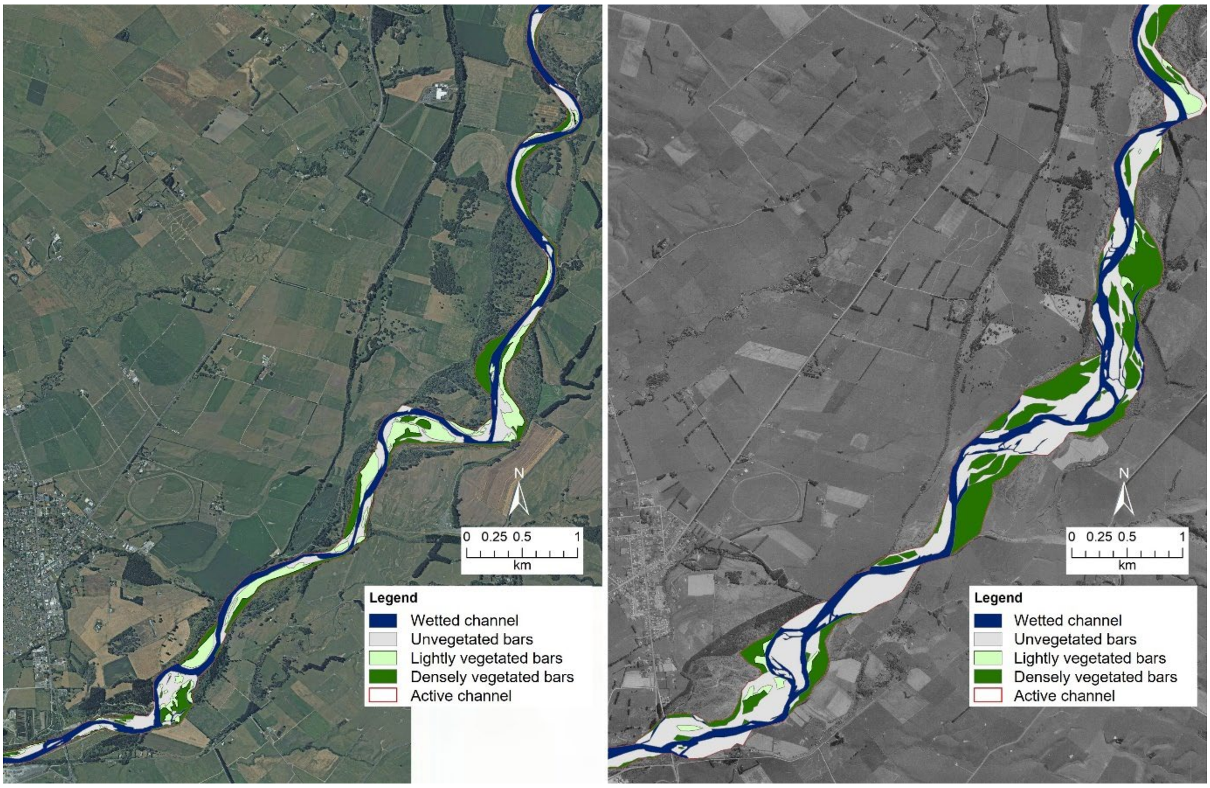


Figure 2.7 Lower Rangitikei (f) river morphology, 1958 (B&W) and 2021 (colour)

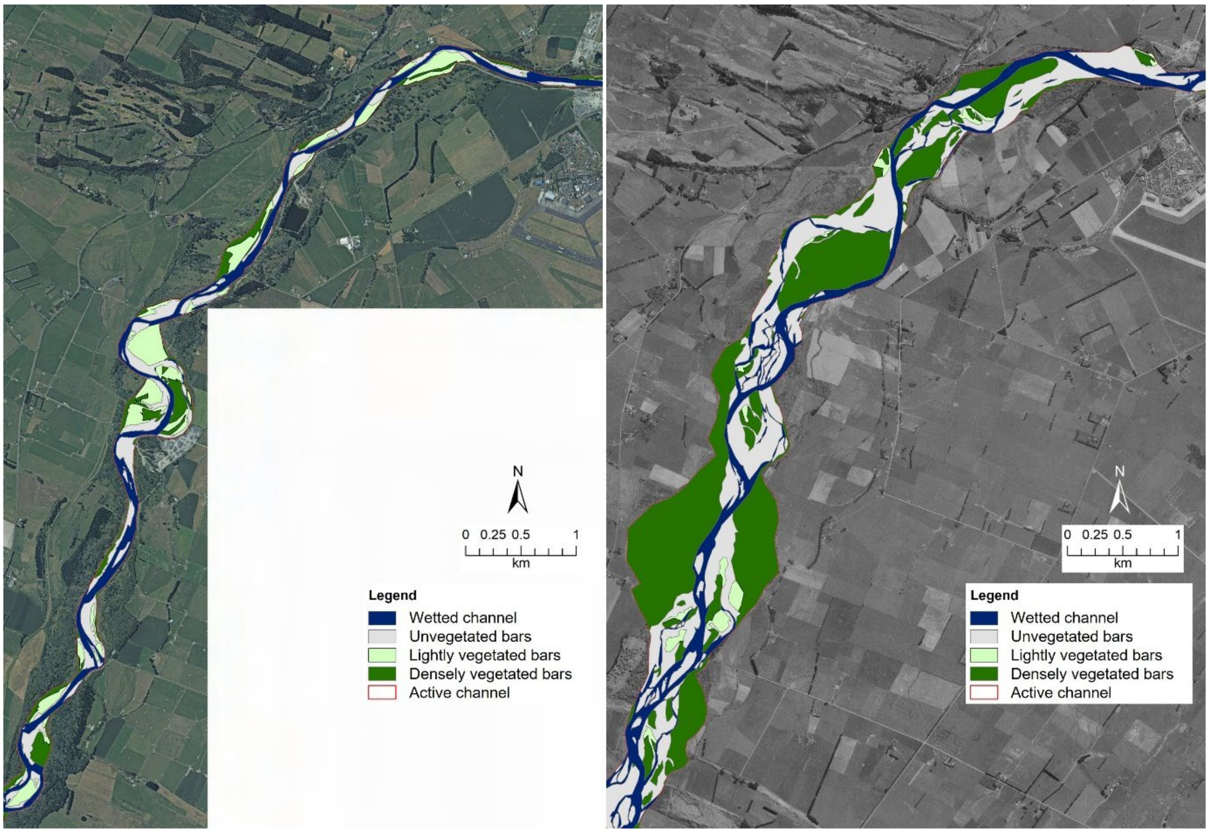


Figure 2.8 Lower Rangitikei (g) river morphology, 1958 (B&W) and 2021 (colour)

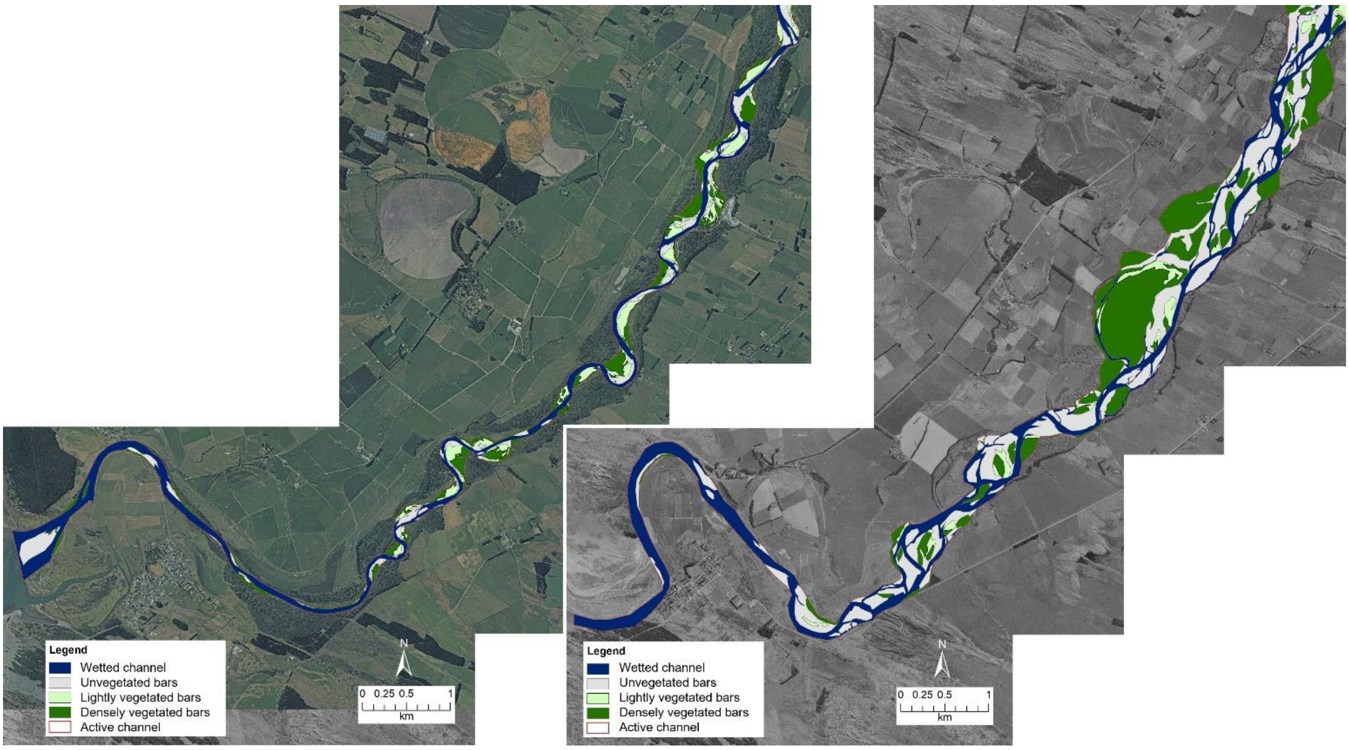


Figure 2.9 Lower Rangitikei (h) river morphology, 1958 (B&W) and 2021 (colour)

2.3 Natural Character Index (NCI)

2.3.1 NCI defined

The NCI compares a river's contemporary morphological characteristics with those at some point in the past (Fuller et al., 2020). Differences between contemporary and past characteristics can be the product of natural or anthropogenic drivers of change. Since large-scale anthropogenic activities have either directly or indirectly modified catchments, the "natural" form of rivers cannot be construed to represent entirely pristine conditions (Fuller et al. 2020).

Quantifying changes in the Kawhatau and upper and lower Rangitikei reaches (Figure 1.3) involves generating an NCI ratio of 'observed' i.e., contemporary geomorphic units, over 'expected' i.e., the nature of corresponding geomorphic units in the 1950s (cf. Fuller et al., 2020). Considering the resolution of aerial photography, the NCI approach is best suited to assessing changes in larger subaerial geomorphic features e.g., gravel bars, as opposed to more nuanced changes in subaqueous features such as pools and riffles (Fuller et al., 2020).

Following mapping (section 2.2), areas of these river characteristics are assessed using the NCI ratio. If no change has occurred, the ratio will be 1.00. If a reduction in the parameter has occurred, then the ratio will be less than 1.00. Conversely, if there has been an increase in the parameter, i.e., the area has increased, the ratio will exceed 1.00. Generating an NCI ratio is demonstrated for the Kawhatau active channel:

$$\text{NCI active channel area} = \frac{\text{Area in 2021}}{\text{Area in 1952}} = \frac{208\text{ ha}}{247\text{ ha}} = 0.84$$

This result indicates a 16% reduction in active channel area along the Kawhatau reach (Figure 2.1) between 1952 and 2021.

It should be noted that the extent of wetted channels in a reach is flow dependent, so parameters measured that are affected by flow conditions (e.g., area or length of wetted channels, and area of bare gravel surfaces (bars) will be dependent on river flow at the time of aerial photo acquisition. Some fluctuation in NCI for these parameters can therefore be expected and the NCI results are inevitably an approximation and provide a first-cut overview of any change in channel characteristics (Fuller et al., 2020).

2.3.2 NCI Results

Tables 2.1 – 2.3 tabulate areas and provide the NCI ratios for Kawhatau (Table 2.1), upper Rangitikei (Table 2.2) and lower Rangitikei (Table 2.3). These values are summarised graphically in Figures 2.10 (Kawhatau), 2.11 (upper Rangitikei) and 2.12 (lower Rangitikei).

Table 2.1 Kawhatau NCI results

Parameter	1952	2021	NCI
Active channel area	247.4 ha	208.1 ha	0.84
Unvegetated bar area	155.5 ha	50.4 ha	0.32
Lightly vegetated bar area	16.5 ha	40.4 ha	2.45
Densely vegetated bar area	27.5 ha	75.3 ha	2.74
Wetted channel area	47.9 ha	42.0 ha	0.88
Wetted channel length	30.09 km	30.20 km	1.00
Midline length	21.54 km	21.17 km	0.98
Braid channel ratio	1.40	1.43	1.02

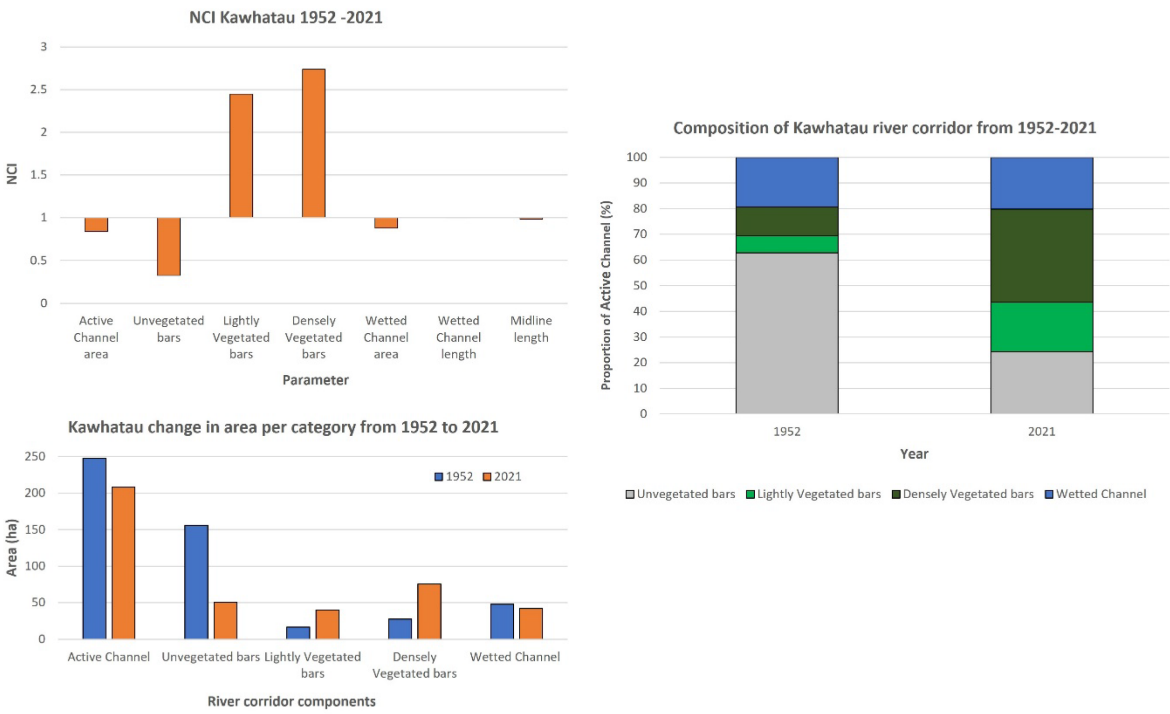


Figure 2.10 Summary of changes in channel characteristics (NCI, areas and composition) in the Kawhatau, 1952-2021.

The most significant changes in the Kawhatau river corridor are the 68% reduction in unvegetated bars and 74% increase in area of densely vegetated bars (Table 2.1, Figure 2.10). The active channel area has also reduced by 16%. Wetted channel length and midline are unchanged, as is the braid channel ratio.

Table 2.2 Upper Rangitikei NCI results

Parameter	1952	2021	NCI
Active channel area	672.3 ha	555.1 ha	0.83
Unvegetated bar area	274.2 ha	148.6 ha	0.54
Lightly vegetated bar area	55.4 ha	97.2 ha	1.75
Densely vegetated bar area	90.2 ha	80.9 ha	0.90
Wetted channel area	253.8 ha	228.5 ha	0.90
Wetted channel length	58.25 km	62.61 km	1.08
Midline length	53.60 km	54.40 km	1.02
Braid channel ratio	1.09	1.15	1.06

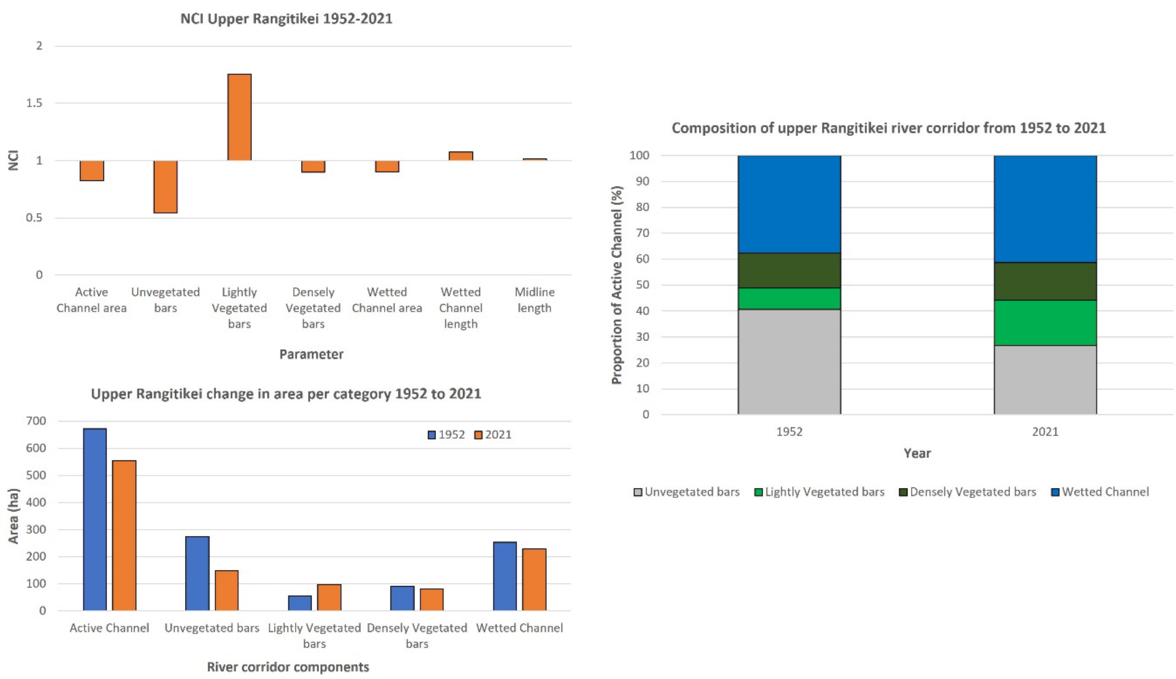


Figure 2.11 Summary of changes in channel characteristics (NCI, areas and composition) in the upper Rangitikei, 1952-2021.

The most significant changes in the upper Rangitikei river corridor are the 46% reduction in unvegetated bars and 75% increase in area of lightly vegetated bars (Table 2.2, Figure 2.11). The active channel area has also reduced by 17%. Wetted channel length and midline are essentially unchanged, as is the braid channel ratio.

Table 2.3 Lower Rangitikei NCI results

Parameter	1958	2021	NCI
Active channel area	2697.4 ha	1160.7 ha	0.43
Unvegetated bar area	986 ha	273.2 ha	0.28
Lightly vegetated bar area	93.5 ha	280.9 ha	3.00
Densely vegetated bar area	955.3 ha	216.1 ha	0.23
Wetted channel area	663.0 ha	390.96 ha	0.59
Wetted channel length	129.0 km	93.12 km	0.72
Midline length	72.8 km	74.52 km	1.02
Braid channel ratio	1.77	1.25	0.71

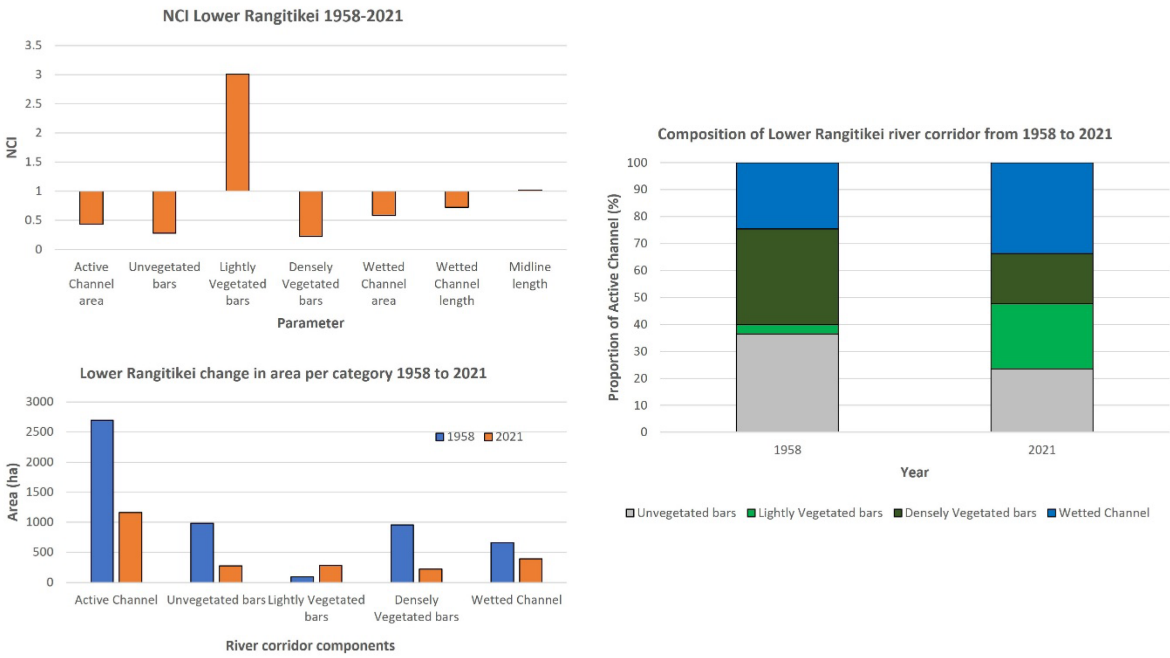


Figure 2.12 Summary of changes in channel characteristics (NCI, areas and composition) in the lower Rangitikei, 1952-2021.

The most significant changes in the lower Rangitikei river corridor are the 72% reduction in unvegetated bars, 77% reduction in densely vegetated bars and 200% increase in lightly vegetated bars (Table 2.3, Figure 2.12). The active channel area has also reduced 57%. Wetted channel length has reduced by 28%, but midline length of channel is essentially unchanged. Braid channel ratio has reduced by 29%.

2.4 Channel Morphology and NCI Discussion

2.4.1 Kawhatau

The overall channel morphology in the Kawhatau could be argued to be little changed between 1952 and 2021 because the braid index, wetted channel length and midline channel length are consistent. The river remains a multi-threaded, confined to partly confined wandering or semi-braided channel. However, while the wetted channel characteristics are consistent over 69 years, the composition of the active channel has changed significantly with the reduction in unvegetated bar surfaces. These bare gravel bars have been colonised by vegetation, and densely vegetated bars are now the primary unit within the active river corridor (Figure 2.10). This compositional change has effectively restricted the work-over area of the active channel, which overall has also reduced by 16%. Effective work-over area is reduced because densely vegetated bar surfaces are far less mobile than bare, unvegetated sediment surfaces. These differences in area are most evident in the partly-confined sections of the Kawhatau reach (Figure 2.1).

Drivers of these changes are in need of further investigation, but could be attributed to a change in flow regime: if flood flows are smaller or less frequent, vegetation is able to colonise bar surfaces and reduce effective active channel area. Furthermore, if the 1952 photography was flown in the aftermath of a very large flood, it is likely that event would have swept the valley floor, which in this confined-partly confined setting is the active channel, removing any colonising vegetation. Assessment of Kawhatau flows from the 1940s-2020s is required to assess these scenarios. These changes may also reflect the spread of exotic vegetation that has been prevalent across New Zealand river corridors in the latter part of the twentieth century and early twenty-first, exotic grasses, lupin, tree lucerne, willow are choking many river corridors. However it is important to recognise that ultimately the flood regime in this period has been favourable to this vegetation growth, with fewer large floods mobilising, reworking and clearing colonising vegetation from the active channel.

It is also possible that human intervention could be responsible for changes in the Kawhatau. Channel training has not been employed, but there are three sites of gravel extraction along the reach (Figure 2.13). Cross section analysis indicates a significant reduction in gravel volumes associated with extraction (30,000 m^3/yr authorised) at the Pourangaki site (xs 21-29, 30-33, Figure 2.14), which is located at the upstream limit of mapping (Figure 2.1). More detailed analysis and discussion of gravel budgets is the focus of section 3. However, it appears that gravel extraction from the Pourangaki site could be contributing to some reduction in active channel area because with less bedload, the active channel area will contract and there is deposition or replenishment of active bars in the reach. Nevertheless, a return to a small net aggradation in the bed at xs 301-308 and 201-410 farther downstream (and still upstream of the McKinnon, Gorringes and McGregror Roache sites) suggests that the impacts of the Pourangaki extraction are spatially shortlived, with sufficient reworking of the active channel recruiting sediment to replenish bed levels. There are no cross-sections downstream of the other extraction sites, so impacts on bed levels are unknown. It is notable that the active channel composition and area changes dramatically immediately downstream of McKinnons-Gorringes (Figure 2.15) where a combined 60,000 m^3/yr is authorised for extraction (30k m^3/yr each from these adjacent sites). This is double the extraction authorised at Pourangaki, so an impact on channel morphology is more likely. Extraction of 30,000 m^3/yr from McGregror Roache is unlikely to significantly impact active channel composition in the Kawhatau at the scale of this analysis because it is located within a confined section of the reach, which means channel morphology is forced by adjacent valley sides, rather than self-adjusting. It is probable, therefore that in the immediate vicinity of gravel extraction sites at McKinnons-Gorringes and Pourangaki, changes in morphology are driven, or at least strongly affected by, gravel extraction, but when averaged over the ~20 km reach of the Kawhatau as a whole, which includes a significant length of confined channel, these impacts are less obvious. In turn this suggests a reasonably resilient and robust river behaviour in the Kawhatau, which is sufficiently dynamic and energetic to absorb anthropogenic disturbance in the form of gravel extraction in the volumes taken to date under the prevailing flow and sediment regime along the ~20 km reach assessed. Nevertheless, change in river corridor composition as a whole has occurred, but probably not in response solely to extraction.

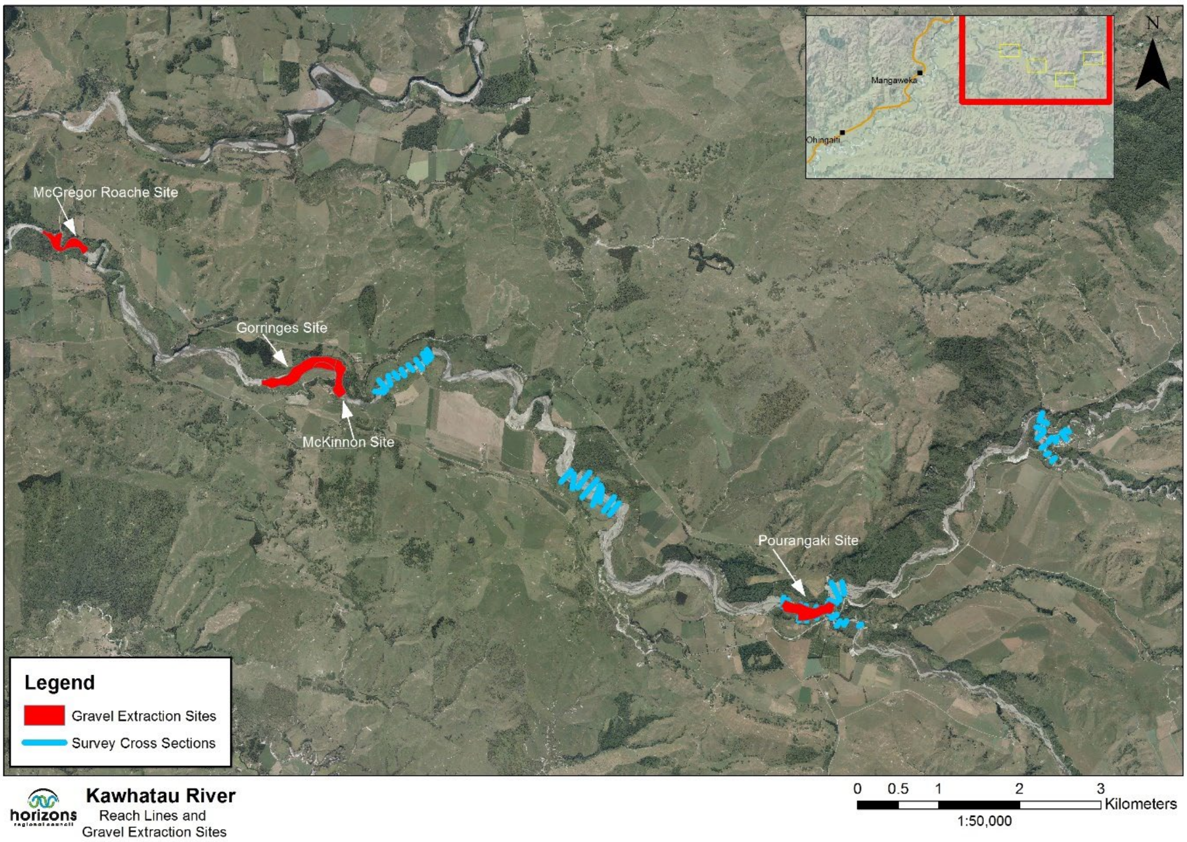


Figure 2.13 Gravel extraction sites and cross section survey locations, Kawhatau (supplied)

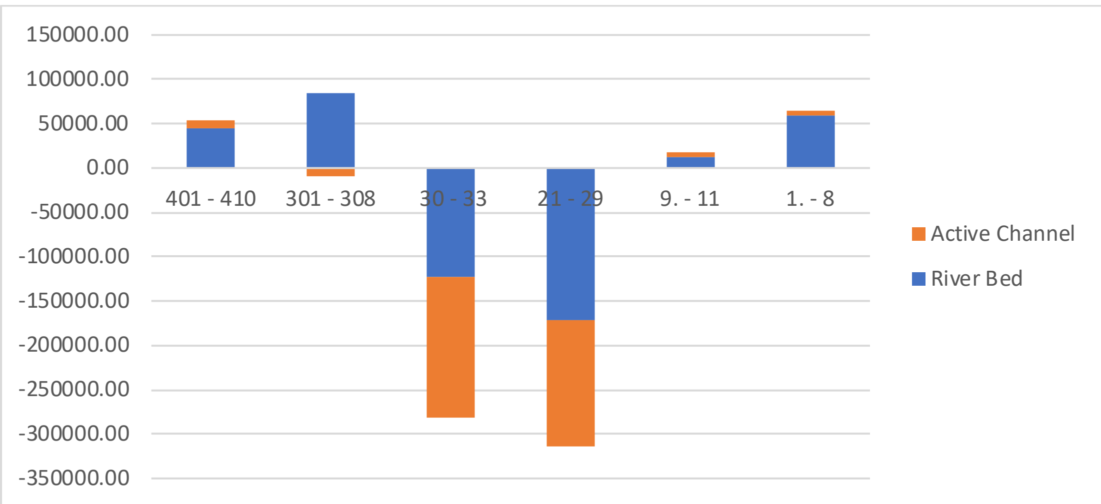


Figure 2.14 Total gravel volume change under active channel and bed per reach, Kawhatau cross-sections 1-8, 9-11, 21-29, 30-33, 301-308, 401-408 (supplied).

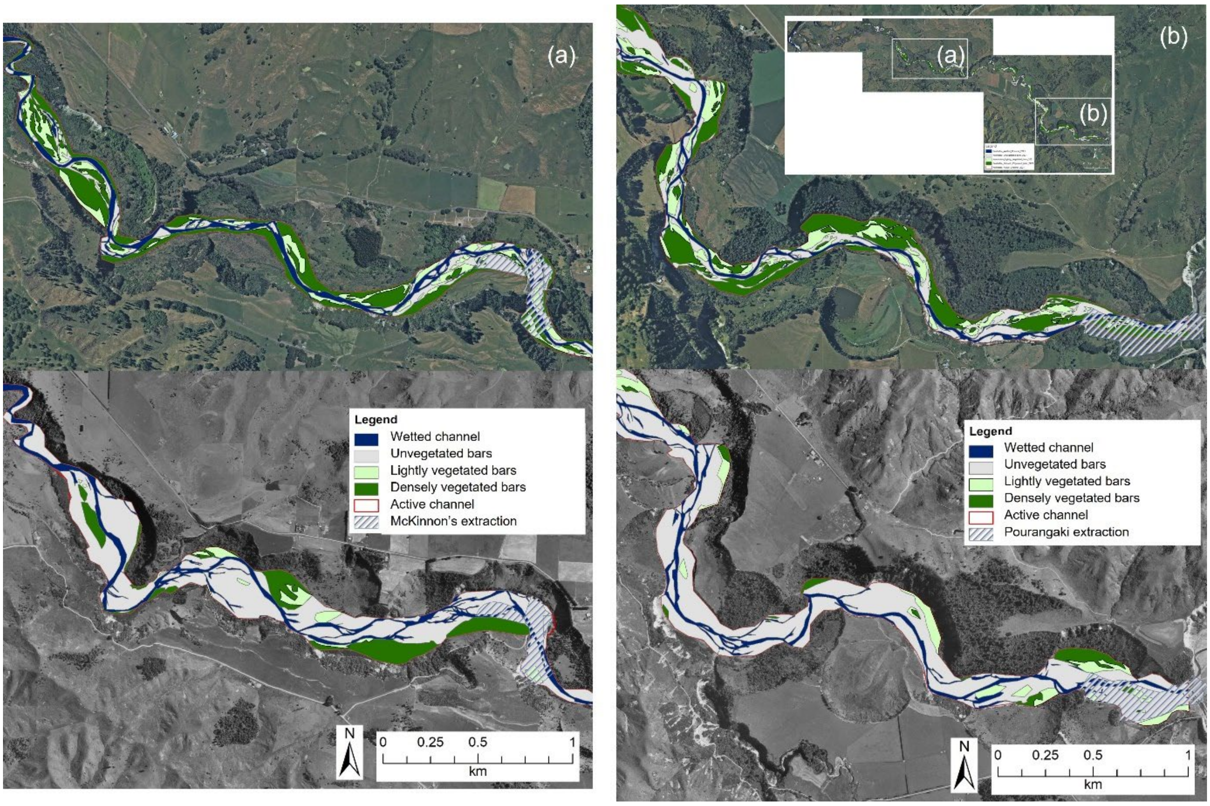


Figure 2.15 Kawhatau channel morphology downstream of the McKinnons-Gorringes (a) and Pourangaki (b) gravel extraction sites, 1952 (B&W) and 2021 (colour) compared.

2.4.2 Upper Rangitikei

Similar to the Kawhatau, the overall channel morphology in the upper Rangitikei was little changed between 1952 and 2021. The braid index, wetted channel length and midline channel length are consistent (slightly increased). This consistent channel morphology reflects significant lengths of confined river corridor, in which there is little capacity of the river to adjust its morphology. The upper Rangitikei is single threaded through these more confined sections and is best characterised as an incised meandering channel with the large-scale meandering form forced by the incised valley floor. Some shifting of the wetted channel and reworking of narrow bars within this inset channel is evident, but overall form is unchanged. However, while the wetted channel characteristics are consistent over 69 years, again the composition of the active channel has changed with the reduction in unvegetated bar surfaces, though not as substantial a reduction as the Kawhatau. This trend is more apparent in the less confined lower reaches of the upper Rangitikei (compare Figures 2.2 and 2.3). Again, bare gravel bars have been colonised by vegetation, but the single primary unit within the active river corridor remains unvegetated bars (Figure 2.11).

The contrast between the upper Rangitikei and Kawhatau probably reflects the nature of the river at this point in the catchment. The mainstem of the Rangitikei receives flow from the entirety of the upper catchment, whereas the Kawhatau is a left-bank tributary rising in the Ruahine Ranges. Sediment-mobilising flows in the mainstem at this point in the catchment are likely more frequent than in the Kawhatau, simply reflecting the contrasting catchment sizes. The proportion of the active channel that is wet is greater in the upper Rangitikei (cf. Figures 2.10 and 2.11) – the river is bigger and confined. This setting means there is less opportunity for vegetation colonisation and remobilising flows are sufficiently energetic to sweep the active channel.

The role of gravel extraction in influencing channel morphology is difficult to determine because there are no cross-sections in this reach. However extraction appears to be at a smaller scale (e.g. 5000 m^3/yr in the vicinity of Mangaweka). More significant extraction occurs in the downstream segment of this reach (Figure 2.16), where 19,000 m^3/yr and 5,000 m^3/yr is authorised from Hunterville-Vinegar Hill. These volumes are significantly smaller than extraction from Kawhatau and the Rangitikei a bigger river and there does not appear to have been such a significant impact on channel morphology even locally, at least not at this scale of analysis (Figure 2.16), but some contribution of gravel extraction to the changes observed cannot be ruled out.

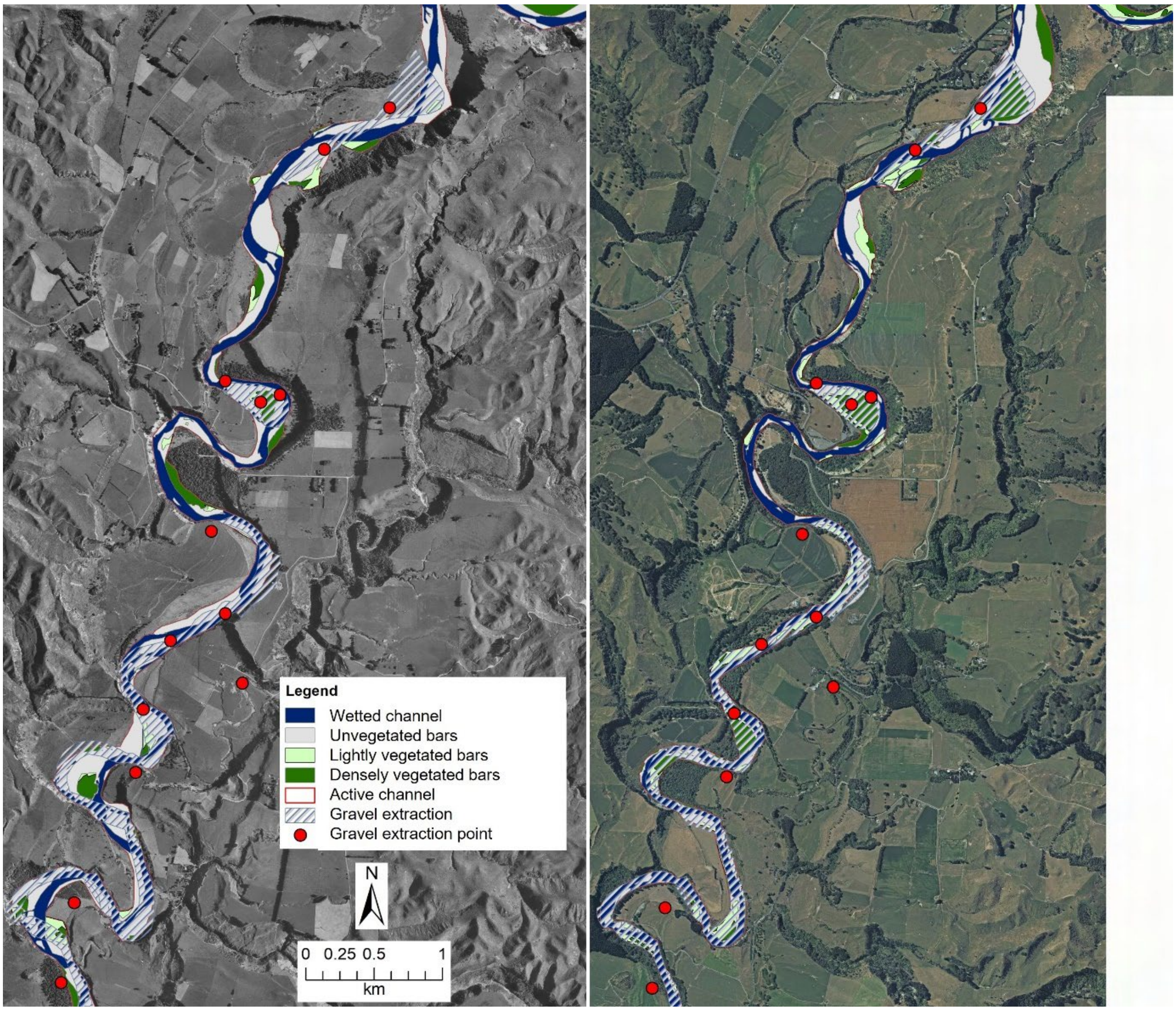


Figure 2.16 Gravel extraction sites in the downstream segment of the upper Rangitikei reach overlaid on channel morphologies in 1952 (B&W) and 2021 (colour). 19,000 m^3/yr is authorised from the two upstream extraction areas shown, which are covered by a single consent (ATH-2011014103.01). The downstream area is authorised to take \$5,000 m^3/yr). Red circles indicate historic consents of similar consented volumes.

2.4.3 Lower Rangitikei

The lower Rangitikei has been directly modified by the river control scheme implemented since the 1950s (Fuller et al., 2012; 2020). Change in the active channel is consistent with changes observed in the floodplain between the 1940s and 2016 reported by Fuller et al. (2020). The active channel has been narrowed via bank protection and assimilation of riparian margins into the floodplain (Richardson & Fuller, 2010). Areas mapped as densely vegetated bars in 1958 have become part of the adjacent floodplain, explaining the reduction in area of these surfaces within the active channel (Table 2.3) in contrast to increases evident in the Kawhatau and upper Rangitikei (cf. Tables 2.1, 2.2). The increase in lightly vegetated bars within the active channel reflects vegetation colonisation within the active channel fairway and may reflect antecedent flow conditions. Channel rationalisation has reduced the wetted channel area and length, although midline length remains similar, which is consistent with channel rationalisation. Comparison of Figures 2.4 – 2.9 indicates a transformation of channel morphology from braided and semi-braided to single-thread and locally divided wandering channel, as reported in previous work at different spatial and temporal scales (Fuller et al., 2012; 2020).

Changes observed between 1958 and 2021 can be consistently linked with direct intervention to manage the lower Rangitikei River. The role of gravel extraction in contributing to the changes evident is difficult, if not impossible, to distinguish from structural measures in this analysis. Extraction of gravel above natural supply rates will certainly contribute to contraction of the active channel area observed. The gravel budget in the lower Rangitikei is the focus of section 3.

3. Morphological budgeting

Morphological budgeting in this analysis utilises two methodologies covering contrasting temporal scales. In the lower Rangitikei and Kawhatau Rivers, cross-sections have been used to detect change along both sub-aerial and subaqueous components of the active channel along each section line, from which an assessment of change in gravel volume can be made (3.1). Cross sections could be considered as providing a more complete assessment of the gravel budget than GCD of dry bar surfaces. However, changes detected by cross-section analysis are restricted to those measured along the section line and interpolated between adjacent lines using end-over-area analysis, and a full three-dimensional assessment of change in gravel storage is not possible.

A budget based on change detection between LiDAR-derived DEMs is presented (3.2) and provides an assessment of sediment volumes derived using geomorphic change detection (GCD) between 2017 and 2021 for sub-aerial (dry) surfaces only, but provides a continuous three dimensional assessment of geomorphic change for these surfaces for the entire 62 km length of managed river in the lower Rangitikei. This GCD derived morphological budget is then compared with a gravel budget based on cross-sectional analyses for the equivalent reach of the lower Rangitikei, covering the period 1997-2021.

3.1 Cross section derived gravel budget

The gravel budget was derived using an approach outlined by Conley (2023). Cross-sections supplied were corrected and overlaid to generate gravel budgets for reaches in the Kawhatau (3.1.1) and Rangitikei (3.1.2). Changes along each cross-section and epoch used in this assessment are included in Appendices A (Kawhatau, 1997-2019), B (Rangitikei XS 32480-1250, 1975-2017) and C (Rangitikei XS 63550-32910, 1975-2021).

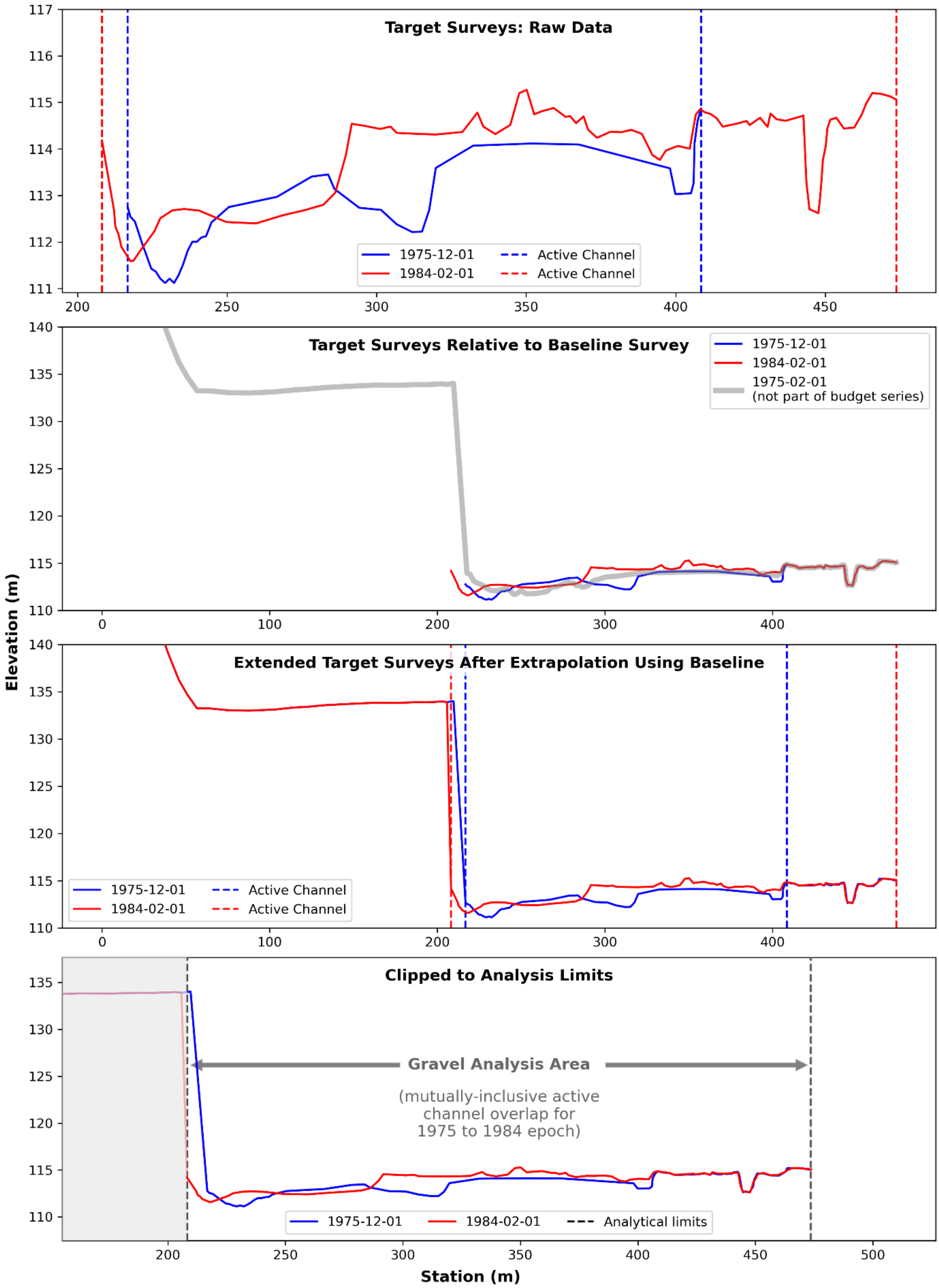


Figure 3.1. General preprocessing steps to enable comparison between individual Rangitikei surveys at a single cross-section. Top: the horizontal extent of any given survey is highly variable across surveys, preventing direct comparison. Second: Earlier surveys of greater horizontal extent were used to extrapolate outside the limits of analysed surveys (assumed to stop at the extent of field-determined change at time of survey). Third: Active

channel extents (field-determined at time of respective surveys) evaluated identify a “window” of comparison for active channel budgeting (bottom).

3.1.1 Kawhatau

Cross-sections were overlaid between 1997 and 2019 for the four monitored reaches in the Kawhatau (Figures 3.2-3.7). Budgets were derived for each coherent reach (mainstem Reach 1-4 and Hikurangi in Reach 1 and Pourangaki in Reach 2)

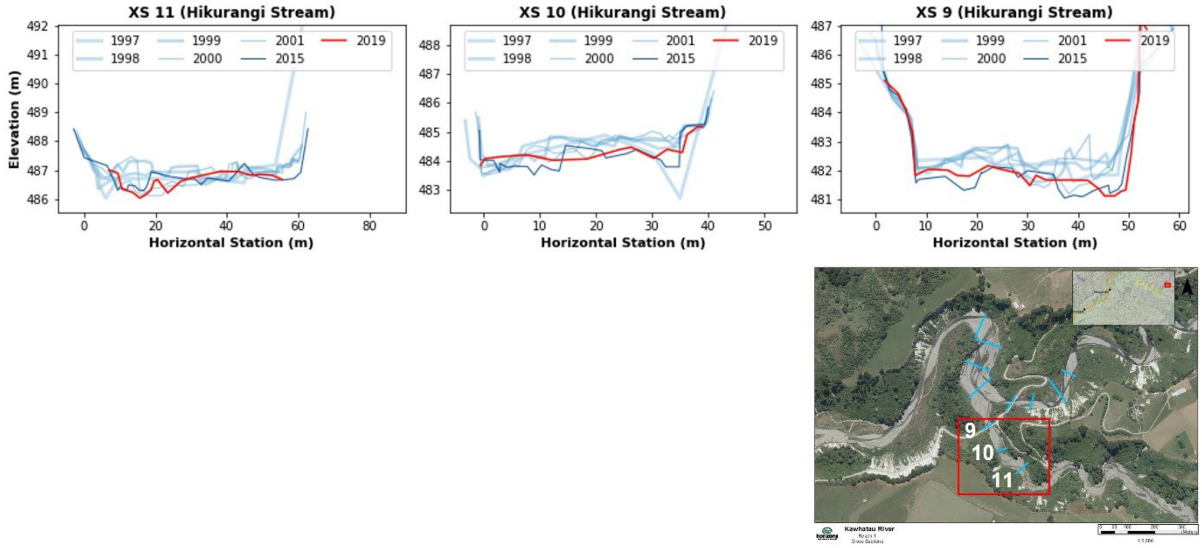


Figure 3.2a Hikurangi Stream cross-section overlays, Kawhatau Reach 1

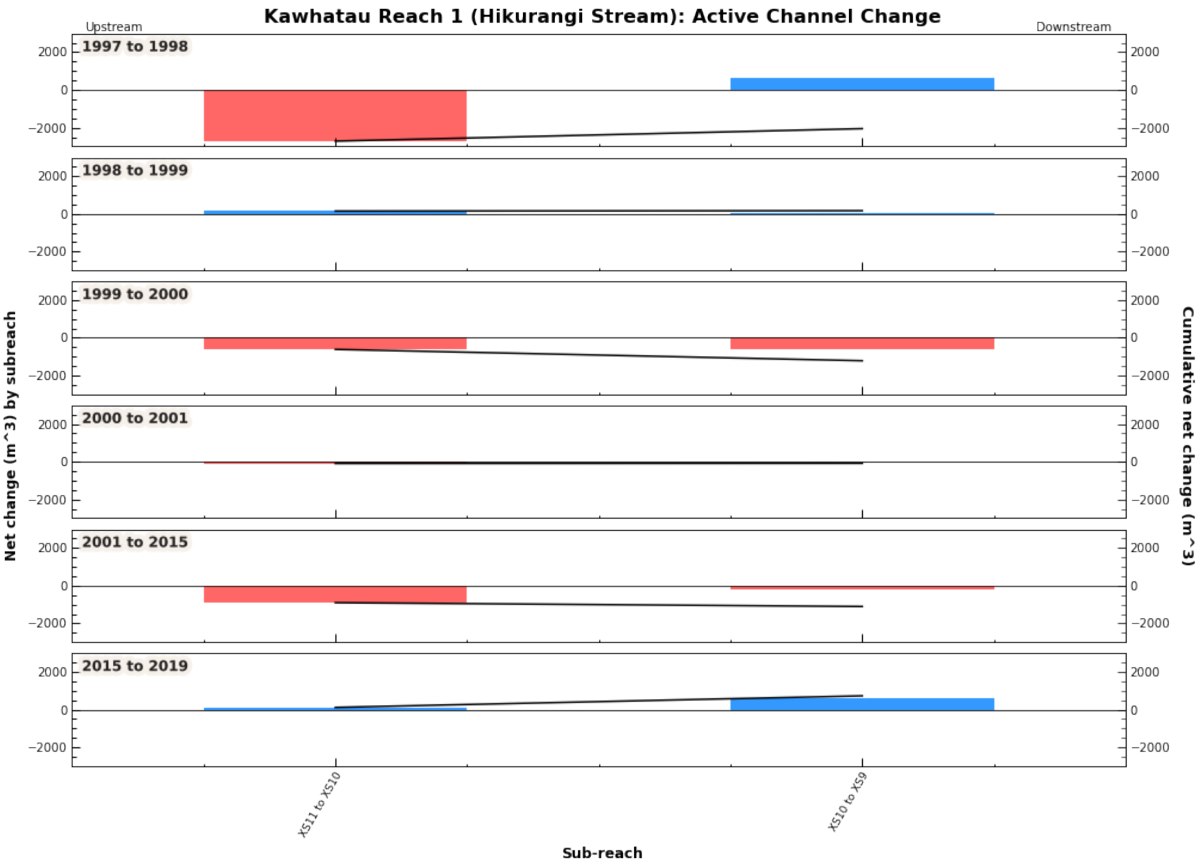


Figure 3.2b Volumetric change for two sub-reaches defined by the three Hikurangi Stream cross-sections.

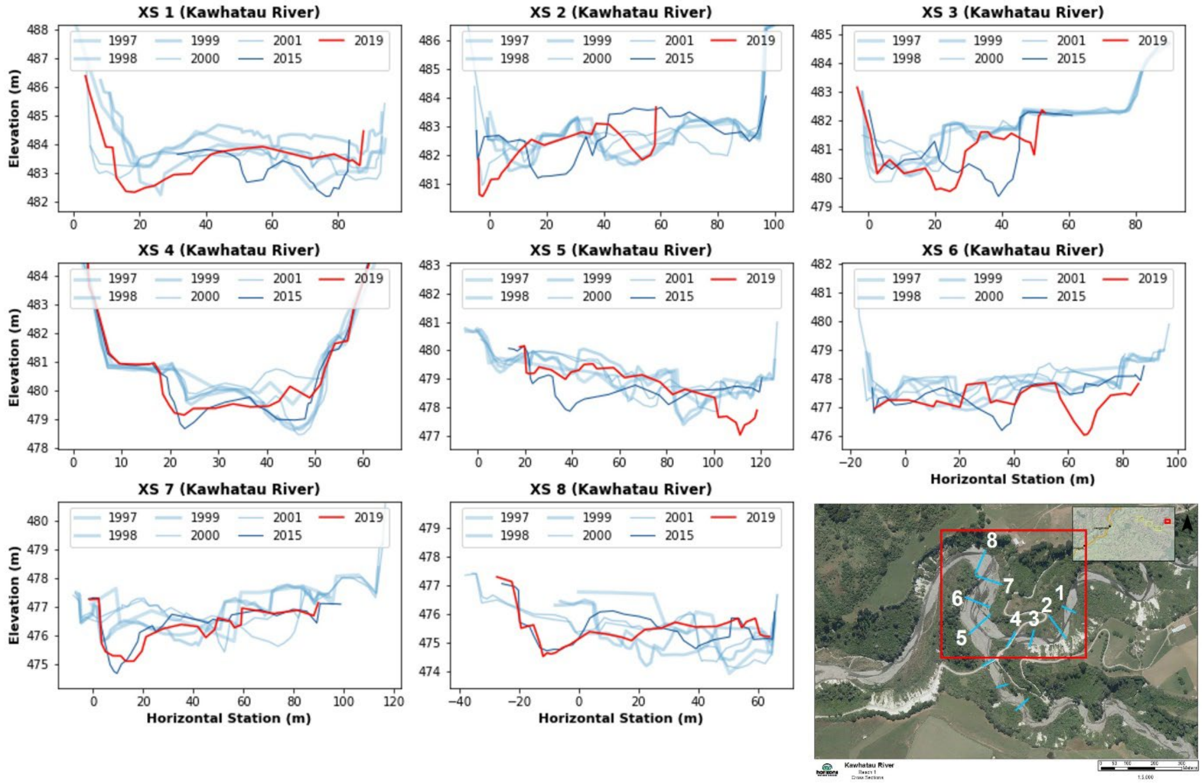


Figure 3.3a Kawhatau mainstem cross-section overlays, Kawhatau Reach 1

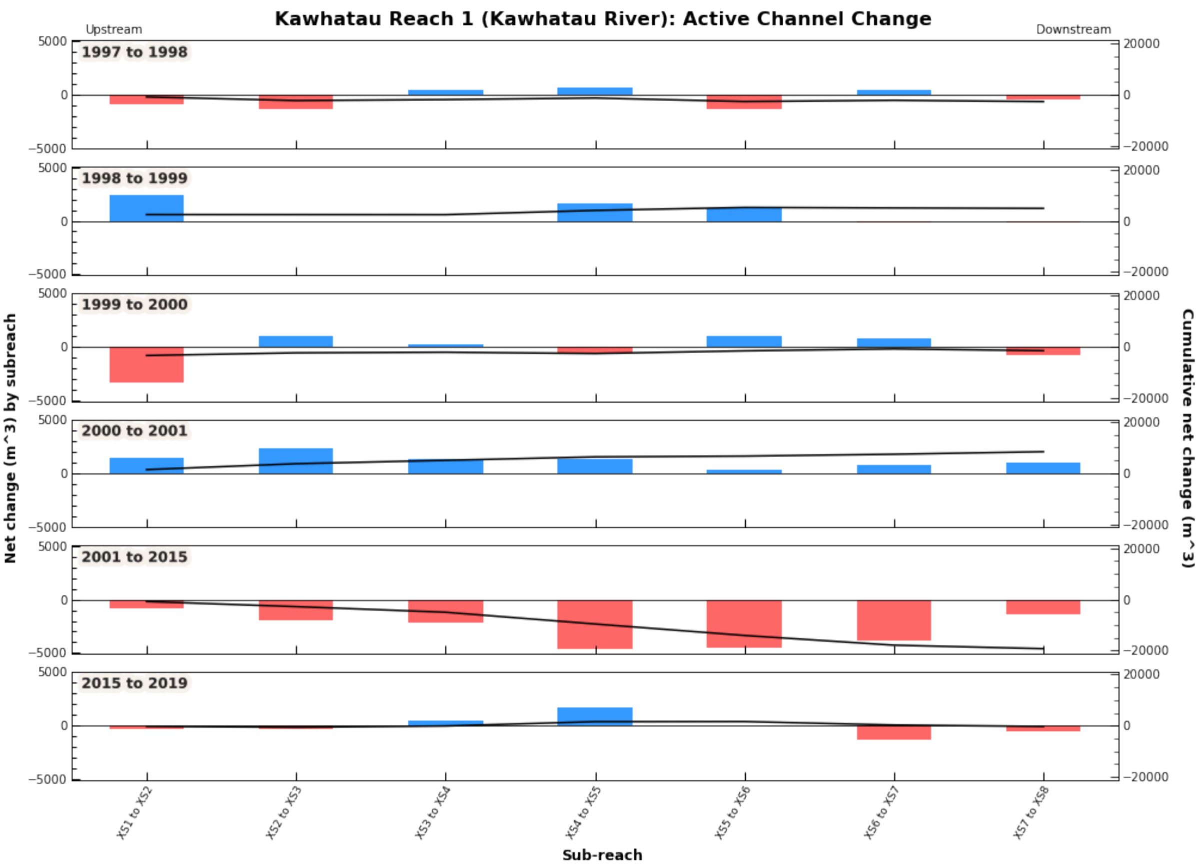


Figure 2.3b Six epochs (periods) of volumetric change for seven contiguous sub-reaches of Kawhatau River Reach 1.

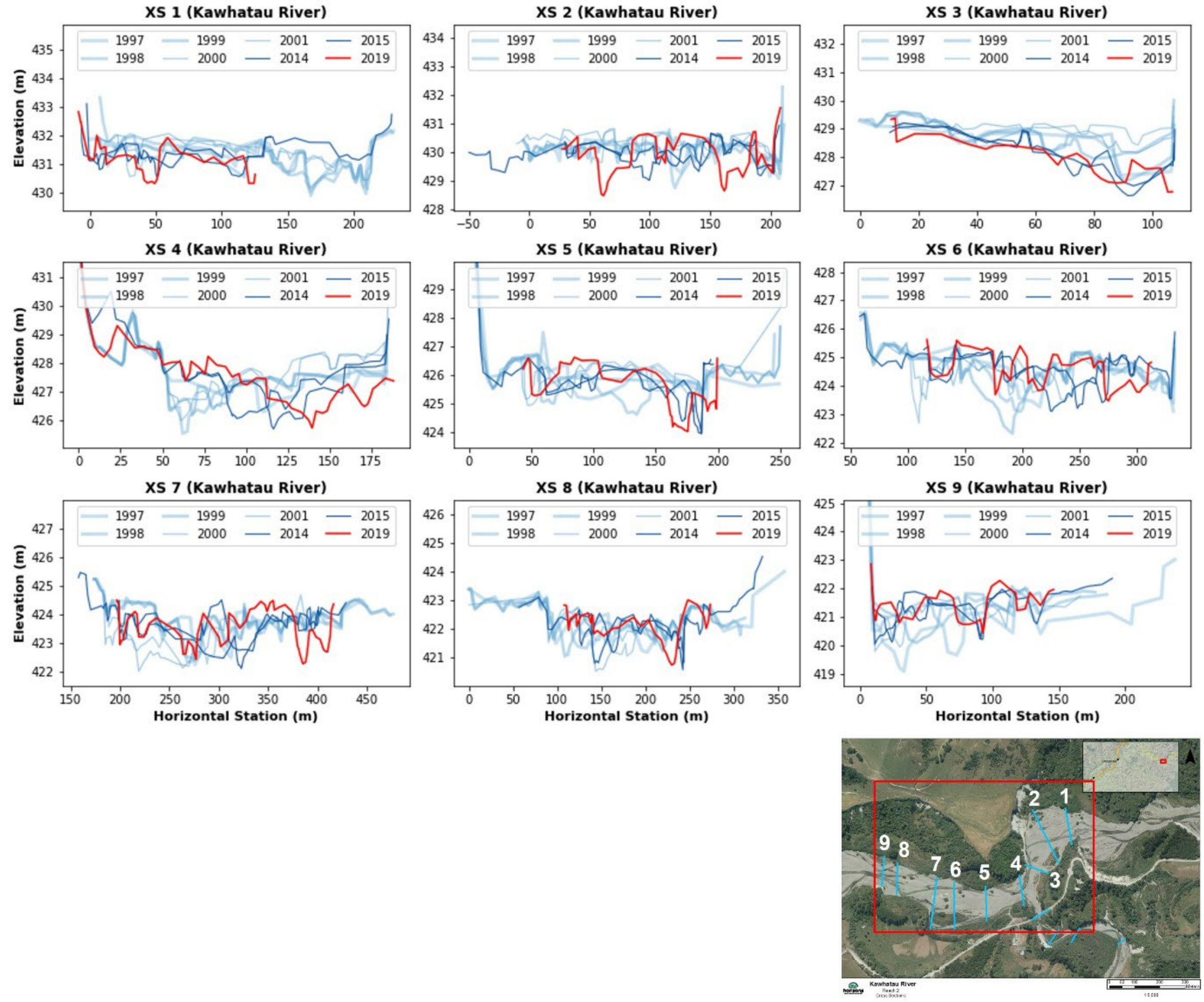


Figure 3.4a Kawhatau mainstem cross-section overlays, Kawhatau Reach 2

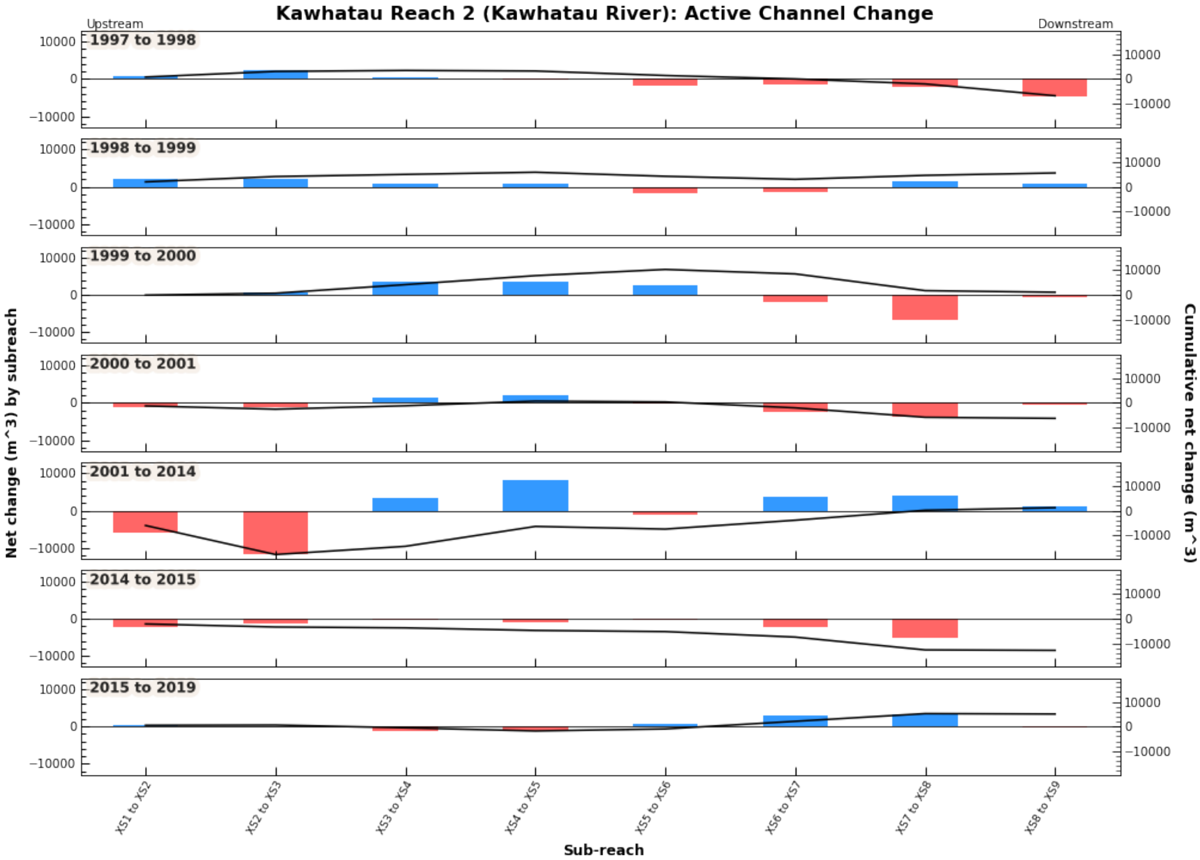


Figure 3.3b. Six epochs (periods) of volumetric change for eight contiguous sub-reaches of Kawhatau River Reach 2.

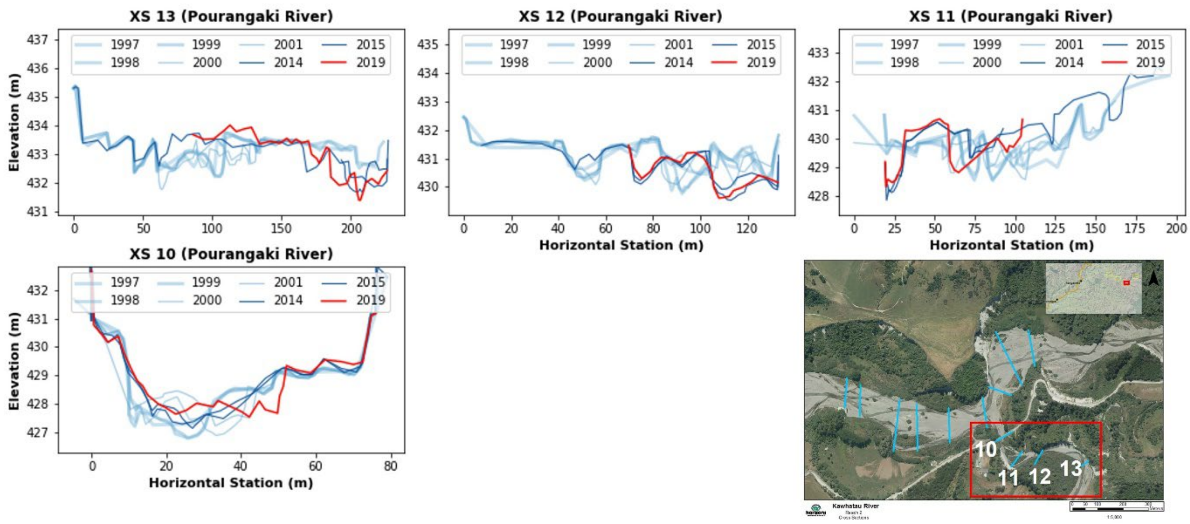


Figure 3.5a Pourangaki River cross-section overlays, Kawhatau Reach 2

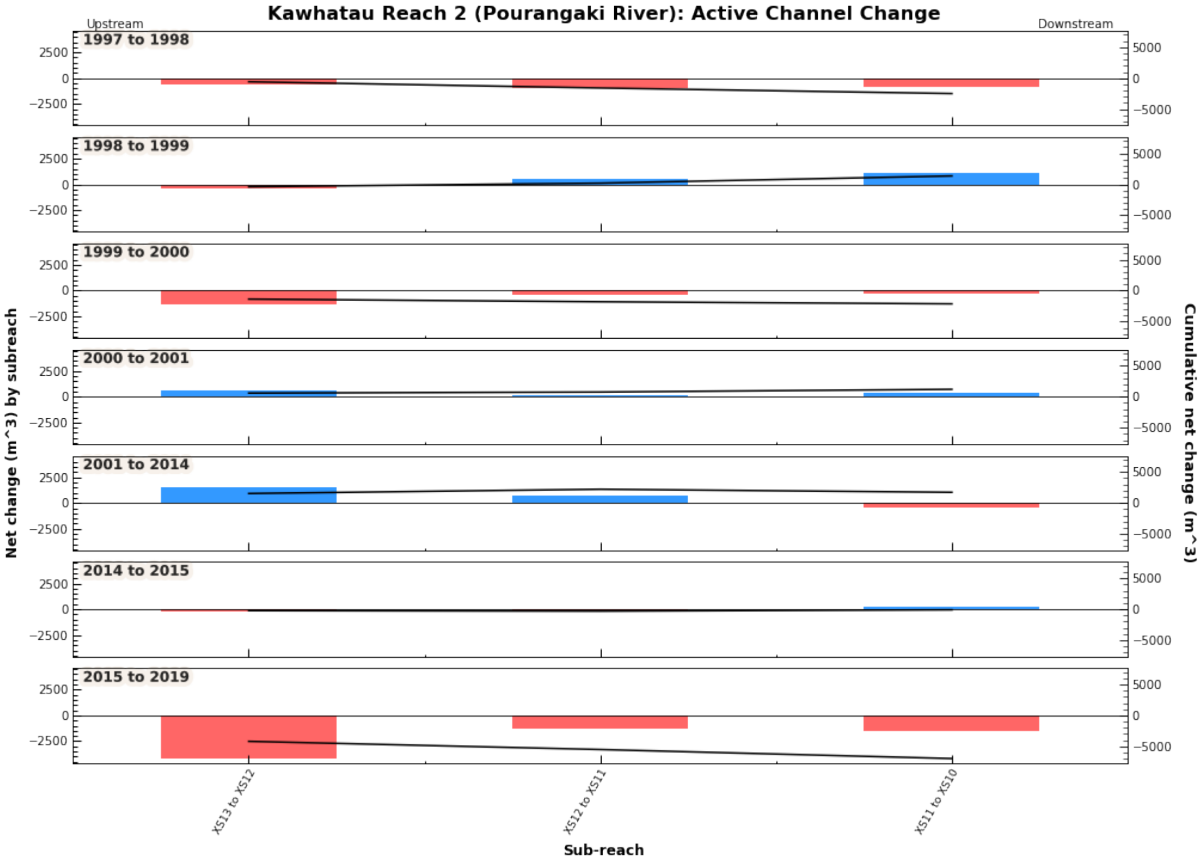


Figure 3.4b. Six epochs (periods) of volumetric change for three contiguous sub-reaches of the Pourangaki River (Kawhatau "Reach 2").

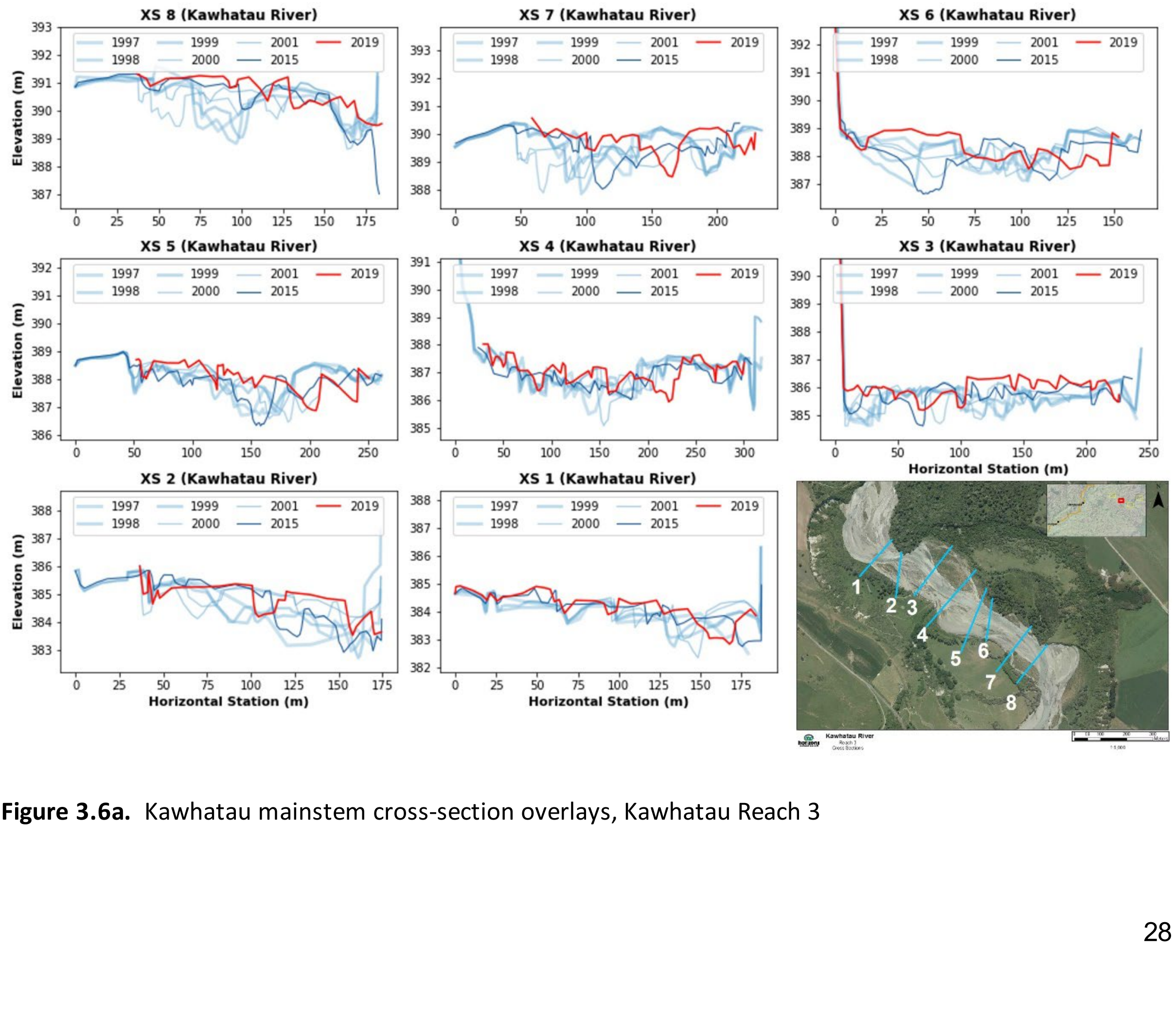


Figure 3.6a. Kawhatau mainstem cross-section overlays, Kawhatau Reach 3

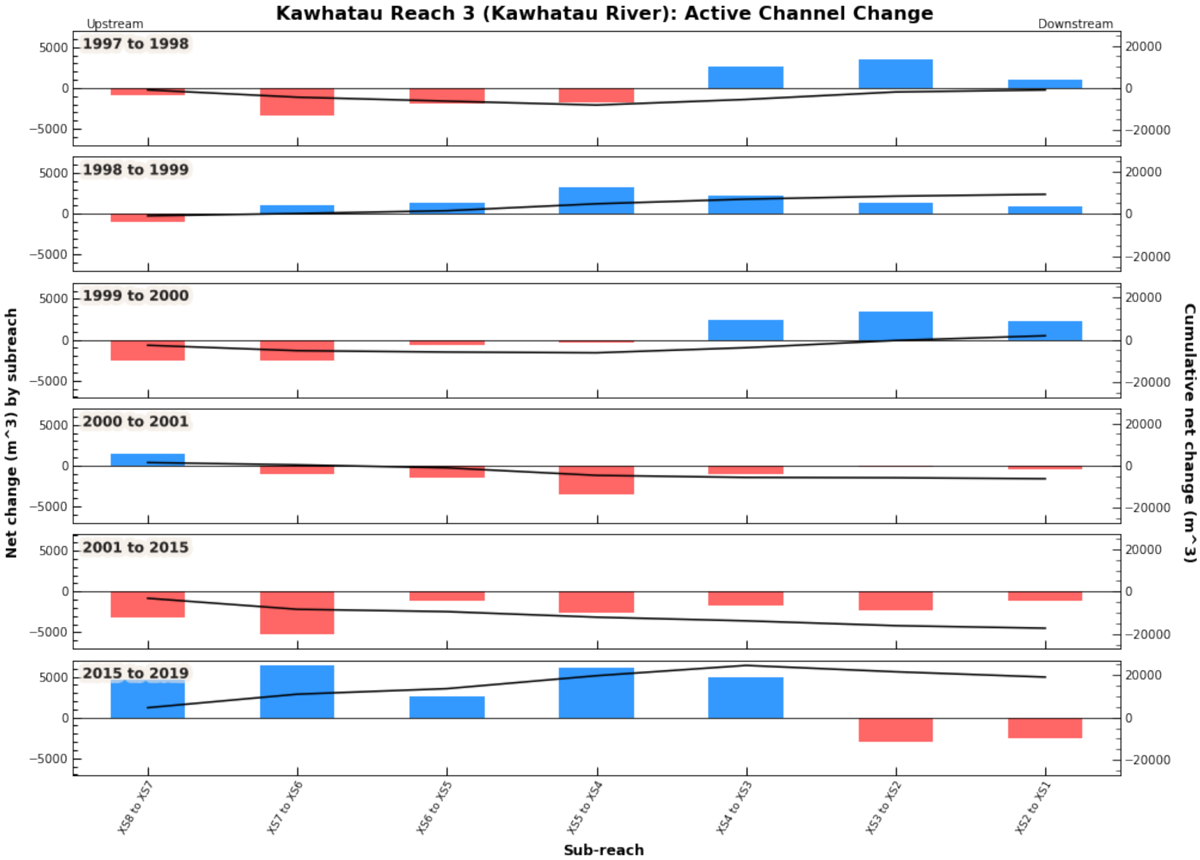


Figure 3.5b. Six epochs (periods) of volumetric change for seven contiguous sub-reaches of Kawhatau River Reach 3.

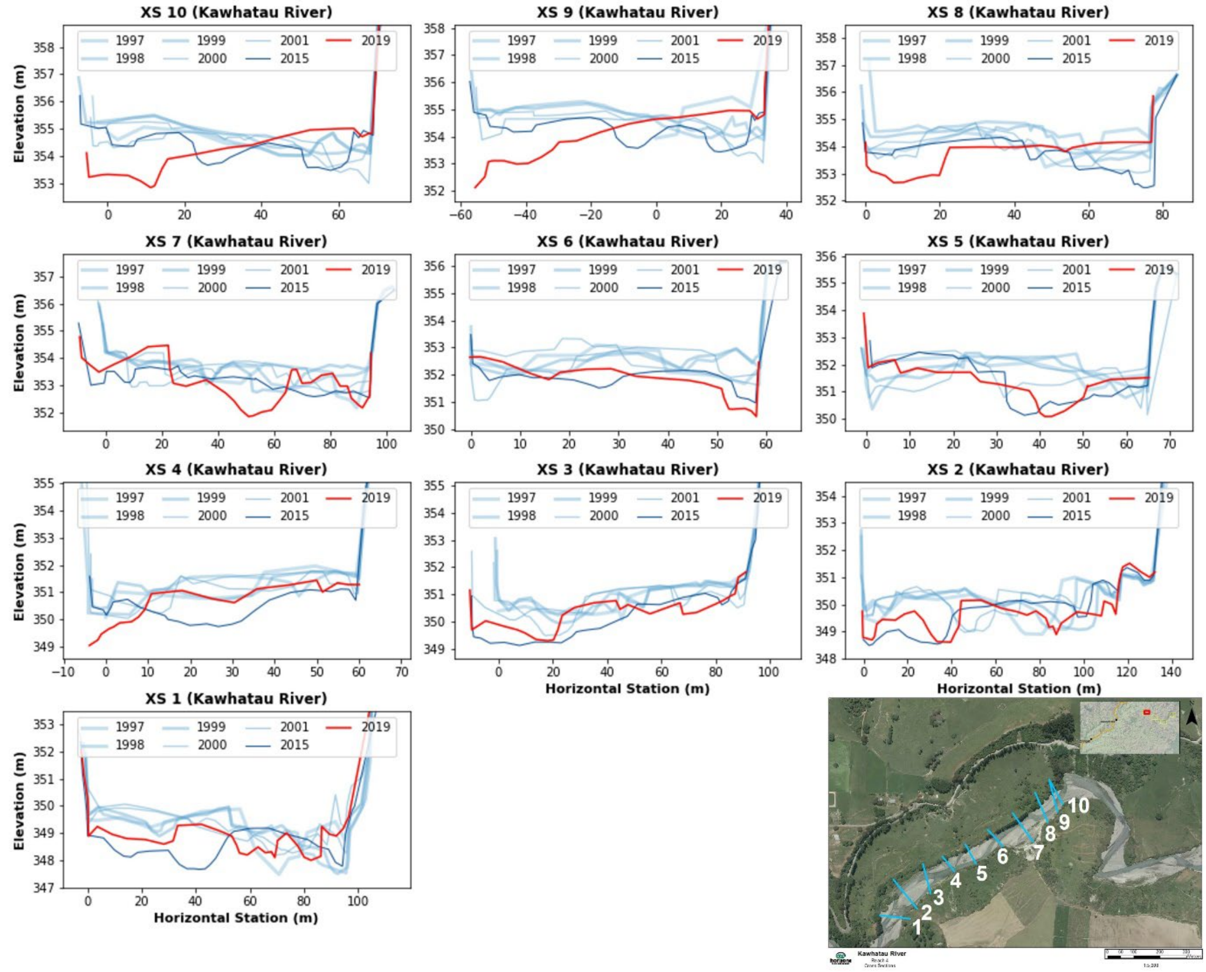


Figure 3.7a Kawhatau mainstem cross-section overlays, Kawhatau Reach 4

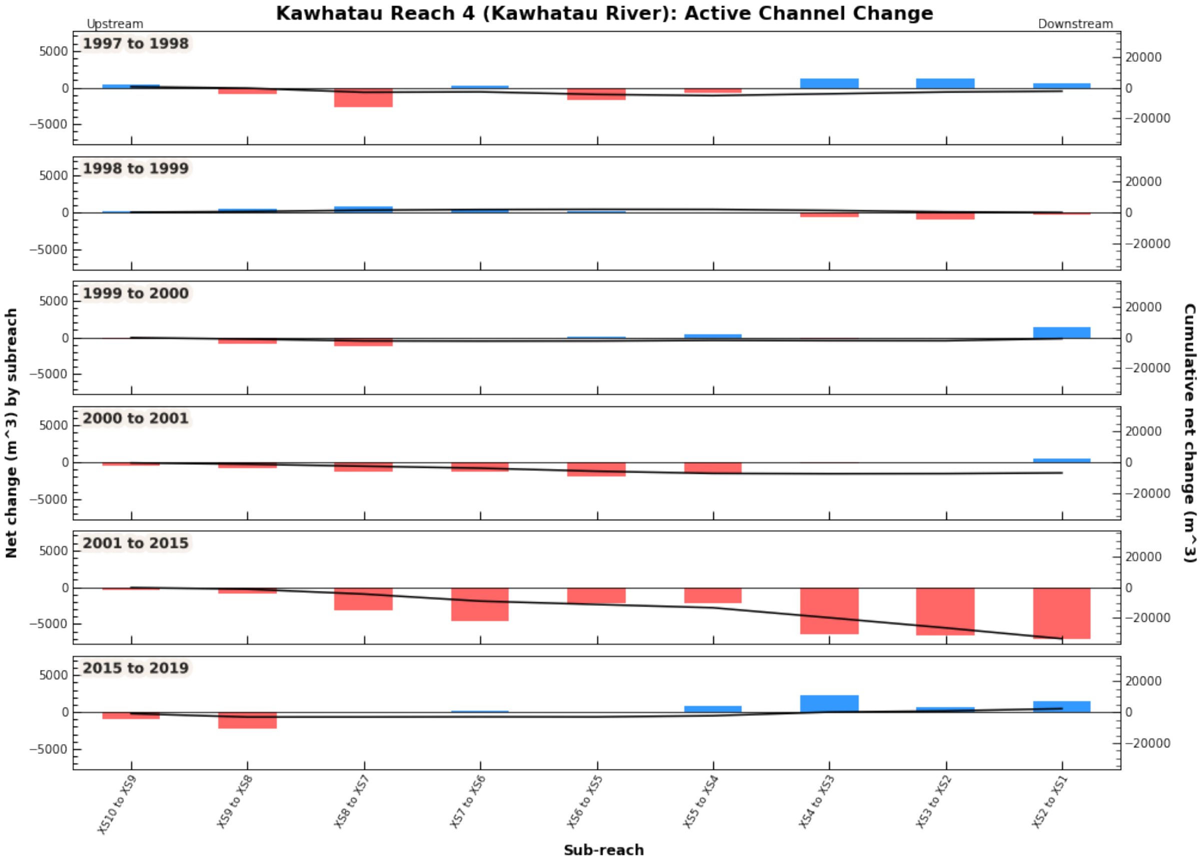


Figure 3.6b Six epochs (periods) of volumetric change for nine contiguous sub-reaches of Kawhatau River Reach 4.

3.1.2 Lower Rangitikei

Cross-sections were overlaid for all dates provided (spanning more than 50 years) for all cross-sections surveyed more than once in the lower 62 km of the Rangitikei (Figures 3.8-3.17). It is impractical to derive a gravel budget from all these cross-sections since there is substantial variability in data collection in space and time. A space-time summary of cross-section surveys (Figure 3.18) was used to select those cross-sections with best spatial and temporal coherence for gravel budget analysis. The changes between epochs for each cross section in the Rangitikei are included in Appendices B and C.

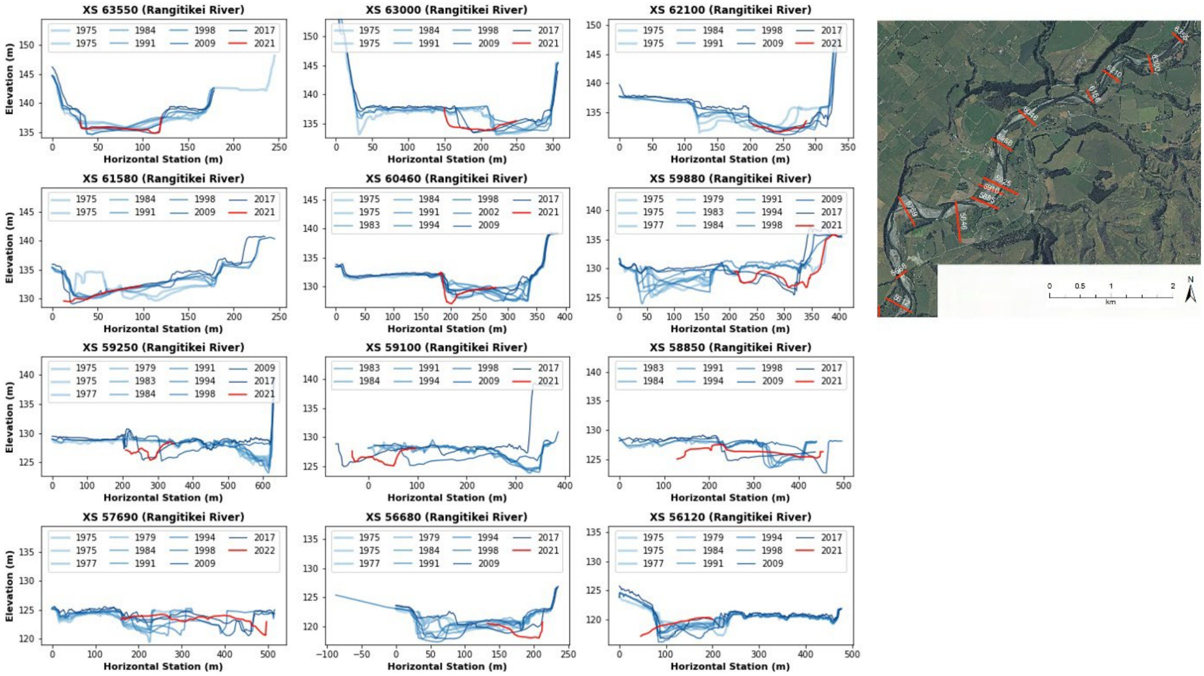


Figure 3.8 Rangitikei cross-section overlays XS63550-56120

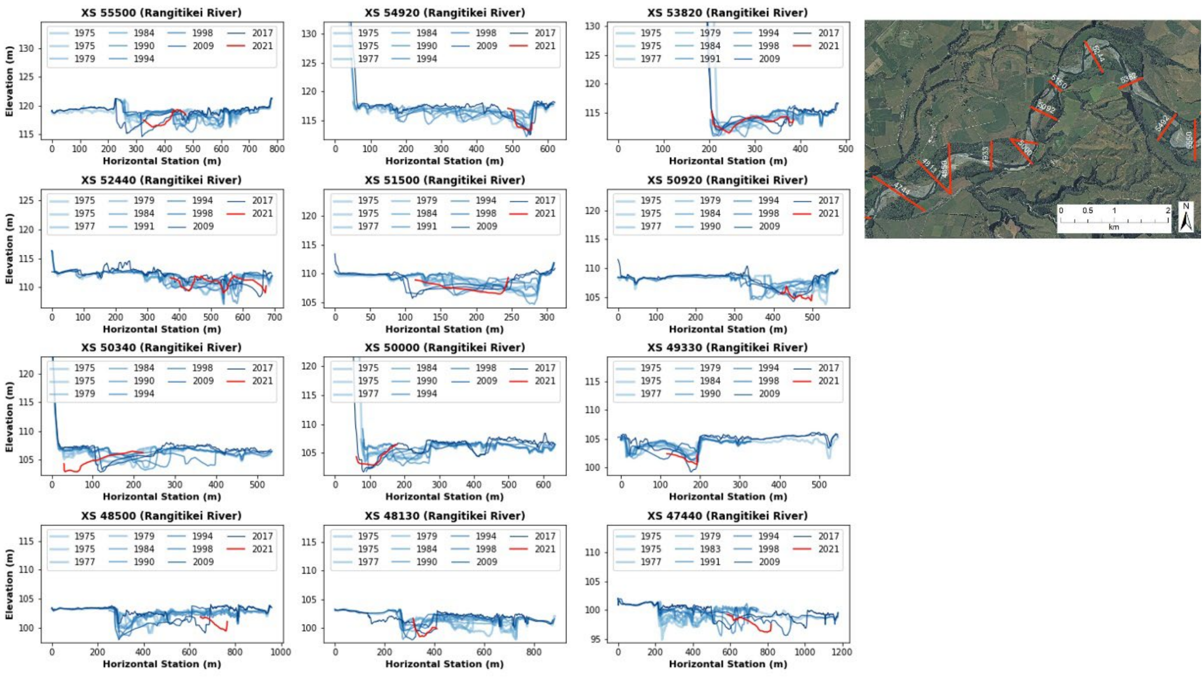


Figure 3.9 Rangitikei cross-section overlays XS55500-47440

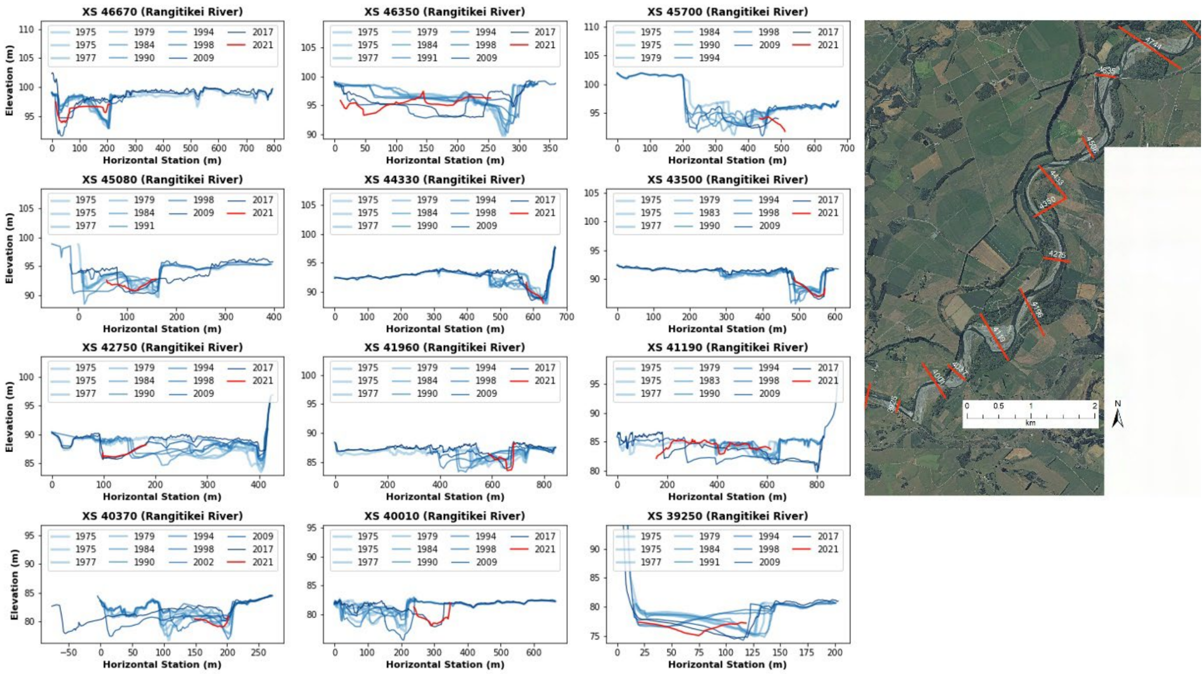


Figure 3.10 Rangitikei cross-section overlays XS46670-39250

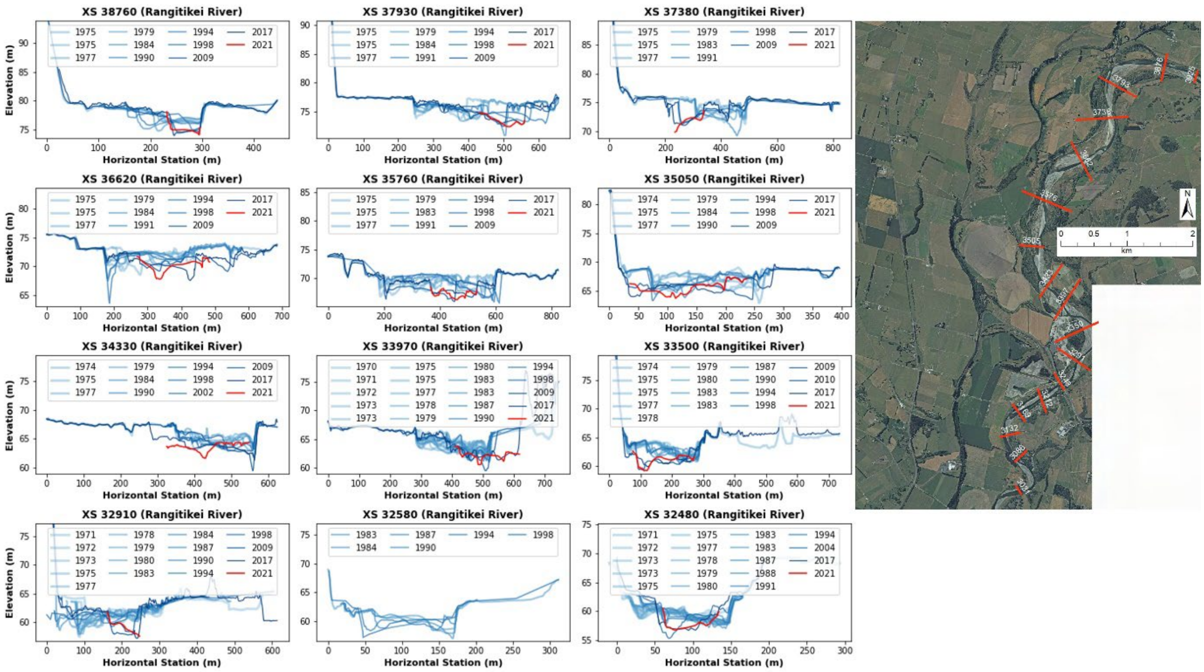


Figure 3.11 Rangitikei cross-section overlays XS38760-32480

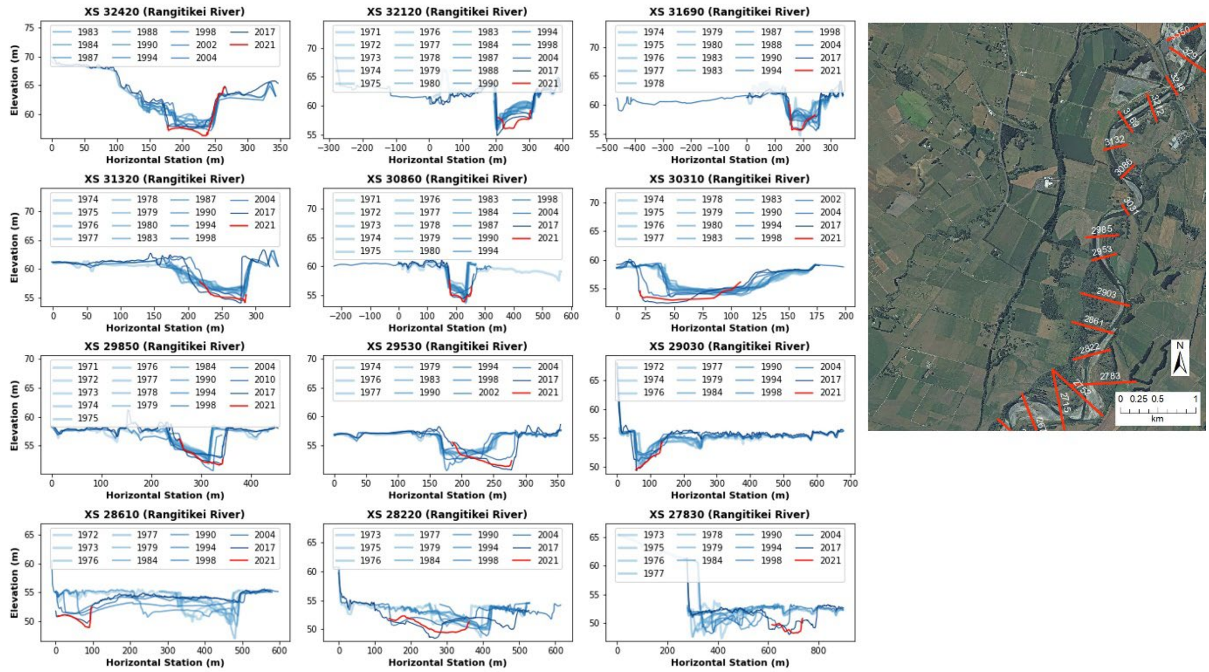


Figure 3.12 Rangitikei cross-section overlays XS32420-27830

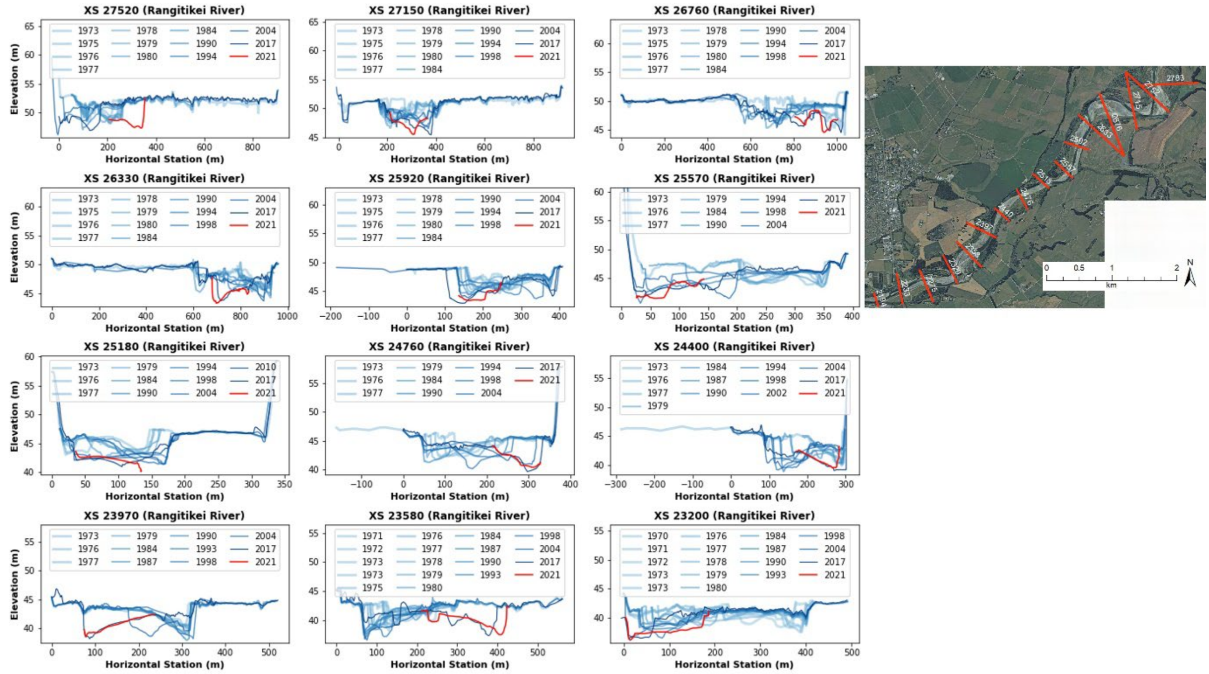


Figure 3.13 Rangitikei cross-section overlays XS27520-23200

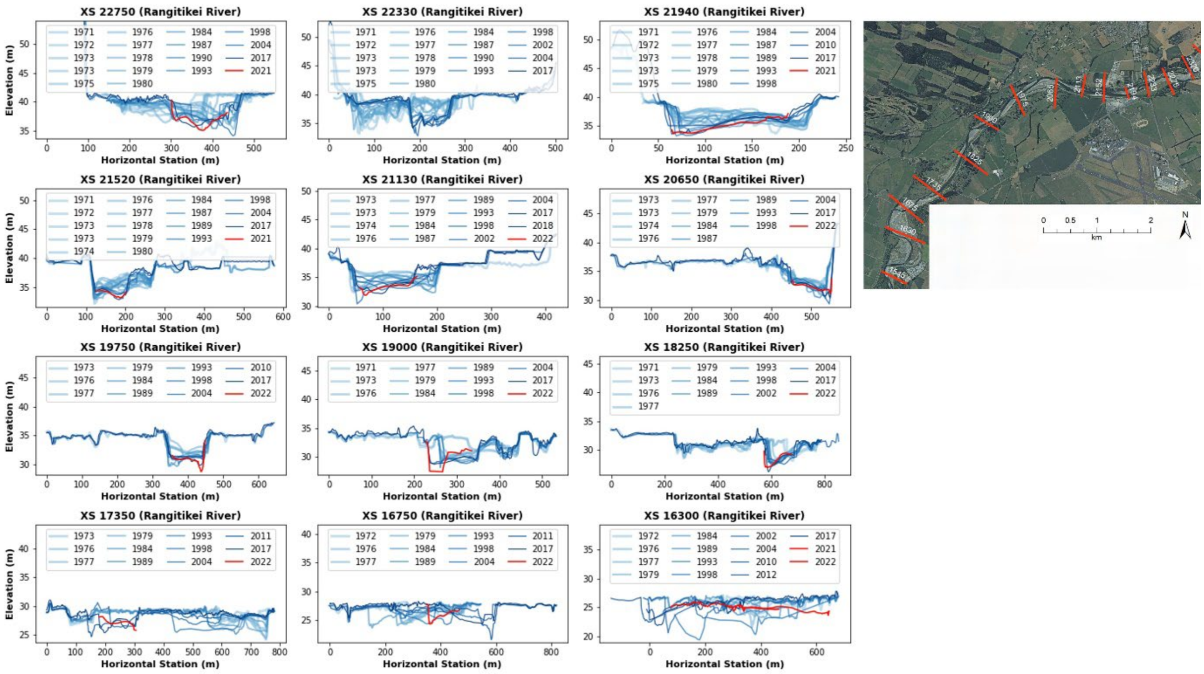


Figure 3.14 Rangitikei cross-section overlays XS22750-16300

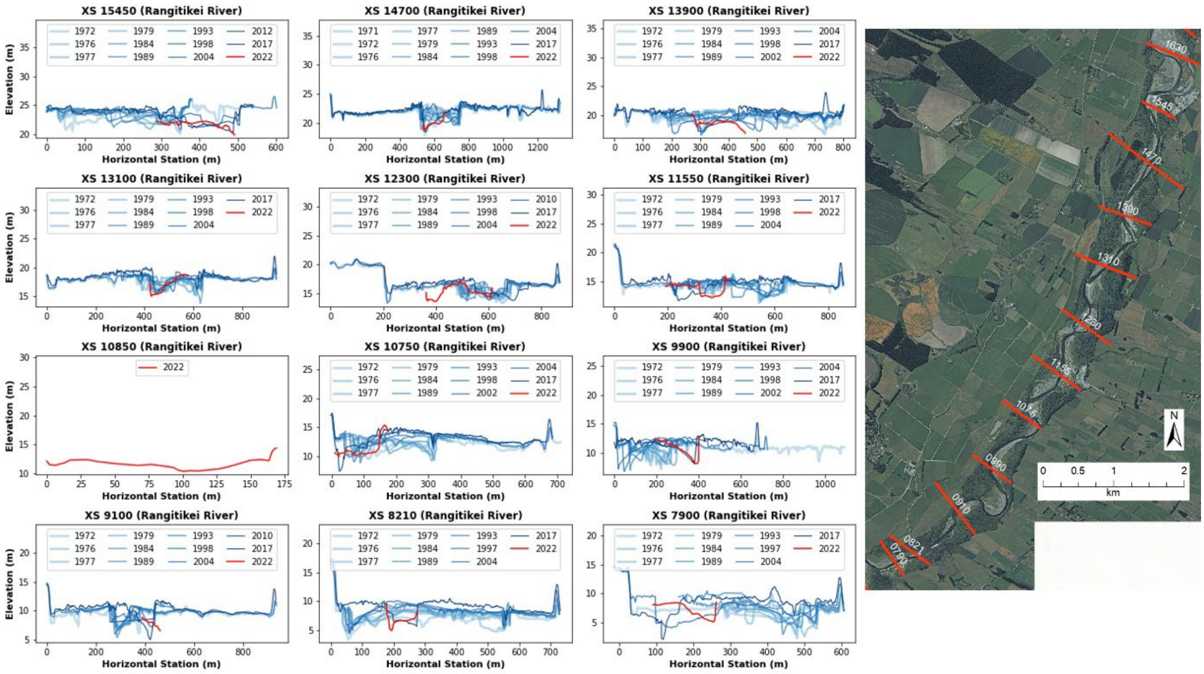


Figure 3.15 Rangitikei cross-section overlays XS15450-7900

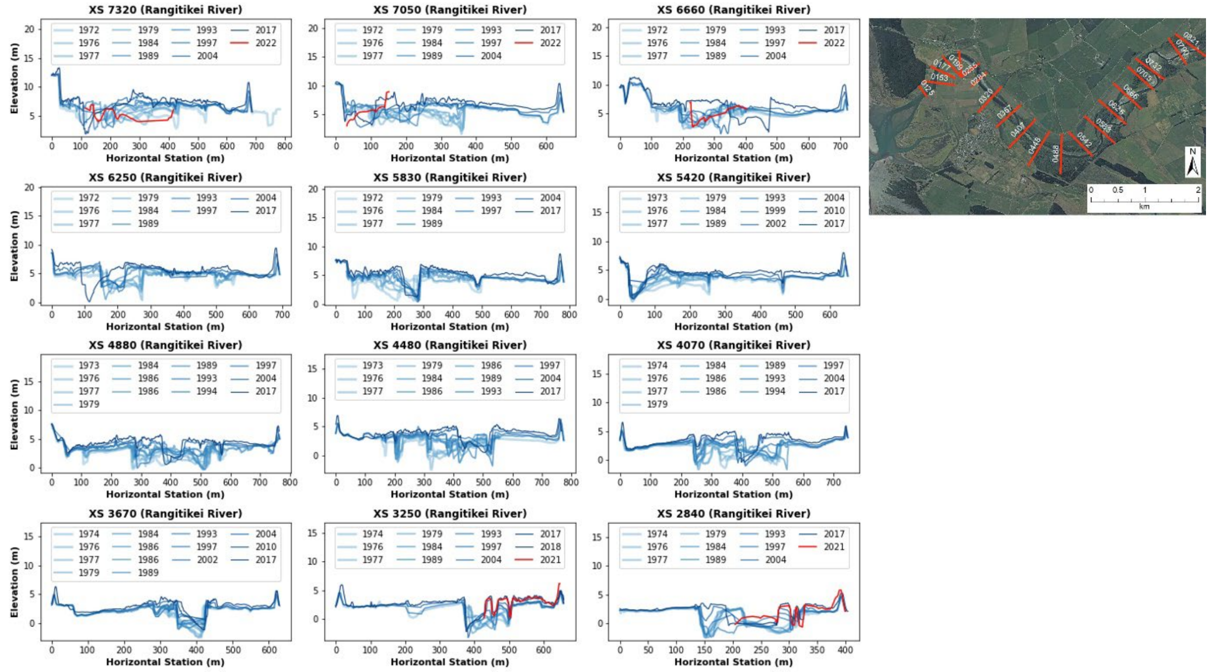


Figure 3.16 Rangitikei cross-section overlays XS7320-2840

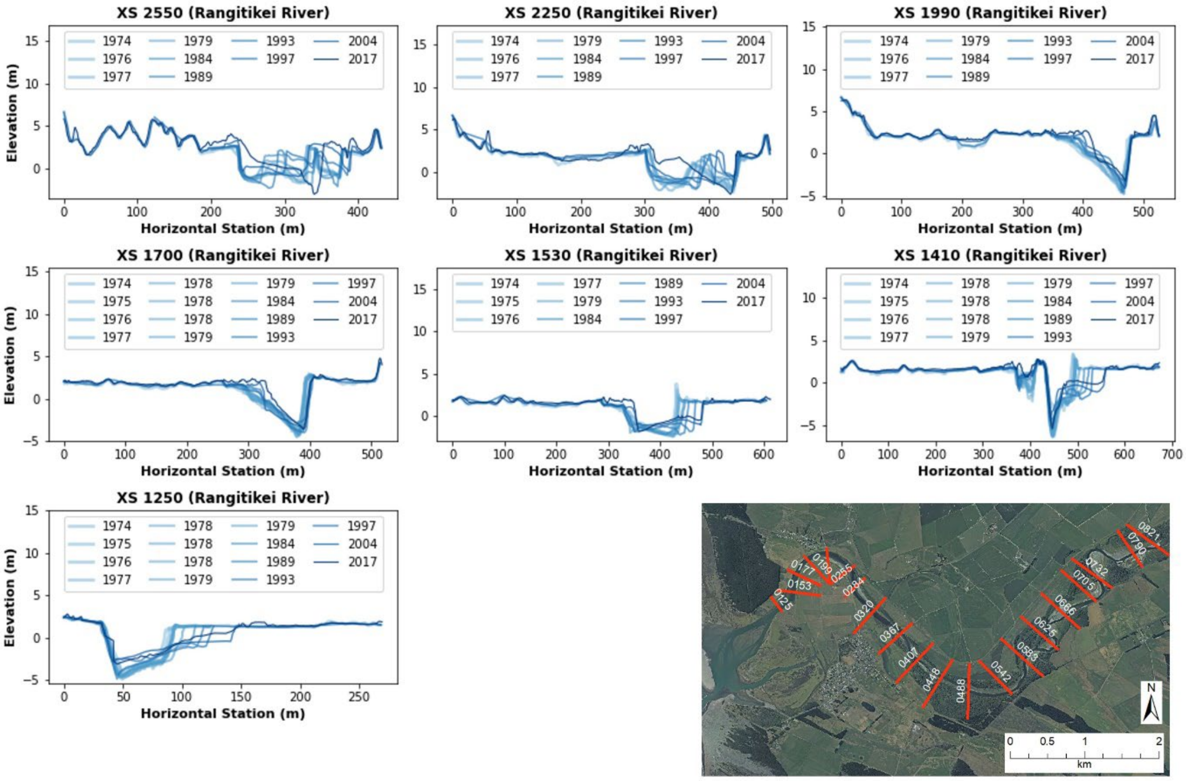


Figure 3.17 Rangitikei cross-section overlays XS2550-1250


surveys by month
0
1
2
XS
Year

Figure 3.18 A heatmap was used for visualising the highly variability space-time distribution of Rangitikei cross-section data and drive selection of surveys to optimise spatiotemporal resolution while ensuring apples-to-apples comparison.

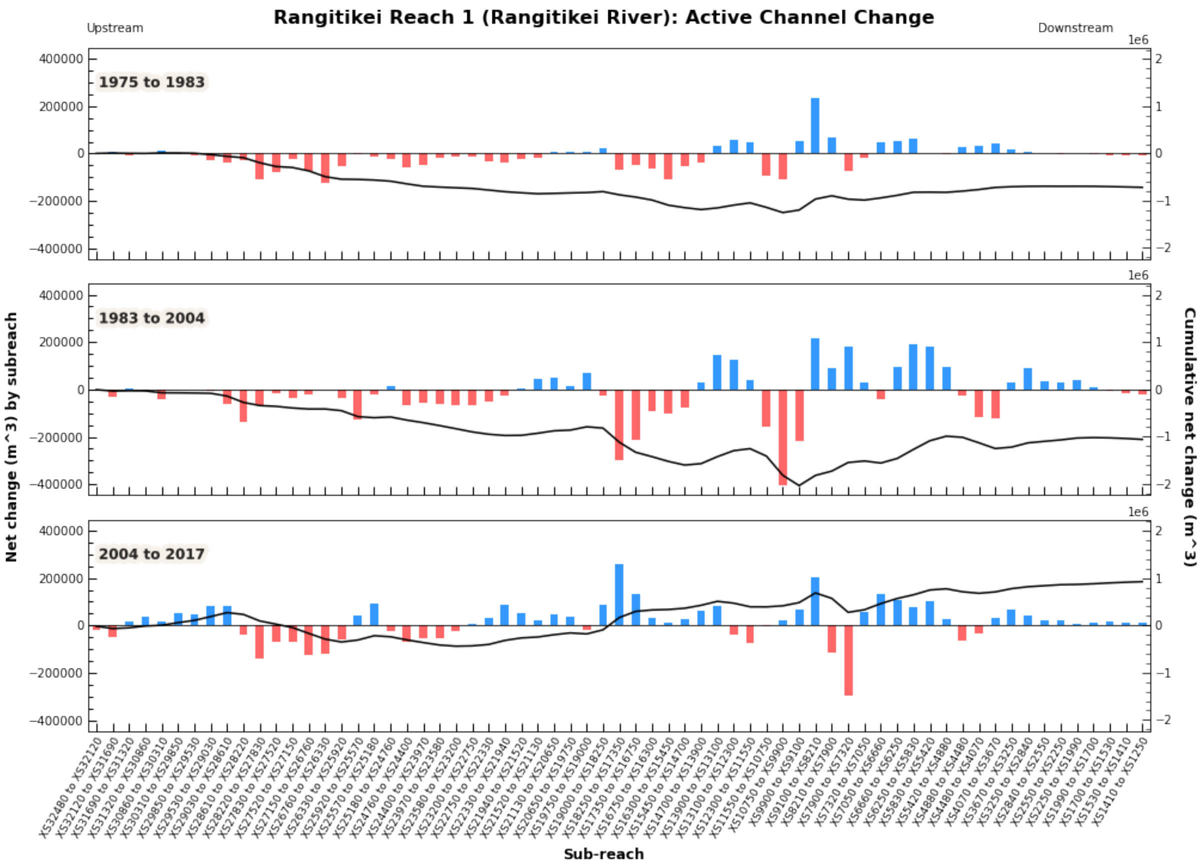


Figure 3.19 Gravel budgets for the lower (river-kms ~1-32) Rangitikei River 1975-1983 (top), 1983-2004 (middle), and 2004-2017 (bottom).

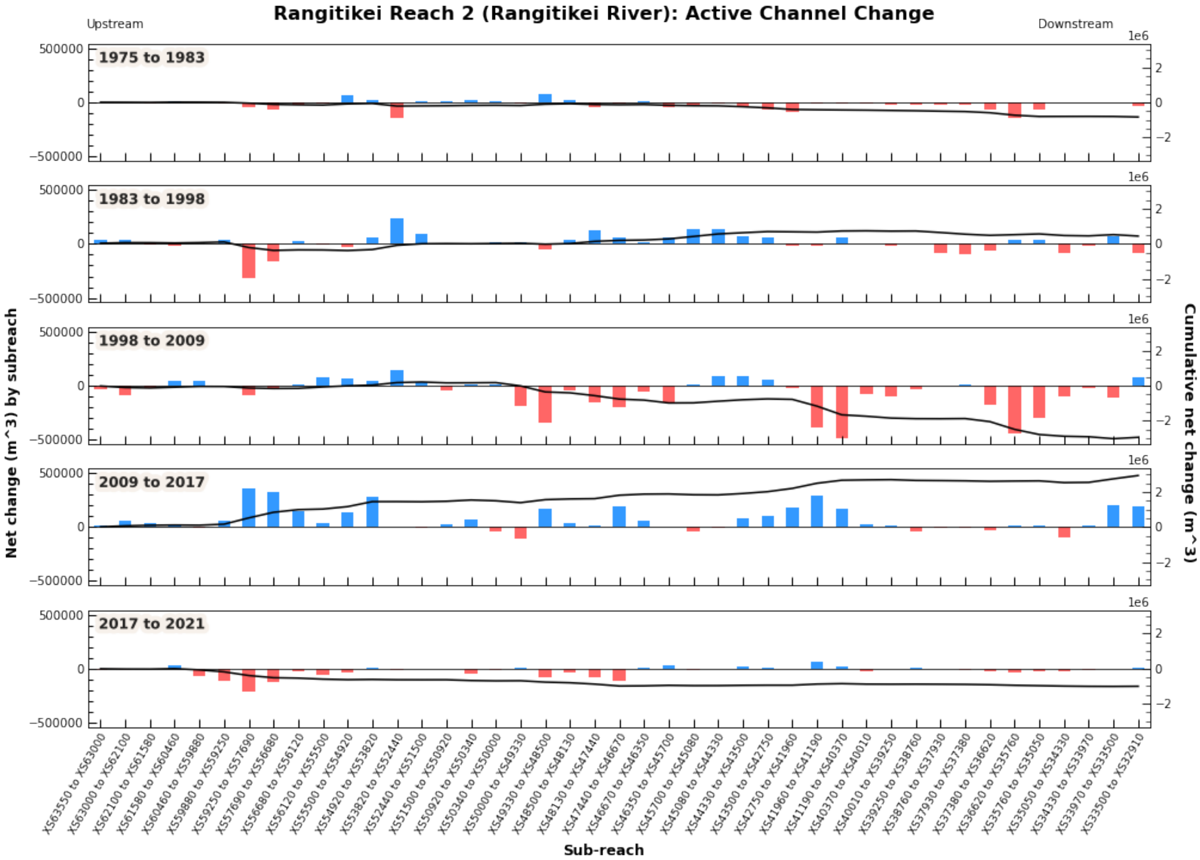


Figure 3.20 Gravel budgets for the upper Rangitikei Reach (river-kms ~63-33) for four epochs (1975-1983, 1983-1998, 1998-2009, 2009-2017).

3.2 LiDAR geomorphic change detection

Change detection utilised DEMs supplied by Horizons Regional Council for 2017 and 2021 in the lower Rangitikei (not available in upper Rangitikei or Kawhatau). The 2017 DEM was adjusted because the vertical datum used is Wellington 1953, while the 2021 DEM used NZVD2016. The stated offset between these datums is 402 mm in Palmerston North (Steffert, pers. comm., January 2023). A series of check points was used to assess the mean elevation difference between stable points in the Rangitikei river corridor, which revealed an offset of 420 mm, so this figure was used to correct the 2017 DEM by subtracting this difference uniformly across the raster dataset in ArcMap, effectively bringing the 2017 surface down to the level of the 2021 DEM.

Conventional LiDAR does not reliably or consistently penetrate the water column. To ensure consistency in analysis the wetted portions of the active channel in the lower Rangitikei were clipped out from the DEM surface used in GCD analysis. This means GCD is from dry surface to dry surface only. Inevitably this action cuts out a potentially significant portion of the gravel budget because subaqueous changes are not considered. This means erosional changes associated with shift in the 2021 wetted channel and deposition infilling the 2017 wetted channel are not identified, because they cannot be reliably detected. As such GCD using these clipped DEMs represents a conservative estimation of change in gravel storage in the lower Rangitikei.

The vertical accuracy of LiDAR data points is given as 0.15 m (supplied). Change detection was thresholded using a uniform value of 0.2 m, which means that elevation changes less than 0.2 m are excluded from analysis. Unthresholded volumes risk including spurious changes that result from inaccuracies in the surfaces being compared. A threshold of 0.2 m provides a conservative estimation of volumes and change detection.

A 'whole of reach' morphological budget based on GCD analysis between 2017 and 2021 is provided in Table 3.1. Morphological changes associated with this budget are presented in Figures 3.21 to 3.33 which present the DEMs of difference (DoDs) used in the GCD analysis, which visualise the areas of erosion (red) and deposition (blue). Channel cross-section locations are overlaid on these DoDs, providing a means of both spatial reference and comparison with the cross-section budget (3.1). A segmented morphological budget for each cross-section sub-reach is given in Figure 3.34.

Table 3.1 Whole of reach volumetric analysis, lower Rangitikei, 2017 to 2021

Attribute	Raw	Thresholded DoD Estimate:			
AREAL:					
Total Area of Surface Lowering (m²)	2,450,327	1,841,205			
Total Area of Surface Raising (m²)	3,916,877	2,971,381			
Total Area of Detectable Change (m²)	NA	4,812,586			
Total Area of Interest (m²)	6,367,204	NA			
Percent of Area of Interest with Detectable Change	NA	76%			
VOLUMETRIC:				± Error Volume	% Error
Total Volume of Surface Lowering (m³)	2,387,056	2,332,320	±	368,241	16%
Total Volume of Surface Raising (m³)	2,185,750	2,090,010	±	594,276	28%
Total Volume of Difference (m³)	4,572,806	4,422,331	±	962,517	22%
Total **Net** Volume Difference (m³)	-201,306	**-242,310**	±	**699,118**	-289%
VERTICAL AVERAGES:				± Error Thickness	% Error
Average Depth of Surface Lowering (m)	0.97	1.27	±	0.20	16%
Average Depth of Surface Raising (m)	0.56	0.70	±	0.20	28%
Average Total Thickness of Difference (m) for Area of Interest	0.72	0.69	±	0.15	22%
Average **Net** Thickness Difference (m) for Area of Interest	-0.03	**-0.04**	±	**0.11**	-289%
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	0.92	±	0.20	22%
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**-0.05**	±	**0.15**	-289%
PERCENTAGES (BY VOLUME)					
Percent Elevation Lowering	52%	53%			
Percent Surface Raising	48%	47%			
Percent Imbalance (departure from equilibrium)	-2%	-3%			
Net to Total Volume Ratio	-4%	-5%			

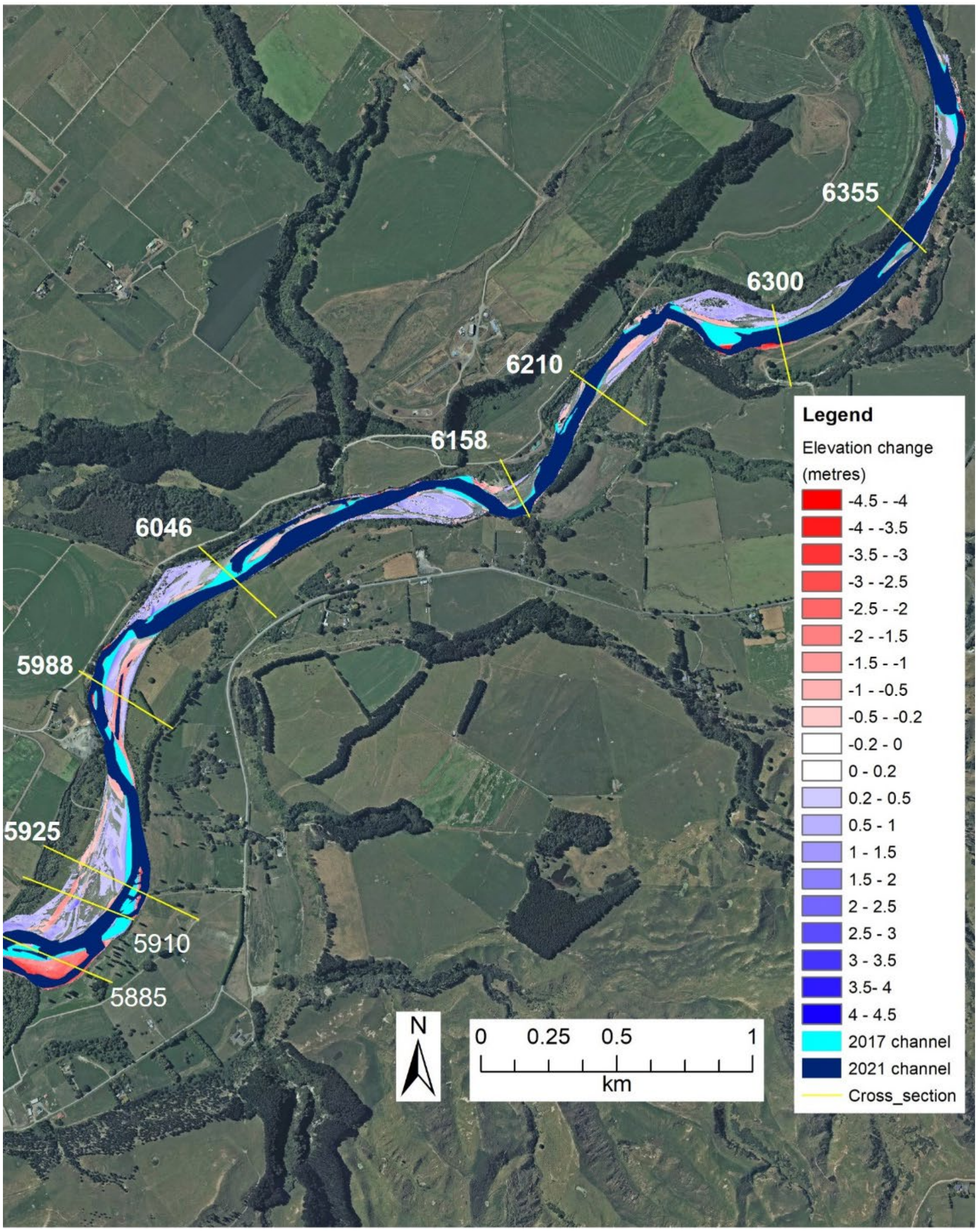


Figure 3.21 DoD xs6355-5910

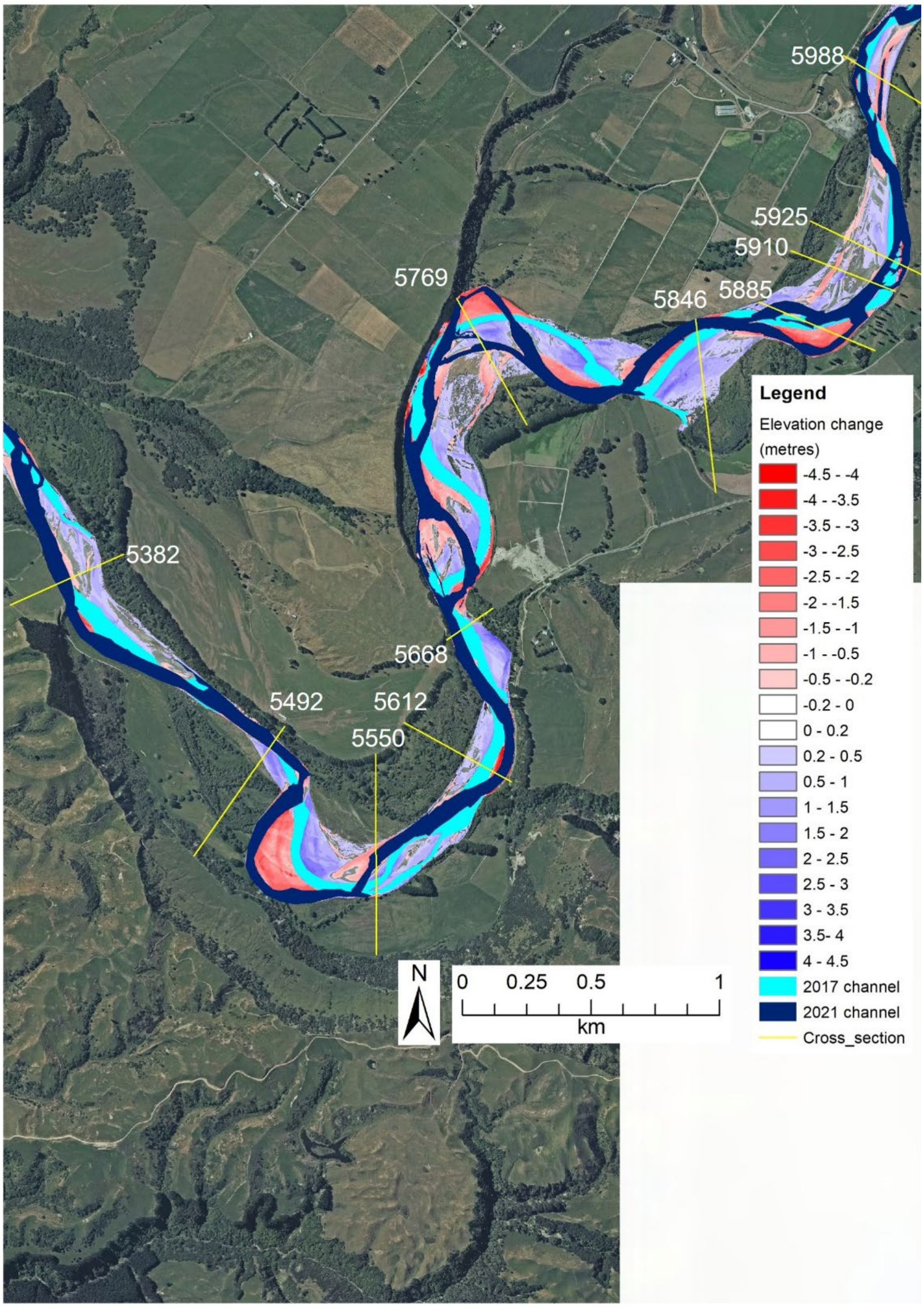


Figure 3.22 DoD xs5910-5382

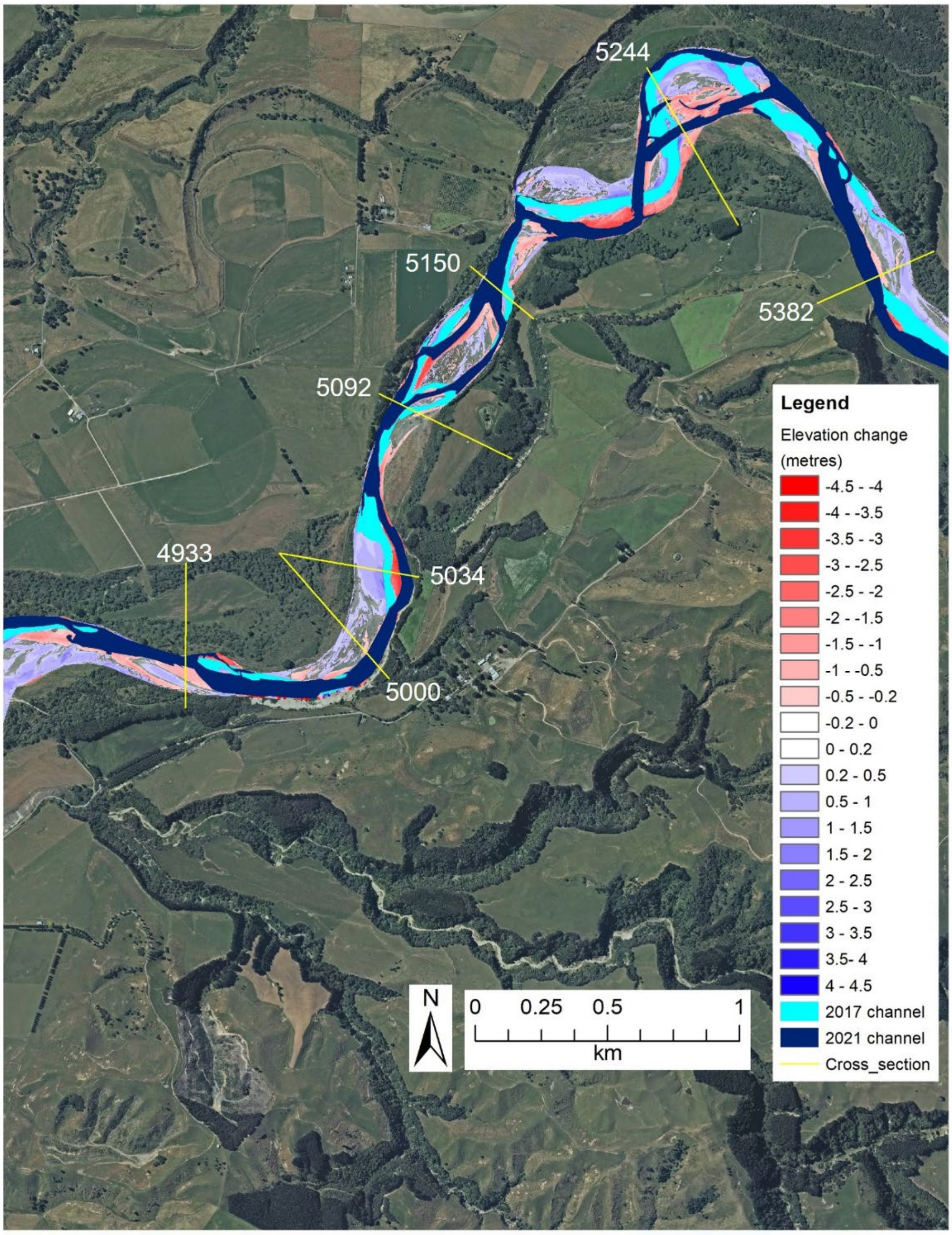


Figure 3.23 DoD xs5382-4933

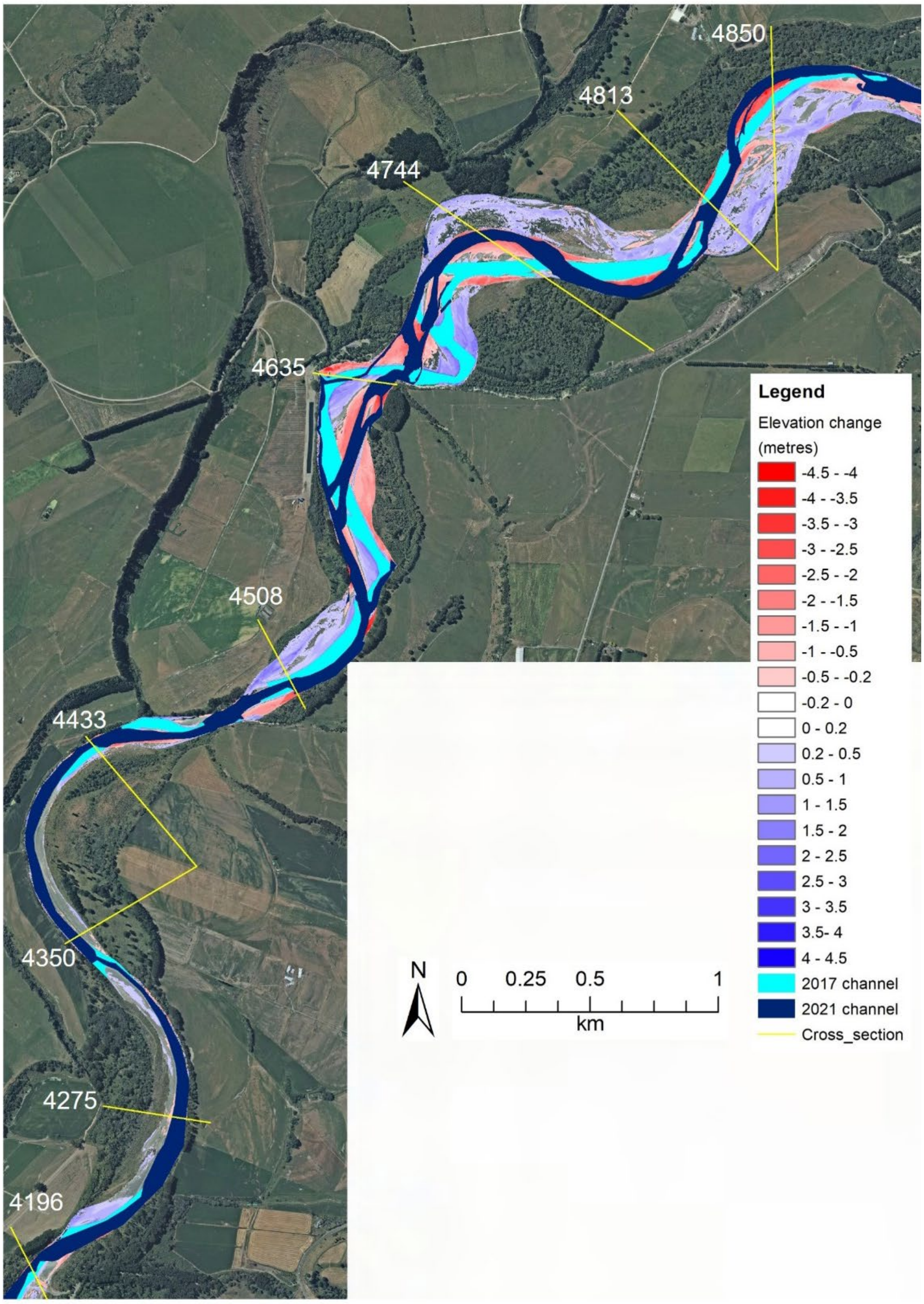


Figure 3.24 DoD xs4850-4196 (NB xs4933 is just cut from this image, but the overlay with the previous Figure is still provided)

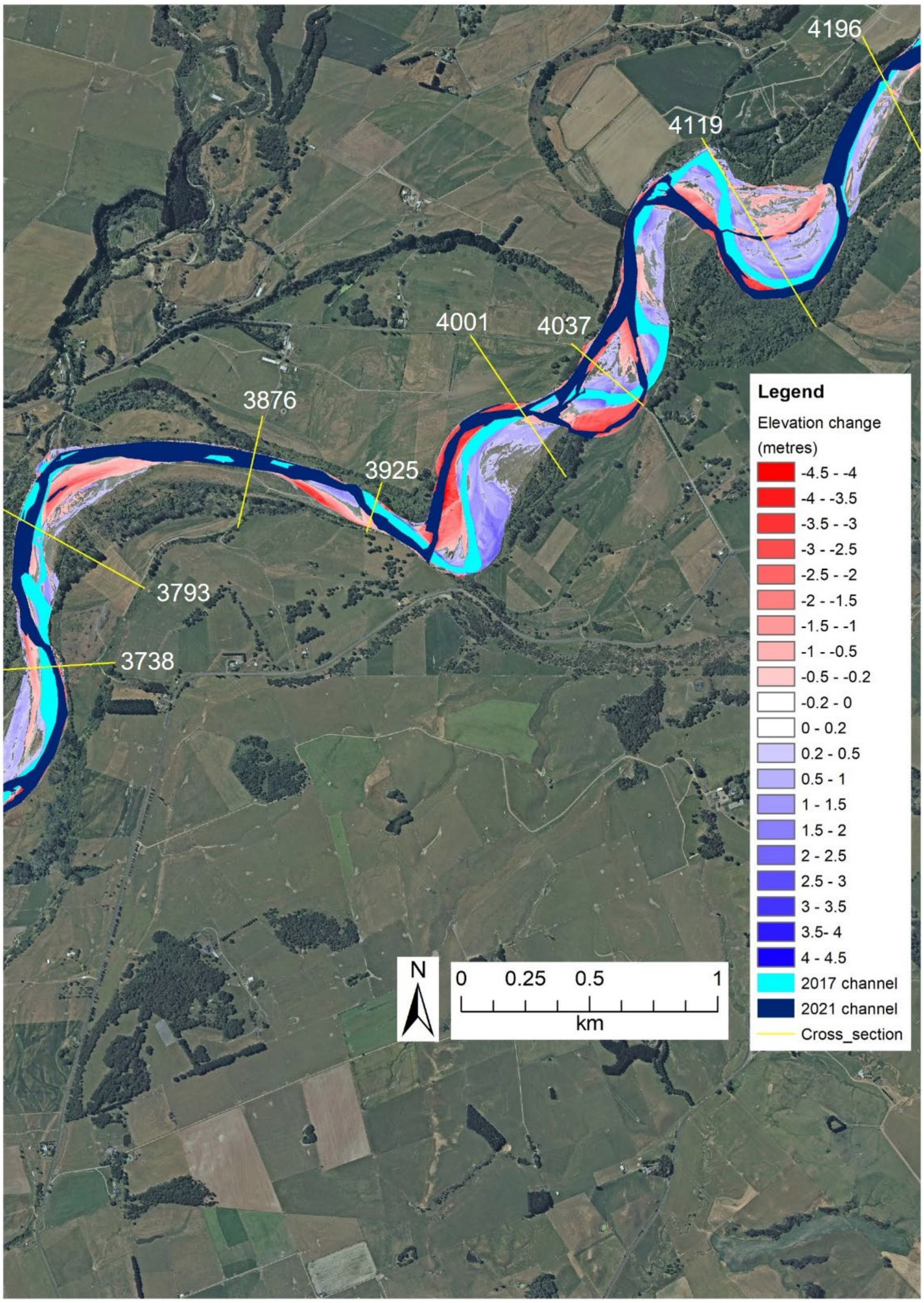


Figure 3.25 DoD xs4196-3738

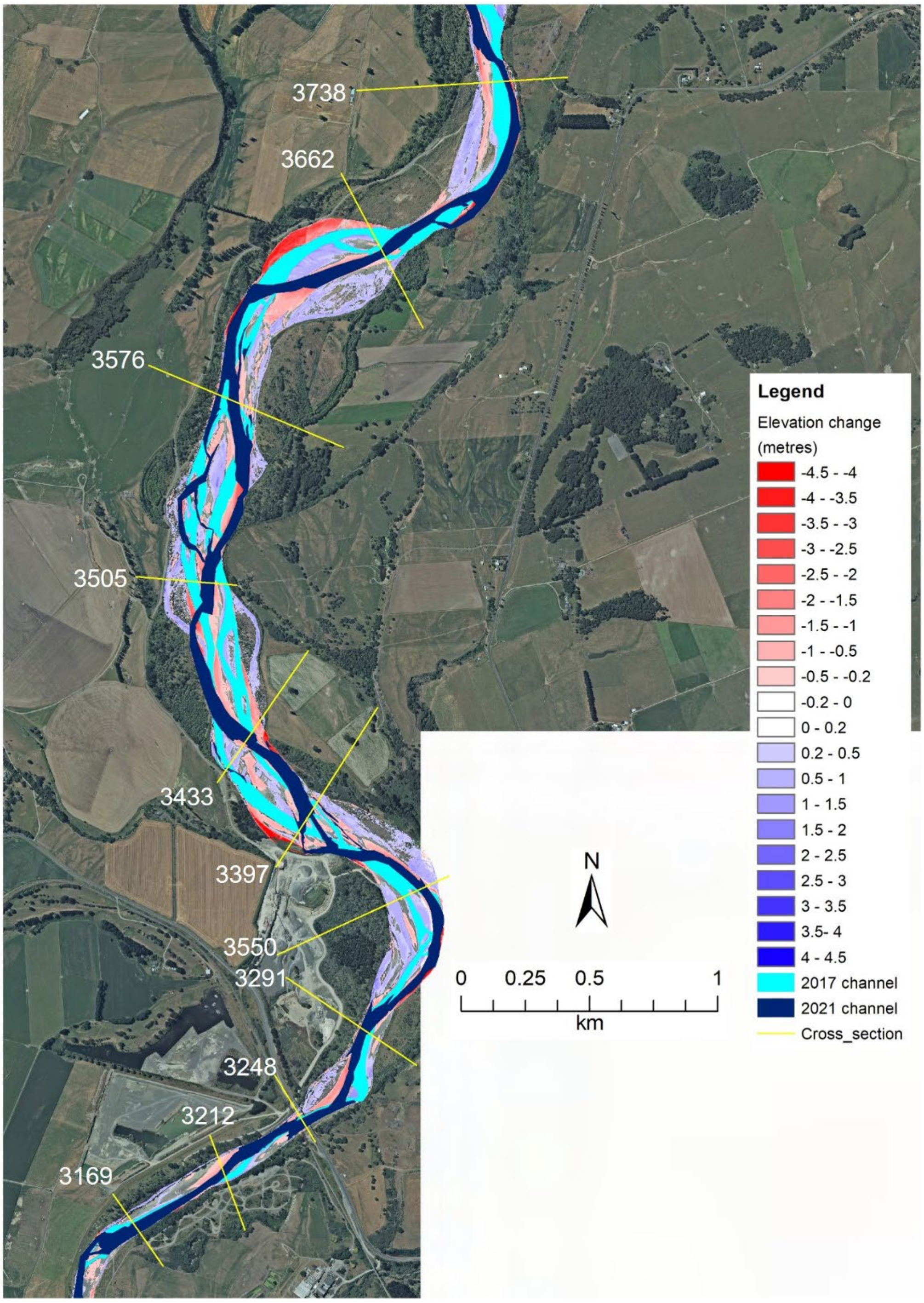


Figure 3.26 DoD xs3738-3169

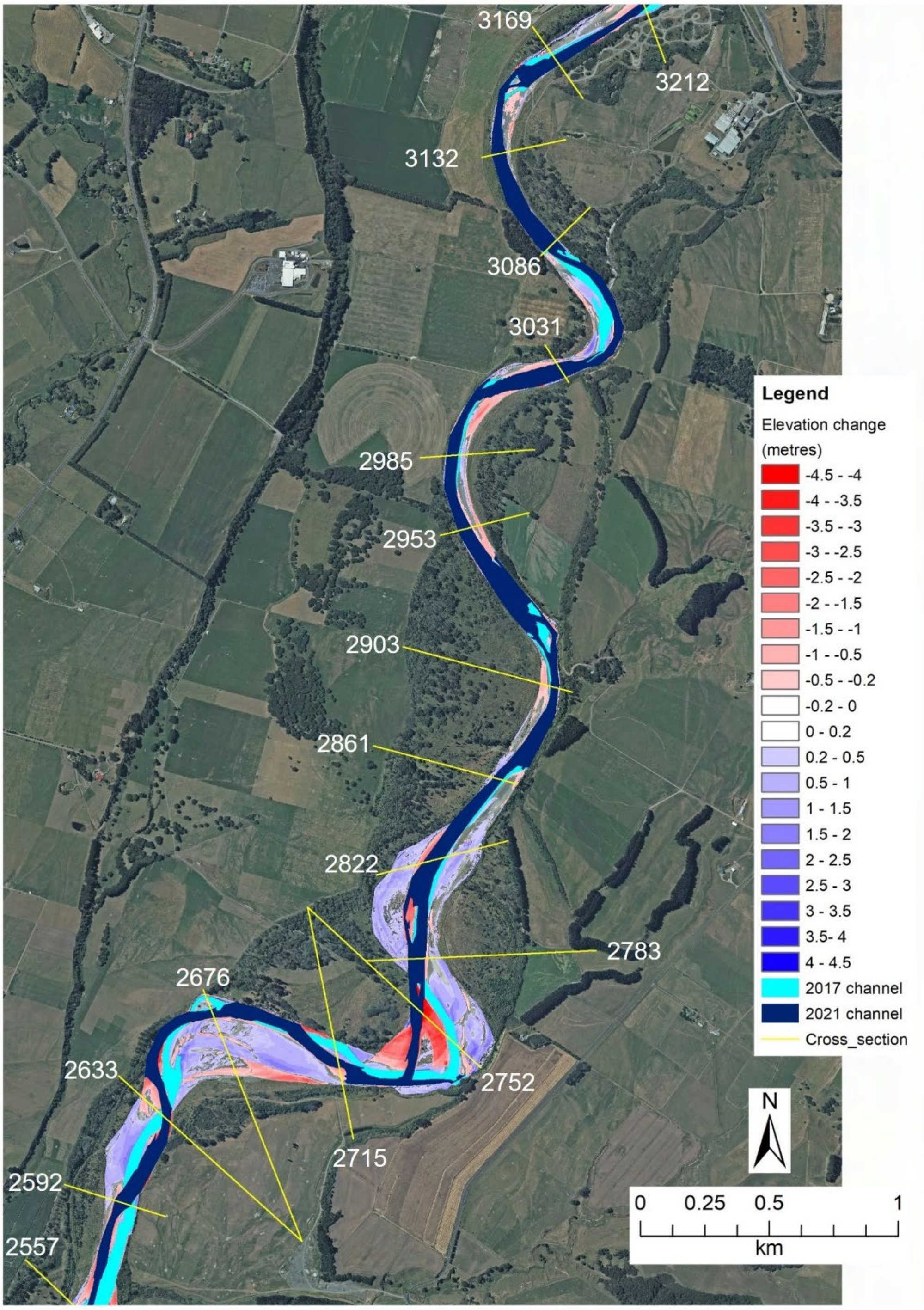


Figure 3.27 DoD xs3169-2592

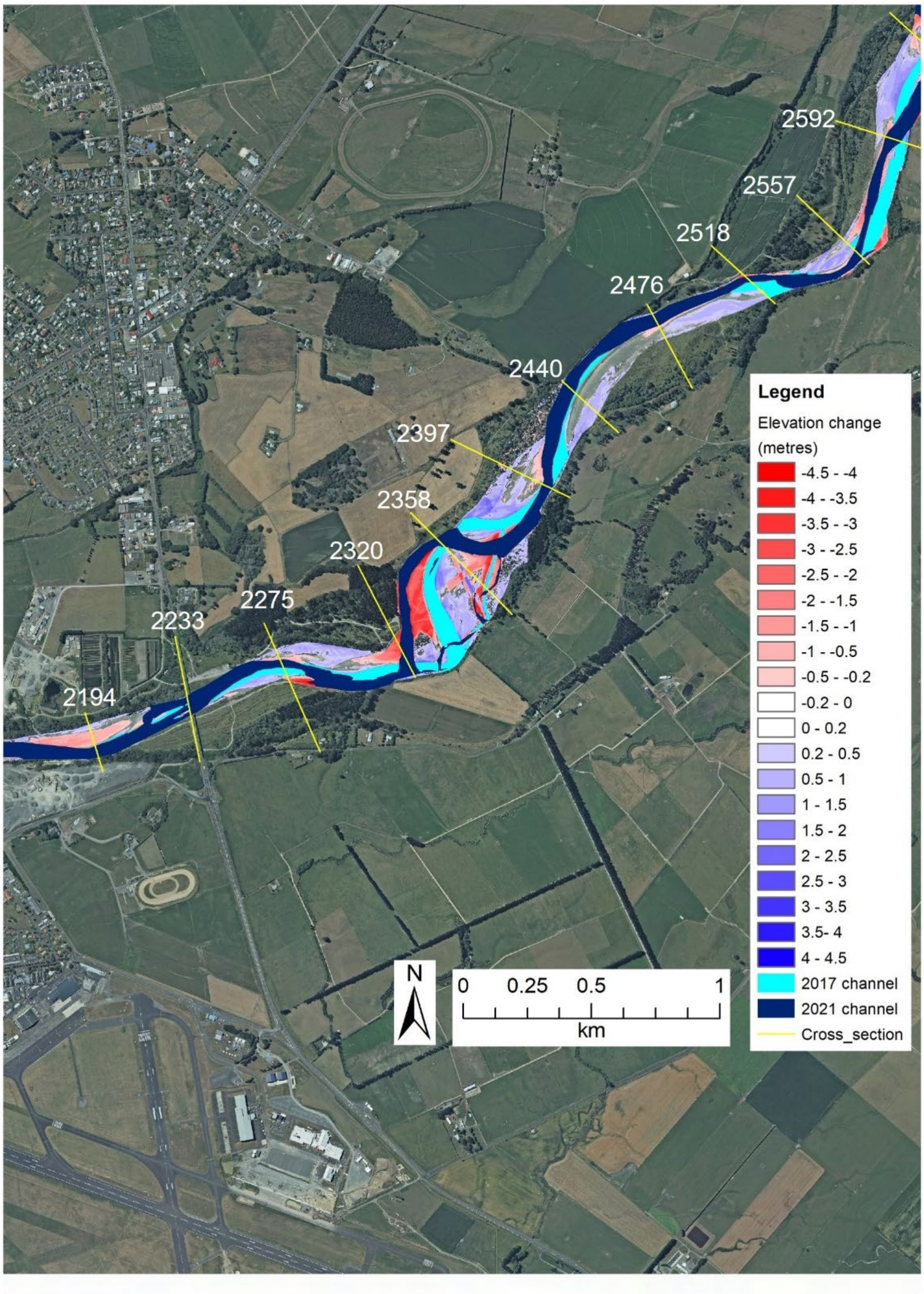
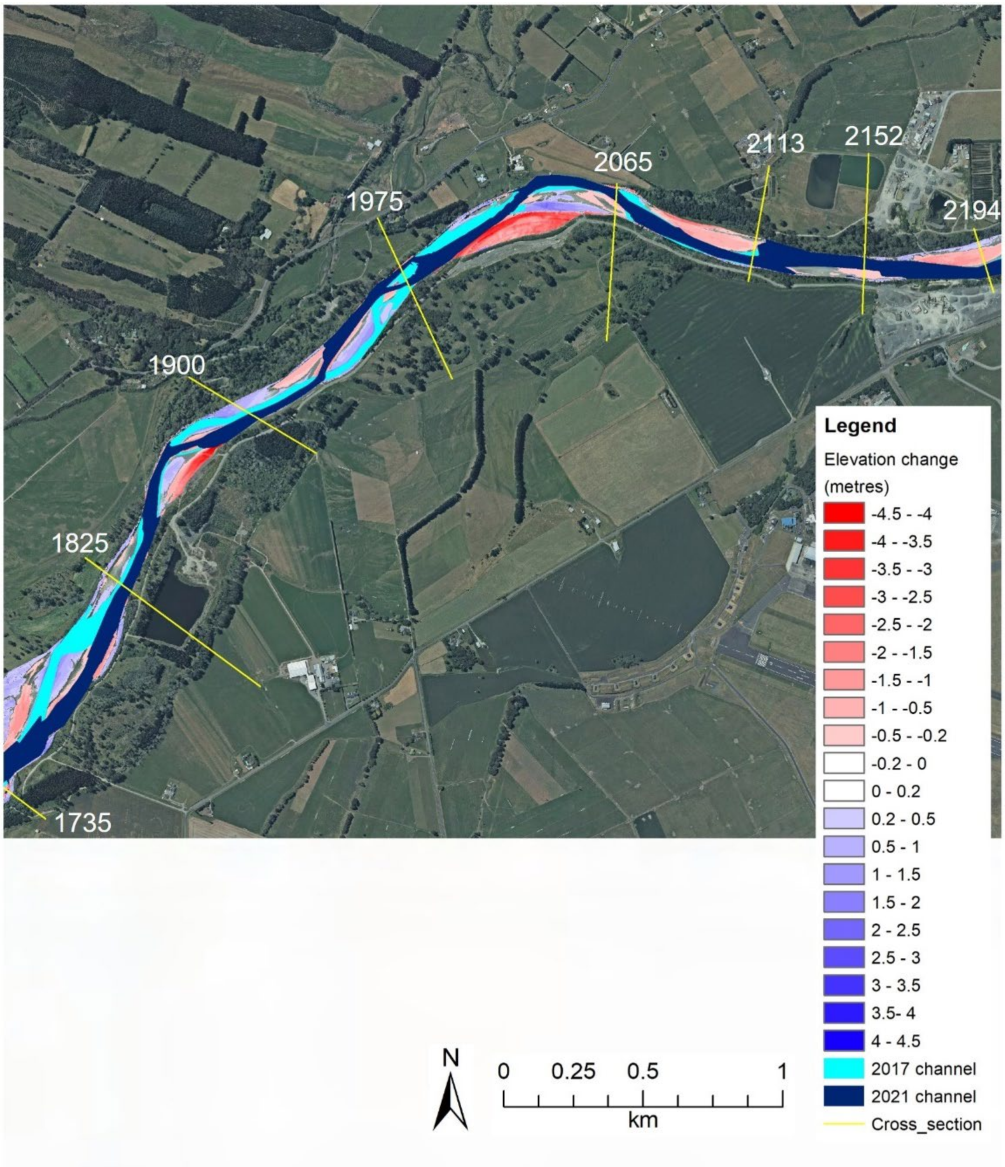


Figure 3.28 DoD xs2592-2194



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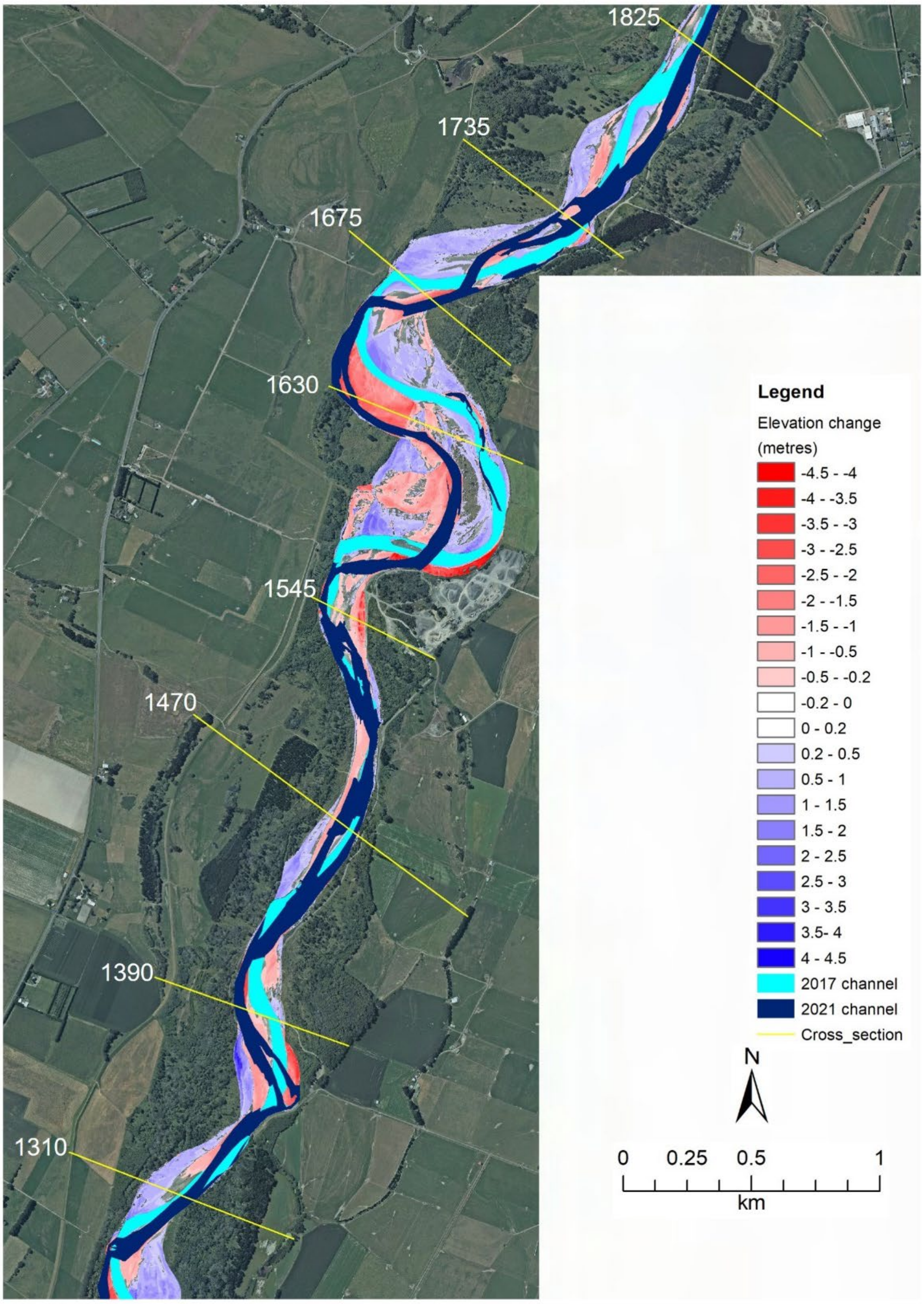

Figure 3.30 DoD xs1825-1310

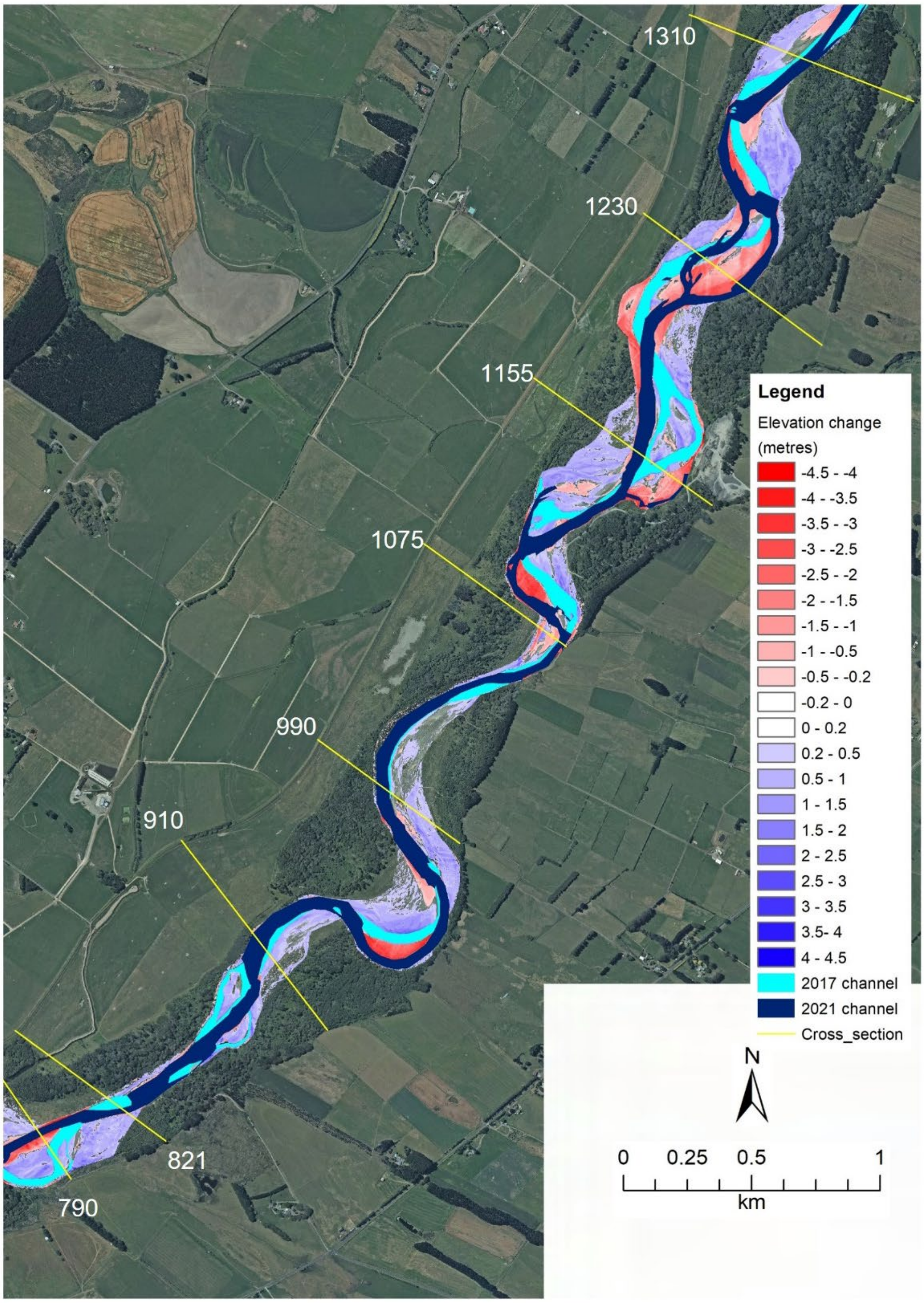

Figure 3.31 DoD xs1310-821

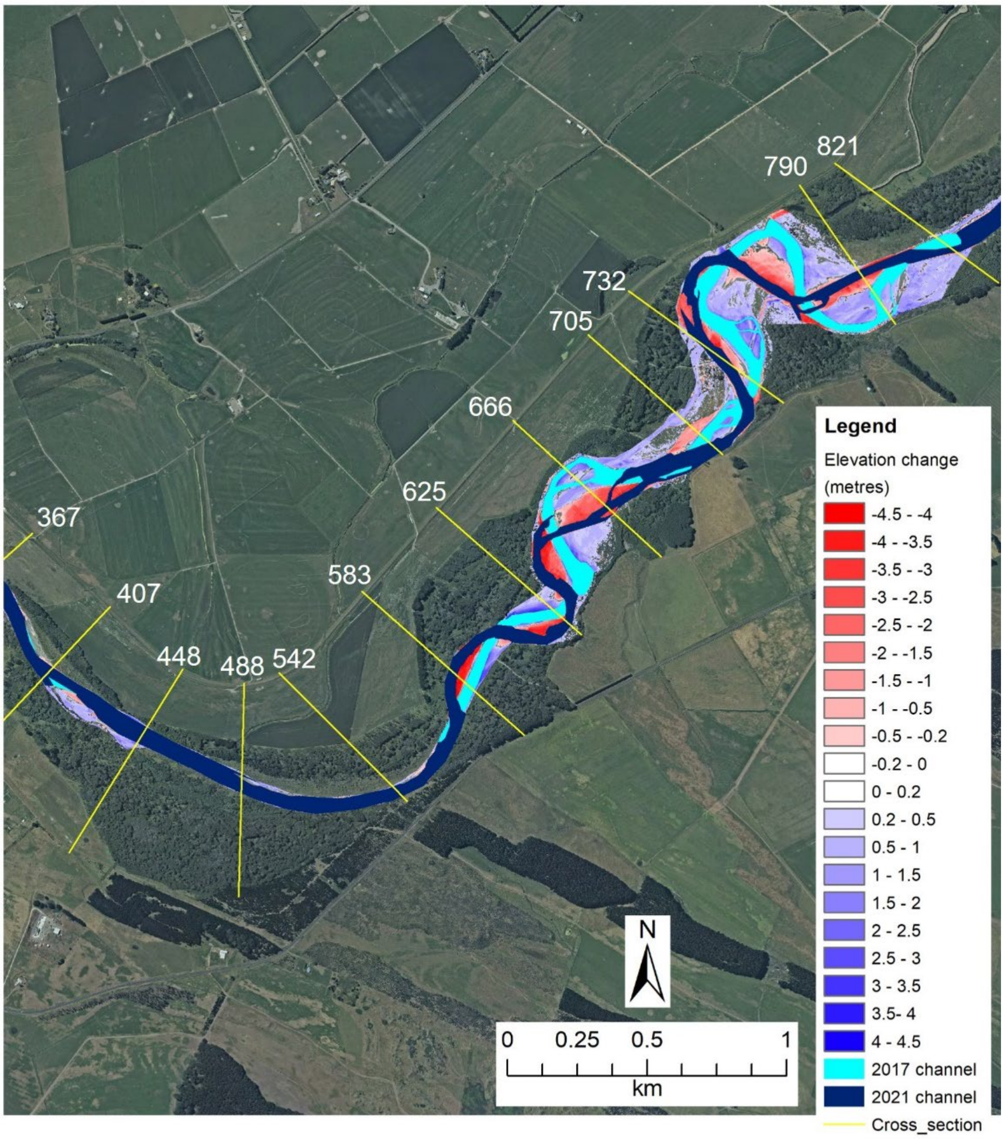

Figure 3.32 DoD xs821-407

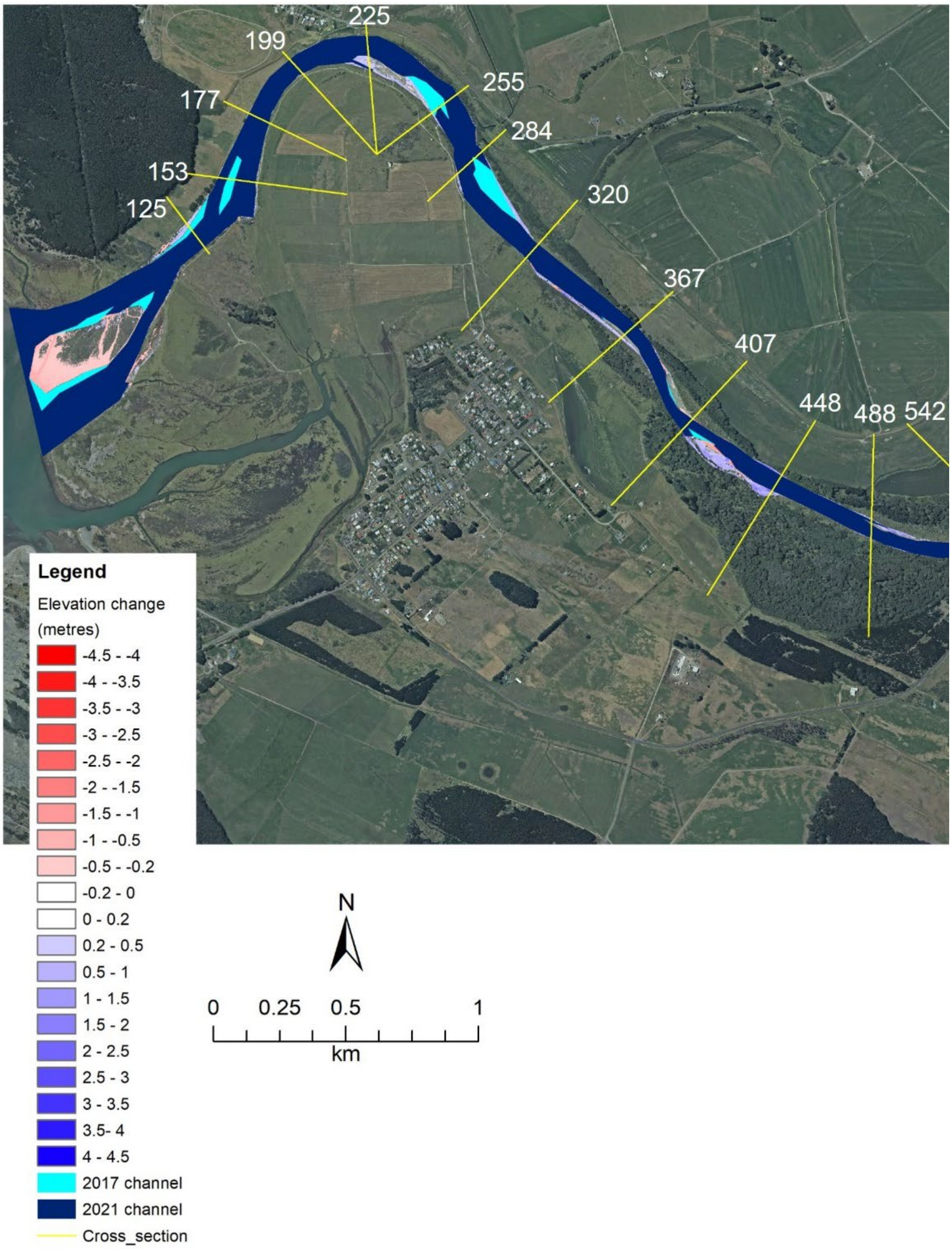

Figure 3.33 DoD xs407-125

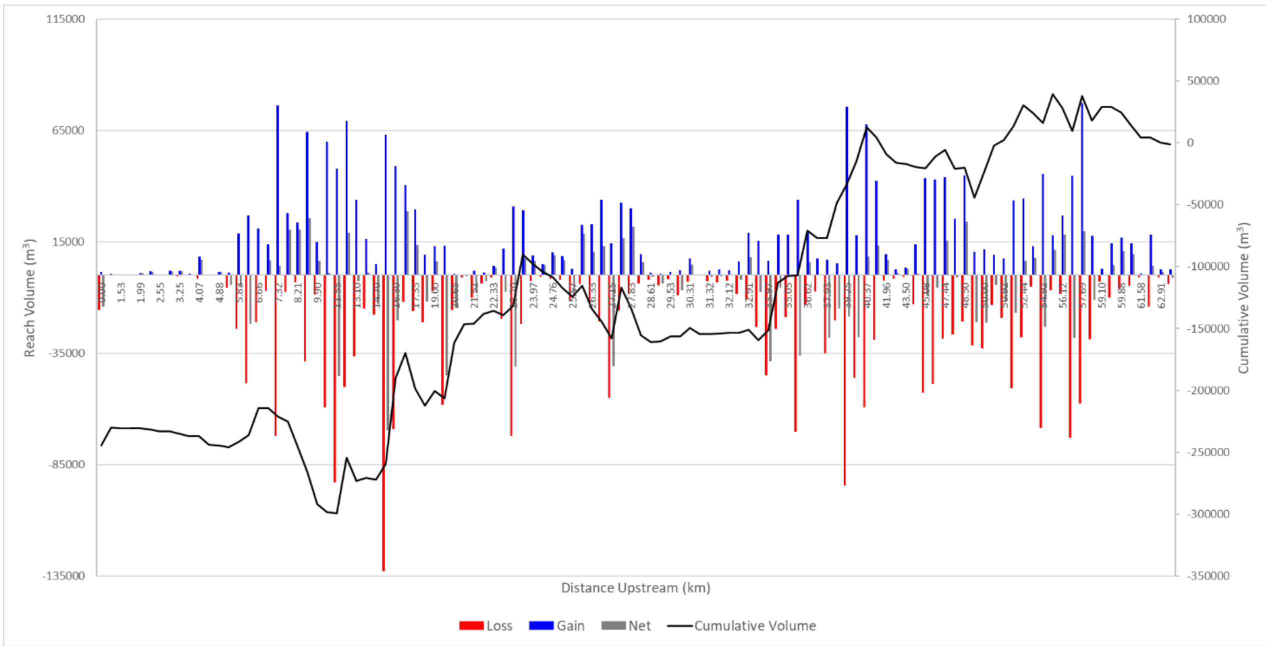

Figure 3.34 Morphological sediment budget based on discrete GCD for each sub-reach defined by channel cross-sections (Figures 3.21-3.33), showing reach volumetric gains (blue bars), losses (red bars) and net storage volume (grey). The cumulative volume (working from upstream to downstream, in the direction of sediment movement) is overlaid.

Figures 3.21-3.33 highlight significant spatial variability in detectable morphological changes along sub-aerial surfaces in the lower 62 km of the Rangitikei River. Some reaches show minimal detectable change, and these generally lack sub-aerial bar surfaces (e.g. Figure 3.21 [XS 6355]. This scenario indicates that dry bar surfaces are actively reworked between 2017 and 2021, with complex patterns of surface lowering (erosion) and raising (deposition) evident, associated with shifting of the channel. The most significant lowering of dry surfaces occurs where lateral erosion of adjacent surfaces has occurred in response to bend migration (e.g. Figures 3.22 [XS 5550-5490 and 3.30 [XS 1630]). This process of adjustment recruits sediment from adjacent floodplain or bars and replenishes gravel in the system. However the net loss of sediment from these surfaces (Table 1) indicates a gravel deficit: export (or extraction) from the 62 km reach exceeds inputs from both lateral replenishment and sediment delivered into the lower Rangitikei from upstream. Table 3.1 and Figure 3.34 reveal a negative net change in gravel storage in the lower Rangitikei between 2017 and 2021 of approximately -242,000 m^3. Dry surfaces in the active river have lost this volume of sediment. This volume must be considered a conservative estimate from the 62 km reach as whole. The spatial distribution of these losses is varied: some reaches in this period reveal a net gain of sediment, but the overall trend is sediment loss (Figure 3.34). Section 4 discusses these results in light of allocable gravel extraction volumes.

4. Discussion: morphological budgeting and allocable gravel volumes

Comparison of the DEM-derived morphological budget (Figure 3.34) is made with allocable volumes from gravel extraction sites in the lower Rangitikei in Figure 3.35. This comparison suggests that extraction from sites upstream could be contributing significantly to the observed gravel deficit in the lower Rangitikei. Allocable volumes are relatively small within the 62 km-long reach and spread across multiple sub-reaches. Most extraction is focused on the lower 20 km, particularly between 16 and 8 km and these lowermost sub-reaches indicate some net gains in sediment. While local changes may lend support to the need to extract gravel, overall there is a deficit: extraction exceeds supply.

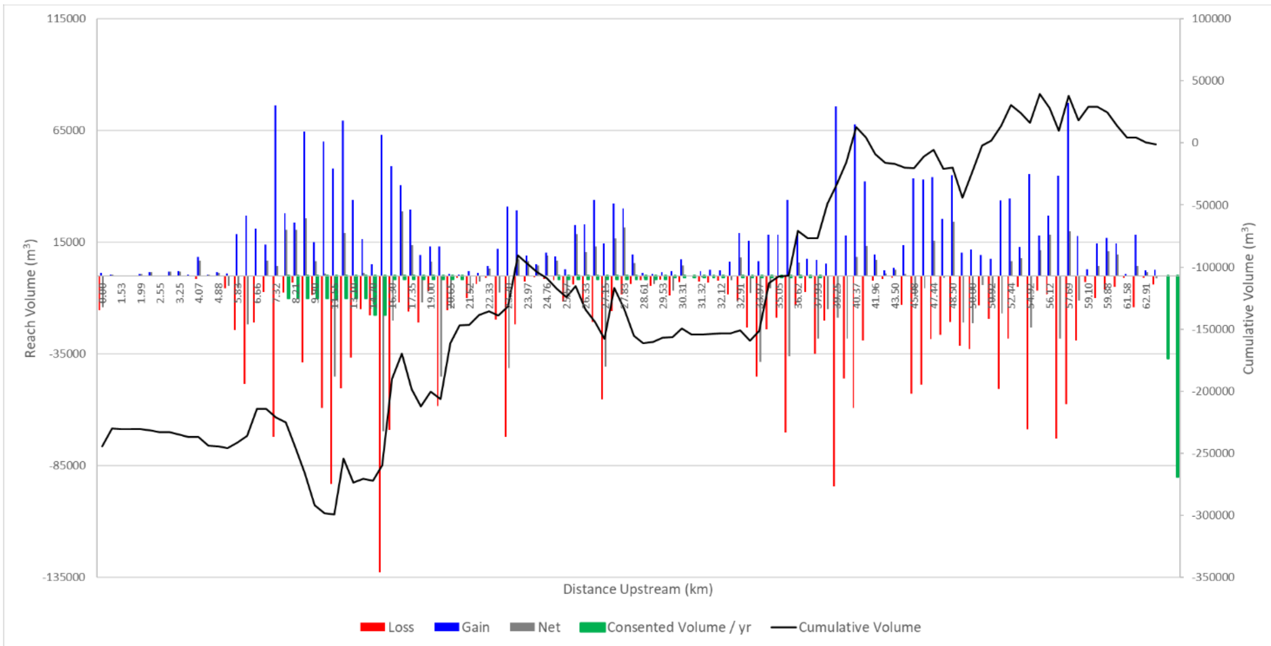

Figure 3.35 GCD-derived morphological sediment budget compared with allocable gravel volumes

Considerable spatial and temporal variability were observed within- and between individual cross-sections. Along-profile trends varied by epoch as well with some patterns across reaches. Reaches 1 and 4 of the Kawhatau both exhibit >20,000 m^3 of cumulative net-erosion upstream-to-downstream for the 2001-2015 epoch. Cumulative fluctuation for the lower (river-kms 1-32) Rangitikei reach mostly falls within a +/- 1x10^6 band, with the lowest ~20 kms appearing generally depositional, but having localised areas of high-magnitude erosion for some epochs. Cumulative losses for 1975-1983 and 1983-2004 in the lower Rangitikei do however indicate that overall this part of the river was losing sediment, presumably reflecting (over) extraction of available gravel resource at this time. The lower reach of the river would normally be expected to be the locus of deposition and to this effect, the 2004-2017 epoch is more in line with how this section of river might be expected to behave (Figure 3.19). This shift towards positive cumulative net change in 2004-2017 *may* reflect the impact of a significant flood in 2004 and / or tighter controls on gravel extraction in this period. The upper portion (river-kms 33-62) of the Rangitikei River shows considerable spatiotemporal variability, with the highest magnitude cumulative change operating within a +/- 3x10^6 range for the 2009-2017 (gain) and 1998-2009 (loss), respectively.

Data interpretation should be performed with the following in-mind:

- The volumetric budgeting performed here assumes like-for-like transfer of material that is unlikely to represent field conditions such as where erosion of mudstone terraces recruits sands and silts that are of no interest for gravel extraction. This assumption was necessary as no information was provided on channel boundary composition and means that the depositional side of the ledger overrepresents gravels. The degree of this effect could be constrained by future work.
- Budgeting doesn't differentiate geomorphic processes related to sediment transfer. Epoch-by-epoch change for each cross-section in Appendix C can greatly help with this interpretation.
- The degree to which localised human-forcing (visible in many of the Appendix C plots) accelerates or amplifies material transfer (such as straighter channel realignments and disruption of armour layers) cannot be accounted for by the data provided. Thus, the results will appear to suggest more transfer is occurring that there likely would be in the absence of management activities.

4.1 GCD and Cross-section results compared

A correspondence between GCD and cross-section budgets is not necessarily to be expected, since the GCD using LiDAR is based on dry surfaces only, albeit directly measured, while cross-sections include both wet and dry areas of channel, based on extrapolated topographic change detected along single lines across the channel. Nevertheless there is an overlap of epochs in the upper part of the Rangitikei (XS63550 to XS32910) for the 2017-2021 period that can be compared. Gravel volumes derived from cross-sections are both larger (as might be expected, since the changes are extrapolated across both wet and dry parts of the channel) and display a negative (loss) change in volume (Figure 3.20). This contrasts with mainly positive changes in the GCD budget (Figure 3.34) in this part of the river, although the cumulative budget is beginning to indicate net losses from dry surfaces downstream from XS40370 (Figure 3.34). This result suggests that epoch may reflect lateral adjustment of the wetted channel along parts of this section, or scour of the wetted channel. Appendix A while most dry bar surfaces aggrade.

It is not possible to make a comparison between GCD and cross-sections in the lower part of the Rangitikei (downstream from XS32910) as there are insufficient data for coherent cross-section analysis in the 2017-2021 epoch. The longer-term behaviour of this lower reach is indicated as being primarily degradational by GCD analysis, which is in contrast to the cumulative aggradation indicated in cross-section analysis for the immediately preceding period (2004-2017, Figure 3.19). This contrast may result from gravel extraction from dry surfaces in this section (Figure 3.35), especially if extraction is not detected by cross-sections if it falls between section lines.

5. Conclusions

Conservative estimation of the gravel-budget in the lower Rangitikei using geomorphic change detection between successive LiDAR surfaces limited to dry surfaces indicates a reduction in gravel storage in the lower 62 km of the river. Extraction appears to exceed supply (to dry surfaces) at present.

Cross-section derived gravel budgets show considerable spatial and temporal variability in both the Rangitikei and Kawhatau. Long-term there is no clear trend either towards net gain or net loss in these rivers. Changes are likely cyclic, reflecting pulsed sediment supply from erosion events both within the active river corridor, and from upstream sediment inputs. However, the lower Rangitikei does appear to display an extended period of negative cumulative change for the epochs 1975-1983 and 1983-2004. This negative trend is particularly unexpected in this part of the system and likely reflects over-extraction of gravel resource. Reversal of this trend in 2004-2017 *may* reflect the impact of a significant flood in 2004 and / or tighter controls on gravel extraction in this period. These trends suggest the lower Rangitikei is sensitive to over-extraction, and gravel supply should be carefully monitored.

The period of cross-section analysis does not correspond with GCD, so a direct comparison between cross-section and GCD budgets cannot be made for the entire river. It is important to recognise that the GCD and cross-section budgets are nuanced in the attributes of the Rangitikei gravel budget to which they relate. Using both approaches enables a more holistic assessment of the gravel budget to be determined than would otherwise be possible from one or the other.

5.1 Recommendations & further work

Careful monitoring of the Rangitikei gravel budget is required in light of both a high degree of spatiotemporal variability indicated by the cross-section budgets, and the cumulative losses indicated in the GCD analysis.

A conservative approach to allocation of gravel volumes is recommended in light of the sensitivities of the Rangitikei (and Kawhatau) gravel budgets.

Further analysis should assess gravel budgets alongside flow records to link changes in channel morphology and gravel budgets to flood timing and magnitude. These linkages would be best assessed using annualised budgets and targeting sub-reaches within the lower 62 km Rangitikei at finer time intervals (cf. Figure 3.18). A whole-of-reach approach for the entire 62 km of river over the extended epochs reported is too coarse a resolution for such an analysis to be particularly meaningful in this report.

Future monitoring should use bathymetric LiDAR for three-dimensional acquisition of both dry and wet channel morphologies, from which GCD can be assessed. Repeat surveys every ~5 years would likely be of sufficient resolution to identify key trends in sufficient time to action any necessary river management protocol (e.g. revised limits on allocable gravel extraction volumes).

It was beyond the scope of this work to fully assess the accuracy of the available LiDAR surfaces, which were largely taken at face value (only corrected for differences in vertical datum). To add further confidence to GCD application, DEM values could be extracted along cross-section lines surveyed contemporaneously with LiDAR acquisition to better validate and assess the accuracy of the LiDAR-derived DEMs.

Boundary composition would be worth exploring to elucidate the extent to which morphological changes observed in both GCD and cross-section analyses actually reflect change in gravel storage (and therefore gravel resource). It is likely that thick drapes of finer-grained deposits, not viable as a source of aggregate, are responsible for some of the changes detected in morphological budgeting reported here. It is possible that (likely) over-extraction responsible for degradation trends in the 1970s to early 2000s may have resulted in a shift towards a more mixed load system as a consequence of erosion of mudstones in the river corridor, since rivers starved of sediment will recruit material to redress the balance in sediment load. Monitoring of bed textures in the active channel can be achieved remotely via high-resolution LiDAR acquisition, with ground-truthing at key locations.

Professor Ian Fuller
Massey University

28 February 2023

References

Ashmore, P. & Church, M. 1998. Sediment transport and river morphology: a paradigm for study. In: Klingeman, P., Beschta, R., Komar, P. & Bradley, J. (eds.). *Gravel Bed Rivers in the Environment*, Colorado: Water Resources Publications LLC, pp. 115-148.

Brierley, G.J. & Fryirs, K.A. (2005). *Geomorphology and River Management.* John Wiley & Sons.

Conley, W. (2023). *Multi-scale morphodynamics of unconfined coarse-bedded rivers in the Ruamāhanga catchment*. PhD thesis, Massey University.

Friend P.F. & Sinha, R. (1993). Braiding and meandering parameters. In: Best, J.L. & Bristow, C.S. (Eds), *Braided Rivers*. Geological Society Special Publication, London, pp 105–111.

Fuller, I.C., Death, R. G., Garcia, H. J., Trenc, N., Pratt, R., Pitiot, C., Matos, B., Ollero, A., Neverman, A., & Death, A. (2020). An index to assess the extent and success of river and floodplain restoration: Recognising dynamic response trajectories and applying a process-based approach to managing river recovery. *River Research and Applications*, 37(2), 163–175. https://doi.org/10.1002/rra.3672

Fuller, I.C., Richardson, J.M., Basher, L., Dykes, R.C. & Vale, S.S. (2012). Responses to river management? Geomorphic change over decadal and annual timescales in two gravel-bed rivers in New Zealand. In: Molina, D. (Ed.), *River Channels: Types, Dynamics and Changes*, Nova Science, New York, pp. 137-163

Nicholas, A.P., Ashworth, P.J., Kirkby, M.J., Macklin, M.G. and Murray, T., 1995. Sediment slugs: large-scale fluctuations in fluvial sediment transport rates and storage volumes. *Progress in Physical Geography*, 19(4): 500-519.

Richardson, J.M. & Fuller, I.C. (2010). Quantification of channel planform change on the lower Rangitikei River, New Zealand, 1949-2007: response to management? GeoScience 2010/2, 1-26. http://muir.massey.ac.nz/handle/10179/1618

List of Appendices

Appendix A: Kawhatau cross section changes between epochs, 1997-2019
Appendix B: Rangitikei cross section changes between epochs, 1975-2017 [XS 3248 to XS1250]
Appendix C: Rangitikei cross section changes between epochs, 1975-2021 [XS 63550 to XS 32910]

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