Appendix E Natural Character Index assessment

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Natural Character Index (NCI) for Waipoua and Mangatarere Rivers

Report for Greater Wellington

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Executive Summary

1. Mapping of river geomorphology using rectified aerial photography from the late 1940s/50s and 2013.

The earliest available photography providing complete coverage extending along the managed lengths of the Waipoua and Mangatarere Rivers was sourced from Retrolens, rectified, and mapped to assess the composition of the active river channel corridor prior to river management. The same area was mapped using the most appropriate available rectified imagery from LINZ flown in the summer of 2013. Shapefiles of the active channel, wetted channel, unvegetated bars, lightly and densely vegetated bars are available electronically. These features provide a broad overview of river geomorphology in the active channel of the Waipoua and Mangatarere 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 historic imagery (1940s) and 2013 was assessed using an NCI approach, which provides a ratio of the parameter assessed in 2013 compared with the feature in the 1940s/50s. A 'whole river' assessment is provided for key parameters identified in section 2.1. Further analysis of channel sinuosity and braiding index focused on discrete, morphologically coherent reaches in each river.

3. Summary of changes

The most significant changes in the Waipoua river corridor were a 49% reduction in active channel area, a 58% reduction in lightly vegetated bars, a 46% reduction in densely vegetated bars, a 44% drop in unvegetated bars, a 35% drop in wetted channel area, and the 34% drop in wetted channel length. However, all parameters have dropped overall. Braiding intensity in partially braided reaches was reduced while sinuosity in meandering reaches was also reduced. These changes indicate channel rationalisation and homogenisation within a narrowed active channel. The 2013 river no longer displayed the alternating meandering-wandering reaches of the 1940s and is largely straight and incised throughout. Interpretation and analysis of historic maps indicate a completely different river in the late 19th – early 20th century in reach 2 and 3. In reach 3, densely vegetated bars have increased by 87% and unvegetated bars have dropped by 15% since the 1950's.

The most significant changes in the Mangatarere river corridor were a 46% reduction in active channel area, a 59% reduction in lightly vegetated bars, a 47% drop in densely vegetated bars, and a 34% drop in unvegetated bars respectively. Of all 3 reaches, reach 2 was the most dynamic and homogenised.

4. Recommendations

Both the Waipoua and Mangatarere Rivers have been modified in their form as a consequence of a narrowing of the river corridor since the 1940s. Narrowing has prevented significant bend development and migration in meandering reaches (Waipoua, reach 3; Mangatarere reach 2) and reduced the width available for channel expansion to accommodate medial bars (Waipoua, reach 2; Mangatarere). To recover a degree of natural character (i.e. characteristics that better reflect the geomorphology that would develop under the prevailing sediment and flow regime), it is recommended that where feasible the river be given more room to adjust and develop these characteristic forms.

If the intention of management approaches is targeted reach restoration, attention should be paid to the pre-management era characteristics of the river at the target reach location. It would not be appropriate to either engineer meandering in what were partially-braided reaches, or braiding in what were single thread reaches.

Acknowledgements

Camlo Carter received a Summer scholarship from Greater Wellington Regional Council to undertake the project work, which is greatly appreciated. Cam sourced the earliest available aerial photography from Retrolens that provided the most complete coverage of the rivers. He mapped the geomorphology of both rivers for these dates, as well as the geomorphology from the most recently available aerial photos downloaded from LINZ. Cam then completed the NCI analysis and generated the maps, graphs and data on which this report is based.

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1. Introduction

1.1 Aim

The primary aim of assessing the Natural Character Index (NCI) for the Waipoua and Mangatarere Rivers between the 1940s/50s and 2013 is to understand the extent to which the geomorphology of these rivers may have changed in this 60 – 70-year period. This information can then be used to inform approaches to river rehabilitation or restoration. It is beyond the scope of this report to explore the drivers of changes in any detail, but it should be noted that the dates analysed in this assessment allow the possibility of identifying potential impacts on these rivers of land-use change and river management practices, which occurred in the second half of the twentieth century and into the twenty-first.

1.2 River types

In undertaking any assessment of river geomorphology, it is important to recognise the range and diversity of river types, which reflect the prevailing controls on channel form at any given reach or segment of any given river. Figure 1 outlines a broad spectrum of New Zealand's River types and summarises their controls and characteristics. It is important to note that any single river could display the range of these characteristics along its full length, from source to sea/lake. As such, it is also important to take into account catchment characteristics to understand what type of river might be expected at a given location within that catchment (section 1.3).

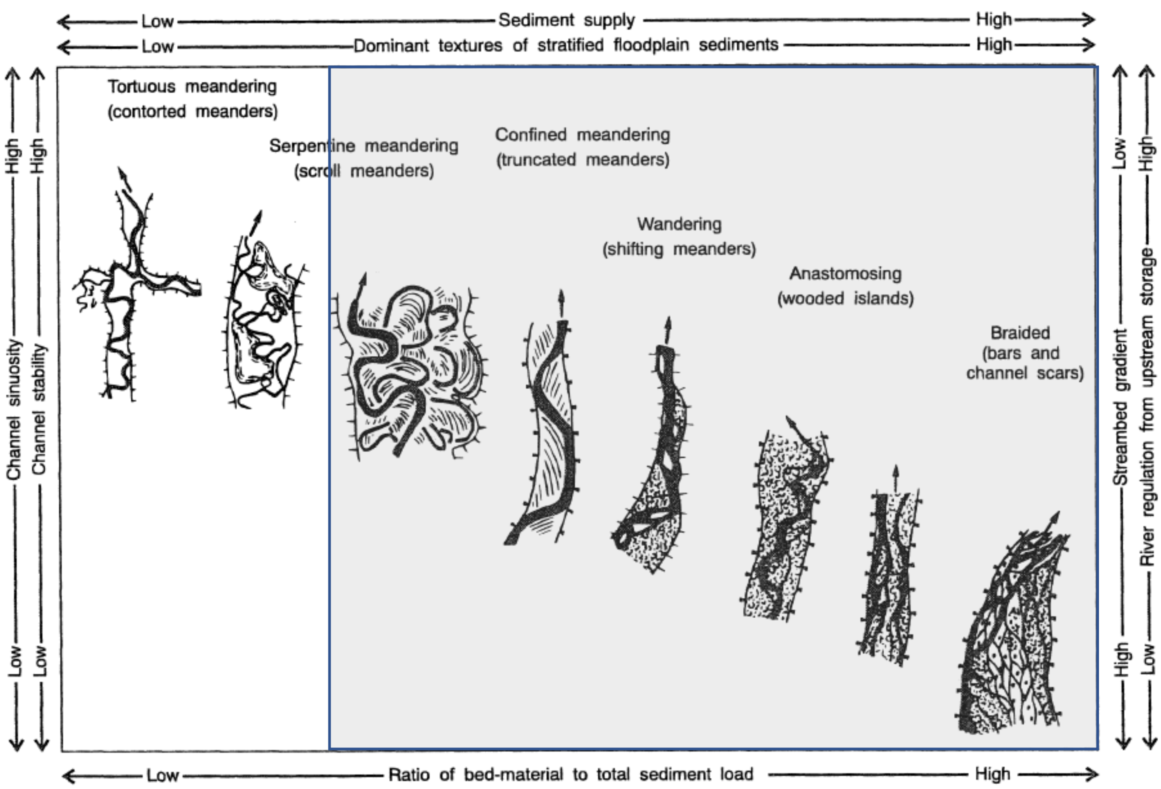

Figure 1. Continuum of river channel types and controlling variables, highlighting the spectrum of gravel-bed river types (shaded), after Mosley (1992).

1.3 Catchment Context

Catchment context must be taken into account when assessing river geomorphology. Figure 2 conceptualises the catchment 'sediment conveyor'. The availability of sediment, its supply and transportability in a river (particularly bedload) shapes the channel form (Figure 1). The geomorphology of gravel bed rivers, which describe both the Waipoua and Mangatarere Rivers, reflects the supply, movement, and storage of the river's bedload (sand, gravel, cobbles, boulders), which is sourced from two key areas in the catchment:

i. Original generation from the source, or production zone, i.e. the catchment headwaters.
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 2).

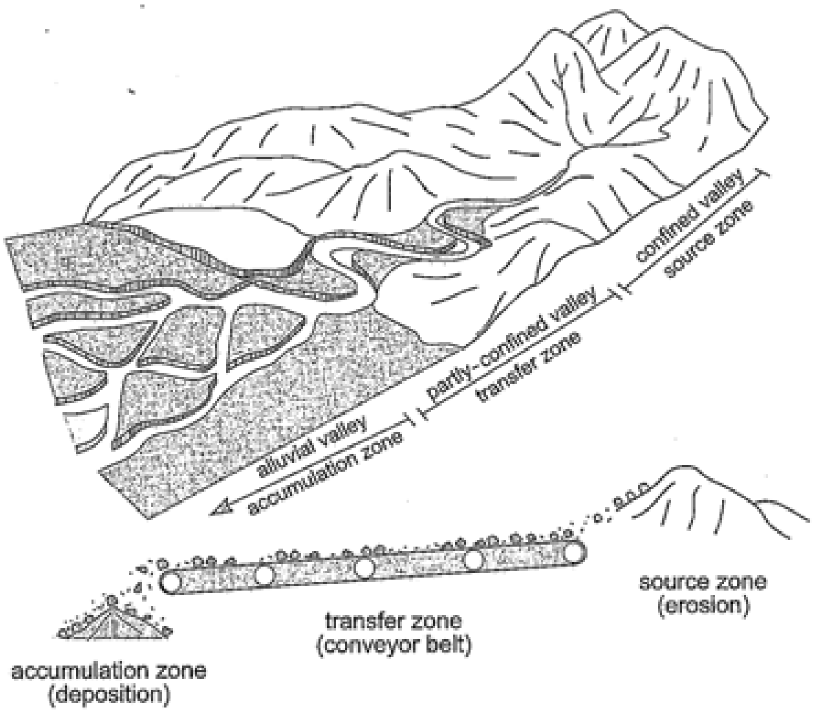

Figure 2. The catchment sediment conveyor (from Brierley & Fryirs, 2005).

The sediment conveyor in the transfer zone is not smooth, but jerky, which means gravel is conveyed often as a series of pulses, bed waves, or slugs (Nicholas et al., 1995). The nature of this transfer zone is 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 addition, besides vertical adjustments, river reaches in this transfer zone may also adjust their form and an 'hour-glass' alternation may be apparent between wider, more active reaches and narrower less laterally active reaches. In rivers where the channel has the capacity to adjust (i.e. it is not confined e.g. by valley sides, terraces, or artificial constraints), more laterally active reaches may become partially or fully braided, relative to more single-threaded wandering, or meandering reaches. A range of river types (Figure 1) may therefore be expected in the transfer zone of gravel-bed rivers.

In the depositional zone, stream energy drops below gravel transport thresholds and the river lacks the 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 deposited. This point in the catchment sediment cascade is also described as the gravel-sand transition, because downstream from this point, the river is only competent to transport sand size material (Figure 3). This point is not attained in the Waipoua and the Mangatarere Rivers, which transport gravel to their respective end points (Ruamahunga confluence and Waiohine confluence, respectively). As such, the form and behaviour of the Waipoua and the Mangatarere Rivers is best understood in the context of higher-energy transfer zones in their respective catchments.

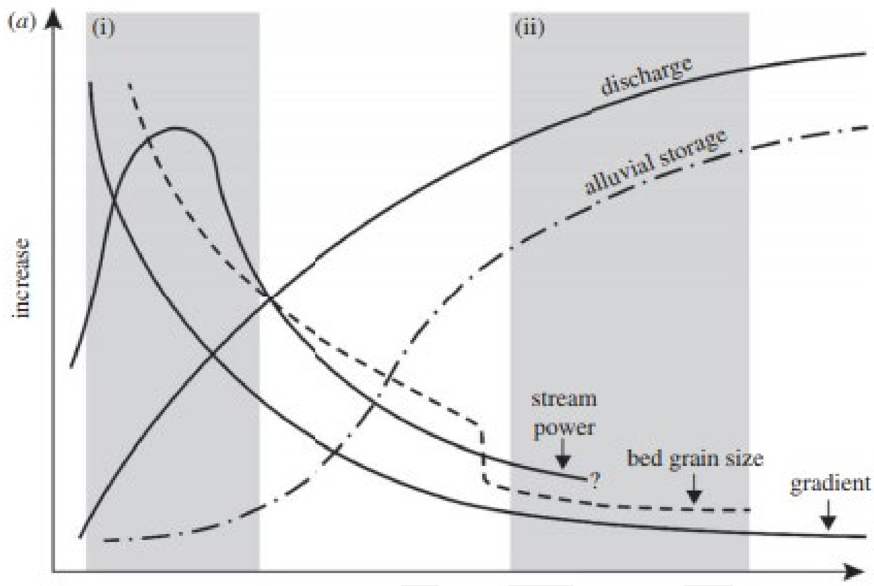

Figure 3. River system attributes in relation to drainage area, the gravel-sand transition is defined as the abrupt change in bed grain size, reflecting critical reduction in gradient and stream power at this point in the catchment (from Macklin et al., 2012).

2. Channel morphology

Channel morphology was mapped for the lengths of the Waipoua and Mangatarere Rivers shown in Figure 4. The extent of mapping was intended to cover the length of each river managed under their respective River Control Schemes.

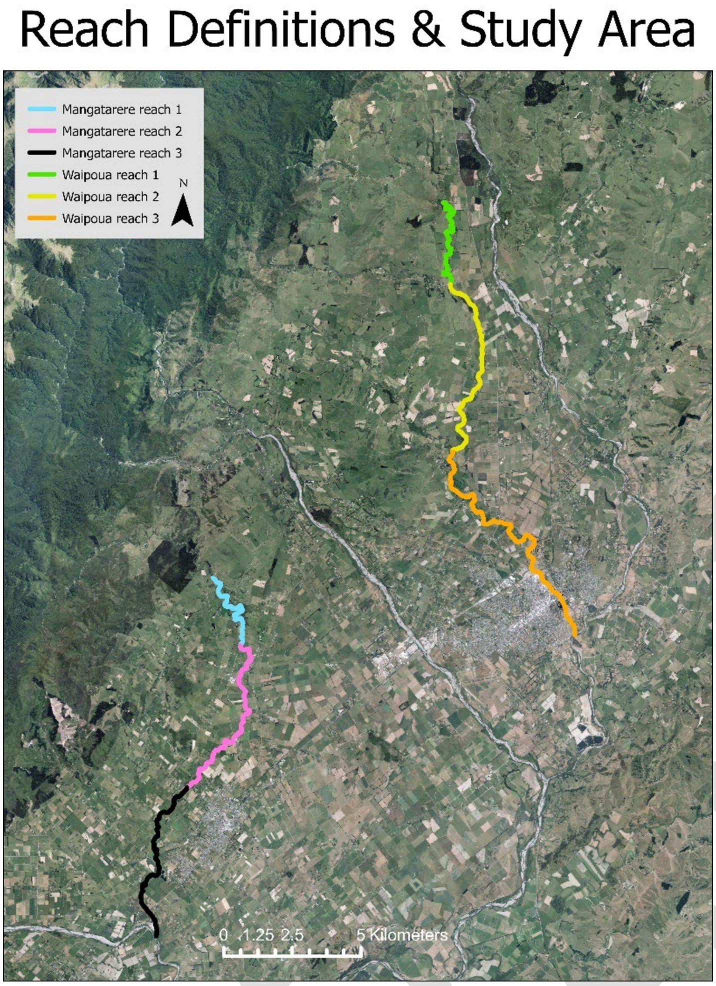

Figure 4. Extents of mapping in the Waipoua and Mangatarere Rivers.

2.1 Mapped and measured parameters

Parameters mapped in both the Waipoua and Mangatarere Rivers are listed below. These features are provided as shape files for use in ArcGIS. Interpretive mapping used applicable aerial imagery of 2013. For comparison and assessment of change in characteristics over time, rectified aerial imagery from various dates from the 1940s and 1950s was used, having been downloaded from Retrolens and rectified/geo referenced in ArcGIS Pro. The resulting maps are provided in section 2.2.

- **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 (vegetated and unvegetated). The active channel excludes areas of mature vegetation and cultivated land that may otherwise be located in the river corridor and classified as floodplain.
- **Wetted channel area:** area of active channel mapped as wet at the time of aerial photography, includes side-channels and backwaters (former channels, now abandoned), and braids. The spatial extent of the wetted channel is dependent on flow discharge at the time of photography. Flows at time of aerial photo acquisition were not known, but assumed to be towards base flow. Large-scale aerial photography as used in this work is generally 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 used.

- **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. Sub-bar scale morphologies were not mapped in this assessment.
- **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 calculate 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:** 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'. Although developed for application in classic braided rivers, this metric can also be used to effectively assess wetted channel complexity, where total length of wetted channels includes side channels and backwaters that remain connected to the main channel.
- **Reach-scale assessments:** considering morphological variability in both the Waipoua and Mangatarere Rivers, the parameters of sinuosity and Brice's (1960) braided index were assessed at a more coherent, reach-scale, rather than whole-of-river:
    - **Sinuosity:** the ratio between channel midline length and straight-line valley length between two points was assessed for discrete reaches of the Waipoua and Mangatarere Rivers. Some reaches of the Waipoua do conform to the classic meander river type (cf. Figure 1), but many reaches are locally divided, which makes sinuosity less meaningful to be applied at a whole-of-river scale than channel length metrics described above.
    - **Braided Index** (Brice, 1960): given by multiplying x2 the total bar length in a reach and dividing by reach length, this metric assesses the complexity of medial (mid-channel) bars in a reach and is a classic descriptor of braiding intensity (Fuller et al., 2013).

2.2 Limitations of the Waipoua river imagery

Imagery acquired from below the Wakamoekau Creek (start of reach 3) was of poor quality and therefore unsuitable for analysis. In lieu of this, the next best imagery was used from the 1950s. However, because the Waipoua was already heavily modified in its lower reaches by the late 1940s, the NCI does not capture the true natural character of river along this length. To overcome this limitation, various high-quality maps from the late 19th century were scrutinised and geo referenced to 2013 imagery (to match the DEM). While the maps do not provide an entire historical overview of reach 3, they do provide valuable insights into the river's geomorphology from the Masterton railway bridge to the confluence with the Ruamahunga.

2.2 Channel morphology maps

2.2.1 Waipoua

Figures 5-21 show the interpretive channel geomorphology mapped for the Waipoua River in the 1940s/50s and 2013, progressing from upstream to downstream.

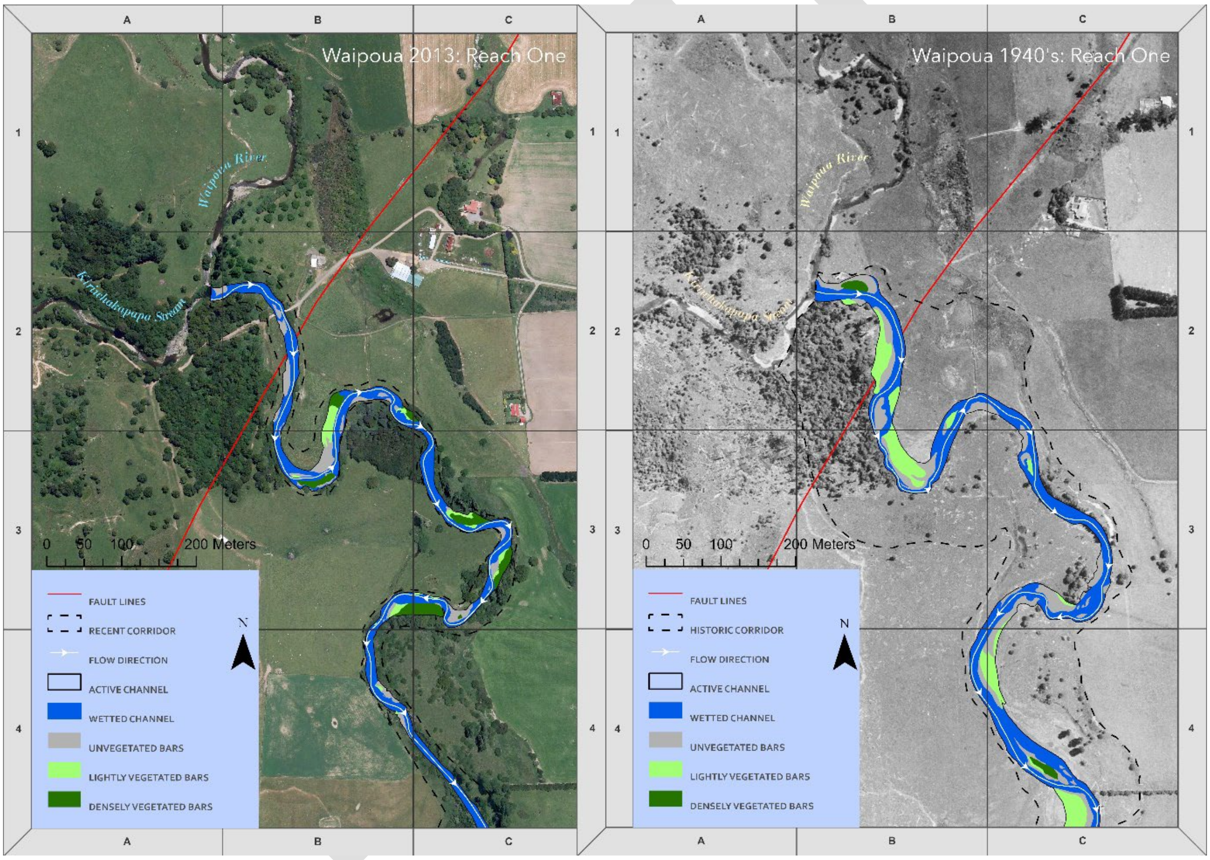

Figure 5: Upper Waipoua geomorphology (Reach 1.0).

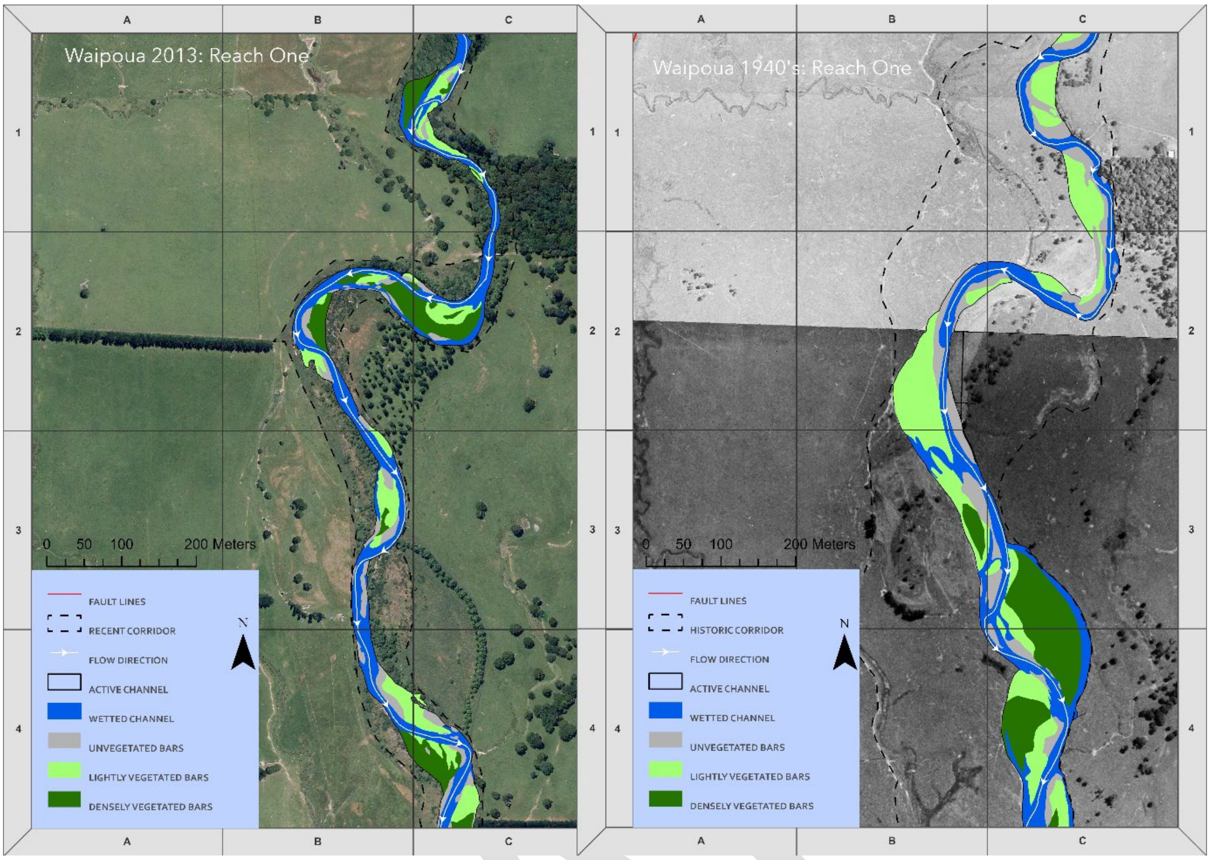

Figure 6. Upper Waipoua geomorphology (Reach 1.1).

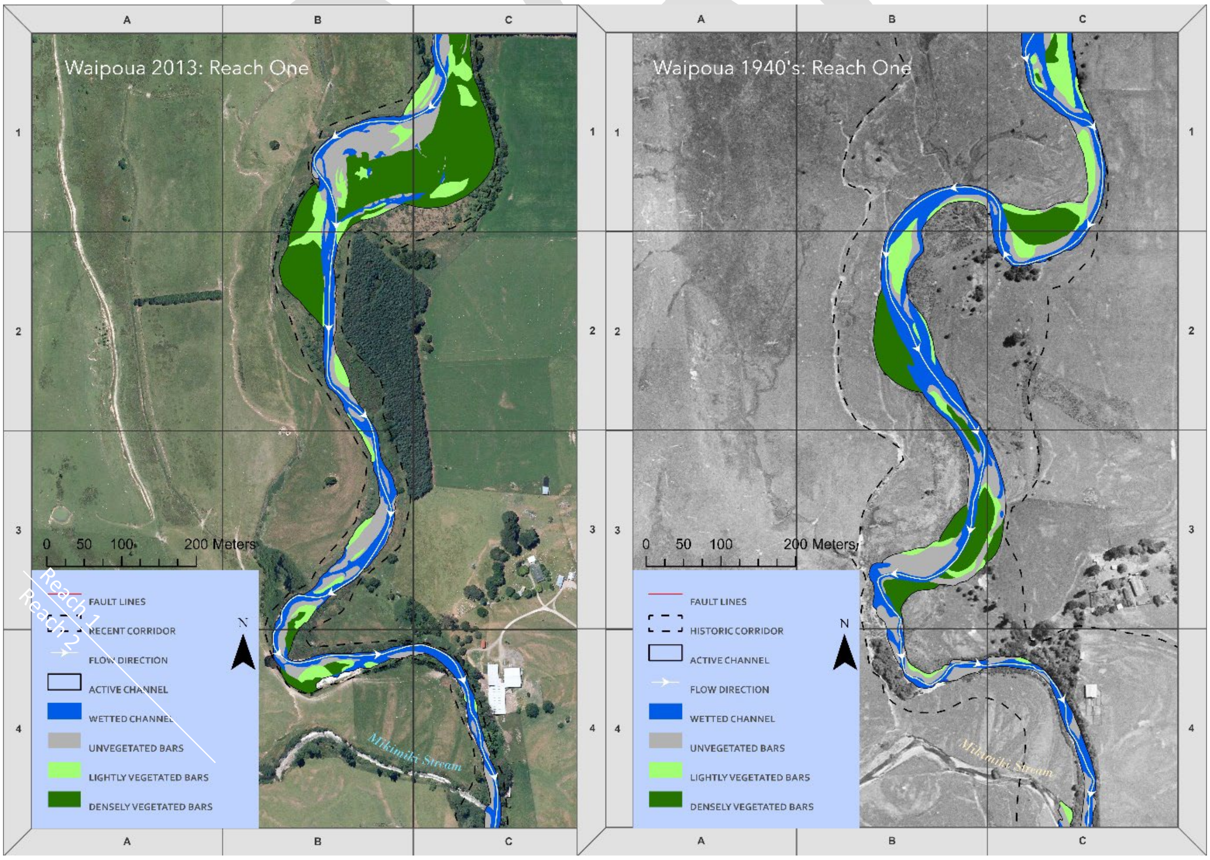

Figure 7. Upper Waipoua geomorphology (Reach 1.2).

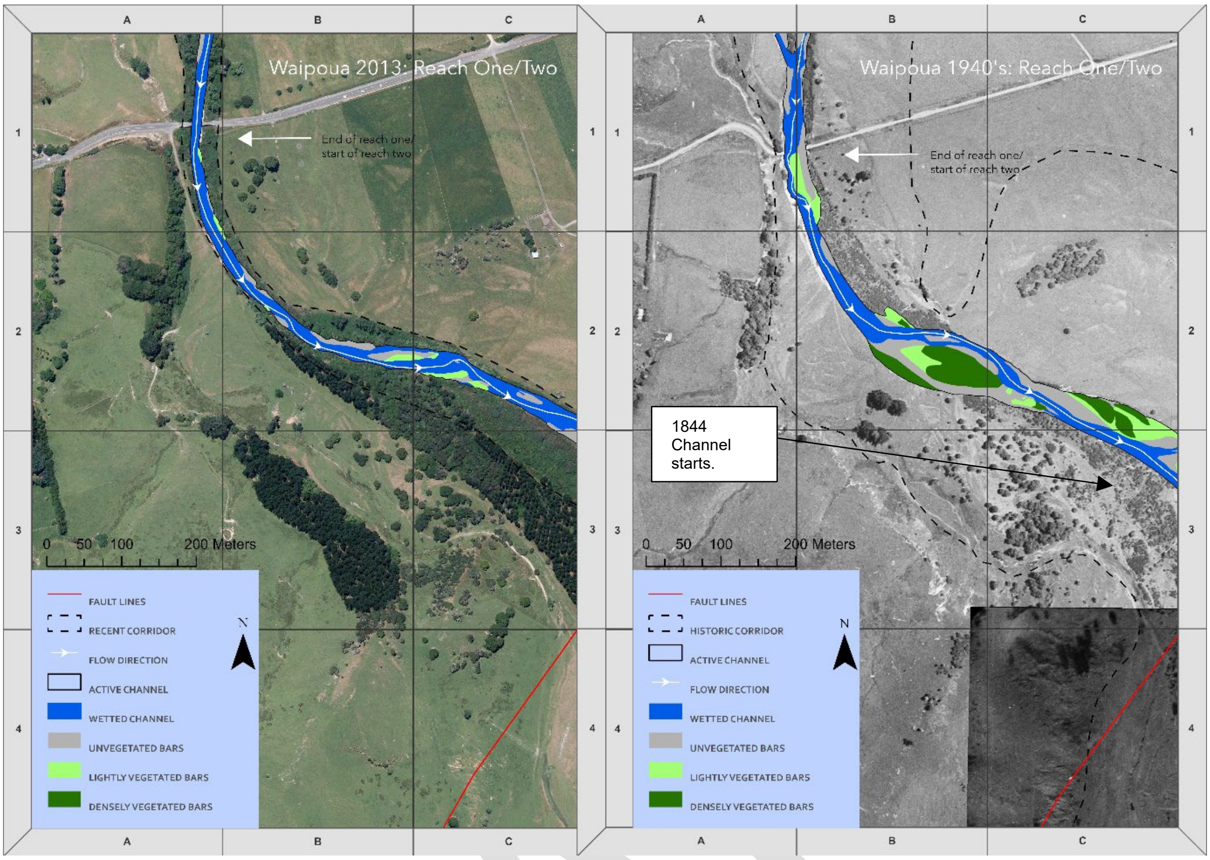

Figure 8: Upper Waipoua geomorphology (Reach 2.0).

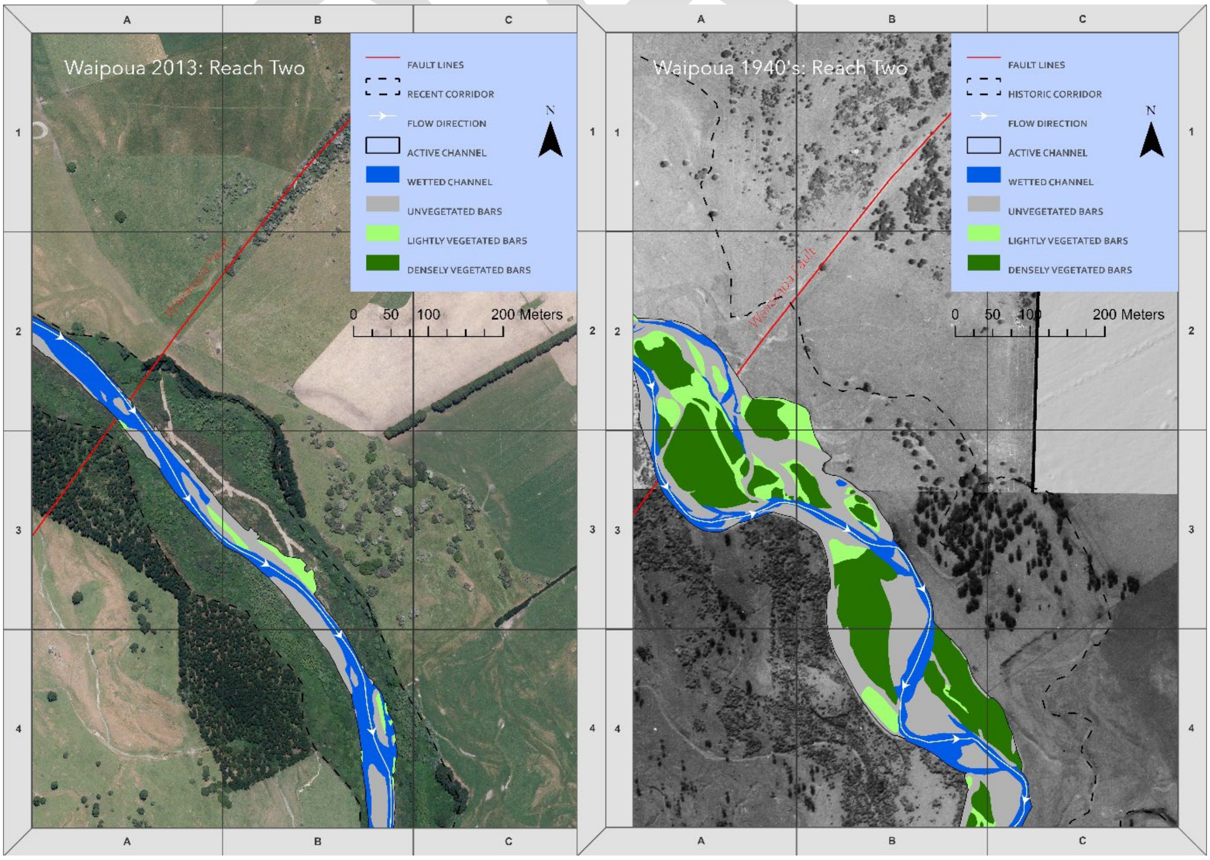

Figure 9. Middle Waipoua geomorphology (reach 2.1).

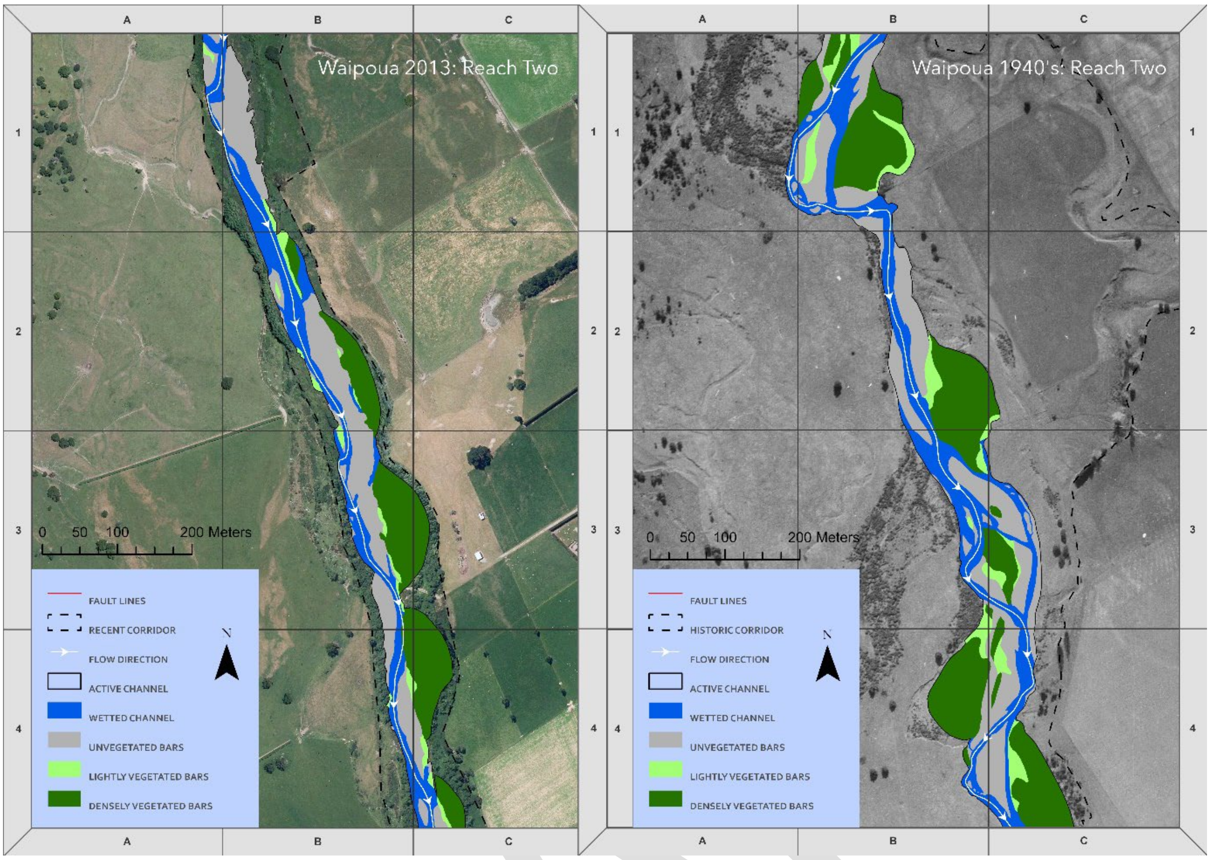

Figure 9. Middle Waipoua geomorphology (reach 2.2).

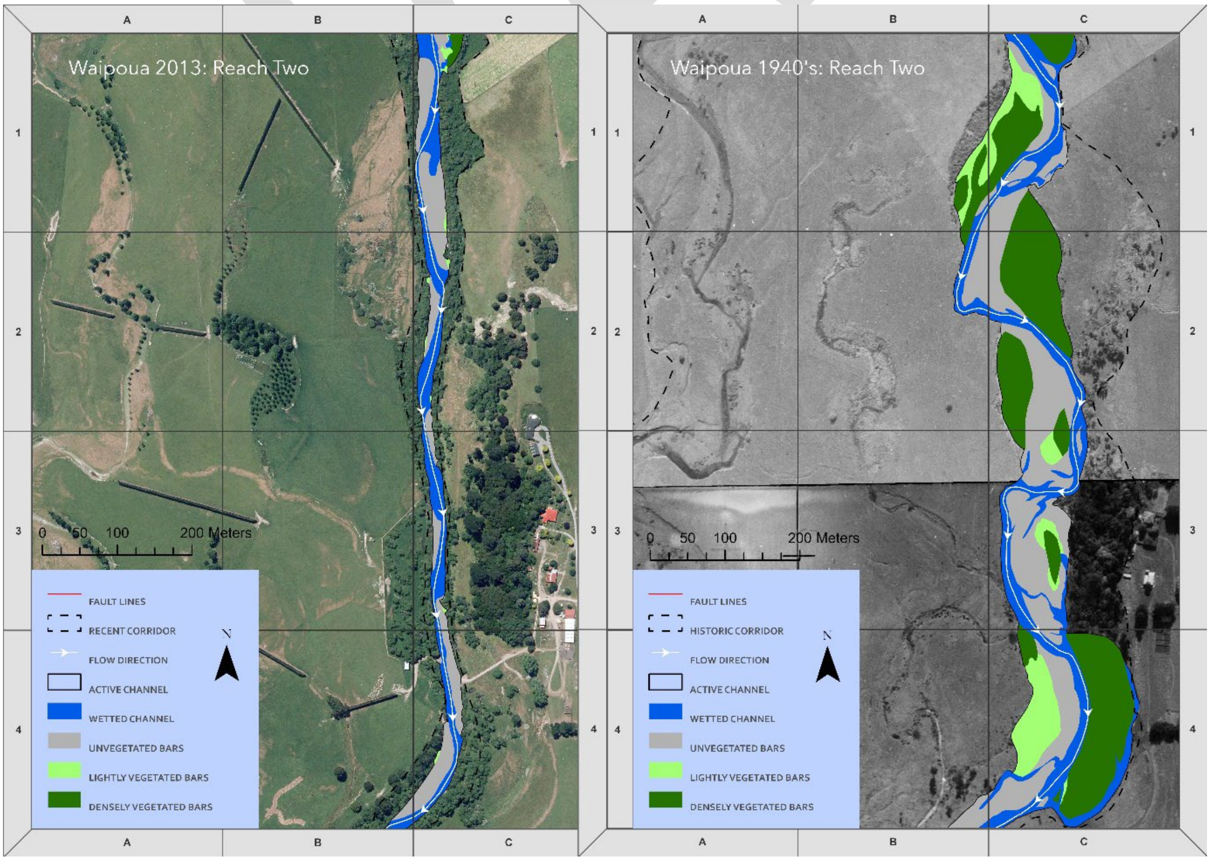

Figure 10. Middle Waipoua geomorphology (reach 2.3).

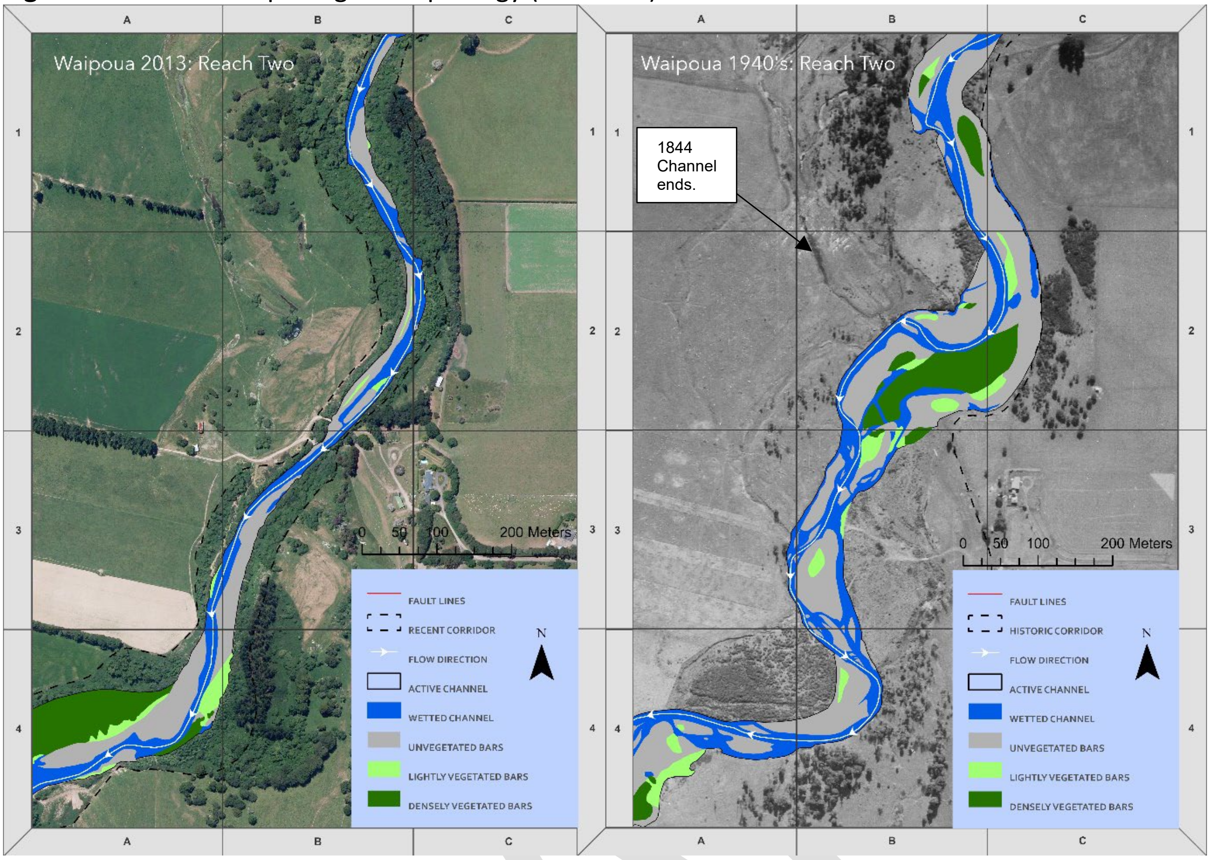

Figure 11. Middle Waipoua geomorphology (reach 2.4)

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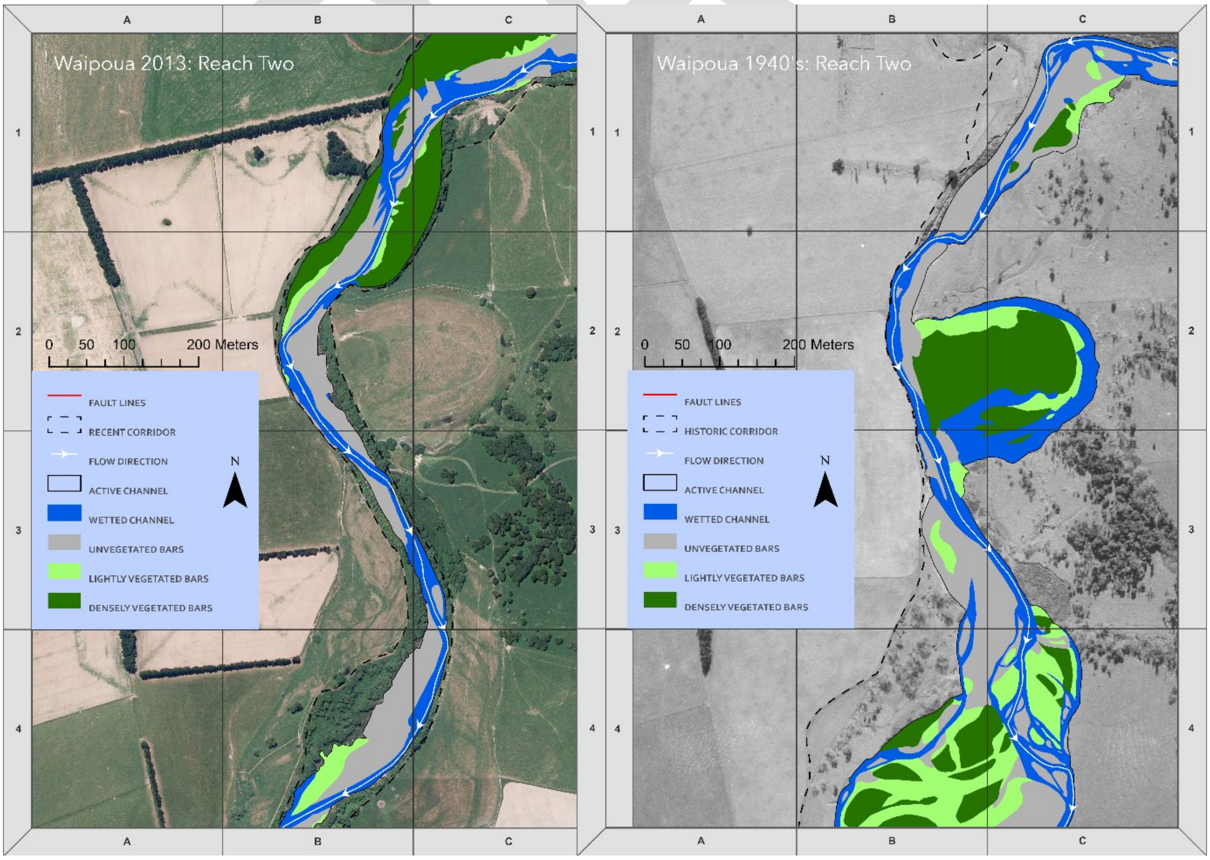


Figure 12. Middle Waipoua geomorphology (reach 2.5).

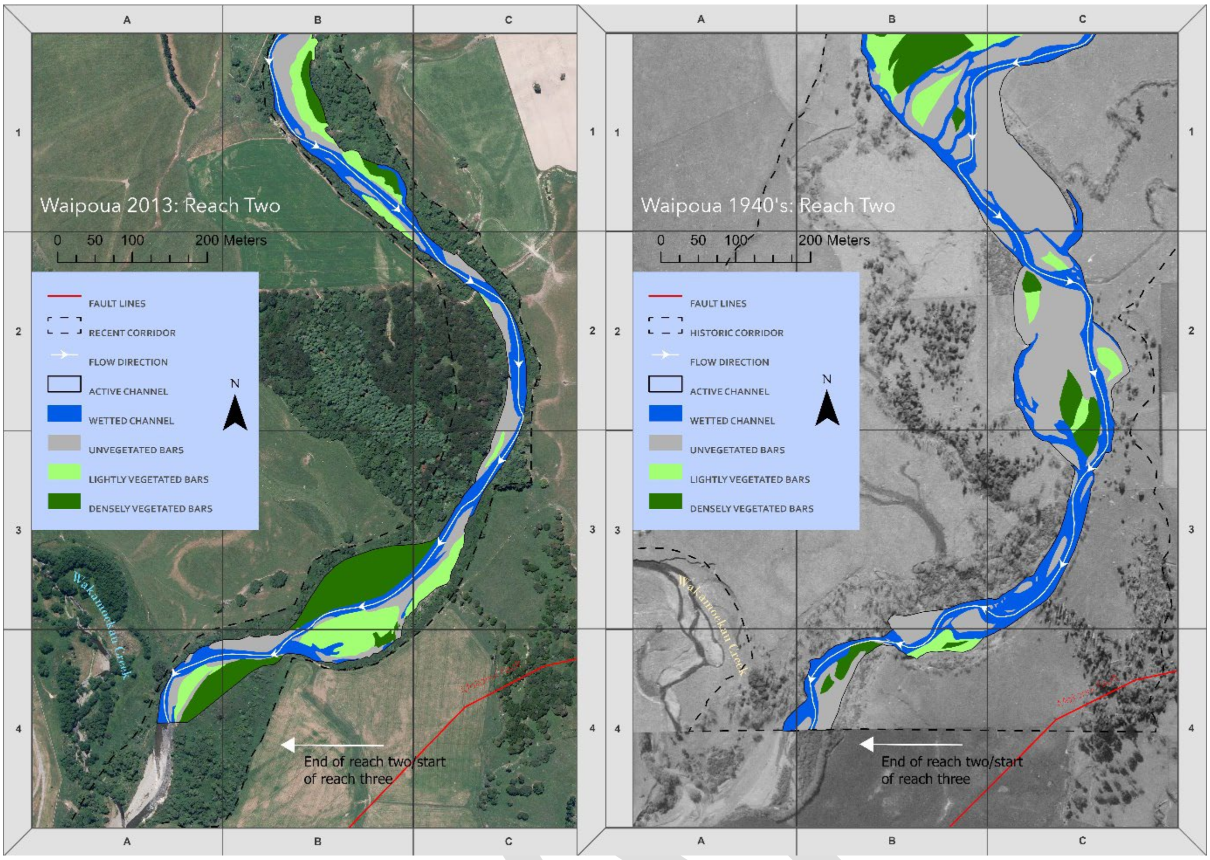


Figure 13. Middle Waipoua geomorphology (reach 2.6).

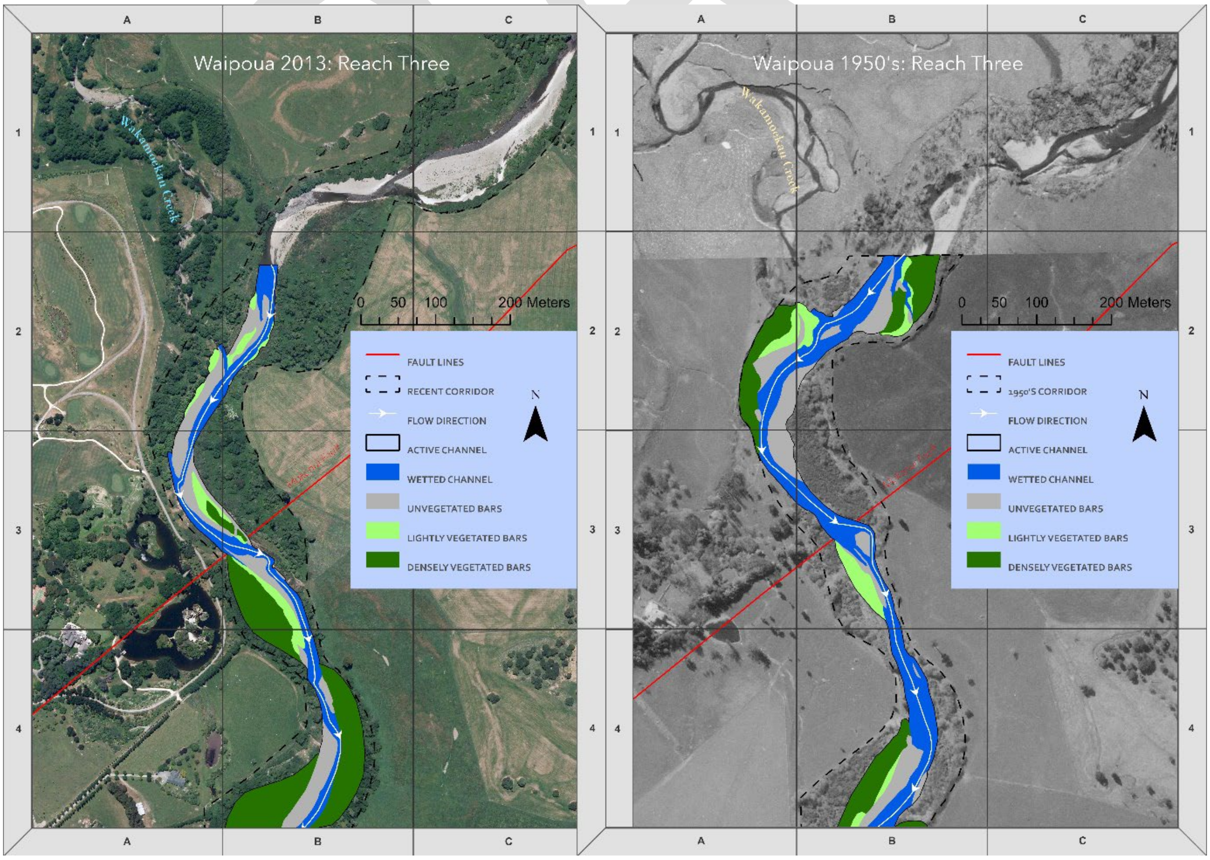


Figure 14. Lower Waipoua geomorphology (reach 3.0).

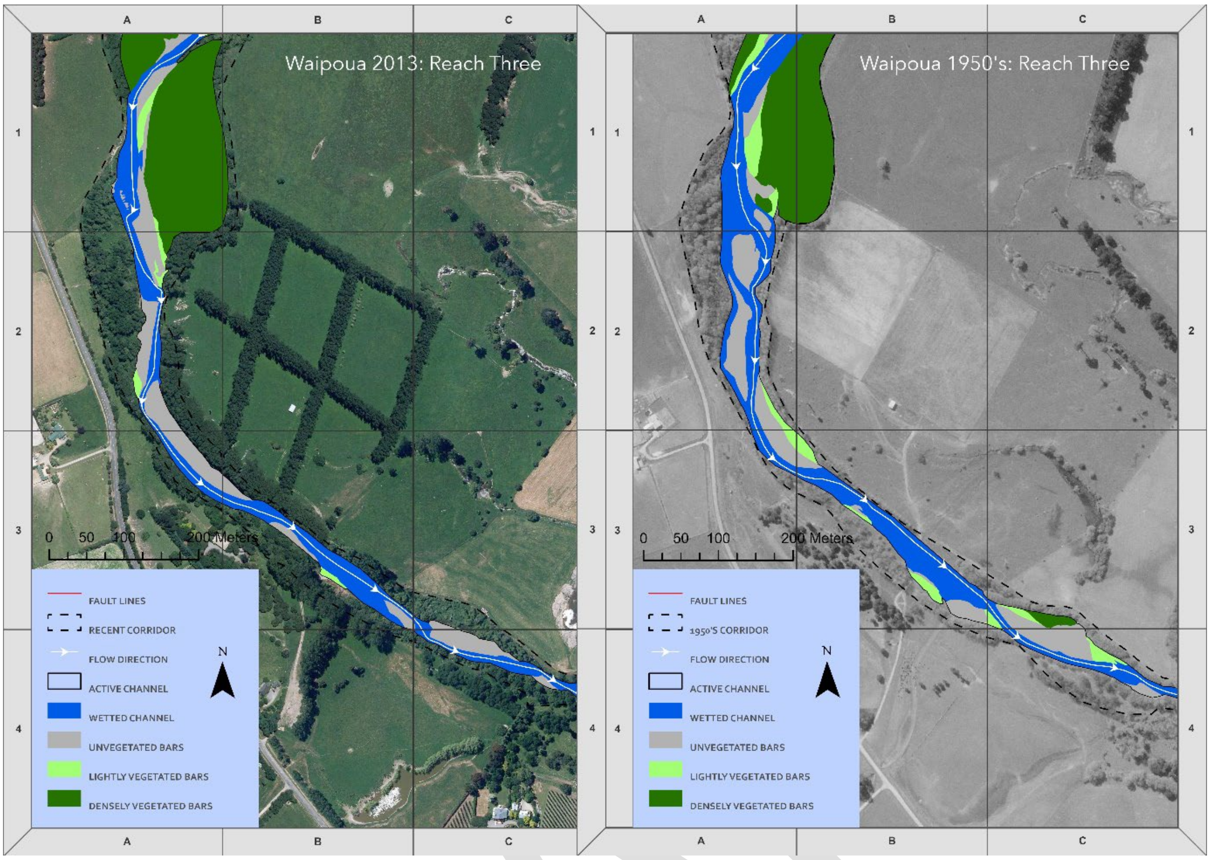


Figure 15. Lower Waipoua geomorphology (reach 3.1).

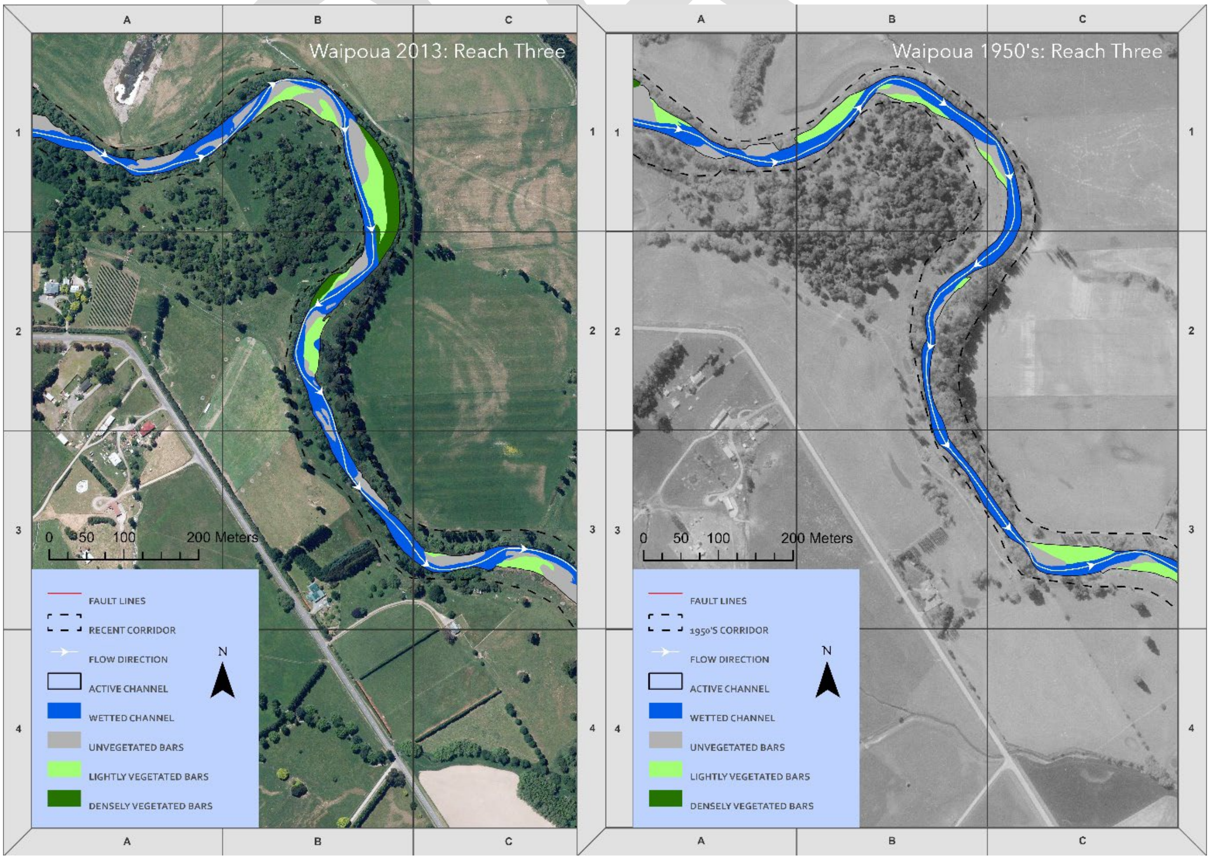


Figure 16. Lower Waipoua geomorphology (reach 3.2).

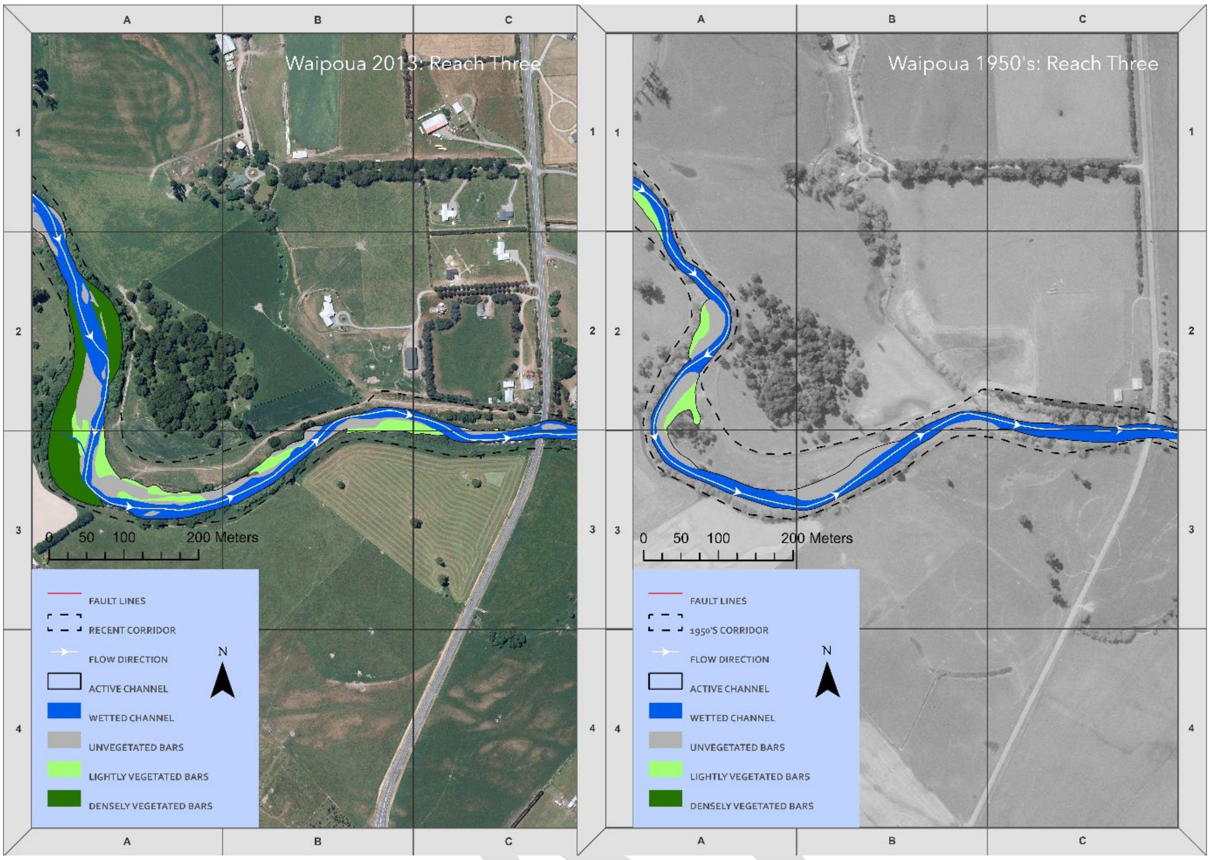


Figure 17. Lower Waipoua geomorphology (reach 3.3).

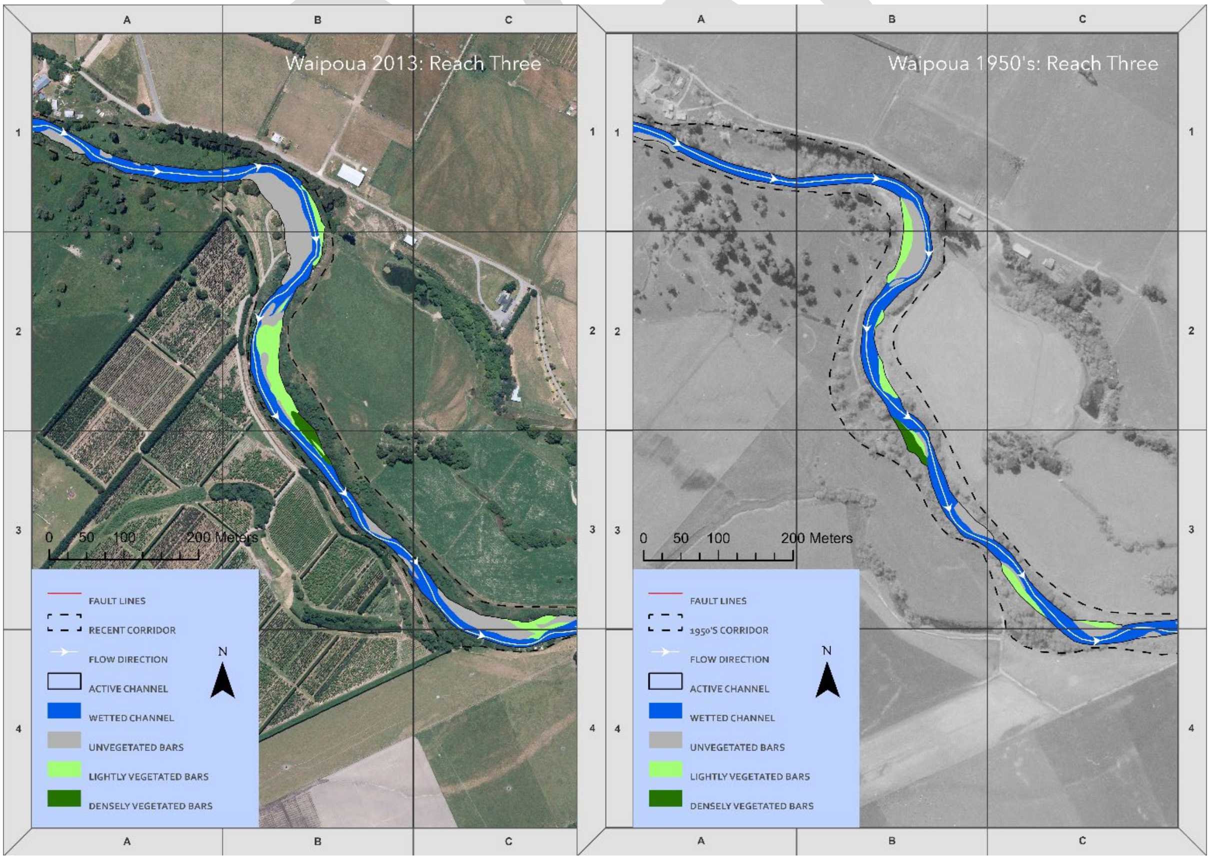


Figure 18. Lower Waipoua geomorphology (reach 3.4).

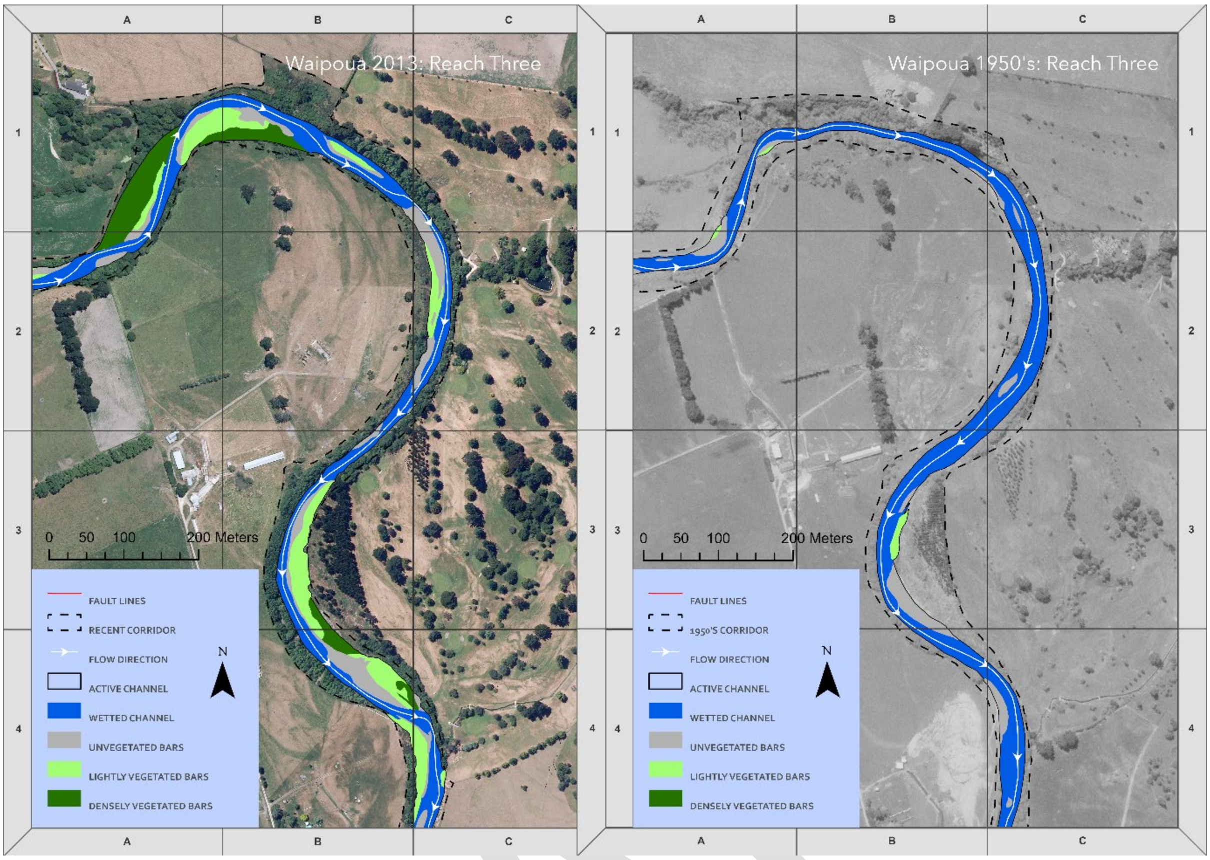


Figure 19. Lower Waipoua geomorphology (reach 3.5).

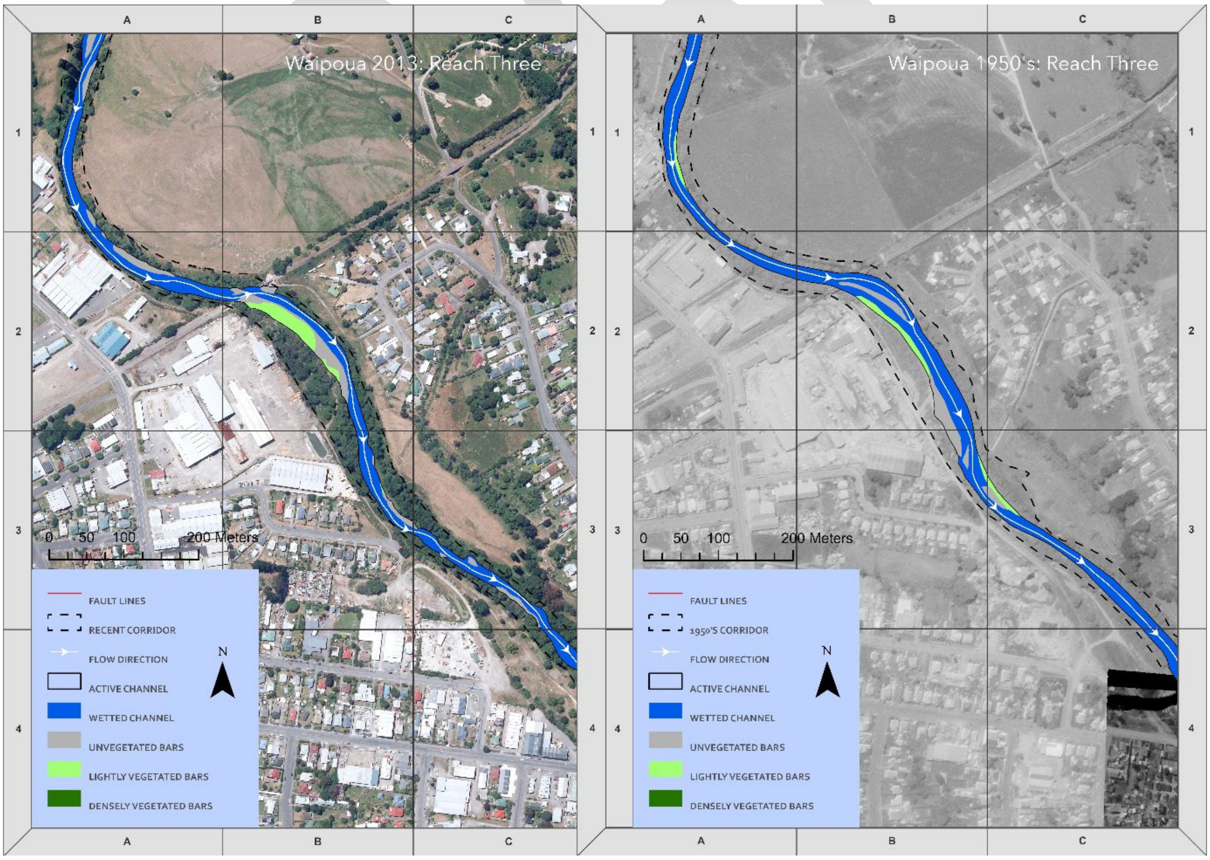


Figure 21. Lower Waipoua geomorphology (reach 3.6).

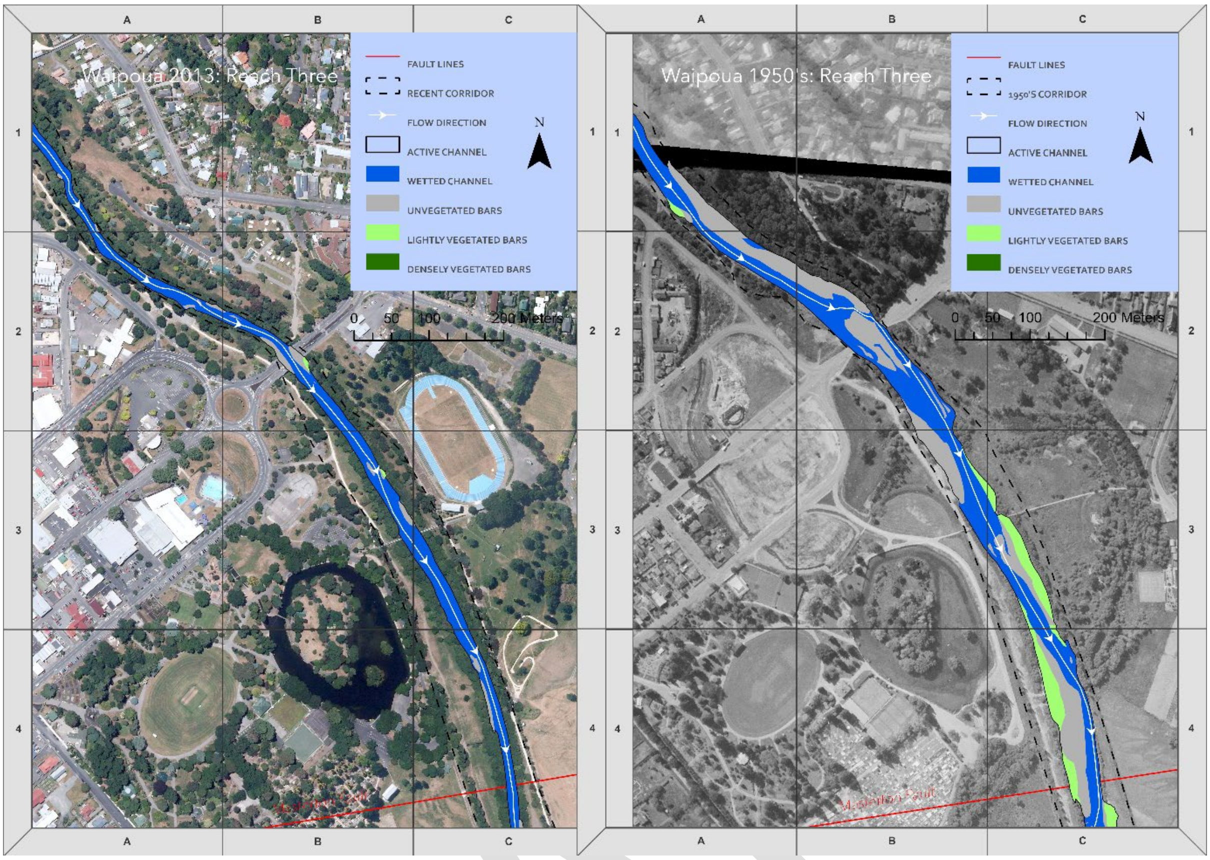


Figure 21. Lower Waipoua geomorphology (reach 3.7).

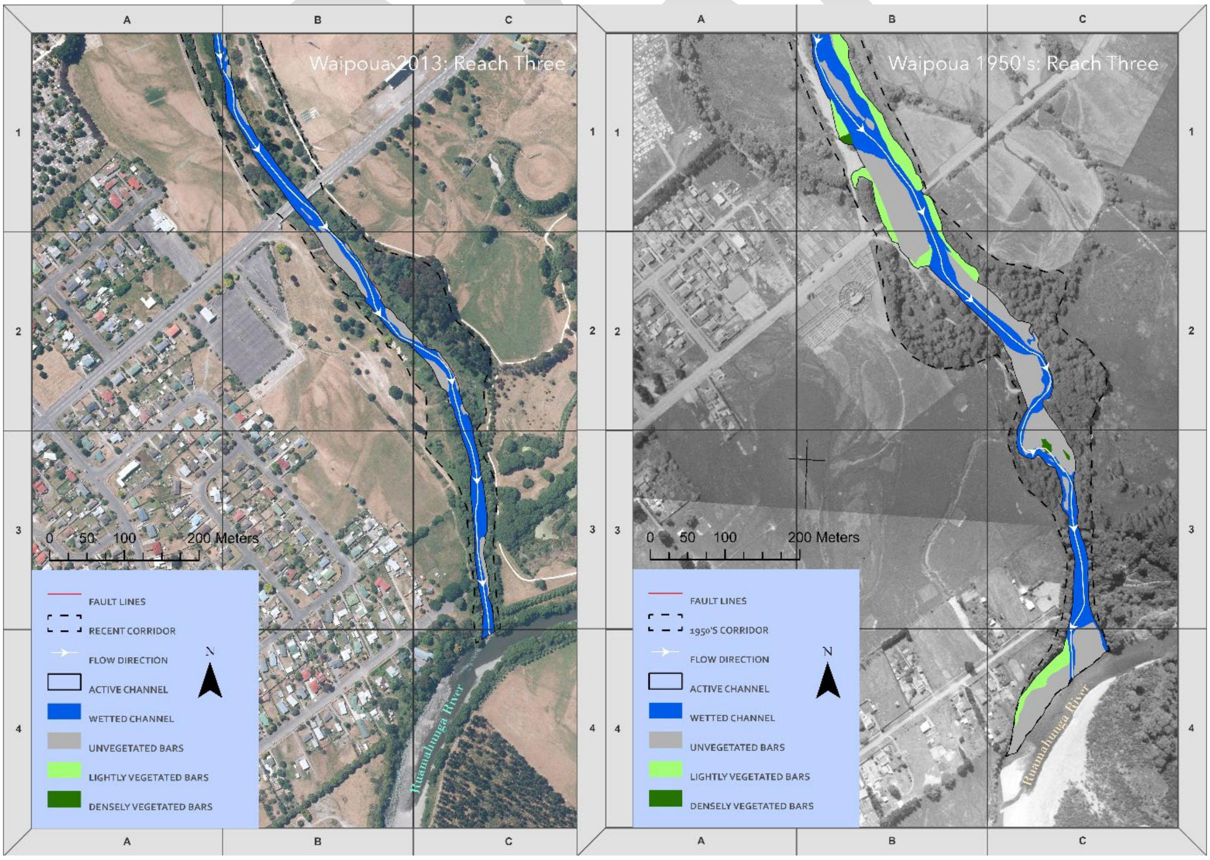


Figure 22. Lower Waipoua geomorphology (reach 3.8).

2.2.2 Mangatarere

Figures 23-37 show the interpretive channel geomorphology mapped for the Mangatarere River in 1953 and 2014 , progressing from upstream to downstream.

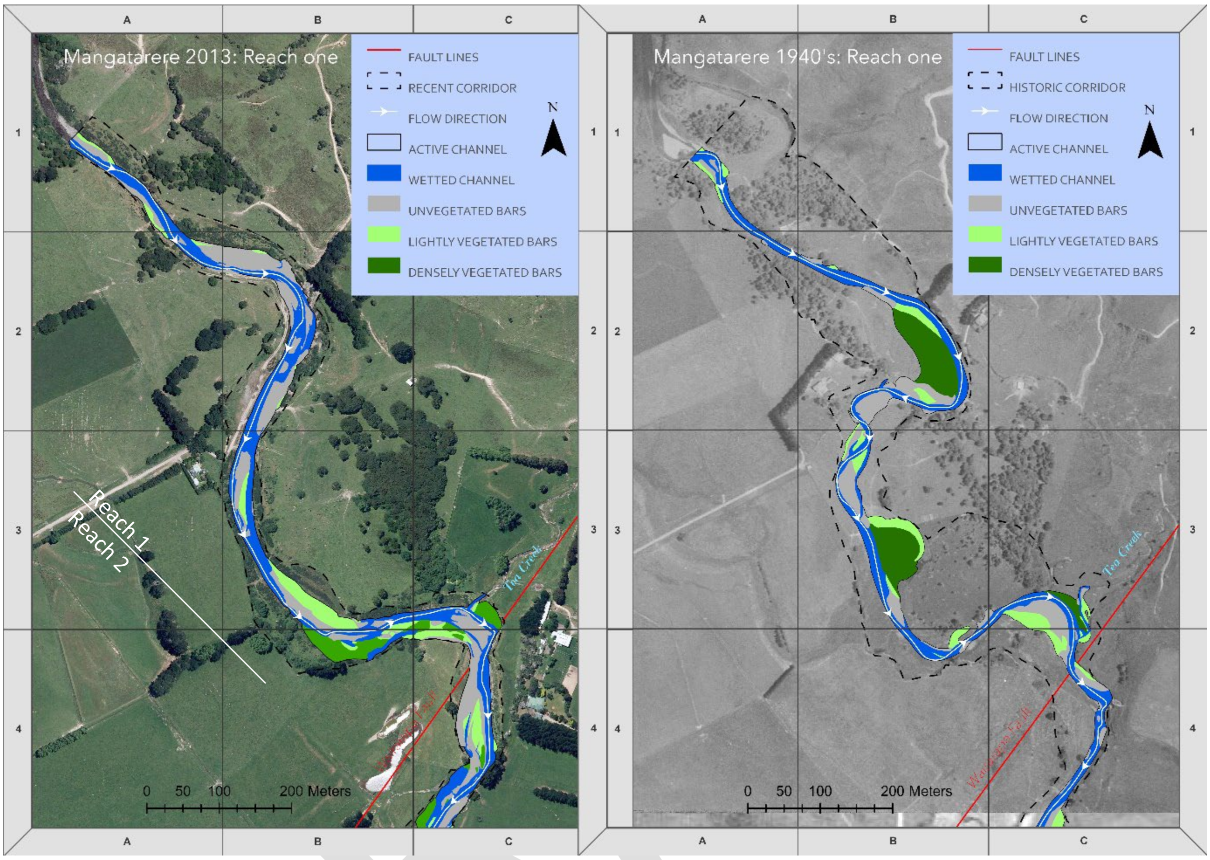


Figure 23. Upper Mangatarere geomorphology (Reach 1.0).

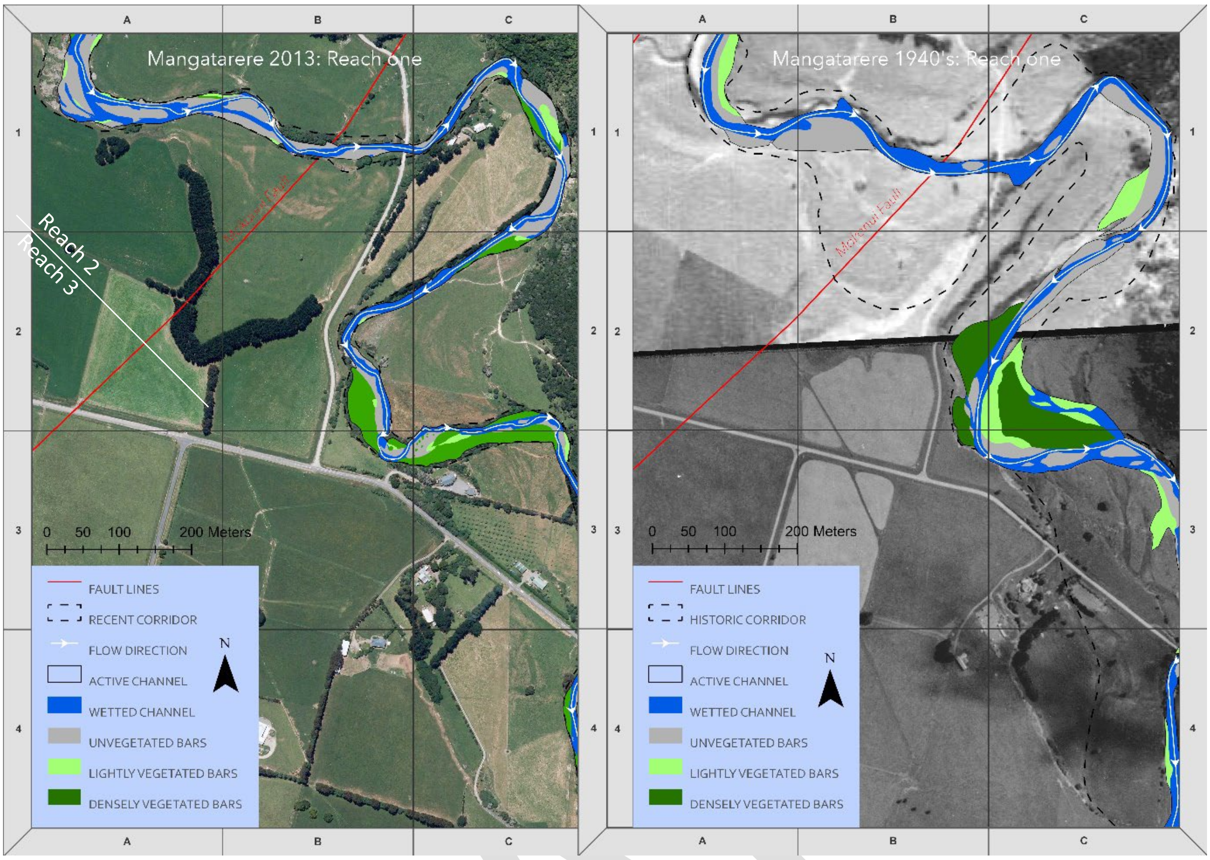


Figure 24. Upper Mangatarere geomorphology (Reach 1.1).

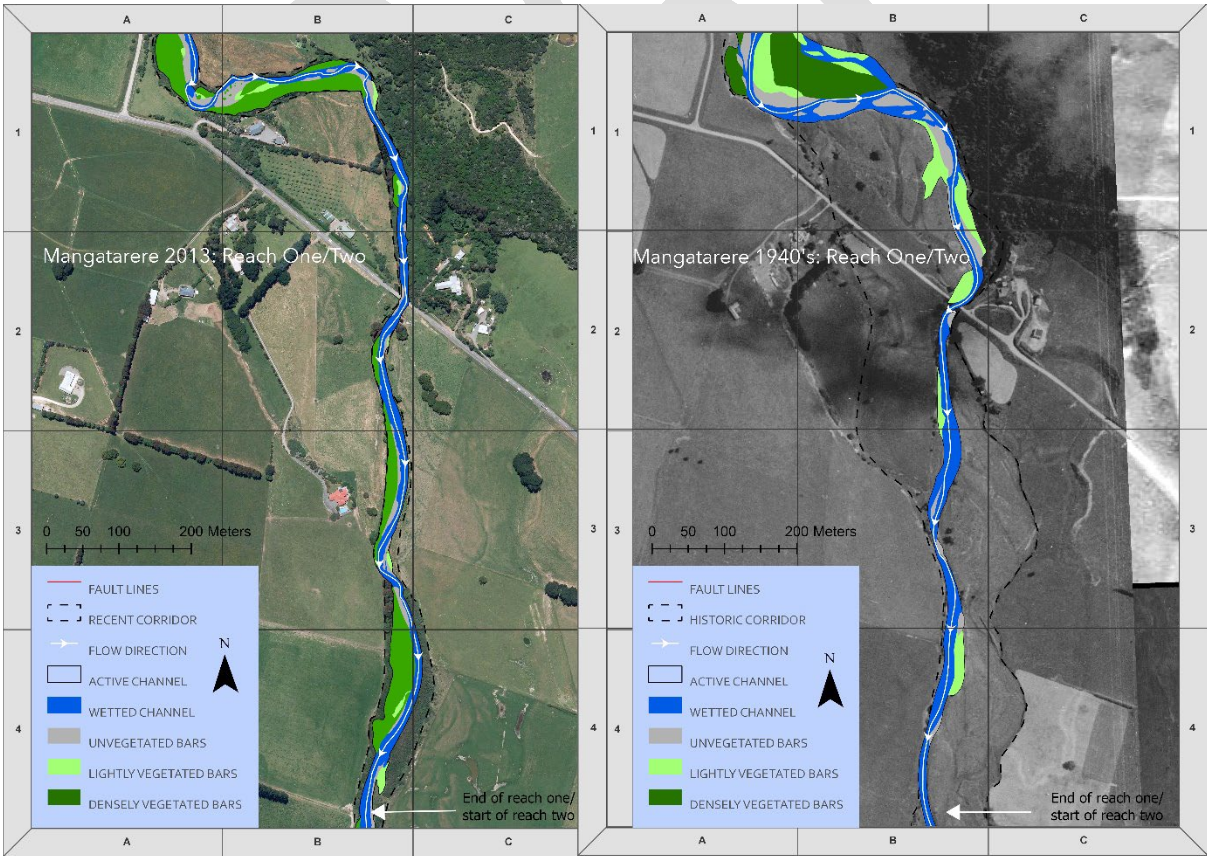


Figure 25. Upper Mangatarere geomorphology (Reach 1.2).

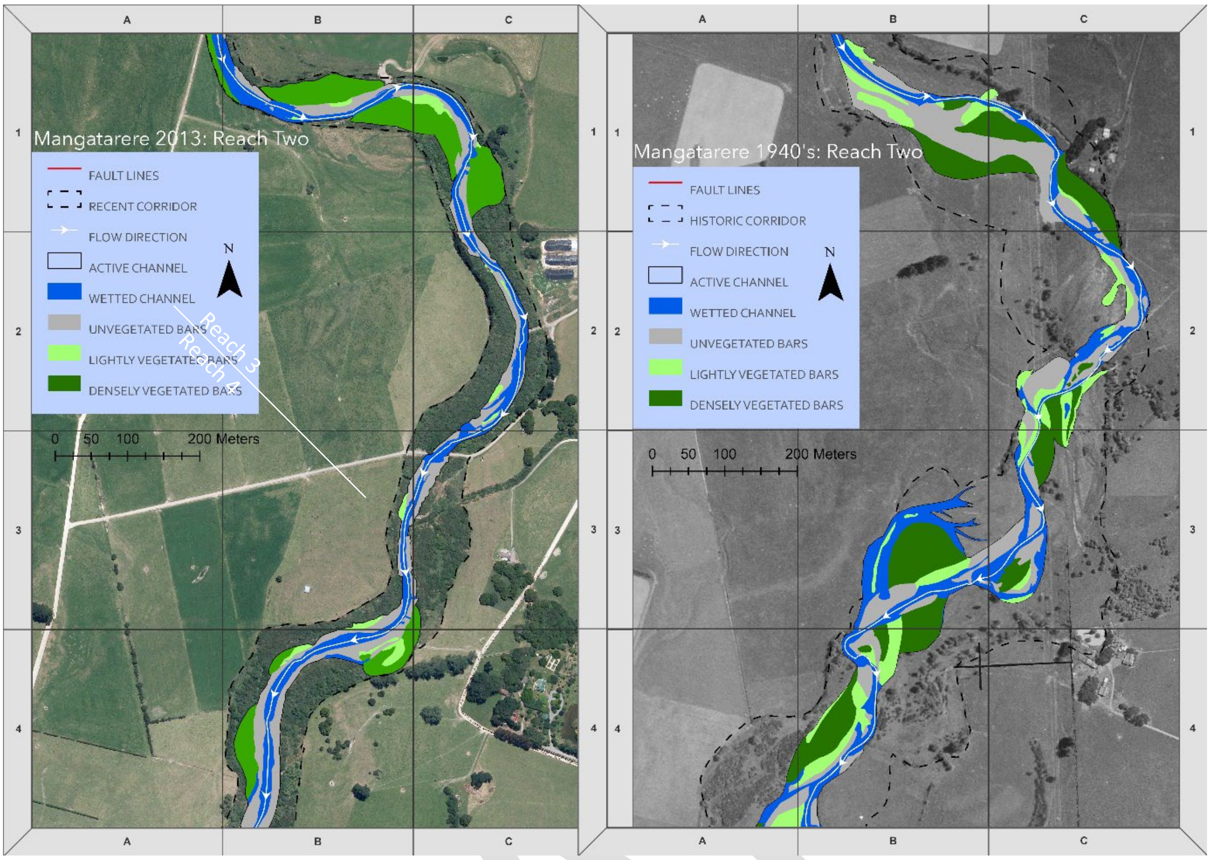


Figure 26. Middle Mangatarere geomorphology (Reach 2.0).

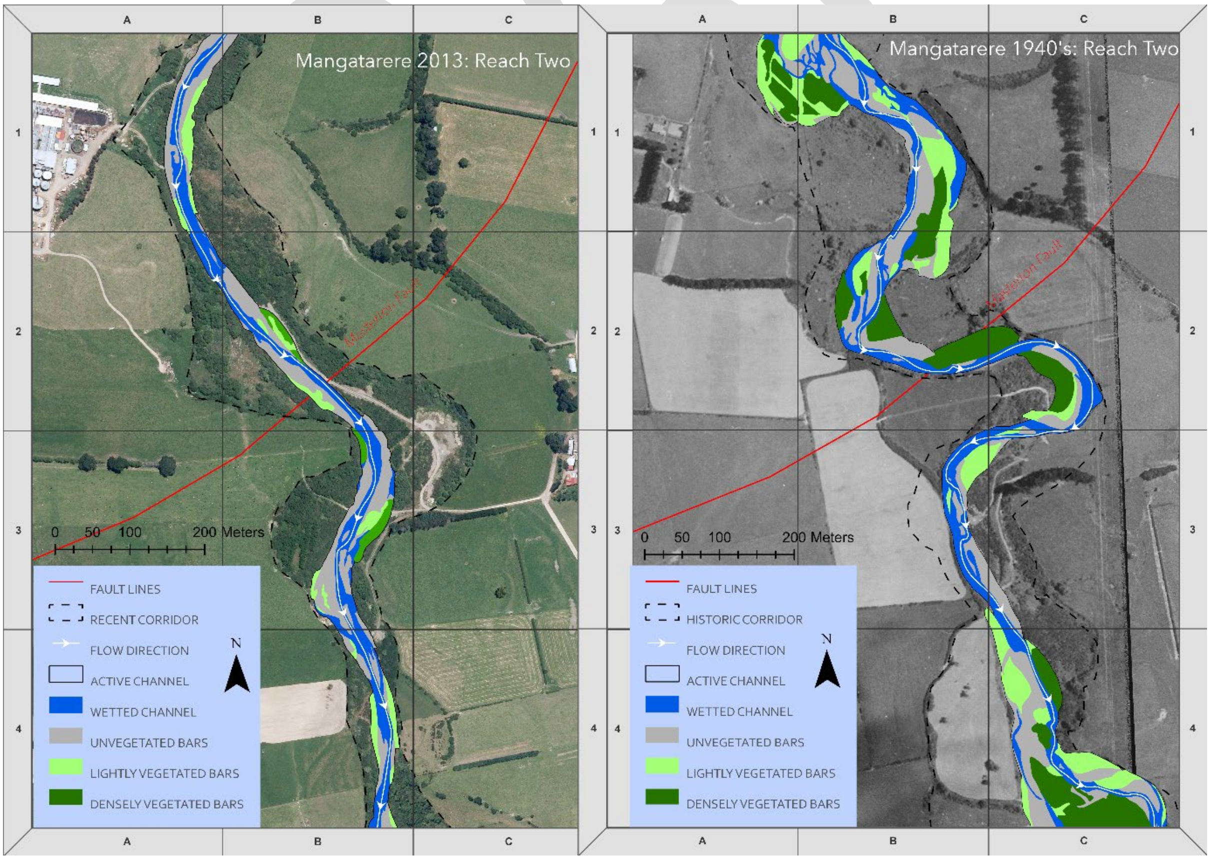


Figure 27. Upper Mangatarere geomorphology (Reach 2.1).

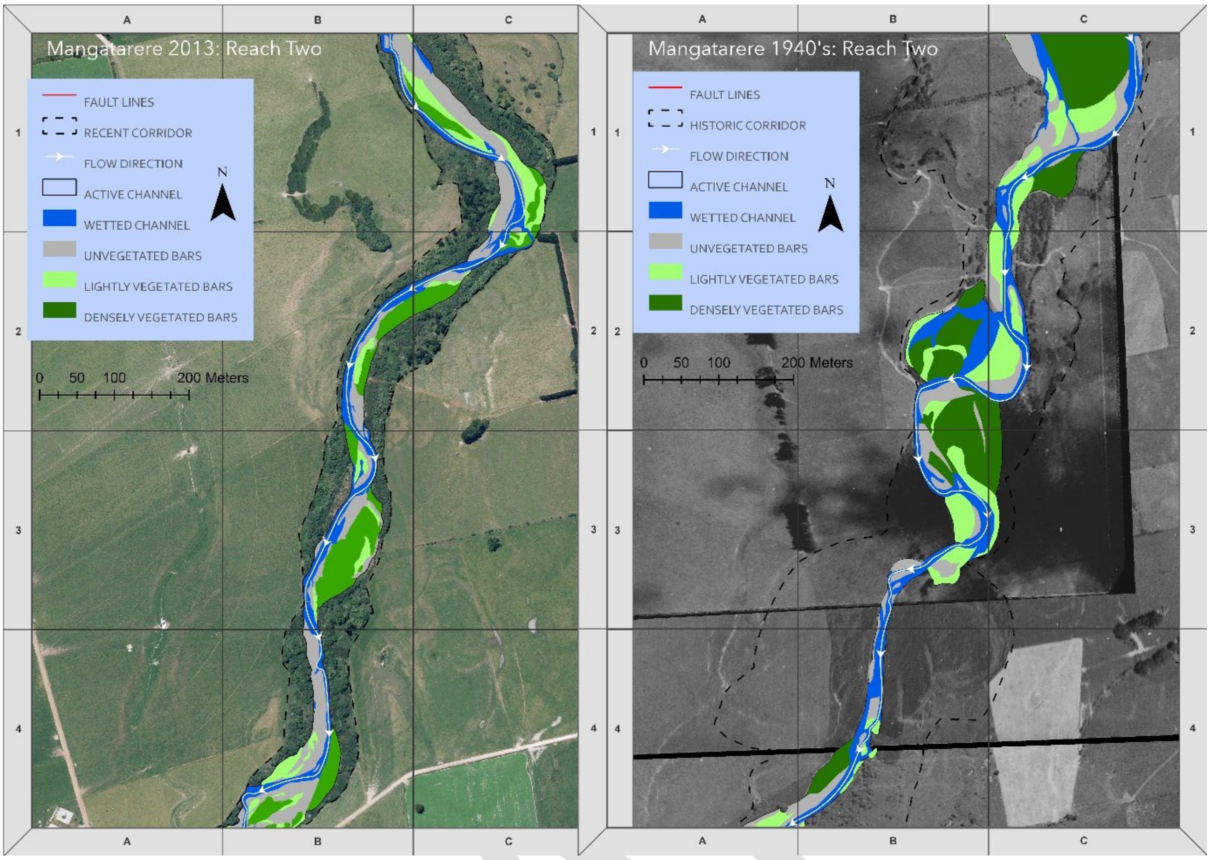


Figure 28. Upper Mangatarere geomorphology (Reach 2.2).

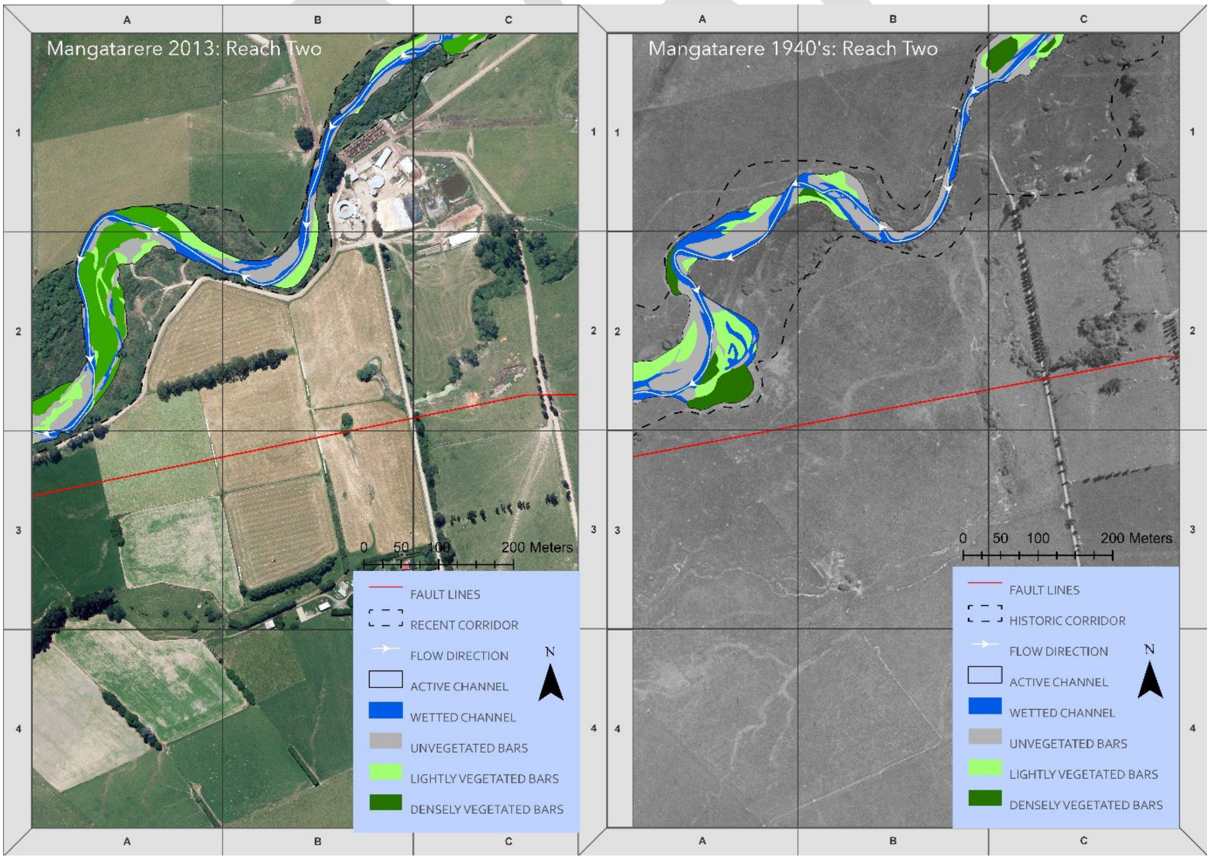


Figure 29. Upper Mangatarere geomorphology (Reach 2.3).

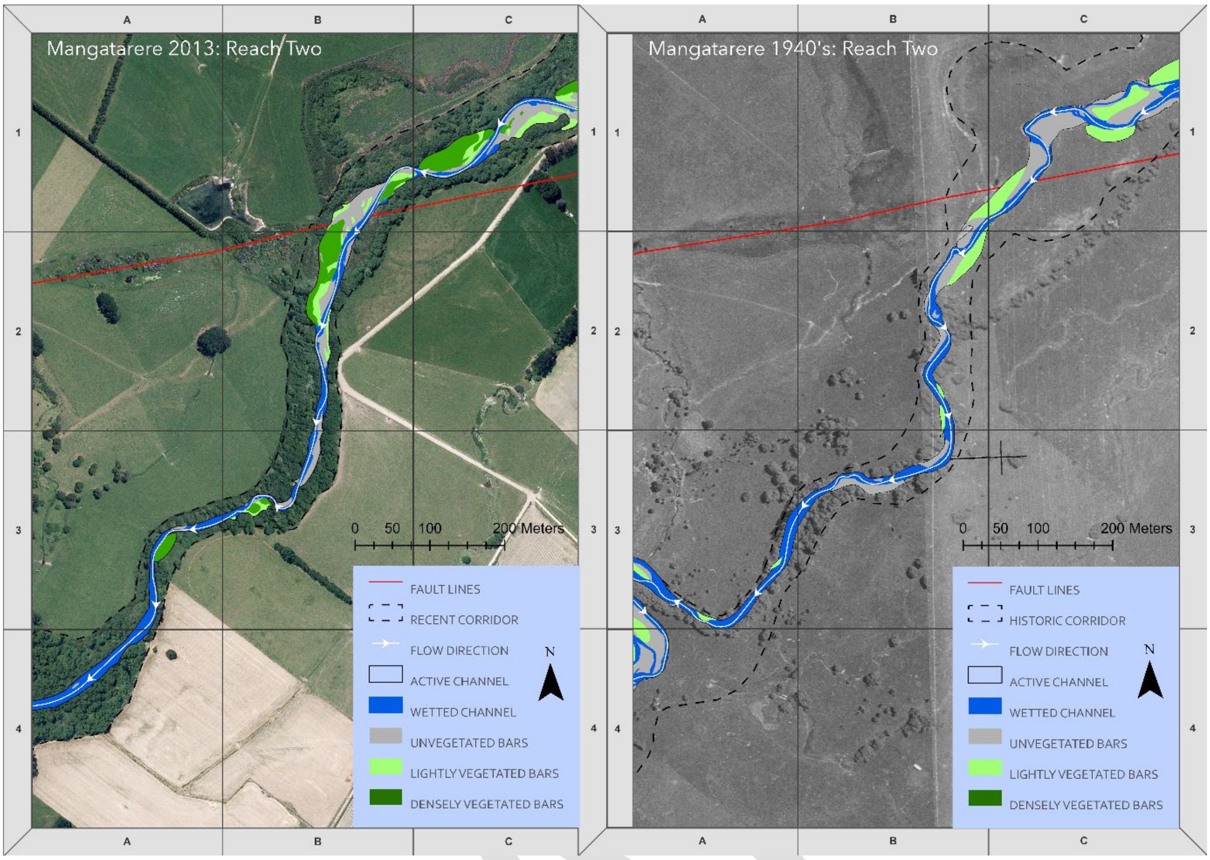


Figure 30. Upper Mangatarere geomorphology (Reach 2.4).

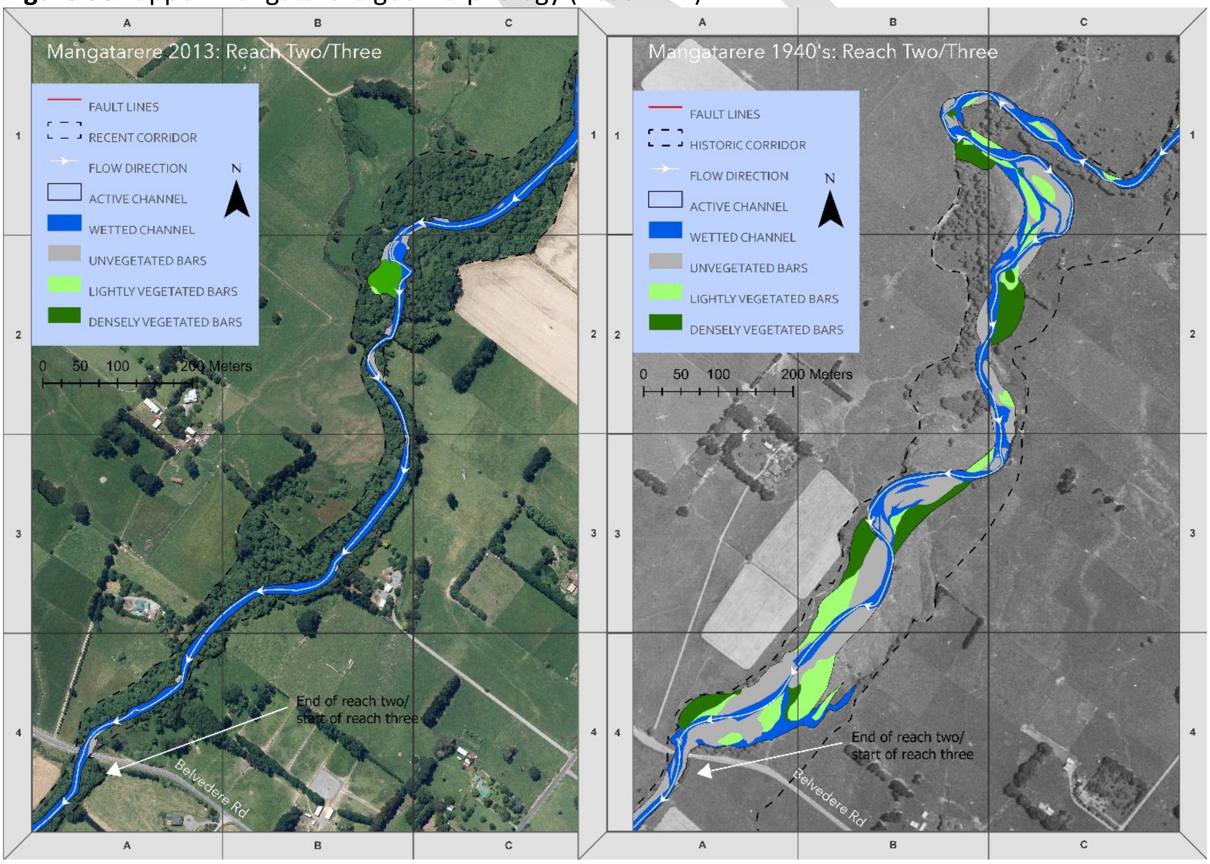


Figure 31. Upper Mangatarere geomorphology (Reach 2.5).

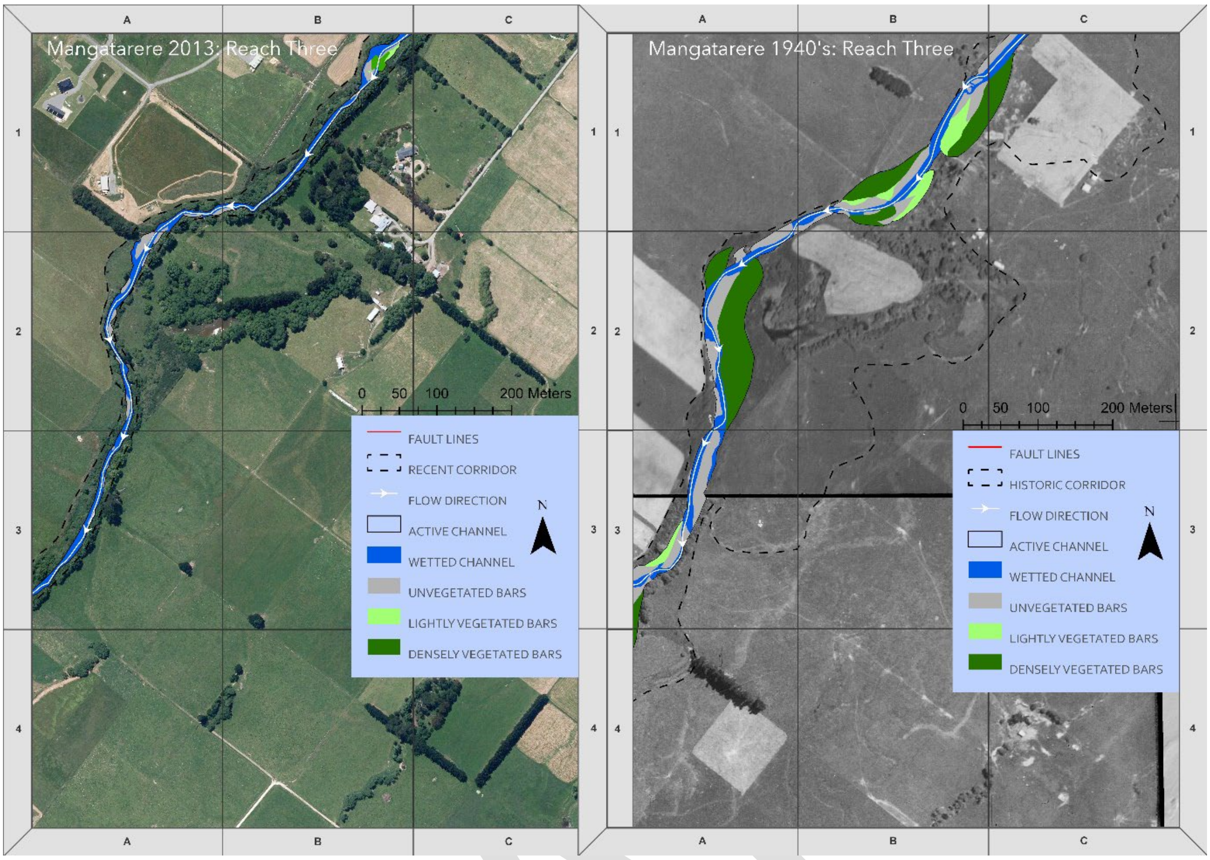


Figure 32. Lower Mangatarere geomorphology (Reach 3.0).

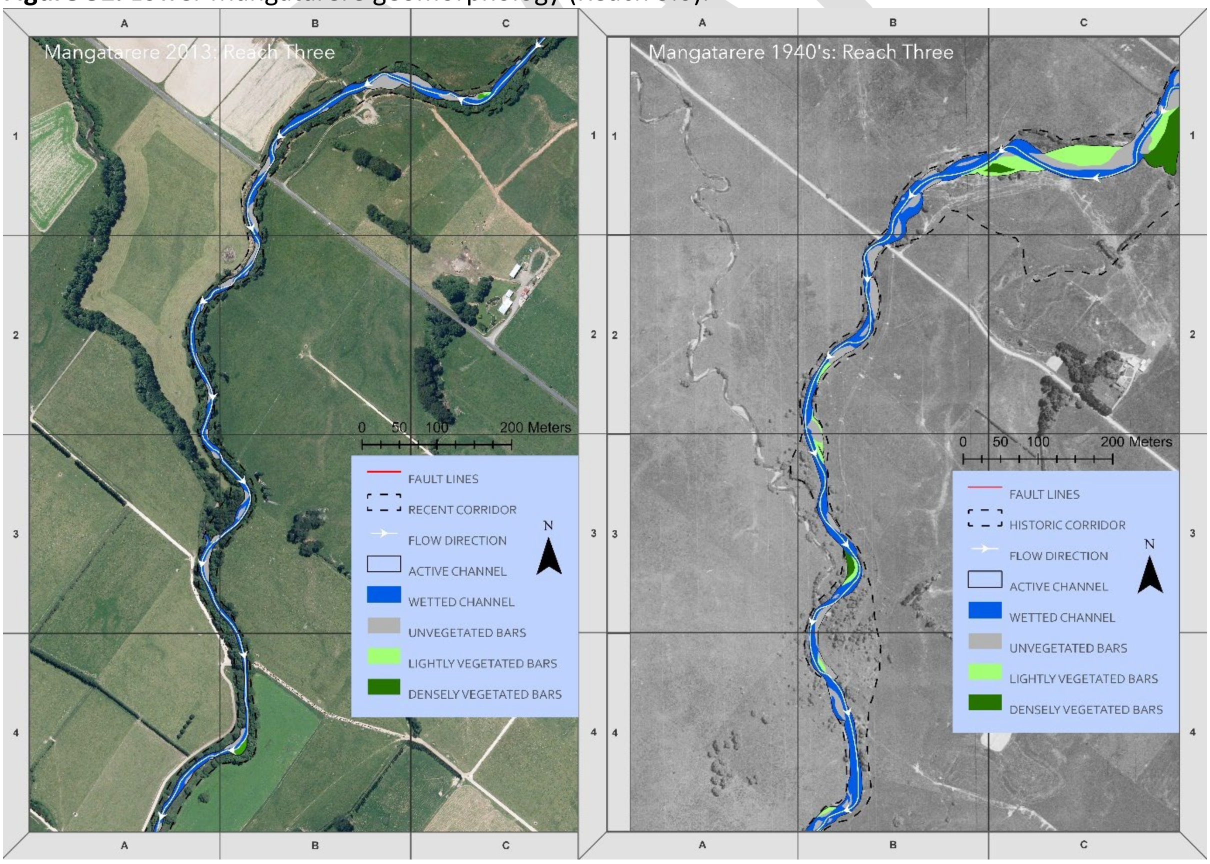


Figure 33. Lower Mangatarere geomorphology (Reach 3.1).

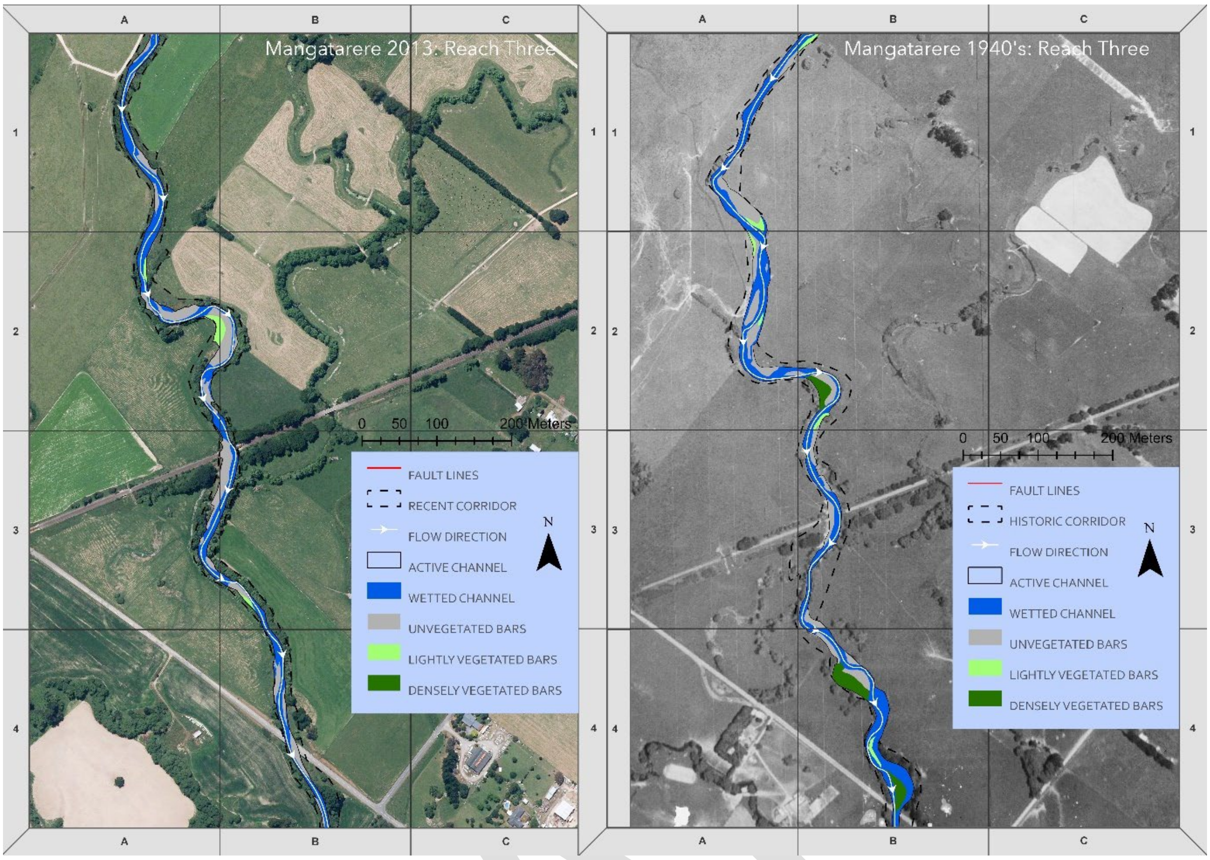


Figure 34. Lower Mangatarere geomorphology (Reach 3.2).

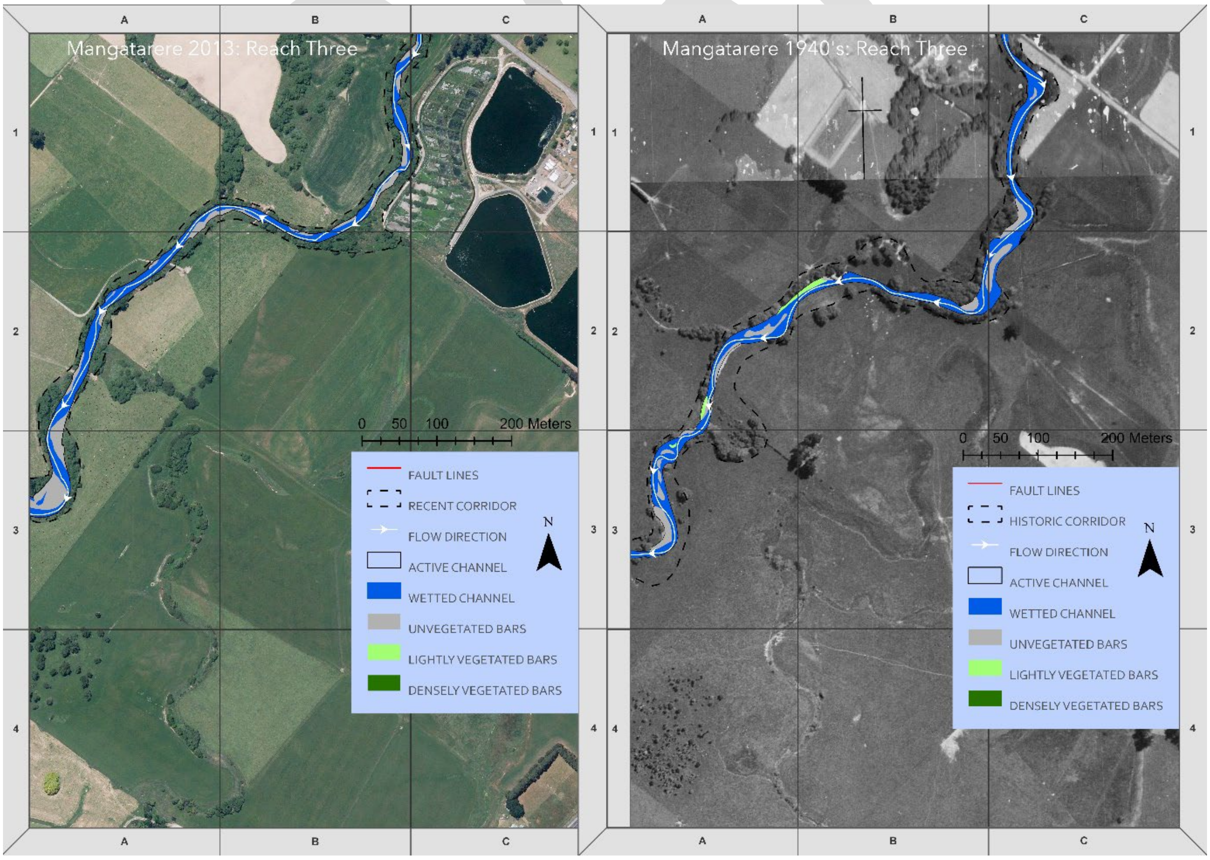


Figure 35. Lower Mangatarere geomorphology (Reach 3.3).

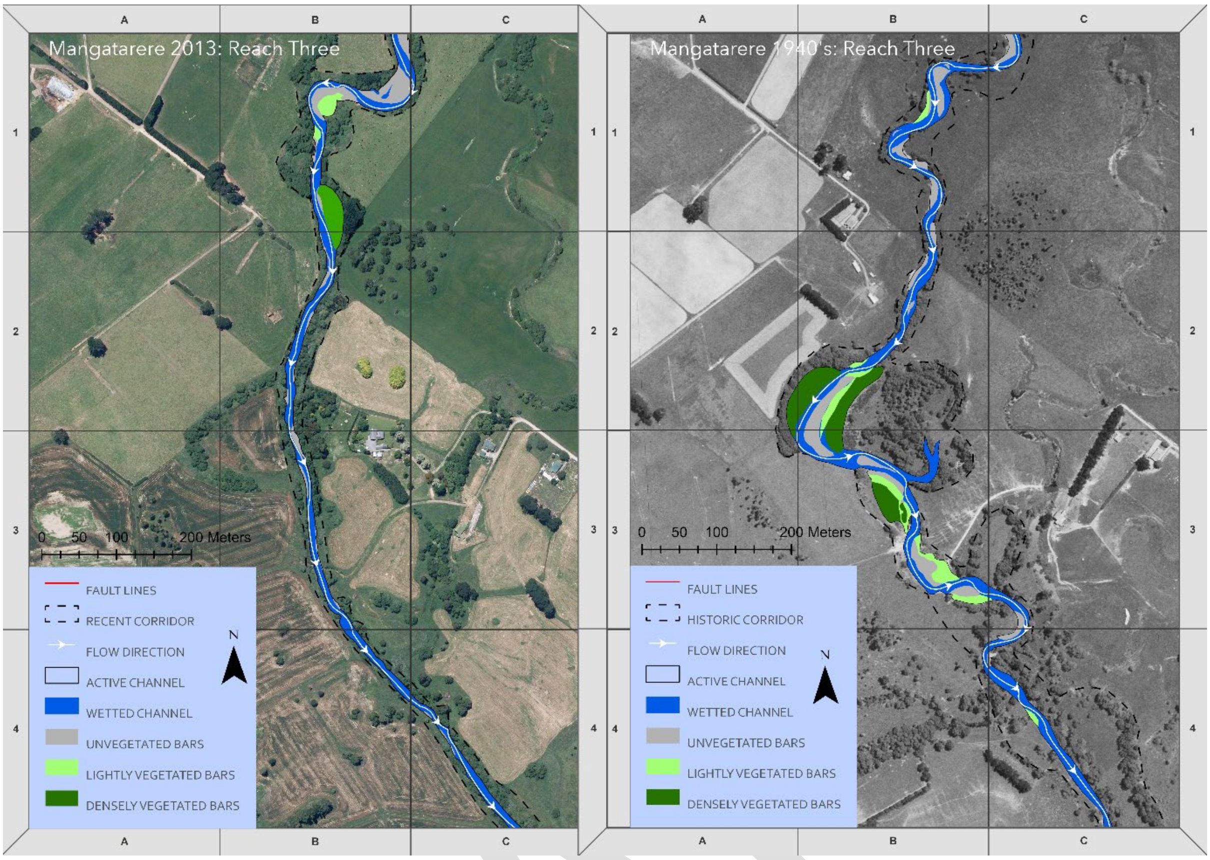


Figure 36. Lower Mangatarere geomorphology (Reach 3.4).

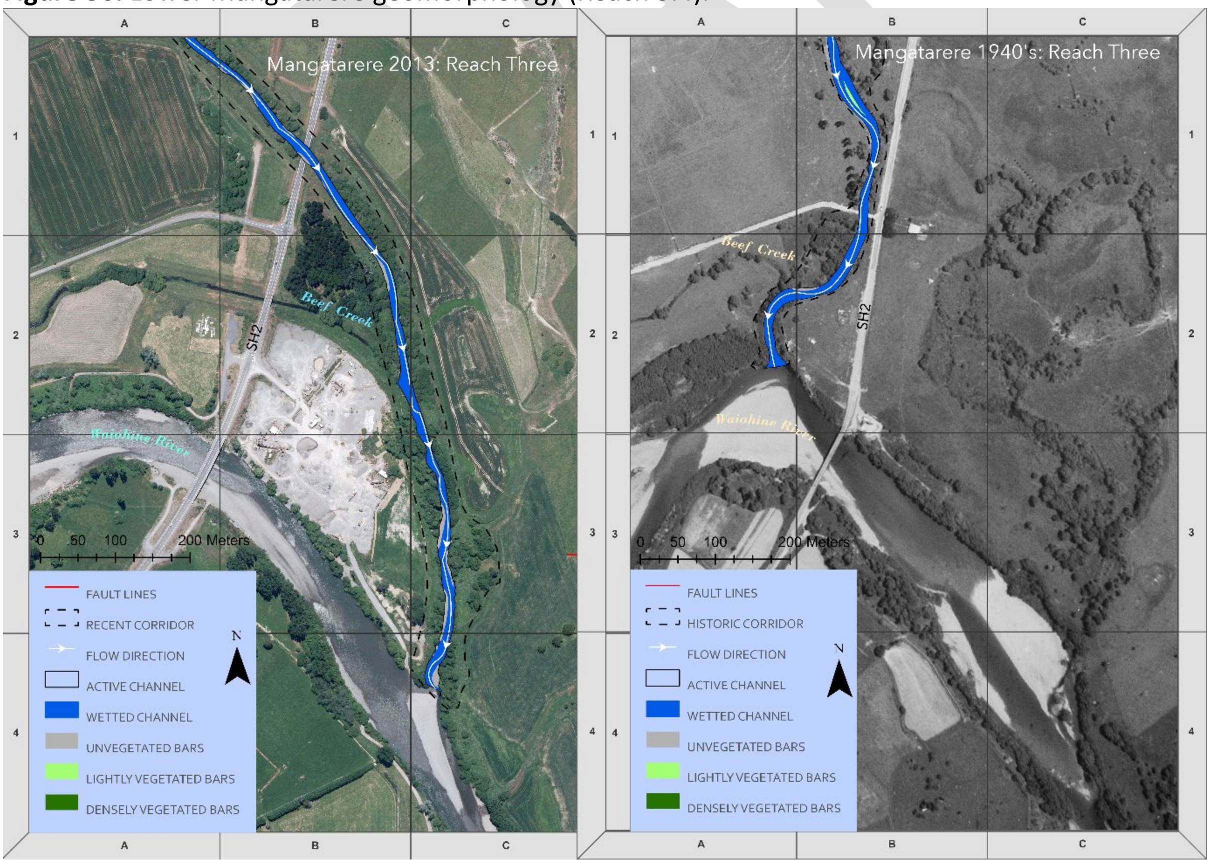


Figure 37. Lower Mangatarere geomorphology (Reach 3.5).

3. Natural Character Index (NCI)

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 Waipoua and Mangatarere reaches (Figures 5-37) involves generating an NCI ratio of ‘observed’ i.e., contemporary geomorphic units, over ‘expected’ i.e., the nature of corresponding geomorphic units in the 1940’s/50’s (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, or details of sub-barscale geomorphology (Fuller et al., 2020).

The details of river characteristics listed in 2.1 and mapped in 2.2 have been 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., area, length, or index has increased, the ratio will exceed 1.00. Generating an NCI ratio is demonstrated for the Waipoua active channel:

$$\text{NCI active channel area} = \frac{\text{Area in 2013}}{\text{Area in 1940s}} = \frac{44.6\ \text{ha}}{87.9\text{ha}} = 0.51$$

This result indicates a 49% reduction in active channel area along the entirety of the Waipoua along reach 1 and 2 (cf. Figures 5-13) between the 1940s and 2013.

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).

3.2 NCI Results

Tables 1 -4 provide the NCI ratios for the Waipoua reaches and Tables 5-8 for the Mangatarere. These values are summarised graphically in Figures 38-41 (Waipoua) and Figures 45-49 (Mangatarere).

3.2.1 Waipoua NCI

Table 1 Waipoua NCI data for reach 1.

Parameter	1940s	2013	NCI
Active channel area	17.5 ha	13.6 ha	0.77
Unvegetated bar area	3.4 ha	2.2 ha	0.65
Lightly vegetated bar area	3.0 ha	1.9 ha	0.65
Densely vegetated bar area	3.8 ha	3.8 ha	1.00
Wetted channel area	7.3 ha	5.5 ha	0.75
Wetted channel length	14451.4 m	13234.7 m	0.92
Midline length	5027.1 m	4825.2 m	0.96
Braiding Index (Brice, 1960)	0.76	0.46	0.61
Sinuosity	1.68 (M)	1.61 (M)	0.96

Note: A river is classified as meandering (M) where sinuosity exceeds 1.5 and as (at least partially) braided (B) where Brice's braiding index exceeds 1.

Figure 38. Summary of changes in channel characteristics (NCI, areas and composition) in the Waipoua river in reach one 1940s – 2013.

Reach one indicates a 23% reduction in the active channel, a 35% reduction in unvegetated bars, and a 35% reduction in lightly vegetated bars. Wetted channel area has dropped by 25% and wetted channel length by 8%. Densley vegetated bars remain the same **(Table 1, figure 38)**.

Table 2 Waipoua NCI data for reach 2.

Parameter	1940s	2013	NCI
Active channel area	70.4 ha	31.0 ha	0.44
Unvegetated bar area	25.0 ha	10.9 ha	0.44
Lightly vegetated bar area	8.0 ha	2.7 ha	0.34
Densely vegetated bar area	18.9 ha	6.2 ha	0.33
Wetted channel area	18.5 ha	11.3 ha	0.61
Wetted channel length	36383.3 m	20416.8 m	0.56
Midline length	8881.8 m	7763.1 m	0.87
Braiding Index (Brice, 1960)	1.14 (B)	0.23	0.20
Sinuosity	1.46	1.27	0.87

Note: A river is classified as meandering (M) where sinuosity exceeds 1.5 and as (at least partially) braided (B) where Brice's braiding index exceeds 1.

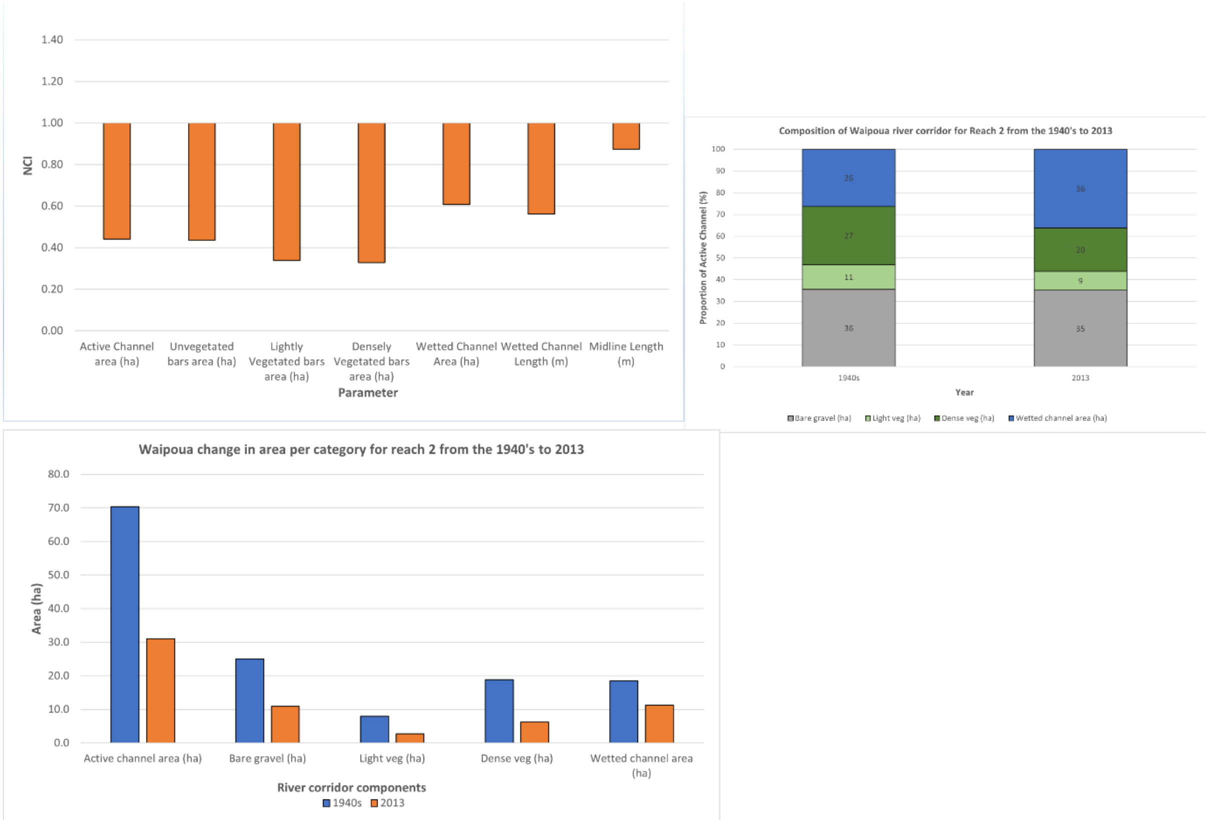


Figure 39. Summary of changes in channel characteristics (NCI, areas and composition) in the Waipoua river in reach two 1940s – 2013.

In reach two, there Is a 56% reduction in the active channel area, a 56% reduction in unvegetated bars (bare gravel), a 66% reduction in lightly vegetated bars, a 67% reduction in densely vegetated bars, a 39% reduction in wetted channel area, and a 13% reduction in midline length **(Table 2, Figure 39)**.

Table 3 Waipoua NCI data for reach 3.

Parameter	1950s	2013	NCI
Active channel area	34.2 ha	31.3 ha	0.92
Unvegetated bar area	8.2 ha	7.0 ha	0.85
Lightly vegetated bar area	3.4 ha	3.4 ha	0.99
Densely vegetated bar area	3.5 ha	6.5 ha	1.87
Wetted channel area	19.1 ha	14.4 ha	0.75
Wetted channel length	25772.4 m	24794.5 m	0.96
Midline length	11188.0 m	10909.5 m	0.98
Braiding Index (Brice, 1960)	0.26	0.13	0.5
Sinuosity	1.39	1.36	0.98

Note: A river is classified as meandering (M) where sinuosity exceeds 1.5 and as (at least partially) braided (B) where Brice's braiding index exceeds 1.

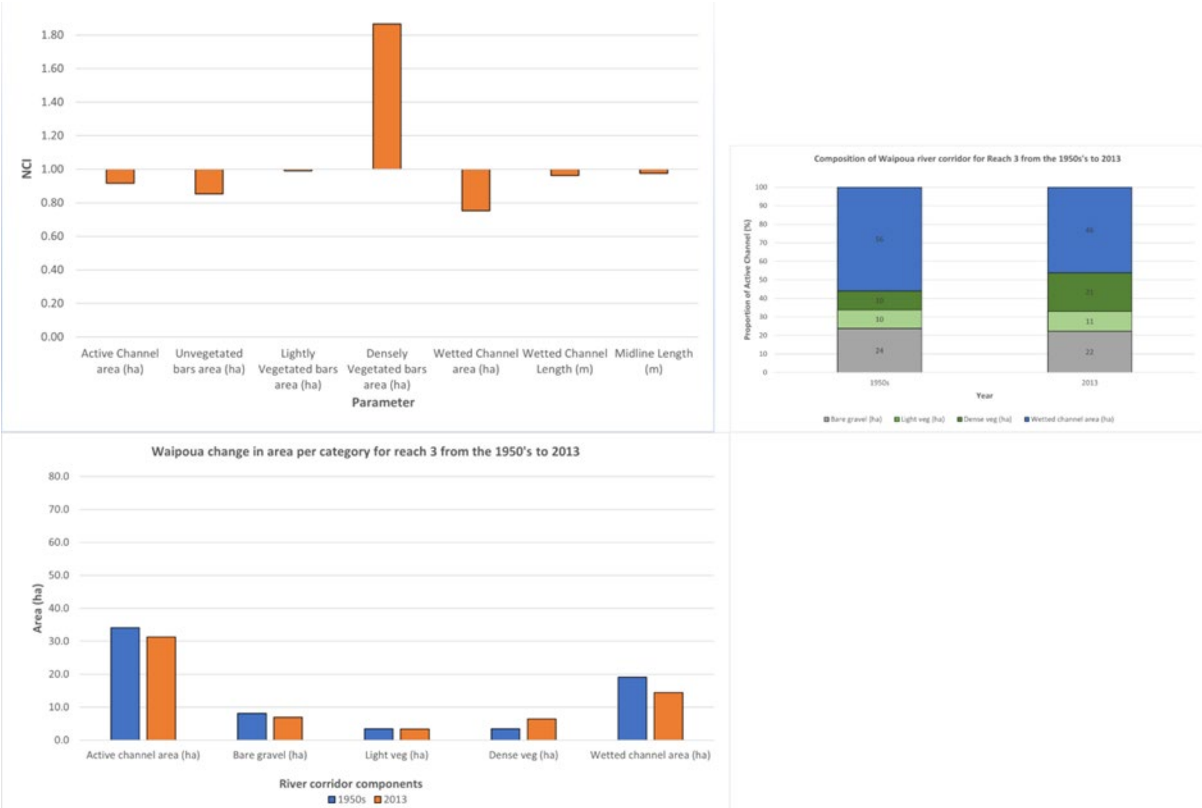


Figure 40. Summary of changes in channel characteristics (NCI, areas and composition) in the Waipoua river in reach three 1950s – 2013.

Densley vegetated bars show a significant increase in 2013 vs 1950, with an 87 % gain in dense vegetation. Wetted channel length has decreased by 25%, and unvegetated bars (bare gravel) has decreased by 15% (Table 3, Figure 40).

Table 4 Waipoua NCI data for reach 1 and 2 combined.

Parameter	1940s	2013	NCI
Active channel area	87.9 ha	44.6 ha	0.51
Unvegetated bar area	28.4 ha	13.1 ha	0.46
Lightly vegetated bar area	11.0 ha	4.6 ha	0.42
Densely vegetated bar area	22.7 ha	10.0 ha	0.44
Wetted channel area	25.8 ha	16.7 ha	0.65
Wetted channel length	50834.7 (m)	33636.2 (m)	0.66
Midline length	13908.8 (m)	12588.3 (m)	0.91
Braiding Index (Brice, 1960)	1.02	0.31	0.31
Sinuosity	1.53	1.38	0.90

NB: Clear imagery was only available for the 1940s in reach one and two, and not for reach three. 1950's imagery was clear enough; however, it would be unreasonable to apply a full NCI on all three reaches combined given that the later imagery was from the following decade and the lower reaches were already heavily modified by this point. An alternative analysis of maps from the late 19th century through Masterton is provided in Figures 42 – 44.

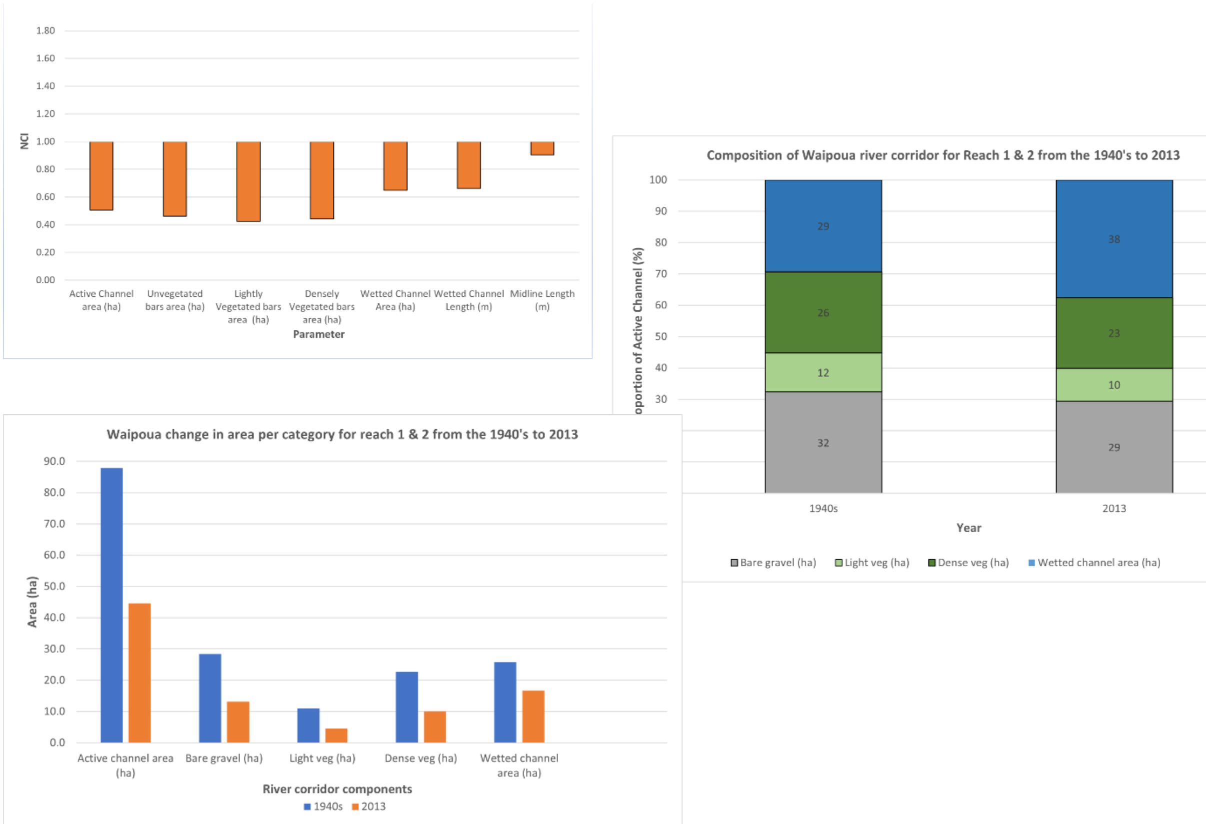


Figure 41. Summary of changes in channel characteristics (NCI, areas and composition) in the Waipoua river in reach one and two 1940s – 2013.

The most significant changes in the Waipoua river corridor in reach one and two combined are a 49% reduction in active channel area, a 58% reduction in unvegetated bars bar (bare gravel), and a 56% reduction in densely vegetated bars. Wetted channel area has reduced by 35% and midline length by 34% (Table 4, Figure 41).

Figure 42. The 1884 river channel with the 2013 channel overlaying.

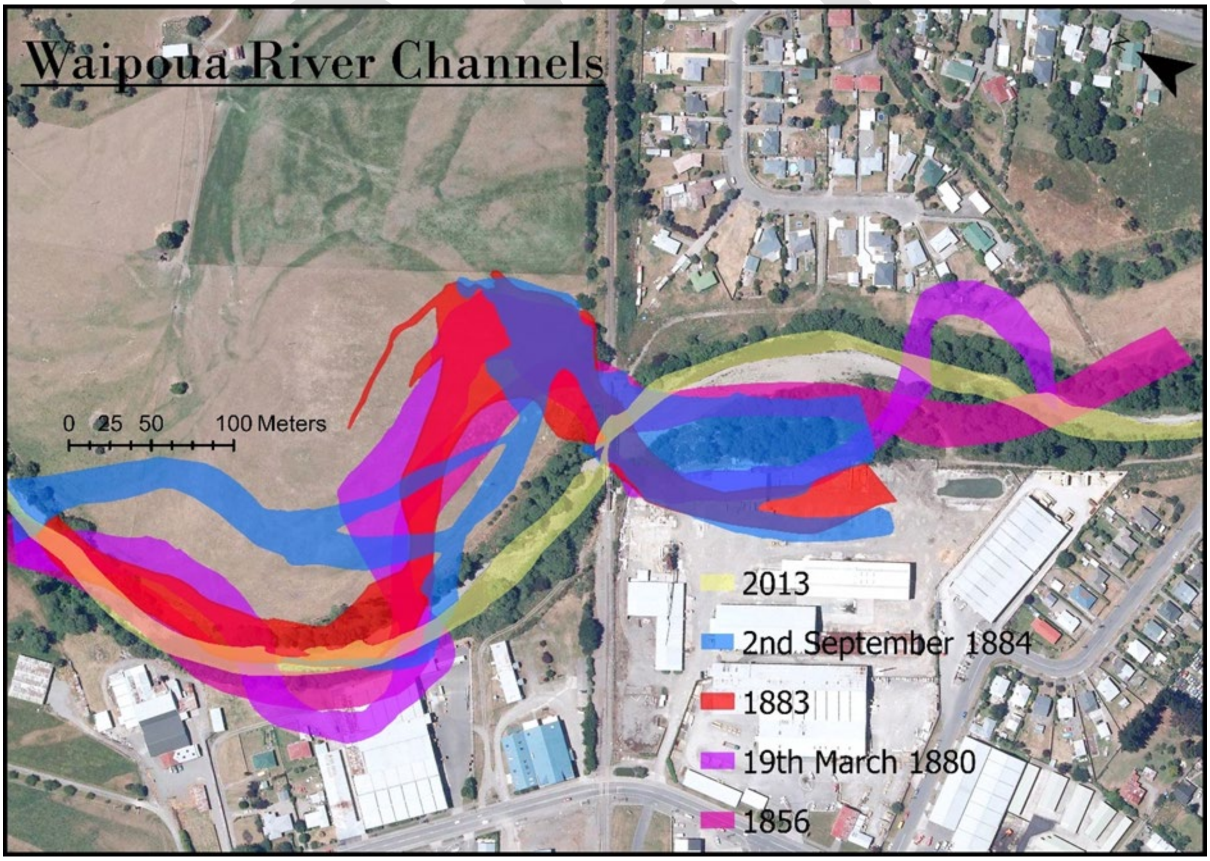


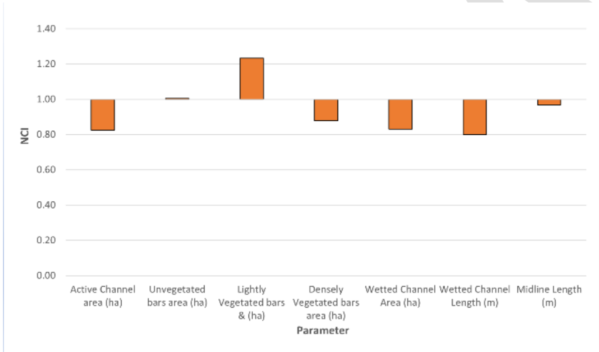
Figure 43. Multiple dates showing the location of the Waipoua's channels at the Masterton railway bridge.

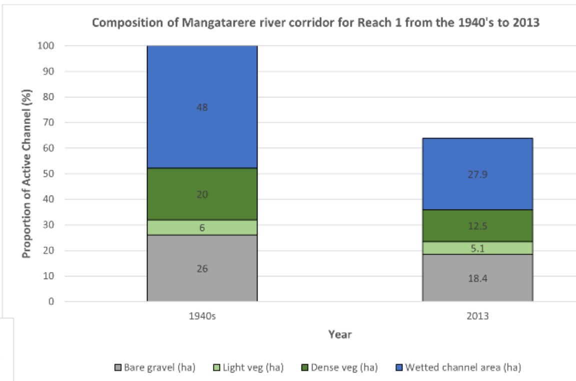
Figure 44. The 1884 channel fitted with the 1886 channel.

3.2.2 Mangatarere NCI

Table 5 Mangatarere NCI for reach 1.

Parameter	1940s	2013	NCI
Active channel area	12.8 ha	10.6	0.83
Unvegetated bar area	3.0 ha	3.0	1.01
Lightly vegetated bar area	0.7 ha	0.8	1.23
Densely vegetated bar area	2.3 ha	2.1	0.88
Wetted channel area	5.5 ha	4.6	0.83
Wetted channel length	10797.5 m	8636.5	0.80
Midline length	4416.8 m	4278.0	0.97
Braiding Index (Brice, 1960)	0.38	0.38	1.0
Sinuosity	1.65 (M)	1.6 (M)	0.97





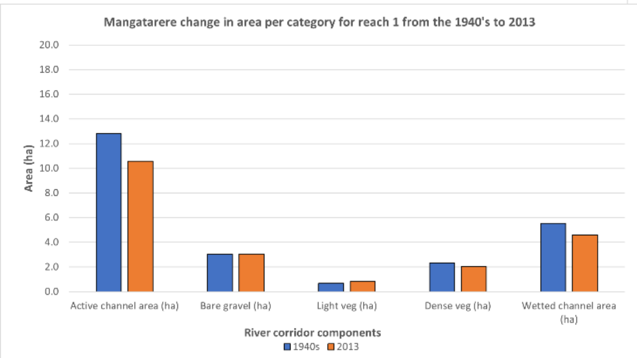


Figure 45. Summary of changes in channel characteristics (NCI, areas and composition) in the Mangatarere for reach 1, 1940s – 2013.

Overall, there is a drop in most parameters, notably a 17% drop in both active channel area and wetted channel area. Channel length is 20% shorter, and densely vegetated bars by 12%. Midline length and unvegetated bars remain the same. There is a 23% increase in lightly vegetated bars.

Table 6 Mangatarere NCI for reach 2.

Parameter	1940s	2013	NCI
Active channel area	40.8 ha	31.0 ha	0.76
Unvegetated bar area	11.2 ha	10.9 ha	0.98
Lightly vegetated bar area	7.7 ha	2.7 ha	0.35
Densely vegetated bar area	9.7 ha	6.2 ha	0.64
Wetted channel area	12.3 ha	11.3 ha	0.91
Wetted channel length	30396.7 m	20416.8 m	0.67
Midline length	8938.0 m	7763.1 m	0.87
Braiding Index (Brice, 1960)	0.76	0.12	0.16
Sinuosity	1.61 (M)	1.40	0.87

Figure 46. Summary of changes in channel characteristics (NCI, areas and composition) in the Mangatarere for reach 2, 1940's – 2013.

Lightly vegetated bars see a 65% drop while unvegetated bars remain similar - Note that in reach 2, the 2013 imagery shows evidence for recent cross blading (Figures 26, 27, 28). Densely vegetated bars have dropped by 36%, wetted channel area by 33%**,** active channel area by 24%, midline length by 13%, and wetted channel area the least, by 9% (Table 6, Figure 46).

Table 7 Mangatarere NCI for reach 3.

Parameter	1940's	2013	NCI
Active channel area	14.4 ha	7.5 ha	0.52
Unvegetated bar area	3.1 ha	1.7 ha	0.53
Lightly vegetated bar area	0.1 ha	0.2 ha	1.18
Densely vegetated bar area	2.5 ha	0.2 ha	0.09
Wetted channel area	7.5 ha	5.5 ha	0.73
Wetted channel length	17974.4 m	15568.4 m	0.87
Midline length	7345.0 m	7289.7 m	0.99
Braiding Index (Brice, 1960)	0.13	0.02	0.15
Sinuosity	1.41	1.32	0.94

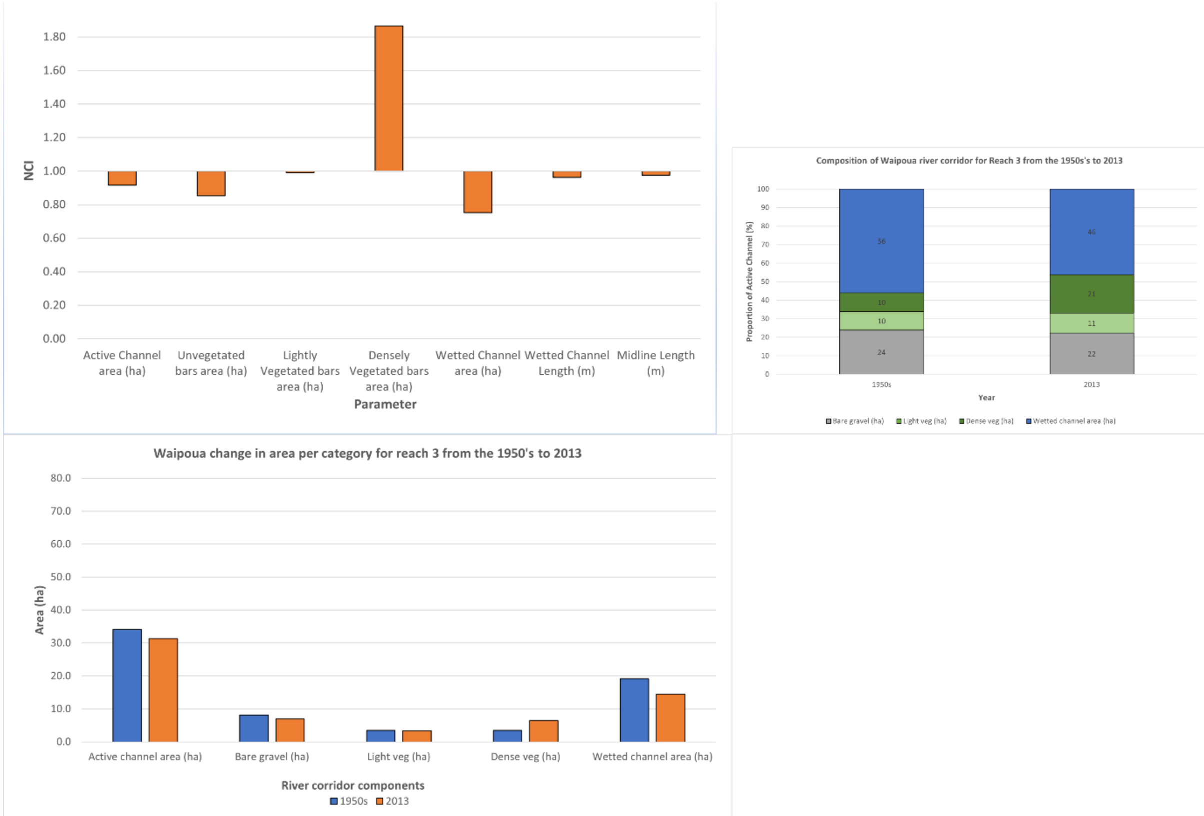


Figure 47. Summary of changes in channel characteristics (NCI, areas and composition) in the Mangatarere for reach 1, 1940s – 2013.

There is a 90% reduction in densely vegetated bars which likely reflects the 48% reduction in the active channel area. Unvegetated bars see a 47% reduction while lightly vegetated bars see an 18% increase Midline length remains ~ the same (Table 7, Figure 47).

Table 8 Mangatarere NCI for reach 1, 2 and 3.

Parameter	1940s	2013	NCI
Active channel area	68.0 ha	40.2 ha	0.6
Unvegetated bar area	17.3 ha	11.4 ha	0.66
Lightly vegetated bar area	8.5 ha	3.5 ha	0.41
Densely vegetated bar area	14.5 ha	7.7 ha	0.53
Wetted channel area	25.4 ha	23.7 ha	0.93
Wetted channel length	59168.6 m	43451.8 m	0.73
Midline length	20699.8 m	19214.9 m	0.93
Braiding Index (Brice, 1960)	0.49	0.14	0.29
Sinuosity	1.61 (M)	1.45	0.90

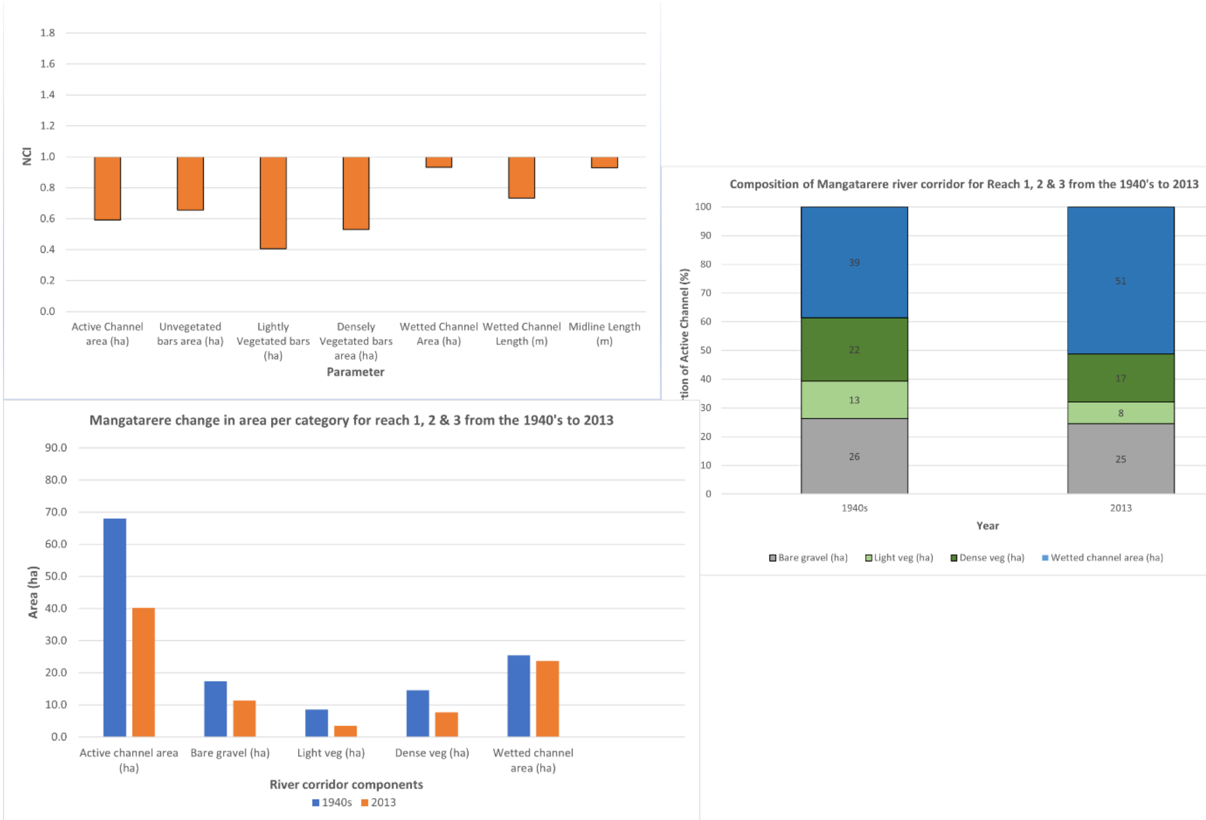


Figure 49. Summary of changes in channel characteristics (NCI, areas and composition) in the Mangatarere for reach 1, 2, 3 , 1940s – 2013.

Overall, there is a 40% reduction in the active channel, a 59% reduction in lightly vegetated bars, a 47% decrease in densely vegetated bars, a 34% drop In unvegetated bars, and a 27% decrease in wetted channel length, a 7% drop in both midline length and wetted channel area.

4. Discussion

4.1 Overview

In both the Waipoua and Mangatarere, NCI analysis has quantified a reduction in nearly all parameters measured with major reductions in the extents of the active channel area (Mangatarere 40%, and Waipoua 50%) (Tables 1 - 8). In reach 3 of the Waipoua, dense vegetation has increased. While overall vegetation area has decreased, since the active channel area has also decreased, the proportion in terms of active channel composition has increased (Figure 40). Channel narrowing is evident through all reaches of the Waipoua but of most concern is reach 2 and 3. The 1855 Wairarapa earthquake has likely played a key role in the activation and relaxation of both rivers in the late 1800s and early 1900s. However, river management since the 1940s is likely more responsible for their current composition and character.

4.2 Waipoua geomorphology and NCI

The upper Waipoua River (Reach 1, Figures 5-8) has the characteristics of a laterally active, sinuous gravel-bed river, with an insufficient number of medial bars in the 1940s to be classified as partially braided. Bends are evident and well developed and therefore the morphology is consistent with a meandering channel planform. Incision appears to be dominant which is indicated by the various flights of terraces on both sides of the main channel. This makes sense given its relative position upstream from the Wairarapa fault where a change in base level takes place. The overall channel morphology is retained in 2013, but the active channel corridor is narrower, with results showing a 23% reduction in active channel area (Table 1, Figure 38). Some movement has occurred over the 70-year period.

Reach 2 in 2013 is entirely different from that of the 1940s, where the 1940s channel displays characteristics of a laterally active wandering planform. Channel bifurcation is dominant in the 1940's, excluding the transition between reach one and two (Figure 8) where the Waipoua crosses the Wairarapa Fault scarp. There is an abundance of backwaters, medial bars, cutoffs, and local flow division. Of note, it appears that the 1884 channel at the start of reach 2 was positioned further to the true right (Figure 8), before re-entering into its original channel (Figure 11). The morphology of the 1884 channel is consistent with a meandering planform with a diverse array of backwaters and paleo channels which is evident by the preservation of geomorphic units. There is no evidence in the DEM to suggest that migration into the 1940s channel was gradual, rather, it appears to have avulsed. It has not been established when this occurred. This reach is classified as partially braided which is consistent with the transition across the Wairarapa fault, enhanced sediment supply following the 1855 earthquake, and a flood rich phase. Reach 2 displays characteristics of a nearly straight river in 2013, with little to no bends nor braiding in reach 2.1-2.2 (Figures 9-10). The overall river in 2013 shows a 56% reduction in both active channel area, unvegetated bars and a 66% reduction in lightly vegetated bars including a very significant drop in all other parameters (Table 2, Figure 39).

Reach 3 displays little change between the 1950's and 2013. While reach 3 is not classified as braided not meandering, it falls closest to meandering. The first three quarters of reach 3 from Wakamoekau Creek is laterally active and contains some well-developed bends. Paleo channels adjacent to the main channel suggest that this reach has actively meandered and wandered over recent centuries. The reach from the Masterton railway bridge the Ruamahunga confluence is nearly straight in both sets of imagery, although some bend development is evident ~250 metres upstream of the confluence in the 1950's. Nevertheless, densely vegetated bars have increased by 87% and unvegetated bars have dropped by 15% (Table 3, Figure 40).

We were able to establish a sinuosity value for the stretch of river from Bentley Street to the Colombo Road bridge just above the Ruamahunga confluence (Figure 42). Sinuosity values align with what is observed according to interpretation of the 1880s maps which show the morphology of a meandering river in the 19th century where extracted sinuosity values = 1.5 (meandering), while in 2013 sinuosity = 1.0 (straight). Meandering morphology is observed in the 1883 channel where the settlers have attempted to push the river back towards the train bridge to stop it out flanking the train bridge run up on the true right (Figure 43), therefore the river type may have been stable. Following the 1884 flood, the river shows a completely different wandering morphology conjunctive with aggradation and channel expansion. Very large fluvial deposits are present, as is channel bifurcation and avulsions on both the true left and right of the prior channel. Given the 1884 and 1886 map are in the same scale, overlap, and are only two years apart, it is not unreasonable to conclude that channel adjustment and expansion continued for quite some time following the 1884 flood (Figure 44). It is likely that the 1884 flood in combination with enhanced sediment supply from the 1855 earthquake led to a breach in threshold conditions to allow for a different river type to form quite rapidly. This may have been through the single 1884 flood event and/or for the following years until 1886 and onwards given the 19th century is known to have been a flood rich phase in the Manawatu/Wairarapa (Fuller et al., 2018).

Alongside the overall reduction in parameters measured for the NCI assessment, a focus on coherent reaches in the Waipoua River indicates that significant changes in river planform have occurred between the late 1800's, 1940's/50's and 2013. These can be summarised as a reduction in both braiding intensity and sinuosity. Those reaches that were partially braided in the 1940's have by and large become single-threaded. In effect the diverse, alternating partially-braided – meandering reaches of the Waipoua River have been homogenised into a narrower, simplified, and consistent planform. This adjustment likely reflects narrowing of the river corridor through aggressive river management techniques, restricting both bend development in meandering reaches, and accommodation space for widened channels required for channel local flow division. When reaches 1 and 2 are combined, we see an overall 49% reduction in the active channel area which likely reflects the 58% reduction in lightly vegetated bars, the 46% reduction in densely vegetated bars, the 44% drop in unvegetated bars, the 35% drop in wetted channel area, and the 34% drop in wetted channel length (Table 4, Figure 41) While overall, we do not have an NCI for Masterton from the 1940's, the historic maps lead to conclusion that the Waipoua is a river which has been highly altered through the Masterton township, despite having been very dynamic over its documented lifespan.

4.3 Mangatarere geomorphology and NCI

Reach one of the Mangatarere (Figures 23 – 25) crosses both the Wairarapa and Mokonui fault, being partially confined in certain sub reaches by high terraces but is laterally active and sinuous (SI) >1.5. It does not display characteristics of braiding at the time of aerial photography and appears to have incised into the sedimentary material in which it crosses. Overall, there is a drop in most parameters, notably a 17% drop in both active channel area and wetted channel area. There is a 23% increase in lightly vegetated bars but midline length and unvegetated bars remain the same (Table 5, Figure 45).

The middle reaches of the Mangatarere are the most dynamic of the 3 reaches. It is laterally active, partially confined towards the top of the reach, but becomes less confined as it leaves its terraces and heads towards the bottom of reach 2 where it. Sinuosity values suggest a meandering planform in the 1940's but is not classified as sinuous in 2013 (Table 6, Figure 46). It should also be noted that while this reach is not classified as braided, it does see a substantial drop in local flow division and channel bifurcation in 2013. There is a remarkable abundance of geomorphic units present in the 1940's i.e. back waters, bars, and islands, which are however, missing from 2013. Reach 2.0, 2.1, 2.2 and 2.3 (Figure 26 – 29) historically take on an hourglass geometry with straighter sub reaches or meanders in between small avulsions or channel cutoffs. Reach 2.5 is heavily locked up by vegetation in 2013 while in the 1940's the river was open and somewhat bare towards belvedere bridge (Figure 31). Back waters here suggest that the river had recently occupied the true left. All parameters have dropped by 2013, with a 65% drop in lightly vegetated bars being the most significant. Unvegetated bars remain similar, but it should be noted that the 2013 imagery shows evidence for recent cross blading which likely exposed more gravel. Densely vegetated bars have dropped by 36%, but this does not mean that there is necessarily more vegetation in the 1940's as the active channel area has dropped by 24% (Table 6, Figure 46).

The lower reaches of the Mangatarere are laterally active and does not meet the requirements for braiding nor meandering in both the 1940's not 2013. This reach loses energy where it opens into the plains below Belvedere Road. There is very little evidence of terracing and energy is likely dissipated across the floodplain when bank full flow is breached (Figures 32 – 37). There is a 90% reduction in densely vegetated bars which likely reflects the 48% reduction in the active channel area. Unvegetated bars see a 47% reduction while lightly vegetated bars see an 18% increase (Table 7). Midline length remains ~ the same. A few partially developed meanders above the SH2 bridge are missing which may reflect straightening of the channel in the 1960's (Figure 36).

When all three reaches are combined, there is a significant reduction in most parameters measured in the NCI. Of particular concern is a 40% reduction in the active channel area. Comparable to the Waipoua, the Mangatarere has changed mostly in reach 2 with a prominent reduction in sinuosity, dynamism, and geomorphic diversity. Areas of localised channel division have become single thread, with the active channel area having become homogenised into a contracted, basic, and consistent planform. Bend development has been heavily restricted.

5. Conclusions and recommendations

Reduction in the active river corridor of the Waipoua and Mangatarere Rivers has resulted in homogenisation of channel forms, with a reduction in diversity, active channel area (half) and complexity of river geomorphology. Both rivers display different characters in all 3 reaches. Reach 1 of both rivers can categorised as somewhat meander channels. Reach two of both rivers can be categorised as wandering but meandering is more prominent in the Mangatarere while wandering is the dominant character of the Waipoua where some bend development and localised partial braiding is present. The lower reaches of both rivers can be confirmed as having been somewhat meandering, particularly the Waipoua through Masterton. However, evidence suggest a very rapid change in river type took place in the lower reaches from 1884. This is consistent with the arrival of sediment from the Waiohine and Waingawa rivers and their short, steep catchments. When the next large seismic event is to occur, it is entirely possible for the river to change planform again and for the Waipoua to wander again which would be characterised by aggradation, avulsions, erosion, channel bifurcation. This should not be unexpected.

To recover a degree of diversity and complexity in the form of these rivers will require an accommodation of natural processes and trajectories in both rivers. A widened river corridor would allow meander bends to develop, migrate and cutoff without the need for intervention in those reaches that would naturally display a meandering form. In those reaches that would tend towards a partially braided form widening of the permitted corridor would provide accommodation space for braids and multiple medial bars to form. A bar-top skimming approach / mechanical disturbance may be appropriate to restore a degree of dynamism in reaches that have become locked-up by thick vegetation cover in the river corridor. Future treatments of this nature should be informed by the template of the reach provided by historic (pre-management) aerial imagery. Monitoring of treatment sites is strongly recommended to track the trajectory of treated reaches and an NCI analysis would provide an objective approach to assess changes in key parameters as adjustment of the channel corridor takes place. Repeated surveys (e.g. using LiDAR, ideally bathymetric) should ideally include collection of topographic data to generate a three-dimensional understanding of changes and trajectories and quantify volumes of sediment eroded and deposited as adjustment to treatment takes place. Assessing 3D form adjustment, as well as planform changes provides a means to holistically assess river behaviour in these reaches.

More broadly, I recommend:

- the use of 'whole river' NCI approaches using the earliest available and most recent archive aerial imagery to understand modification of river corridor characteristics in light of river management approaches deployed over the past ~50 years across the region;
- the use of targeted NCI assessments to inform treatments intended to restore mobility and diversity to river corridors in the region;
- an assessment of coherent reach geomorphology in Wairarapa rivers to provide a more detailed geomorphic description of each coherent reach, including key morphological characteristics and channel type in order to aid understanding of river types, trajectories and capacities for adjustment, and potential (or need) for restoration.

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