Lower Manawatū Gravel Study

Natural Character Index (NCI) and HQI Report

September 2024

horizons
REGIONAL COUNCIL

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REPORT

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Executive summary

The Natural Character Index (NCI) is a simple, but objective measure of river geomorphic change, which is applied here to assess changes to the active channel area of the lower Manawatū River between 1941 and 2022. Application of the NCI showed that the overall area of the active channel has approximately halved in this time, particularly associated with a reduction in heavily vegetated bar area. This reduction in the active channel area has a potentially significant impact on the river's behaviour and character, including its response to flood flows, bank erosion, and future room for re-adjustment within its historical floodplain. The migration and change of the active channel over time revealed a narrowing of the river, but also some meander cutoff.

Our approach to delineating active channel area for the NCI was compared with the delineation by Horizons Regional Council for ten different years of aerial imagery from 1941 to 2022. Comparison showed that our approach generally took a broader definition of the active channel to incorporate vegetated surfaces within the active river corridor. Notwithstanding this difference, the HRC approach also shows that the overall active channel area has significantly reduced.

1 Introduction

1.1 Purpose and scope

Tonkin & Taylor Ltd (T+T) was engaged by Horizons Regional Council (HRC) to complete an assessment of the current state of the gravel resource of the lower Manawatū River, between the Manawatū Gorge and the sea. This report is one of three being prepared to address gravel resource in the lower Manawatū River and provide an assessment of past river character. The collective suite of reports is referred to as the *Lower Manawatū Gravel Study*. The other reports cover:

- A gravel budget of the lower Manawatū River,
- An assessment of the HRC 'Seven Bends'.

This report has been prepared in accordance with the agreement dated 17 November 2023 and countersigned dated 21 December 2023. This report has been re-issued in accordance with outcomes of a workshop with HRC on 3 July 2024, and a following variation agreement dated 27 August 2024.

To help inform future management practices and room needed for the lower Manawatu River, assessment of the NCI to determine the extent of change over time in the composition and character of the river corridor was completed. HRC have also sought advice regarding the delineation of the active channel using bank lines. Comparison of their methods of delineation using ten sets of successive aerial imagery over the last 84 years, with our mapping using NCI is provided.

1.2 Background

Understanding the character of a river and its recent trajectories of change is important to make geomorphologically informed management decisions. A high-level assessment of sediment processes and geomorphic trends in the lower Manawatū River was undertaken by T+T in 2019, to provide an overview of geomorphic processes in the catchment (Tonkin and Taylor, 2019). This report identified a series of river types used to define the contemporary character of the river channel in the lower Manawatu, but did not quantify river corridor composition, or change therein. HRC have previously carried out gravel studies in 2012 (Bell, 2012) and 2019 (Whale, 2019) to quantify gravel flux in the lower Manawatū River. Surveys of the lower Manawatū River have been undertaken at various times since 1992, with the most recent data collection undertaken in 2023. These previous studies undertook gravel budget analysis using survey data acquired along monumented cross-sections but have not assessed changes in the composition of the river corridor.

HRC has sought information on the adjustments to the active channel corridor and its character from the 1940s to the present day, which covers the inception and development of the Manawatū flood scheme. This is to understand the potential impacts management approaches adopted since the 1940s have had on the river character and form, which will also inform the gravel resource reported in the other reports delivered for the Lower Manawatu Gravel Study. Assessing the natural character using NCI informs the higher-level changes underpinning morphological budgets and the changes seen at the 'Seven Bends'. The Natural Character Index assessment is valuable because it compares the pre-intervention state of the river with its current, post-intervention state. The NCI is a simple, objective means of identifying the change in a particular characteristic or parameter of the river's geomorphology. This can be built upon through a discussion of the drivers of this change, and by applying this index method to coherent reaches of the river with similar character.

Bank lines, which were delineated by HRC to show the active channel in aerial imagery over the last 84 years, can show the channel changes through this time. These channel changes inform change in spatial extent of any gravel resource, and the planform of the river over time. By reviewing these bank lines, based on 8 sets of aerial imagery between 1958 and 2016, the progressive adjustment of the channel between the detailed mapping of 1941 and 2022 can also be compared with the corridor in the present day as well as the 1940s. This work allows us to ascertain if the limits of the active channel have remained within the early (1940s) envelope.

1.3 Site context

The Manawatū River is 235 km long and drains a catchment of 5,898 km^2 (LAWA, 2019). It drains from the eastern Ruahine Ranges, through the gap between the Ruahine and Tararua Ranges formed by the Manawatū Gorge, and across a large floodplain to the Tasman Sea at Foxton. The land use of the catchment is generally agricultural, with some indigenous forest and urban areas (Landcare Research, 2012). The lower Manawatū River runs slightly over 100 km from the mouth of the Manawatū Gorge to the Tasman Sea at Foxton Beach. It is generally a sinuous, passive meandering river with a sand bed in its lower reaches, while the gravel phase from the Gorge to Ōpiki has a more wandering planform. The Manawatū floodplain was once dominated by Kahikatea forest and swampland, however forest clearance and drainage has developed the floodplain for agriculture and urban use since the late 1800s.

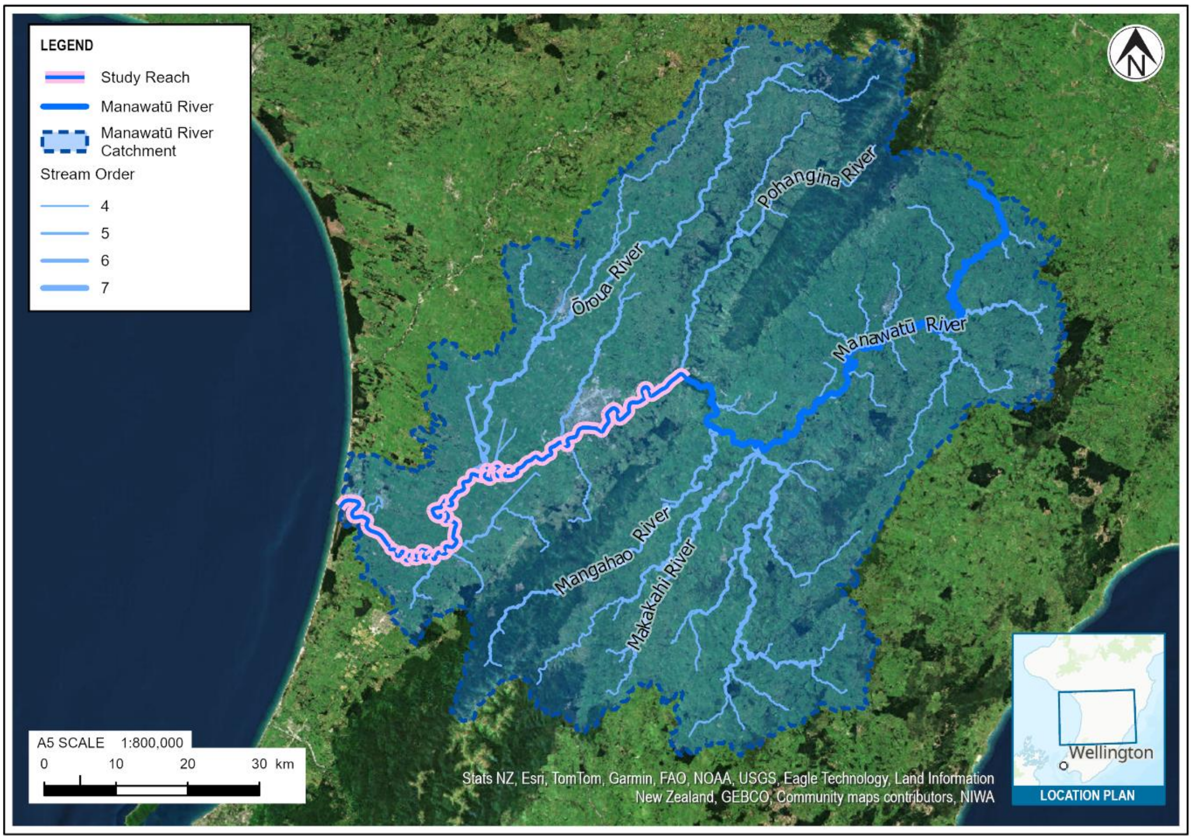

Figure 1.1: Manawatū River catchment, with major tributaries labelled and lower Manawatū study reach highlighted.

Figure 1.1 shows the study reach in the context of the Manawatū River catchment. Classification of the contemporary channel in the study reach by Tonkin and Taylor (2019) identified four key river types, which are described in Section 2.1 below. The geomorphic character of the study reach is informed by the 'sediment conveyor model' (Nicholas et al., 1995) where sediment is sourced from erosion in confined headwaters, transferred through partly confined valleys, and deposited in an accumulation zone within an alluvial valley. This is a conceptual model, which, in reality, is often more complex. For the Manawatū River, a more complex geological setting (Figure 1.2), especially with the Manawatū Gorge mid-catchment, means that the process is not entirely linear. However, the lower Manawatū operates as both a transfer zone from the Gorge to Ōpiki and as an accumulation zone as a function of bed profile flattening in the vicinity of and downstream from Ōpiki (Figure 1.3).

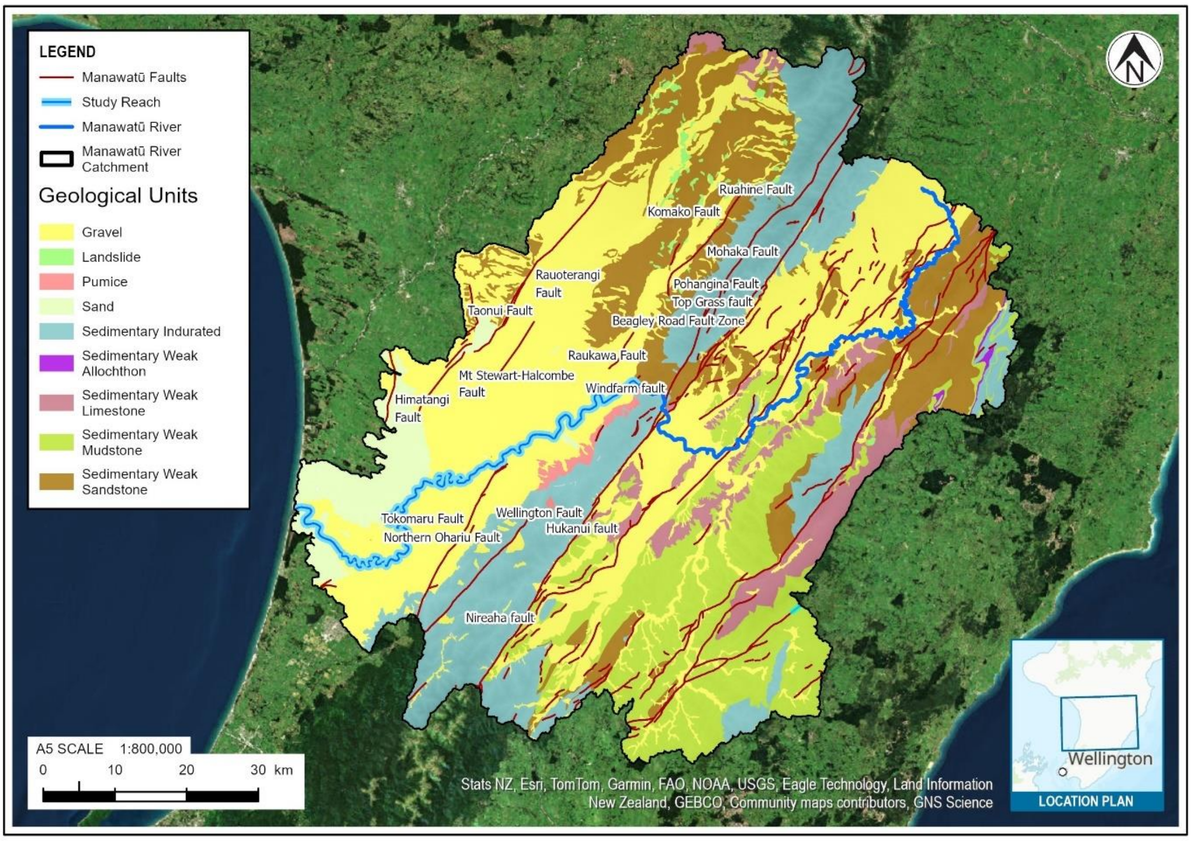

Figure 1.2: Manawatū catchment geology. The study reach and length of the Manawatū river are shown. Major faults within the Manawatū catchment are shown, with key faults named.

Figure 1.2 shows the geology of the Manawatū catchment. Gravels are principally sourced from indurated sedimentary greywacke in the catchment, as well as reworked terraced alluvium. The lower section of the river is tidal, with fine sediment exchange across the coastal margin.

The river has high cultural, economic, and ecological significance. Active meanders form the southern margin of the city of Palmerston North, which presents a challenge for management, particularly during storm events. Throughout the catchment, the February 2004 storm caused widespread erosion, changed the river's course, and caused over $300 million of damage (Vale, 2016). The Manawatū catchment is an important site for aquatic species, with 23 different fish species in the river. The Manawatū River is also an important feature for tangata whenua, with Rangitāne o Manawatū and Rangitāne o Wairarapa o Rangitāne Tamaki Nui-a-Rua ancestors having a connection to the waterways for over seven hundred years, which underlines the importance of informed and proactive management in the lower reaches of the awa.

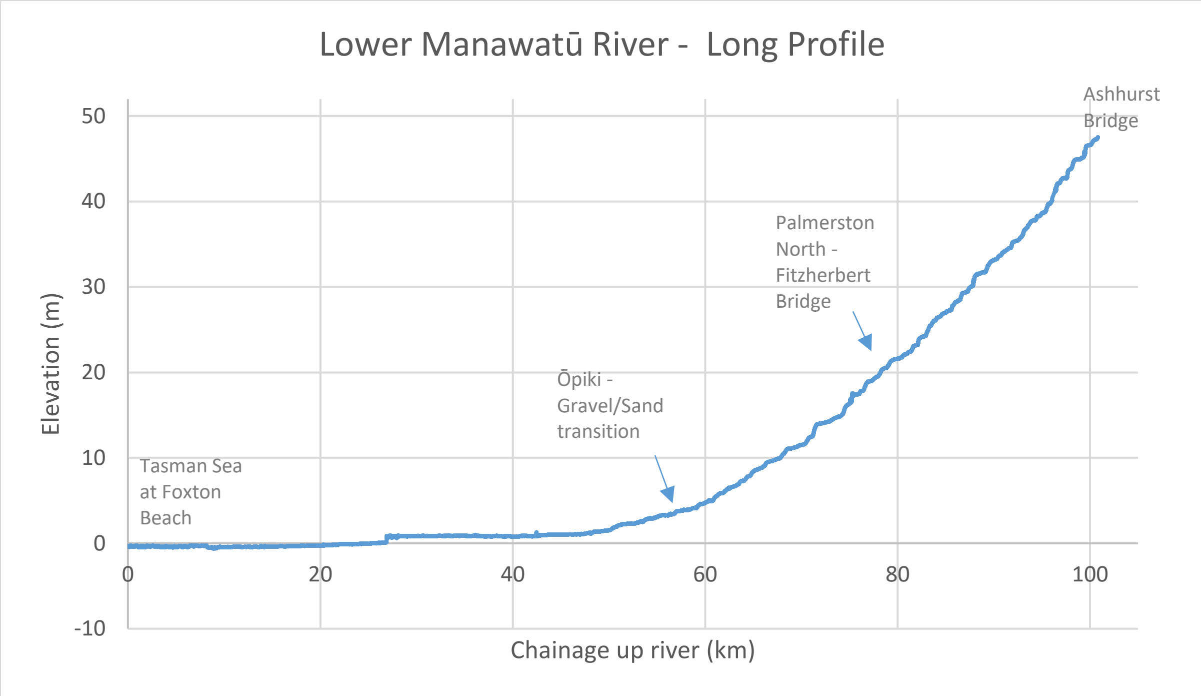

Figure 1.3: Channel long profile from 2022 LiDAR along the centreline of the lower Manawatū River, with annotations.

Downstream from the Gorge, where the river is confined and bedrock-lined, the lower Manawatū River becomes an unconfined, actively wandering to meandering river, up to the transition from gravel to sand bed at Ōpiki (Page & Heerdegen, 1985). Downstream of Ōpiki the river becomes a more passive meandering channel. This change is predominantly due to a change of energy from a slope transition (Figure 1.3).

In an alluvial river like the lower Manawatū, bankfull flows perform the most geomorphic work. These flows correspond roughly to the 2-year Annual Recurrence Interval (ARI) flood event and are the dominant flows for transporting bedload (i.e. gravel), reworking sediment stored within the active channel, and initiating bank erosion. Suspended sediment is mainly transported at lower flows than the Mean Annual Flood (MAF) (Basher et al., 2012). This sediment may accumulate during lower flows, with larger floods being responsible for flushing this sediment and scouring the riverbed (Watson, 2008).

Changes in the river course throughout the river's history are evidenced by numerous palaeochannels across the floodplain (Lo Re et al., 2018). These palaeochannels form the wider active corridor which has, and will continue to be, reworked by the river through erosional and depositional processes. Some of these palaeochannels are demarcated by oxbow lakes and cutoffs. Changes in the active river channel can be seen throughout the temporal extent of aerial imagery, with new channels being occupied between the earliest full coverage of aerial imagery in 1941 and the most recent, in 2022. Throughout this time, changes in catchment land use, flood management (including the building of stop banks), erosion protection, and changes to the flood regime have all affected the river's geomorphic character. Stop banks have artificially confined the river, in places causing both rapid floodplain accretion and channel incision (Fuller et al., 2018).

1.4 Outline and approach

Having provided the purpose, background, and site context in Section 1, Section 2 of this report will detail the method used to complete the NCI assessment, including the reaches and parameters used in this assessment. Section 3 will present the results from NCI assessment and Section 4 will discuss these results. Section 5 will provide a review of the bank lines provided by HRC, comparing the active channel in intermediate years with the active channel based on earliest (1941) and most recent (2022) imagery.

Appendix A includes a series of maps which compare the mapped channel composition for the 1941 and 2022 active channel for the NCI.

Appendix B includes a series of maps showing the active channels delineated by HRC for each year, from 1941 to 2022.

Appendix C includes a series of maps which compare active channel areas delineated for the NCI and the areas delineated by HRC, for both 1941 and 2022.

2 NCI method

Assessment of the river character and how this has changed over time (1941-2022) was completed using an NCI (Natural Character Index) approach. This approach provides an assessment of long-term changes of key river characteristics. The NCI was introduced as a tool for preliminary assessment of the extent of change in river character by Fuller et al. (2020). The NCI is calculated by comparing parameters mapped by digitising imagery from the earliest available georectified aerial imagery, and comparing the same parameter mapped using the most recent imagery. The same approach was used for the Rangitikei River in a report to HRC by Fuller and Conley (2023).

Quantifying changes in river character using the NCI involves generating a ratio of 'observed' i.e., contemporary geomorphic units, over 'expected' i.e., the nature of corresponding geomorphic units in the 1940s (cf. Fuller et al., 2020). Considering the resolution of aerial imagery, 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, 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 reported by Fuller and Conley (2023):

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

This result indicates a 16% reduction in active channel area along the Kawhatau between 1952 and 2021 (Fuller and Conley, 2023).

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 imagery 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).

In the case of the lower Manawatū, the earliest imagery providing complete coverage of the length of the lower Manawatū is from 1941, and the most recent is from 2022. For both years of imagery, the wetted channel, unvegetated bar area, lightly vegetated bar area, and densely vegetated bar area were all digitised to polygonal areas, allowing for a calculation of total area covered by each mapped parameter. The NCI is calculated by dividing the mapped area of a channel component in the most recent imagery, by the area in the earliest imagery. This index is calculated for each of the four channel components, and for the active channel (the sum of the four components). An index was also calculated for sinuosity and active floodplain width, using the same methods. These indices have been calculated for coherent reaches with similar features, described in Section 2.1.

2.1 Reaches

The contemporary channel of the lower Manawatū River has been classified into four stream types (Tonkin and Taylor, 2019): partially confined wandering gravel bed, artificially confined meandering mixed bed, artificially confined meandering sand bed, and estuary. For the purpose of assessing the NCI of the river corridor this assessment of the natural character of the lower Manawatū was achieved by splitting the lower Manawatū into three reaches of broadly coherent geomorphic character (Figure 2.1). These are:

- Manawatū Gorge to Palmerston North.
- Palmerston North to Ōpiki.
- Ōpiki to Tasman Sea.

The upper reaches, both upstream and downstream of Palmerston North are both gravel phase and, comprise partially confined wandering gravel bed and artificially confined meandering mixed bed river types (Tonkin and Taylor, 2019). The boundary between these river types does not exactly match the two NCI reaches, because we have accommodated the 'Seven Bends' in the Gorge to Palmerston North reach, to be able to more clearly relate results from the NCI to the 'Seven Bends' geomorphic assessment. All seven of the Seven Bends are contained within the upper of these reaches (Manawatū Gorge to Palmerston North). Also, this section has additional relevance for management decisions which relate to Palmerston North, as this is the reach where changes to natural character will particularly affect the potential flood and erosion resilience of the urban area.

The third reach, Ōpiki to Tasman Sea, has a clearly different geomorphic character from the other reaches, as it has a sand bed and a much lower channel slope (Figure 1.3). Therefore, this reach also has lower stream power and different bed and bank material composition and channel behaviour when compared with the upstream reaches. This reach comprises the lower sections of river type artificially confined meandering mixed bed, and river types: artificially confined meandering sand bed, and estuary (Tonkin and Taylor, 2019). The river corridor downstream from Ōpiki is essentially perched above the adjacent floodplain, which used to comprise flax swamp (Tonkin and Taylor, 2019), and therefore treated as coherent in geomorphic character.

The NCI results are presented in Section 3 for each of these three discrete reaches, in addition to combining results for the 'gravel reach' (Gorge to Ōpiki) and the whole lower Manawatū (Gorge to Foxton).

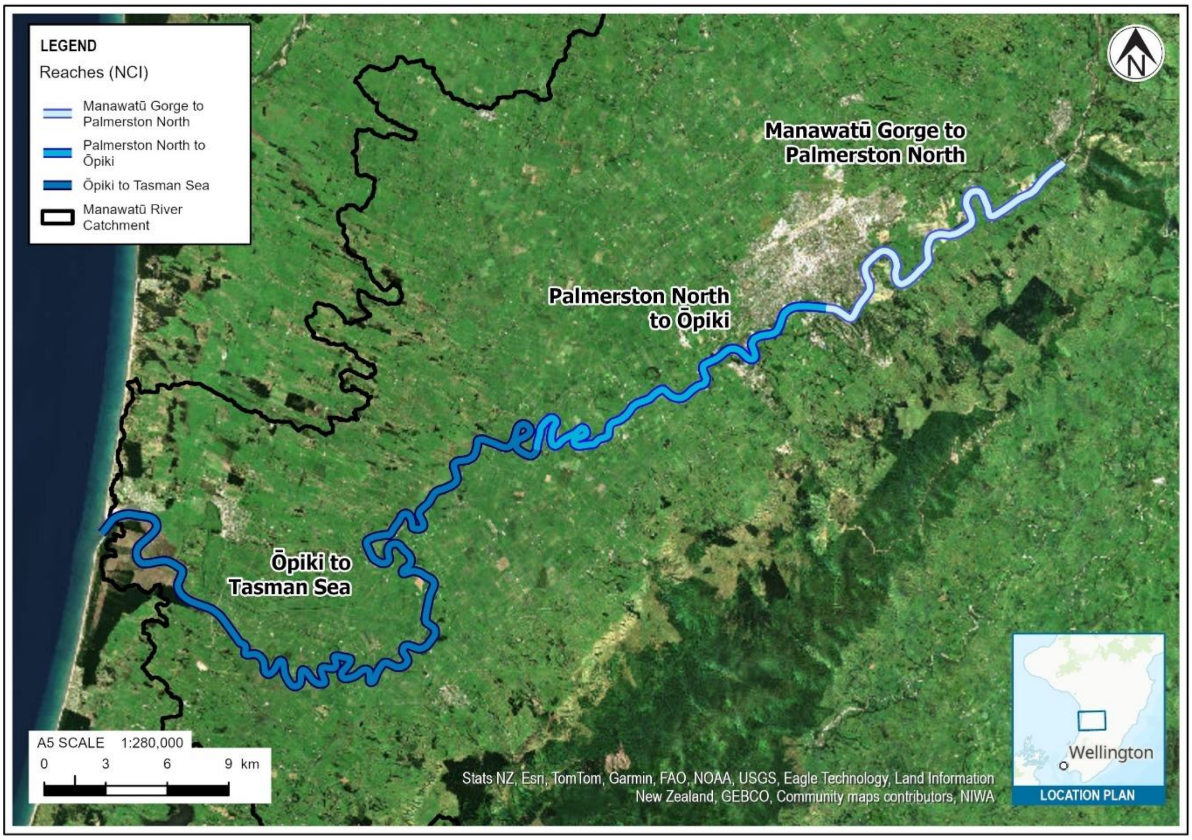

Figure 2.1: Study reaches for the assessment of NCI.

2.2 Parameters

Several parameters were mapped for the length of the lower Manawatū River, in assessing NCI. These were mapped from 1941 and 2022 aerial imagery using both QGIS and ArcGIS Pro, and generated two sets of shapefile polygons, from which NCI values were calculated. These shapefiles have been provided to HRC as part of this package of work. There is some uncertainty in the NCI introduced by natural variances in flow, vegetation density, geo-rectification, and colour rectification in the imagery. Within the 1941 black-and-white imagery, some features were hard to distinguish. More accuracy was enabled by the colour imagery of 2022, combined with the use of the most recent high-resolution LiDAR DEM for reference. These are similar to the parameters used by Fuller and Conley (2023) for the Rangitikei River, in their report to HRC.

The following parameters, listed below, were mapped:

- **Active channel area:** the zone of the current river floodplain interpreted as being actively or recently reworked by the river channel. This is the sum of the wetted channel and all bar areas, but excludes any cultivated land, mature forest, or developed land that would otherwise have been within the river corridor.
- **Wetted channel area:** area of active channel which was wet at the time of the aerial imagery. This parameter depends on an assumption that flow is approximately equivalent across both sets of imagery. It includes any side-channels, back-waters, braids, or high-flow secondary channels that were wetted at the time of imagery. Large-scale aerial imagery 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.

- **Exposed bar area:** the area of the active channel that is exposed, with no vegetation. This is the most recently active portion of the active channel that is not wetted, where vegetation has not colonised due to repeated flooding in higher flows. These bars are depositional features, and their growth indicates active bedload accretion. However, flood flows can erode and lower sections of bars.
- **Lightly vegetated bar area:** area within the active channel with patchy or young vegetation, indicating initial colonisation or sparse growth. From aerial imagery, this was interpreted as areas with vegetation present, while exposed bed material remained visible. These areas indicate either a lack of recent high flows crossing bars, allowing vegetation colonisation, or that this part of the river corridor is becoming less active. Light vegetation growth does not prevent remobilisation of sediments during larger floods; however, it does facilitate finer sediment accretion as these sediments get trapped by the vegetation.
- **Heavily vegetated bar area:** area within the active channel where bars have become completely vegetated by grass, shrubs, or small tree growth. This does not include areas of cultivation, development, or forest. From the aerial imagery, this was interpreted as vegetated areas without visible exposed bed material, without large trees, and without signs of human cultivation or development. These bar areas are the least active part of the channel and are receive less frequent inundation. They are not yet floodplain, as they have the potential to be reworked in a particularly large flood event.
- **Active channel width:** the active channel width is defined as the active channel area divided by the length of the river centreline. This parameter accounts for changes in the river length between years.
- **Sinuosity:** sinuosity is defined as the ratio between the valley length and the river centreline length. This helps to quantify the extent of meandering, and when compared between successive years, indicates whether the active channel has become straighter or more sinuous.

3 NCI results

A full series of maps is included in Appendix A showing the areas delineated for each parameter for the length of the lower Manawatū River, comparing both 1941 and 2022.

Table 3.1: Tabulated NCI results and values for each parameter, reach, and aggregated reaches

Reach	Characteristic	Value (1941)	Value (2022)	NCI
Manawatū Gorge to Palmerston North	Wetted channel area [ha]	203.84	109.40	0.54
	Exposed bars area [ha]	142.97	86.32	0.60
	Lightly vegetated bars area [ha]	30.52	17.91	0.59
	Heavily vegetated bars area [ha]	409.55	126.16	0.31
	Active channel area [ha]	**786.88**	**339.79**	***0.43***
	Active width [m]	*346.92*	*160.00*	*0.46*
	Valley length [km]	*13.68*	*13.65*	*1.00*
	River centreline length [km]	*22.68*	*21.24*	*0.94*
	Sinuosity index	*1.66*	*1.56*	*0.94*
Palmerston North to Ōpiki	Wetted channel area [ha]	179.90	126.02	0.70
	Exposed bars area [ha]	182.08	57.98	0.32
	Lightly vegetated bars area [ha]	104.67	9.51	0.09
	Heavily vegetated bars area [ha]	332.79	103.94	0.31
	Active channel area [ha]	**799.44**	**297.46**	***0.37***
	Active width [m]	*348.88*	*125.48*	*0.36*
	Valley length [km]	*15.31*	*15.66*	*1.02*
	River centreline length [km]	*22.91*	*23.71*	*1.03*
	Sinuosity index	*1.50*	*1.51*	*1.01*
Ōpiki to Tasman Sea	Wetted channel area [ha]	786.03	563.57	0.72
	Exposed bars area [ha]	93.70	12.23	0.13
	Lightly vegetated bars area [ha]	97.84	0.50	0.01
	Heavily vegetated bars area [ha]	230.34	206.99	0.90
	Active channel area [ha]	**1,207.90**	**783.30**	***0.65***
	Active width [m]	*187.28*	*140.20*	*0.75*
	Valley length [km]	*21.02*	*21.17*	*1.01*
	River centreline length [km]	*64.50*	*55.87*	*0.87*
	Sinuosity index	*3.07*	*2.64*	*0.86*
Gravel reach (Manawatū Gorge to Ōpiki)	Wetted channel area [ha]	383.75	235.43	0.61
	Exposed bars area [ha]	325.05	144.30	0.44
	Lightly vegetated bars area [ha]	135.18	27.42	0.20
	Heavily vegetated bars area [ha]	742.35	230.10	0.31
	Active channel area [ha]	**1,586.32**	**637.25**	***0.40***

	Active width [m]	*347.90*	*141.79*	*0.41*
	Valley length [km]	*28.99*	*29.31*	*1.01*
	River centreline length [km]	*45.60*	*44.94*	*0.99*
	Sinuosity index	*1.57*	*1.53*	*0.97*
Full length (Manawatū Gorge to Tasman Sea)	Wetted channel area [ha]	1,169.78	799.00	0.68
	Exposed bars area [ha]	418.74	156.54	0.37
	Lightly vegetated bars area [ha]	233.02	27.92	0.12
	Heavily vegetated bars area [ha]	972.69	437.09	0.45
	Active channel area [ha]	**2,794.23**	**1,420.55**	***0.51***
	Active width [m]	*253.80*	*140.91*	*0.56*
	Valley length [km]	*50.01*	*50.48*	*1.01*
	River centreline length [km]	*110.09*	*100.82*	*0.92*
	Sinuosity index	*2.20*	*2.00*	*0.91*

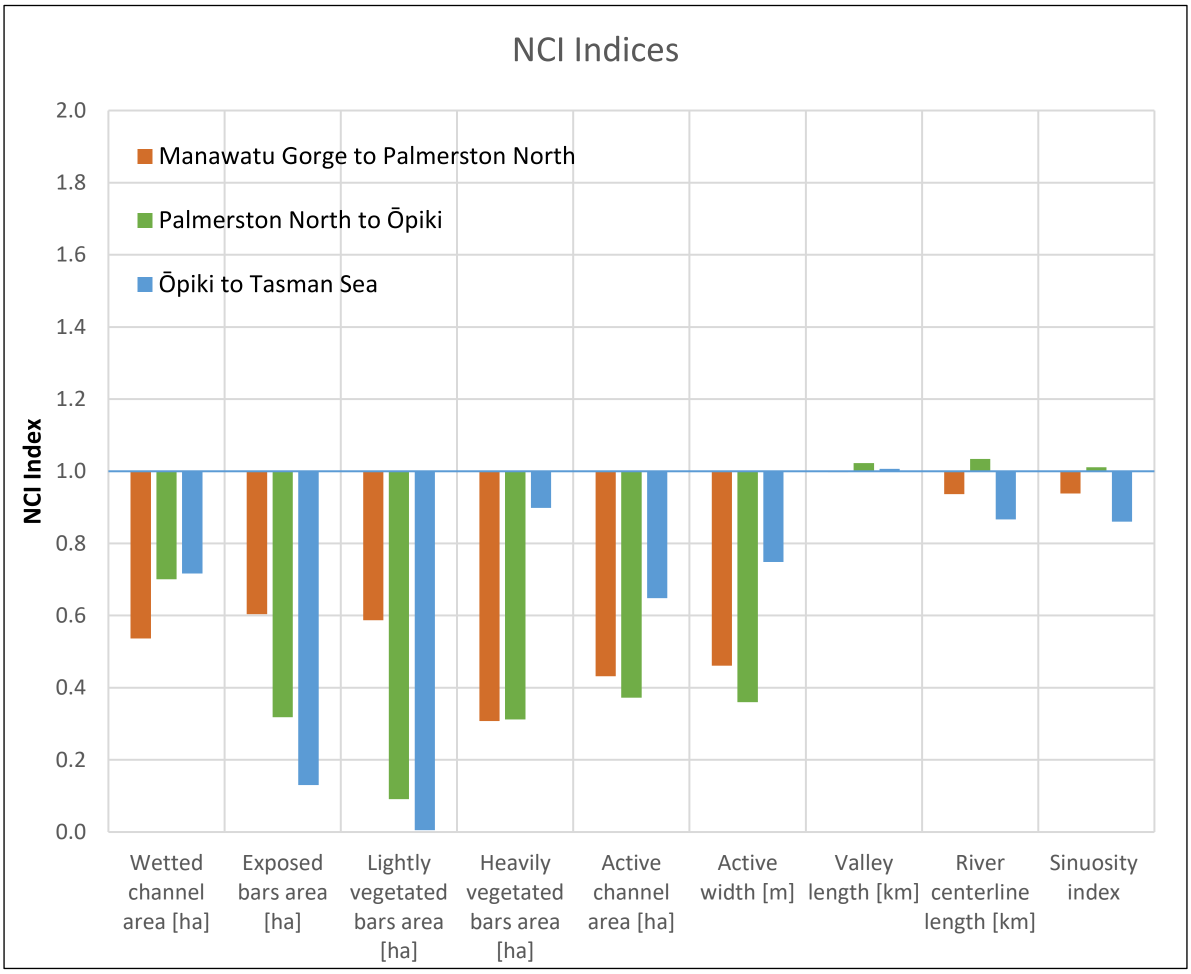

Figure 3.1: Comparison of NCI results for each parameter, with 1 (no change) being the horizontal axis. This graph shows that the largest relative changes are for the bars (exposed, lightly vegetated, and heavily vegetated). Sinuosity experienced the least relative change. All change was in the negative direction (the assessed parameter was lower in 2022 than in 1941), except for a small increase in sinuosity between Palmerston North and Ōpiki.

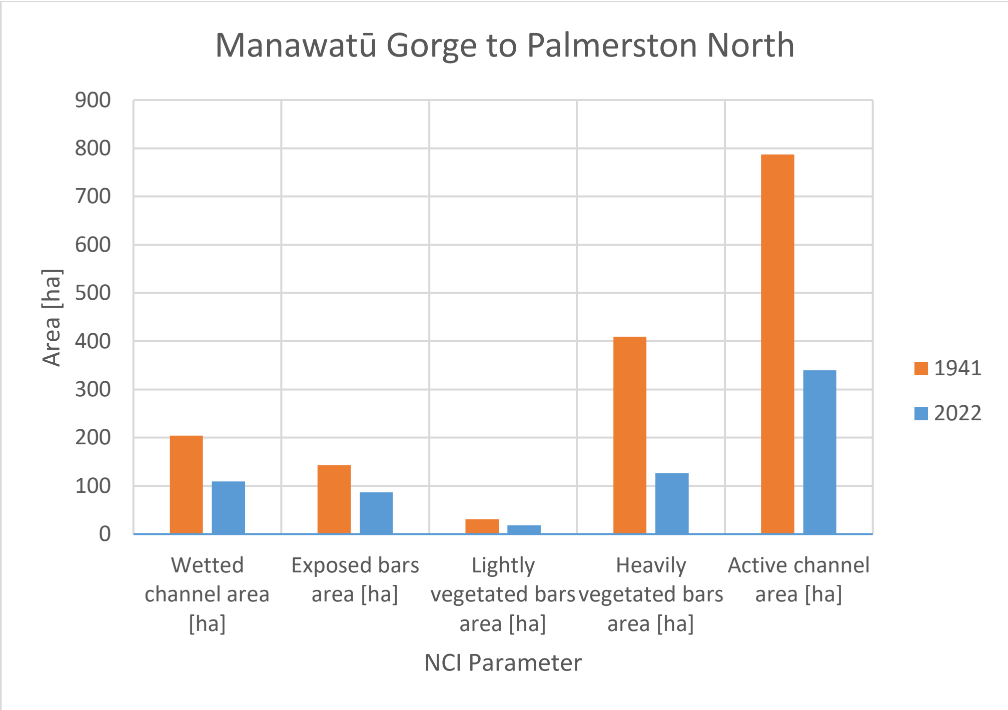

Figure 3.2: Comparison of areas for each NCI parameter for the upper reach, from the Manawatū Gorge to Palmerston North. Of the parameters which make up the total active channel area, heavily vegetated bars were the largest in both 1941 and 2022.

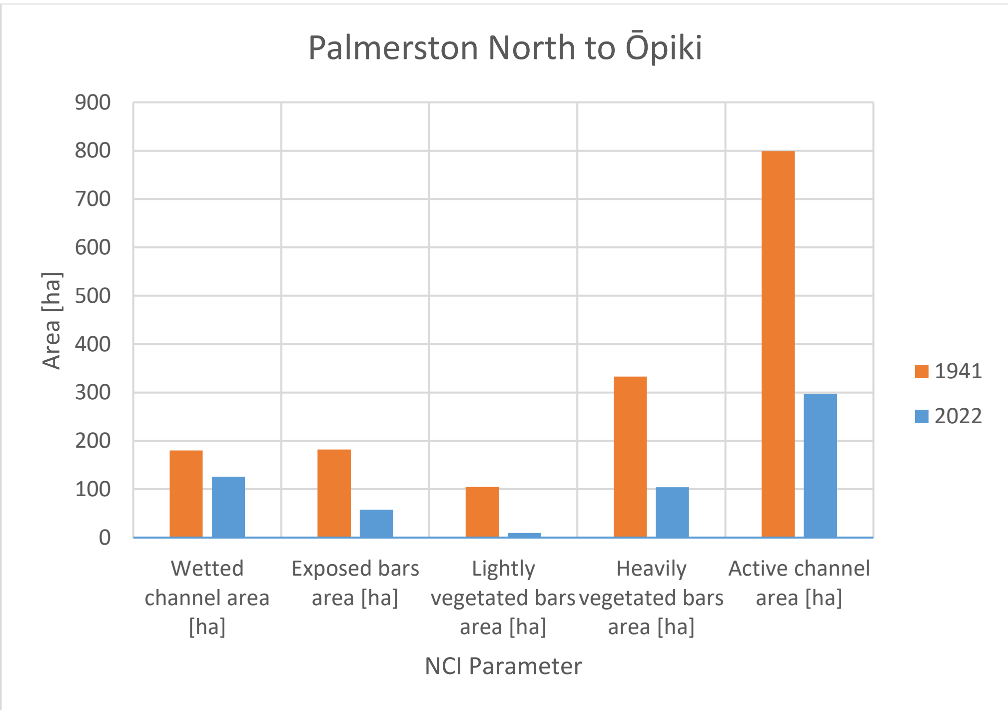

Figure 3.3: Comparison of the areas for each NCI parameter for the central reach, from Palmerston North to Ōpiki. The parameter that made up the largest proportion of the active channel was heavily vegetated bars in 1941, but was less large than wetted channel area in 2022.

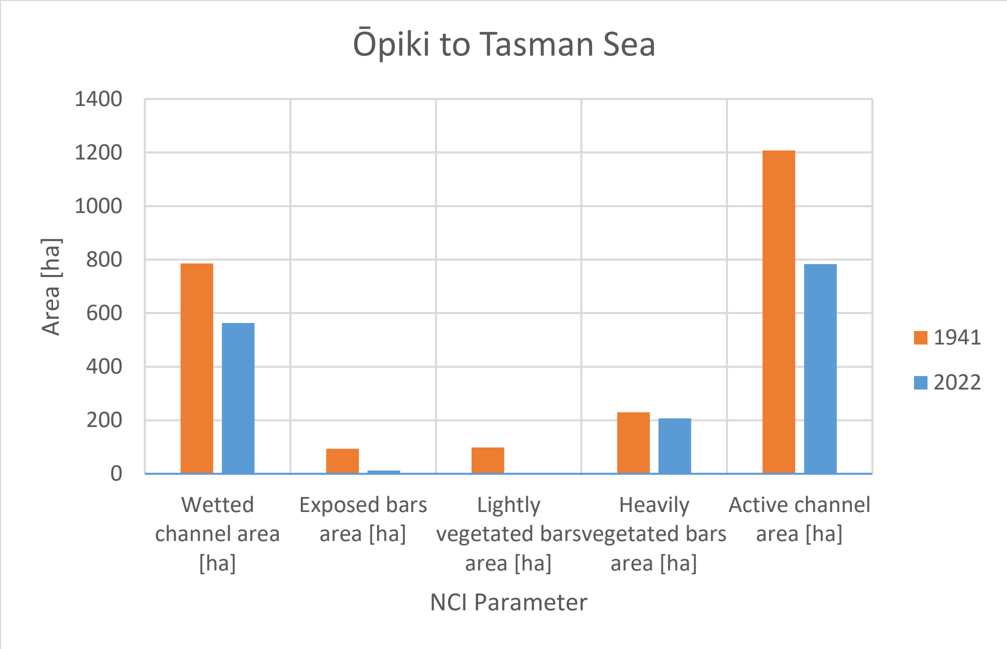

Figure 3.4: : Comparison of the areas for each NCI parameter for the lower reach, from Ōpiki to the Tasman Sea. In this reach, most of the active channel area was wetted channel.

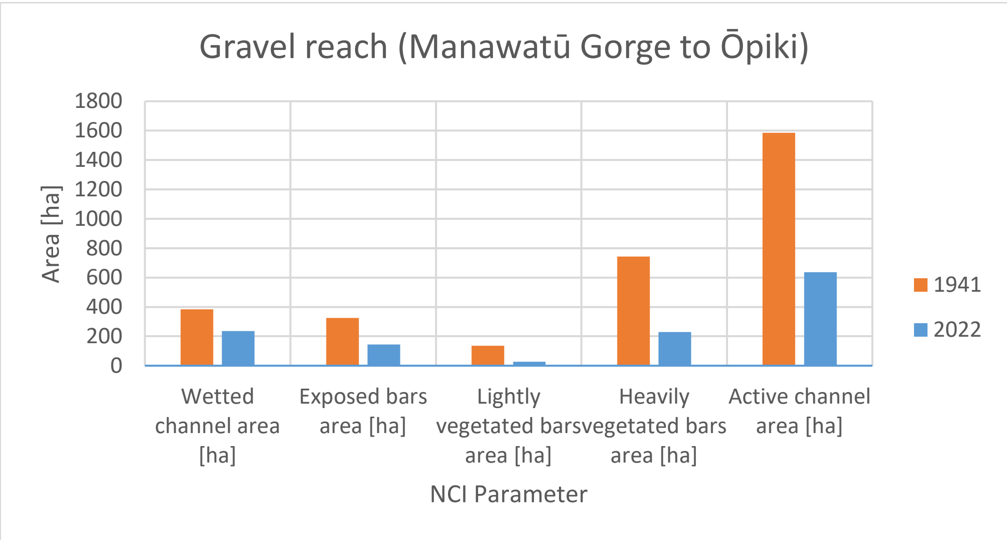

Figure 3.5: Comparison of the areas for each NCI parameter across the gravel reach, from the Manawatū Gorge to Ōpiki. Within this section, heavily vegetated bars were the predominant unit within the active channel in 1941, but reduced in area significantly to 2022.

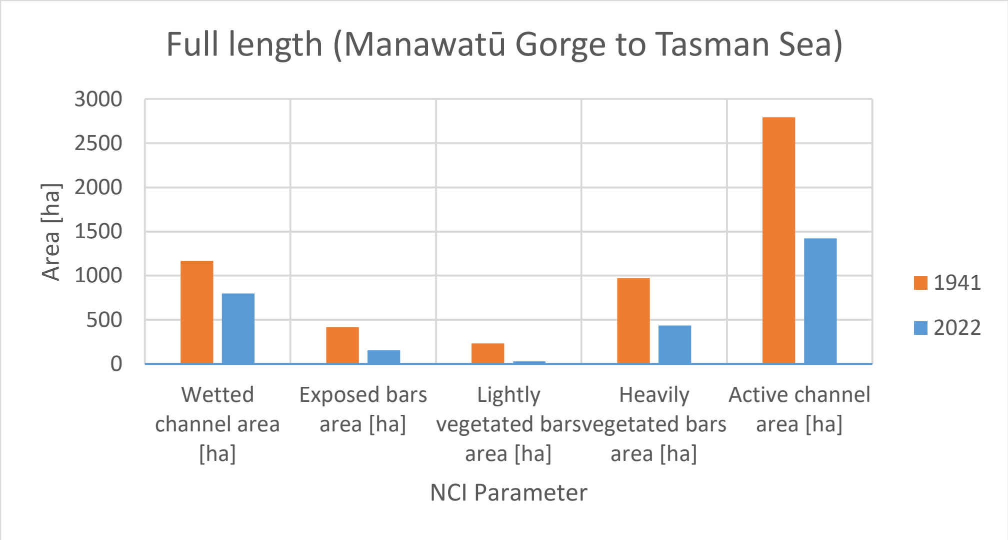

Figure 3.6: Comparison of the areas for each NCI parameter for the entire study length, from the Manawatū Gorge to the Tasman Sea. Because of the width of the wetted channel in lower reaches, this is the slightly more predominant unit overall.

4 NCI discussion

4.1 Channel change

The use of the Natural Character Index (NCI) reveals that the active channel area of the lower Manawatū River has undergone substantial changes in the past 80 years. The largest of these changes is an overall reduction in active channel area. Across all three reaches, the active channel area is approximately 51% of the size of the equivalent active channel area in 1941 aerial imagery. This change indicates a narrowing of the river corridor, reducing the room for the river's natural adjustment.

Narrowing of the active channel was more substantial in the gravel reach, from the Gorge to Ōpiki. Across this length, the active channel was 60% of the 1941 size in 2022 and active width reduced by 59%. Narrowing has limited the capacity of the river to adjust laterally through this reach, potentially confining flood flows, reducing flood energy dissipation and disconnecting the river from its floodplain. Across the gravel reach, especially upstream of Palmerston North, many palaeochannels can be seen in the floodplain, indicating more expansive past flow paths. In 1941, the active channel incorporated a wider area of this historic floodplain, but overall sinuosity is largely unchanged.

In the lower reaches of the lower Manawatū, from Ōpiki to the Tasman Sea, less change has occurred, with a 35% reduction in active channel area and 25% reduction in active width between 1941 and 2022. A particular change in this reach is the cutoff of the Foxton Loop, as a consequence of straightening works which were already underway in 1941, and sinuosity is more significantly reduced (14%). The Loop has been removed from the modern-day active channel. Although this section is now reconnected, the minor flow through the Loop means that from a geomorphological perspective, sediments in the Foxton Loop are not connected to the main channel.

Using the four 'units' measured using the NCI (wetted channel, exposed bars, lightly vegetated bars, and heavily vegetated bars), some further changes to the channel of the lower Manawatū can be identified:

4.2 Wetted channel

Across all the reaches, the wetted channel area has experienced some reduction from 1941 to 2022. However, assuming that the river is carrying a similar amount of flow in both sets of imagery (which may or may not be the case; however, both were taken in late summer low flow conditions), a reduction in wetted channel area means that higher flows must be accommodated through some other means. This may be either due to channel deepening (which would be a sign of channel incision in the case that the wetted area had decreased) or an increase in velocity. In the upper reach (Manawatū Gorge to Palmerston North), where the reduction of the wetted channel area was most significant, channel incision likely combined with a straightening of the channel (sinuosity reduced by 6%) as a consequence of flood protection works for the city of Palmerston North. Channel straightening increases the channel slope, therefore increasing the stream power and allowing the river to carry its flow faster in a more efficient cross-sectional area.

4.3 Lightly vegetated bars

Lightly vegetated bars contribute much less area than heavily vegetated bars in the matrix of geomorphic units which form the lower Manawatū active channel. Lightly vegetated bars usually form due to small amounts of vegetation growing over a limited number of seasons on a flood-prone gravel (or sand) bar. The amount of lightly vegetated bars seen in a river corridor is dependent on recent flood history, and so fluctuates over time. However, a reduction in lightly vegetated bars may also be due to a reduction in river heterogeneity, with fewer mid-channel transverse and longitudinal bars, which may have an elevated and partly vegetated section exposed to only very high flows. The large reduction (88%) in lightly vegetated bar areas across all reaches of the lower Manawatū is likely a symptom of this reduction in heterogeneity.

4.4 Heavily vegetated bars

Heavily vegetated bars formed a large amount of the total active channel area across both years of imagery. Heavily vegetated bars are typically areas where large amounts of vegetation grow on bars that are infrequently flooded by the river, and where material is only eroded, deposited, or transported in the highest of flows. However, since these high flows are effective geomorphic agents, the total channel area where sediments may be entrained during these flows is crucial to the geomorphic character of the river corridor. The large reduction in heavily vegetated bars from 1941 to 2022 (55%) is mainly due to several large contiguous bar areas being removed from the active channel, whether due to transformation to agriculture or due to the development of stopbanks, or the change in river behaviour leaving them out of the active channel.

4.5 Exposed bars

In the gravel reach of the river, exposed bars formed approximately 20% of the total active channel area (in 1941). In this reach, the reduction in exposed bar areas from 1941 to 2022 (55%) is similar to the reduction in active channel area. Partly, the reduction in exposed bars reflects a reduction in the width and heterogeneity of the active channel, with fewer mid-channel and lateral bars. With fewer concurrent channels, and reduced wetted area, less area is left exposed. Increased incision of the channel means that fewer bars are regularly inundated with the possibility of sediment being re-mobilised and keeping them clear from vegetation. In the lower reach of the river, where bed and bank materials are sand rather than gravel, the exposed bar area is lower as a proportion of the active channel area. This is mainly due to the less dynamic nature of the river here, as well as the difference in sediment sizes. This reach had the smallest NCI value for this parameter (0.01), showing that most of the previously exposed bar areas had disappeared. This is largely due to the encroachment of vegetation and agricultural development, and a narrowing of the area between the immediate banks of the river.

4.6 Drivers of change

More investigation would be required to be able to better identify the specific drivers of change in different sub-reaches of the lower Manawatū. However, there are several broad drivers that are likely to be responsible for much of the reduction in active channel area and reduction in geomorphic heterogeneity through the last 80 years, as reported by Tonkin and Taylor (2019). A key driver is deliberate river work, since the intent of the Manawatū flood scheme is to narrow channels, promote incision and remove sediment accumulation in order to increase sediment transport and reduce flood risk (Watson, 2008).

Stop banks are responsible for much of the channel narrowing, incision, and loss of heterogeneity. Stop banks were developed along much of the lower Manawatū from the 1950s onwards and have reduced the area through which flood flows can both deposit and entrain sediment and have concentrated these flows into a narrower area (Figure 4.1). This has led over time to an incision of the wetted channel, as a narrower channel must either get deeper or faster to carry the same flow. These stop banks have artificially confined the active channel, and deposition of fine sediments now only takes place between the stop-banked area. This accretion of sediments has begun to perch the stopbanked floodplain above the formerly active channel downstream of Palmerston North (Figure 4.1).

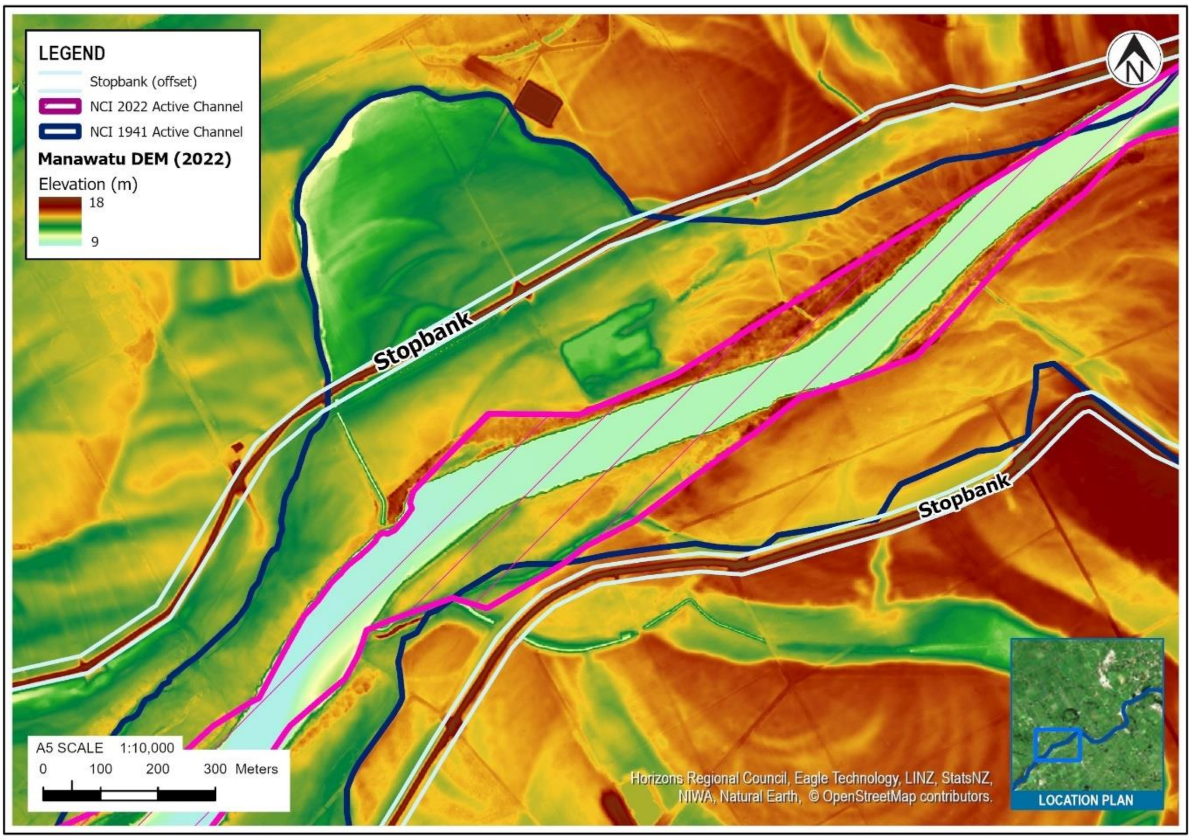

Figure 4.1: Ground level elevation each side of the stopbank on the north side of the river is seen through the colour gradient of the LiDAR DEM. This is compared with the 1941 active channel, which spread outside of the area now constrained by the stopbank.

Sediments were likely in a dynamic equilibrium of erosion and deposition through this bend prior to stop-banking, but since then, there has been increased deposition within the more confined channel, causing the ground elevation to increase through accretion of flood-deposited sediments, a process that was reported by Fuller et al. (2018).

Agricultural intensification of the lower Manawatū floodplain has also contributed to dramatic changes in the river corridor. Many previously heavily vegetated bars now are part of cultivated farmland on the floodplain. This development has encroached on the river corridor and flood and erosion protection, including riparian planting, groynes, and other actions to harden or protect channel edges, all reduce the planform migration of the river within its natural floodplain, and instead confine it to a narrower corridor. Other flood protection works have also constrained the river to protect urban development, particularly near Palmerston North city. These include groynes, river straightening, riprap, revetments, and rock-walls. These engineering works, while effective at protecting from erosion (at least in the short-term), constrain the river to one course, and reduce the sediment supply to the river. This increases the energy available for erosion, and often promotes incision of the river channel, as well as higher velocity flood flows which ultimately may increase the 'need' for more erosion protection.

Gravel extraction also affects the natural character of the river, with several gravel extraction pits now being placed in the previous active channel. Gravel extraction reduces the total sediment available for entrainment by the river, while these floodplain extraction pits, when kept out of the active channel, act to further narrow the active channel.

4.7 River character and behaviour

The change in the natural geomorphic character of the lower Manawatū river corridor identified through the NCI is indicative of changes to the river's character and behaviour. A river which is artificially confined, with a narrowed active channel, a more incised wetted channel (Tonkin and Taylor, 2019), and less room for readjustment will experience a potential sediment deficit because it is unable to replenish material by re-working the extent of river corridor that once was available. Meanwhile, the river also has less room across which it can deposit sediments, which are instead entrained in the river. In a large flood event, confined flood flows traveling at faster speeds have the potential to produce significant geomorphic changes, including damage to flood protection works.

5 Bank lines review

HRC has provided T+T with polygon shapefile areas of their interpretation of the active channel (with left and right margins being the 'bank lines') for each year of aerial imagery from 1941 to 2022. This section aims to compare HRC's previous interpretation of the active channel with T+T's, and to compare the active channel in intermediate years with the active channel in the first and last years of imagery. This is to verify that work based on 1941 and current day active channels (such as river management lines) do not miss geomorphological changes that occurred between these years. It is also to compare and contrast the approaches taken by HRC and T+T. Finally, a set of maps have been developed for Appendix B of this report, which show the changes in active channel extent, using the shapefiles provided by HRC. These are also discussed as they show the channel changes and migration through the past 80 years.

5.1 Approaches to active channel delineation

The approach adopted to delineate the active channel used for the NCI utilised aerial imagery, as well as elevation data in the form of the LiDAR DEM. Typically, the active channel was considered as the area encompassed by the wetted channel and exposed bars of the lower Manawatū, as well as any non-cultivated or forested adjacent area which formed the lightly and heavily vegetated bars. This allowed the delineated active channel to encompass the full width within the river corridor where the river had the ability and freedom to rework, move, and entrain sediment. Although some of these areas, such as the heavily vegetated bars, would only have sediment mobilised in the largest of flood flows, they provide an important part of the active channel corridor. Flows exceeding bankfull are effective geomorphic agents in the river corridor and play an important role in river function, and so the ability for these flows to re-work sediments in their wider active channel allows for the geomorphic quality, character, and sediment supply of the river to be maintained. Meanwhile, allowing the river to flood to these widths without flooding cultivated or developed land helps to reduce damage, and slows down flood flow velocities. Despite these areas not always appearing as obvious 'river channel', geomorphically they provide an important part of the river corridor.

The approach used by HRC in the years between 1941 and 2022 also matches closely to the aerial imagery. There are, however, some key differences, in the delineation. Approximately 40 % of the area included in the active channel for the purpose of the NCI in 1941 was not included in the HRC active channel delineation. Nearly 80% of the difference comes from heavily vegetated bar areas, which, as described above, contributes to the active channel. As the example in Figure 5.1 shows, there are some areas (in blue) where HRC has designated an area to be active channel, which has not been delineated for the NCI. With a few individual exceptions, this is a thin line across the margin of the banks, which fits within a margin of uncertainty based on digitising from aerial imagery. The exceptions, which contribute to a significant amount of the area seen in Table 5.1 below are due to the Foxton Loop being included in the Horizon's active channel, as well as the area upstream of the Ashhurst bridge, which is still downstream of the gorge. For consistency, the Ashhurst bridge was used as the upstream margin for analysis within the NCI. Figure 5.1 also shows the extent of heavily vegetated bars designated as active channel for the purpose of the NCI, based on being uncultivated, adjacent to the wetted channel. These areas show natural vegetation growth, with signs of disturbance due to flood events. Not including these areas risks viewing the active channel as a much more constrained and less dynamic area. Differences between the delineation of the active channel for the entire study reach, for both 1941 and 2022, can be found in a series of maps in Appendix C.

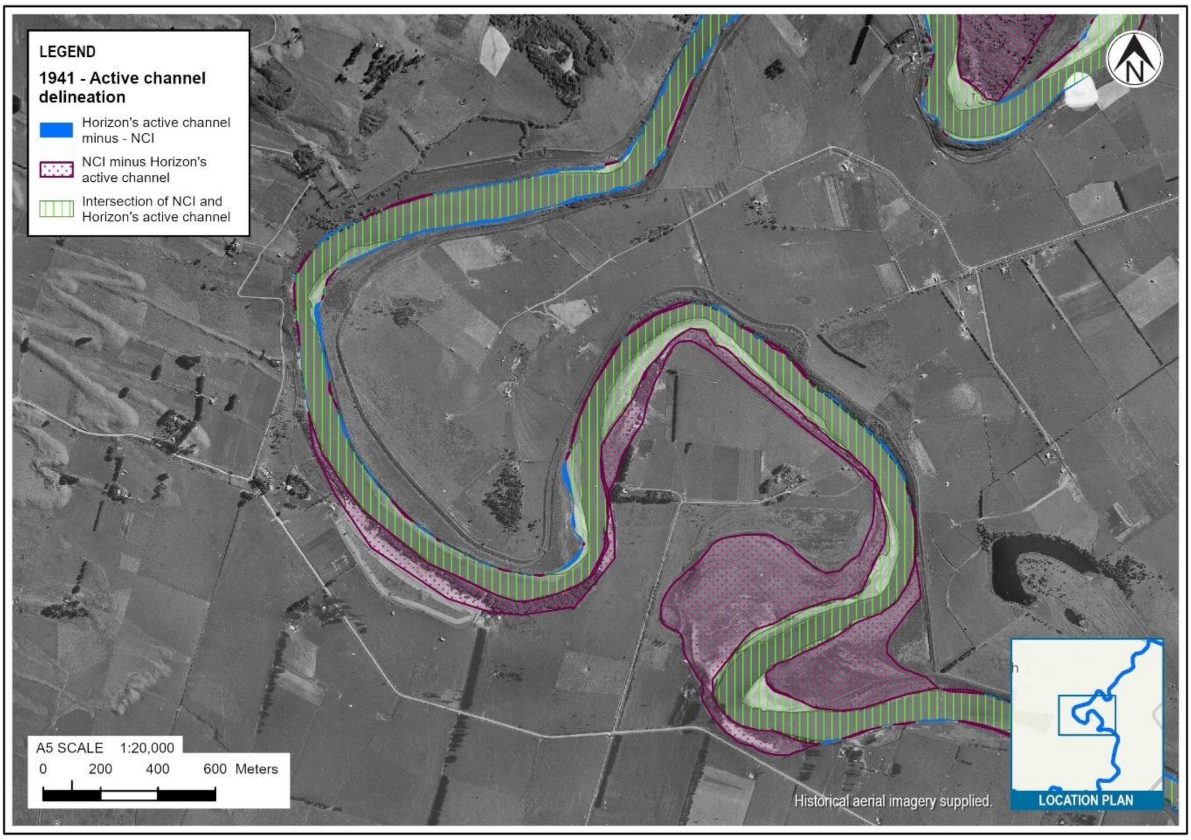

Figure 5.1: Comparison of the active channel delineated for the NCI and the active channel delineated by HRC. The area shown by the green slanted lines is the active channel area delineated by both, while the area in pink is the active channel delineated only for the NCI, and the area in blue is only delineated by HRC.

Table 5.1 compares the areas classified as active channel in each analysis for each year. It also compares the areas under each analysis which fall outside of the area designated in the other analysis. To show the relative importance of heavily vegetated bars in creating the difference between the two analyses, heavily vegetated bar areas are also included. It is important to note that although the precise areas defined between the NCI approach and Horizons' definition differ, the overall change in active channel still demonstrates a marked reduction in area (0.65).

Table 5.1: Comparison of active channel and heavily vegetated areas delineated for the NCI and by HRC in 1941 and 2022

Parameter	NCI area		HRC active channel		NCI areas outside of HRC active channel		HRC active channel outside of NCI area	
	1941	2022	1941	2022	1941	2022	1941	2022
Active channel area [ha]	**2,791.4**	**1,421.5**	**1,724.0**	**1,125.9**	**1,146.7**	**431.8**	**79.7**	**140.0**
Heavily vegetated bar [ha]	970.3	437.0	N/A	N/A	899.1	396.1	N/A	N/A

5.2 Active channel area in intermediate years (1958-2016)

Using the active channels for each year, it was possible to identify whether the envelope formed by 1941 and 2022 active channels encompassed the envelope for all intermediate years, with 8 sets of imagery from 1958-2016. Channel changes already identified mean that the 2022 channel is very different from the 1941 channel. However, channel changes, migration and bank erosion are not linear processes, with successive erosional and depositional changes throughout a flood and geomorphic history producing the active channel and geomorphic landscape at any time. This means that intermediate years may show an active channel which is outside of the envelope of the 1941 and 2022 channels. These intermediate changes are important to assess, and assist in understanding the extent to which decisions, management lines, and assessments of the natural character can be made using only the first set of aerial imagery, or whether all intermediate years should also be considered.

Table 5.2 shows the area in each year which sits outside of the 1941 and 2022 envelope. Much of this area is the same between years, with the aggregated area covered by all of these intermediate years much less than the sum of the areas. A lot of this area comes from thin margins at the side of each bank, where the active channel was delineated slightly wider. There is also a large area (approximately 65 ha) which has been delineated by HRC upstream of the Ashhurst Bridge. Outside of this, however, there are several locations where the additional active channel area is a product of a migrated or wider active channel, rather than differences in delineation. There are three or four key locations where this is the case down the length of the active channel. The largest of these areas is at the channel mouth to the Tasman Sea. Here, the outlet of the Manawatū has migrated north and south, between the pine forest to the south and the town of Foxton Beach to the North. This is likely a product of sand bars moving through flood events as well as coastal storm surges and tidal events. As this is at the coastal interface and is informed by a combination of fluvial and coastal processes, further investigation would be necessary before delineating a geomorphologically-informed long-term active channel here.

Table 5.2: Area outside of the active channel envelope delineated for 1941 and 2022 NCI for each intermediate year

Intermediate year	Area outside 1941 + 2022 active channel [ha]
1958	102.9
1965	126.6
1970	137.9
1974	101.5
1995	87.2
2005	91.2
2011	65.9
2016	59.2
Aggregated intermediate year envelope	**287.6**

Other locations are typically bends or now-cutoff bends which have experienced migration during these intermediate years. Figure 5.2 shows one of the largest such areas, where several intermediate years of imagery showed exposed bars and wetted secondary channels which have developed beyond the 1941 and 2022 active channel envelope. This shows how dynamic the lower Manawatū is, particularly in the steeper upper gravel reaches. This area, which was part of the active channel as recently as 1958, is now a site of gravel extraction, which has confined the river. It is also necessary to add that the method of delineation for these intermediate years, similarly to the 1941 and 2022 Horizon's delineated active channel, takes a narrow definition of the active width within the river corridor. For example, in Figure 5.2, the area indicated by the orange cross is not cultivated nor forested and appears to be an active part of the channel but is not delineated as part of the active channel.

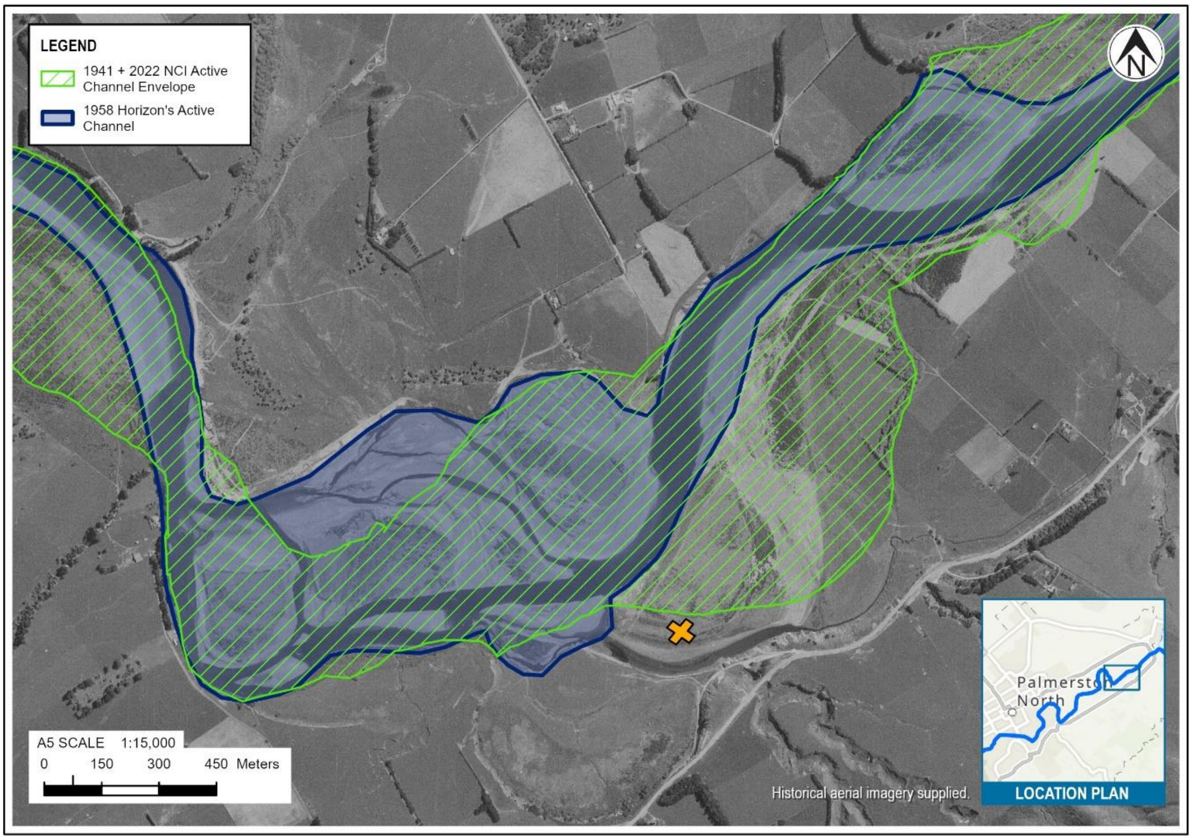

Figure 5.2: Comparison of area encompassed by the 1941 and 2022 active channel areas delineated for the NCI, and the 1958 active channel delineated by HRC. The orange 'x' indicates an area that is likely part of the active channel, but has not been encompassed by either envelope.

Due to the width of the channel in intermediate years in some locations exceeding the width of the 1941 and 2022 envelope, it is important to recognise these intermediate years as being part of the longer-term active channel envelope of the lower Manawatū. The river is highly dynamic, and this means that successive flood flows may re-activate sediment outside of the prior active channel, which may be then, in the future, re-colonised by vegetation and become cultivated or managed. Despite an increase in pressures on the room for the river since the first aerial imagery in 1941, the river's dynamic behaviour means that it has still shown bend migration and channel change throughout the last 80 years.

5.3 Active channel change and migration through successive aerial imagery

The active channel areas delineated by HRC help to show the typical channel changes that have occurred to the lower Manawatū through the last 80 years. Through visualisation of these active channels, it is possible to validate the results of the NCI, although considering that these are developed with a narrower definition of the channel extents. In general, the visualisation of this confirms the results of the NCI, with a narrowing of the active channel width and a simplification of the river. However, this change is non-linear, and there are locations which have seen a widening or an increase in sinuosity.

A full set of maps which show this successive change is included in Appendix B.

Figure 5.3 shows a reach of the lower Manawatū highlighting typical changes to the channel. It shows a gradual narrowing of the active channel through successive years, with less room encompassed by the corridor. This is aligned with a simplification of the river mosaic and a slight straightening of meanders.

Figure 5.3: Comparison of HRC active channels for each year of aerial imagery, showing channel simplification for a reach downstream of Palmerston North, before Ōpiki.

Figure 5.4 shows a change to the river channel which modifies the active channel envelope but does not show a reduction in the geomorphic character. This is a situation where there is a lateral migration of the channel through natural erosional and depositional processes. Although this change does not affect the natural character of the river, it shows that any management lines or delineated river corridor needs to account for natural channel migration and the dynamic equilibrium of the geomorphology, as well as any potential disequilibrium caused by anthropogenic drivers.

Figure 5.4: Comparison of HRC active channels for each year of aerial imagery, showing lateral meander migration for a reach downstream of Ōpiki.

Figure 5.5 visualises how some of the channel change likely reflects direct river modification works. Here, the bend appears to have been artificially cutoff, between the 1941 and 1958 imagery. This has led to a much narrower, slightly steeper, and (presumably) a more incised channel.

In some situations, however, the river is continuing to evolve and re-work new floodplain. Figure 5.6 shows a meander forming in the lower section of the river, forming slowly through erosion of the sand banks and deposition on the inside of the bend. Despite pressure on the room for the river, it continues to evolve geomorphically.

Figure 5.5: Comparison of HRC active channels for each year of aerial imagery, showing river modification works causing meander cutoff for a reach downstream of Ōpiki.

Figure 5.6: Comparison of HRC active channels for each year of aerial imagery, showing meander development in a sand-bed reach just upstream of the Foxton loop.

6 Applicability

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

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Appendix A Natural Character Index Map Figures

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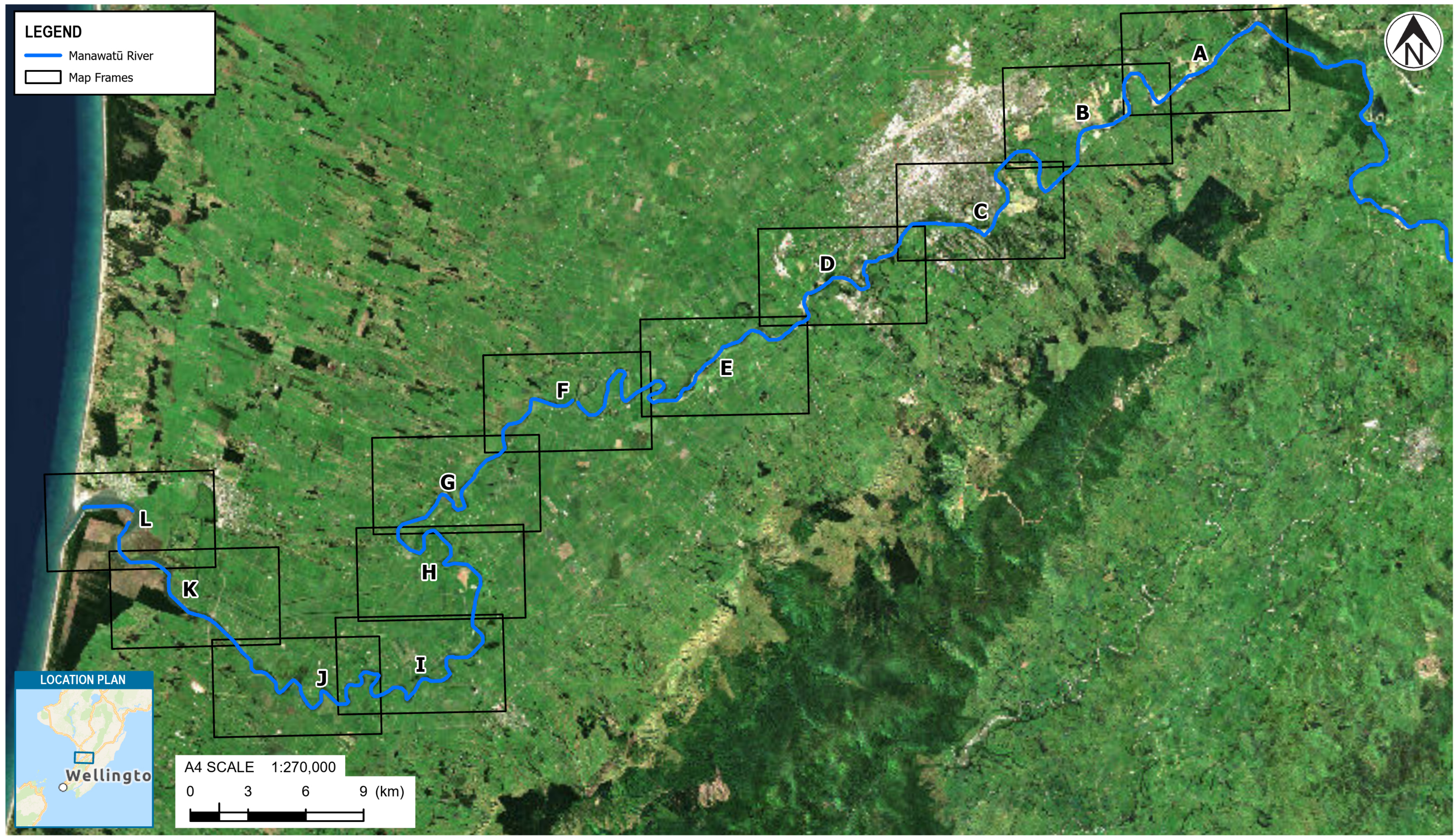

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NOTES:
Basemap: 2022 Aerial (LINZ)

REVISIONS	NO.	BY
First version (5/04/24)	0	DSMI

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TITLE NATURAL CHARACTER INDEX - MAP SHEET INDEX

SCALE (A4) 1:270,000 FIG No. APPENDIX A (FIGURE 1) REV 0

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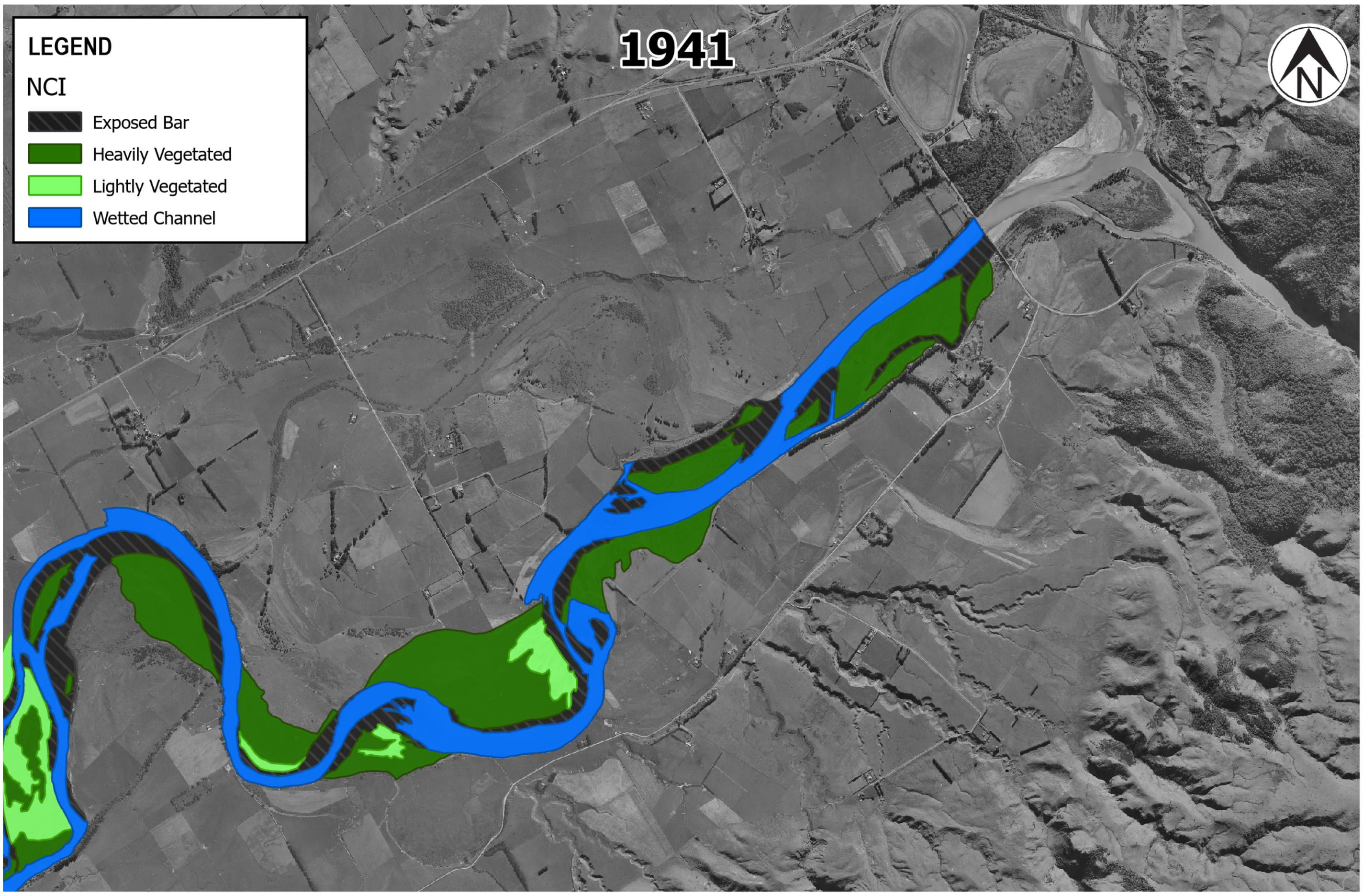

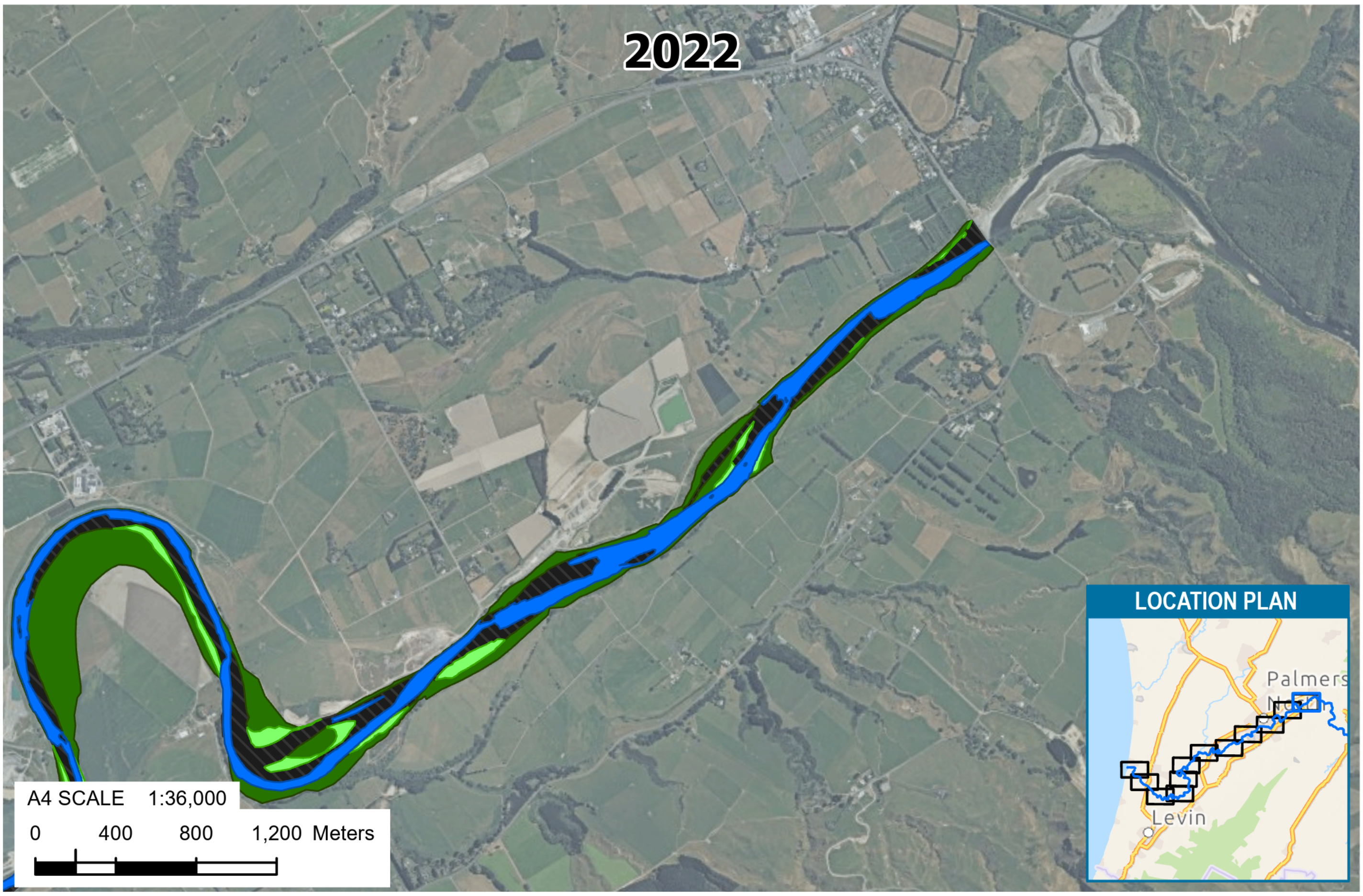

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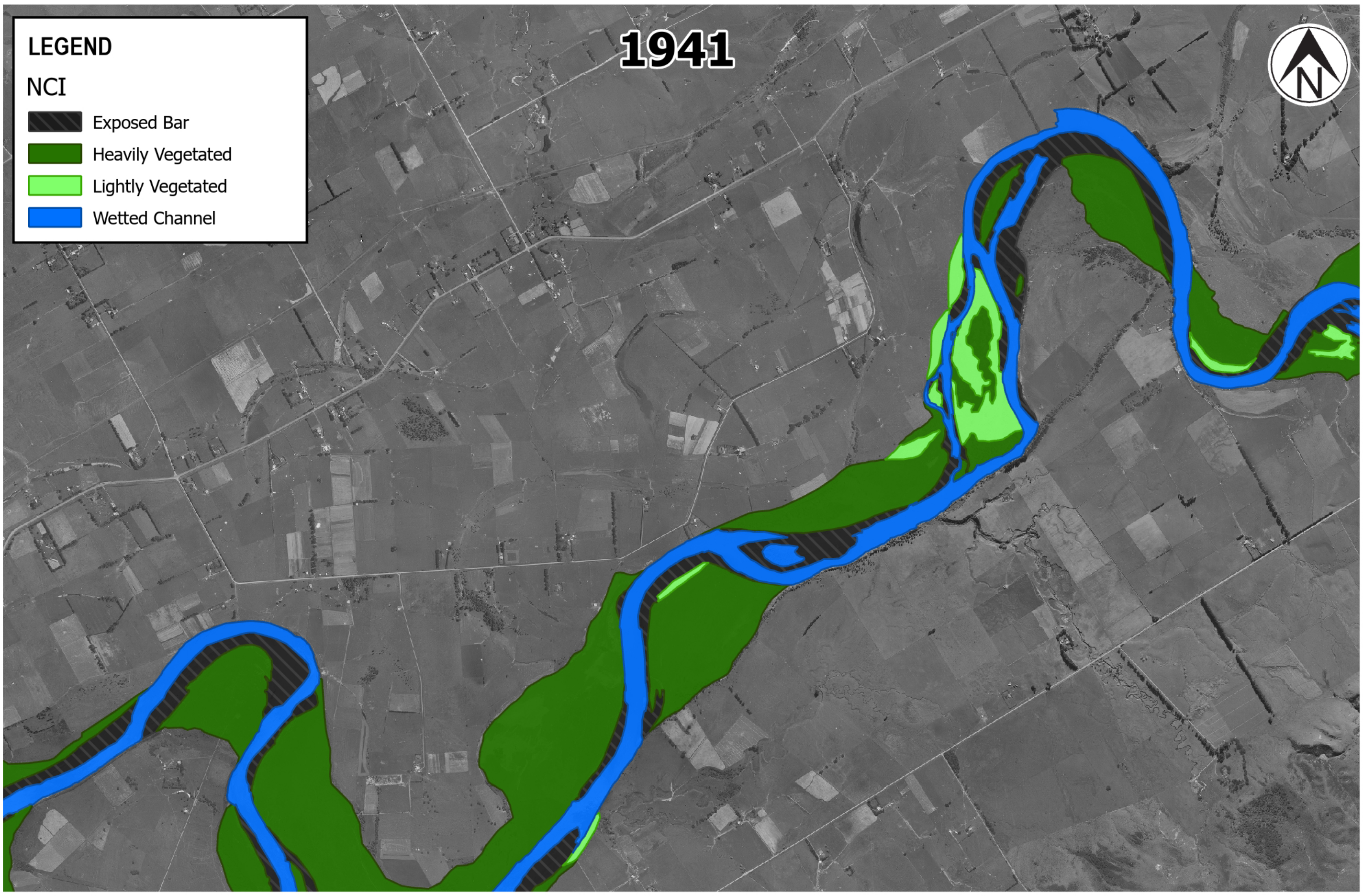
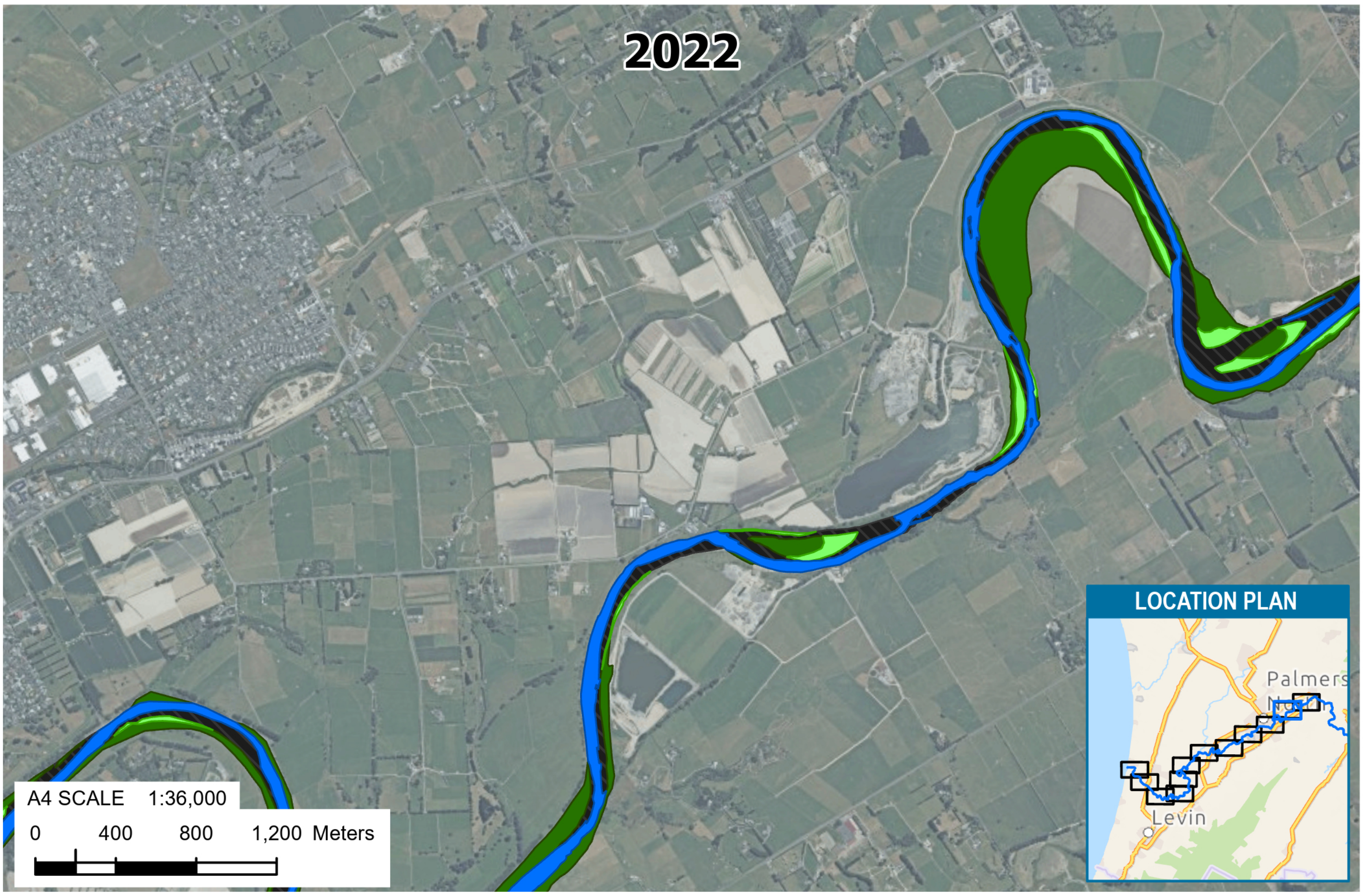
TITLE NATURAL CHARACTER INDEX
SCALE (A4) 1:36,000 FIG No. APPENDIX A (FIGURE 1-A) REV 0





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TITLE NATURAL CHARACTER INDEX
SCALE (A4) 1:36,000 FIG No. APPENDIX A (FIGURE 1-B) REV 0

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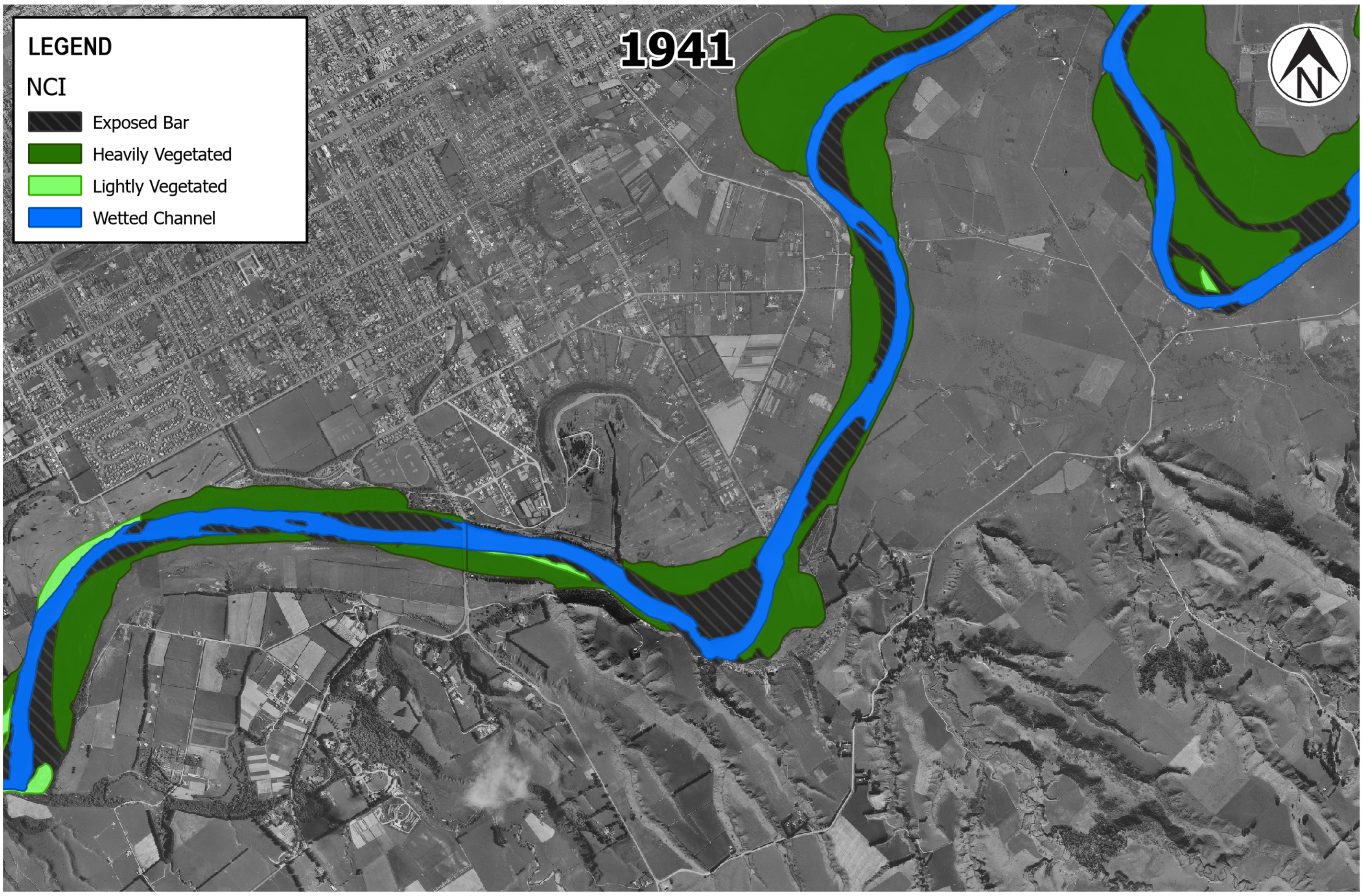

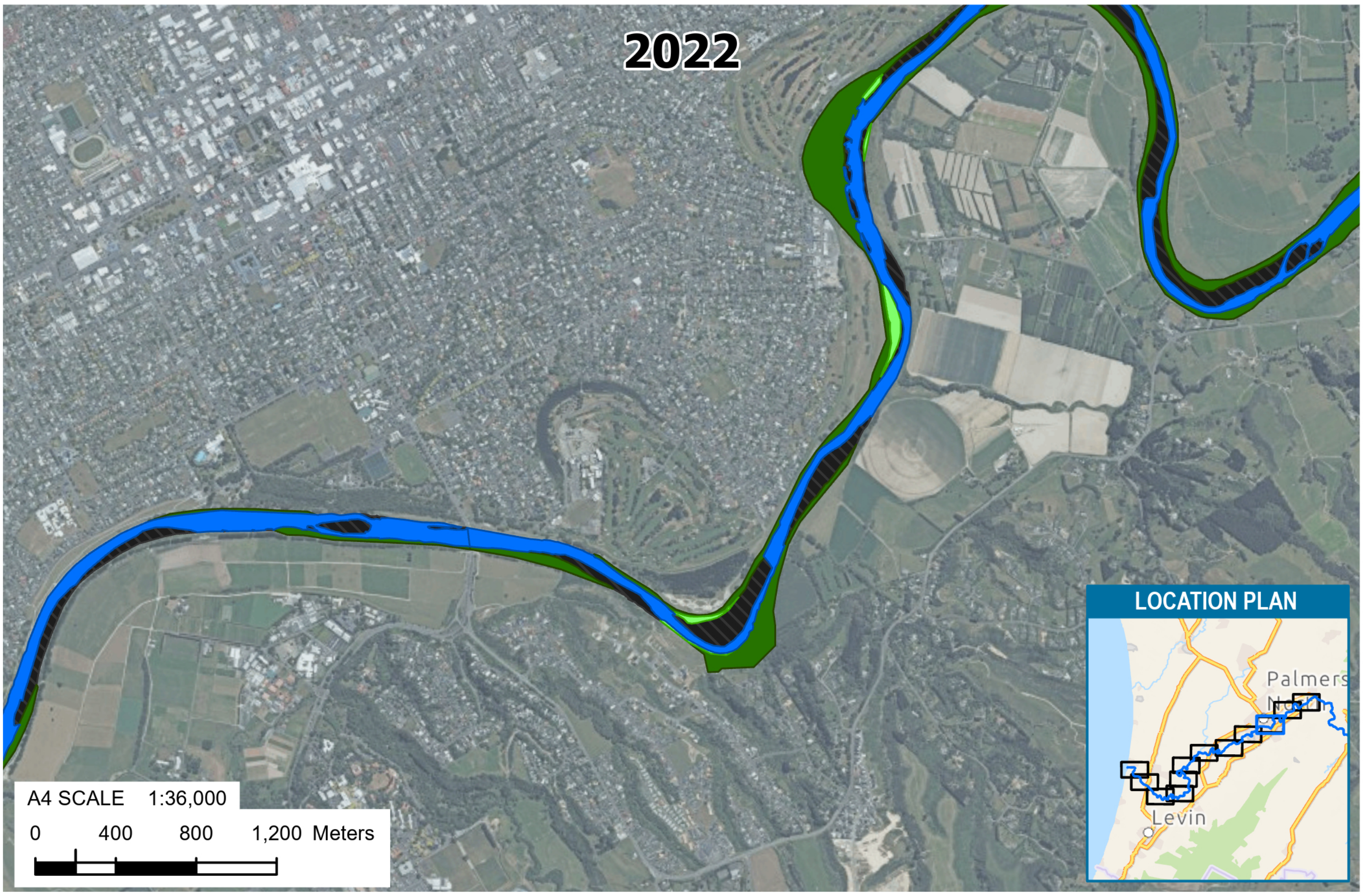

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TITLE NATURAL CHARACTER INDEX

SCALE (A4) 1:36,000 **FIG No.** APPENDIX A (FIGURE 1-C) **REV** 0

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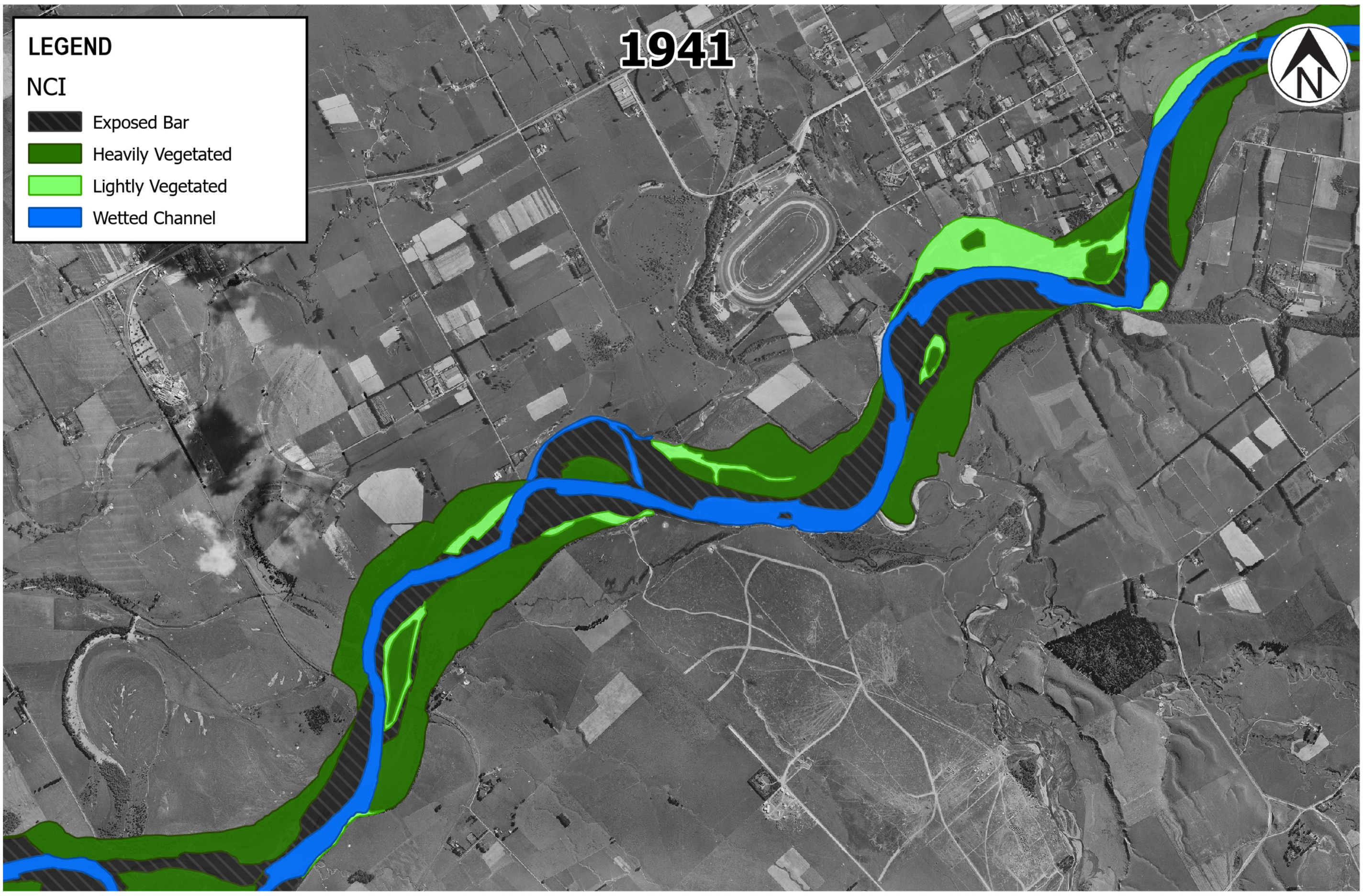

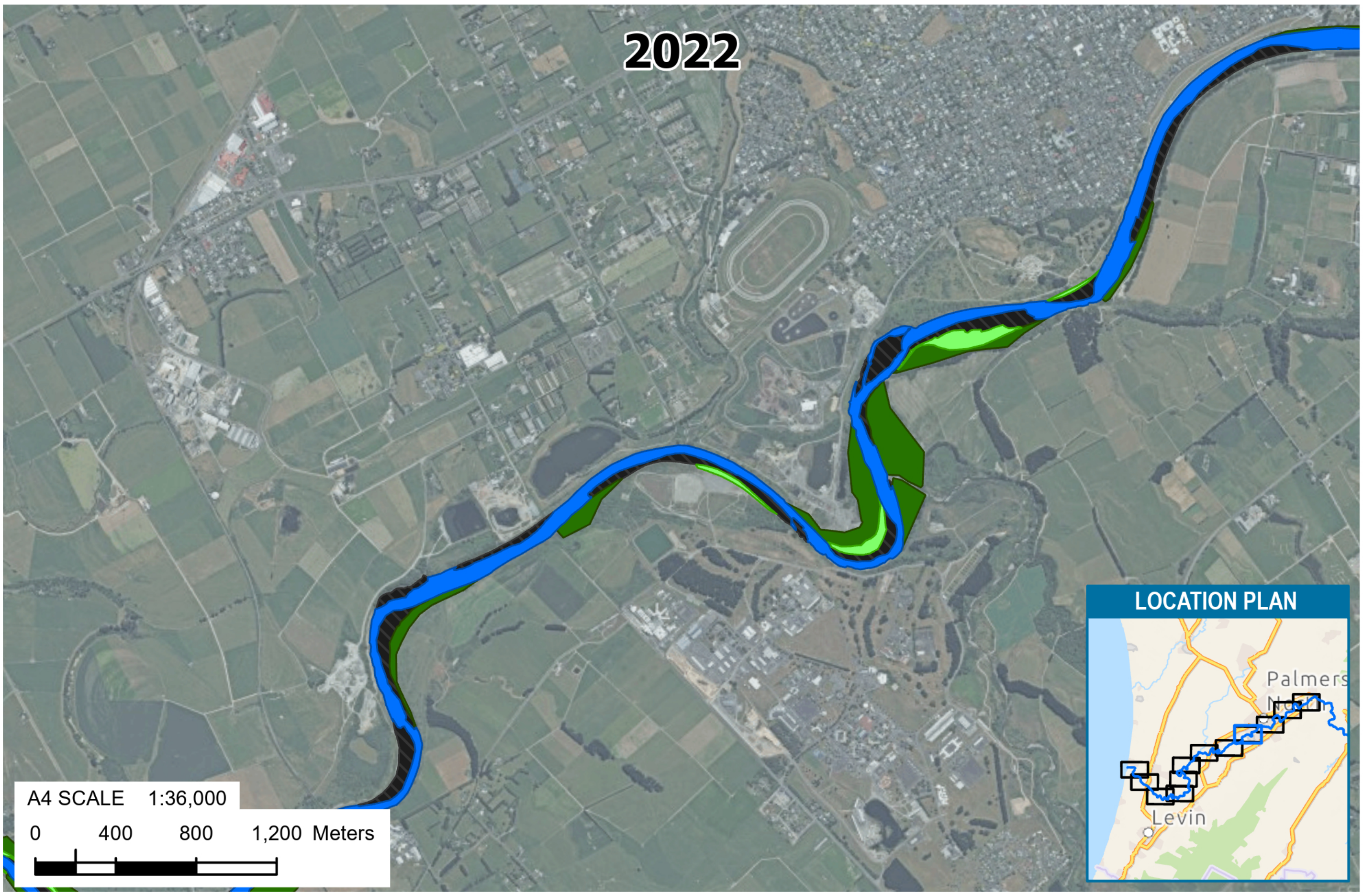

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SCALE (A4) 1:36,000 FIG No. APPENDIX A (FIGURE 1-D) REV 0

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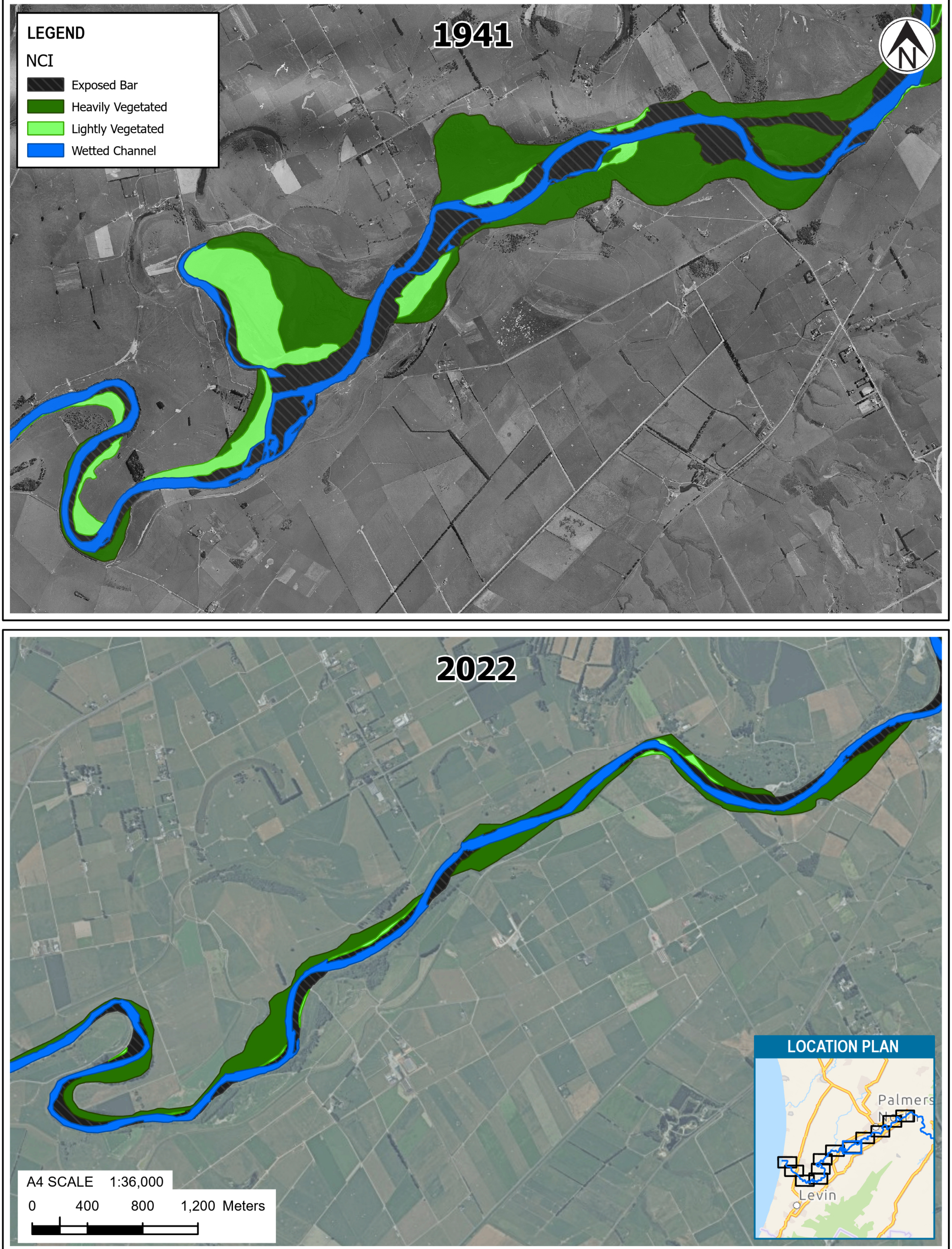

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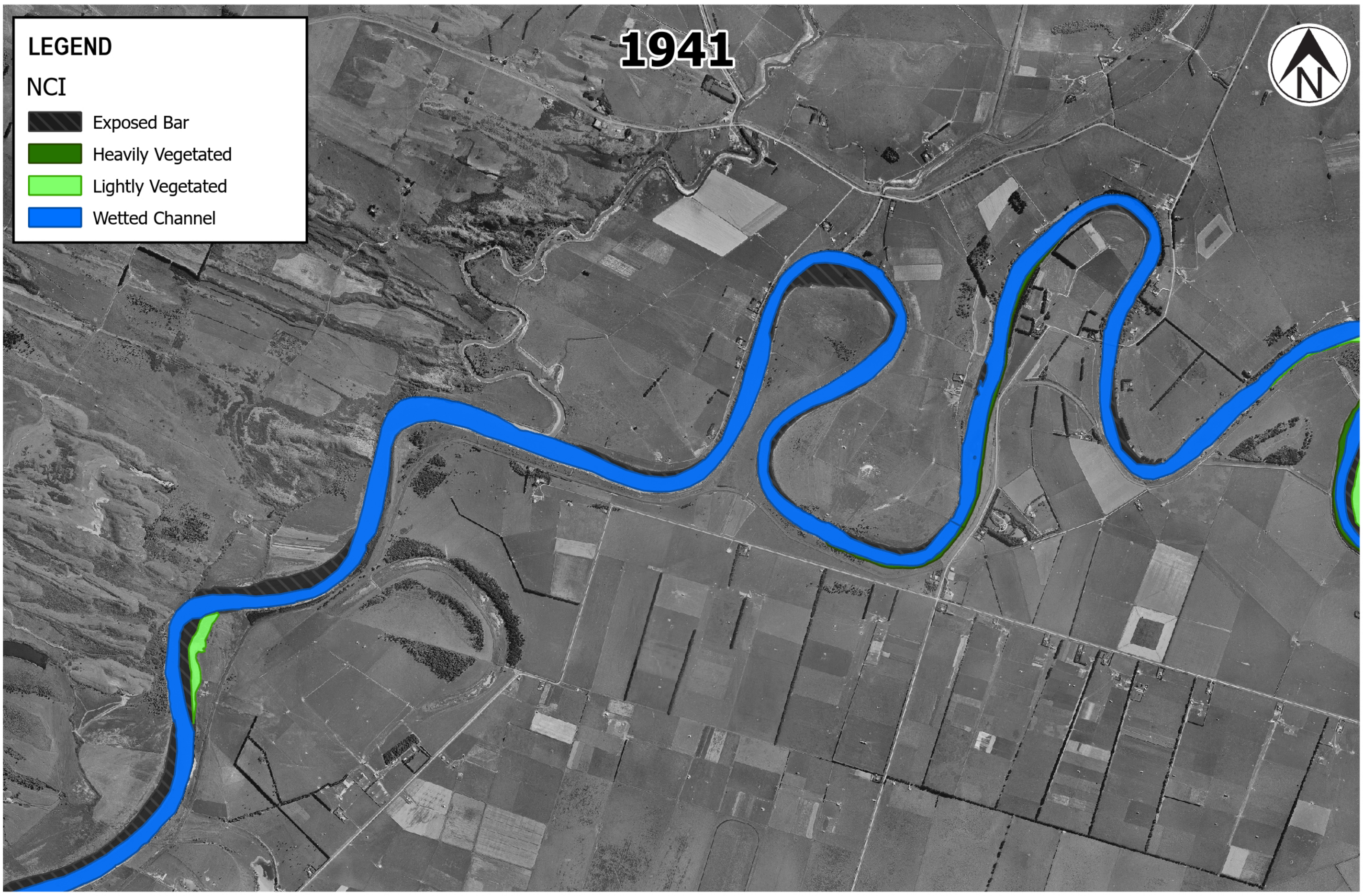

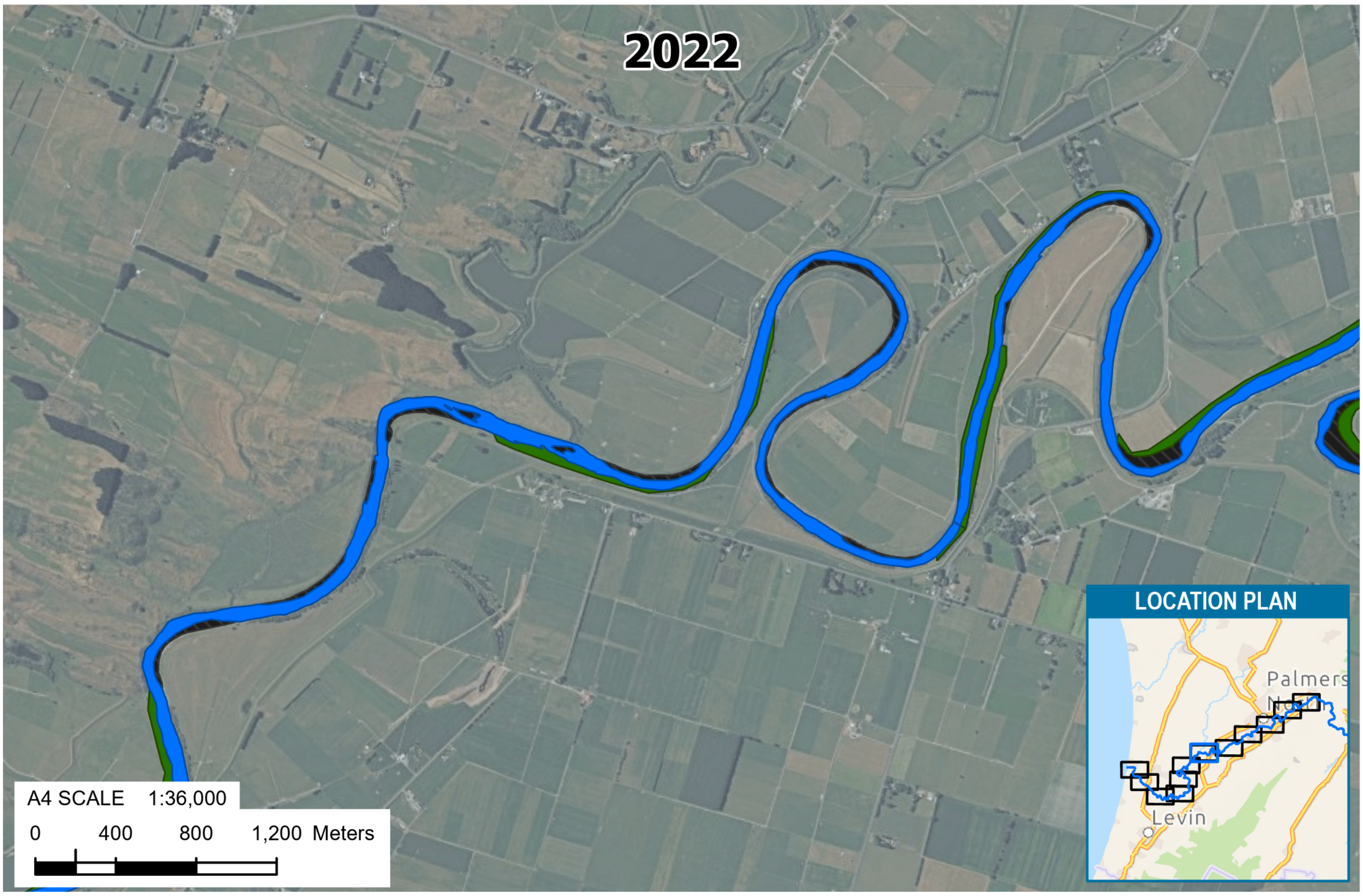

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SCALE (A4) 1:36,000 FIG No. APPENDIX A (FIGURE 1-F) REV 0

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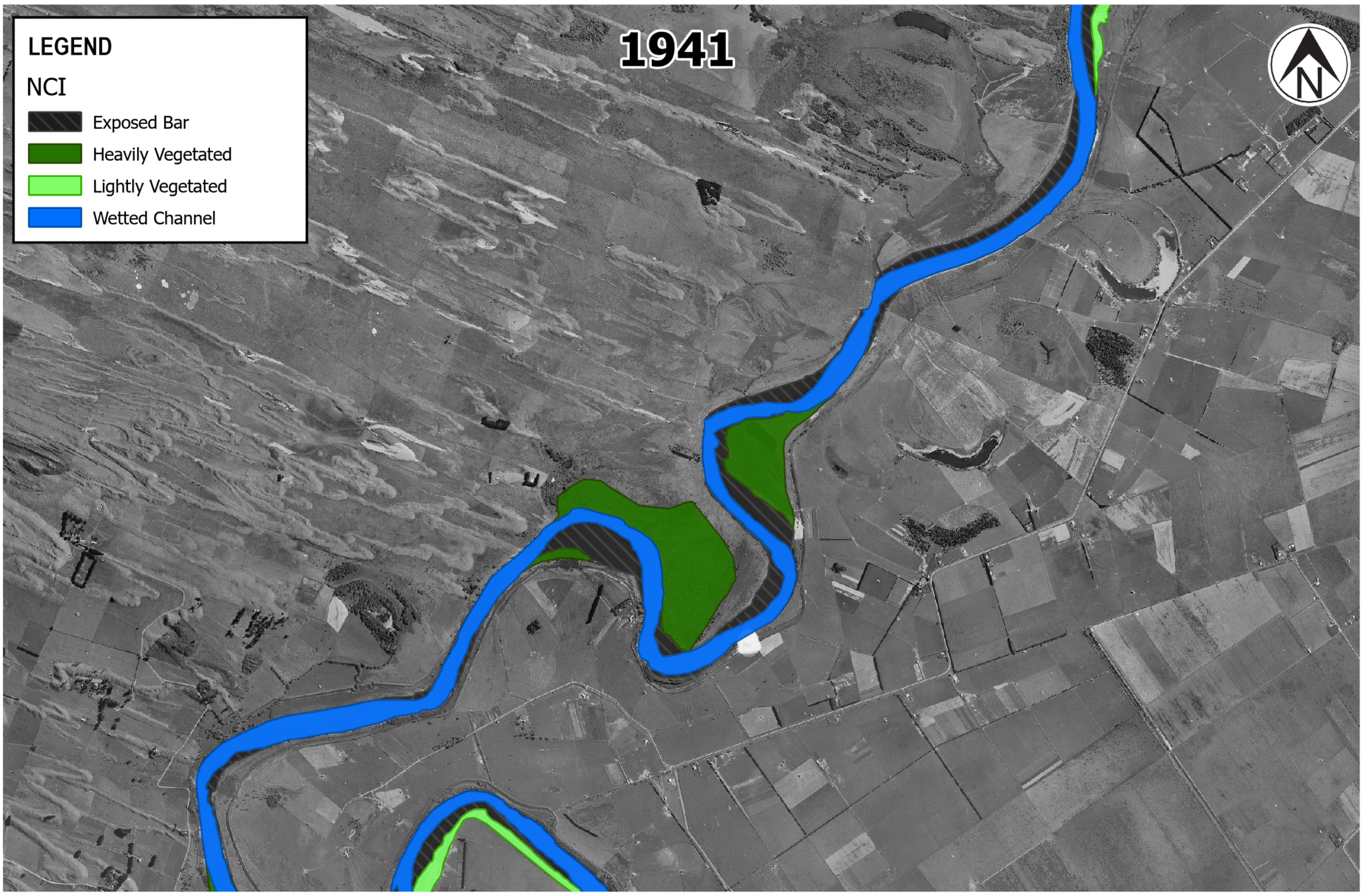

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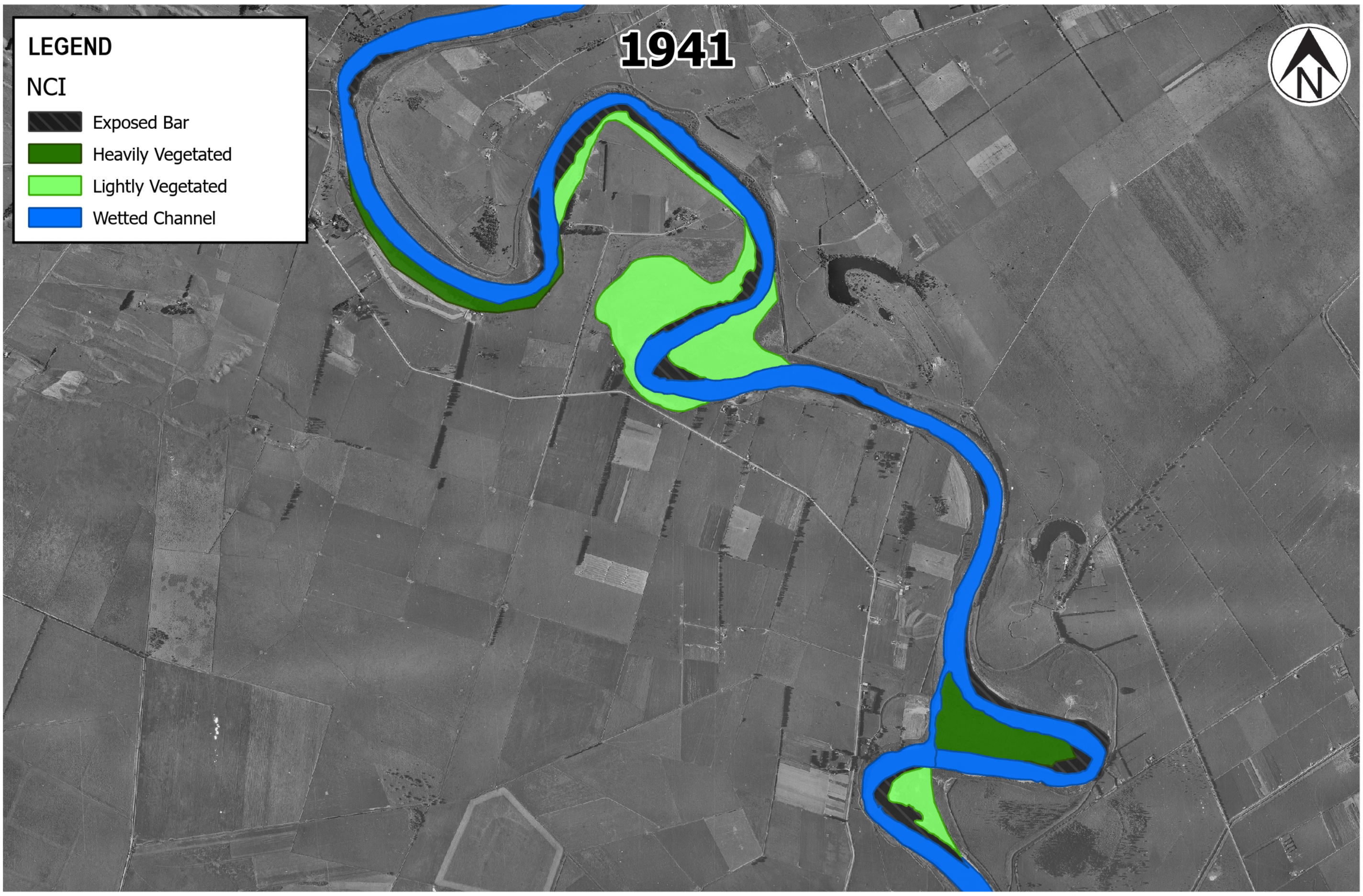
SCALE (A4) 1:36,000 FIG No. APPENDIX A (FIGURE 1-G) REV 0



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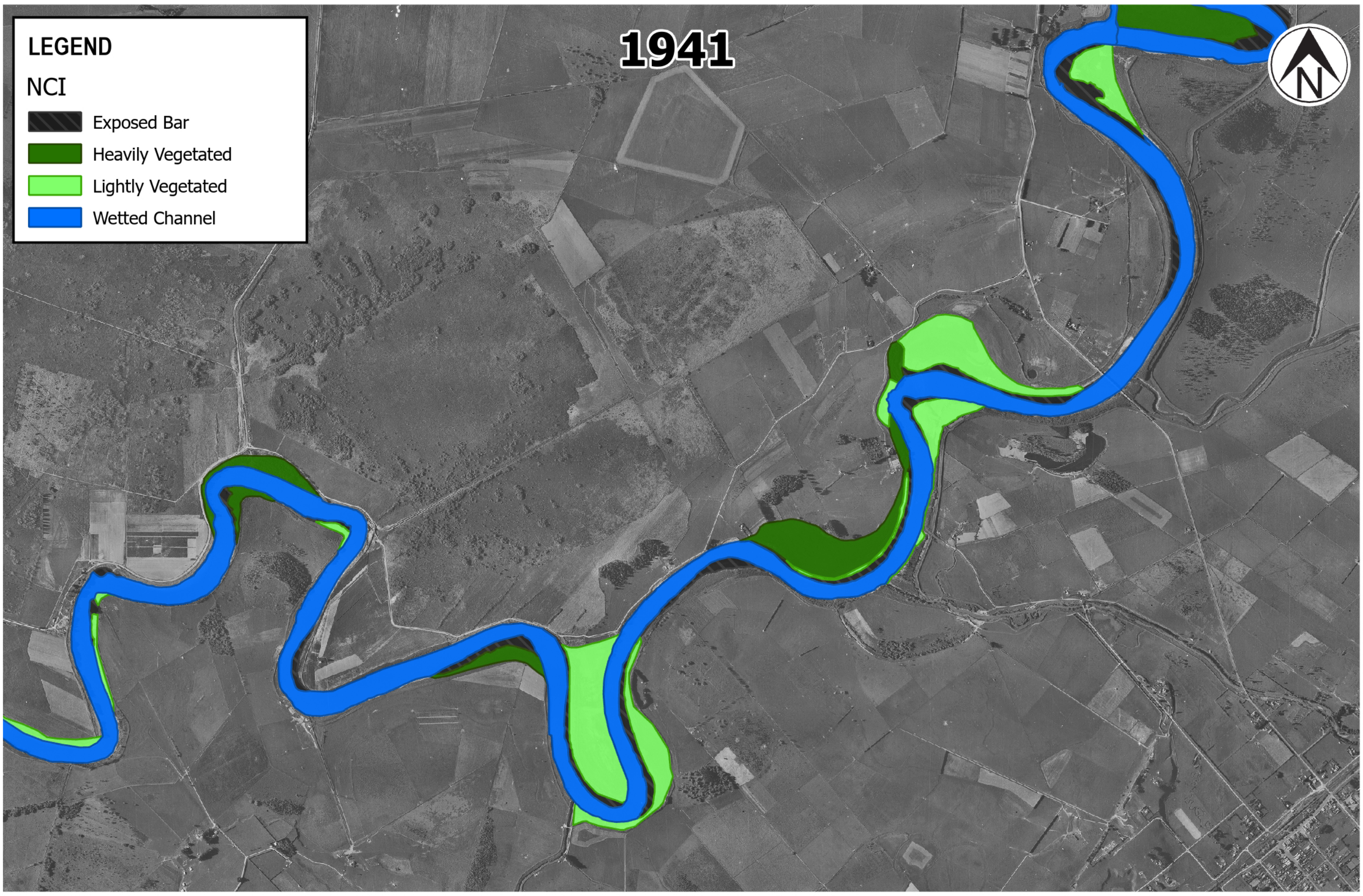
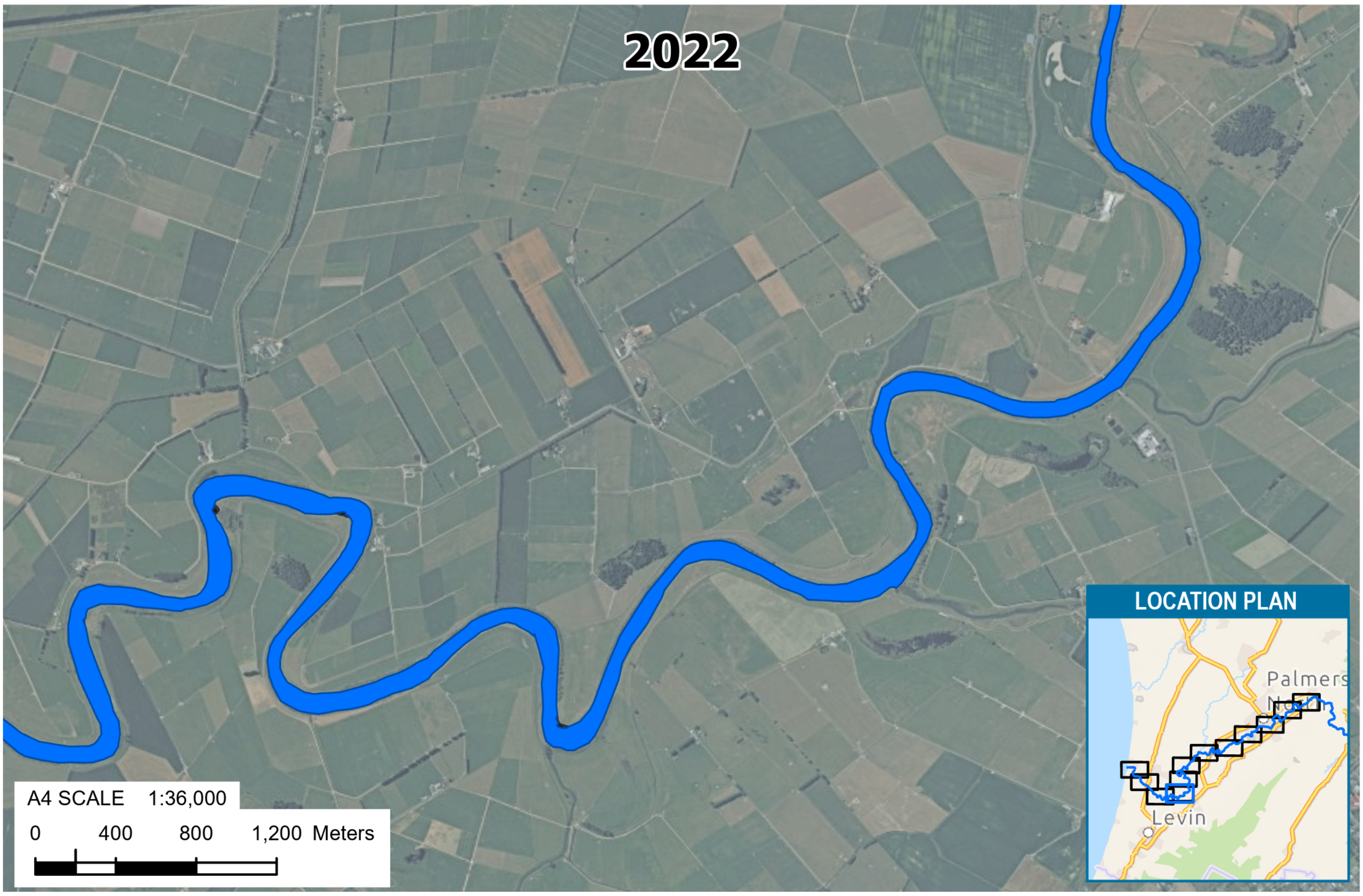
SCALE (A4) 1:36,000 FIG No. APPENDIX A (FIGURE 1-H) REV 0





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SCALE (A4) 1:36,000 **FIG No.** APPENDIX A (FIGURE 1-I) **REV** 0

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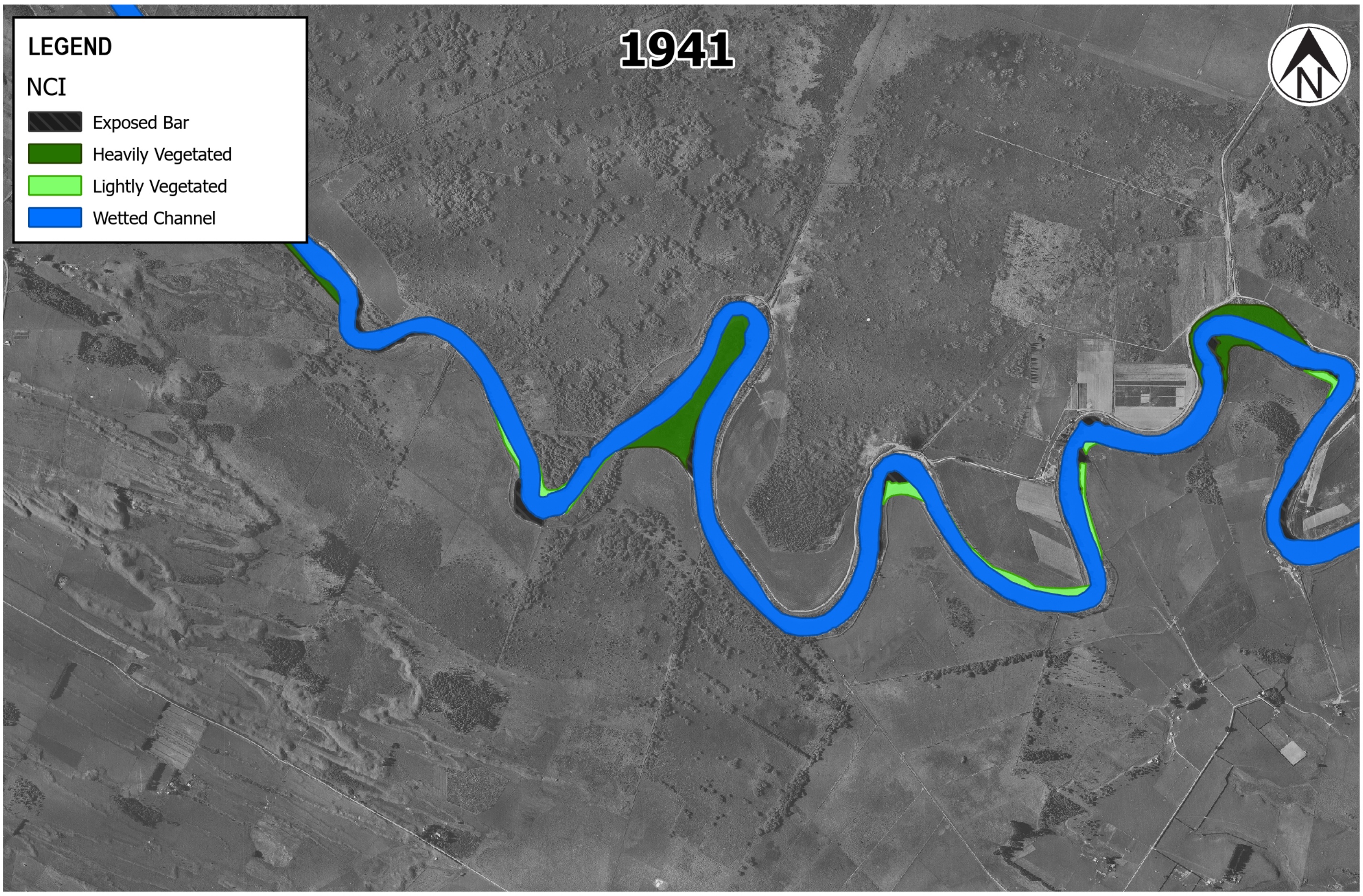

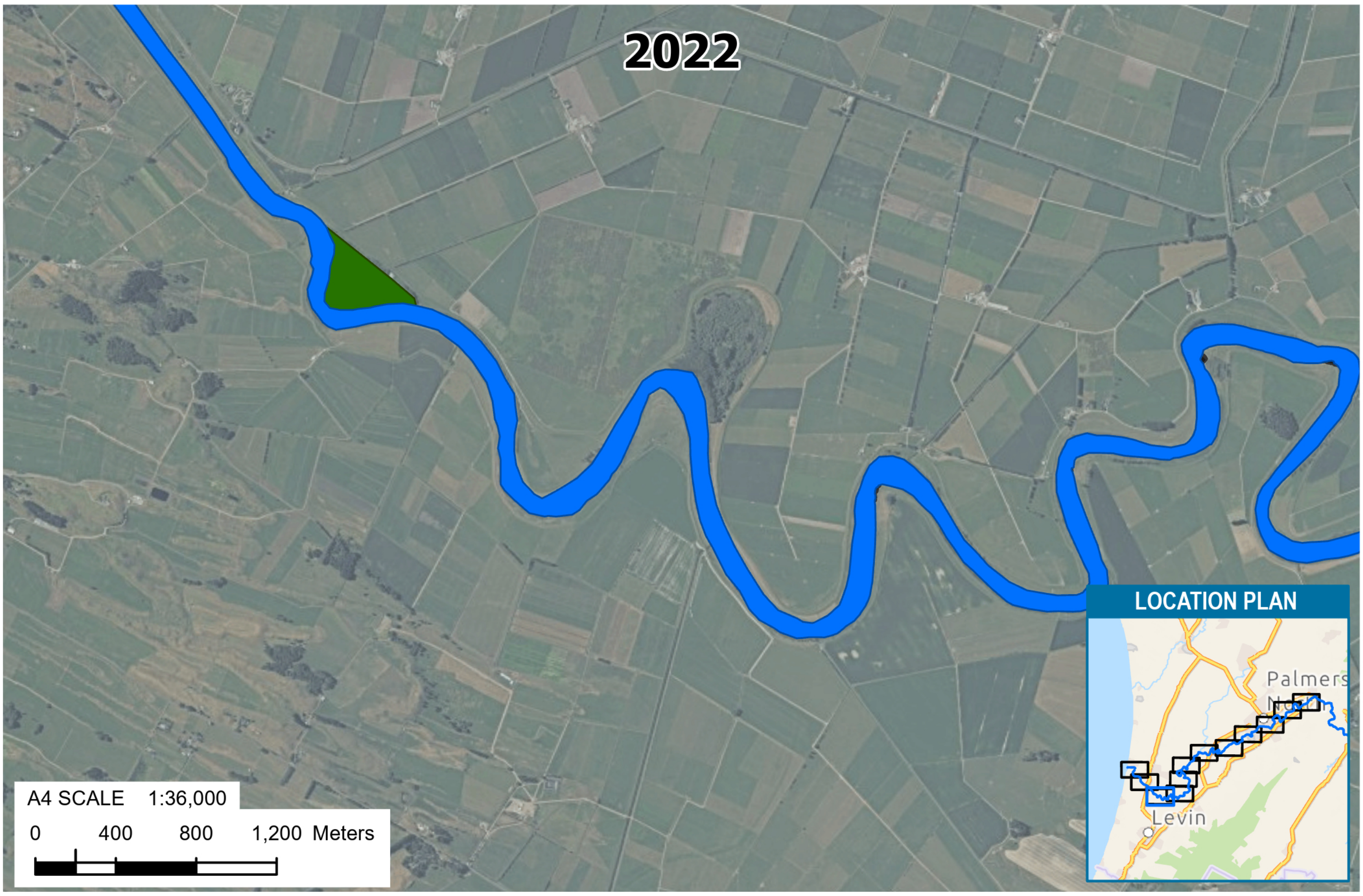

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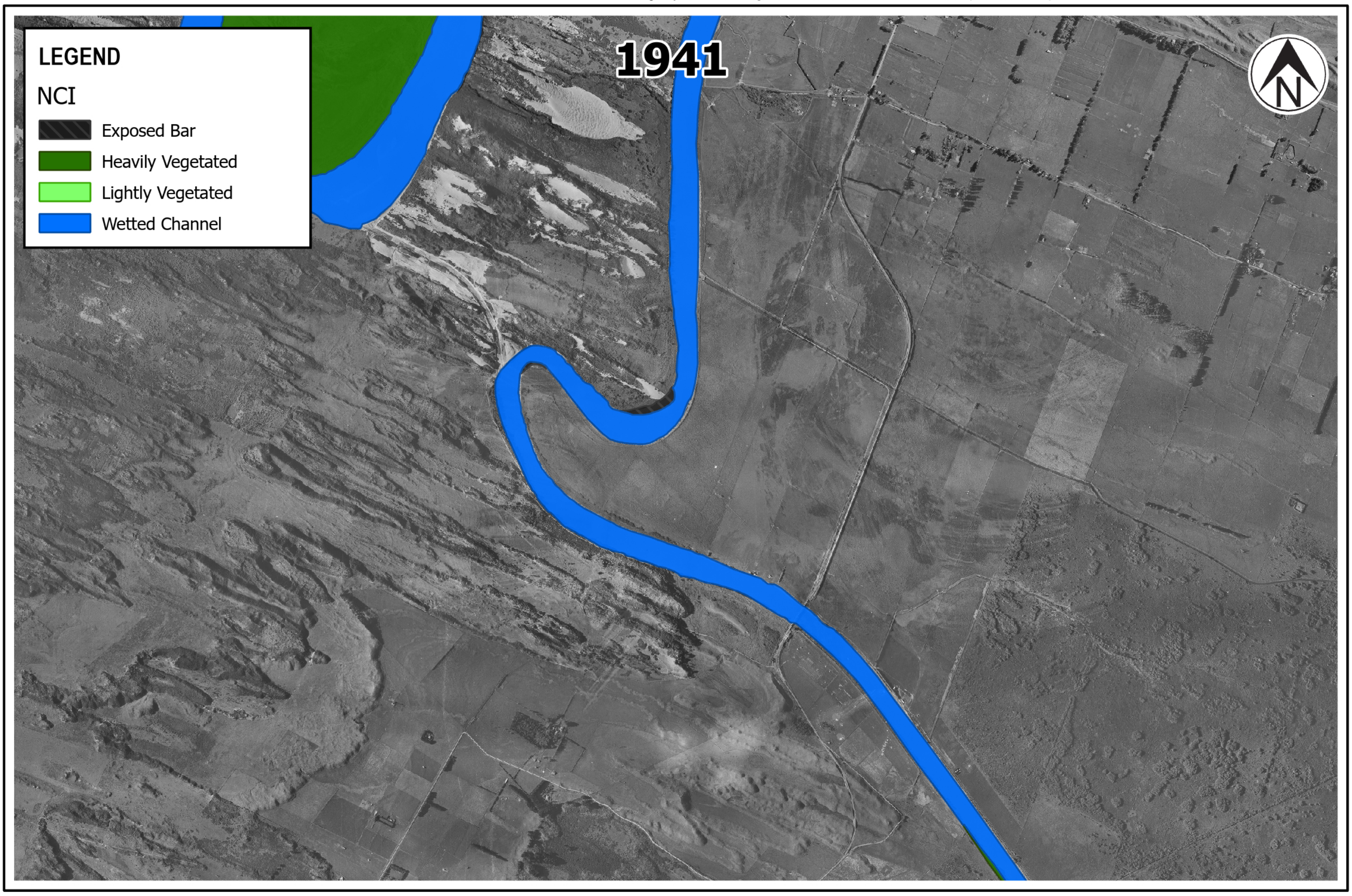
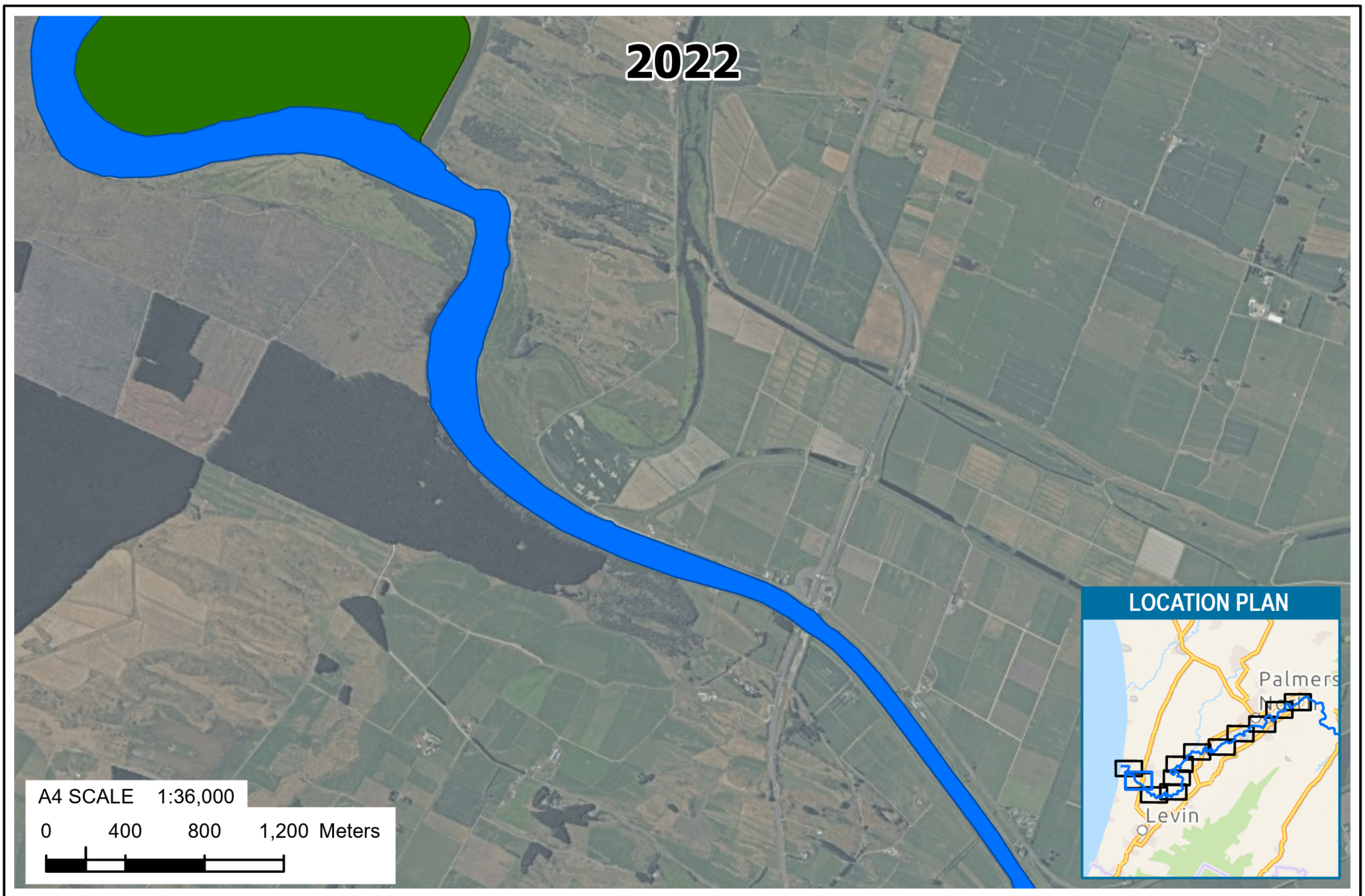
SCALE (A4) 1:36,000 FIG No. APPENDIX A (FIGURE 1-J) REV 0





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SCALE (A4) 1:36,000 FIG No. APPENDIX A (FIGURE 1-K) REV 0

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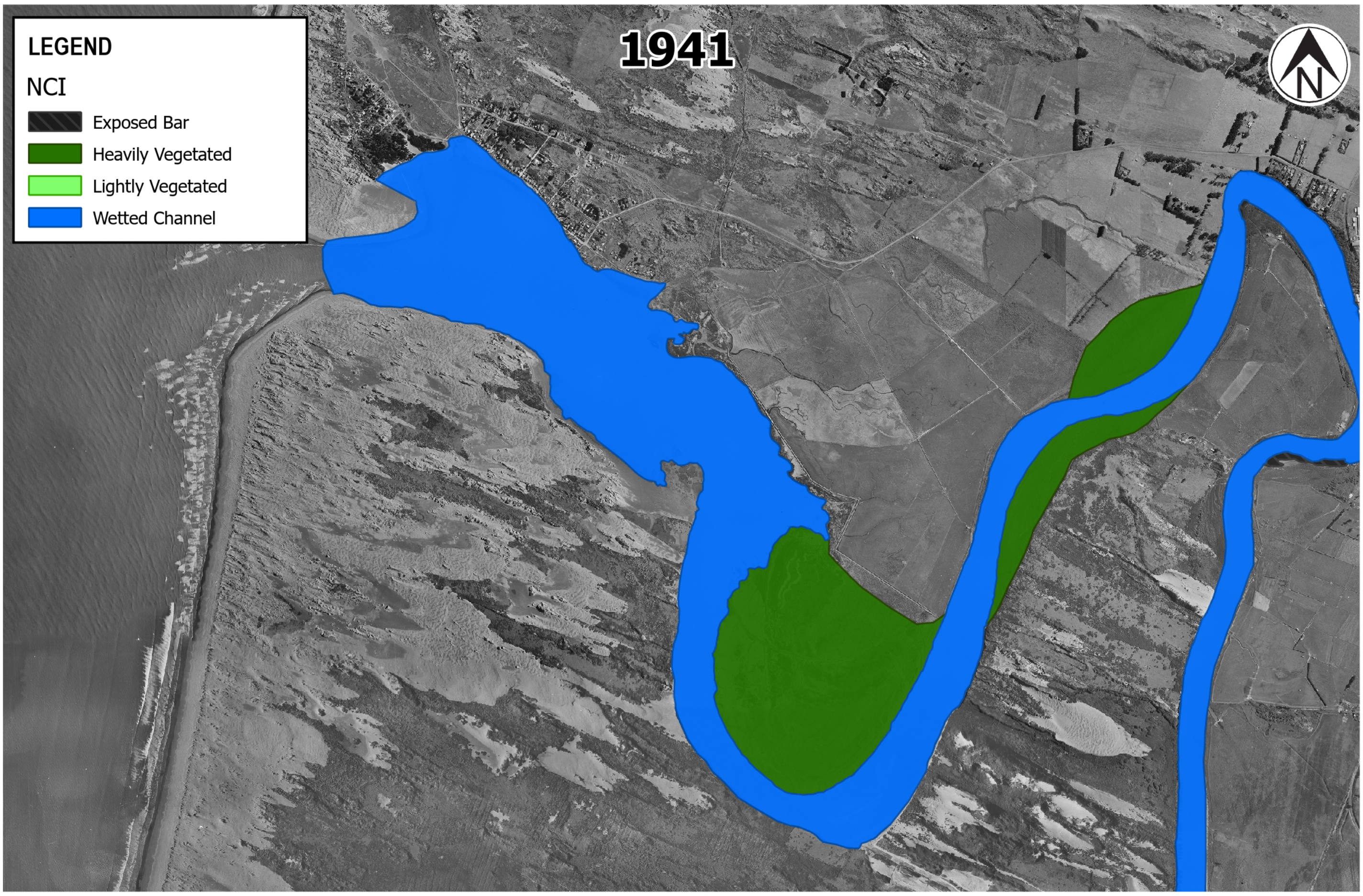

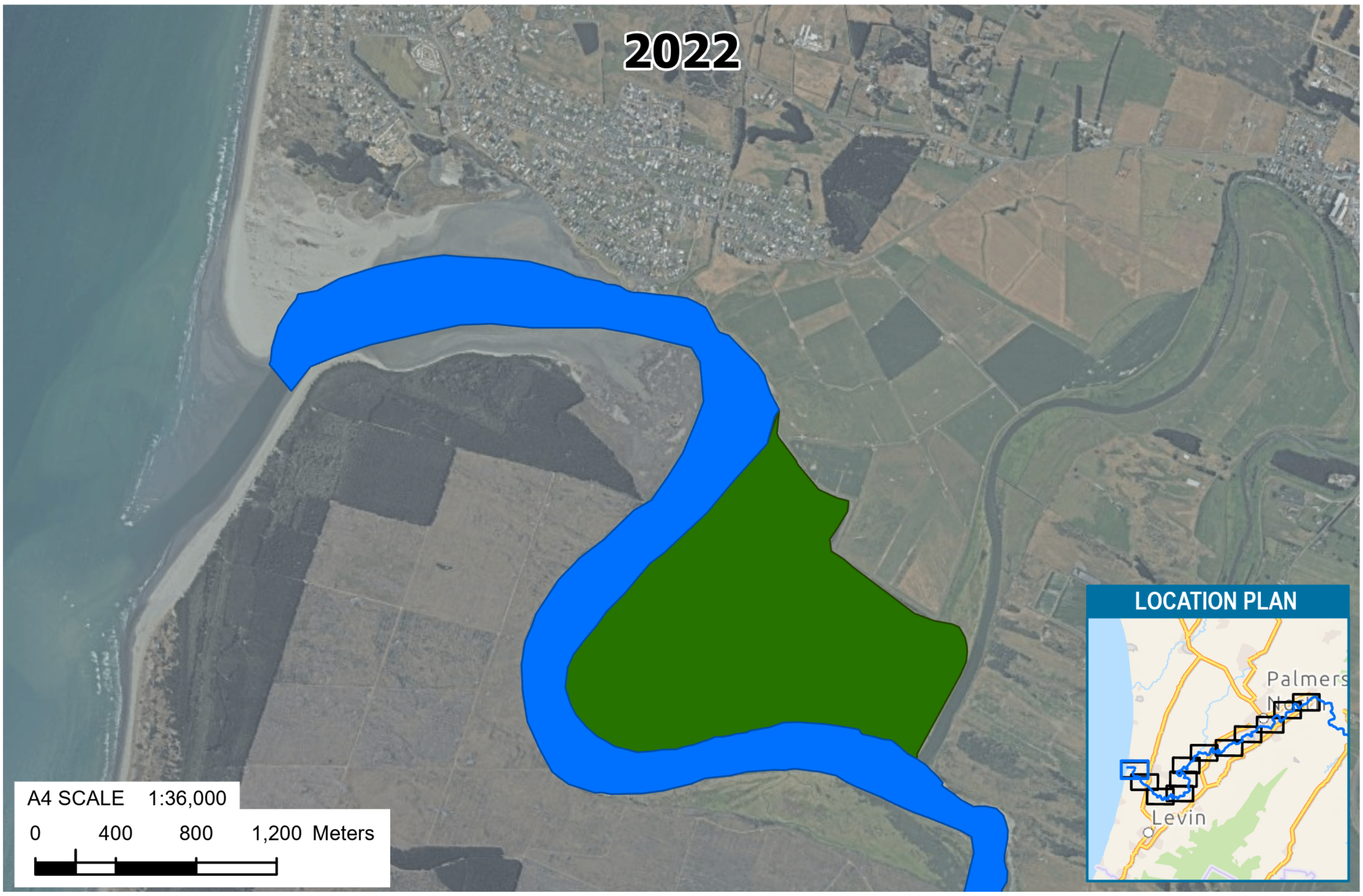

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SCALE (A4) 1:36,000 FIG No. APPENDIX A (FIGURE 1-L) REV 0

Appendix B Bank Lines Assessment Map Figures

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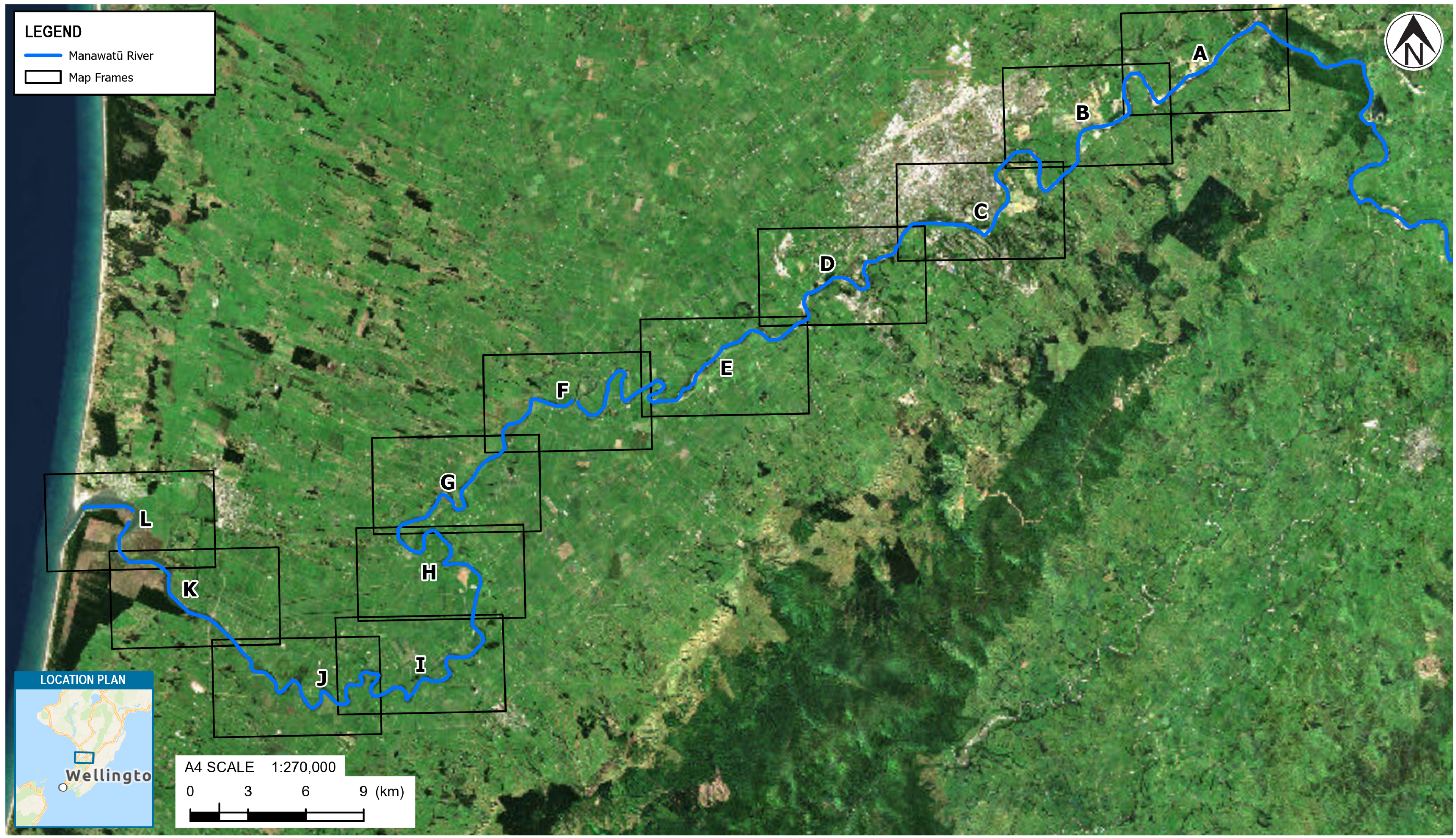

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TITLE BANK LINES ASSESSMENT - MAP SHEET INDEX

SCALE (A4) 1:270,000   FIG No. APPENDIX B (FIGURE 1)   REV 0

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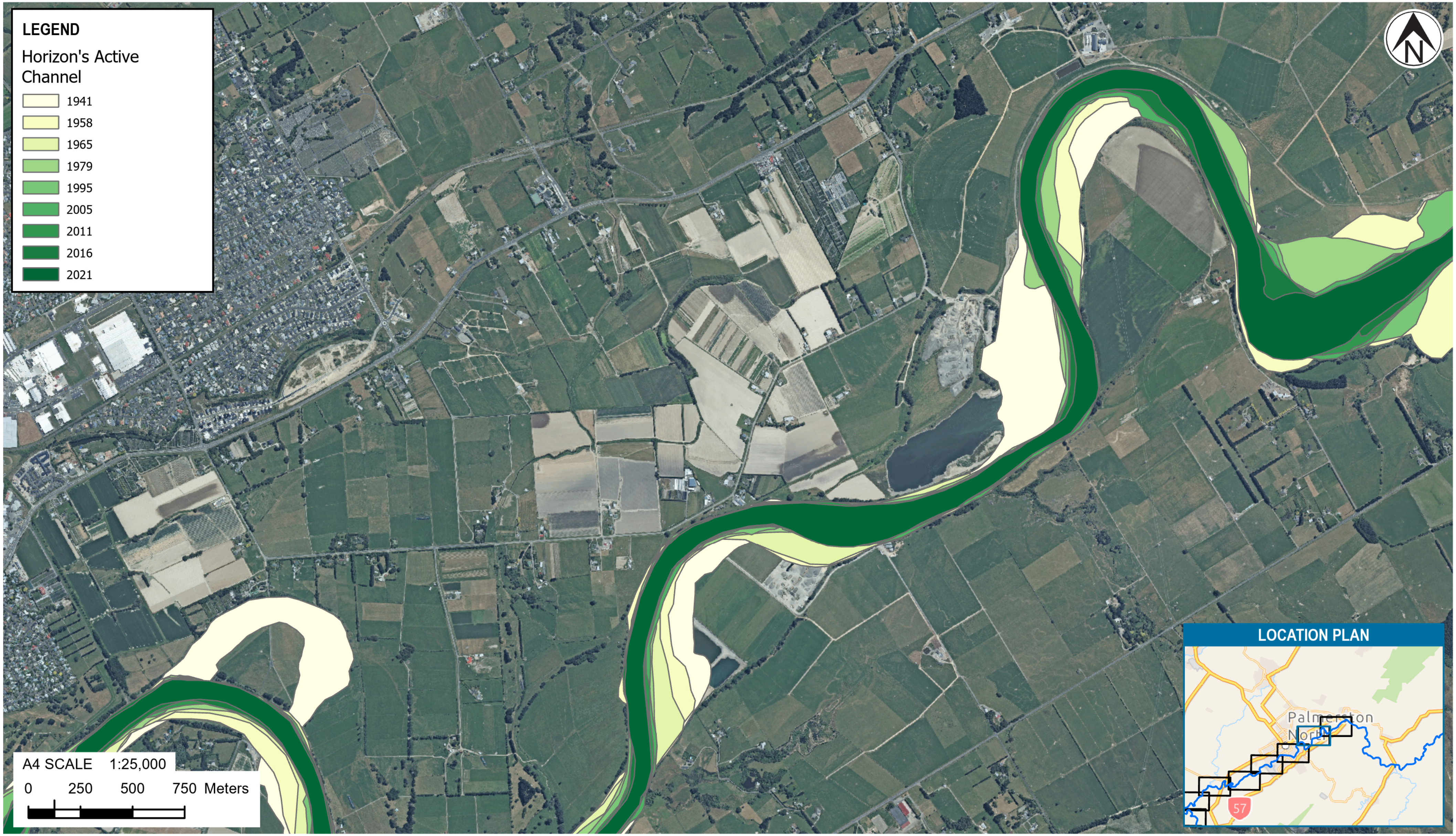
TITLE BANK LINES ASSESSMENT
SCALE (A4) 1:26,000 FIG No. APPENDIX B (FIGURE 1-A) REV 0



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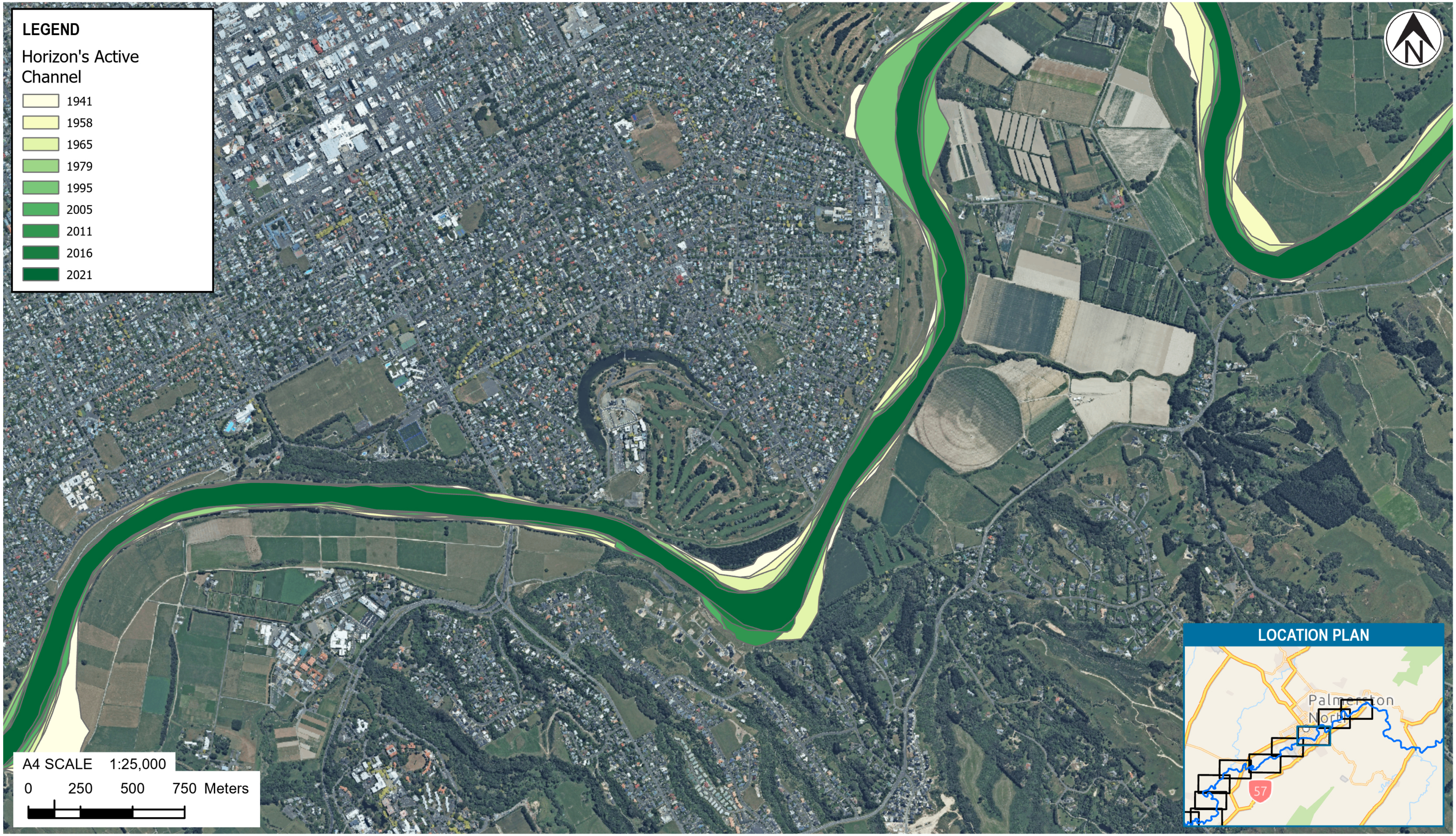
SCALE (A4) 1:25,000 FIG No. APPENDIX B (FIGURE 1-B) REV 0



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SCALE (A4) 1:25,000 FIG No. APPENDIX B (FIGURE 1-C) REV 0

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SCALE (A4) 1:25,000 FIG No. APPENDIX B (FIGURE 1-D) REV 0

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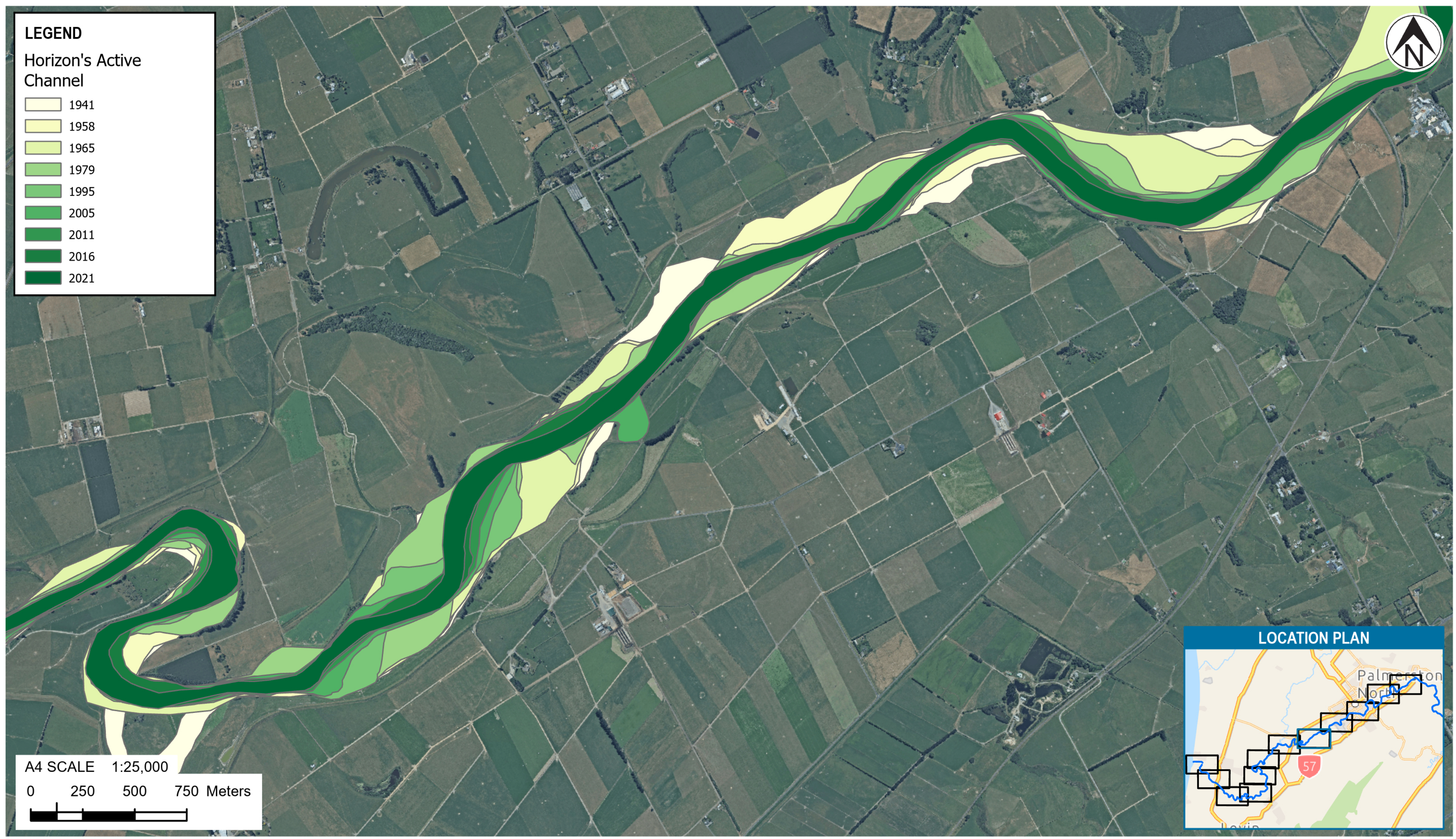

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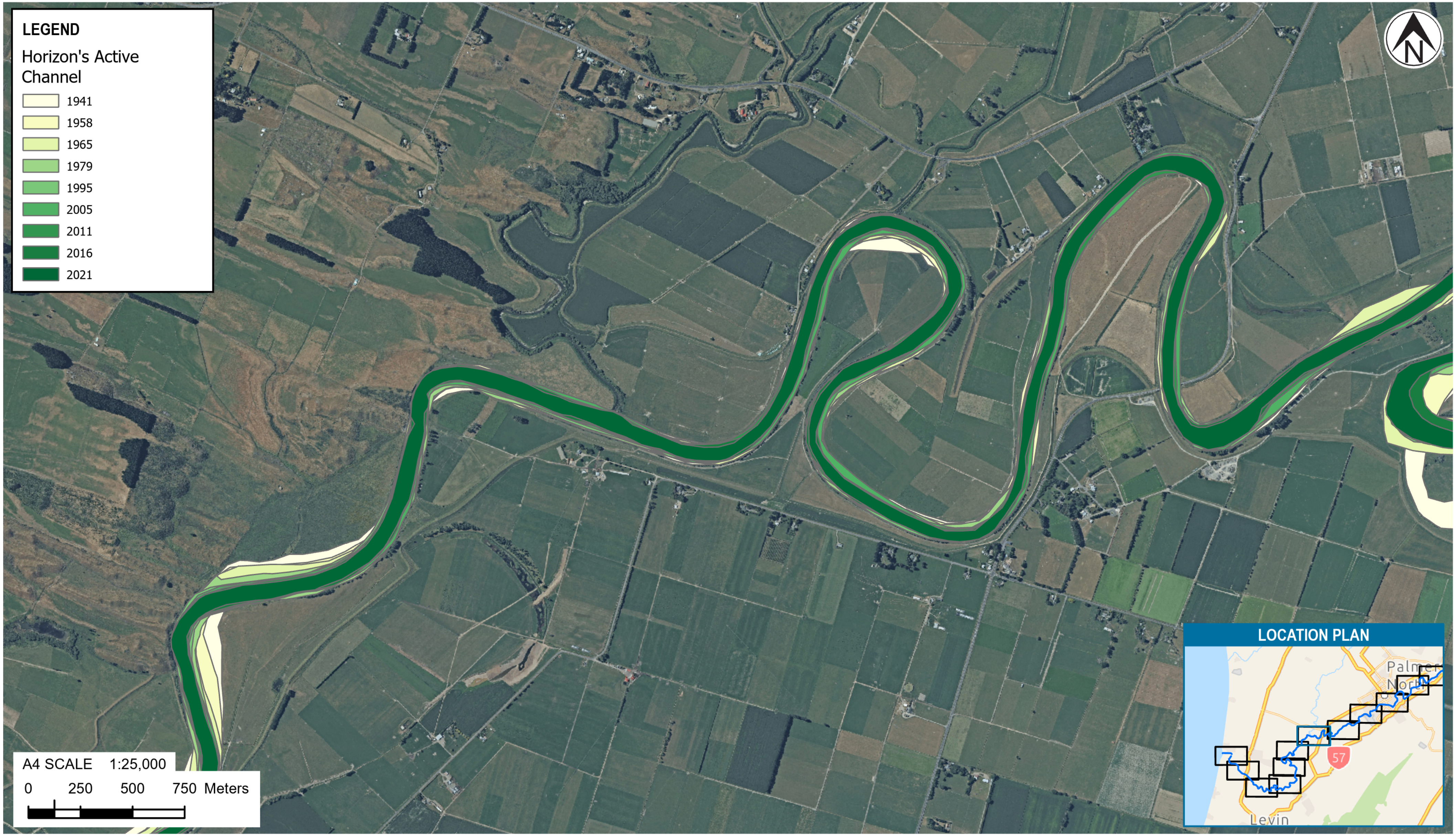
SCALE (A4) 1:25,000 FIG No. APPENDIX B (FIGURE 1-E) REV 0



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TITLE	BANK LINES ASSESSMENT
SCALE (A4)	1:25,000
FIG No.	APPENDIX B (FIGURE 1-F)
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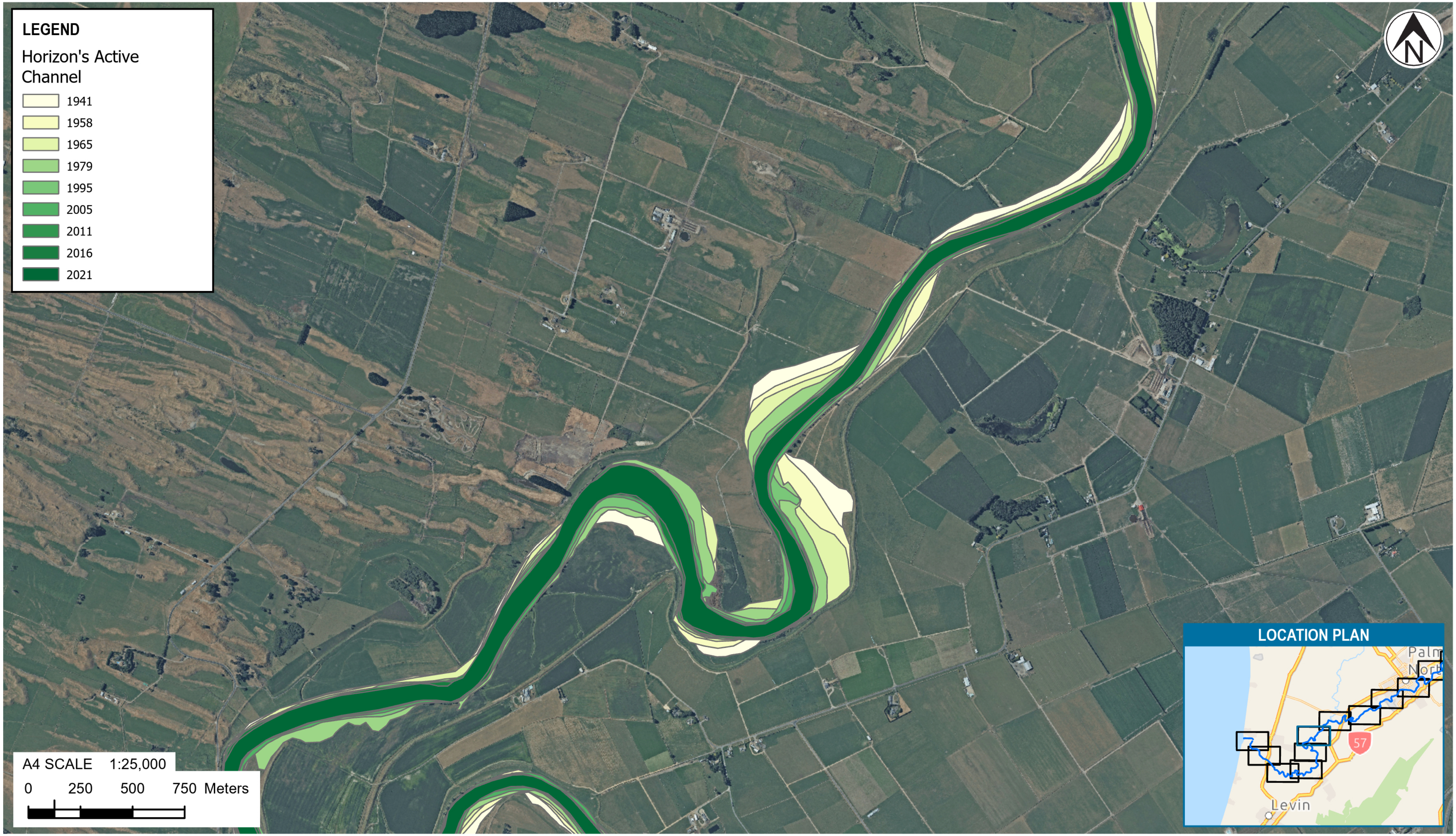

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SCALE (A4) 1:25,000 FIG No. APPENDIX B (FIGURE 1-G) REV 0

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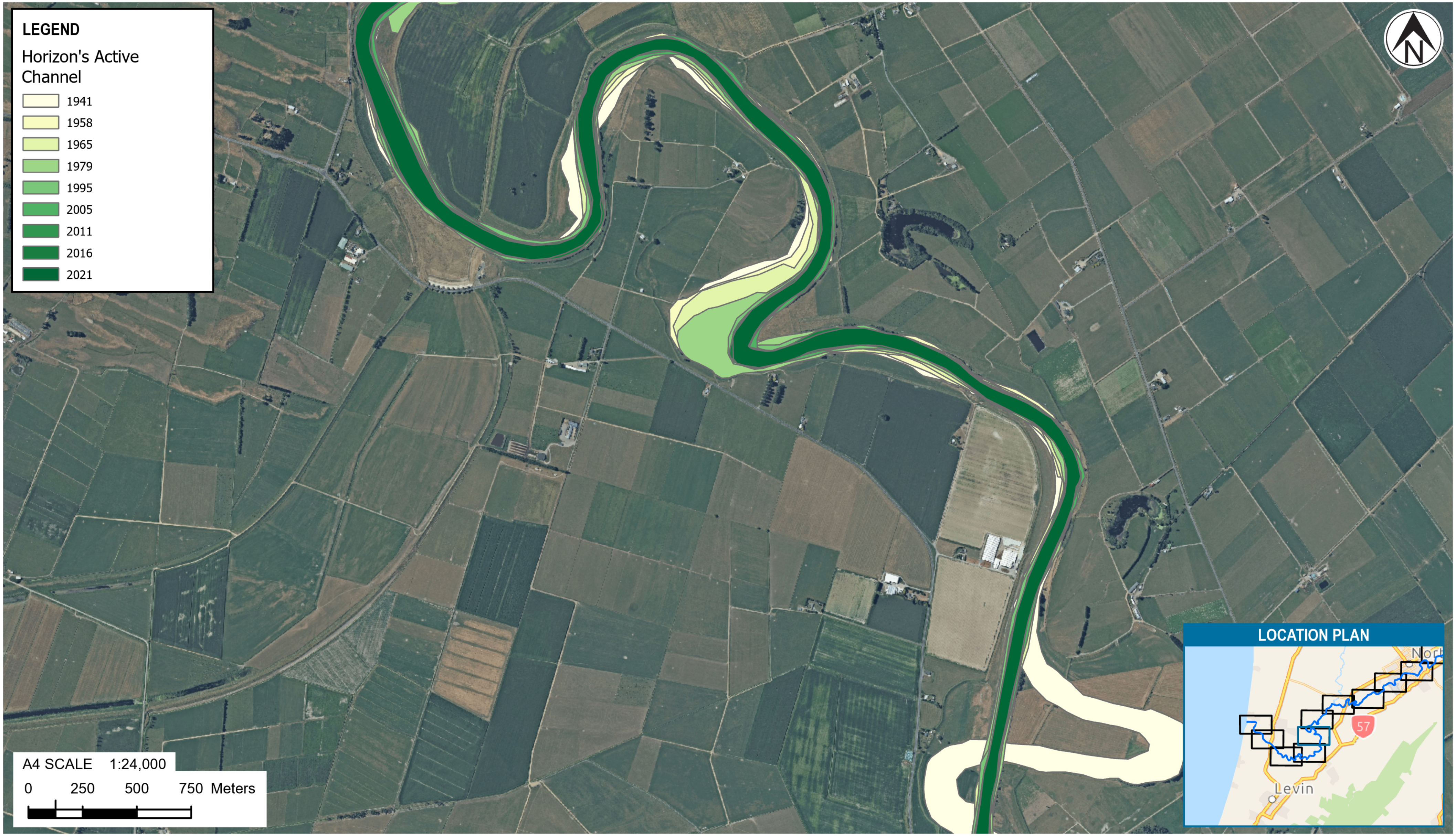

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SCALE (A4) 1:24,000 FIG No. APPENDIX B (FIGURE 1-H) REV 0

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SCALE (A4) 1:25,000 FIG No. APPENDIX B (FIGURE 1-I) REV 0

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FIG No.	APPENDIX B (FIGURE 1-J)
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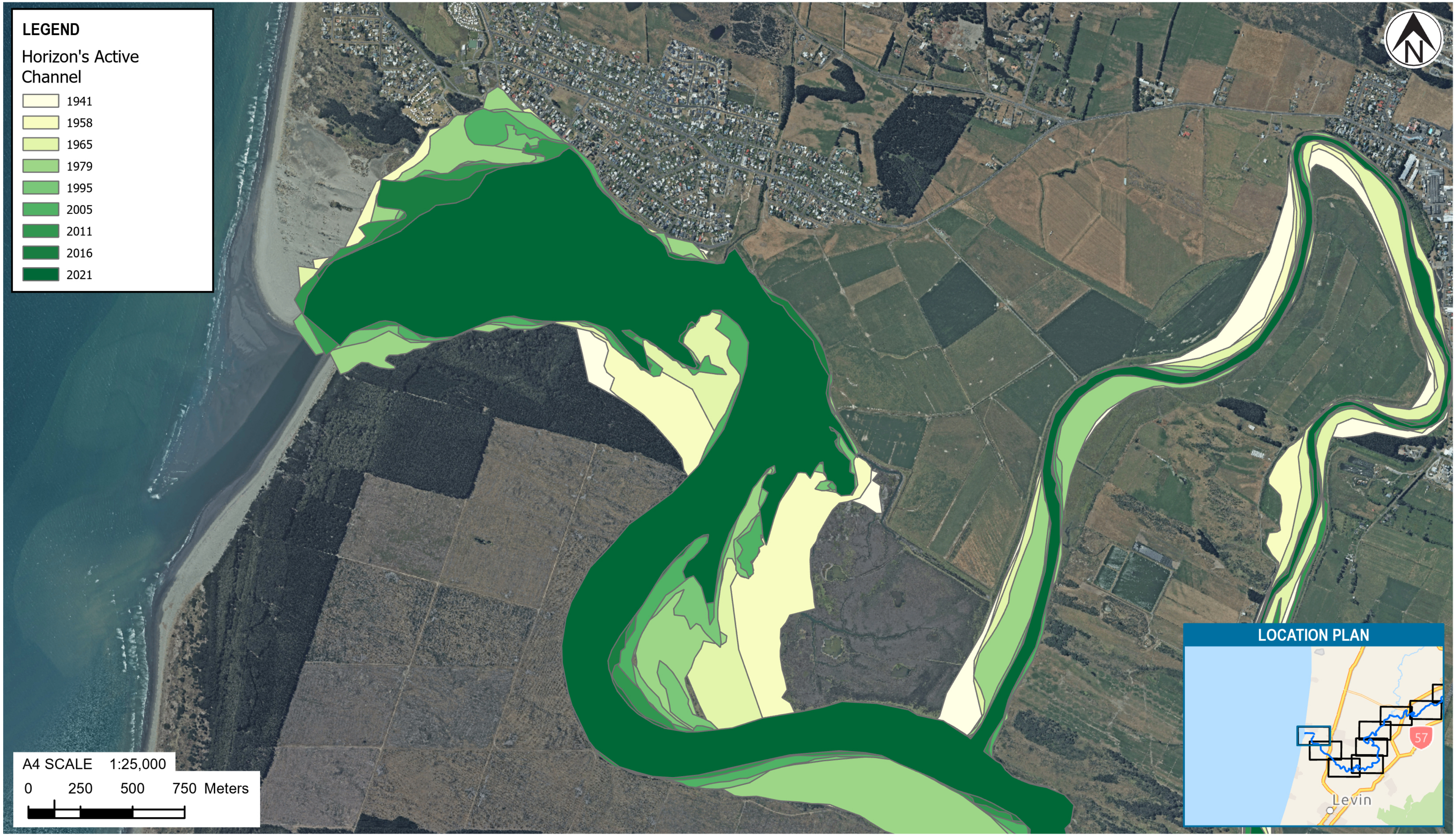
SCALE (A4) 1:25,000 FIG No. APPENDIX B (FIGURE 1-K) REV 0



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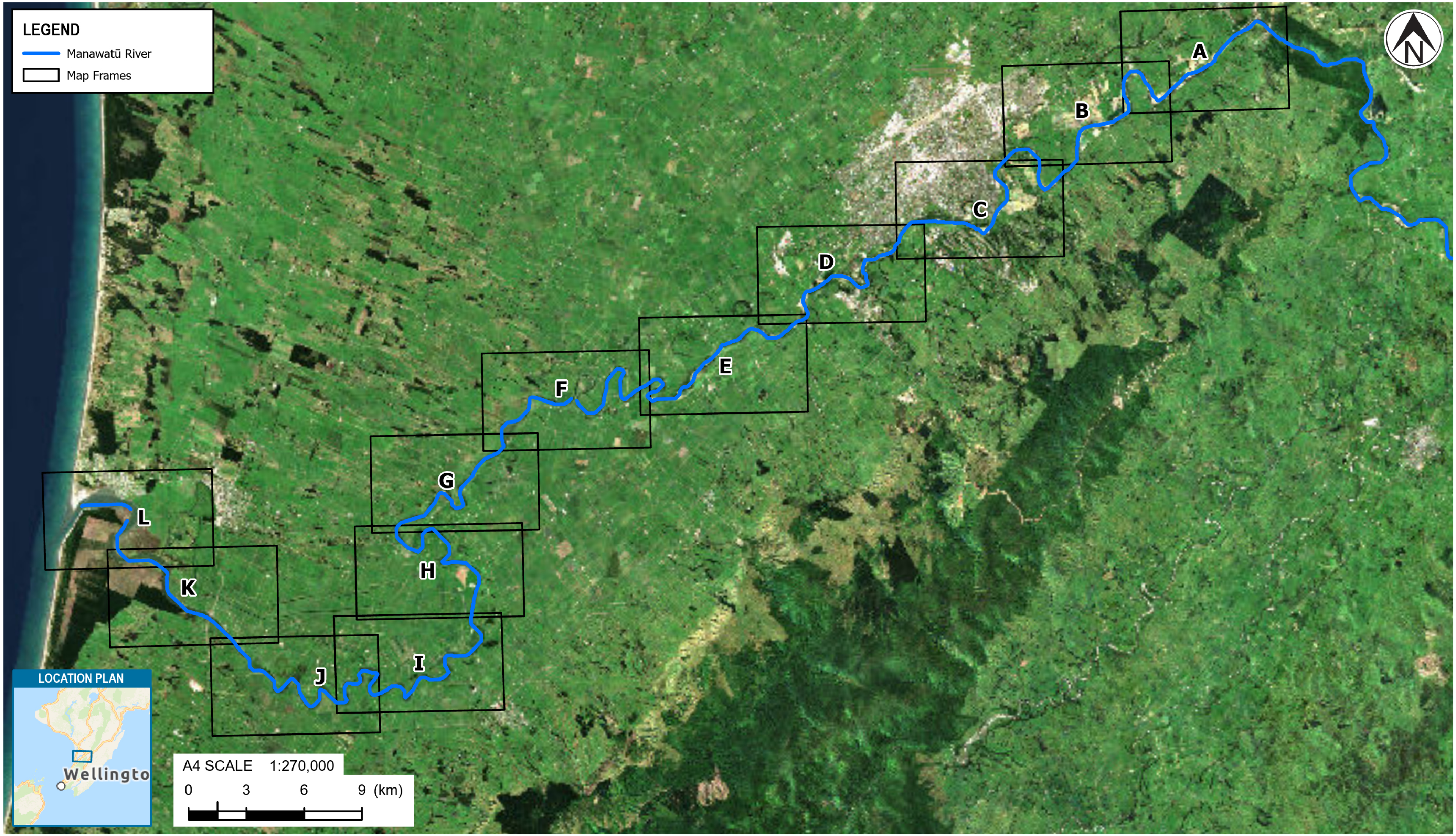
SCALE (A4) 1:25,000 FIG No. APPENDIX B (FIGURE 1-L) REV 0

Appendix C Comparison of Active Channel Delineation Map Figures



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TITLE COMPARISON OF ACTIVE CHANNEL DELINEATION - MAP SHEET INDEX

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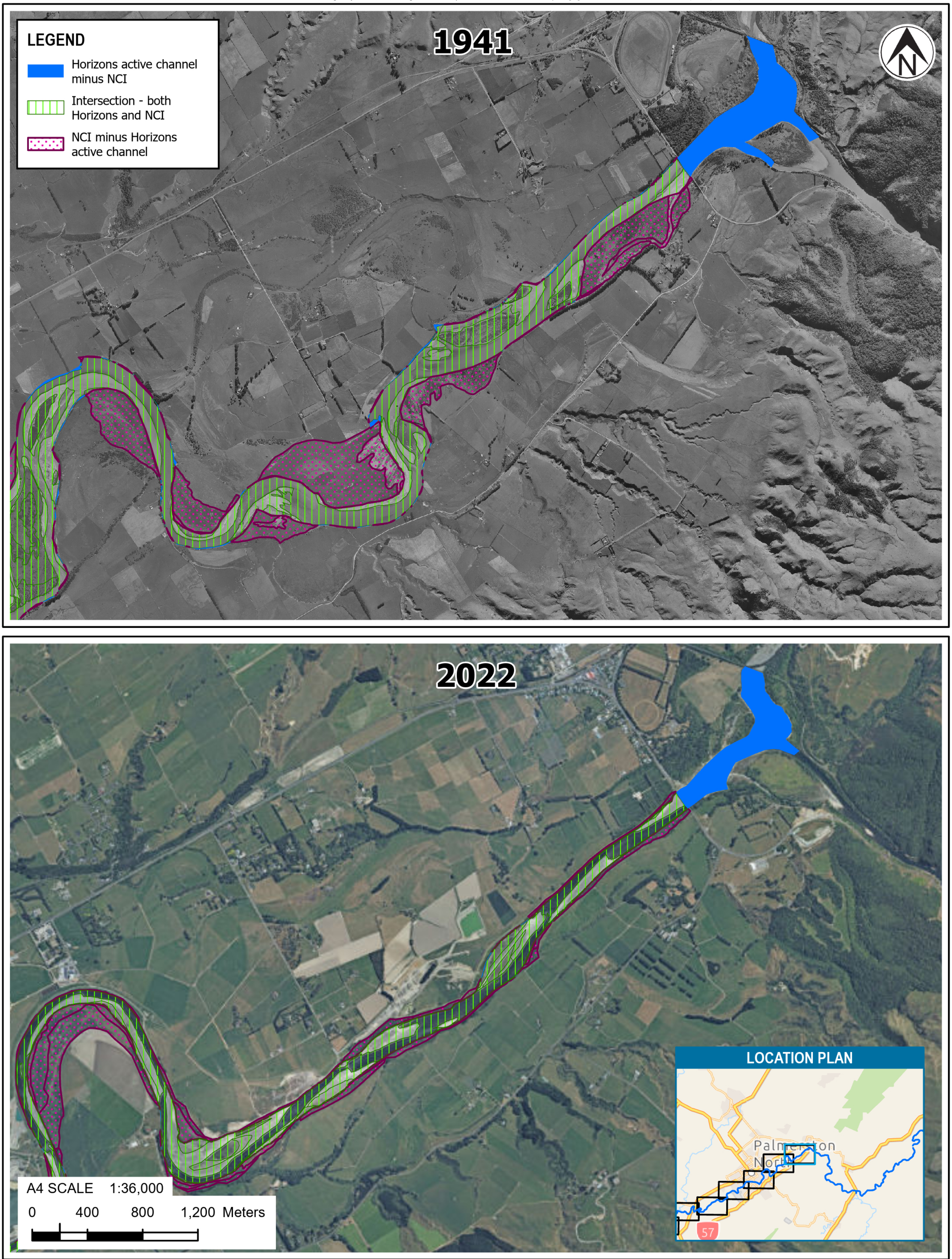

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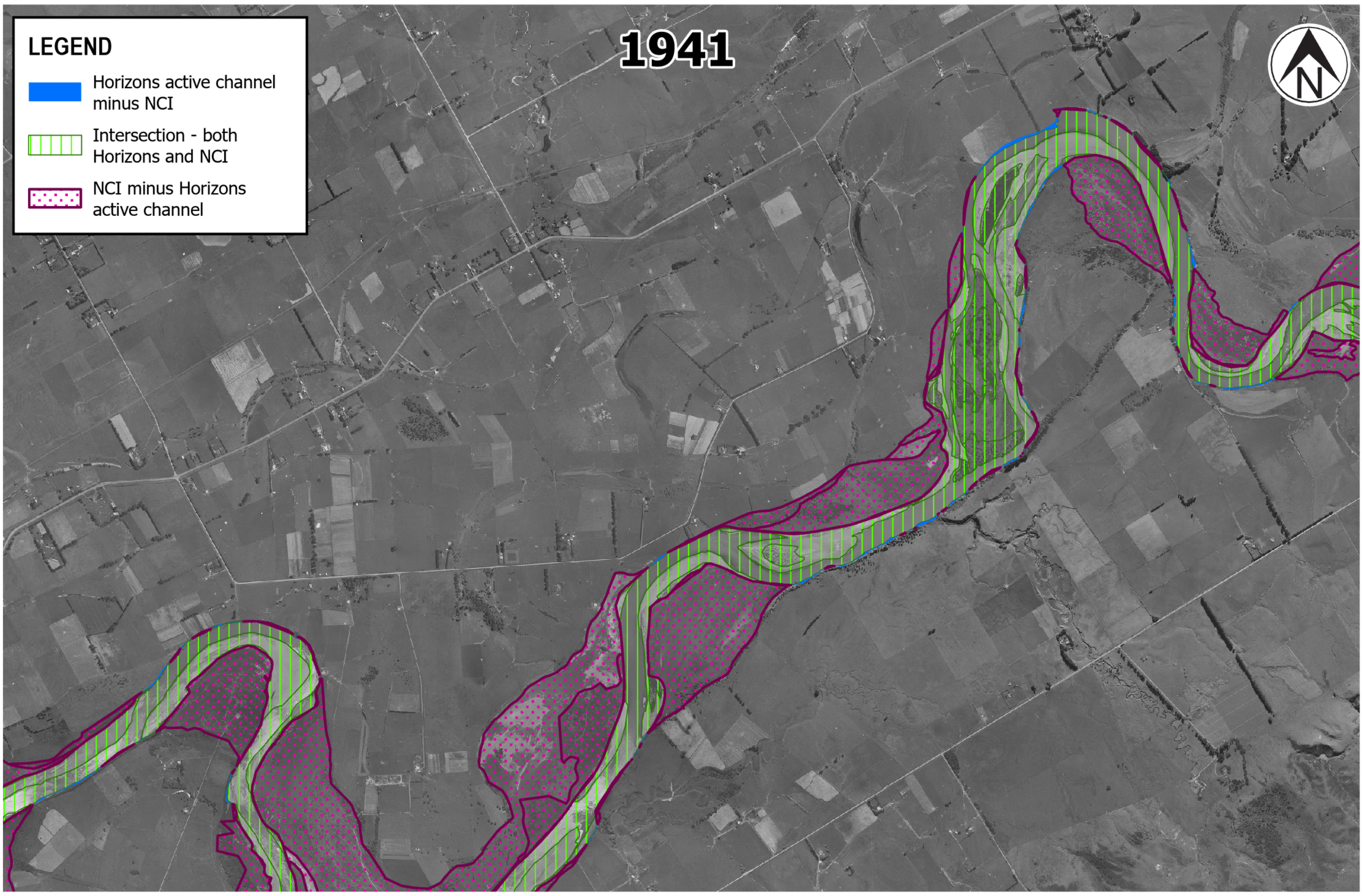
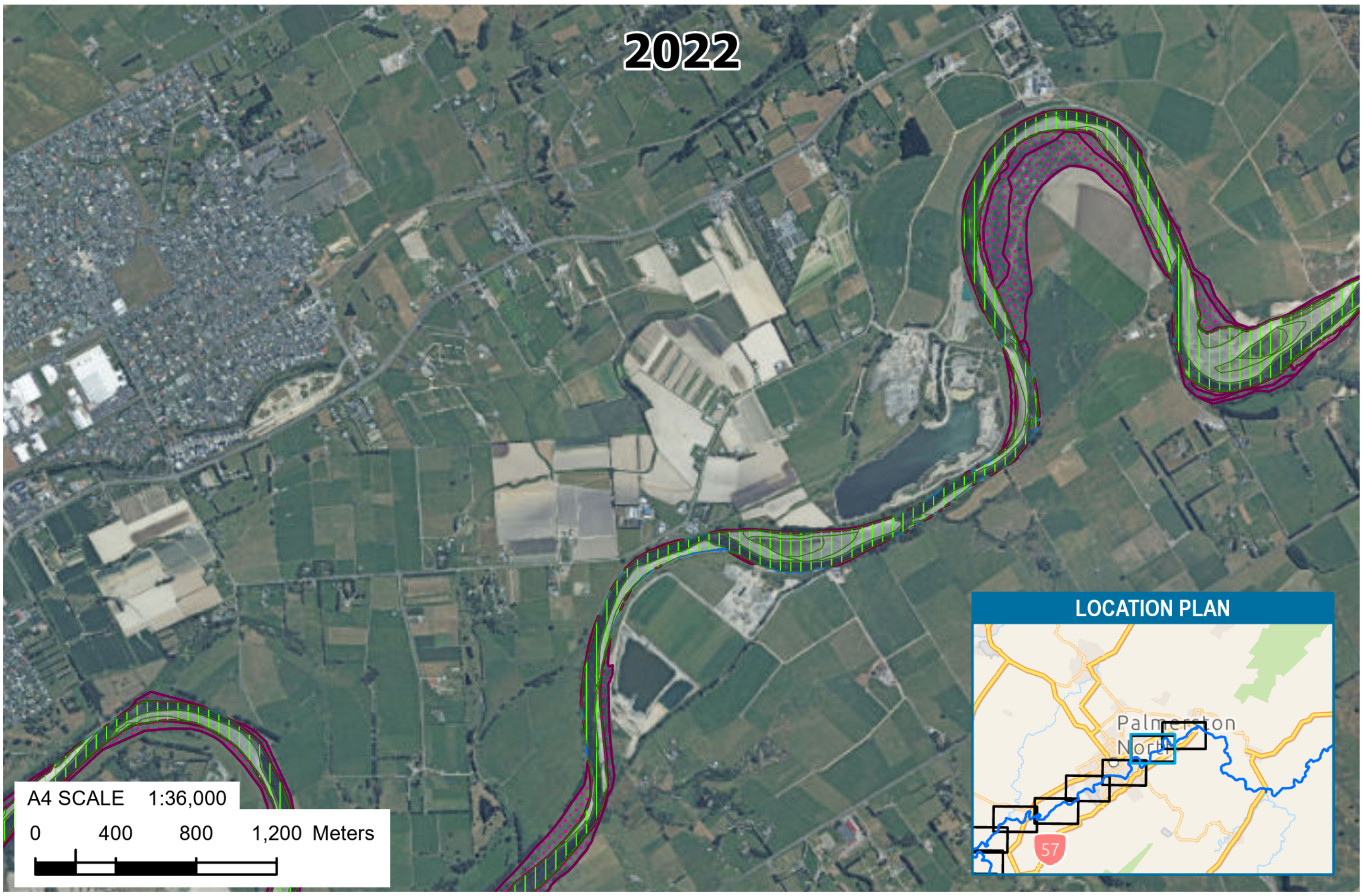
TITLE COMPARISON OF ACTIVE CHANNEL DELINEATION

SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-A) REV 0





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SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-B) REV 0

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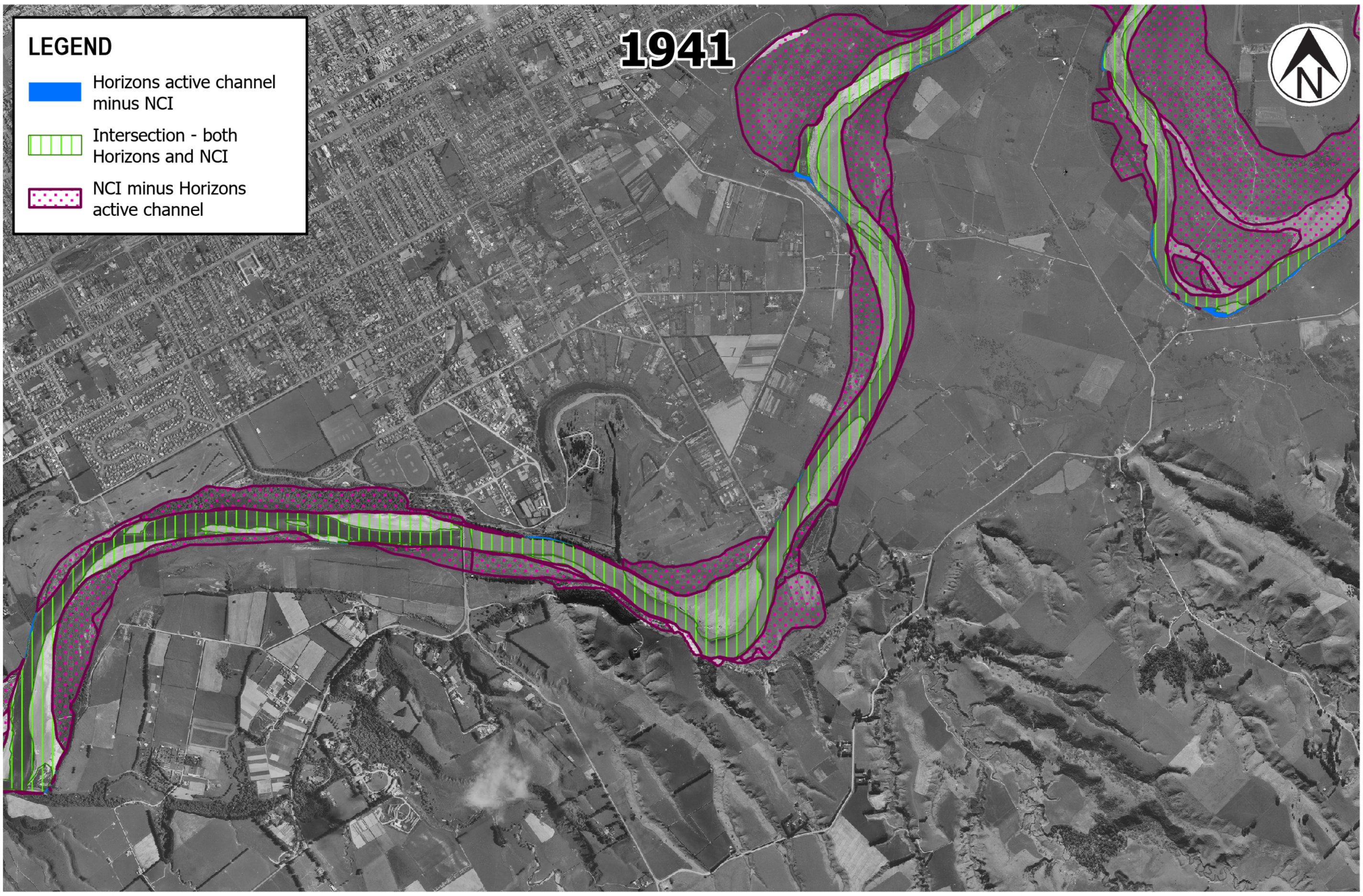

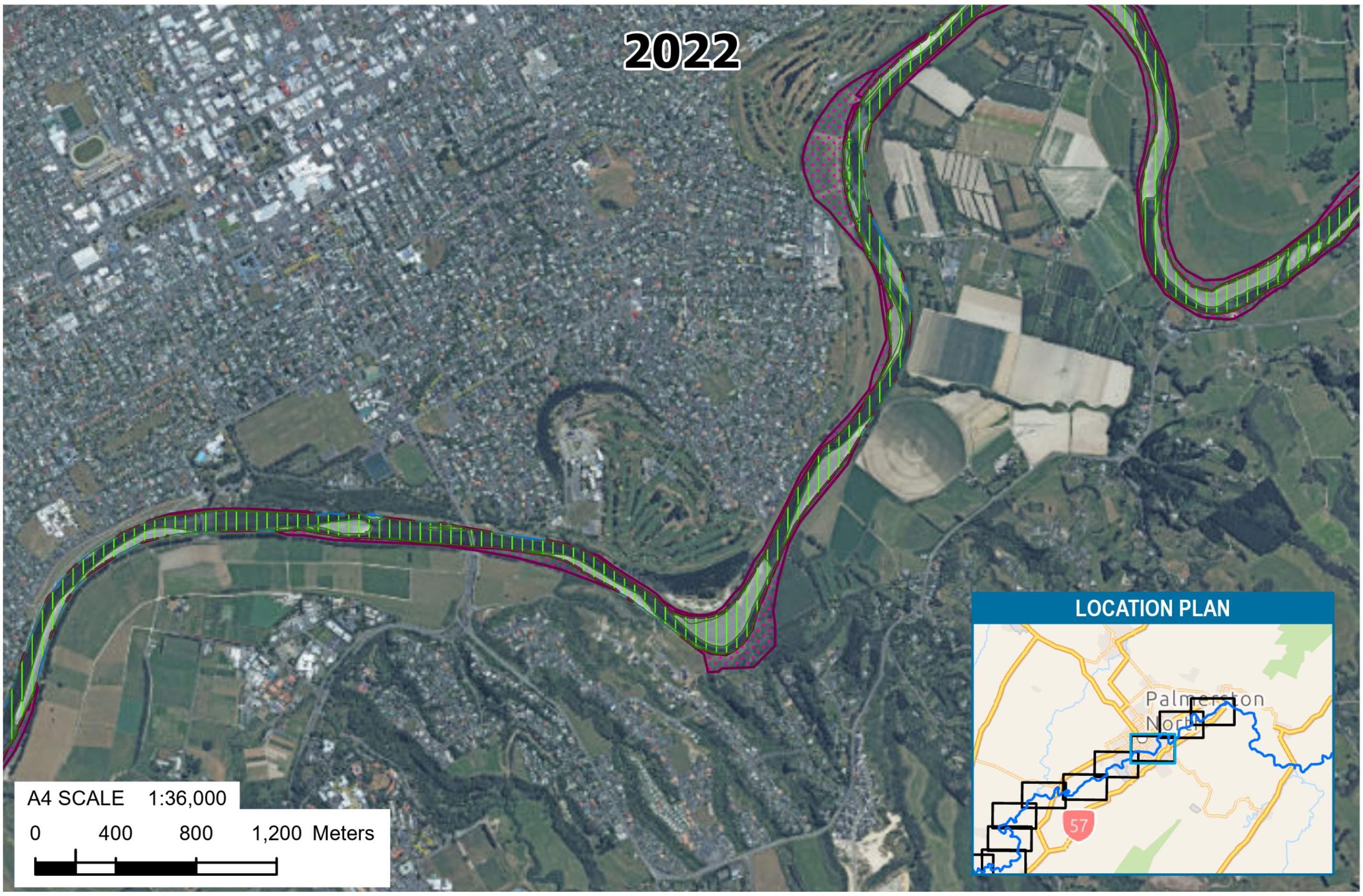

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SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-C) REV 0

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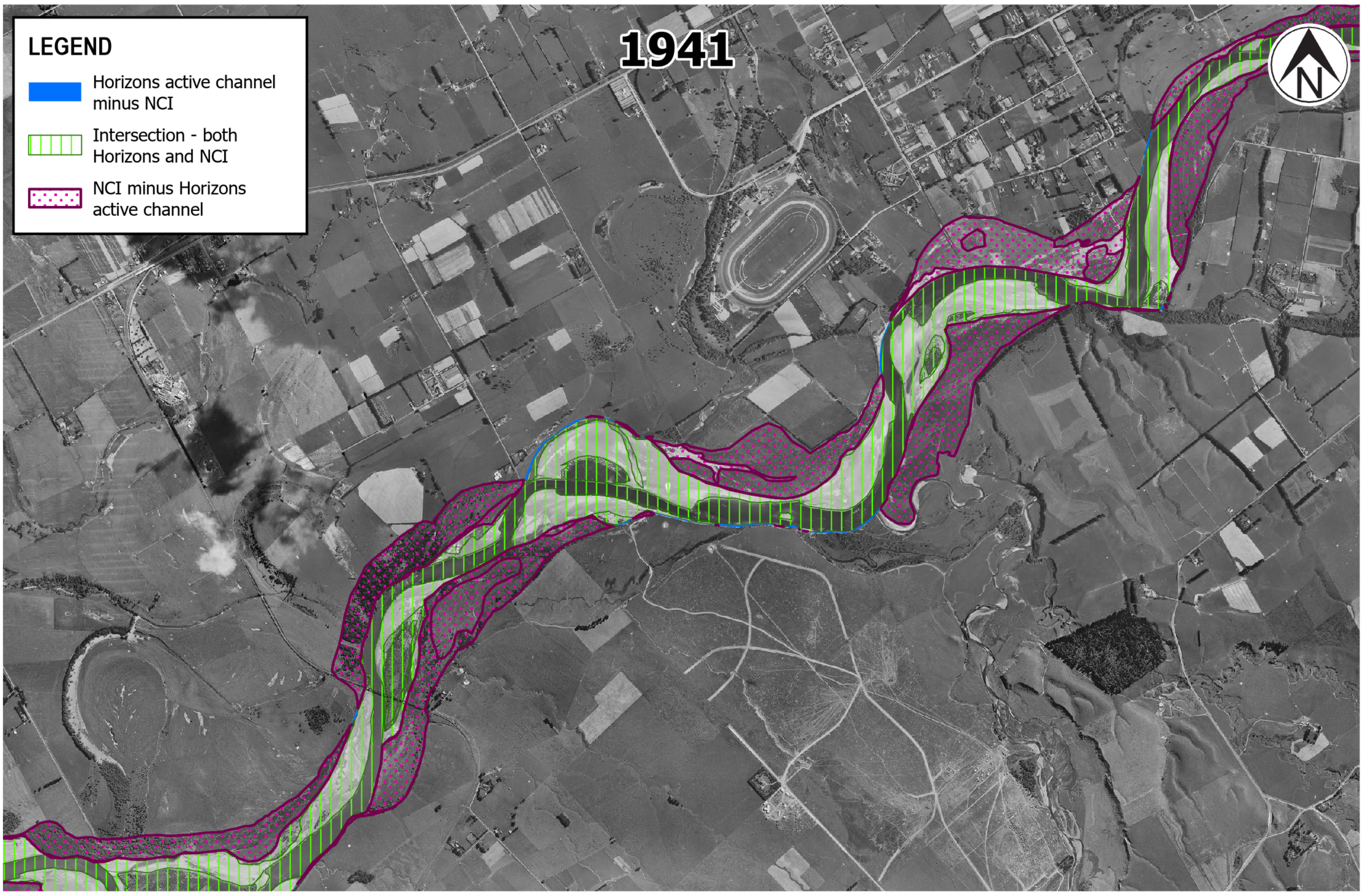

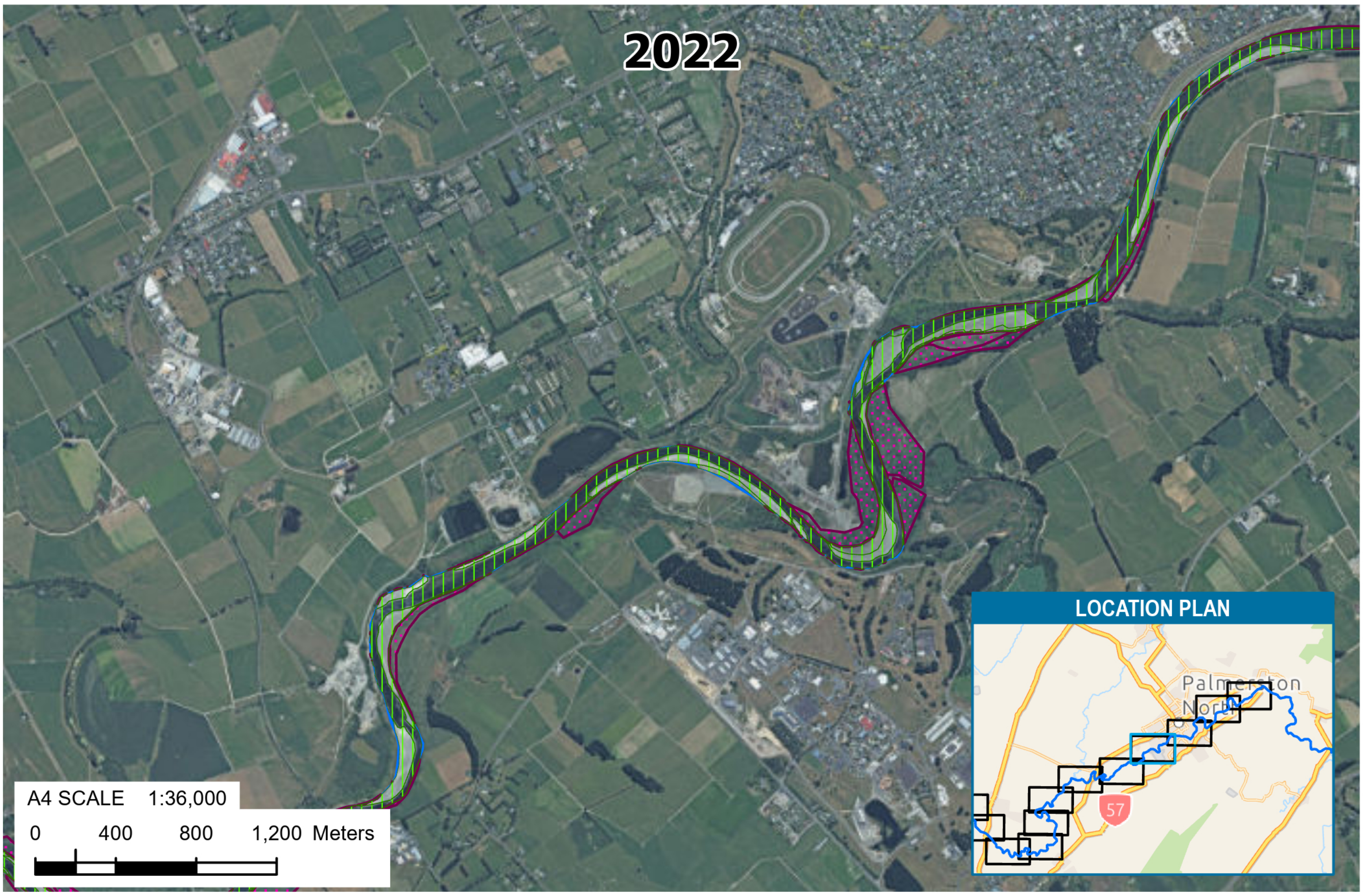

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FIG No. APPENDIX C (FIGURE 1-D) REV 0

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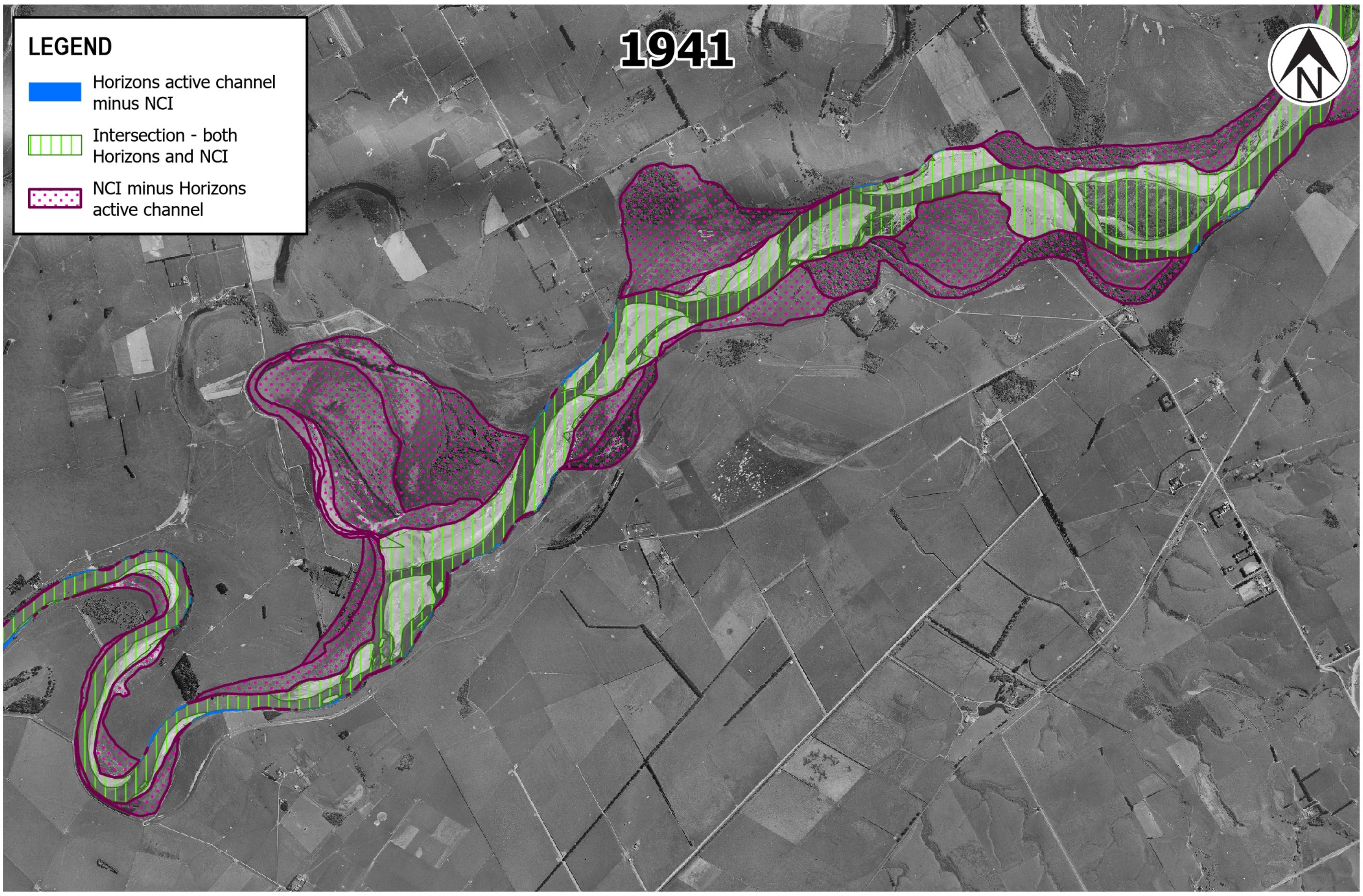

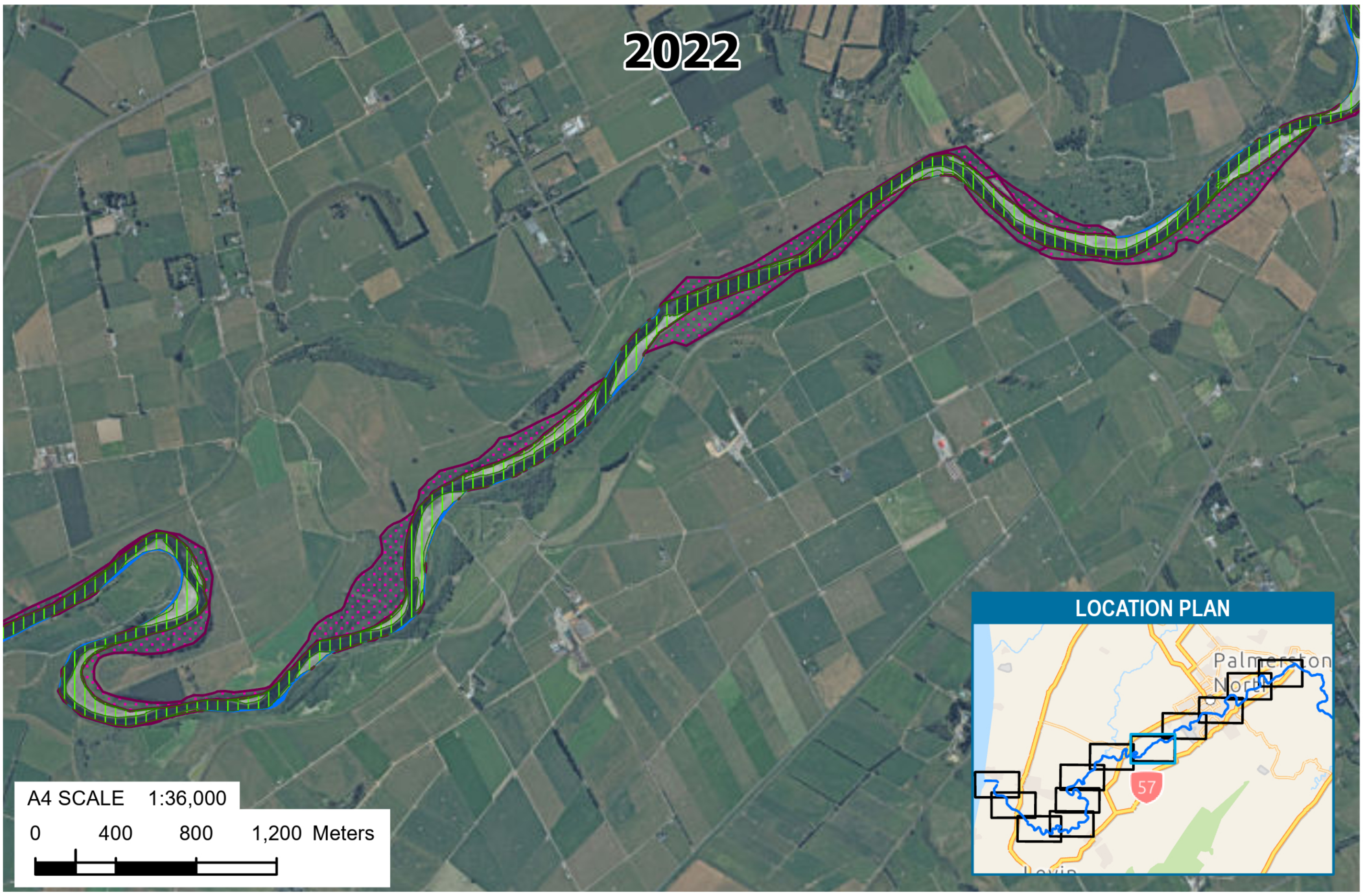

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SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-E) REV 0

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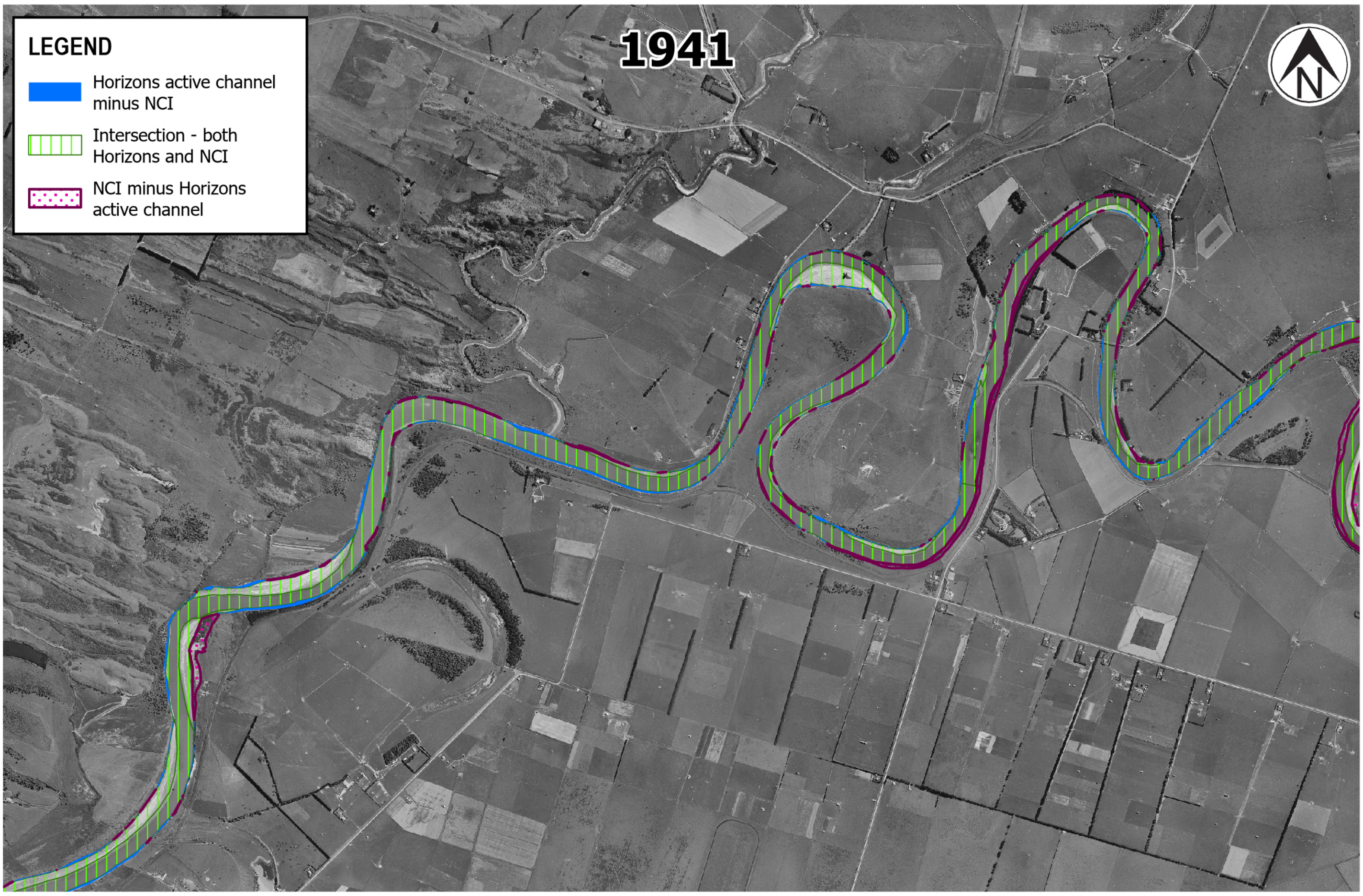

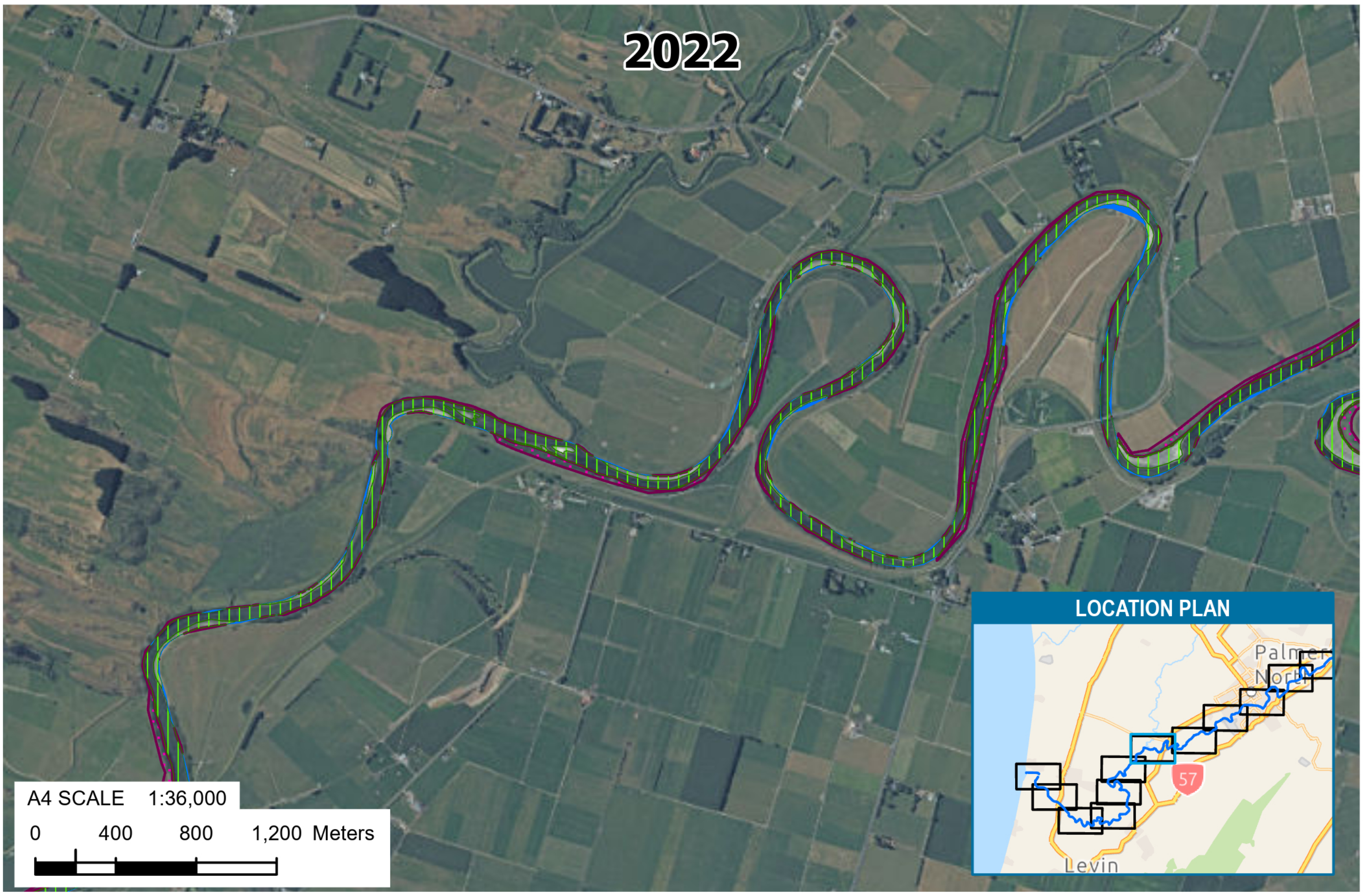

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SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-F) REV 0

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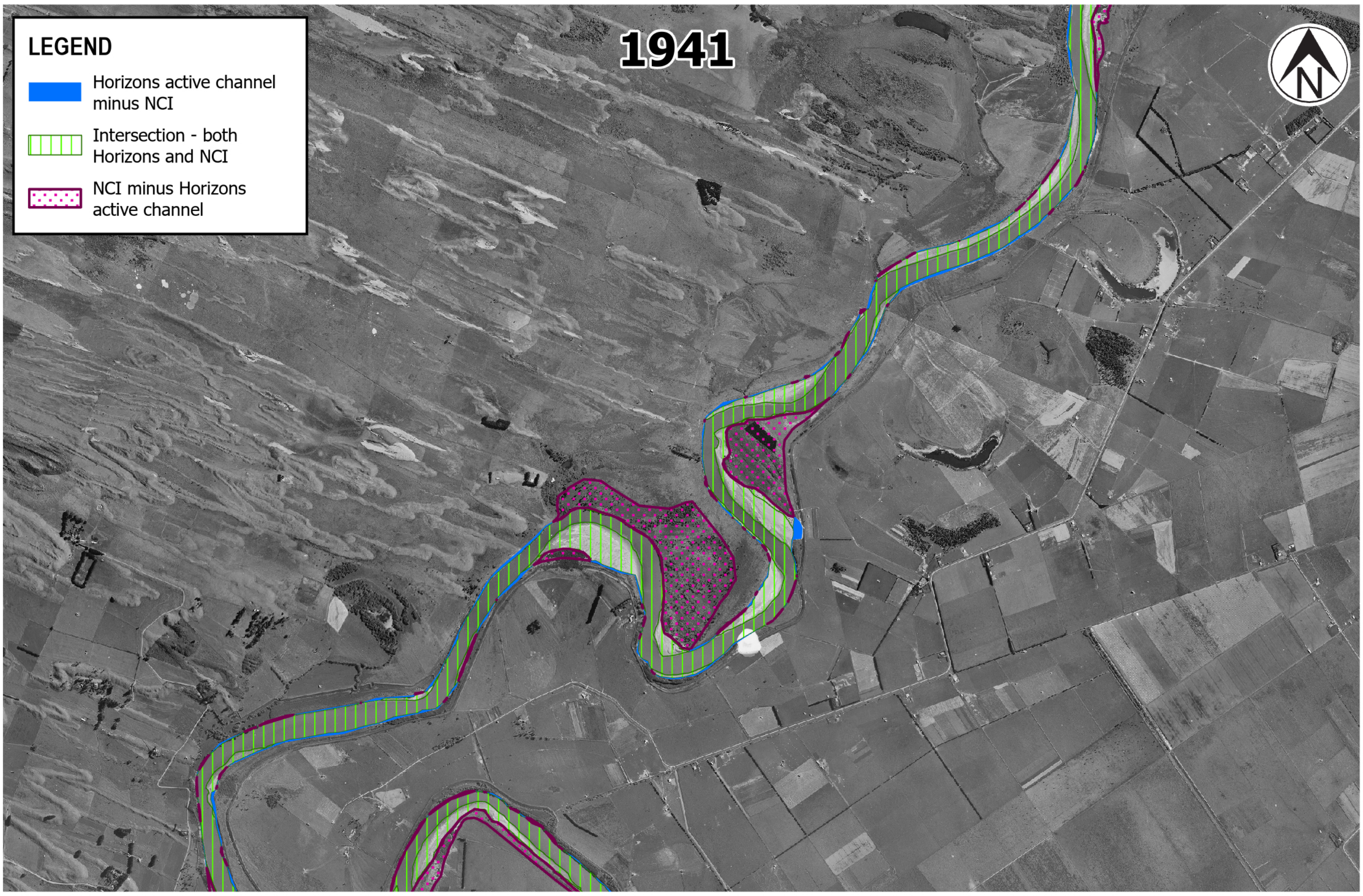

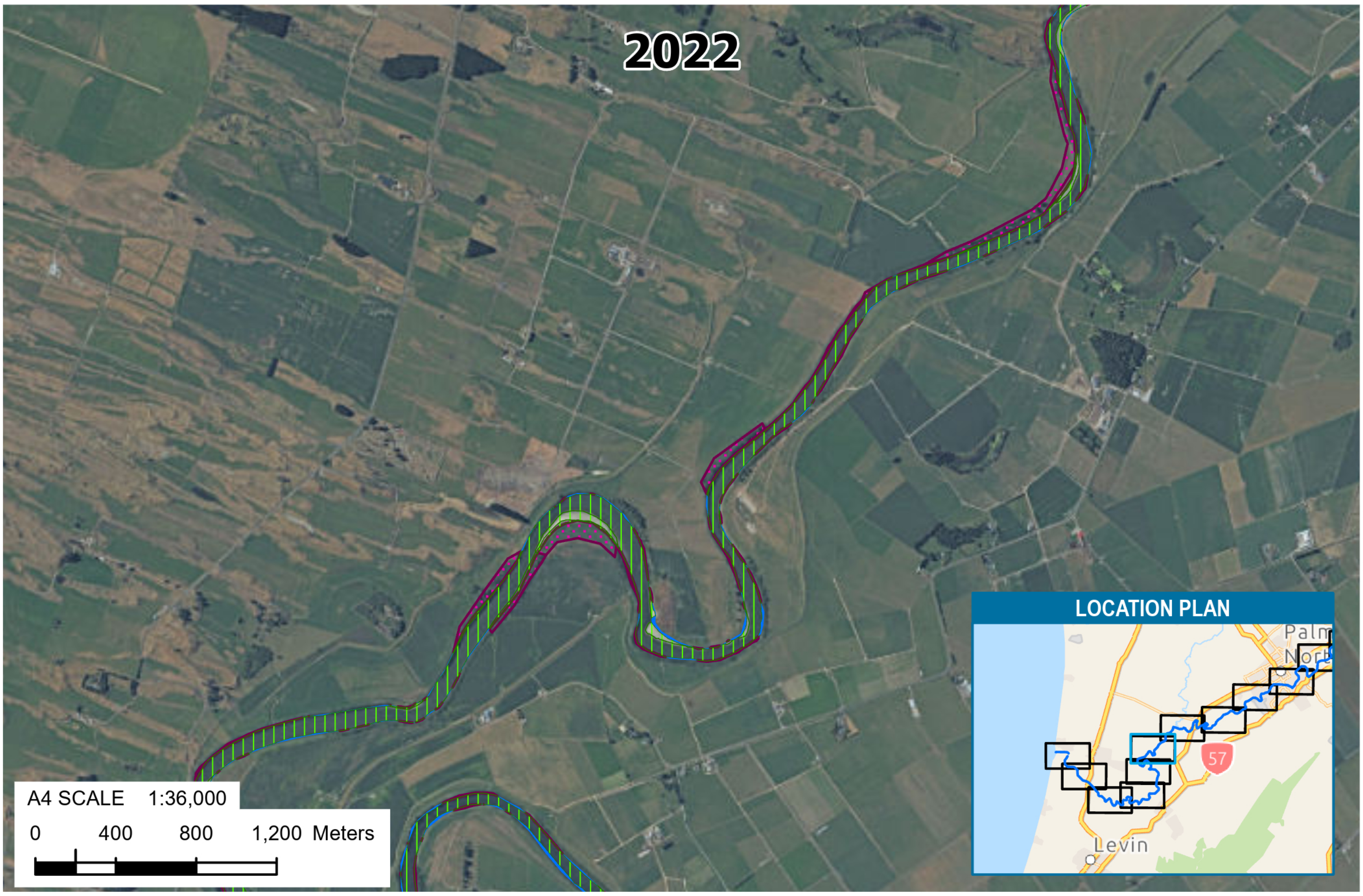

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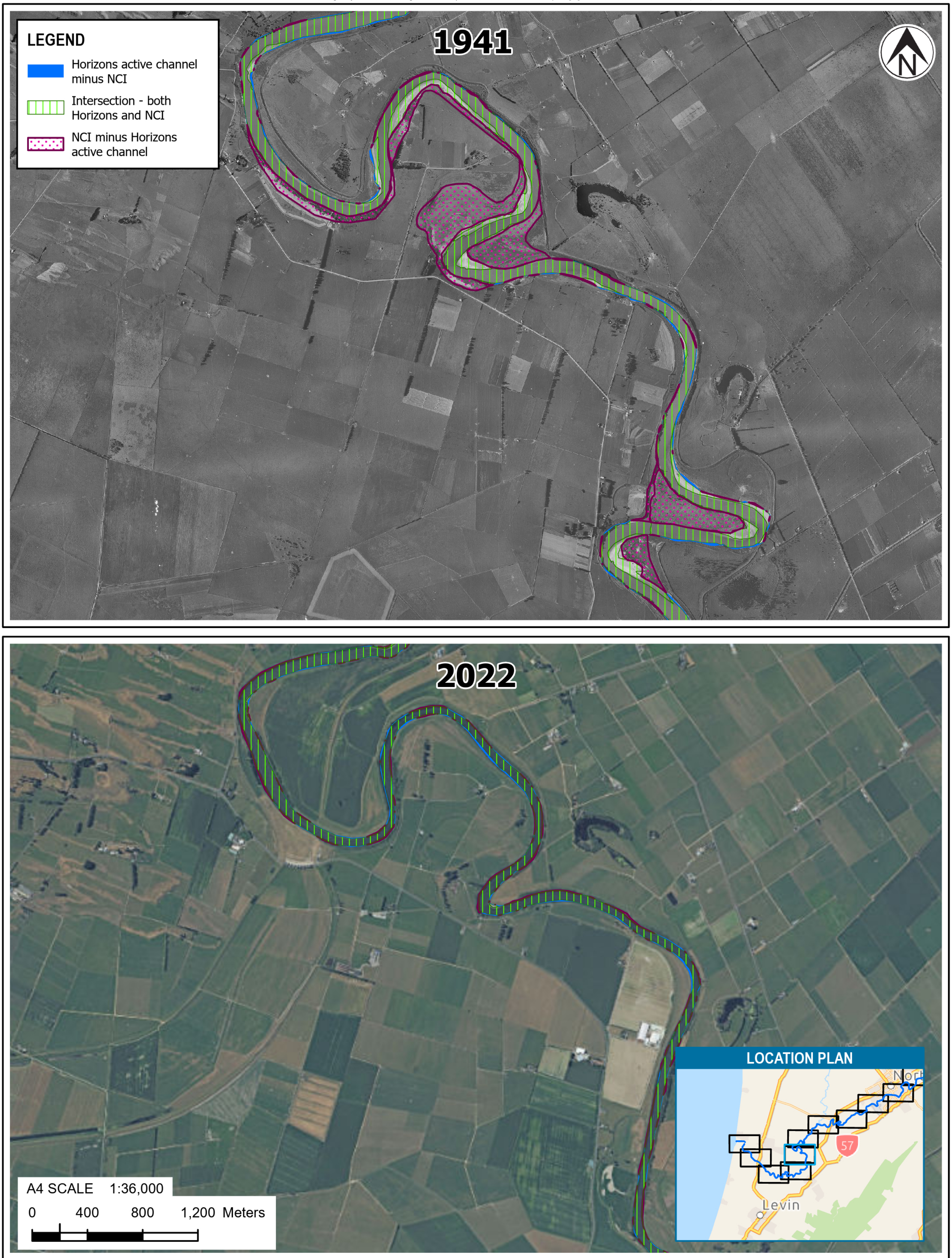
SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-G) REV 0



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SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-H) REV 0

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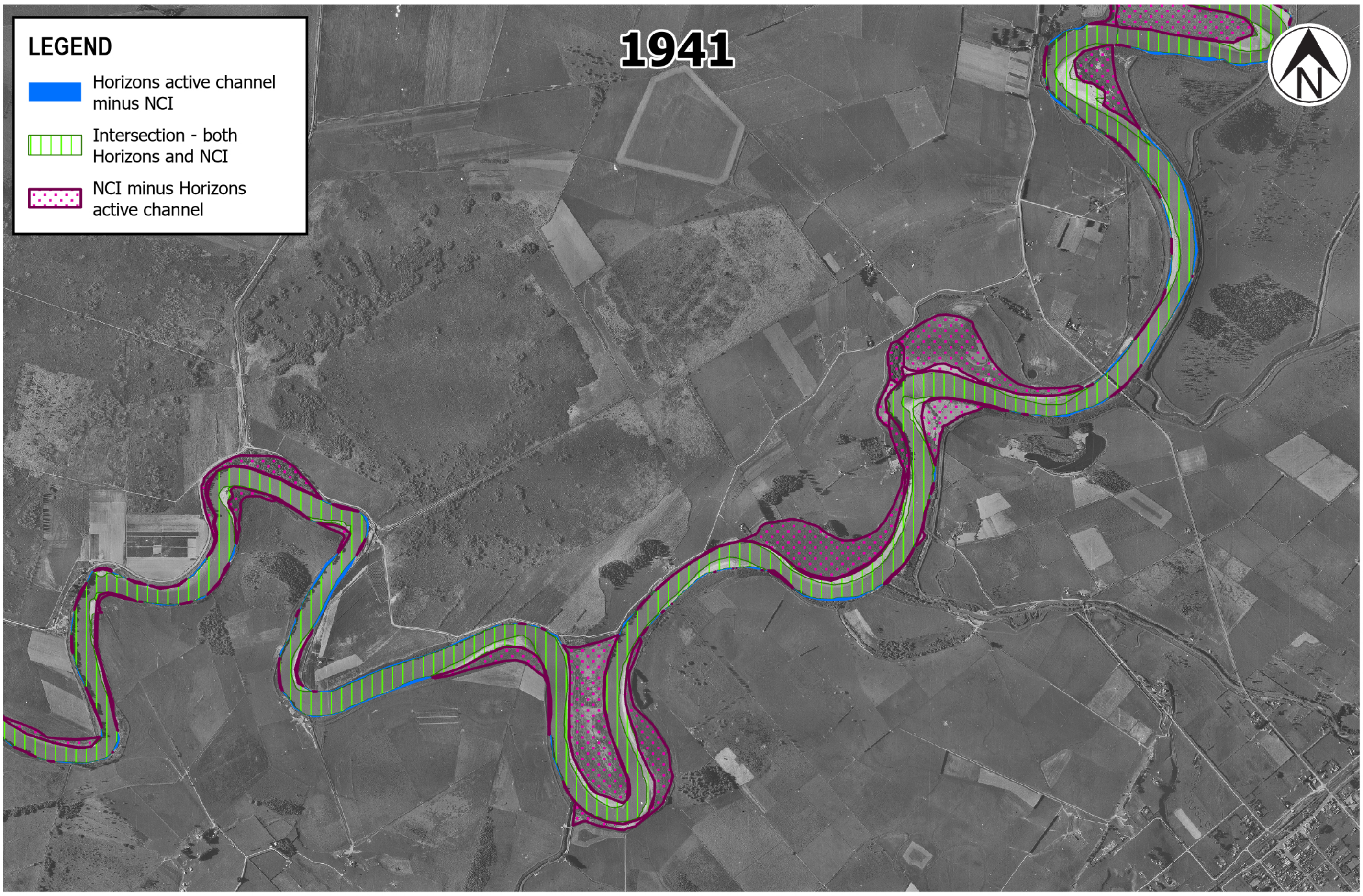

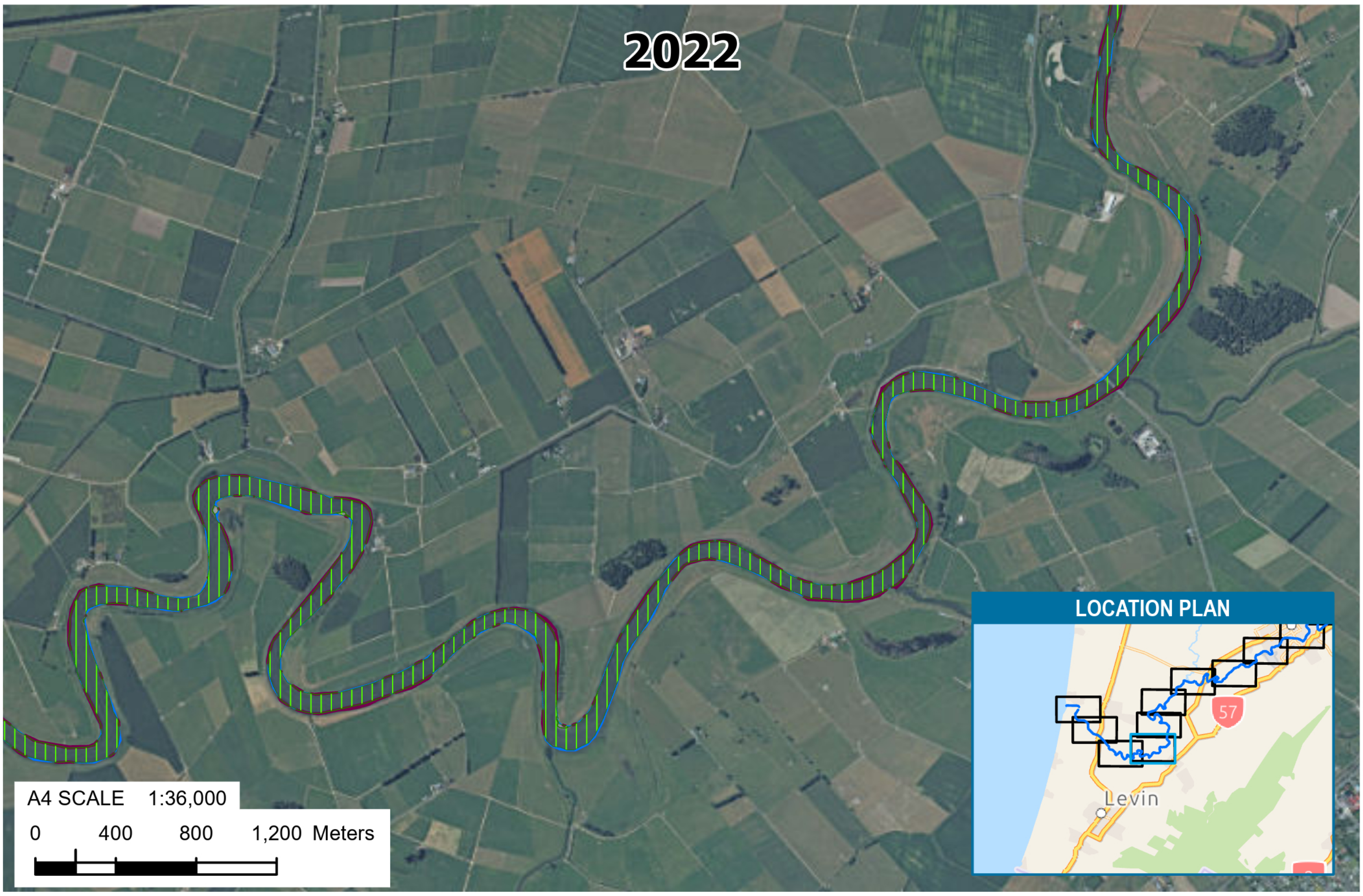

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SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-I) REV 0

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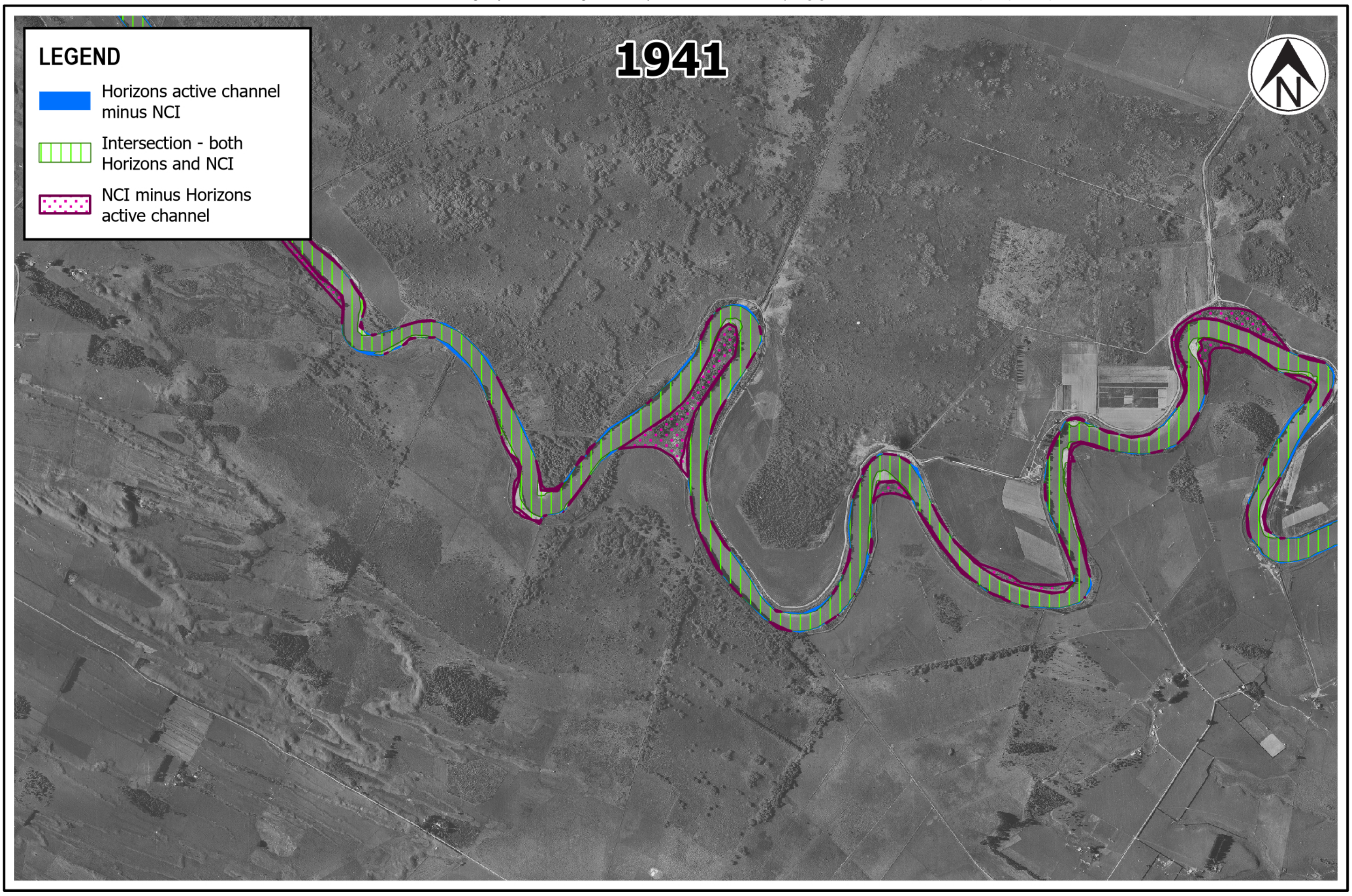

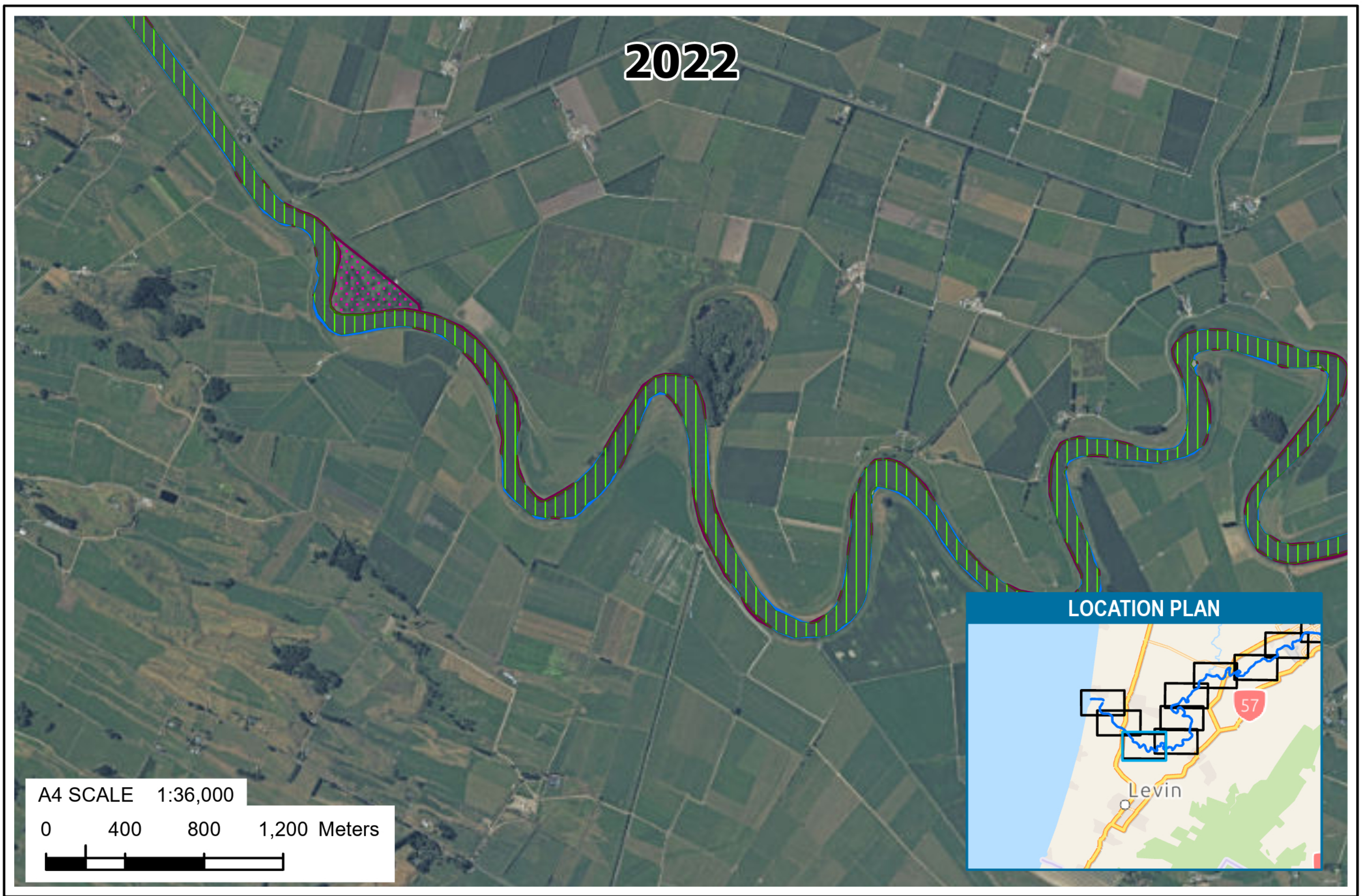

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SCALE (A4)	1:36,000
FIG No.	APPENDIX C (FIGURE 1-J)
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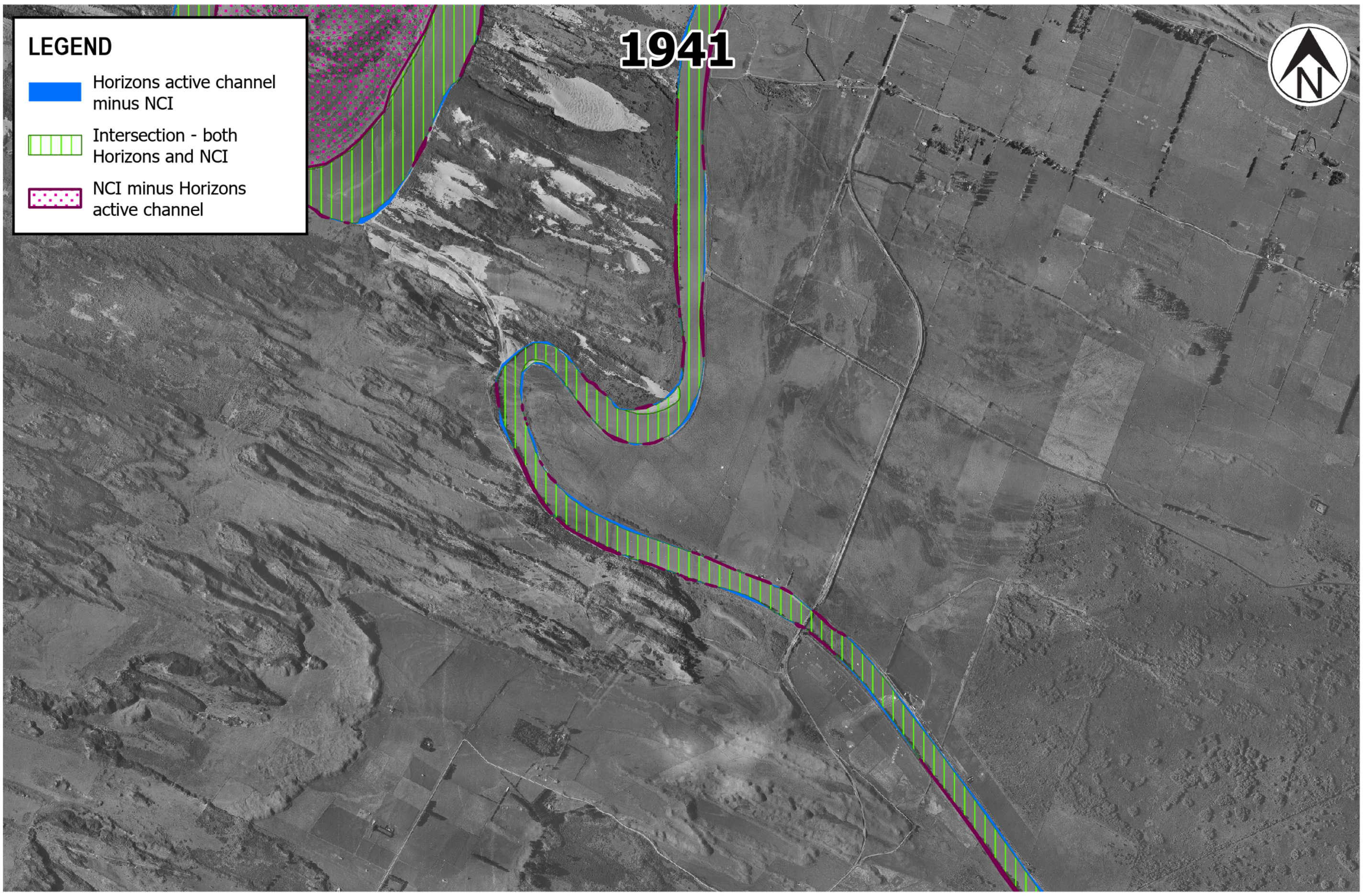

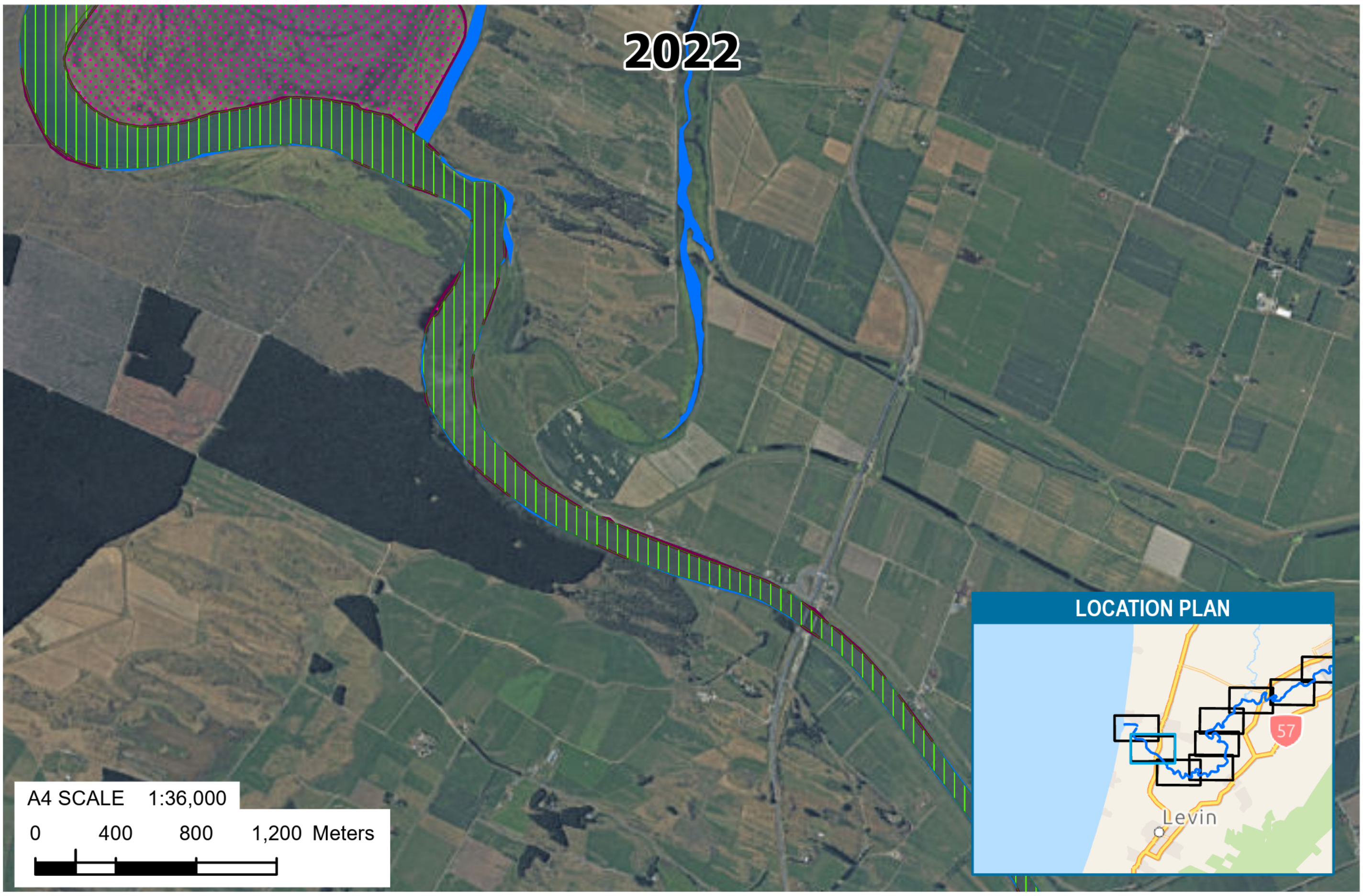

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SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-K) REV 0

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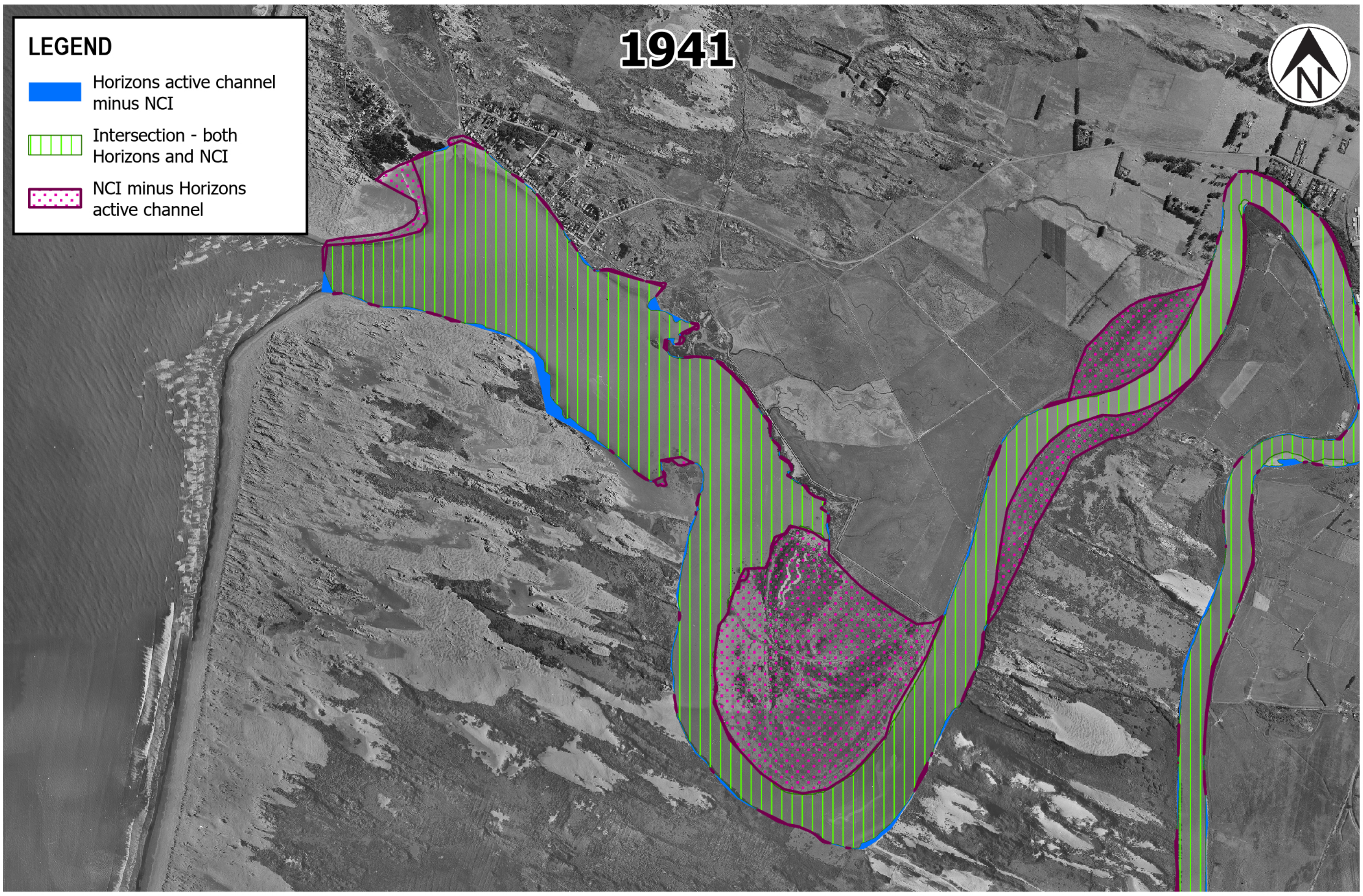

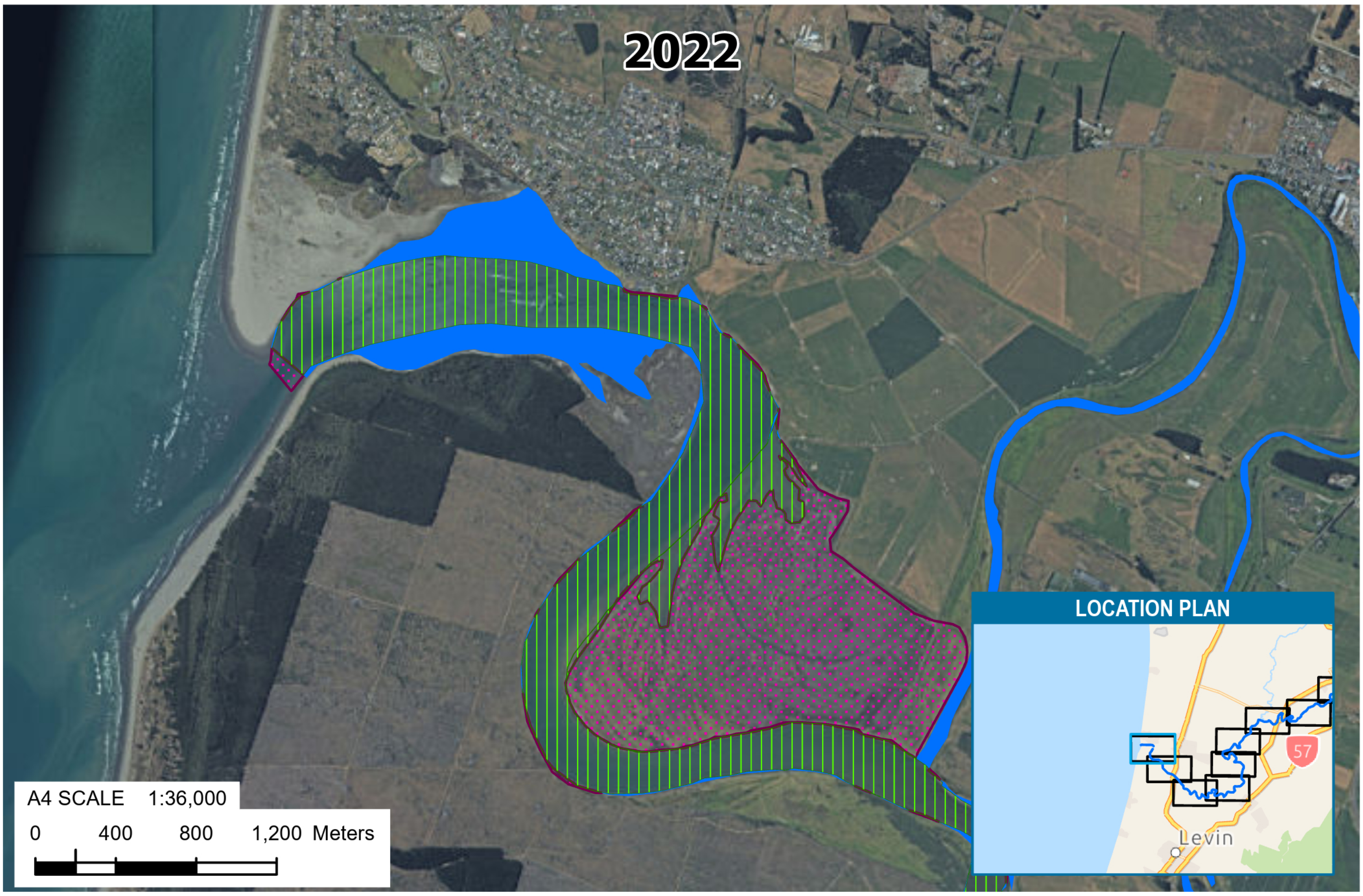

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SCALE (A4) 1:36,000 FIG No. APPENDIX C (FIGURE 1-L) REV 0

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