Warkworth to Wellsford

Flood Modelling

Technical Report

July 2019

QUALITY ASSURANCE

Prepared by

Jacobs GHD Joint Venture in association with Tonkin & Taylor Ltd. Prepared subject to the terms of the Professional Services Contract between the Client and Jacobs GHD Joint Venture for the Route Protection and Consenting of the Warkworth to Wellsford Project.

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GLOSSARY AND DEFINED TERMS

Refer to the Water Assessment Report for a master glossary and defined terms table.

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1 INTRODUCTION

1.1 Project background

The NZ Transport Agency (Transport Agency) is lodging a Notice of Requirement (NoR) and applications for resource consent (collectively referred to as "the Application") for the Warkworth to Wellsford Project (the Project).

The Project involves the construction, operation and maintenance of a new four lane state highway. The route is approximately 26 km long. The Project commences at the interface with the Pūhoi to Warkworth project (P-Wk) near Woodcocks Road. It passes to the west of the existing State Highway 1 (SH1) alignment near The Dome, before crossing SH1 just south of the Hōteo River. North of the Hōteo River the Project passes to the east of Wellsford and Te Hana, bypassing these centres. The Project ties into the existing SH1 to the north of Te Hana near Maeneene Road. The proposed designation boundary and Indicative Alignment are shown in Figure 1.

For description purposes the Project has been divided into the following sections (as shown in Figure 1). These sections also reflect the indicative construction programme and sequencing.

a) Southern Section: From the southern extent of the Project at Warkworth to the northern tunnel portal.

b) Central Section: From the northern tunnel portal to the Hōteo River (southern abutment.

c) Northern Section: From the Hōteo River (northern abutment) to the northern tie in with existing SH1 near Maeneene Road.

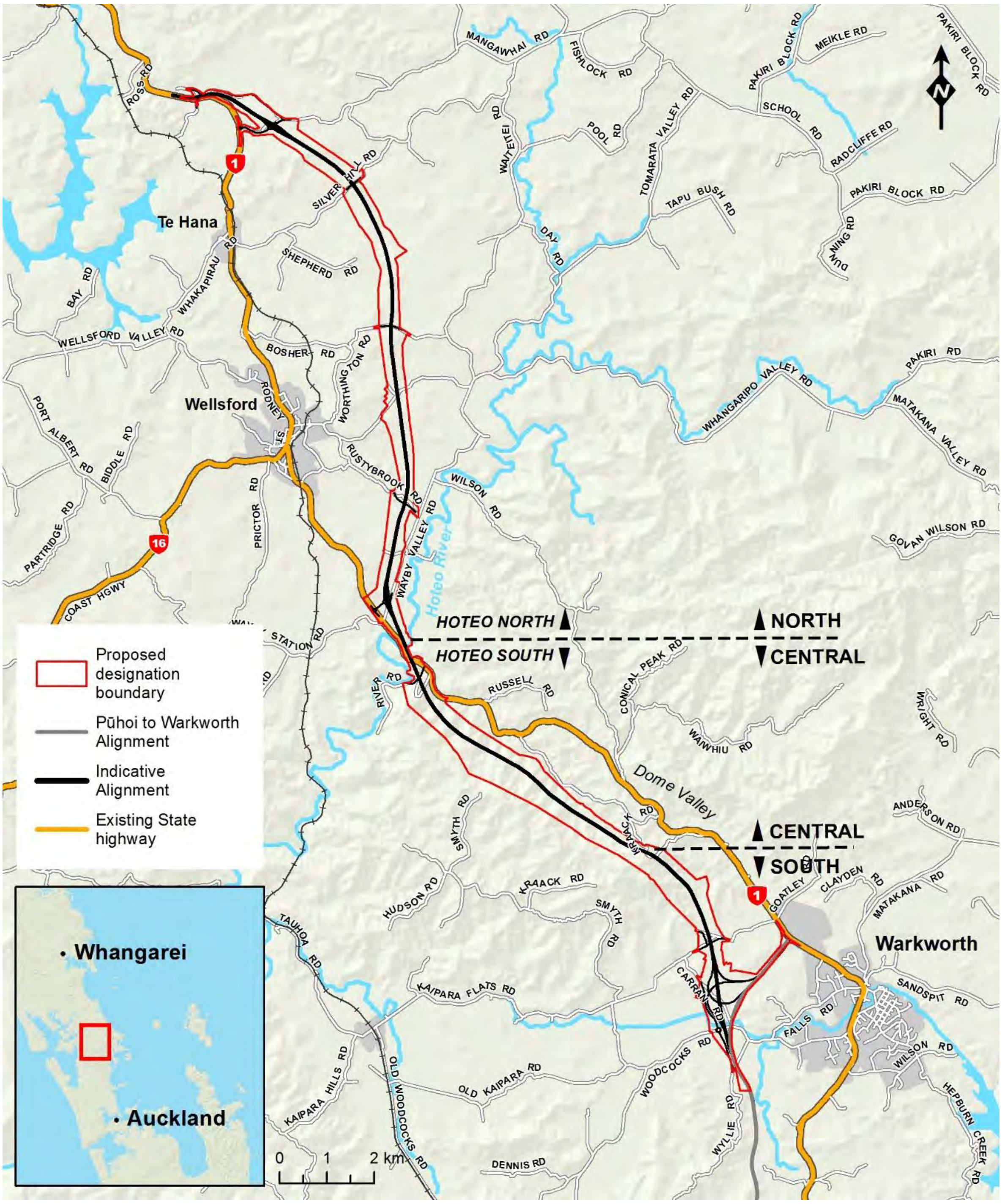

Figure 1 – Project Sections and Indicative Alignment

The proposed designation boundary and freshwater catchments relevant to the Project are shown in Figure 2 below.

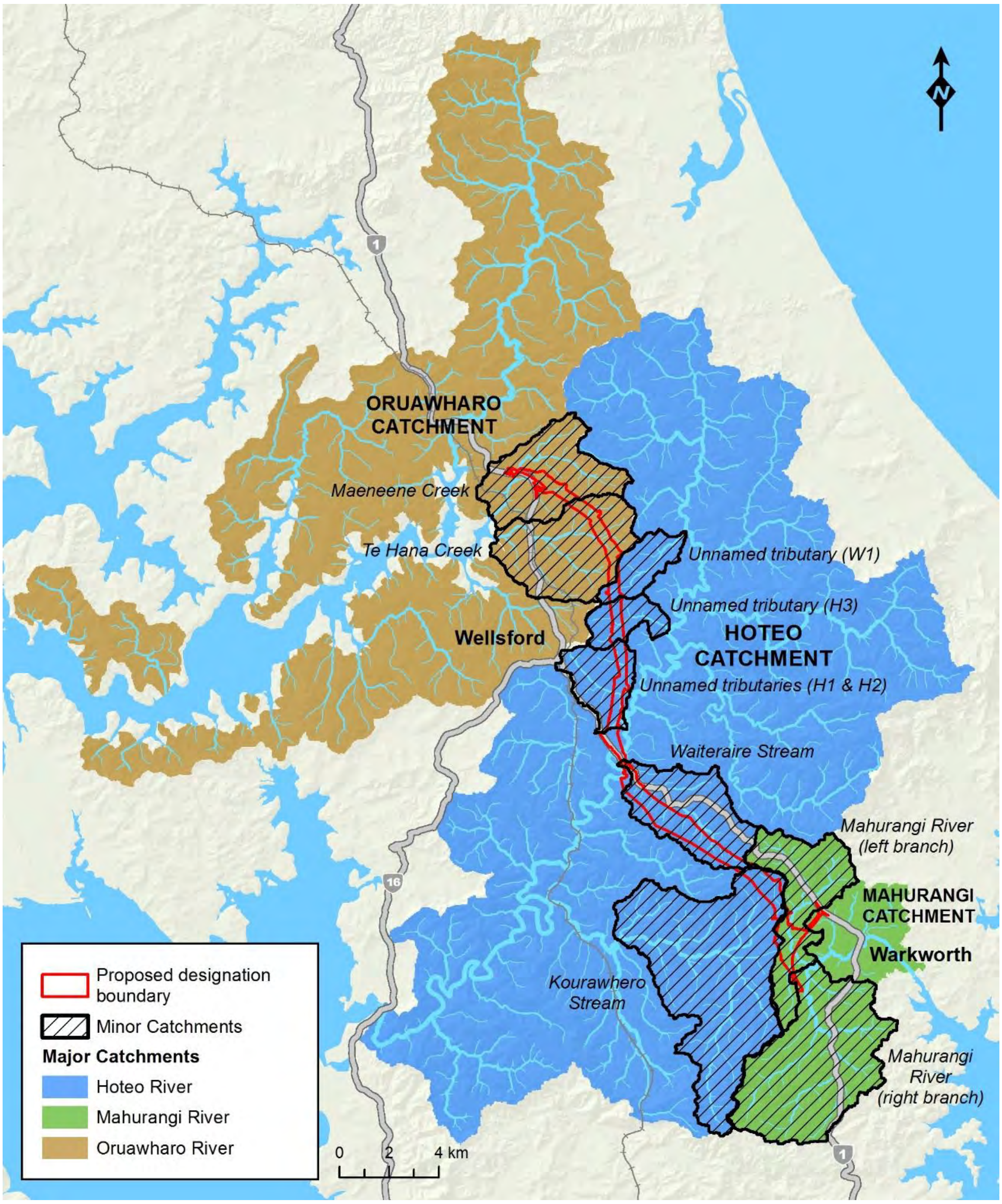

Figure 2 – Proposed designation boundary and freshwater catchments

1.2 Project features

The key features of the Project, based on the Indicative Alignment, are as follows:

a) A new four lane dual carriageway state highway, offline from the existing State Highway 1, with the potential for crawler lanes on the steeper grades.

b) Three interchanges as follows:

i. Warkworth Interchange, to tie-in with the Pūhoi to Warkworth section of state highway and provide a connection to the northern outskirts of Warkworth.

ii. Wellsford Interchange, located at Wayby Valley Road to provide access to Wellsford and eastern communities including Tomarata and Mangawhai.

iii. Te Hana Interchange, located at Mangawhai Road to provide access to Te Hana, Wellsford and communities including Port Albert, Tomarata and Mangawhai.

c) Twin bore tunnels under Kraack Road, each serving one direction, which are approximately 850 metres long and approximately 180 metres below ground level at the deepest point.

d) A series of steep cut and fills through the forestry area to the west of the existing SH1 within the Dome Valley and other areas of cut and fill along the remainder of the Project.

e) A viaduct (or twin bridge structures) approximately 485 metres long, to span over the existing SH1 and the Hōteo River.

f) A tie in to existing SH1 in the vicinity of Maeneene Road, including a bridge over Maeneene Stream.

g) Changes to local roads:

   i. Maintaining local road connections through grade separation (where one road is over or under the other). The Indicative Alignment passes over Woodcocks Road, Wayby Valley Road, Whangaripo Valley Road, Mangawhai Road and Maeneene Road. The Indicative Alignment passes under Kaipara Flats Road, Rustybrook Road, Farmers Lime Road and Silver Hill Road.

   ii. Realignment of sections of Wyllie Road, Carran Road, Kaipara Flats Road, Phillips Road, Wayby Valley Road, Mangawhai Road, Vipond Road, Maeneene Road and Waimanu Road.

   iii. Closing sections of Phillips Road, Robertson Road, Vipond Road and unformed roads affected by the Project.

h) Associated works including bridges, culverts, drainage, stormwater treatment systems, soil disposal sites, signage, lighting at interchanges, landscaping, realignment of access points to local roads, and maintenance facilities.

i) Construction activities, including construction yards, lay down areas for storage of materials and establishment of construction access and haul roads.

A full description of the Project including its current design, construction and operation is provided in Section 4: Description of the Project and Section 5: Construction and Operation of the AEE contained in Volume 1 and shown on the Drawings in Volume 3.

The Indicative Alignment is a preliminary alignment for a state highway that could be constructed within the proposed designation boundary. The assessment within this flood modelling report considers the effects of the Indicative Alignment, but also considers the sensitivity to effects if the alignment shifts within the proposed designation boundary when the design is finalised.

The final alignment for the Project (including the detailed design and location of associated works including bridges, culverts, stormwater management systems, soil disposal sites, signage, lighting at interchanges, landscaping, realignment of access points to local roads, and maintenance facilities), will be refined and confirmed at the detailed design stage.

1.3 Purpose and structure of this report

The Flood Modelling Technical Report (this Report) forms part of a suite of water related design and technical reports prepared for the Ara Tūhono – Pūhoi to Wellsford – Warkworth to Wellsford section (the Project).

These reports are listed below with a short description of each:

- **Water Assessment Report (WAR) –** This report contains a summary of the work carried out and assessment of water related effects associated with construction and operation of the Project.
- **Flood Modelling technical report (This report)** – A model has been developed to predict any changes to flood risk associated with the Project. This report summarises any changes.
- **Construction Water Management Design technical report –** This report contains indicative details of the proposed construction methodology, proposed erosion and sediment controls (ESCs), and other construction phase mitigation measures recommended to reduce and erosion and sediment laden stormwater discharges from entering the receiving environment during construction.
- **Operational Water Design technical report** – This report contains details of the operational stormwater management and other operational phase mitigation by design.
- **Existing Water Quality technical report** – This report summarises water quality monitoring carried out by Auckland Council and for the Project.
- **Catchment Sediment Modelling technical report** – Sediment models have been developed to predict changes in sediment and water quality within receiving watercourses associated with the Project. This report summarises the modelling methodology and results.
- **Operational Water – Road Runoff technical report** – An assessment has been carried out to predict changes to water quality in relation to the Project and pollutants.
- **Hydrological technical report** – Catchment analysis has been developed to predict catchment wide hydrological changes associated with the Project. This report summarises predicted changes to the hydrological environment.

The purpose of this report is to describe the findings of the flood modelling related to the loss of flood storage and changes to flow path due to the location of the Indicative Alignment within the floodplain and due to the crossings of rivers and streams. The results of the modelling have been used to identify changes to flooding in areas that are expected to have potential to be affected by the Indicative Alignment. The findings of this report will inform the Water Assessment Report and the Assessment of Effects on the Environment (AEE). Figure 3 below summarises the relationship between each of the water related technical and assessment reports and the AEE.

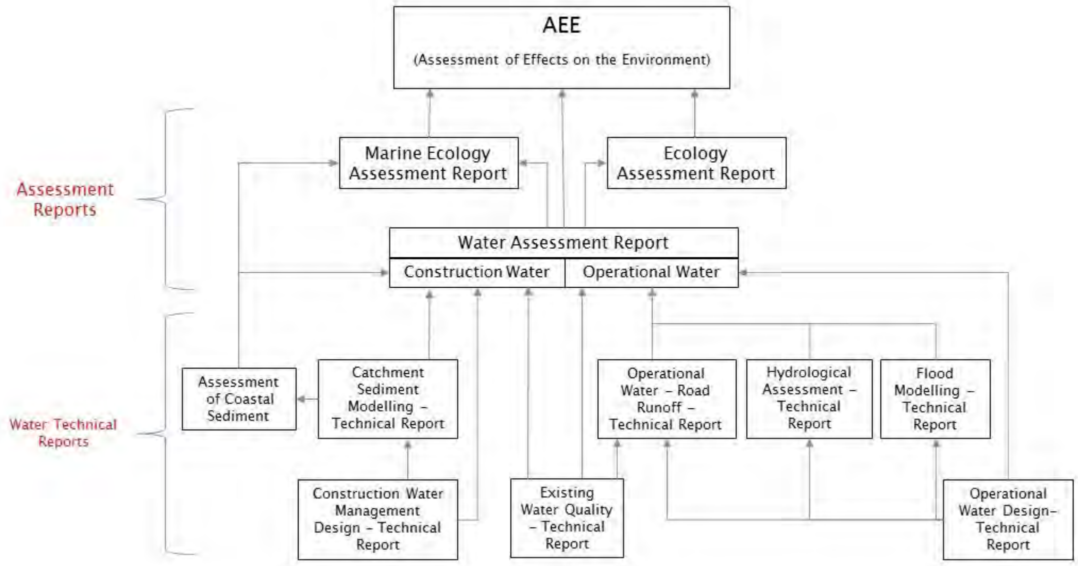

Figure 3 – Flood Modelling Technical Report – relationship to other reports

The scope of this report is to describe the models used to simulate the existing scenario and modifications made to the model to include the proposed works. The models have been run with the 2, 10, 20 and 100 Year ARI floods including an allowance for climate change. The results from this report are used as the basis for assessment of flooding effects in the Water Assessment Report.

The structure of this Report is as follows:

- **Section 1** describes the Project, the purpose of this report and the methods adopted for flood assessment.
- **Section 2** discusses the flood model built for the Mahurangi Catchment and the changes to the extents of flooding due to the Indicative Alignment proposed within the floodplain.
- **Section 3** describes the hydraulic model constructed for the Kourawhero Catchment and the impact of Indicative Alignment, culverts and bridges on flooding.
- **Section 4** discusses the flood model built for the Hōteo Catchment and the changes to the extents of flooding due to the Indicative Alignment proposed within the floodplain.
- **Section 5** presents the impact of mitigation planting proposed by the ecologists and landscape architects within the Mahurangi and Hōteo Catchments on flooding.
- **Section 6** presents the model limitations; and
- **Section 7** discusses the conclusions made on basis of results obtained from the flood models.

1.4 Identification of important crossings

The proposed Warkworth to Wellsford Indicative Alignment passes through the catchments of Mahurangi, Hōteo, Te Hana and Maeneene. Rapid Flood Hazard Assessment (RFHA) maps developed for the 100-year ARI event by Auckland Council show the locations where flooding is predicted to occur. The proposed designation boundary was overlaid across the flood extents and shows that the Indicative Alignment coincides with the flood extents at many locations (Figure 4).

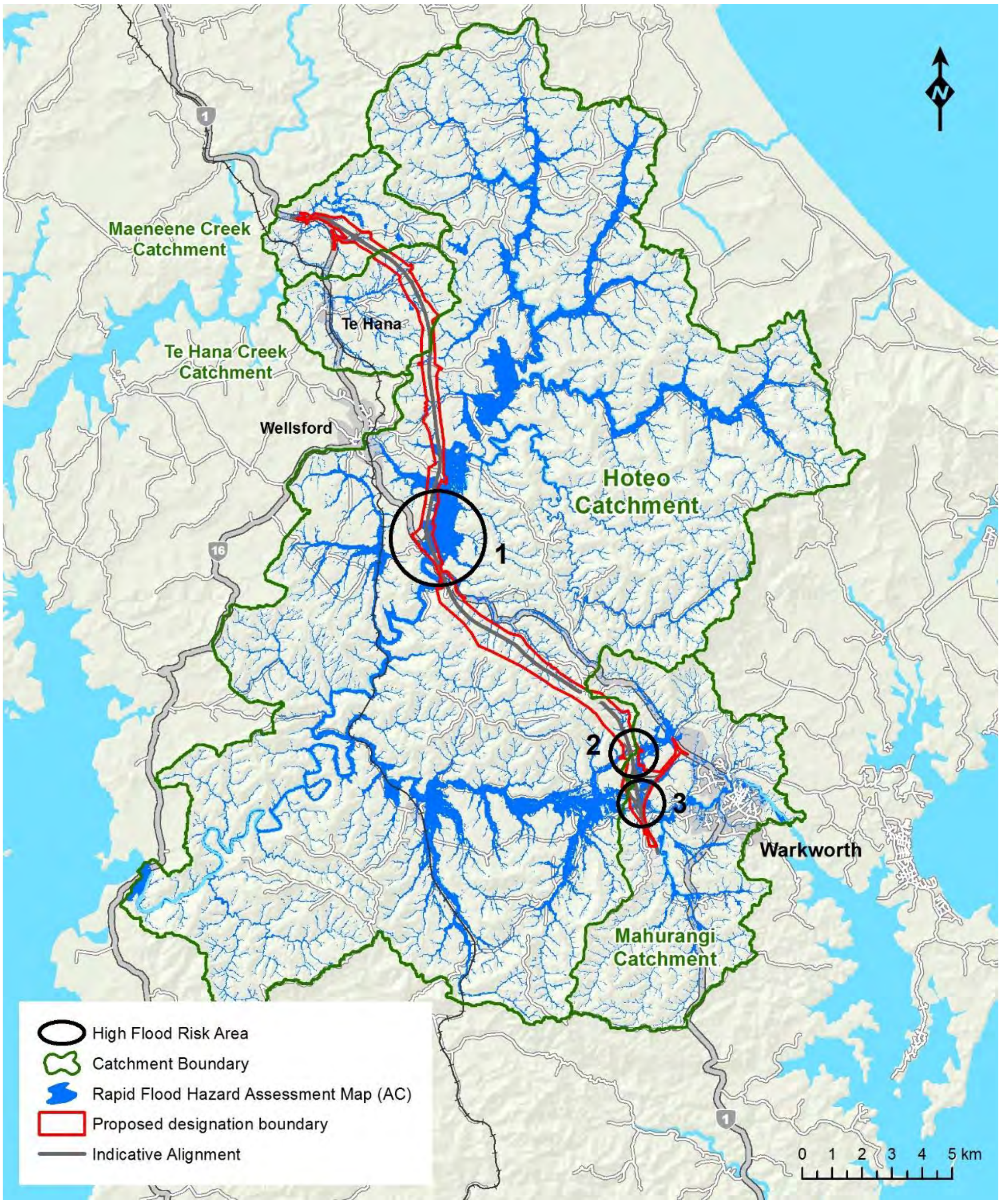

Figure 4 – Catchment Boundaries with Indicative Alignment and rapid flood hazard assessment map (source: Auckland Council)

There are three high flood risk areas where the Indicative Alignment may exacerbate the flooding in Mahurangi, Kourawhero (a tributary of the Hōteo River) and Hōteo catchments (Figure 4). In this study, Maeneene and Te Hana catchments are screened out of modelling and assessment at an early stage as the Project will have minimal interactions with these catchments and the risk of adverse flood effects are low and can be managed in detailed design using consent conditions for flood performance. In view of this, the impact of the Indicative Alignment on flood depth was assessed at the following three locations by developing hydraulic models:

- Mahurangi River and its tributaries crossings.
- Crossings of Hōteo tributary (Kourawhero Stream) south of the proposed tunnel.
- Areas along Wayby Valley Road due to flood water from the north branch of the Hōteo River.

1.5 Flood effects assessment [method]

For assessing the effects of the Project on the flood levels in Mahurangi, Kourawhero and Hōteo catchments (Figure 4), the floods of 2, 10, 20 and 100 Year ARI event were adopted, with an allowance for climate change to 2130.

Flood models have previously been built and studies undertaken by third parties for the Mahurangi catchment. The methodologies used and the models created in the previous work were assessed and, as far as possible, adapted for use on the Project. For the Kourawhero and Hōteo catchment new models were developed for this assessment.

Mahurangi floodplain: flood effects assessment methodology

A hydrological and hydraulic model for the Mahurangi catchment was developed by Auckland Council using Infoworks ICM software. The Auckland Council model was revised for the P-Wk project (Northern Express Group, 2018), and this model was adopted for this study. Hydrological inputs used in this assessment were based on the rainfall profiles derived for undertaking flood assessment for P-Wk project and rainfall depths were transformed into runoff using the methodology as described in the Auckland Regional Council's "Technical Publication 108 - Guidelines for stormwater runoff modelling in the Auckland Region" (1999), which is referred to in this report as TP108.

Kourawhero Model: flood effects assessment methodology

A new hydraulic model was constructed for the Kourawhero Stream using MIKE Flood software. Hydrological inputs to the model were based on flows derived by following the methodology as described in TP108.

Hōteo floodplain: flood effects assessment methodology

A hydraulic model was constructed for the Hōteo floodplain in the vicinity of the southern end of Wayby Valley Road using MIKE Flood software. Hydrological inputs to the model were based on area-adjusted flood-frequency analysis from the flow gauge 'Hōteo River at Gubbs', using the area adjustment method specified in the NZTA Bridge Manual (Third Edition, May 2016). Climate change to the year 2130 was accounted for by adopting factors as outlined in section 1.6. A sensitivity analysis was undertaken using TP108 derived flows.

1.6 Climate change

Current guidance from Ministry for the Environment (MfE) provides tools for estimating the effects of future climate change on extreme (storm) rainfall through until the year 2090. For the Project, the effects of climate change were considered for 100 years post-road construction, i.e., approximately 2130. This section outlines the proposed method for allowing for the effects of climate change to 2130 for the flood modelling of the Project.

The proposed method consists of three aspects:

- Evaluation of projected changes in seasonal and annual mean temperature from baseline to 2130.
- Evaluation of projected changes in extreme rainfall based on the projected changes in temperature from baseline to 2130.
- Evaluation of projected changes in flood magnitude based on the projected changes in extreme rainfall from baseline to 2130.

The proposed method refers to the following documents:

- MfE (2010): Tools for Estimating the Effects of Climate Change on Flood Flows: A guide for local government in New Zealand.
- MfE (2016): Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment.
- Opus (2014): Peka Peka to North Otaki Expressway Effects of Major Watercourse Crossings on Floods Adjusted for Possible Climate Change to 2130.

Projected changes in temperature, baseline to 2130

The most recent climate change projections for New Zealand were reported by MfE (2016) and focus on the future changes in New Zealand climate out to 2101-2120 relative to a current-climate 'baseline' of 1986-2005. The report draws on the IPCC Fifth Assessment Report climate model simulations, downscaled to New Zealand. The projected changes between 1986-2005 and 2101-2120 for the Northland and Auckland regions are given in Table 1 for the models that have data available beyond 2100. The changes are given for three RCPs where the ensemble average is taken over four models. The values in each column of Table 1 represent the ensemble average, and in brackets the range (5th to 95th percentile) over all models within that ensemble.

Table 1 – Projected changes in seasonal and annual mean temperature (in °C) between 1986-2005 and 2101-2120 for Northland and Auckland regions

		Summer	Autumn	Winter	Spring	Annual
Northland	rcp 8.5	4.1 (2.9, 5.9)	4.0 (3.0, 5.5)	3.6 (2.7, 4.5)	3.4 (2.8, 4.2)	3.7 (2.9, 5.0)
	rcp 4.5	1.8 (1.1, 2.5)	1.8 (1.2, 2.3)	1.6 (1.0, 2.2)	1.5 (1.0, 2.2)	1.7 (1.2, 2.2)
	rcp 2.6	0.8 (0.2, 1.3)	0.8 (0.3, 1.3)	0.7 (0.5, 1.2)	0.7 (0.3, 1.2)	0.8 (0.4, 1.3)

		Summer	Autumn	Winter	Spring	Annual
Auckland	rcp 8.5	4.1 (2.9, 6.1)	4.0 (3.0, 5.6)	3.6 (2.8, 4.7)	3.4 (2.7, 4.3)	3.8 (2.9, 5.2)
	rcp 4.5	1.8 (1.1, 2.9)	1.8 (1.2, 2.3)	1.6 (1.0, 2.2)	1.5 (1.0, 2.2)	1.7 (1.2, 2.3)
	rcp 2.6	0.7 (0.0, 1.5)	0.8 (0.3, 1.4)	0.7 (0.4, 1.2)	0.7 (0.4, 1.2)	0.7 (0.4, 1.3)

Of note, there is little difference between the projections for Northland and Auckland, with the mid-range scenario (rcp 4.5) results being identical.

We have adopted the mid-range scenario results (for rcp 4.5) to incorporate the effects of climate change into the Project design. This approach gives a projected mean annual temperature increase between 1986-2005 and 2101-2120 for the Project area of 1.7°C.

Analysis of large floods in the Hōteo River indicates that most (70%) of the annual maximum floods over the last 40 years have occurred during winter. The mid-range scenario increase in winter temperature through until 2101-2120 is 1.6°C. Thus adopting an increase of 1.7°C is deemed to be appropriate.

The temperature changes projected in MfE (2016) are through to 2101-2120, taken to be 2110. Linear extrapolation of the trend in annual mean temperature change from 2110 to 2130 gives a temperature change from 1986-2005 to 2130 of 2.0°C. Linear extrapolation appears reasonable (Figure 5).

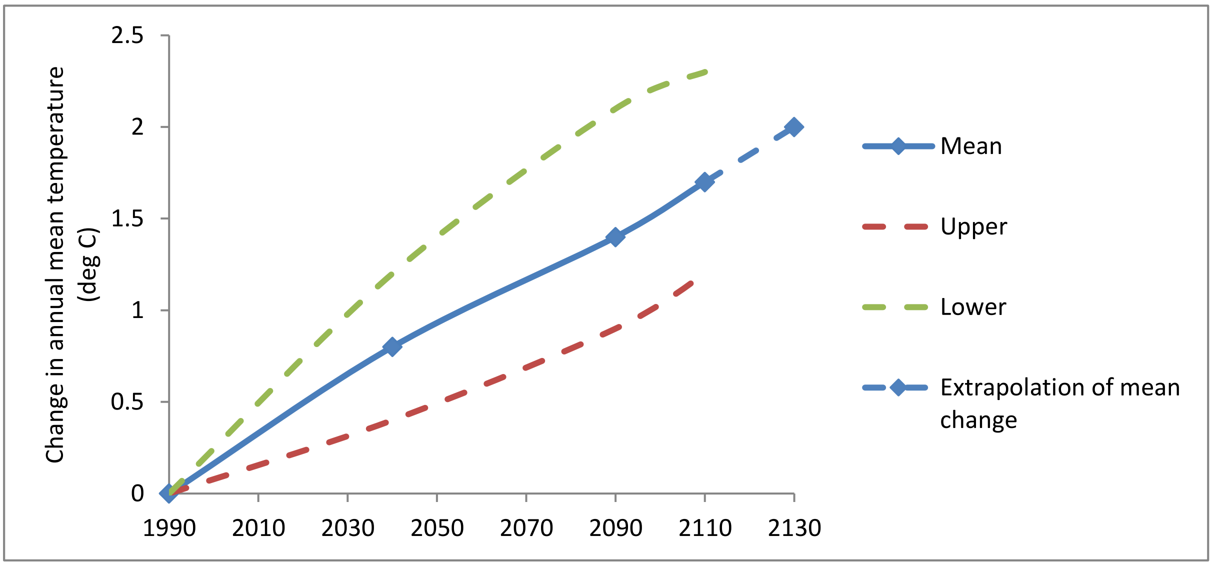

Figure 5 – Projected changes in annual mean temperature, baseline to 2130

MfE (2010) give percentage adjustment factors to apply to extreme rainfall totals per percent change in temperature between 1990 and 2090. We have assumed that the adjustment factors also apply to projected changes in temperature beyond 2090 (i.e. to 2130), as was also assumed by Opus (2014).

The TP108 method for estimating peak flows was utilised for the Kourawhero and Mahurangi catchments. TP108 uses a rainfall duration of 24 hours. The adjustment factors (percentage increase in rainfall per 1°C temperature increase) to apply to the 24-hour rainfall depths for ARIs of 2 years to 100 years, from MfE 2010, are shown in Table 2. Assuming a 2°C increase in temperature for the Project area, through to 2130, the adjustment factors to apply to rainfall for the Project are given in the bottom row of Table 2.

Table 2 - Proposed adjustment factors to apply to 24-hour storm rainfall depths for 2 to 100 year ARIs, for the Project

ARI (Year)	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year
Adjustment factor per 1°C increase	1.043	1.054	1.063	1.072	1.080	1.080
Adjustment factor for the Project	1.086	1.108	1.126	1.144	1.160	1.160

It is noteworthy that mean winter rainfall is projected to remain approximately the same (1% increase for a mid-range scenario) by 2101-2120 (MfE, 2016). Thus, although extreme (storm) rainfalls are likely to increase due to the projected temperature increase, overall catchment conditions such antecedent moisture conditions during the season when most floods occur in the Hōteo River are not predicted to substantially change.

For the Hōteo River, design flood peaks have been derived by flood frequency analysis using flow gauging records of Gubbs station, instead of adopting methodology of TP108. The guidance given by MfE (2010) is for adjusting extreme rainfall to account for the effects of climate change, rather than for adjusting peak flows.

In other recent state highway projects (Peka Peka to Otaki - PP2O and MacKays to Peka Peka - M2PP), a flood frequency analysis methodology was used to calculate peak flows on the large rivers (Otaki and Waikanae) with the climate change increases applied to peak flow (Opus, 2014).

The methodology applied in PP2O and M2PP analysed relationships between rainfall and flow at the river gauges. For M2PP a 5% increase in flow to rainfall was applied, while in the case of PP2O the increase for rainfall and flow were equivalent.

Unfortunately, it is not possible to analyse the relationship between rainfall and flow of the Hōteo River at Gubbs Station due to the relative location of the rainfall gauges. Furthermore, the location of rainfall and flow gauges has made it challenging to develop a calibrated rainfall runoff model in this catchment.

Hence, to determine what climate change factor should be applied to flows in the Hōteo catchment, we analysed the TP108 rainfall runoff models that were developed for the culvert design. As a result of this analysis we found that the increase of flow was about 26.4%, when the flows estimated without and with climate change were compared.

2 MAHURANGI RIVER

The Indicative Alignment crosses the Mahurangi floodplain in a number of locations as shown in Figure 6. There are two causes for potential increase in flood level in this area from the Indicative Alignment:

- Loss of flood storage and changes to flow paths due to the location of road embankments within the floodplain.
- Bridges associated with connecting ramps affecting the flood capacity of the left tributary of the Mahurangi River.

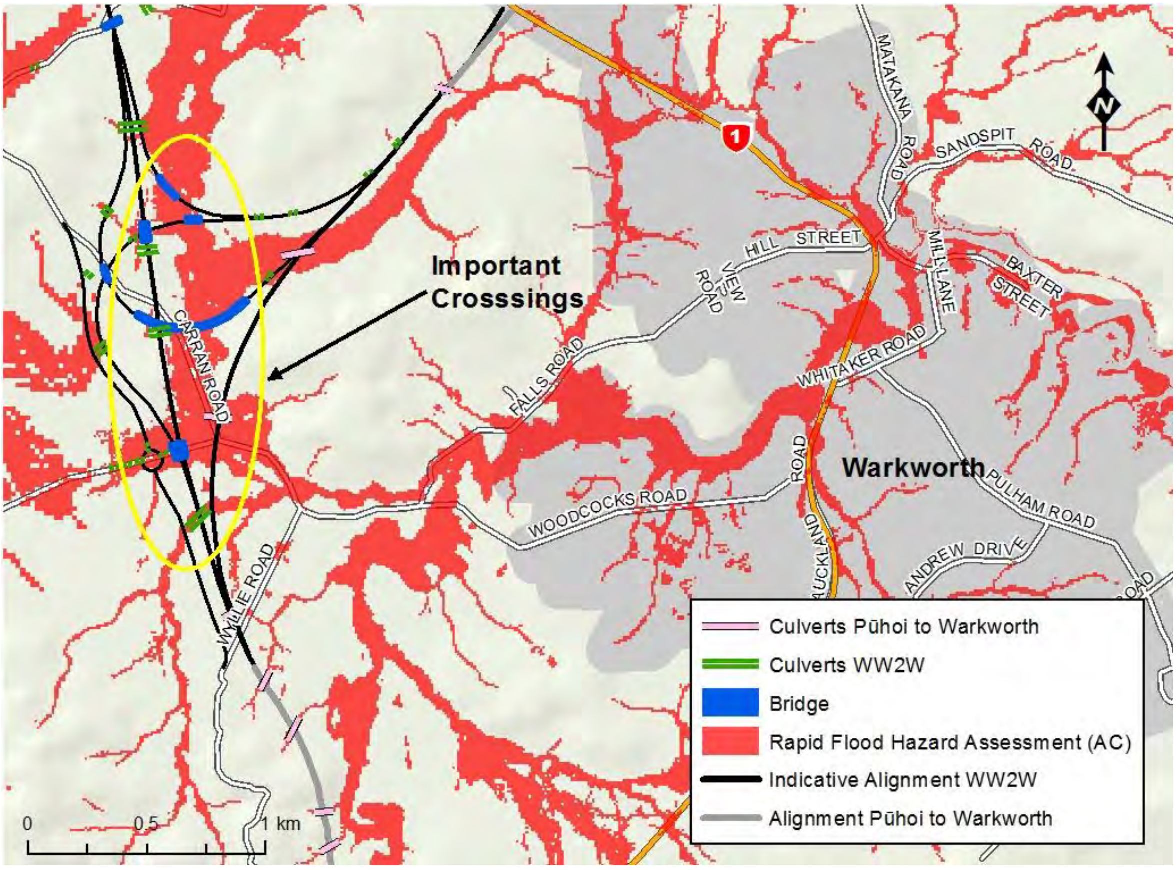

Figure 6 – Important crossings in the Mahurangi catchment

2.1 Extent and boundaries

The flood model of the Mahurangi Catchment built for P-Wk project (Northern Express Group, 2018) was obtained for this study, which is referred to in this report as P-Wk model. The model was built in accordance with the Auckland Council Standard Stormwater Hydraulic Modelling Specifications, as per the Mahurangi River Catchment Flood Hazard Mapping Report by Auckland Council (2017).

While revising Auckland Council's model for the P-Wk project, the extents of the 2D surface and 1D model were not modified (Northern Express Group, 2018). The urban, future urban and some rural parts of the Mahurangi Catchment were represented by 2D surface, while the remainder of the catchment was modelled with lumped hydrology connected to the 1D models of the streams. The specific land use of the future urban area has not been considered in the flood assessment of the Indicative Alignment. It is appropriate to assume that the flood effects of future development will be addressed by the developer at the time of development. The Mahurangi River and its left and right branches and major tributaries were modelled in 1D as shown below in Figure 7.

To perform flood assessment for P-Wk project, the P-Wk State Highway alignment, stream diversions, culverts and a bridge were included in the 2D extent. Besides these modifications, changes were also introduced in the hydrological parameters in order to match the P-Wk hydrological assessments.

The details of these changes are provided in subsequent sections of this report.

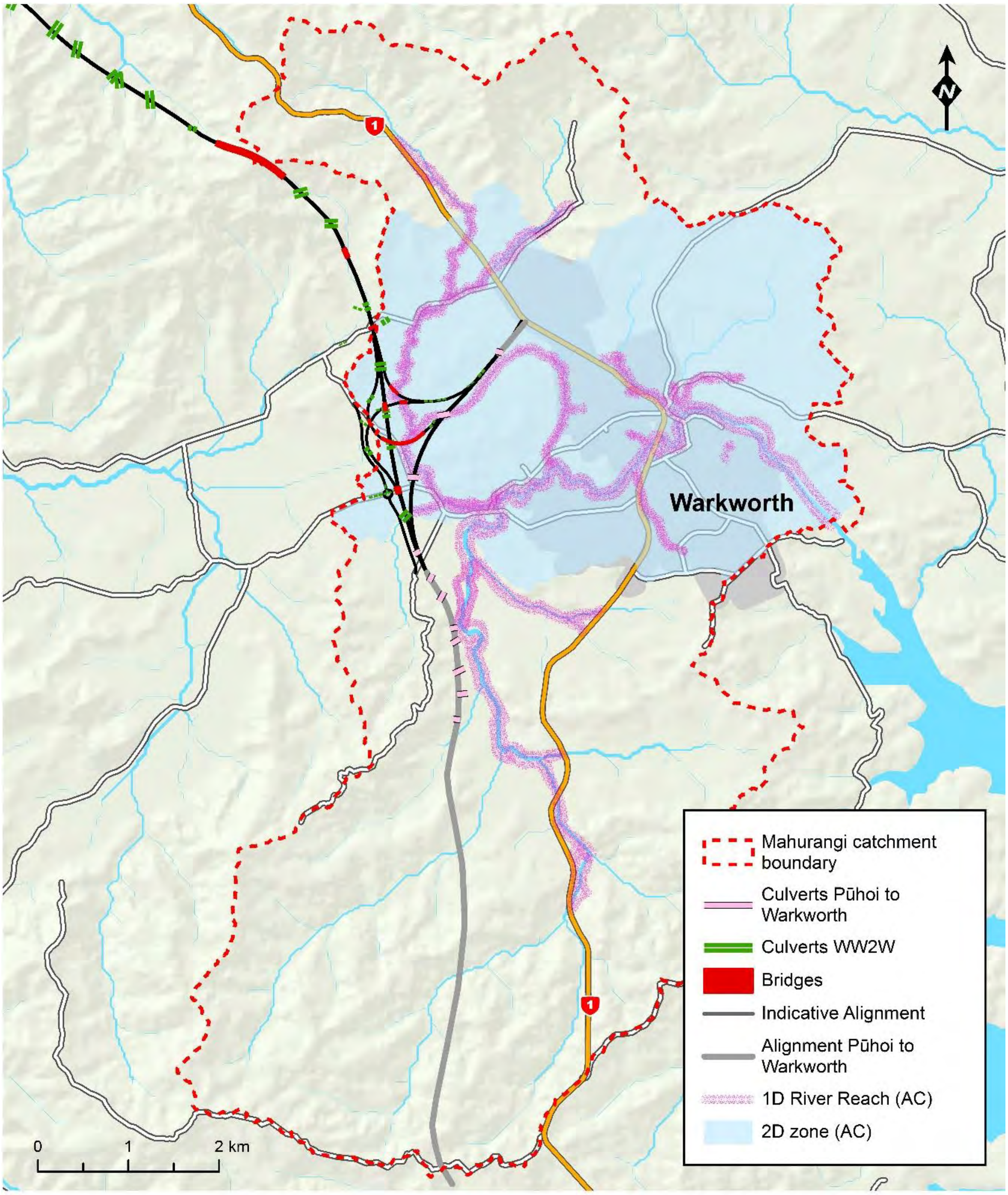

Figure 7 - 1D and 2D Zones of the P-Wk's Mahurangi River catchment hydraulic model

2.2 Hydrology

2.2.1 Method

As per Mahurangi River Catchment Flood Hazard Mapping Report of Auckland Council (2017), the guidelines outlined in TP108 were adopted to model stormwater catchment runoff in Infoworks ICM software. The flood flows estimated using the TP108 methodology are conservative (larger) when compared to flood flows estimated from the statistical record using the flood frequency analysis method.

In Auckland Council's model, the TP108 method was parameterised as follows:

- Rainfall depths and pattern: derived from TP108 isohyet maps and increased for climate change by multiplying rainfall depths with factors as given below in Table 3. Developed rainfall patterns based on TP108 having peak rainfall intensity at mid-duration.
- Time of concentration: calculated using the empirical lag equation given in TP108 (Equation 4.3 on page 12). A minimum time of concentration of 10 minutes was adopted, as per TP108.
- Initial abstraction: adopted 0 mm for impervious areas and 5 mm for pervious areas, as per TP108.
- Curve number: assigned using tables supplied in TP108 (Appendix B). As per Auckland Council's Mahurangi River Catchment Flood Hazard Mapping report, curve numbers selected based on land use and soil types.

As described earlier, the P-Wk model was obtained for the flood assessment of the Indicative Alignment. In order to estimate flows comparable with the flows obtained from flood frequency analysis based on empirical data, the following modifications were introduced for the P-Wk project as key hydrological parameters in the Auckland Council model:

- Revised Curve Numbers (CN) for all the sub-catchments;
- Modified time of concentration (> 10 minutes) of sub-catchments; and
- Two models were constructed for each of the pre and post development scenarios using CN66 and CN74. Besides CN and time of concentration, the rainfall depths were also revised for the P-Wk model.

In this study for the Project, the modifications introduced for the P-Wk project were adopted for flood assessment of the Indicative Alignment.

2.2.2 Incorporating the impacts of climate change on rainfall depths

The effects of climate change on rainfall depths as at 2130 are incorporated into the design hydrology of the Mahurangi catchment. The method used for incorporating the effects of climate change is to increase the rainfall depths of different return periods by the factors in Table 3 (refer to Section 1.6).

Table 3 - Climate change adjustment factors for different return periods

ARI (year)	2	10	20	100
Adjustment factor for the Project	1.086	1.126	1.144	1.160
Adjustment factor as per Mahurangi River Catchment Flood Hazard Mapping Report of Auckland Council (2017)	1.091	1.132	1.151	1.168

The above climate change adjustment factors were derived using the information provided in MfE (2016), based on a mid-range climate change temperature increase scenario to

2090, linearly extrapolated to 2130, and assuming an 8% increase in rainfall intensity per 1°C increase in temperature (MfE, 2010).

The climate change adjustment factors derived by Auckland Council (2017) were adopted to include the impact of climate change to 2130 for the Mahurangi Catchment. This approach is the same as that adopted for P-Wk model (Table 3).

2.3 Hydraulic model setup

A LIDAR derived DEM with a grid size of 1 m × 1 m procured from Auckland Council was used as a ground model in Infoworks ICM based hydraulic model of the Mahurangi Catchment.

The hydraulic model of the Mahurangi Catchment obtained from Auckland Council comprises of 775 sub-catchments. To study the impact of Indicative Alignment, culverts (CLVT_MCG0_280 to CLVT_49500) and bridges on flood levels, the sub-catchments located along the Indicative Alignment were either split or merged in order to include the effect of the Indicative alignment on catchment boundaries. For assessing the cumulative Project and P-Wk road impacts on flooding, the 2D Zone was extended in the south to include the sub-catchments located along both of these road alignments as shown in Figure 8.

Besides this, adjustments were made to two key parameters (Curve Number - CN and time of concentration) of Auckland Council's model in order to achieve a better match between the model and the gauge data. According to the P-Wk flood model report (Northern Express Group, 2018), CN66 and CN74 were used for all the sub-catchments in order to develop two models, one relating to each CN number. Besides changes to CN values, the sub-catchments with a time of concentration greater than 10 min were identified and their times of concentration were revised. Like the P-Wk model, two models were also developed for this study by introducing the above modifications into Auckland Council's model.

In addition to CN and time of concentration, the rainfall depths were also adjusted and were determined on the basis of detailed hydrological assessment for CN66 (Northern Express Group, 2018). The rainfall depths adopted for this modelling are given below in Table 4.

Table 4 - 24 hr design rainfall depths including climate change derived for CN66 (source: Northern Express Group, 2018)

ARI (Year)	2	5	10	20	50	100
Rainfall Depth (mm)	151	194	223	251	285	307

In contrast to the use of above rainfall depths for CN66, the rainfall depths including the impact of climate change as reported in Mahurangi River Catchment Flood Hazard Mapping Report of Auckland Council (2017) were adopted for CN74 as suggested in P-Wk Flood Model Report (Northern Express Group, 2018).

In both Auckland Council model and P-Wk Model, the areas along the Mahurangi River and its tributaries within 2D Zone (Figure 7) were represented with fine resolution mesh and a coarse mesh was used for the elevated areas. The fine resolution mesh has maximum triangle area of 10 m^2 and minimum element area of 5 m^2, while the size of elevated areas' mesh have a maximum triangle area of 100 m^2 and a minimum element area of 25 m^2. Based on these models, the same features were adopted to develop fine and coarse resolution mesh for the revised 2D zone (Figure 8).

In both Auckland Council model and P-Wk model, the modelled stormwater network is the same and Table 5 below summarises the components of Auckland Council's Mahurangi model:

Table 5 – Summary of hydraulic model components

Hydraulic model components	Values
Pipe network	
Total number of stormwater network system nodes	1,082
Total number of stormwater network system pipes	1,030
Total numbers of weirs	43
Total number of outlets	10
River/stream network	
Total numbers of bridges	19
Total numbers of culverts	49

In addition to the culverts (49) modelled by Auckland Council (Table 5), the Project culverts from CLVT_MCG0_280 to CLVT_49500 (14) were modelled as conduits in a 1D model with a single dummy Outfall upstream and downstream inserted into the 2D model (Figure 9). Besides these culverts, two new bridges (Bridge No. 5 and Bridge No. 6) proposed to cross the left branch of the Mahurangi River located south of Kaipara Flats Road were modelled (Figure 9).

The P-Wk alignment was included in both pre and post development scenarios, while this Project's Indicative Alignment was considered only in the post development scenario. The culverts in the P-Wk alignment obtained from NZTA were also included in the model and their locations are shown below in Figure 9.

For the pre and post development scenario, the models developed for CN66 and CN74 were simulated for 2, 10, 20 and 100 Year ARI events.

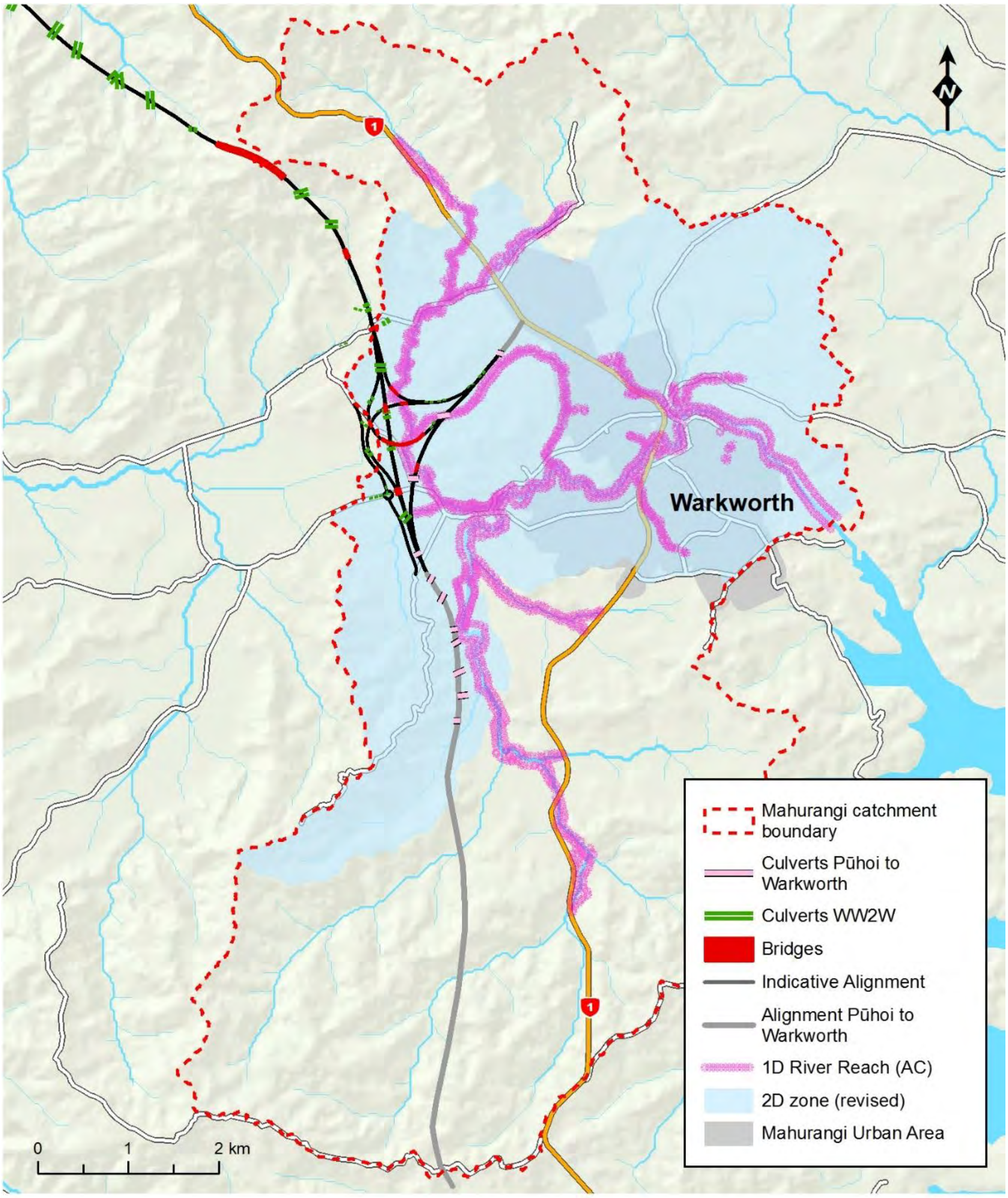

Figure 8 – Revised 2D zone of the Mahurangi hydraulic model

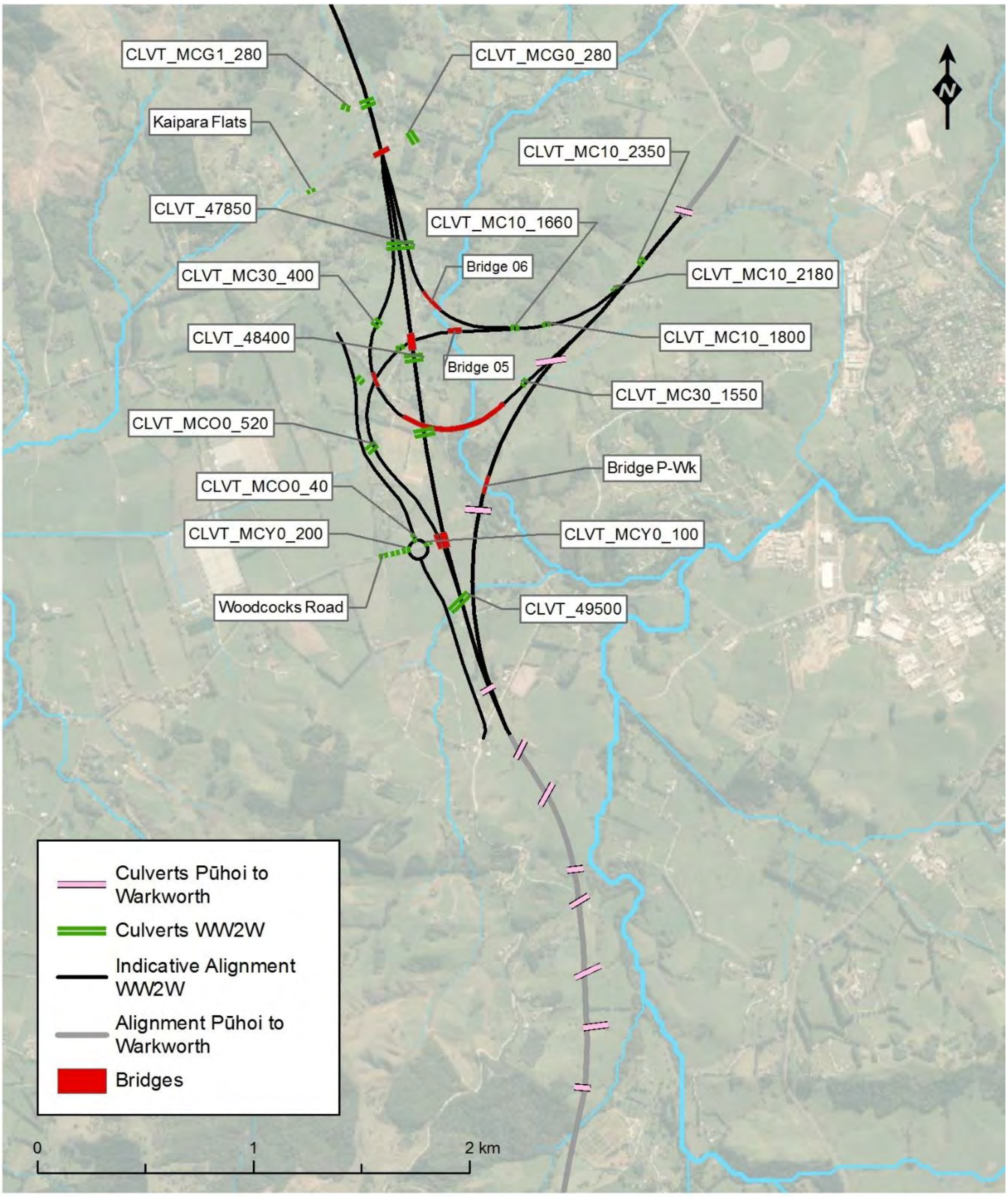

Figure 9 – Location of culverts and bridges for the Project (indicative) and Pūhoi to Warkworth alignment

2.4 Peak flows at the Mahurangi River flow gauge

The purpose of this section is to compare the model outputs derived for this Project with those derived by the P-Wk modelling approach. A good comparison would indicate alignment with empirical flow gauge data from the geographic area.

After incorporating the changes in Auckland Council's model as discussed in Section 2.3 for CN66 and CN74, the projected peak flows were found to be comparable with the peak flows as reported in P-Wk flood model report (Northern Express Group, 2018) and as are given below in Table 6. The results of P-Wk model and revised WW2W model (Table 6) indicate that the revised model set up is suitable to support the flood assessment of the Indicative Alignment.

For CN66, the projected peak flow of 100 Year ARI event is slightly higher (2.5%) than the peak estimated for the same event as reported in P-Wk flood model report (Northern Express Group, 2018). This is potentially due to either slight differences in subcatchments along the Indicative Alignment caused by the splitting or merging of catchments. The peak flows estimated for 2, 10 and 20 Year ARI events are also reasonably comparable (Table 6).

Similarly, the results for CN74 of 2, 10, 20 and 100 Year ARI events are also comparable with the peak flows as reported in P-Wk flood model report (Northern Express Group, 2018).

Table 6 – Peak flows at the Mahurangi River flow gauge estimated for Pre-development scenario

ARI (Year)	Peak Flows (m^3/s) (source: Northern Express Group, 2018)		Estimated Peak Flows using revised WW2W model (m^3/s)	
	CN66	CN74	CN66	CN74
2	151	161	159	166
10	274	311	285	329
20	328	390	339	412
100	438	568	449	595

2.5 Results

For our study, the flood assessment was undertaken for the Indicative Alignment and associated design with major stream crossings where bridges are proposed to cross the left branch of the Mahurangi River, and also at the minor stream crossings where culverts are proposed.

2.5.1 Proposed bridges across the Mahurangi River

Bridge No. 5 and Bridge No. 6 have indicative spans of 65.0 m and 110.0 m respectively, with the bridge span and crest level based on road geometrics rather than by flood hydraulics. At the detailed design stage, a bridge with smaller dimensions could increase flood levels, but these effects may be able to be contained within the designation or be within acceptable levels. The requirements for detailed design of bridges and culverts are best informed by performance based resource consent conditions.

The projected flood levels obtained for CN66 and CN74 at proposed bridges for the 100 Year ARI event are given below in Table 7 and Table 8.

Table 7 – Predicted Flood Levels at Bridges for the 100 Year ARI Event for CN66

Bridge	Length (m)	Soffit Level (m)	Predicted Flood Level (m)		Projected Increase in Flood Depth (m)
			Pre-Development	Post-Development	
Proposed Mahurangi Bridge (Bridge 5)	65.0	40.2	36.65	36.70	0.05
Proposed Mahurangi Bridge (Bridge 6)	110.0	41.0	37.06	37.13	0.07

Table 8 – Predicted Flood Levels at Bridges for the 100 Year ARI Event for CN74

Bridge	Length (m)	Soffit Level (m)	Predicted Flood Level (m)		Projected Increase in Flood Depth (m)
			Pre-Development	Post-Development	
Proposed Mahurangi Bridge (Bridge 5)	65.0	40.2	36.98	37.00	0.02
Proposed Mahurangi Bridge (Bridge 6)	110.0	41.0	37.49	37.53	0.04

Figure 10 to Figure 13 show slight reductions in flow at Bridge 5 and Bridge 6 across the left branch of the Mahurangi River obtained for CN66 and CN74, compared to pre-development conditions.

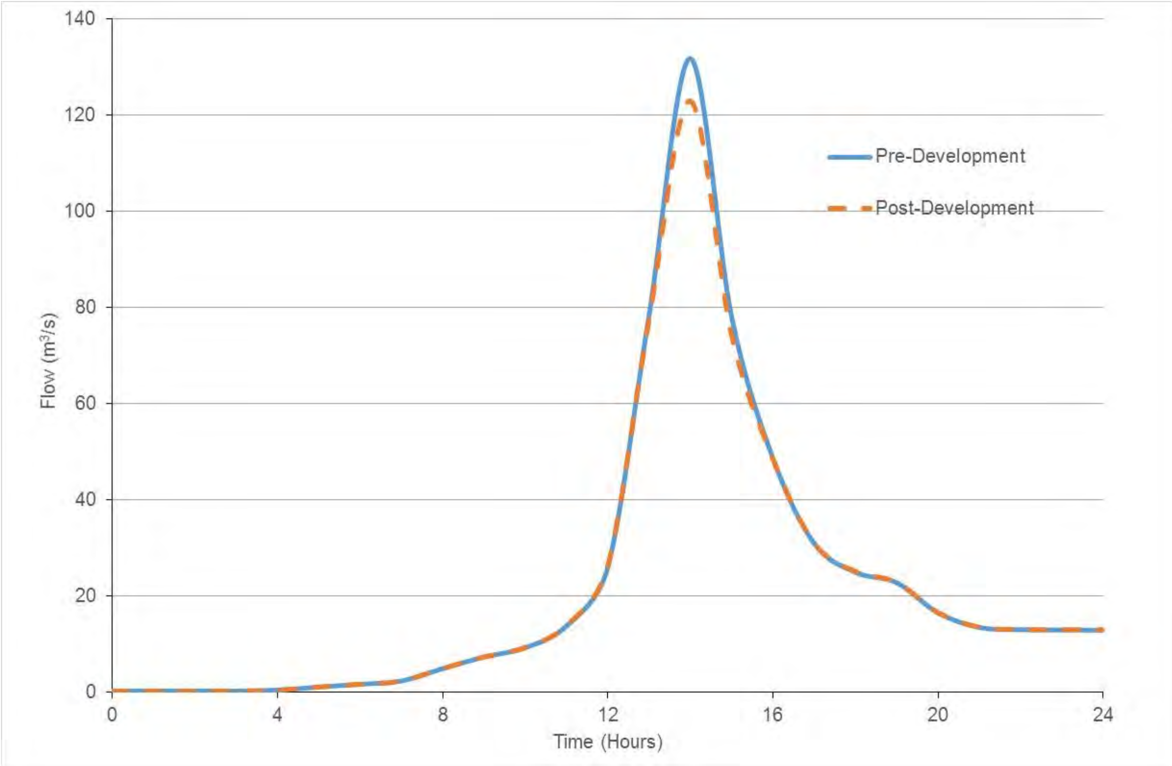

Figure 10 – Comparison of flow for 100 year ARI event at Bridge No. 5 Mahurangi left branch bridge for CN66

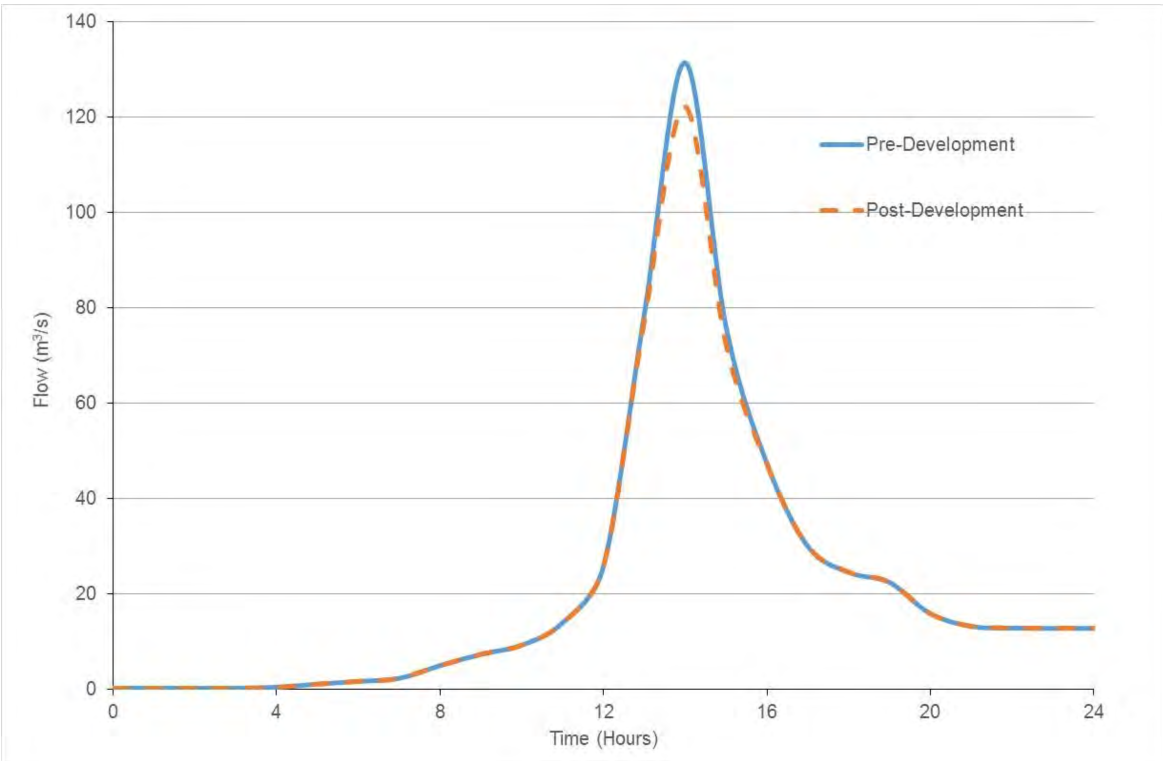

Figure 11 – Comparison of flow for 100 year ARI event at Bridge No. 6 Mahurangi left branch bridge for CN66

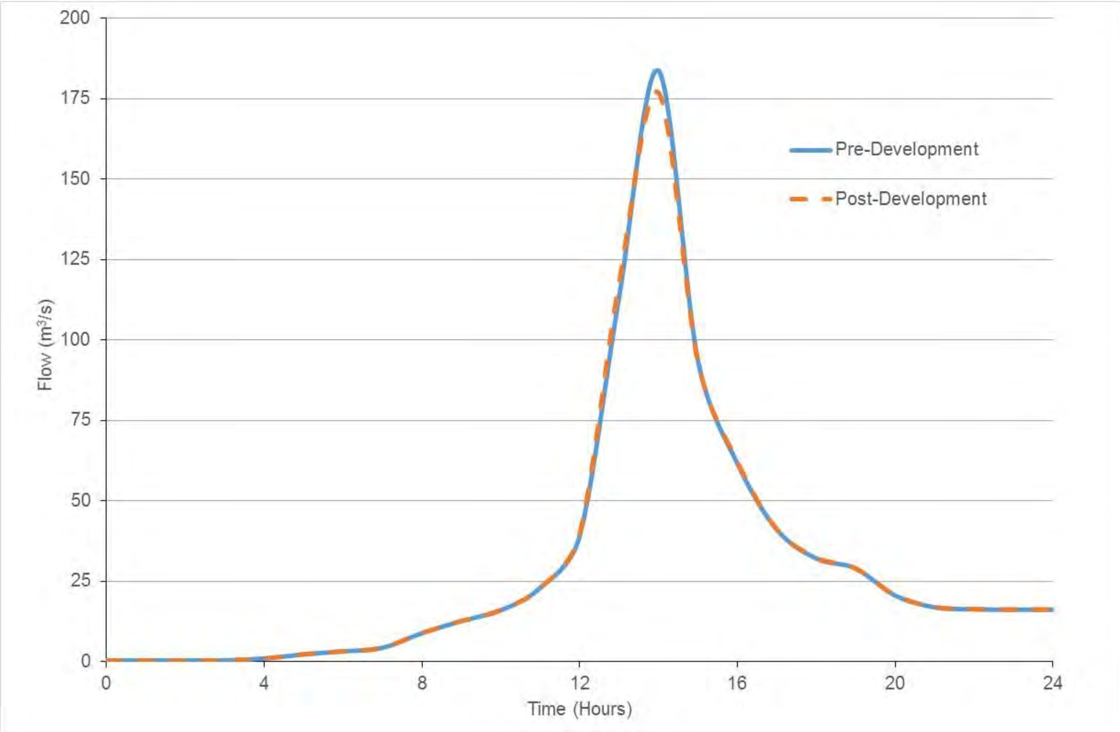

Figure 12 – Comparison of flow for 100 year ARI event at Bridge No. 5 Mahurangi left branch bridge for CN74

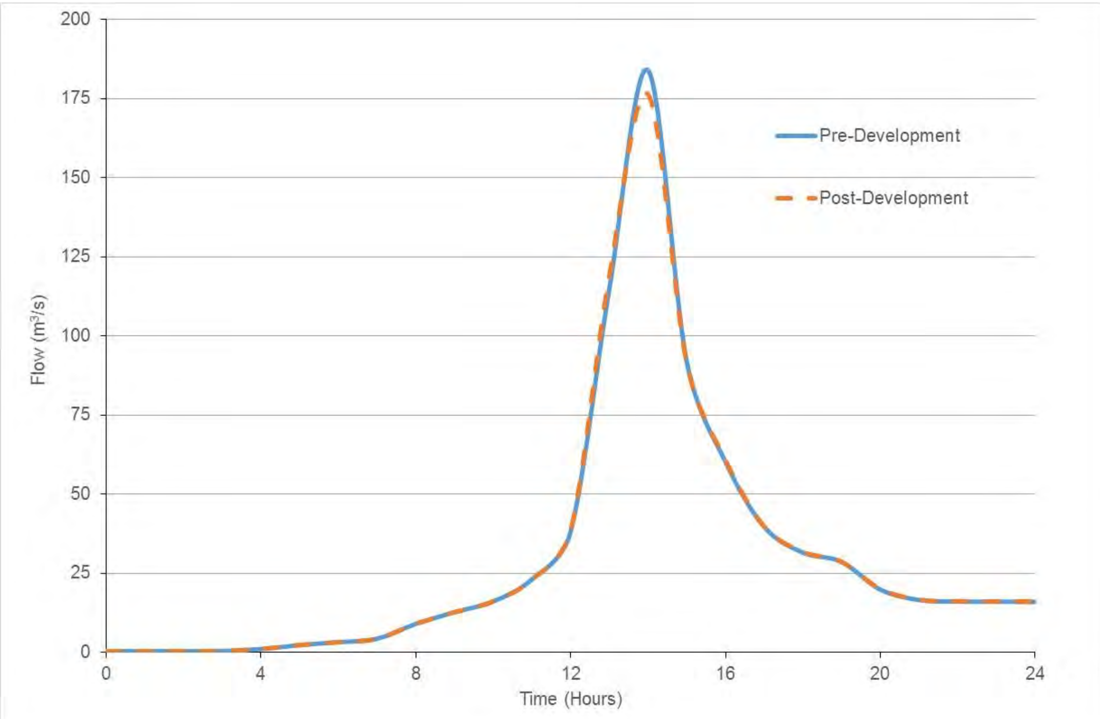

Figure 13 – Comparison of flow for 100 year ARI event at Bridge No. 6 Mahurangi left branch bridge for CN74

2.5.2 Floodplain extent changes

Figure 14 to Figure 21 show the flood extents obtained for CN66 and CN74 for 2, 10, 20 and 100 Year ARI events. The pre-development flood extent is plotted over the post-development flood extent, so the change in flood extent where it is larger for post-development can be seen. These figures show that the proposed State Highway structures including embankment, bridges and culverts, only have a small impact on the extent of flood inundation for the Mahurangi in this area. The change in flood extents are within the designation.

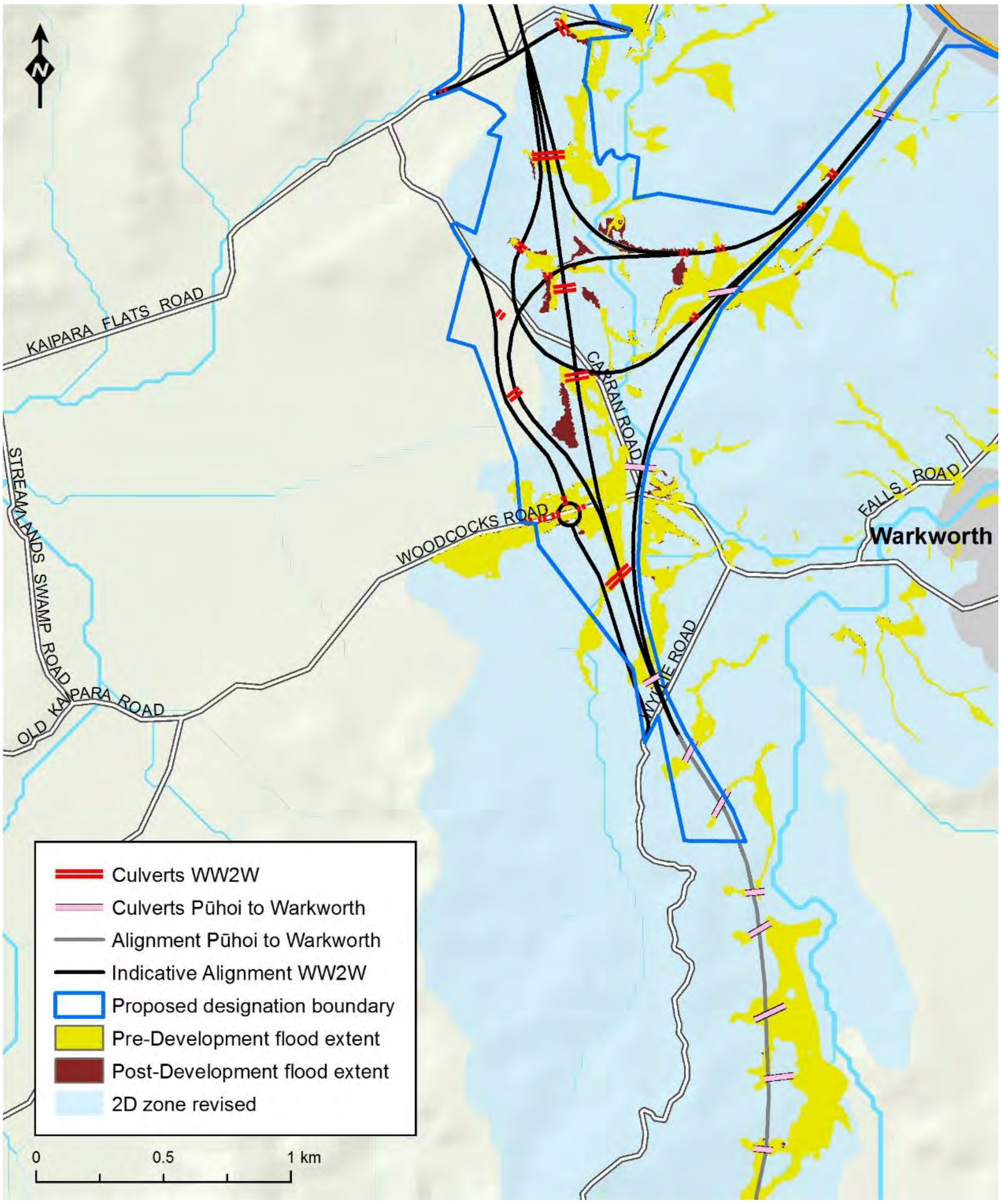

Figure 14 - Comparison of flood extents for pre and post-development scenarios for the 2 year ARI event obtained for CN66

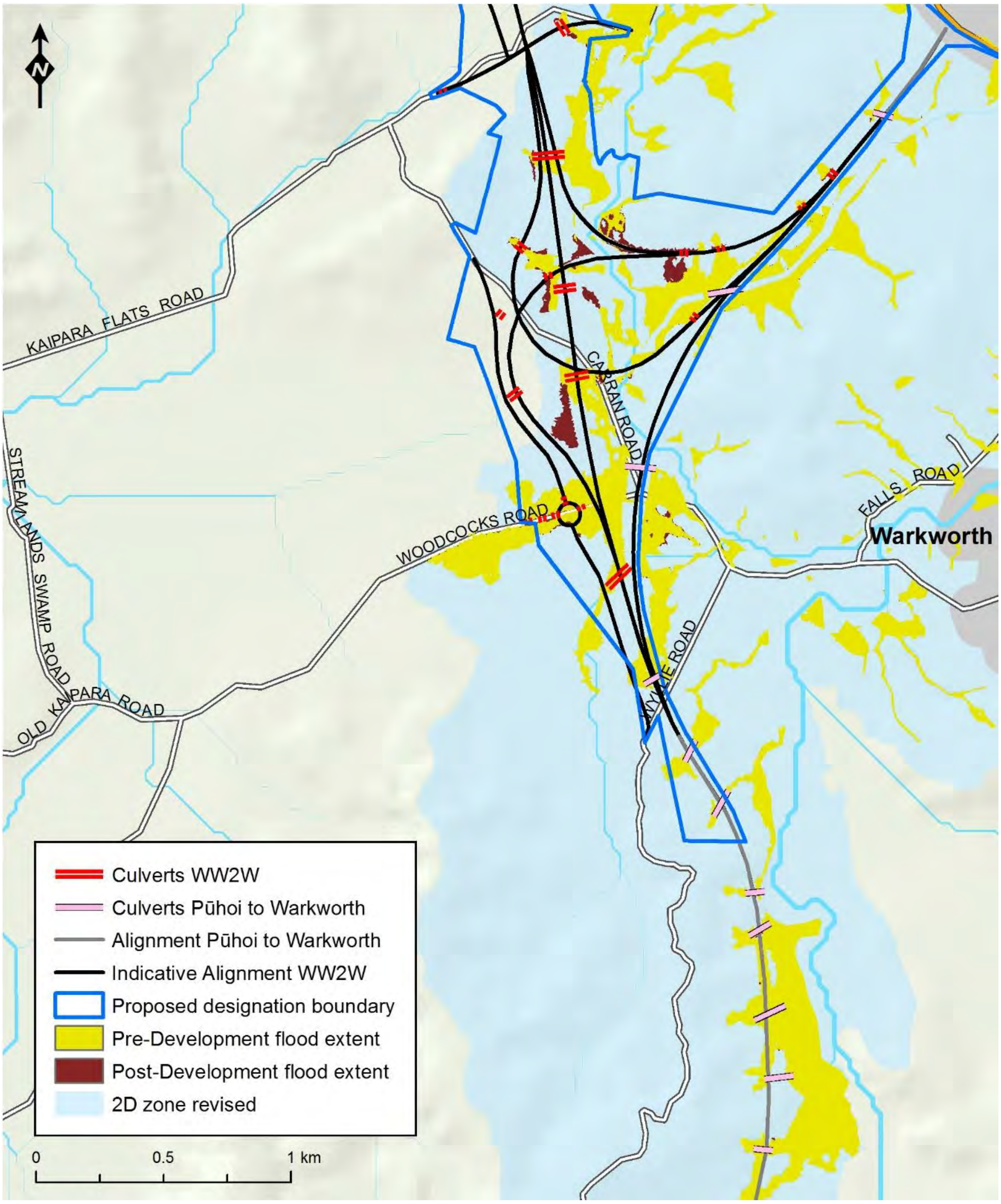

Figure 15 - Comparison of flood extents for pre and post-development scenarios for the 10 year ARI event obtained for CN66

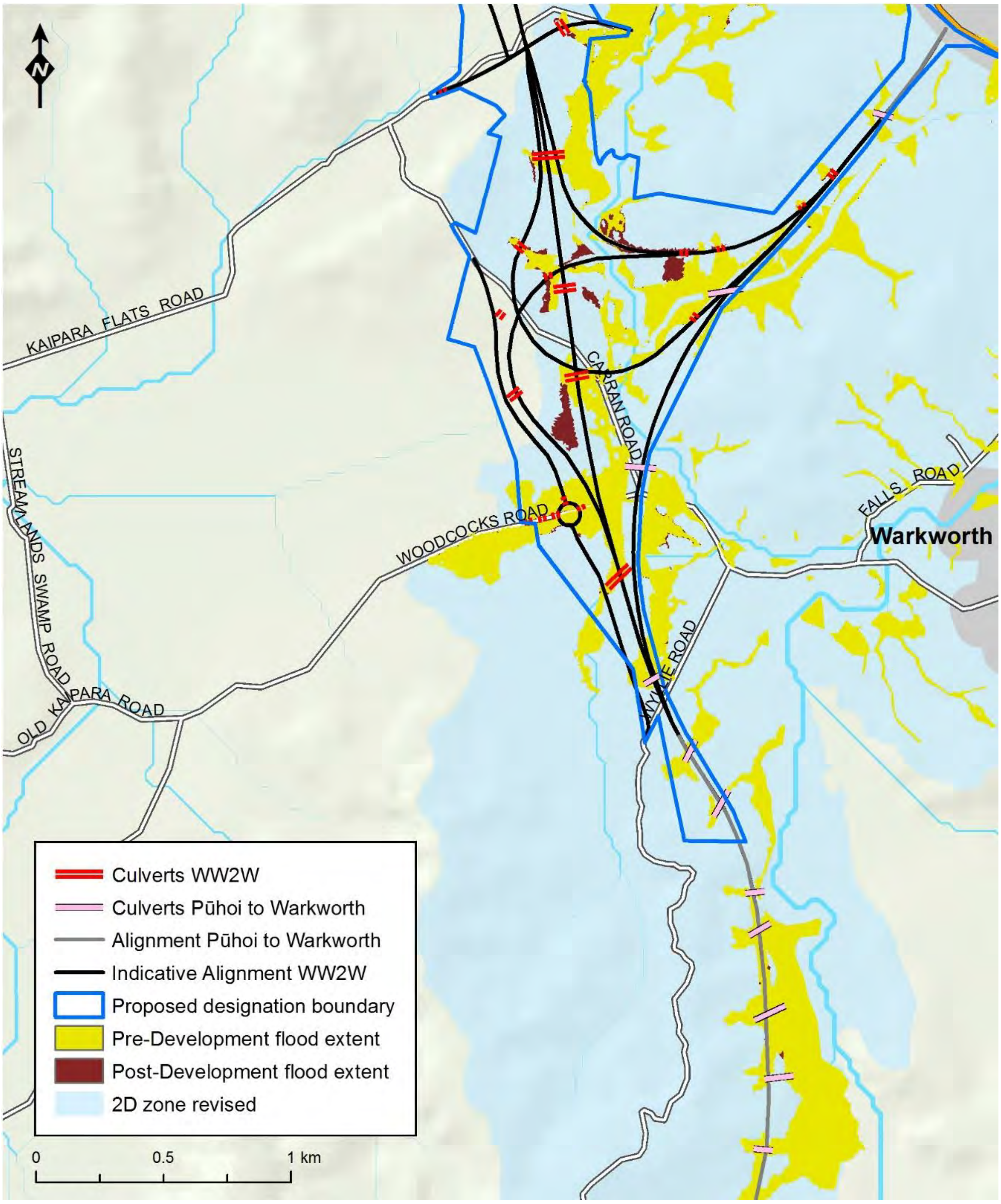

Figure 16 - Comparison of flood extents for pre and post-development scenarios for the 20 year ARI event obtained for CN66

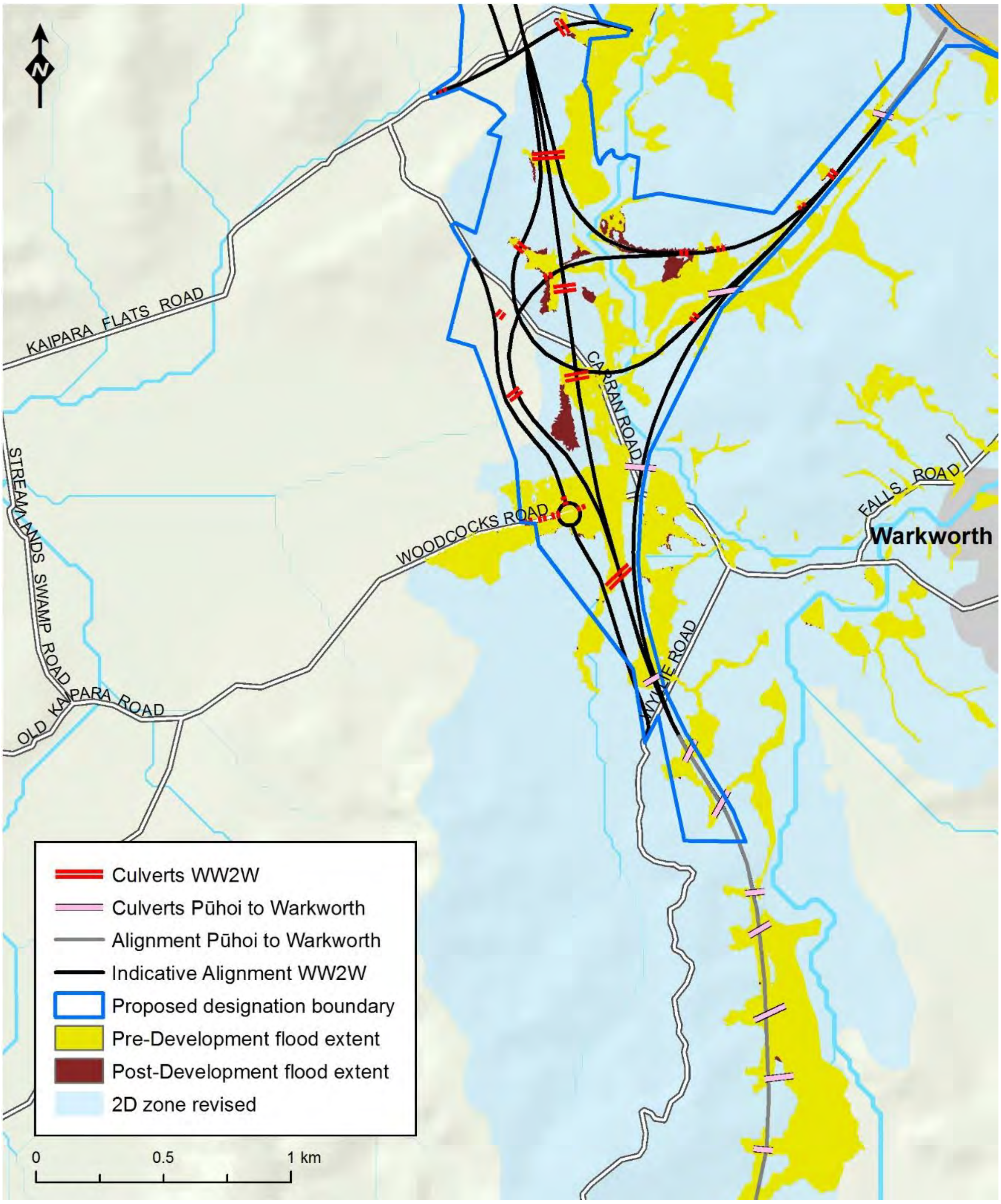

Figure 17 – Comparison of flood extents for pre and post-development scenarios for the 100 year ARI event obtained for CN66

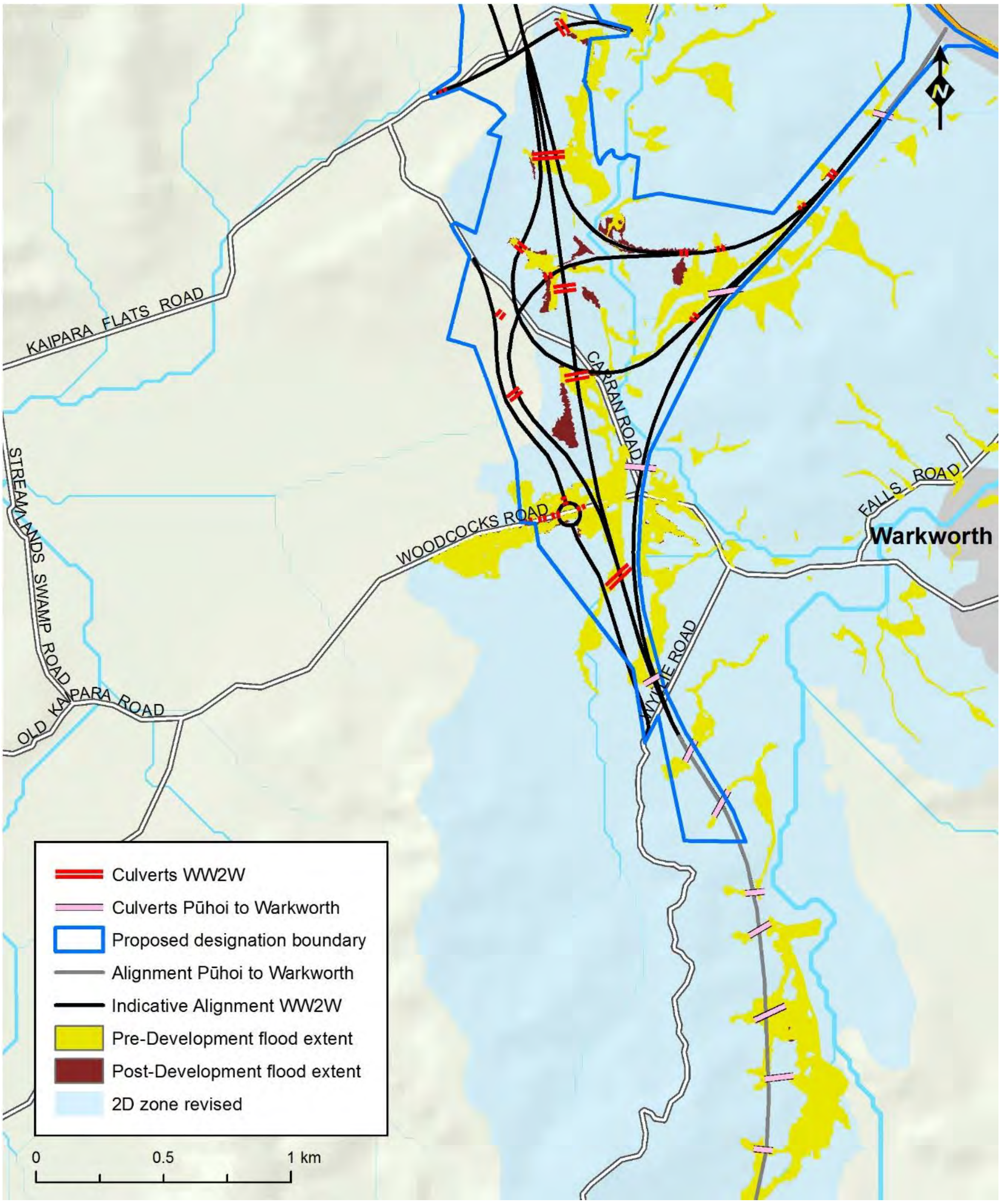

Figure 18 – Comparison of flood extents for pre and post-development scenarios for the 2 year ARI event obtained for CN74

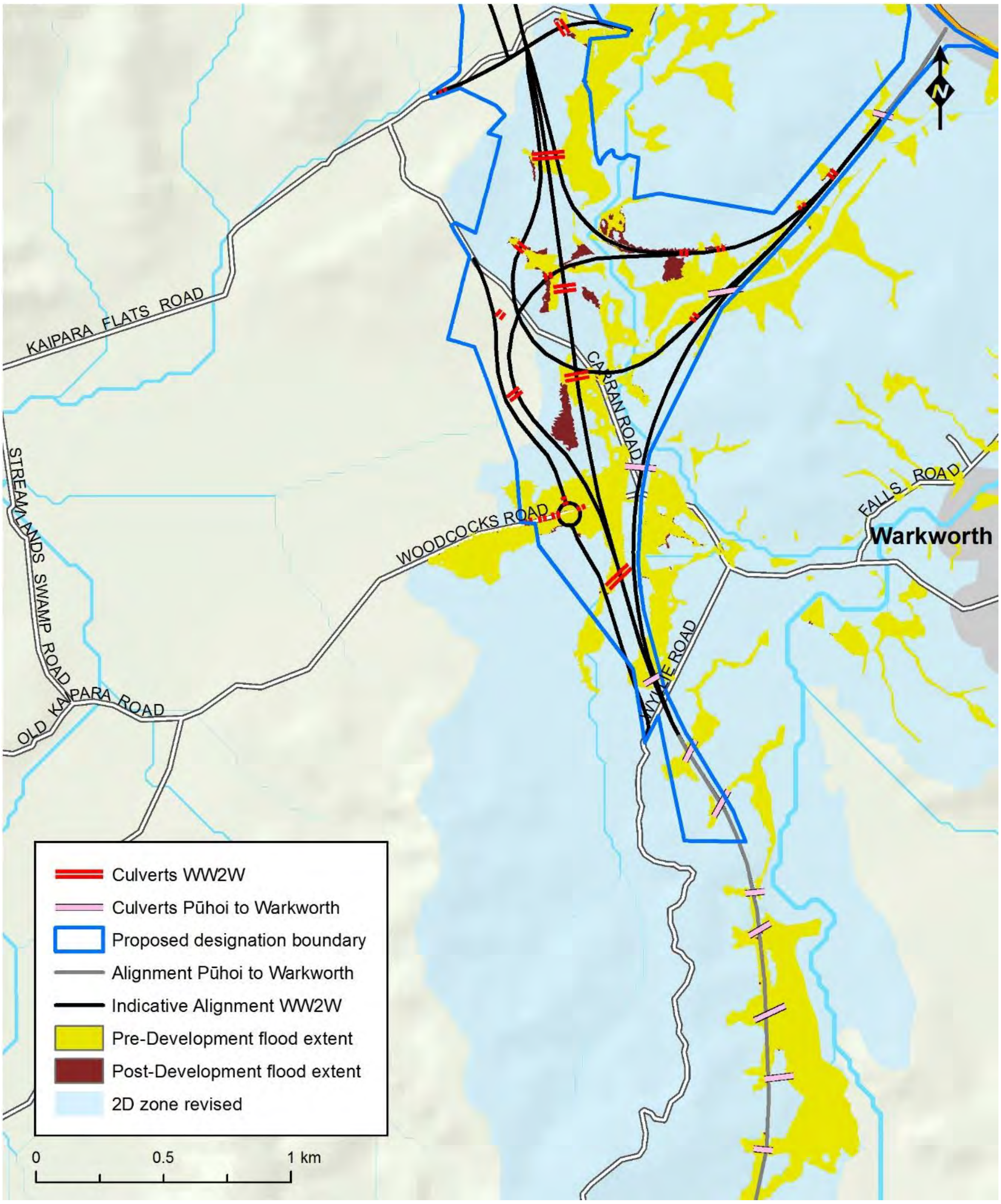

Figure 19 – Comparison of flood extents for pre and post-development scenarios for the 10 year ARI event obtained for CN74

GHD JACOBS

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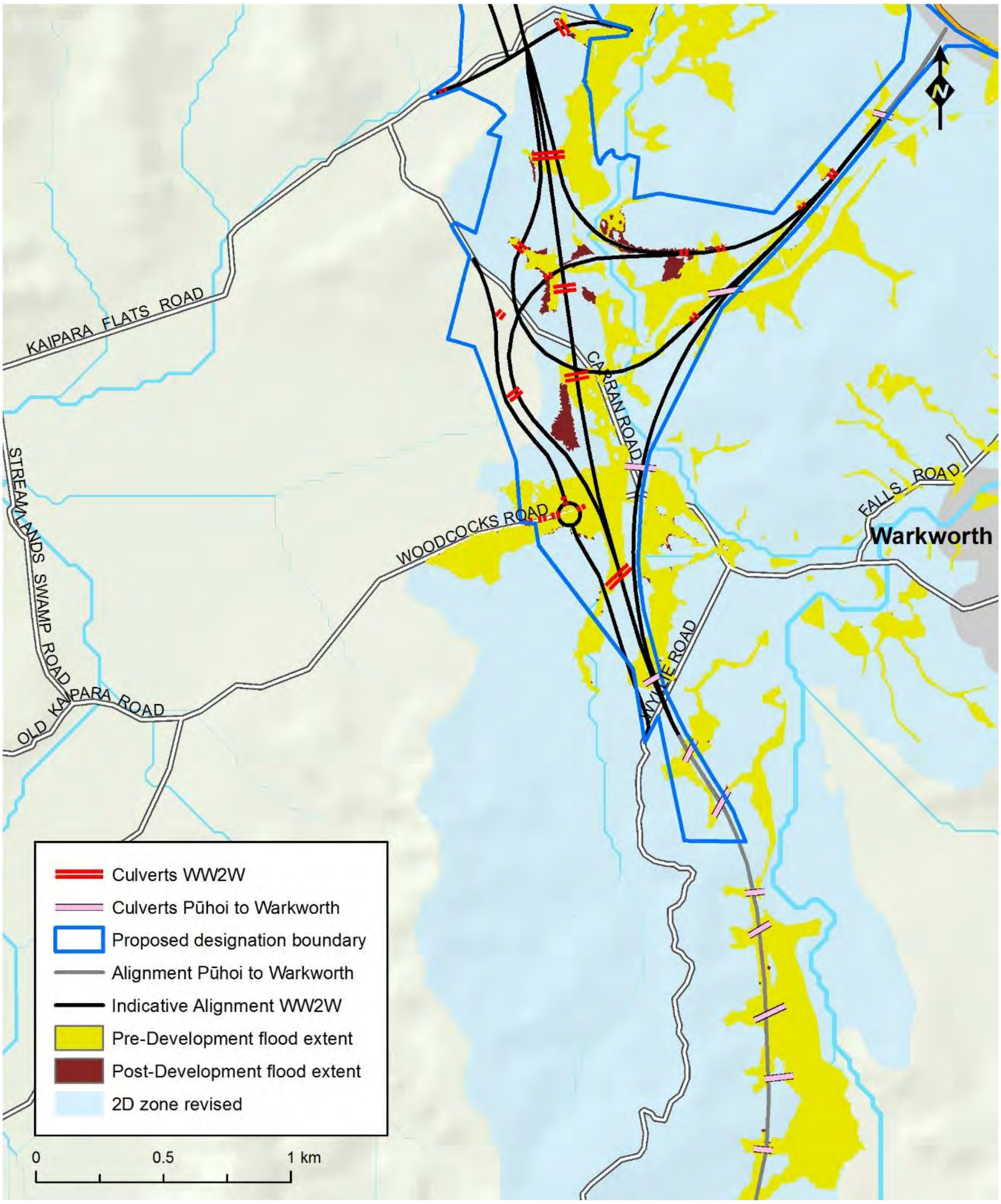

Figure 20 – Comparison of flood extents for pre and post-development scenarios for the 20 year ARI event obtained for CN74

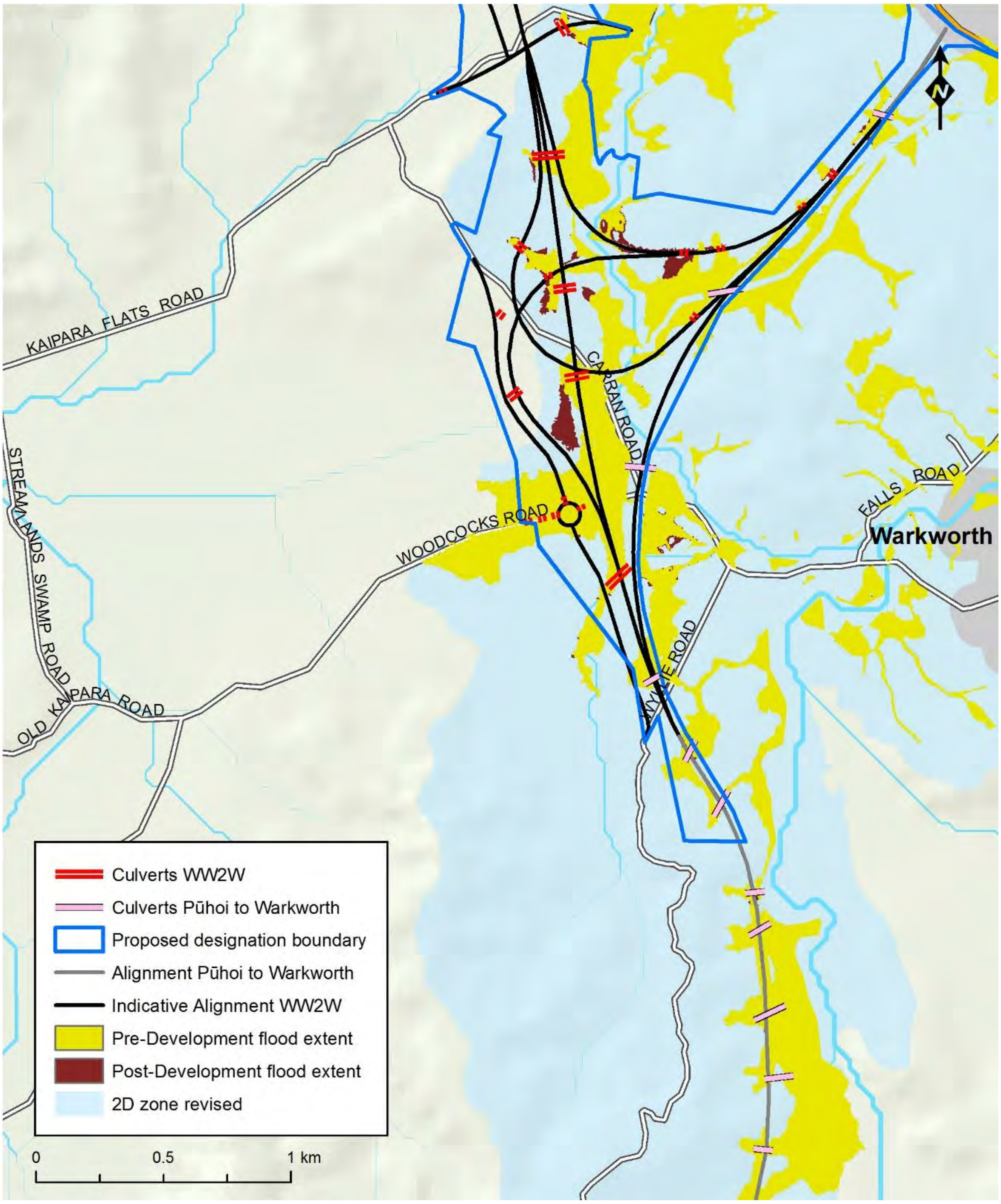

Figure 21 - Comparison of flood extents for pre and post-development scenarios for the 100 year ARI event obtained for CN74

2.5.3 Floodplain depth changes

Figure 22 to Figure 29 show the change in flood depth for the post development scenario compared to pre development for 2, 10, 20, and 100 Year ARI events for CN66 and CN74. These figures show that the proposed State Highway structures including embankment, bridges and culverts, only have a small impact on the flood depths of flood inundation for the Mahurangi in this area. The change in flood extents are within the designation.

Since the results obtained for both CN66 and CN74 are comparable (Figure 22 to Figure 29) and the peak discharge at the Mahurangi College gauge is a better match at CN66, the results of CN66 are therefore adopted for this flood assessment.

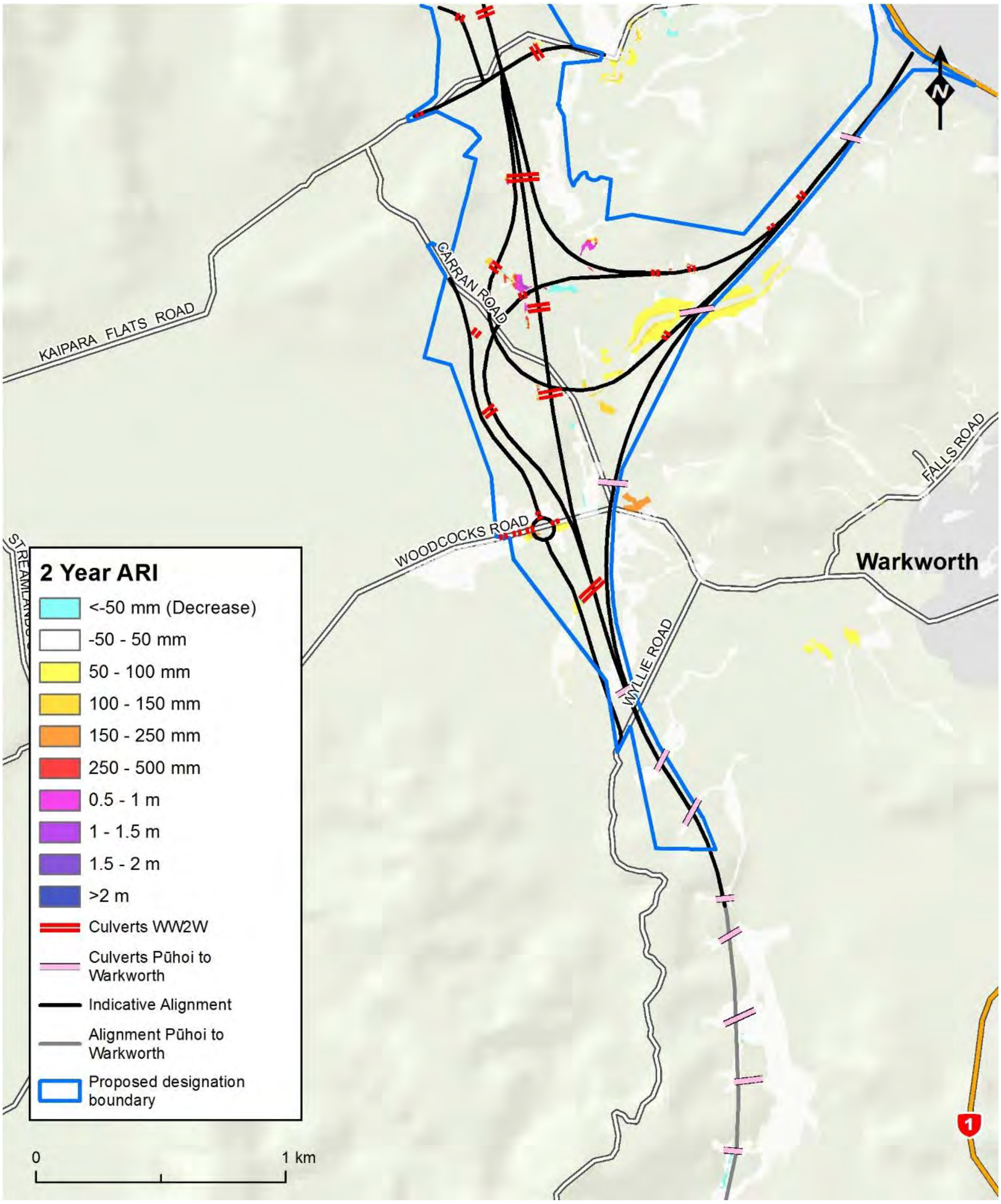

Figure 22 - Change in flood depths due to the Project for the 2 year ARI event obtained for CN66

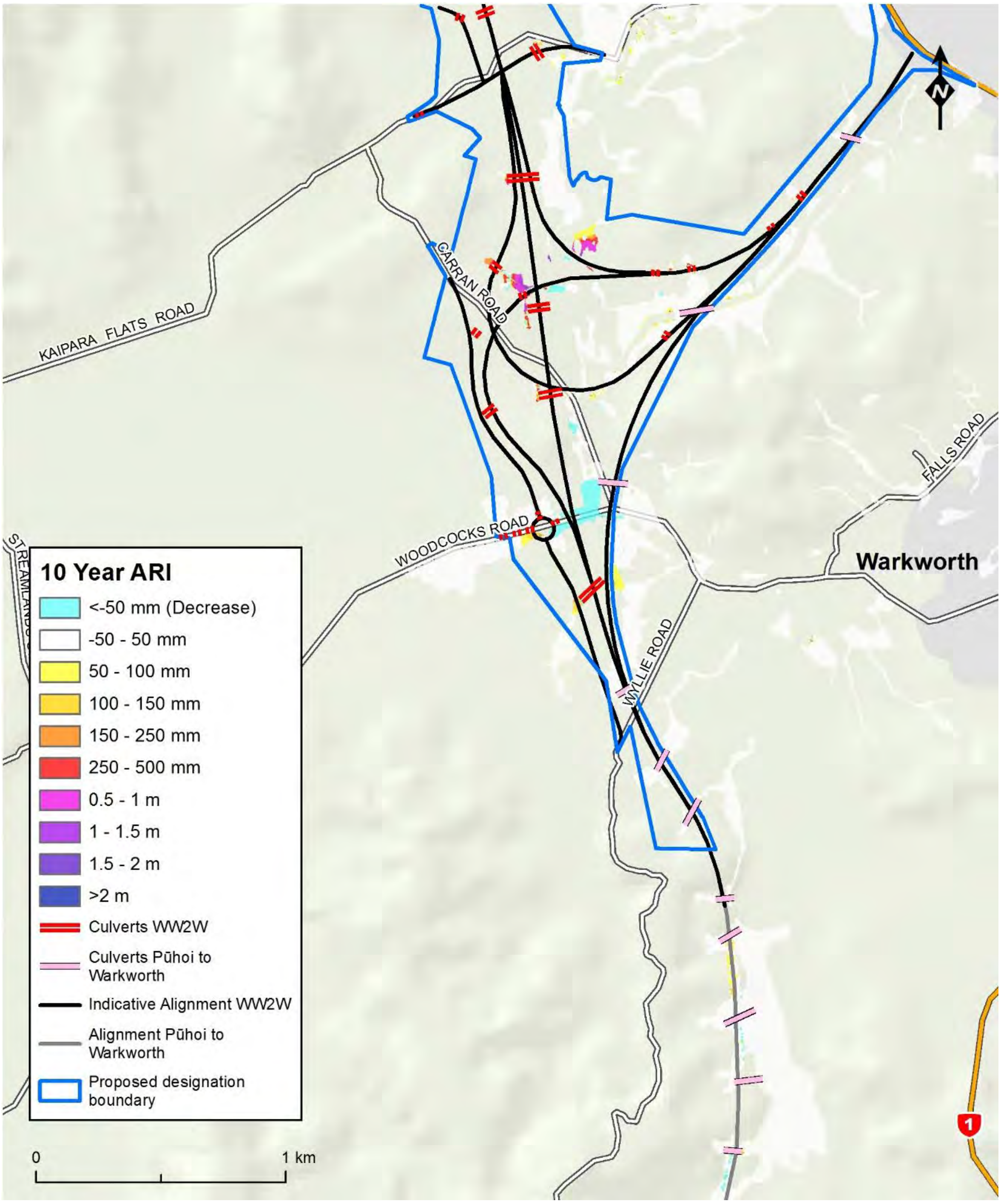

Figure 23 – Change in flood depths due to the Project for the 10 year ARI event obtained for CN66

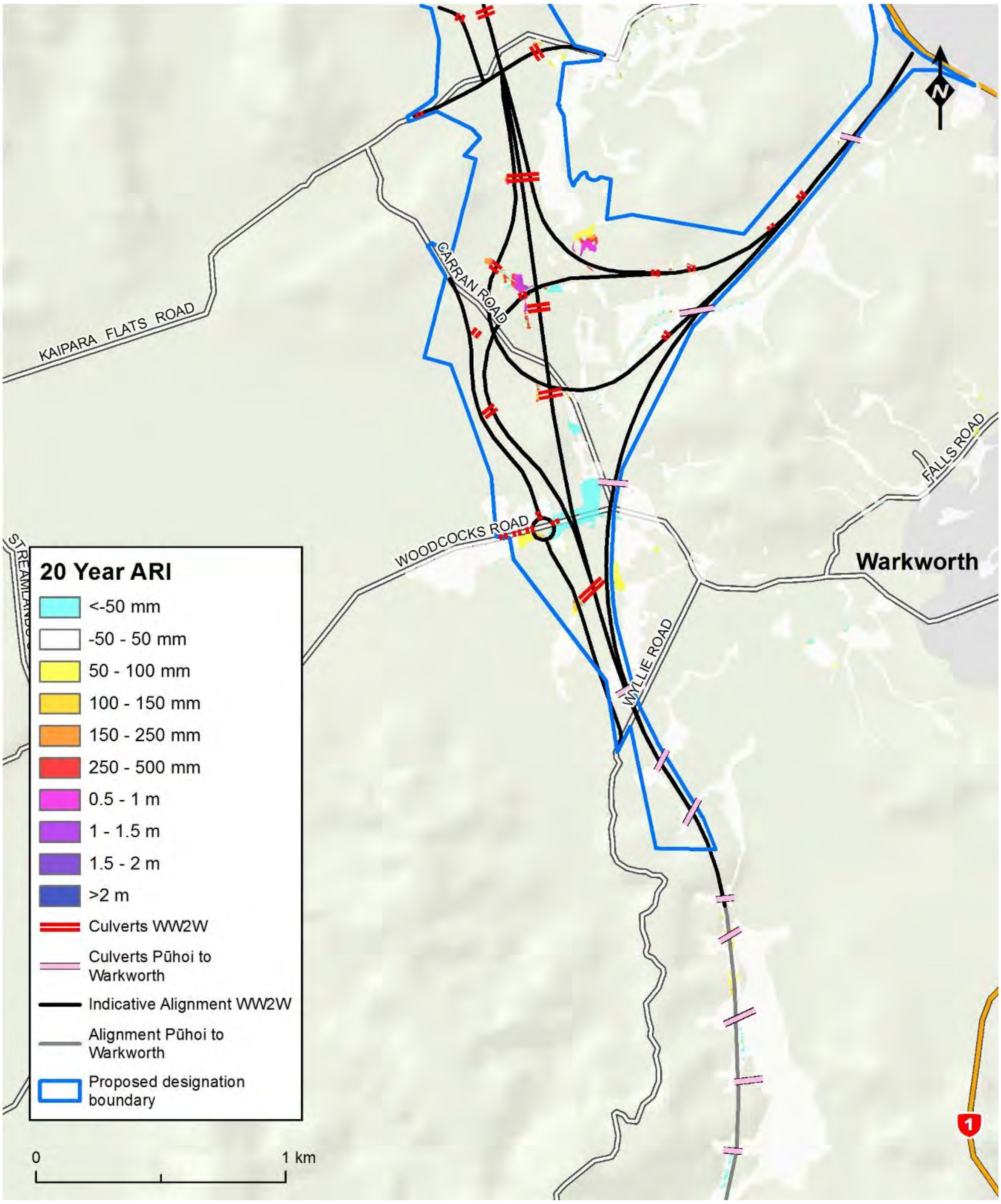

Figure 24 - Change in flood depths due to the Project for the 20 year ARI event obtained for CN66

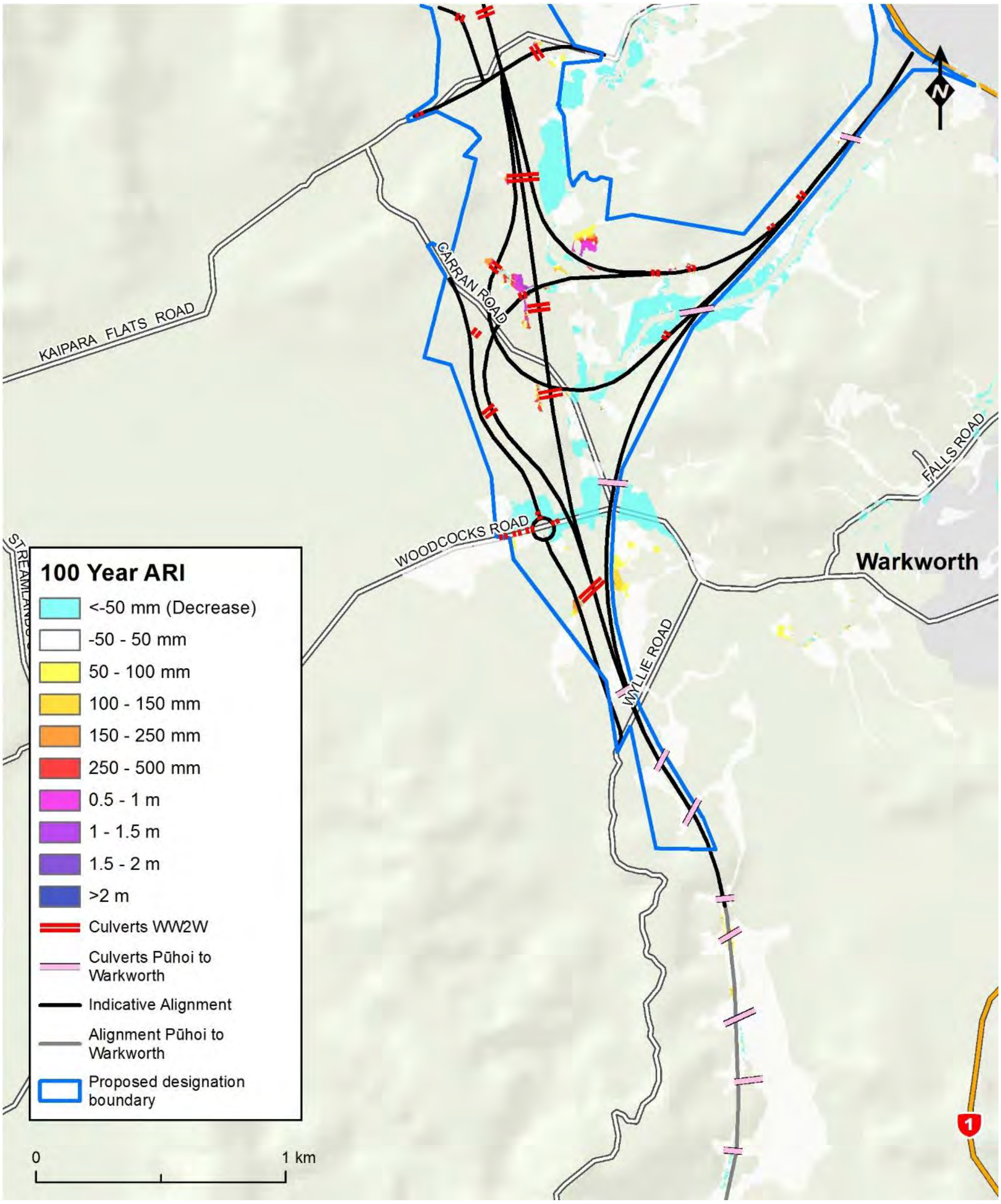

Figure 25 - Change in flood depths due to the Project for the 100 year ARI event obtained for CN66

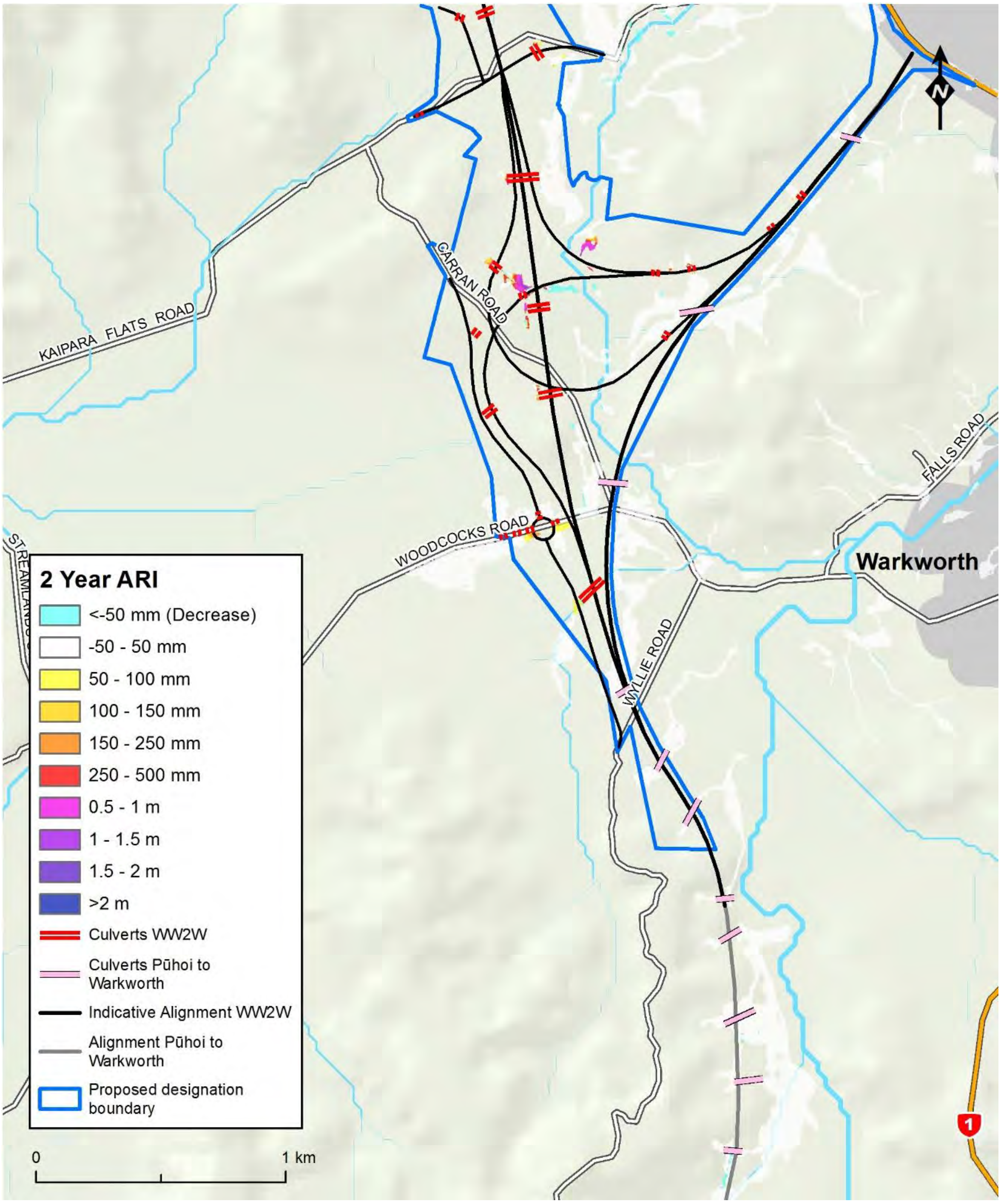

Figure 26 – Change in flood depths due to the Project for the 2 year ARI event obtained for CN74

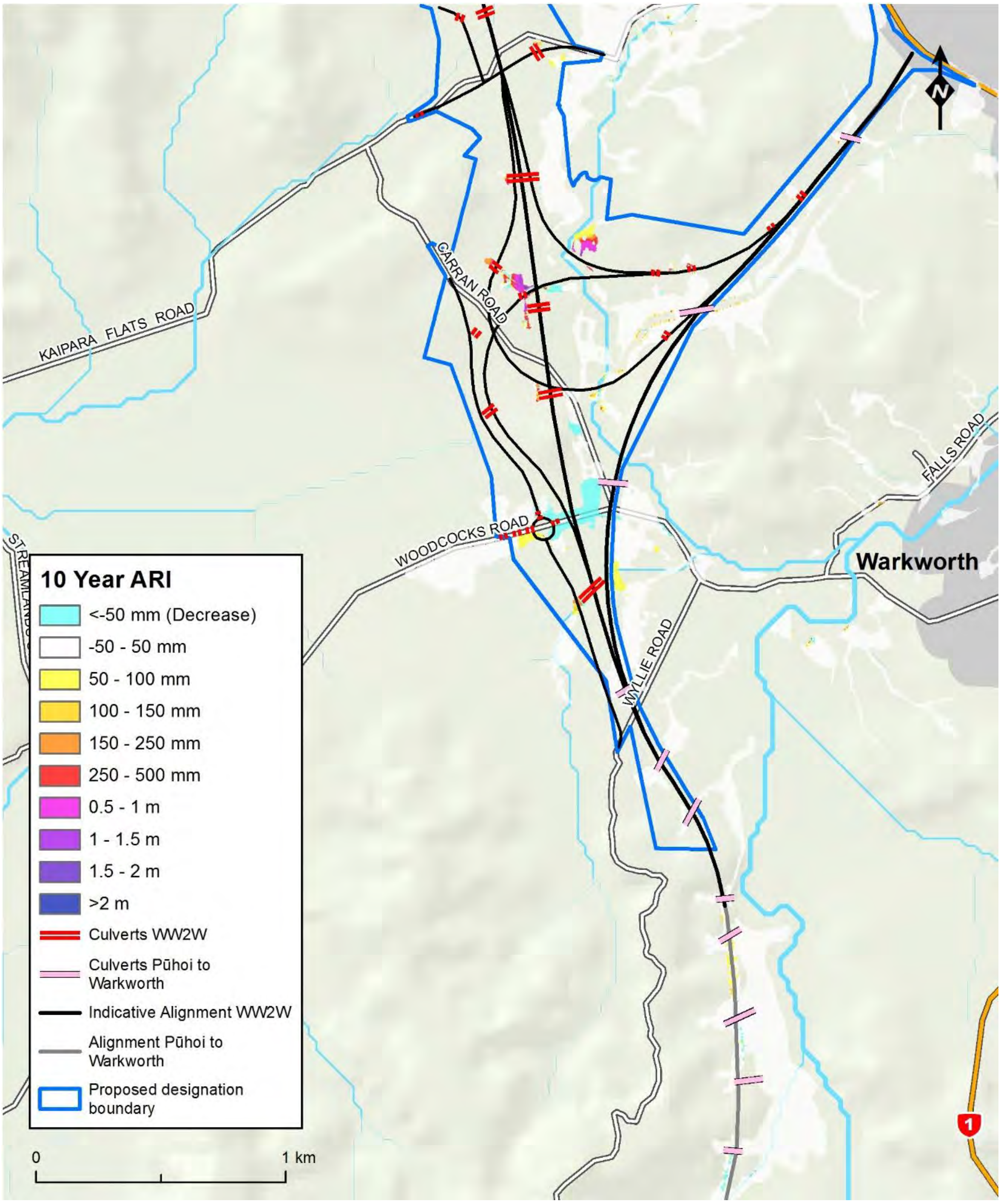

Figure 27 – Change in flood depths due to the Project for the 10 year ARI event obtained for CN74

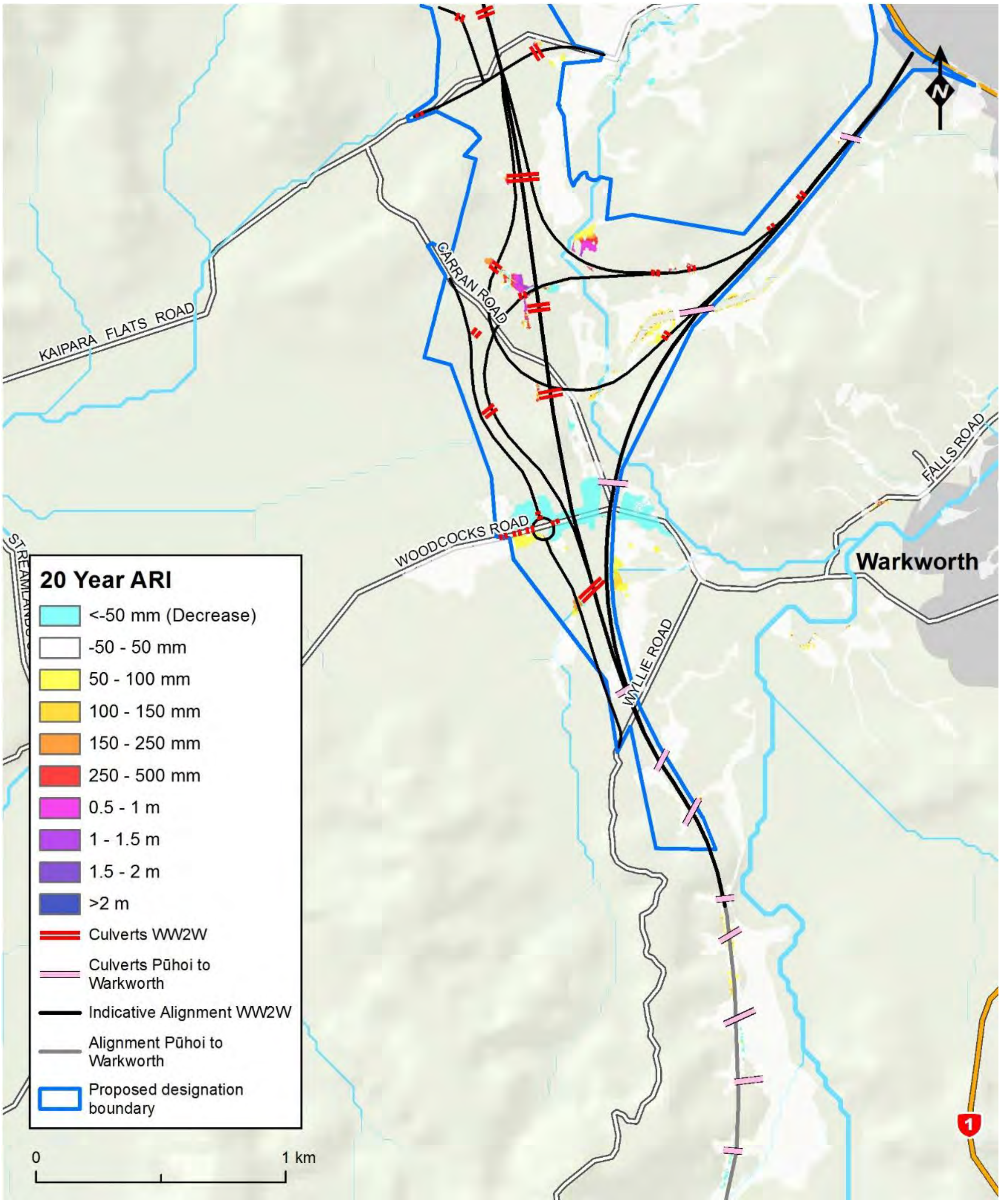

Figure 28 – Change in flood depths due to the Project for the 20 year ARI event obtained for CN74

GHD JACOBS

Tonkin+Taylor

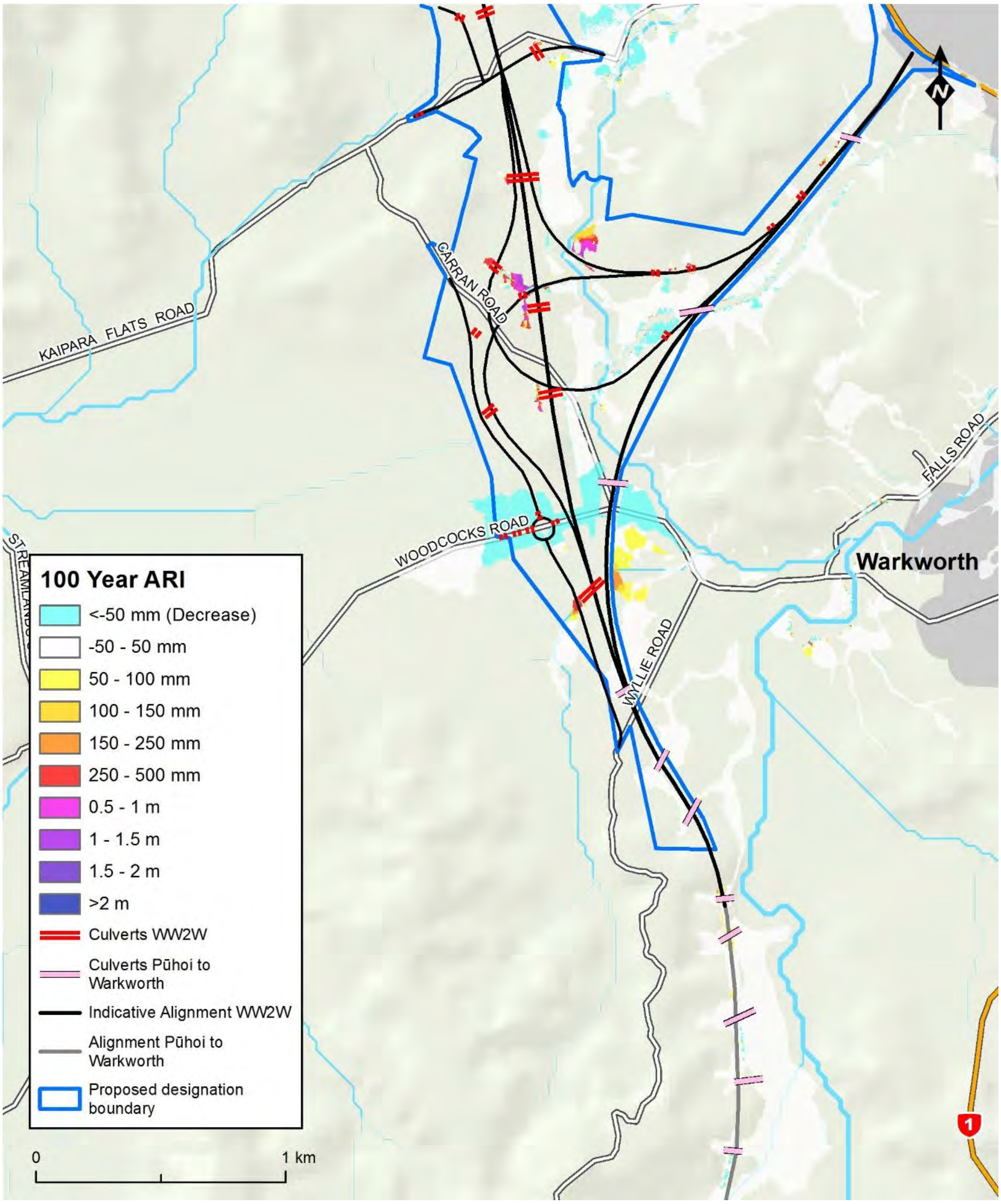

Figure 29 – Change in flood depths due to the Project for the 100 year ARI event obtained for CN74

2.5.4 Floodplain depth changes in specific locations

Figure 30 shows the change in flood depth for the post development scenario compared to pre development for the 100 year ARI event at the Indicative Warkworth Interchange. The areas, where the flood depth increases, are fully contained within the proposed designation boundary and no dwellings outside the designation are affected by the increased flood depth.

Upstream of CLVT_48700, the proposed increase of flood depth ranges from 50 to 250 mm within the proposed designation boundary over the grassland. In addition to the CLVT_48700, there is an increase of flood depth obtained upstream and downstream of CLVT_48400 within the proposed designation boundary. This can be mitigated by including diversion channels at the detailed design stage.

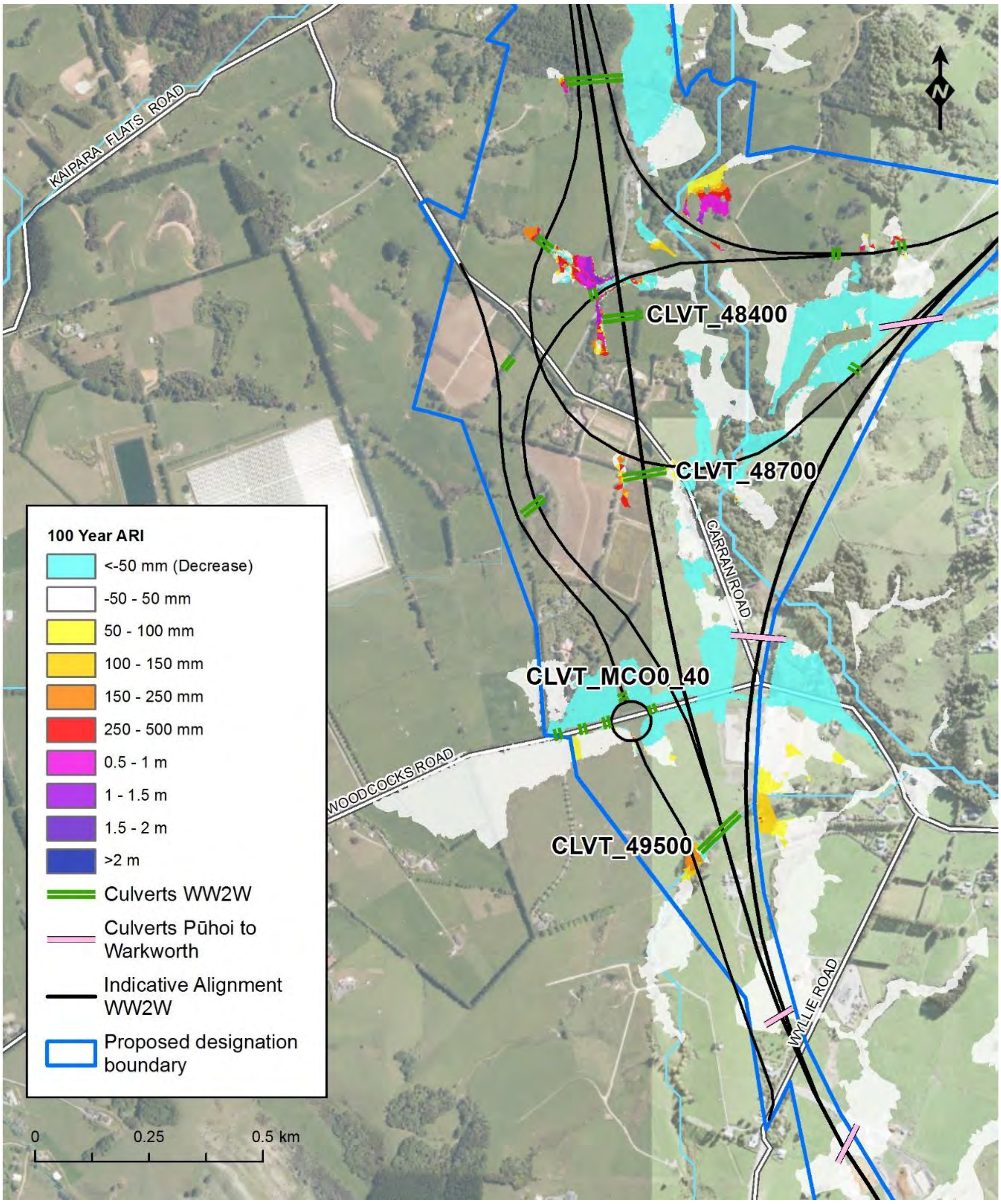

Figure 30 – Change in flood depths due to the Project for 100 year ARI event obtained for CN66 – Warkworth Interchange

The increase of flood depth upstream and downstream of culvert CLVT_49500 ranges from 50 to 250 mm (Figure 31) within the proposed designation boundary for the 100 Year ARI event. Upstream of culvert CLVT_49500, the increase of flood depth remained within the riparian margins and over the forest land use, and within the designation. Figure 31 shows that the extents of the increase of flow depth downstream of culvert CLVT_49500 are relatively wider, impacting the riparian margins and over grassland within the designation. However, there is no increase of flood depth at the location of dwellings outside the designation.

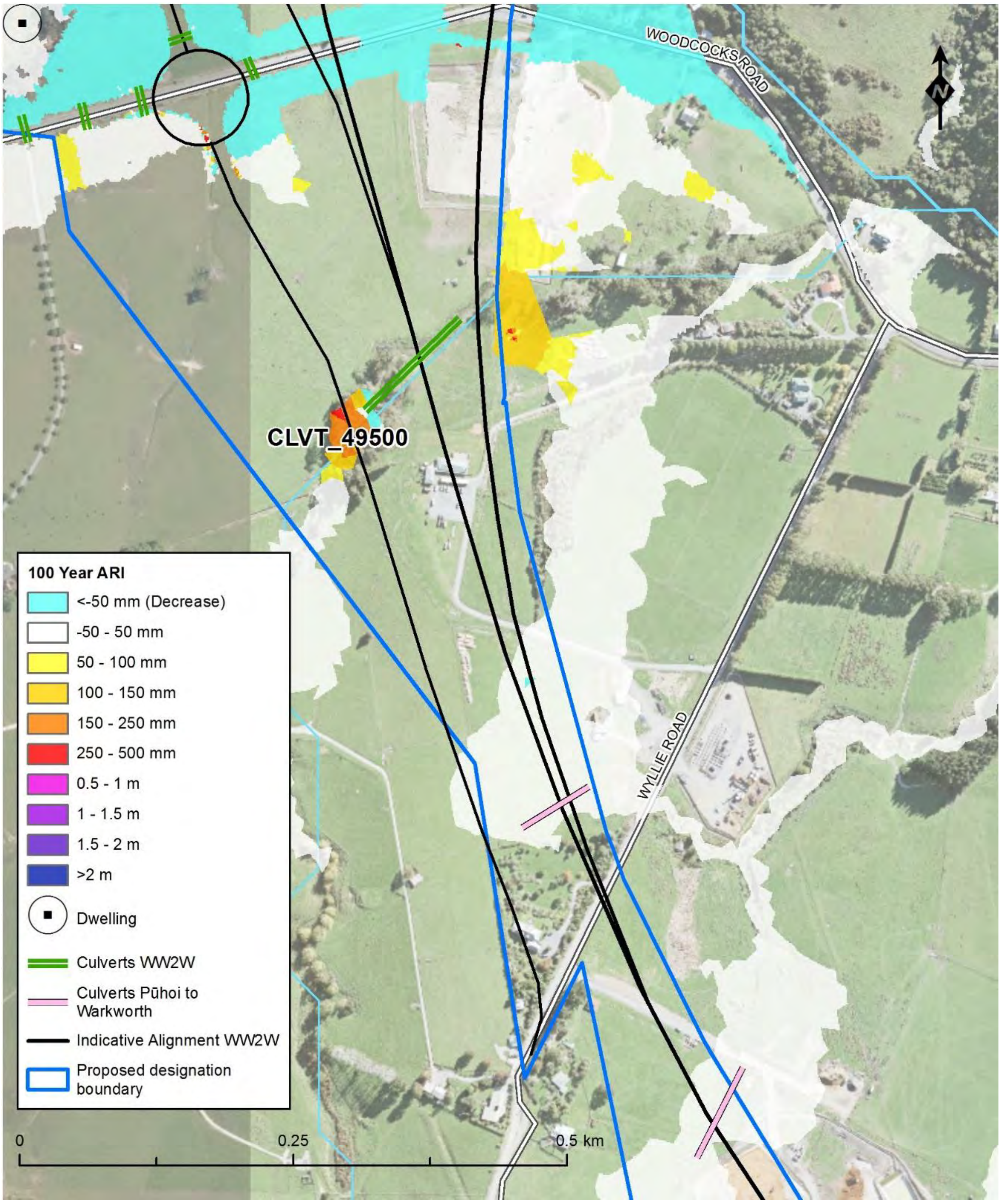

Figure 31 – Change in flood depths due to the Project for the 100 year ARI event obtained for CN66 – Woodcocks Road

As per our flood extent map of the 100 Year ARI event (Figure 17), a section of Carran Road remained underwater for both pre and post development scenarios, where the increase of flow depth ranges from 35 to 75 mm (Figure 32). No dwellings are affected by the increased flood depth in this area. Over Carran Road, the flood depths obtained for pre-development scenario ranges from 2 mm to 9 mm, while flood depths obtained for post development scenario ranges from 40 mm to 75 mm.

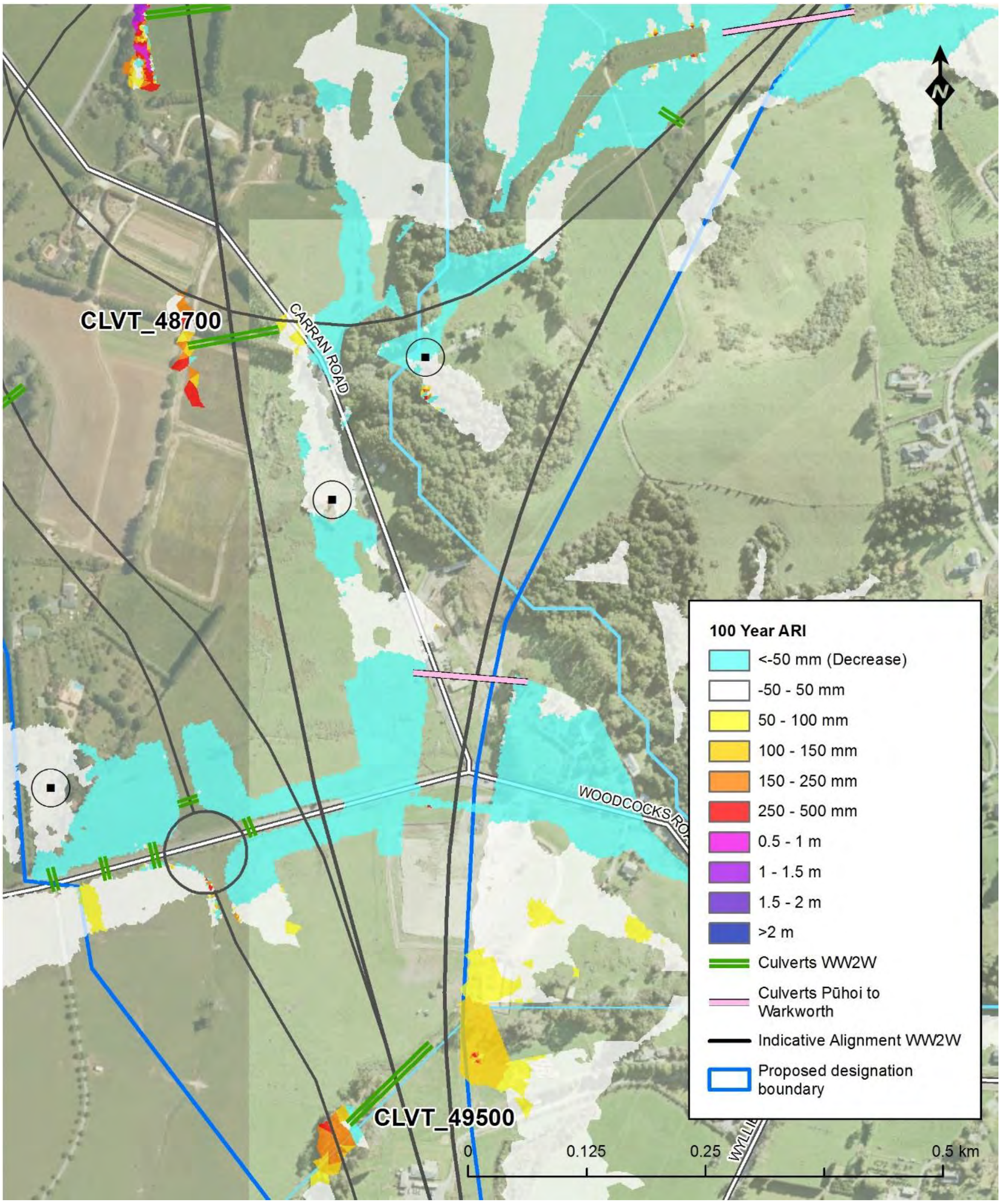

Figure 32 – Change in flood depths due to the Project for the 100 year ARI event obtained for CN66 – Carran Road

Figure 33 shows that the Indicative Alignment increases the flood depth over a small area upstream of Bridge 5 and Bridge 6 along the left branch of the Mahurangi River ranging from 50 mm to 1 m for the 100 Year ARI event within the proposed designation, which is over grassland.

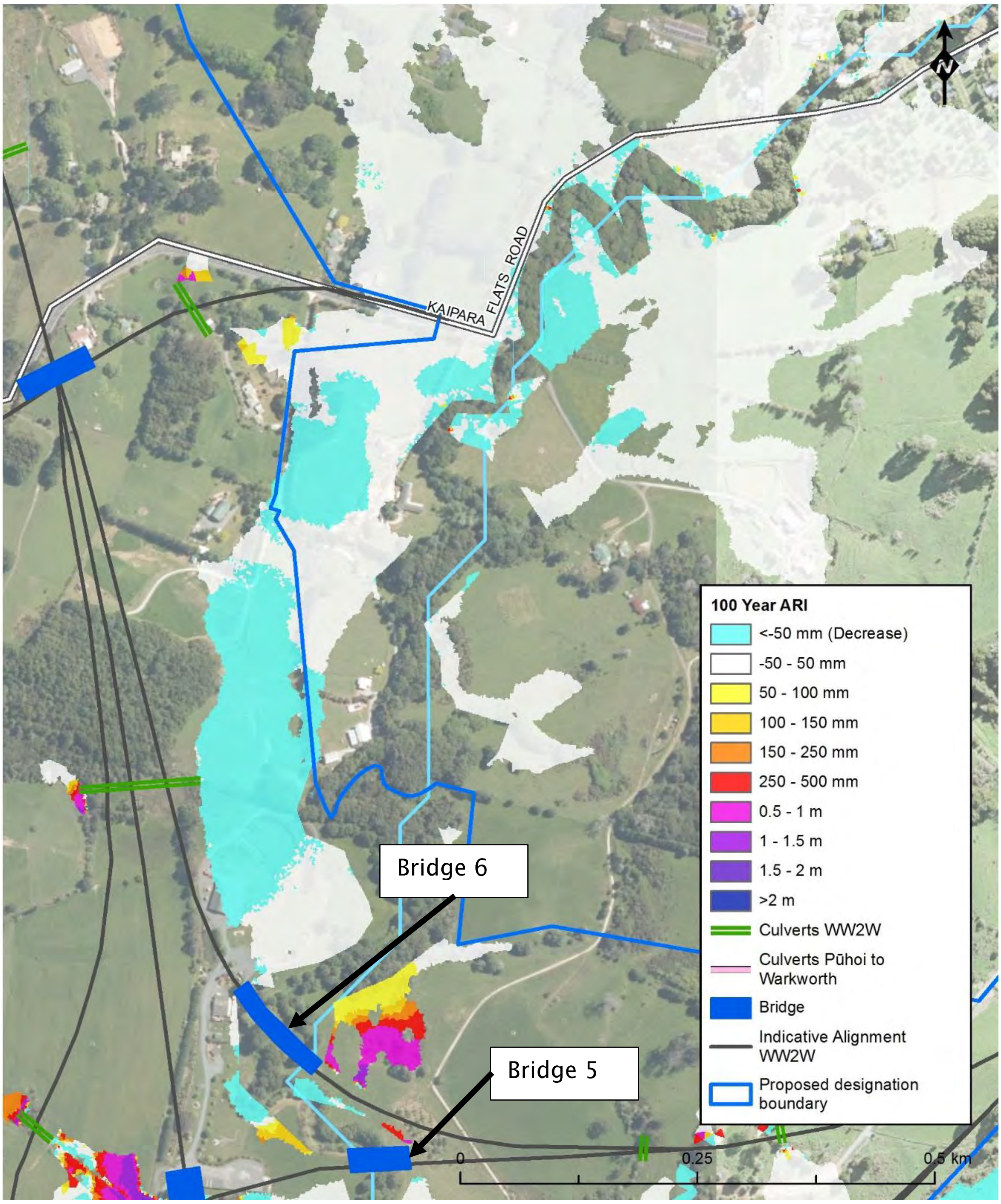

Figure 33 – Change in flood depths due to the Project for the 100 year ARI event obtained for CN66 – Kaipara Flats Road

2.5.5 Culverts

As described earlier, the peak discharge at the Mahurangi College gauge is a better match at CN66 while the flows estimated for CN74 are relatively conservative. Therefore, the results of CN66 are adopted for flood assessment of culverts.

Flood water remains well below the proposed road level at all locations along the Indicative Alignment for CN66 and meets the design criteria of having a freeboard of equal or greater than 0.5 m (Table 9).

Table 9 – Predicted peak flood levels at proposed culverts for CN66

Culvert	Diameter/ height x No. of barrels (m)	Length (m)	Predicted flood levels after completion of Warkworth to Wellsford Project (m)		Road level (m)	Freeboard (m)
			Upstream	Downstream		
CLVT_MCG0_280	1.50 x 1	64.9	46.94	44.57	55.0	> 1 m
CLVT_47850	2.10 x 1	128.7	42.75	38.42	48.7	> 1 m
CLVT_MC30_400	1.95 x 1	45.3	43.28	40.24	45.8	> 1 m
CLVT_MC10_1100	1.0 x 2	27.5	38.10	38.00	38.6	= 0.5 m
CLVT_MC10_1660	0.5 x 2	26.5	42.30	39.15	43.3	= 1.0 m
CLVT_MC10_1800	1.0 x 2	25.9	43.18	40.61	43.8	> 0.5 m
CLVT_MC10_2180	1.0 x 3	17.7	38.61	36.56	40.0	> 1 m
CLVT_MC10_2350	1.0 x 2	31.6	38.60	36.12	39.6	= 1 m
CLVT_48400	2.3 x 1	89.8	37.44	37.22	46.1	> 1 m
CLVT_48700	1.65 x 1	96.8	36.91	35.37	44.3	> 1 m
CLVT_MCO0_40	1.5 x 2	22.4	32.69	32.69	45.4	> 1 m
CLVT_49500	3.5 x 3	120.6	34.12	33.87	35.1	> 0.5 m

3 KOURAWHERO STREAM

3.1 Extent and boundaries

Immediately north of Kaipara Flats Road, the Indicative Alignment is in the same valley as the Kourawhero Stream and has a number of crossings (Figure 34). A hydraulic model was built to identify the effects on flooding and assess methods for mitigating these effects.

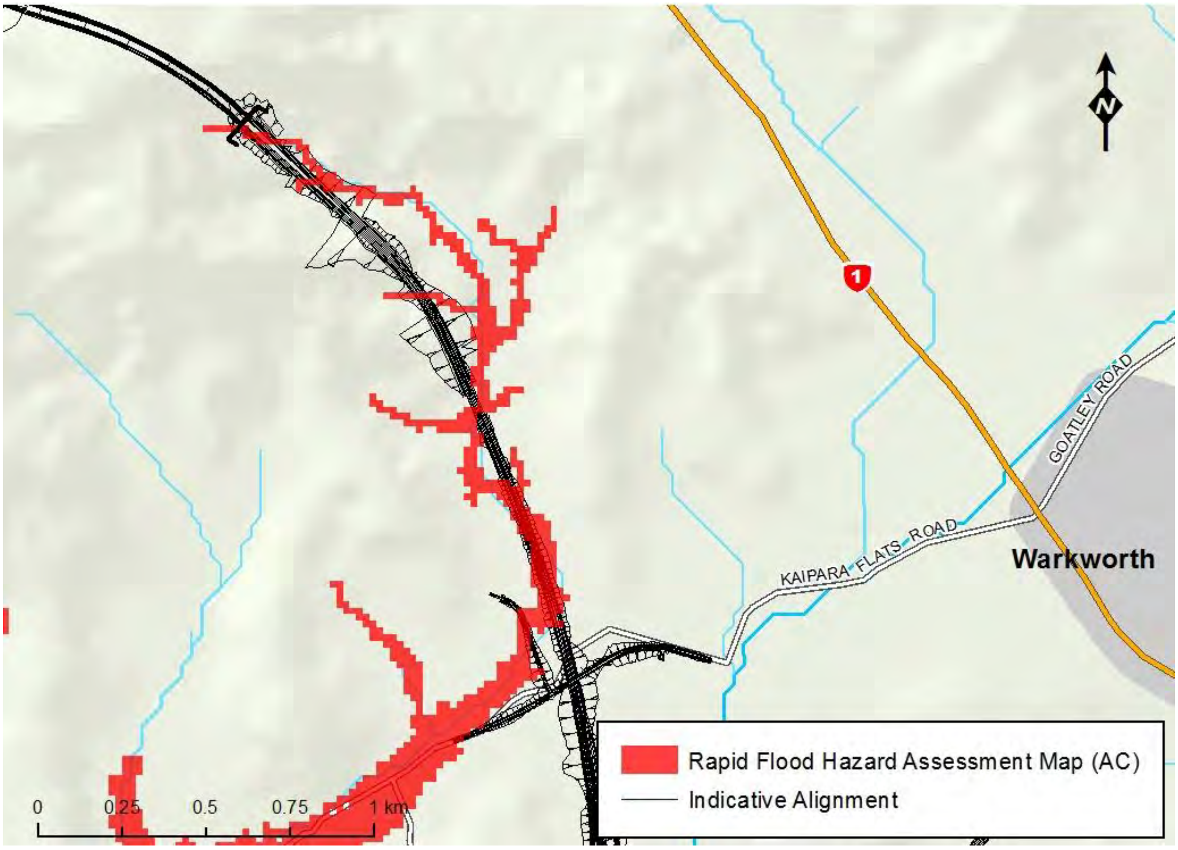

Figure 34 – Indicative Alignment over the natural flow path of the Kourawhero Stream

3.2 Hydrology

3.2.1 Method

To derive peak flows of 2, 10, 20 and 100 Year ARI events for the Kourawhero catchment we used the TP108 Graphical Method. This method is endorsed by Auckland Council. TP108 method was parameterised as follows:

- Rainfall depths: derived from TP108 isohyet maps and increased for climate change by multiplying rainfall depths with factors as given below in Table 10.
- Time of concentration: calculated using the TP108 equation (Equation 4.3 on page 12), using a channelization factor of 0.9 and catchment length and slope derived using a 1 m resolution raster provided by Auckland Council. A minimum time of concentration of 10 minutes was adopted, as per TP108.

- Initial abstraction: adopted 0 mm for urban areas and 5 mm for pervious areas, as per TP108.
- SCS soil group: assigned following an analysis of soil types and considering Auckland Council guidance in TR 2009/0072. The soil in the Project area was defined using the GIS-based New Zealand Land Resource Inventory (NZLRI) soil maps of Landcare Research. The soil type within the catchment boundary include clay and clay loam.
- Curve number: assigned using tables supplied in TP108 (Appendix B) and related to the land use categories from the New Zealand Land Cover Database version 4 (LCDBv4). As per this database, the average calculated value of curve number for the Kourawhero catchment was 75. A curve number of 75 is likely to be conservative from comparison with the Mahurangi Model and should be considered in more detail for the detailed design of the Project.

3.2.2 Incorporating the impacts of climate change on rainfall depths

The effects of climate change on rainfall depths as at 2130 are incorporated into the design hydrology of the Kourawhero catchment. The method used for incorporating the effects of climate change is to increase the rainfall depths of different return period by the following factors, Table 10.

Table 10 - Climate change adjustment factors for different return periods

ARI (Year)	2	10	20	100
Adjustment factor for the Project	1.086	1.126	1.144	1.160

The above climate change adjustment factors were derived using the information provided in MfE (2016), based on a mid-range climate change temperature increase scenario to 2090, linearly extrapolated to 2130, and assuming an 8% increase in rainfall intensity per 1°C increase in temperature (MfE, 2010).

3.2.3 Estimated peak flows

The catchment of the Kourawhero Stream has been divided into five sub-catchments, which are shown in Figure 35. For these sub-catchments, the flows of 2, 10, 20 and 100 Year ARI events have been computed by following the TP108 methodology. The graphical method of TP108 predicts flood peaks only. The computed peaks are given below in Table 11.

Table 11 - Estimated peak flow of sub-catchments with allowance of climate change for 2, 10, 20 and 100 year ARI events

Culvert name	Catchment area (km^2)	Peak flow (m^3/s)			
		2 Year	10 Year	20 Year	100 Year
CLVT_45650	0.23	3.79	6.35	8.17	10.70
CLVT_46150	0.06	1.03	1.92	2.45	3.20
CLVT_47200	0.16	1.33	2.97	3.45	4.87
CLVT_MCG1_280	0.34	3.27	7.14	8.29	11.97
Proposed bridge	0.72	5.91	13.15	15.27	21.55

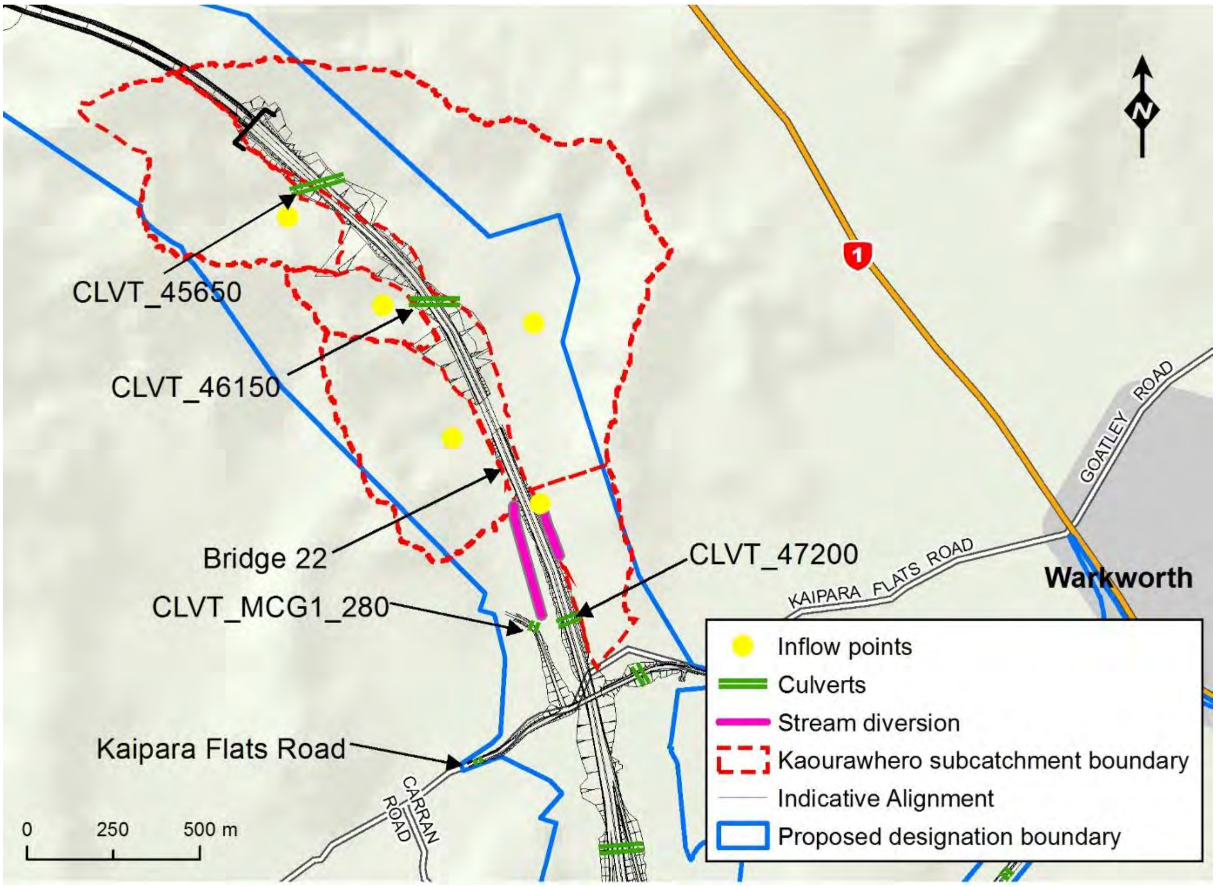

Figure 35 – Catchment boundaries with inflow points, culverts and stream diversions

3.3 Hydraulic model setup

A hydraulic model of the Kourawhero area has been developed in MIKE Flood software. In this model, the Project area was modelled in MIKE 21 software to represent the floodplains and channel flow paths. For the study area, the mesh has been generated with an average size of 26 m^2.

To undertake the hydraulic modelling of this area, a LIDAR derived 1 m resolution DEM was obtained from Auckland Council. The LCDBv4 of Landcare Research was utilised to define the roughness of floodplains. The values adopted as a Manning's Roughness Coefficient (n) for different land covers (Christchurch City Council, 2015) are provided below in Table 12.

Table 12 – Manning's n for different land covers

Land cover description	n	Land cover description	n
River	0.045	High Producing Exotic Grassland	0.05
Exotic Forest	0.15	Manuka and/or Kanuka	0.10
Indigenous Forest	0.15	Mangrove	0.125
Orchard, Vineyard or Perennial Crop	0.05	Built-up Area	0.10
Urban Parkland/Open Space	0.033	Transport Infrastructure	0.016

Land cover description	n	Land cover description	n
Surface Mine or Dump	0.06	Lake or Pond	0.02
Low Producing Grassland	0.09	Herbaceous Saline Vegetation	0.10
Flaxland	0.16	Gorse and/or Broom	0.125
Broadleaved Indigenous Hardwoods	0.10	Deciduous Hardwoods	0.125
Mixed Exotic Shrubland	0.08	Forest – Harvested	0.16

Culverts and a proposed bridge (Bridge No. 22) across the Kourawhero stream were modelled in MIKE 11 as a part of MIKE Flood model with a single cross section upstream and downstream.

The Indicative Alignment obstructs the natural flow path at different locations, stream diversion and cut-off drains will be required at locations. The stream diversions were modelled in MIKE 21 by introducing channels in the bathymetry.

Model Simulations were conducted for pre and post development scenarios considering 2, 10, 20 and 100 Year ARI events with an allowance of climate change.

3.4 Comparison of model results with rapid flood hazard assessment map of Auckland Council

In order to build confidence in the results of the hydraulic model, the flood extents of pre-development scenario for the 100 Year ARI event were compared with the RFHA Map procured from Auckland Council.

Overall, it was found that the flood extents of pre-development scenario are reasonably comparable with RFHA map of Auckland Council where they can be compared as shown below in Figure 36. However, Figure 36 shows that our model did not generate flood extents at three locations within the catchment boundary shown on the RFHA Map. The flood extents were not simulated for streams in the north and to the east since the model hydrology input node is downstream of this location. The flood extents for the reach where the bridge is proposed is not shown because it is modelled in MIKE11 rather than in MIKE21. A more detailed model should be developed as part of the detailed design.

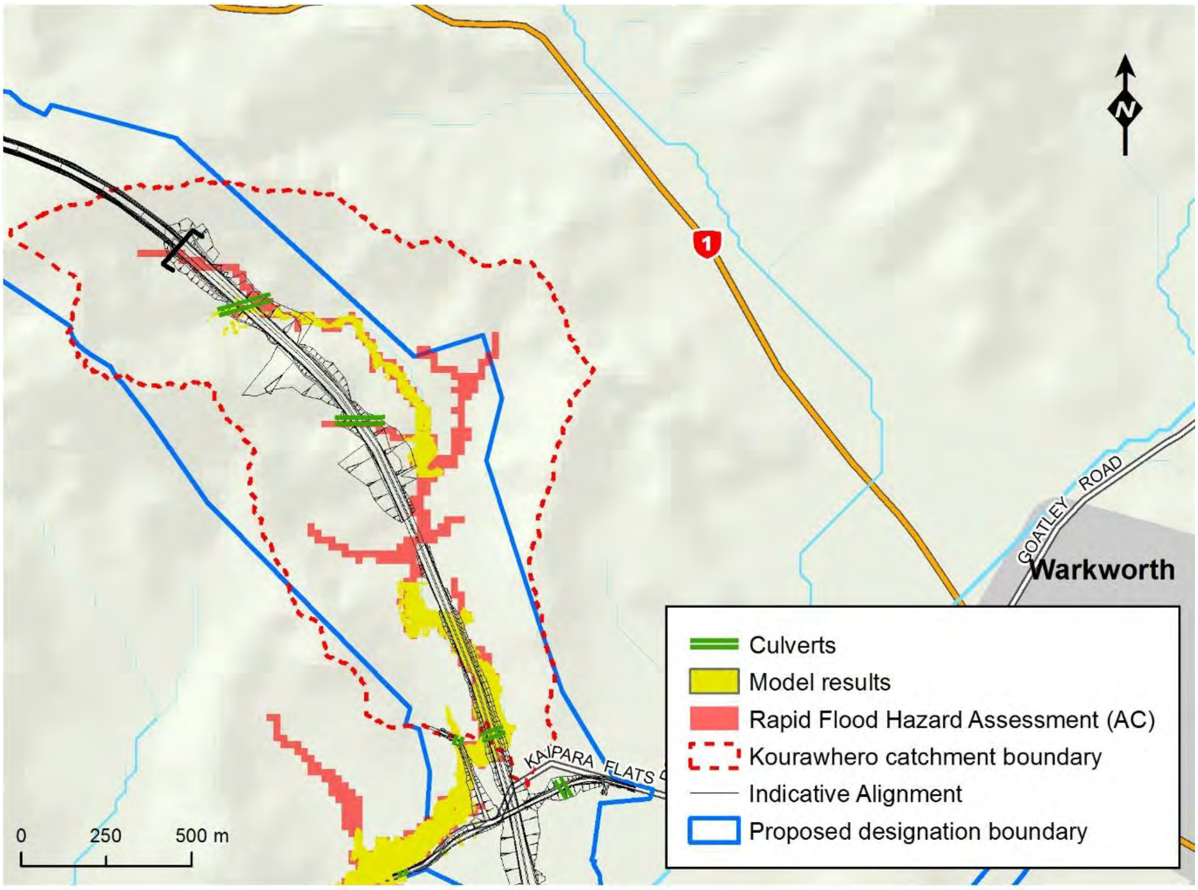

Figure 36 – Flood extents comparison of model results with RFHA map of Auckland Council for the 100 year ARI event

3.5 Results

We carried out a flood assessment, not only at the major stream crossings where the bridge is proposed across the Kourawhero Stream, but also at the minor stream crossings through the indicative design of culverts.

3.5.1 Proposed bridge across Kourawhero Stream

The Kourawhero bridge has been designed to maintain the existing floodplain extent, with the objective of maintaining the hydrological connectivity of the wetlands on the east and western side of the State Highway. The bridge soffit level is governed by the road geometry and is significantly higher than the floodplain. As illustrated in Table 13, the wide span of the bridge means that there is negligible impact of the bridge on flood levels and the bridge has ample freeboard.

The projected flood levels at proposed bridge for 100 Year ARI event are given below in Table 13.

Table 13 – Predicted flood levels at the Kourawhero Bridge for the 100 year ARI event

Bridge	Length (m)	Soffit level (m)	Predicted flood level (m)		Projected increase in flood depth (m)
			Pre-development	Post-development	
Proposed Kourawhero Bridge (Bridge 22)	96.0	63.82	55.068	55.071	0.003

Figure 37 indicates that flood hydrographs obtained at the proposed bridge of the Kourawhero Stream are identical for pre-development and post development scenarios.

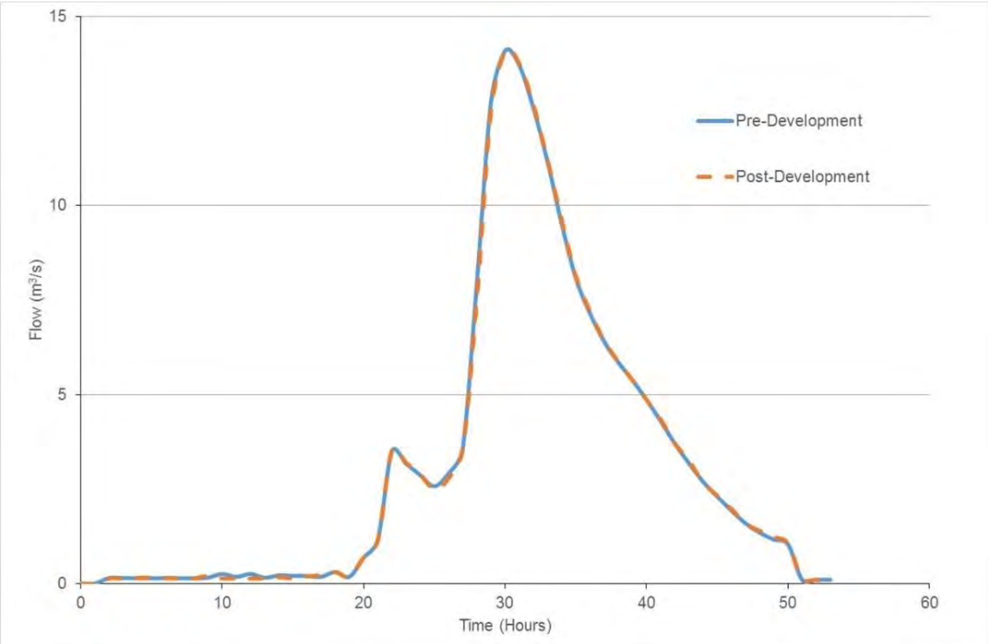

Figure 37 – Comparison of flow for the 100 Year ARI event at the Kourawhero Bridge

3.5.2 Floodplain extent changes

Figure 38 to Figure 41 show the change in flood extents for 2, 10, 20 and 100 Year ARI events. The pre-development flood extent is plotted over the post-development flood extent, so the change in flood extent where it is larger for post-development can be seen. These figures show that the culverts, bridges and earthworks within the Kourawhero Catchment have a small impact on the extents of flood inundation with the exception of increases in flood extents on the west of the Indicative Alignment, which is inside the designation and due to the diversion of the stream on the western side.

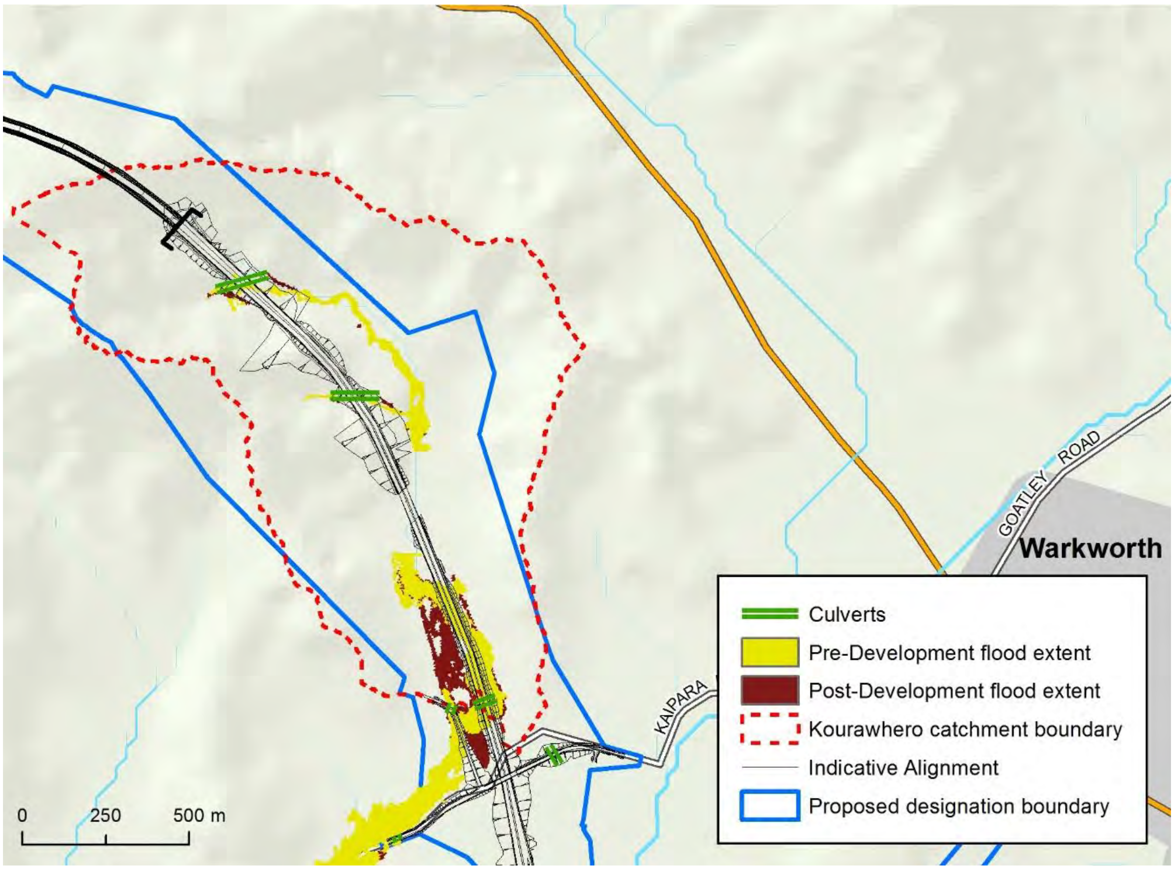

Figure 38 – Comparison of flood extents for pre and post-development scenarios for the 2 year ARI event

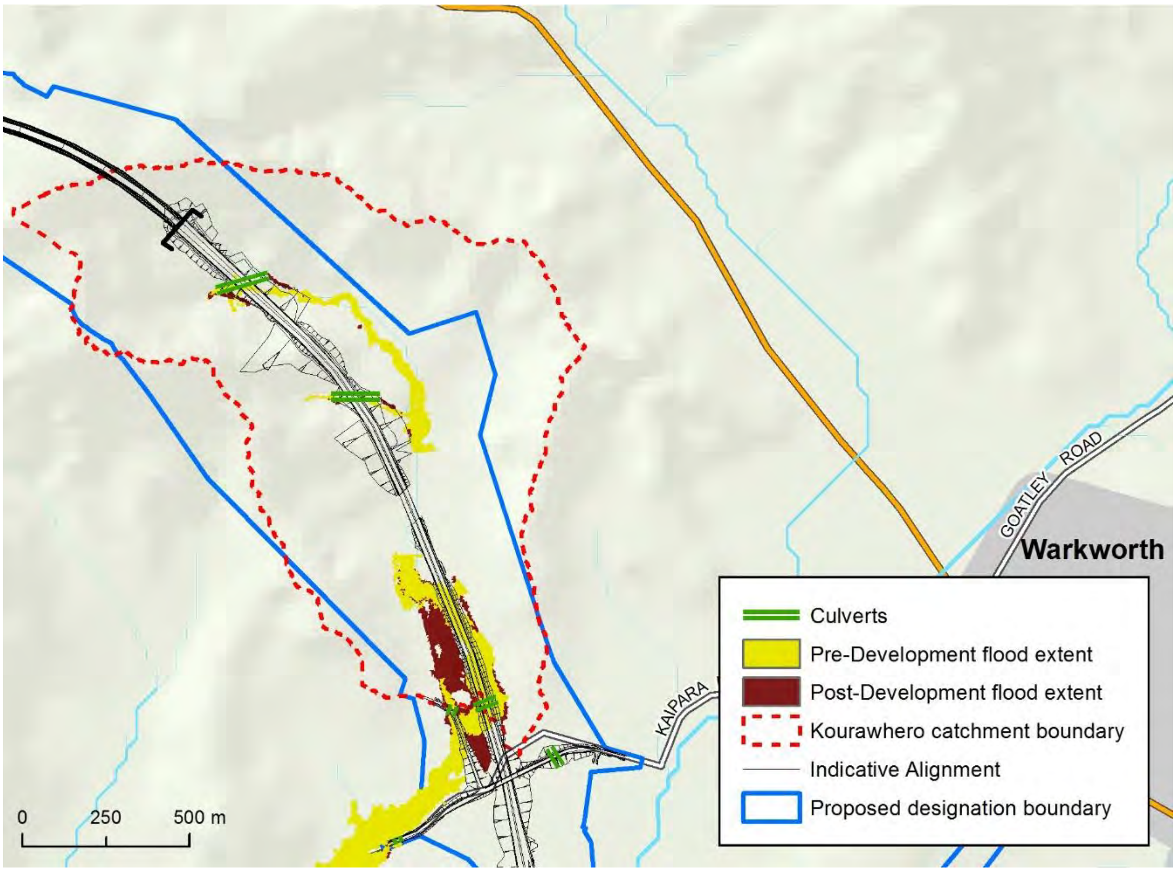

Figure 39 - Comparison of flood extents for pre and post-development scenarios for the 10 year ARI event

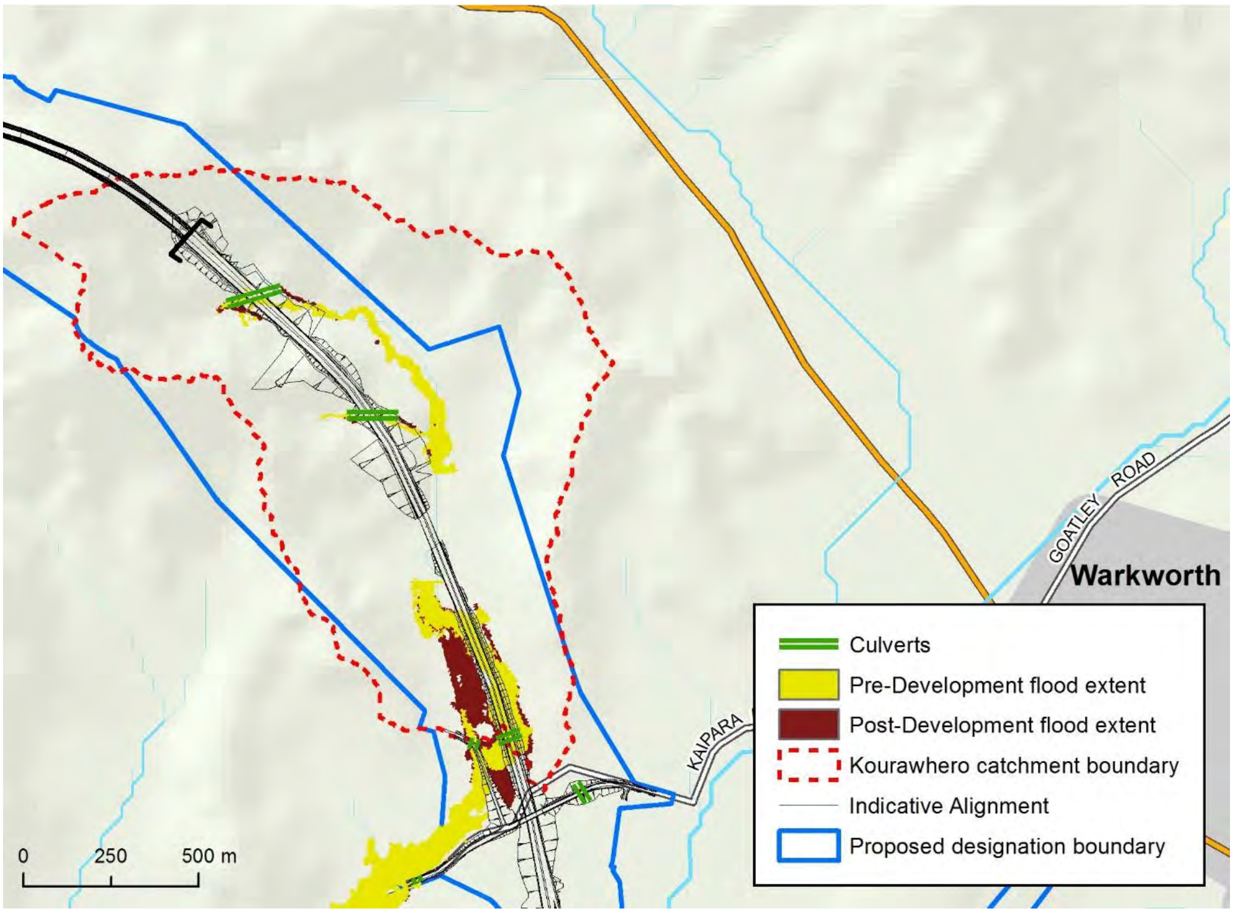

Figure 40 - Comparison of flood extents for pre and post-development scenarios for the 20 year ARI event

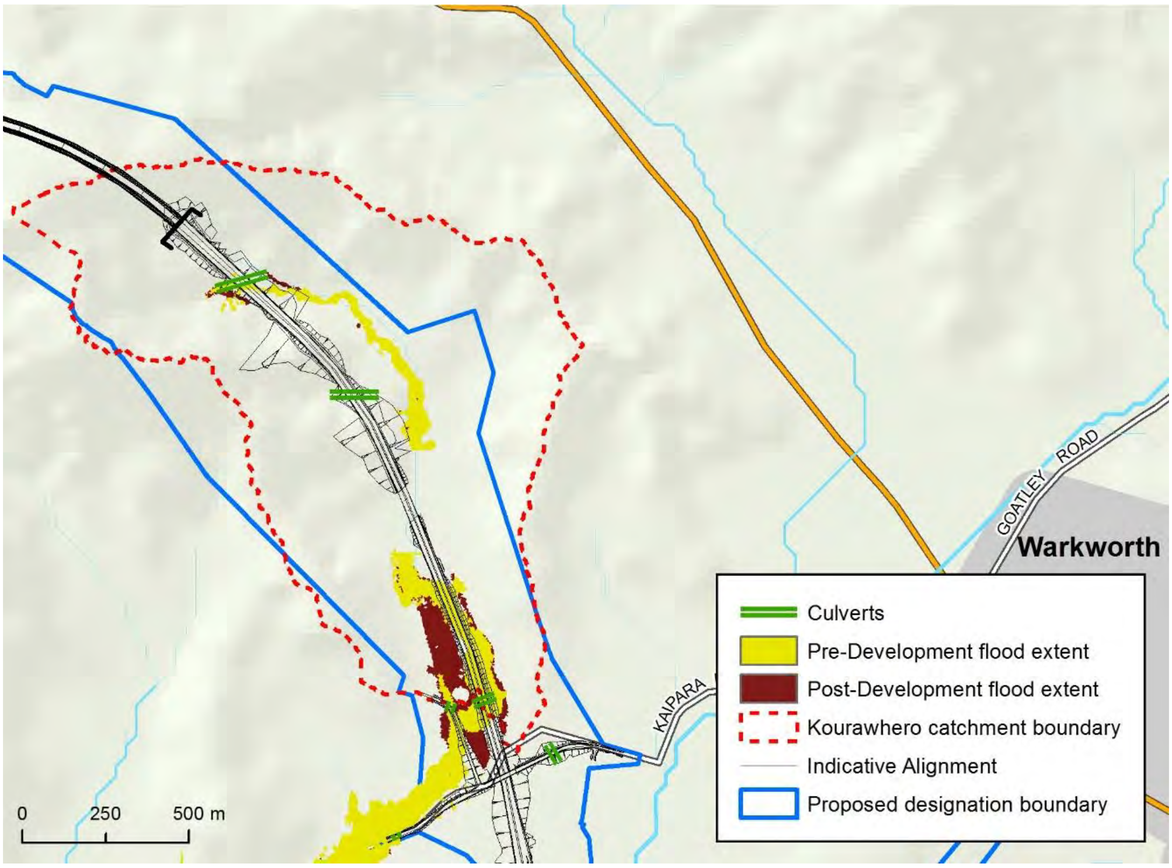

Figure 41 - Comparison of flood extents for pre and post-development scenarios for the 100 year ARI event

3.5.3 Floodplain depth changes

Figure 42 to Figure 45 show the change in flood depth for the post development scenario compared to pre development for 2, 10, 20, and 100 Year ARI events.

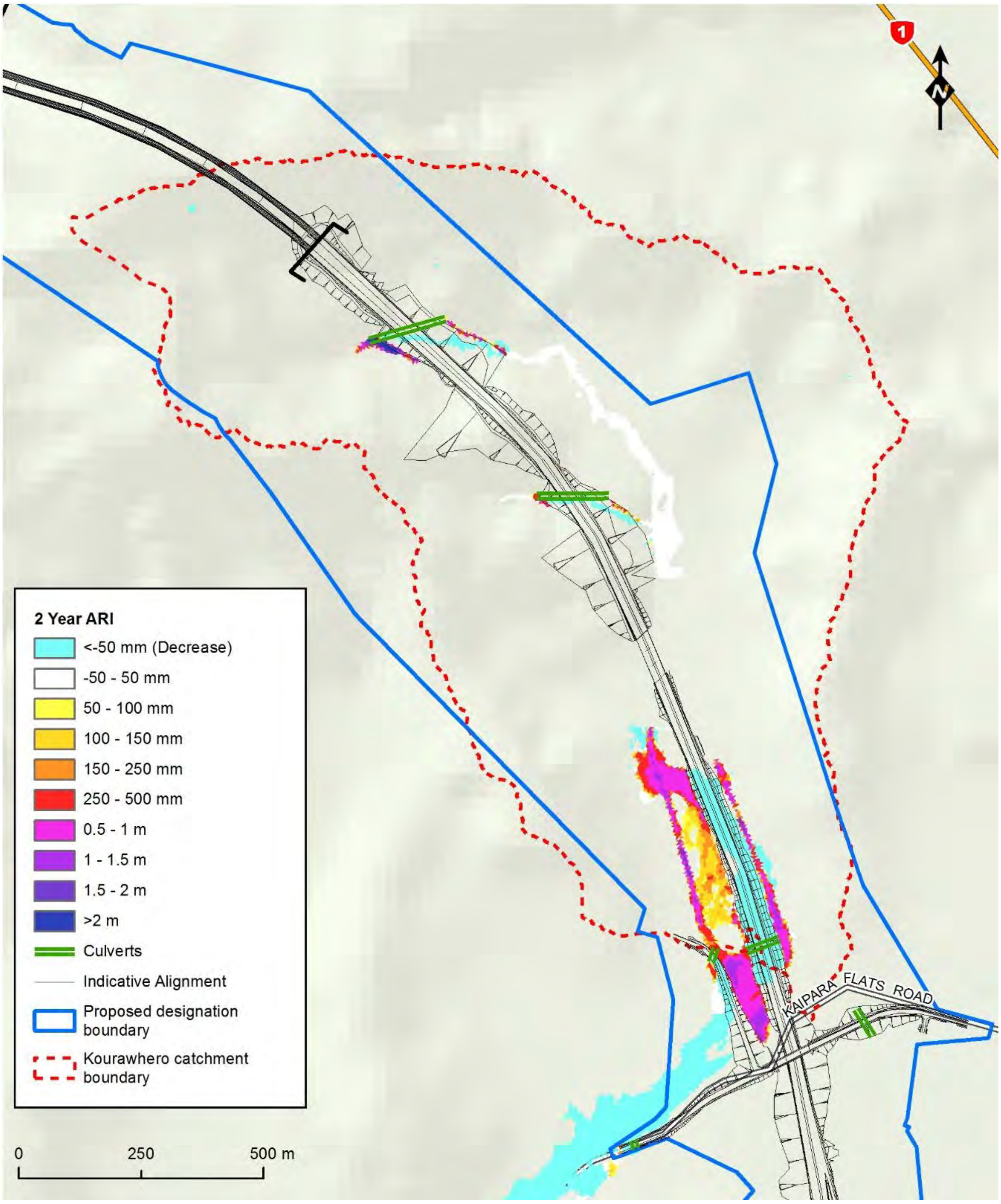

Figure 42 – Change in flood depths due to the Project for the 2 year ARI event

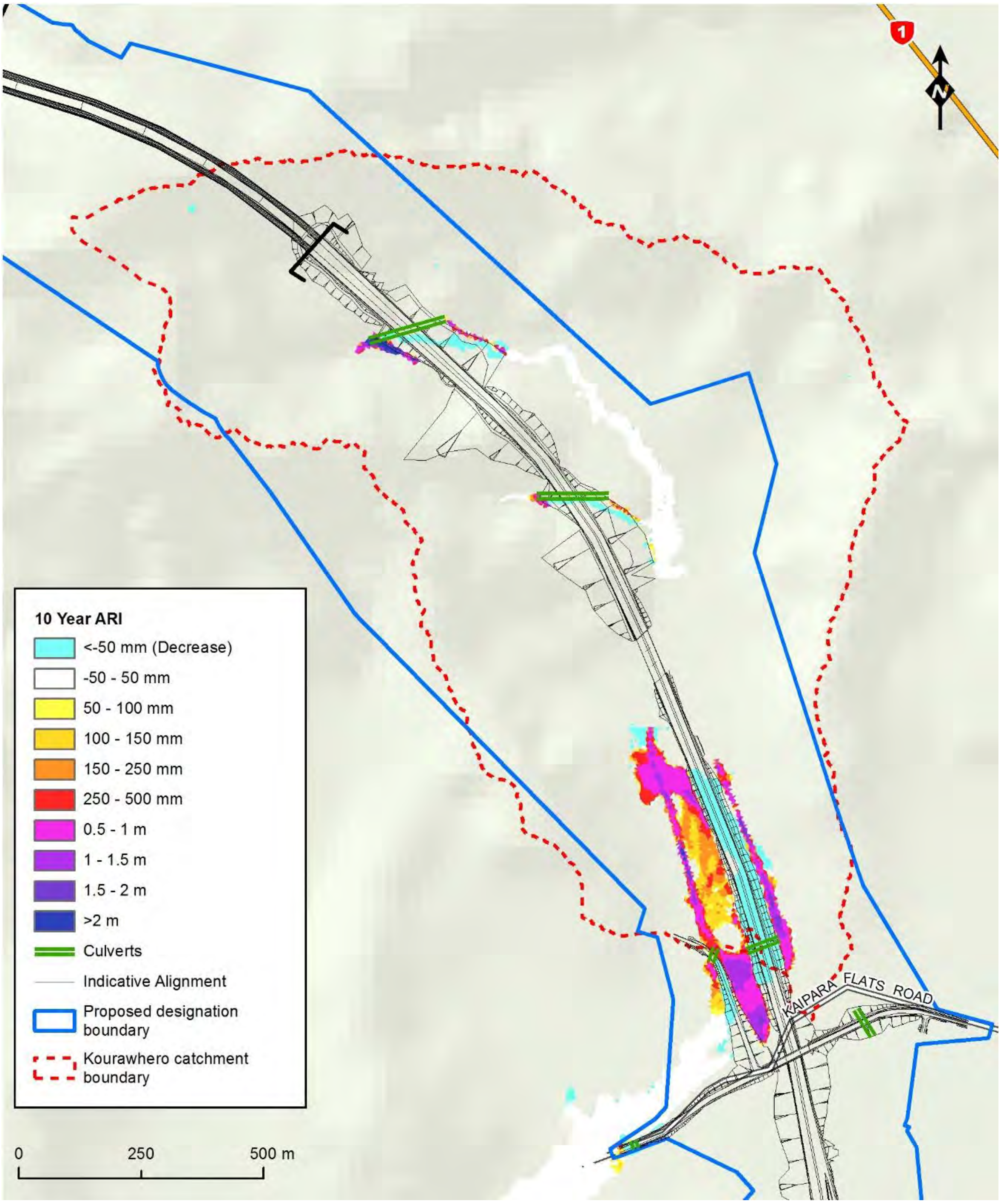

Figure 43 - Change in flood depths due to the Project for the 10 year ARI event

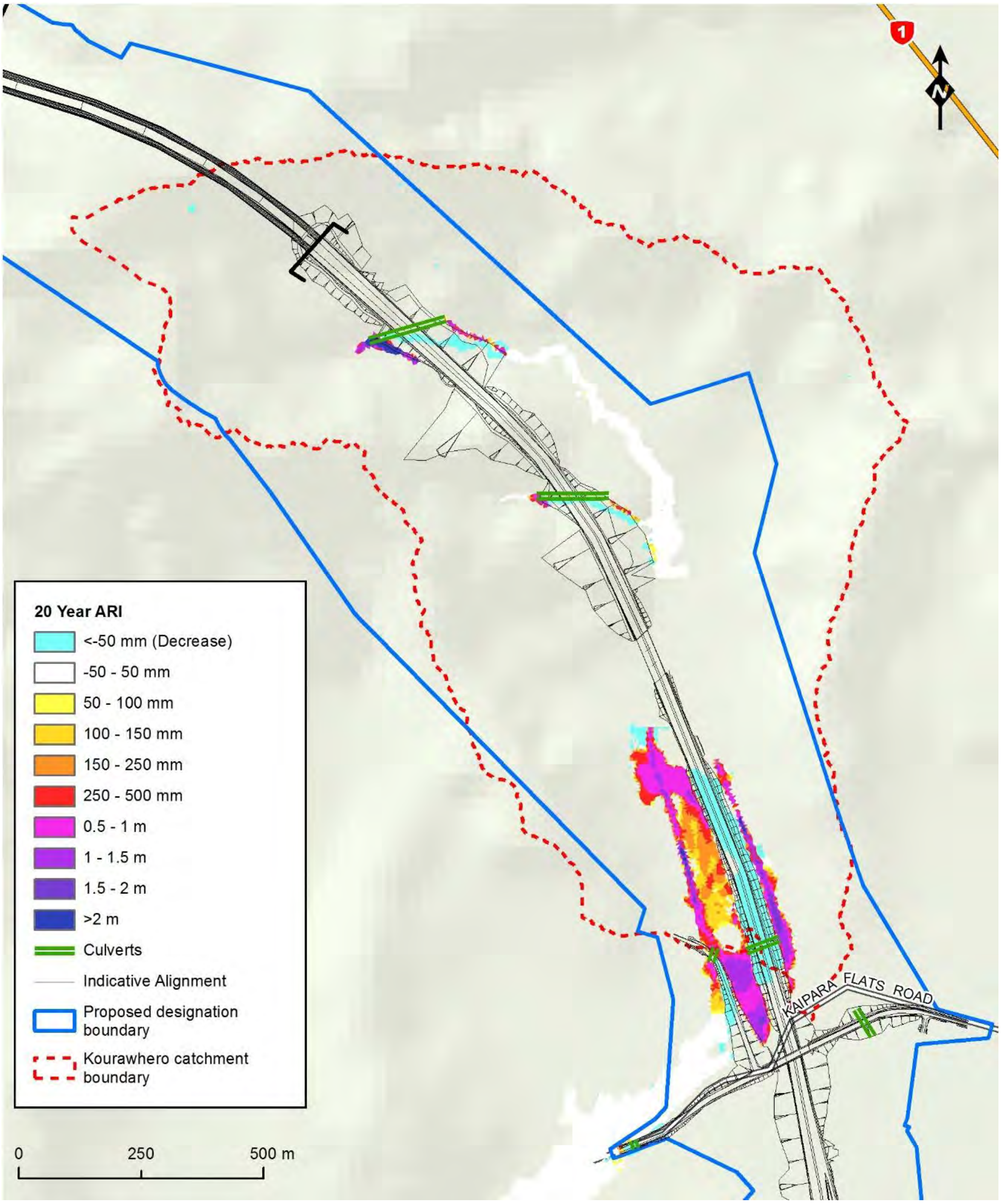

Figure 44 – Change in flood depths due to the Project for the 20 year ARI event

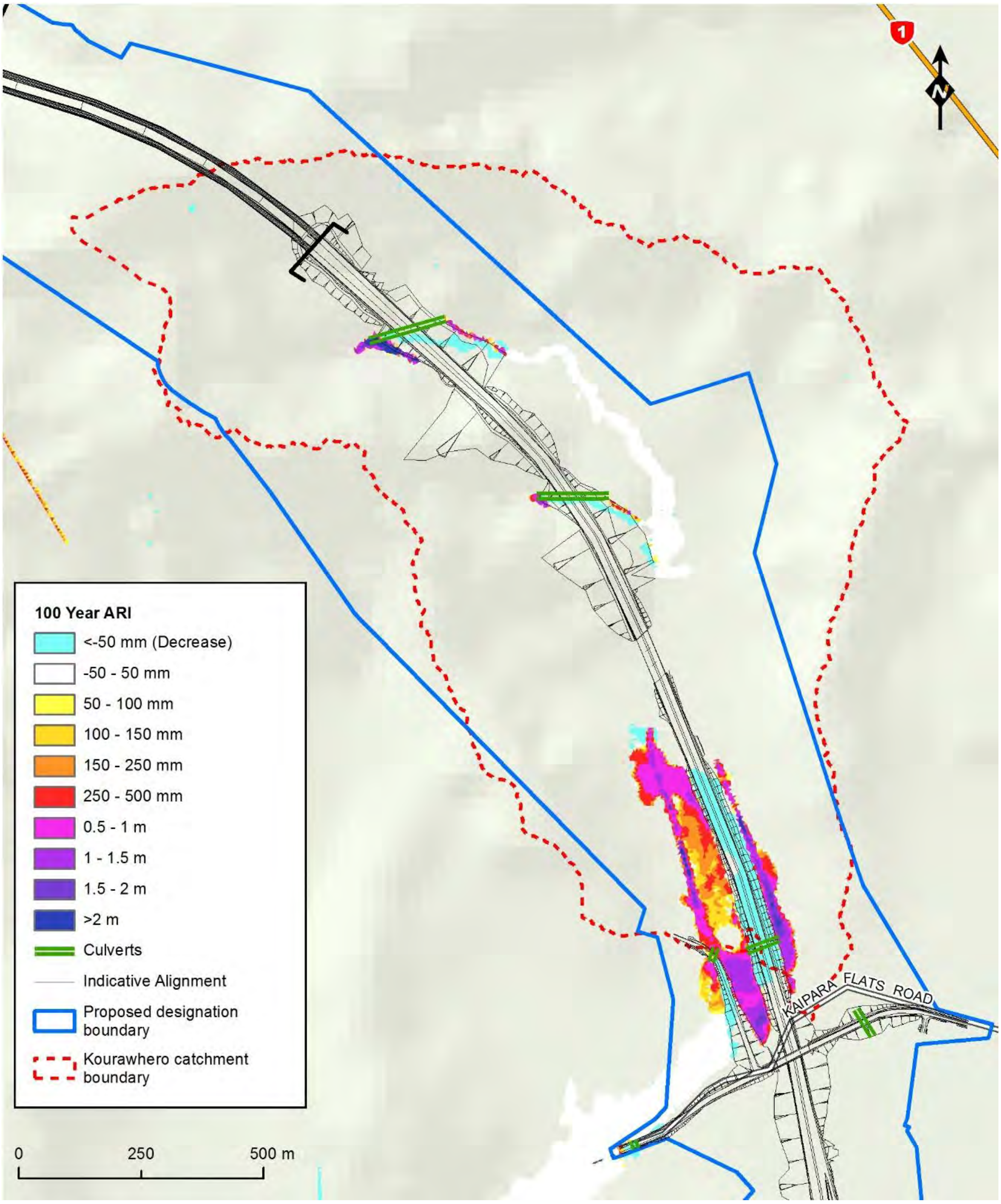

Figure 45 – Change in flood depths due to the Project for the 100 year ARI event

3.5.4 Floodplain depth changes in specific locations

There are three areas where flood depth increases as a result of the design aspects of the Project, all of which are contained within the proposed designation boundary.

Two of these areas are in the northern part of the model at culvert CLVT_46150 and culvert CLVT_45650 (Figure 35), where the increases are confined to small areas over forestry land cover.

Larger increases (> 0.2 m) are predicted upstream of culvert CLVT_47200 and culvert CLVT_MCG1_280 north of Kaipara Flats road for the 100 Year ARI event, which are contained within the proposed designation boundary, refer Figure 46. Likewise at these locations, the flood depth increase (> 0.2 m) was also observed within the proposed designation boundary for 2, 10 and 20 Year ARI events.

Culvert CLVT_MCG1_280 is proposed under the local road Phillips Road. Upstream and downstream of this culvert, the increase of flood depth ranges from 0.3 m to 0.5 m for the 100 Year ARI event. A small section of Phillips Road will get inundated due to flood water as shown below in Figure 47.

Building Information available on Auckland Council's GIS web-portal, shows there are three dwellings potentially affected by flood increases within the proposed designation (Figure 46) and these will likely be purchased by the Crown. Table 14 compares the flood depths obtained from modelling results for pre-development and post-development scenarios for the 100 Year ARI event.

Table 14 – Dwellings affected by flooding for the 100 year ARI event

Street address of dwelling affected	Pre-development flood depth (m)	Post-development flood depth (m)	Project increase in flood depth (m)	Location Related to the Project Designation
11 Phillips Road	0.80	1.78	0.98	Within proposed designation
18 Phillips Road	0.0	0.13	0.13	Within proposed designation
30 Phillips Road	0.55	1.52	0.97	Within proposed designation

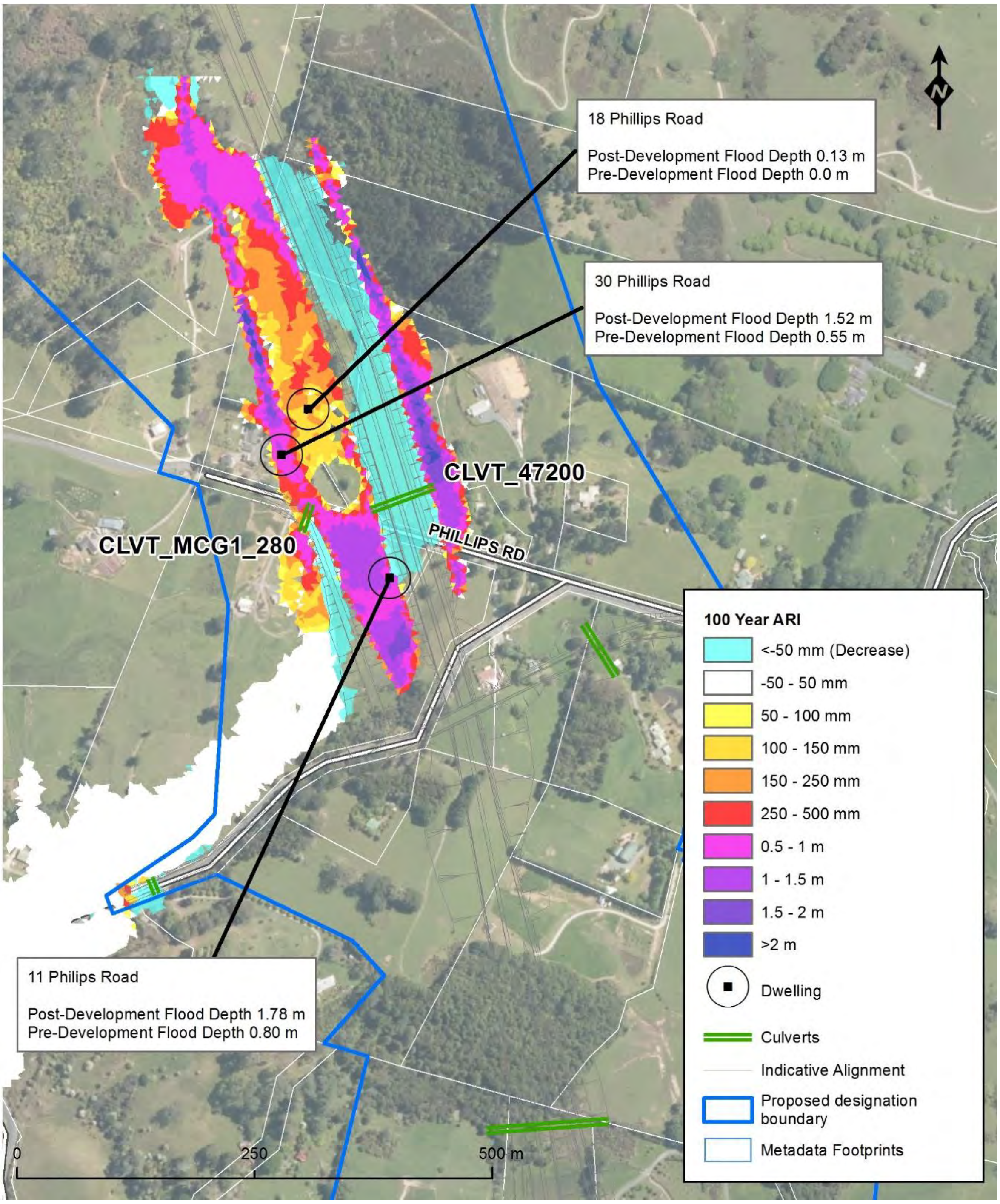

Figure 46 – Change in flood depths due to the Project for the 100 year ARI event – Kaipara Flats Road

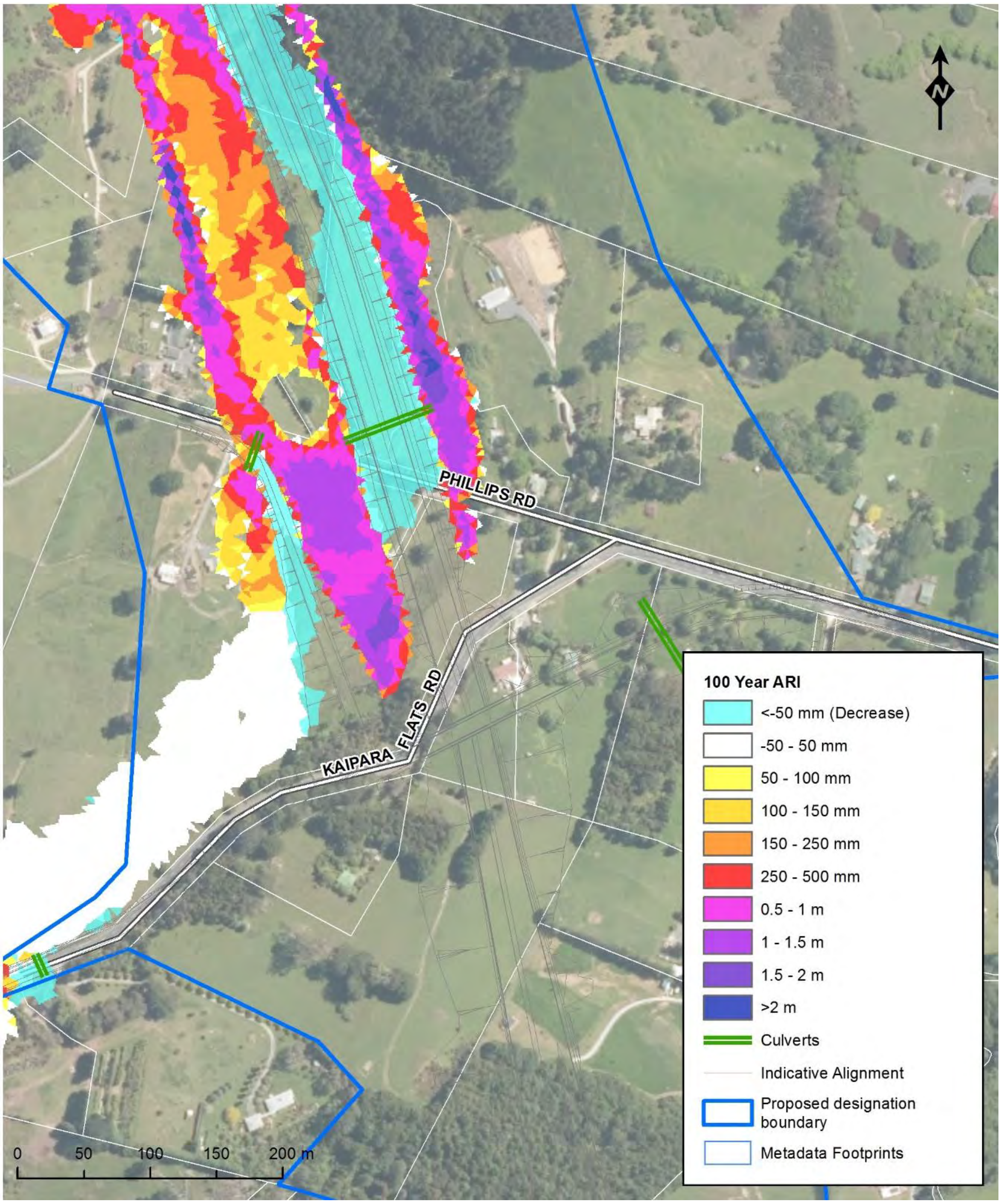

Figure 47 – Change in flood depths due to the Project for the 100 year ARI event – Phillips Road

3.5.5 Culverts

Flood water remains well below the proposed road level at most locations and achieves the design criteria of having a freeboard of equal or greater than 0.5 m and cover on each culvert of 1.0 m as given below in Table 15.

Table 15 – Predicted peak flood levels for proposed culverts

Culvert	Diameter/ height x No. of barrels (m)	Length (m)	Predicted flood levels after completion of Warkworth to Wellsford Project (m)		Road level (m)	Freeboard (m)
			Upstream	Downstream		
CLVT_45650	2.55 x 1	139.6	104.28	98.04	111.5	> 1 m
CLVT_46150	2.10 x 1	134.7	73.65	72.12	83.23	> 1 m
CLVT_47200	2.30 x 1	62.5	48.86	48.09	52.09	> 1 m

4 HŌTEO RIVER

The Indicative Alignment interacts with the Hōteo River floodplain in Wayby as shown in Figure 48. The Indicative Alignment is located within the identified floodplain from the proposed Hōteo Viaduct to culvert CLVT_37630. There are two sources of flood change in this area:

- Impoundment of water upstream of the Indicative Alignment, which is caused by the construction of the earthworks; and
- Changes in water levels in the main Hōteo River and floodplain due to embankments and the proposed Hōteo Viaduct.

Mitigation planting also has the potential to result in further changes to the floodplain and is assessed in Section 5.

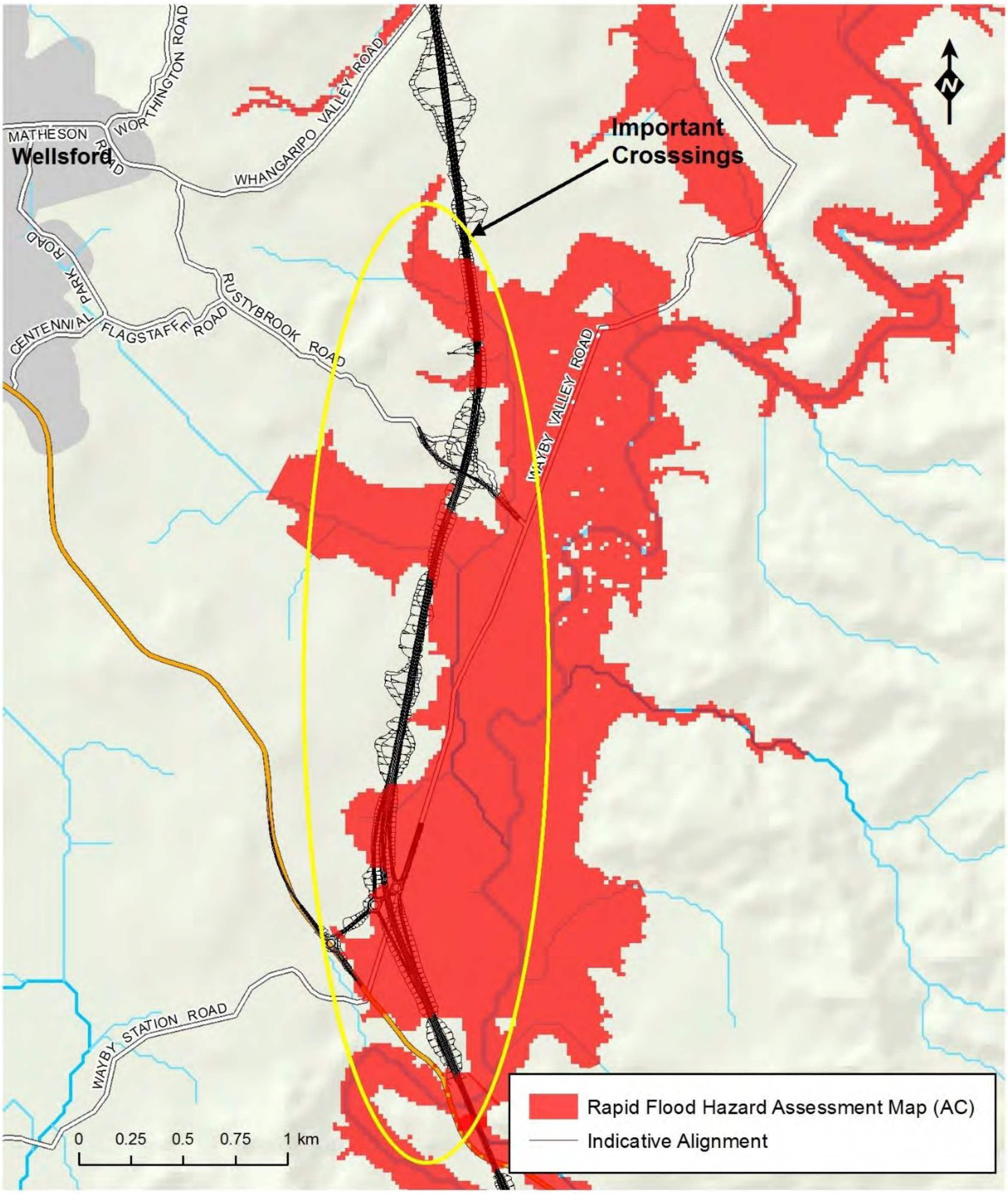

Figure 48 - Important Crossings in Hōteo Catchment

4.1 Extent of hydraulic model

The catchment areas of the Hōteo River at the proposed Hōteo Viaduct and Gubbs station are about 197 and 266 km^2 respectively. For modelling purposes, the catchment area above Gubbs station was split into 11 sub-catchments as shown below in Figure 49. In order to estimate peak flows for each sub-catchment, a scaling at-site flood frequency method was adopted which is described below in Section 4.2.

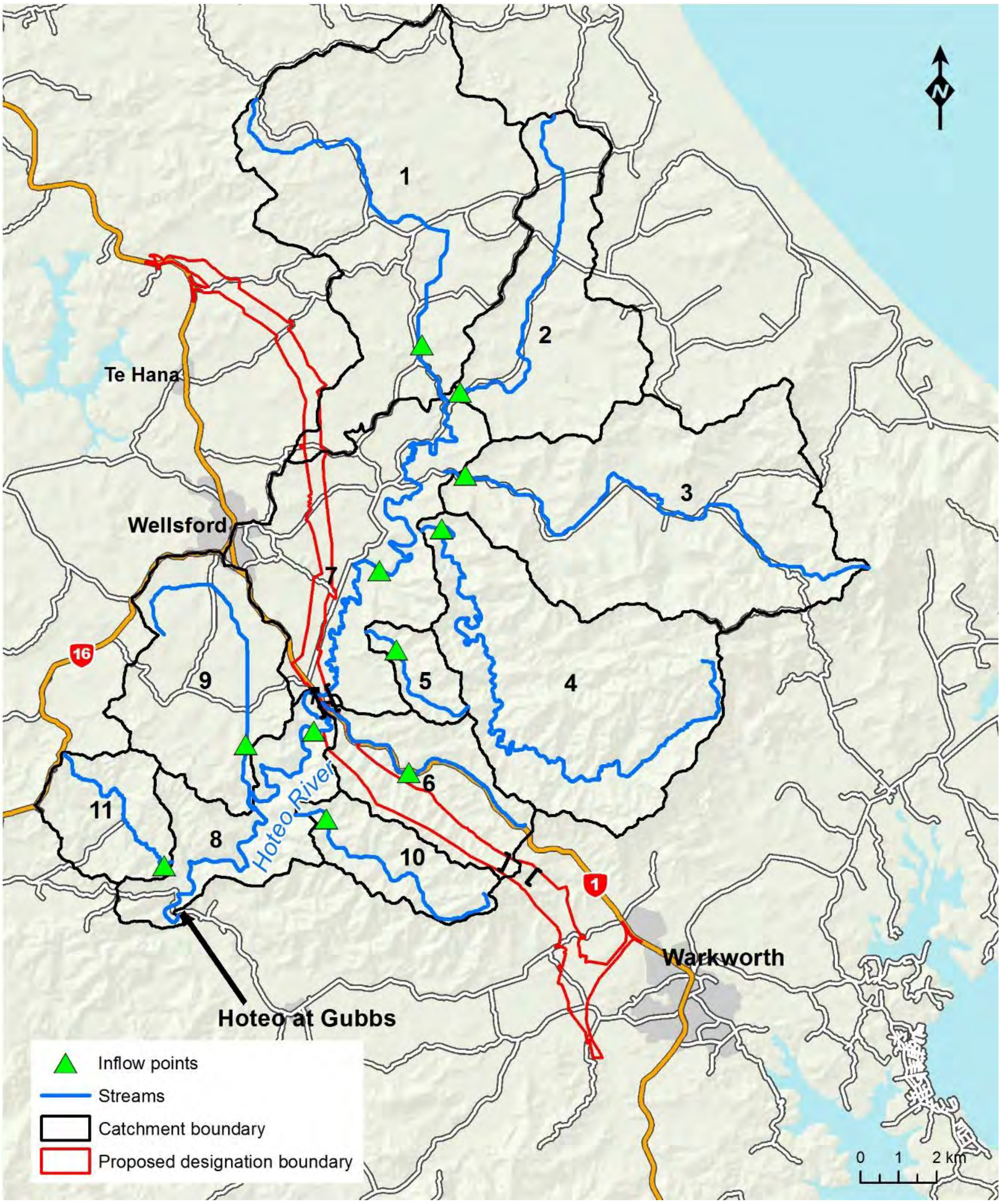

Figure 49 - Sub-Catchments of the Hōteo River with inflow locations and proposed designation boundary

4.2 Hydrology

4.2.1 Method

Due to relative location of rain gauges, it is not possible to develop calibrated rainfall runoff model by following the TP108 methodology for Hōteo catchment. In view of this, the most appropriate method for deriving the peak flows of 2, 10, 20 and 100 Year ARI events for the Hōteo sub-catchments is scaling at-site flood frequency estimates for Auckland Council's monitoring site 'Hōteo River at Gubbs'. The Gubbs station is located approximately 10 km downstream of the proposed Hōteo Viaduct site and has a record of approximately 40 years. The relatively long length of record and close proximity of gauge means that it provides a robust source of hydrological data for this Project. This methodology is in accordance with Section 2.3.3 of the NZTA Bridge Manual.

4.2.2 Incorporating the impacts of climate change on peak flows

As described earlier, climate change increases applied to peak flow on other recent state highway projects and climate change factors were estimated by building relationships between rainfall and runoff (Opus, 2014).

IPCC 5th assessment (MfE, 2016) provides updated estimates of temperature increase compared with the 4th assessment (MfE, 2010), and predicts a 16% increase in rainfall for the 100 Year ARI event. By comparing the flows computed for without and with climate change using the rainfall-runoff model developed for the culvert design (refer to Section 1.6), it was assumed a further increase of 10% for 20 Year and 100 Year ARI event flows for the flood effect assessment of the Hōteo River (i.e. 16% increase in rainfall results in a 26% increase in flow for 100 Year ARI Event).

4.2.3 Estimated peak flows

For frequency analysis, the annual flood maxima series of Gubbs station for the period from 1978 to 2016 was utilised for analysis in Hilltop Hydro (Version 6.55)[1]. Figure 50 shows the comparison of fit of EV1 and GEV distributions to the observed values.

[1] Hilltop Hydro (version 6.55), Hilltop Software Ltd 1998 - 2017.

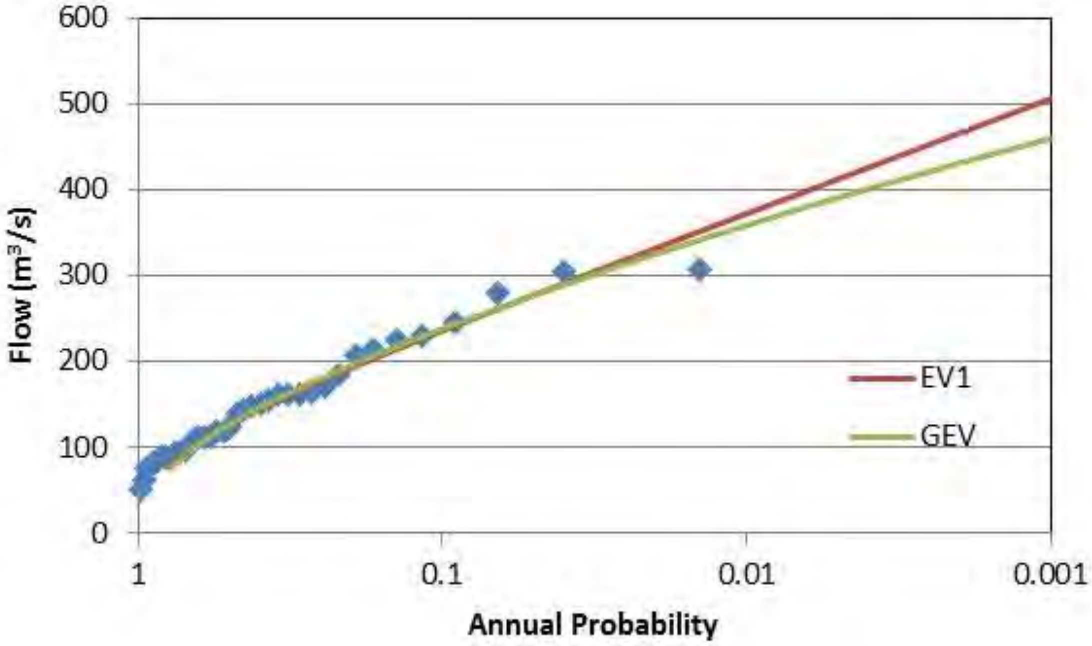

Figure 50 – Comparison of fit of frequency distributions for Hōteo at Gubbs Station

Since the results of EV1 probability distribution follows the trend of observed floods and projected conservative flood peak for the 100 Year ARI event, the estimated peaks, as given in Table 16, have been used for flood assessment of the Project.

Table 16 – Frequency Analysis results of EV1 for Hōteo at Gubbs Station (without climate change)

ARI (Year)	AEP (%)	Flow (m^3/s)
2	50	124
5	20	193
10	10	236
20	5	278
50	2	332
100	1	373

For each sub-catchment of the Hōteo River (Figure 49), the peak flows were computed on the basis of the Catchment Area Ratio Method, as described in the NZTA Bridge Manual. The computed peak flows released in each sub-catchment in MIKE Flood model for the 2, 10, 20 and 100 Year ARI events as given below in Table 17.

Table 17 – Estimated peak flow of sub-catchments with allowance of climate change for the 2, 10, 20 and 100 Year ARI flood events

Catchment No.	Peak flow (m^3/s)			
	2 Year	10 Year	20 Year	100 Year
1	38.8	78.2	94.4	129.3
2	21.1	42.5	51.3	59.57
3	34.2	68.9	83.2	114.0
4	30.3	61.1	73.7	101.0

Catchment No.	Peak flow (m³/s)			
	2 Year	10 Year	20 Year	100 Year
5	4.9	9.8	11.9	16.20
6	13.7	27.7	33.4	45.80
7	25.9	52.0	62.8	76.30
8	14.2	28.6	34.5	47.2
9	18.8	37.9	45.8	62.7
10	9.2	18.5	22.3	30.6
11	9.9	19.9	24.0	32.8

The hydrograph shapes were obtained by scaling with observed hydrographs of Waiteitei at Sandersons and Hōteo at Gubbs gauging sites. Six flood hydrographs of different events observed at Gubbs (Figure 51) were used to check the performance of the hydraulic model. Hydrographs analysis indicates that hydrograph shape is very similar between events as shown below in Figure 51. A normalised hydrograph for each of these events were derived by dividing each ordinate by their peak flow rate. An average normalised hydrograph was adopted for this study which is shown below in Figure 51.

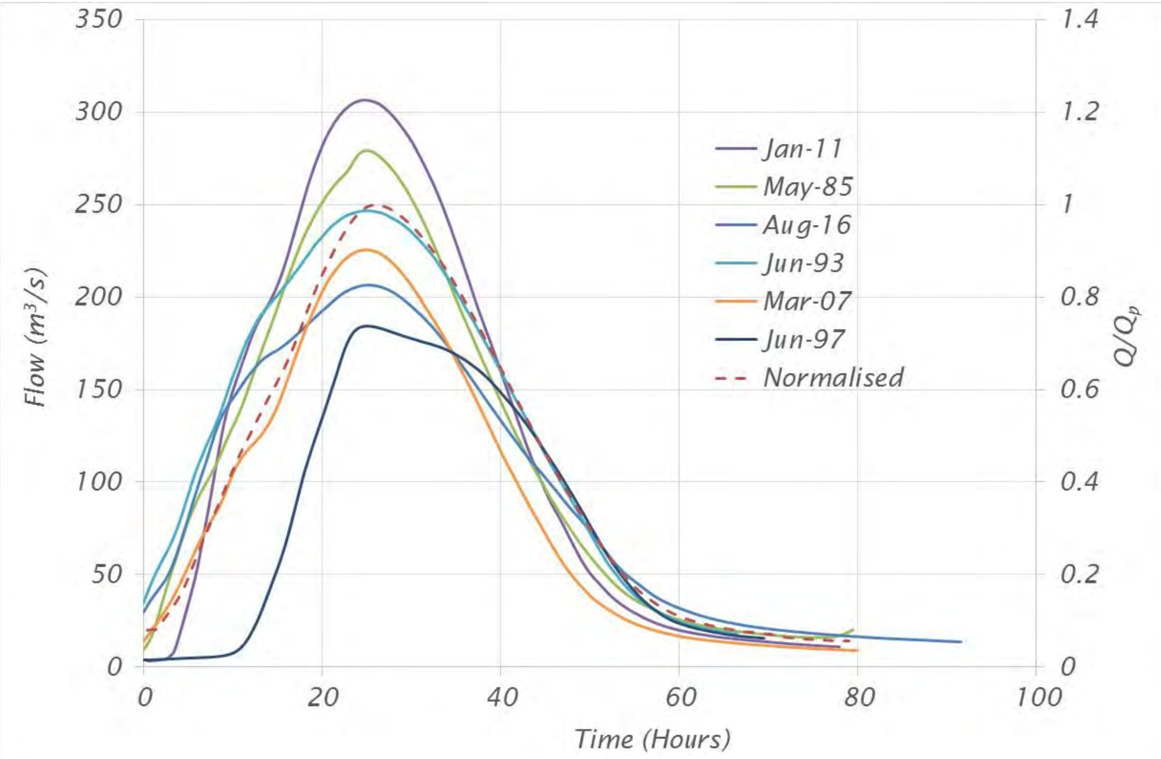

Figure 51 – Shape of observed hydrographs of different events with normalised hydrograph of Hōteo at Gubbs

4.3 Hydraulic model setup

A hydraulic model of the Project area was developed in MIKE Flood software. In this model, the area upstream of the proposed viaduct over the Hōteo River was modelled in 2D to represent the floodplains and channel flow paths.

The 2D terrain used by the hydraulic model used Auckland Council's 1m resolution DEM derived from LIDAR (2013). The New Zealand Land Cover Database Version 4 (LCDBv4) was utilised to define the roughness of the floodplain and overland flow areas.

The reach of the Hōteo River from the proposed viaduct to Gubbs station, along with its three tributaries, was modelled in 1D.

The flexible mesh of about 73 km^2 area was generated for the flood zone. The areas along the Hōteo River and the Indicative Alignment were represented with fine resolution and a coarse mesh was used for the elevated areas. The fine resolution mesh is under 500 m^2, while the coarse mesh for elevated areas' mesh is under 1000 m^2. Overall, the average size of mesh is 492 m^2. Figure 52 and Figure 53 show that the extracted cross-sections from the mesh are comparable with the cross-sections of DEM.

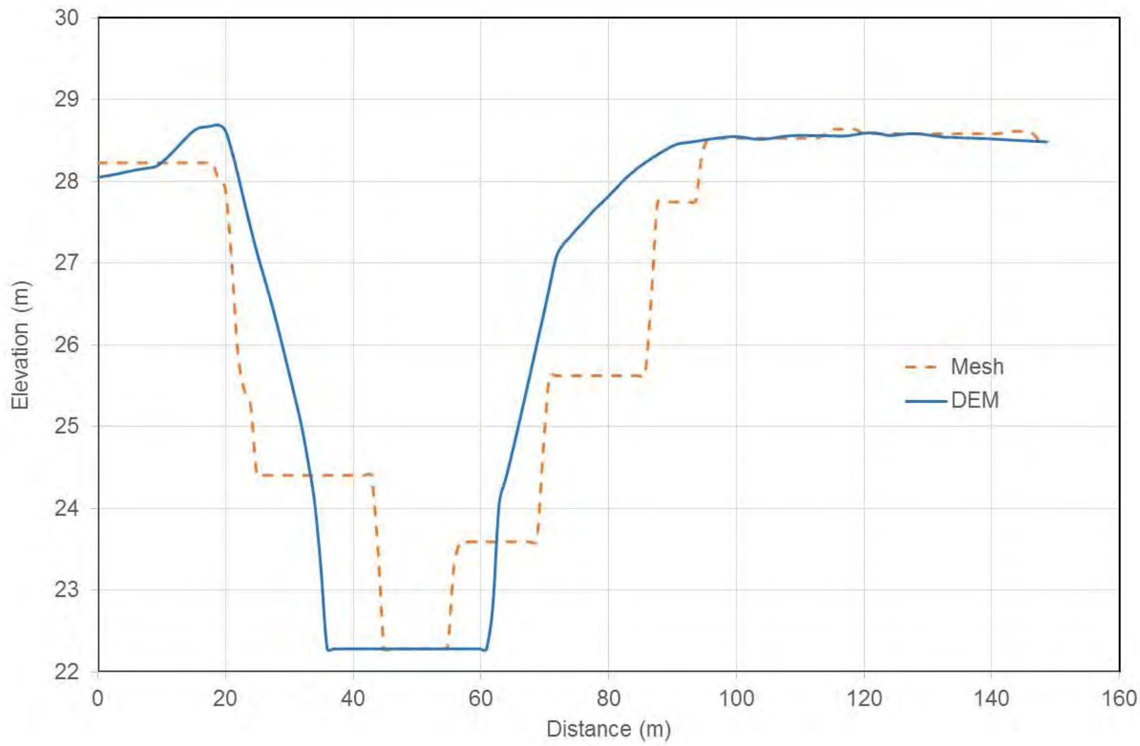

Figure 52 - Comparison of cross-sections of the Hōteo River extracted from LIDAR based DEM and the model mesh

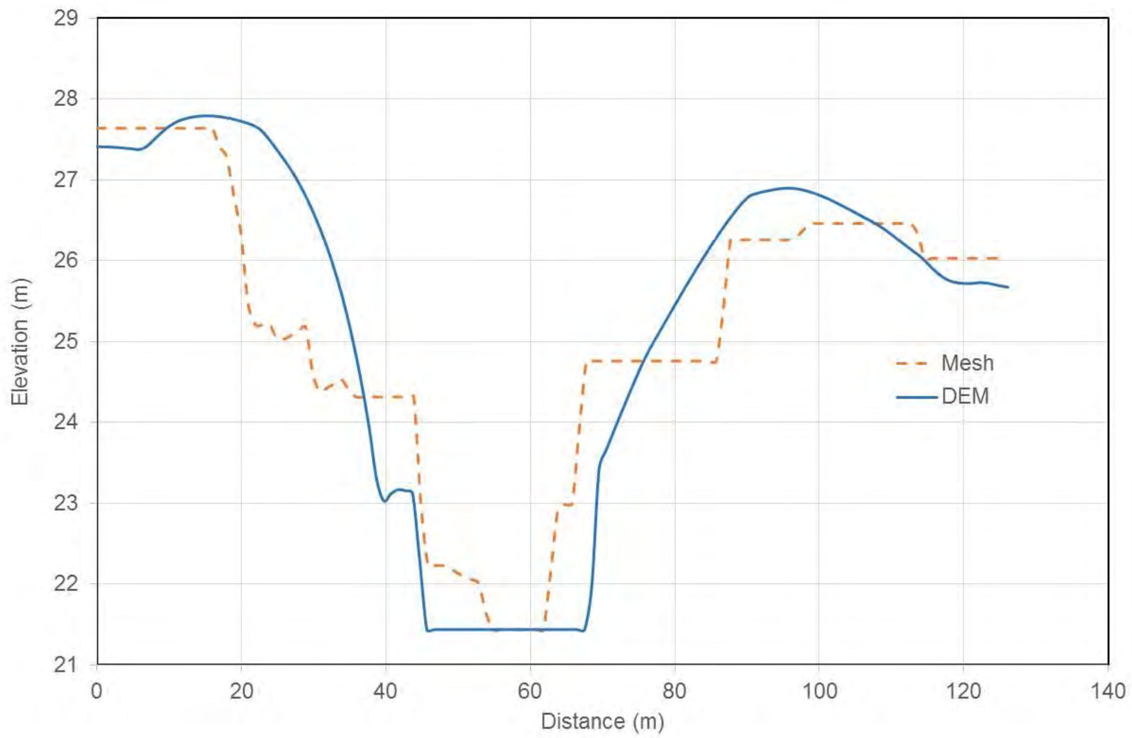

Figure 53 - Comparison of cross-sections of the Hōteo River extracted from LIDAR based DEM and the model mesh

Culverts from CLVT_MCF0_670 to CLVT_37630 (Figure 54) and the proposed viaduct across the Hōteo River were modelled in 1D as a part of MIKE Flood model with a single cross section upstream and downstream. In the same way, the existing bridges across the Hōteo River were also modelled in 1D. Limited datasets on existing bridge dimensions were available. In view of this, assumptions were made to model these bridges, and this is reflected in the model. However, the model is reliable for our purpose.

A value of 0.045 for Manning's roughness coefficient (n) was adopted in the model for channel based on the information available for the Hōteo River in the handbook "Roughness Characteristics of New Zealand Rivers". The values adopted as a Manning's n for other land covers were given previously in Table 12.

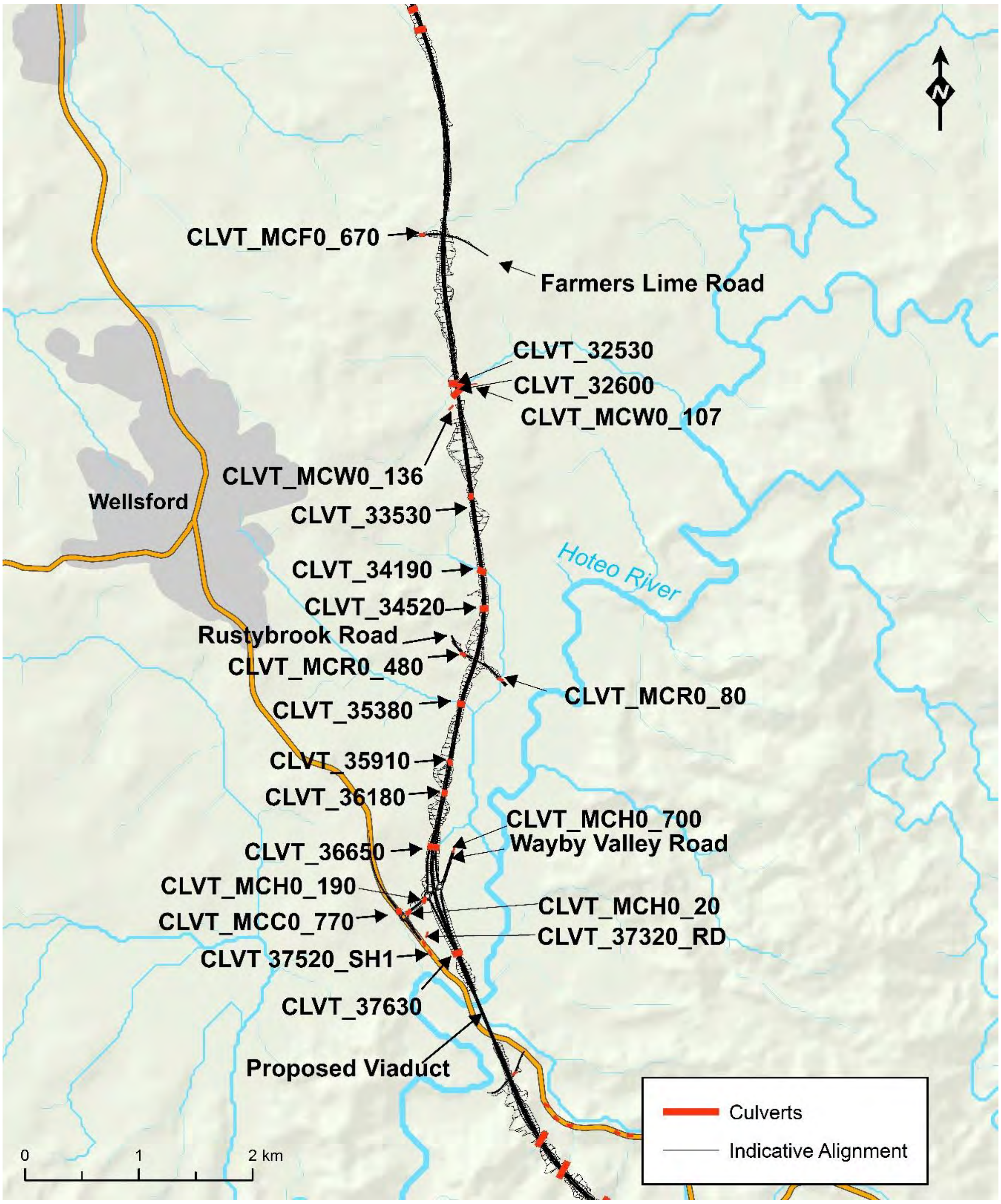

Figure 54 – Location of culverts with indicative road alignment

Hydrology inflow points were set close to the downstream end of most sub-catchments, except for sub-catchments 6 and 7. The inflow locations for these sub-catchments are approximately in the centre. While for sub-catchment 8, the inflow location is set close to its upstream boundary (Figure 49). These adjustments help the model to achieve flood peak comparable to flood peak obtained from frequency analysis for the 100 Year ARI event. The downstream boundary is based on flow/level hydrograph data at Gubbs station, which was assessed as having a peak flow of 373 m^3/s for the 100 Year ARI event.

Model simulations were conducted for pre development scenarios considering 2, 10, 20 and 100 Year ARI events. Under the pre-development scenario, the model results obtained for the existing conditions were compared with the RFHA Map of Auckland Council, as described in Section 4.4. As a second step of the baseline case, the model flows were updated with an allowance for climate change. Finally, the Indicative Alignment was introduced in the bathymetry to complete the flood risk assessment for post-development scenario.

4.4 Comparison of model results with observed hydrographs and rapid flood hazard assessment map of Auckland Council

As described earlier in Section 4.2, the peak flow of each sub-catchment was estimated on the basis of the Catchment Area Ratio Method. The estimated peak flows were scaled to a normalised hydrograph based on observed hydrographs of Gubbs and Sandersons in order to define their shape. To produce a peak flow (373 m^3/s) at Gubbs comparable to flood peak obtained from frequency analysis for the 100 Year ARI event, the timing of peak flow for each sub-catchment was adjusted either by delaying or making it earlier without changing the shape of a hydrograph. Furthermore, an optimal location of inflow points along natural flow paths within each catchment were identified by an iterative process.

As a result of these adjustments, the MIKE Flood model generated a peak flow of 372 m^3/s at Gubbs, which is similar to the flood peak obtained from frequency analysis for the 100 Year ARI event. Figure 55 shows the comparison of modelled and gauged hydrographs of different events of the Hōteo River observed at Gubbs. The shape of the modelled hydrograph is steeper prior to the peak and higher after the peak. These differences reflects that the model simplifies the hydrology; however the hydrograph is suitable for assessment purposes as the peak and volumes are replicated.

To further check the model results, the model was re-run using the hydrographs with an allowance for the effects of climate change. The result of this simulation produced a peak of 472 m^3/s at Gubbs, which is also comparable with the peak obtained by frequency analysis with allowance for climate change i.e. 471 m^3/s.

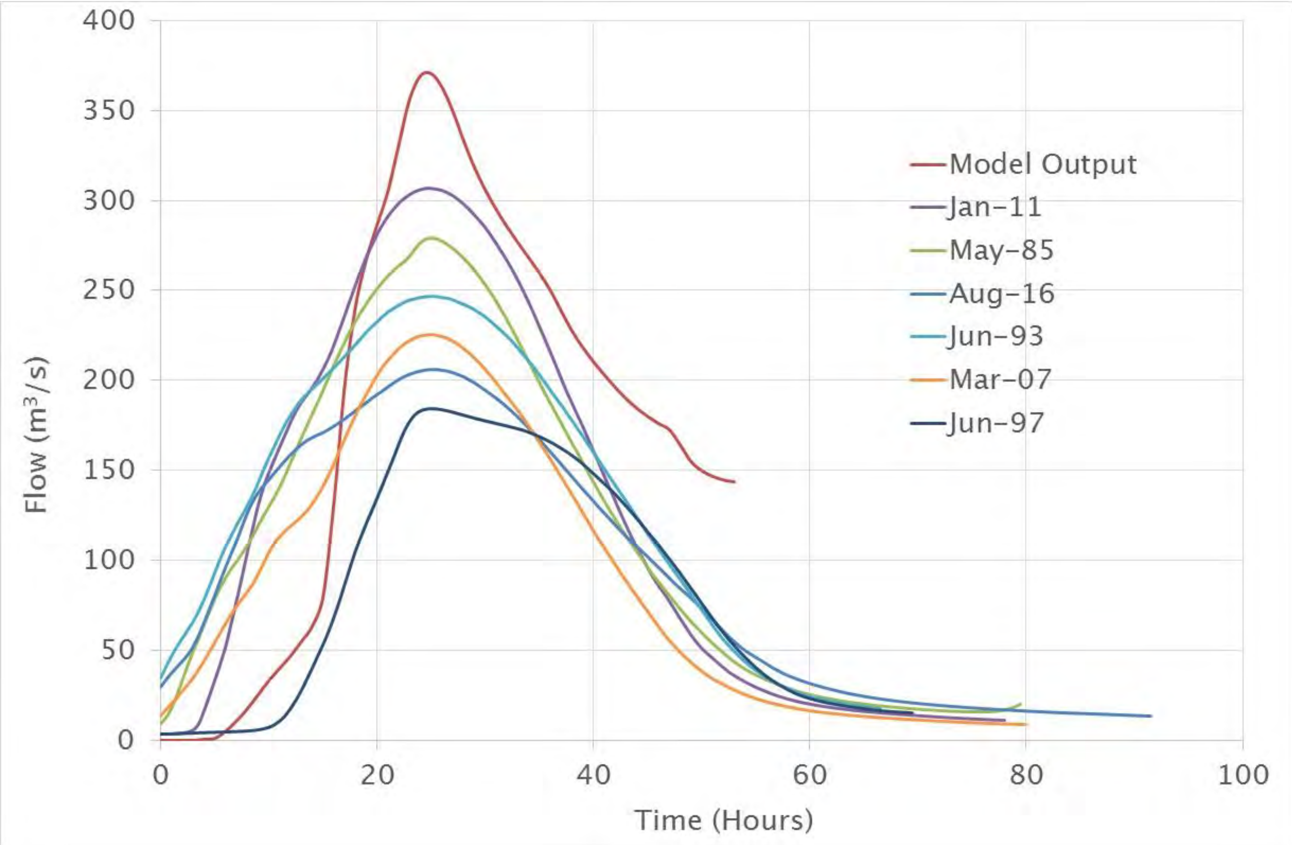

Figure 55 – Comparison of modelled hydrograph and gauged hydrographs of different events of the Hōteo River observed at Gubbs Station

The resulting modelled flood extents (without and with climate change) are comparable with the RFHA map supplied by Auckland Council for the area upstream of the proposed viaduct over the Hōteo River (Figure 56 and Figure 57). The RFHA map supplied by Auckland Council was developed using flows that were derived without including the allowance for the effects of climate change.

Since the inflow location was set in the centre for catchment 7 (Figure 49), the model has not projected the flood extents for the area located in the west of the Hōteo River between Rustybrook Road and Whangaripo Valley Road.

The flood map developed by the model (without climate change) between the proposed viaduct and Rustybrook Road indicates a slightly reduced extent and is more patchy when compared to the RFHA floodplain. The flood model is likely to be predicting less flow than the RFHA due to the use of the flood-frequency hydrological method that is based on observed data and is preferred for that reason. The flood maps are more different in extents above the Rustybrook Road (Figure 56), but this is outside the areas of interest for this assessment.

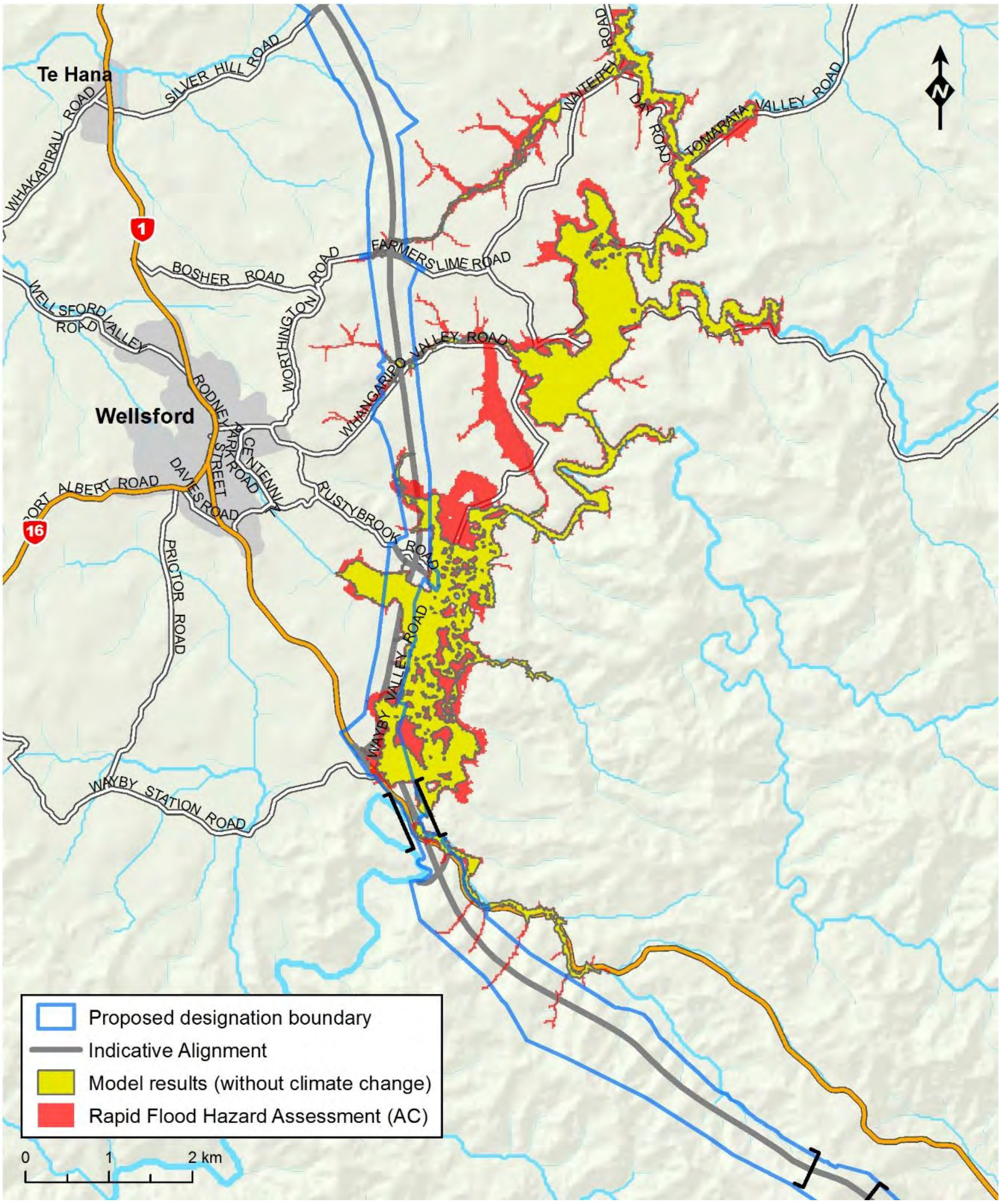

Figure 56 - Flood extents comparison of model results (without climate change) with RFHA map of Auckland Council for the 100 Year ARI flood event

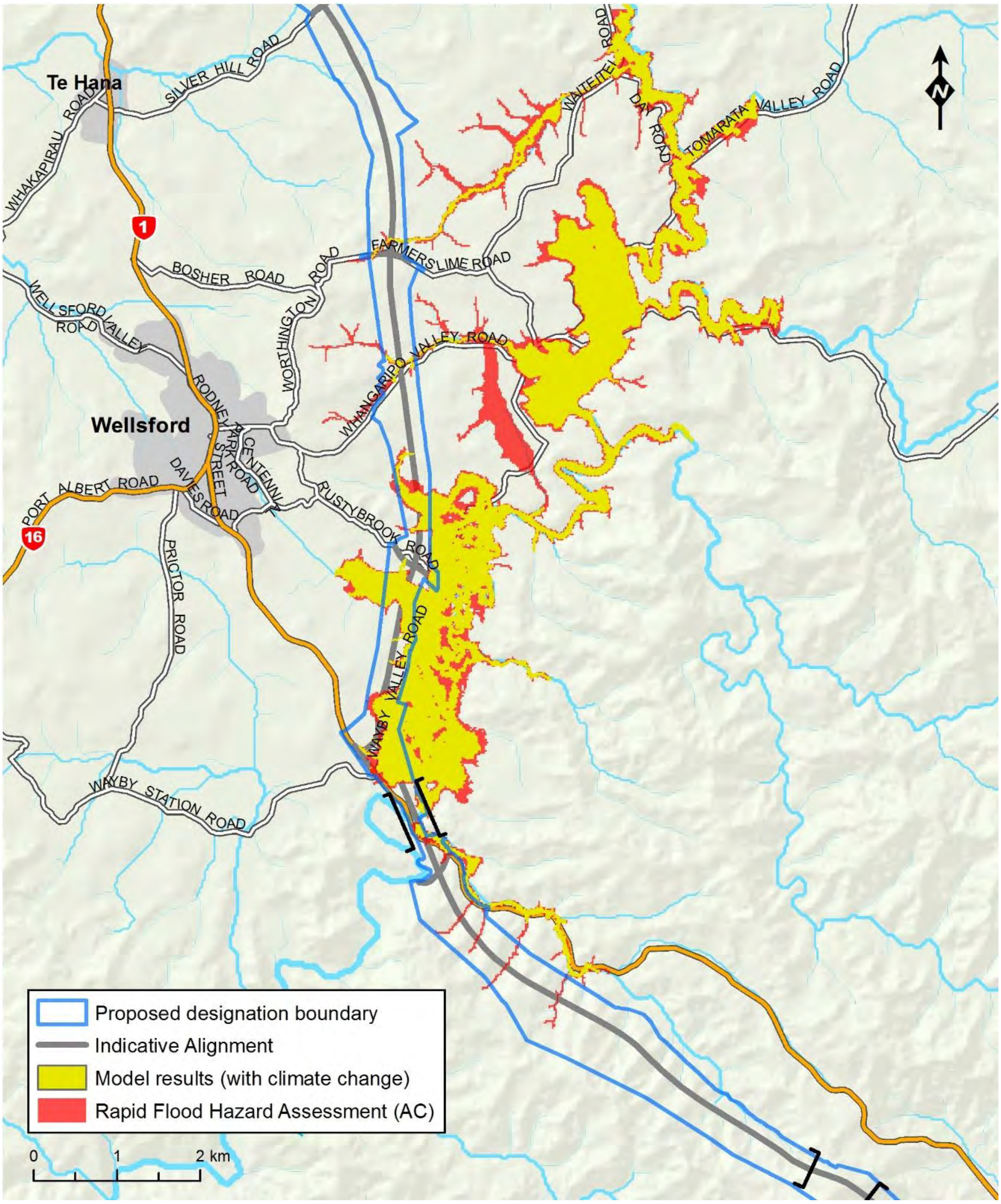

Figure 57 – Flood extents comparison of model results (with climate change) with RFHA map of Auckland Council for the 100 Year ARI event

4.5 Results

As a part of this study, the flood assessment was carried out not only at the major stream crossings where the proposed viaduct crosses the Hōteo River, but also at the minor stream crossings via culverts.

The pre and post development scenario were simulated for 2, 10, 20 and 100 Year ARI events with an allowance for climate change.

4.5.1 Proposed viaduct across the Hōteo River

The existing State Highway 1 (SH1) bridge crossing of the Hōteo River is approximately 85 m downstream of the proposed viaduct. There is another private bridge that lies about 32 m upstream of the existing SH1 bridge. Overall, the SH1 and private bridges are of approximately similar length i.e. 70.0 m and 62.0 m respectively. The proposed viaduct has indicative span of 490.0 m and is at a higher level than the existing bridges. The bridge span and crest level have been defined by road geometrics, rather than driven by flood hydraulics. At the detailed design stage, a bridge with different dimensions could achieve a similar level of flood level performance.

The projected flood levels at bridges for 100 Year ARI event is given below in Table 18.

Table 18 – Predicted flood levels at bridges for 100 Year ARI event (with climate change)

Bridge	Length (m)	Soffit level (m)	Predicted flood levels (m)		Projected increase in flood depth (m)
			Pre-development	Post-development	
Proposed Hōteo Viaduct (Bridge 11)	490.0	41.38	27.814	27.850	0.036
Existing Private Bridge	62.0	28.20	27.803	27.807	0.004
Existing SH1 Bridge	70.6	29.76	27.409	27.412	0.003

Figure 58 shows that flood hydrographs obtained at the proposed viaduct of the Hōteo River are identical for pre-development and post development scenarios. The hydrographs and the predicted flood levels indicate that the proposed Hōteo Viaduct will have negligible effect on flooding within the Hōteo River.

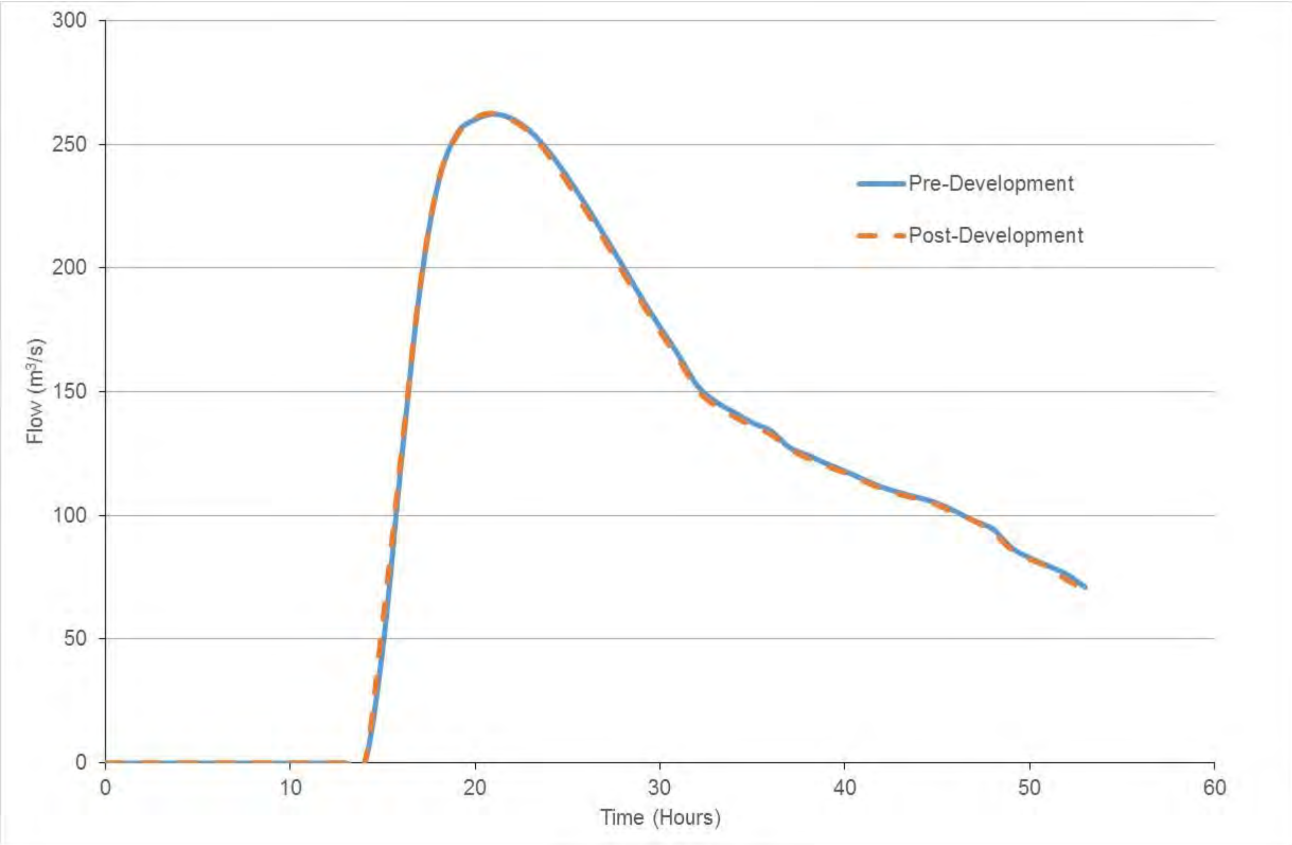

Figure 58 – Comparison of flow for 100 Year ARI Event at the proposed Hōteo Viaduct

4.5.2 Floodplain extent changes

Figure 59 to Figure 62 show flood extents upstream of proposed bridge across Hōteo River for 2, 10, 20 and 100 Year ARI events including the allowance for the effect of climate change. These figures show that the proposed culverts and bridges within the Hōteo catchment have a negligible impact on the extents of flood inundation.

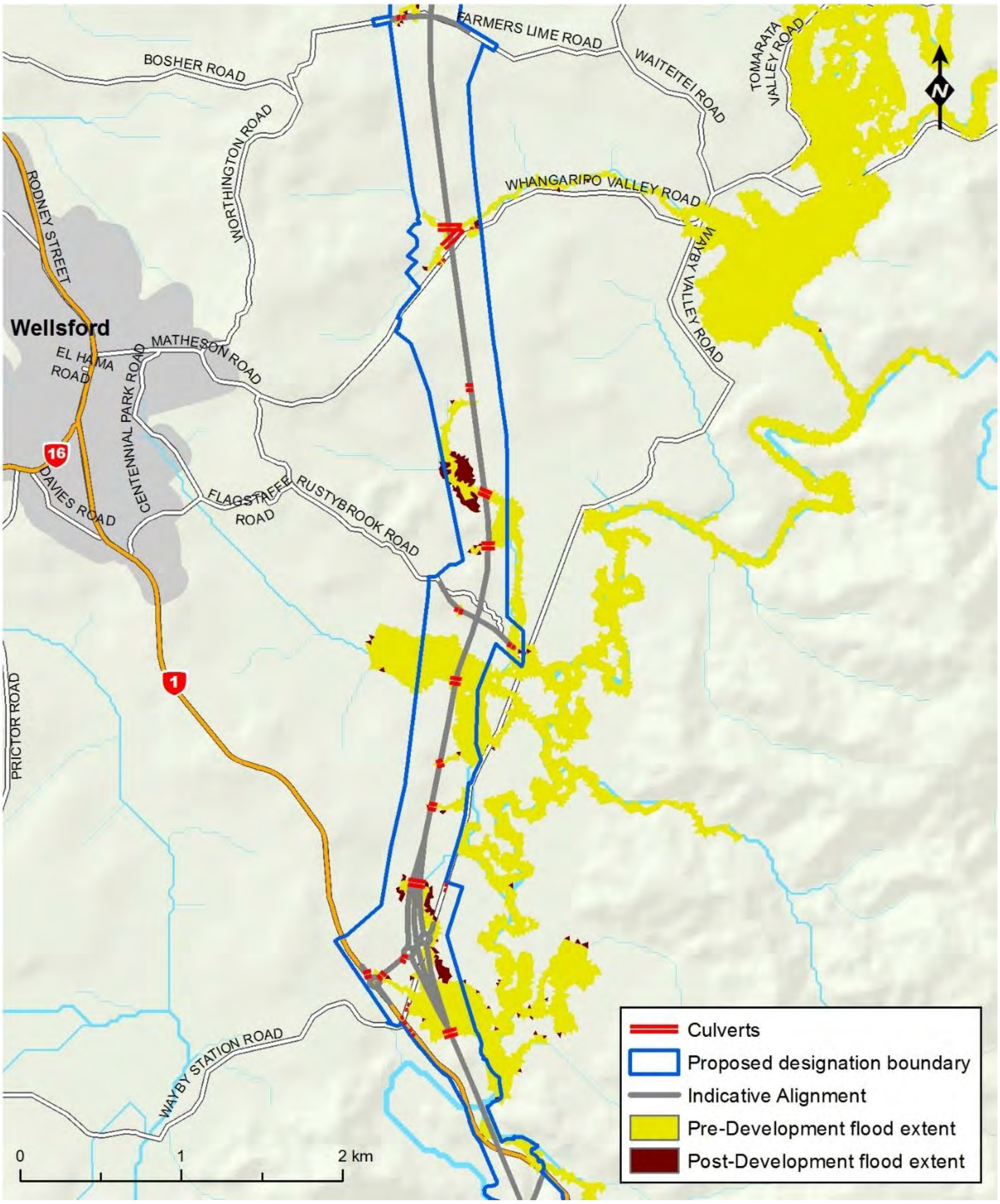

Figure 59 - Comparison of flood extents for pre and post-development scenarios for the 2 year ARI event (with climate change)

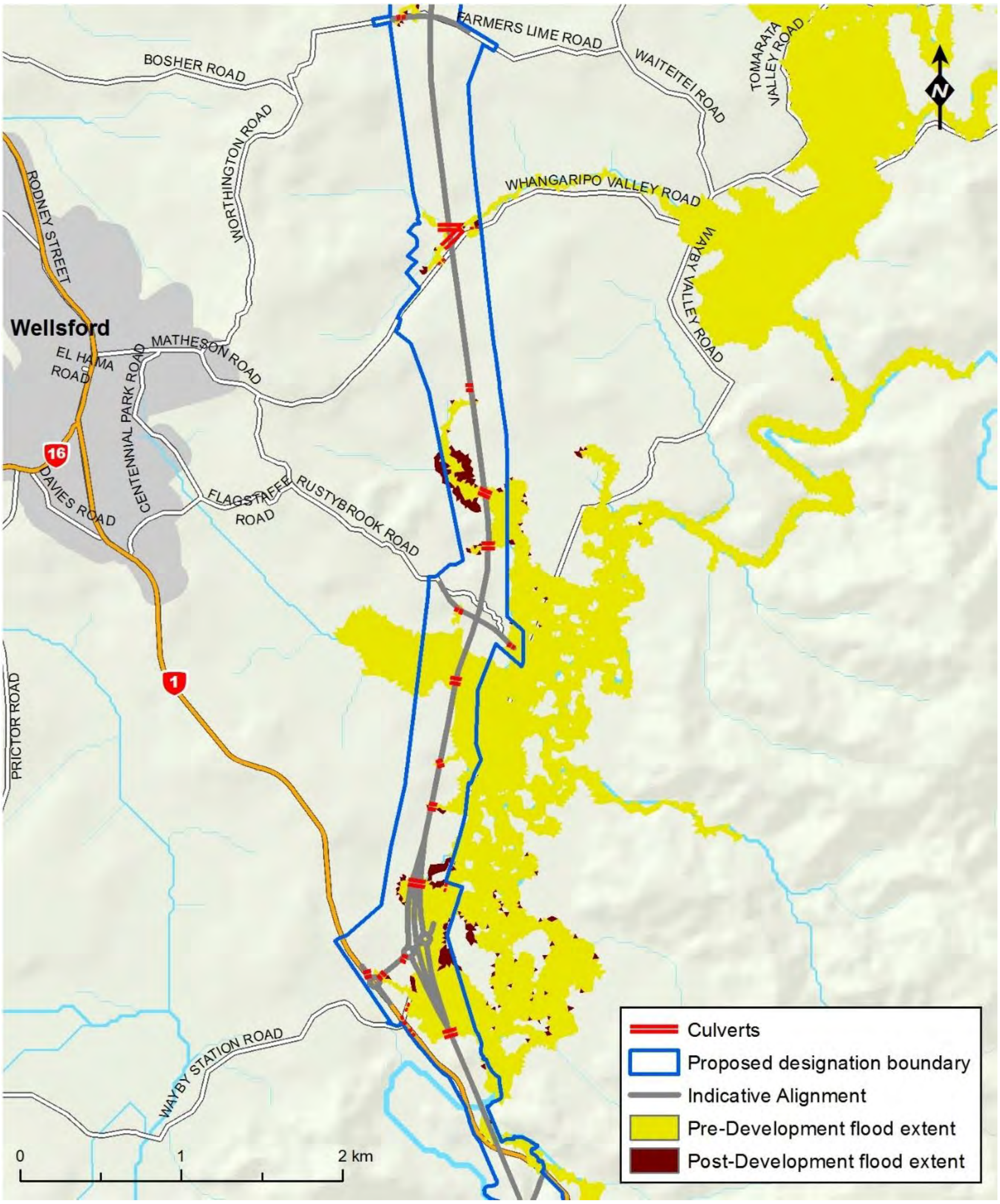

Figure 60 – Comparison of flood extents for pre and post-development scenarios for the 10 year ARI event (with climate change)

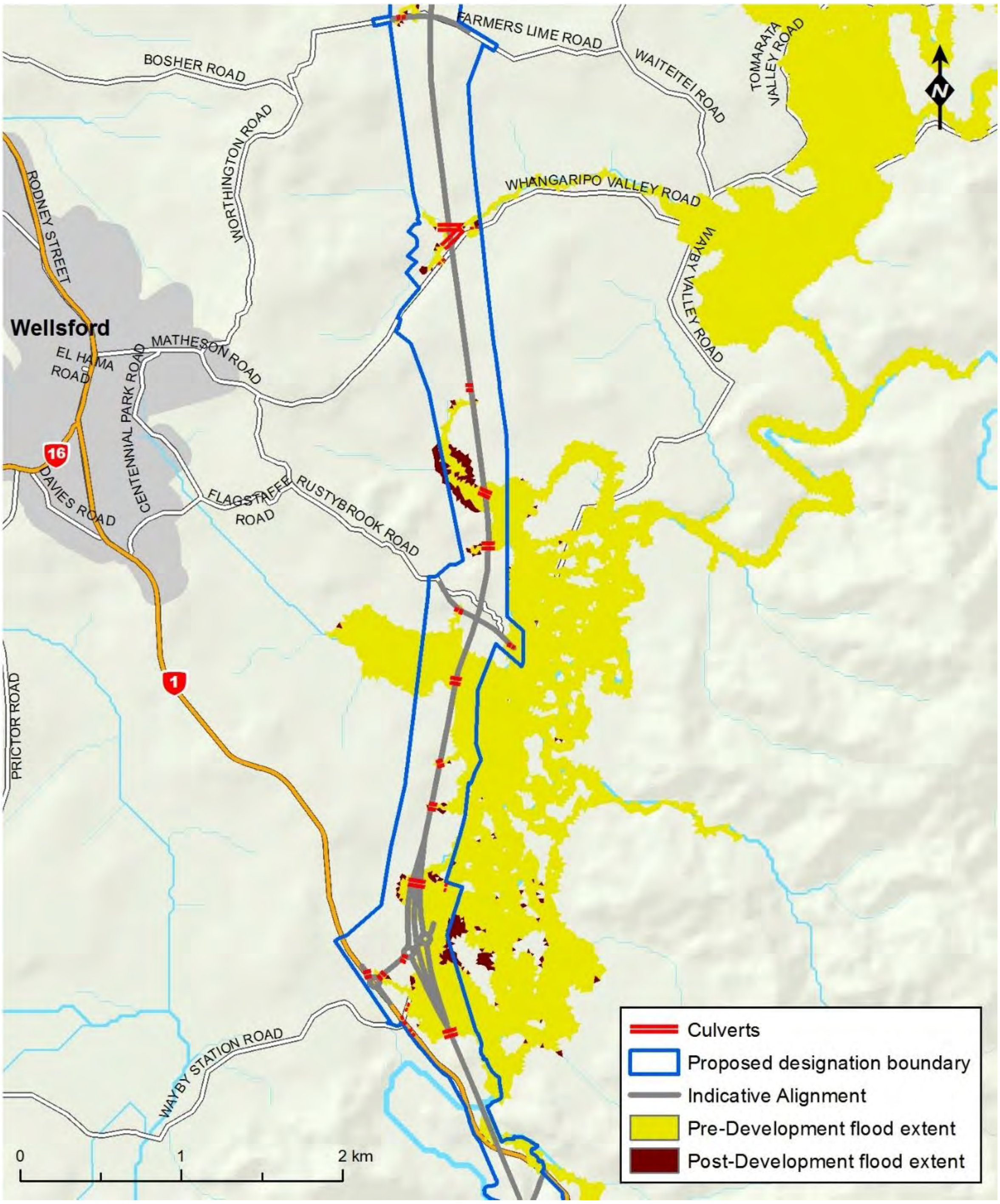

Figure 61 - Comparison of flood extents for pre and post-development scenarios for the 20 year ARI event (with climate change)

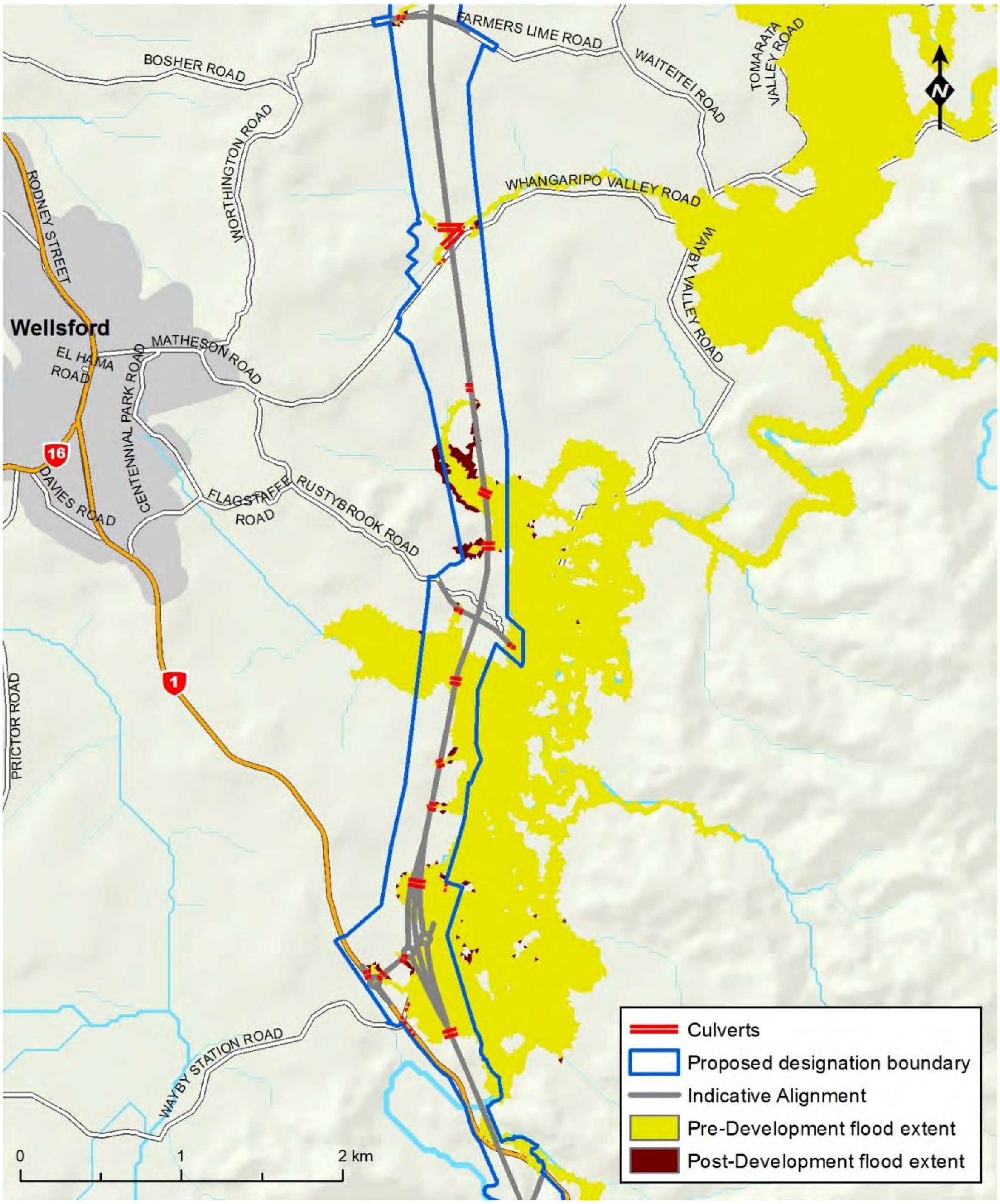

Figure 62 - Comparison of flood extents for pre and post-development scenarios for the 100 Year ARI event (with climate change)

4.5.3 Floodplain depth changes

Figure 63 to Figure 66 show the change in flood depths along the Indicative Alignment for both pre and post development scenarios for 2, 10, 20 and 100 Year ARI events including allowance for the effect of climate change. These figures show that the proposed culverts and bridges within the Hōteo catchment do change flood depth.

The increases in flood depths that occur outside of the designation on the west (upstream) side of the Project are limited in area and consist of a small incremental increase at the edge of the existing foodplain. The increases in flood depths that occur outside the designation on the east (downstream) side of the Project are within the existing floodplain. All of these areas are over pasture, have a short term duration and occur infrequently. They could be mitigated during the detailed design process.

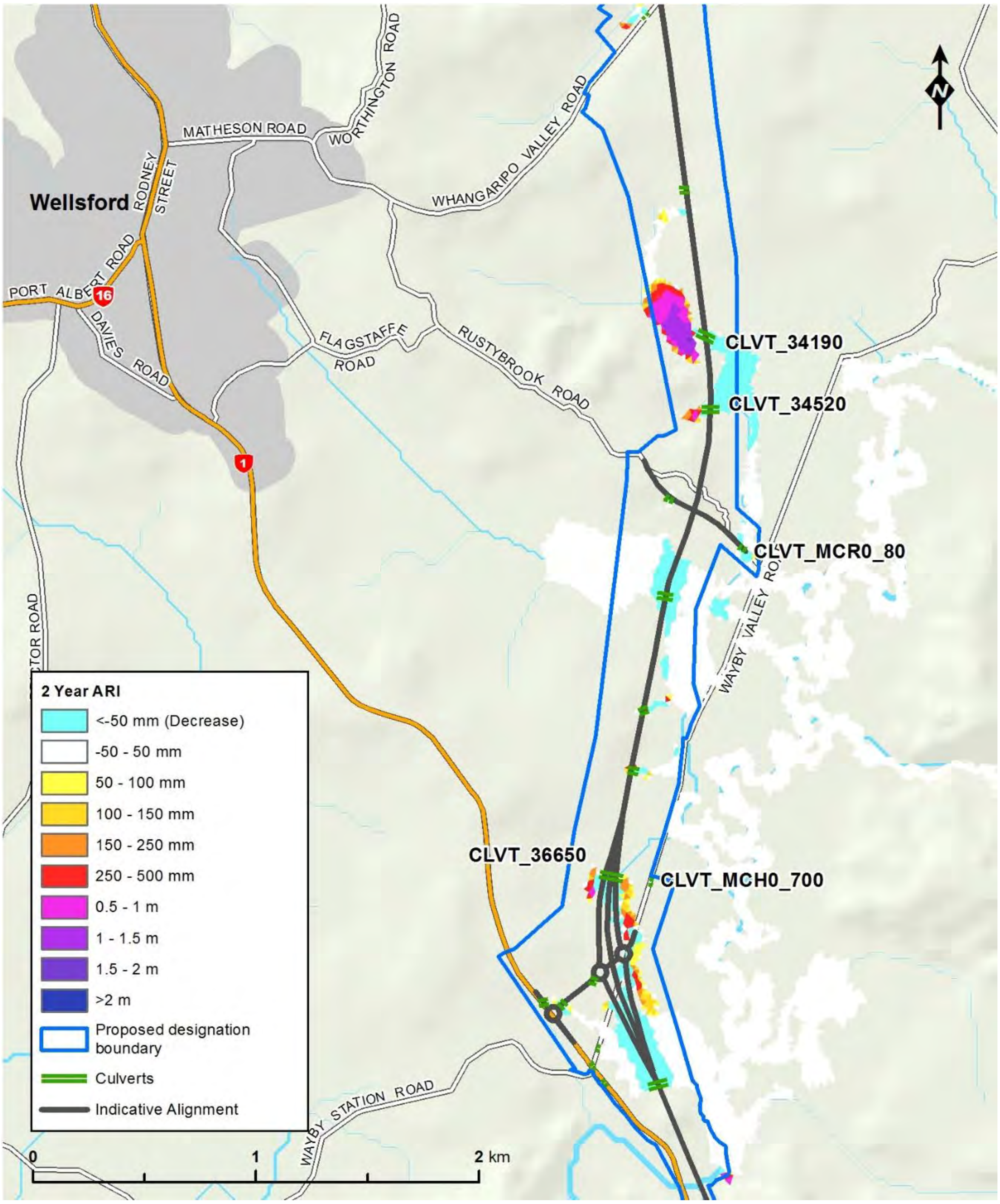

Figure 63 – Change in flood depths due to the Project for the 2 Year ARI event

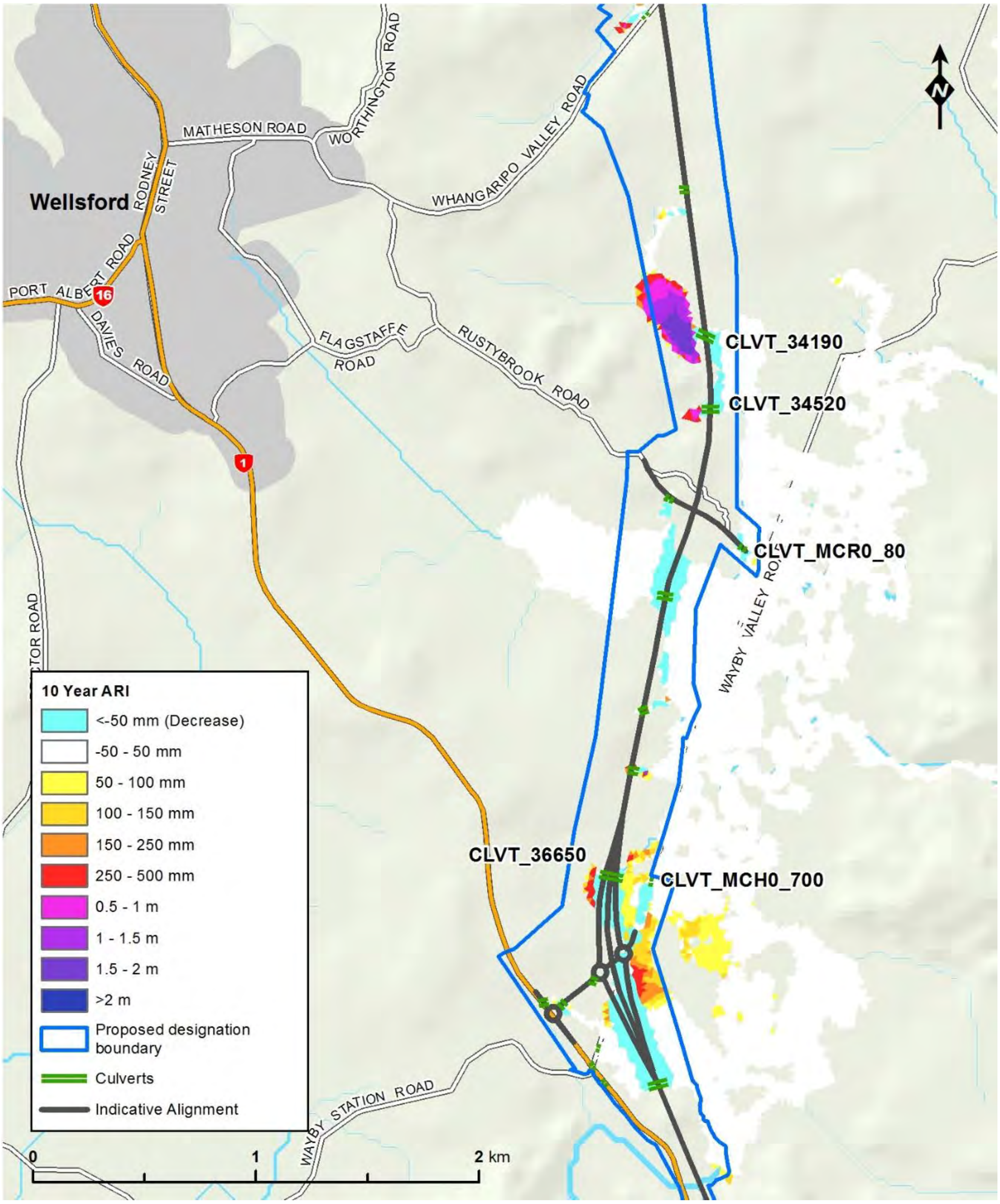

Figure 64 – Change in flood depths due to the Project for the 10 year ARI event

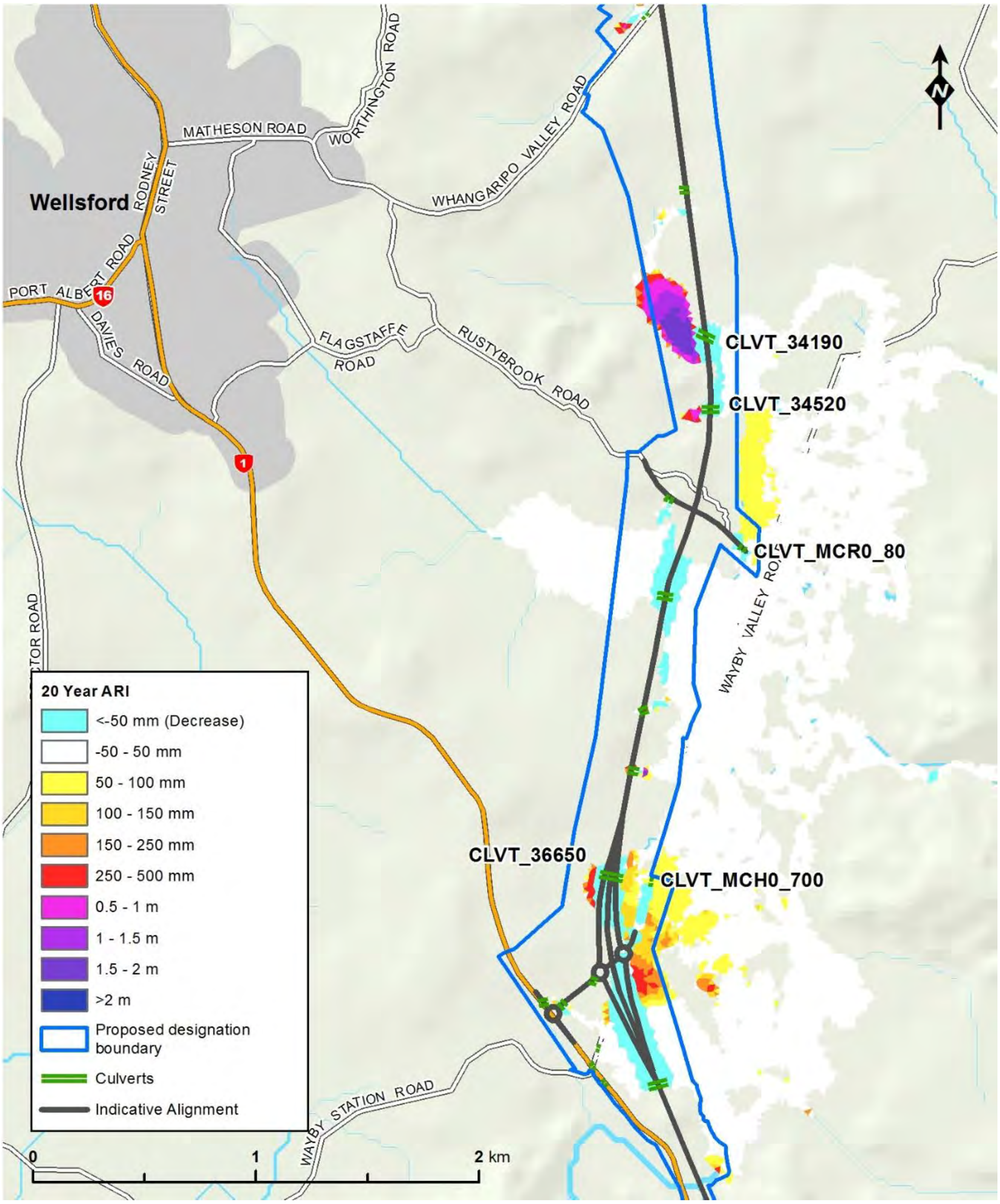

Figure 65 – Change in flood depths due to the Project for the 20 year ARI event

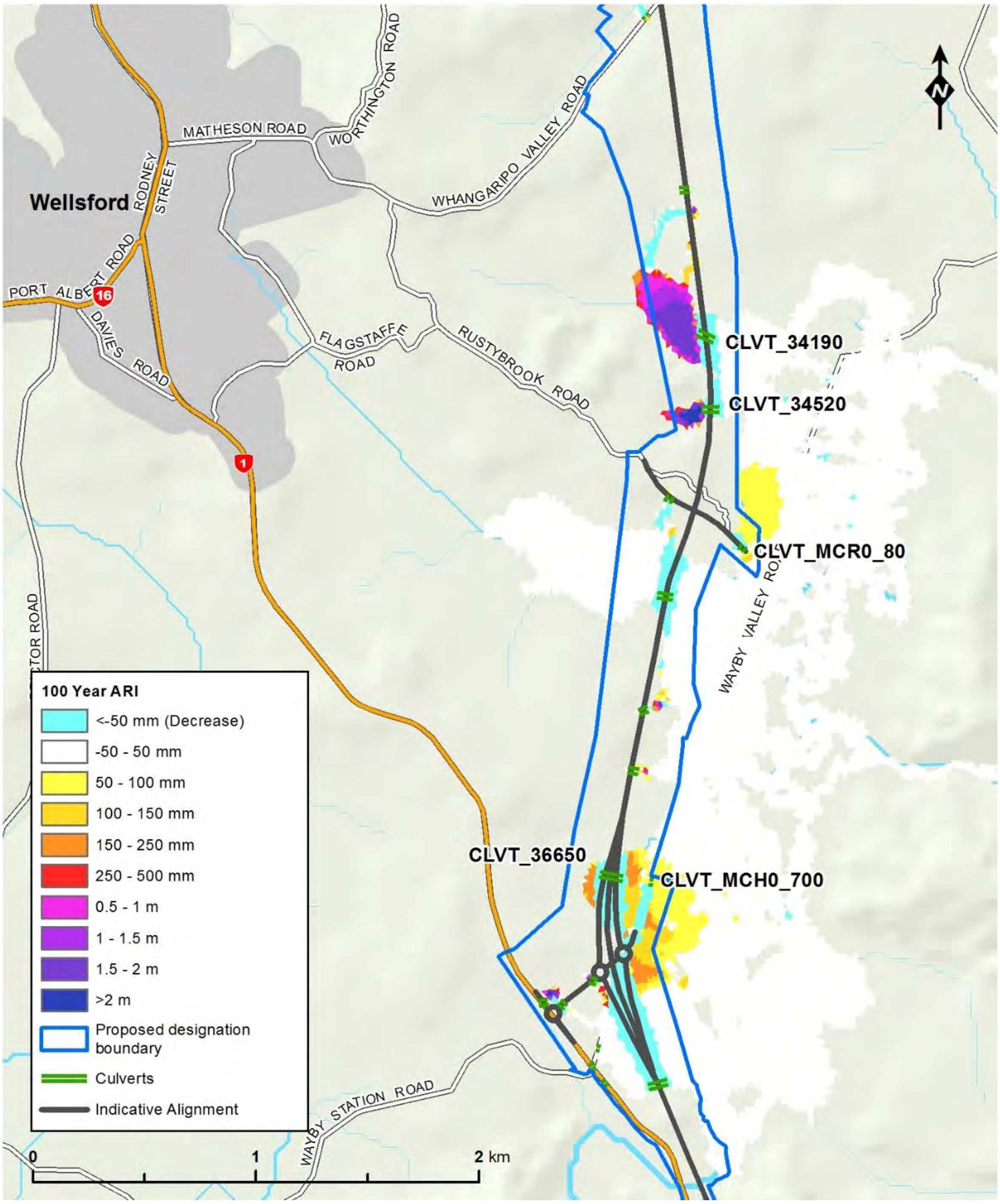

Figure 66 – Change in flood depths due to the Project for the 100 year ARI event

4.5.4 Floodplain depth changes in specific locations

North of Rustybrook Road, the Project increases the flood depth upstream of the proposed culverts in some locations (CLVT_34190 and CLVT_34520) for 2, 10, 20 and 100 Year ARI events (Figure 63 to Figure 66). Within and outside the proposed designation boundary, the increase of flood depth was up to 2 m for 100 Year ARI event at those locations as shown below in Figure 67. This flooding occurs over pasture land.

Upstream of culvert CLVT_34520, the change in flood depth extents obtained for 2, 10 and 20 Year ARI events remained within the proposed designation boundary (Figure 63 to Figure 65) and exceeds it for the 100 Year ARI (Figure 66).

Upstream of CLVT_ 34190 the increase of flood depth upstream obtained for 2, 10 and 20 Year ARI events goes beyond the proposed designation boundary like the results of 100 Year ARI event (Figure 63 to Figure 66). Those high flow depths are possibly due to high tail water levels. Moreover, the model has not captured the existing small channels draining water from the catchment that also triggers flow depths. A cut-off drain needs to be considered at detailed design stage to reduce flooding at this location. The Water Assessment Report will make recommendations to establish performance requirements for flooding that can be then met at the detailed design stage.

Before the intersection of Rustybrook Road and Wayby Valley Road, the Project increases the flood depth upstream of culvert CLVT_MCR0_80 ranging from 50 to 100 mm for 20 Year (Figure 65) and 100 Year ARI events (Figure 66). While, the results show that there is no increase of flood depth for 2 Year and 10 Year ARI events obtained at this location (Figure 63 and Figure 64).

According to building information available on Auckland Council's GIS web-portal, there is a dwelling affected by flood increase within the proposed designation (Figure 67). This dwelling will likely be purchased by the Crown. Table 19 compares the flood depths obtained for pre-development and post-development scenarios of 100 Year ARI event at 237 Rustybrook Road.

Table 19 – Dwelling affected by flooding for the 100 year ARI event

Street address of dwelling affected	Pre-development flood depth (m)	Post-development flood depth (m)	Project increase in flood depth (m)	Location Related to the Project Designation
237 Rustybrook Road	2.18	2.23	0.05	Within proposed designation

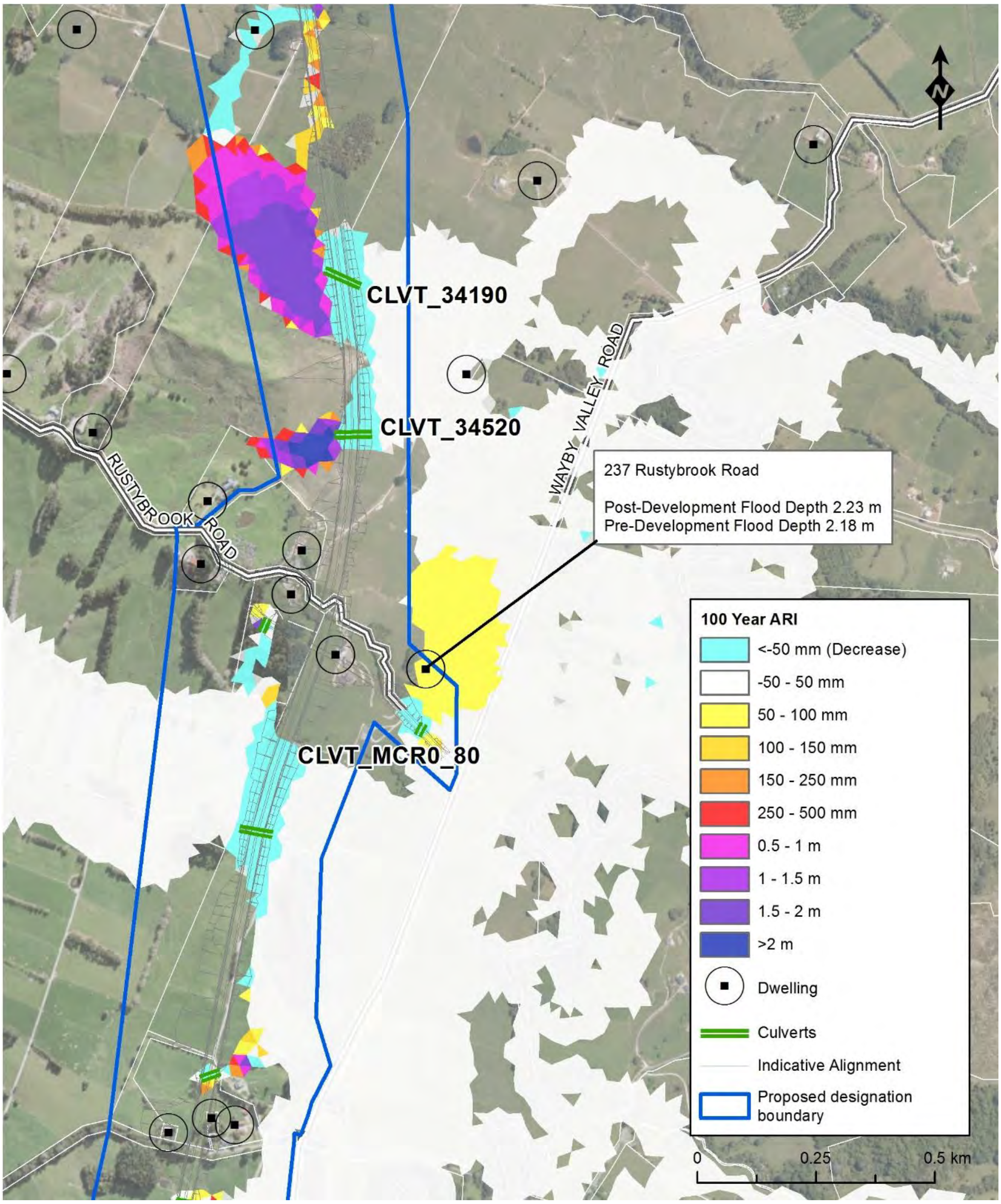

Figure 67 - Change in flood depths due to the Project for the 100 year ARI event - Rustybrook Road

North of the interchange of the existing SH1 and Wayby Valley Road, the Indicative Alignment raises the flood depth at both upstream and downstream of both culvert CLVT_36650 and culvert CLVT_MCH0_700 for the 100 Year ARI event (Figure 68).

Upstream of culvert CLVT_36650, the increase in flood depth ranges from 100 to 200 mm within the proposed designation boundary, which occurs over pasture land.

The flood depth increase was up to 250 mm within the proposed designation boundary upstream of culvert CLVT_MCH0_700 and up to 75 mm outside the designation downstream of culvert CLVT_MCH0_700, which occurs over pasture land.

Likewise at these locations, the flood depth increase was also observed within and outside the proposed designation boundary for 10 and 20 Year ARI events (Figure 64 and Figure 65). Whereas, the increase of flood depth for 2 Year ARI event is confined to within the proposed designation (Figure 63). The model results show that the Project increases the flood depth over Wayby Valley road ranging from 50 to 100 mm for 10, 20 and 100 Year ARI event (Figure 64, Figure 65 and Figure 68). In this area, dwellings are not affected by the flood depth increase as shown in Figure 68 and Figure 68.

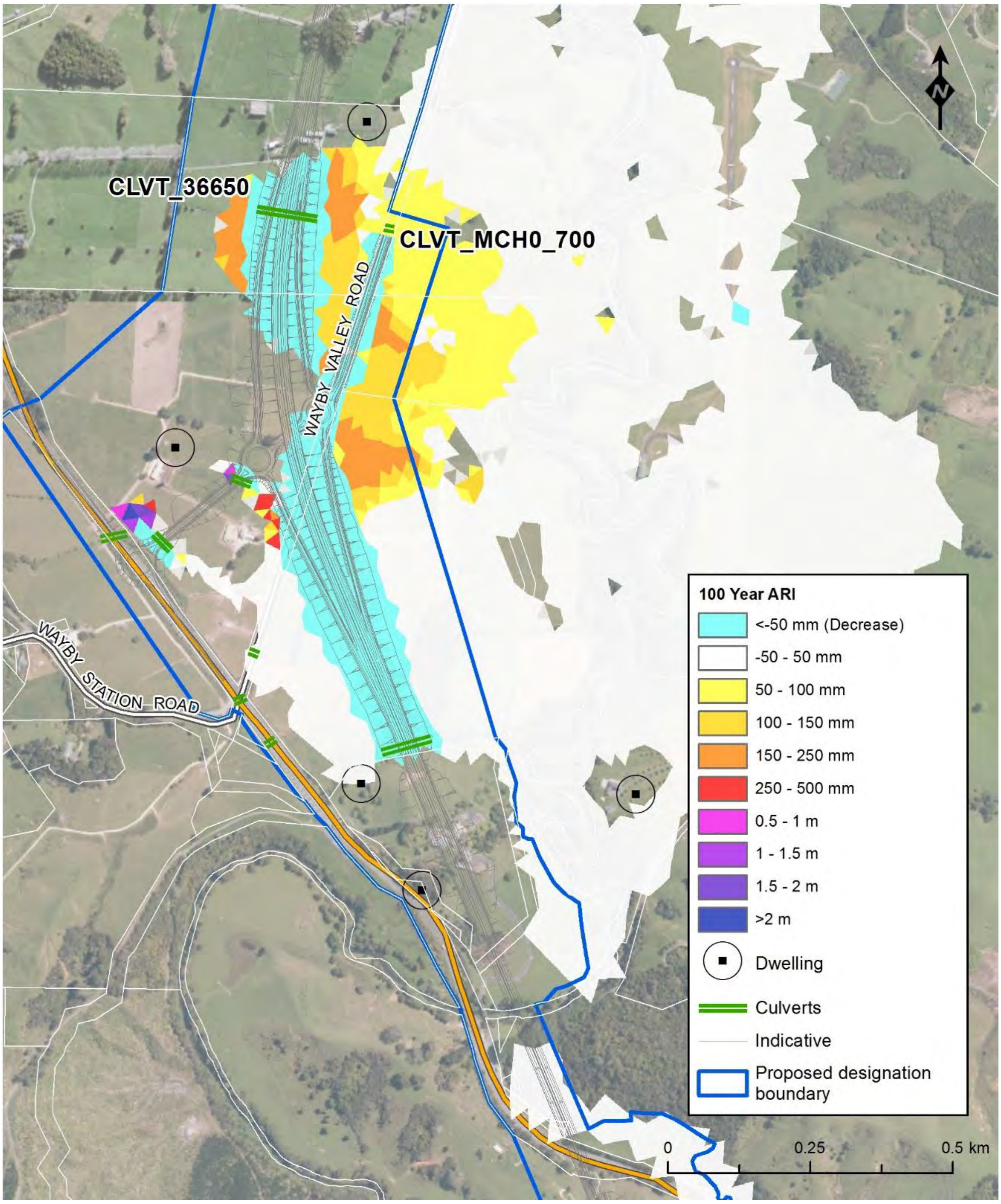

Figure 68 – Change in flood depths due to the Project for the 100 Year ARI Event – SH1 and Wayby Valley road

4.5.5 Culverts

Flood water remains well below the proposed road level at most locations and achieves the design criteria of having a freeboard of equal or greater than 0.5 m and cover on each culvert of 1.0 m as given below in Table 20.

Table 20 – Predicted peak flood levels for 100 Year ARI event at proposed culverts

Culvert	Diameter/ height * No. of barrels (m)	Length (m)	Predicted flood levels after completion of the Warkworth to Wellsford Project (m)		Road level (m)	Freeboard (m)
			Upstream	Downstream		
CLVT_37630	3.05 * 2	90.6	28.28	28.28	33.19	> 1 m
CLVT_MCH0_20	1.80 * 2	41.4	34.31	32.08	35.92	> 1 m
CLVT_MCH0_700	2.50 * 2	23.9	28.96	28.81	30.23	> 1 m
CLVT_36650	3.05 * 2	109.3	29.02	29.03	32.57	> 1 m
CLVT_35380	4.00 * 3	71.8	30.33	30.33	32.27	> 1 m
CLVT_34520	2.30 * 1	81.3	34.63	31.25	36.04	> 1 m
CLVT_34190	3.05 * 2	82.9	32.80	31.25	35.11	> 1 m
CLVT_32600	2.10 * 3	167.0	53.24	49.66	63.55	> 1 m
CLVT_32530	2.55 * 3	148.5	51.73	50.88	64.23	> 1 m
CLVT_MCF0_670	2.05 * 2	28.9	76.29	75.70	77.58	> 1 m

5 Mitigation Planting Along the Hōteo and Mahurangi Rivers

As recommended by ecologists and landscape architects, mitigation planting is being proposed inside of the Project designation boundary for both the Hōteo and Mahurangi Catchments (see EM plan series in the Volume 3, Drawing set). The mitigation planting is located upstream of the proposed viaduct between Wayby Valley Road and the Hōteo River as marked in Figure 69. While within the Mahurangi Catchment, the mitigation planting is proposed along its left bank tributary (Figure 71). The effect of this potential planting has been assessed in the flood model as the planting has the potential to increase the "roughness" of the floodplain, and therefore slow flood flows and to increase flood levels.

According to Plan Land Cover Database (LCDBv4) and confirmed from aerial photographs, the existing land cover of the Hōteo Catchment is defined as High Producing Exotic Grassland, which has a roughness of 0.05 (Table 12) in the flood model. While the area marked in the Mahurangi Catchment has a roughness of 0.08.

According to the ecological and landscape mitigation planting plans, the planting proposed within the Hōteo and Mahurangi Catchments are of following types:

- Landscape Mitigation Planting; and
- Ecology Vegetation Mitigation

For Landscape Mitigation Planting and Ecology Vegetation Mitigation areas, ecologists have proposed that 30% of the area is to be Canopy trees (Kahikatea and Totara as clusters of ~20 trees), 40% Flax/Cabbage trees/Manuka and 30% Wetland grasses.

In view of the above land cover characteristics, the appropriate Manning's 'n' values have been selected from the literature and their details are given below, Table 21.

Table 21 – Selected Values of Manning's Roughness Coefficient for Riparian Planting Areas

Proposed Plantation	Manning's n	Reference
Kahikatea and Totara Trees	0.1	Tonkin and Taylor (2014)
Flax/Cabbage trees/Manuka	0.085	Auckland Council (2011)
Wetland Grasses	0.075	Auckland Council (2011)

Manning's n (roughness coefficient) for the proposed plantation area was computed by taking a weighted area average, which is 0.087.

In this study, the impact of proposed mitigation planting on flooding was assessed by using the Project's flood models of Hōteo and Mahurangi catchments.

In order to consider the impact of the proposed mitigation planting in the hydraulic modelling, the land roughness of the area with planting was changed to 0.087.

Figure 69 and Figure 71 compare the flood extents obtained for post development scenarios with mitigation planting for a 100 Year ARI event including the allowance for the effect of climate change for the Hōteo and Mahurangi Catchments. For both the catchments, the post-development flood extent without planting is plotted over the proposed mitigation planting flood extent. The figures indicate that the flood extent is not increased with planting in either location.

For the Hōteo Catchment there is no change in flood extent, however the model predicts an increase of flow depths upstream of the proposed viaduct ranging from 50 mm to 150 mm with the greatest increase immediately outside the Project designation and reducing to 50 mm depth with distance (Figure 70).

Figure 72 shows the increase of flood depth within the Mahurangi Catchment ranging from 50 to 100 mm in very small areas within the proposed designation boundary.

Figure 70 and Figure 72 show that there are no dwellings directly affected by the increased flood depth in either of the catchments.

We note that the increase in flood depth outside the designation in the vicinity of the Hōteo viaduct occurs in an area of pasture already subject to flooding. The flood depth increase predicted due to planting in the 100 Year ARI event will be of limited duration and occur infrequently. It is not predicted to affect dwellings.

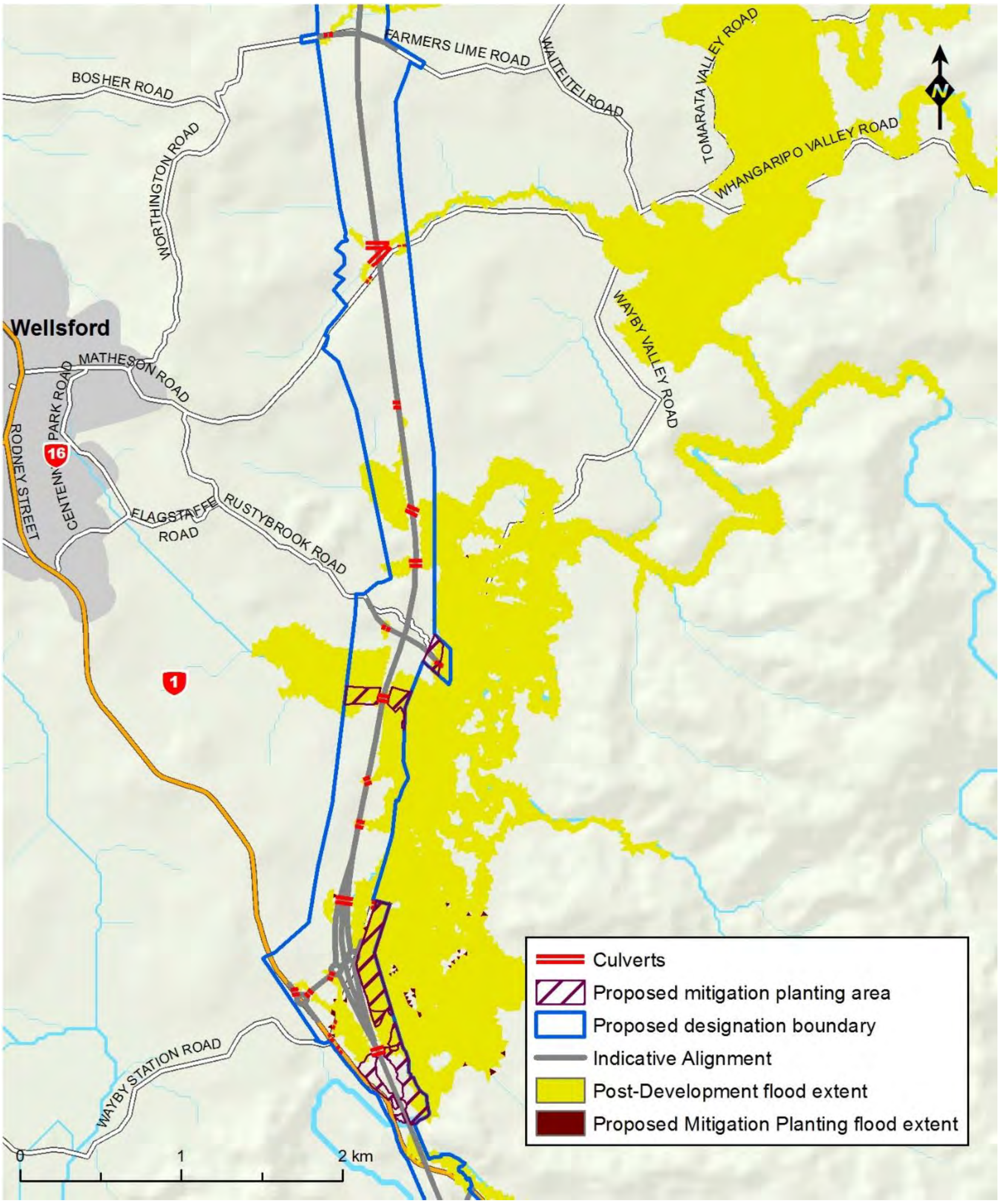

Figure 69 – Comparison of flood extents of the Hōteo Catchment for proposed mitigation planting and post-development scenarios for the 100 year ARI event (with climate change)

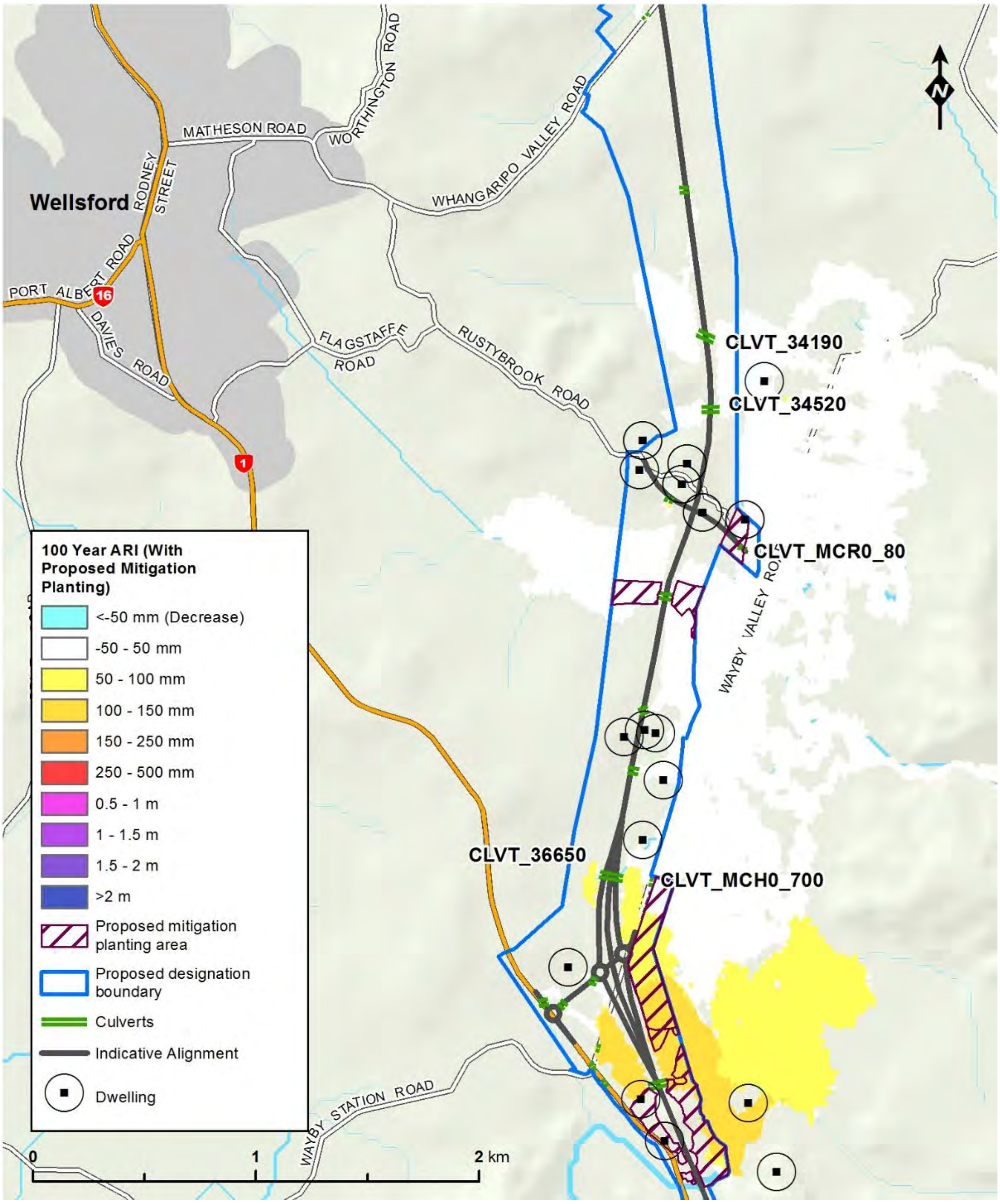

Figure 70 – Change in flood depths within the Hōteo Catchment due to the Project for 100 year ARI event with proposed mitigation planting scenario

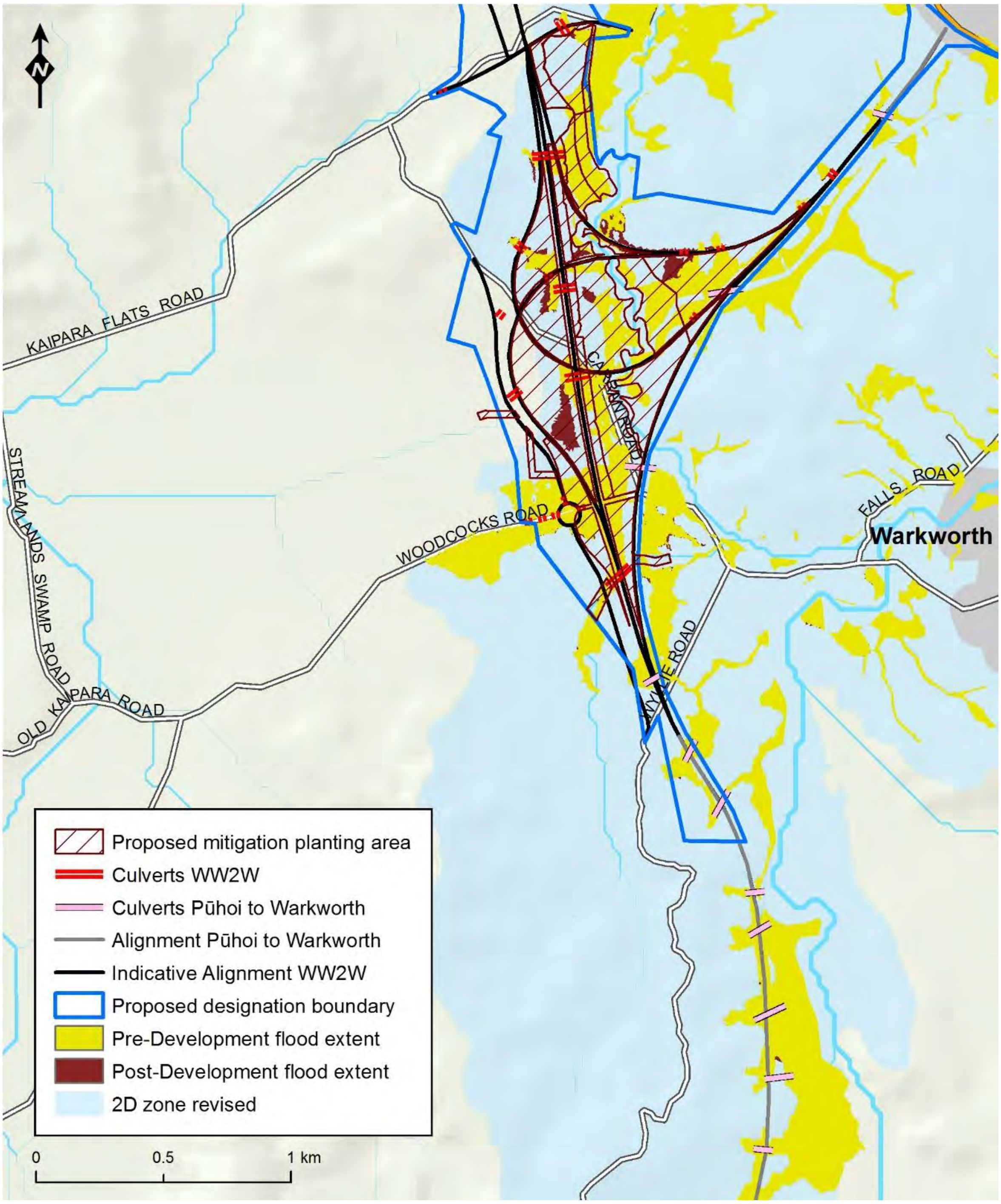

Figure 71 - Comparison of flood extents of the Mahurangi Catchment for proposed mitigation planting and post-development scenarios for the 100 year ARI event (with climate change)

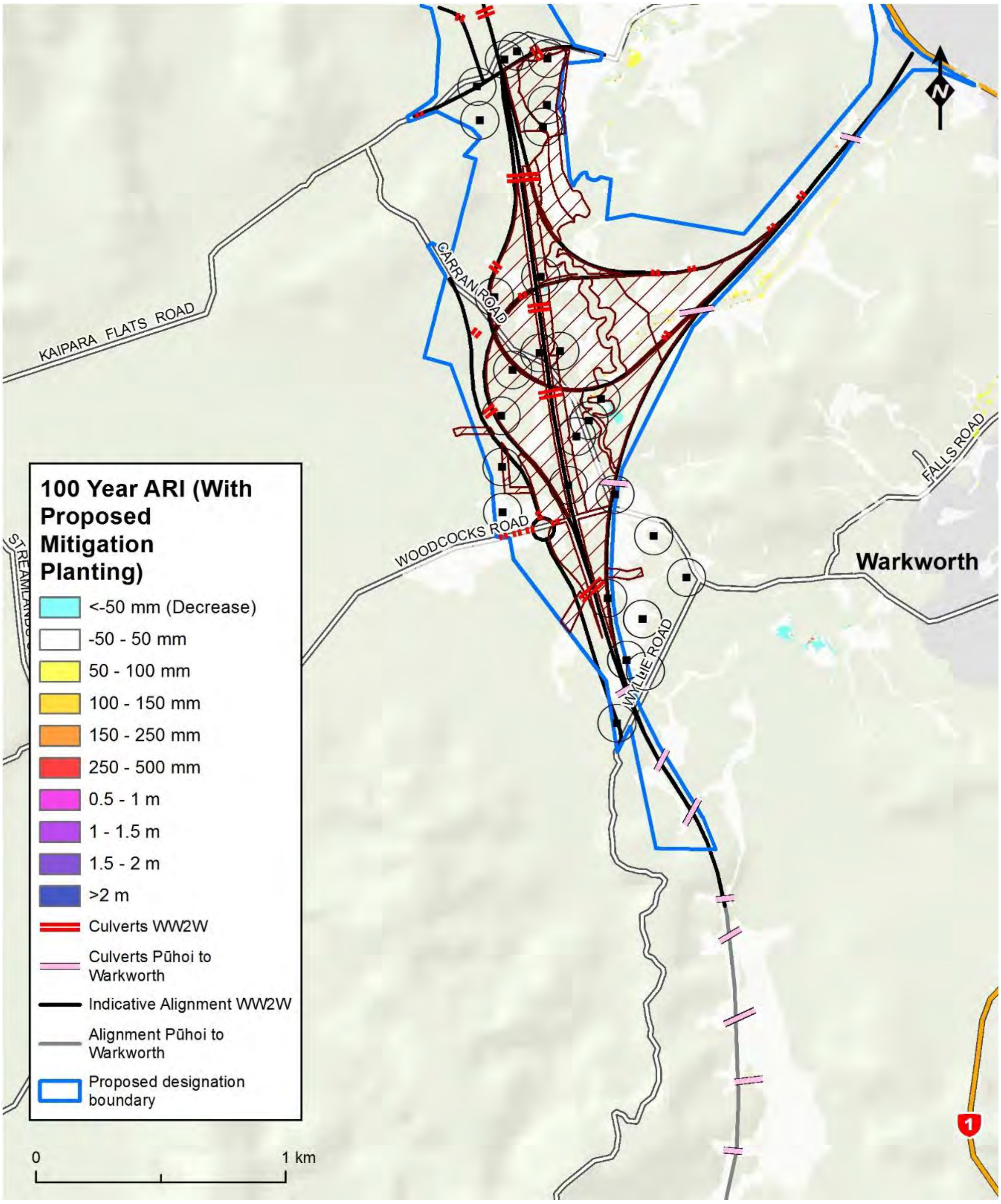

Figure 72 – Change in flood depths within the Mahurangi Catchment due to the Project for 100 year ARI event with proposed mitigation planting scenario

6 FLOOD MODELLING LIMITATIONS

Limitations of the flood modelling work are as follows:

- The hydrological and hydraulic modelling approaches for the Hōteo, Kourawhero and Mahurangi all have limitations as described previously. The modelling approaches are suitable for assessing the effects of the Project and Indicative Alignment at this stage of design detail. However, they will need to be refined for detailed design.

- The use of diversion channels was not considered while carrying out the hydraulic modelling of the Hōteo and Mahurangi Rivers. However, the diversion channels/cut-off drains proposed within the Kourawhero catchment are sized using the flows of the respective sub-catchments and modelled as rectangular channels.

- This flood assessment, only relates to the flood effects related to the loss of flood storage due to the volume of the road in the floodplain and the changes in drainage associated with culverts, diversions and bridges. Curve numbers of the area, where the Project is proposed, have not been updated to reflect the increase in imperviousness in hydrological models developed to compute flows for Hōteo, Kourawhero and Mahurangi catchments.

- This flood assessment only considers the planting types and areas proposed by the landscape architects and ecologists at the time of writing (Section 5 of this report) and based on mitigation plans included in the Ecology mitigation series, Volume 3 of the Application: Drawing Set.

7 CONCLUSIONS

In the light of results of this study, following conclusions have been made:

- The models are suitable for identifying the likely effect of the Indicative Alignment.
- The results of the modelling show that the changes to flooding from the Indicative Alignment on flooding are mostly negligible. Where the changes are not negligible, the increase in flooding can be mitigated by standard engineering methods during the design phase and controlled by resource consent conditions.
- Diversion channels proposed within catchments will influence flood levels local to them rather than the main floodplain flood levels. Flood modelling to support detailed design can confirm that diversion channels (with all other aspects) meet flood performance requirements set out in resource consents.
- The impact on flood levels of changes in imperviousness is expected to be very small. In our view, the changes in flood levels presented in this report, provide a good basis for estimating the overall flood effects.
- This assessment considers the impact on flood levels and extents of the Indicative Alignment. If in the detailed design phase the alignment was to shift or the size and location of cross-drainage (culverts and bridges) was to change, then the flood changes may also be different.
- This assessment predicts that the mitigation planting in the Hōteo Catchment has the potential to increase flood depths on pasture land outside the designation in the 100 year ARI event. This is not predicted to affect dwellings.
- The scale of flood effects presented in this report is likely to be representative of a similar alignment within the proposed designation boundary. However, at the detailed design stage, further hydraulic modelling will be required to ensure the road can meet relevant performance requirements established in resource consent conditions and in NZTA requirements.

8 REFERENCES

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APPENDIX A: HŌTEO SENSITIVITY ANALYSIS

Sensitivity analysis of Hōteo Model was undertaken because we developed a calibrated model of the Hōteo, and Auckland Council does not have a detailed hydraulic model of the Hōteo River.

Sensitivity analysis of Hōteo Model was carried out by studying the variation in model results due to change in Manning's roughness coefficient, peak flows of the 100 Year ARI event with allowance of climate change and peak flows of TP108. These are described in further detail below.

Sensitivity analysis was not undertaken for Kourawhero, because this is a small catchment, and there is no flow data to calibrate a model. Sensitivity analysis was not undertaken for the Mahurangi, because we adopted the Auckland Council model and the model built for Pūhoi to Warkworth project. The parameters within the Auckland Council model were calibrated as part of that model development. However, the design flows used in the model are based on the TP108 methodology, and these design flows are conservative when compared to the flood frequency estimates of design flows, using the statistical record. At the detailed design stage, the hydrology for the Mahurangi catchment may be revised.

Manning's roughness coefficient

Sensitivity of hydraulic model was checked by reducing the Manning's roughness coefficient to 0.040 and by increasing its value to 0.050. This scenario showed little impact over the generated peak flows at Gubbs station. The peak flow obtained at Gubbs station for 0.040 was 373 m^3/s, whereas by increasing the roughness to 0.050, the value of peak flow obtained at Gubbs station was 370 m^3/s. The results show that the model is not substantially affected by a change in roughness.

Peak flow

Besides studying the impact of Manning's roughness coefficient over peak flows, the sensitivity of model was also checked by increasing the peak flows by 26.5% to represent the effects of climate change. As a result of the increased inflow, the projected water depth at proposed bridge location was increased by 500 mm and raised the flood peak at Gubbs station to 472 m^3/s.

TP108

Table 22 compares the peak flows calculated using TP108 and Flood Frequency methods for the 100 Year ARI event for sub-catchments of the Hōteo River.

Table 22 – Peak low comparison of TP108 and flood frequency analysis for the 100 year ARI flood (with allowance for the effect of climate change)

Catchment No.	Peak flow (m^3/s)	
	TP108	Frequency analysis
1	401.1	129.3
2	188.63	59.57

Catchment No.	Peak flow (m^3/s)	
	TP108	Frequency analysis
3	392.2	114.0
4	344.5	101.0
5	85.8	16.20
6	237.5	45.80
7	111.75	76.30
8	101.5	47.2
9	217.5	62.7
10	172.9	30.6
11	181.6	32.8

As Table 22 shows the TP108 flows are very conservative. This is likely to be because the catchment size of most sub-catchments of the Hōteo River exceed 12 km^2, which is one of the application limitations of TP108.

Figure 73 shows the extents of flooding for both pre and post-development scenarios assessed for the 100 Year ARI event of TP108. Figure 74 below illustrates the change in flood depth obtained for the 100 Year ARI event of TP108 with the Indicative Alignment. The setup of the hydraulic model is identical to the model as discussed in Section 4.3 above, except for the flows.

The model results show that with TP108 flows, the flood depths on Wayby Valley Road are increased by between 100 mm – 400 mm (Figure 74).

However, the flows calculated using TP108 are not realistic for the Hōteo River and a much more reliable estimate of the flow is predicted using the flood frequency method, this is illustrated in Section 4.2.

As compared to Manning's roughness coefficient, the model results are more sensitive to peak flows.

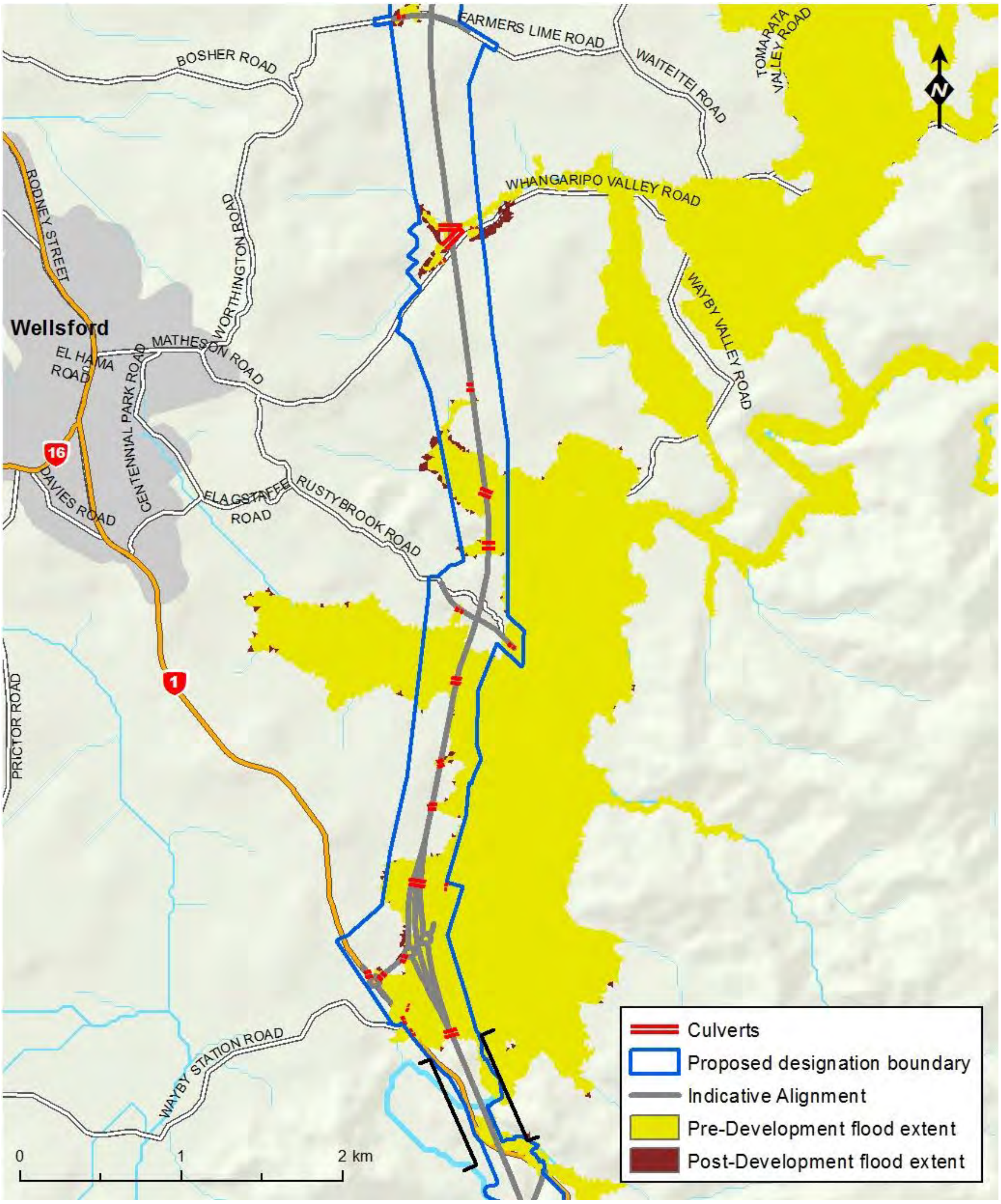

Figure 73 - Comparison of Flood Extents for Pre and Post-Development Scenarios for the 100 Year ARI Event of TP108

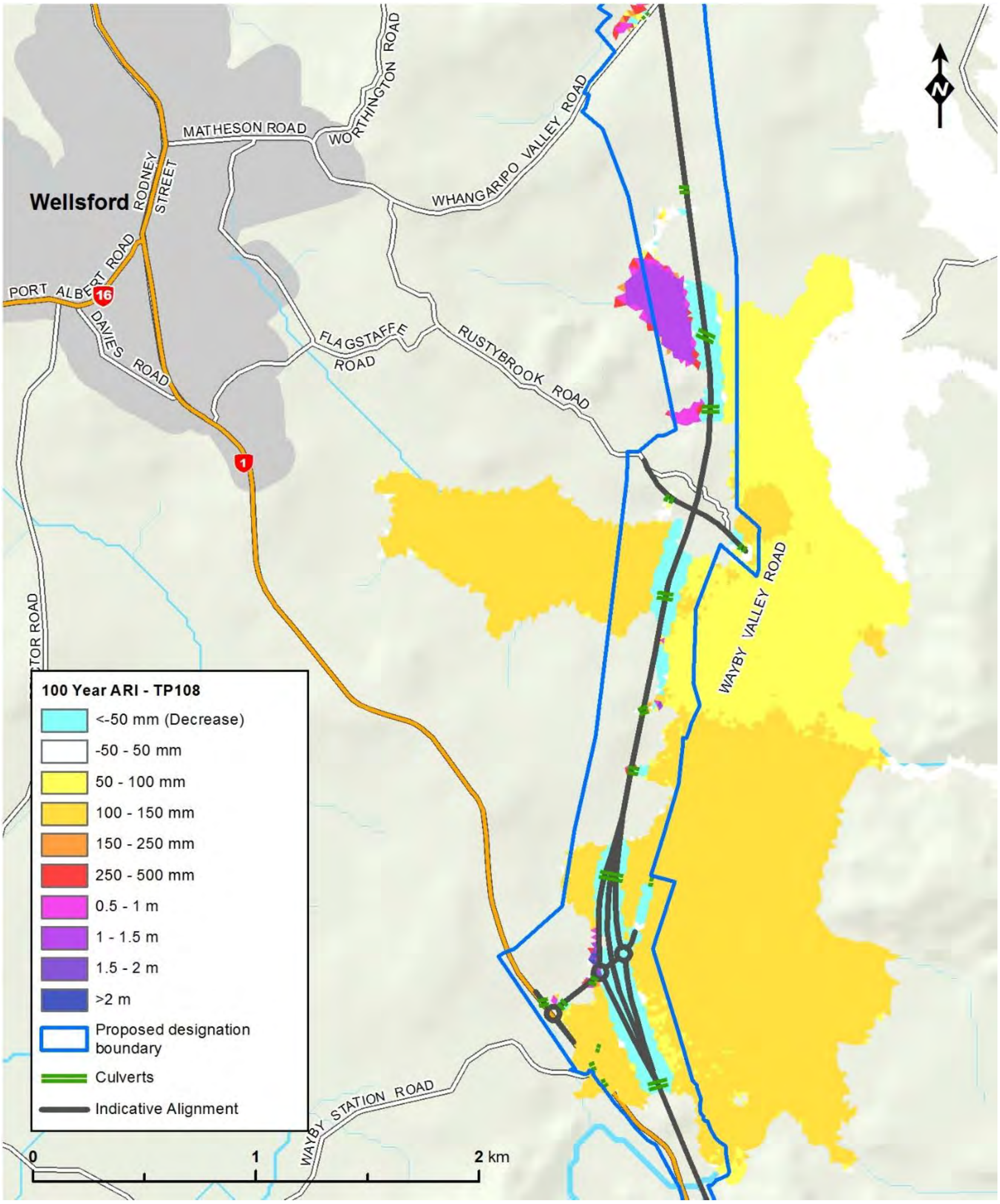

Figure 74 - Change in flood depths due to the Project for the 100 Year ARI Event of TP108