Belfast to Pegasus Motorway & Woodend Bypass Pre-implementation and MSQA Professional Services

Flood Assessment Report

NZ Transport Agency (NZTA)

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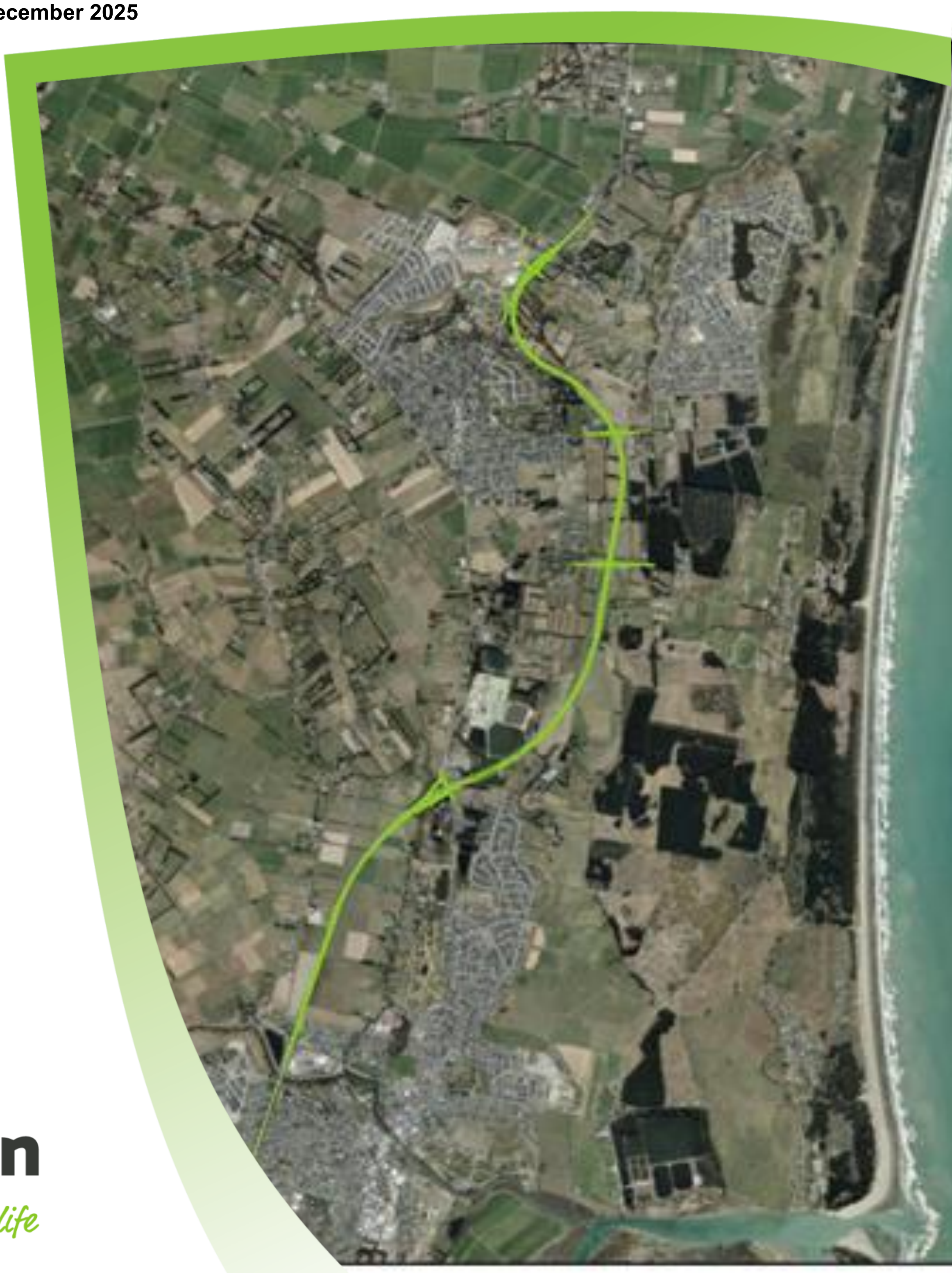

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Document prepared by:

Aurecon New Zealand Limited

Level 2, Iwikau Building
93 Cambridge Terrace
Christchurch 8013
New Zealand

T +64 3 366 0821
F +64 3 379 6955
E christchurch@aurecongroup.com
W aurecongroup.com

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Approval			
Author signature		Approver signature	
Name	Yanni Hooi	Name	Haden Walters
Title	Senior Water Engineer	Title	Design Manager

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1 Introduction and Background

1.1 Background

Waka Kotahi has engaged Aurecon to support the resource consent applications in the proposed Belfast to Pegasus Motorway and Woodend Bypass. In line with this project, a flood assessment has been conducted to evaluate the impact of a 100-year and 200-year Average Recurrence Interval (ARI) storm event on the proposed road development.

For the purposes of the current assessment and to optimise the computation time, a cut-down catchment model tailored to the Project Site and adjacent surroundings as shown in Figure 1-1 has been built using TUFLOW modelling software. The model will be referred to as the “B2P Flood Model” throughout the rest of this report.

The purpose of this report is to outline the following:

- The methodology for building the B2P Flood Model
- A comparison of flood impacts before and after the road development

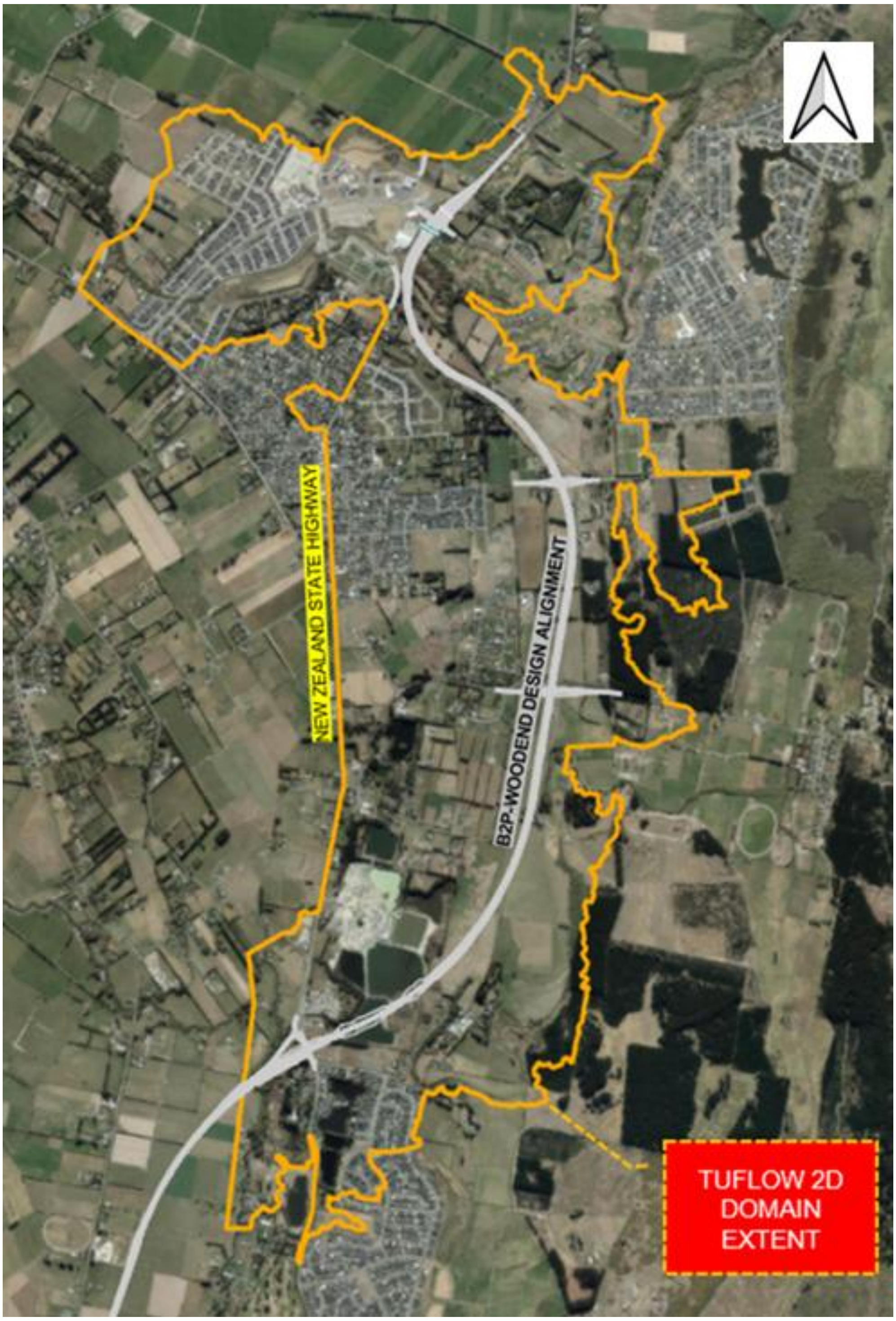


Figure 1-1 B2P Flood Model Extent with the Proposed Belfast to Pegasus Motorway and Woodend Bypass Road Alignment

1.2 Objectives and Scope of Assessment

The objectives of the current assessment include developing the B2P Flood Model to analyse flood impacts before and after development.

Based on local authority advice, the following objectives have been established for this project:

- No significant increase in flood levels at neighbouring dwellings for the 100-year ARI event.
- Any increase in flood levels at neighbouring dwellings for the 200-year ARI event should be limited to 20 mm.

- Reduce the risk of ponding/runoff buildup that will be brought about by the barrier effect of the proposed road development on adjacent surroundings. Mitigation measures will consist of provision of additional culverts across the road alignment, improvement/rehabilitation of existing culvert structures, and provision of additional channels to improve flow of runoff.

1.3 Flood Model History

Figure 1-2 shows the model extent of the Waimakariri District Council (WDC) South Ashley Flood Model. This flood model was developed in 2019 by DHI using MIKE by DHI modelling software. Detailed information with regard to model build is documented in the May 2020 "Flood Hazard Models Update" report[1].

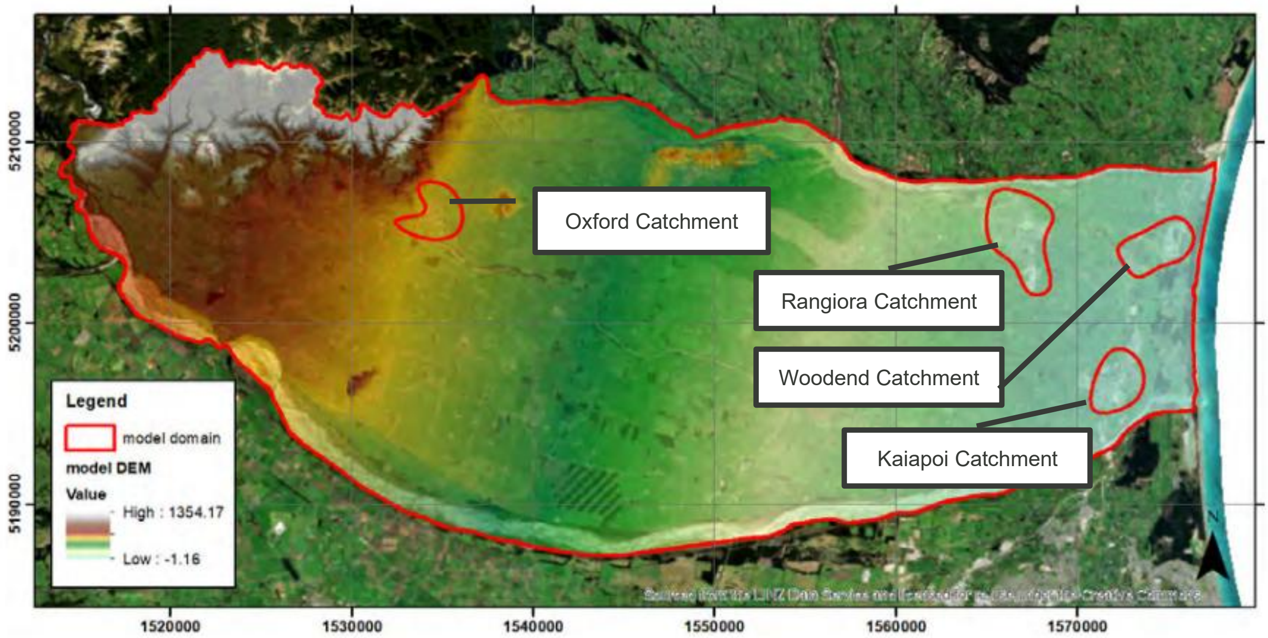


Figure 1-2 South Ashley Model catchment extent[2]

In this study, the B2P Flood Model has been created for the Project Site by utilising TUFLOW modelling software (Figure 1-3), using the WDC South Ashley Model as a reference.

[1] DHI (May 2020). *Flood Hazard Models Update*.

[2] Extracted from Flood Hazard Models Update Report.

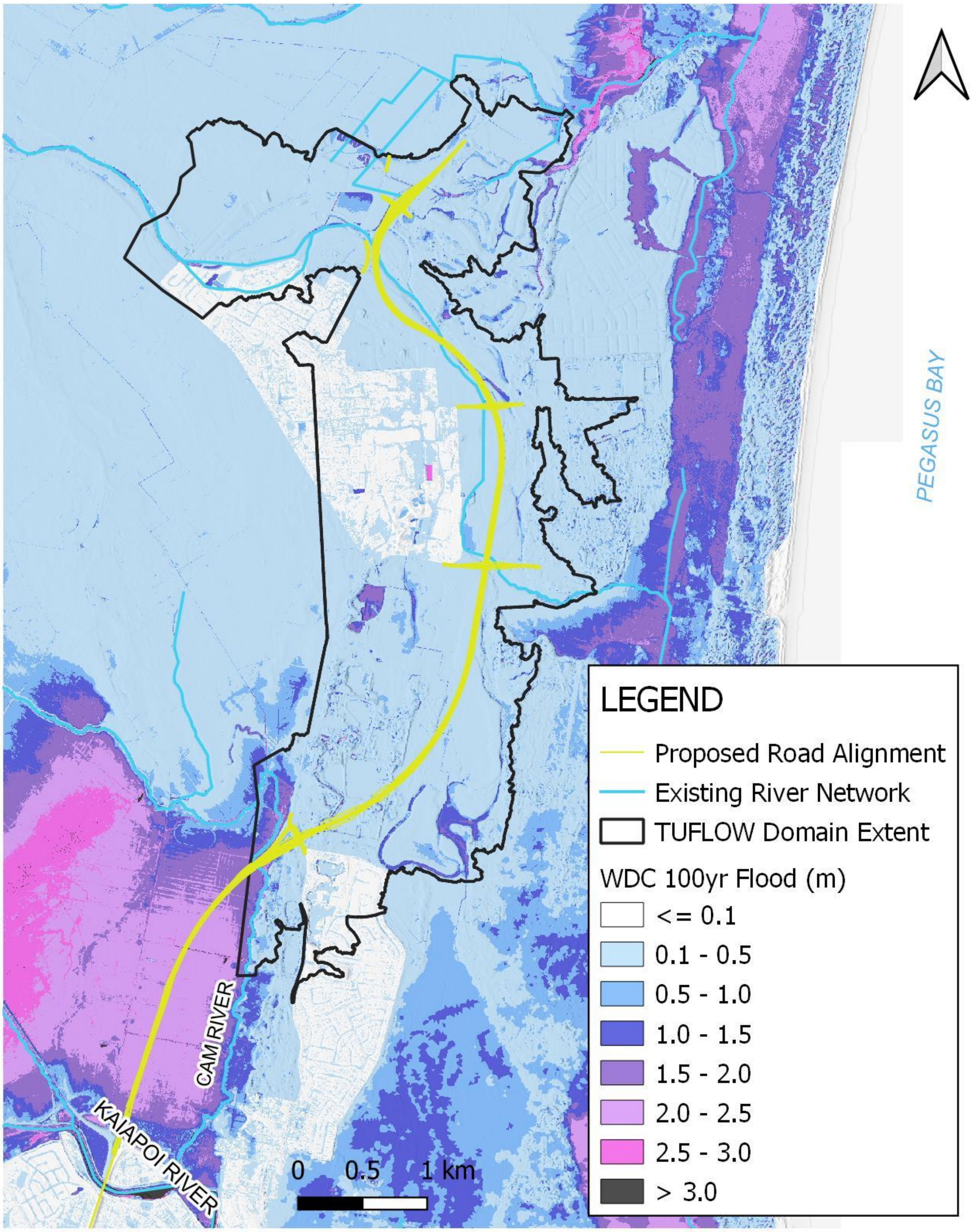


Figure 1-3 Model Extent of B2P - Woodend Flood Model

2 B2P Flood Model Development

The B2P Flood Model extent is a cut-down catchment model tailored to the Project Site and has been built using TUFLOW modelling software. Three modelling scenarios, the Pre-development, Post-development, and Mitigation scenarios were developed and assessed.

The purpose of each scenario is listed in Table 2-1. Further details of these scenarios are discussed in Appendix A Each scenario has been run for the 100-year and 200-year ARI storm events.

Table 2-1 Model scenarios and purpose

Model Scenario	Scenario Case	Purpose
PREDEV	Existing/pre-development scenario	To understand the existing flooding conditions. This will be the baseline model for the flood impact assessment.
POSTDEV	Design/post-development scenario with Bypass Motorway included	To understand the potential flood impacts due to Bypass Motorway if no mitigation measure are undertaken.
MITIG	Design/post-development scenario with the Bypass Motorway and mitigation solutions included	To resolve flood impacts identified under the design scenario.

The B2P Flood Model terrain has been updated to incorporate the 2020 LiDAR Digital Elevation Model (DEM) and available surveyed data. The hydrological and hydraulic input data such as rainfall, ground infiltration, and surface roughness are extracted from the WDC South Ashley Model. The detailed model build methodology is described in Appendix A.

Note that for vertical datum, as described in Appendix A, the original flood model was carried out in Lyttleton Vertical Datum (LVD), whereas the B2P Flood Model is in New Zealand Vertical Datum 2016 (NZVD16). Levels within this memorandum are quoted in NZVD16 unless otherwise stated.

The B2P Flood Model is mainly built as a two-dimensional (2D) model, integrating open channels into the DEM, with culverts represented using a one-dimensional (1D) model. Pipe reticulation has been excluded from the B2P Flood Model, in compliance with the WDC requirements regarding the modelling of full pipe blockages.

In the B2P Flood Model, three principal river channels have been identified, as shown in Figure 2-1: Taranaki Stream, located to the north of Bob Robertson Drive; Waihora Creek, situated near Garlick Street; and McIntosh Drain, which lies between Quarry Lake and Woodend Beach Road. Taranaki Stream flows northward towards Waikuku Beach, while the Waihora Creek initially flows south, then turns east towards Kairaki Creek, close to Woodend Beach Road. McIntosh Drain also flows south and ultimately merges with the Kaiapoi River.

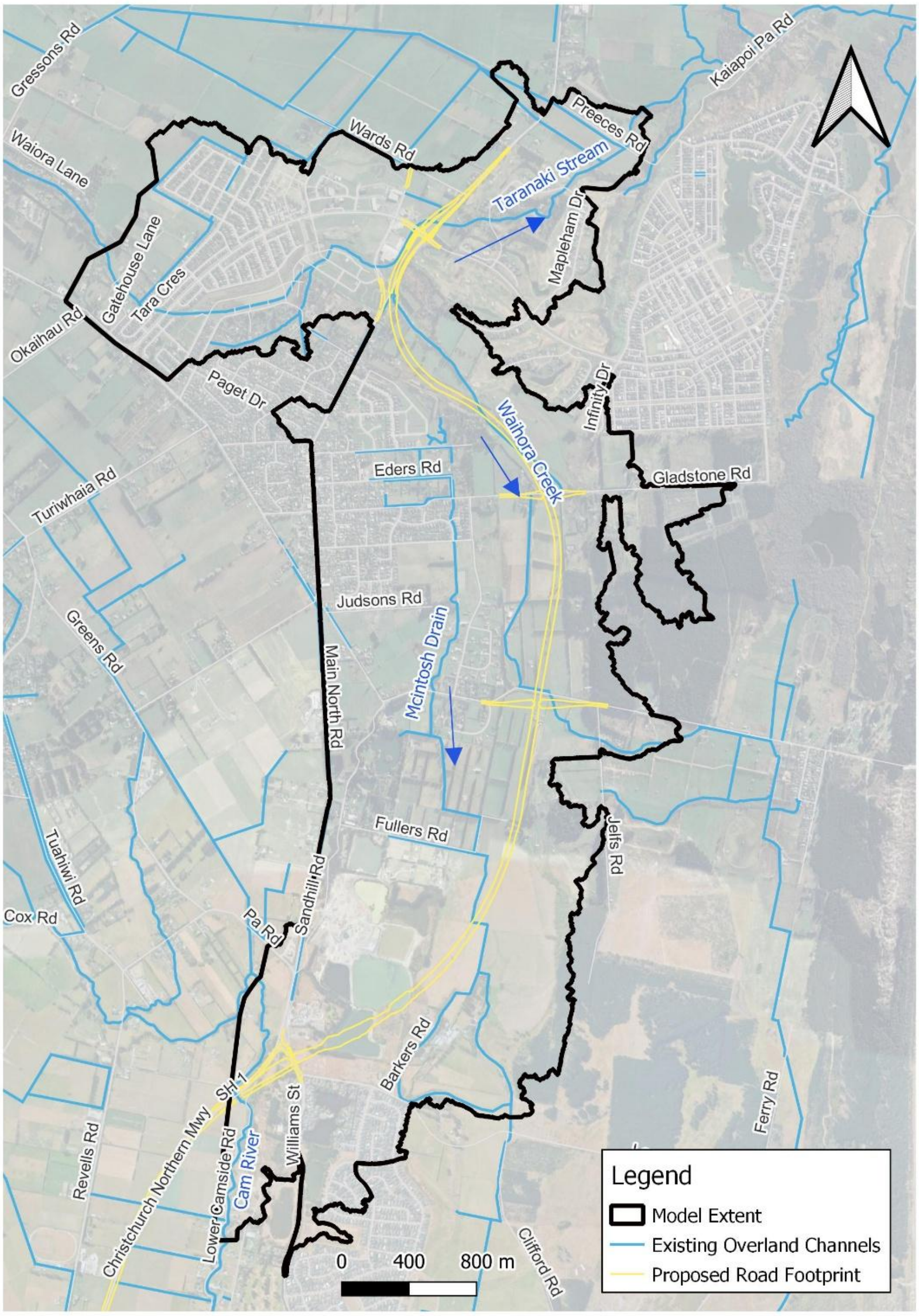


Figure 2-1 Principal River channels within the model catchment extent

A detailed description of the model development methodology is provided in Appendix A, while the updates representing various post-development and mitigation scenarios can be found in Appendix B.

2.1 B2P Pre-Development Model

The detailed model build methodology for B2P Flood Model pre-development scenario (PREDEV) is described in Appendix A Table 1.

Figure C-1 and Figure C-2 (refer to Appendix C) show the maximum flood depth and flood level of the pre-development scenario under the 100-year ARI storm event, Figures C-3 and C-4 present the maximum flood depth and flood level under the 200-year ARI storm event.

The pre-development model comprises of six existing culverts, that are crossing the project site as shown in Figure 2-2. This includes an irregular twin DN1800 culvert[3] on Bob Robertson Drive, a 2.2m x 1.2m box culvert[3], and a DN750[4] circular culvert that cross State Highway 1 (SH1) discharging into the Taranaki Stream, a 4m x 1.5m box culvert[3] crossing SH1 that discharges into Waihora Creek, and a 1.25m x 0.5m box culvert located on Gladstone Road and a DN300 circular pipe situated on Woodend Beach Road.

Survey shows that the existing irregular twin DN1800 was embedded by 300mm as part of the fish passage consideration, which will be maintained in the Post-Development and Mitigation scenarios. Ecological assessments have also found that fish are present along the major streams that are affected by the proposed roadway, namely Mcintosh Drain, Taranaki, and Waihora Streams. Accessibility for fish movement will be preserved along these streams and will be considered in the proposed mitigation measures.

The Stormwater Network and Culverts inventory, as discussed in Appendix A, details all the culverts that have integrated the passage of fish, in all three case scenarios. Only the effective flow opening area of these culverts have been modelled, with higher surface roughness to incorporate the substrate infill within the culvert.

[3] To simplify the modelling process, culverts with fish passage considerations are modelled using only their effective flow opening area.
[4] Existing 0.85 (W) x 0.65 (H) arch culvert. For modelling simplicity, culvert modelled as DN750 circular culvert.

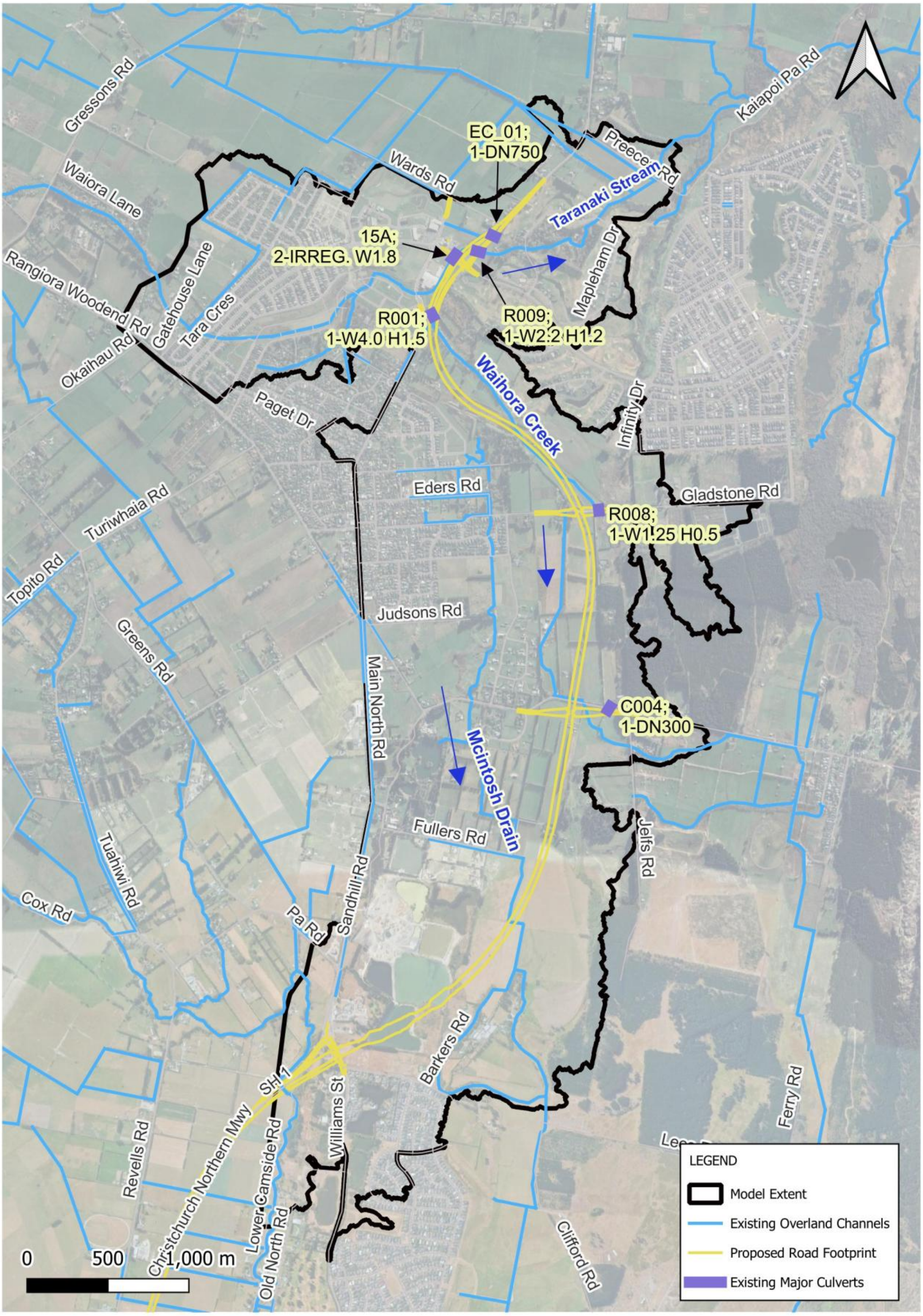


Figure 2-2 Existing culverts crossing proposed road alignment

As shown in Figure 2-3, the runoff splits into three directions:

- The Taranaki Stream catchment flow northward towards Waikuku Beach
- The Waihora Creek catchment flow towards the south and turns east towards the Kairaki Creek
- The McIntosh Drain flow south and ultimately merges with the Kaiapoi River.

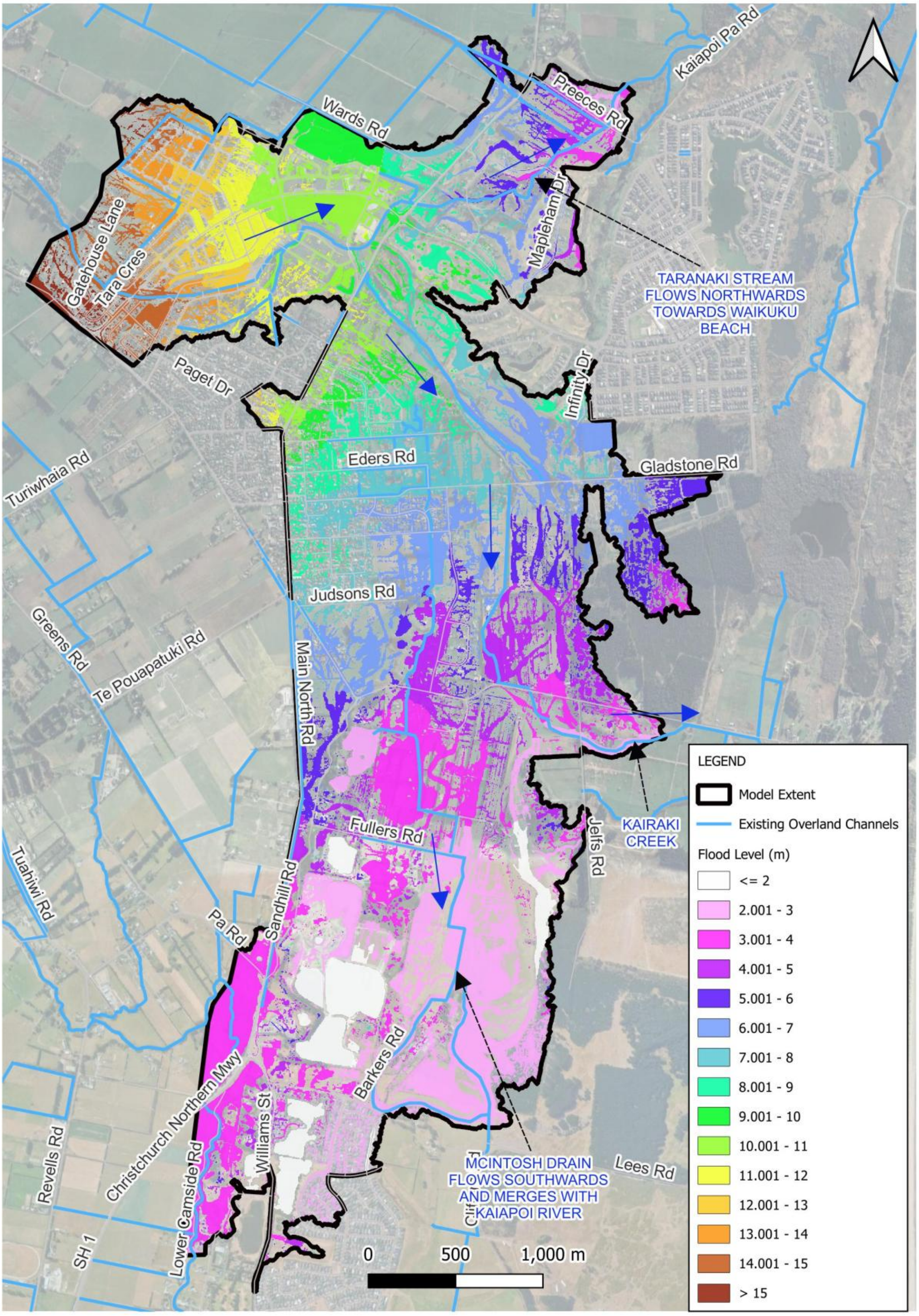


Figure 2-3 B2P Flood Model pre-development flood level under 100-year ARI

2.1.1 Flood Model Validation

Figure 2-4 shows the maximum predicted flood depths for the Existing Scenario in the WDC South Ashley Model for the 100-year ARI event. In comparison with the maximum predicted flood depths of the B2P Flood Model (refer to Figure 2-5), it can be observed that the flood extents are relatively similar, except for a few localised areas which are discussed in Table 2-2.

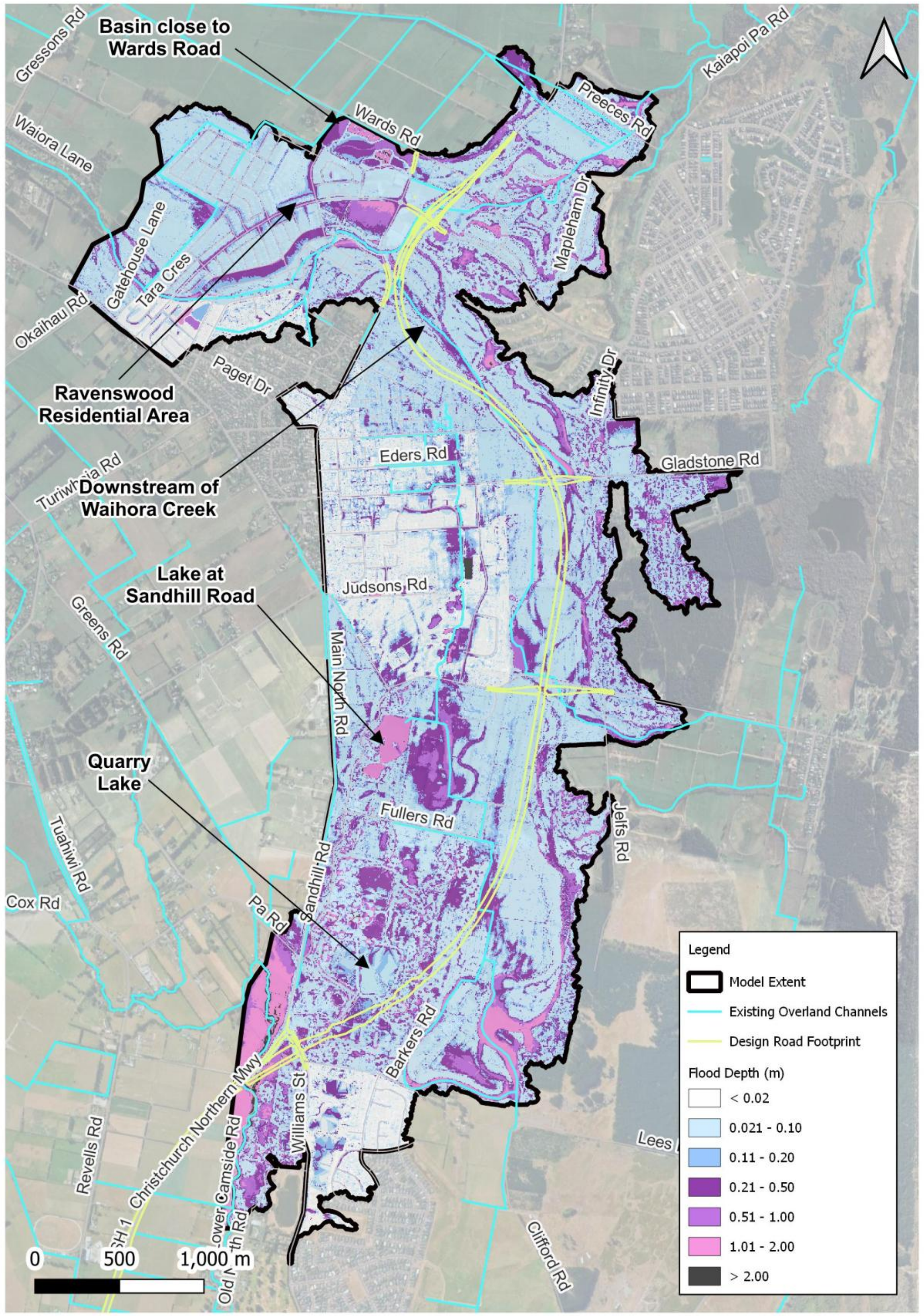


Figure 2-4 WDC South Ashley Model pre-development flood depth for 100-year ARI event

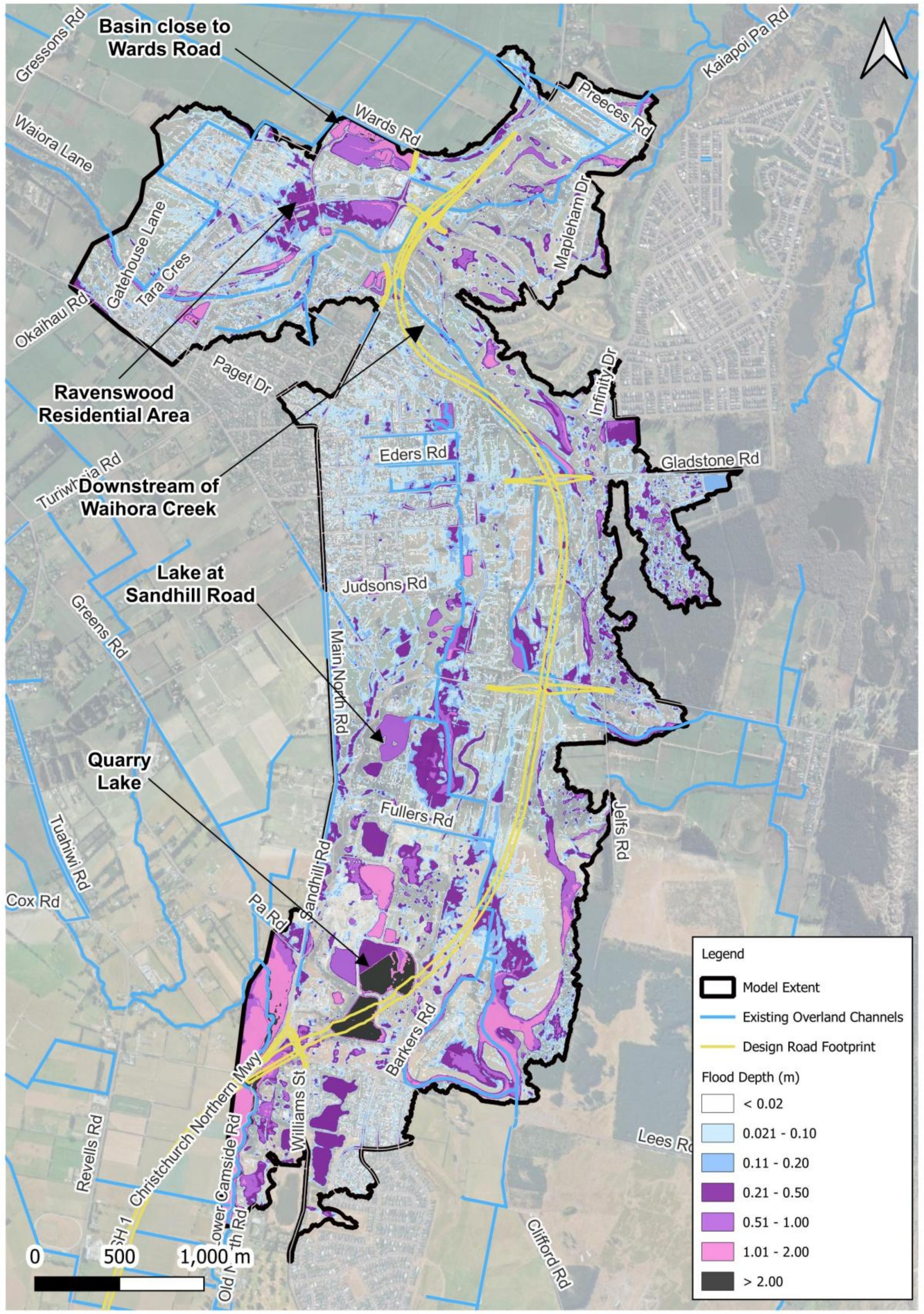


Figure 2-5 B2P-Woodend flood model pre-development flood depth for the 100-year ARI event

Figure 2-6 illustrates the differences in flood depth between the B2P Pre-development flood model and the localised flood depth map from the WDC South Ashley Model, specifically for the 100-year ARI event. Areas shaded in cooler colours indicate regions where the flood depth is greater in the WDC South Ashley Model compared to the B2P Pre-development flood model, while warmer colours show the opposite.

Figure 2-7 shows the differences in ground level between the B2P Pre-development flood model and the localised flood depth map from the WDC South Ashley Model. Areas marked in blue indicate regions where the ground level is higher in the WDC South Ashley Model than in the B2P Pre-development flood model, and vice versa.

Overall, the discrepancies in results can be attributed to several factors. These include the coarser cell sizes utilised in the WDC South Ashley Model, large cross-sectional areas of open channels burnt in the road to represent cross culverts in that model, and recent ground level updates in newly developed areas. The locations where significant differences have been identified are summarised in Table 2-2.

Table 2-2 Locations where large discrepancies are identified

Locations	Reasons
Ravenswood residential area (B2P Flood Model > WDC South Ashley Model)	As shown in Figure 2-6 and Figure 2-7, discrepancies were observed in the Ravenswood residential area since the 2020 LiDAR DEM did not reflect its full development, which resulted to higher flood depths in the B2P Flood model, due to its original land form. On the other hand, the WDC South Ashley model already integrated the current development (only west side of the development area) with higher topographic levels which consequently yielded lower flood depths. These discrepancies produced a positive afflux between the B2P Flood Model and the WDC South Ashley Model.
Basin near to Wards Road (B2P Flood Model > WDC South Ashley Model)	As shown in Figure 2-7, the basin was not included in the WDC South Ashley Model but has been incorporated into the B2P Flood Model. This inclusion has resulted in increased flood depths in the affected areas.
Downstream of Waihora Creek (WDC South Ashley Model > B2P Flood Model)	Figure 2-8 shows a 40m wide trapezoidal cross-section was used in the WDC South Ashley Model to represent the existing 4m x 2m box culvert. This design facilitates a higher runoff flow downstream, leading to greater flood depths in those areas when compared to the B2P Flood Model. This has been replaced by a 1D network in the B2P Flood Model.
Lake at Sandhill Road (WDC South Ashley Model > B2P Flood Model)	As shown in Figure 2-7, variations in flood depths may have resulted from the DEM which have captures a higher water levels during the LiDAR data collection in the WDC South Ashley Model compared to the B2P Flood Model.
Quarry Lake (B2P Flood Model > WDC South Ashley Model)	As shown in Figure 2-7, variations in flood depth resulted from the ground levels, which have captured a higher water level in the B2P Flood Model compared to the WDC South Ashley Model.

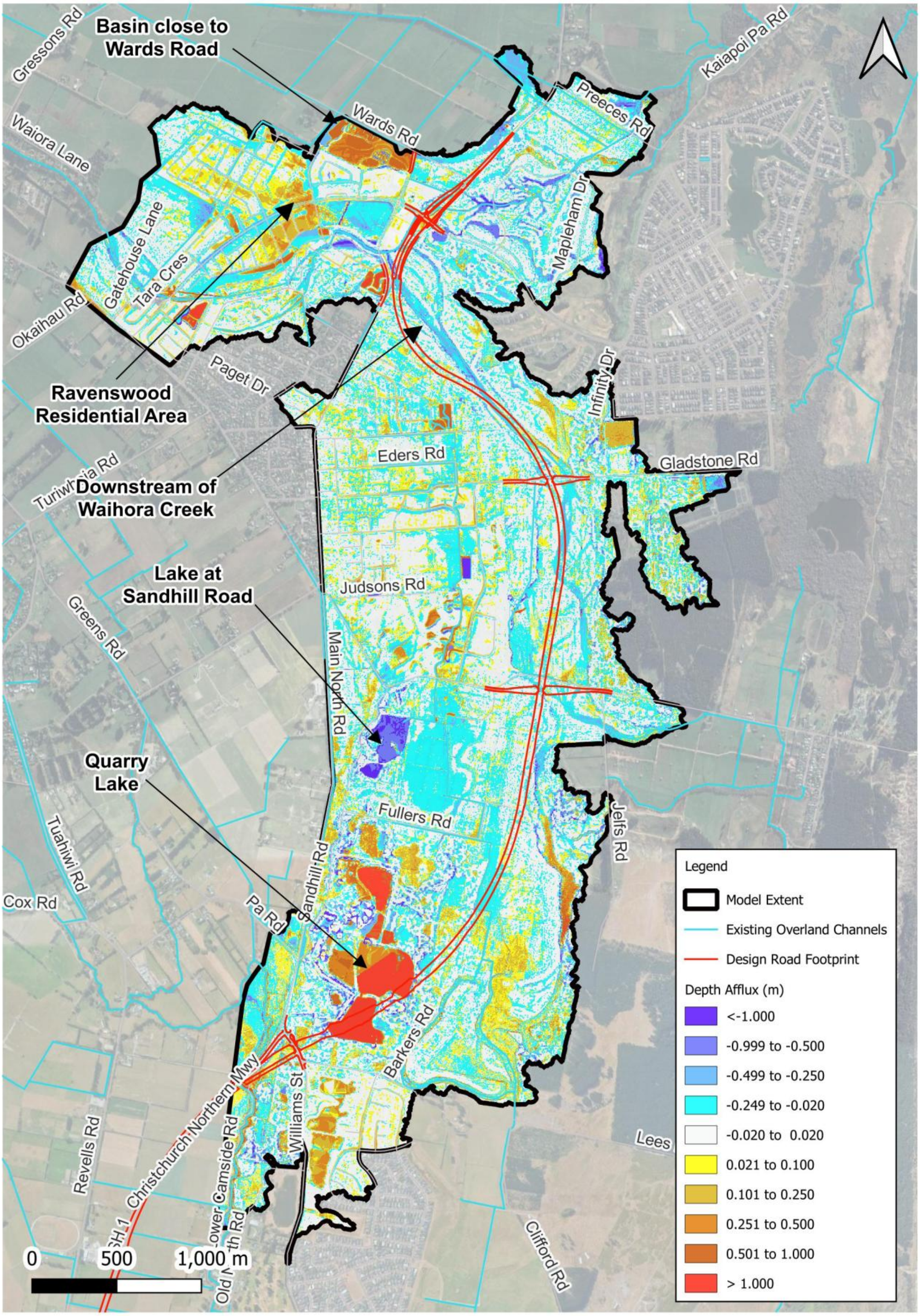


Figure 2-6 B2P Flood Pre-development model 100year ARI flood depth minus WDC South Ashley Model localised flood depth map under 100-year ARI event

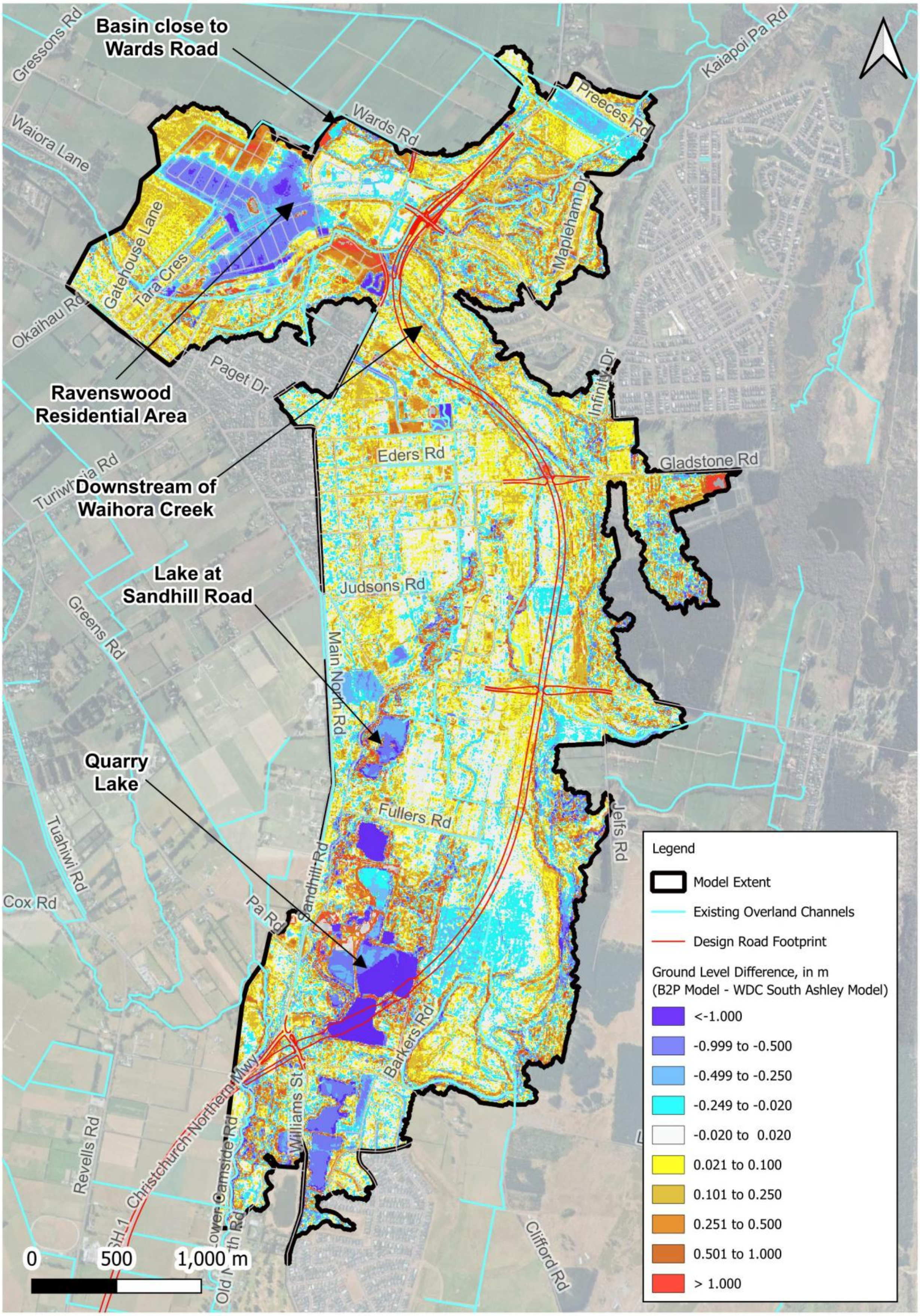


Figure 2-7 B2P Flood Model ground level minus WDC South Ashley Model ground level

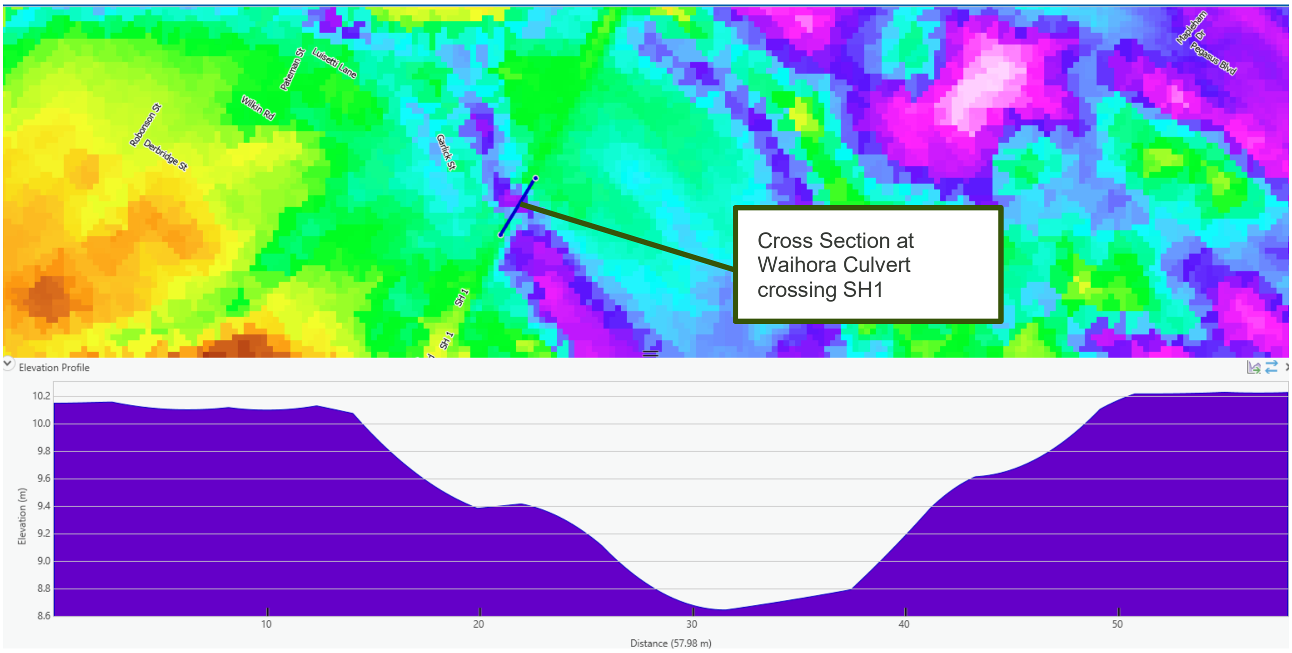


Figure 2-8 WDC Model Ground Level representing an existing 4m x 2m box culvert

2.2 B2P Post-Development Flood Model

The detailed model build methodology for B2P Flood Model post-development scenario (POSTDEV) is described in Appendix A Table 6.

Figure 2-9 illustrates the proposed design surface level for the entire road alignment. The proposed alignment generally follows the existing ground levels, with raised embankments incorporated along its length. However, the construction of these embankments alters the natural flow path, leading to the potential for water pooling behind the embankments due to the disruption of drainage. No mitigation measures have been developed in this model since the goal is to determine the effects of the bypass road and its comparison with the Pre-Development Model.

Existing culverts that fell within the designation boundary were removed, while culverts that are outside were maintained. The only culvert that was modelled with a fish passage consideration was the DN1800 culvert that crosses Bob Robertson drive, similar to the Pre-Development Model.

Comparable to the baseline flood model, the post-development flood model was developed under the assumption that any stormwater pipes are completely blocked.

Figure C-5 and Figure C-6 (refer to Appendix C) show the maximum flood depth and flood level of the post-development scenario under the 100-year ARI storm event, while Figure C-7 and Figure C-8 present the maximum flood depth and flood level under the 200-year ARI storm event.

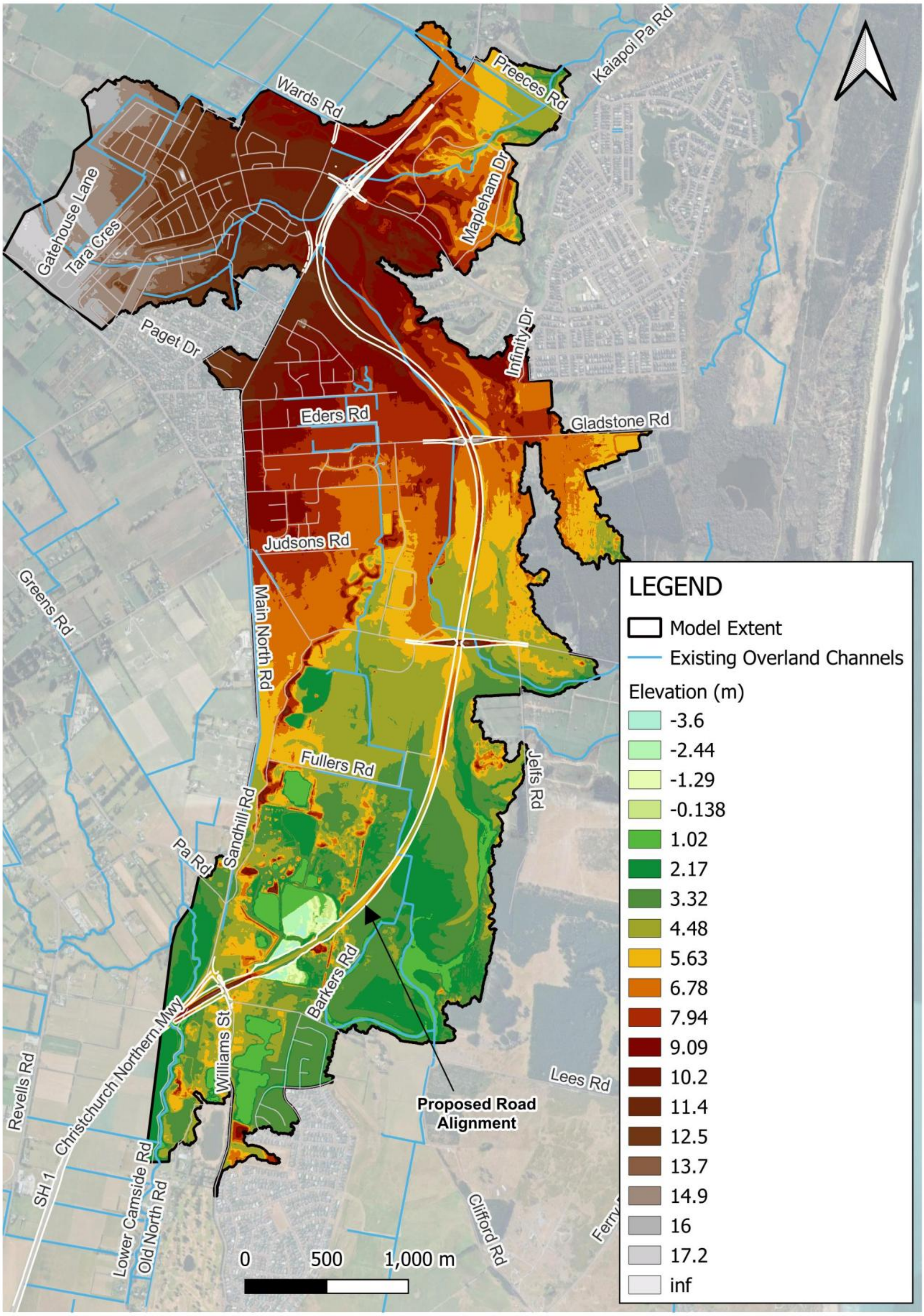


Figure 2-9 **Proposed B2P-Woodend design surface level**

2.2.1 Post-Development Scenario Result Discussion

Maximum flood level difference maps were developed to compare the post-development scenario with the pre-development scenario. These are presented in Figures C-9 and C-10 (see Appendix C) for the 100-year and 200-year ARI events.

Based on the Figures C-9, C-10, the proposed state highway remains dry under both the 100-year and 200-year ARI scenarios, with the exception of the road section north of Bob Robertson Drive, where floodwaters overtop the road as shown in Figure 2-10. The road overtopping is primarily due to a low existing road level and undersized existing culverts. To address this issue, the 2.2m x 1.2m culverts at Taranaki stream and DN750 at north of Taranaki stream are proposed to be upsized. This will allow more runoff to be conveyed downstream through culverts instead of overtopping the road.

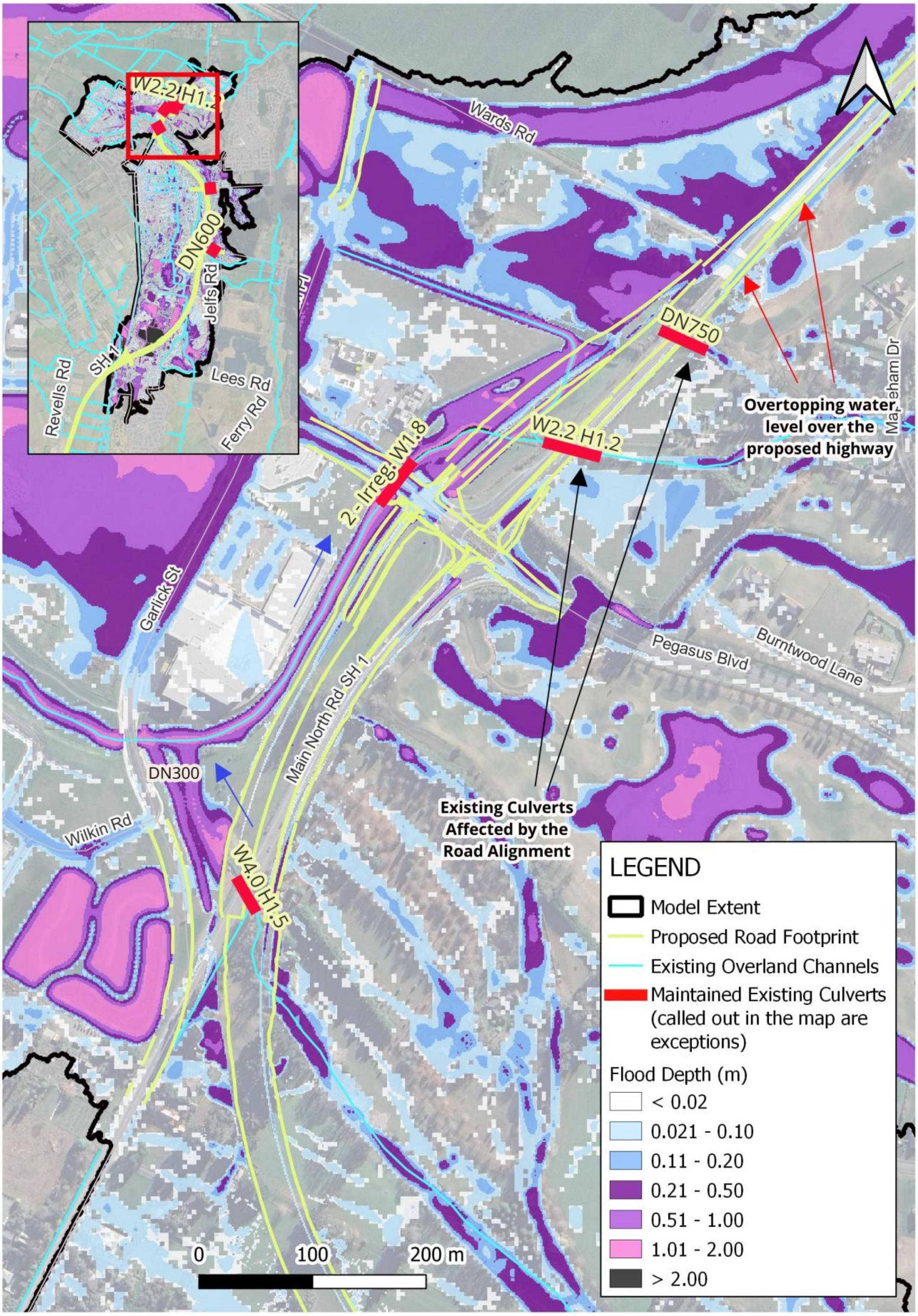


Figure 2-10 Floodwaters overtop the road at north of Bob Robertson Drive (200 year ARI Post-Development Scenario)

Figures C-9 and Figures C-10 indicate that most flooded zones are confined adjacent to the proposed road corridor. However, elevated flood levels are observed in the residential area along Main North Road, Woodend Beach Road and Wards Road during both the 100-year and 200-year ARI events.

The increase in flood level is attributed to the impact of road embankment towards the natural flow of runoff, such that existing channels are blocked by the road embankment that eventually contributed to the runoff buildup. Flood depth, flood levels, and their differences at the eight impacted properties (as shown in Figure 2-11 are presented in Table -3).

The following tables present the findings in terms of flood level and their difference between the post-development and pre-development cases at varying ARIs (100 and 200-year):

Table 2-3 100-year and 200-year ARI Flood Levels and Differences (Post-Development vs. Pre-Development Scenario)

Point ID	Location	100-year ARI			200-year ARI		
		Pre-development flood level (mRL)	Post-development flood level (mRL)	Difference (mm)	Pre-development flood level (mRL)	Post-development flood level (mRL)	Difference (mm)
1	5 Wards Rd*	8.28	8.42	140	8.37	8.5	137
2	196 Woodend Beach Rd	4.13	4.33	193	4.23	4.57	335
3	1271 Main North Rd*	8.11	8.29	183	8.16	8.33	171
4	1263 Main North Rd	8.28	8.31	30	8.29	8.35	58
5	1279 Main North Rd*	8.01	8.13	120	8.03	8.15	114
6	1273 Main North Rd*	8.10	8.24	140	8.15	8.28	130
7	1277 Main North Rd*	8.02	8.18	160	8.07	8.21	142
8	1319 Main North Road	6.41	6.44	27	6.46	6.55	91

*Property will be acquired as part of project work delineation. Flood impacts within designation have been considered acceptable

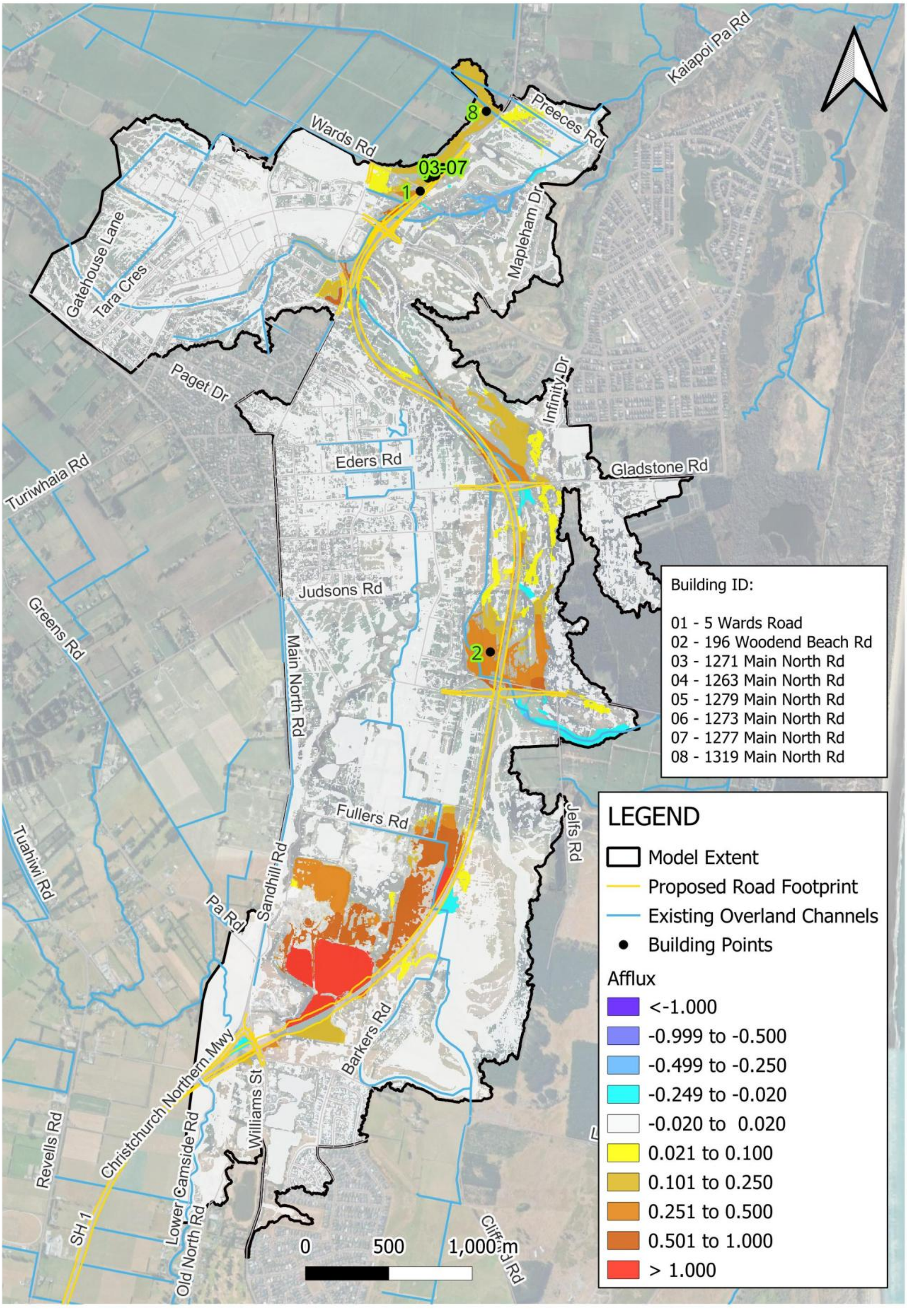


Figure 2-11 Impacted properties with 200yr afflux level map (post-development scenario) as background

These findings indicate that the increases exceeded the project objectives, which require that no flood level increase affecting neighbouring properties under the 100-year ARI event, and that any increase for the 200-year ARI event should not exceed 20 mm.

Of the eight impacted properties, five will be acquired as part of the project work delineation. Flood impacts within the designated area have been considered acceptable, if the flooding does not overtop the road.

Given the increase in flooding at the above three locations, flood mitigation measures are necessary to reduce impacts on these zones. The following solutions will be considered during detailed design:

- Provision of adequate culverts across the design road alignment.
- Divert impounded runoff through additional channel alignments.

2.3 B2P Mitigation Flood Model

The methodology for the B2P Flood Model post-development scenario with mitigation solution is outlined in Appendix A Table 6. The key components of the mitigation solution include:

- Provision of Culvert Crossings:
  - Culvert structures have been added along critical areas beside the road alignment to avoid runoff build-up and ponding issues. These structures are incorporated in the flood model to properly represent the mitigation solution once the road embankment is constructed.
  - Culverts have been added to connect the proposed treatment swales and cut-off drains to the designated discharge points across the proposed motorway.
  - Culverts sizing at Taranaki Stream, Waihora Creek and McIntosh Drain include the 300mm embedment depth to accommodate fish passage. Only the flowable portions of the culvert cross-sectional area are represented in the flood model, and the average channel roughness has also been accounted for.
  - The design invert levels for the culvert structures are based on the provided survey data, for best stream channel tie in at upstream and downstream end and achieve a minimum adequate slope to convey runoff without overflowing at the road level.
  - Where road widening is proposed at Bob Robertson Drive, existing culverts are to be extended or replaced with like-to-like sizes to avoid introducing flood impacts downstream.
- Provision of flow path Diversion Channels (DIV. CHAN.):
  - Additional channels are included for the model to ensure smooth flow behaviour of impounded runoff from upstream to downstream.
  - The design slopes of the channels are established to match the natural topography and to permit the flow of runoff, preventing any impounding upstream.
  - Channels are designed to maintain and replicate original overland flow paths and permanent streams that have been affected by the development.
- Provision for Treatment Swales (TS), and Cut-off Drains (CD)
  - Treatment swales are designed to collect and treat stormwater runoff generated from the road corridor while conveying it towards designated discharge locations. Bio-retention and bio-infiltration basins are also proposed to provide treatment of runoff adjacent to the proposed road before discharging to the receiving environment.
  - Cut-off Drains are proposed to intercept water from external overland catchments and convey it to the designated discharge points, best maintaining hydraulic neutrality and avoiding inter-catchment transfer.

  - Both systems are designed to direct runoff to the discharge locations such as permanent streams and overland flow paths.
  - Treatment swale, treatment basins and cut off drains are represented in the flood model through the design surface model.
- Raising the weir level at Garlick Street to 10.40 m to utilise the existing basin volume:
  - Raising the weir level at Garlick Street to 10.40 m increases the storage capacity of the existing basin, allowing it to hold a greater volume of runoff. 0This enhancement helps to reduce the amount of runoff discharging downstream, thereby managing flood risks more effectively.

Figure 2-12, Figure 2-13, Figure 2-14, Figure 2-15, and Figure 2-16 show the locations where culverts and designed waterways are proposed as part of the mitigation solutions. Some major flow changes due to proposed mitigating structures are shown in the following figures. Blue arrowheads represent the flow direction of runoff.

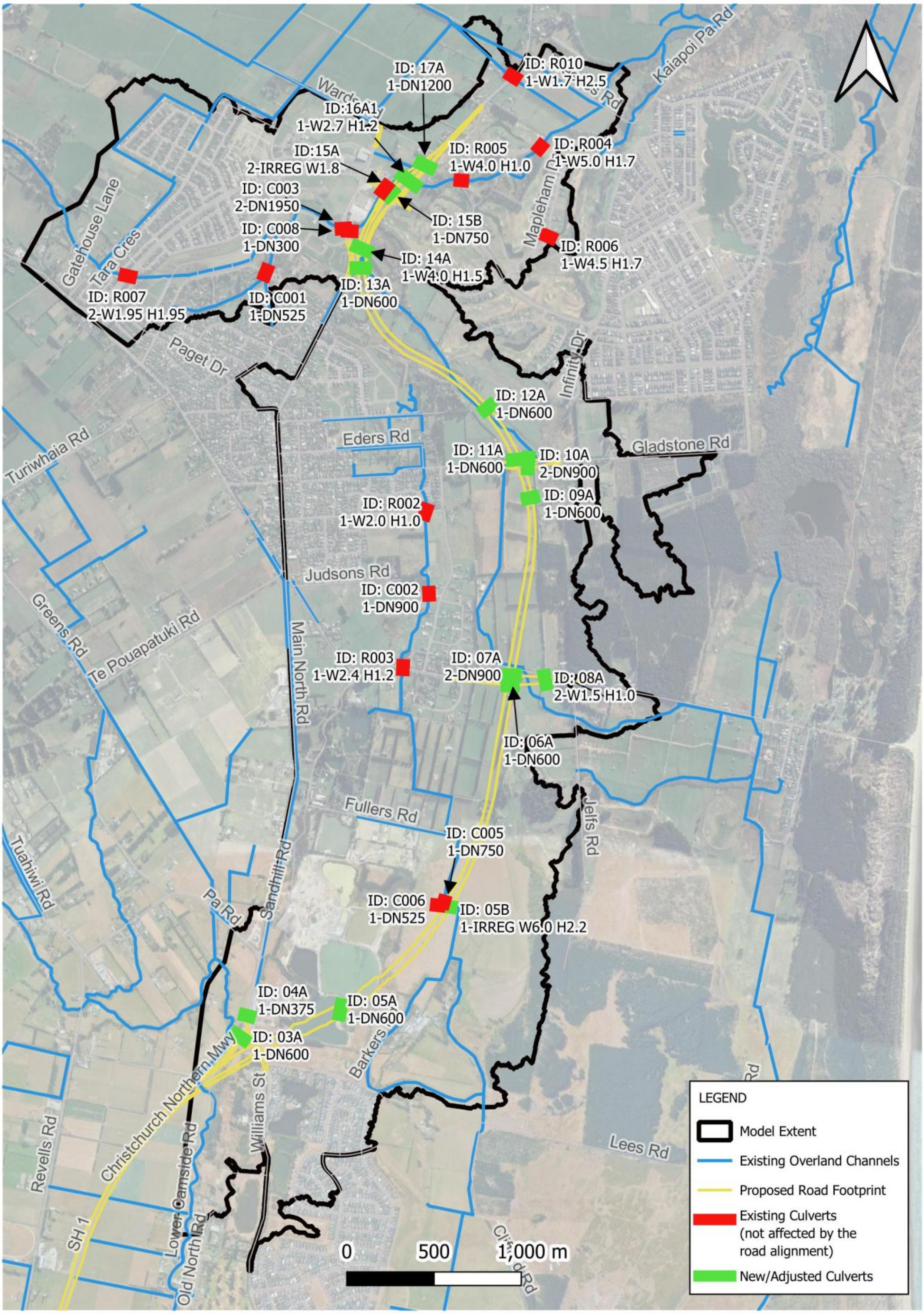


Figure 2-12 Proposed mitigation scheme adjacent to the road alignment

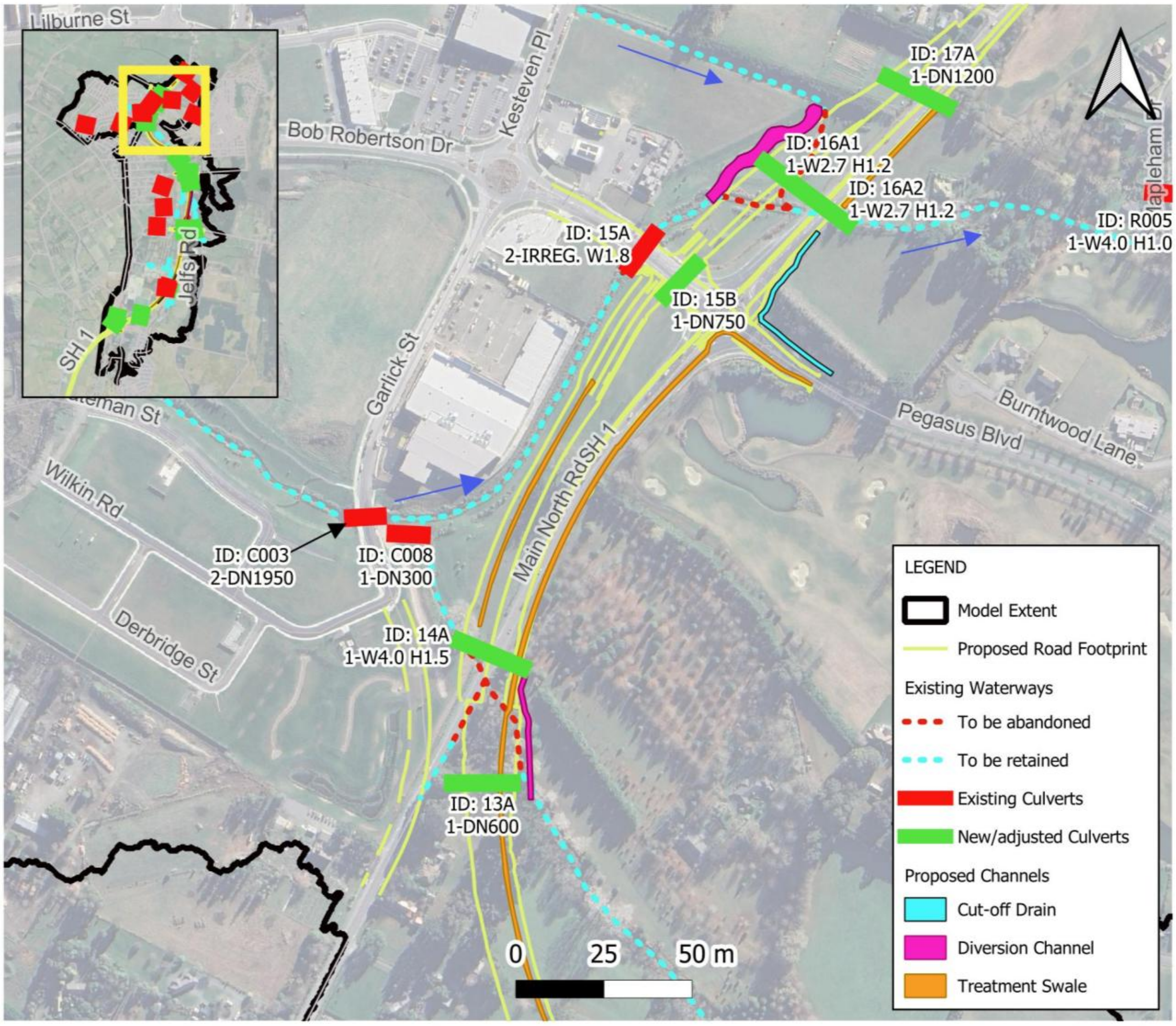


Figure 2-13 Proposed culvert alignments (upper zone)

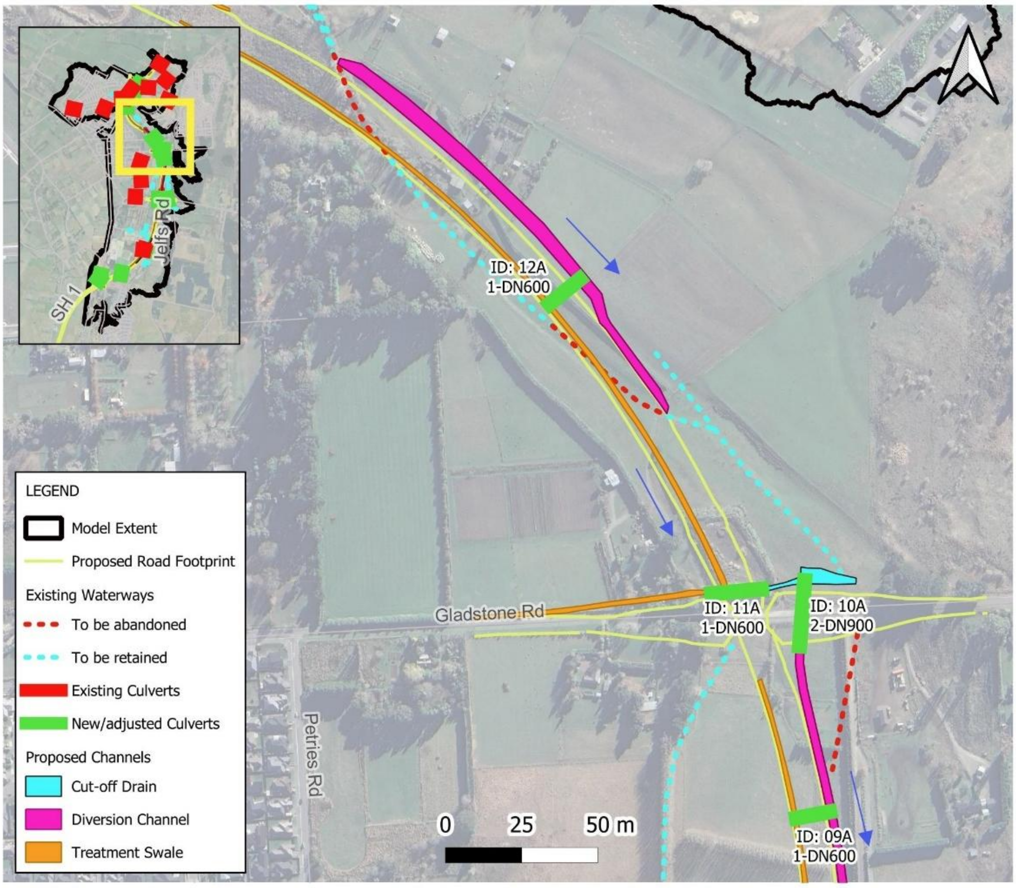


Figure 2-14 Proposed culvert alignments (upper central zone)

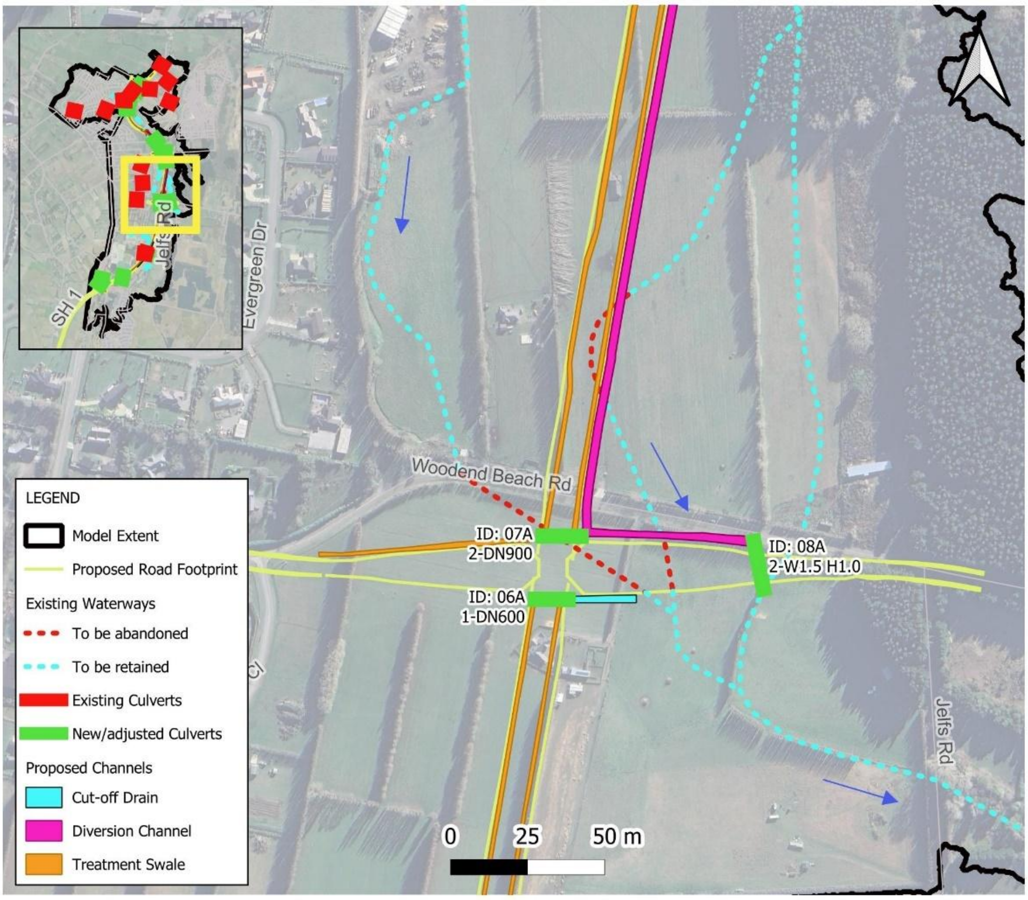


Figure 2-15 Proposed culvert alignments (lower central zone)

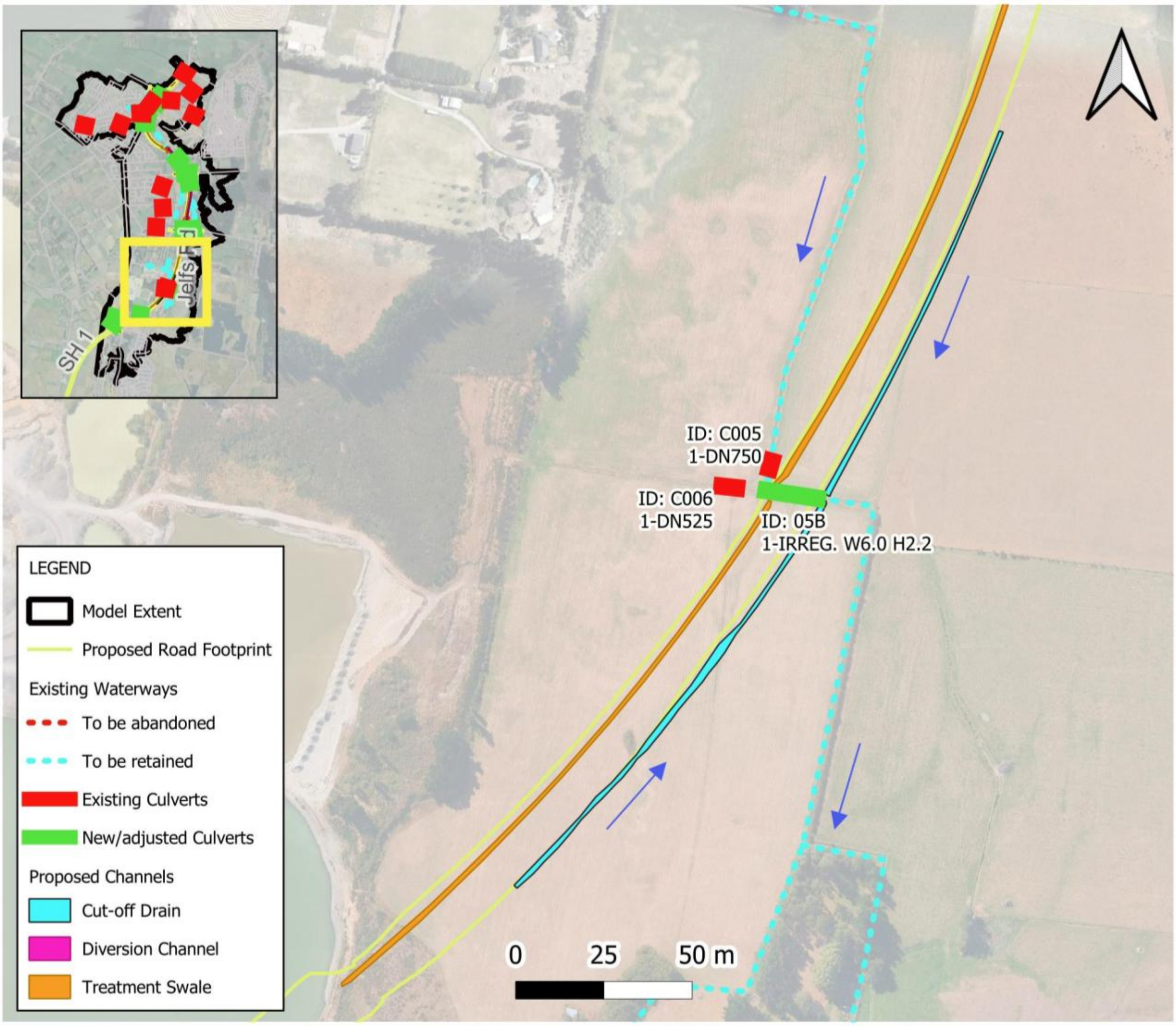


Figure 2-16 Proposed culvert alignments (lower zone)

2.3.1 Mitigation Scenario Result Discussion

Figures C-11 and C-12 (refer to Appendix C) illustrate the maximum flood depth and flood level for the mitigation scenario under a 100-year ARI storm event, while Figures C-13 and C-14 represent these parameters for the 200-year ARI storm event.

Maximum flood level difference maps, comparing the mitigation and pre-development scenarios, are shown in Figures C-15 and C-16 for the 100-year, and 200-year ARI events, respectively. Based on these figures, with the mitigation measures implemented, the proposed state highway remains dry under both the 100-year and 200-year ARI scenarios.

Table 2-4 100-year and 200-year ARI flood level and differences (Mitigation vs Pre-development scenario)

Point ID	Location	100-year ARI			200-year ARI		
		Pre-development flood level (mRL)	Post-development flood level (mRL)	Difference (mm)	Pre-development flood level (mRL)	Post-development flood level (mRL)	Difference (mm)
1	5 Wards Rd*	8.06	7.64	-420	8.36	7.92	-440
2	196 Woodend Beach Rd	4.13	4.14	10	4.23	4.23	0
3	1271 Main North Rd*	8.11	8.06	-50	8.15	8.09	-60
4	1263 Main North Rd	8.28	8.29	10	8.29	8.29	0
5	1279 Main North Rd*	8.01	8.01	0	8.03	8.01	-20
6	1273 Main North Rd*	8.10	8.11	10	8.14	8.11	-30
7	1277 Main North Rd*	8.02	8.01	-10	8.06	8.03	-30
8	1319 Main North Road	8.28	8.29	10	8.29	8.29	0

* Properties will be acquired as part of project work delineation. Flood impacts within designation have been considered acceptable.

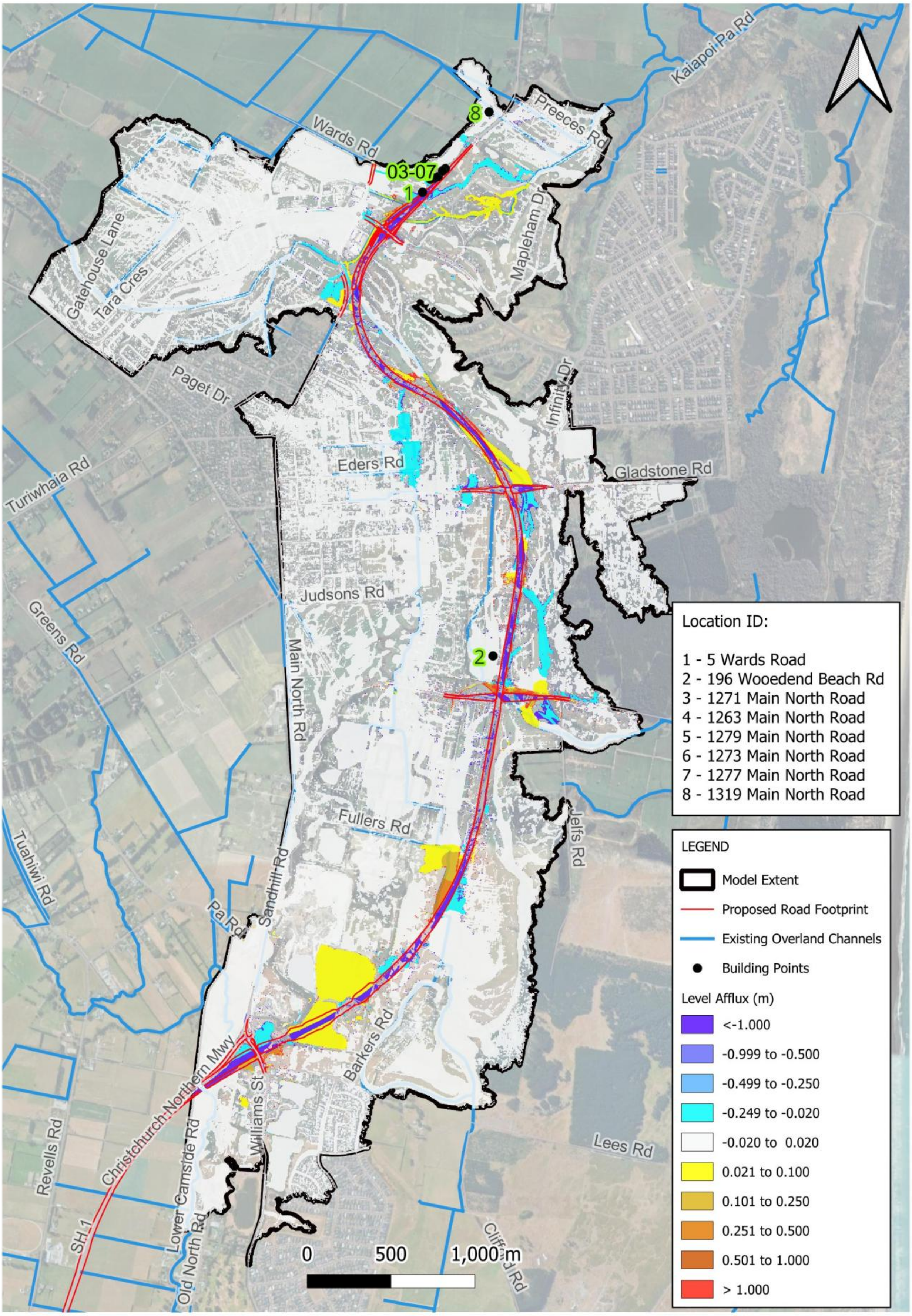


Figure 2-17 Impacted buildings with 200yr afflux level map (Mitigation scenario) as background

Based on the results presented in Table 2-4 and illustrated in Appendix C, the mitigation model has successfully reduced flood impacts across most areas, including previously affected buildings (excluding the five buildings identified for acquisition as part of project delineation) during the 100-year and 200-year ARI event.

Water level increases have been observed in the locations listed in Table 2-5 and as shown in Figure 2-18, Figure 2-19, and Figure 2-20. However, these increases do not affect any property buildings.

Table 2-5 Locations with Flood Level Differences

Locations	Afflux (mm)		Comments
	100-yr	200-yr	
1. Downstream Reach of Taranaki	3	10	Afflux maps show, at the downstream reach of the Taranaki Stream (after Mapleham Drive), minimal flood depth differences, both for the 100-year and 200-year storm events. It signifies that the additional flow, that was diverted from the original overland flow path along the golf course, was conserved and eventually discharged at the same location, maintaining both flow (Figure 2-21 and Figure 2-22) and flood levels
2. Mapleham Drive	10	70	Higher water levels were observed downstream along the Taranaki Stream, particularly near Mapleham Drive, similar to the pattern noted in item 1. However, these elevated levels remain confined within the stream channel and do not impact any nearby buildings. For example, the property at 61 Mapleham Drive, located midstream, has a floor level of approximately 6.0 meters RL. During the 200-year flood event, the pre-development flood level was 5.47 mRL, providing a freeboard of 530 mm; Under mitigation scenario flood level rises to 5.54 mRL , still maintaining a freeboard of 460 mm, ensuring that the property remains protected from flooding.
3. Taranaki Stream downstream of SH1	70	130	The increase in water depth is due to the upsizing of the Taranaki Stream culvert. However, the impacts remain within the channel and do not affect any buildings.
4. Golf Course bounded by SH1 and Mapleham Drive	0	-110	The original overland flow path for the 200-year flood event, caused by the overtopping of SH1 (see Appendix C Figures C-2 and C-4), no longer existed as the excess runoff is now conveyed into the Taranaki Stream via Culvert 16A. This change has resulted in a negative afflux within the golf course area bounded by SH1 and Mapleham Drive.
5. Taranaki Stream close to Harvey Norman (upstream of Bob Robertson Drive)	-200	60	The section of the Taranaki Stream upstream of Bob Robertson Drive exhibits a negative afflux during the 100-year flood event, while a positive afflux is observed under the 200-year event. Flows during the 100-year event are conveyed efficiently due to the increased capacity of the upsized Taranaki culvert. However, during the 200-year flood, the positive afflux occur because culvert 16A reaches its maximum capacity, inducing tailwater upstream of Waihora Creek.
6. Upstream section of Taranaki (upstream of Garlick Street)	-90	-40	For both the 100-year and 200-year ARIs, decreased flood levels were observed in the upstream section of Taranaki Stream, primarily due to improved conveyance of the Taranaki culvert. Any increase in flood depth within the stream extends only as far as Garlick Street (see Figure C-16), beyond which additional runoff is effectively redirected

Locations	Afflux (mm)		Comments
	100-yr	200-yr	
			southward through Waihora Creek, continuing downstream to Woodend Beach Road.
7. Garlick Street and Basin within Ravenswood residential area	150	70	The designed Garlick Street extension has a sag elevation of 10.4m RL, which is 0.15m higher than the existing sag level but is consistent with the consented weir level. The sag point acts as an overflow weir that connects the basins to Waihora Creek. Consequently, more water is detained in the basins with a higher weir level so that the basin storage can be better utilized. Less water is discharged to the Taranaki and Waihora streams and resulted to lower flood depths in the downstream areas. For 200 year events, basin flood level under post development is already as high as 10.41m RL, makes the raising of weir level less effective in storing water in the basins.
8. Downstream of Waihora Creek	110	130	Higher water levels at this location were primarily caused by the reduced channel storage due to the proposed SH1 cutting off Waihora Creek. The impacts remain contained within the channels and do not affect any buildings.
9. Floodplain North of Gladstone Road	-260	40	During the 100-year flood event, excess runoff was efficiently conveyed through the Gladstone Road culvert (10A), resulting in a negative afflux. For the 200-year event, the design intentionally impounds more water within the existing floodplain north of Gladstone Road to attenuate flows and reduce downstream impacts, particularly near Woodend Beach Road. The impacts remain contained within the floodplain and do not affect any properties.
10. East of Copper Beach Road	260	180	Water ponding is due to the motorway cutting off an existing overland flow path. The ponding is localised and does not impact any buildings.
11. Floodplain North of Woodend Beach Road	500	550	The Woodend Beach Road culvert (08A) was designed to impound and attenuate water before it discharges into Kairaki Creek, resulting in a positive afflux during both the 100-year and 200-year flood events. The adjacent floodplain effectively stores the excess water, ensuring that no buildings or properties are impacted.
12. Downstream of Woodend Beach Road	130	0	Higher flood levels were observed downstream of Woodend Beach Road during the 100-year ARI event, primarily due to more efficient conveyance in the upstream sections, including the culverts at Gladstone and Woodend Beach Road. Despite this increase, no buildings were affected, and all impacts remained contained within the proposed diversion channel. For the 200-year event, the Woodend Beach Road culvert (08A) was specifically designed to limit discharge toward Kairaki Creek so that the flood level remains. The storage capacity of the floodplain north of Woodend Beach Road is well utilized.
13. Upstream of McIntosh Drain	140	320	The increase in flood levels is caused by the proposed SH1 cutting off the existing Mcintosh Drain. The impact is largely confined to land owned by NZTA which does not include any residential properties.

Locations	Afflux (mm)		Comments
	100-yr	200-yr	
14. Within the Quarry Lake.	0	90	The increase in water levels was primarily caused by the loss of storage resulting from the infilling of the lake for the proposed bypass road. The water levels in the ponds generally represent existing groundwater levels, and the model assumes no infiltration. However, since the quarry bottom is directly connected to the groundwater, flood afflux is expected to be minimal due to the continuous exchange between surface water and groundwater

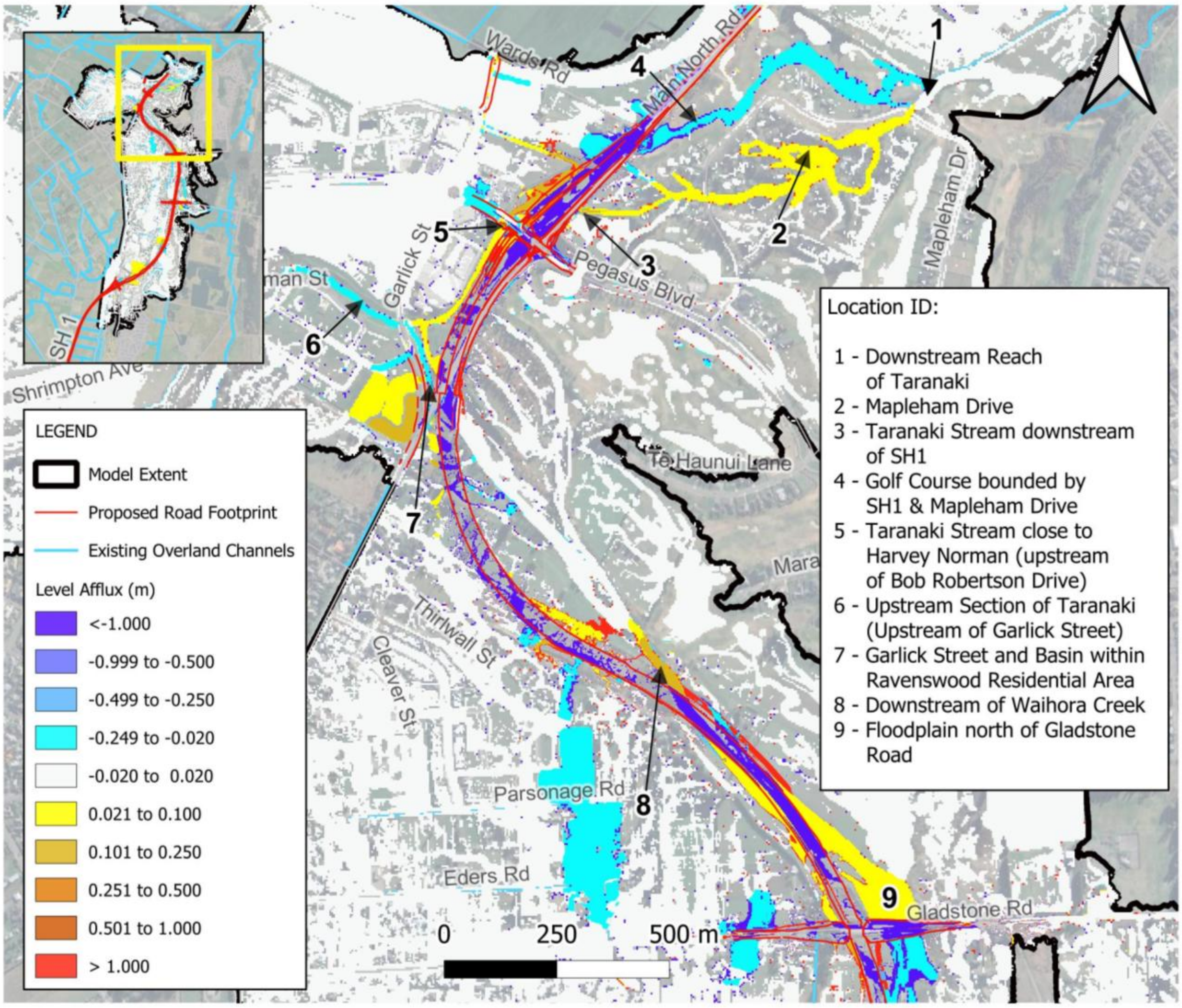


Figure 2-18 Residual impacts outside the designation (upper zone) but does not impact any property buildings (200 year ARI afflux level)

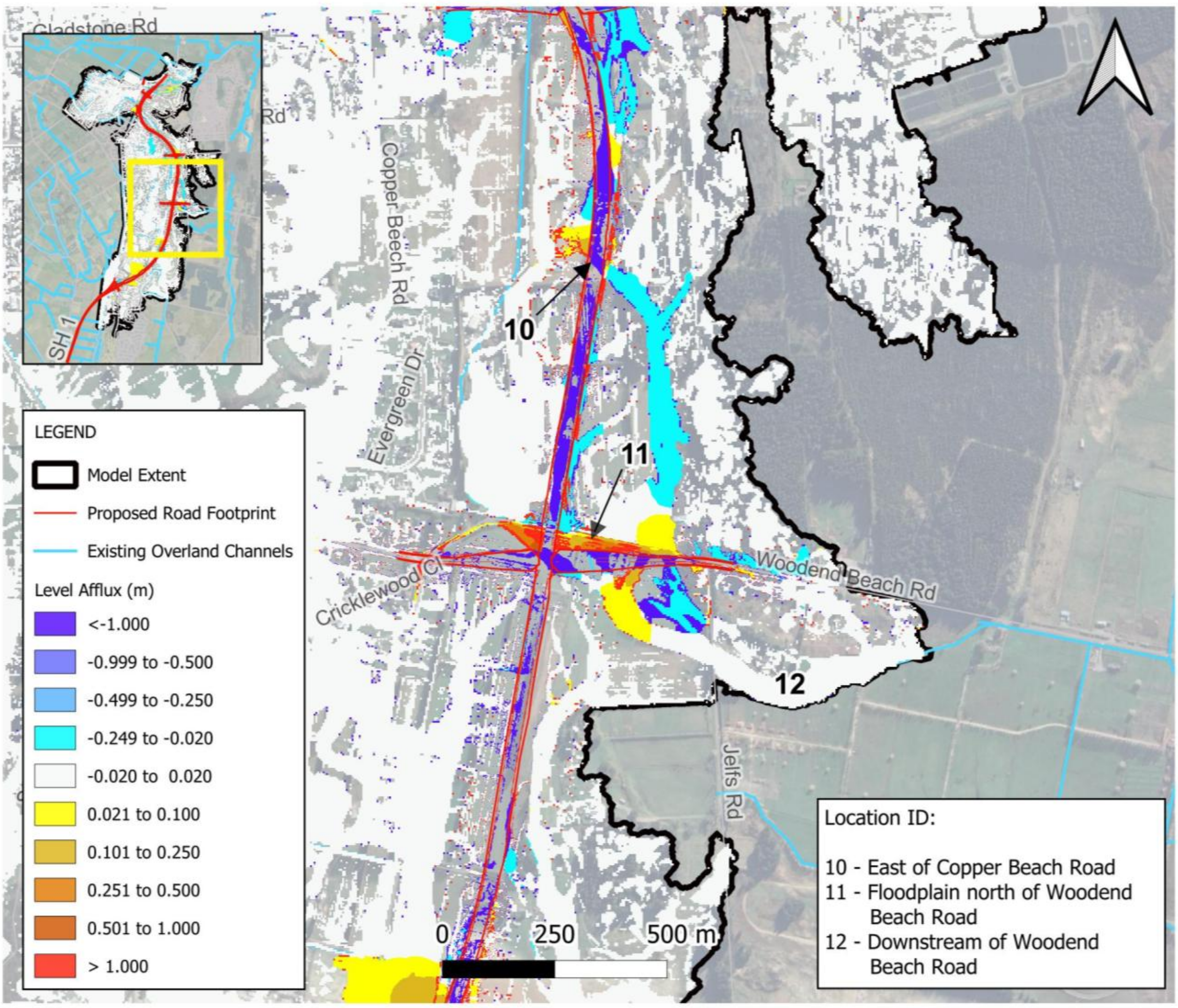


Figure 2-19 Residual impacts outside the designation (central zone) but does not impact any property buildings (200 year ARI afflux level)

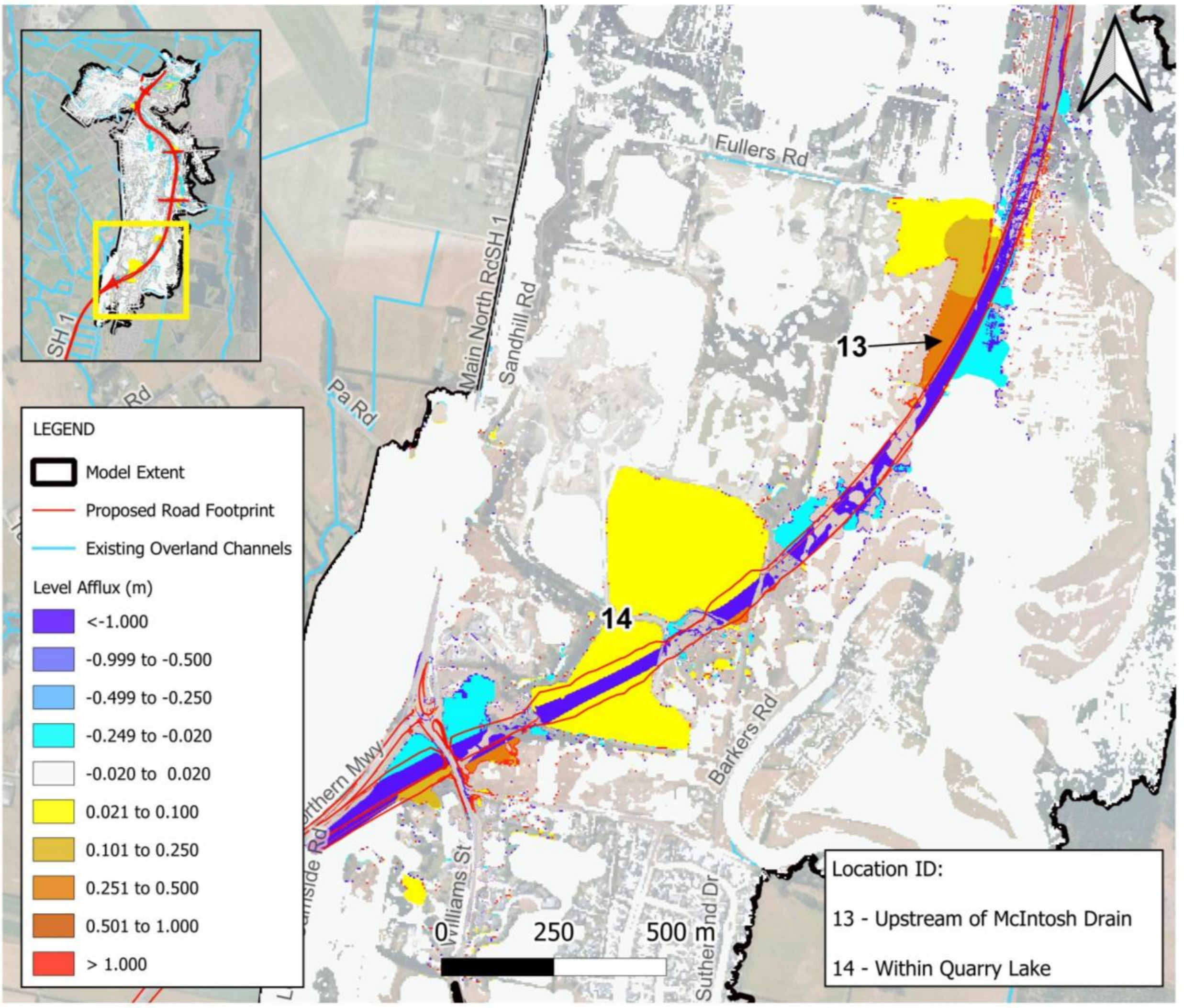


Figure 2-20 Residual impacts outside the designation (lower zone) but does not impact any property buildings (200 year ARI afflux level)

2.3.2 Flood Impact Discussion

Flood impact assessment between the Pre-Development and Mitigation Scenarios were done to determine if a prolonged flood event was observed and if there are possible negative risks that might not have been accounted for due to the limited extent of the flood model. The assessment focuses on major waterways that intersect the proposed bypass road and areas that these waterways directly discharge to. Four locations were identified, which have also been the site of most mitigation measures with the goal of maintaining existing overland flow paths:

- Ravenswood Existing Basin
- Downstream of Taranaki Stream
- Waikuku Beach
- Waihora Creek to Gladstone Road
- Woodend Beach Road
- Woodend Beach and Stalkers Road
- McIntosh Drain

Ravenswood Existing Basin

In the B2P Mitigation Flood Model, the road level at the sag of Garlick Street has been raised to 10.40m RL. Model results indicate higher water levels within the Ravenswood basin and wetland, primarily due to the increased weir elevation at Garlick Street; a slight reduction in downstream flood levels for the 100-year ARI event and a minor increase in downstream flood levels for the 200-year ARI event.

In the Mitigation Model, the property adjacent to the existing Ravenswood basin showed a reduction in freeboard due to the increase of flood level in the basin. However, it still maintained a minimum of 0.527 m freeboard under the 100-year ARI event and 0.478 m under the 200-year ARI event. Ravenswood Harvey Norman showed an increase of freeboard (0.592m) for the 100-year event due to the reduction in flood level downstream of the weir, and a reduction of freeboard (0.054m) for the 200-year event due to the increase in flood level downstream of the weir.

Table 2-6 summarizes weir level change and modelled flood level change for Ravenswood Basin between pre-development model and mitigation model. Table 2-7 summarises freeboard changes of the properties between pre-development model and mitigation model.

Table 2-6 Ravenswood Basin Weir Level Change and Modelled Flood Level Change

Scenario	Weir Level	Weir Length	Modelled flood level in the basin (m RL)	
			100-year ARI	200-year ARI
Pre-development	**10.19 m**	**8.0 m**	**10.28**	**10.41**
Mitigation	10.40 m	10.0 m	10.43	10.48

Table 2-7 Properties Freeboard Changes

Scenario	Freeboard of the property adjacent to the basin (m)		Freeboard of Ravenswood Harvey Norman (m)	
	100-year ARI	200-year ARI	100-year ARI	200-year ARI
Pre-development	0.68	0.54	1.69	1.76
Mitigation	0.53	0.48	2.28	1.71

Downstream of Taranaki Stream

To assess the potential downstream effects, hydrographs were extracted at two locations within the overland flow path (Lines 34 and 42, as shown in Figure 2-21 and Figure 2-22).

As illustrated in Figure 2-21 and Figure 2-22, the differences in discharge between the pre-development and mitigation scenarios under the 100-year ARI event are marginal, which is consistent with the afflux map as shown in Appendix C Figure C-15 (with no impacts shown further downstream).

Under the 200-year ARI event, the peak discharge at Line 34 increases by approximately 1 m^3/s due to additional flow being diverted from the north (overland flowpath within golf course) toward the Taranaki culverts. However, at Line 42, where the northern overland flow branch merges with the main Taranaki flow path at the downstream, the difference becomes less significant, at around 0.25 m^3/s or 3%.

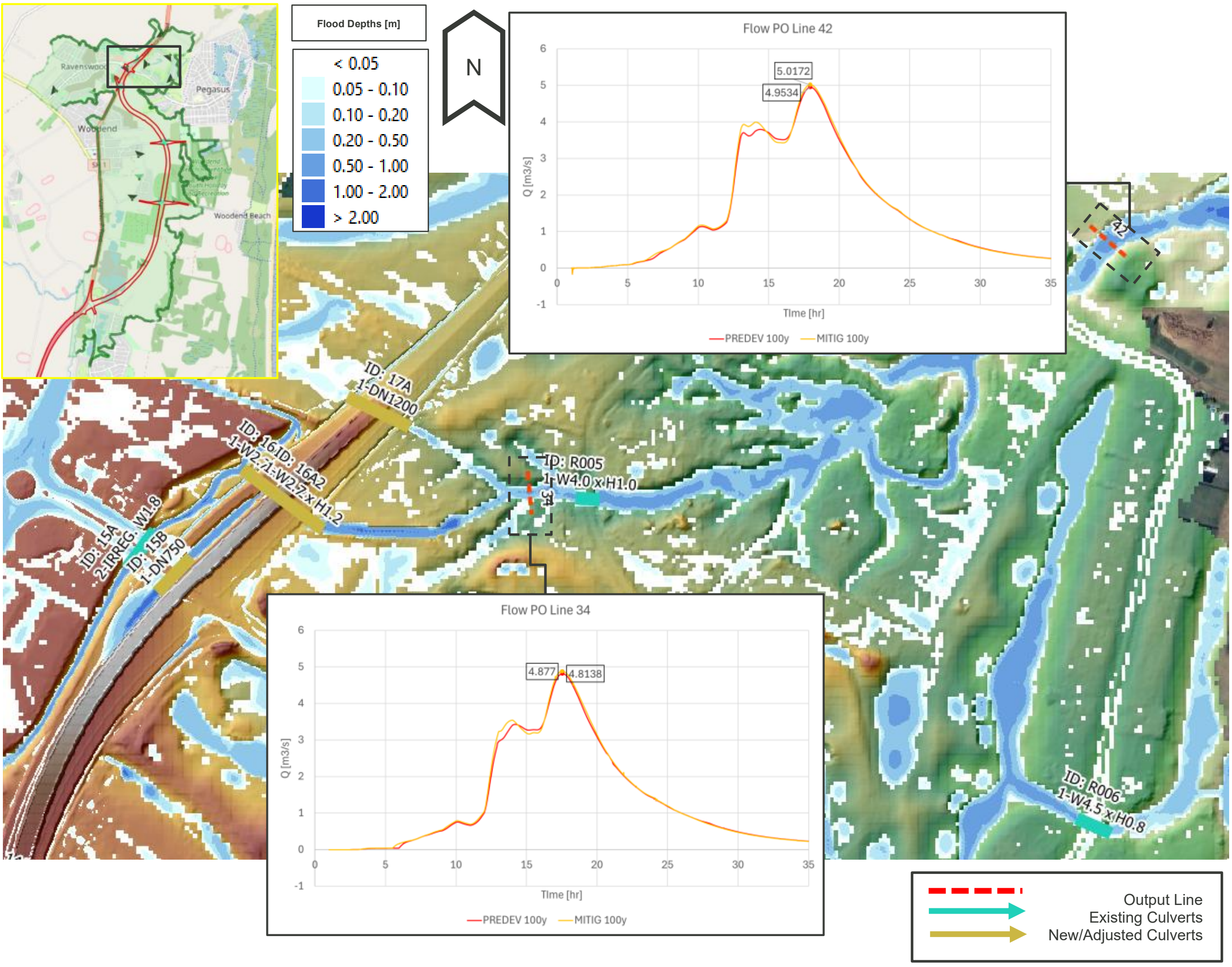


Figure 2-21 Taranaki Stream 100-year Flood Duration Assessment

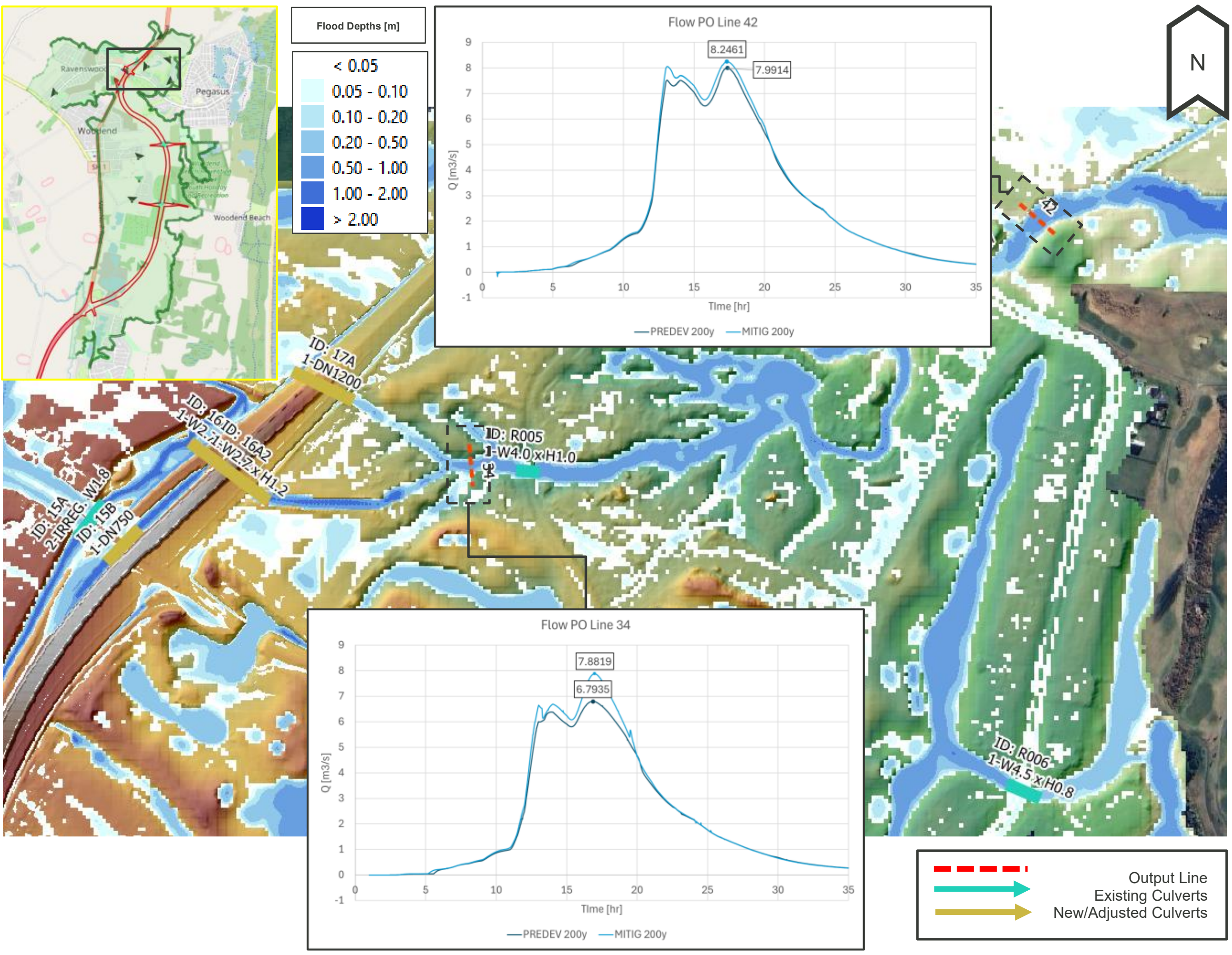


Figure 2-22 Taranaki Stream 200-year Flood Duration Assessment

Waikuku Beach

A volumetric assessment for Waikuku Beach, which is within the interdunal area at the downstream portion of the Taranaki Stream, where runoff ultimately reaches Pegasus Bay, was done to ensure no aggravation of impacts was observed in this area. Pre- and post-development volumes were calculated from the hydrographs at the very downstream end of the model and were subtracted to determine the potential amount of water that would be conveyed towards Waikuku Beach. Two ponding areas were established, based on the WDC Flood Model extents, which are connected by the Taranaki Stream (Figure 2-25). Details and calculations of the volumetric assessment are shown in Table 2-8

For a more conservative approach, relative levels of 3.20 mRL and 1.5 mRL were established for ponding areas 1 (Figure 2-23) and 2 (Figure 2-24), respectively, which are based on the flood extents of the 200-year storm event of the WDC model. Additionally, the two areas were assumed to be hydraulically separated with no outflow; Whereas in reality, flow exchange between the two areas would result to lower flood levels and smaller flood extents.

Table 2-8 Total Volumetric Water Difference - Waikuku Beach

Parameter	PREDEV	MITIG	DIFFERENCE
100-year ARI Total Volume [m^3]	191,016	193,913	2,897
200-year ARI Total Volume [m^3]	320,922	330,826	9,904
Ponding Area 1 [ha]	104		
Ponding Area 2 [ha]	170		
100-year ARI			

Parameter	PREDEV	MITIG	DIFFERENCE
Ponding Area 1			
Depth Increase [mm]	2.79		
Assumed Water Level [mRL]	3.20		
Final Water Level [mRL]	3.202		
Ponding Area 2			
Depth Increase [mm]	1.71		
Assumed Water Level [mRL]	1.5		
Final Water Level [mRL]	1.502		
200-year ARI			
Ponding Area 1			
Depth Increase [mm]	9.53		
Assumed Water Level [mRL]	3.2		
Final Water Level [mRL]	3.209		
Ponding Area 2			
Depth Increase [mm]	5.83		
Assumed Water Level [mRL]	1.5		
Final Water Level [mRL]	1.506		

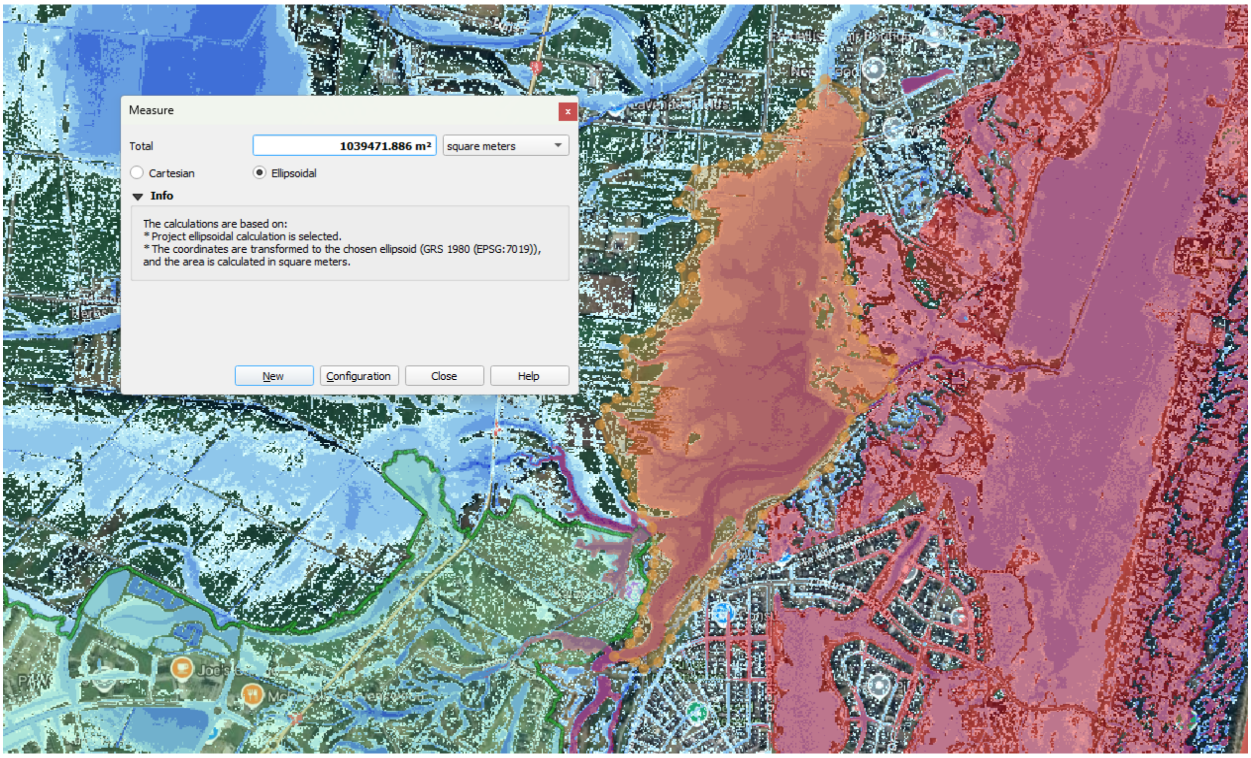


Figure 2-23 Bathtub 1 extent (Downstream of Taranaki Stream)

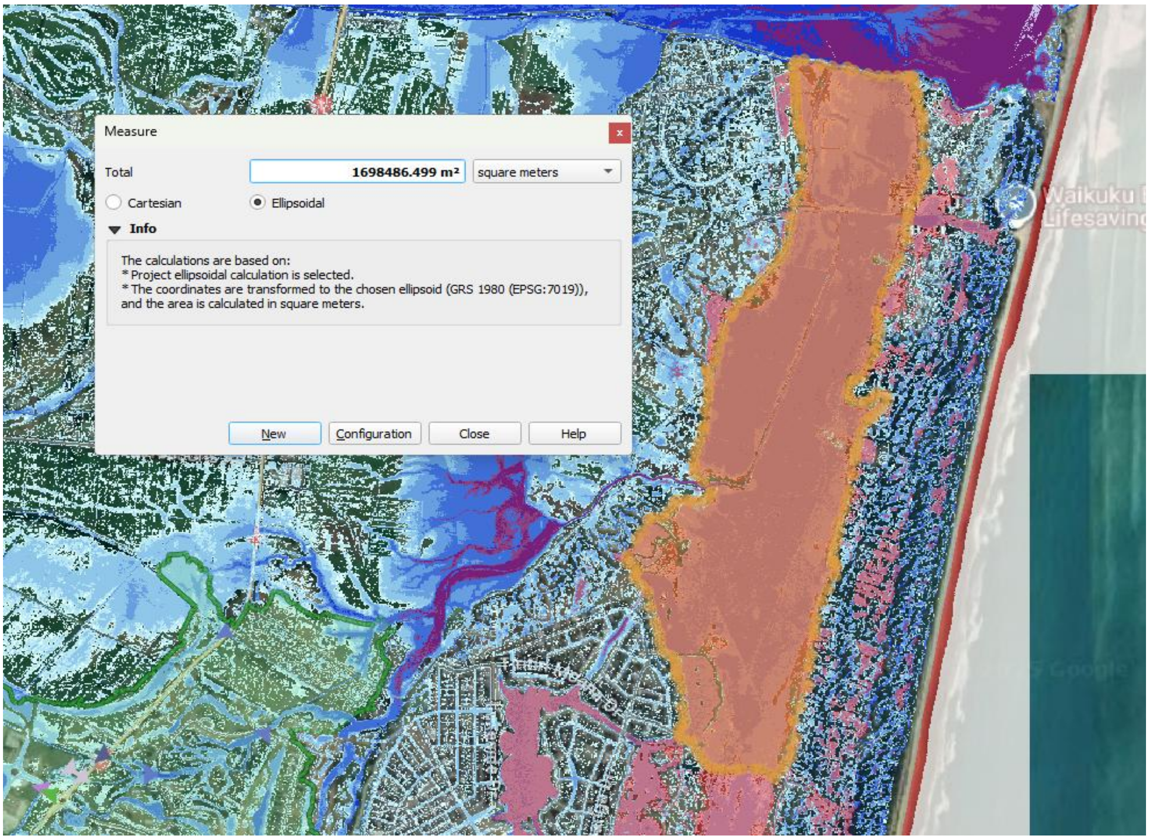


Figure 2-24 Bathtub 2 extent (Downstream of Taranaki Stream)

Figure 2-26 and Figure 2-27 show the post-development flood extents for the 200-year storm event. It is evident from the pictures that any excess runoff stored within the ponding areas results in a negligible increase of extents, moreover, no additional vulnerable entities are affected. The extents were contained within the existing flooded areas, with no houses or structures affected.

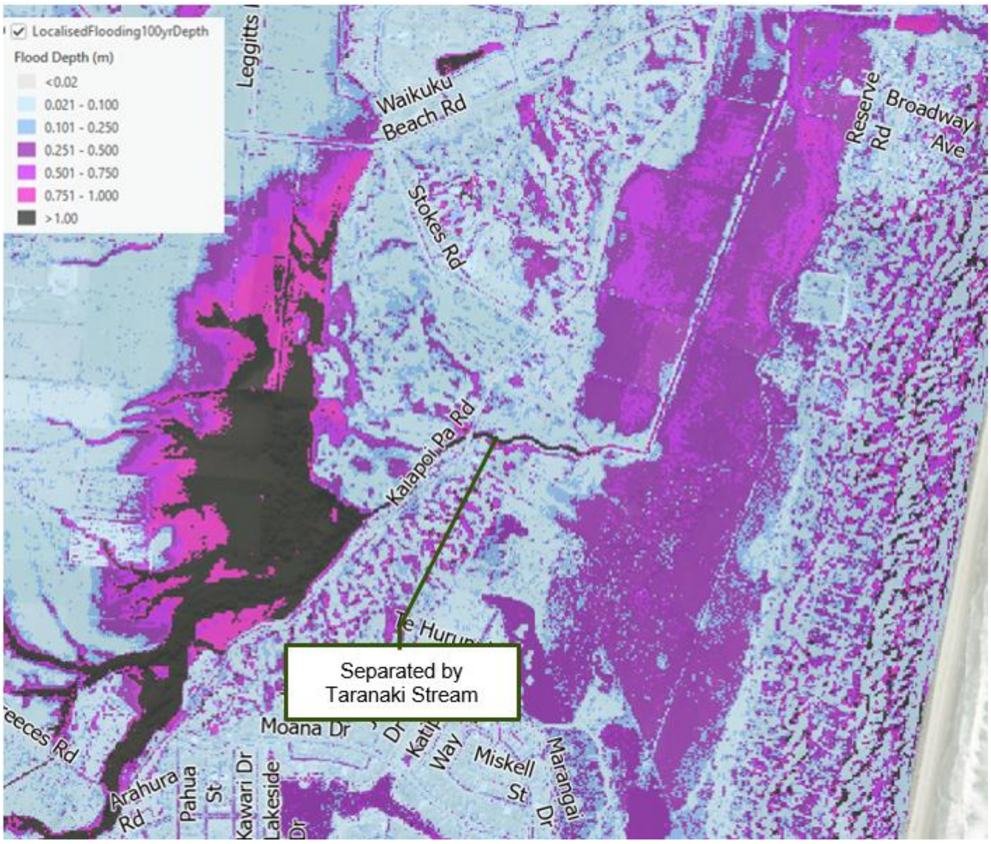


Figure 2-25 Bathtubs downstream of Taranaki Stream

Figure 2-26 Flood Extents results from the Volumetric Assessment (Brown– Pre-development Scenario; Green – Mitigation Scenario

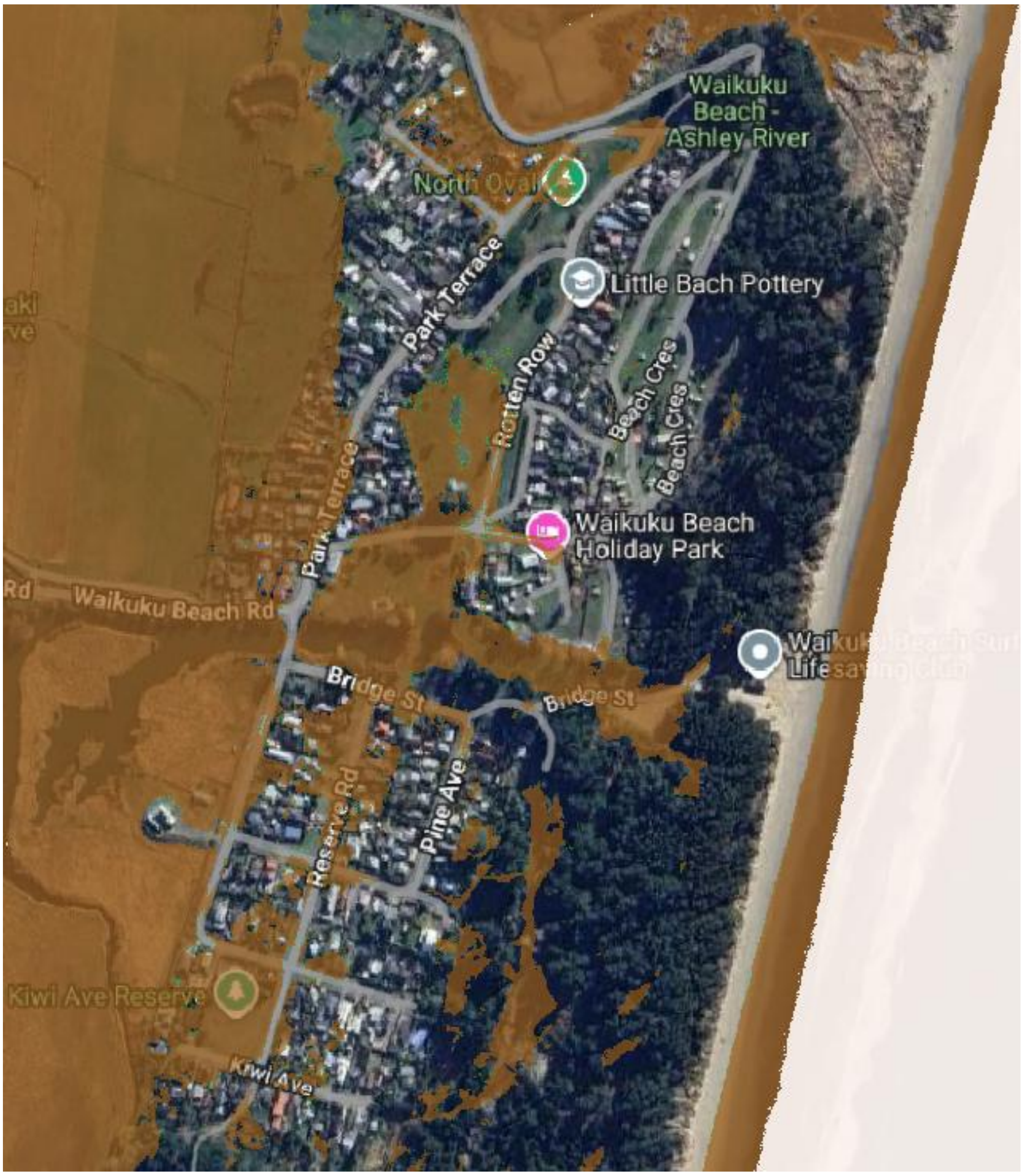


Figure 2-27 Flood Extents results from the Volumetric Assessment (Brown– Pre-development Scenario; Green – Mitigation Scenario

Waihora Creek to Gladstone Road

The overland flow path connecting Waihora Creek to Gladstone Road functions as a key drainage route, conveying runoff through to Woodend Beach Road and ultimately eastward.

During the 100-year ARI event (Figure 2-28), the upstream hydrograph near the Waihora Culvert shows a 0.08 m^3/s increase in the mitigation scenario compared to the pre-development scenario resulting from the disposal of excess runoff coming from the treatment swales and cut-off drains (refer to Section 2.3). This excess runoff was translated to the downstream section, near Gladstone Road, where a larger hydrograph was observed in the mitigation scenario. The downstream section is showing a much bigger volume of flow, primarily due to the proposed SH1 cutting off Waihora Creek thus channel storage is reduced. The proposed diversion channel doesn't make up for the lost channel storage thus more water is passed downstream.

In the 200-year ARI event (Figure 2-29) the upstream hydrograph shows a dual-peak pattern. The mitigated scenario has a lower first peak as more flow is initially conveyed to Taranaki Stream through the larger proposed culvert. Once the Taranaki Stream culvert reaches capacity, excess flow backs up and diverts into Waihora Creek, resulting in a higher second peak in the mitigation scenario (as discussed also in Table 2-5). The downstream hydrograph for the mitigated scenario signifies the intended storage of excess runoff in the flood plain, north of Gladstone Road, by limiting the flow through culvert 10A in the 200-year ARI event (i.e. flattened hydrograph). Figure C-16 also shows the positive afflux caused by the design storage.

Despite these local affluxes, flood extents remain unchanged and no increased flood risk to is expected to nearby properties.

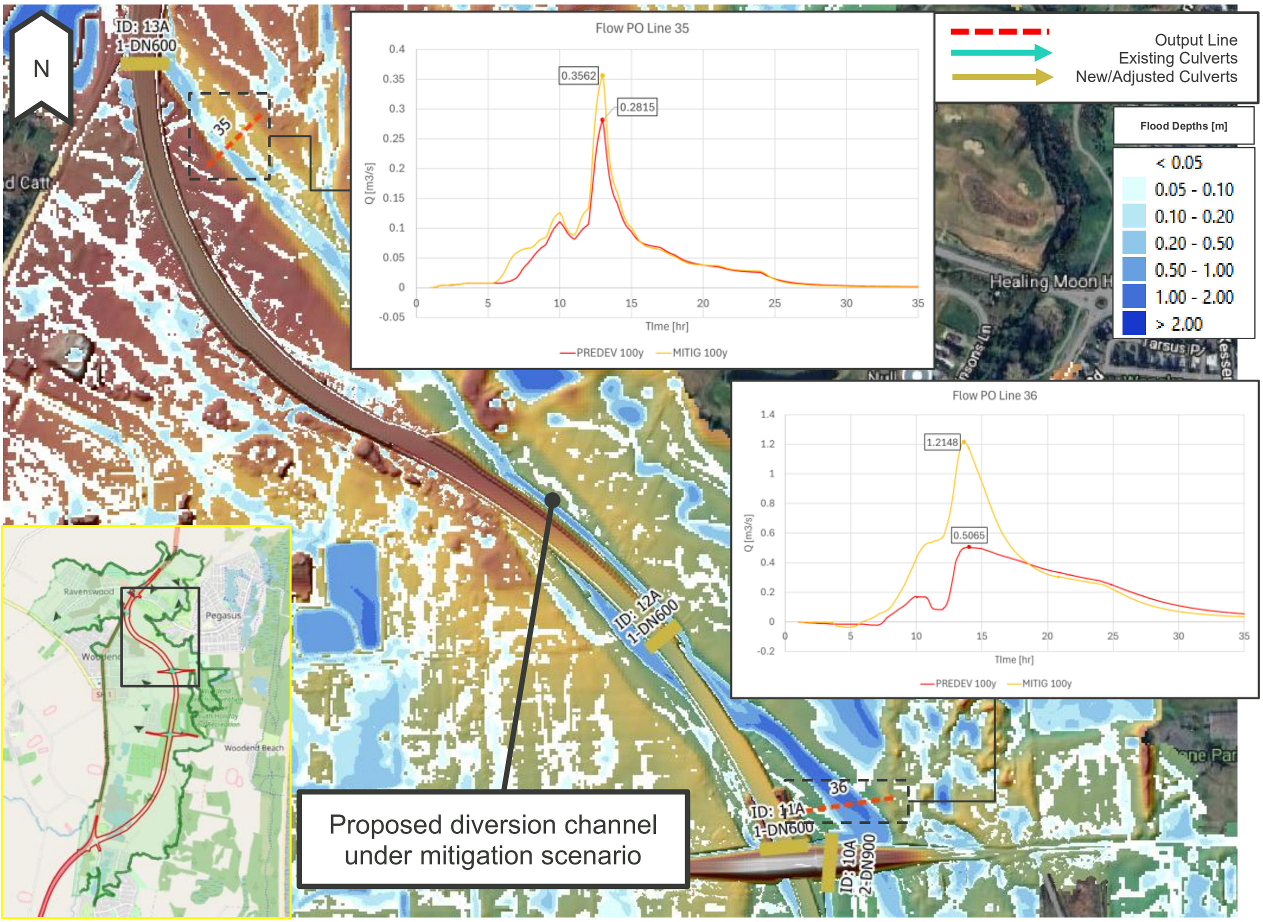


Figure 2-28 Waihora Creek to Gladstone Road 100-year Flood Duration Assessment

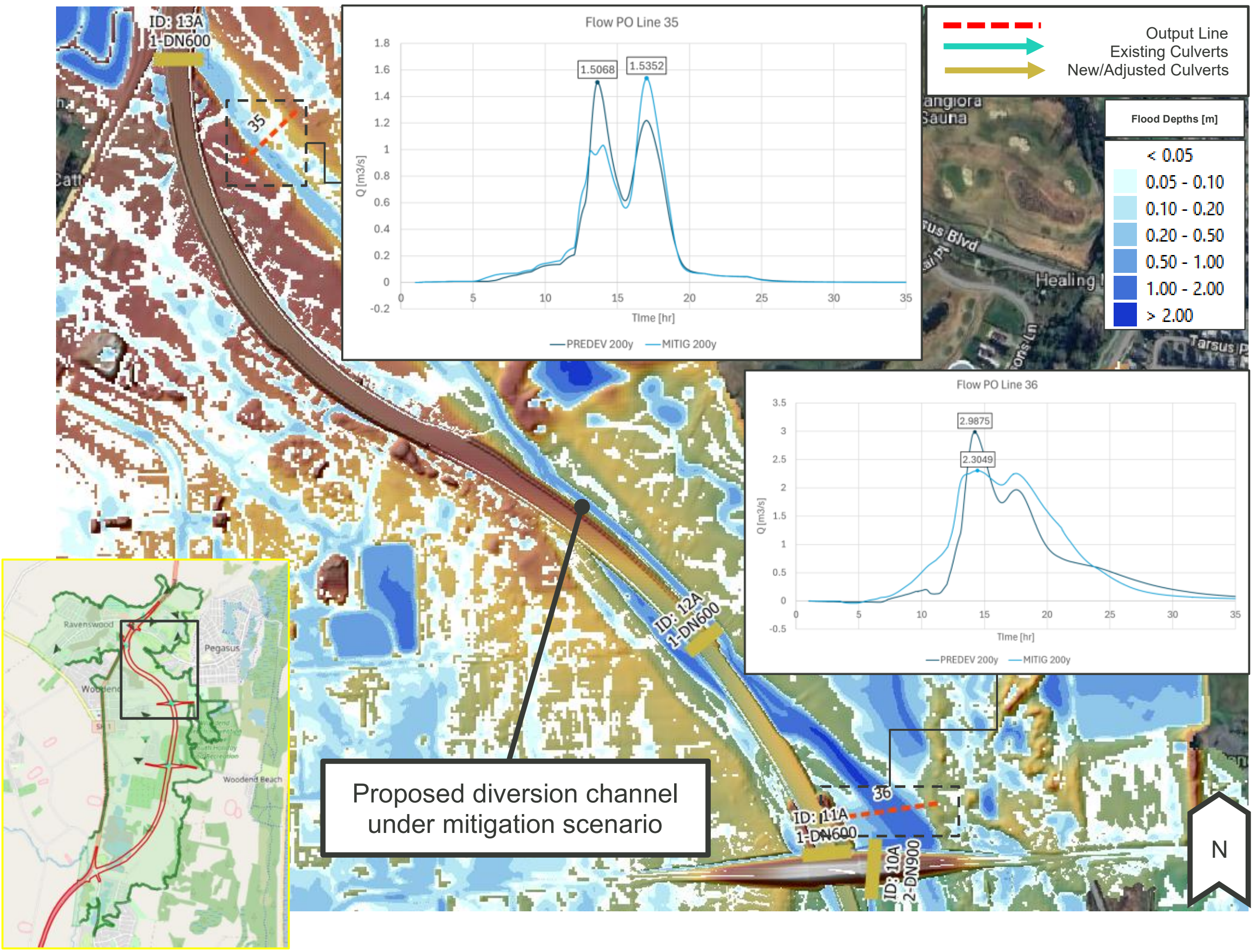


Figure 2-29 Waihora Creek to Gladstone Road 200-year Flood Duration Assessment

Woodend Beach Road

Similar to the situation at Gladstone Road, the proposed interchange at Woodend Beach Road functions as an impounding structure, temporarily storing runoff from the proposed eastern waterways of the bypass.

For the 100-year ARI event (Figure 2-30), the hydrographs at both the upstream and downstream of Woodend Beach Road show higher peaks in the mitigation scenario. This is due to the proposed larger culvert, which enables greater flow conveyed downstream. In the existing scenario, runoff ponds behind the road before overtopping downstream. Positive afflux was also observed at the downstream area but was contained within the existing flood plain and overland flow path (Figure C-15).

For the 200-year ARI event (Figure 2-31), the higher peak between the pre-development and mitigation scenario hydrographs at the upstream and downstream sections switched which indicates a constricted flow through the proposed culvert 08A in the mitigation scenario, with the intension of utilizing the storage behind Woodend Beach Road. This was effective in controlling the afflux at the downstream section with pre-development levels maintained, as shown in Figure C-16. Although, it should be noted that the total volume of water for the mitigation scenario in the downstream hydrograph was still higher than the pre-development scenario hydrograph.

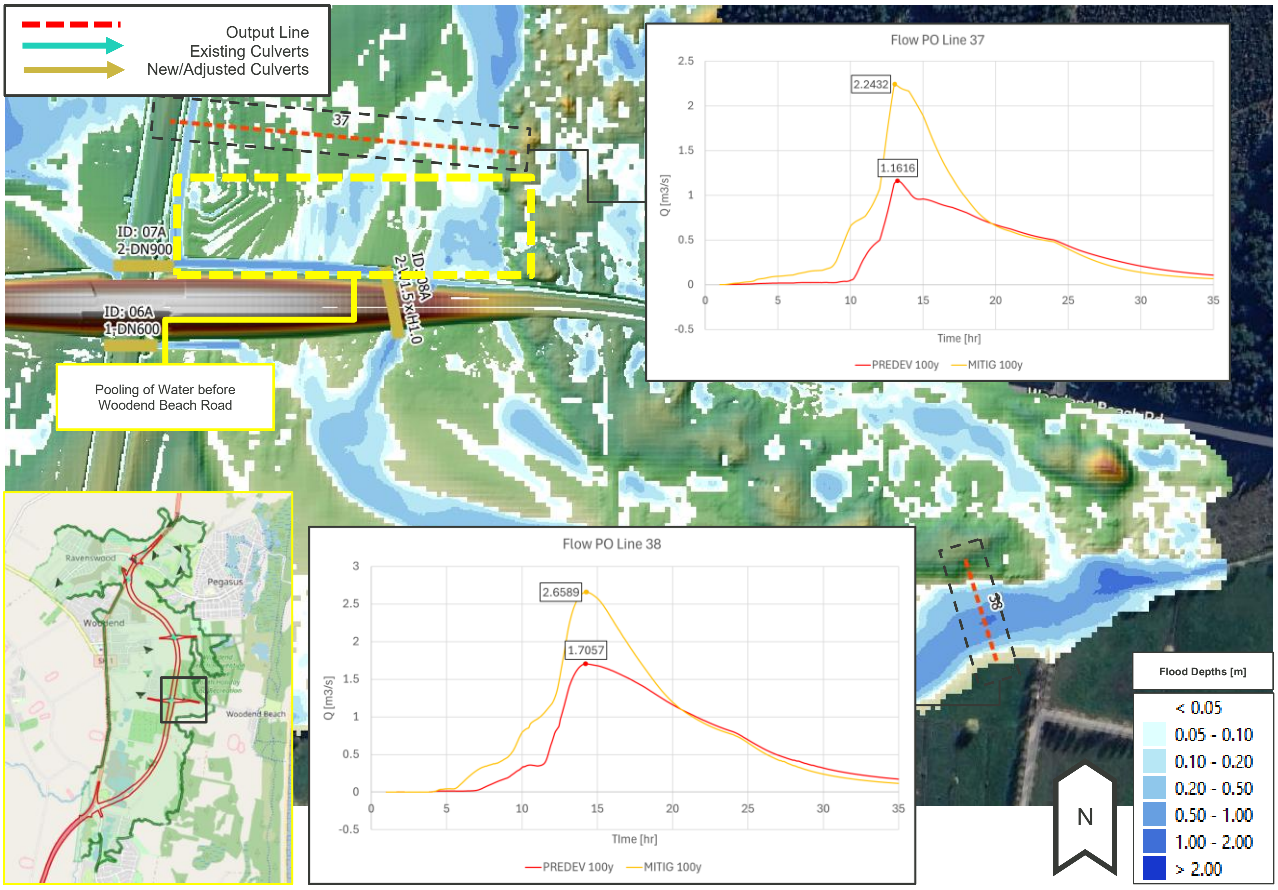


Figure 2-30 Woodend Beach Road 100-year Flood Duration Assessment

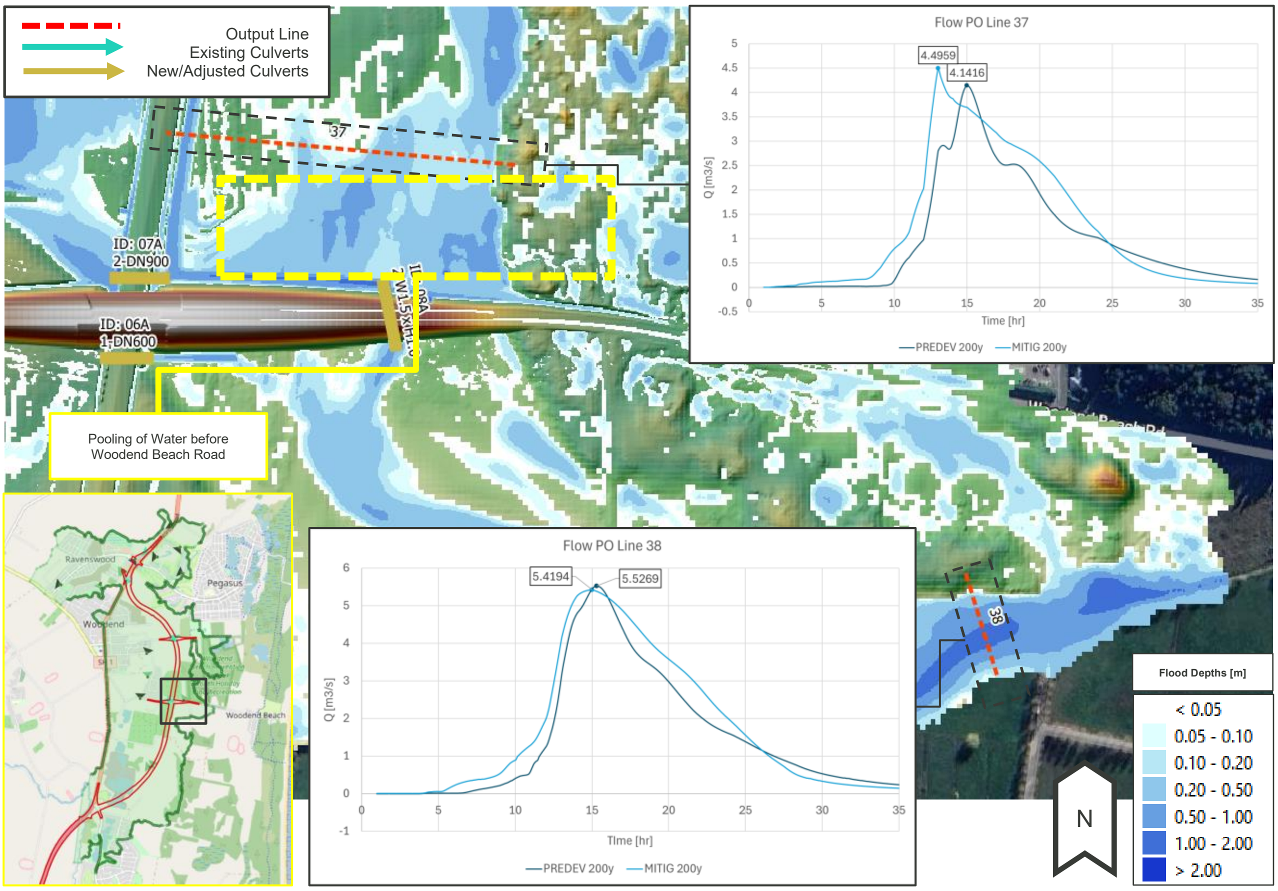


Figure 2-31 Woodend Beach Road 200-year Flood Duration Assessment

Woodend Beach and Stalkers Road

A volumetric assessment at the interdunal ponding areas further downstream of Waihora Creek (outside of the model domain) was done to quantify any potent9ial impacts in this area, specifically in Woodend Beach, and communities near Stalkers Road. Table 2-9 shows the calculated total volume difference between the two scenarios.

Table 2-9 Total Volumetric Water Difference – Woodend Beach Road and Stalkers Road

Parameter	PREDEV	MITIG	DIFFERENCE
100-year ARI Total Volume [m^3]	75,399	96,706	21,306.78
200-year ARI Total Volume [m^3]	182,601	212,238	29,636.82
Ponding Area [ha]	106.28		
100-year ARI			
Depth Increase [mm]	20.00		
Assumed Water Level [mRL]	1.20		
Final Water Level [mRL]	1.22		
200-year ARI			
Depth Increase [mm]	27.88		
Assumed Water Level [mRL]	1.20		
Final Water Level [mRL]	1.2278		

A conservative bathtub storage assessment was done to establish the water level that corresponds to the 200-year flood extents of the WDC model. An assumed relative level of 1.20mRL was determined that matched the flood extents best and has become the basis for the total ponding area, which is approximately 106.28 ha. (Figure 2-32). The volume difference and the ponding area translated to a potential maximum 27.88mm increase. Pre- and post-development flood extents were overlaid (Figure 2-33) using the calculated water levels and showed minimal increase to the extents with no impacts to buildings and properties. The assessment is considered conservative as it assumes that no increased water discharges from the ponding area due to higher inflows.

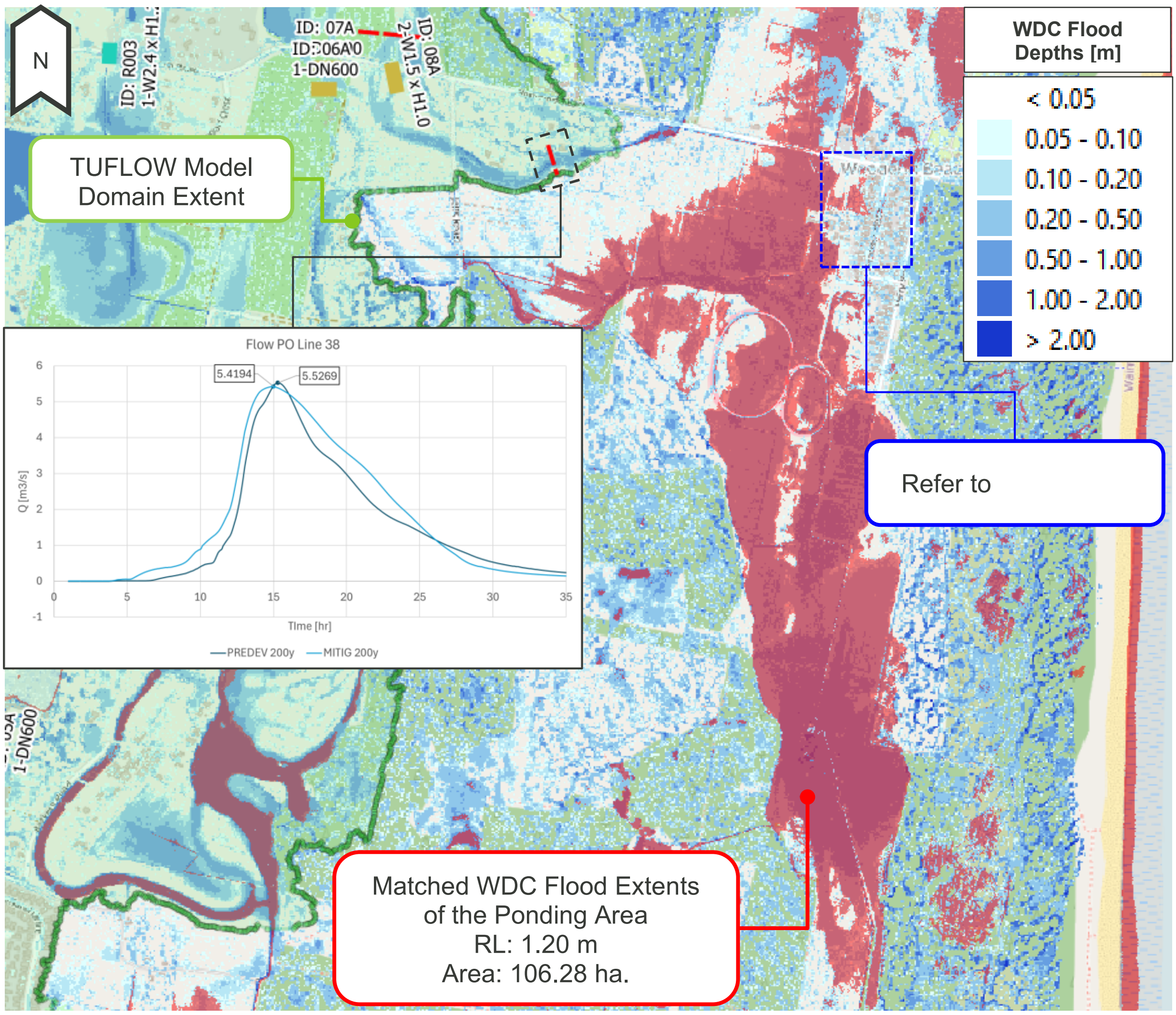


Figure 2-32 Bathtub Assessment using the WDC Flood Model Results

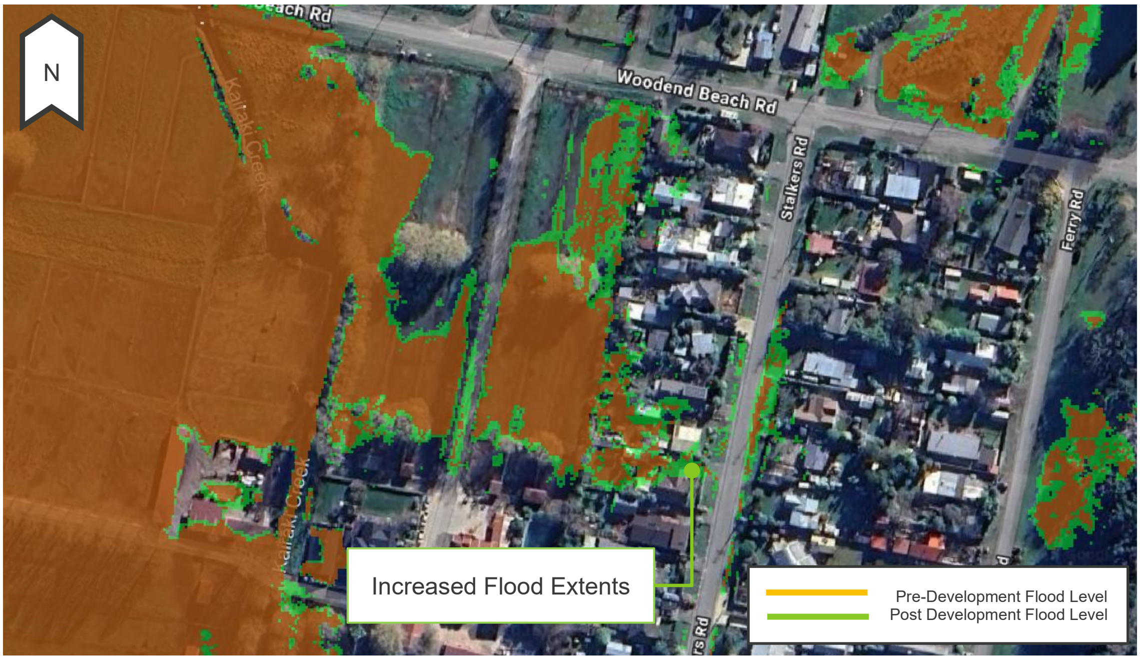


Figure 2-33 Woodend Beach and Stalkers Road Flood Levels

McIntosh Drain

The hydrographs for both the 100-year and 200-year ARI events (Figure 2-34 and Figure 2-35) show similar flow patterns between the pre-development and mitigation scenarios, with the pre-development scenario exhibiting a slightly higher peak. This is due to the wider overland flow path available under existing conditions (Figure 2-3), which becomes more constrained in the mitigation scenario as flows are directed through the proposed bypass and the proposed culvert.

Overall, the drainage function is maintained. A positive afflux is observed upstream of McIntosh Drain (Figure C-15 and C-16), attributed to the raised elevation of the proposed road and a reduced cross-sectional flow area, which limits downstream conveyance. A wider flow path may be required to match pre-development levels. However, as there are no vulnerable assets within the affected floodplain, no increase in flood risk is anticipated.

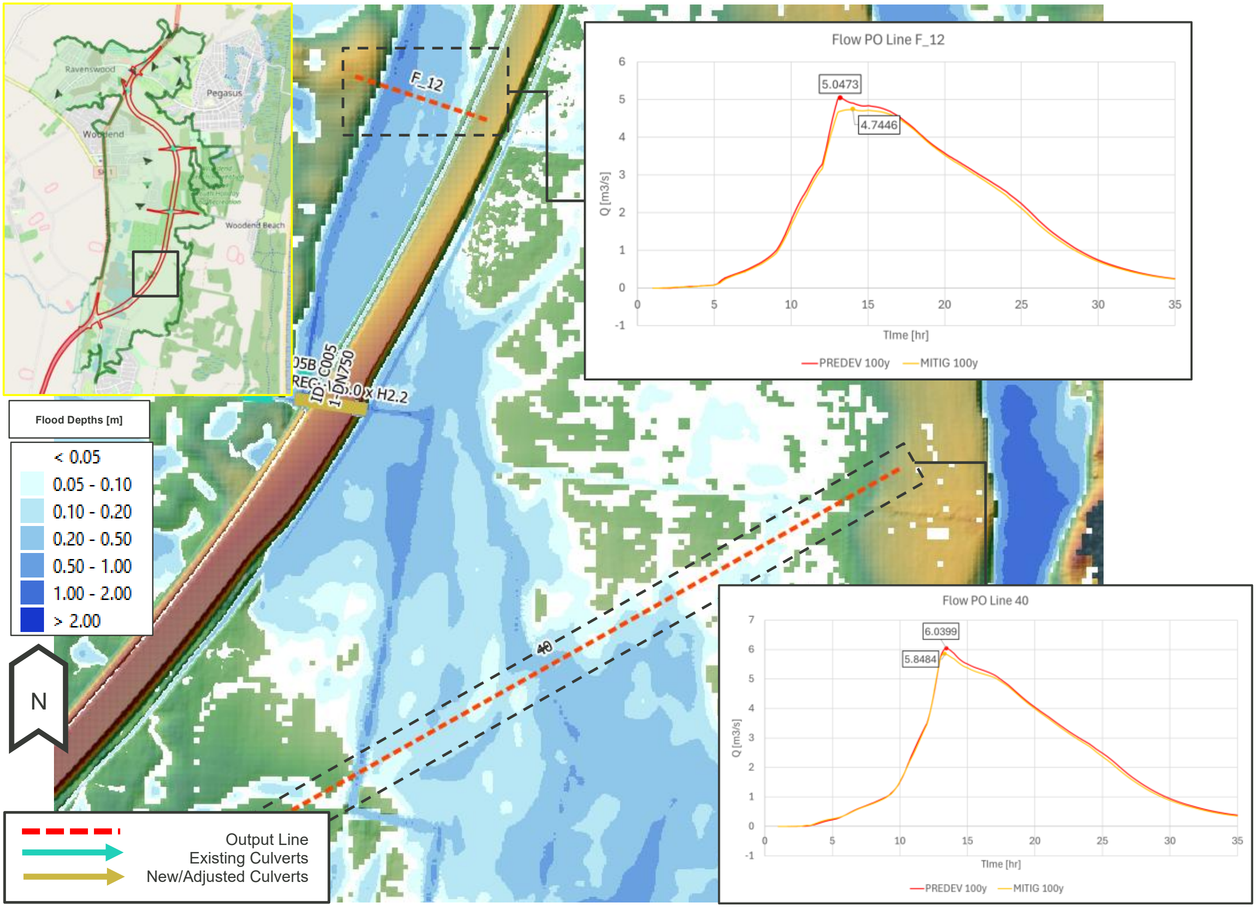


Figure 2-34 Mcintosh Drain 100-year Flood Duration Assessment

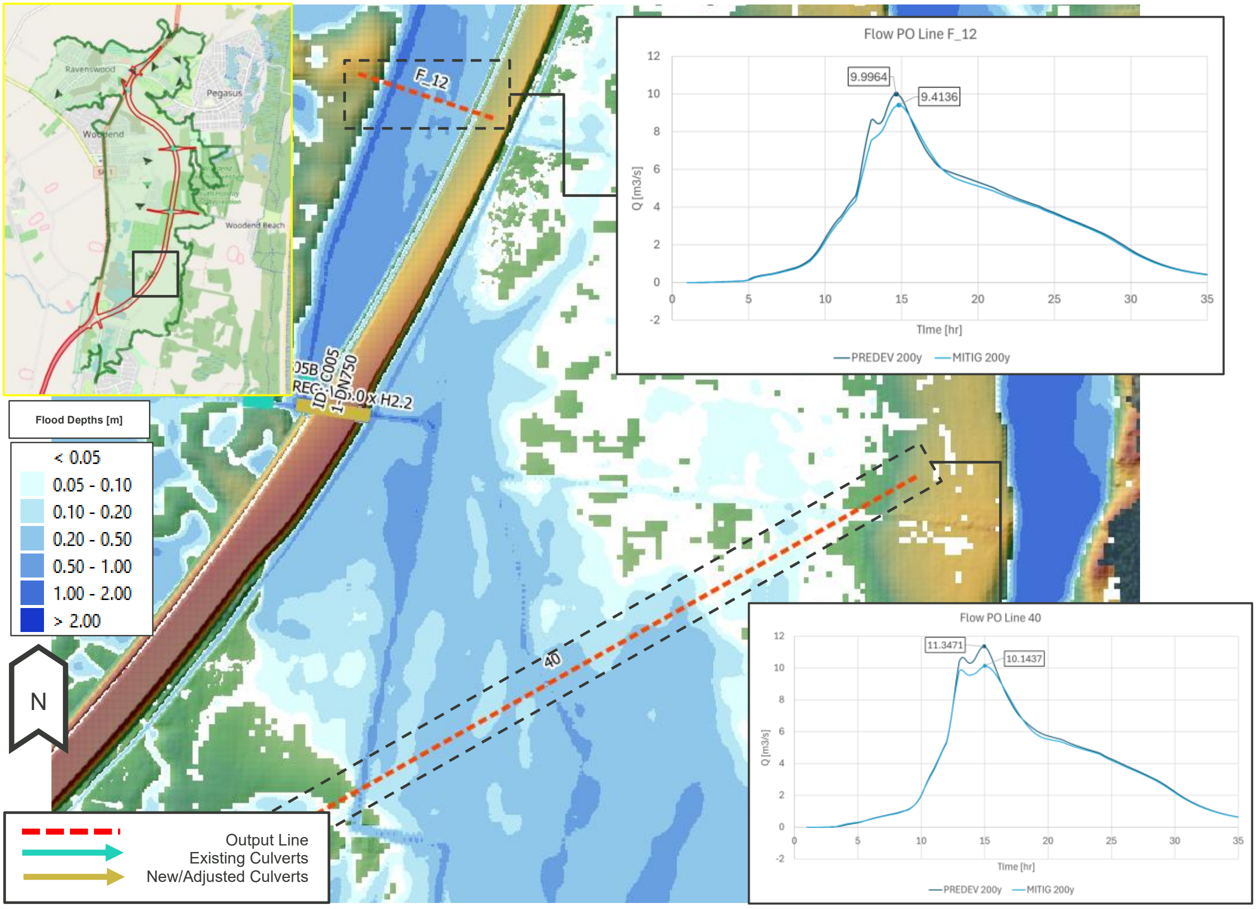


Figure 2-35 Mcintosh Drain 200-year Flood Duration Assessment

3 Limitation and Applicability

The limitations and applicability of the study include the following:

- As with any model, this model still includes assumptions and simplifications of the complex real-world processes. On a broad scale, the model build provides a reasonable representation of flood depths and extents. The model, therefore, is deemed fit for purpose for broad-scale planning measures and for testing of flood impacts from proposed stormwater design and flood mitigation options.
- The B2P Flood Model has been developed using the hydraulic and hydrological data from WDC South Ashley Model. With this, all assumptions and limitations from the WDC model also apply. The 'Flood Hazard Models Update' report[5] can be referred to for further information.
- Terrain data:

  a. The B2P Flood Model is a snapshot of the catchment when the LiDAR was flown in 2020 and does not include new developments and future development. It may, therefore, not be applicable where flows from newly developed areas impact on results.

  b. The existing basin surrounding the Ravenswood development area has not been accurately represented due to a lack of survey data and was not captured in the 2020 LiDAR data.
- It should be noted that localised ponding depths may vary significantly where overland flow is obstructed or blocked (e.g. by obstacles, debris, solid fences, retaining walls, sheds, etc.). Results could also be impacted in places which are not necessarily fully resolved by the 2-m grid used in this study.

[5] DHI (May 2020). *Flood Hazard Models Update*.

4 Conclusion

This assessment has been carried out to investigate the flood impacts associated with the proposed Belfast to Pegasus Road development. A B2P Flood Model was developed using TUFLOW modelling software for this assessment. The following are the objectives of the flood assessment:

- No significant increase in flood levels at neighbouring dwellings for the 100-year ARI event.
- Any increase in flood levels at neighbouring dwellings for the 200-year ARI event should be limited to 20 mm.
- Ensure that the risks associated with the barrier effect induced by the proposed road development on the adjacent areas are reduced through various mitigation measures such as additional culverts, improvement/rehabilitation of existing culverts, and provision of additional channels to maintain or improve flow of runoff.

Three models have been developed, namely Pre-Development, Post-Development, and Mitigation models. The Pre-Development model assessed the current conditions of the model domain, including existing culverts and overland flow paths. It was considered as the base line model where flows, flood levels, and extents will be maintained through the proposed mitigation measures. The model was calibrated and validated with the WDC Flood Model in terms of flood levels and extents. The observed variations were attributed to mainly topographical differences and areas between the WDC and B2P Flood Models. The computational grid resolution was also seen as a factor to the differences of results. The Post-Development model accounts for the proposed roadway, without the mitigation measures and shows the exacerbation of impacts and flood levels. These impacts were reduced in the Mitigation model through the installation of new culverts and channels to maintain the original drainage line and storage capacities of the surrounding areas.

The assessment findings indicate a flood level increase in various locations due to the proposed road development, with most impacted zones confined to the vicinity of the proposed road corridor. Additionally, elevated flood levels were observed in the residential areas along Main North Road and Woodend Beach Road, during both the 100-year and 200-year ARI events.

To ensure compliance with the regional policy statement and council requirements, two primary measures were proposed and modelled to reduce the flood impacts: the introduction of additional culverts and the diversion of flow path channels, including drainage channels, treatment swales, and cut-off drains. The mitigation measures have demonstrated effective reduction in flood impacts across most areas during both the 100- and 200-year ARI events. The three impacted properties in the post-development model have been fully resolved in the mitigation model, with impacts of less than 20mm afflux.

Positive affluxes are still observed in areas outside of the designation boundary; but some of these areas were intended to be flooded and it was ensured that no property will be affected. A conservative analysis was conducted for areas outside of the model domain to ensure that no risk is exacerbated. It showed that a marginal increase in the hazard is imminent, but due to the absence of buildings and properties, it is expected that the overall risk is maintained from the pre-development scenario.

Appendices

Appendix A
B2P Flood Model Build Methodology

B2P Flood Model Development

Appendix A Table 1 provides an overview of the model build methodology of the B2P Flood Model for pre-development scenario (PREDEV) and summarises the hydrological and hydraulic parameters used. This also compares the parameters used in the B2P Flood model with the WDC South Ashley Model.

Appendix A Table 1 Comparison of WDC South Ashley Model and B2P Flood Model build

Parameter	WDC South Ashley Model	B2P Flood Model (PREDEV)
Software version	• MIKE FLOOD	• TUFLOW-2023-03-AC-iSP-w64
Projection	• NZGD 2000 New Zealand Transverse Mercator	• NZGD 2000 New Zealand Transverse Mercator
Vertical datum	• Lyttelton Vertical Datum (LVD)	• New Zealand Vertical Datum 2016 (NZVD16)
Computational and simulation parameters	• Minimum timestep: 1e-05s • Maximum timestep: 1s • Simulation time: 56hr • Results save timestep: 5min	• 1d timestep: 0.1s • 2d timestep: 0.5s • Simulation time: 35hr • Time series output interval: 60s • Map out interval: 300s
Catchment delineation	• Model extent covering Waimakariri district	• Project extent covering Pegasus in the north and Kaiapoi in the south. • Refer to Appendix A Catchment Delineation Section
Topography	• Model grid element size: 5-m rectangular flexible mesh grid • 5-m LiDAR DEM 2014 from WDC South Ashley Model	• Model grid element size: 4-m rectangular grid with sub-grid sampling • 1-m LiDAR DEM 2020 from LINZ server • Surveyed LiDAR for Kaiapoi Market Square pre-development
Hydrology		
Rainfall	• 24-hr nested storm profile as derived from HIRDS v4 for the RCP 8.5 (2081-2100) climate change scenario.	• 24-hr nested storm profile for 100-year and 200-year ARI as extracted from WDC South Ashley Model
Initial Condition	• Catchment is assumed dry initially	• Catchment is assumed dry initially
Boundary Condition	• Constant water level downstream boundary of 1.4m RL at the confluence of Kaiapoi River and Waimakariri River • Free outflow for the remaining areas downstream of the model	• Inflow boundaries (QT) applied upstream of the pipe network as extracted from WDC South Ashley Model • Water level boundaries (HT) applied downstream as extracted from WDC South Ashley Model • Refer to Appendix A Boundary Condition Section
Ground infiltration	• Infiltration method: MIKE21 infiltration and leakage module • Parameters such as initial infiltration, leakage, porosity, and initial saturation were applied	• Infiltration Method: TUFLOW Horton • Parameters such as initial loss, initial loss rate, final loss rate, porosity, and initial moisture were applied as extracted from WDC South Ashley Model • Exponential decay rate was applied as extracted from Waterways, Wetlands, and Drainage Guide of the Christchurch City Council • Refer to Appendix A Ground Infiltration Section

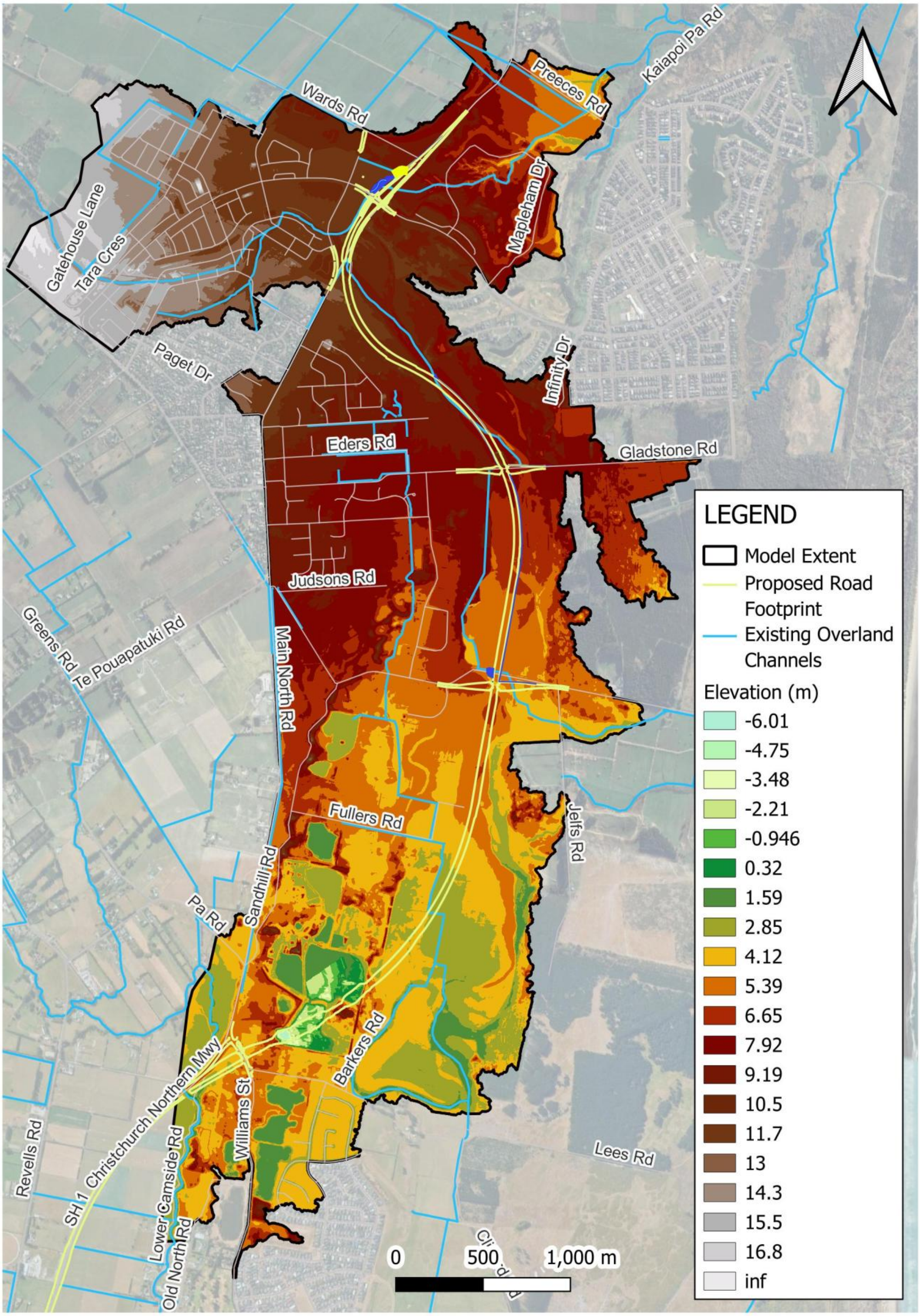
Parameter	WDC South Ashley Model	B2P Flood Model (PREDEV)
Surface roughness	• Manning's surface roughness 'M' based on LCDB v4.1 database shapefiles	• Manning's surface roughness 'n' as extracted from WDC South Ashley Model • Refer to Appendix A Surface Roughness Section
Stormwater network		
Pipe network & Culverts	• Stormwater asset data covering the Waimakariri District • Culverts are not defined in the model. Where flow path is blocked by existing road, existing road level has been lowered down to provide overland flow path	• Models were run with the assumption of 100% pipe blockage. • For culvert modelling, refer to Section Stormwater Network and Culverts under Appendix A

Terrain

The topographic data used in the B2P Flood Model comprises of the collected survey data and the 2020 LiDAR Digital Elevation Model (DEM) from LINZ. The survey covers the entire length of the designation of the proposed roadway bypass, including newly developed communities near the project site that were not covered in the 2020 LiDAR DEM. The Flood Mitigation Scenario Model was re-ran with the finalised proposed roadway surface to analyse the effectivity of the measures with the ultimate design.

Catchment Delineation

The catchment was delineated using the 1m DEM LiDAR 2020 to determine the B2P Flood Model extent as shown in Appendix A Figure 1. The model extent is simplified by defining the catchment boundary covering the road alignment mostly in the towns of Pegasus, Woodend and Kaiapoi. Upper catchments were just represented as inflow boundary condition lines to avoid longer model runtime.



Appendix A Figure 1 B2P Flood Model catchment delineation

Hydrology

Rainfall

Rainfall was ingested into the model domain using a set of 50m x 50m resolution time varying 24-hour nested rainfall grid which was extracted from the WDC Flood Model. The rainfall grids have an hourly timestep with the first observation of rainfall starting at hour 1. As stated in Appendix A Table 1, the dataset was derived from HIRDS and incorporates a climate change scenario of RCP 8.5 for the period of 2081-2100.

Boundary Condition

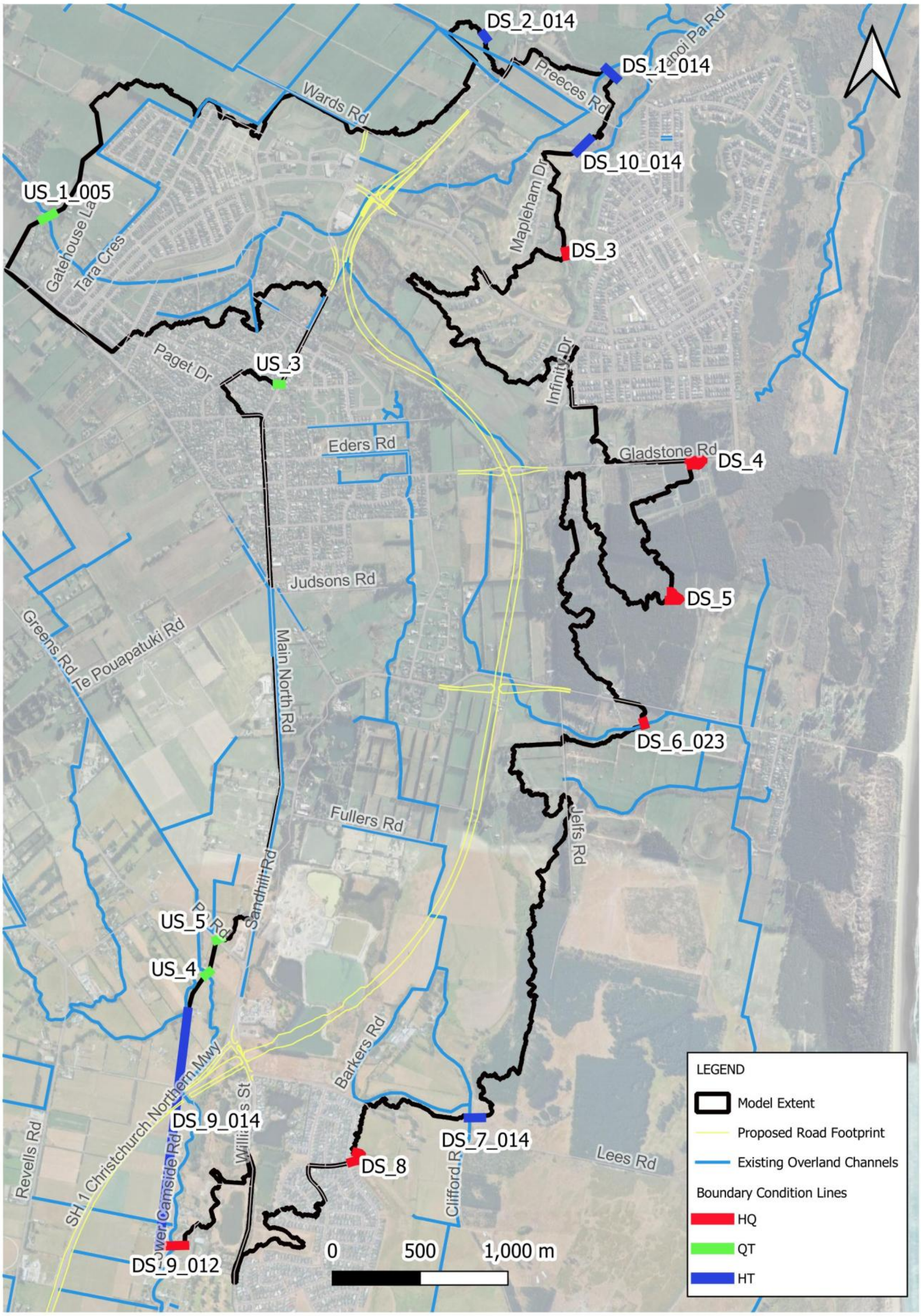
The WDC Flood Model was the basis of all the boundary condition locations, where major drainage lines cross the extents of the model domain. Upstream flow BCs (QT) and downstream water level BCs (HT) were extracted also from the WDC Flood Model. Open boundaries, as represented by the slope, were calculated from the topographical data used in the TUFLOW model.

Flow hydrographs were used as an upstream boundary condition (US_1_005, US_3, US_4, US_5) along major drainage lines (e.g. rivers and streams) which are connected to upstream catchments and have been the source of water for the model domain. These are represented as a Flow vs. Time (QT) input with locations shown in Appendix A Figure 2. The 100- and 200-year ARI flow events are shown in Appendix A Figure 3.

Water level boundaries, Head vs Time (HT), are applied downstream of the model (DS_1_014, DS_2_014 and DS_10_014) at Waikuku to the north and at the western side of the Cam River (DS_9_014), as shown in Appendix A Table 2 and Appendix A Figure 4.These boundaries are influenced by other sources of water, specifically for areas near river or stream junctions that were not considered in the model domain. The same approach was applied to the floodplain at the southwestern boundary of the model (near Cam River) to simplify the movement of water since the WDC model shows that the area is a catch basin of water from different locations, apart from the Cam River.

A water level boundary Appendix A Figure 4 was also established at a major overland flow at a drain located east of quarry lake (DS_7_014). The flow paths connect to a small drainage channel that can constrict flow in rare storm events, consequently funnelling water and producing tailwater conditions.

Free flow boundaries, as shown in (HQ), have been placed at the downstream cross section of the Cam River (DS_9_012), and a few other streams that eventually discharges towards the east (DS_3, DS_4, DS_5, DS_8), and specifically the downstream end of the Waihora Creek (DS_6_023). These areas drain water freely out of the model domain.



Appendix A Figure 2 B2P Flood Model inflow and downstream boundaries

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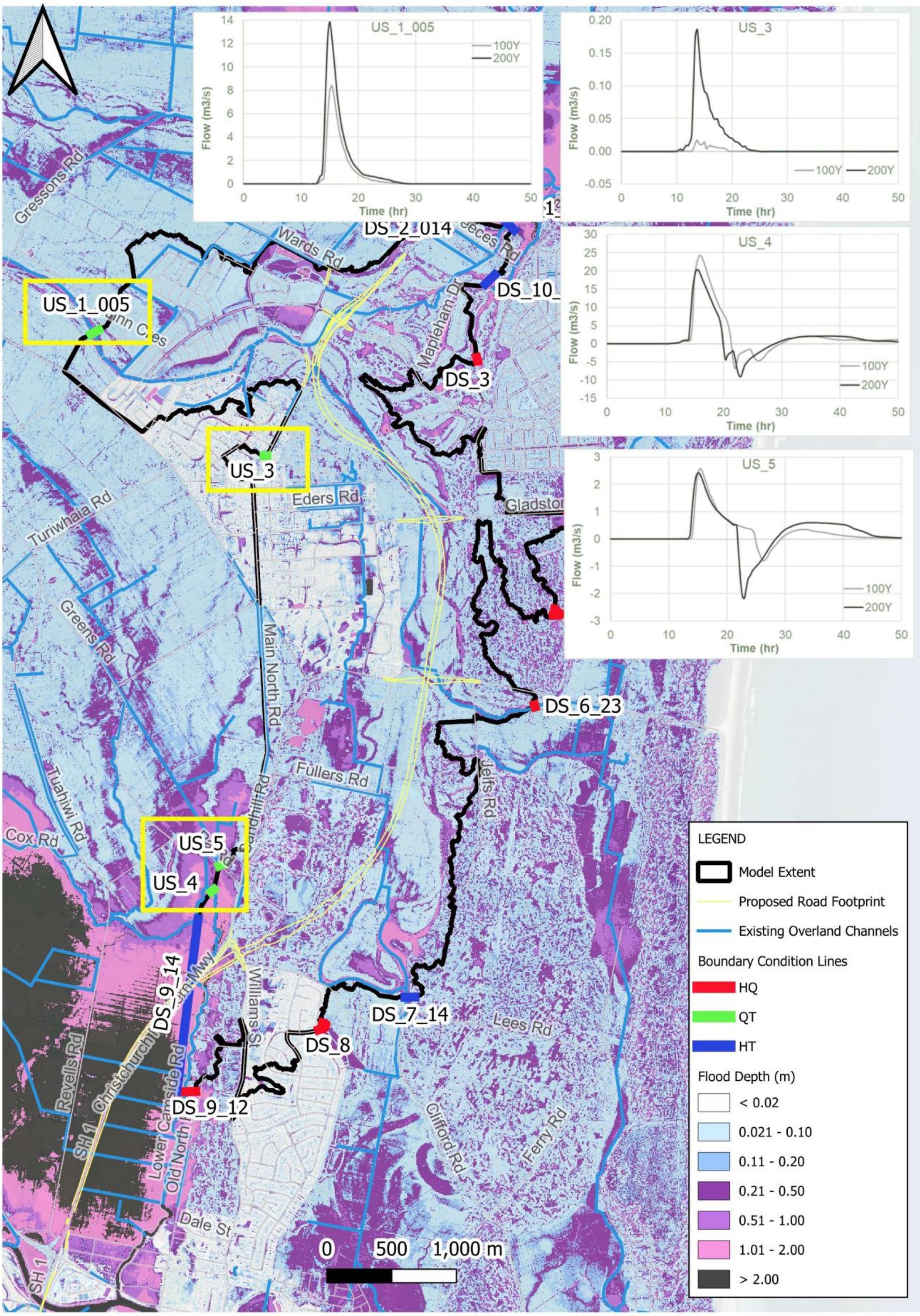
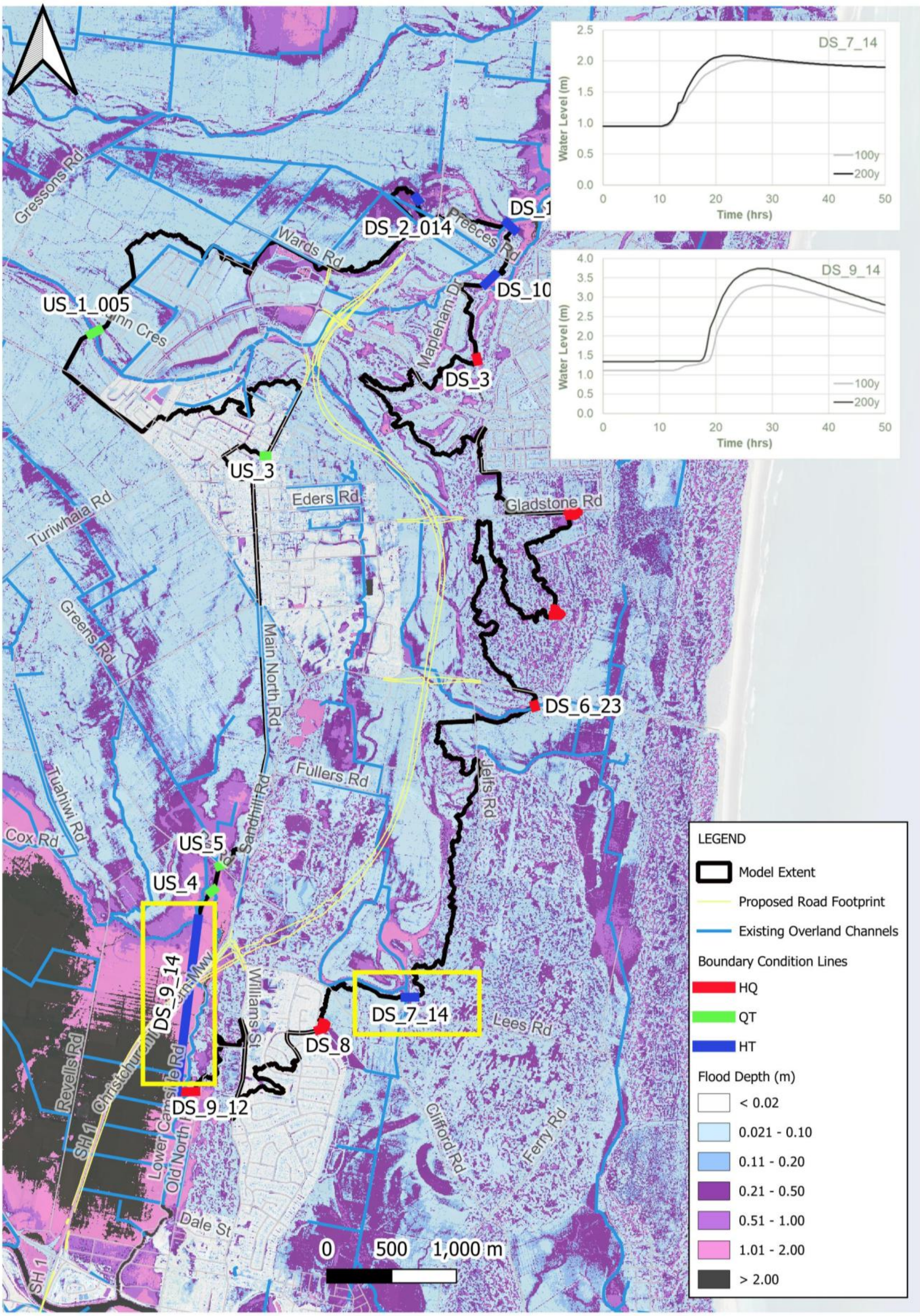


Appendix A Figure 3 Boundary Conditions with Equivalent Inflow hydrographs



Appendix A Figure 4 Boundary Conditions with Equivalent Stage hydrographs

Appendix A Table 2 Water Level Downstream Boundary Conditions

BC Line	100-year Level (m)	200-year Level (m)
DS_1_014	2.93	2.94
DS_2_014	5.31	5.31
DS_10_014	2.93	2.94
DS_7_014	Varying Water Level (Appendix A Figure 4)	
DS_9_014		

Appendix A Table 3 Normal Depth Downstream Boundary Conditions

BC Line	Slope
DS_3	0.0036
DS_4	0.0041
DS_5	0.0041
DS_6_023	0.0017
DS_8	0.0008
DS_9_012	0.0008

Ground Infiltration

The soils infiltration losses are applied to the B2P Flood Model using the parameters of the Horton method. Parameters such as the dry loss, initial loss rate, final loss rate, porosity, and initial moisture were extracted from WDC South Ashley Model. Detailed information on ground infiltration methodology can be referred to Section 3.2.2 of 'Flood Hazard Models Update' report.

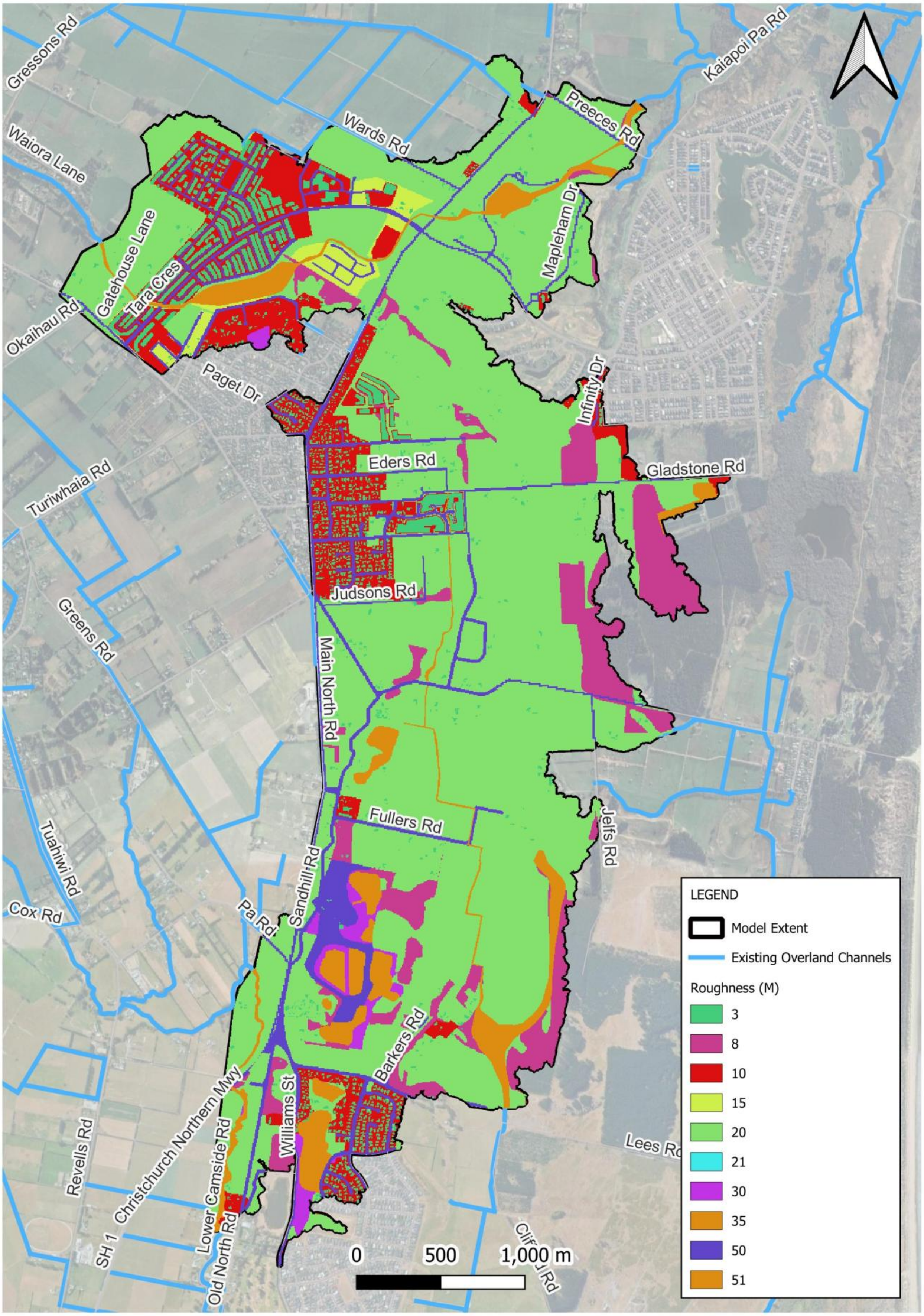
The exponential decay rate (k) parameter was determined based on the Waterways, Wetlands, and Drainage Guidelines (WWDG) of the Christchurch City Council (CCC), as detailed in Appendix A Table 4 decay rate was identified based on the initial infiltration rate extracted from WDC South Ashley Model.

Appendix A Table 4 Horton decay rate extracted from WWDG

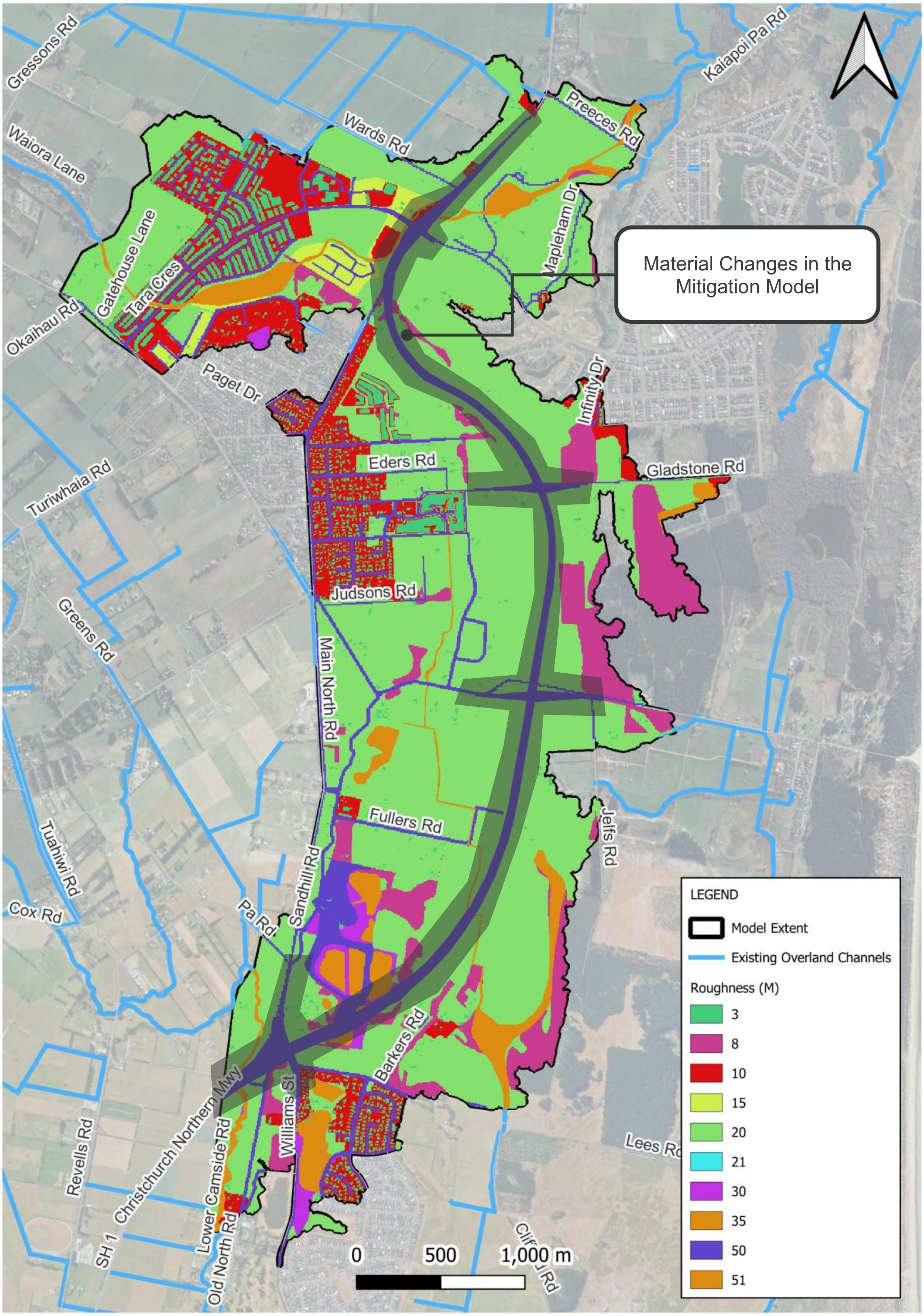
Initial infiltration rate (mm/hr)	Horton decay rate, k	Infiltration type
0 – 5	0.0015	Poor
5 – 10	0.0001	Moderate
10 – 15	0.00003	Free

Surface Roughness

The surface roughness as shown in Appendix A Figure 5 is applied to the B2P Flood Model. The surface roughness information is extracted from WDC South Ashley Model (refer to Appendix A Figure 7) A few changes to the surface roughness have been done in the Mitigation Scenario, to account for the proposed measures, such as the adjustment of the Taranaki Stream near Bob Robertson Drive (refer Appendix A Figure 6).



Appendix A Figure 5 **Surface roughness applied in B2P Flood Models (Existing Scenario)**



Appendix A Figure 6 Surface roughness applied in B2P Flood Models (Proposed Scenario)

Table 3-2: MIKE 21 roughness

Name_2012	Manning's M	Manning's n
Broadleaved Indigenous Hardwoods	8	0.125
Buildings	3	0.33
Built-up Area (settlement)	10	0.1
Deciduous Hardwoods	8	0.125
Depleted Grassland	50	0.02
Estuarine Open Water	35	0.029
Exotic Forest	8	0.125
Fernland	8	0.125
Flaxland	8	0.125
Forest - Harvested	8	0.125
Gorse and/or Broom	8	0.125
Gravel or Rock	50	0.02
Herbaceous Freshwater Vegetation	10	0.1
Herbaceous Saline Vegetation	10	0.1
High Producing Exotic Grassland	20	0.05
Indigenous Forest	8	0.125
Lake or Pond	35	0.029
Landslide	50	0.02
Low Producing Grassland	10	0.1
Manuka and/or Kanuka	8	0.125
Matagouri or Grey Scrub	10	0.1
Mixed Exotic Shrubland	20	0.05
Orchard, Vineyard or other Perennial Crop	20	0.05
River	35	0.029
Road	50	0.02
Sand or Gravel	50	0.02
Short-rotation Cropland	20	0.05
Sub Alpine Shrubland	20	0.05
Surface Mine or Dump	50	0.02
Tall Tussock Grassland	10	0.1
Transport Infrastructure	10	0.1
Urban Parkland/Open Space	20	0.05

Appendix A Figure 7 Surface roughness table extracted from 'Flood Hazard Models Update' report

Stormwater Network and Culverts

Appendix A Figure 8 shows the existing stormwater culverts along the major rivers and channels around the proposed development. For the B2P flood modelling purposes, urban pipe networks were assumed to be at full capacity during the 100-yr and 200-yr storm events, essentially not providing any storage and conveyance functionalities.

Geometric details of the pipes were extracted from the WDC database and were cross-referenced with the on-going topographical and drainage inventory survey along the designation of the proposed roadway. For areas that were not covered by the survey, details from the WDC database were considered absolute and were used whenever available since a few culverts lacked geometric details, such as the sizes and invert elevations. Details for culverts that did not have any data, both from the WDC database and survey, were assumed intuitively using satellite imagery and topographic information.

Appendix A Table 5 shows the inventory of all the culverts modelled in the B2P Flood Model. It indicates which culvert were either new, maintained, adjusted, or removed in the Mitigation Scenario:

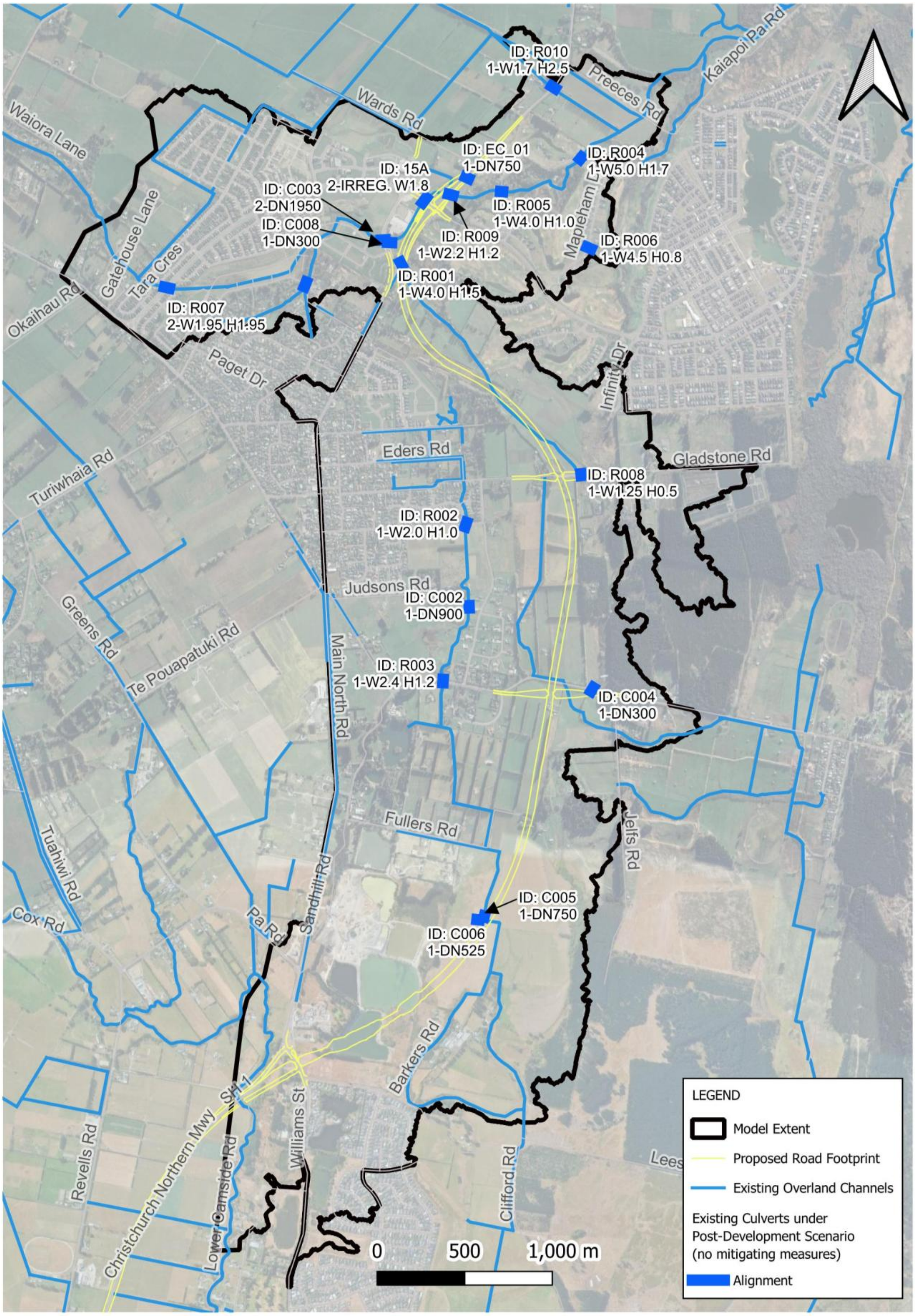
- Maintained – culverts were preserved from the Pre-Development Scenario Model since these were outside of the Proposed Roadway Designation and are not affected by the development.
- Adjusted – geometrical properties and/or alignment changes to the culvert. IDs of the adjusted culverts have been renamed in the Mitigation Model Scenario.
- Removed – decommissioned culverts due to changes of the overland flow path and have been affected by the Proposed Roadway Designation
- New Culvert – completely new culverts as part of the proposed mitigation measures

The table also details the culverts that are present in each model scenario (Pre-Development, Post-Development, or Mitigation).

Appendix A Table 5 Modelled Culvert Inventory

ID	Size	No. of Barrels	Roughness (Manning's n)	Source	Dummy Geometry [Y/N]	Fish Passage [Y/N]	Model Scenario Present	MITIG Scenario Status
C001	DN525	1	0.013	Stormwater_Pipes - 6254-SW007089	N	N	PREDEV, POSTDEV, MITIG	Maintained
C002	DN900	1	0.013	Stormwater_Pipes - 4248-SW022584	N	N	PREDEV, POSTDEV, MITIG	Maintained
C003	DN1950	2	0.013	Survey	N	N	PREDEV, POSTDEV, MITIG	Maintained
C004	DN300	1	0.013	Survey	N	N	PREDEV, POSTDEV, MITIG	Maintained
C005	DN750	1	0.013	Survey	N	N	PREDEV, POSTDEV, MITIG	Maintained
C006	DN525	1	0.013	Survey	N	N	PREDEV, POSTDEV, MITIG	Maintained
15A	Embedded Pipe with Fish Passage	2	0.0203	Survey	N	Y [300mm Embedment]	PREDEV, POSTDEV, MITIG	Maintained
C008	DN300	1	0.013	Survey	N	N	PREDEV, POSTDEV, MITIG	Maintained
EC_01	DN750	1	0.013	Survey	N	N	PREDEV, MITIG	Adjusted (MITIG ID: 17A)
R001	4.0m X 1.5m	1	0.013	Survey	N	N	PREDEV, MITIG	Adjusted (MITIG ID: 14A)
R002	2.0m X 1.0m	1	0.013	Stormwater_Pipes - 6636-SW025220	-	N	PREDEV, POSTDEV, MITIG	Maintained
R003	2.4m X 1.2m	1	0.013	Stormwater_Pipes - 4726-SW007089	-	N	PREDEV, POSTDEV, MITIG	Maintained
R004	5.0m X 1.7m	1	0.013	-	-	N	PREDEV, POSTDEV, MITIG	Maintained
R005	4.0m X 1.0m	1	0.013	-	-	N	PREDEV, POSTDEV, MITIG	Maintained
R006	4.5m X 0.8m	1	0.013	-	-	N	PREDEV, POSTDEV, MITIG	Maintained
R007	1.95m X 1.95m	2	0.013	Stormwater_Pipes - 8475-SW031268	-	N	PREDEV, POSTDEV, MITIG	Maintained
R008	1.25m X 0.5m	1	0.013	Survey	N	N	PREDEV, MITIG	Removed
R009	2.2m X 1.2m	1	0.013	Survey	N	N	PREDEV, MITIG	Adjusted (MITIG ID: 16A)
R010	1.7m X 2.5m	1	0.013	Survey	N	N	PREDEV, POSTDEV, MITIG	Maintained

ID	Size	No. of Barrels	Roughness (Manning's n)	Source	Dummy Geometry [Y/N]	Fish Passage [Y/N]	Model Scenario Present	MITIG Scenario Status
03A	DN699	1	0.013	-	-	N	MITIG	New Culvert
04A	DN375	1	0.013	-	-	N	MITIG	New Culvert
05A	DN600	1	0.013	-	-	N	MITIG	New Culvert
05B	6.0m x 2.2m	1	0.017	-	-	Y [300mm Embedment]	MITIG	New Culvert
06A	DN600	1	0.013	-	-	N	MITIG	New Culvert
07A	DN900	2	0.013	-	-	N	MITIG	New Culvert
08A	1.5m x 1m	2	0.013	-	-	N	MITIG	New Culvert
09A	DN600	1	0.013	-	-	N	MITIG	New Culvert
10A	DN900	2	0.013	-	-	N	MITIG	New Culvert
11A	DN600	1	0.013	-	-	N	MITIG	New Culvert
12A	DN600	1	0.013	-	-	N	MITIG	New Culvert
13A	DN600	1	0.013	-	-	N	MITIG	New Culvert
14A	4.0m x 1.5m	1	0.026	-	-	Y [300mm Embedment]	MITIG	Adjusted (PREDEV ID: R001)
15B	DN750	1	0.013	-	-	N	MITIG	New Culvert
16A	2.7m x 1.2m	1	0.0233	-	-	Y [300mm Embedment]	MITIG	Adjusted (PREDEV ID: R009
17A	DN1200	1	0.013	-	-	N	MITIG	Adjusted (PREDEV ID: EC_01)



Appendix A Figure 8 Existing culverts within the proposed project site

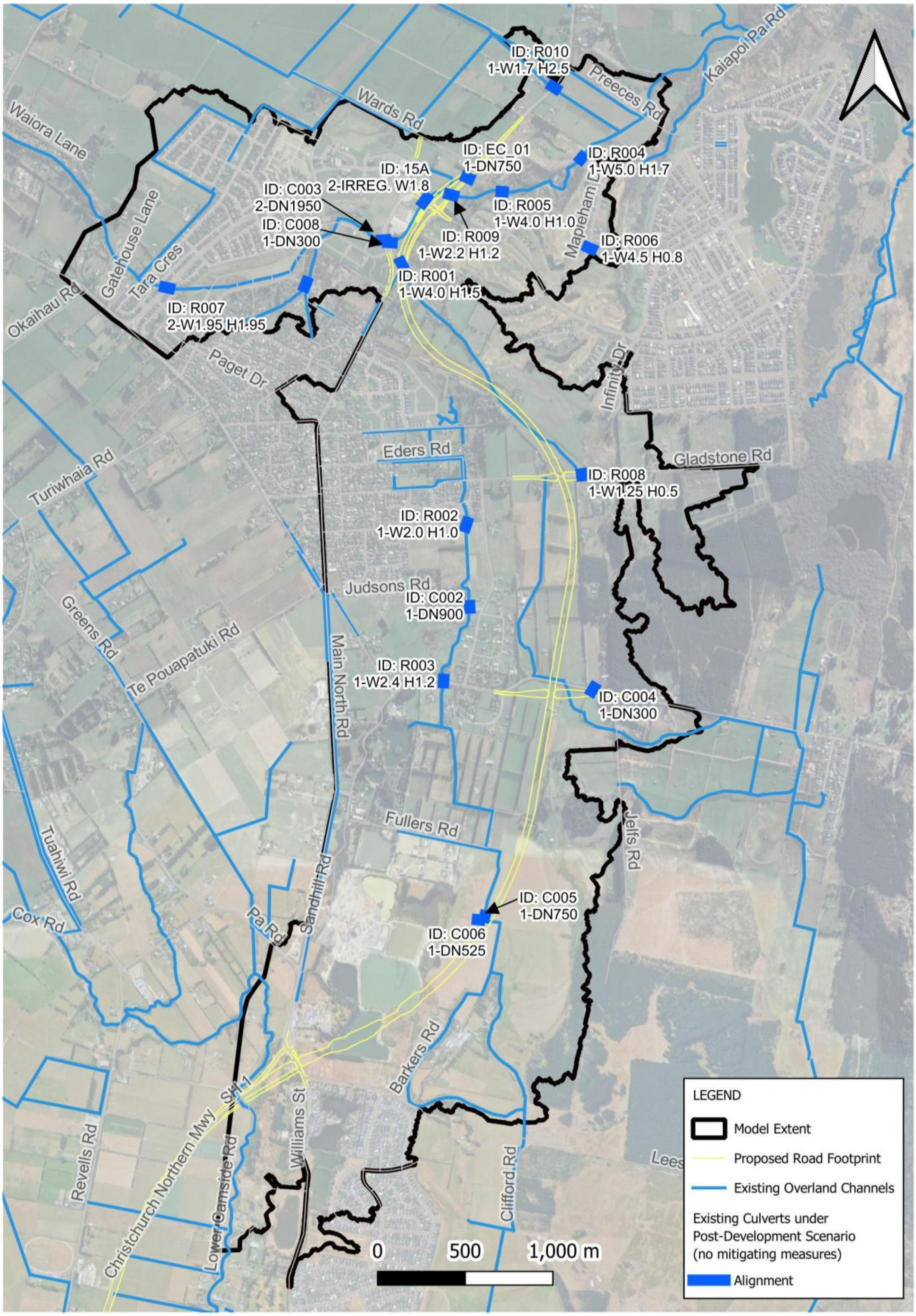
Flood Modelling Scenarios

Appendix A Table 6 summarises the baseline and design scenarios that were modelled in the study for the flood impact assessment of the road development. This includes the details and corresponding changes in each modelled scenario, as well as figures for reference.

Appendix A Table 6 List of modelled scenarios

Item	Figure	Modelled Scenarios
1	Figure B-1	PREDEV: Existing/pre-development scenario • Baseline model for flood impact assessment • Refer to Table A-11 for B2P Flood Model setup
2	Figure B-2	POSTDEV: Design/post-development scenario with proposed B2P road alignment included • PREDEV with the following changes: o included design surface of proposed B2P road development o modifications on surface roughness to represent proposed B2P road alignment.
3	Figure B-3	MITIG: Design/post-development scenario with mitigation solution implemented • POSTDEV with the following changes: o Propose additional culverts o Propose additional flow path channels.

Appendix B
B2P Flood Model Modifications and Input Data



Appendix B Figure 1 Model Setup for the pre-development scenario

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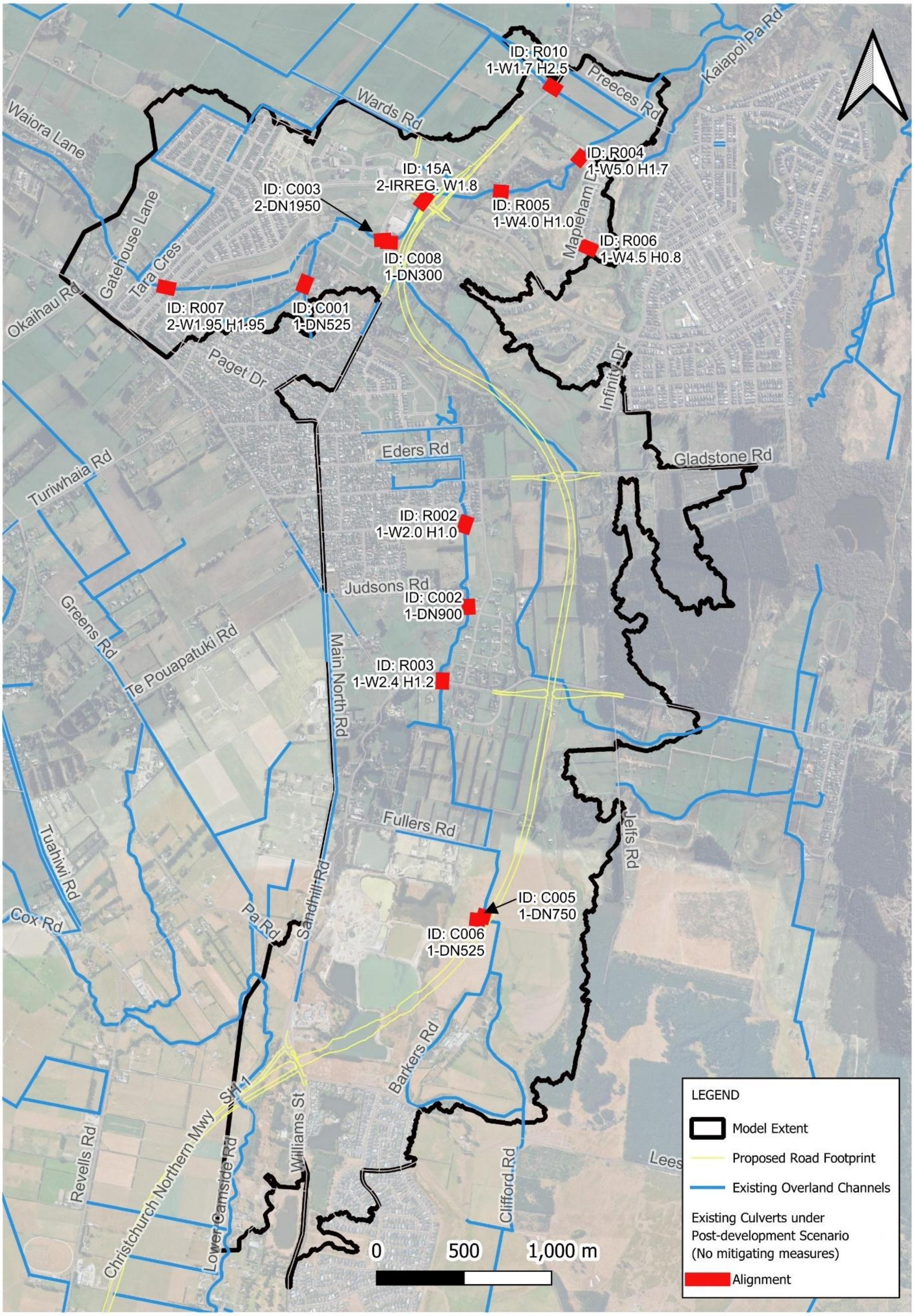
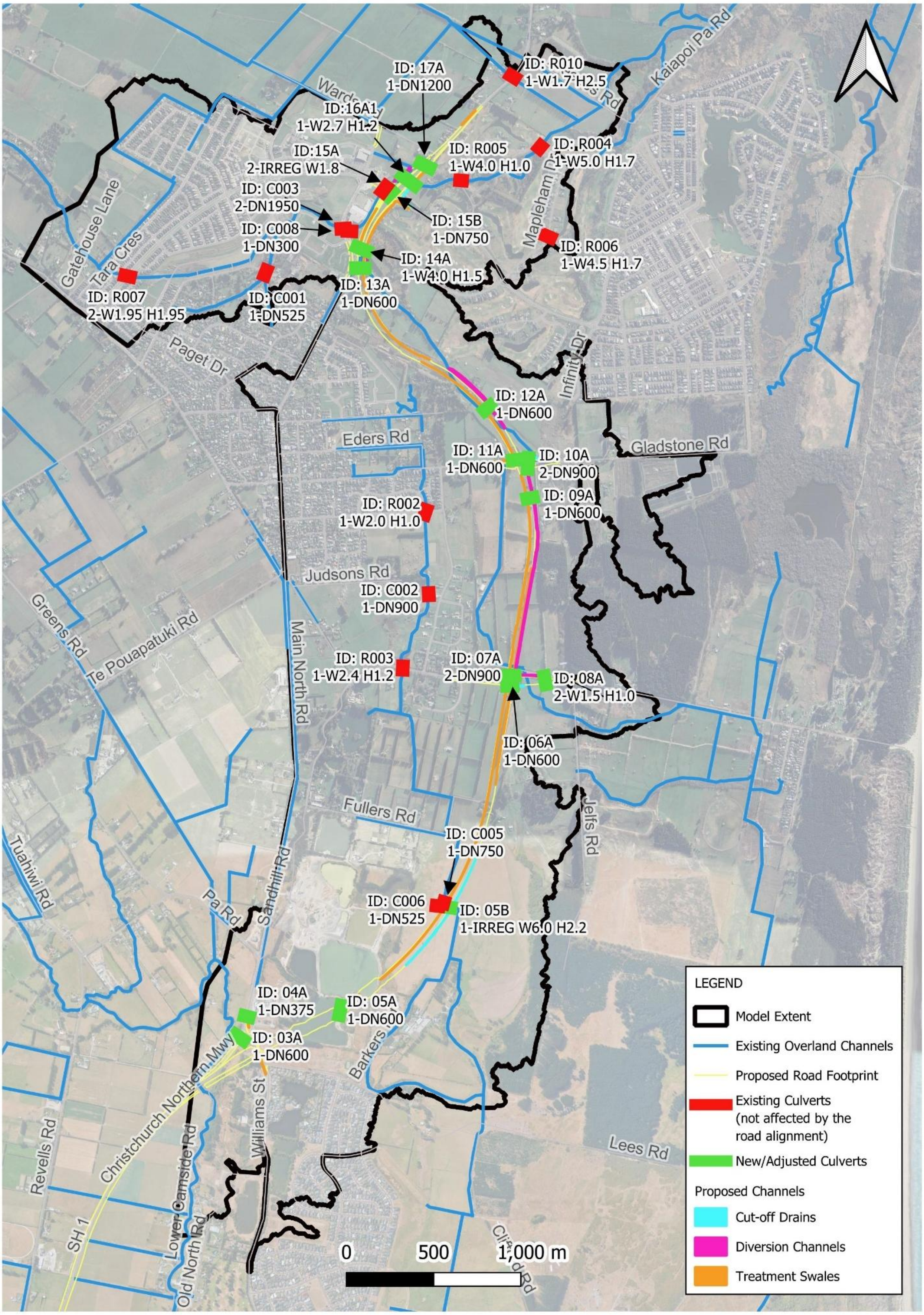


Appendix B Figure 2 Model Setup for the post-development scenario



Appendix B Figure 3 Model Setup for the post-development with mitigation scenario

Appendix C
Woodend Flood Model Results

Item	Figure	Modelled Scenarios
1	Figure C-1	Pre-development Model (PREDEV) Flood Depth - 100yr ARI Storm
2	Figure C-2	Pre-development Model (PREDEV) Flood Level - 100yr ARI Storm
3	Figure C-3	Pre-development Model (PREDEV) Flood Depth – 200yr ARI Storm
4	Figure C-4	Pre-development Model (PREDEV) Flood Level – 200yr ARI Storm
5	Figure C-5	Post-development Model (POSTDEV) Flood Depth - 100yr ARI Storm
6	Figure C-6	Post-development Model (POSTDEV) Flood Level - 100yr ARI Storm
7	Figure C-7	Post-development Model (POSTDEV) Flood Depth – 200yr ARI Storm
8	Figure C-8	Post-development Model (POSTDEV) Flood Level – 200yr ARI Storm
9	Figure C-9	Flood Level Difference – Post-development (POSTDEV) minus Pre-development (PREDEV) - 100yr ARI Storm
10	Figure C-10	Flood Level Difference – Post-development (POSTDEV) minus Pre-development (PREDEV) – 200yr ARI Storm
11	Figure C-11	Post-development Model (MITIG) Flood Depth – 100yr ARI Storm
12	Figure C-12	Post-development Model (MITIG) Flood Level – 100yr ARI Storm
13	Figure C-13	Post-development Model (MITIG) Flood Depth – 200yr ARI Storm
14	Figure C-14	Post-development Model (MITIG) Flood Level – 200yr ARI Storm
15	Figure C-15	Flood Level Difference – Post-development (MITIG) minus Pre-development (PREDEV) – 100yr ARI Storm
16	Figure C-16	Flood Level Difference – Post-development (MITIG) minus Pre-development (PREDEV – 200yr ARI Storm

Document prepared by

Aurecon New Zealand Limited
Level 2, Iwikau Building
93 Cambridge Terrace
Christchurch 8013
New Zealand

T +64 3 366 0821
F +64 3 379 6955
E christchurch@aurecongroup.com
W aurecongroup.com