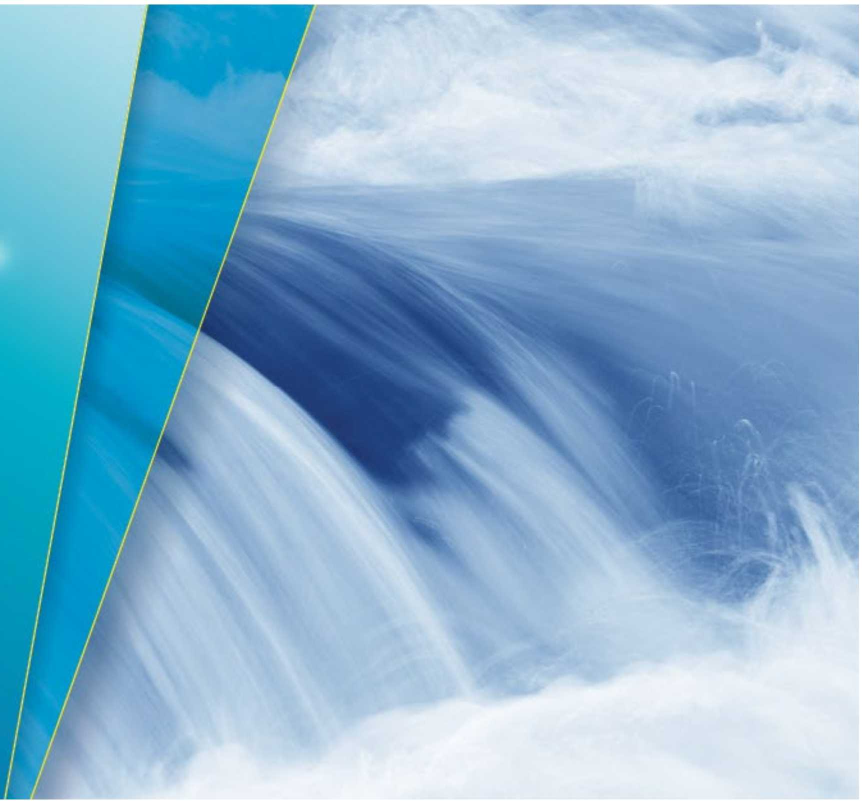
REPORT

Tonkin+Taylor



Ashhurst Drainage Scheme

Flood Hazard Assessment

Prepared for

Horizons Regional Council

Prepared by

Tonkin & Taylor Ltd

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Executive summary

The purpose of this project was to assess the performance of the existing Ashhurst Drainage Scheme (ADS) using the TUFLOW model that was previously developed for Palmerston North City Council (PNCC). The model has been used to identify parts of the ADS that do not currently deliver the 100-year ARI level of service. In addition, the model has been used to assess areas of the ADS that would most likely benefit from upgrading to achieve at least a 100-year average recurrence interval (ARI) present-day level of service.

Several deficiencies in the performance of both the ADS and associated hydraulic assets, identified early in the modelling processes, showed that the scheme in its current state did not meet the 100-year ARI level of service. This finding led to the simulation of two performance scenarios, in addition to the existing base case, to understand the scheme performance more completely.

A methodology of applying “glass-walls” (of infinite height) to all existing stopbank crest locations and making conceptual upgrades to culvert crossings at road intersections along the Ashhurst Stream, to help prevent breakout flows from the Ashhurst Stream, were applied to the model. The purpose of assessing stopbank performance using this methodology was to ensure that overland flows from the Ashhurst Stream are contained within the stopbanks, giving the worst-case scenario for peak flood levels from which to assess performance against.

Key conclusions from the assessment are detailed in the following points:

- Existing stopbank crest elevations upstream of road crossings are the most likely to be exceeded by peak flood levels generated in the ARI events modelled due to road culvert crossings on the Ashhurst Stream being under-capacity and the poor hydraulic grade of some of the stream reaches.
- Under base case conditions, breakout flows were modelled to occur between North St and Oxford St, at the true left stream bank where there is no flood protection, and where the existing stopbank ties into Oxford St. This presents an immediate constriction to the existing scheme, resulting in breakout flows and subsequent lower flood levels downstream of Oxford St.
- “Glass-walling” stopbank crest levels resulted in better containment of flows upstream of Oxford St but resulted in an increase in flood levels downstream of Oxford St and subsequent breakout flows at Wyndham St. This revealed that to best contain flows within the scheme, incremental upgrading of stopbanks and culvert crossings along the Ashhurst Stream need to be considered in unison.
- A high-level consequence assessment based on potentially flooded building counts showed that with the inclusion of upsized culverts, the number of potentially flooded buildings decreases by up to 20%, compared to existing conditions. This is double the number of buildings protected if only ADS assets are upgraded, indicating that to realise the full effects of making upgrades to the scheme, upgrades to associated hydraulic structures are also required. It also shows that breakout flows from the Ashhurst Stream are not the only contributor to flooded buildings in this area.
- Although not technically a part of the ADS assets, several surveyed culverts along the Ashhurst Stream were observed to be partially blocked with debris and other miscellaneous farm structures, which would likely affect their hydraulic efficiency. For the purposes of this modelling, they are assumed to be unblocked. To best manage the efficiency of the ADS, it is advised the critical hydraulic structures are left unobstructed and maintained.
- Further to the above, one culvert and one pipe located at Mulgrave St, and discharging to the Ashhurst Stream, was observed not to contain a flap-gate. As such, base case modelling

showed significant backflow was lost to the scheme, contributing to flooding outside of the stopbanks.

- Similarly, to above, portions of the Ashhurst Stream were observed to be heavily vegetated. Given the relatively shallow depths of open channel relative to the height and density of vegetation, these areas were shown in the model to cause a constriction on flood conveyance, resulting in elevated flood levels. Maintenance of stream channel vegetation will contribute to improved hydraulic performance of the scheme.
- This ADS performance assessment makes a key assumption that the entire length of the scheme is upgraded all at once, when only some of the scheme may be upgraded at any one time. Upgrading one portion of the scheme may result in reduced performance elsewhere while in a temporary state. Conversely, upgrading one portion of the scheme may provide similar benefits to upgrading the entire scheme.
- There is potential to optimise how the scheme is upgraded through a modelling options assessment to better understand the benefits of targeted upgrades, rather than the wholescale upgrades assumed in this assessment. It is advised that scheme upgrades are considered in unison with upgrades to hydraulic structures along the Ashhurst Stream.

1 Introduction

Tonkin & Taylor Ltd (T+T) was engaged by the Horizons Regional Council (HRC) to undertake a flood hazard assessment of the existing Ashhurst Drainage Scheme (ADS) using TUFLOW flood modelling software.

The purpose of this project was to assess the performance of the existing ADS using the TUFLOW model that was previously developed for Palmerston North City Council (PNCC). It is understood by T+T that Horizons Regional Council (HRC) have a desired level of service of at least the 100-year average recurrence interval (ARI) event under present-day climate, so the primary assessment has focused on the ability of the ADS to deliver this.

A TUFLOW flood model for Ashhurst town was previously developed for PNCC in 2020 (T+T, 2020) to enable them to understand potential floodable areas and to use as a tool to identify areas that might benefit from flood mitigation works. As a follow-on from this previous work for PNCC, updates were made to the model to represent critical features more accurately such as the Ashhurst Stream channel and the ADS flood protection assets prior to assessing performance.

The modelling and reporting have been prepared for HRC in accordance with the conditions of engagement dated 19 March 2021.

1.1 Model build purpose and limitations

The purpose of this assessment is to identify parts of the ADS that do not currently deliver the 100-year ARI level of service. In addition, the model has been used to assess areas of the ADS that would most likely benefit from upgrading to achieve at least a 100-year ARI present-day level of service. As is described further in Section 6, several deficiencies in the performance of both the ADS and associated hydraulic assets were identified early in the assessment and led to the simulation of two performance scenarios, in addition to the existing base case, to understand the scheme performance more completely. Several assumptions have been made in assessing the performance of the scheme. These, and the limitations associated with them, have been detailed in Section 6.2.

2 Model updates

The following updates have been made to the Ashhurst TUFLOW model that was previously built in 2020 by T+T, as documented in T+T (2020a) and T+T (2020b). Any model elements not mentioned in this report, remain as per those documented previously.

2.1 Model solver

The model has been updated to run the latest version (2020-10-AA) of TUFLOW HPC software which includes new default features such as sub-grid sampling and the WU turbulence scheme. This has relatively minor effect on any results but ensures that the computation engine is kept up-to-date with the latest software developments.

2.2 Digital elevation model (DEM)

The LiDAR derived DEM, captured in 2018, remains the same as was used in previous modelling. However, refinements have been made to the terrain to reflect more detailed surveyed data captured by HRC in March 2021. On-the-ground survey data is generally more accurate than LiDAR data, and has been captured at specific areas of interest such as the Ashhurst Stream and Barnes Drain open channels and stopbank and flood wall crest locations. Although not as spatially detailed, the detail at discrete survey locations was preferred over the coarser terrain representation of LiDAR data.

It is understood by T+T that all survey data was captured in New Zealand Vertical Datum 2016 (NZVD2016) consistent with the model DEM. All levels referred to in this report are relative to this datum.

It is understood by T+T that stopbank crest elevations were surveyed at approximately 20 m intervals or at any point where there was a distinct change in crest elevation. For areas of the stopbank crest where data was not captured, linear interpolation between captured survey points was applied. Figure 2.1 shows locations where stopbank crest survey data was applied to the DEM, and a series of stopbank crest long sections, along with the result from this study described further in Section 6, are shown in Appendix E.

Figure 2.1: Locations where 2021 surveyed stopbank crest elevation data was applied to the model

Open channel cross sections were surveyed at roughly 50 m intervals along Ashhurst Stream and have been used to derive a 2-dimensionsal channel DEM for the Ashhurst Stream and Barnes Drain. The channel DEM was derived using a tool developed in-house by T+T that interpolates along a curvilinear path between cross section points to derive a digital terrain model that is fitted between cross-sections. The interpolation tool accounts for bends in the channel to derive a smooth surface that is faithful to the shape of the open channel. The channel DEM has been derived only for cross section terrain elevations surveyed between left and right stream banks, with LiDAR terrain values preferred for areas outside of the stream banks, due to the greater spatial resolution. This approach is considered by T+T to provide the best representation of terrain, as in-channel terrain values are often poorly represented by LiDAR data, due to vegetation cover and standing water.

Figure 2.2 shows the extent of the cross-section channel DEM derived and applied to the model and Figure 2.3 shows example cross sections comparing survey data and the derived channel DEM.

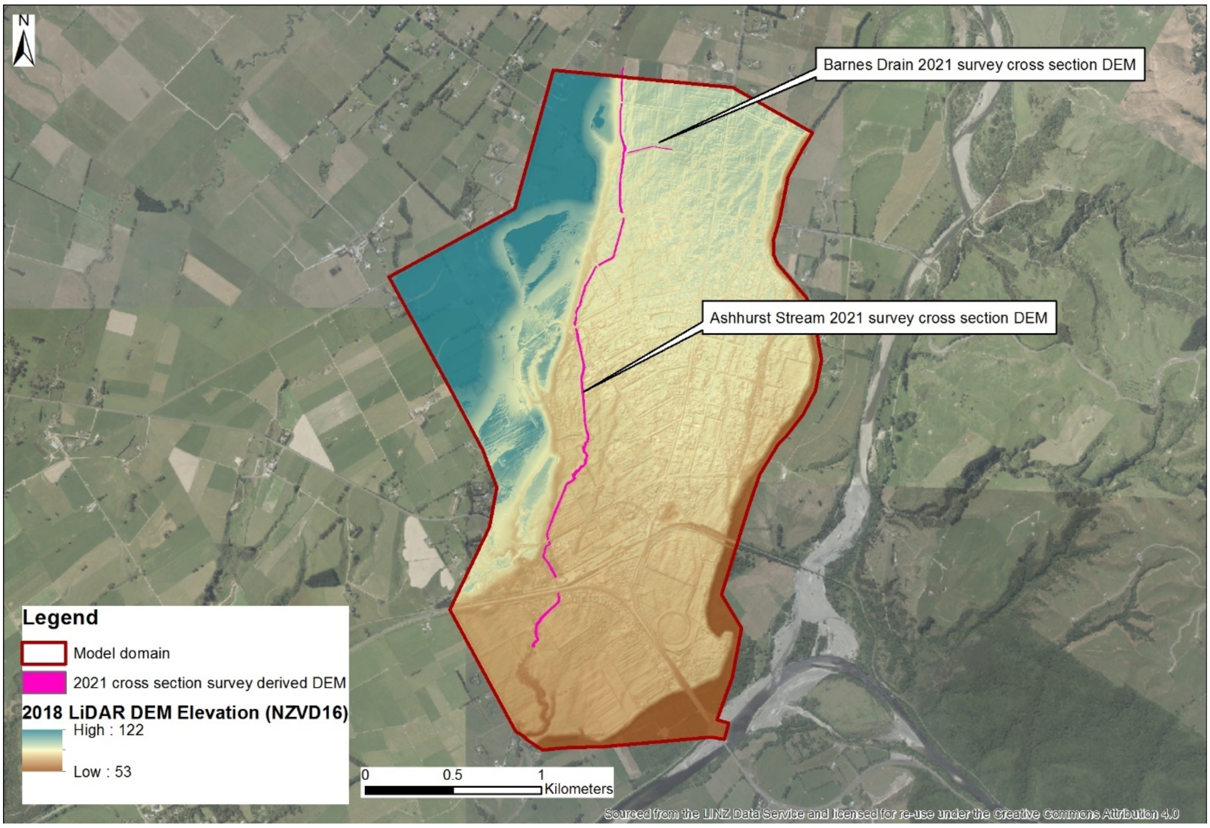

Figure 2.2: Locations where 2021 surveyed channel cross section DEM was applied to the model

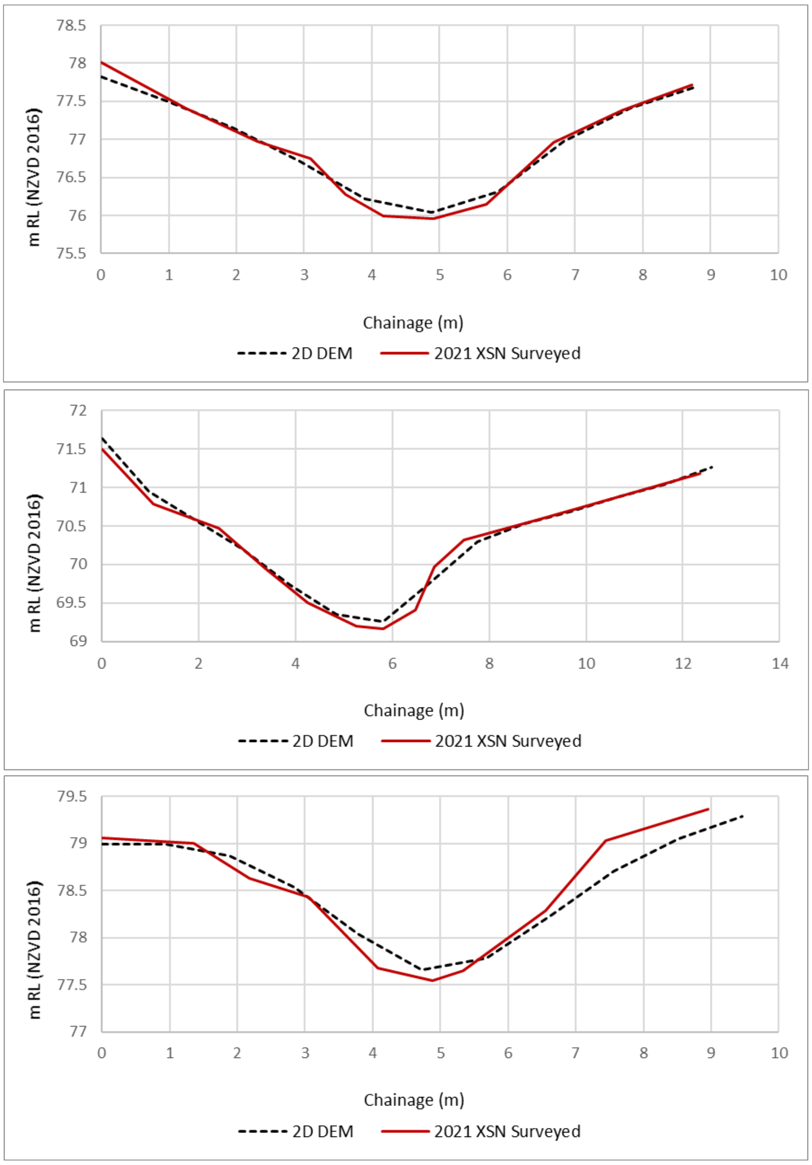

Figure 2.3: Comparisons between cross section survey and derived 2D channel DEM at three example locations

The model uses a 2 m x 2 m computational grid and applies sub-grid-sampling at a 1m resolution. Sub grid sampling allows the underlying DEM volume and conveyance relationships to be represented within a more coarse computational grid, preserving overland flow and storage features while allowing a coarser base resolution. As the 2D channel representation is key for assessing scheme performance, computational grid size was reduced to 1 m x 1 m (the same resolution as the DEM) as a sensitivity test and results showed convergence with those derived using a 2 m x 2 m grid.

It should be noted that the LiDAR DEM, on which the majority of the model domain relies, represents a bare earth terrain with all buildings and above-ground features having been removed. Using this approach, it is sometimes possible that flooding is shown to occur through the area occupied by large buildings. This is because the model does not recognise these as buildings and works only off the DEM. Care should therefore be exercised in the interpretation of results, particularly in areas where there is a high percentage of ground area covered by above-ground features (trees, buildings, etc).

2.3 Hydrological approach and loss parameters

2.3.1 Land use roughness

Land use roughness zones and associated Manning n roughness values have been refined from previous modelling to include the following elements:

- Surface roughness zones adopted in the model floodplain were updated to the latest Landcare Research's Land Cover Database version 5 (LCDBv5). This database was released in January 2020 and considers land use classification up until the end of 2018 and was not available for inclusion in the previous model. A visual comparison to LCDBv4 (which was used in the previous model) revealed very little difference in land use cover within the model domain.
- More detailed spatial estimation of the Ashhurst Stream Manning n roughness values was made using photographs taken by HRC surveyors at cross sections along the stream (as shown in Figure 2.4). The previous modelling had included use of a single Manning n value for the full stream length, as it was based on desktop assessment only. The current approach applied has allowed for spatial variation to roughness in accordance with site observations. It should be noted that there are limitations with this approach, in that vegetation can grow or be removed, which means the Manning's n values applied to the model are only representative of the time in which survey photographs were taken. Although sensitivity testing of base case Manning n roughness coefficients indicated relatively minor differences in peak flood levels, it is advised that any future adjustment to stopbank crest elevations considers the potential impact of spatial change in channel roughness on peak flood levels – possibly through the implementation of a freeboard allowance.
- As requested by HRC, future growth areas identified by PNCC have been included as roughness zones in the floodplain. In addition to changing the roughness in these areas, an estimated percentage imperviousness of 50% for these areas was agreed with HRC.
- Building outlines have been applied to the model as separate depth varying roughness values as per latest industry practice. Using this approach, roughness over building footprints is low when inundation depth is small. This represents the situation when rainfall lands on a building roof and is shed from that surface relatively quickly. As depth increases, and overland flow is initiated, the roughness increases to represent the effects, on overland flow, that above ground features such as buildings, fences and vegetation may have as flow passes through built-up areas.

Figure 2.5, Table 2.1 and Table 2.2 below show updated roughness zones and associated Manning n roughness coefficients applied to the model.

Figure 2.4: From the left, examples of low, medium and high vegetation cover types applied to open channels in the model

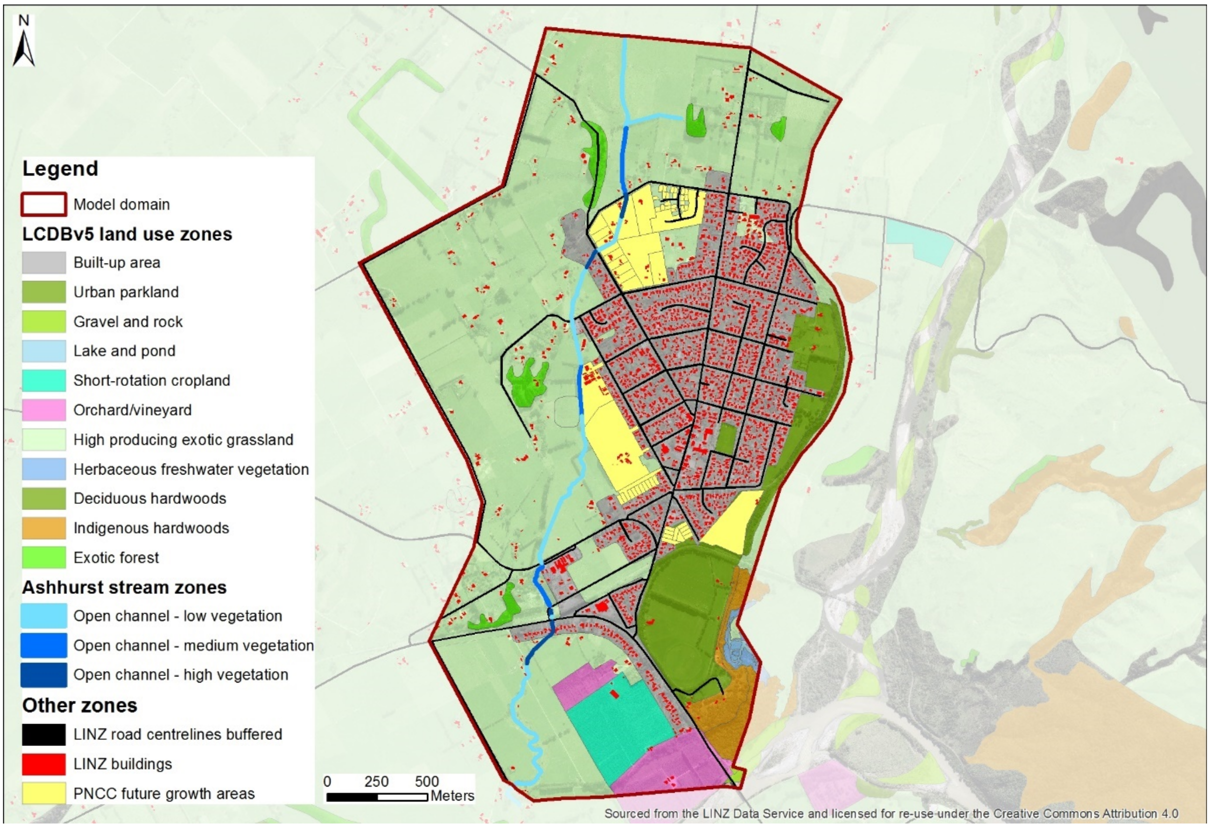

Figure 2.5: Manning n roughness zones updated in the model

Table 2.1: Manning n roughness coefficients updated in the model

Description	Manning's n coefficient	Percentage impervious
Built-up areas	0.1	25
PNCC future growth areas	0.1	50
Open channel - low vegetation	0.03	100
Open channel - medium vegetation	0.05	100
Open channel - high vegetation	0.07	100
LINZ building outlines	Depth varying (refer Table 2.2)	100

Table 2.2: Depth varying roughness for building outlines

Water depth	Manning's n coefficient
Less than 50 mm	0.015
50 mm – 100 mm	The value varies linearly from 0.015 to 0.3
Greater than 100 mm	0.3

2.3.2 Soil infiltration

Soil infiltration parameters were kept the same as previous modelling. However, with the update of Manning n roughness zones mentioned in Section 2.3.1, and with the inclusion of new land use zones (such as future urban growth areas) less soil infiltration has resulted due to updated estimates of percentage impervious area.

2.4 Stormwater infrastructure

2.4.1 1D culverts

Survey data was captured by HRC in March 2021 and included culverts and bridge structures located along the Ashhurst Stream. Figure 2.6 shows the culvert structures represented in the model as 1D elements, linked to the 2D model domain.

Several culverts were observed in photographs to be partially obstructed by fences and other miscellaneous structures, seemingly to prevent debris build-up in the culvert itself. These obstructions are likely to affect the hydraulic efficiency of the structures to convey flood flows. However, for the purpose of this scheme performance assessment, all structures were assumed to be unobstructed. Where model performance may differ from observations under flood conditions, this is a likely reason for the discrepancy.

According to information that we have been provided with, one 900 mm diameter culvert and one 300 mm diameter pipe outfall, both of which protrude through the stopbanks upstream and downstream of Mulgrave St, are not flap-gated. Under flood flow conditions these allow back-flow that contributes to flooding of areas outside of the stopbanks.

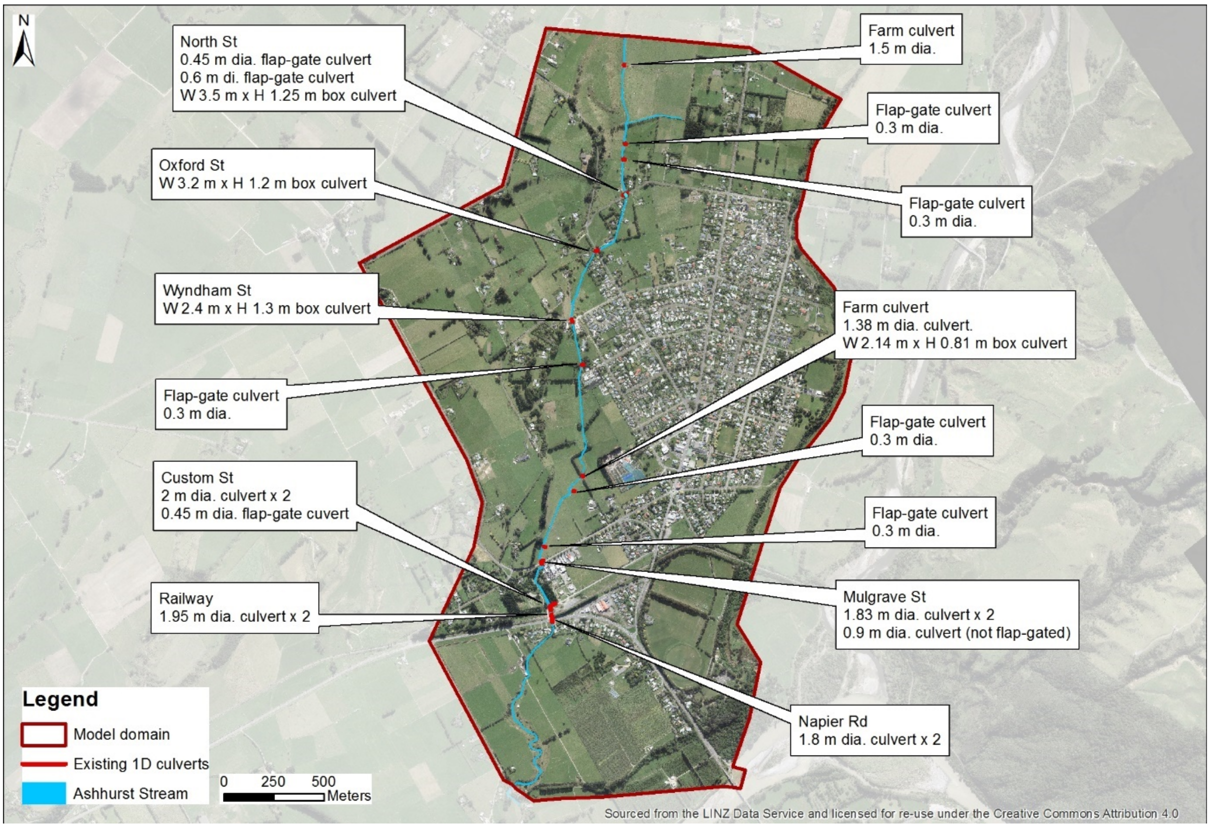

Figure 2.6: 1D culvert structures applied to the model

2.5 2D Bridges

TUFLOW 2D layered flow constriction was used to represent bridge structures in the model at locations shown in Figure 2.7. Layered flow constriction allows blockages and form losses to be applied directly to the 2D model cells at different elevations to account for energy losses such as the bridge deck and handrails, while other losses, such as the contraction and expansion through the bridge structure are solved implicitly through the 2D solution. For bridges along the Ashhurst Stream, which are relatively small and do not contain bridge piers, this was considered by T+T to be more appropriate than using 1D elements as the additional energy losses associated with these bridge structures occur only once water levels reach the bridge deck. This approach also allows for continuous mapped results through these structures.

As was the case for culvert structures, for the performance assessment it was assumed that bridges were unobstructed.

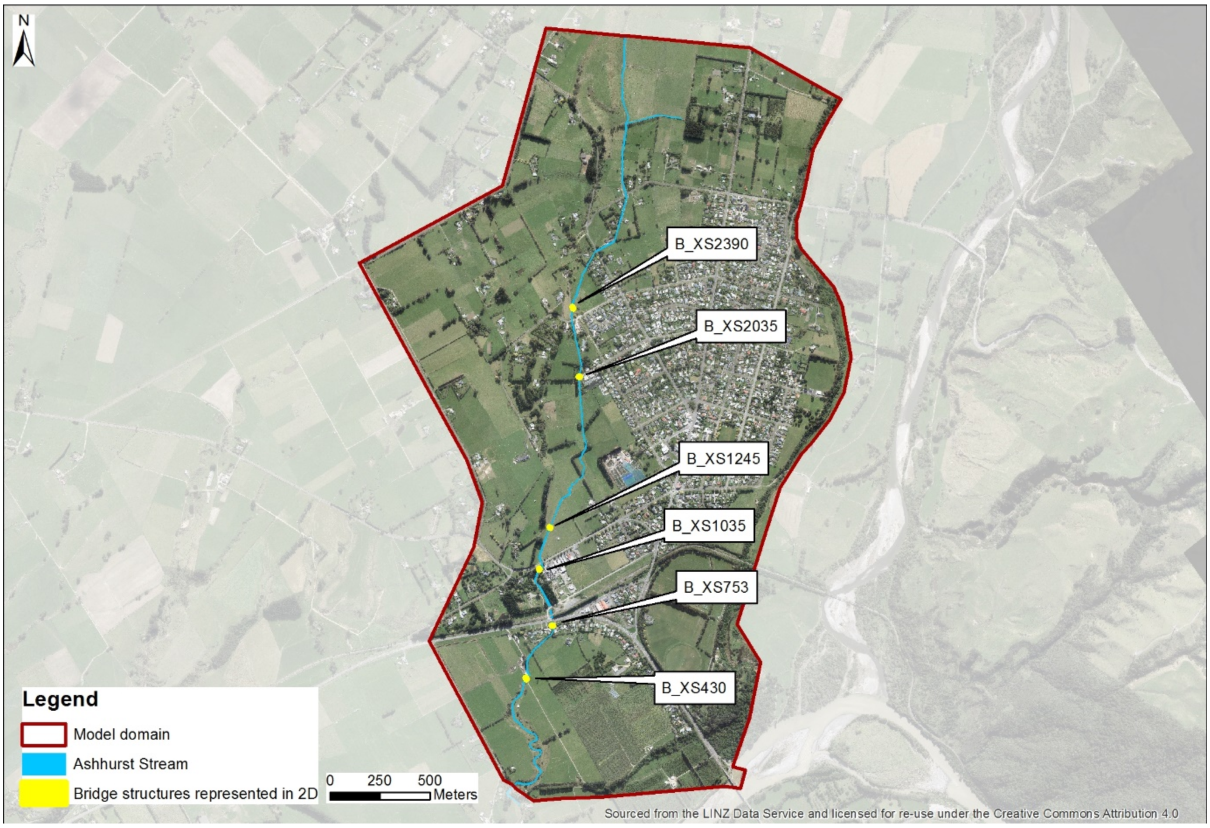

Figure 2.7: 2D bridge structures applied to the model

Table 2.3 shows photographs taken of the bridge structures by HRC, and the blockage factors and form loss coefficients applied to the model to represent these hydraulic elements in the model.

Table 2.3: Bridges applied to TUFLOW using 2D layered flow constriction

Bridge ID	Image (courtesy of HRC)	Bridge opening blockage ratio (%)	Bridge deck soffit (m NZVD16)	Bridge deck (m NZVD16)	Bridge deck blockage ratio (%)	Handrail crest level (m NZVD16)	Handrail blockage ratio (%)
B_XS430		0	67.66	68.14	100	69.07	5
B_XS753		0	70.04	70.17	100	71.1	5
B_XS1035	No image available	0	72.13 - 71.86	72.57 - 72.07	100	73.35 - 73.02	5
B_XS1245	No image available	0	72.24	70.17	100	N/A	N/A
B_XS2035		0	76.93	77.29	100	N/A	N/A
B_XS2390	 	20	78.44	78.63	100	N/A	N/A

2.6 Boundary data

2.6.1 Hydrology

100-year ARI and 200-year ARI rainfall events, using a present-day climate, were requested by HRC for simulation in the hydraulic model, along with the future climate events, previously modelled for PNCC. As described in previous reporting, hydrological boundaries have been applied to the hydraulic model domain using direct rainfall, and separately modelled lumped catchment hydrology that accounts for the primary inflow of the Ashhurst Stream rural catchment, located to the north of the Ashhurst Township, as shown in Figure 2.8.

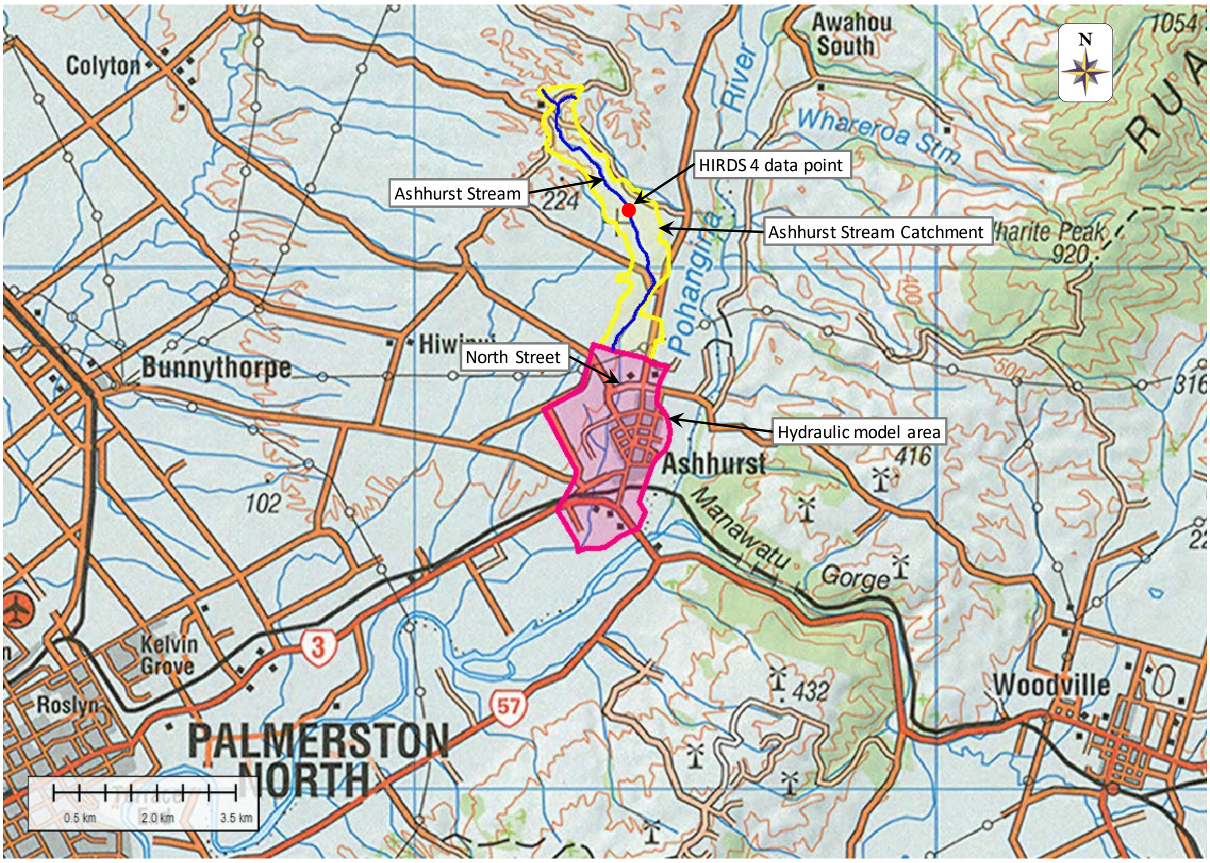

Figure 2.8: Catchment hydrology inputs into the hydraulic model domain.

Table 2.4 shows the HIRDSV4 rainfall depths applied as direct rainfall, while Table 2.5 shows peak flows derived for the Ashhurst Stream. Further details on lumped catchment hydrological modelling have been included in Appendix A. A lack of available calibration data has meant that there is some uncertainty in the hydrological response. Due to these uncertainties in catchment runoff for the Ashhurst Stream, lower and upper bound hydrographs have been derived, which differ by the constant rainfall loss value used. These have been applied to the hydraulic model to test sensitivity of the ADS to the different flow estimates. Sensitivity testing, described further in Section 4, showed only minor increases in flood depth when using upper bound hydrographs compared to lower boundary hydrographs, and as such, these have been applied to the model for conservatism.

Table 2.4: HIRDSV4 rainfall depth data applied as direct-rainfall to the hydraulic model domain

Ashhurst Stream Catchment				
Latitude: 40.25 South	**Longitude: 175.754**			
ARI (years)	**Climate horizon**	**Storm depth (mm) for duration (hours)**		
		1	**6**	**12**
100	Present-day	39.6	76.0	96.4
100	RCP6.0 2081-2100	48.4	90.3	112.2
200	Present-day	45.1	85.3	107.5
200	RCP6.0 2081-2100	55.1	101.3	125.2

Table 2.5: ARI flood event lumped catchment hydrology peak flows applied to the model

Flood event ARI	Event duration	Climate horizon	Lower bound hydrograph peak discharge (m^3/s)	Upper bound hydrograph peak discharge (m^3/s)
100-year	1	Present-day	4.32	5.03
	6		**9.48**	**12.7**
	12		6.08	9.98
100-year	1	RCP6.0 2081-2100	8.13	8.9
	6		**13.28**	**16.6**
	12		8.47	12.5
200-year	1	Present-day	6.68	7.49
	6		**11.95**	**15.24**
	12		7.76	11.72
200-year	1	RCP6.0 2081-2100	11.09	12.00
	6		**16.17**	**19.59**
	12		10.44	14.47

2.6.2 Downstream boundary

Given the fall in topography at the southern and eastern boundaries of the model, which can be seen in Figure 2.1) the downstream boundary condition remains a "free-outfall" (i.e. one that provides no backwater effect) consistent with previous modelling.

3 Model run matrix

Table 3.1 shows a run matrix of all simulations completed.

Table 3.1: Model run matrix

Run no.	Purpose	Flood event ARI	Event duration	Climate horizon	Appendix Figure Reference
1	Sensitivity No Direct Rainfall	100-year	6	Present-day	B2
2	Sensitivity Manning n +20%	100-year	6	Present-day	B3
3	Sensitivity Manning n -20%	100-year	6	Present-day	B4
4	Sensitivity Ashhurst Stream Constant Loss 8mm/hr	100-year	6	Present-day	B5
5	Sensitivity Culvert Structure Blockage 50%	100-year	6	Present-day	B6
6	Scenario 1: Base Case	100-year	1	Present-day	C1 – C4 D1.1 – D1.3
7			6		
8			12		
9	Scenario 1: Base Case	100-year	1	RCP6.0 2081-2100	
10			6		
11			12		
12	Scenario 1: Base Case	200-year	1	Present-day	

Run no.	Purpose	Flood event ARI	Event duration	Climate horizon	Appendix Figure Reference
13			6		
14			12		
15	Scenario 1: Base Case	200-year	1	RCP6.0 2081-2100	
16			6		
17			12		
18	Scenario 2: Glass-Wall	100-year	1	Present-day	D2.1 – D2.3
19			6		
20			12		
21	Scenario 2: Glass-Wall	100-year	1	RCP6.0 2081-2100	
22			6		
23			12		
24	Scenario 2: Glass-Wall	200-year	1	Present-day	
25			6		
26			12		
27	Scenario 2: Glass-Wall	200-year	1	RCP6.0 2081-2100	
28			6		
20			12		
30	Scenario 3: Glass-wall and culvert upsize	100-year	1	Present-day	D3.1 – D3.3
31			6		
32			12		
33	Scenario 3: Glass-wall and culvert upsize	100-year	1	RCP6.0 2081-2100	
34			6		
35			12		
36	Scenario 3: Glass-wall and culvert upsize	200-year	1	Present-day	
37			6		
38			12		
39	Scenario 3: Glass-wall and culvert upsize	200-year	1	RCP6.0 2081-2100	
40			6		
41			12		

4 Base case model sensitivity

Five sensitivity tests were undertaken where model parameters were varied to determine the confidence in base case flood outputs for the 100-year ARI design event with a 6-hour duration and a present-day climate. Model sensitivity is likely to vary with ARI event and event duration, so for practicality purposes only the 6-hour duration was tested. The 6-hour duration was selected as this event provides the critical peak flow in the Ashhurst Stream. The sensitivity tests included the following scenarios:

- Manning’s n roughness coefficients + 20%;
- Manning’s n roughness coefficients – 20%;

- Ashhurst Stream hydrology constant loss 8mm/hr (lower bound inflow hydrograph);
- Ashhurst Stream structure blockage +50%; and
- No direct rainfall (only Ashhurst Stream lumped catchment inflow).

Where Manning's n roughness values have been adjusted by ± 20%, this adjustment has been made to base case values.

Appendix B shows a "fuzzy" map of the base case and sensitivity model runs which gives an indication of results confidence in areas that are flood prone. The figure was produced by firstly removing any flood depths less than 100 mm, as this is the threshold depth above which flooding has been considered to be "real" and not potentially an artefact of inaccuracies in the DEM. For each input grid (four sensitivity scenarios (note that "the no-direct rainfall" scenario was not included) detailed above and the one corresponding base case scenario (five in total)) the grid is classed as either 1, if the results grid is wet or 0, if dry. The total score for each grid cell is summed and then divided by the total number of input grids. A value of 1 indicates that the cell was wet in all simulations while a value of 0.2 indicates the cell was wet only once across all five simulations. Where the map is pink there is a low confidence of flooding, yellow and green indicate that the area may flood, and the blue areas show areas that have greater than 100 mm flood depth in all of the sensitivity runs. The blue areas show a high confidence that the area will flood for the event modelled.

Sensitivity testing of the effects of removing direct-rainfall from the model domain shows a distinct constriction point in the scheme at Oxford St, where breakout flows from the Ashhurst Stream occur. This sensitivity test also shows significant flooding in areas outside of the scheme (around Mulgrave St and Custom St) without the effect of Ashhurst Stream.

Further analysis of the effects of adjustment of the individual parameters is also found in Appendix B showing the change in peak flood depth, compared to the base case, caused by changing the individual parameters. The greatest change in flood depth is caused by applying a 50% blockage to culverts located in the Ashhurst Stream. Although survey photographs indicated several structures to have obscured culvert entrances in their current state, for the purposes of this ADS performance assessment, culverts have been assumed to be unblocked. However, as this sensitivity testing shows, culvert blockage is likely to result in water levels higher than those reported in this assessment.

Other sensitivity testing was shown to have a very minor effect on peak flood depths.

5 Model outputs

Model outputs, represented as "peak of peak" maximum outputs for each of the simulated ARI events, have been derived. "Peak of peak" outputs are the enveloped maximum value for a given parameter (e.g. flood depth and level) reached at any one cell in the model domain across the three event durations simulated and provide a "worst-case" estimate. The "peak of peak" overlays do not come from any single event simulation, but are compiled from all event simulations. Table 5.1 shows an example of the process of enveloping model outputs to determine one result file.

Table 5.1: Process for deriving peak of peak model outputs

Model run	Design event (ARI)	Rainfall event duration (hours)	Process	Result
7	100	1	Envelope to find maxima across all durations	"Peak of peak" 100-year ARI event data
8		6		
9		12		

Peak of peak flood depths for base case model outputs are shown in Appendix A. Also included are peak of peak flood depths maps for the ADS performance assessment scenarios described in Section 6. Flood depths less than 50 mm have been removed from flood maps as requested by HRC.

6 Existing ADS performance

6.1 Methodology

Using peak of peak flood level outputs derived using the methodology described in Section 5, the performance of the existing ADS scheme was assessed at each of the surveyed stopbank crest locations. A “glass wall” (of infinite height) was applied to all existing stopbank crest locations to prevent overtopping. If the stopbank surveyed crest elevation was exceeded by peak flood levels, this location was flagged as being under capacity to convey the respective flood flows, while the height that the water level reached indicated the minimum height the stopbank needed to be to provide the respective ARI level of service.

The purpose of assessing stopbank performance using this methodology is to ensure that overland flows from the Ashhurst Stream are contained within the stopbanks. This gives the worst-case scenario for peak flood levels from which to assess performance against. There are limitations with this approach, described further in Section 6.2, in that it assumes that the entire length of the scheme is upgraded all at once, which may mean results are not representative if only part of the scheme is upgraded at any one time. For example, if a section of stopbank is actually overtopped, then less flow is conveyed to downstream as some of the flow exists via the overtopping. Flood level compliance is easier to achieve downstream of a breach because of this.

On initial inspection of model results, it was clear that culvert crossings at all locations along the Ashhurst Stream were under capacity to convey peak flows in the 100-year ARI present-day flood event – that which is the least severe of those to have been assessed. Model results showed culverts located at North St and Oxford St to have the capacity to convey a peak flow of up to 7 m^3/s, significantly less than the required 100-year peak flow of 12.7 m^3/s (refer Section 2.6.1). As shown in Figure 6.1, this resulted in flood waters overtopping North St causing inundation of areas west of Ashhurst Stream between North St and Oxford St. Additional breakout flows also occurred from the true left bank of the Ashhurst Stream, where there is no formal scheme protection, and at the Oxford St culvert crossing, suggesting the culvert crossings and open channel are both under capacity to convey 100-year ARI peak flows.

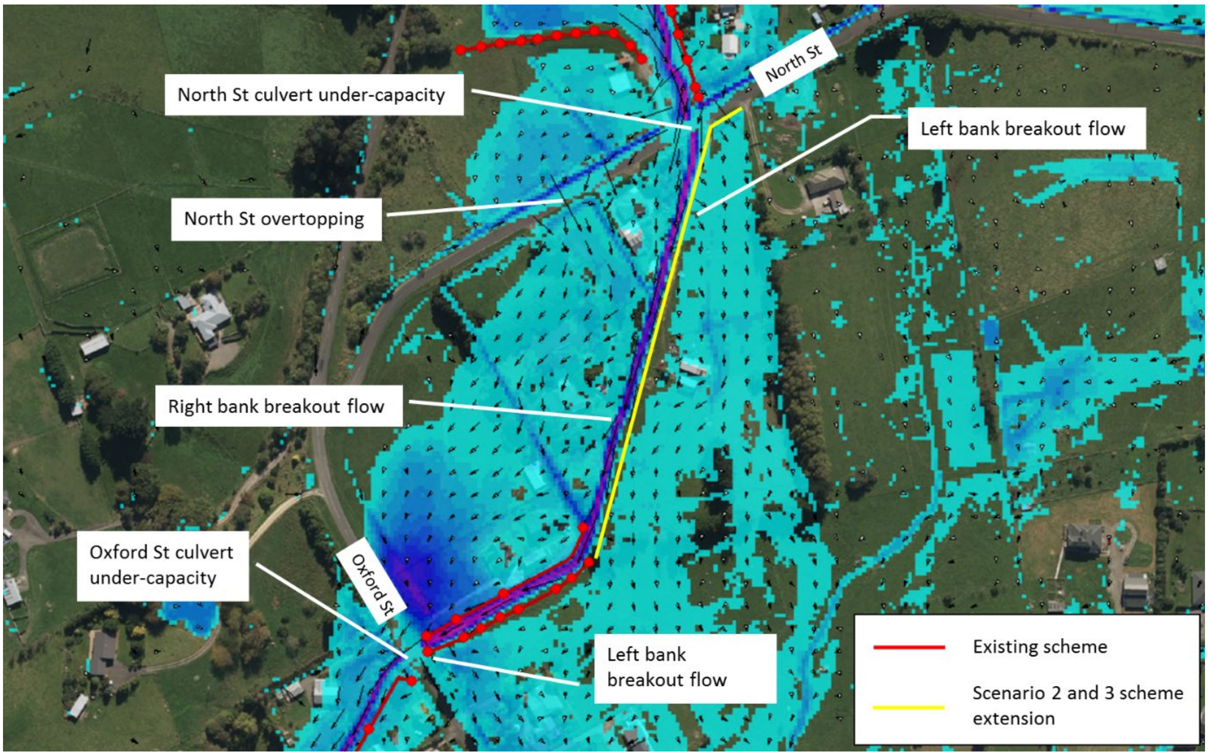

Figure 6.1: Ashhurst Stream breakout flow locations upstream of Oxford St in a 100-year ARI present-day event with a 6-hour duration under base case conditions

With the breakout of flows at these locations resulting in significant loss of volume from the Ashhurst Stream, applying a "glass-wall" to both the existing stopbanks and at locations where breakout flows were occurring (as shown in Figure 6.1), was required to better assess the performance of the scheme downstream of Oxford St.

However, doing so did not remove breakout flows completely, with these still occurring over and across road embankments, where extending stopbank height is not practically possible. In an attempt to better contain breakout flows, stopbank crests were tied into the road embankments, and culvert sizes through the road embankments were upsized to reflect the approximate width of the channel. Due to the restriction of road levels, increasing culvert height was not simulated at North St and Oxford St. Table 6.1 shows the culverts that were changed in the model (together with the assumed dimensions), while their locations in the model are shown in Figure 2.6.

Culverts downstream of Mulgrave St were left unchanged due to the complexity of having three separate in-line road/rail crossings and needing to balance provision of meaningful results with what might realistically be achievable flood conveyance upgrades.

It should be noted that modelled culvert upgrades are conceptual at this stage and for the purpose of this assessment and should be considered in more detail should any further consideration be proposed.

In addition to culvert upgrades, a flap-gate was added to the 300 mm pipe and 900 mm diameter culvert discharging to the Ashhurst Stream at Mulgrave St to prevent back-flow out of the Ashhurst Stream.

Table 6.1: Indicative culvert dimensions simulated in the model for the scheme performance assessment

Culvert location	Simulated indicative culvert dimensions
North St	W 6 m x H 1.25 m
Oxford St	W 6 m x H 1.25 m
Wyndham St	W 6 m x H 2.0 m
Mulgrave St	W 6 m x H 2.0 m
Upstream of Mulgrave St	900 mm dia. culvert (flap-gate added)
Downstream of Mulgrave St	300 mm dia. pipe (flap-gate added)

Given the aforementioned constraints with the existing ADS, three performance assessment scenarios have been modelled for comparison:

- **Scenario 1:** Existing scheme assets as per 2021 survey data (no glass-walling or culvert upgrades)
- **Scenario 2:** Glass-walling of the existing scheme assets and those areas upstream of Oxford St without scheme protection (refer Figure 6.1 for indicative scheme extension)
- **Scenario 3:** Glass-walling of existing scheme assets and those areas upstream of Oxford St without scheme protection (refer Figure 6.1 for indicative scheme extension) and upsizing of culverts at road crossings detailed in Table 6.1

6.2 Summary and limitations

In summary, the following assumptions have been made for the purposes of assessing the scheme performance and should be considered in detail when interpreting the results.

- All existing stopbanks and flood walls have been "glass-walled" (i.e. set to an infinite height so as not to overtop) and tied into the existing road embankments so that water cannot outflank them without first overtopping the road. The glass-walling has been based on an assumption of a vertical addition to the top of any stopbank.
- The flood wall located on the right bank of the Ashhurst Stream upstream of Oxford St has not been glass-walled, as it becomes outflanked by overland flow spilling across North St and any raising of this floodwall will not prevent flooding from the stream.
- In Scenario 2, culverts detailed in Table 6.1 have been upsized. The culverts have been sized to the approximate stream width upstream and downstream of the road embankment and remain at the invert of the existing culverts.
- All ADS culverts are assumed to be hydraulically efficient and do not contain blockages.
- Vegetation cover in the Ashhurst Stream is assumed to be as per channel conditions observed and photographed during the 2021 survey (noting that this may change with time).

Furthermore, the following limitations to this scheme performance assessment approach should be understood:

- The approach assumes that the entire length of the scheme is upgraded all at once when parts of the scheme may be upgraded at different times. Upgrading one portion of the scheme may result in declined performance elsewhere while in a temporary state.
- The approach for Scenario 3 assumes that culverts are upgraded at locations shown in Table 6.1. The upgrading of any culvert affects flood levels upstream and downstream of road crossings as well as the overall distribution of flood volume through the scheme.

6.3 Performance assessment

Appendix D shows maps that identify the ARI event at which existing stopbank crest levels are exceeded. The ARI exceedance event has been defined as the least severe ARI event modelled that generates a peak flood level that exceeds the stopbank crest surveyed level. For example, if a surveyed stopbank crest level is exceeded by all events more severe than, and including, the 200-year ARI event (with a present-day climate) flood level, then a 200-year ARI event (with a present-day climate) has been considered the exceedance event.

It should be noted that if the level of exceedance is defined as the 100-year ARI event (with a present-day climate) – the least severe of the events modelled for this study – this does not necessarily mean that the stopbank crest will not be exceeded by events less severe (not modelled as part of this study) than this event.

To supplement this information, Appendix E shows peak flood level long sections for each of the existing scheme assets shown in Figure 6.2. These long sections show modelled peak flood levels relative to surveyed stopbank crest levels on a reach-by-reach basis, with the reaches as defined in Figure 6.2.

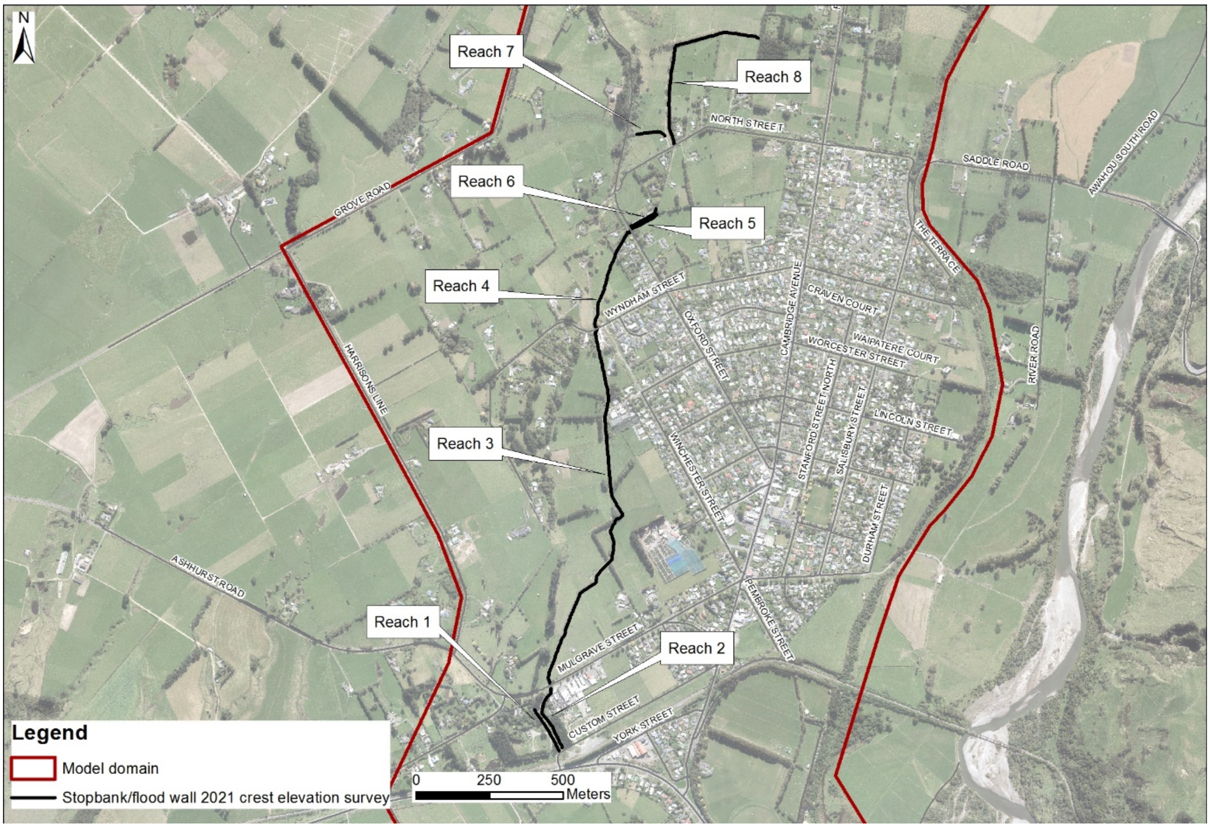

Figure 6.2: Existing scheme stopbank "reaches". Refer to Appendix E for associated peak flood level long sections.

Results of the stopbank performance assessment show stopbank crest elevations upstream of road crossings are the most likely to be exceeded by peak flood levels generated in the ARI events modelled due to culvert crossings being under-capacity.

In base case conditions (Scenario 1), North St and Oxford St are the main constrictions, which means that less flow volume is transferred downstream of Oxford St due to breakout flows. As a result, stopbank crest levels downstream of Oxford St, particularly Reach 4, have a lower exceedance probability. Conversely, if stopbanks are raised (Scenario 2), stopbank crest elevations at Reach 4 have a higher exceedance probability as more flow volume is conveyed downstream, and as a result, Wyndham St becomes the main constriction.

In Scenario 3, where stopbanks are raised and most culverts are upsized, Custom St becomes the main constriction, and stopbank exceedance probability at Reach 1 and 2 increases. It was decided not to include the upsizing of culverts at the downstream end of the ADS, due to the complexity of having three separate in-line road/rail crossings and wanting to balance providing meaningful results with what might realistically be achievable flood conveyance upgrades. Should these three crossings also be upsized, then it will likely reduce the exceedance probability of Reach 1 and 2.

It should be noted that although the upgrading of culverts as part of Scenario 3 was aimed at improving conveyance through road embankments to reduce upstream flood levels and associated breakout flows from the scheme, the poor hydraulic grade available at North St and Oxford St, meant upsizing culverts had only a minor improvement on the peak flows conveyed. With greater available hydraulic grade at Wyndham St and Mulgrave St, upsizing culverts was more effective at reducing upstream flood levels and preventing breakout flows.

7 Consequence assessment

A high-level consequence assessment has been undertaken to understand the benefits of scheme protection for the different ARI events and scenarios modelled. For the purposes of this study, flood protection benefits have been determined based on whether a building is estimated to be "flooded" or "not flooded". Whether a building is flooded has been interpreted as being when the flood level within a building footprint exceeded the estimated building floor level.

Prior to the use in this assessment, flood level data outputs from the model were "cleaned" by removing any flood levels attributed to flood depths less than 100 mm, as this is the threshold depth above which flooding has been considered to be "real" and not potentially an artefact of inaccuracies in the DEM.

Surveyed floor levels are not available for buildings within the study area so have been inferred based on assumed offsets above ground level. The following assumptions were made in inferring building floor level:

- Using the LINZ building outline dataset, all building footprints less than 300 m^2, and greater than 20 m^2, are assumed to be residential, while all buildings footprints greater than or equal to 300 m^2, are assumed to be commercial buildings.
- Building footprints less than 20 m^2 have been excluded from the total count of potentially flooded buildings as these are likely to be garden sheds or other structures that have not been considered as "buildings". Garages or other minor dwellings larger than 20 m^2 that are not attached to main dwellings have been counted as separate buildings in the consequence assessment.
- Floor levels for residential buildings have been inferred by adding a 300 mm offset to the minimum underlying LiDAR derived Digital Elevation Model (DEM) level sampled within the building outline. This is based on a house on piles which appears to be the predominant foundation type from sampling houses on Google Street View.
- Floor levels for commercial and industrial buildings have been inferred by adding a 100 mm offset to the minimum underlying LiDAR derived DEM level assuming concrete slab foundations.

Table 7.1 shows the number of potentially flooded buildings assessed for each of the ARI events and the three modelled scenarios detailed in Section 6.

It is important to note that the purpose of this assessment is to understand the relative differences in number of potentially flooded buildings at a catchment scale and is not intended to provide absolute numbers of potential flooded buildings at a property scale. Furthermore, building counts are used here on an “unders and overs” basis, meaning that zooming in to property scale resolution may give rise to error.

Table 7.1: Potential flood building counts

Flooded building counts	Scenario 1: Base Case	Scenario 2: stopbanks "glass-walled"	Total no. reduction	% reduction	Scenario 3: stopbanks "glass-walled" and culverts upsized	Total no. reduction	% reduction
100yr present-day	166	150	16	10%	142	24	14%
100yr RCP6.0 2100	239	216	23	10%	193	46	19%
200yr present-day	210	192	18	9%	176	34	16%
200yr RCP6.0 2100	278	254	24	9%	229	49	18%

The percentage reduction of potentially flooded buildings for Scenario 2 is similar for each ARI event and climate horizon modelled, while Scenario 3 shows that the more severe the ARI event, the greater reduction to the number of potentially flood buildings. This shows the relative ineffectiveness of upgrading scheme assets without also upgrading associated hydraulic structures. It also shows that breakout flows from the Ashhurst Stream are not the only contributor to flooded buildings in this area.

Results show that for Scenario 3, the number of potentially flooded buildings decreases by up to 20% compared to Scenario 1 conditions, in a 100-year ARI event including climate change. This is double the number of buildings protected compared to Scenario 2, further indicating that to realise the full effects of making upgrades to the scheme, upgrades to associated hydraulic structures is also required.

The consequence of flood hazard on future urban development areas is not quantifiable through assessing potential flooded building counts (as future buildings do not yet exist). Figure 7.1 compares peak flood extents at PNCC future urban growth areas for Scenario 1 and 3 in a 200-year ARI event with a present-day climate. Flood extents are shown to reduce in these areas, but are not eliminated, as a result of Scenario 3 scheme upgrades. Of note is the area of future urban growth between North St and Oxford St (indicated in Figure 7.1) where modelling showed an increase in peak flooding depths if scheme upgrades along the Ashhurst Stream left bank were applied.

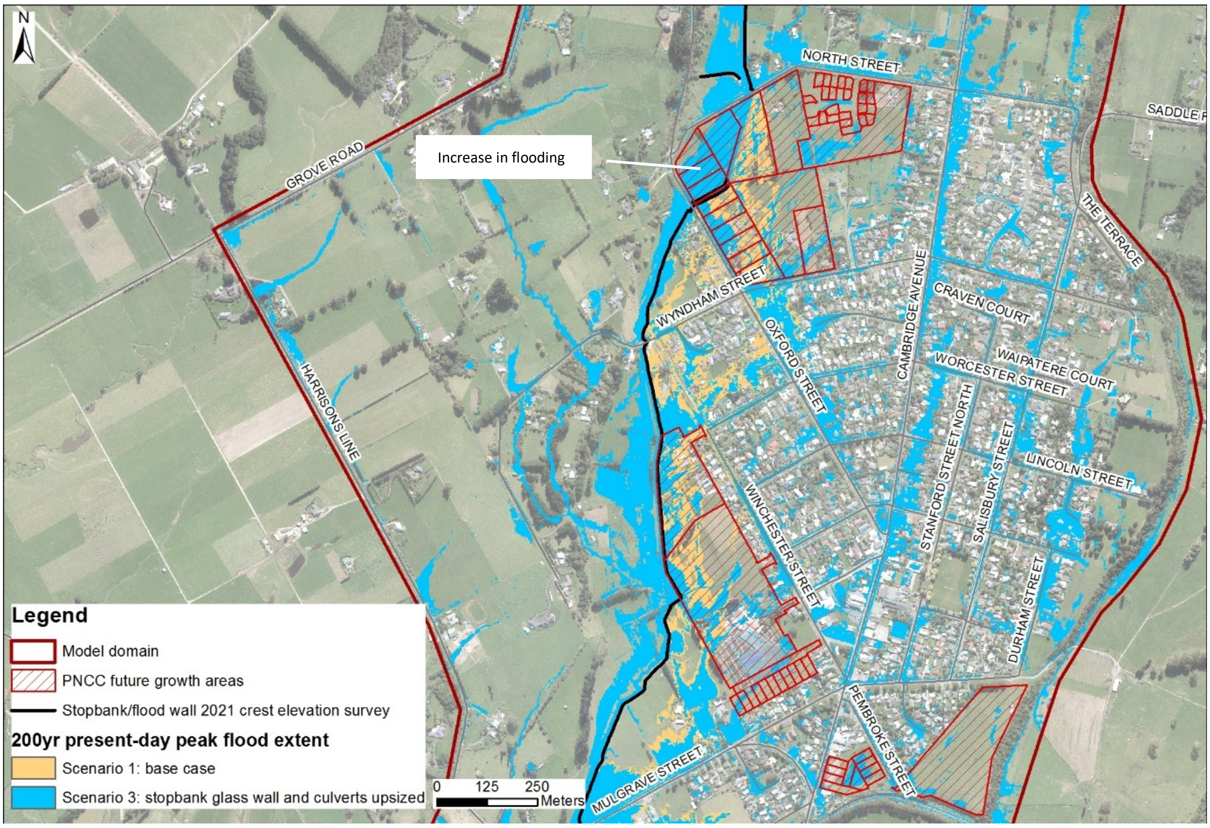

Figure 7.1: Peak flood extents based on flood depths less than 100 mm at PNCC future urban growth areas for Scenario 1 and Scenario 3 model outputs

8 Conclusions and next steps

The following points summarise key findings from the existing ADS performance assessment:

- Existing stopbank crest elevations upstream of road crossings are the most likely to be exceeded by peak flood levels generated in the ARI events modelled due to road culvert crossings on the Ashhurst Stream being under-capacity and the poor hydraulic grade of some of the stream reaches.
- Under base case conditions, breakout flows were modelled to occur between North St and Oxford St, at the true left stream bank where there is no flood protection, and where the existing stopbank ties into Oxford St. This presents an immediate constriction to the existing scheme, resulting in breakout flows and subsequent lower flood levels downstream of Oxford St.
- “Glass-walling” stopbank crest levels resulted in better containment of flows upstream of Oxford St but resulted in an increase in flood levels downstream of Oxford St and subsequent breakout flows at Wyndham St. This revealed that to best contain flows within the scheme, incremental upgrading of stopbanks and culvert crossings along the Ashhurst Stream needs to be considered in unison.
- A high-level consequence assessment based on potentially flooded building counts showed that with the inclusion of upsized culverts, the number of potentially flooded buildings decreases by up to 20%, compared to existing conditions. This is double the number of buildings protected if only ADS assets are upgraded, indicating that to realise the full effects of making upgrades to the scheme, upgrades to associated hydraulic structures is also required. It also shows that breakout flows from the Ashhurst Stream are not the only contributor to flooded buildings in this area.

The following points are advised for HRC to consider with management of ADS assets and associated hydraulic structures:

- Although not technically a part of the ADS assets, several surveyed culverts along the Ashhurst Stream were observed to be partially blocked with debris and other miscellaneous farm structures, which would likely affect their hydraulic efficiency. For the purposes of this modelling, they are assumed to be unblocked. To best manage the efficiency of the ADS, it is advised the critical hydraulic structures are left unobstructed and maintained.
- Further to above, one culvert and one pipe located at Mulgrave St, and discharging to the Ashhurst Stream, were observed not to contain a flap-gate. As such, base case modelling showed significant backflow was lost to the scheme, contributing to flooding outside of the stopbanks.
- Similarly, to above, portions of the Ashhurst Stream were observed to be heavily vegetated. Given the relatively shallow depths of open channel relative to the height and density of vegetation, these areas were shown in the model to cause a constriction on flood conveyance, resulting in elevated flood levels. Maintenance of stream channel vegetation will contribute to improved hydraulic performance of the scheme.

The following points are advised for HRC to consider for next steps in assessing options for improving the performance of the ADS:

- This ADS performance assessment makes a key assumption that the entire length of the scheme is upgraded all at once, when only some of the scheme may be upgraded at any one time. Upgrading one portion of the scheme may result in declined performance elsewhere while in a temporary state. Conversely, upgrading one portion of the scheme may provide similar benefits to upgrading the entire scheme.
- There is potential to optimise how the scheme is upgraded through a modelling options assessment to better understand the benefits of targeted upgrades, rather than the wholescale upgrades assumed in this assessment. It is advised that scheme upgrades are considered in unison with upgrades to hydraulic structures along the Ashhurst Stream.

9 References

T+T (2020a). Ashhurst Flood Hazard Modelling. Report prepared for Palmerston North City Council. January 2020. Job number 851994.50.

T+T (2020b). Ashhurst Stormwater Modelling: Model updates for 200-year ARI scenario. Letter report prepared for Palmerston North City Council. August 2020. Job number 851994.50.

10 Applicability

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

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Michael Fifield	Peter Cochrane
Water Resource Consultant	Project Director

Technically review by Mark Pennington, Technical Director Water Resource Engineering

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Appendix A: Hydrology report

Memo

To:	**Michael Fifield**	**Job No:**	**851994.5000**
From:	**John Hansford**	**Date:**	**30 March 2021**
cc:	**Mark Pennington**		
Subject:	**Ashhurst Stream Hydrology**		

1 Introduction

Previous hydrological assessments of flow in the Ashhurst Stream for Palmerston North City Council included:

- Memo: Ashhurst Stream Hydrology dated 27 September 2019
  - Calibration of a HEC-HMS initial and constant loss model for the Ashhurst Stream
  - Storm rainfall over the catchment (HIRDS V4 database)
  - Generation of 2 and 5 year ARI hydrographs using present day rainfall
  - Generation of 10, 20, 50 and 100 year ARI hydrographs using rainfall with allowance for climate change at 2081-2100 time horizon according to RCP 6.0
- Letter report: Ashhurst Stormwater Modelling: Model updates for 200 year ARI scenario
  - Generation of 200 year ARI hydrographs with allowance for climate change at 2081-2100 time horizon according to RCP 6.0

This assignment uses the calibrated HEC-HMS model to generate 100 and 200 year ARI hydrographs from present day storm rainfall.

For completeness this memo incorporates input data and outputs from the previous assignments together with the inputs and outputs from the current study (March 2021).

2 Storm rainfall

Storm rainfall data for the catchment was estimated using the HIRDS V4 database, from NIWA, at the location near the centroid of the catchment. These data are summarised in Table 2.1.

Table 2.1: HIRDS 4 storm rainfall used in the analyses

Ashhurst Stream Catchment				
Latitude: 40.25 South Longitude: 175.754				
ARI (years)	**Storm depth (mm) for duration (hours)**			
	1	**6**	**12**	**24**
Present day				
2	14.8	31.0	40.6	52.6

5	19.9	40.7	52.9	67.9
10	23.9	48.2	62.2	79.3
20	28.2	56.0	71.9	91.1
50	34.5	67.1	85.6	108.0
100	39.6	76.0	96.4	120.5
200	45.1	85.3	107.5	133.7
Climate change RCP 6.0 2081 to 2100				
10	29.0	56.7	71.9	89.8
20	34.3	66.2	83.3	103.3
50	42.0	79.5	99.4	122.3
100	48.4	90.3	112.2	137.4
200	55.1	101.3	125.2	152.4

Hyetographs for each storm duration and ARI generated using the HIRDS 4 temporal distributions for East of North Island. These hyetographs were input to the HEC-HMS model to generate hydrographs for calibration of the model and for input to the hydraulic model.

3 HEC-HMS modelling for the Ashhurst Stream

An initial and constant loss model was set up in HEC-HMS. Initial loss was set at 27.3 mm (0.2 x Soil storage following the SCS approach). The constant loss was estimated, based on SCS soil groups in the catchment, between 4 and 8 mm/hr. The catchment lag of 101 minutes was estimated as two thirds the time of concentration for the catchment calculated using the TP108 formula.

Simulated hydrograph peaks are summarised in Table 3.1 and the hydrograph plots with constant losses of 4 and 8 mm/hr in Figure 3.1 to Figure 3.2.

Table 3.1: Simulated hydrograph peaks

	Peak discharge (m^3/s) for storm duration			
	1 hour	**6 hour**	**12 hour**	**24 hour**
Scenario	**Constant loss 4 mm/hr**			
100 year ARI PD	5.03	**12.67**	9.98	6.00
100 year ARI RCP 6.0 2090	8.97	**16.61**	12.45	7.44
200 year ARI PD	7.49	**15.24**	11.72	7.12
200 year ARI RCP 6.0 2090	12.00	**19.59**	14.47	8.71
	Constant loss 6 mm/hr			
100 year ARI PD	4.67	**11.06**	8.02	3.90
100 year ARI RCP 6.0 2090	8.55	**14.93**	10.46	5.33
200 year ARI PD	7.08	**13.59**	9.73	5.02
200 year ARI RCP 6.0 2090	11.55	**17.87**	12.46	6.60
	Constant loss 8 mm/hr			
100 year ARI PD	4.32	**9.48**	6.08	1.80
100 year ARI RCP 6.0 2090	8.13	**13.28**	8.47	3.22
200 year ARI PD	6.68	**11.95**	7.76	2.91

200 year ARI RCP 6.0 2090	11.09	**16.17**	10.44	4.50

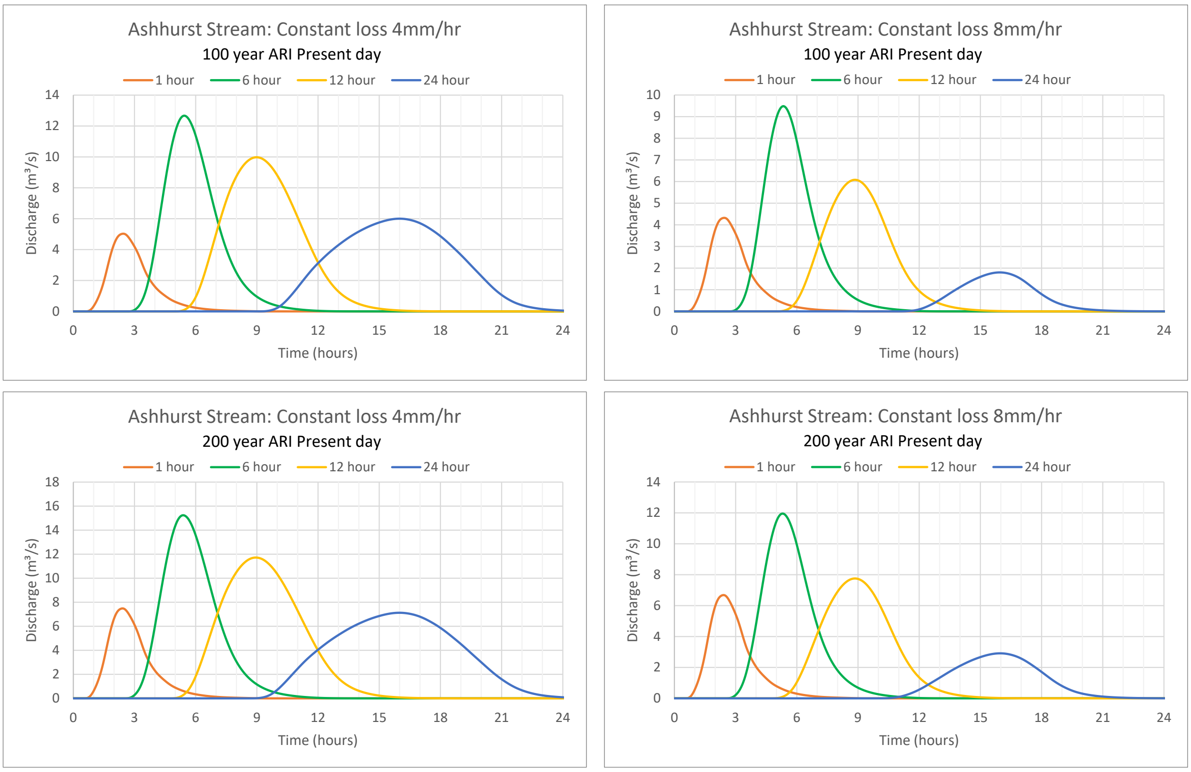

Figure 3.1: Ashhurst Stream: Present day climate hydrographs

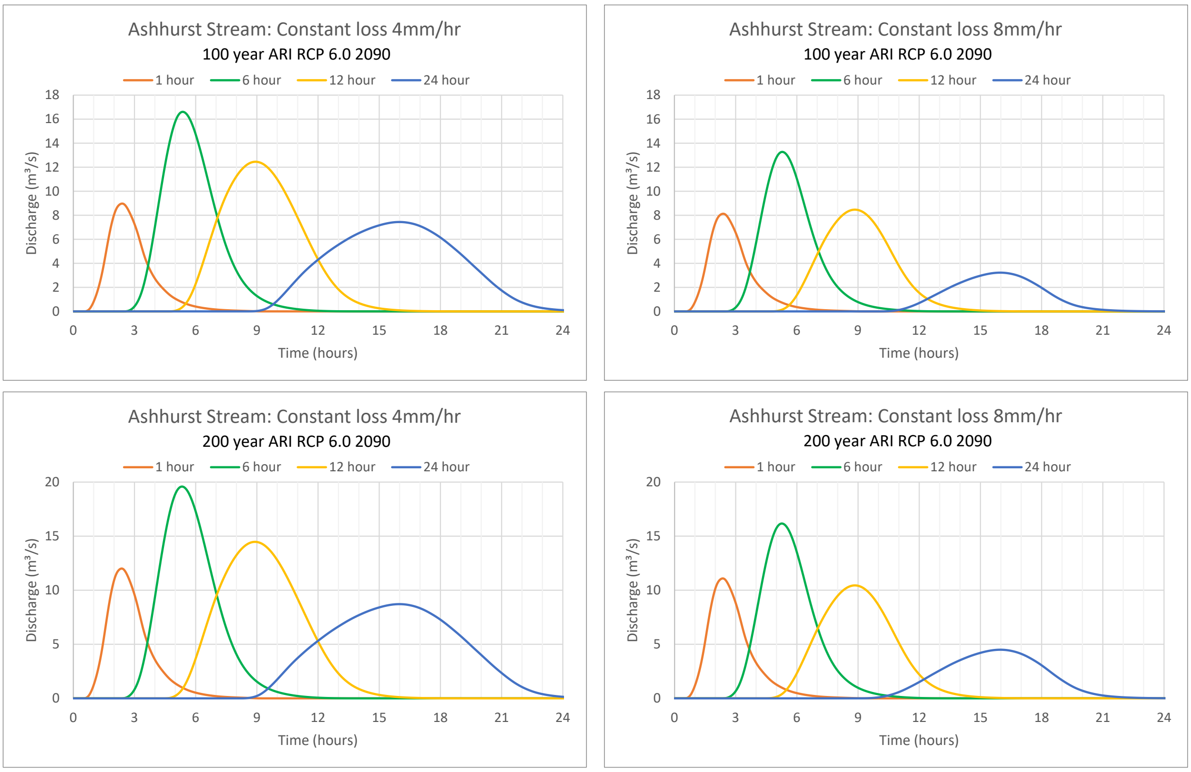

Figure 3.2: Ashhurst Stream: Projected 2081-2100 RCP 6.0 hydrographs

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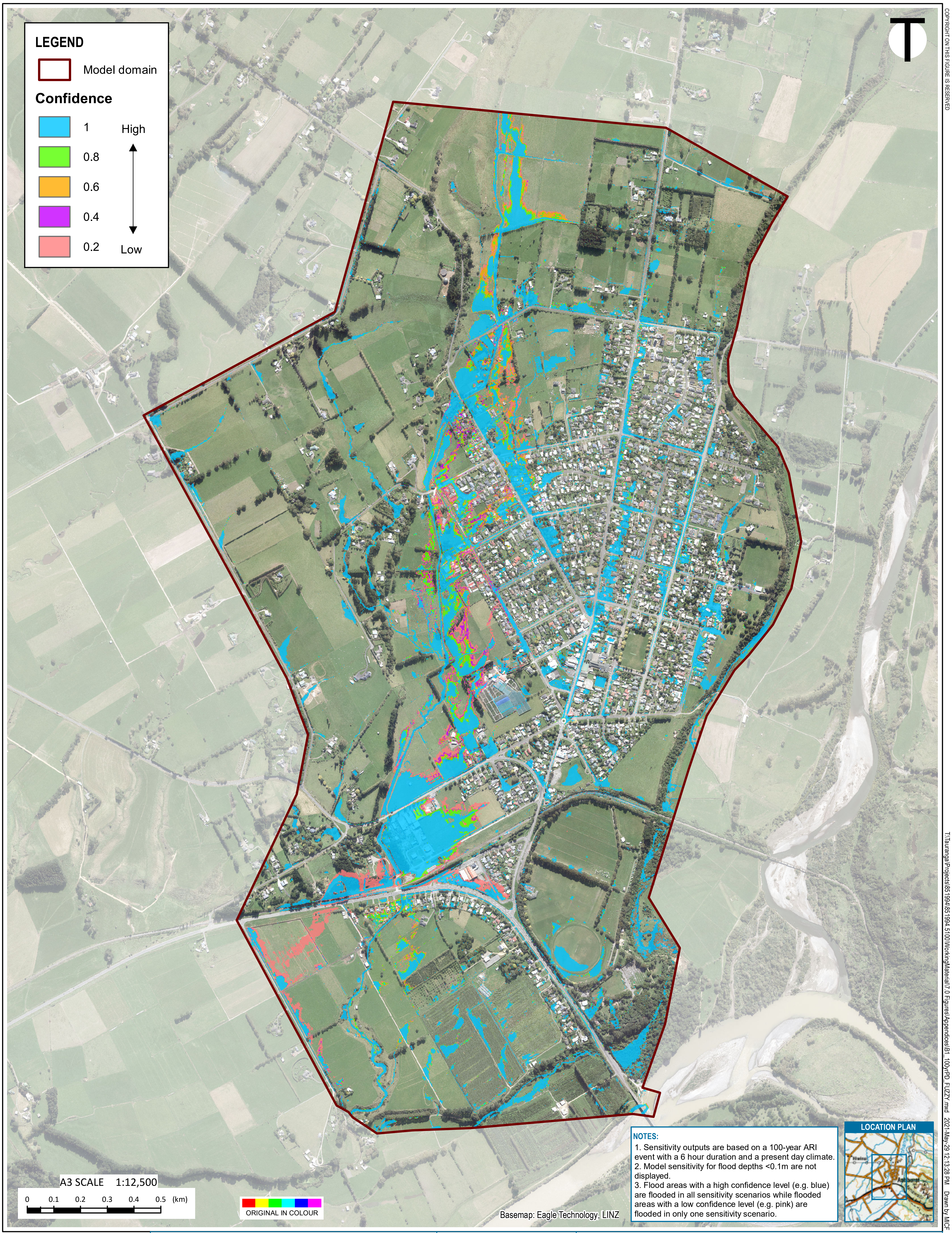
Appendix B: Model sensitivity testing

- **Figure B1: 100-year ARI 6-hour duration “fuzzy” map**
- **Figure B2: 100-year ARI 6-hour duration with and without direct rainfall peak flood extent difference**
- **Figure B3: 100-year ARI 6-hour duration high roughness difference map**
- **Figure B4: 100-year ARI 6-hour duration low roughness difference map**
- **Figure B5: 100-year ARI 6-hour Ashhurst Stream inflow constant loss difference map**
- **Figure B6: 100-year ARI 6-hour structure blockage difference map**



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NOTES:

To be read in conjunction with the Ashhurst Drainage Scheme Flood Hazard Assessment Report. The information presented on these figures is based on a numerical representation of the physical reality and is reliant upon input data and therefore bears uncertainty.

REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	29/05/21

PROJECT No.	851994.51	
DESIGNED	MICF	JUN.21
DRAWN	MICF	JUN.21
CHECKED	MSP	JUN.21
APPROVED	PRC	JUN.21

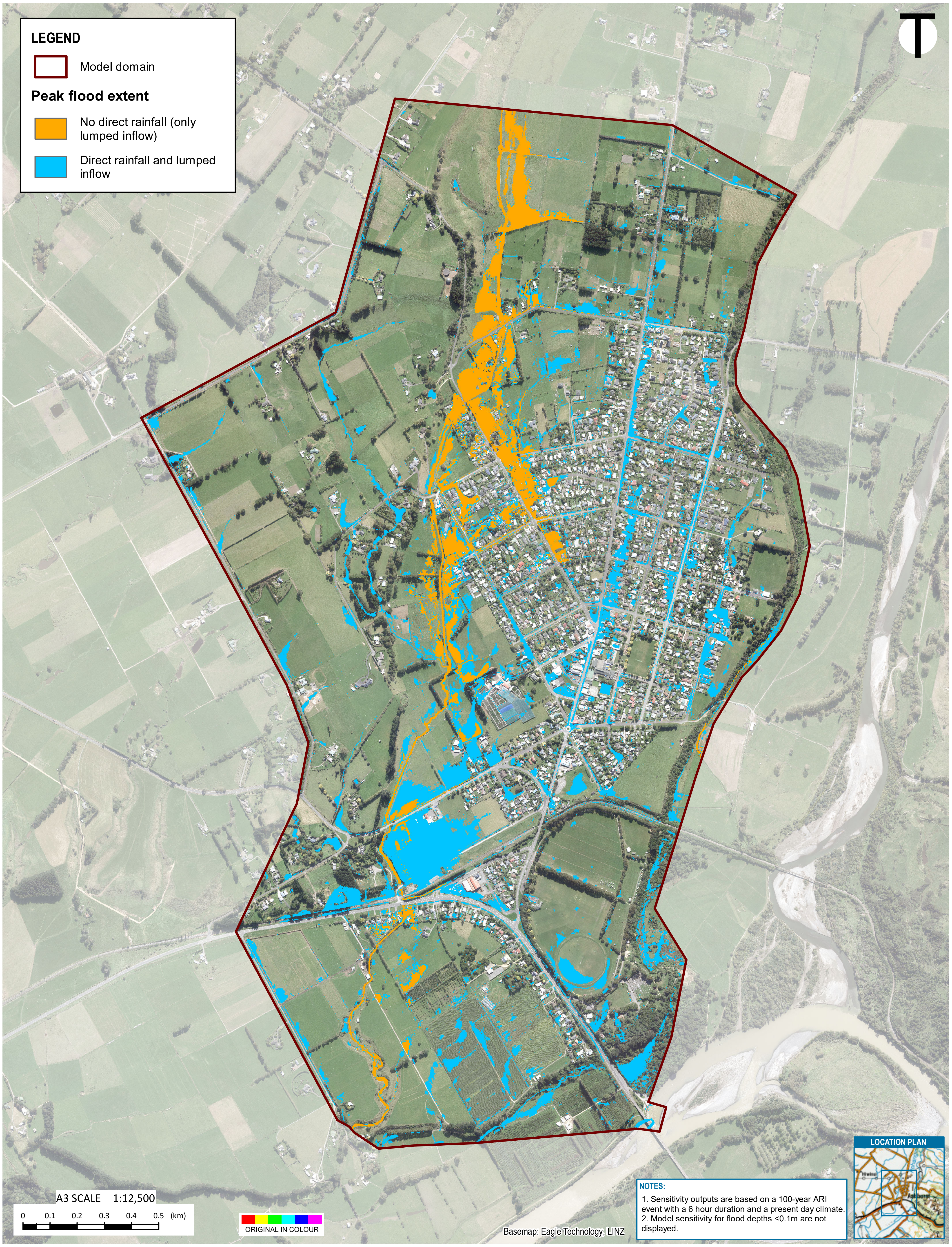
CLIENT: **HORIZONS REGIONAL COUNCIL**

PROJECT: **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**

TITLE: PEAK FLOOD DEPTH SENSITIVITY "FUZZY" MAP

100 YEAR ARI PRESENT-DAY DESIGN EVENT

SCALE (A3): 1:12,500 | FIG No. FIGURE B1. | REV 0



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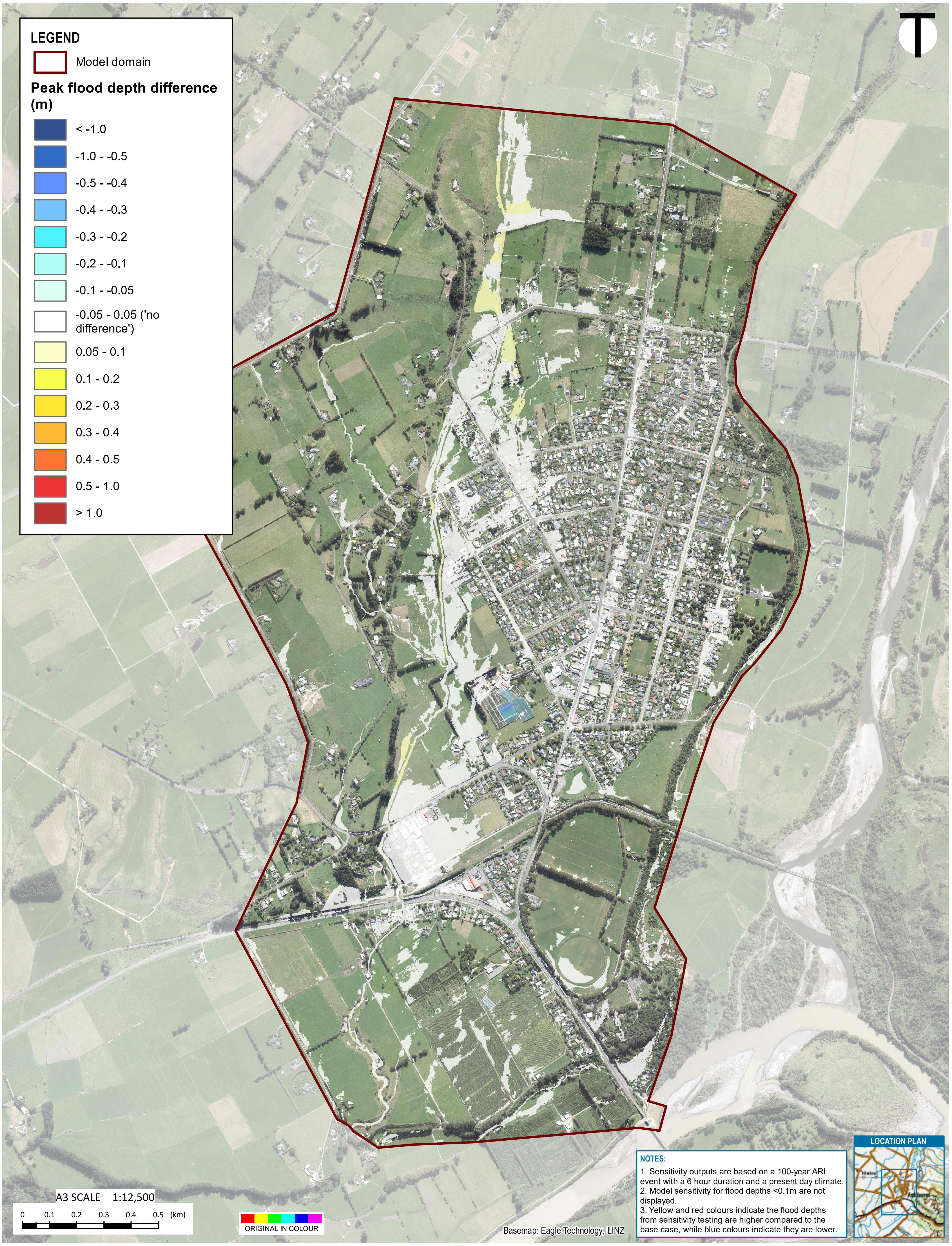
REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	29/05/21

PROJECT No.	851994.51	
DESIGNED	MICF	JUN.21
DRAWN	MICF	JUN.21
CHECKED	MSP	JUN.21
APPROVED	PRC	JUN.21

CLIENT HORIZONS REGIONAL COUNCIL
PROJECT ASHHURST DRAINAGE SCHEME FLOOD MODELLING
TITLE NO DIRECT RAINFALL PEAK FLOOD EXTENT DIFFERENCE 100 YEAR ARI PRESENT-DAY DESIGN EVENT
SCALE (A3) 1:12,500 FIG No. FIGURE B2. REV 0



NOTES:
1. Sensitivity outputs are based on a 100-year ARI event with a 6 hour duration and a present day climate.
2. Model sensitivity for flood depths <0.1m are not displayed.
3. Yellow and red colours indicate the flood depths from sensitivity testing are higher compared to the base case, while blue colours indicate they are lower.

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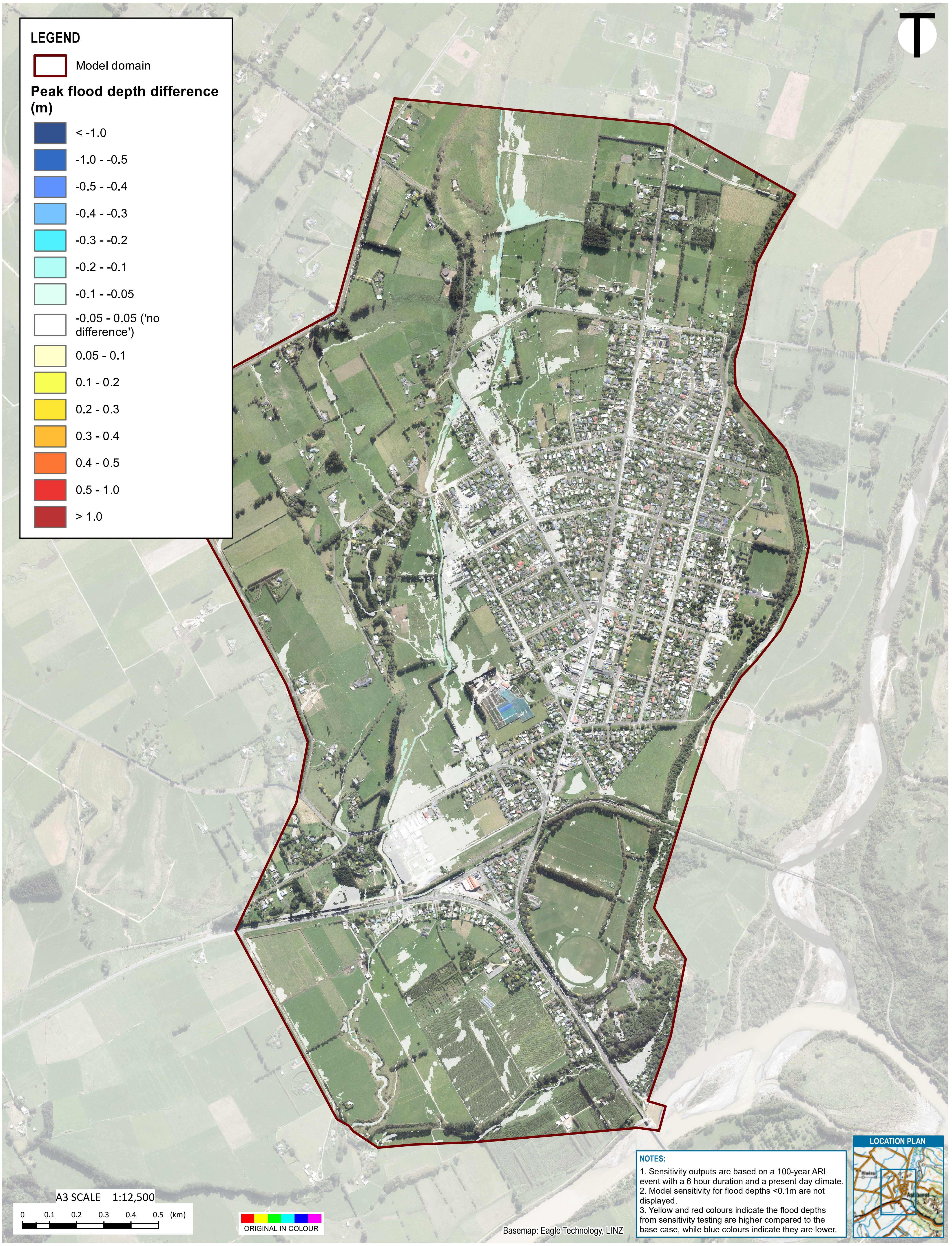
REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	29/05/21	PRC	JUN.21

PROJECT No.	851994.51	
DESIGNED	MICF	JUN.21
DRAWN	MICF	JUN.21
CHECKED	MSP	JUN.21

CLIENT: HORIZONS REGIONAL COUNCIL
PROJECT: ASHHURST DRAINAGE SCHEME FLOOD MODELLING
TITLE: HIGH MANNING N PEAK FLOOD DEPTH DIFFERENCE
100 YEAR ARI PRESENT-DAY DESIGN EVENT
SCALE (A3): 1:12,500 FIG No. FIGURE B3. REV 0



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NOTES:
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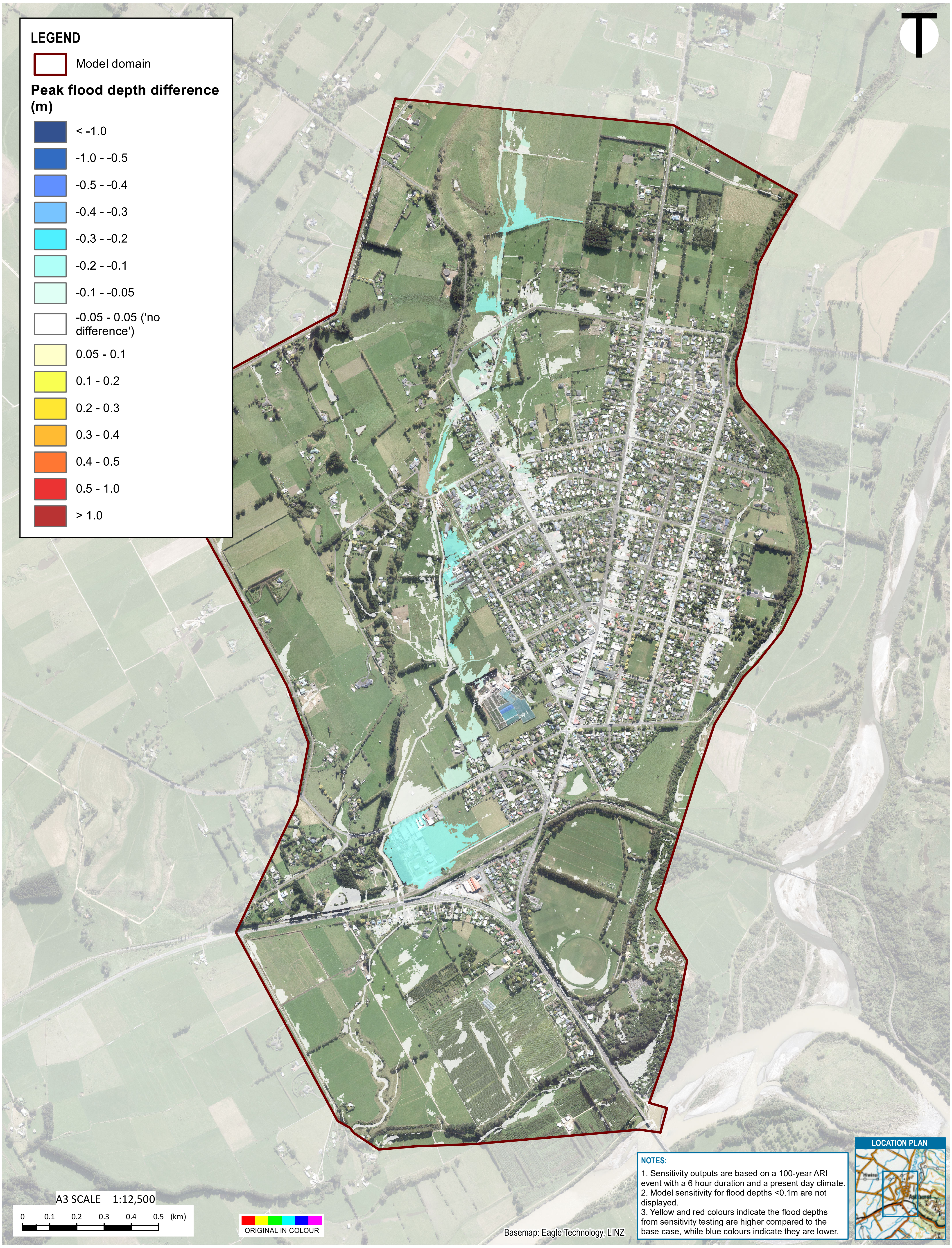
REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	17/11/21

PROJECT No.	851994.51	
DESIGNED	MICF	NOV.21
DRAWN	MICF	NOV.21
CHECKED	MSP	NOV.21
APPROVED	PRC	NOV.21

CLIENT: **HORIZONS REGIONAL COUNCIL**
PROJECT: **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE: LOW MANNING N PEAK FLOOD DEPTH DIFFERENCE
100 YEAR ARI PRESENT-DAY DESIGN EVENT

SCALE (A3) 1:12,500 | FIG No. FIGURE B4. | REV 0



NOTES:
1. Sensitivity outputs are based on a 100-year ARI event with a 6 hour duration and a present day climate.
2. Model sensitivity for flood depths <0.1m are not displayed.
3. Yellow and red colours indicate the flood depths from sensitivity testing are higher compared to the base case, while blue colours indicate they are lower.

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NOTES:
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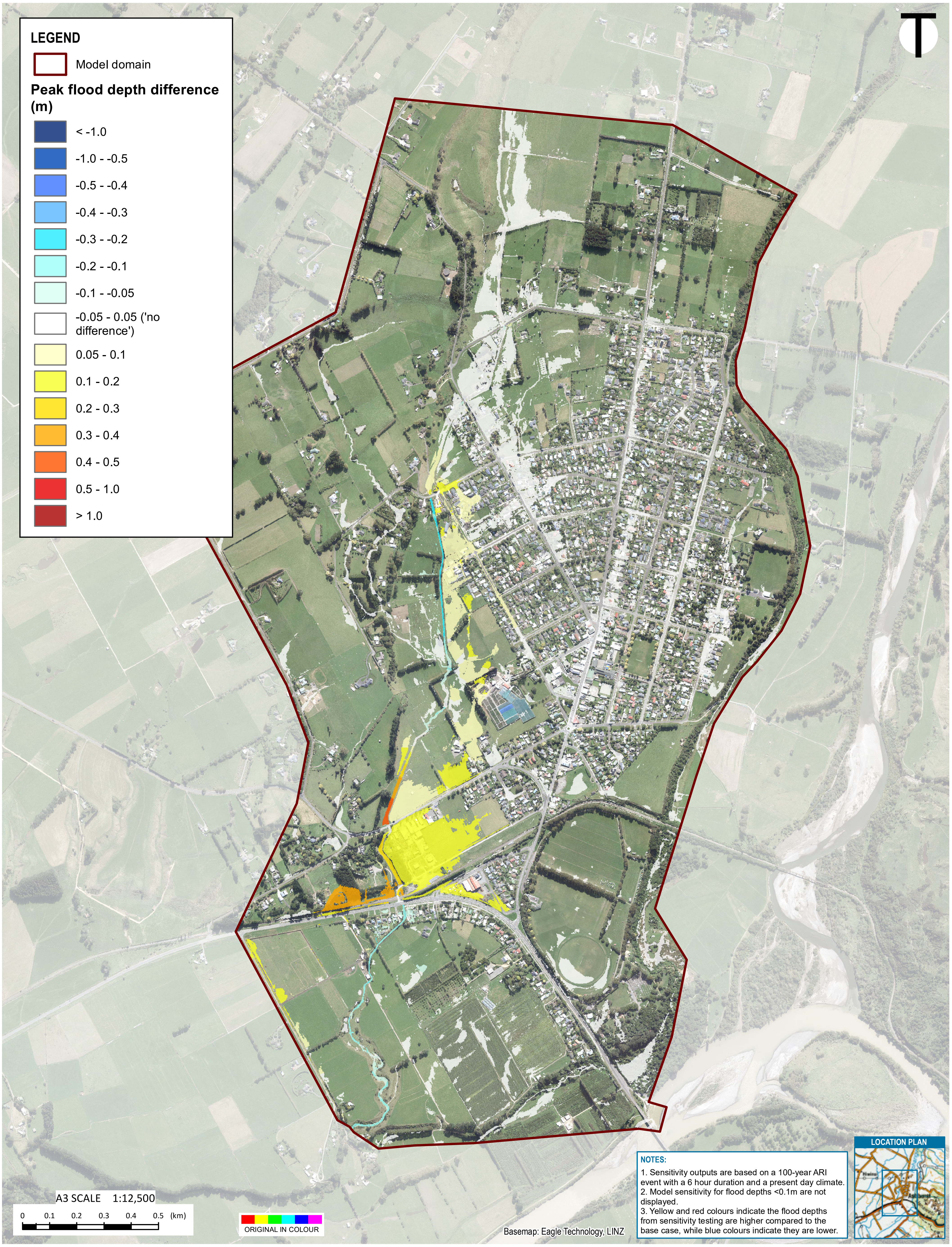
0	Final	MICF	MSP	17/11/21

PROJECT No.	851994.51	
DESIGNED	MICF	NOV.21
DRAWN	MICF	NOV.21
CHECKED	MSP	NOV.21
APPROVED	PRC	NOV.21

CLIENT	**HORIZONS REGIONAL COUNCIL**
PROJECT	**ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE	HIGH CONSTANT LOSS PEAK FLOOD DEPTH DIFFERENCE 100 YEAR ARI PRESENT-DAY DESIGN EVENT

SCALE (A3) 1:12,500 FIG No. FIGURE B5. REV 0



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REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	17/11/21

PROJECT No.	851994.51	
DESIGNED	MICF	NOV.21
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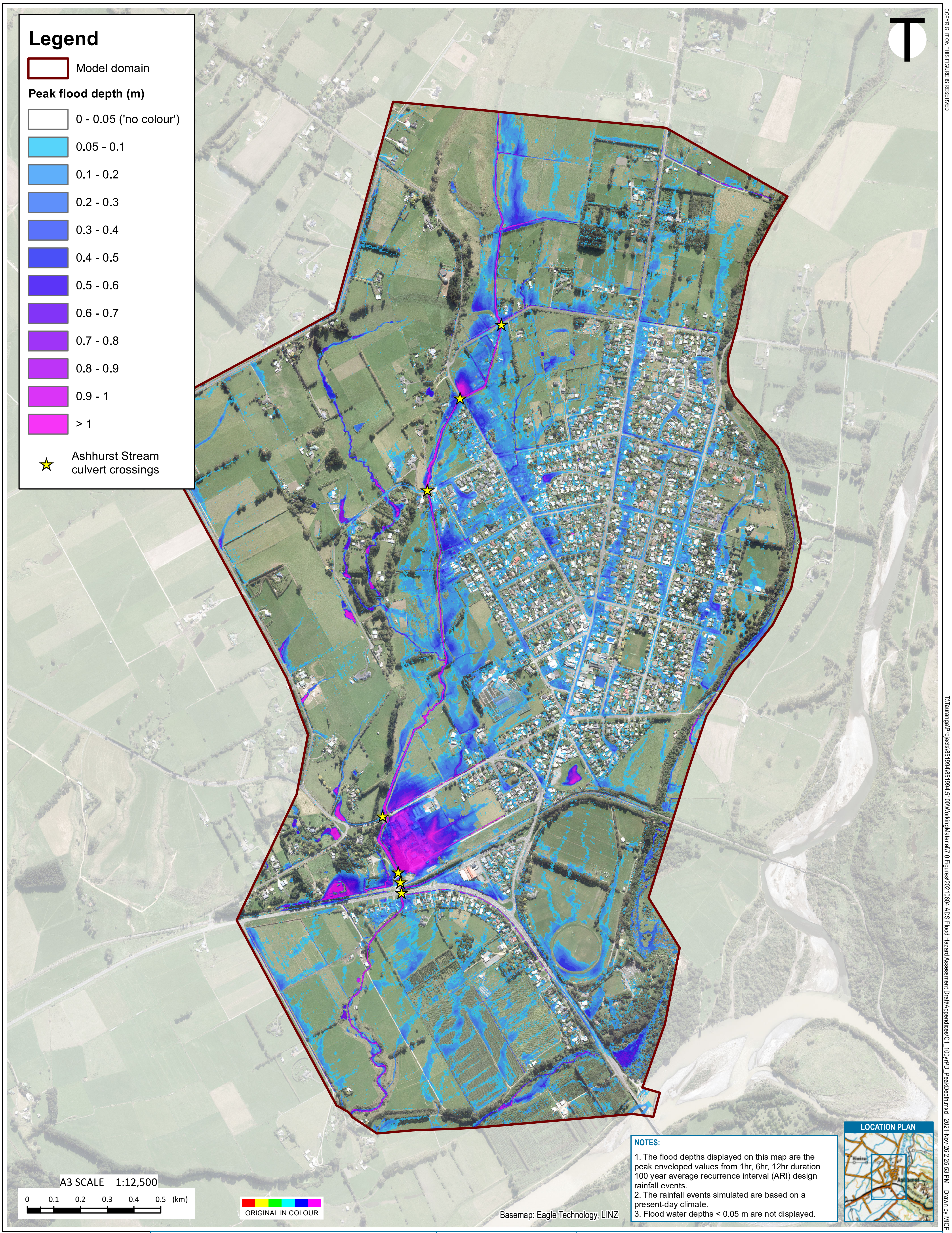
CHECKED	MSP	NOV.21
APPROVED	PRC	NOV.21

CLIENT: **HORIZONS REGIONAL COUNCIL**
PROJECT: **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE: CULVERT BLOCKAGE PEAK FLOOD DEPTH DIFFERENCE 100 YEAR ARI PRESENT-DAY DESIGN EVENT

SCALE (A3) 1:12,500 | FIG No. FIGURE B6. | REV 0

Appendix C: Peak Flood Depth Maps

- **Figure C1: Base Case 100-year ARI present-day climate peak of peak flood depths**
- **Figure C2: Base Case 100-year ARI RCP6.0 2100 climate peak of peak flood depths**
- **Figure C3: Base Case 200-year ARI present-day climate peak of peak flood depths**
- **Figure C4: Base Case 200-year ARI RCP6.0 2100 climate peak of peak flood depths**
- **Figure C5: Scenario 2: 100-year ARI present-day climate peak of peak flood depths**
- **Figure C6: Scenario 2: 100-year ARI RCP6.0 2100 climate peak of peak flood depths**
- **Figure C7: Scenario 2: 200-year ARI present-day climate peak of peak flood depths**
- **Figure C8: Scenario 2: 200-year ARI RCP6.0 2100 climate peak of peak flood depths**
- **Figure C9: Scenario 3: 100-year ARI present-day climate peak of peak flood depths**
- **Figure C10: Scenario 3: 100-year ARI RCP6.0 2100 climate peak of peak flood depths**
- **Figure C11: Scenario 3: 200-year ARI present-day climate peak of peak flood depths**
- **Figure C12: Scenario 3: 200-year ARI RCP6.0 2100 climate peak of peak flood depths**



T:\Tauranga\Projects\851994\851994.5100\WorkingMaterial\7.0 Figures\20210604 ADS Flood Hazard Assessment Draft\Appendices\C1_100yrPD_PeakDepth.mxd 2021-Nov-26 2:25:53 PM Drawn by MICF

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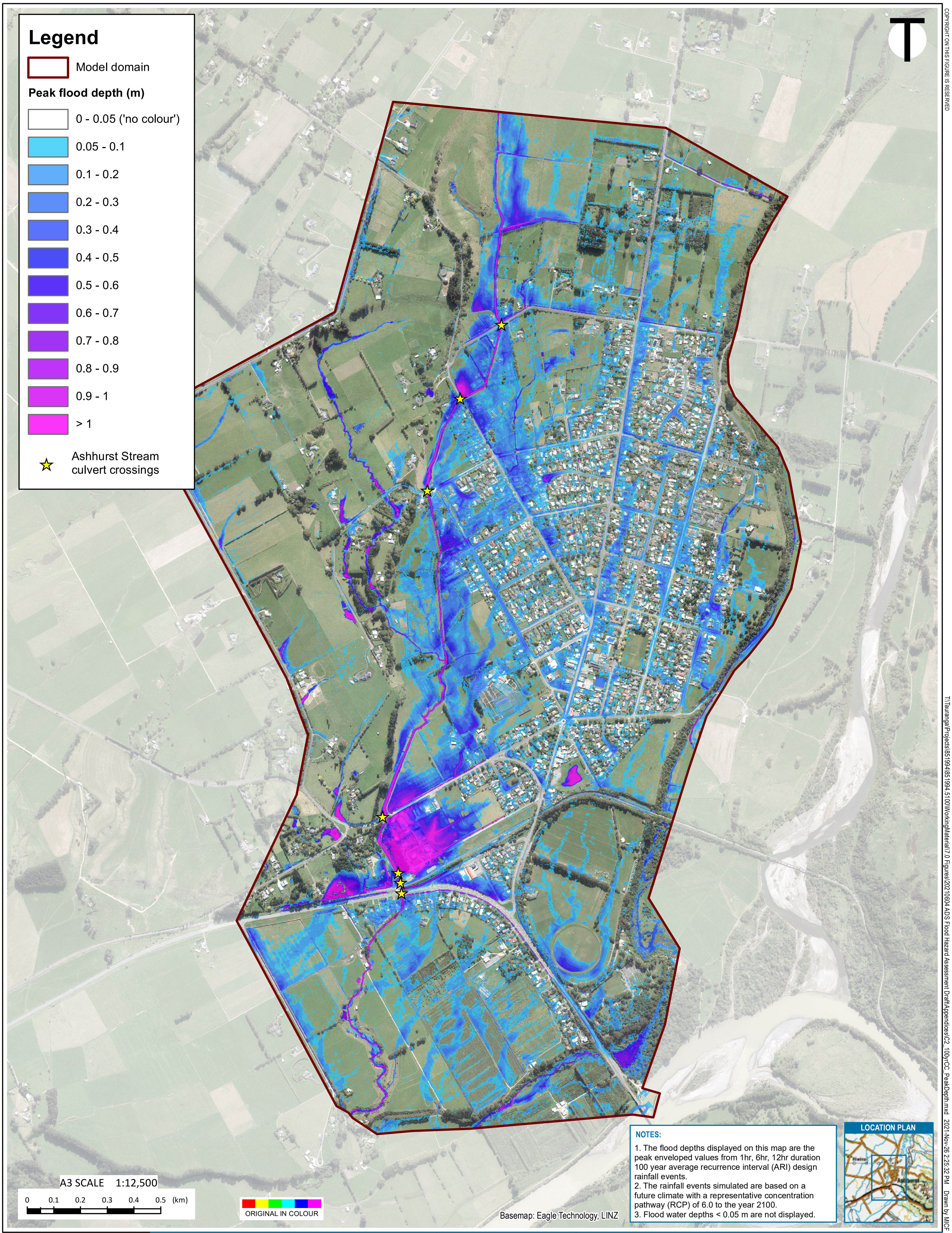
REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	06/12/21	PRC	DEC.21

PROJECT No. 851994.51

DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21

CLIENT **HORIZONS REGIONAL COUNCIL**
PROJECT **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE PEAK FLOOD DEPTH: BASE CASE (SCENARIO 1)
100 YEAR ARI PRESENT-DAY DESIGN EVENT
SCALE (A3) 1:12,500 FIG No. FIGURE C1. REV 0



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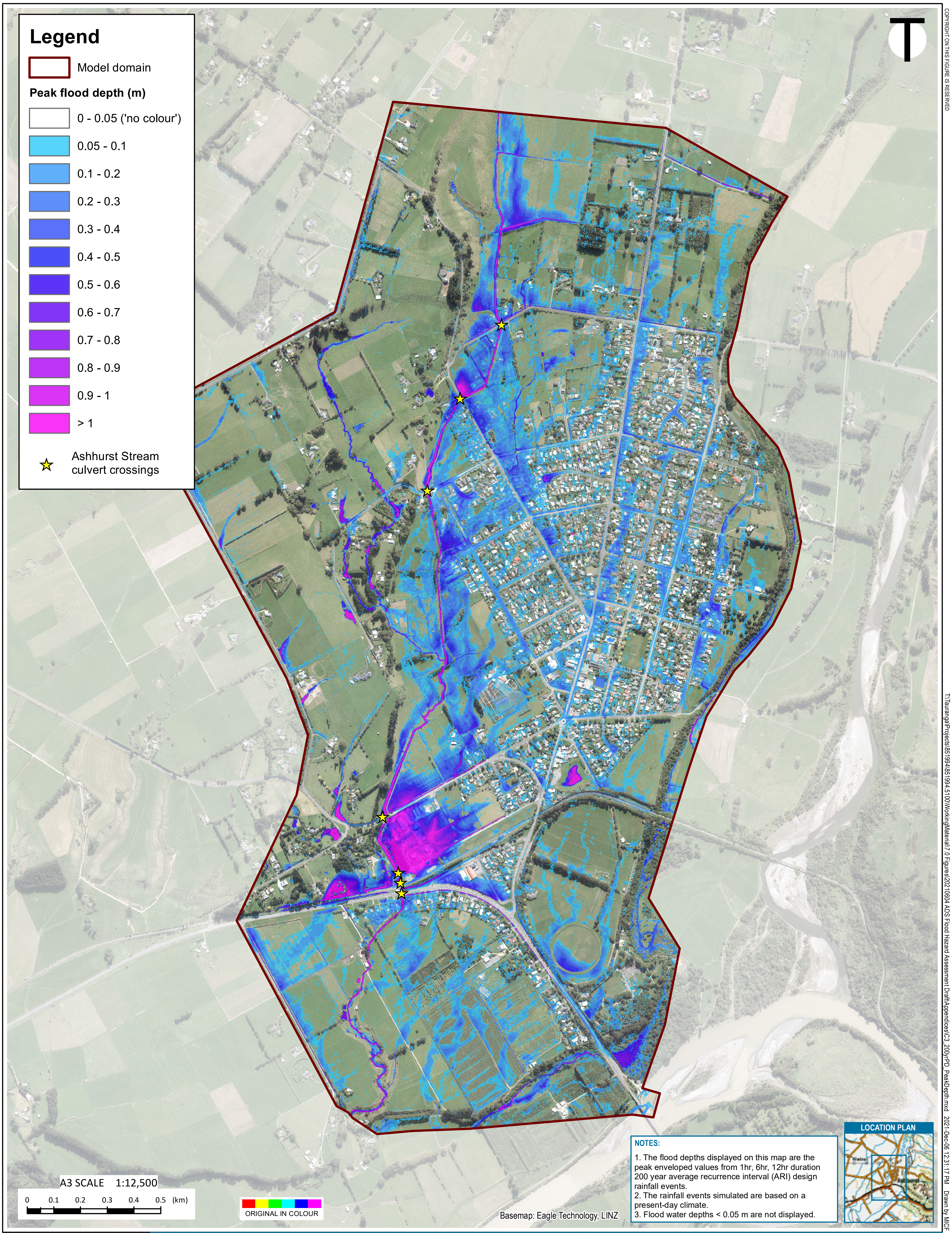
REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	06/12/21	PRC	DEC.21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21

CLIENT HORIZONS REGIONAL COUNCIL
PROJECT ASHHURST DRAINAGE SCHEME FLOOD MODELLING
TITLE PEAK FLOOD DEPTH: BASE CASE (SCENARIO 1)
100 YEAR ARI RCP6 2100 DESIGN EVENT
SCALE (A3) 1:12,500 FIG No. FIGURE C2. REV 0



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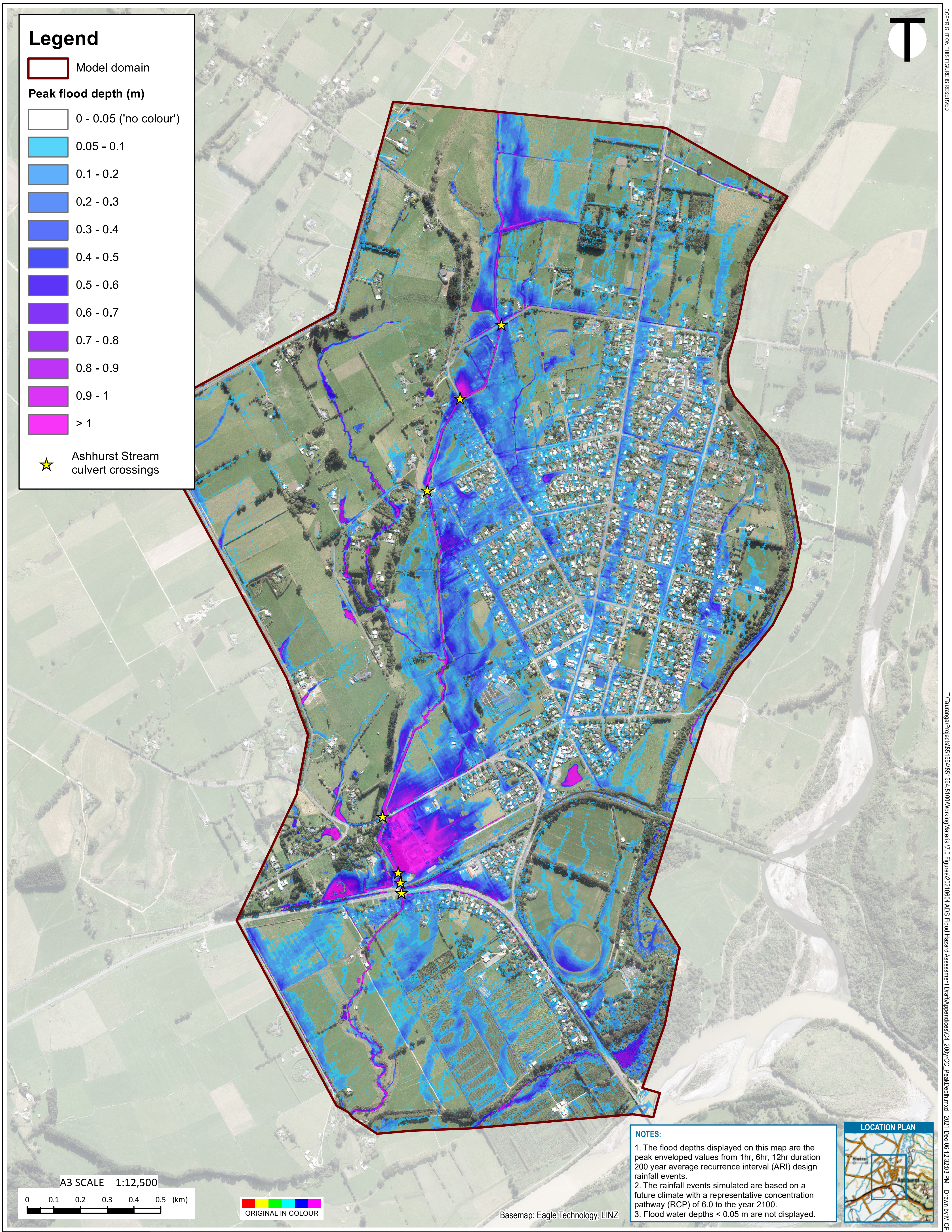
REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	06/12/21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21
APPROVED	PRC	DEC.21

CLIENT	HORIZONS REGIONAL COUNCIL
PROJECT	ASHHURST DRAINAGE SCHEME FLOOD MODELLING
TITLE	PEAK FLOOD DEPTH: BASE CASE (SCENARIO 1) 200 YEAR ARI PRESENT-DAY DESIGN EVENT
SCALE (A3)	1:12,500
FIG No.	FIGURE C3.
REV	0



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REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	06/12/21	PRC	DEC.21

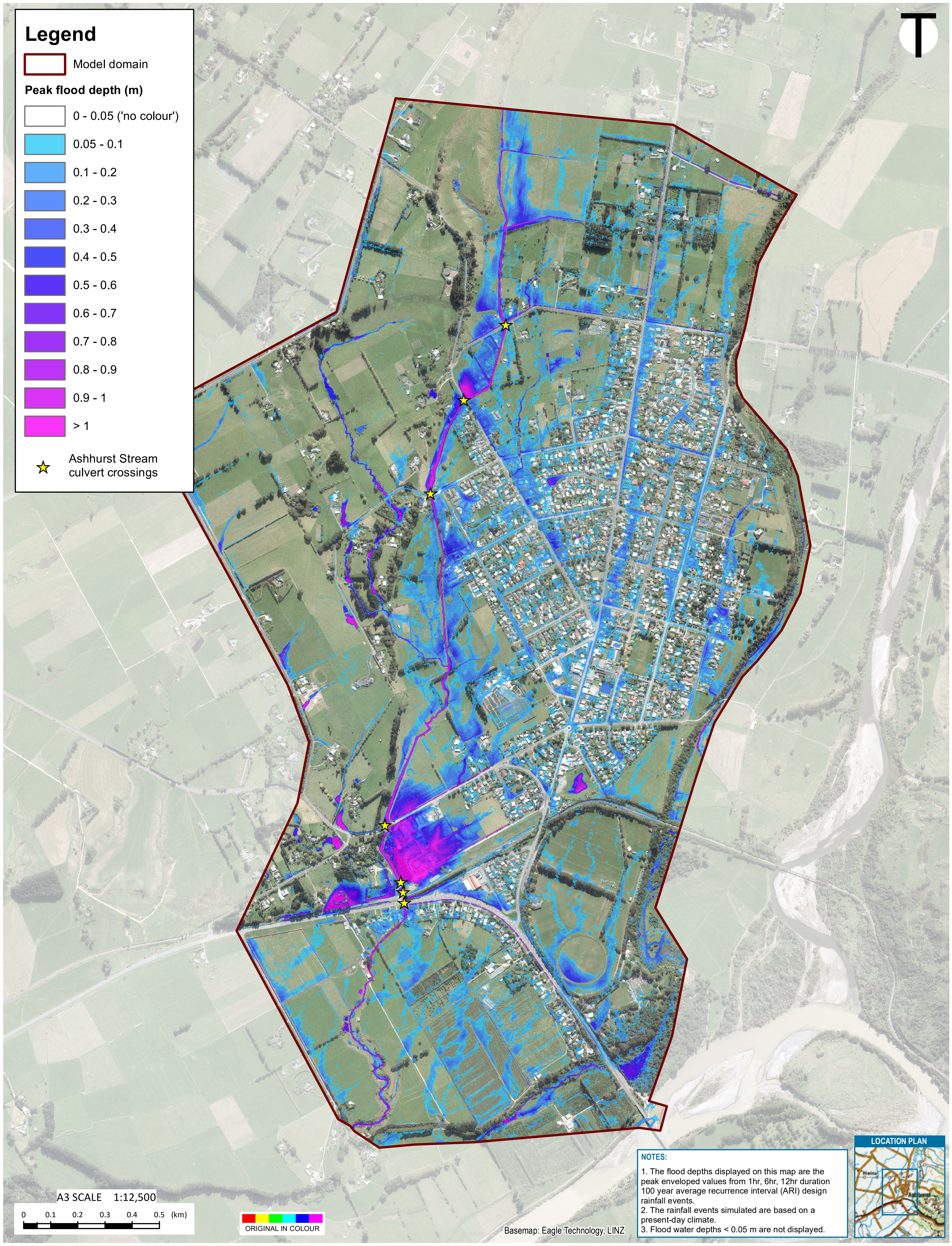
PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21

CLIENT: **HORIZONS REGIONAL COUNCIL**

PROJECT: **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**

TITLE: PEAK FLOOD DEPTH: BASE CASE (SCENARIO 1) 200 YEAR ARI RCP6 2100 DESIGN EVENT

SCALE (A3): 1:12,500 FIG No. FIGURE C4. REV 0



NOTES:

1. The flood depths displayed on this map are the peak enveloped values from 1hr, 6hr, 12hr duration 100 year average recurrence interval (ARI) design rainfall events.
2. The rainfall events simulated are based on a present-day climate.
3. Flood water depths < 0.05 m are not displayed.

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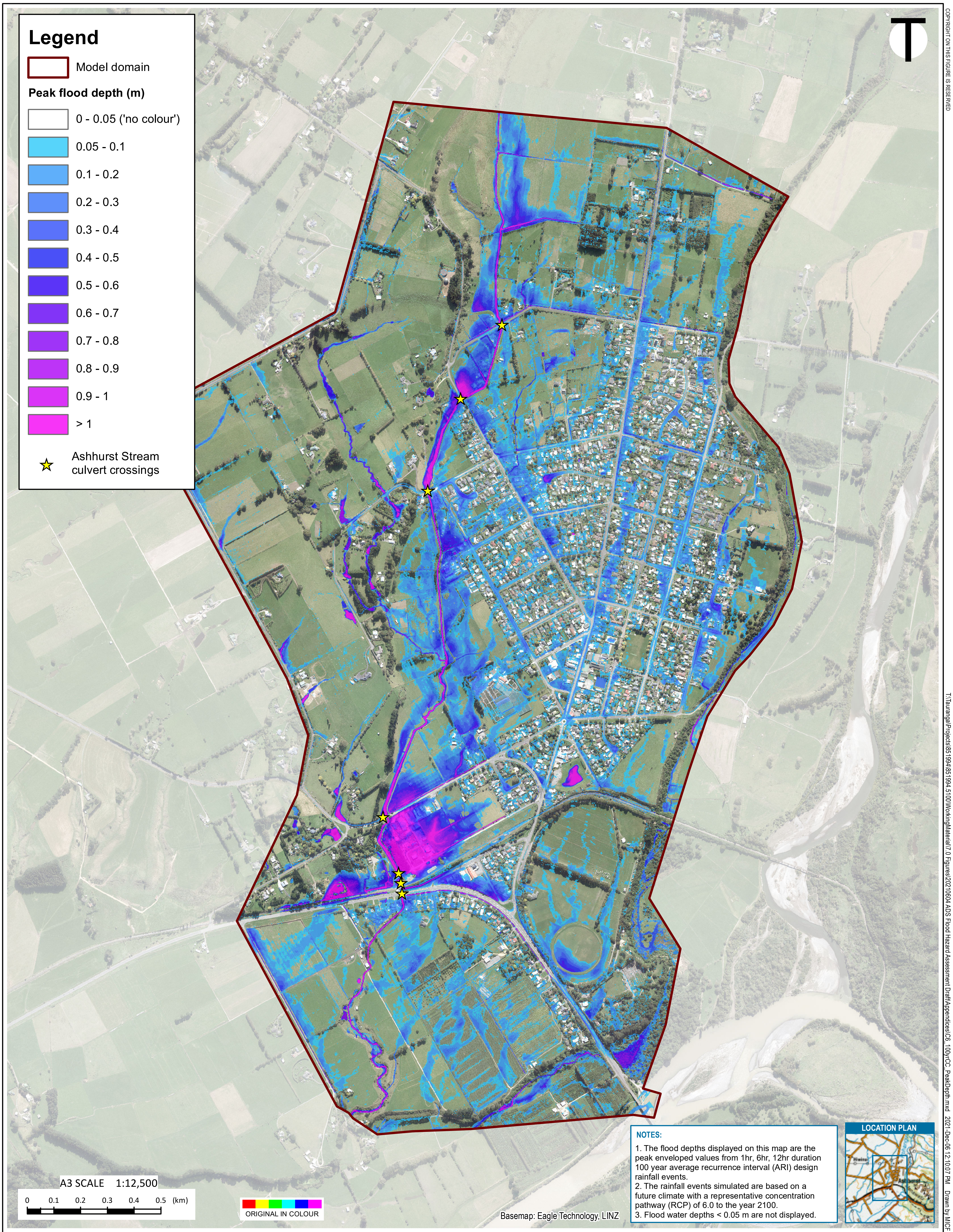
REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	06/12/21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21
APPROVED	PRC	DEC.21

CLIENT: **HORIZONS REGIONAL COUNCIL**
PROJECT: **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE: PEAK FLOOD DEPTH: SCENARIO 2
100 YEAR ARI PRESENT-DAY DESIGN EVENT
SCALE (A3): 1:12,500 FIG No. FIGURE C5. REV 0



NOTES:

1. The flood depths displayed on this map are the peak enveloped values from 1hr, 6hr, 12hr duration 100 year average recurrence interval (ARI) design rainfall events.
2. The rainfall events simulated are based on a future climate with a representative concentration pathway (RCP) of 6.0 to the year 2100.
3. Flood water depths < 0.05 m are not displayed.

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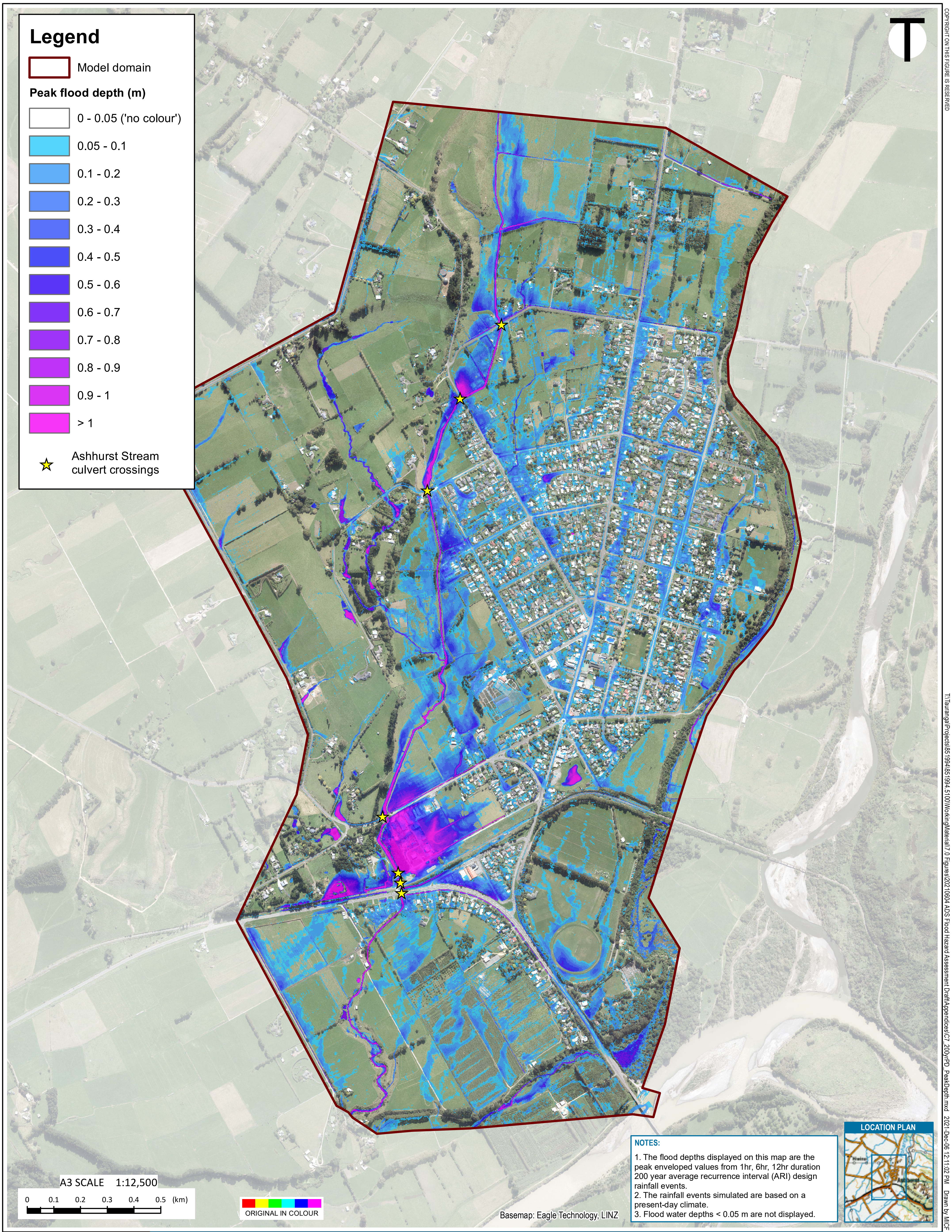
REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	06/12/21	PRC	DEC.21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21

CLIENT **HORIZONS REGIONAL COUNCIL**
PROJECT **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE PEAK FLOOD DEPTH: SCENARIO 2
100 YEAR ARI RCP6 2100 DESIGN EVENT
SCALE (A3) 1:12,500 FIG No. FIGURE C6. REV 0



NOTES:

1. The flood depths displayed on this map are the peak enveloped values from 1hr, 6hr, 12hr duration 200 year average recurrence interval (ARI) design rainfall events.
2. The rainfall events simulated are based on a present-day climate.
3. Flood water depths < 0.05 m are not displayed.

LOCATION PLAN

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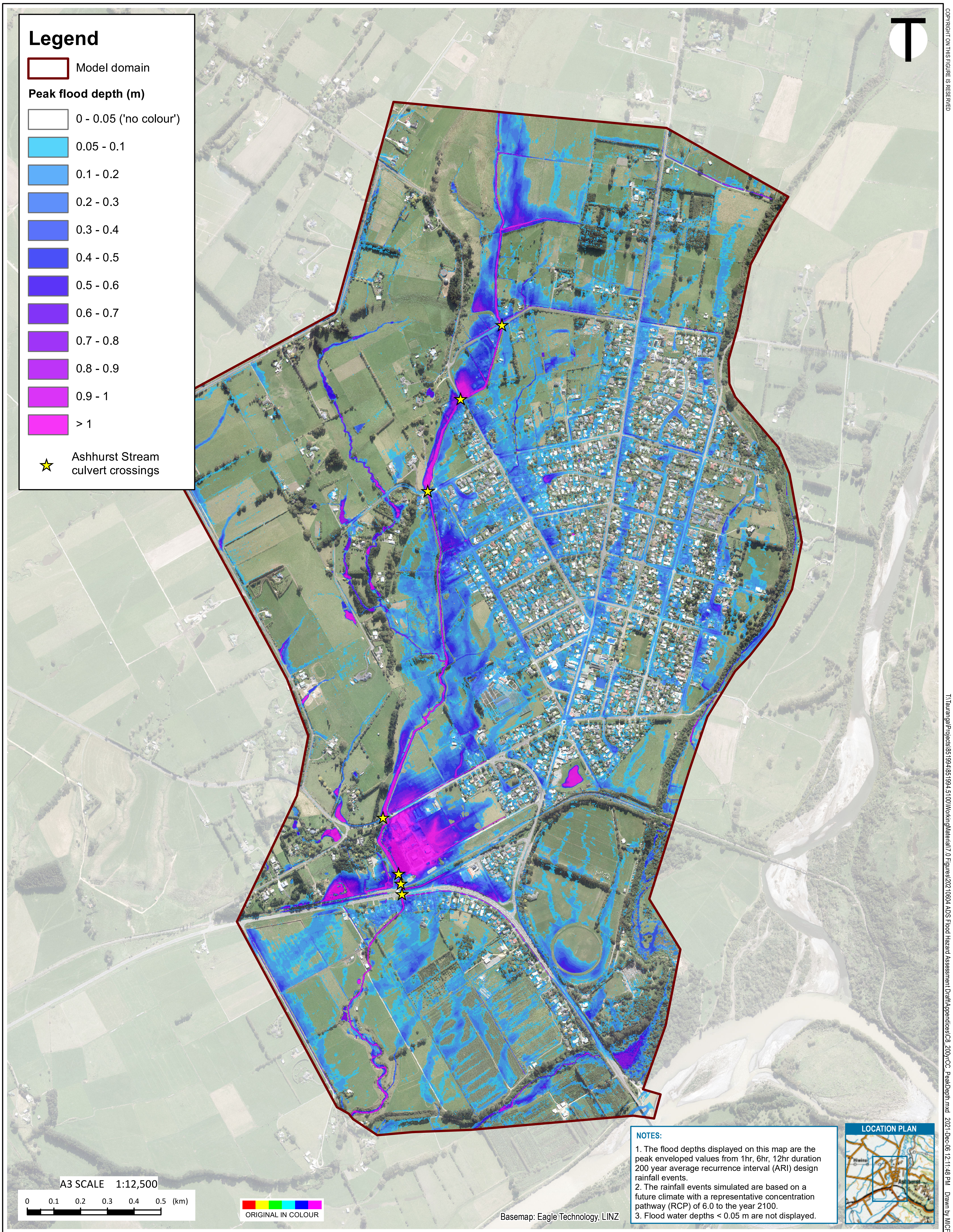
REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	06/12/21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21
APPROVED	PRC	DEC.21

CLIENT HORIZONS REGIONAL COUNCIL
PROJECT ASHHURST DRAINAGE SCHEME FLOOD MODELLING
TITLE PEAK FLOOD DEPTH: SCENARIO 2
200 YEAR ARI PRESENT-DAY DESIGN EVENT
SCALE (A3) 1:12,500 FIG No. FIGURE C7. REV 0



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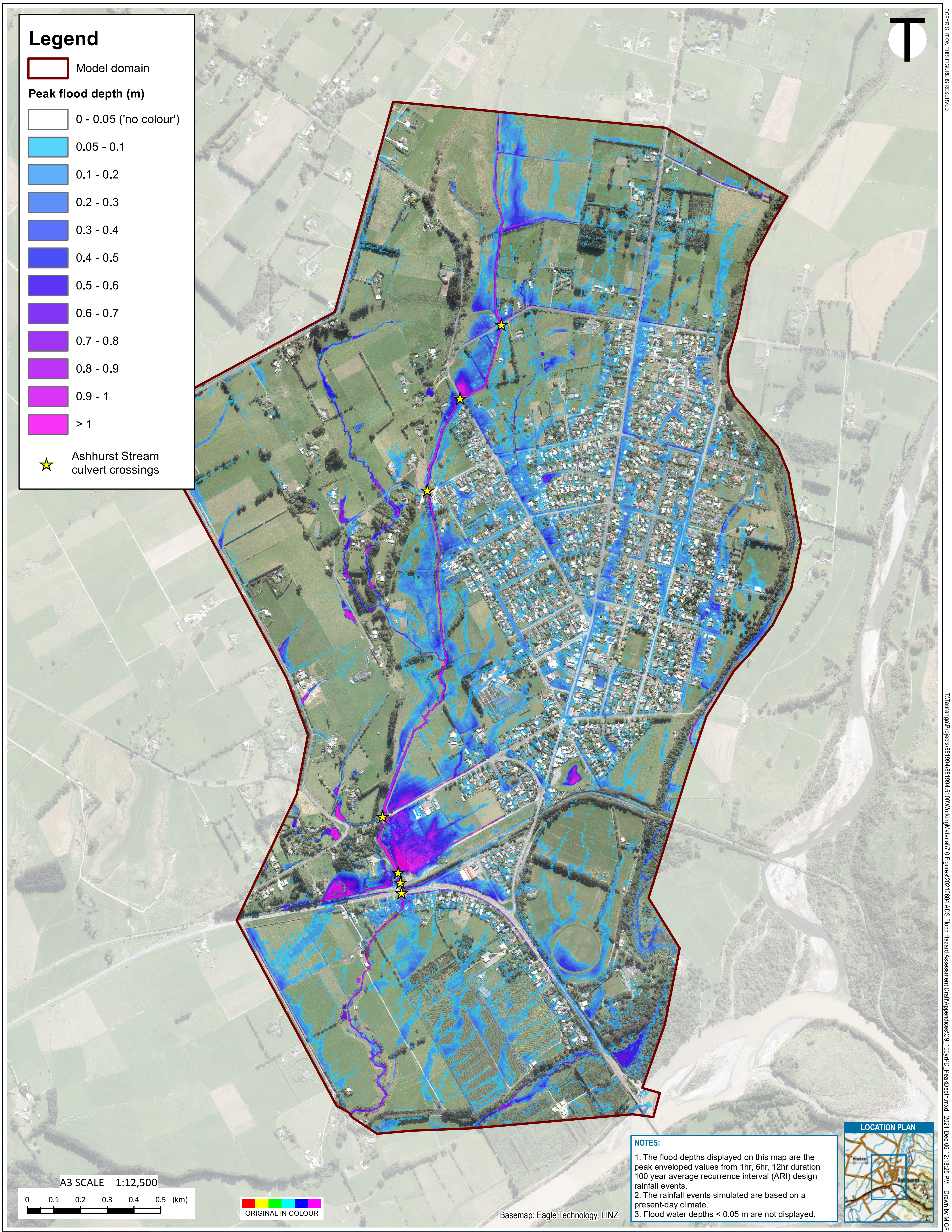
REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	06/12/21	PRC	DEC.21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21

CLIENT **HORIZONS REGIONAL COUNCIL**
PROJECT **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE PEAK FLOOD DEPTH: SCENARIO 2
200 YEAR ARI RCP6 2100 DESIGN EVENT
SCALE (A3) 1:12,500 FIG No. FIGURE C8. REV 0



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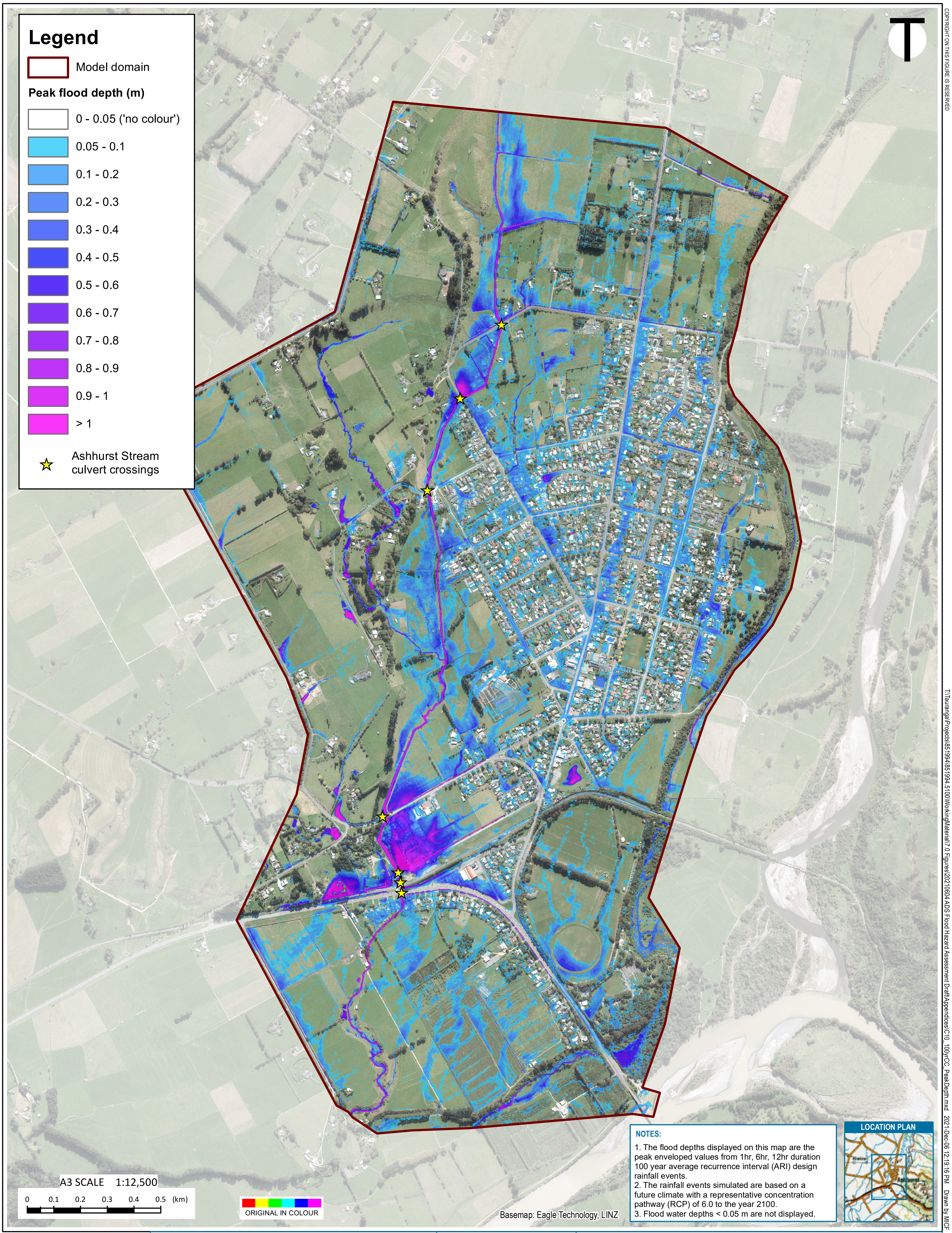
REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	06/12/21	PRC	DEC.21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21

CLIENT **HORIZONS REGIONAL COUNCIL**
PROJECT **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE PEAK FLOOD DEPTH: SCENARIO 3
100 YEAR ARI PRESENT-DAY DESIGN EVENT

SCALE (A3) 1:12,500 FIG No. FIGURE C9. REV 0



NOTES:
1. The flood depths displayed on this map are the peak enveloped values from 1hr, 6hr, 12hr duration 100 year average recurrence interval (ARI) design rainfall events.
2. The rainfall events simulated are based on a future climate with a representative concentration pathway (RCP) of 6.0 to the year 2100.
3. Flood water depths < 0.05 m are not displayed.

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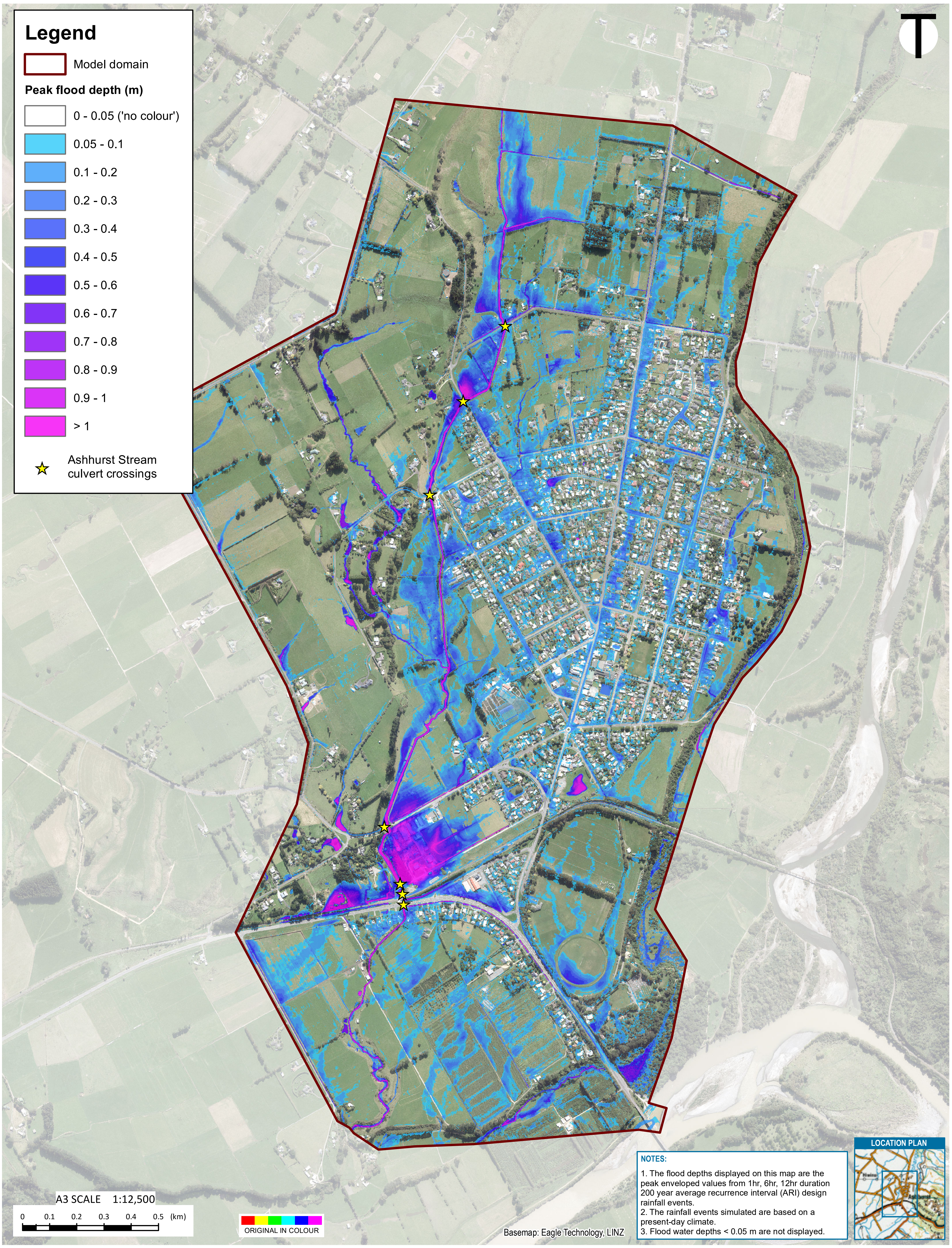
REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	06/12/21	PRC	DEC.21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21

CLIENT: HORIZONS REGIONAL COUNCIL
PROJECT: ASHHURST DRAINAGE SCHEME FLOOD MODELLING
TITLE: PEAK FLOOD DEPTH: SCENARIO 3
100 YEAR ARI RCP6 2100 DESIGN EVENT

SCALE (A3) 1:12,500 | FIG No. FIGURE C10 | REV 0



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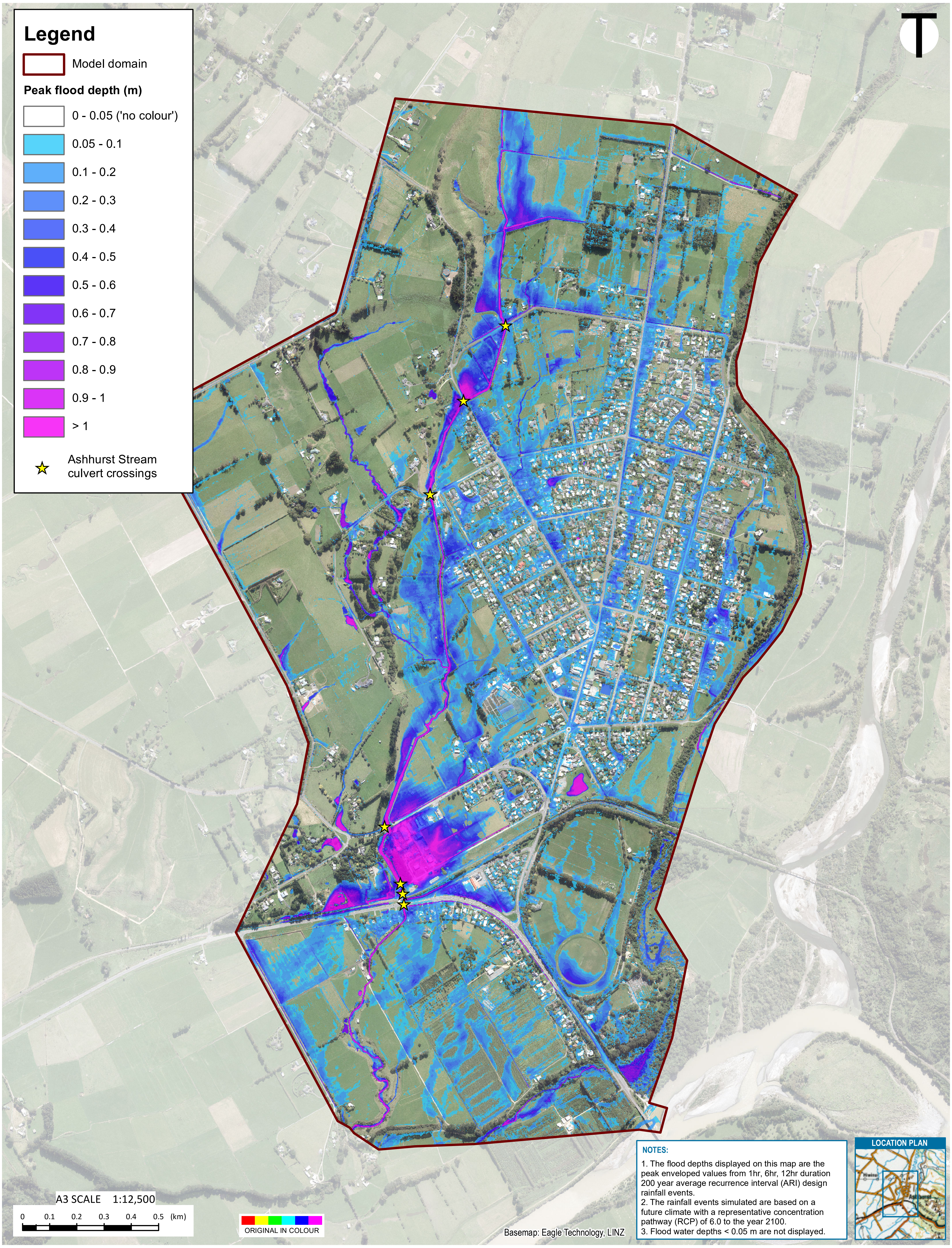
REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	06/12/21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21
APPROVED	PRC	DEC.21

CLIENT **HORIZONS REGIONAL COUNCIL**
PROJECT **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE PEAK FLOOD DEPTH: SCENARIO 3
200 YEAR ARI PRESENT-DAY DESIGN EVENT
SCALE (A3) 1:12,500 FIG No. FIGURE C11. REV 0



NOTES:

1. The flood depths displayed on this map are the peak enveloped values from 1hr, 6hr, 12hr duration 200 year average recurrence interval (ARI) design rainfall events.
2. The rainfall events simulated are based on a future climate with a representative concentration pathway (RCP) of 6.0 to the year 2100.
3. Flood water depths < 0.05 m are not displayed.

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REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	06/12/21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21
APPROVED	PRC	DEC.21

CLIENT: HORIZONS REGIONAL COUNCIL

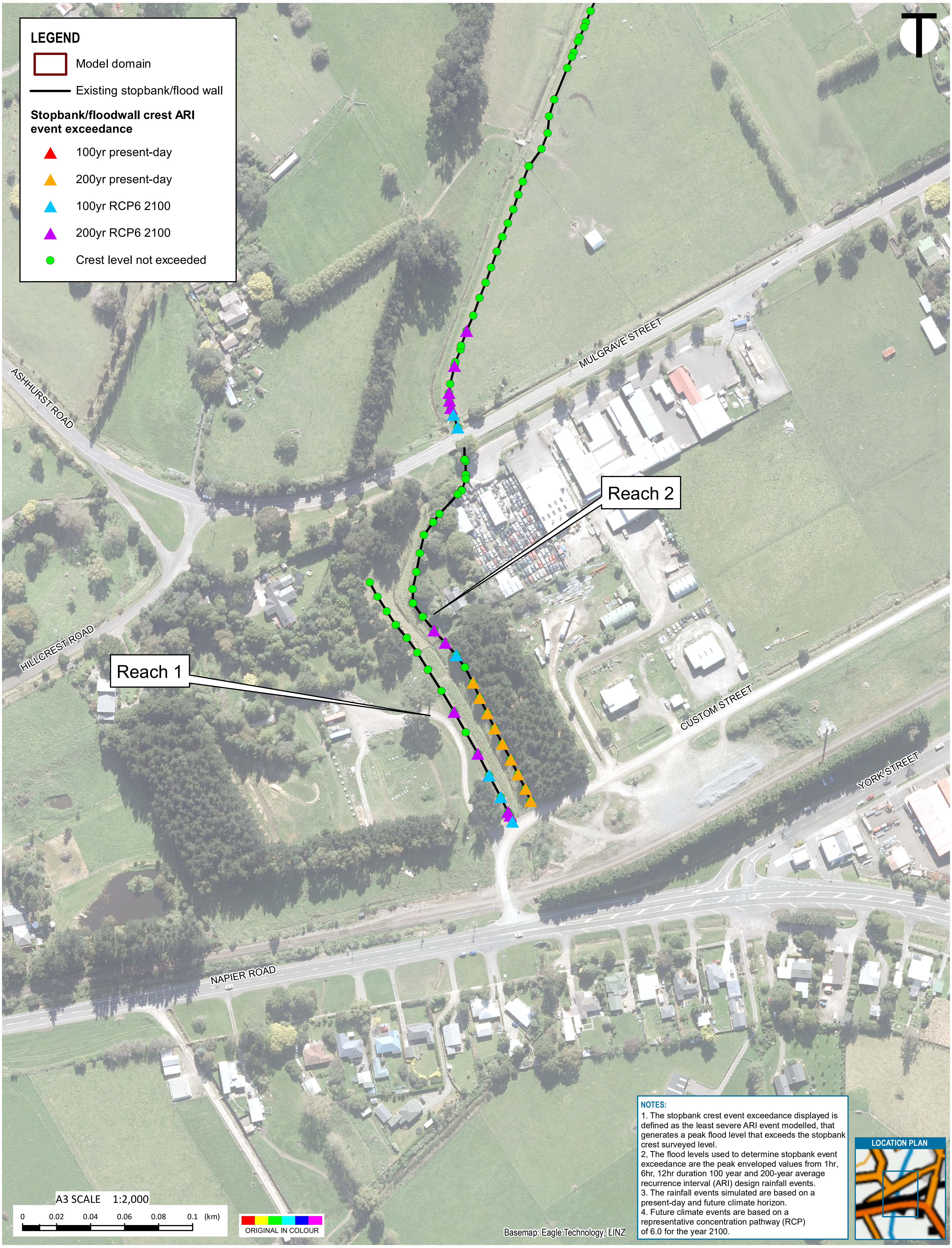
PROJECT: ASHHURST DRAINAGE SCHEME FLOOD MODELLING

TITLE: PEAK FLOOD DEPTH: SCENARIO 3
200 YEAR ARI RCP6 2100 DESIGN EVENT

SCALE (A3): 1:12,500 FIG No. FIGURE C12. REV 0

Appendix D: Scheme performance maps

- **D1.1: Base Case: Existing stopbank crest level exceedance**
- **D1.2: Base Case: Existing stopbank crest level exceedance**
- **D1.3: Base Case: Existing stopbank crest level exceedance**
- **D2.1: Scenario 2: Stopbank “glass wall” event exceedance**
- **D2.2: Scenario 2: Stopbank “glass wall” event exceedance**
- **D2.3: Scenario 2: Stopbank “glass wall” event exceedance**
- **D3.1: Scenario 3: Stopbank “glass wall” and culvert upsize event exceedance**
- **D3.2: Scenario 3: Stopbank “glass wall” and culvert upsize event exceedance**
- **D3.3: Scenario 3: Stopbank “glass wall” and culvert upsize event exceedance**



NOTES:
1. The stopbank crest event exceedance displayed is defined as the least severe ARI event modelled, that generates a peak flood level that exceeds the stopbank crest surveyed level.
2. The flood levels used to determine stopbank event exceedance are the peak enveloped values from 1hr, 6hr, 12hr duration 100 year and 200-year average recurrence interval (ARI) design rainfall events.
3. The rainfall events simulated are based on a present-day and future climate horizon.
4. Future climate events are based on a representative concentration pathway (RCP) of 6.0 for the year 2100.

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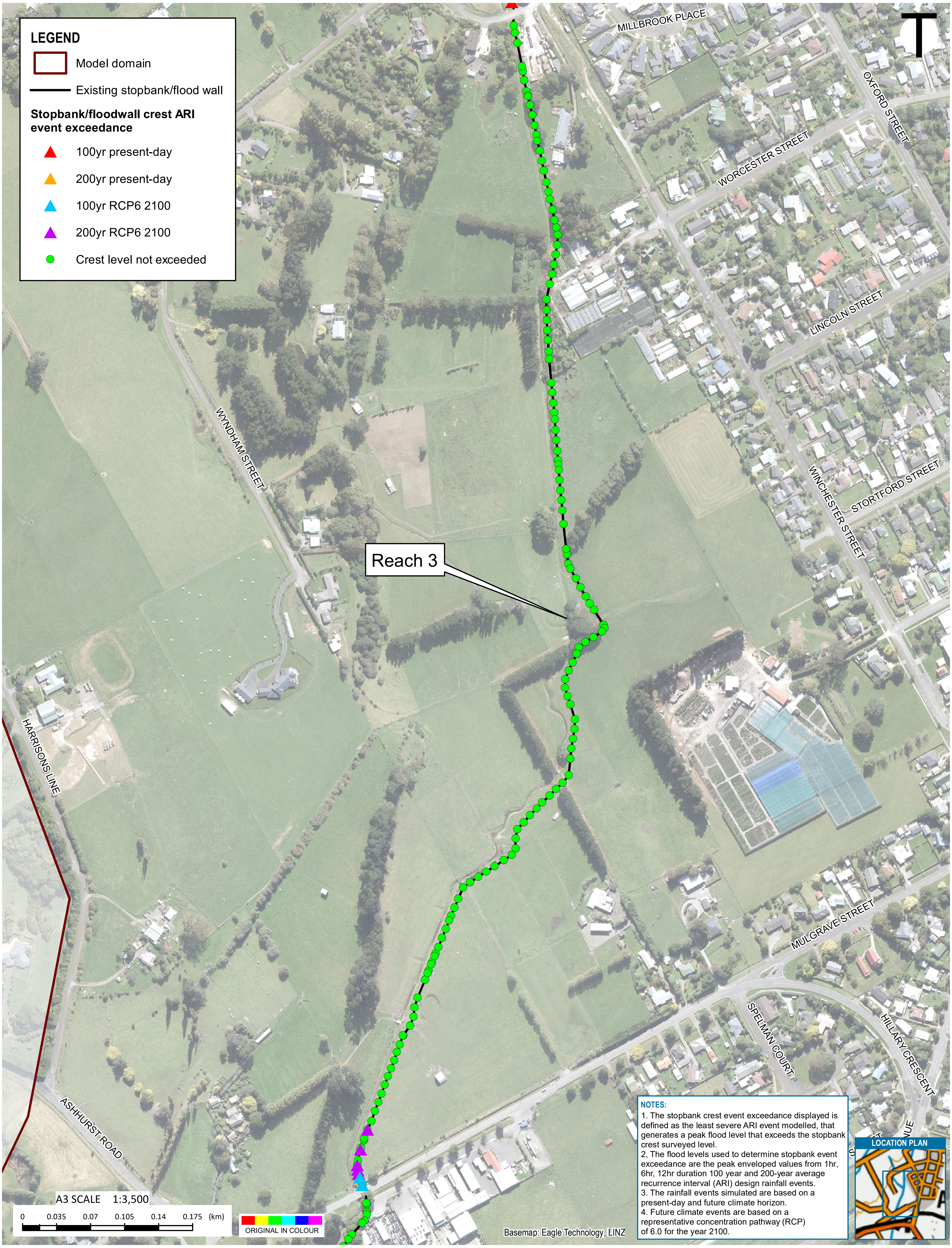
REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	01/06/21

PROJECT No.	851994.51	
DESIGNED	MICF	JUN.21
DRAWN	MICF	JUN.21
CHECKED	MSP	JUN.21
APPROVED	PRC	JUN.21

CLIENT: HORIZONS REGIONAL COUNCIL
PROJECT: ASHHURST DRAINAGE SCHEME FLOOD MODELLING
TITLE: SCENARIO 1: EXISTING STOPBANK CREST EVENT EXCEEDANCE PRESENT-DAY AND FUTURE CLIMATE DESIGN EVENTS
SCALE (A3): 1:2,000 FIG No. FIGURE D1.1. REV 0



NOTES:
1. The stopbank crest event exceedance displayed is defined as the least severe ARI event modelled, that generates a peak flood level that exceeds the stopbank crest surveyed level.
2. The flood levels used to determine stopbank event exceedance are the peak enveloped values from 1hr, 6hr, 12hr duration 100 year and 200-year average recurrence interval (ARI) design rainfall events.
3. The rainfall events simulated are based on a present-day and future climate horizon.
4. Future climate events are based on a representative concentration pathway (RCP) of 6.0 for the year 2100.

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REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	01/06/21	PRC	JUN.21

PROJECT No. 851994.51

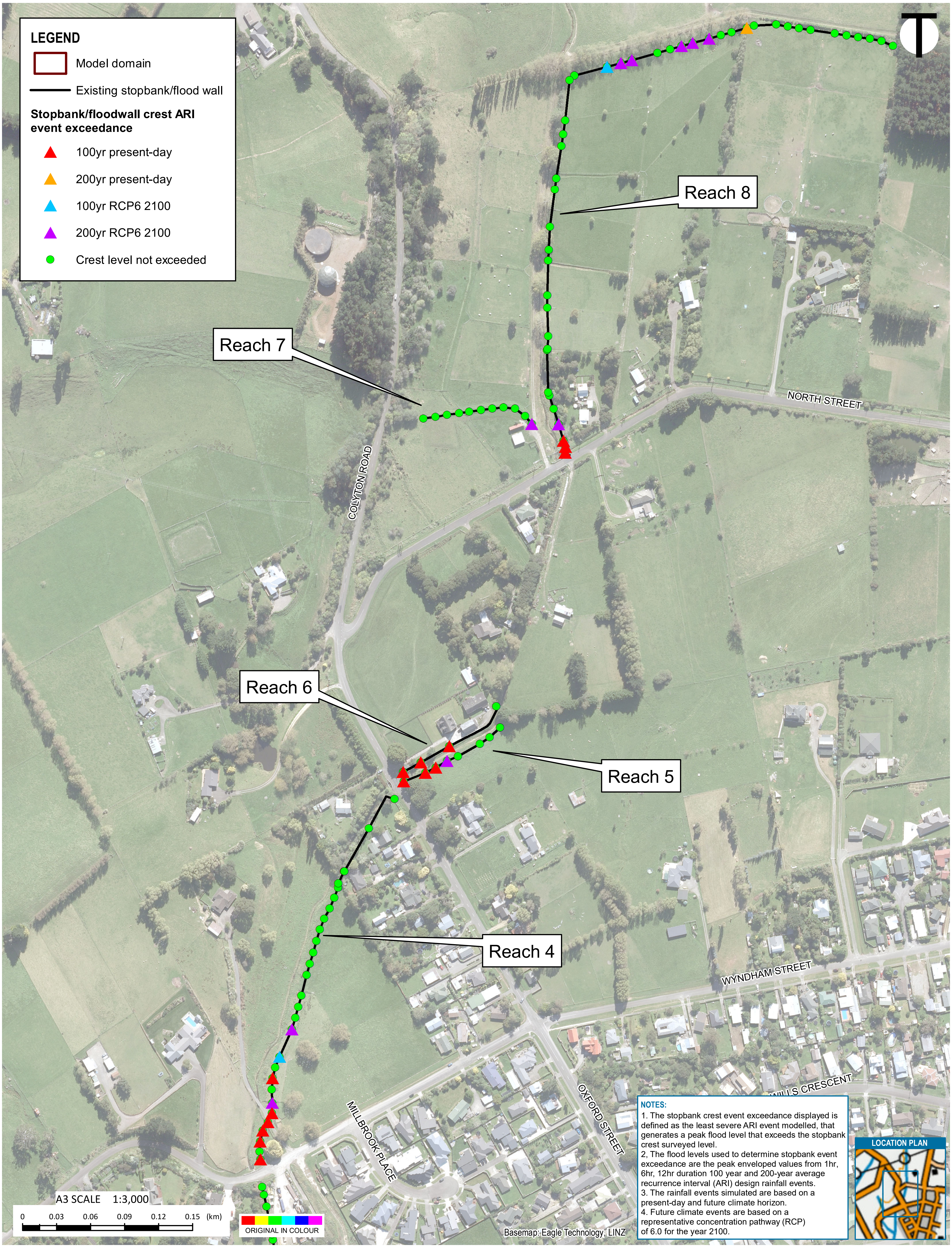
DESIGNED	MICF	JUN.21
DRAWN	MICF	JUN.21
CHECKED	MSP	JUN.21

CLIENT HORIZONS REGIONAL COUNCIL

PROJECT ASHHURST DRAINAGE SCHEME FLOOD MODELLING

TITLE SCENARIO 1: EXISTING STOPBANK CREST EVENT EXCEEDANCE PRESENT-DAY AND FUTURE CLIMATE DESIGN EVENTS

SCALE (A3) 1:3,500 FIG No. FIGURE D1.2. REV 0



NOTES:

1. The stopbank crest event exceedance displayed is defined as the least severe ARI event modelled, that generates a peak flood level that exceeds the stopbank crest surveyed level.
2, The flood levels used to determine stopbank event exceedance are the peak enveloped values from 1hr, 6hr, 12hr duration 100 year and 200-year average recurrence interval (ARI) design rainfall events.
3. The rainfall events simulated are based on a present-day and future climate horizon.
4. Future climate events are based on a representative concentration pathway (RCP) of 6.0 for the year 2100.

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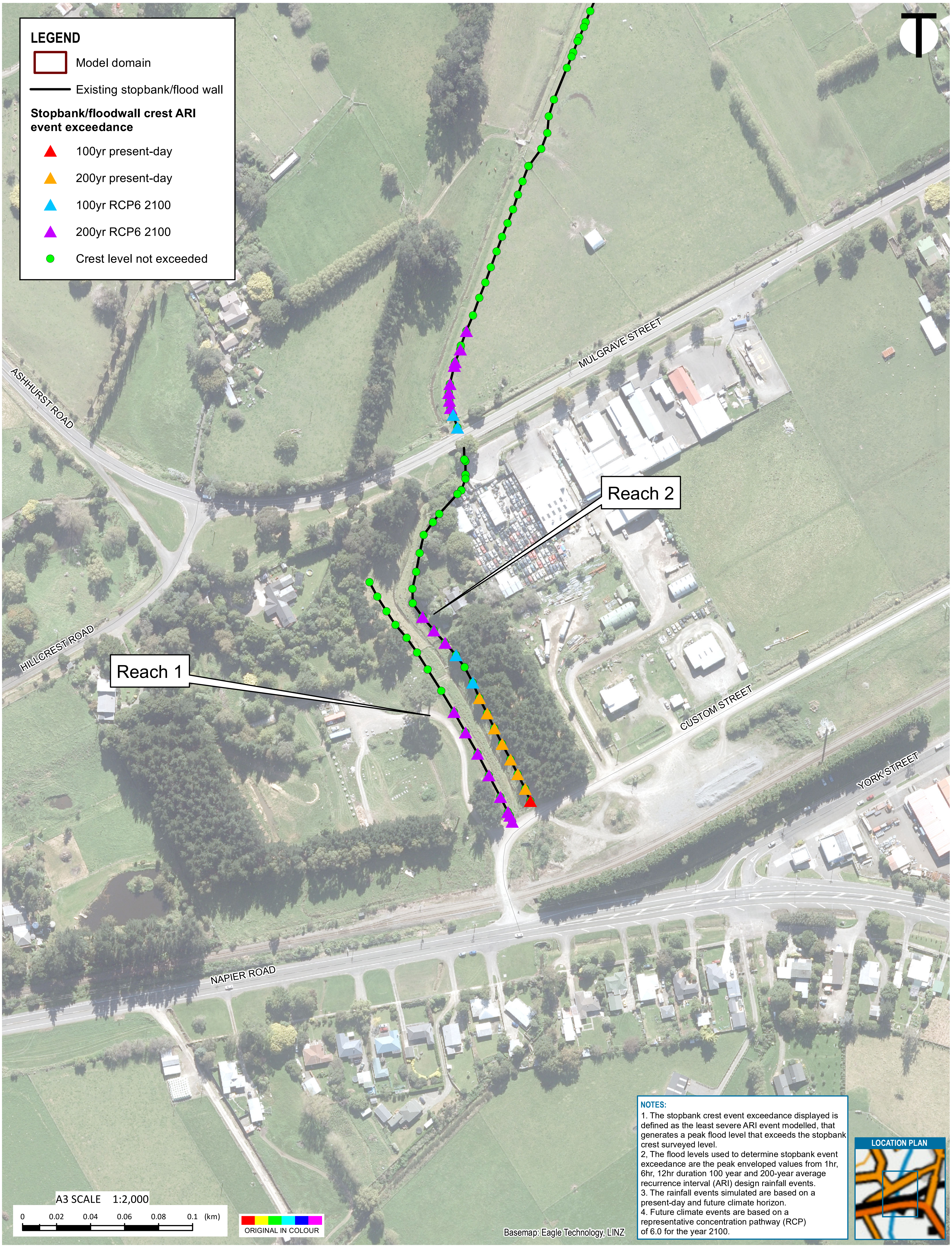
REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	01/06/21	PRC	JUN.21

PROJECT No.	851994.51	
DESIGNED	MICF	JUN.21
DRAWN	MICF	JUN.21
CHECKED	MSP	JUN.21

CLIENT **HORIZONS REGIONAL COUNCIL**
PROJECT **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE SCENARIO 1: EXISTING STOPBANK CREST EVENT EXCEEDANCE PRESENT-DAY AND FUTURE CLIMATE DESIGN EVENTS

SCALE (A3) 1:3,000 FIG No. FIGURE D1.3. REV 0



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REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	06/12/21

PROJECT No.	851994.51	
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21
APPROVED	PRC	DEC.21

CLIENT: **HORIZONS REGIONAL COUNCIL**
PROJECT: **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE: SCENARIO 2: STOPBANK "GLASS-WALL" EVENT EXCEEDANCE PRESENT-DAY AND FUTURE CLIMATE DESIGN EVENTS

SCALE (A3) 1:2,000 FIG No. FIGURE D2.1. REV 0

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NOTES:

To be read in conjunction with the Ashhurst Drainage Scheme Flood Hazard Assessment Report. The information presented on these figures is based on a numerical representation of the physical reality and is reliant upon input data and therefore bears uncertainty.

REV	DESCRIPTION	GIS	CHK	DATE
0	Final	MICF	MSP	06/12/21

PROJECT No.	851994.51	
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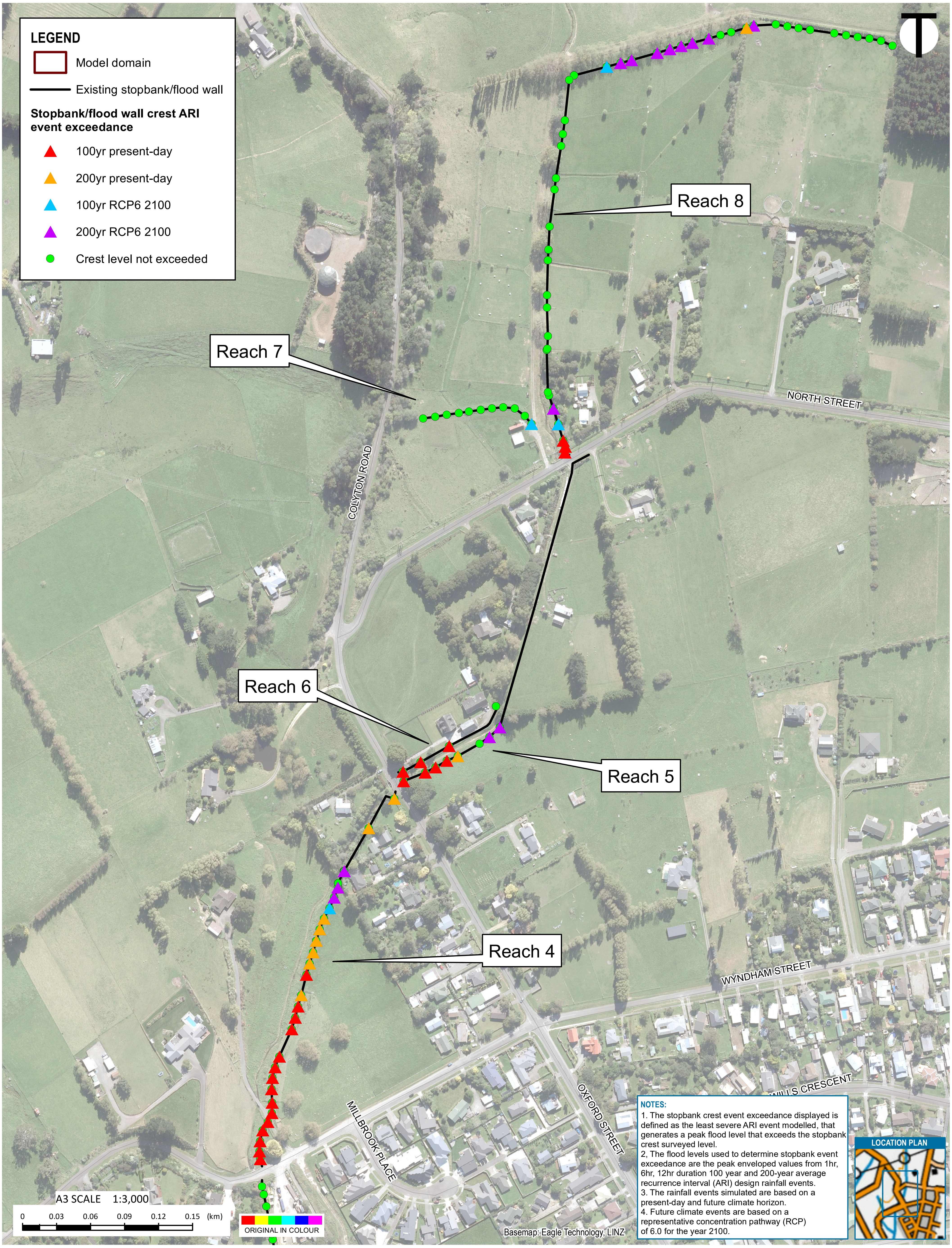
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21
APPROVED	PRC	DEC.21

CLIENT: HORIZONS REGIONAL COUNCIL

PROJECT: ASHHURST DRAINAGE SCHEME FLOOD MODELLING

TITLE: SCENARIO 2: STOPBANK "GLASS-WALL" EVENT EXCEEDANCE PRESENT-DAY AND FUTURE CLIMATE DESIGN EVENTS

SCALE (A3) 1:3,500 FIG No. FIGURE D2.2. REV 0



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PROJECT No.	851994.51	
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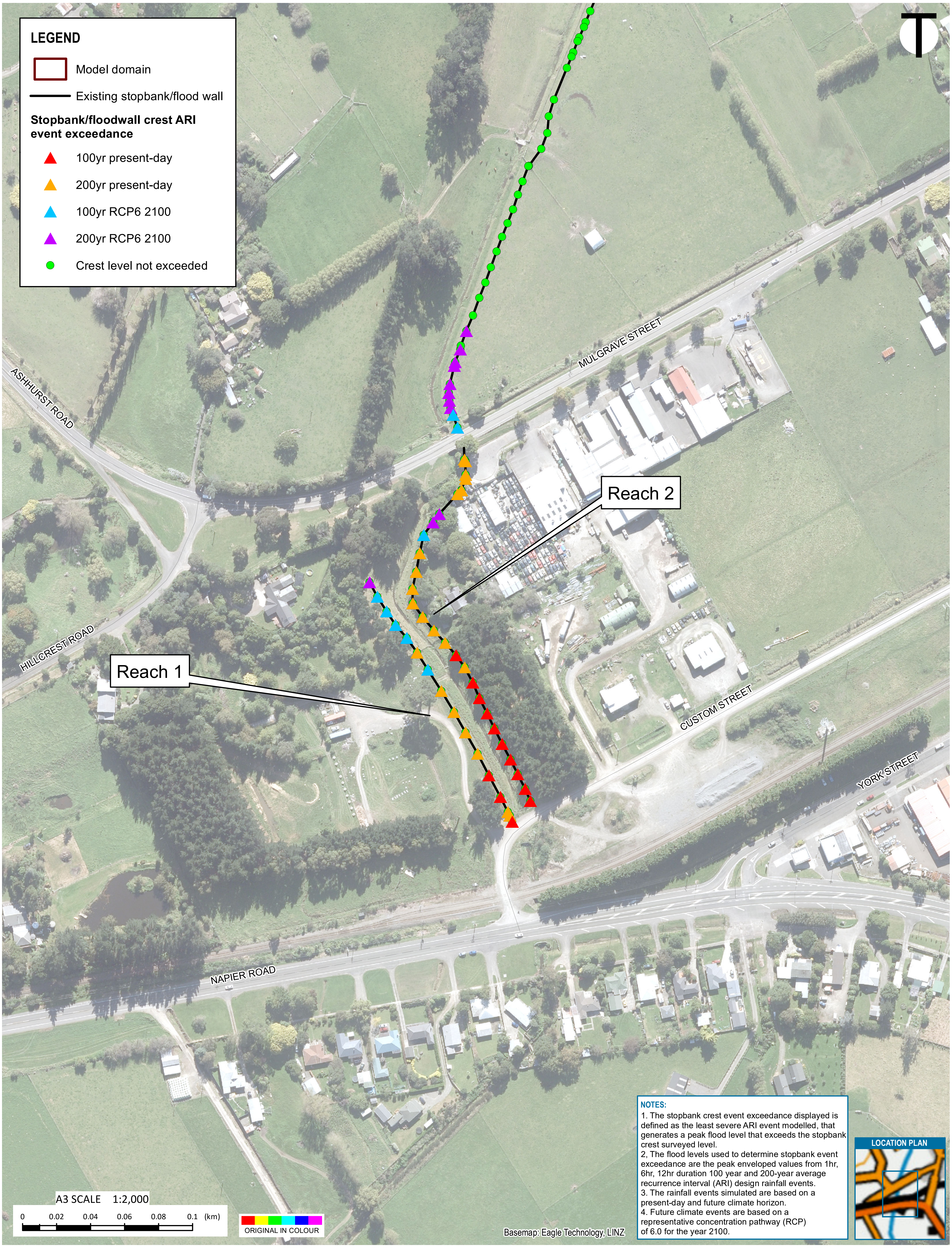
APPROVED	PRC	DEC.21

CLIENT HORIZONS REGIONAL COUNCIL
PROJECT ASHHURST DRAINAGE SCHEME FLOOD MODELLING
TITLE SCENARIO 2: STOPBANK "GLASS-WALL" EVENT EXCEEDANCE PRESENT-DAY AND FUTURE CLIMATE DESIGN EVENTS
SCALE (A3) 1:3,000 FIG No. FIGURE D2.3. REV 0



NOTES:

1. The stopbank crest event exceedance displayed is defined as the least severe ARI event modelled, that generates a peak flood level that exceeds the stopbank crest surveyed level.
2, The flood levels used to determine stopbank event exceedance are the peak enveloped values from 1hr, 6hr, 12hr duration 100 year and 200-year average recurrence interval (ARI) design rainfall events.
3. The rainfall events simulated are based on a present-day and future climate horizon.
4. Future climate events are based on a representative concentration pathway (RCP) of 6.0 for the year 2100.

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0	Final	MICF	MSP	06/12/21	PRC	DEC.21

PROJECT No. 851994.51

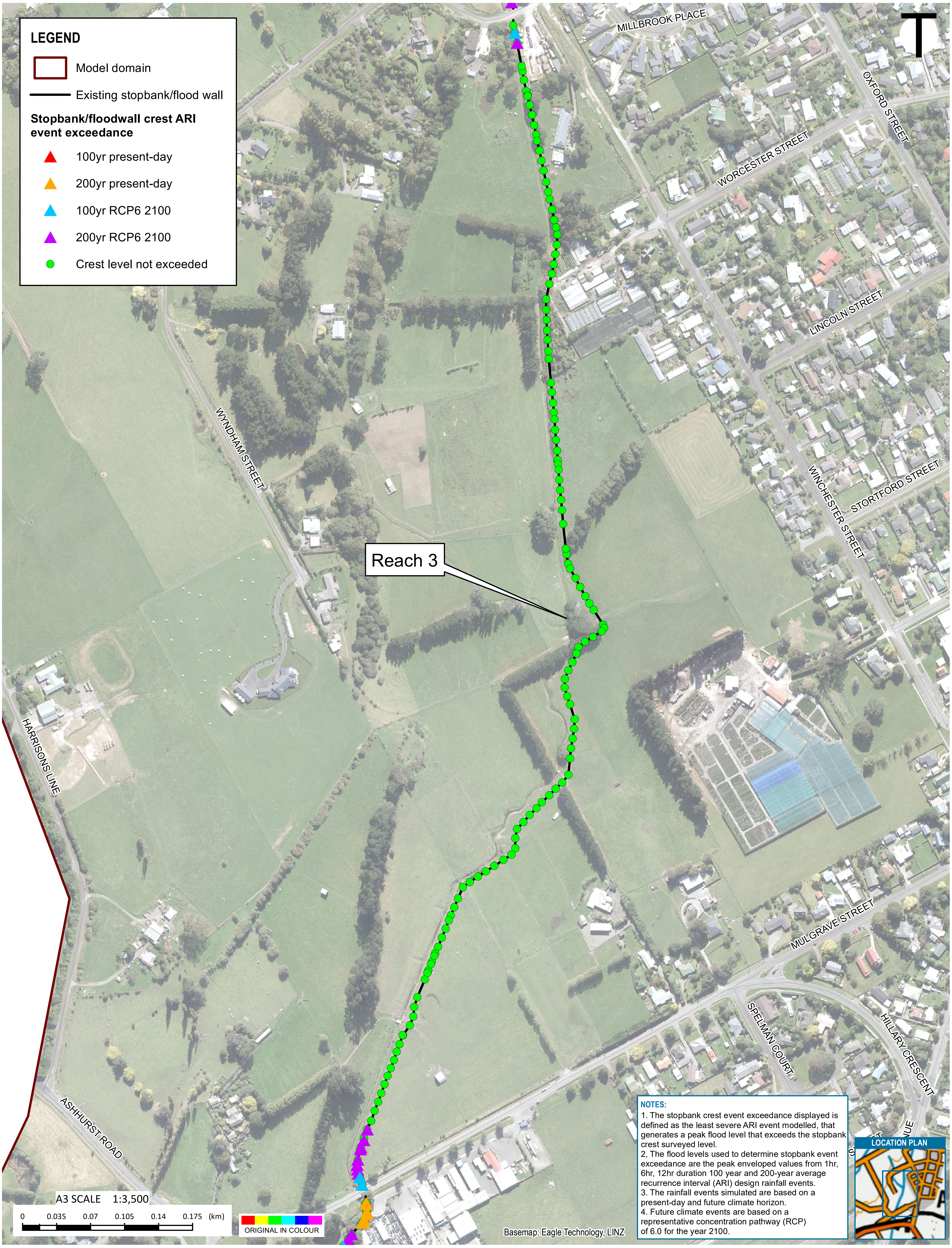
DESIGNED	MICF	DEC.21
DRAWN	MICF	DEC.21
CHECKED	MSP	DEC.21

CLIENT HORIZONS REGIONAL COUNCIL

PROJECT ASHHURST DRAINAGE SCHEME FLOOD MODELLING

TITLE SCENARIO 3: STOPBANK "GLASS WALL" AND CULVERT UPSIZE EVENT EXCEEDANCE: PRESENT-DAY AND FUTURE CLIMATE DESIGN EVENTS

SCALE (A3) 1:2,000 FIG No. FIGURE D3.1. REV 0



NOTES:
1. The stopbank crest event exceedance displayed is defined as the least severe ARI event modelled, that generates a peak flood level that exceeds the stopbank crest surveyed level.
2, The flood levels used to determine stopbank event exceedance are the peak enveloped values from 1hr, 6hr, 12hr duration 100 year and 200-year average recurrence interval (ARI) design rainfall events.
3. The rainfall events simulated are based on a present-day and future climate horizon.
4. Future climate events are based on a representative concentration pathway (RCP) of 6.0 for the year 2100.

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REV	DESCRIPTION	GIS	CHK	DATE	APPROVED	DATE
0	Final	MICF	MSP	06/12/21	PRC	DEC.21

PROJECT No. 851994.51
DESIGNED MICF DEC.21
DRAWN MICF DEC.21
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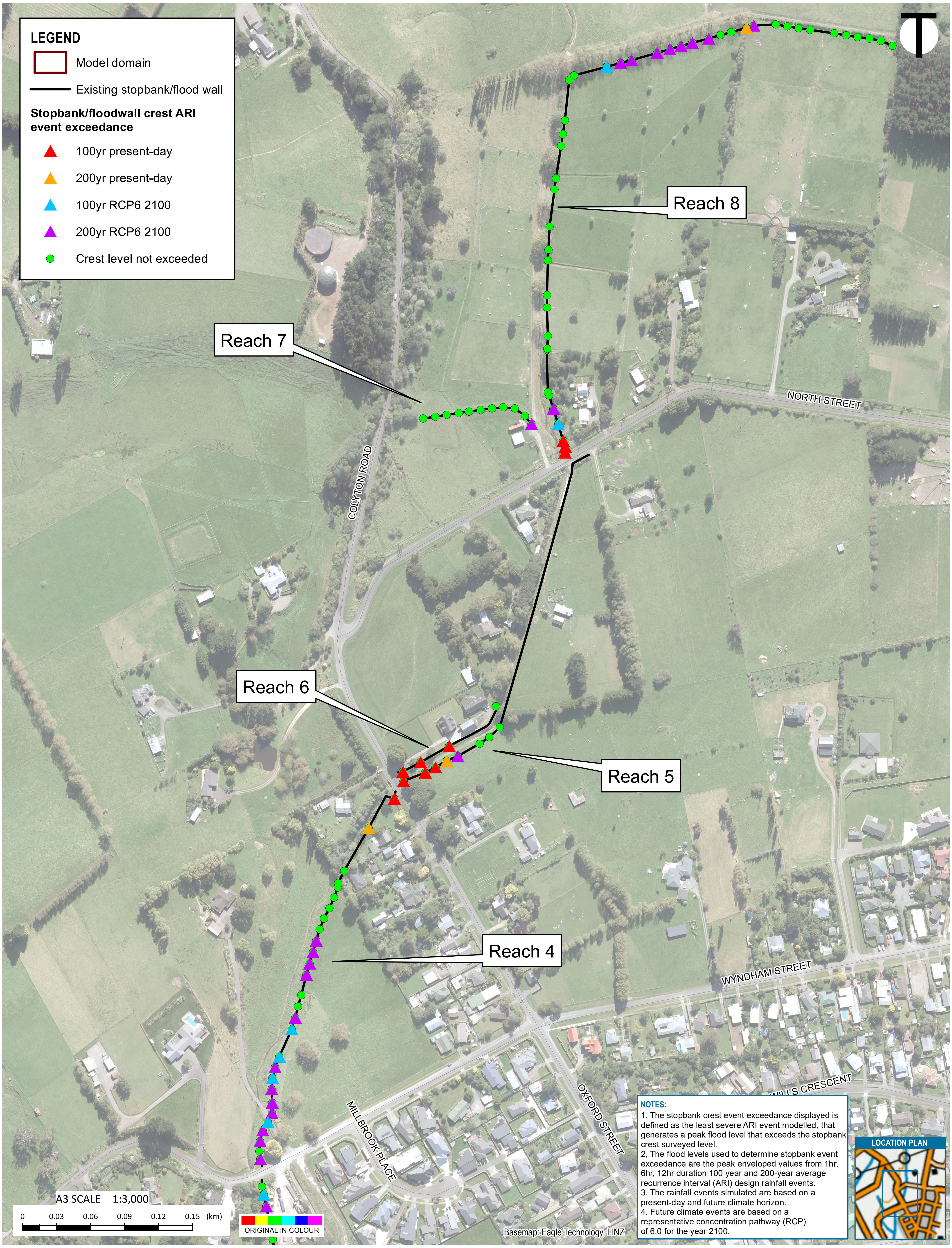
CLIENT HORIZONS REGIONAL COUNCIL
PROJECT ASHHURST DRAINAGE SCHEME FLOOD MODELLING
TITLE SCENARIO 3: STOPBANK “GLASS WALL” AND CULVERT UPSIZE EVENT EXCEEDANCE: PRESENT-DAY AND FUTURE CLIMATE DESIGN EVENTS

SCALE (A3) 1:3,500 FIG No. FIGURE D3.2. REV 0



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CLIENT **HORIZONS REGIONAL COUNCIL**
PROJECT **ASHHURST DRAINAGE SCHEME FLOOD MODELLING**
TITLE SCENARIO 3: STOPBANK "GLASS WALL" AND CULVERT UPSIZE EVENT EXCEEDANCE: PRESENT-DAY AND FUTURE CLIMATE DESIGN EVENTS

SCALE (A3) 1:3,000 FIG No. FIGURE D3.3. REV 0

Appendix E: Scheme performance long-sections

Reach 1

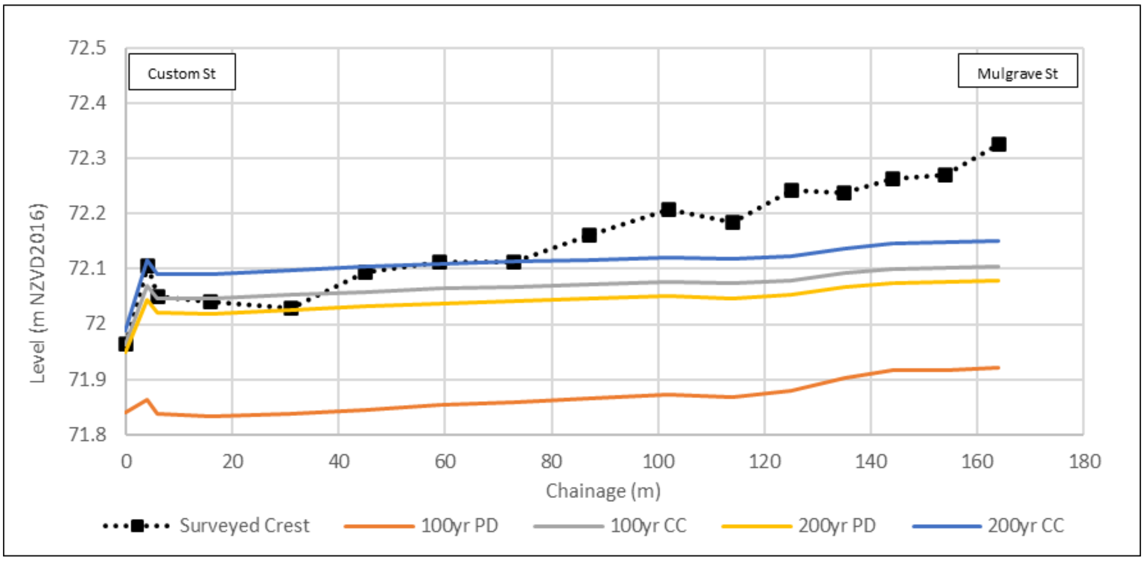

Figure 1: Scenario 1 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 1

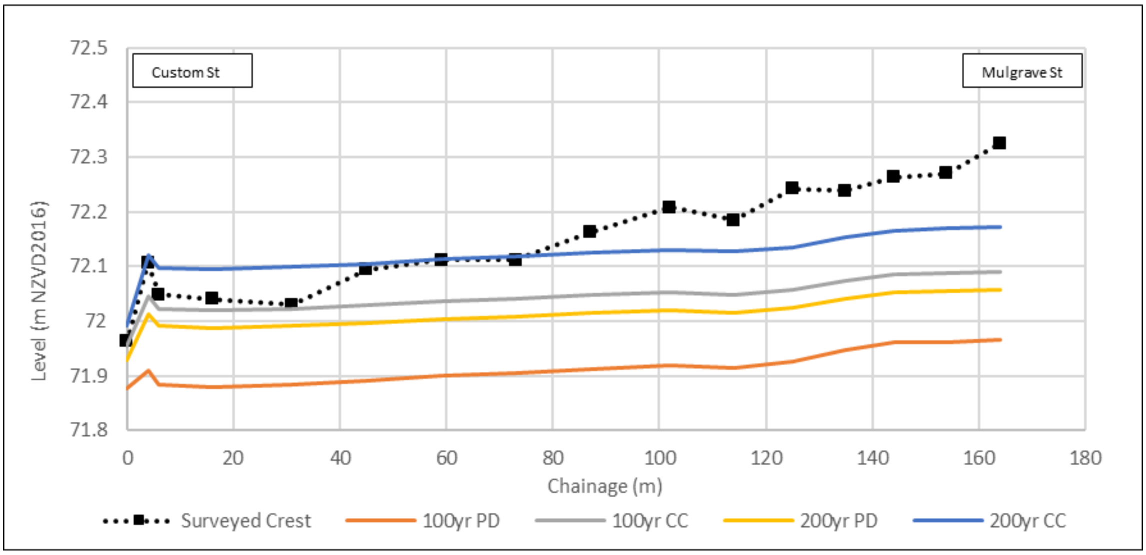

Figure 2: Scenario 2 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 1

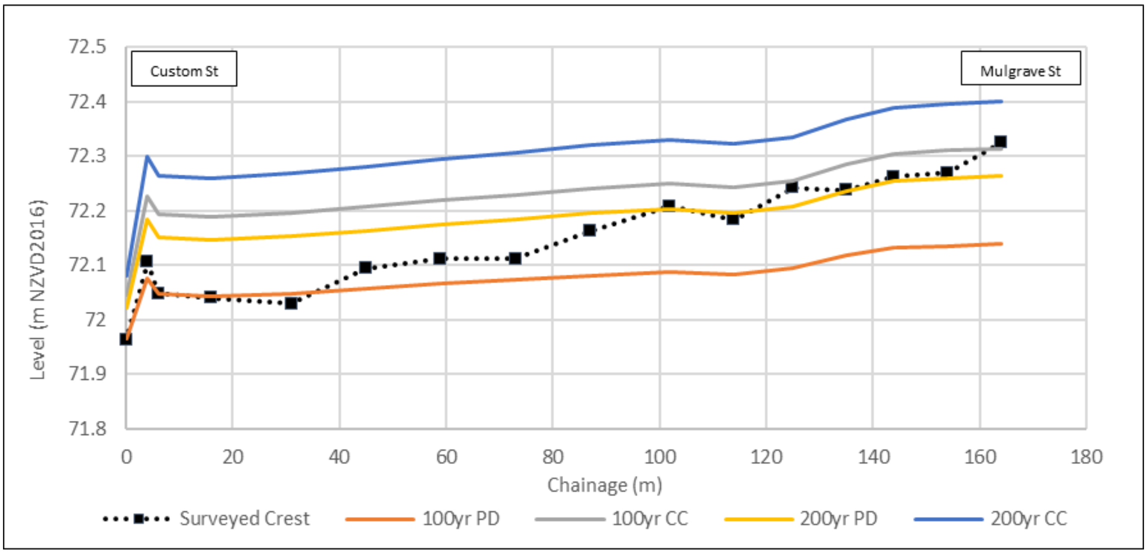

Figure 3: Scenario 3 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 1

Reach 2

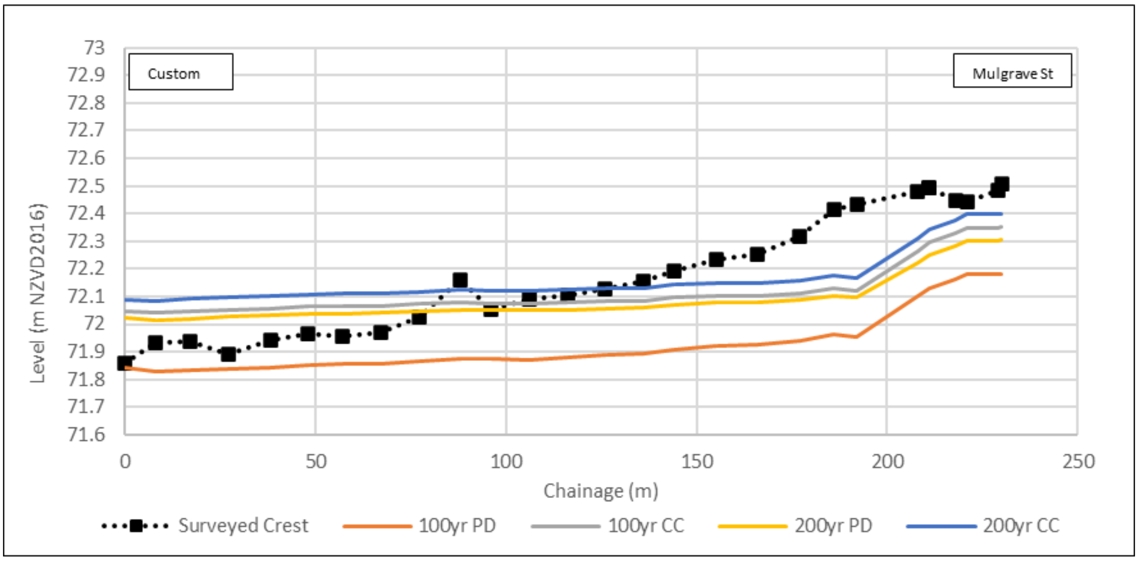

Figure 4: Scenario 1 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 2

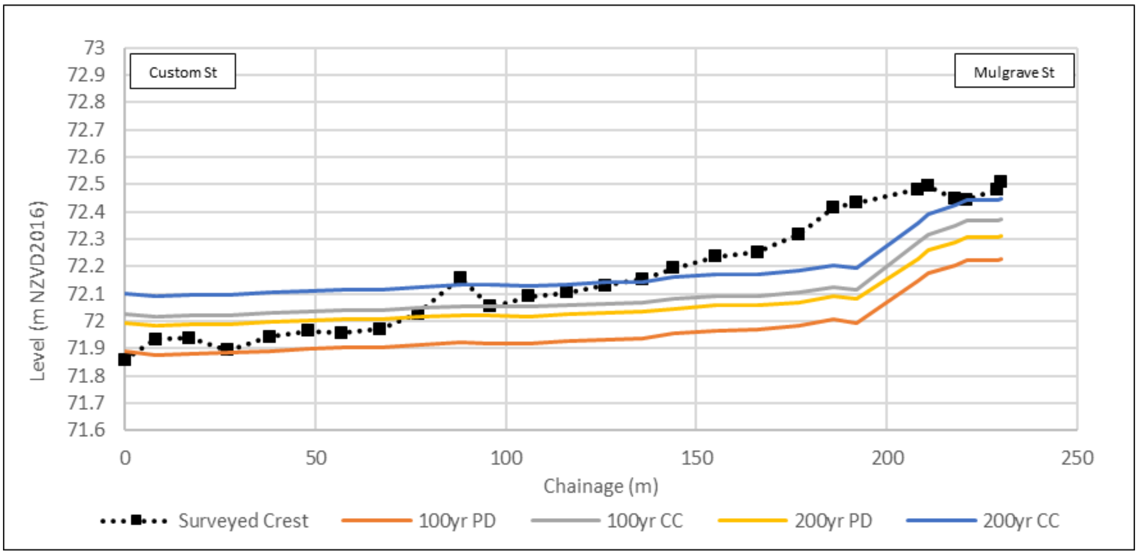

Figure 5: Scenario 2 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 2

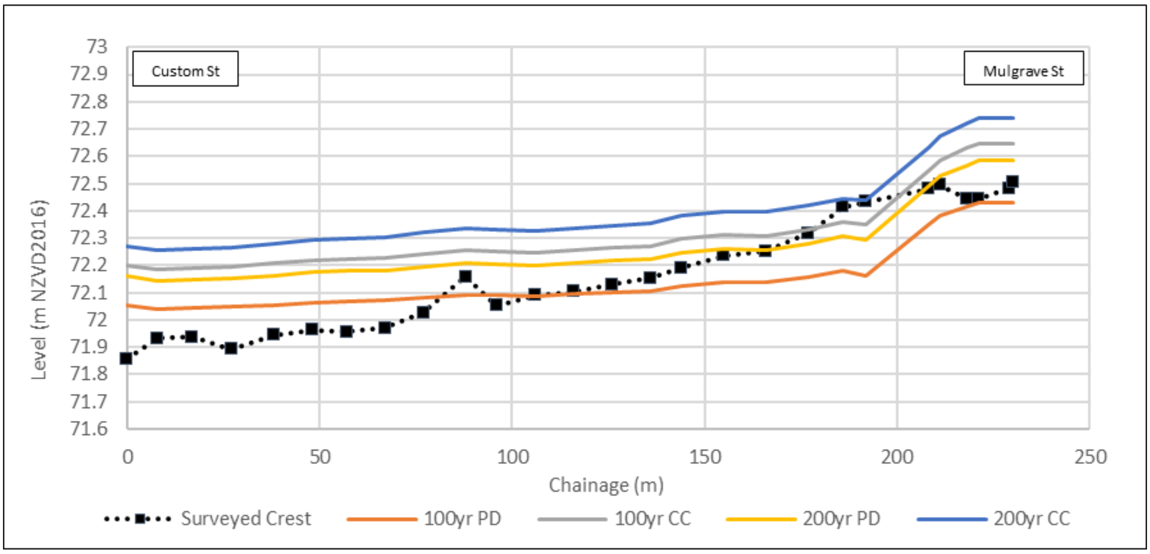

Figure 6: Scenario 3 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 2

Reach 3

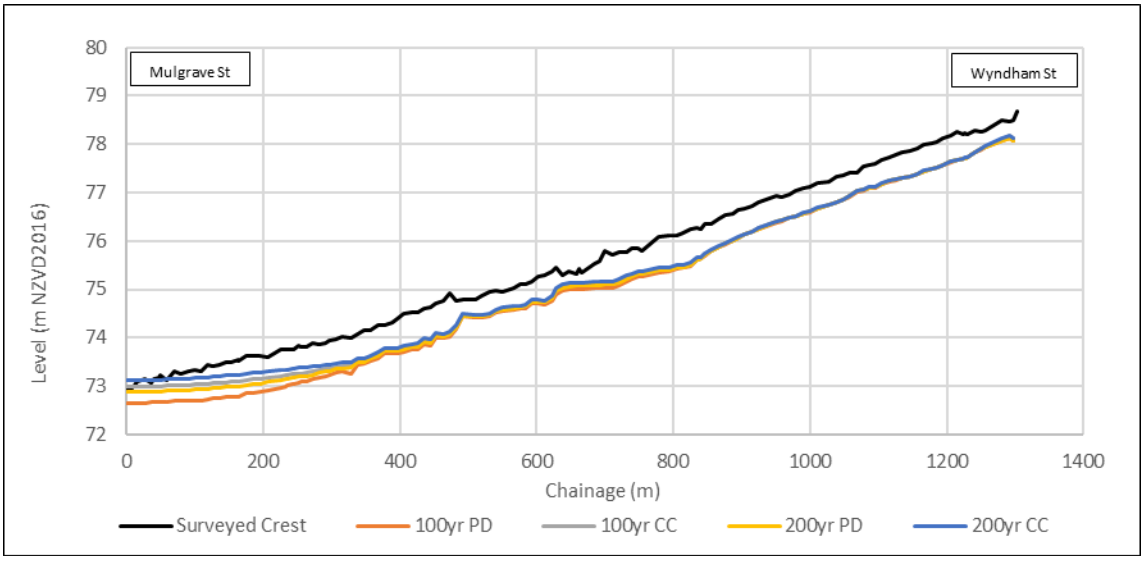

Figure 7: Scenario 1 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 3

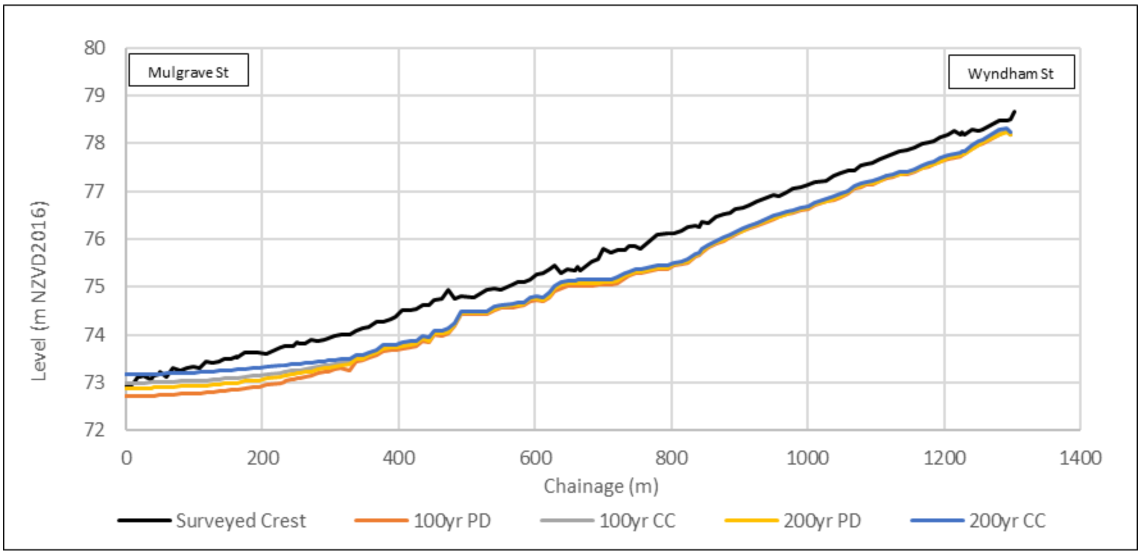

Figure 8: Scenario 2 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 3

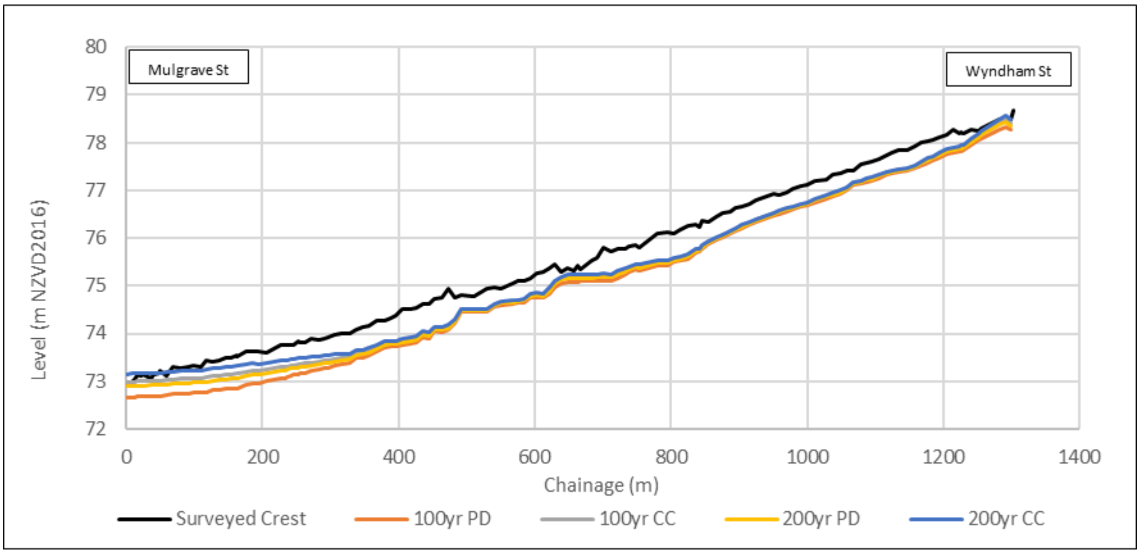

Figure 9: Scenario 3 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 3

Reach 4

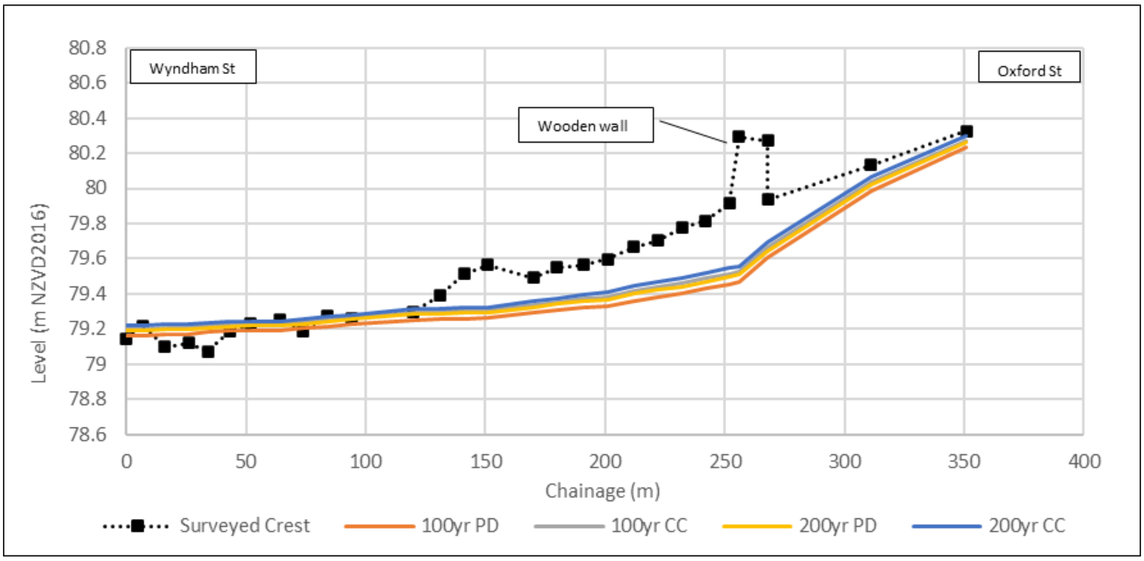

Figure 10: Scenario 1 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 4

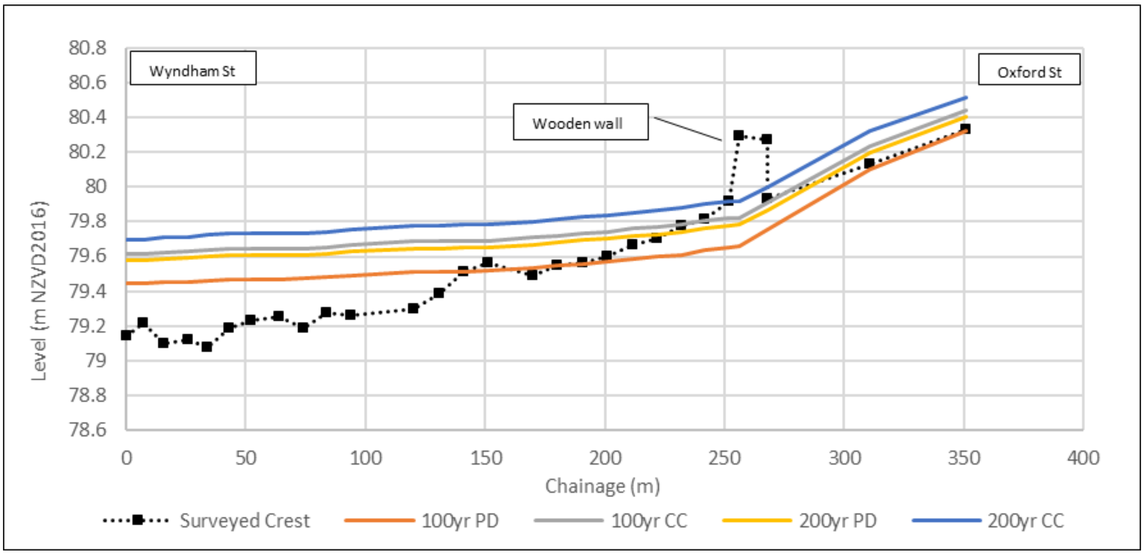

Figure 11: Scenario 2 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 4

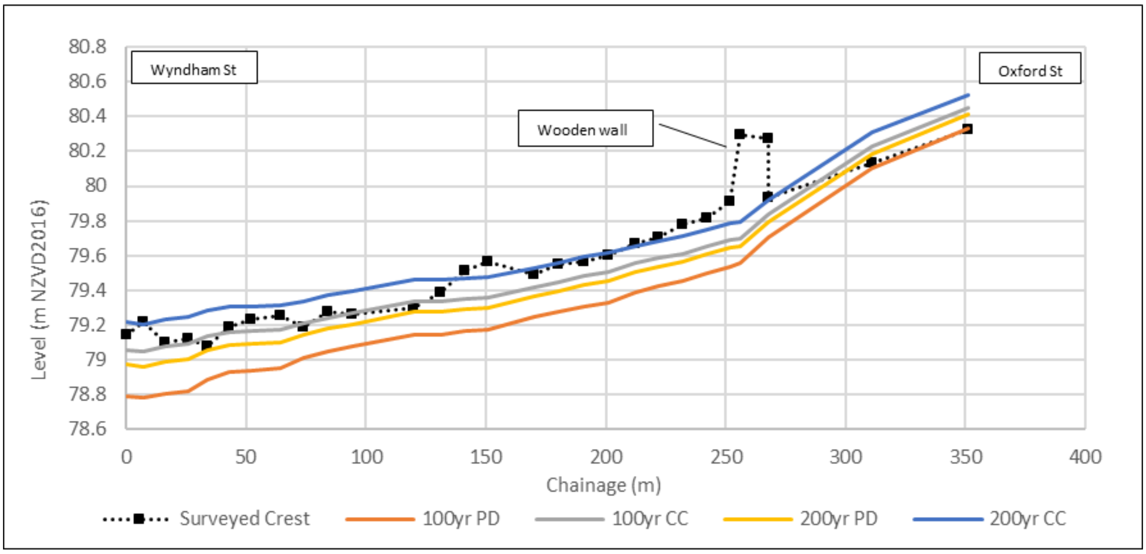

Figure 12: Scenario 3 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 4

Reach 5

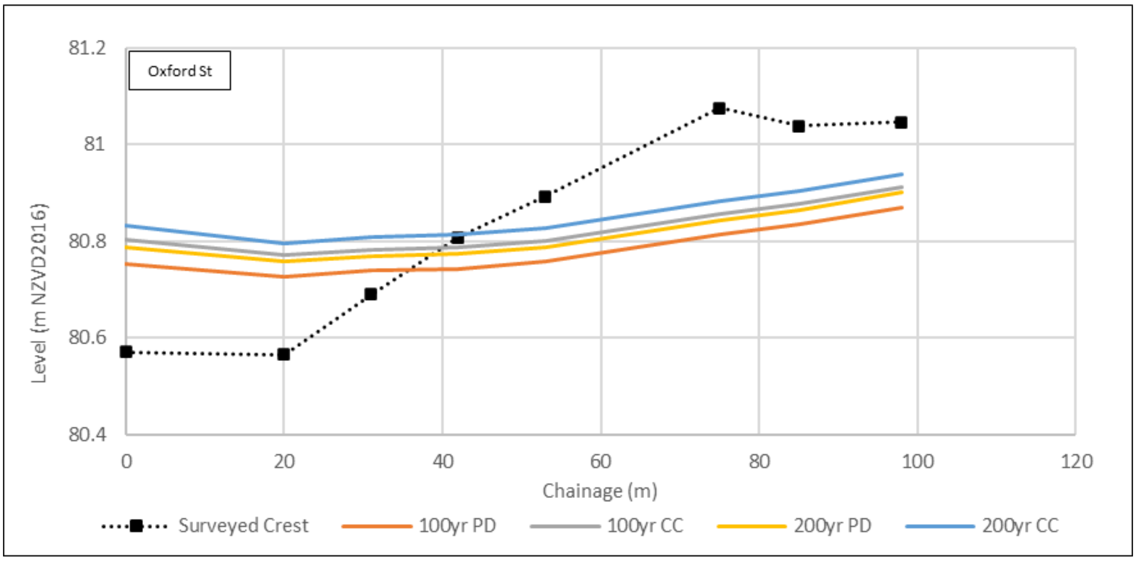

Figure 13: Scenario 1 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 5

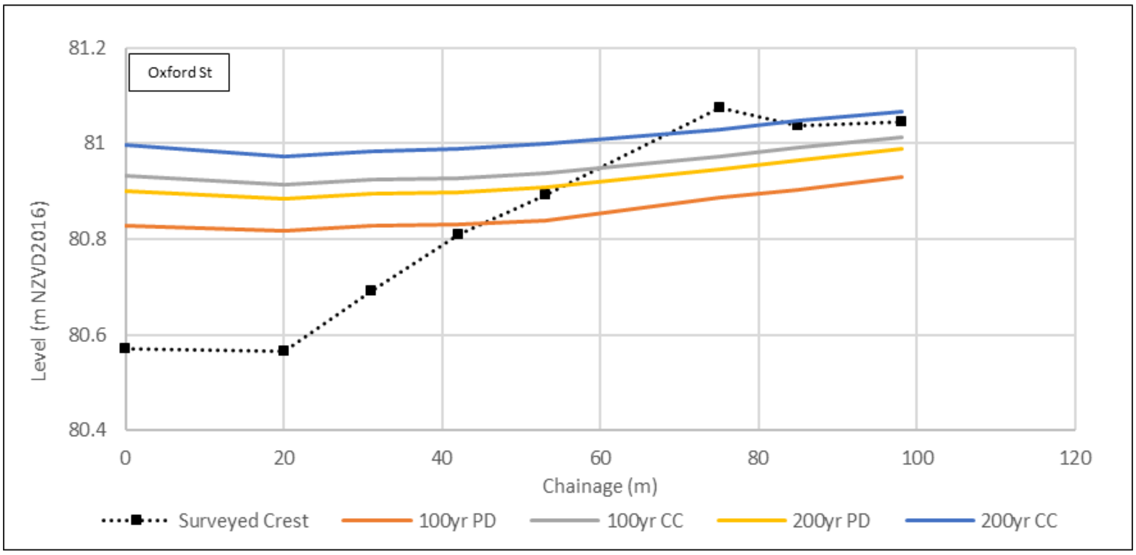

Figure 14: Scenario 2 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 5

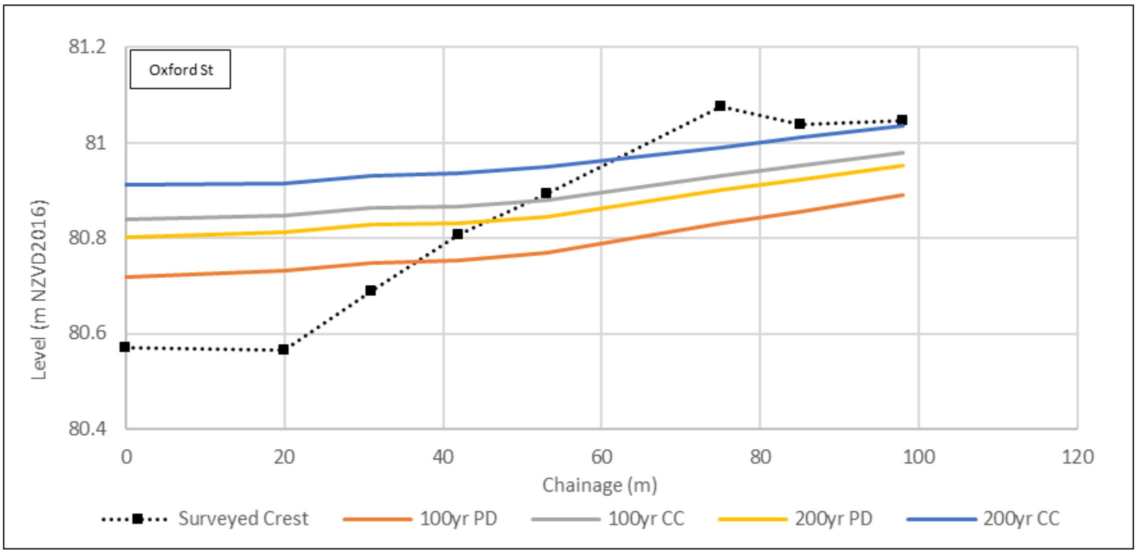

Figure 15: Scenario 3 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 5

Reach 6

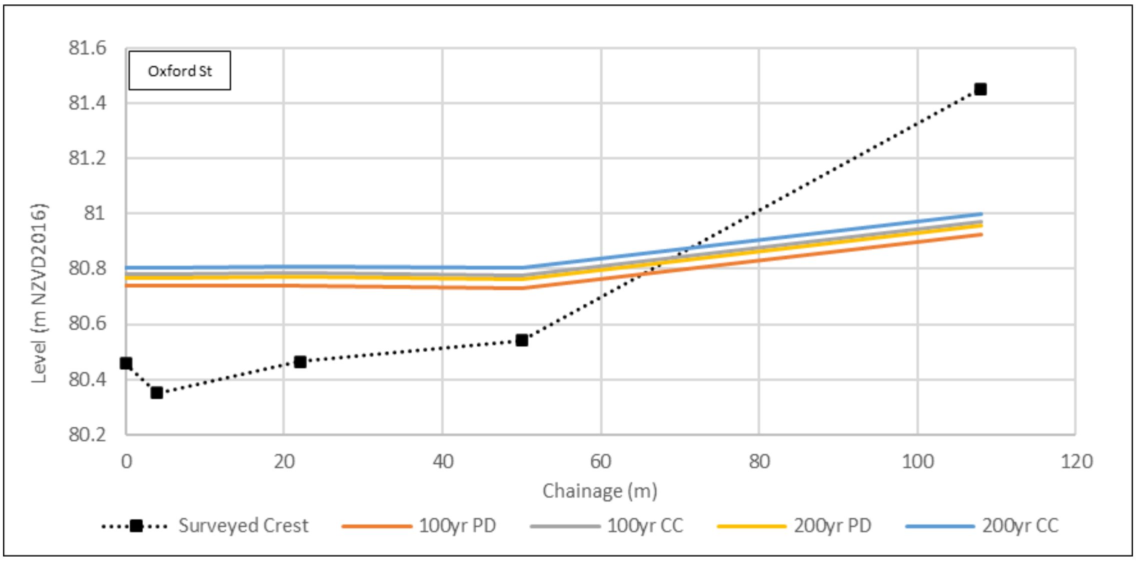

Figure 16: Scenario 1 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 6

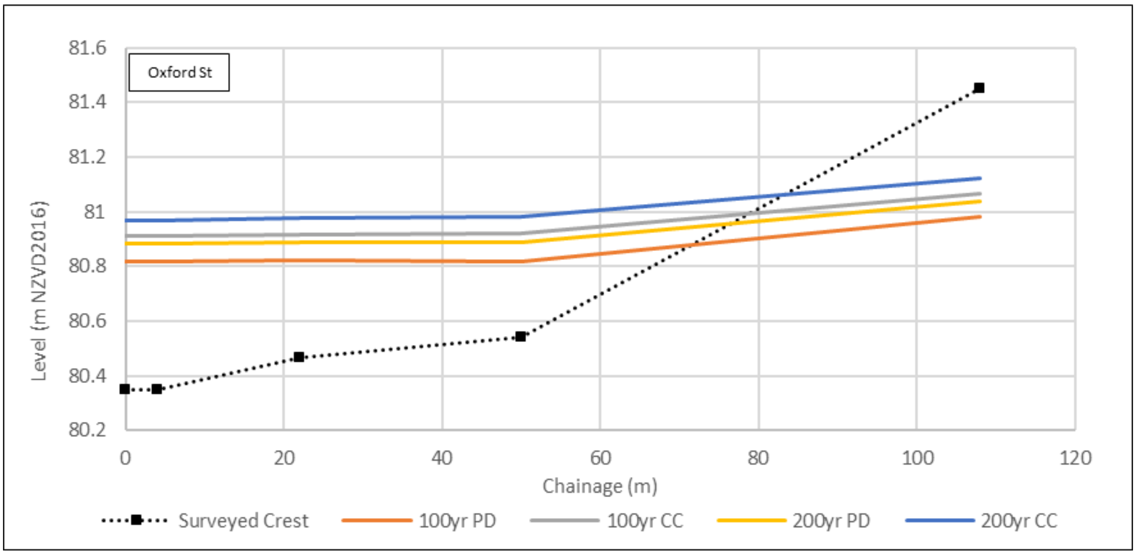

Figure 17: Scenario 2 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 6

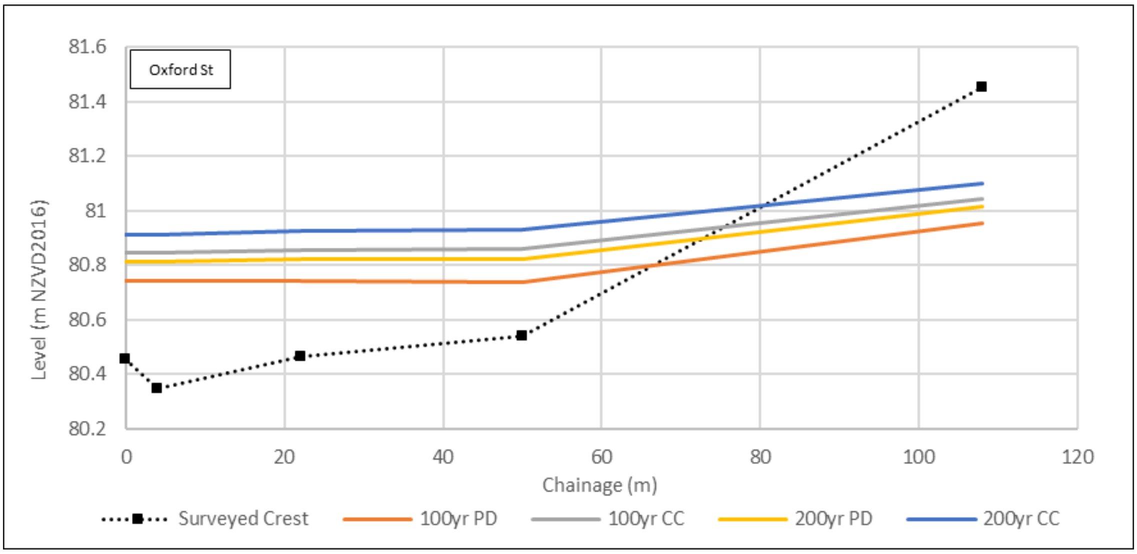

Figure 18: Scenario 3 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 6

Reach 7

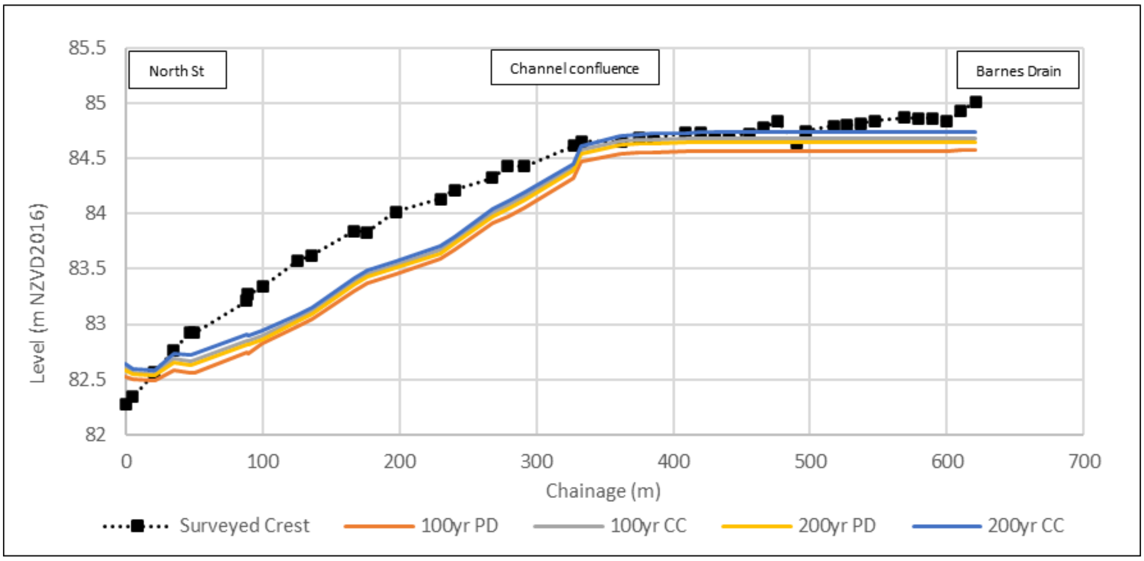

Figure 19: Scenario 1 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 7

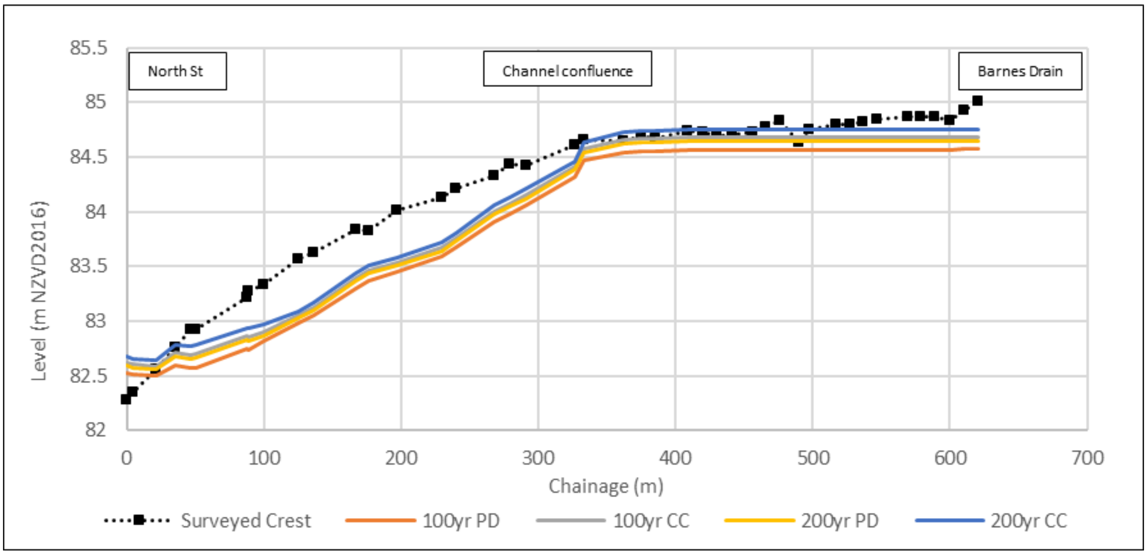

Figure 20: Scenario 2 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 7

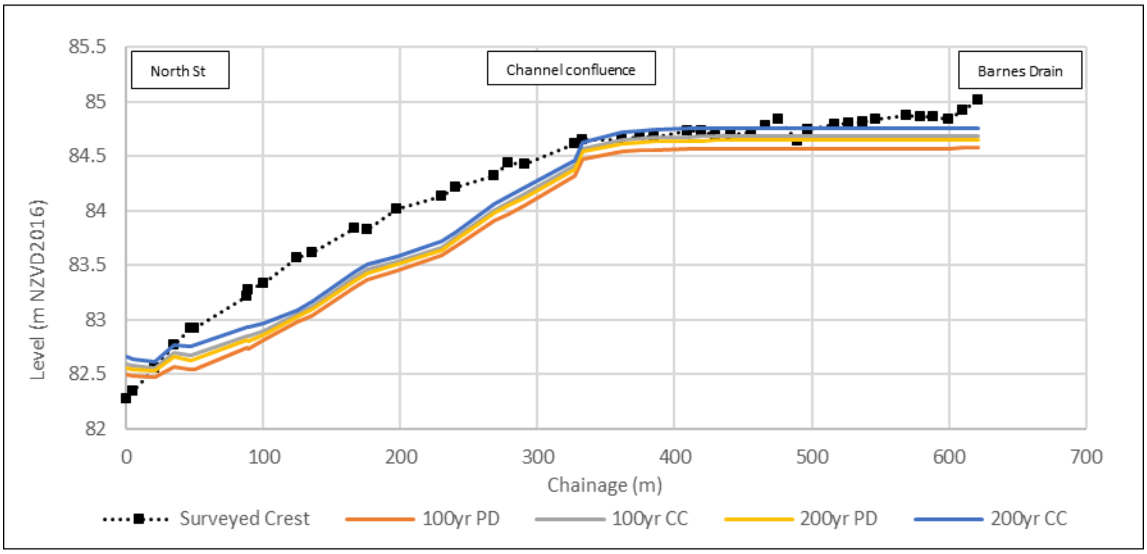

Figure 21: Scenario 3 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 7

Reach 8

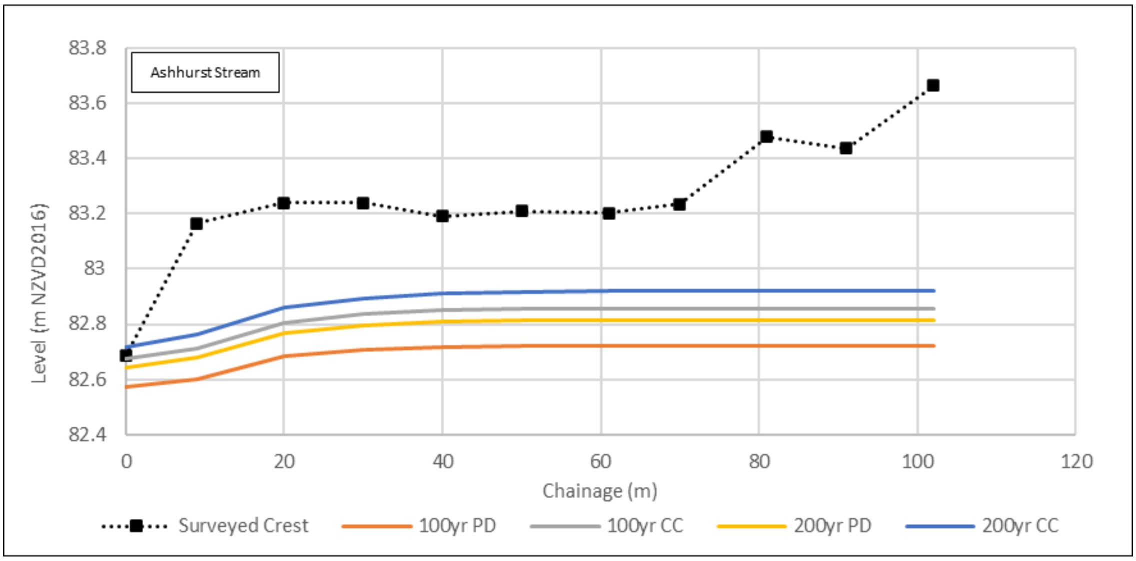

Figure 22: Scenario 1 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 8

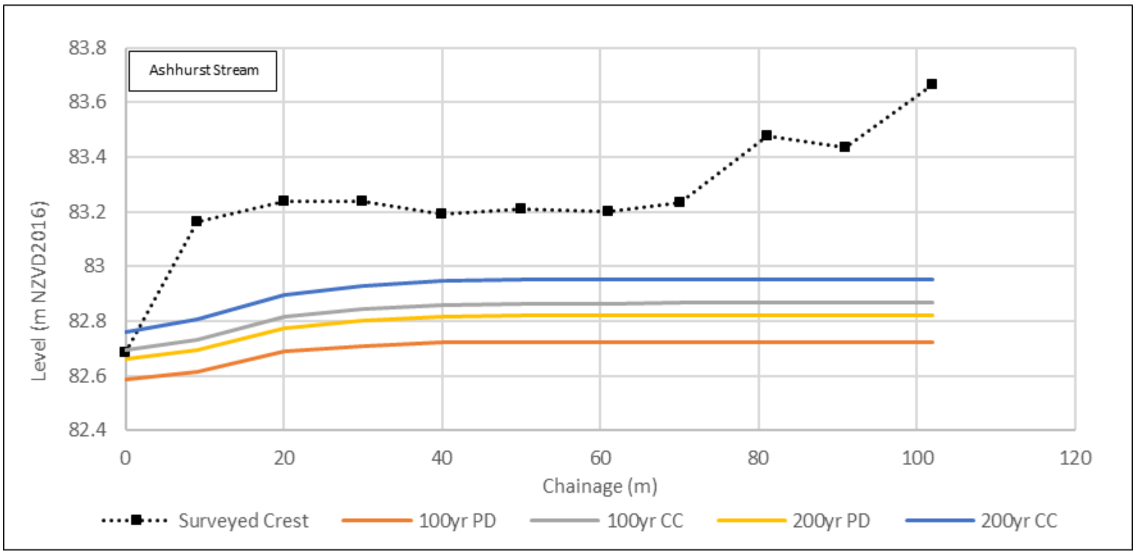

Figure 23: Scenario 2 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 8

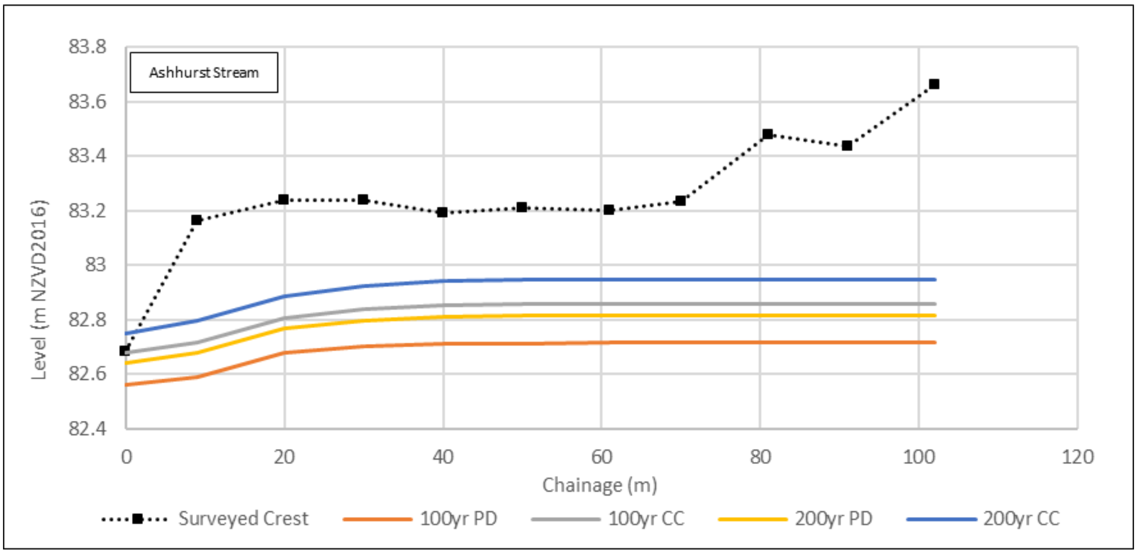

Figure 24: Scenario 3 modelled peak flood levels and 2021 surveyed stopbank crest levels at Reach 8