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Report

Owhiro Stream Flood Hazard Study

Prepared for Otago Regional Council

Prepared by Beca Limited

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Revision History

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1	**Carey Lintott**	Draft for client review	18 June 2018
2	Carey Lintott	Revised draft for client review (addressing hydrology updates and revised rainfall data)	8 March 2019
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Document Acceptance

Action	Name	Signed	Date
Prepared by	**Carey Lintott**		10 May 2019
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Approved by	**Michael Law**		10 May 2019
on behalf of	Beca Limited		

Executive Summary

This report outlines a flood hazard study undertaken by Beca Ltd for the Owhiro Stream catchment, including Mosgiel and the surrounding rural area near Dunedin, Otago. It aims to define flood hazard levels for the Owhiro Stream and determine how the rural floodplain area south of Mosgiel, including the Lower Taieri Flood Protection Scheme Lower Pond, is impacted in flood events.

Owhiro Stream drains a 32.1 km^2 catchment comprising of the Mosgiel township, the large flat rural area to the west, and several small hill catchments to the south of the stream. The stream is stopbanked downstream of Gladfield Road to provide protection for the 20-year ARI event, with the flat rural land beyond these stopbanks known as the Lower Pond intended to act as a storage area for larger flood events. Further stopbanks along Lower Pond, and large double culverts with flapgates in both the Lower Pond and Owhiro Stream, provide protection against flood flows from the Taieri River.

A HEC-HMS hydrological model, using the SCS Curve Number method, has been used to generate net rainfall and runoff data for all catchments. This data has been incorporated into an unsteady state 1D/2D coupled hydraulic model built in HEC-RAS which provides detailed output on flooding depths, extents and duration across the catchment. The hydraulic model has combined 2D rain on grid modelling on flat, floodplain areas, together with a 1D model of Owhiro Stream and Quarry Creek that includes detailed survey of the stream profile and key culverts and bridges. The hydrological and hydraulic models have been calibrated using data from the July 2017 flood event which occurred during the model build.

Existing development and future development land use scenarios (based on the Dunedin City Council Second Generation District Plan) have been compared for 10, 50 and 100 year Average Recurrence Interval storm events. The effects of climate change have also been assessed (in the 50 and 100 year event). All models are based on a five day closure of the Owhiro Stream and Lower Pond floodgates, with an additional sensitivity check (for the 100 year future development event) with no gate closure occurring. Maximum flood depth maps have been produced for all model runs, and this data is provided in GIS format with this report.

According to the modelling, overall the effects of the land use changes proposed in the District Plan, on duration, extent, and height of flooding in the Owhiro Stream and Lower Pond, will be minor, with 2% increase in runoff expected across the entire catchment. However, there will be significant localised increases to total runoff volume and peak flow (up to 30% at individual plot scale) in areas immediately downstream of proposed land use changes. The constant gate closure duration used for all model runs limited the ability to assess changes in duration of flooding between model scenarios. Expected climate change over the next 100 years (around 2°C warming) will have more of an impact on flooding in the Owhiro Stream and Lower Pond than anticipated land use changes, with around 24% increase in runoff expected across the catchment.

Owhiro Stream and Quarry Creek exhibit extensive flooding throughout their catchments in the storm events tested under both existing and future development scenarios, and this flooding will be exacerbated by climate change. This impacts the location and feasibility of future development in the area. Given the significant localised effects seen in runoff from anticipated land use changes modelled in this study, future development in the area should be undertaken with careful consideration of local impacts on peak flow and runoff volume, and loss of storage capacity due to filling in of floodplain areas.

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1 Overview

1.1 Catchment description

Owhiro Stream is located west of Dunedin, Otago, and drains to the Taieri River. The stream has a catchment of 32.1 km^2, which is part of the East Taieri Plain, a basin depression between the coastal hills and low inland mountain ranges (Silver Peaks and Maungatua). Owhiro Stream runs through the urban area of Mosgiel and collects runoff from several small hill catchments along its left bank and 12km^2 of flat rural land as shown in Figure 1. Note that while the full areas in red have been modelled in this study, they represent a larger area than just the Owhiro Stream catchment. To the north, the Owhiro catchment is boarded by Silver Stream which also drains to the Taieri River approximately 4km upstream of the Owhiro Stream confluence.

Owhiro Stream is stopbanked downstream of Gladfield Road to provide protection for the 20-year ARI[1] ('return period') event. The large, flat, rural area on the right bank of the Owhiro Stream and downstream of Mosgiel is known as the Lower Taieri Flood Protection Scheme Lower Pond and acts as a storage area when the 20 year event is exceeded. As well as the stopbanks along the Owhiro, the Lower Pond is also protected with stopbanks along the left bank of the Taieri River. Both the Lower Pond and Owhiro Stream drain to the Taieri River through large double culverts with flapgates which provide protection against high Taieri River flows.

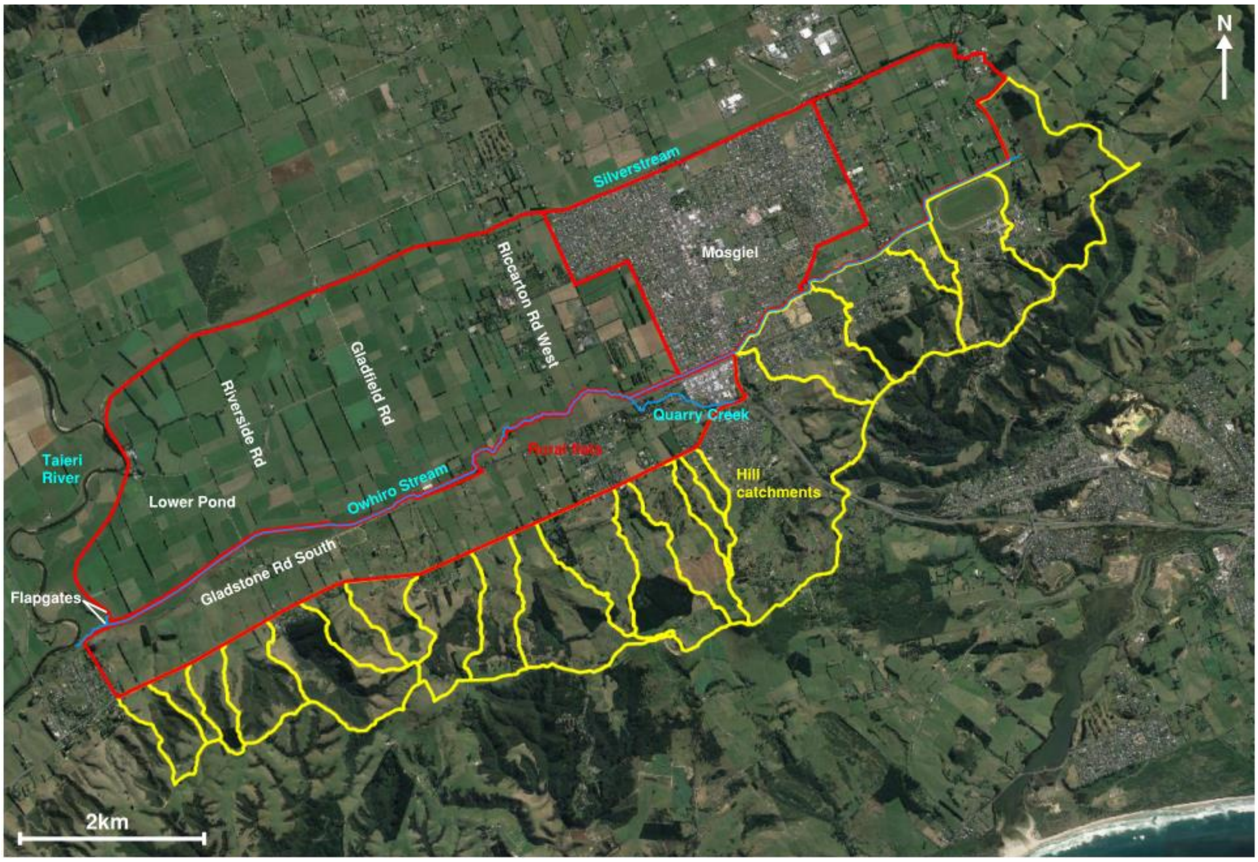

Figure 1 - Overview of Owhiro Stream catchment

[1] ARI: Average Recurrence Interval

1.2 Purpose of Study

This study aims to define flood hazard levels for the Owhiro Stream and to determine how the floodplain area is impacted in flood events and by development in the upper catchment.

2 Modelled scenarios

Ten scenarios have been modelled in this study as indicated in Table 1.

Three different rainfall events - 100, 50, and 10 year Average Recurrence Interval (ARI) have been modelled, each with two different land use scenarios (existing and future development); giving six scenarios in total. The intention of these runs is to assess the effects of land use change on flood levels in the Owhiro Stream and Lower Pond.

A further three model runs have been completed, all based on the future land use scenario, to act as sensitivity checks. The 100 year and 50 year ARI events have each been modelled with climate change applied to assess sensitivity to increased runoff in the catchment. There has also been one event run with the 100 year rainfall event and no gate closure in the Owhiro Stream or Lower Pond, to assist with understanding of the effects of floodgate closure.

The 20 July 2017 flood event, which saw 166 mm rain fall at the Silver Stream at Taieri Depot rain gauge, putting it between the 50 and 100-year ARI, was also modelled with the existing land use scenario in order to calibrate the hydrological and hydraulic models.

Table 1 - Modelled scenarios

Rainfall event	Existing development	Future development
100 year ARI	✓	✓
50 year ARI	✓	✓
10 year ARI	✓	✓
100 year ARI with no floodgate closure (sensitivity check)		✓
100 year ARI, with climate change (sensitivity check)		✓
50 year ARI, with climate change (sensitivity check)		✓
Calibration event (20 July 2017)	✓	

3 Input data

Otago Regional Council made the following data sources available for this study. Two site visits were also undertaken together with ORC staff; one on 7 June 2017, and a second visit after the July flood event, on 1 August 2017.

3.1.1 Background information

- ORC (2006) *Owhiro Creek Flood April 2006* draft report
- ORC (2006) *Review of the Capacity of the East Taieri Tributary Channels – The Owhiro Stream* draft report

3.1.2 Topographic data

- LiDAR of Taieri East Plains (2016)
- Updated cross-section and structure data for Owhiro Stream and Quarry Creek (2017)
- Locations and dimensions of key structures between the railway and Main Road South, SH1 (19 culverts)
- Surveyed crest levels for stop bank on river left of Owhiro Stream (2018)
- Previous surveyed cross-sections and structures (bridges and culverts) and associated photos of Quarry Creek (2015)
- Previous surveyed cross-sections and associated photos of Owhiro Stream (2005)
- Structure data used in previous modelling of Owhiro Stream (2005)
- GIS data for Owhiro Stream (shapefiles of drains, bridges, culverts, rivers, recorder sites etc.)
- Topo50 topographic map
- Past catchment map “Owhiro Creek East Taieri Rating Area – Catchment No. 9

3.1.3 Landuse data

- Dunedin City Second Generation District Plan zones
- Building footprints for Woodland and Gladstone Rd
- GIS layout of Mosgiel stormwater network

3.1.4 Model boundary condition data

- Mill Creek pump rating curves
- Recorder data for:
  - Flow, Taieri River at Outram
  - Stage, Taieri River at Outram
  - Stage, Taieri River at Mill Creek Pump
  - Stage, Taieri River at Otokia
  - Rainfall at Silver Stream at Taieri Depot
- NIWA daily rainfall data at Mosgiel Town

3.1.5 Model calibration data (July 2017 event)

- Stage, flow and rainfall data for event:
  - Flow, Taieri River at Outram
  - Stage, Taieri River at Outram
  - Stage, Taieri River at Mill Creek Pump
  - Stage, Taieri River at Otokia
  - Stage, Owhiro at Outfall
  - Rainfall at Silver Stream at Taieri Depot
- Debris levels from July 2017 event (also from April 2006 event)
- Photos and video (from aerial footage) of flood event, morning Friday 22 July
- Satellite image of Upper and Lower Ponds, midmorning Sunday 24 July (after flood peak)

4 Software used

This flood hazard study has used two key hydrological and hydraulic modelling software tools from the U.S. Army Corps of Engineers Hydrologic Engineering Centre (HEC):

- HEC-HMS v4.2 has been used for hydrological modelling
- HEC-RAS v5.0.3 has been used for 1D/2D coupled hydraulic modelling

5 Hydrology

5.1 Catchment delineation

The Owhiro Stream catchment was divided into two distinct areas for hydrological analysis, hill catchments and rural flats, as outlined in black and red in Figure 2 below:

- **Hill catchments:** O2a, O2b, O2c, O3a, O3b, O4, O5a, O5b, O5c, O5d, O6, O7a, O7b, O8, O8a, O8c, O9, O10, O10a, O11, O12
- **Flat catchments:** Lower, Urban, Upper, South, South Urban, Floodplain2

Larger rainfall depths were applied to the hill catchments than those applied to the flat catchments. The two groups of catchments have then used the same methods to calculate infiltration depths (initial and continuing), but differ in how runoff has been routed and applied to the hydraulic model.

Given that Silver Stream (along the northern boundary of the modelled area) has stopbanks along the length of the area of interest, it has been assumed that no water spills from this stream toward the Owhiro Stream or the Lower Pond.

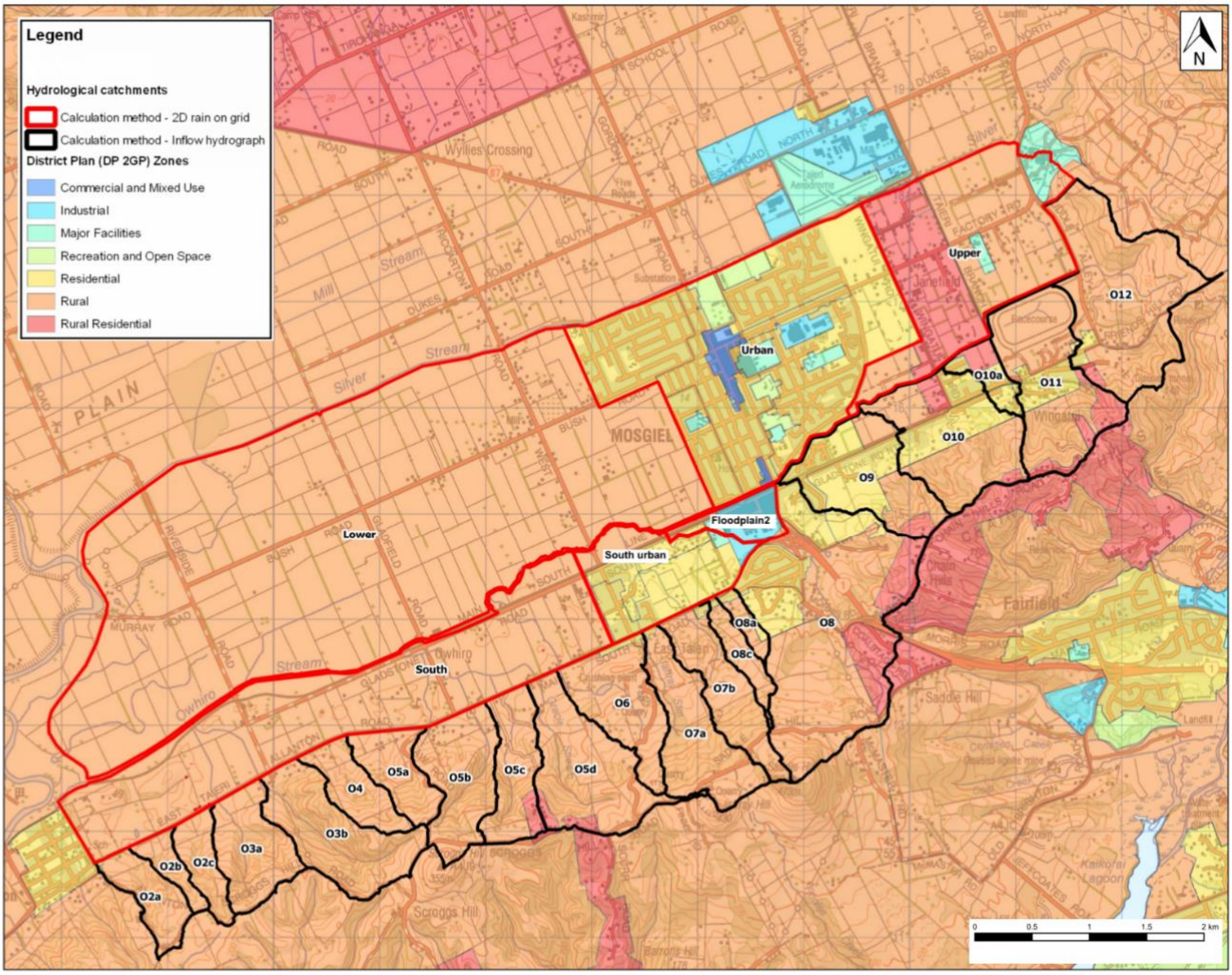

Figure 2 - Catchment delineation and land-use characteristics

5.1.1 Hill catchments

The hilly areas along the left bank of the Owhiro Stream have been divided into smaller sub-catchments based on location of outlets into the Owhiro Stream and flat floodplain areas. A LiDAR surface with 0.5m grid spacing was used for catchment delineation. For these catchments, net rainfall and associated runoff have been assessed in HEC-HMS using the SCS Curve Number and SCS Unit Hydrograph methods. Runoff data has then been entered into the hydraulic model as a series of inflow hydrographs at the outlet of each catchment.

5.1.2 Rural flats

The urban area of Mosgiel, and the surrounding rural flat areas including the Lower Pond, have been modelled using a rain on grid approach.

The rain on grid approach was selected because few well-defined watercourses or catchment boundaries exist in these areas, and the approach also allows floodplain storage to be taken into account in larger storm events. It is important to note that these catchments have been extended across the full rural area between Silver Stream and Owhiro Stream rather than limited to a precise catchment boundary, as the rain on grid approach will determine whether runoff in any given area will travel towards Owhiro catchment or not.

Excess rainfall hyetographs calculated in HEC-HMS were applied directly to the terrain in the hydraulic model, and the rain on grid approach was used in HEC-RAS to determine how much runoff reached the Owhiro Stream. The flat area has been split into six sub-catchments, shown in red in Figure 2, so that spatial variation in excess runoff between urban and rural areas could be incorporated into the rain on grid runoff modelling (HEC-RAS only allows a single rainfall hyetograph per rain on grid catchment).

The stormwater system in Mosgiel has not been included in the model. The absence of stormwater network in the model means that modelled flood extents may be overestimated in Mosgiel.

5.2 Rainfall

Rainfall depth-duration-frequency data was obtained for the centre of the Owhiro catchment from the NIWA High Intensity Rainfall Design System (HIRDS v3[2]), with and without climate change applied. Variability in depth-duration-frequency across the catchment (hilly and flat areas) was examined using HIRDSv3 and a 10.8% increase in 24 hour rainfall depths was applied to the hill catchments compared to depths used for the flat catchments.

The impact of climate change on rainfall was accounted for by considering the temperature increase rate up to 2090. Average annual mean temperature increase for Otago from 1986-2005 to 2101-2120 is defined as 1.93°C (MfE, 2016 pg. 39 Table 7).

Table 2 compares 24 hour rainfall depths for the 10, 50 and 100 year event, for hill and flat areas, with and without climate change applied. Rainfall hyetographs have been developed using the nested storm approach, for 10, 50, and 100 year events of 24 hour duration, for each of these rainfall scenarios. The nested storm approach incorporates maximum rainfall intensities for each duration from 10 minutes up to 24 hours, for a given ARI event, in one artificial event.

Figure 3 shows the nested storm profile for each event, for the flat catchments and hill catchments, without climate change applied.

[2] Current at the time of modelling

Table 2 - Comparison of 24 hour rainfall depths used in Owhiro flood model

Rainfall event	24 hour rainfall depth (mm)			
	No climate change applied		**Climate change applied**	
	Flat catchments	**Hill catchments**	**Flat catchments**	**Hill catchments**
10 year ARI	76.6	84.9	85.9	95.2
50 year ARI	112.4	124.4	129.8	143.7
100 year ARI	132.2	146.3	152.6	168.9

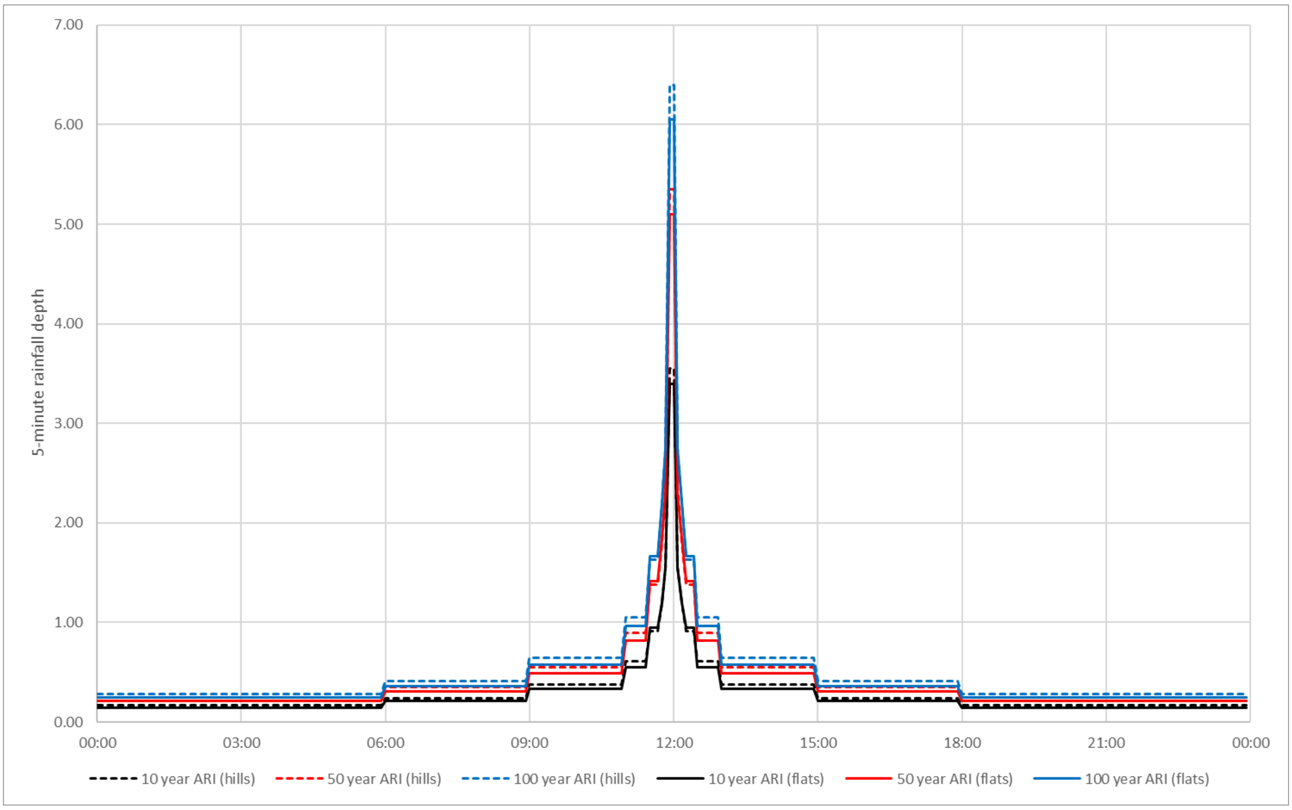

Figure 3 - 24hr nested storm rainfall hyetograph for 10, 50 and 100 year event, for hills and flats (no climate change)

5.3 HEC-HMS hydrological modelling

A hydrological model containing all catchments (hills and flats) was set up in HEC-HMS to calculate excess rainfall and runoff inputs for the HEC-RAS hydraulic model. Details on the inputs for this modelling are as follows.

5.3.1 Calculation methods

The SCS Curve Number method was used to calculate rainfall losses (both initial and continuing), and the SCS unit hydrograph method used to create runoff hydrographs for each catchment. A 1-minute time step was used and models run for a 10 day duration, the 24hr nested storm occurring at the beginning of the 10 days.

5.3.2 Time of concentration

Time of concentration for a catchment is the time it would take all rainfall to translate to runoff, i.e. the lag time between the start of rainfall and its translation to runoff at the outlet of each catchment.

Catchment areas were defined in the catchment delineation process, with areas and length of longest flow paths for each catchment determined using LiDAR data and the slope calculated using equal area method. Different time of concentration calculation methods including TP108, Kirpich, Bransby-Williams, and the SCS method were compared and the TP108 method (based on rural Auckland catchments) was selected as an appropriate estimate for this area.

5.3.3 Soil infiltration parameters (SCS Curve Numbers and initial abstraction)

Infiltration loss parameters for each catchment were assessed using the SCS Curve Number method, where initial abstraction and net runoff are determined by assigning a Curve Number based on soil conditions and landcover type.

Landcover estimates for the existing development scenario were based on aerial imagery, while for the future development scenario, Dunedin City Second Generation District (2GP) zones were used to estimate any changes in landcover type.

Composite SCS Curve numbers were assessed for each catchment by calculating a weighted average value according to the proportion of area in each soil group, and then the proportion of landcover type within each soil group. Curve Numbers used for each soil type and landcover type are as indicated in Table 3. In both scenarios, roads have been included within the urban portion for each catchment. Curve Numbers were selected assuming soils had good hydrological condition, as an outcome of model calibration.

A factor of 0.1*S (S is the potential maximum retention) was used to determine initial abstraction. This factor is recommended elsewhere for undeveloped landcover and gave appropriate initial abstraction values.

The following exceptions were made to this method:

- A considerable area of hilly catchment near the downstream end of Owhiro Stream (within catchments O2a to O6) is classified as “well-drained soil” in the online S-Map tool[3]. Given the steep nature of the land and the predominant landcover types (grass and scrub), the initial abstraction values given when using soil group “A” were considered too high, so the areas of concern were adjusted to soil group “B” Curve Numbers during the model calibration process.
- For the flat catchments, proportions of each landcover type were assessed for each catchment as whole, rather than within each soil group as was done for the hill catchments. Catchments were then assigned Curve Numbers considering both proportion of each landcover type and proportion of each soil type.

[3] https://smap.landcareresearch.co.nz/

Table 3 - SCS Curve Numbers (derived from SCS guidelines, 1986)

Landcover	Soil group				Assumptions
	A (well drained)	B (moderately well drained)	C (poorly or imperfectly drained)	D (very poorly drained)	
Grass	39*	61	74	80	Good hydrologic condition
gorse ('brush')	30*	48	65	73	Good hydrologic condition
trees	30*	55	70	77	Good hydrologic condition
Urban (Mosgiel, other urban areas and all new development)	61	75	83	87	average 38% impervious (¼ acre residential property)
Urban (area south of Mosgiel – larger sections)	54	70	80	85	average 25% impervious (½ acre residential property)
industrial	81	88	91	93	average 72% impervious

**All areas classified as soil group "A" were assigned to soil group "B" to give more realistic initial abstraction values*

5.3.4 Worked example – individual plot scale

A worked example of a small sub-area within the "South urban" sub-catchment is shown here to clarify how curve numbers have been calculated in the model. The area marked "Example plot" in Figure 4 is 100% rural (90% grass with some trees) currently and is zoned to become 100% residential area in the future. The area is a mix of poorly and imperfectly drained soil types, both designated as soil class "C" in the SCS curve number method.

Figure 4 - "South urban" sub-catchment with example plot shown

The calculation method weights curve numbers by area in each soil class and area in each land use type as shown below.

Existing CN for example plot	Area	CN	CN weighted by % area
grass	90%	74	66.6
trees	10%	70	7
urban (1/4 acre)	0%	83	0
Overall CN for plot	**74**		
S (potential max retention after runoff begins)	91.1	mm	
Initial abstraction, Ia=0.1S	9.11	mm	

Future CN for example plot	Area	CN	CN weighted by % area
grass	0%	74	0
trees	0%	70	0
urban (1/4 acre)	100%	83	83
Overall CN for plot	**83**		
S (potential max retention after runoff begins)	52.0	mm	
Initial abstraction, Ia=0.1S	5.20	mm	

These results translate to the following runoff volumes and peak flows for the 50 year event.

Table 4 - Comparison of runoff volume and peak flow with land use change for example plot changing from 100% rural to 100% urban land use

	Existing land use	Future land use	Difference
Runoff volume	3,340 m^3	4,350 m^3	1,010 m^3 (30%)
Peak flow	0.45 m^3/s	0.59 m^3/s	0.14 m^3/s (31%)

5.3.5 Worked example – sub-catchment scale

A worked example for the full “South urban” sub-catchment, giving the new overall Curve Numbers for existing and future land use used in the model is shown below, illustrating how the method extends to cover a full sub-catchment with multiple land uses. The “South urban” sub-catchment referred to is the largely urban 2D rain on grid sub-catchment south of Quarry Creek, and is expected to see considerable growth in proportion of residential area (see yellow areas, which are district plan Residential zoning, in Figure 4 above).

Existing CN for "South urban" sub-catchment

Soil type	Area (%)	A (0%)	B (19% area)	C (81% area)	D (0%)
		CN weighted by % area			
grass	50%	0	30.5	37	0
gorse ('brush')	0%	0	0	0	0
trees	10%	0	5.5	7	0
urban	40%	0	28	32	0
industrial	0%	0	0	0	0
Weighted CN for soil type		**0**	**64**	**76**	**0**
Overall CN for South urban	**74**				
S (potential max retention after runoff begins)	90.7	mm			
Initial abstraction, Ia=0.1S	9.06	mm			

Future CN for "South urban" sub-catchment

Soil type	Area (%)	A (0%)	B (19% area)	C (81% area)	D (0%)
		CN weighted by % area			
grass	12%	0	7.32	8.88	0
gorse ('brush')	0%	0	0	0	0
trees	5%	0	2.75	3.5	0
urban	40%	0	28	32	0
new urban (1/4 acre)	40%	0	30	33.2	0
industrial	3%	0	2.64	2.73	0
Weighted CN for soil type		**0**	**71**	**80**	**0**
Overall CN for South urban	**78**				
S (potential max retention after runoff begins)	69.7	mm			
Initial abstraction, Ia=0.1S	6.97	mm			

These results translate to the following runoff volumes for the 50 year event (peak flows not shown as these are not calculated directly in the hydrological model).

Table 5 - Comparison of runoff volume for existing and future landuse for South urban sub-catchment

	Existing land use	Future land use	Difference
Runoff volume	62,500 m^3	70,700 m^3	8,200 m^3 (13.1%)

5.3.6 Outputs used for HEC-RAS hydraulic modelling

Two different types of output from the HEC-HMS hydrological model have been used as inputs to the HEC-RAS model.

For the flat catchments, excess rainfall hyetographs (total rainfall minus losses) were taken directly from HEC-HMS and applied as rain on grid for each catchment. Figure 5 shows an example of excess rainfall hyetograph output used to model rain on grid in HEC-RAS for the “South Urban” catchment that has been used as a worked example above. The chart compares the 50 year event in the existing and future landuse scenarios, and also with climate change applied.

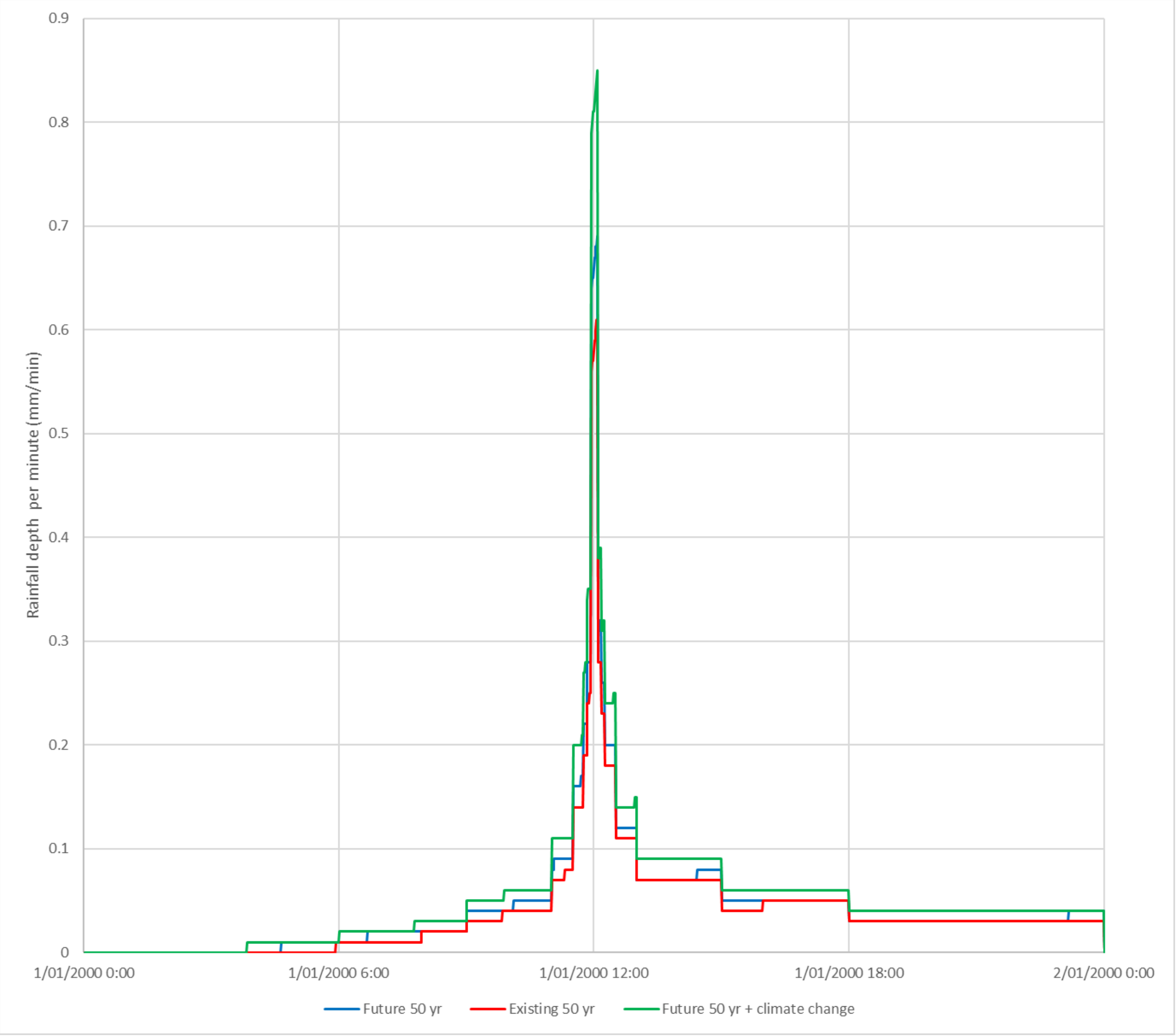

Figure 5 - Example HEC-HMS excess rainfall hyetograph output used as rain on grid input in HEC-RAS. This is the data used for the “South urban” catchment which will see increases in residential and industrial area in the future land-use scenario

For the hill catchments, runoff hydrograph outputs from HEC-HMS were applied as inflows to the 1D Owhiro Stream and Quarry Creek models as well as to the 2D floodplain areas on the Owhiro Stream’s left bank in HEC-RAS. Figure 6 shows an example of runoff hydrograph output used as inflow data in HEC-RAS for catchment “O9”, a catchment where there will be a significant increase in impervious landuse according to the district plan. The chart compares the 50 year event in the existing and future landuse scenarios, and also with climate change applied. The hydrographs indicate that the effect of climate change on total runoff volume and peak flow from the catchment is likely to be much larger than the effect of landuse change.

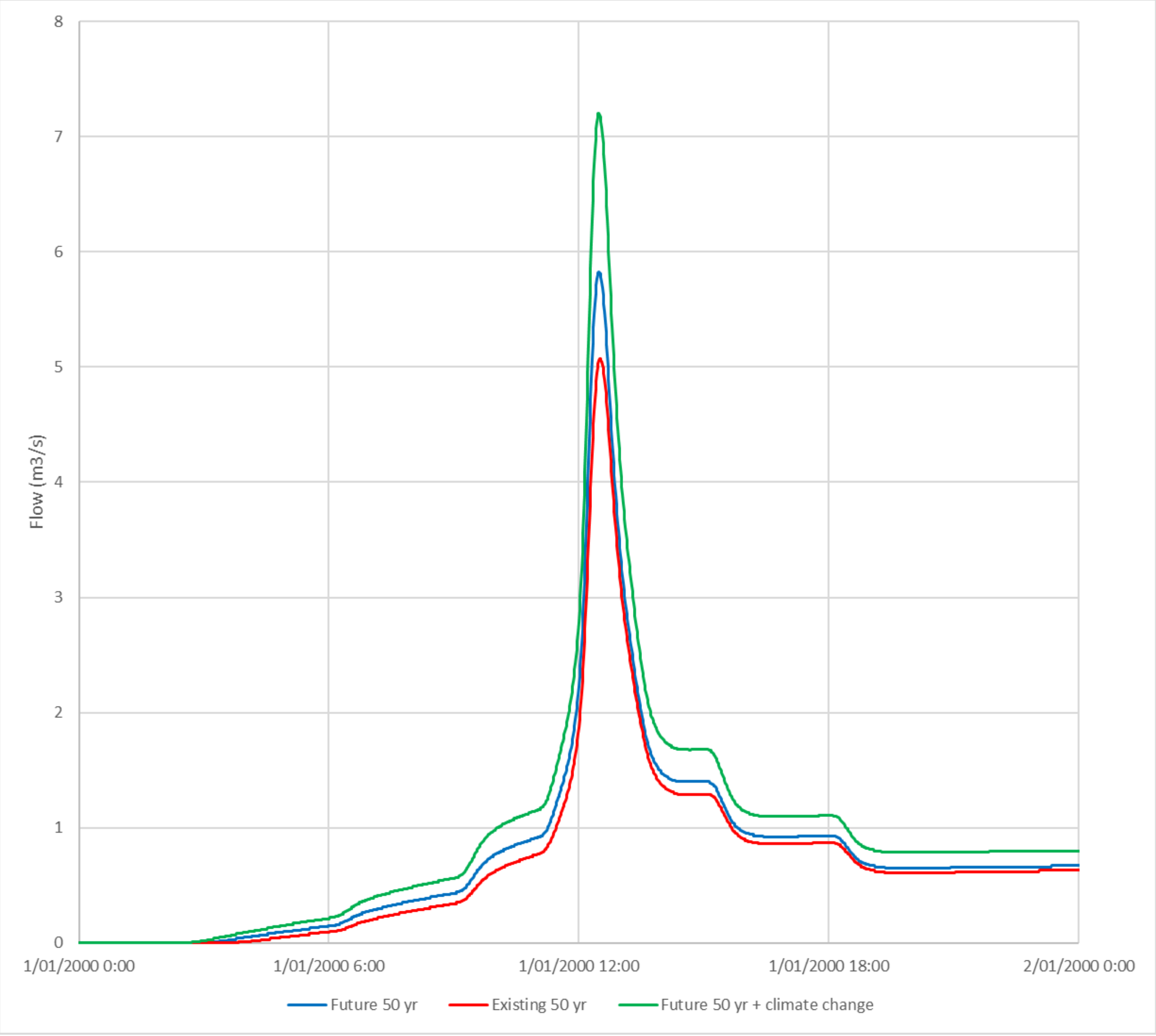

Figure 6 - Example HEC-HMS runoff hydrograph output used as input for HEC-RAS model. The chart shown is for catchment "O9" which will expand its residential and industrial area in the future land-use scenario.

6 Hydraulic Model

6.1 Overview

The Owhiro model has been set up as a 1D/2D coupled hydraulic model in HEC-RAS v5.0.3 that links directly to hydrological model outputs from HEC-HMS. The model covers a 12 km stretch of the Owhiro Stream, and extends from the stopbanks along Silver Stream in the North, toward the hills to the East and South, to the Lower Pond stopbanks and confluence of the Owhiro Stream and Taieri River in the South West. Figure 7 shows an overview of the 1D/2D coupled hydraulic model set up in HEC-RAS.

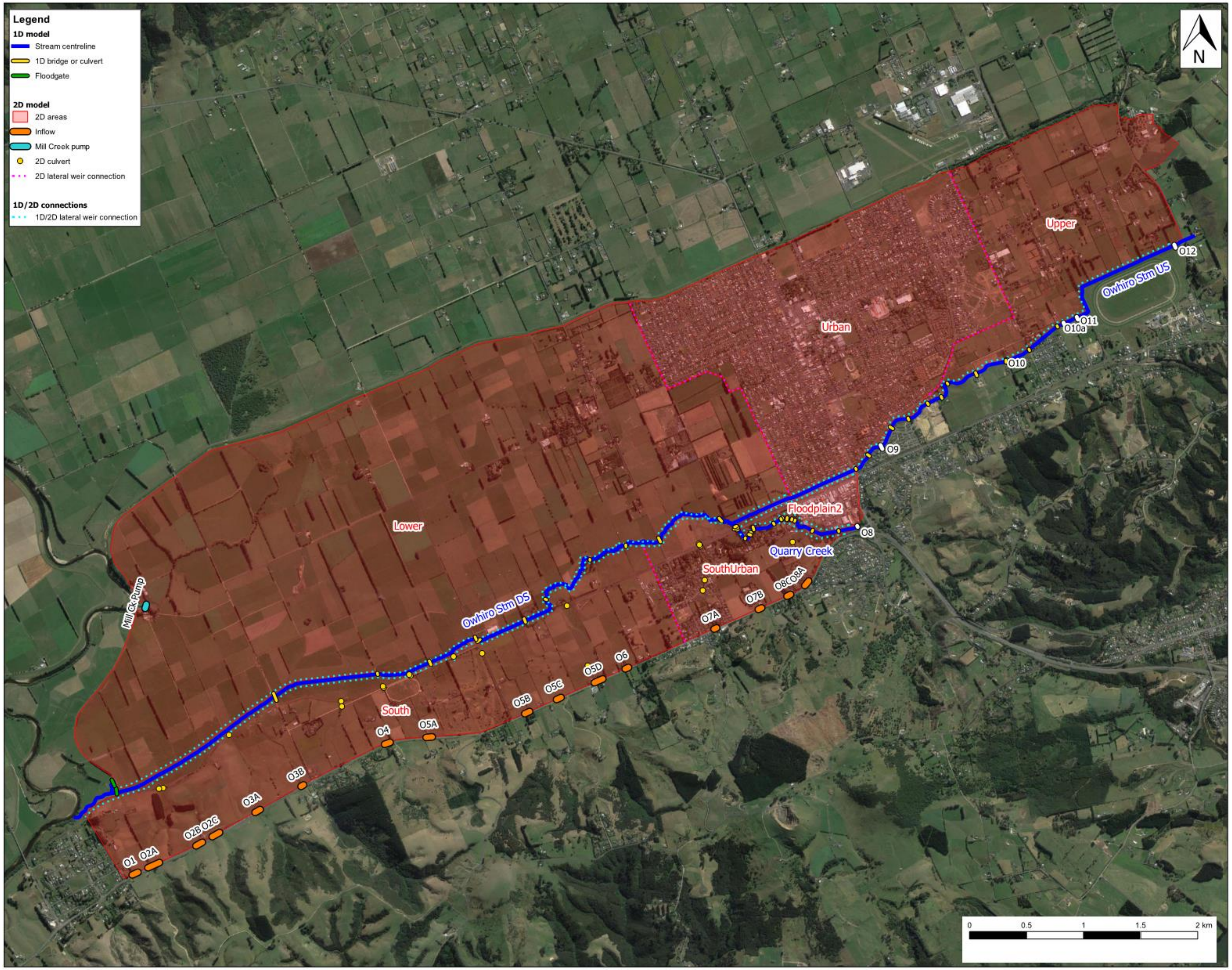

Figure 7 - 1D/2D hydraulic model network setup in HEC-RAS

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6.2 Model file layout

Table 6 outlines the HEC-RAS model plans set up to model each of the required scenarios, together with the associated geometry and flow files. All model runs are based on a single geometry file, i.e. only the hydrological data changes between each scenario.

Table 6 - HEC-RAS model file directory

Plan	Rainfall event	Climate change	Landuse scenario	Geometry file	Unsteady flow file
Owhiro_EXG_10yrNoCC	10 yr	No	Existing	Owhiro_Calibrated 1802	Owhiro_EXG_10yrNoCC
Owhiro_MPD_10yrNoCC	10 yr	No	Future	Owhiro_Calibrated 1802	Owhiro_MPD_10yrNoCC
Owhiro_EXG_50yrNoCC	50 yr	No	Existing	Owhiro_Calibrated 1802	Owhiro_EXG_50yrNoCC
Owhiro_MPD_50yrNoCC	50 yr	No	Future	Owhiro_Calibrated 1802	Owhiro_MPD_50yrNoCC
Owhiro_EXG_100yrNoCC	100 yr	No	Existing	Owhiro_Calibrated 1802	Owhiro_EXG_100yrNoCC
Owhiro_MPD_100yrNoCC	100 yr	No	Future	Owhiro_Calibrated 1802	Owhiro_MPD_100yrNoCC
Owhiro_MPD_50yrCC	50 yr	Yes	Future	Owhiro_Calibrated 1802	Owhiro_MPD_50yrCC
Owhiro_MPD_100yrCC	100 yr	Yes	Future	Owhiro_Calibrated 1802	Owhiro_MPD_100yrCC
Owhiro_MPD_100yrNoCC_no gate	100 yr	No	Future	Owhiro_Calibrated 1802	Owhiro_MPD_100yrNoCC _no gate
Owhiro_EXG_Calibration_July 2017_v2	July 2017 event	N/A	Existing	Owhiro_Calibrated 1802	Owhiro_EXG_Calibration_ July2017_FINAL

6.3 Model computation settings

Given that a gate closure of five days was being modelled, each model was run for an 8 day simulation period to allow for the stream to drain after the gates had opened. Table 7 shows the key computation setting used. The calibration event was run for 6 days from 21 July 2017, 00:00 to 27 July 2017 00:00, with the same computation interval applied.

Table 7 - Hydraulic model computation settings

Parameter	Value
Start date	1 Jan 2000, 00:00
End date	9 Jan 2000, 00:00
Duration of simulation	8 days
Computation interval	1 second
Data output interval	10 minutes

6.4 Model network

The model has been set up as a 1D/2D coupled hydraulic model, with Owhiro Stream and Quarry Creek modelled as 1D streams, and the surrounding flats modelled as 2D surfaces as shown in Figure 7 earlier in this section on page 13. The same network file has been used for all modelled scenarios.

It should be noted that no stormwater pipe network data has been included in the model.

6.4.1 1D model

Owhiro Stream and Quarry Creek have been modelled as 1D river reaches. One junction in the model, where Quarry Creek meets Owhiro Stream, means that the Owhiro Stream is split into two separate reaches, upstream and downstream of the confluence with Quarry Creek. 1D cross-section and structure data has been based on up to date 2017 survey data provided by ORC. Where additional information was required, previous survey has been referred to, as has LiDAR data. Additional cross-sections have been interpolated between surveyed locations to improve model resolution and stability, so that cross-sections are typically 50 to 100 m apart in Owhiro Stream, and 5 to 10 m apart in Quarry Creek.

There are 22 culverts and bridges modelled along Owhiro Stream, and 15 on Quarry Creek. These structures have typically been modelled with a roughness of n=0.012, entrance loss (k) of 0.2 and outlet loss of 1. In addition there are the floodgates on Owhiro Stream and in the Lower Pond stopbank which have been modelled as inline structures with flapgates preventing upstream flow. These have been modelled with a slightly coarser roughness of n=0.014, entrance loss of 0.5 and outlet loss of 1.

The HEC-RAS setup details for the floodgates are given in Table 8. Data for all other structures are attached in Appendix B.

Table 8 - Floodgate setup details. Culvert dimensions from supplied photos, invert levels from LiDAR

Gate location	Location in HECRAS	US IL (m RL)	DS IL (m RL)	Weir crest level (m RL)	Culvert dimensions	Floodgate setup
Owhiro Stream	Chainage 2080m, Owhiro Stream. Set up as inline structure.	100.67	100.67	107.5	2x 2.4m circular culverts	Prevents upstream flow
Lower Pond	At 2D flow area boundary. Set up as lateral weir.	101.84	101.84	107.7	2x 2.4m circular culverts	Prevents upstream flow

6.4.2 2D model

A 2D model has been constructed to represent runoff from the flat areas using the rain on grid approach. In HEC-RAS, a single net rainfall hyetograph can be applied for a given 2D flow area, so the urban areas around Mosgiel and adjacent to Quarry Creek have been set up as separate 2D flow areas, linked by weir structures at ground level. Separate 2D flow areas allow for differing runoff to be applied in these areas due to land cover.

As shown in Figure 7 on page 13, six distinct 2D flow areas have been set up. Each 2D area consists of a computation grid of 20m x 20m cells with an underlying 0.5m x 0.5m terrain surface produced from LiDAR data. The 20m x 20m computation grid drops down to a smaller cell resolution (5m) in key areas such as along 1D/2D interfaces. HEC-RAS can compute at sub-grid resolution, meaning that within the larger 20m computation grid, small terrain features such as narrow waterways and roads in the 0.5m terrain surface are still considered when assessing flow between cells.

A method known as “wormhole culverts” has been used to model 19 key structures between the railway and Main South Road in 2D. This method overcomes the limitations in modelling internal structures in HEC-RAS v5.0.3 and allows each culvert to be modelled with the correct length and inlet and outlet locations. Details provided by ORC to set up these culverts are tabulated in Appendix B.

6.4.3 Roughness parameters

Manning's roughness (n) has been set as 0.035 in the 1D channels, aside from the straight, channelized section of Owhiro Stream running through Mosgiel, where roughness has been decreased to 0.03. These values are appropriate for natural stream channels with fairly uniform sections, and some vegetation. Roughness for culverts has typically been modelled as 0.012 (concrete), with the floodgates modelled slightly rougher at 0.014.

Roughness in the 2D flow areas has been modelled using the Dunedin City Second Generation District Plan district plan to determine land use types, and designating each land use type a Manning's n roughness value as indicated in Table 9.

Table 9 - Manning's n roughness by landcover type

Landcover type	Manning's n roughness
Commercial and Mixed Use	0.02
Industrial	0.02
Major facilities	0.02
Recreation and open space	0.05
Residential	0.05
Rural	0.05
Rural Residential	0.05
Road	0.014

6.4.4 1D/2D Coupling

The 1D and 2D model networks have been coupled using lateral weir connections. The lateral weir profiles have been based on LiDAR but at a fairly coarse resolution to aid model stability (allowing only gradual, steady changes in weir level helped to reduce differences in calculated water levels between adjacent 1D and 2D regions). An exception was the downstream end of the stopbank on the Owhiro Stream right bank, where detailed survey was provided – this detail was included in the model. The profile for this lateral weir is shown as an example in Figure 8 and Figure 9 (close-up).

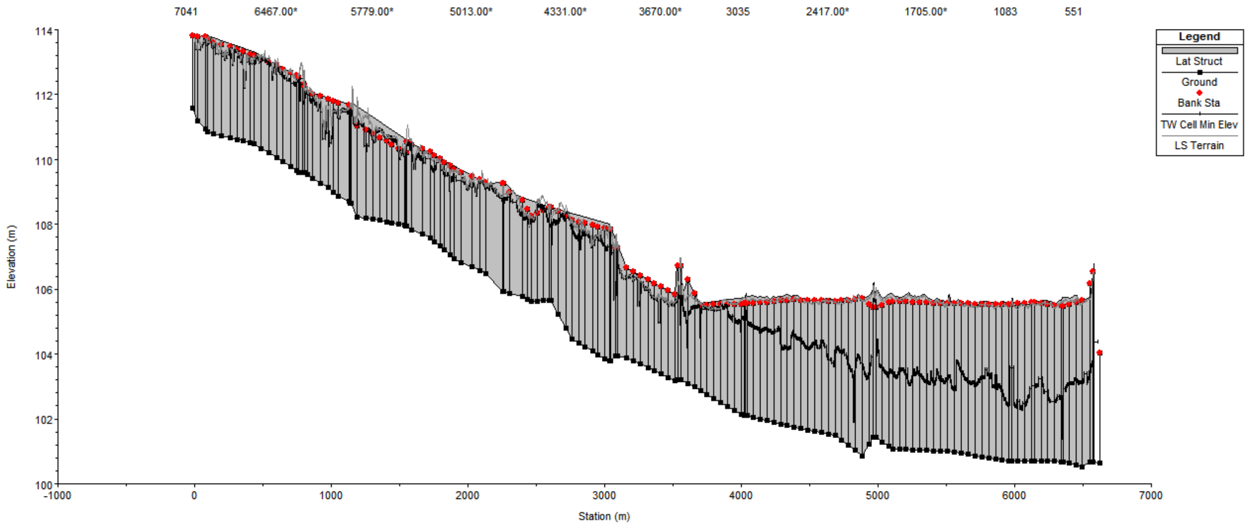


Figure 8- Example of 1D/2D model coupling using lateral weir connection (Lower end of Owhiro right bank shown). Stopbank exists along downstream reach, which is why weir level sits higher than surrounding terrain in this area

The close-up in Figure 9 shows the different data used to calculate movement of water between the coupled 1D and 2D models. The red points are the top of bank in the 1D model, the black outlines are the minimum elevations in 2D cells adjacent to the 1D stream, and the grey outline is the weir crest (based on survey and LiDAR) defined as the link between the two models.

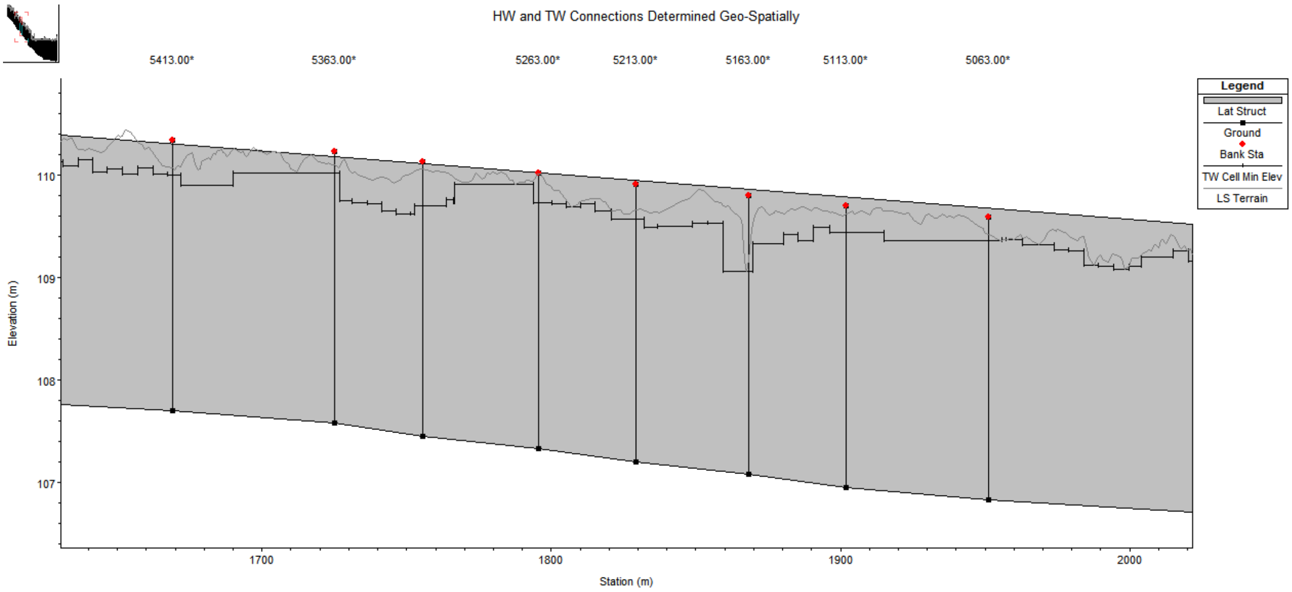


Figure 9 - Close-up of lateral weir shown in Figure 8

6.5 Boundary conditions

6.5.1 Design inflows

A different flow file has been used for each model scenario (changing with different land use, storm event size, and climate change effects).

Section 5 outlines how inflow data was calculated in the HEC-HMS hydrological model. The resulting inflow data has been applied to the hydraulic model in three distinct ways as listed below. All of these inflows were set up in HEC-RAS as direct links to the HEC-HMS result files, allowing for easy updates to the hydrological model parameters as required. As noted in Section 5,

- Runoff from the hilly catchments to the south and east of Owhiro Stream has been modelled using HEC-HMS, and inflow hydrographs have been applied either:
  - Directly to the 1D stream where the catchment outlet meets the 1D model or;
  - At the 2D surface boundary where there is 2D model area between the catchment outlet and the 1D model.
- Runoff from the flat 2D surfaces has been modelled by applying rain on grid directly onto the terrain, using net rainfall hyetographs produced in the HEC-HMS model.

A steady minimum flow of 1 m^3/s was input at the upstream ends of Owhiro Stream and Quarry Creek throughout the model duration for stability (the 1D models cannot be allowed to run dry). This does not affect modelled flood levels, extents or durations.

6.5.2 Mill Creek pump

Two pumps are set up to operate at the Mill Creek outlet to the Taieri River during flood events. ORC provided rating curve data for the two pumps as shown in Appendix C and summarised in Table 10. The average flows and starting level data were combined to build a simple rating curve boundary condition that approximates the two pumps working together.

Table 10 - Mill Creek pump station data provided by ORC (Data highlighted in yellow has been used in the model. See Appendix C for full pump data)

Pump	Starting level	Flow range (m^3/min)	Average flow (m^3/min)	Average flow (m^3/s)
Pump 1	102.5	18 to 34	30	0.5
Pump 2	102.75	56 to 79	73	1.2

6.5.3 Downstream boundary

Frequency analysis by ORC suggests that the Owhiro Stream floodgates are closed for five days in a 50 year event (see Figure 10). Five days is the maximum closure duration that has been observed to date. As such, and at the request of ORC, this has been used as a conservative estimate of closure time for the 10, 50 and 100 year modelled events, for both the Owhiro Stream gates and the Lower Pond gates.

In the hydraulic model the five day gate closure has been modelled using a stepped time-series stage hydrograph. The gates are held closed by a steady, elevated downstream water level for 5 days from the start of the model run (i.e. from 12 hours before the peak of the rainfall event), and then water level at the downstream boundary drops instantly to a level representative of base flow in the Taieri River, causing the gates to open and allowing floodwater to drain.

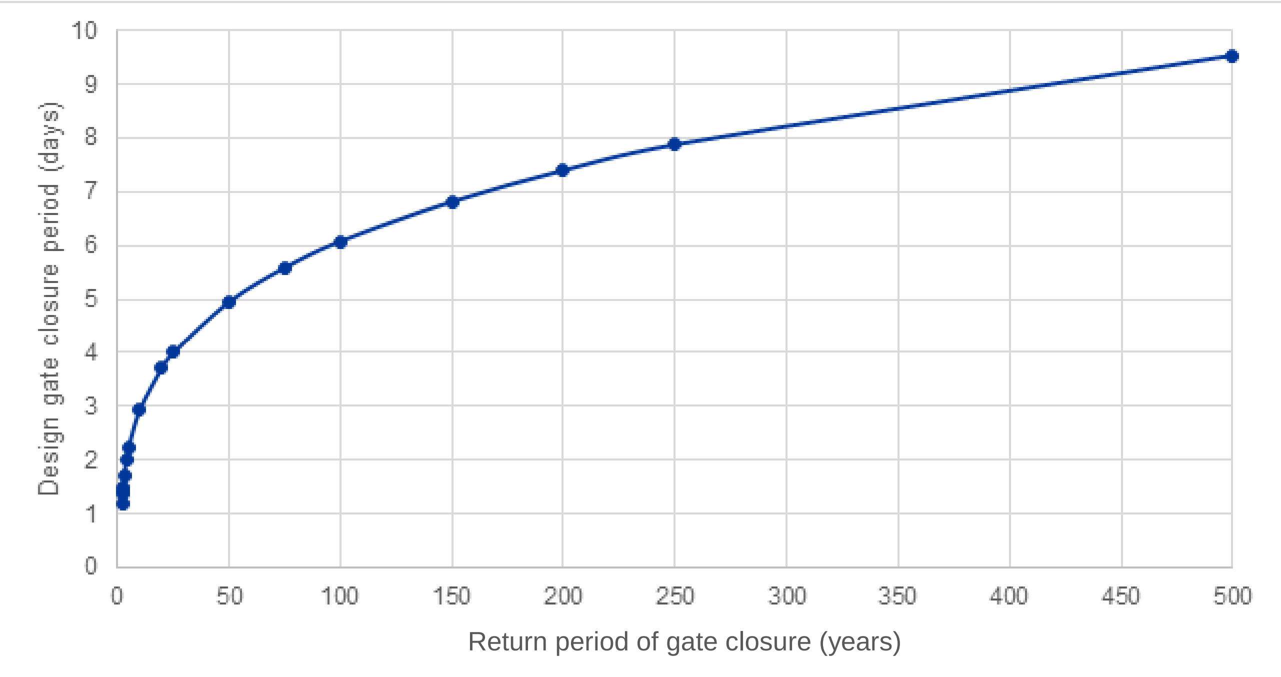


Figure 10 - Generalised extreme value distribution (GEV) frequency analysis for closure periods of the Owhiro flood gate as provided by ORC

In one sensitivity run, the model has been run with no gate closure. In this run, the downstream boundary has been set at normal depth based on the channel slope. No backflow has been allowed from the Taieri River, i.e. in this model run it is assumed that there is a flood event in the Owhiro but not in the main Taieri catchment.

In the calibration model, of the July 2017 event, the downstream boundaries at the Owhiro Stream floodgate and at the Lower Pond floodgate were set as stage hydrographs based on recorded water levels for the Taieri River at Mill Creek (adjusted by -0.75m to account for difference in location). Initially, a similar type of boundary was going to be used for the design runs as well, where a design hydrograph of Taieri water levels controlled the duration of gate closure, but this has been replaced with the set 5 day closure boundary as requested by ORC.

It is not intended that the model simulates backflow from a flooded Taieri River into the Owhiro Stream or the Lower Pond, so this situation has not been allowed to occur.

7 Model Calibration

The Owhiro hydrological and hydraulic models have been calibrated against the July 2017 flood event. This event, at 166 mm of rain at the Silver Stream at Taieri Depot rainfall gauge, is greater than a 100 year ARI event for the catchment (based on NIWA HIRDS depth-duration-frequency data), and provided a unique opportunity for calibration in that the event occurred during the modelling project.

An error in ORC's rainfall data collection during the July 2017 event meant that the initial calibration work done by Beca was based on a total depth of 126 mm for the July 2017 rainfall event (the rain gauge stopped working during the event and missed 40 mm of rainfall data). Model calibration has been re-assessed with manually corrected data (provided by ORC in early 2019) and the information in the following sections reflects this updated data.

7.1 Model inputs

Hydrological modelling for this event was based on existing land-use, and used rainfall data for Silver Stream at Taieri Depot between 20 July 2017 and 26 July 2017, provided by ORC.

Figure 11 shows total and net runoff data for one of the hill catchments (catchment "O9") as an example of the hydrological data inputs used to model this event, as well as the resulting runoff hydrograph for this catchment. The data shown is the corrected rainfall data provided by ORC in early 2019 (gap between 00:00hrs and 04:00hrs on 22/07/2017 which previously had no data, has been filled in with a uniform rainfall depth to account for the missing 40mm). Note that rainfall was recorded in 0.5mm increments, thus the step-like nature of the hyetograph. The rainfall data for catchment "O9" and other hill catchments was increased by 10.8% as per the design model, to account for increased rainfall on the hills compared to the flats.

In the hydraulic model, water level data for Taieri River at Mill Creek has been used as a tailwater condition to drive operation of the Owhiro and Lower Pond floodgates in the model. To account for the difference in location between the Owhiro Stream outlet and the Mill Creek recorder site, 0.75 m was subtracted from water levels, as shown in Figure 12. Aside from the hydrology inputs and tailwater conditions, model setup was identical to that of the design runs.

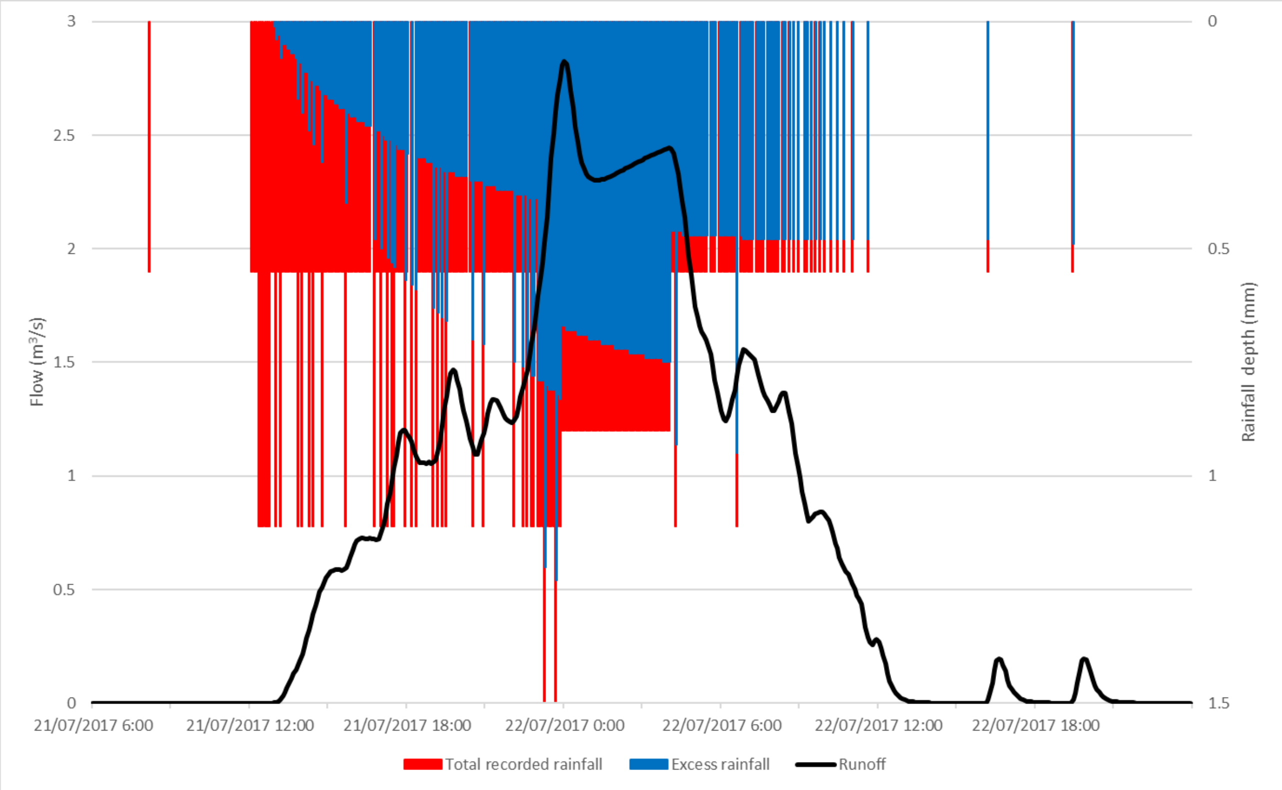


Figure 11 - Example rainfall and runoff outputs from HEC-HMS model for catchment "O9" for the July 2017 flood event.

7.2 Calibration data

Several data sources were available allowing comparison of modelled and actual water levels for the July 2017 event. These comparisons allowed for refinement of several aspects of the model during calibration:

- Water level data for Owhiro Stream at Outfall (i.e. just upstream of the Owhiro floodgate)
- Debris marks indicating peak water levels along Owhiro Stream, Quarry Creek, and in the Lower Pond surveyed on 22 July 2017
- Satellite imagery of Lower Pond taken midmorning 24 July 2017
- Photos and video footage from a helicopter flyover of flood event, taken morning 22 July 2017
- Site walkover after the flood event had subsided, on 1 August 2017 by ORC and Beca staff
- Gauged flow of 16.4 m3/s at 11:58 NZST 22 July 2017, 400m downstream of Riverside Road (by ORC)

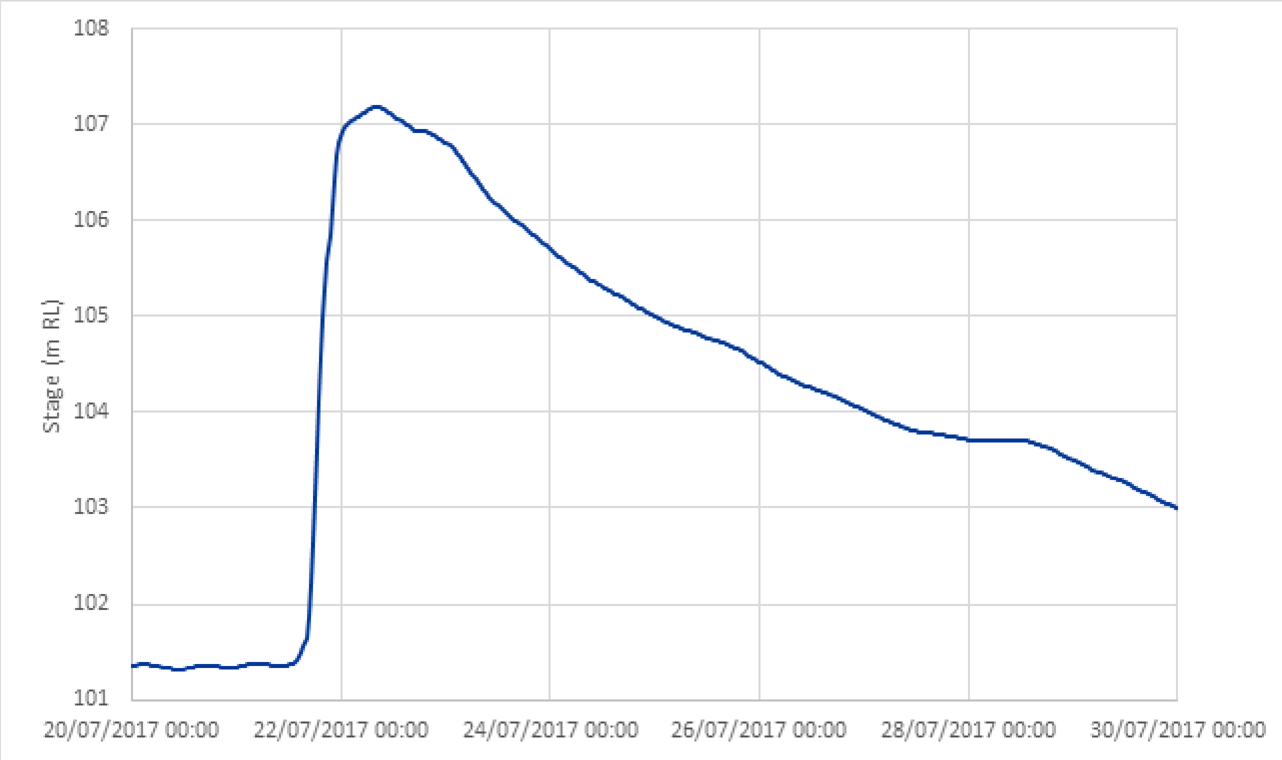


Figure 12 – Recorded water level data for Taieri at Mill Creek in the July 2017 flood event (adjusted by -0.75m to reflect level at Owhiro Stream outlet)

Figure 13 - Satellite imagery of July 2017 event (image taken midmorning 24 July 2017, after peak of event), provided by ORC. Red lines are stopbanks and white lines are key roads.

7.3 Calibration outcomes

During the calibration process and with consultation with ORC several changes, outlined in this section, were made to the model to improve the relationship between recorded and modelled water level data.

It should be acknowledged that the hydrological and hydraulic models involve many simplifications and assumptions and the results won't match recorded data exactly. For example, there was evidence of some backflow around the Owhiro Stream floodgate, as well as leakage through the stopbank at the Mill Creek pump site. Neither of these phenomena were incorporated into the model but would affect water levels seen in the Owhiro Stream and Lower Pond. There are also limitations to survey and LiDAR data, and from stormwater network information being excluded from the model. With these limitations noted, the calibration phase has helped produce a detailed and representative model that will allow for effective comparison between existing and future land-use conditions in different flood events.

7.3.1 Variation in rainfall between hills and flats

In the initial model set up, a single 24 hr rainfall depth, representative of the rural flats in the Owhiro area, was used across the whole catchment. During calibration, comparison of HIRDS v3 24hr rainfall depths across the catchment indicated a greater depth in the hill areas compared to the flats. This difference was built into the model hydrology, with the hill catchments set up with 10.8% larger rainfall depths than flat catchments, and helped to increase the modelled runoff bringing it closer to that seen in the July 2017 event.

7.3.2 Infiltration parameters

It is likely that the July 2017 event occurred with wet antecedent soil conditions typical of the winter season. This would have reduced the soil's initial abstraction compared to a similar event occurring in drier conditions. The July 2017 event water levels have still been used for calibration, though may be a conservative estimate of the soil's drainage capacity. A study by ORC on infiltration in the neighbouring Silver Stream catchment indicated a typical CN of 79 for the area – this has also been considered during calibration.

"Poor" hydrological condition parameters were tested in an effort to generate more runoff, as initially the calibration model water levels were lower than recorded data, but through discussion with ORC it was decided to set hydrological condition of soils as "good" in the model (i.e. reasonably high permeability) and to address the difference in runoff by varying rainfall inputs.

"Good" hydrological conditions gave average SCS Curve Numbers (CNs) of around 72 but appeared to overestimate initial losses for some catchments. Initial losses were calculated using a factor of 0.1*S rather than 0.2*S to help account for this. This factor is recommended elsewhere for undeveloped landcover and gave appropriate initial abstraction values for the catchment including for urban areas such as Mosgiel (i.e. <5mm).

A considerable area of hill catchment classified as soil type "A" (well-draining soils) was also downgraded to soil type "B" parameters to address the unrealistically high initial losses that were occurring for some catchments.

7.3.3 Changes to roughness parameters

Roughness values in the straight, channelized section of Owhiro Stream alongside Mosgiel were decreased from 0.035 to 0.03 as requested by ORC because modelled water levels were reading higher than surveyed debris mark levels in this area. This did not make very much difference to water levels in this area, but it is possible that given the steep nature of the river banks in this area, debris might have fallen as the stream receded and be sitting lower than the peak water level.

Entrance losses and roughness at the floodgates were also altered compared to other culverts in the model during calibration.

7.3.4 Improved modelling of structures

ORC provided crest level survey data for the stopbank along the lower right bank of the Owhiro Stream in February 2018. This data was incorporated into the 1D/2D coupling data to improve accuracy of the water volume passing over the stopbank into the Lower Pond. This is an area where the model is very sensitive, as a small change in stopbank height over a long distance and duration of flooding will cause a significant change in volume of overflow.

Key bridges over the Owhiro Stream including Riverside Road, Gladfield Road, Riccarton Road West, and Wingatui Road were given more detail in the 1D model during calibration, based on available survey data and photographs. Debris mark survey still indicated higher water levels than those modelled above these culverts after these changes, but it is possible that blockage from flood debris caused water to back up in the event, and effects of blockage have not been accounted for in this model.

One minor culvert “QC7”, over a driveway at chainage 380m in the model, has been excluded from all model runs as it caused severe model instability during calibration tests.

7.3.5 2D model area extended to include left bank of Owhiro Stream.

The model was originally set up such that only the flats to the right of Owhiro Stream were modelled in 2D, with the 1D HEC-HMS catchments extended all the way to the Owhiro’s left bank. As requested by ORC during calibration, the 2D model area was extended to include the flats on the Owhiro Stream left bank up to Main South Road (including several key culverts within this area in the 2D model) as shown in Figure 14.

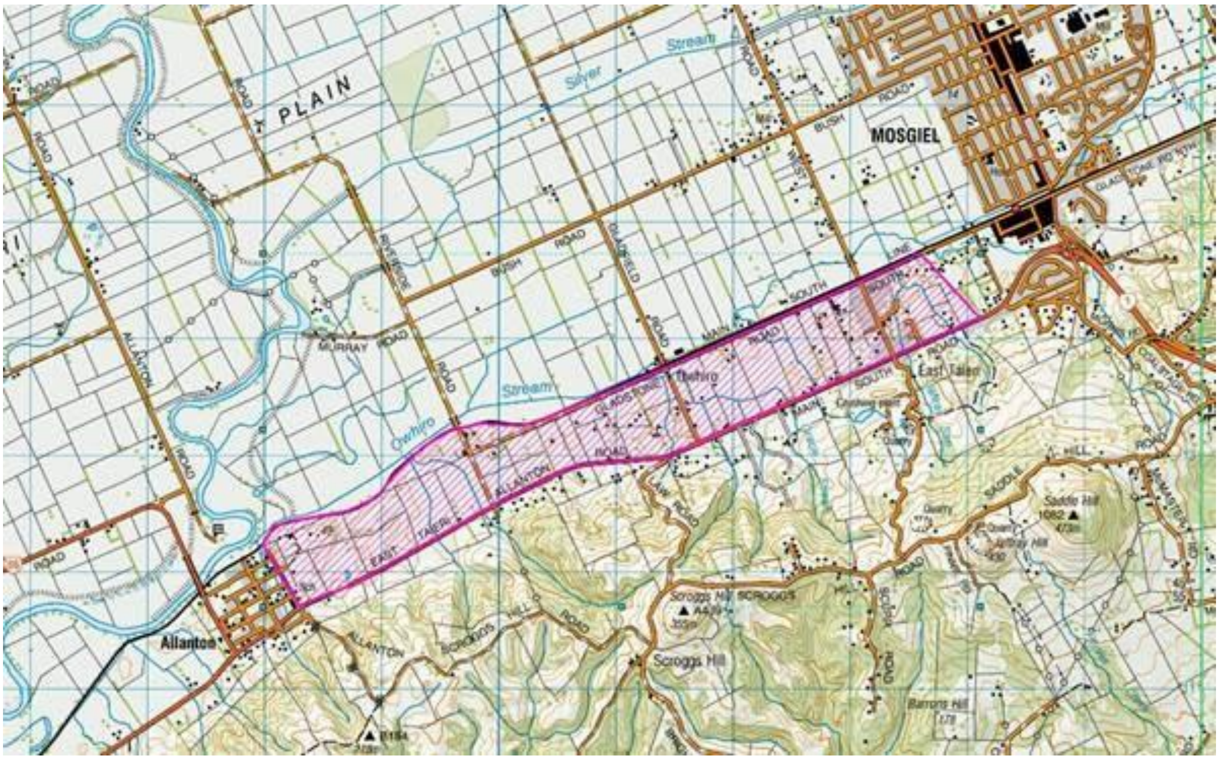


Figure 14 - Additional 2D area requested to include in model (image provided by ORC)

7.3.6 Change in type of downstream boundary condition

In the calibration model, adjusted Taieri at Mill Creek water level data (adjusted by -0.75 m to account for difference in location between Mill Creek and the Owhiro Stream outlet) was used as a downstream boundary condition which controlled flood gate closure duration. The floodgates would close in the model whenever water levels at the downstream boundary were higher than those upstream of the gate (i.e. prevent backflow from occurring). This same method was initially proposed to control gate closure in the design runs, with each Owhiro Stream event return period matched to a smaller Taieri River event as follows (on the basis that it would be unlikely for both catchments to experience a large return period event at the same time):

- 100-year Owhiro event with 20-year Taieri event
- 50-year Owhiro event with 10-year Taieri event
- 10-year Owhiro event with 2-year Taieri event

After feedback from ORC during model calibration, a different approach was decided for the design model runs. Gate closure has been fixed at 5 days, from the start of the model run (i.e. 12 hours before the peak of the storm event), for all storm events modelled. This duration has been selected based on frequency analysis by ORC, indicating that 5 days is the duration of gate closure in the 50 year event, and also on the basis of this being the longest gate closure duration experienced to date.

7.4 Calibration model results

The results described here are from a final run of the calibration model after the model changes described in section 7 were made. They indicate that with the assumptions and simplifications made, the hydrological and hydraulic models were able to replicate the water levels and flood durations observed in the July 2017 event to a reasonable level. As such, the models can be considered appropriate for their intended use (inferring relative changes in flooding from land use change).

7.4.1 Ponding in Owhiro Stream

Water level in the Owhiro Stream was recorded upstream of the floodgate during the July 2017 event. Figure 15 compares the Owhiro Stream water level data provided by ORC with modelled water level upstream of the floodgate in the July event. The adjusted Taieri at Mill Creek recorder data, which was used as a downstream boundary condition in the model is also shown for reference. In the model the Owhiro Stream ponds (creating spill to the lower pond) after gate closure at within 10mm of the recorded ponding level. The model ponded for a slightly shorter duration overall (rising slightly slower than recorded levels at the start of the event, and dropping faster than recorded levels once the floodgates opened), but the importance of this difference in duration is not significant since timing of gate closure has been set as constant in the design event model runs.

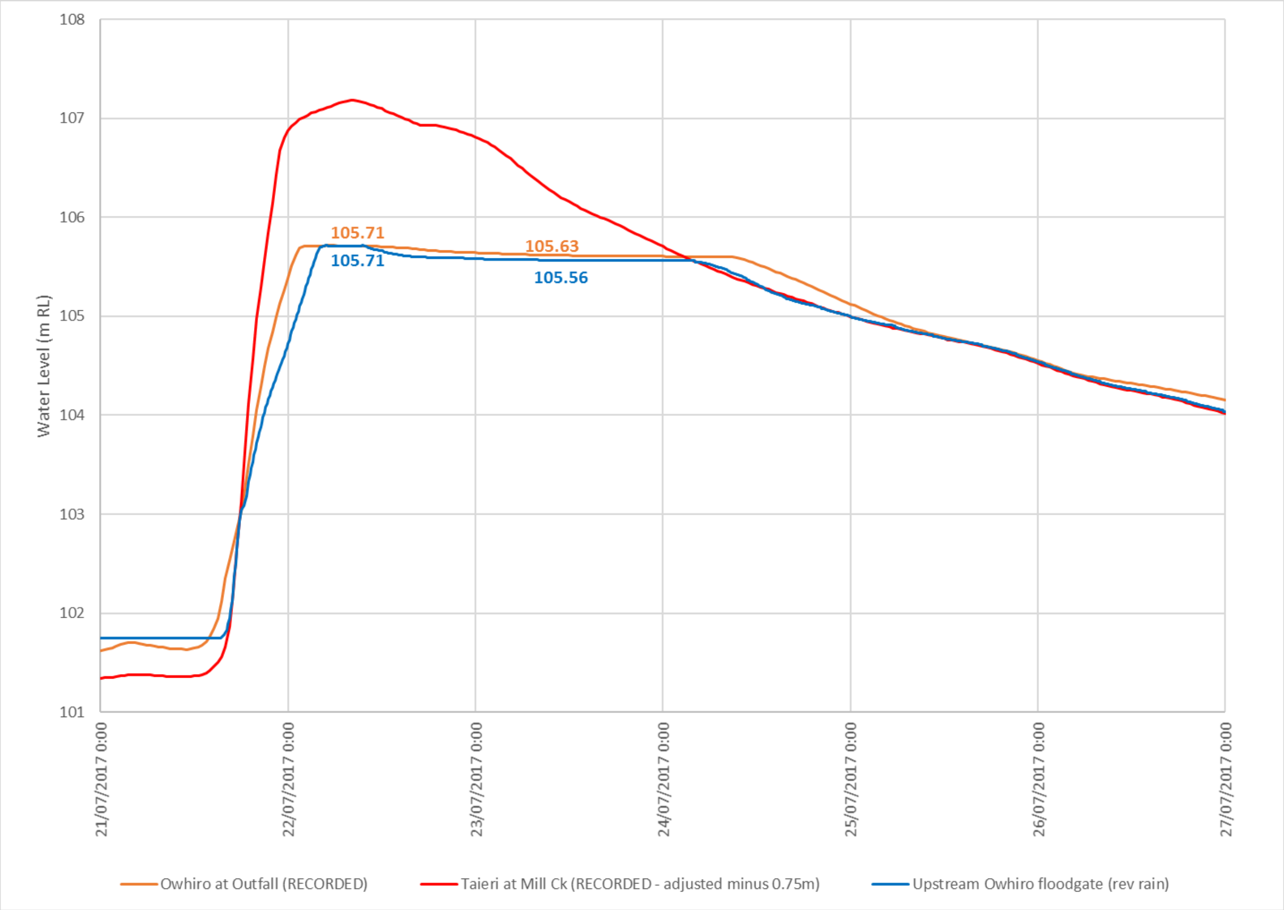


Figure 15 – Water level hydrograph comparing recorded and modelled levels in Owhiro Stream, upstream of the flood gate for the July 2017 flood event. The adjusted Taieri level used as the downstream boundary is shown for reference.

7.4.2 Debris mark survey comparison – long-section

Figure 16 shows a long-section of Owhiro Stream and Quarry Creek, together with debris survey levels taken along each stream as well as along the boundary of the Lower Pond. Key road crossings are marked for reference.

Overall the water level profile aligns well with the debris marks. There are some areas above road crossings where water levels are lower than surveyed levels, and during calibration efforts were made to adjust culvert parameters to improve these areas but some differences still remain. Debris marks for Lower Pond are shown for reference only – these levels represent the levels in the Lower Pond where water has spilled over the stopbank, so are expected to be lower than the levels in the Owhiro Stream channel itself.

7.4.3 Debris mark survey comparison – map of debris marks and flood extent

A map comparing surveyed debris mark levels against maximum modelled water levels, and showing the modelled maximum flood extent of the July 2017 event, is provided in Appendix D. This map refers to the same debris mark data as Figure 16 but, being in plan view, provides comparison of flood extent as well as levels. In the map yellow markers indicate where modelled maximum water levels were within ±100mm of surveyed debris levels. Red and orange markers indicate that modelled levels were higher than surveyed, and green markers indicate where modelled levels were lower than those surveyed.

The debris map shows that the extent and water levels modelled in Lower Pond closely match surveyed debris marks. In Owhiro Stream and Quarry Creek, modelled levels are often within 100mm (with variation up to around ± 500mm) from debris marks. Producing iterations of this map was helpful throughout the calibration process to highlight areas where improvements were needed. However a moderate level of variation between modelled levels and debris survey levels is expected due to the model being a simplification of reality, as well as possible movement of flood debris after the event peak.

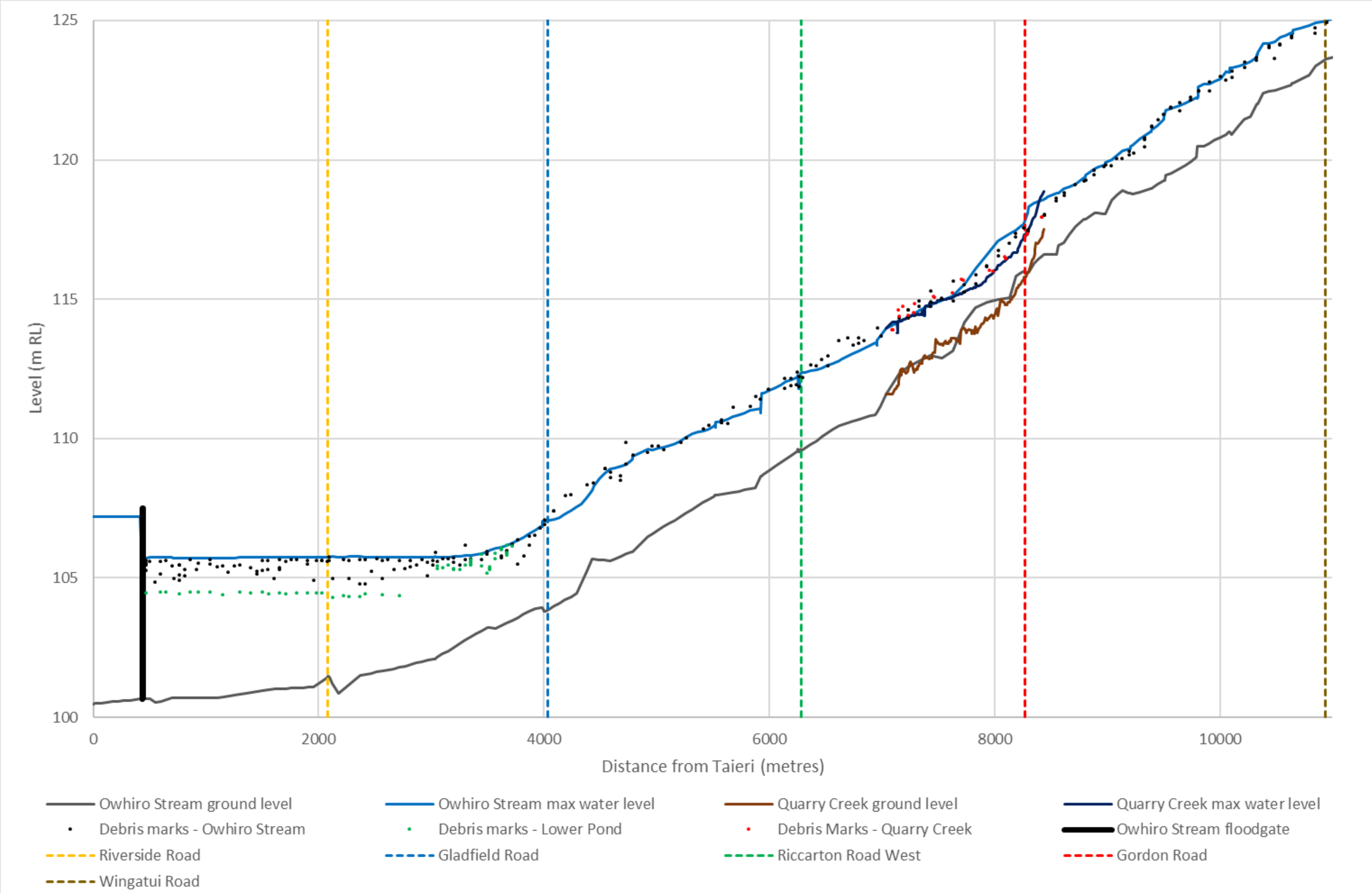


Figure 16 – Long section of Owhiro Stream and Quarry Creek comparing debris mark survey levels with maximum water level in July 2017 calibration event

8 Design run hydrological model results

This section presents key results from the HEC-HMS hydrological model, using the 50 year existing and future hydrological model outputs to illustrate effects of land use at whole catchment, sub-catchment and plot scale. The land use change referred to is the comparison between existing development and future development, under the 50 year rainfall event. The climate change data is based on the future development landcover and looks at changes to runoff due to the increased rainfall depth forecast associated with temperature increases.

8.1 Total difference in runoff volume

As shown in Table 11, in the 50 year event a 1.9% increase in total runoff volume could be seen in the hydrological model, across the whole catchment, due to land use change. Climate change could cause a much greater increase (24%) in total runoff.

Table 11 - Comparison of total runoff volume for 50 year event with land use change and with climate change

	Existing development	Future development	Future development with climate change	Increased runoff volume due to land use change	Increased runoff volume due to climate change
Total runoff volume	2,379,000 m^3	2,425,000 m^3	3,008,000 m^3	**46,000 m^3 (1.9%)**	**583,000 m^3 (24%)**

8.2 Differences in runoff volume by sub-catchment

Figure 17 and Figure 18 compare peak flows and total runoff volume for each sub-catchment in each scenario, while Table 12 lists percentage increases related to land use change and to climate change, for the 50 year flood event. These percentages are based on catchment outflows taken directly from the HEC-HMS hydrological model, i.e. before the data is applied to the hydraulic model.

These values show that predicted land use change may result in up to 14% increase in runoff in the hillside sub-catchments with the most land use change predicted. A large portion of the catchment is rural and likely to see very little land use change, thus these changes in runoff make a very small difference to the behaviour of Owhiro Stream as a whole in a given flood event.

The effects of climate change on flooding in the Owhiro catchment could be significant throughout the catchment, with up to 35% increase in peak flows and similar increases seen for total runoff volumes.

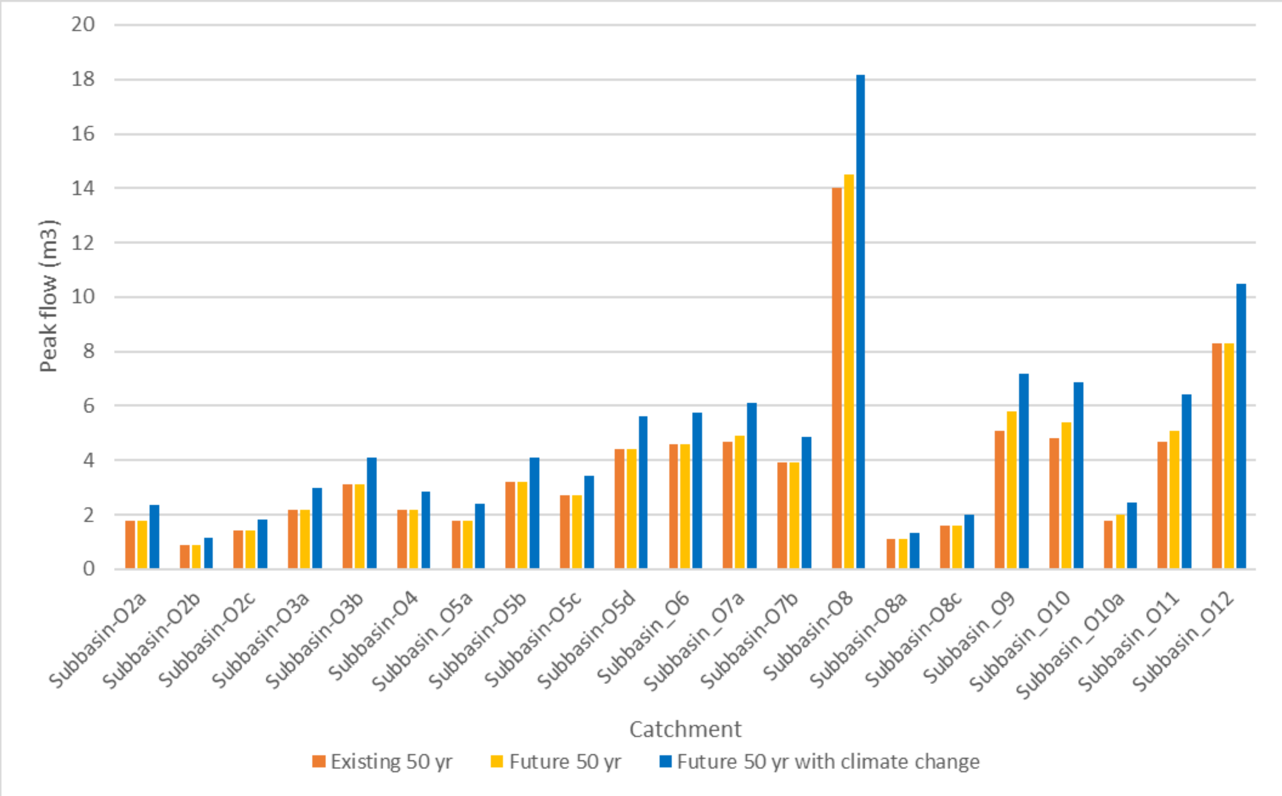


Figure 17 - Comparison of peak flows by sub-catchment for 50 year design runs. 2D catchments not shown as peak flows not calculated in hydrological model.

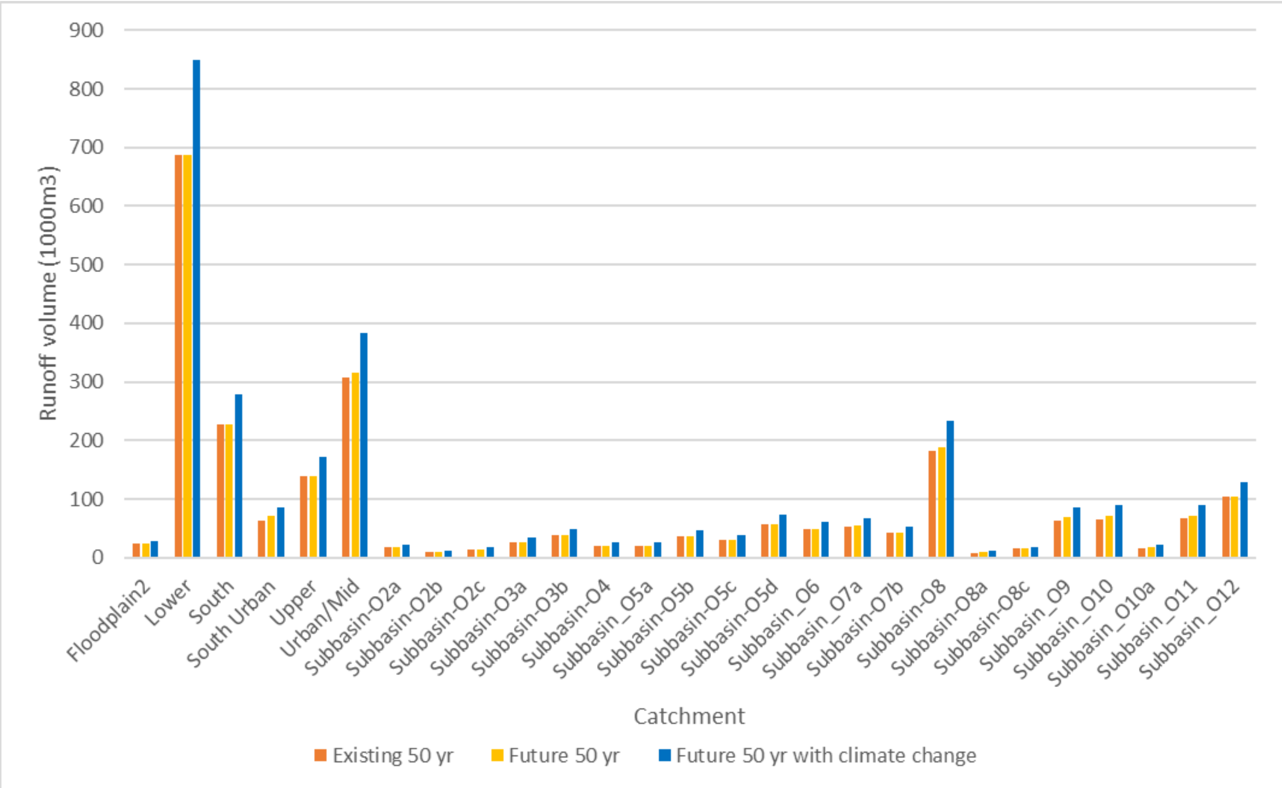


Figure 18 - Comparison of runoff volume by sub-catchment for 50 year design runs

Table 12 – Percentage increase in peak runoff and runoff volume with landuse change and with climate change for each sub-catchment

Sub-catchment	Percentage increase with landuse change (100yr event)		Percentage increase due to climate change (100yr event)	
	Peak runoff (m3/s)	Volume runoff (m3)	Peak runoff (m3/s)	Volume runoff (m3)
Floodplain2	Not calculated (used in hydraulic model as rain on grid)	6%	Not calculated (used in hydraulic model as rain on grid)	18%
Lower		0%		23%
South		0%		23%
South Urban		13%		22%
Upper		0%		24%
Urban/Mid		3%		21%
O2a	0%	0%	31%	29%
O2b	0%	0%	28%	29%
O2c	0%	0%	29%	30%
O3a	0%	0%	35%	30%
O3b	0%	0%	32%	31%
O4	0%	0%	30%	28%
O5a	0%	0%	33%	28%
O5b	0%	0%	28%	29%
O5c	0%	0%	27%	28%
O5d	0%	0%	28%	27%
O6	0%	0%	25%	25%
O7a	4%	3%	25%	25%
O7b	0%	0%	24%	25%
O8	4%	3%	25%	25%
O8a	0%	2%	22%	24%
O8c	0%	0%	26%	24%
O9	14%	12%	24%	23%
O10	13%	10%	27%	26%
O10a	11%	8%	22%	22%
O11	9%	6%	26%	26%
O12	0%	0%	26%	25%

8.3 Effects of land use change in example sub-catchments

This section focuses on two sub-catchments with different characteristics and significant land use change predicted, to explore what runoff changes could be expected at local scale:

- South urban – a 2D modelled sub-catchment, flat urban area with considerable land use change planned (new residential developments)
- O9 – a hill sub-catchment with considerable land use change planned (new residential developments)

8.3.1 Sub-catchment "South urban" – Flat/2D catchment with considerable land use change

The "South urban" sub-catchment covers the residential area South of Quarry Creek as shown in Figure 19. The yellow areas in the figure represent residential zoning in the district plan, thus a large proportion of the sub-catchment is to be developed. There is also some expansion in industrial area expected (blue areas).

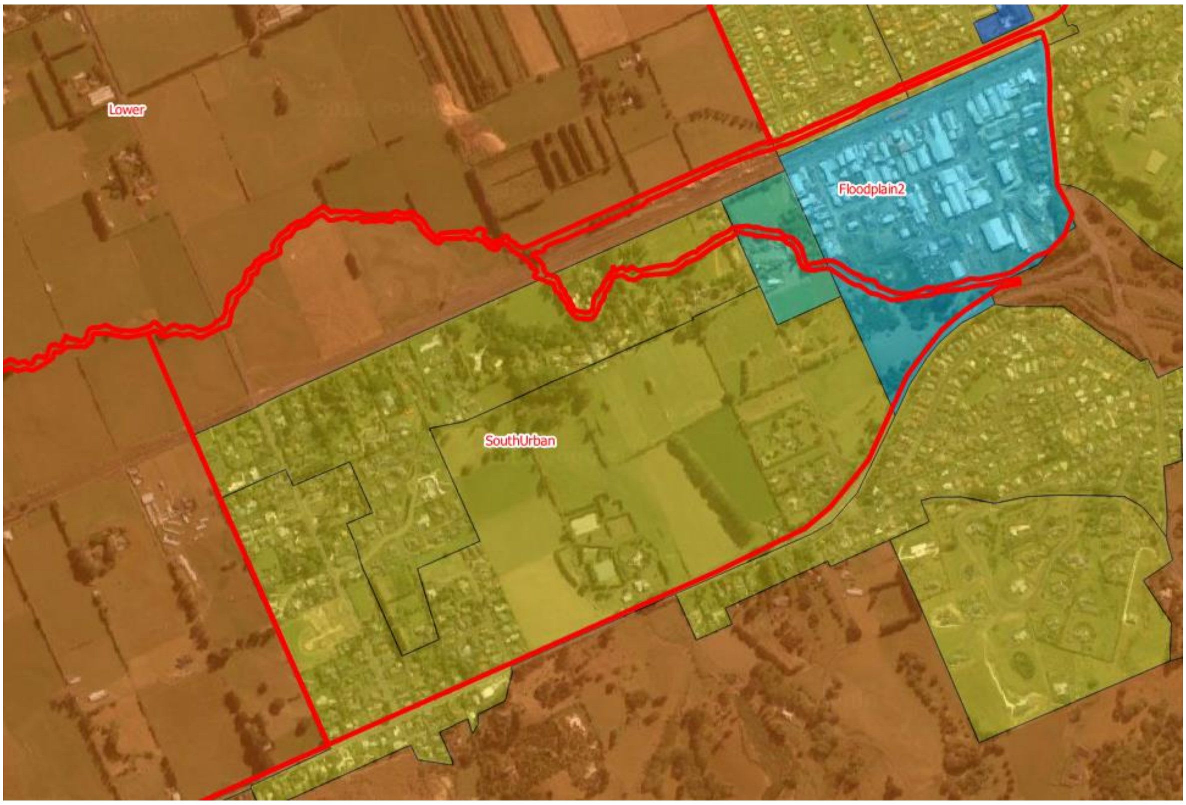


Figure 19 - "South urban" sub-catchment

Figure 20 shows excess rainfall for the sub-catchment for existing and future land use. Note this is shown as excess rainfall rather than runoff as this is a sub-catchment modelled as 2D rain on grid in the hydraulic model. There is an 8200 m^3 (13%) difference in total runoff volume between existing and future land use. This is a significant increase at the sub-catchment scale but a small contribution to total runoff in the context of the whole Owhiro Stream catchment.

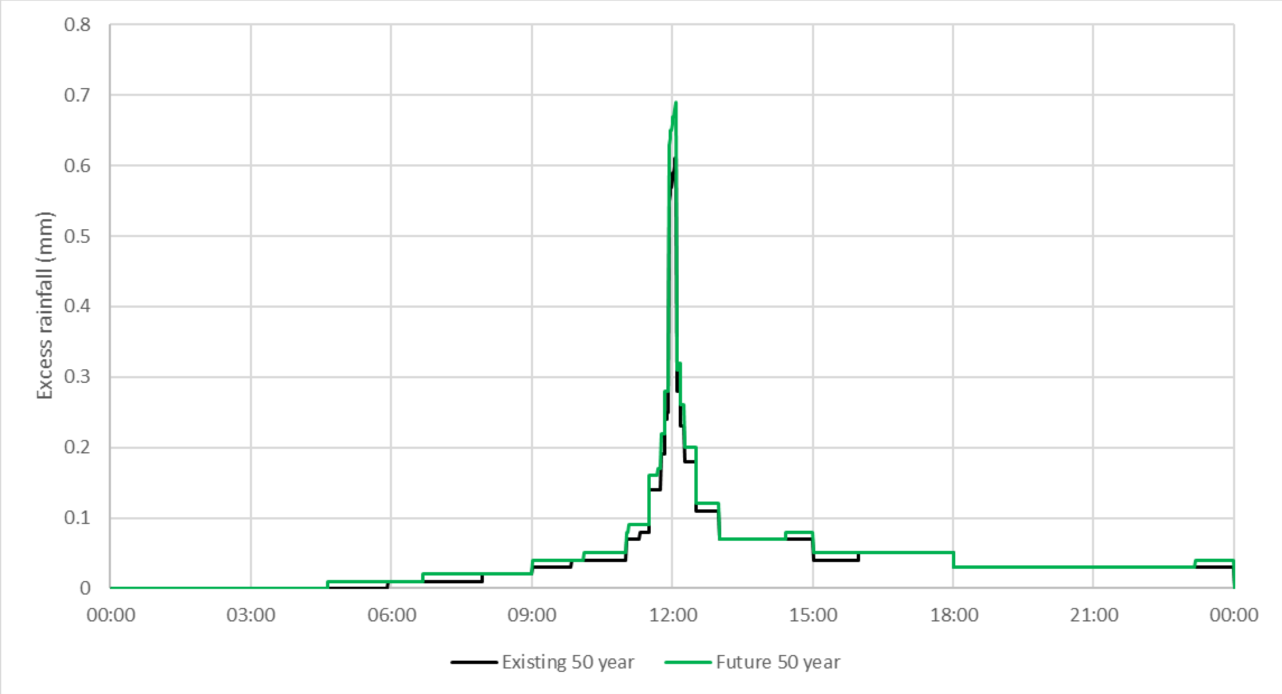


Figure 20 - Comparison of excess rainfall for “South urban” sub-catchment

8.3.2 Sub-catchment O9 – Hill catchment with considerable land use change

Figure 21 shows hill sub-catchment O9. Again, yellow areas are district plan residential zoning, and it can be seen that a significant area is marked for future development in this sub-catchment.

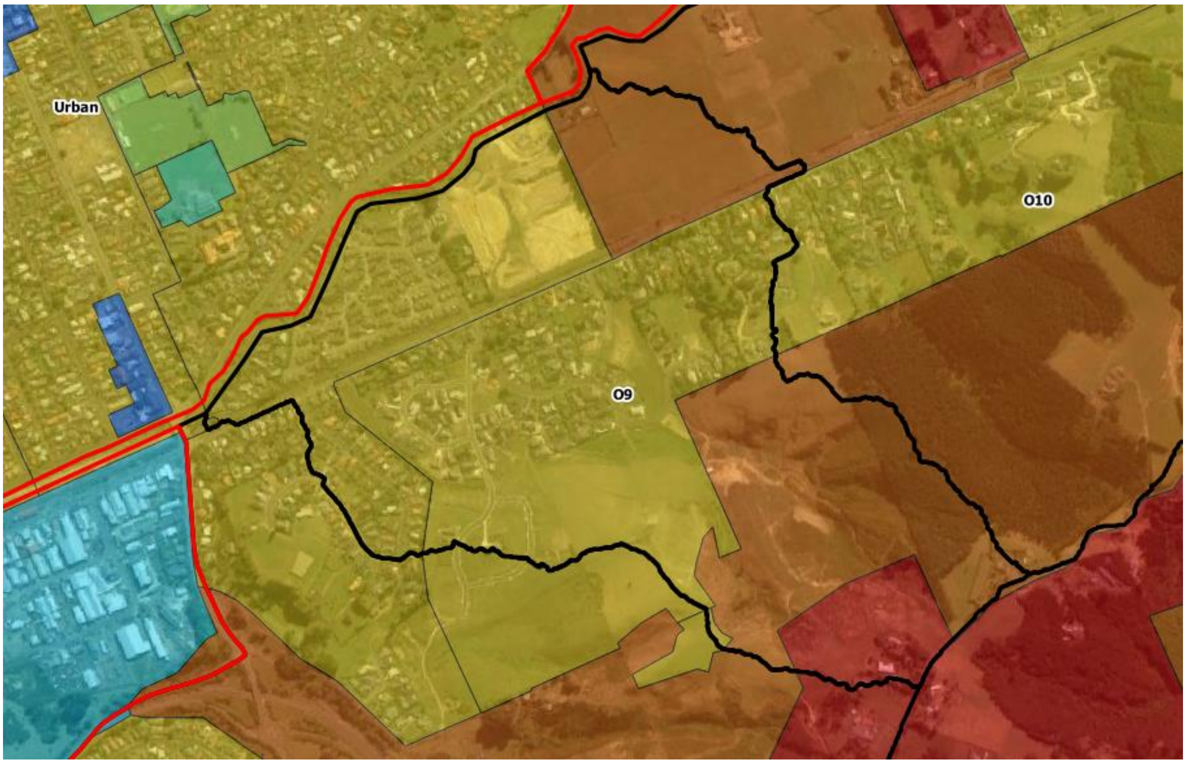


Figure 21 – Sub-catchment O9

Figure 22 shows runoff for sub-catchment O9. Similar to the "South urban" sub-catchment, a 7,500 m^3 (12%) difference is seen between existing and future land use in the model run, but again it isn't too significant in terms of the whole Owhiro Stream catchment.

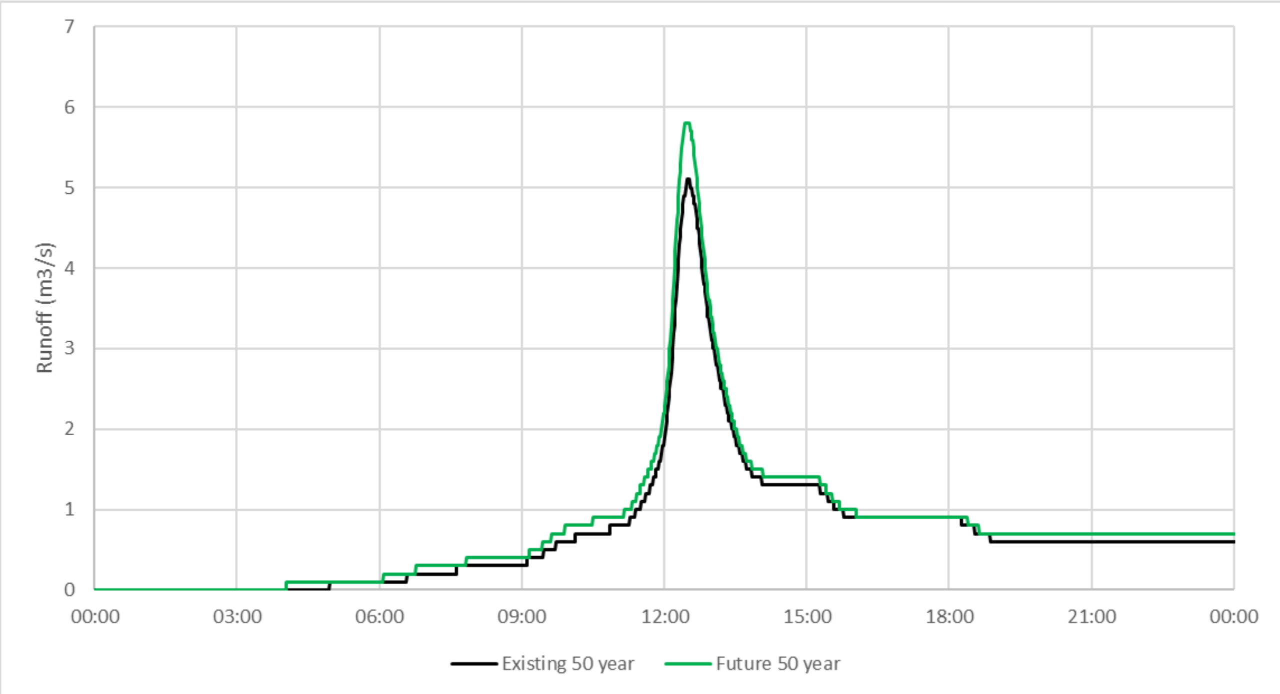


Figure 22 - Comparison of runoff for Sub-catchment O9

8.4 Plot scale effects of land use change

A worked example of a small sub-area within the "South urban" sub-catchment was shown earlier in the hydrological inputs section of this report. The area marked "Example plot" in Figure 4 is 100% rural (90% grass with some trees) currently and is zoned to become 100% residential area in the future. The area is a mix of poorly and imperfectly drained soil types, both designated as soil class "C" in the SCS curve number method.

The change from 100% rural to 100% urban land use in the example plot resulted in an approximate 30% increase in both peak flow and total runoff volume (Table 4 from the hydrological inputs section is repeated below as Table 13 showing full results).

Table 13 - Comparison of runoff volume and peak flow with land use change for example plot changing from 100% rural to 100% urban land use

	Existing land use	Future land use	Difference
Runoff volume	3,340 m^3	4,350 m^3	1,010 m^3 (30%)
Peak flow	0.45 m^3/s	0.59 m^3/s	0.14 m^3/s (31%)

Figure 23 - “South urban” sub-catchment with example plot shown

9 Design run results

9.1 Maximum flood depth maps

Maximum flood depths for all events are presented in Appendix E. For each flood event modelled, there are two maximum flood depth maps – one showing the full Owhiro Stream catchment, and an inset showing detail around Quarry Creek. The maps presented are as follows in Table 14.

Table 14 - Maximum flood depth maps presented in Appendix E

Map number	Scenario modelled	Map extent
3362485-WA-1001	Existing development / 100 year ARI	Full Owhiro Stream catchment
3362485-WA-1002	Existing development / 100 year ARI	Quarry Creek
3362485-WA-1003	Future development / 100 year ARI	Full Owhiro Stream catchment
3362485-WA-1004	Future development / 100 year ARI	Quarry Creek
3362485-WA-1005	Existing development / 50 year ARI	Full Owhiro Stream catchment
3362485-WA-1006	Existing development / 50 year ARI	Quarry Creek
3362485-WA-1007	Future development / 50 year ARI	Full Owhiro Stream catchment
3362485-WA-1008	Future development / 50 year ARI	Quarry Creek
3362485-WA-1009	Existing development / 10 year ARI	Full Owhiro Stream catchment
3362485-WA-1010	Existing development / 10 year ARI	Quarry Creek
3362485-WA-1011	Future development / 10 year ARI	Full Owhiro Stream catchment
3362485-WA-1012	Future development / 10 year ARI	Quarry Creek
3362485-WA-1013	Future development / 100 year ARI / Climate change (sensitivity check)	Full Owhiro Stream catchment
3362485-WA-1014	Future development / 100 year ARI / Climate change (sensitivity check)	Quarry Creek

Map number	Scenario modelled	Map extent
3362485-WA-1015	Future development / 50 year ARI / Climate change (sensitivity check)	Full Owhiro Stream catchment
3362485-WA-1016	Future development / 50 year ARI / Climate change (sensitivity check)	Quarry Creek
3362485-WA-1017	Future development / 100 year ARI / No gate closure (sensitivity check)	Full Owhiro Stream catchment
3362485-WA-1018	Future development / 100 year ARI / No gate closure (sensitivity check)	Quarry Creek

9.2 Owhiro Stream flow and water level hydrographs

Figure 25 and Figure 26 show water level hydrographs in Owhiro Stream downstream of areas where residential and industrial landcover is forecast to increase in the future development scenario. The locations where these hydrographs have been extracted from, and the associated areas where landcover is expected to increase, are highlighted in Figure 24. These locations were selected as they are close to the landcover changes and should be most sensitive to change in water level, and are clear of the effects of backwater in the downstream reaches of the Owhiro Stream caused by gate closure.

Majority of increased development in the 2GP District Plan is in the vicinity of Quarry Creek on the South banks of the Owhiro Stream. The expected increases in residential and industrial landcover are minor relative to the scale of the overall catchment and as such, the associated increases in water level in Owhiro Stream downstream of these areas are very small.

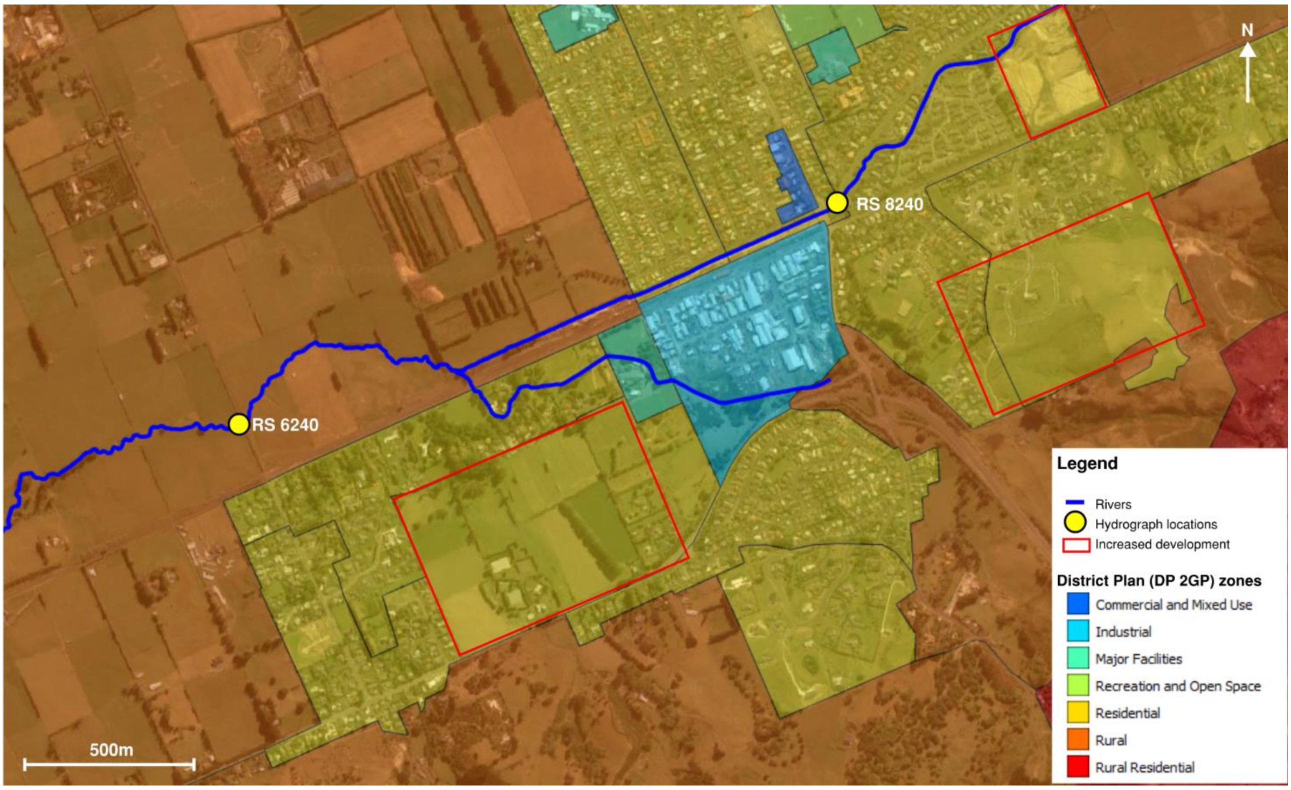


Figure 24 - Locations of water level hydrographs and relevant areas where residential and industrial landcover is expected to increase

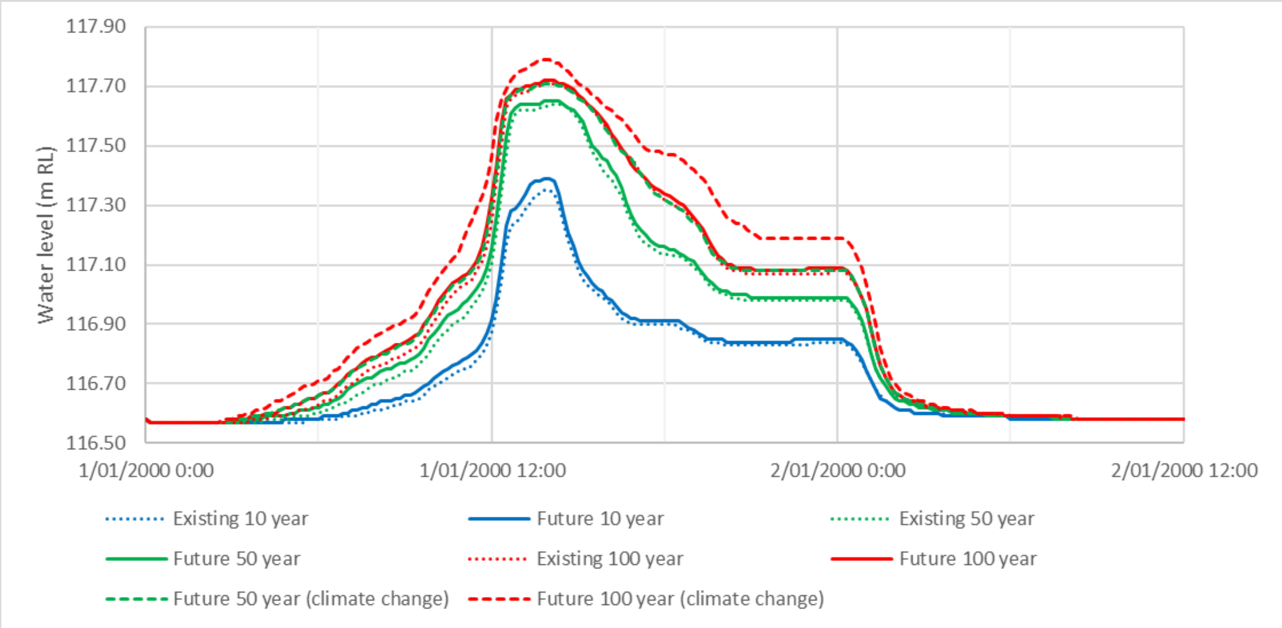


Figure 25 - Water level in Owhiro Stream downstream of Gordon Road (RS 8240 in hydraulic model)

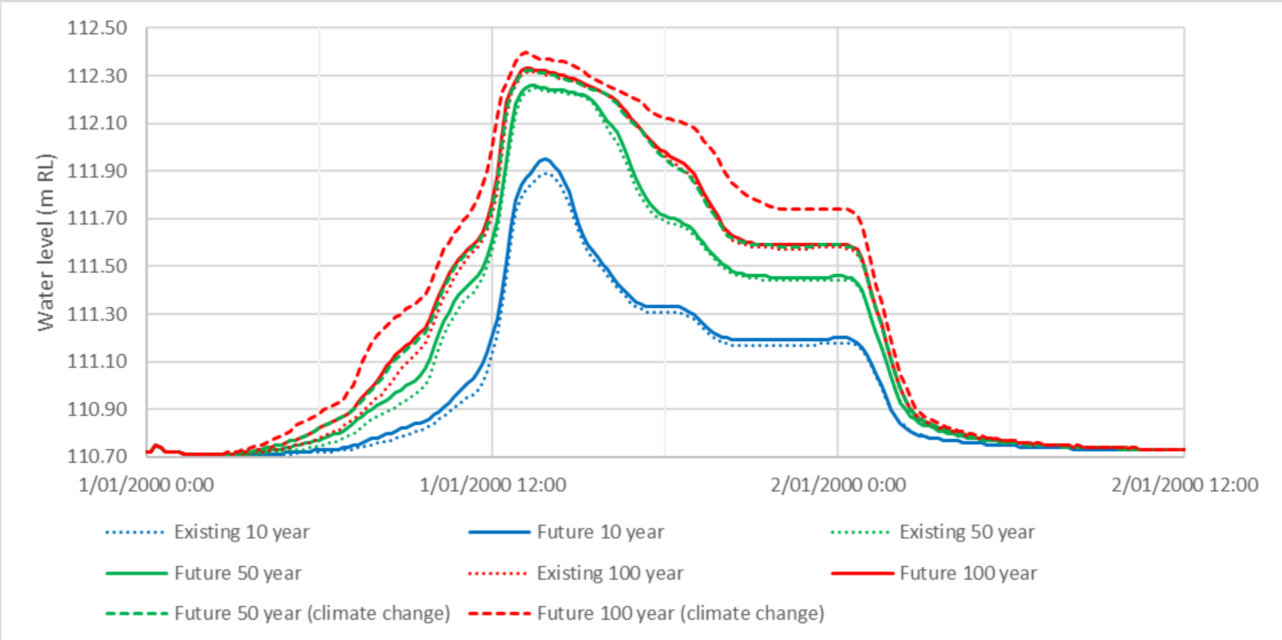


Figure 26 - Water level in Owhiro Stream downstream of Quarry Creek confluence and Riccarton Road West (RS 6240 in hydraulic model)

9.3 Owhiro Stream and Quarry Creek long-section and ponding levels

A long-section of Owhiro Stream, with maximum water levels in the future development 10, 50 and 100 year ARI events, is shown in Figure 27. The July 2017 calibration model profile, as well as the profile for the sensitivity check with no gate closure, are also shown for comparison. The existing development profiles have not been shown to help with clarity in the chart, but these sit very closely to the future development profiles for each storm event. A long-section showing the future development 10, 50 and 100 year ARI events for Quarry Creek follows in Figure 28.

The three different storm events produce similar ponding levels in Owhiro Stream, between 105.63 and 105.72m RL. This level of ponding means that water is backed up to about 2.5km upstream of the Owhiro floodgate (halfway between Riverside Rd and Gladfield Rd. This is in line with the ponding level of 105.71m observed in the calibration model run, which was close to surveyed debris marks from the July 2017 event. All three events (10, 50 and 100 year ARI) pond to a similar level regardless of the different rainfall volumes, and a similar level to that observed in July 2017 despite the different gate closure duration. There is a larger difference between water levels for each storm event in the upper reaches of the stream compared to the downstream reaches, because of the extent of ponding.

Water flows from the Owhiro Stream (right bank overtopping) into the Lower Pond at a relatively low level, well below the 50 or 100 year events. As such, the ponding level observed in the stream in the model runs reaches just above the maximum height of the stopbank to the lower pond, as at this level overflow into Lower Pond can start to occur. As storm runoff decreases, the ponding level for all storm events recedes slightly and stabilises at 105.59 m RL until floodgates are open again – at this level there is no longer overflow into the lower pond. Duration of ponding is five days, in line with the five days of gate closure controlling downstream water levels.

For comparison, with no gate closure the maximum water level reached upstream of the Owhiro floodgate is 104.01 m RL, which is not high enough to overflow into the Lower Pond.

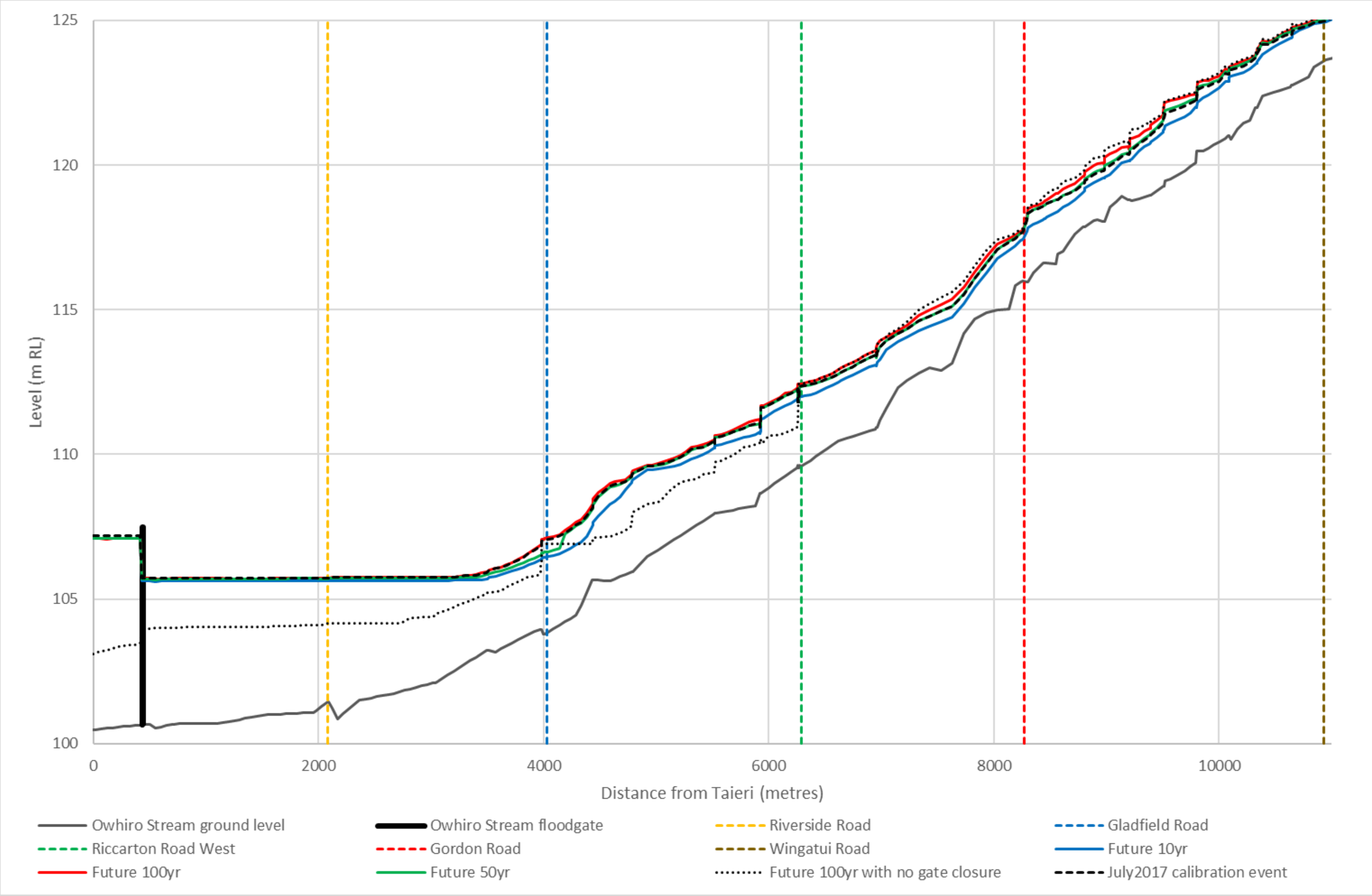


Figure 27 Long section showing maximum water level in Owhiro Stream in future development scenario model runs, with and without gate closure. Water levels from the July 2017 event are shown for reference

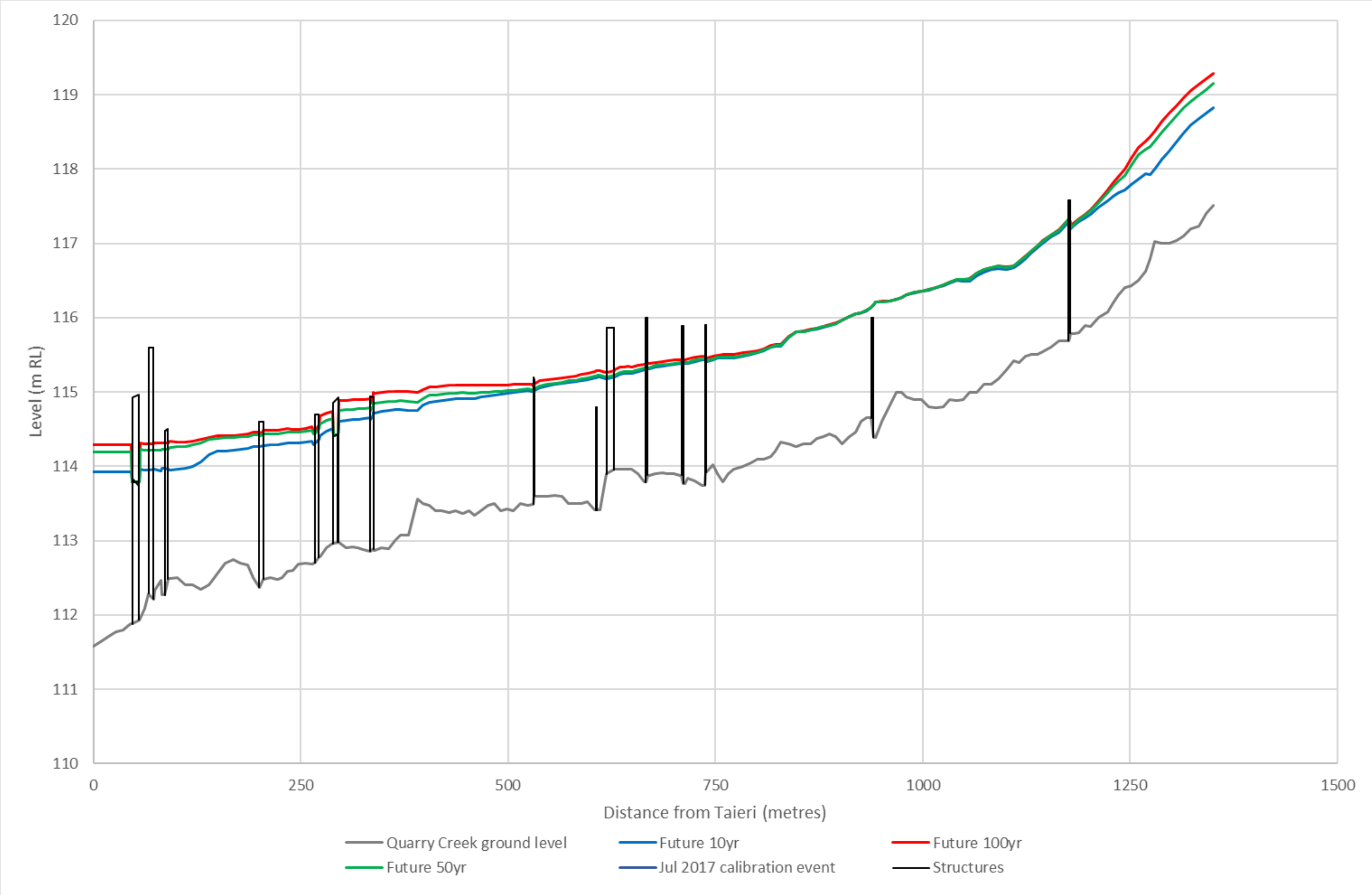


Figure 28 Long section showing maximum water level in Quarry Creek in future development scenario model runs.

9.4 Likely constriction points

9.4.1 Owhiro Stream

Several culverts and bridges along Owhiro Stream and Quarry Creek appear to be acting as constriction points, backing up water upstream and causing a drop in levels downstream of the culverts. Two examples of these are shown in Figure 29: Gordon Road, a major bridge in the urban area of Mosgiel, where the Owhiro Stream is deep and channelized; and a minor farm bridge further downstream in the rural area, where the stream has a more meandering planform and no stopbanks are present.

Gordon Road (chainage 8280, shown in Figure 29 and with the red dashed line in the Figure 27 channel profile) is an example of such a constriction point. In this area, the Owhiro Stream is deep and channelized and has enough capacity, especially downstream, to contain elevated water levels within its banks upstream of the constriction for the 10 year event, but overflow occurs in the larger 100 year event.

The small farm bridge at chainage 5916m constricts flow enough to cause some overflow even in the 10 year event, and in the 100 year event there is an extensive area of flooding in the area around the bridge.

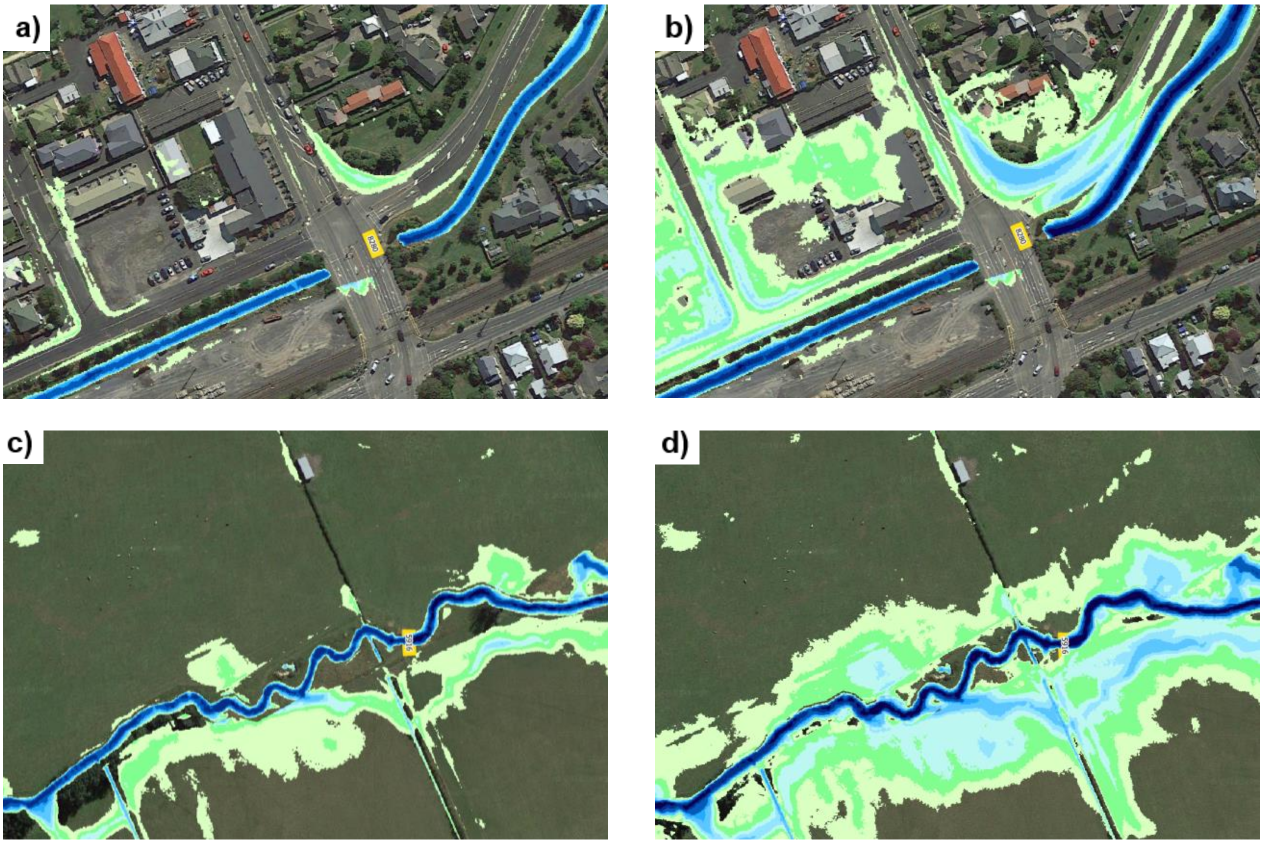


Figure 29 - Flood extent around Gordon Road bridge (chainage 8280m) and a small farm bridge (chainage 5916m)

a) Future development, 10 year ARI at Gordon Road bridge (chainage 8280m)
b) Future development, 100 year ARI at Gordon Road bridge (chainage 8280m)
c) Future development, 10 year ARI at small farm bridge (chainage 5916m)
d) Future development, 100 year ARI at small farm bridge (chainage 5916m)

9.4.2 Quarry Creek

As shown in the Quarry Creek long-section in Figure 28 above, water levels in the downstream end of Quarry Creek, near the confluence with Owhiro Stream, are affected by ponding and backflow from the main Owhiro Stream channel in all the flood events tested. As such, the three culverts close together at the downstream end of Quarry Creek don't appear to be a major constriction point. Figure 30 shows an example flow hydrograph for the furthest culvert downstream (see Figure 31 for culvert location). The dip in flow at the peak of the storm event indicated backflow from the main Owhiro Stream channel.

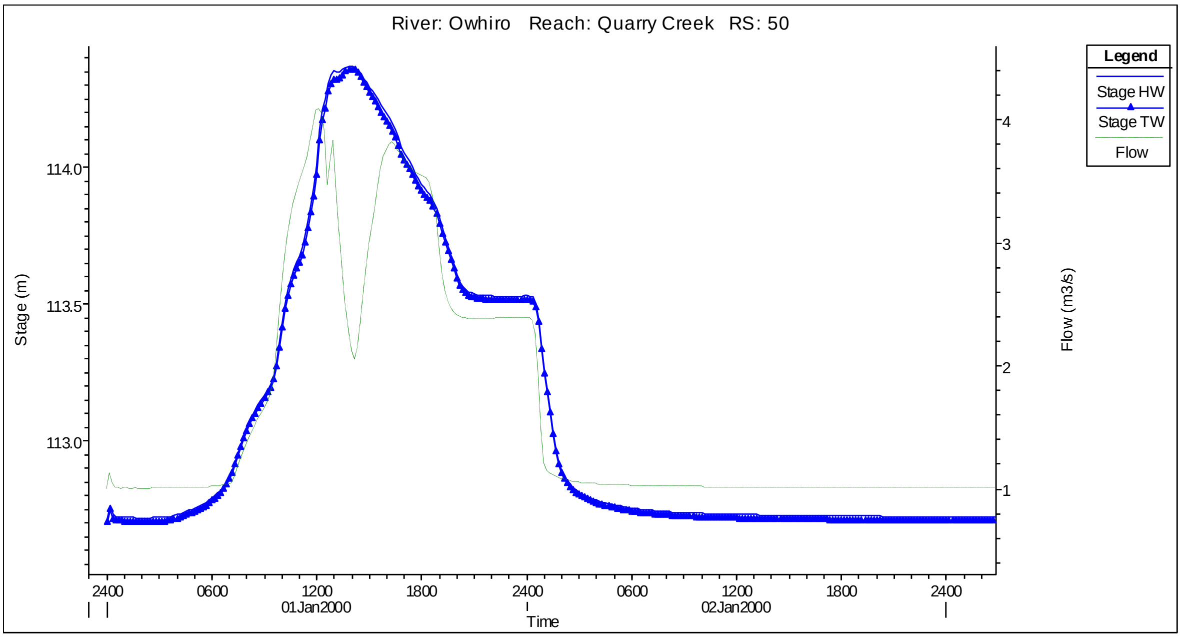


Figure 30 - Example flow hydrograph for culvert "RS50" at downstream end of Quarry Creek in the future development 100 year event, affected by backwater from Owhiro Stream. "Stage HW" refers to water level upstream of the culvert, and "Stage TW" refers to water level downstream of the culvert.

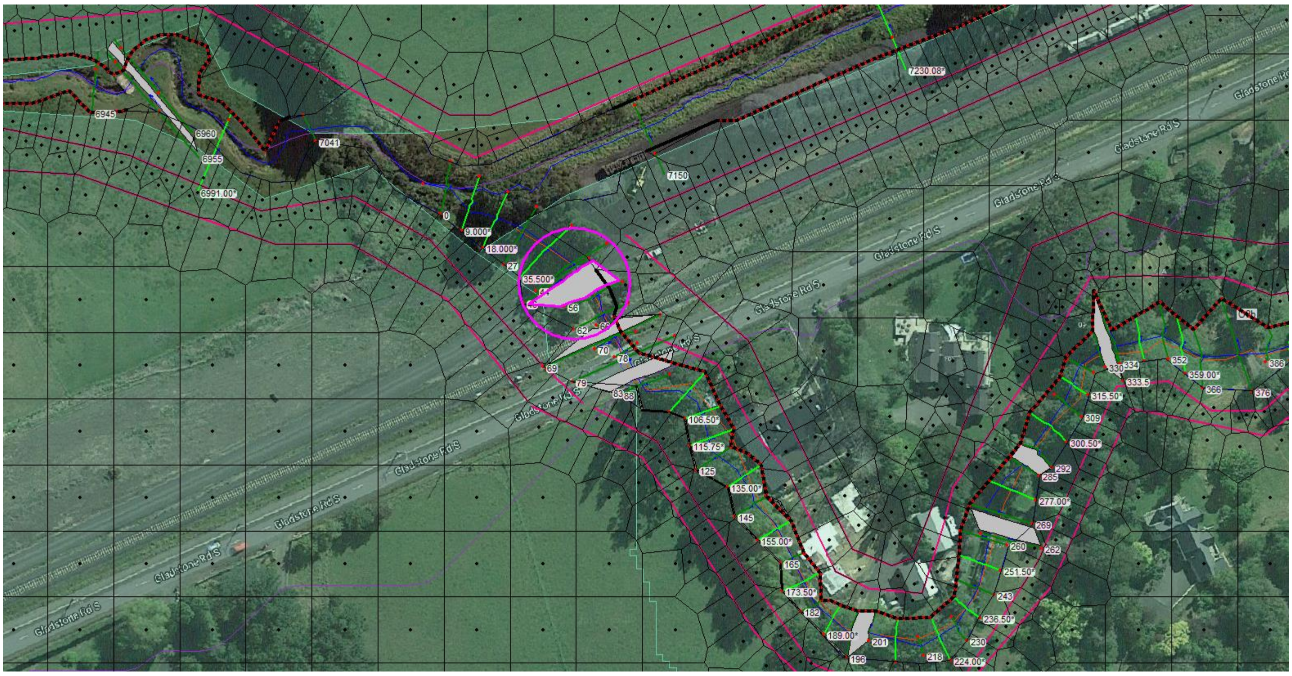


Figure 31 - Location of culvert "RS50", with flow plotted in previous figure. Culvert circled in pink.

The private driveway culverts slightly further upstream of Gladstone Road South (in particular those circled below in Figure 33) are above the ponding extent and present more of an issue in terms of constriction. Figure 32 shows a hydrograph for one of these culverts and indicates a significant headwater difference at the peak of the storm event.

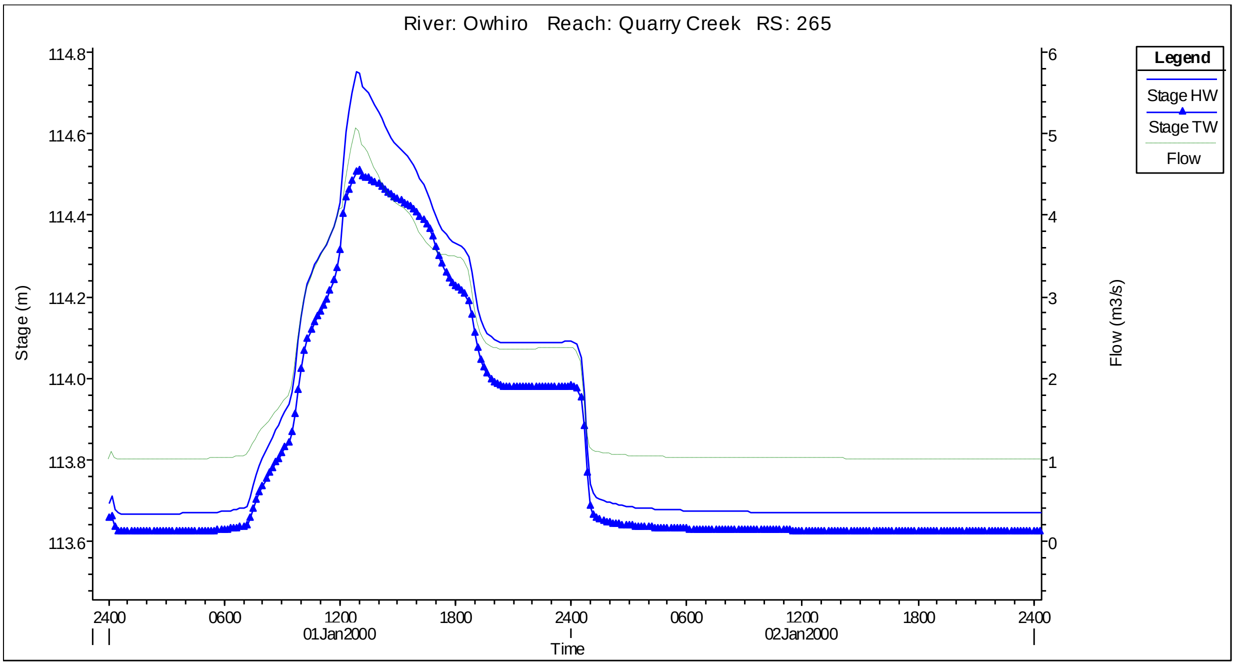


Figure 32 - Flow hydrograph for culvert "RS265" in the future development 100 year event, private driveway culvert that is an example of a likely constriction point for Quarry Creek. “Stage HW” refers to water level upstream of the culvert, and “Stage TW” refers to water level downstream of the culvert.

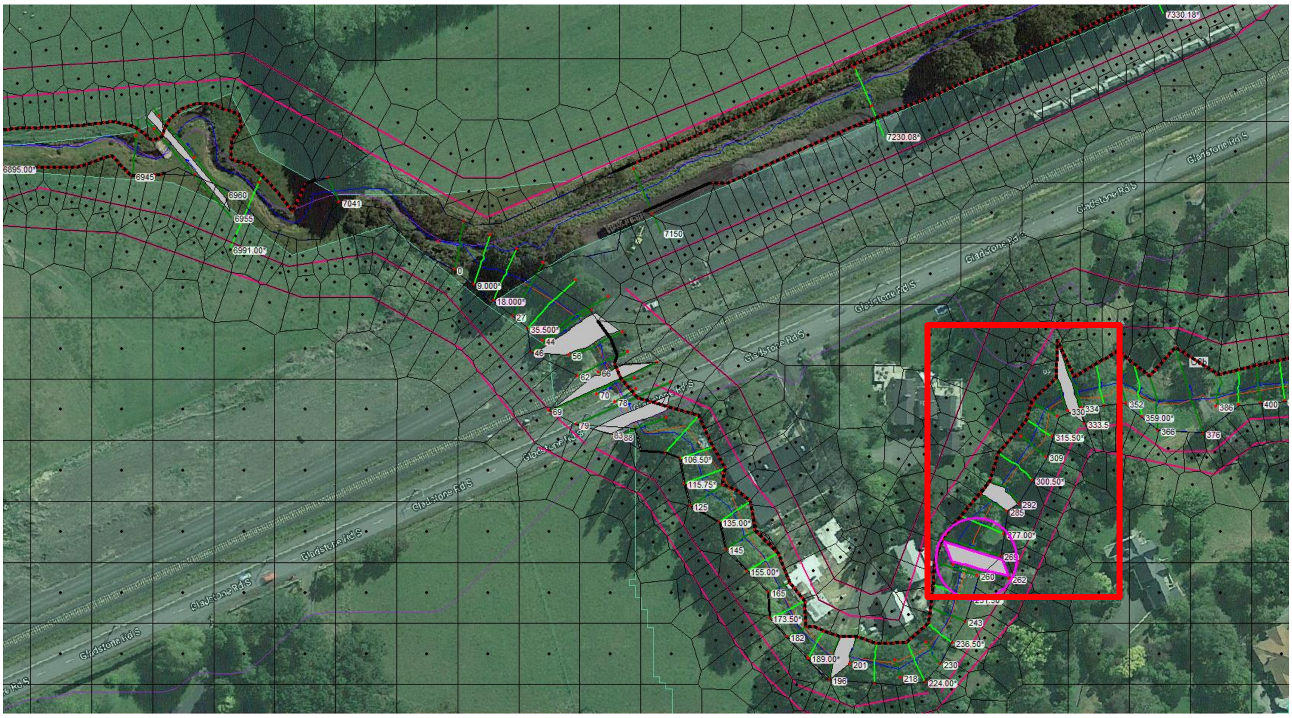


Figure 33 - Culvert "RS265" with flow shown in previous figure is circled in pink. The three culverts contained in the red outline are constriction points for Quarry Creek

9.5 Owhiro Stream and Quarry Creek maximum capacity

Table 15 and Figure 34 indicate the approximate maximum capacity of Owhiro Stream and Quarry Creek in different reaches based on the areas first expected to overtop in a flood event.

The flows reported are those modelled in the reach when that reach first overtopped in the flood model. The future development 10 year event model was focussed on to assess these, and the 100 year event with no gate closure was also examined, as the largest flow event (with no ponding) modelled.

Table 15: Estimates of maximum capacity for each channel

Stream	Reach	Approximate maximum flow m^3/s
Owhiro Stream	Lower reach below confluence with Quarry Creek	10 (can contain up to 25 m^3/s in larger sections)
Owhiro Stream	Engineered channel through Mosgiel urban area	20-25
Owhiro Stream	Upstream of Mosgiel	2-3
Quarry Creek	Lower reach	4-5
Quarry Creek	Upper reach	6-8

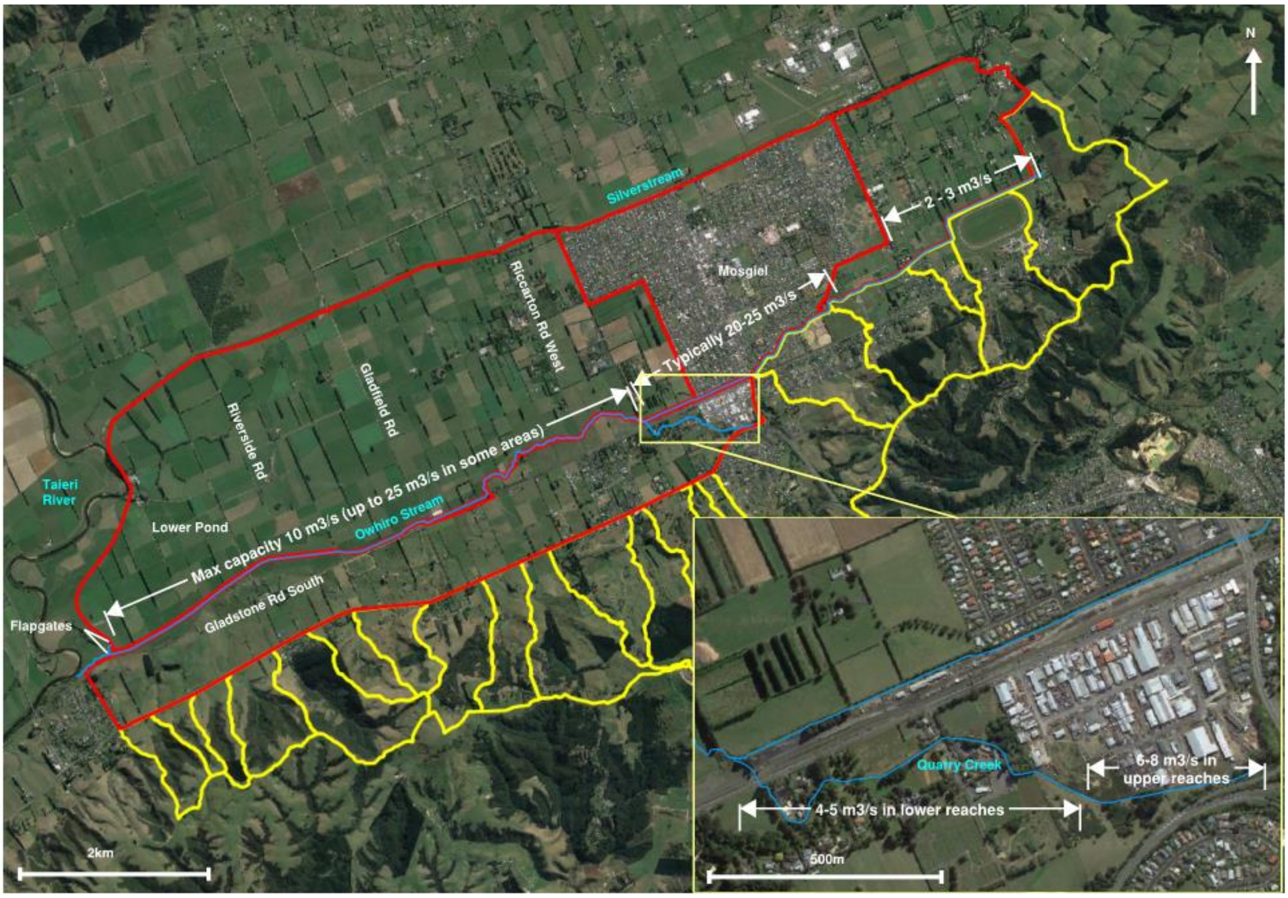


Figure 34 - Map showing typical capacity in Owhiro Stream and Quarry Creek

10 Model limitations

The results from this flood hazard study are affected by the following limitations:

- Mosgiel stormwater network has been excluded from model. This would reroute some of the initial runoff away from the surface from the Mosgiel area, but its absence from the model should not be significant in the larger flood events that have been modelled, where surface flows would dominate.
- Effects of debris blockage on structures has not been considered, and in some cases structures have been simplified or approximated using culverts.
- Changes to infiltration capacity, and thus runoff, are the only factors that have been considered when assessing effects of land-use change in this study. There has been no change to the surfaces used in terms of terrain (and thus storage capacity) or roughness.
- Accuracy of the hydraulic model will be limited to the accuracy of underlying survey and LiDAR data, and also how this data has been interpreted in the model build. An example of this is how in the connections between 2D floodplain areas and the main Owhiro Channel, resolution of terrain has been decreased to aid model stability.

11 Conclusions

11.1 Effects of land use change

At a local scale the Owhiro Stream model indicates significant increases in runoff due to land use change. At plot scale level, a single plot changing from 100% rural land use to 100% urban land use is expected to see a 30% increase in runoff volume and peak flow. Scaling this up to the land-use change predicted in the Second Generation District Plan, the sub-catchments experiencing most land-use change will see up to a 12 to 13% increase in runoff volume and peak flow.

In the context of the entire Owhiro Stream catchment, the effects of the land use changes proposed in the Second Generation District Plan, on duration, extent, and height of flooding in the Owhiro Stream and Lower Pond, will be minor overall, with a 1.9% increase in runoff expected. This is because the extent of new development proposed in the District Plan is small relative to the catchment area.

11.2 Effects of climate change

Expected climate change over the next 100 years (around +2°C) will have more of an impact on flooding in the Owhiro Stream and Lower Pond than the land use changes anticipated in the District Plan, with around 24% increase in runoff expected across the catchment.

11.3 Implications for future development

Owhiro Stream and Quarry Creek exhibit extensive flooding throughout their catchments in the storm events tested under both existing and future development scenarios. This impacts the location and feasibility of future development in the area. Predicted increases to rainfall due to climate change will exacerbate the duration, extent and depth of flooding throughout the catchment.

Future development in the area will have significant localised effects on runoff, and the following effects should be considered:

- Local increases to peak flow and volume of discharge from newly developed sites
- Loss of storage capacity due to filling in of floodplain areas.

12 References

MfE, 2016. Climate change projections for New Zealand: Atmospheric projections based on simulations undertaken for the IPCC 5th Assessment. Wellington: Ministry for the Environment.

Appendix A

Hydrological model inputs

Summary of HEC-HMS hydrological model inputs by catchment

Table 16 - Existing development soil drainage conditions for HEC-HMS modelled catchments

Catchment number	Area (km2)	SCS Curve Number	Initial abstraction (mm)	Lag time (min)
O2a	0.40	62	15.32	16.54
O2b	0.19	64	14.49	18.37
O2c	0.31	62	15.84	17.37
O3a	0.66	59	17.55	23.93
O3b	0.98	58	18.11	25.90
O4	0.41	65	13.74	14.57
O5a	0.45	63	14.89	22.09
O5b	0.8	63	14.82	24.17
O5c	0.61	65	13.95	22.40
O5d	1.12	66	13.34	30.53
O6	0.79	73	9.43	21.52
O7a	0.89	71	10.41	23.04
O7b	0.68	72	10.12	21.33
O8	2.97	72	9.91	31.37
O8a	0.13	75	8.29	11.67
O8c	0.23	75	8.58	15.94
O9	0.99	73	9.35	28.15
O10	1.22	67	12.75	32.47
O10a	0.23	78	7.16	14.62
O11	1.27	67	12.41	37.09
O12	1.70	72	10.11	28.73

Table 17 - Existing conditions for rain on grid catchments

Catchment number	Area (km2)	SCS Curve Number	Initial abstraction (mm)
Lower	12.62	73	9.19
Urban	4.73	79	6.74
Upper	2.72	71	10.53
South	4.06	74	9.15
South urban	1.12	74	9.07
Floodplain2	0.29	87	3.66

Table 18 – Future development soil drainage conditions for HEC-HMS modelled catchments (highlighted catchments have changed from existing condition)

Catchment number	Area (km2)	SCS Curve Number	Initial abstraction (mm)	Lag time (min)
O2a	0.40	62	15.32	16.54
O2b	0.19	64	14.49	18.37
O2c	0.31	62	15.84	17.37
O3a	0.66	59	17.55	23.93
O3b	0.98	58	18.11	25.90
O4	0.41	65	13.74	14.57
O5a	0.45	63	14.89	22.09
O5b	0.8	63	14.82	24.17
O5c	0.61	65	13.95	22.40
O5d	1.12	66	13.34	30.53
O6	0.79	73	9.43	21.52
O7a	0.89	72	10.12	22.77
O7b	0.68	72	10.12	21.33
O8	2.97	73	9.28	31.00
O8a	0.13	76	7.89	11.53
O8c	0.23	75	8.58	15.94
O9	0.99	77	7.47	26.86
O10	1.22	70	10.70	31.31
O10a	0.23	81	5.95	14.13
O11	1.27	69	11.31	36.19
O12	1.70	72	10.06	28.73

Table 19 – Future development conditions for rain on grid catchments (highlighted catchments have changed from existing condition)

Catchment number	Area (km2)	SCS Curve Number	Initial abstraction (mm)
Lower	12.62	73	9.19
Urban	4.73	80	6.27
Upper	2.72	71	10.53
South	4.06	74	9.15
South urban	1.12	78	6.97
Floodplain2	0.29	89	3.22

Appendix B

Hydraulic model structure data

Table 20 - Owhiro Stream structure data used in HEC-RAS model. All data based on 2017 survey provided by ORC, unless stated otherwise

ID	Structure Description	Type	Chainage in HECRAS[2] (m)	Length (m)	Distance from upstream XS[2] (m)	US IL (m RL)	DS IL (m RL)	Deck height (m RL) / Culvert dimensions	Soffit level (m RL)
B1	Riverside Rd	Bridge[1]	2080	8.26	5	101.434	101.434	1x 6.37W x 3.2H	104.66
B2		Bridge	3030	3.85	6	102.1	102.1	106.03	105.18
B3		Bridge	3505	3.8	18	103.22	103.22	107.3	106.82
B4	Gladfield Rd	Bridge[2]	3980	9.6	2	103.94	103.94	2x 3.66W x 2.49H	106.96
B5		Bridge	4005	3.3	3	103.79	103.79	107.8	107.05
B6		Bridge	4436	2.8	3	105.66	105.66	109.68	108.46
B7		Bridge	4785	3.1	3	106.94	106.94	109.3	108.97
B8		Bridge	5520	1.9	1	107.96	107.96	110.6	109.8
B9		Bridge	5916	2.85	3	108.66	108.66	111.8	110.52
B10	Riccarton Rd	Bridge[1]	6260	9.6	7.5	109.61	109.61	2x 3.66W x 2.27H	111.8
B11		Bridge	6958	2.7	1	110.93	110.93	113.45	113.17
B12	Gordon Rd	Bridge	8280	35.1	5	115.95	115.99	118.57 US, 118.95 DS	118.02 US 118.06 DS
B13	First road u/s Gordon Rd	Bridge	8460	7.4	15	116.62	116.62	118.84	119.05
B14		Bridge	8800	10	5	117.87	117.87	120.83	120.13
B15		Bridge	8980	4.2	4	118.05	118.05	120.12	119.66
B16		Bridge	9210	9.1	3	118.8[2]	118.8[2]	120.95	120.15
B17		Bridge	9390	3	3	118.96	118.96	121.43	121.18
B18		Bridge	9510	4.1	3	119.27	119.27	122.08	121.4
B19		Bridge	9795	4	3	120.5	120.5	122.5	122.13
B20		Bridge	10085	3.8	1	121.01	121.01	122.8	122.4
B21	Wingatui Rd	Bridge[1]	10330	12.6	1	122.49[2]	122.49[2]	2x 1.80W x 1.74H	124.25
B22		Bridge	10645	3.15	2	122.76	122.76	124.7	124.15

1) Bridge with piers, modelled as one (B1) or two (B4, B10, B21) box culverts. B10 and B21 modelled with one culvert partly filled.

2) Parameters estimated graphically in HEC-RAS

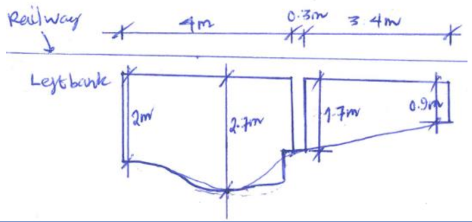
Table 21 – Quarry Creek structure data used in HEC-RAS model. Data based on 2017 survey provided by ORC, except for those structures supplemented with past survey data as indicated

ID	Type/Description	Chainage in HECRAS[2] (m)	Length (m)	Distance from upstream XS[2] (m)	Upstream invert level (m RL)	Downstream invert level (m RL)	Soffit level (m RL)	Deck height (m RL)
QC1	Culverts (2x 1.8dia)	50	7.8	1	111.99[1]	111.99[1]	113.80[1]	114.96[1]
QC2	Bridge	68	6	0.5	112.21	112.29[1]	114.45	115.60[1]
QC3	Bridge	83	3.7	2	112.49[1]	112.27	114.00	114.50[1]
QC4a	Bridge	198	4.8[1]	0.1	112.48[1]	112.37[1]	114.08[1]	114.60[1]
QC4	Bridge	265	5.1	1	112.78[1]	112.70	114.41	114.70
QC5	Culvert (concrete semi-circle 2.7m wide)	290	6	0.5	112.98[1]	112.96[1]	114.41	114.95[1]
QC6	Bridge	332	3.6	0.2	112.89	112.86[1]	114.44	114.94[1]
QC7	1.5dia culvert (EXCLUDED from model, unstable)	380	4.6	2	113.42[1]	113.56[1]	115.02[1]	115.83[1]
QC8	Bridge (footbridge)	526	0.9	6	113.60[1]	113.49	115.00	115.20
QC9	Bridge (footbridge)	605	1.1	3	113.41	113.53[1]	114.70	114.80
QC10	Bridge (Cemetery Rd)	620	9.2	0.5	113.96	113.90	115.51	115.87[1]
QC11	Bridge	662	2.4	1	113.88	113.79[1]	115.58	116.00
QC12	Bridge	706	2.4	2	113.77	113.88[1]	115.48	115.89
QC13	Bridge	732	0.9	1	113.92	113.75[1]	115.66	115.90
QC14	Bridge (derelict)	935	2.4	2	114.39	114.65[1]	115.88	116.00
QC15	Bridge	1170	2.2	0.5	115.79[1]	115.69[1]	117.38	117.58

1) Data sourced from past (2015) survey

2) Parameters estimated graphically in HEC-RAS

Table 22 - Data for culverts in 2D area between railway and Main Road South, as provided by ORC

Culvert Code	Easting	Northing	Length (m)	Width (m)	Height (m)	Material	Remarks
1	1388613.4521	4912501.6319	4.3	3.2	2.1	Concrete	Across Railway
2	1388649.8588	4912507.5586	10	0.8	0.8	Rock	Across Railway
3	1389227.1279	4912972.5541	12.4	1.2	1.2	Concrete	Across Railway
4	1390210.8507	4913268.6235	14	450mm dia		Concrete	Across Railway
5	1390216.4069	4913221.7921	10	250mm dia		Concrete	Across road
6	1390576.7702	4913398.2696	5.5	900mm dia		Concrete	Across Railway
7	1390582.3264	4913385.3050	10	600mm dia		Concrete	Across road
8	1390806.9581	4913500.9281	4.1			Concrete	Across Railway. Bridge, see detail
9	1390817.8061	4913490.8739	10	1500mm dia		Concrete	Across road
10	1391195.6318	4913659.1492	44	300mm dia		Steel	Across Railway+Road
11	1391446.1927	4913687.4597	5.3	1.9	1.2	Concrete	Across road
12	1392372.0246	4913579.6506	5.5	900mm dia		Concrete	Across road
13	1392189.5914	4914103.8821	32	0.9	1.4	Brick	Across Railway+Road
14	1393345.4050	4914647.0717	7.4	twin 1050mm dia		Concrete	Across road
15	1393350.3792	4914638.2875	7.4	twin 1000mm dia		Concrete	Across Railway
16	1393357.4701	4914627.4925	10	2.5	1.3	Concrete	Across road
17	1393380.3985	4914237.3900	25.1	1050mm dia		Concrete	Across road
18	1393397.0672	4914328.6714	40	1050mm dia		Concrete	Across road
19	1394167.5531	4914662.9202	19	twin 450mm dia		Plastic	Across road

Appendix C

Hydraulic model boundary conditions

Table 23 - Inflow boundary conditions details

Catchment	Inflow type	Location		
		Chainage	**River**	**2D flow area**
O2a	2D inflow hydrograph			South
O2b	2D inflow hydrograph			South
O2c	2D inflow hydrograph			South
O3a	2D inflow hydrograph			South
O3b	2D inflow hydrograph			South
O4	2D inflow hydrograph			South
O5a	2D inflow hydrograph			South
O5b	2D inflow hydrograph			South
O5c	2D inflow hydrograph			South
O5d	2D inflow hydrograph			South
O6	2D inflow hydrograph			South
O7a	2D inflow hydrograph			South urban
O7b	2D inflow hydrograph			South urban
O8	1D inflow hydrograph	1346	Quarry Creek	
O8a	2D inflow hydrograph			South urban
O8c	2D inflow hydrograph			South urban
O9	1D inflow hydrograph	8616	Owhiro Stream	
O10	1D inflow hydrograph	10104	Owhiro Stream	
O10a	1D inflow hydrograph	10711	Owhiro Stream	
O11	1D inflow hydrograph	10846	Owhiro Stream	
O12	1D inflow hydrograph	12046	Owhiro Stream	
Upper	Rain on grid			Upper
Urban	Rain on grid			Urban
Lower	Rain on grid			Lower
South	Rain on grid			South
South urban	Rain on grid			South urban
Floodplain2	Rain on grid			Floodplain2

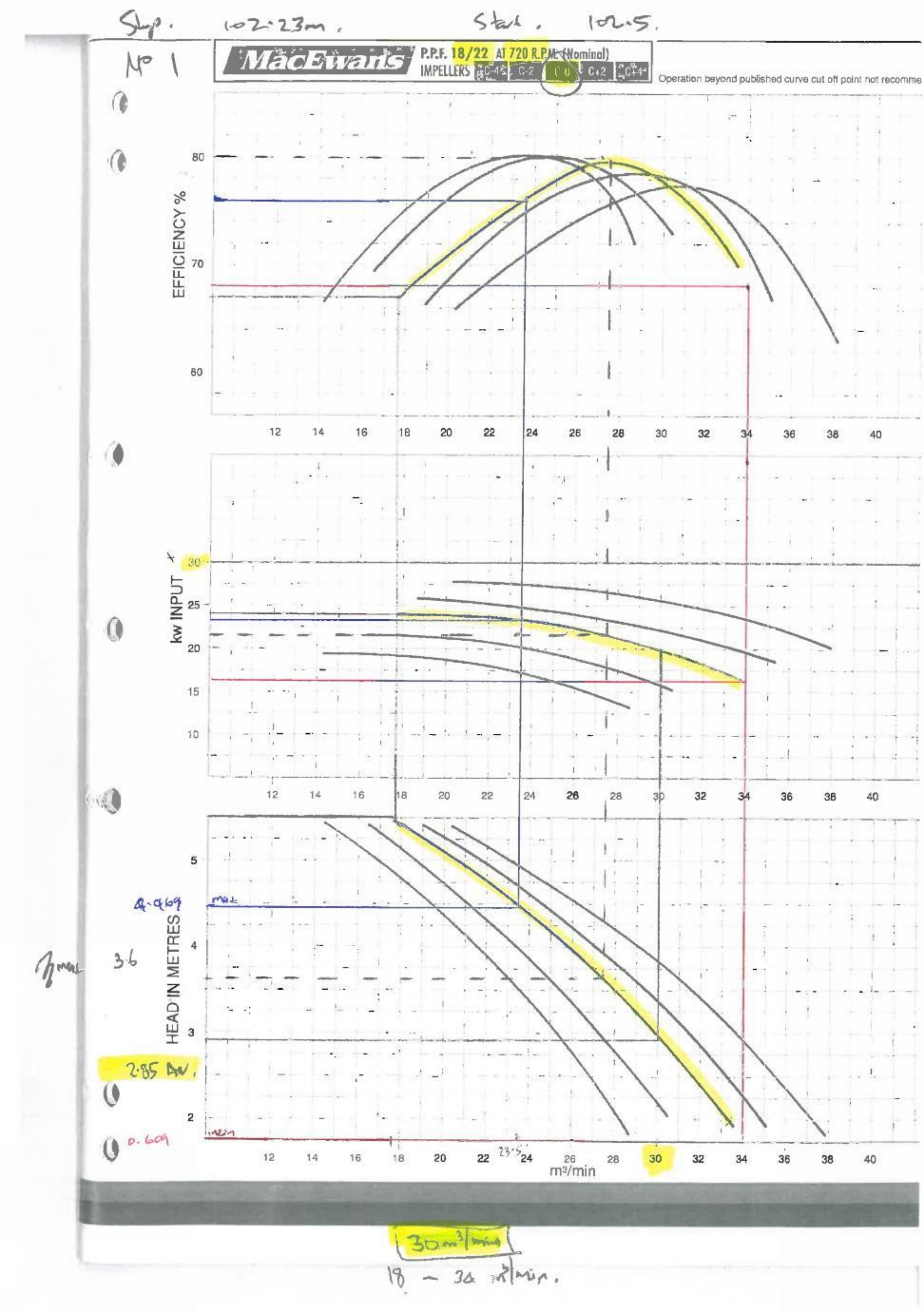


Figure 35 - Mill Creek pump rating curves supplied by ORC - Pump 1

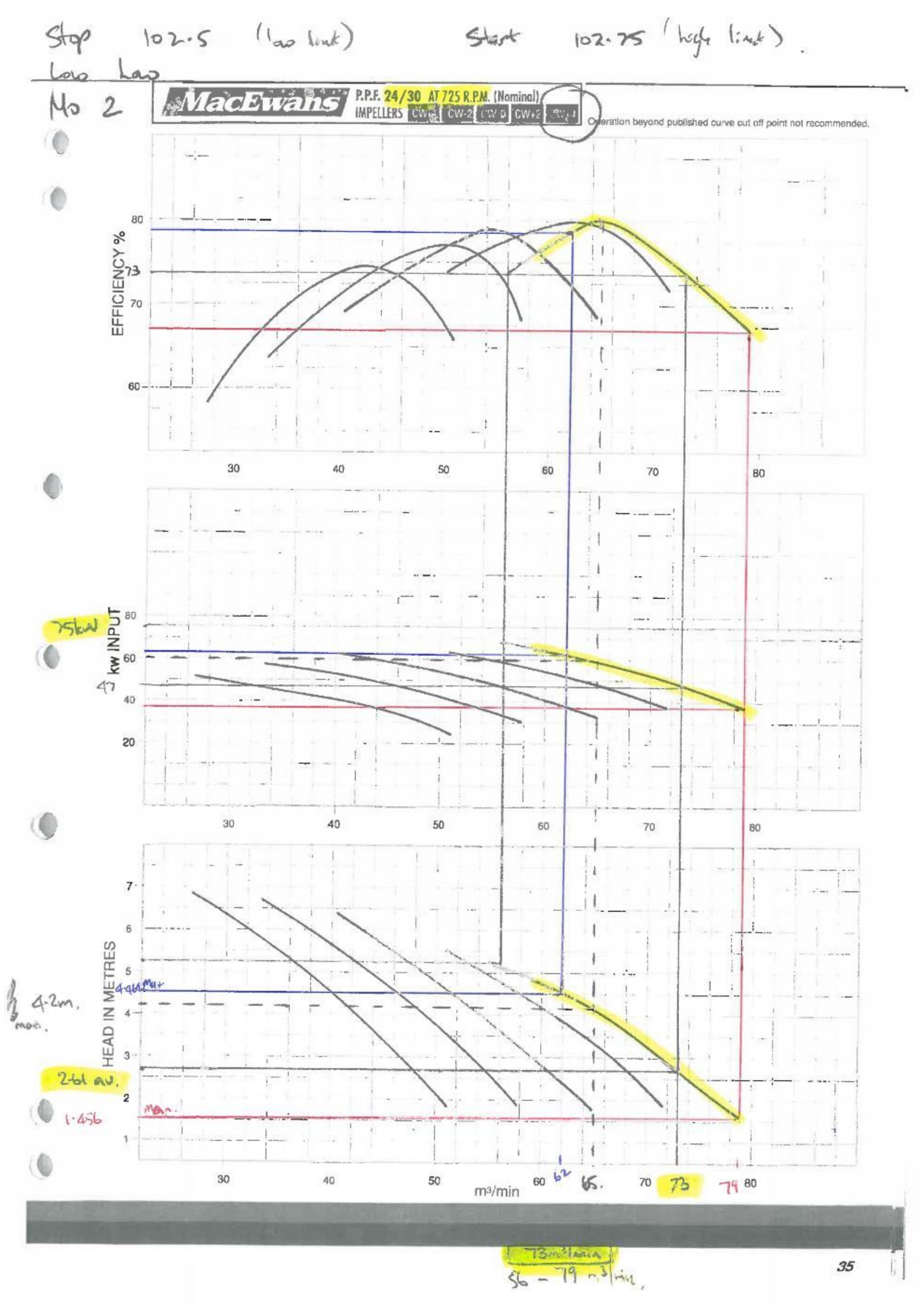


Figure 36 - Mill Creek pump data supplied by ORC - Pump 2

Appendix D

Calibration model result maps

3362485-WA-0001	Comparison between modelled water levels and debris marks	
3362485-WA-0002	Maximum Flood Depth – July 2017 calibration event	Full Owhiro Stream catchment
3362485-WA-0003	Maximum Flood Depth – July 2017 calibration event	Quarry Creek

Legend

- Max flood extent modelled (depths above 100mm shown only)

Difference between modelled water level and debris mark levels in July 2017 event

- -1.50 to -0.30
- -0.30 to -0.10
- -0.10 to 0.10
- 0.10 to 0.30
- 0.30 to 1.50

This map compares modelled peak water levels with surveyed debris marks for the July 2017 flood event in Owhiro Stream.

Orange and red markers (positive values) indicate that modelled water level is higher than surveyed debris marks.

Yellow markers indicate the modelled water levels are within +/- 100mm of surveyed debris marks.

Green markers (negative values) indicate the modelled water levels are lower than surveyed debris marks.

0 500 1000 1500 m

Notes:

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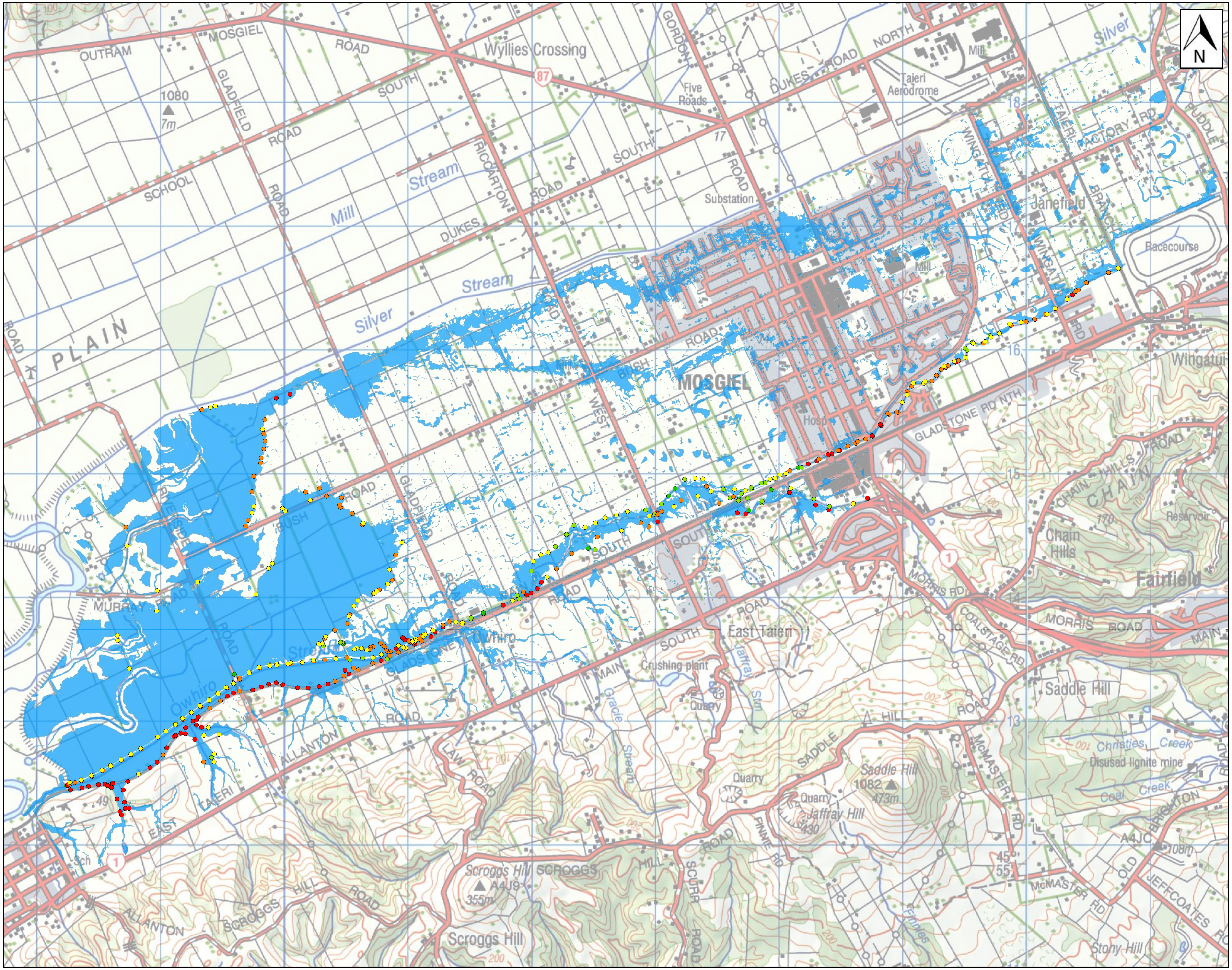

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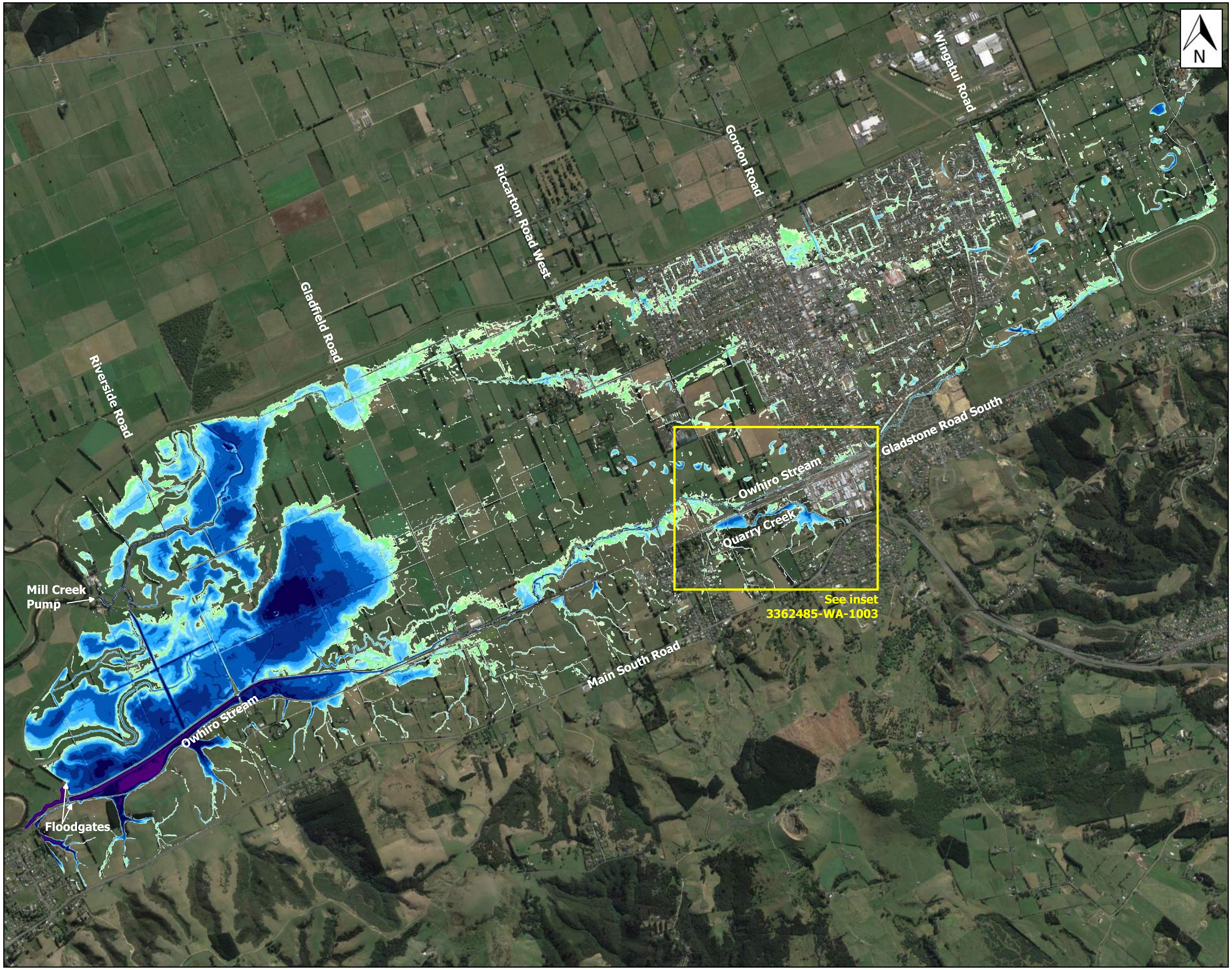
DRAWING No.	3362485-WA-0001	

OWHIRO FLOOD HAZARD STUDY

COMPARISON BETWEEN MODELLED WATER LEVELS AND DEBRIS MARKS

JULY 2017 CALIBRATION EVENT

Beca



Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m

Notes:

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SCALE (AT A3 SIZE)	1:30,000	
DRAWING No.	3362485-WA-1002	

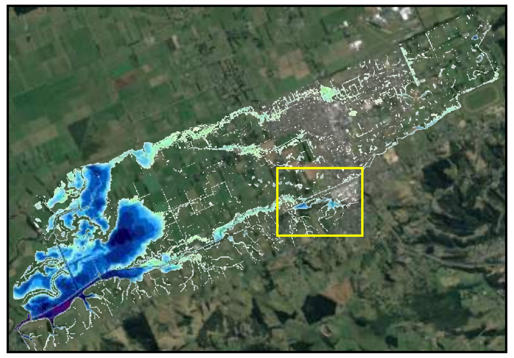
OWHIRO FLOOD HAZARD STUDY

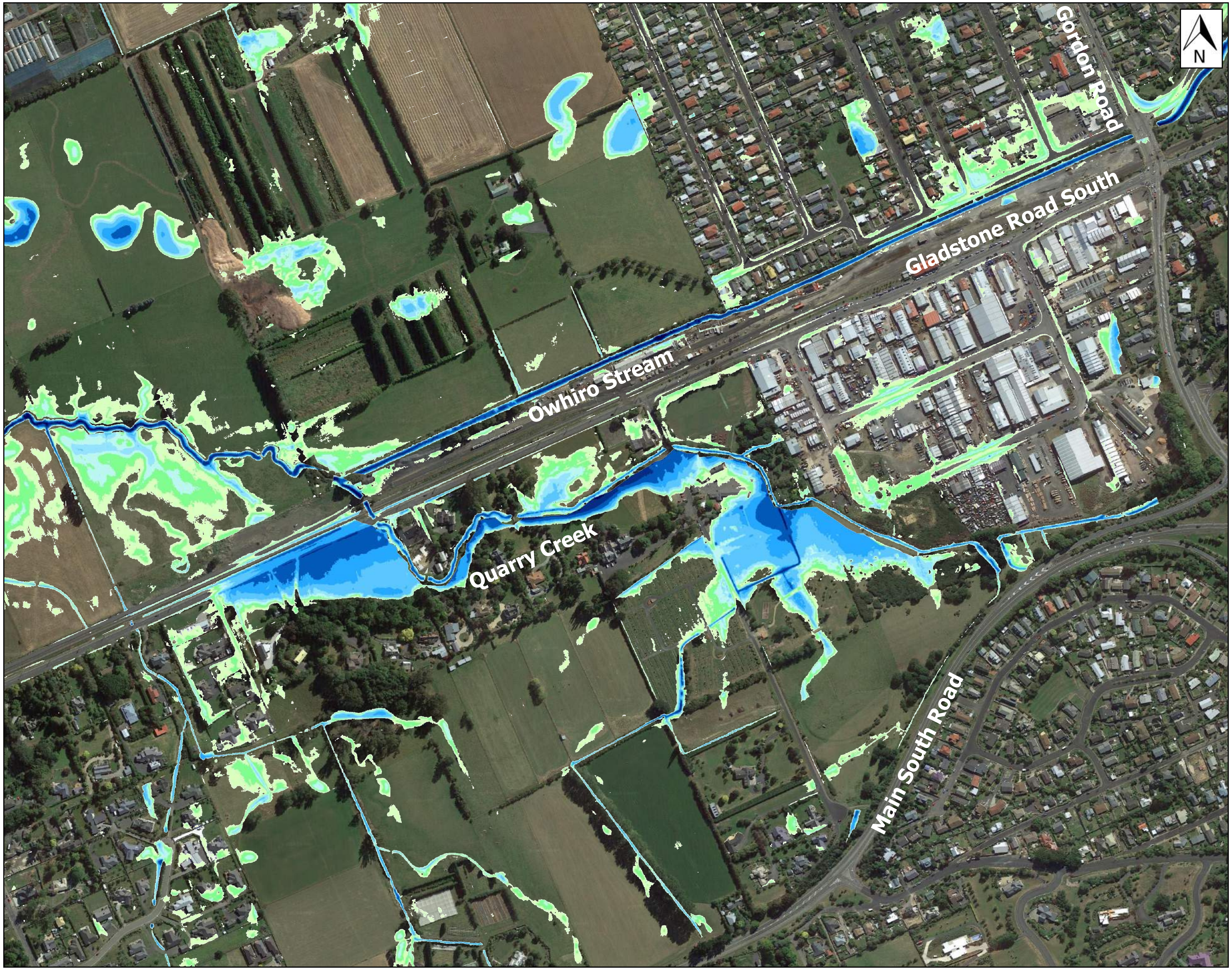
MAXIMUM FLOOD DEPTH

FUTURE LAND USE - JULY 2017 CALIBRATION EVENT

FULL OWHIRO STREAM CATCHMENT

Beca





Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m

Notes:

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SCALE (AT A3 SIZE)	1:5,000	
DRAWING No.	3362485-WA-0003	

OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

EXISTING LAND USE - JULY 2017 CALIBRATION EVENT

QUARRY CREEK

Beca

Appendix E

Maximum Flood Depth maps

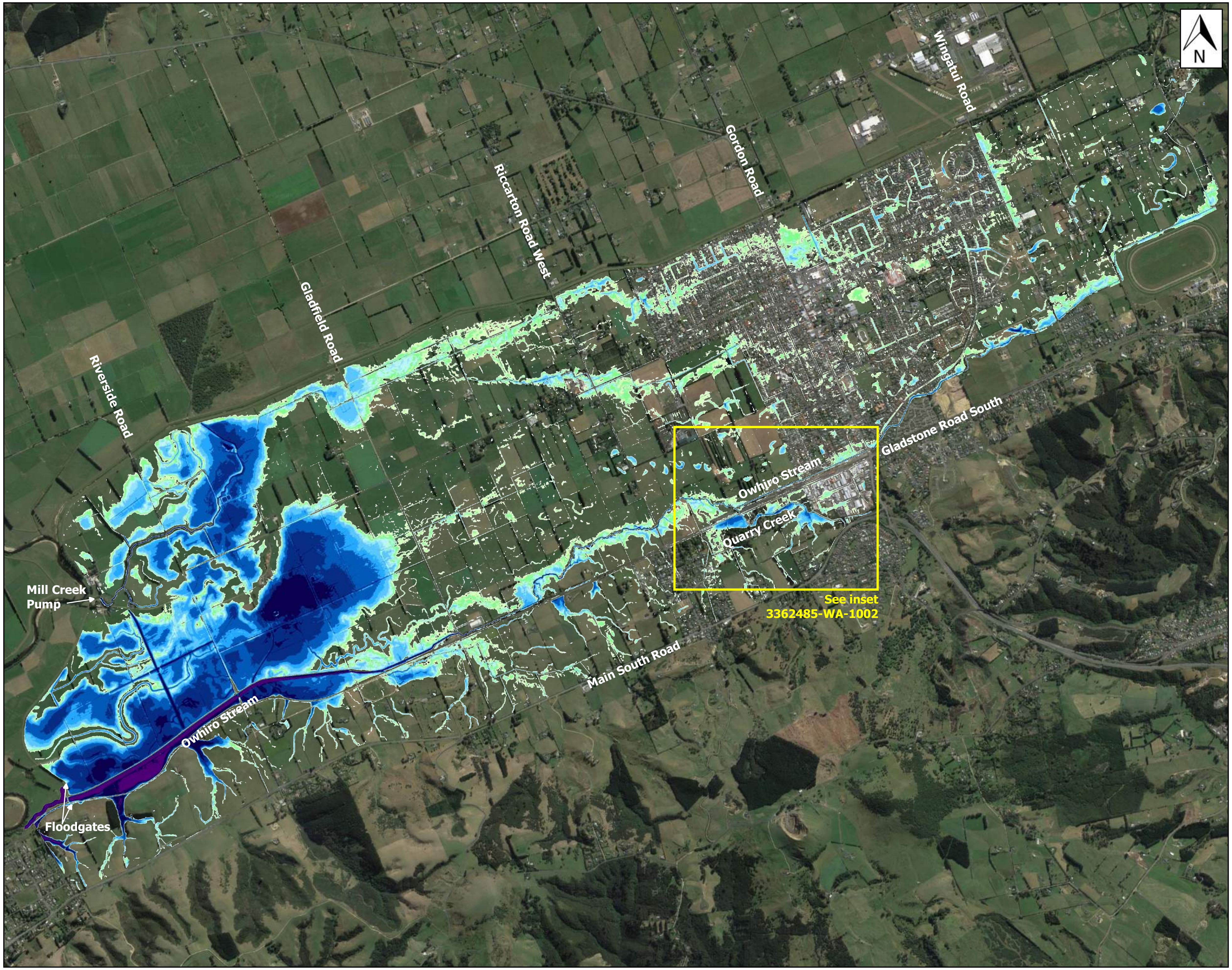
3362485-WA-1001	Existing development / 100 year ARI	Full Owhiro Stream catchment
3362485-WA-1002	Existing development / 100 year ARI	Quarry Creek
3362485-WA-1003	Future development / 100 year ARI	Full Owhiro Stream catchment
3362485-WA-1004	Future development / 100 year ARI	Quarry Creek
3362485-WA-1005	Existing development / 50 year ARI	Full Owhiro Stream catchment
3362485-WA-1006	Existing development / 50 year ARI	Quarry Creek
3362485-WA-1007	Future development / 50 year ARI	Full Owhiro Stream catchment
3362485-WA-1008	Future development / 50 year ARI	Quarry Creek
3362485-WA-1009	Existing development / 10 year ARI	Full Owhiro Stream catchment
3362485-WA-1010	Existing development / 10 year ARI	Quarry Creek
3362485-WA-1011	Future development / 10 year ARI	Full Owhiro Stream catchment
3362485-WA-1012	Future development / 10 year ARI	Quarry Creek
3362485-WA-1013	Future development / 100 year ARI / Climate change (sensitivity check)	Full Owhiro Stream catchment
3362485-WA-1014	Future development / 100 year ARI / Climate change (sensitivity check)	Quarry Creek
3362485-WA-1015	Future development / 50 year ARI / Climate change (sensitivity check)	Full Owhiro Stream catchment
3362485-WA-1016	Future development / 50 year ARI / Climate change (sensitivity check)	Quarry Creek
3362485-WA-1017	Future development / 100 year ARI / No gate closure (sensitivity check)	Full Owhiro Stream catchment
3362485-WA-1018	Future development / 100 year ARI / No gate closure (sensitivity check)	Quarry Creek

Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m



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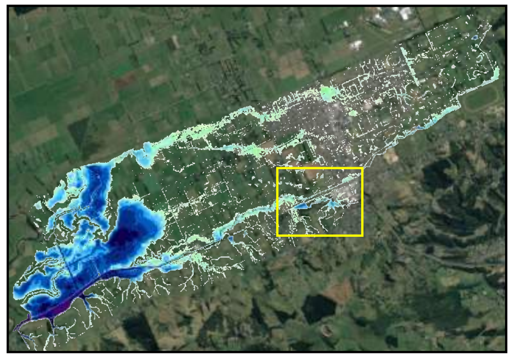
DRAWING No.	3362485-WA-1001	

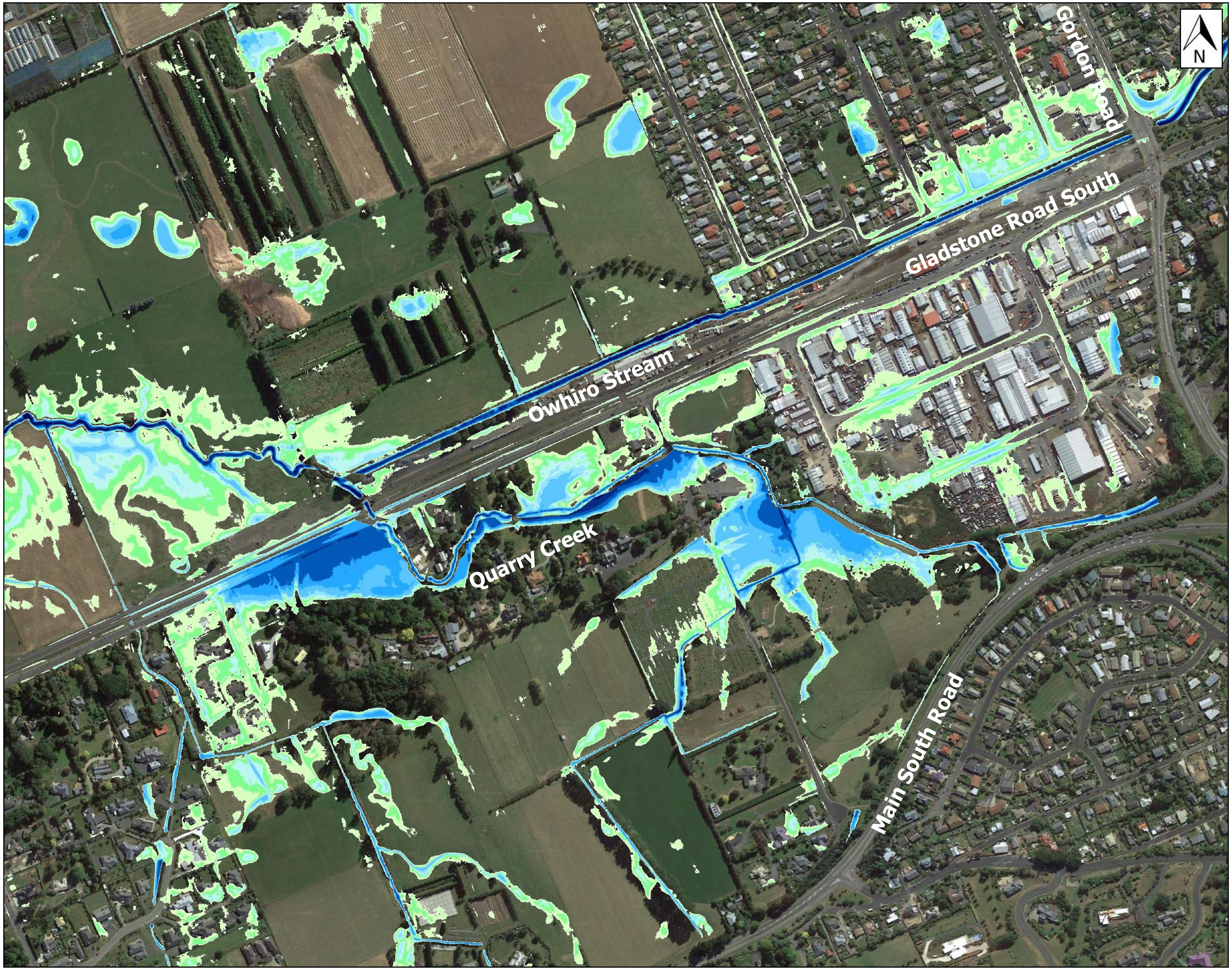
OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

EXISTING LAND USE - 100YR ARI RAIN EVENT

FULL OWHIRO STREAM CATCHMENT





Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m

Notes:

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OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

EXISTING LAND USE - 100YR ARI RAIN EVENT

QUARRY CREEK

Beca

Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m

Notes:

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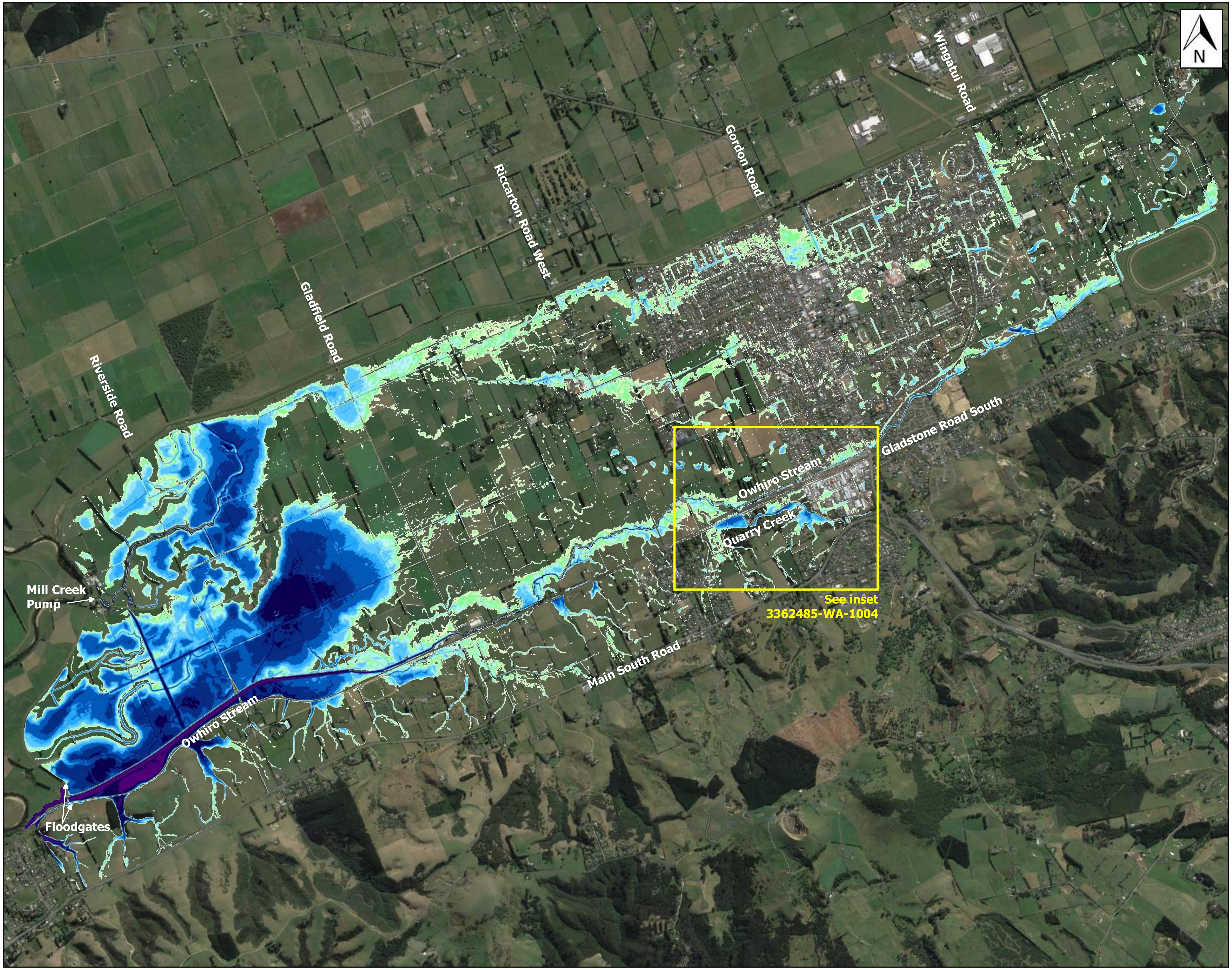


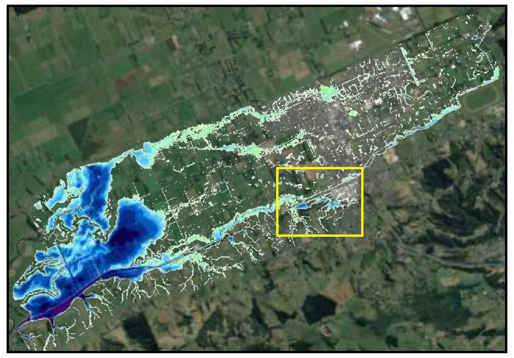
OWHIRO FLOOD HAZARD STUDY

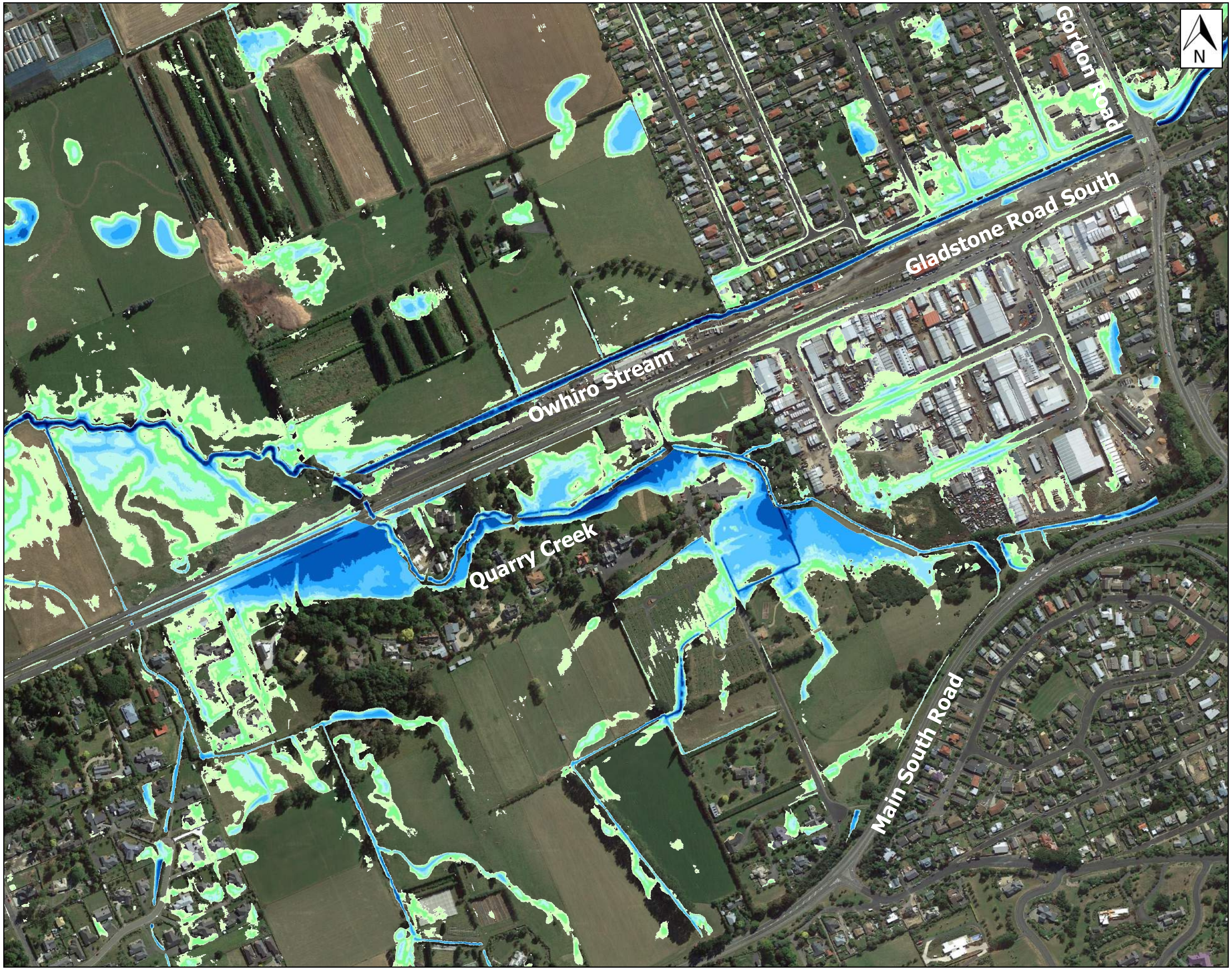
MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 100YR ARI RAIN EVENT

FULL OWHIRO STREAM CATCHMENT

Beca





Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m

Notes:

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OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 100YR ARI RAIN EVENT

QUARRY CREEK

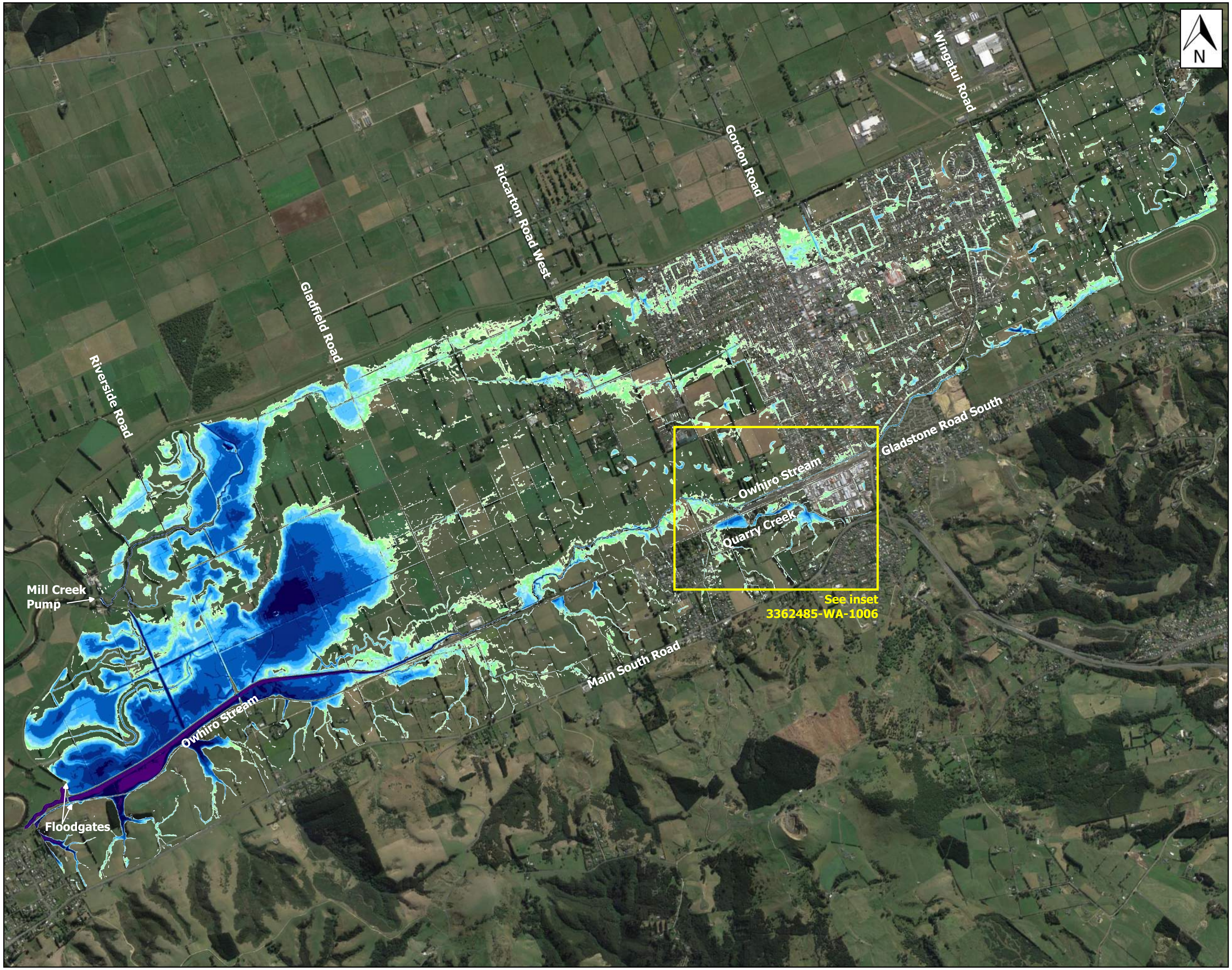
Beca

Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m



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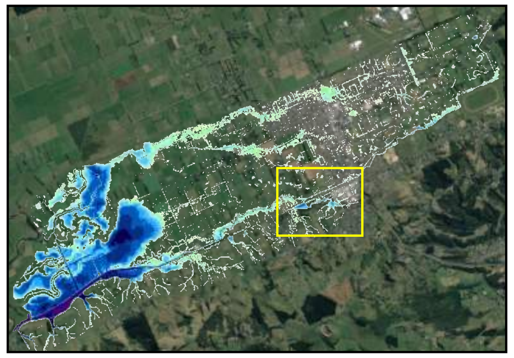
OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

EXISTING LAND USE - 50YR ARI RAIN EVENT

FULL OWHIRO STREAM CATCHMENT

Beca



Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m

Notes:

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OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

EXISTING LAND USE - 50YR ARI RAIN EVENT

QUARRY CREEK

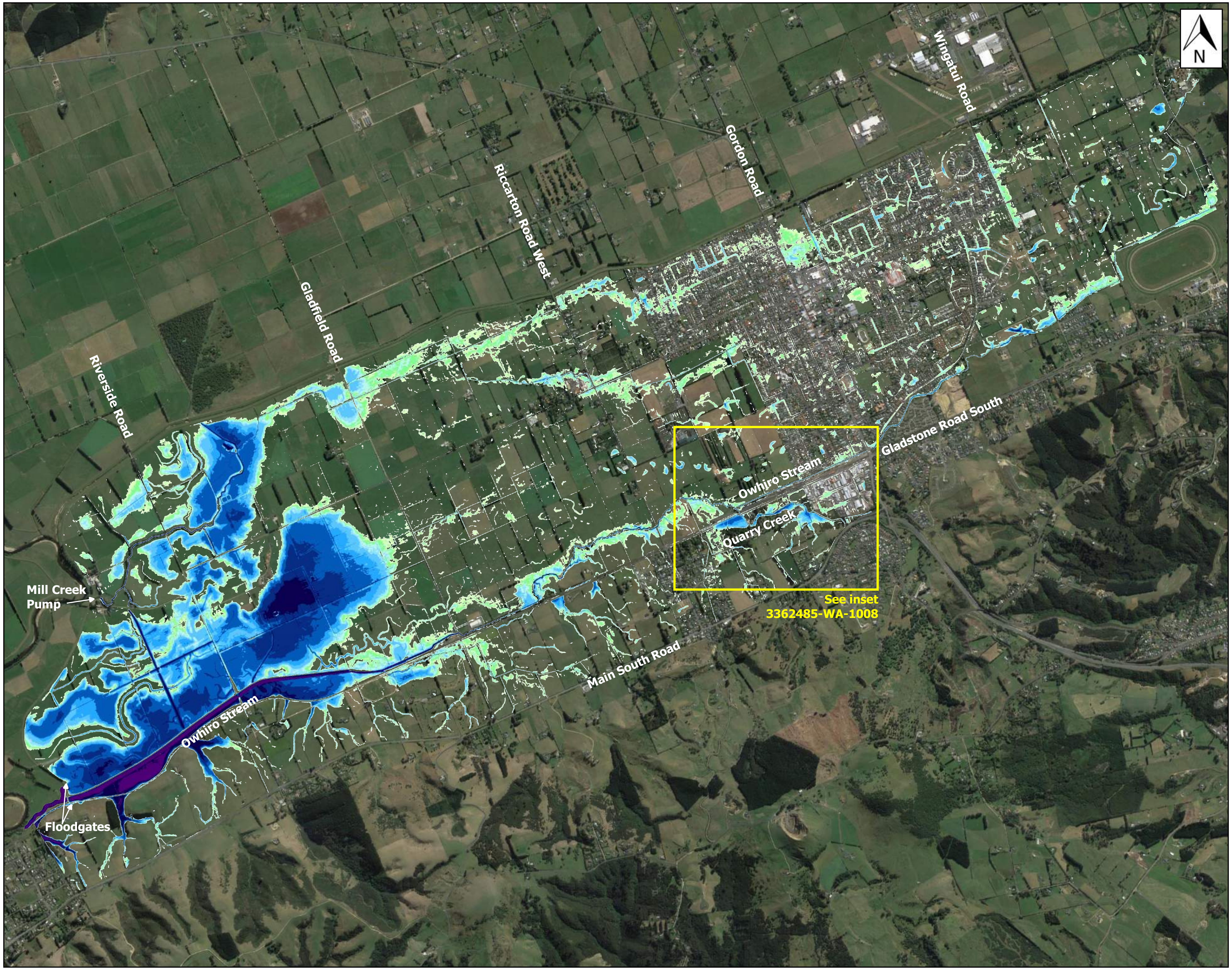
Beca

Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m



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SCALE (AT A3 SIZE)	1:30,000	
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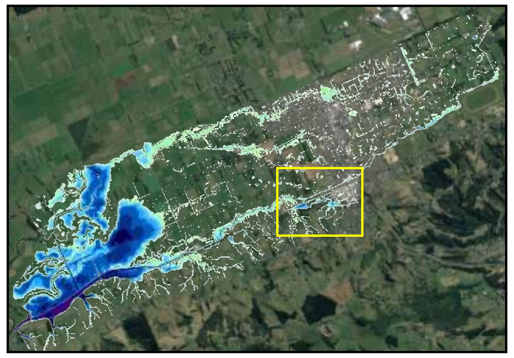
OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 50YR ARI RAIN EVENT

FULL OWHIRO STREAM CATCHMENT

Beca



Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m

Notes:

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SCALE (AT A3 SIZE)	1:5,000	
DRAWING No.	3362485-WA-1008	

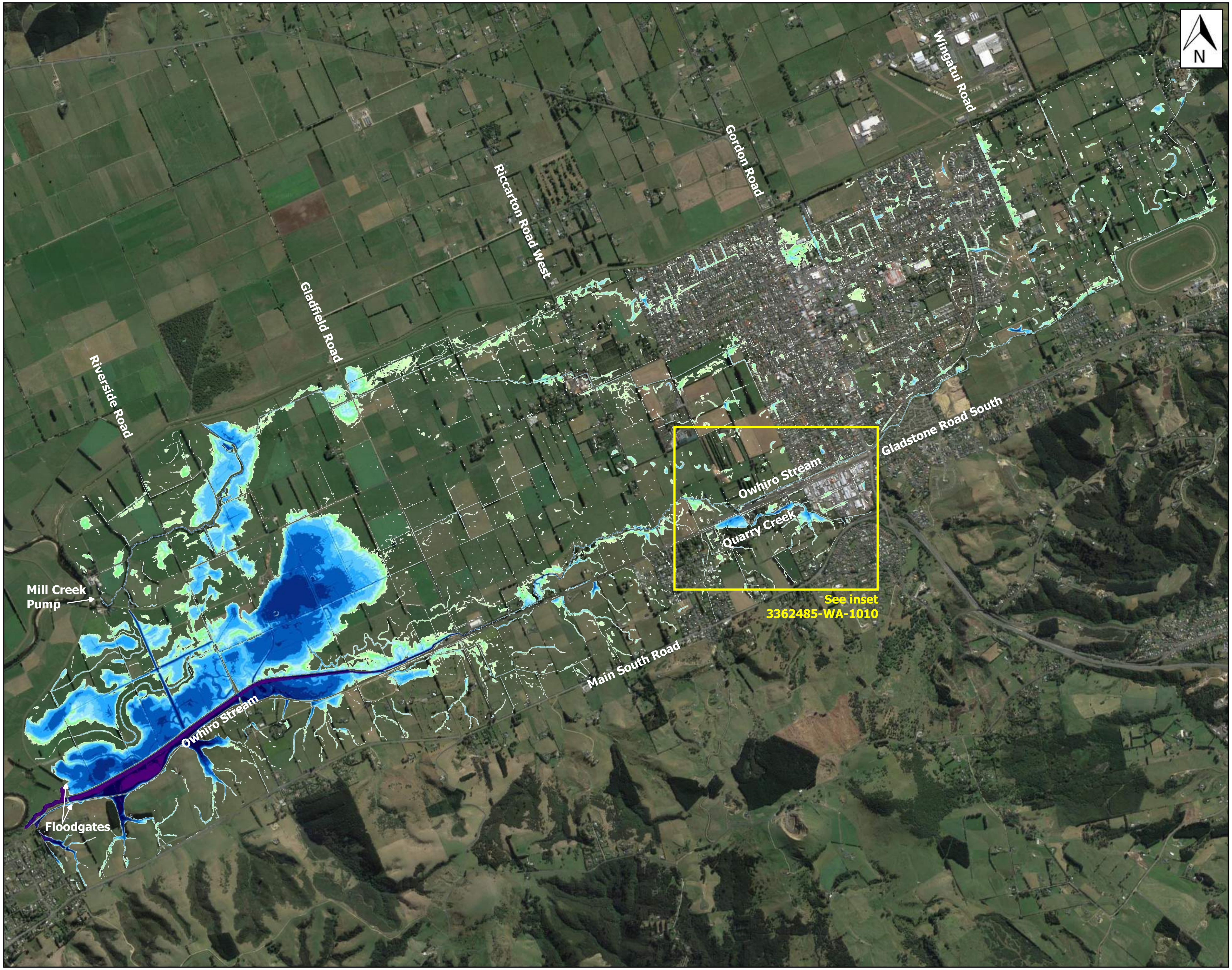
OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 50YR ARI RAIN EVENT

QUARRY CREEK

Beca



Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m

Notes:

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SCALE (AT A3 SIZE)	1:30,000	
DRAWING No.	3362485-WA-1009	

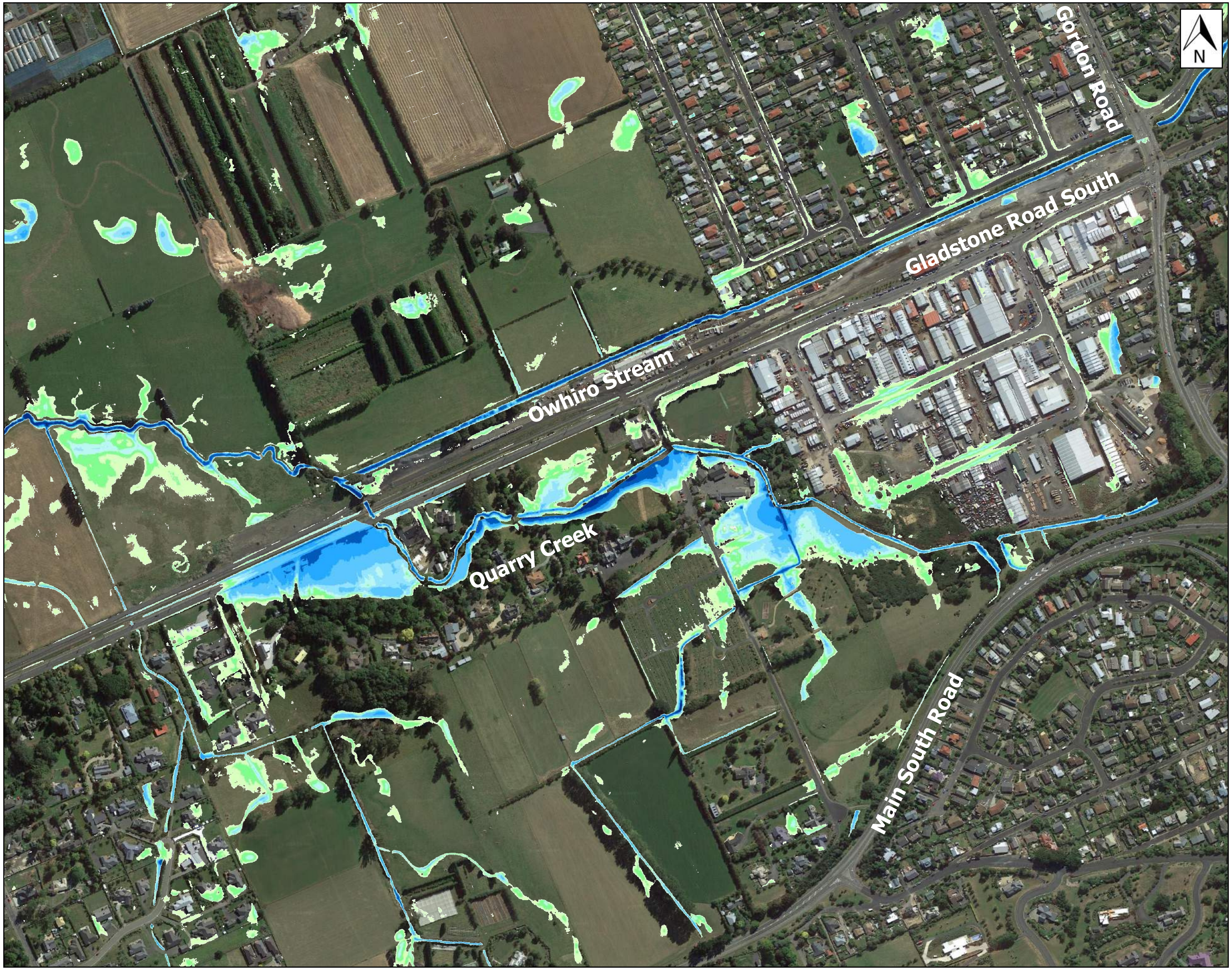
OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

EXISTING LAND USE - 10YR ARI RAIN EVENT

FULL OWHIRO STREAM CATCHMENT

Beca



Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m

Notes:

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Map intended for distribution as a PDF document. Scale may be incorrect when printed

DRAWN	C Lintott	1/03/2019
CHECKED	E Tuck	6/03/2019
APPROVED	M Law	6/03/2019
GIS FILE	P:\336\3362485\THY\GIS\Owhiro_QGIS.qgs	
SCALE (AT A3 SIZE)	1:5,000	
DRAWING No.	3362485-WA-1010	

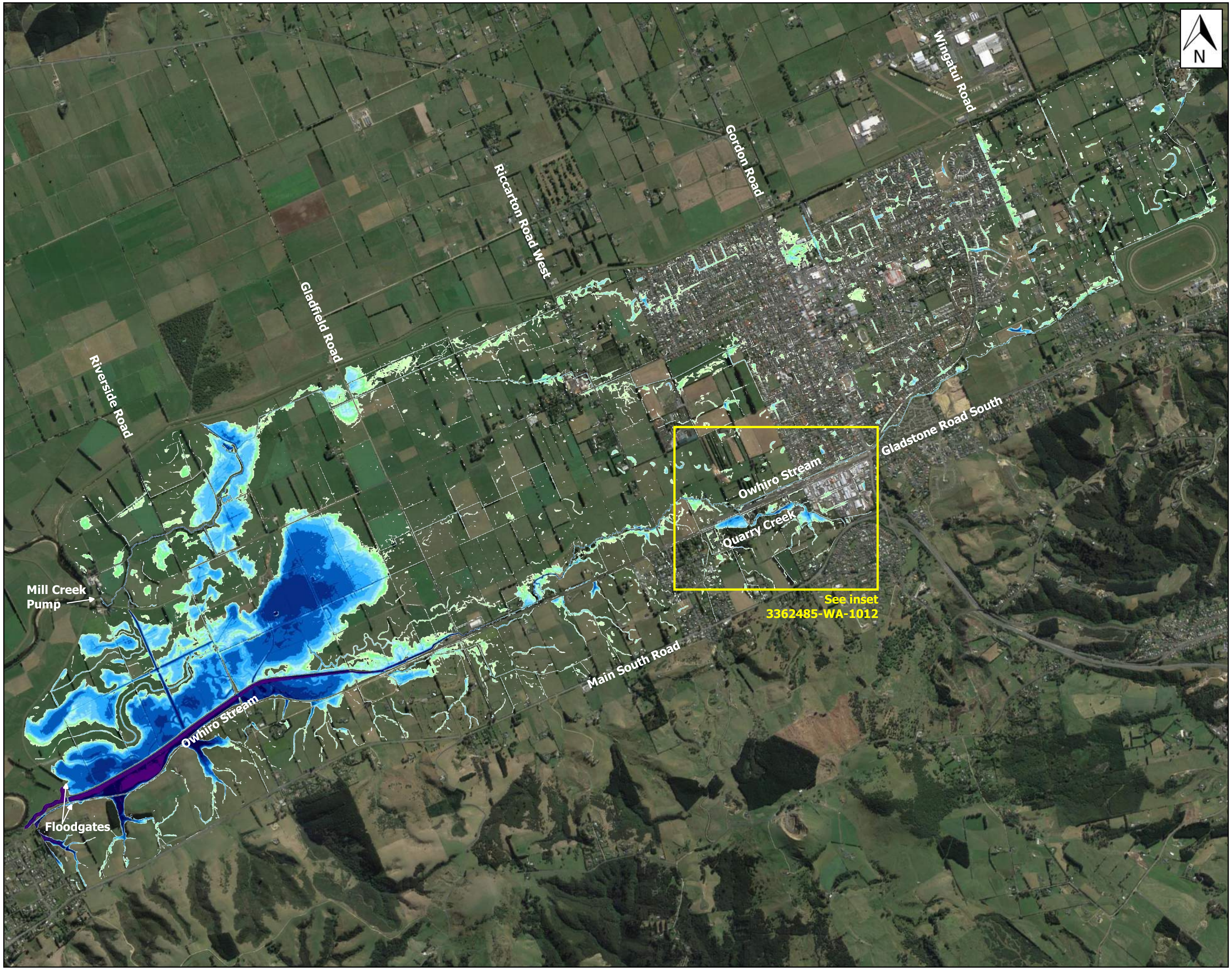
OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

EXISTING LAND USE - 10YR ARI RAIN EVENT

QUARRY CREEK

Beca



Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m

Notes:

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DRAWN	C Lintott	1/03/2019
CHECKED	E Tuck	6/03/2019
APPROVED	M Law	6/03/2019

GIS FILE
P:\336\3362485\THY\GIS\Owhiro_QGIS.qgs

SCALE (AT A3 SIZE)
1:30,000

DRAWING No.
3362485-WA-1011

OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 10YR ARI RAIN EVENT

FULL OWHIRO STREAM CATCHMENT

Beca

Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m

Notes:

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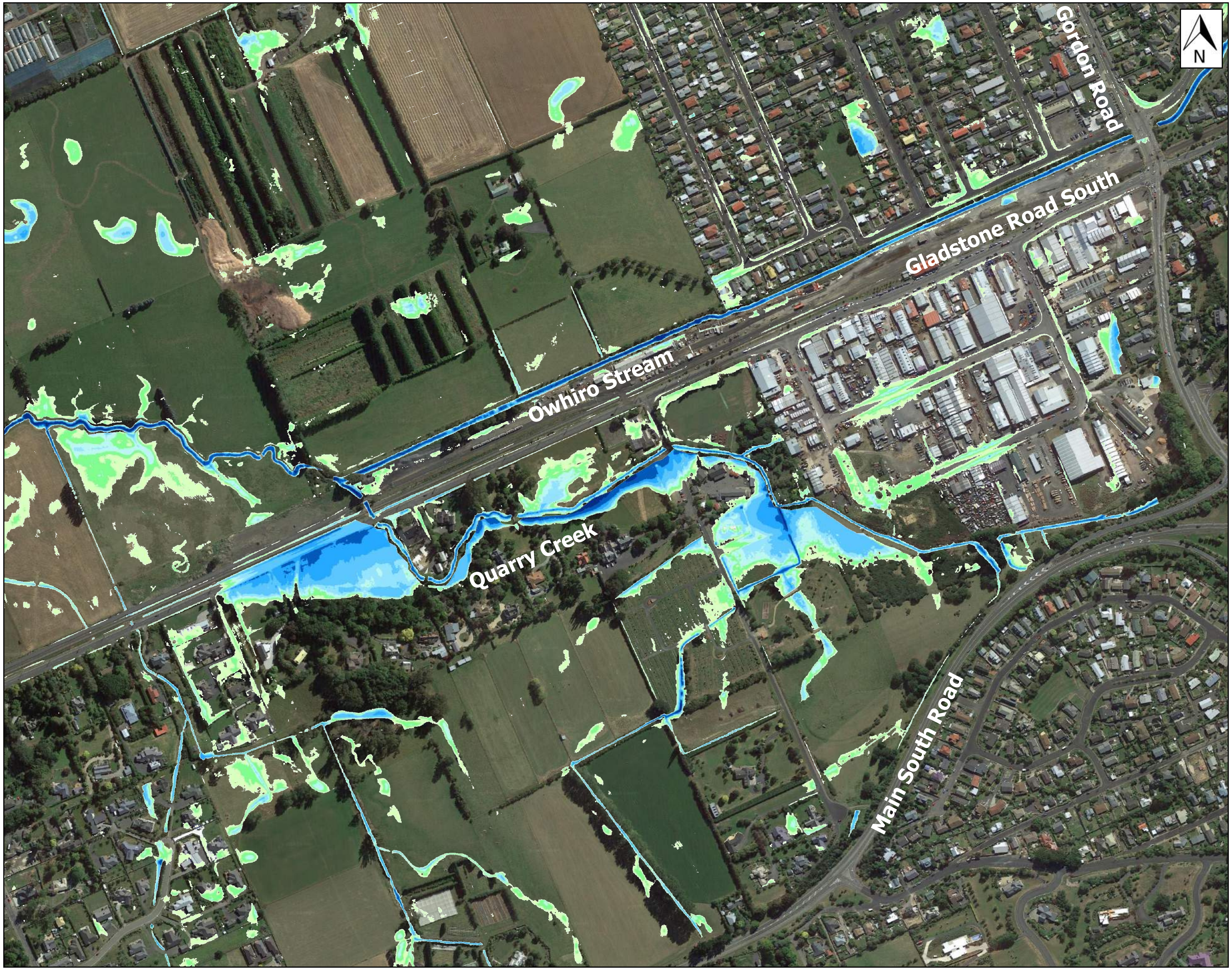
DRAWN	C Lintott	1/03/2019
CHECKED	E Tuck	6/03/2019
APPROVED	M Law	6/03/2019
GIS FILE	P:\336\3362485\THY\GIS\Owhiro_QGIS.qgs	
SCALE (AT A3 SIZE)	1:5,000	
DRAWING No.	3362485-WA-1012	



OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 10YR ARI RAIN EVENT

QUARRY CREEK

Beca

Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m

Notes:

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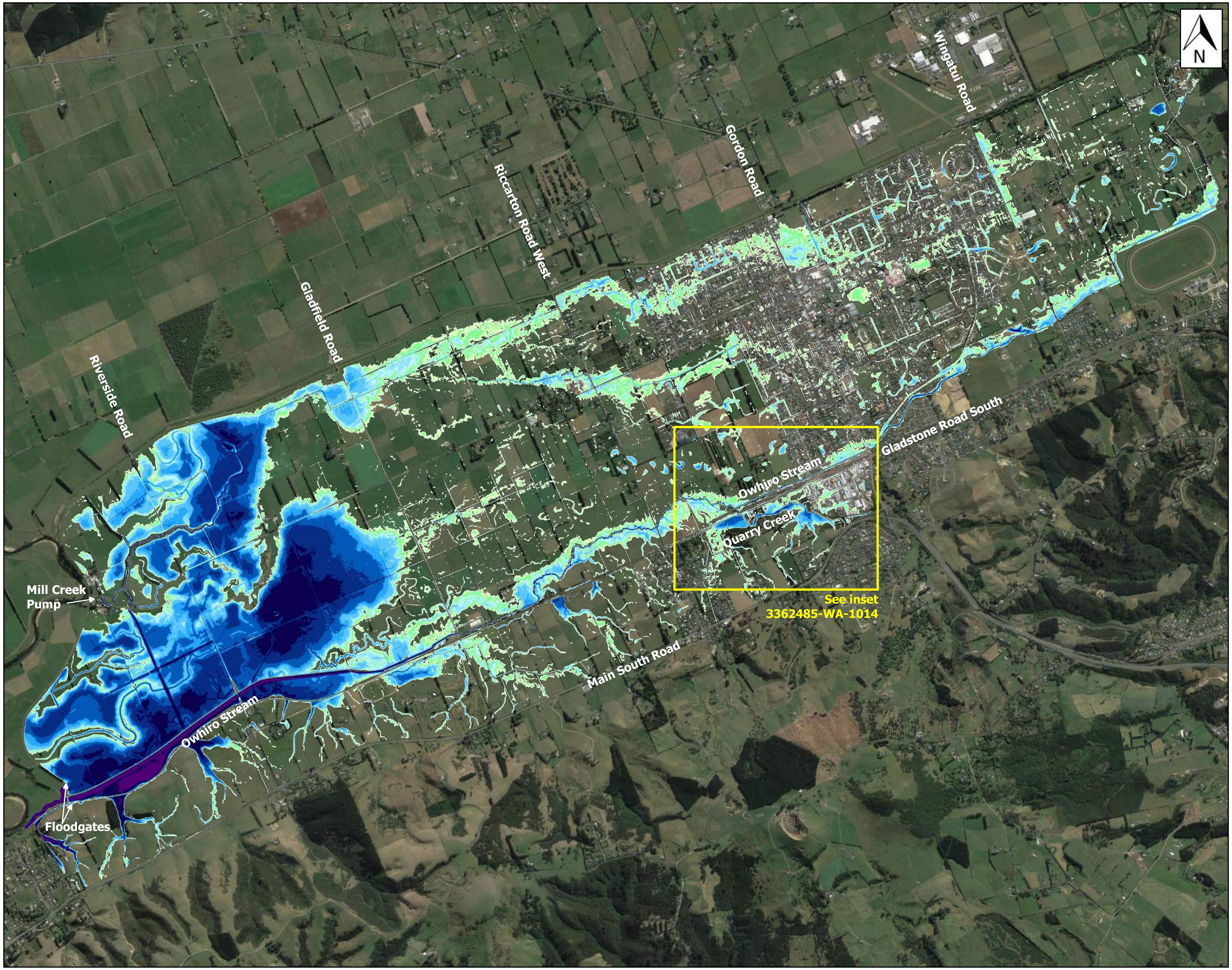


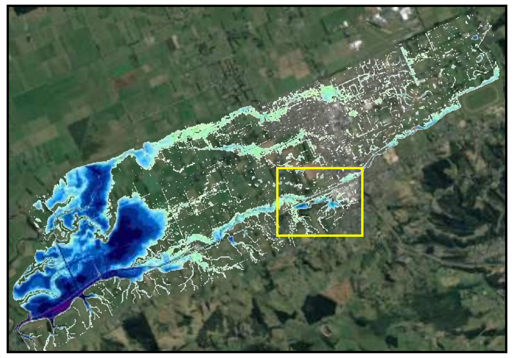
DRAWN	C Lintott	1/03/2019
CHECKED	E Tuck	6/03/2019
APPROVED	M Law	6/03/2019
GIS FILE	P:\336\3362485\THY\GIS\Owhiro_QGIS.qgs	
SCALE (AT A3 SIZE)	1:30,000	
DRAWING No.	3362485-WA-1013	

OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 100YR ARI RAIN EVENT WITH CLIMATE CHANGE (SENSITIVITY CHECK)
FULL OWHIRO STREAM CATCHMENT

Beca

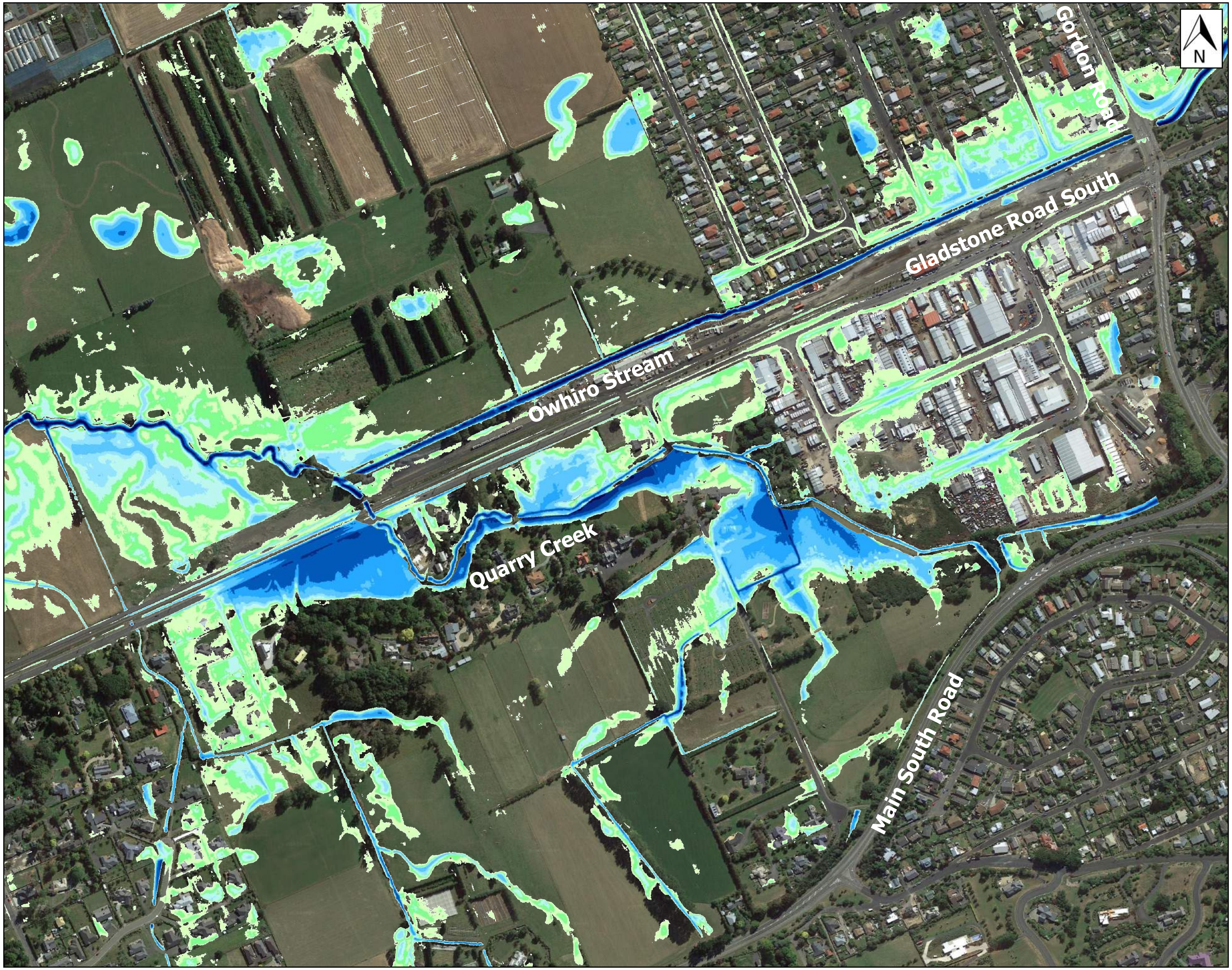


Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m



Notes:

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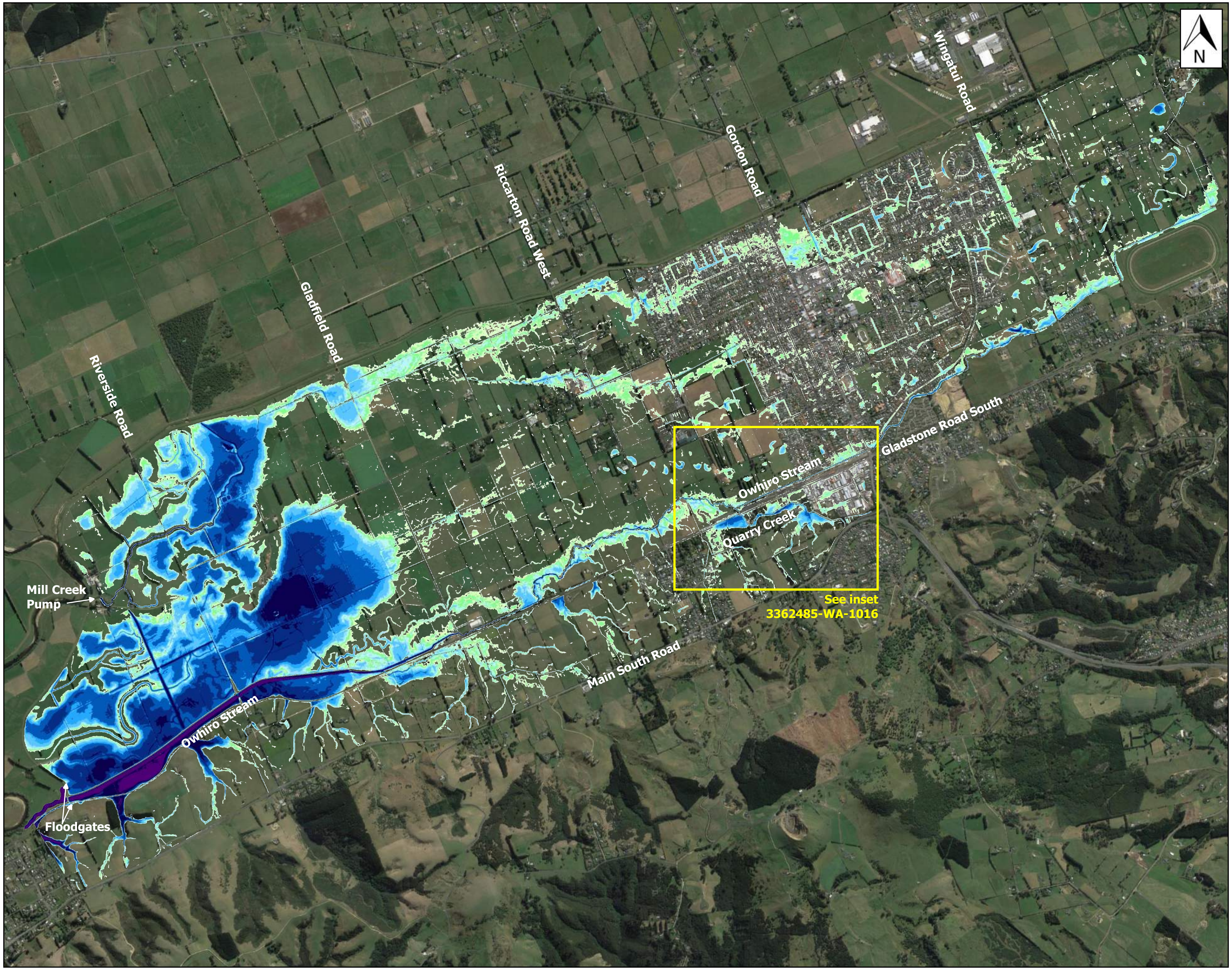
DRAWN	C Lintott	1/03/2019
CHECKED	E Tuck	6/03/2019
APPROVED	M Law	6/03/2019
GIS FILE	P:\336\3362485\THY\GIS\Owhiro_QGIS.qgs	
SCALE (AT A3 SIZE)	1:5,000	
DRAWING No.	3362485-WA-1014	

OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 100YR ARI RAIN EVENT WITH CLIMATE CHANGE (SENSITIVITY CHECK)
QUARRY CREEK

Beca



Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m

Notes:

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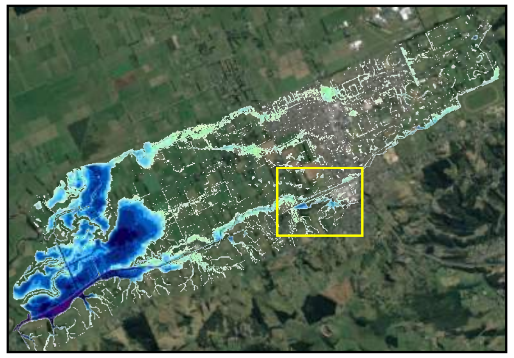
DRAWN	C Lintott	1/03/2019
CHECKED	E Tuck	6/03/2019
APPROVED	M Law	6/03/2019
GIS FILE	P:\336\3362485\THY\GIS\Owhiro_QGIS.qgs	
SCALE (AT A3 SIZE)	1:30,000	
DRAWING No.	3362485-WA-1015	

OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 50YR ARI RAIN EVENT WITH CLIMATE CHANGE (SENSITIVITY CHECK)
FULL OWHIRO STREAM CATCHMENT

Beca



Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m

Notes:

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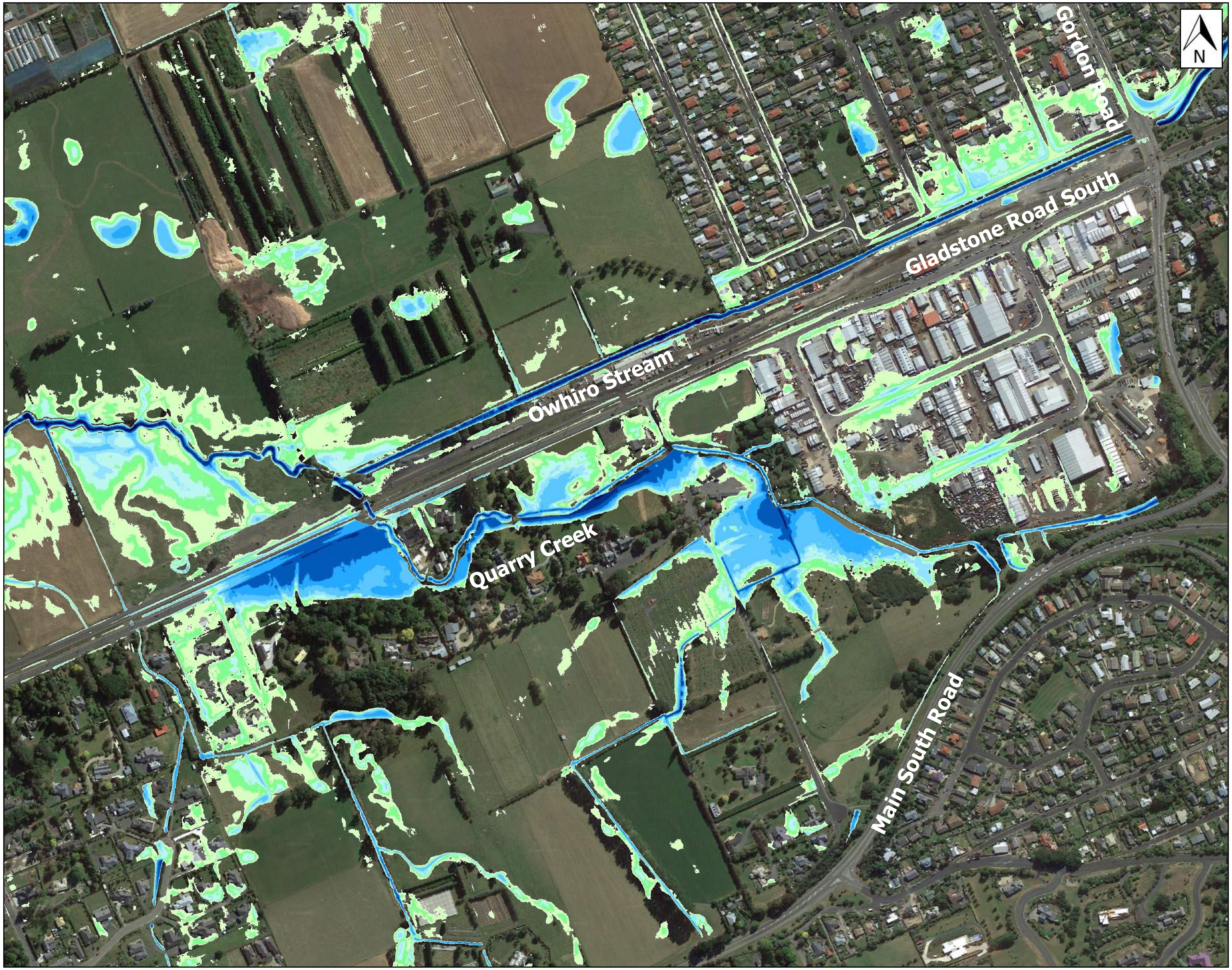
DRAWN	C Lintott	1/03/2019
CHECKED	E Tuck	6/03/2019
APPROVED	M Law	6/03/2019
GIS FILE P:\336\3362485\THY\GIS\Owhiro_QGIS.qgs		
SCALE (AT A3 SIZE) 1:5,000		
DRAWING No. 3362485-WA-1016		



OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 50YR ARI RAIN EVENT WITH CLIMATE CHANGE (SENSITIVITY CHECK)

QUARRY CREEK

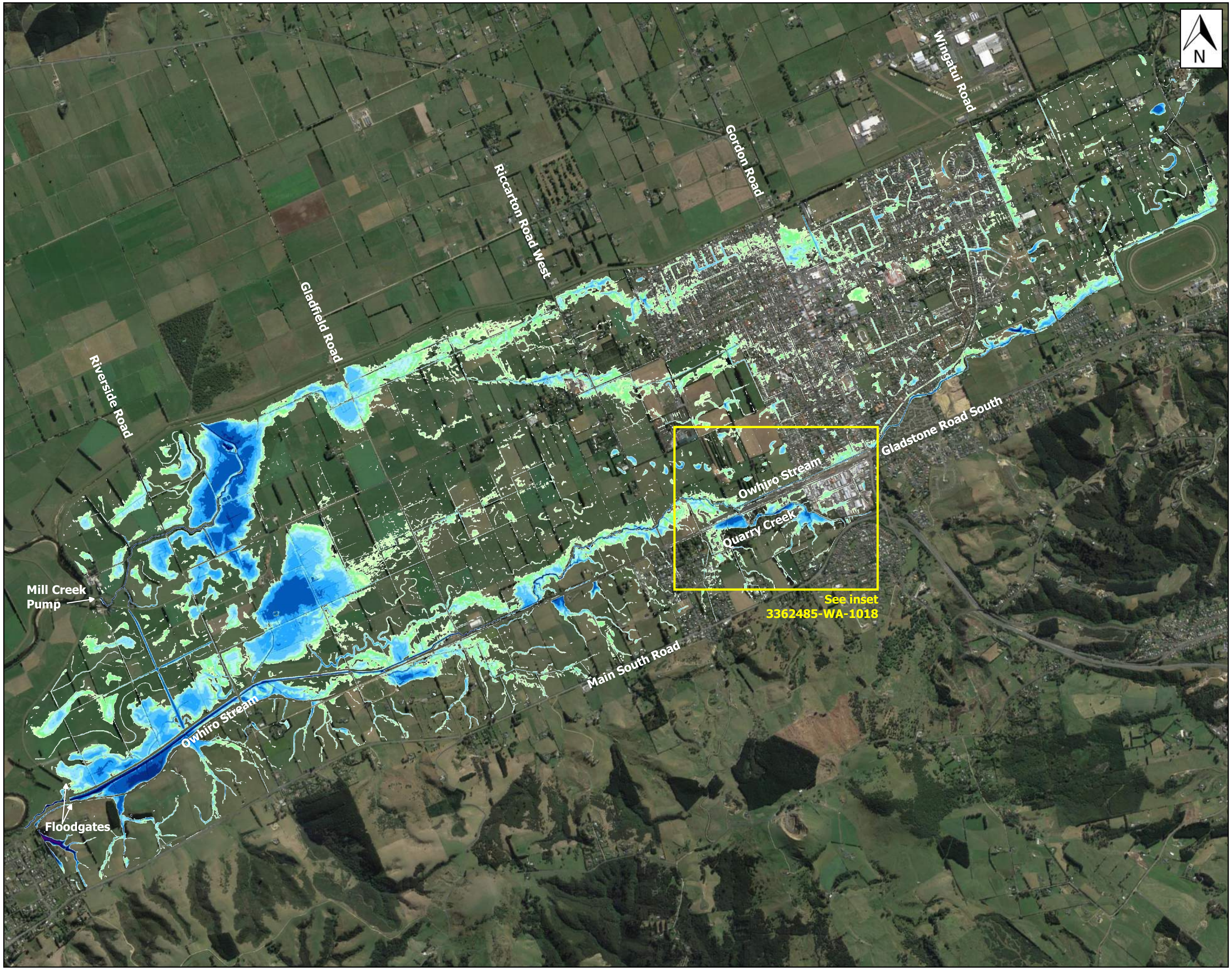
Beca

Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 500 1000 1500 m



Notes:

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Scale may be incorrect when printed

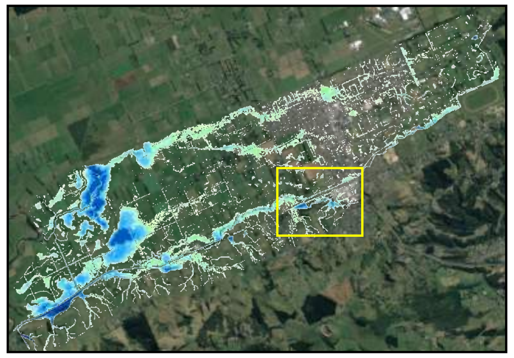
DRAWN	C Lintott	1/03/2019
CHECKED	E Tuck	6/03/2019
APPROVED	M Law	6/03/2019
GIS FILE	P:\336\3362485\THY\GIS\Owhiro_QGIS.qgs	
SCALE (AT A3 SIZE)	1:30,000	
DRAWING No.	3362485-WA-1017	

OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 100YR ARI RAIN EVENT WITH NO GATE CLOSURE (SENSITIVITY CHECK)
FULL OWHIRO STREAM CATCHMENT

Beca



Legend

Maximum flood depth (m)

- <= 0.1 (not shown)
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- > 3

0 50 100 150 200 250 m

Notes:

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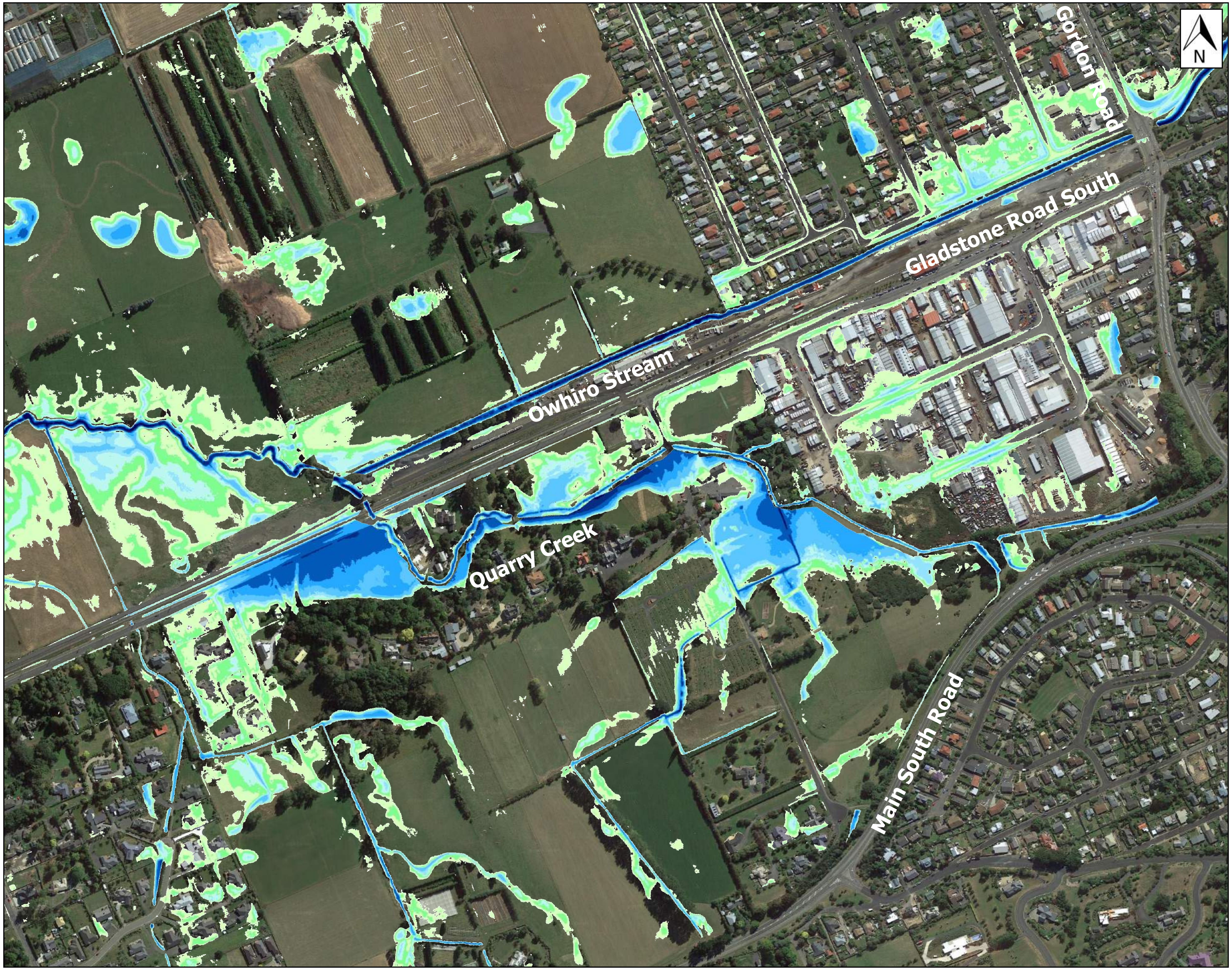
Scale may be incorrect when printed

DRAWN	C Lintott	1/03/2019
CHECKED	E Tuck	6/03/2019
APPROVED	M Law	6/03/2019
GIS FILE	P:\336\3362485\THY\GIS\Owhiro_QGIS.qgs	
SCALE (AT A3 SIZE)	1:5,000	
DRAWING No.	3362485-WA-1018	



OWHIRO FLOOD HAZARD STUDY

MAXIMUM FLOOD DEPTH

FUTURE LAND USE - 100YR ARI RAIN EVENT WITH NO GATE CLOSURE (SENSITIVITY CHECK)
QUARRY CREEK

Beca