IN THE ENVIRONMENT COURT
AT CHRISTCHURCH

I TE KŌTI TAIAO O AOTEAROA
ŌTAUTAHI ROHE

ENV-2018-CHC-290

UNDER	the Resource Management Act 1991 (RMA)
IN THE MATTER	of an appeal under Clause 14 of the First Schedule of the RMA in relation to the Proposed Second Generation Dunedin City District Plan (2GP)
BETWEEN	**OTAGO REGIONAL COUNCIL**
	Appellant
AND	**DUNEDIN CITY COUNCIL**
	Respondent

AFFIDAVIT OF BIKESH SHRESTHA FOR THE APPELLANT IN SUPPORT OF AN APPLICATION UNDER SECTION 293

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AJL-266090-1013-1279-V3

AFFIDAVIT OF BIKESH SHRESTHA FOR THE APPELLANT IN SUPPORT OF AN APPLICATION UNDER SECTION 293

I, **BIKESH SHRESTHA**, of Hamilton, Water Resources Engineer, swear –

Introduction

1. I am a Water Resources Engineer employed by Bloxam Burnett & Olliver.

Statement of Professional Qualifications and Experience

2. I **attach** my curriculum vitae as Exhibit "**A**".

3. I was a Natural Resources Engineer for the Otago Regional Council ("ORC"), based in Dunedin from February 2017 to May 2021.

4. My work included modelling associated with the Silver Stream and the assessment of the Gordon Road Spillway.

5. I am familiar with both.

Code of Conduct

6. I acknowledge that I have read and agree to comply with the Environment Court's Code of Conduct for Expert Witnesses, contained in the Environment Court Practice Note 2014. I have complied with the Code in preparing my evidence.

7. The data, information, facts, and assumptions I have considered in forming my opinions are set out in my evidence to follow. The reasons for the opinions expressed are also set out in the evidence to follow.

8. Unless I state otherwise, this evidence is within my sphere of expertise, and I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Materials Considered

9. ORC provided me with all the culvert data for Mill Creek and data for culverts through the cut-off bank. ORC also provided the inflow boundary for Mill Creek at the Railway line and six catchments to the north.

Scope of Evidence

10. This evidence relates to the hydraulic modelling I undertook at the request of the Otago Regional Council on how the Gordon Road Spillway and Floodway operate during flood events.

11. Modelling was carried out for the 2017 flood event and the 100-year ARI event.

12. I produced the modelling report as Exhibit "**B**".

BS AH

Model

13. The model used was HEC-RAS software. This software is commonly used amongst practitioners to model river flows and flood impacts. I have used this software many times in the past.

14. The HEC-RAS model is widely used to simulate flood extents, depths, and velocities.

15. For the purposes of this investigation, I utilised the HEC-RAS hydraulic model maintained by the Otago Regional Council for the Silver Stream.

16. I am familiar with the model from my previous work with the Regional Council, because I developed the model. I have used the model successfully in the past.

17. The existing model had been calibrated using a 2015 flood event and validated for May 2006, May 2010, and July 2017 events.

18. Several modifications were made by me to the existing model for the purposes of this investigation. These are detailed in the modelling report on page 9.

19. The original Silver Stream hydraulic model was set up, calibrated and validated using HEC-RAS Version 5.0.3. This model was further refined, extended and transferred by me to HEC-RAS Version 5.0.7.

20. The model was re-evaluated against the observed high-water marks for July 2017 flood. The comparison of modelled water levels against debris marks indicates the modelled values aligned well. However, along the downstream cut-off bank, the modelled water levels were more than 500mm higher than observed data. During the July 2017 event there was over topping of the cut-off bank at several locations, hence the surveyed debris line may not represent the actual water levels at the cut-off bank during the peak of the event, when the cut-off bank was overtopped.

21. I am satisfied that the model operated as I would have expected from my previous experience with HEC-RAS. The results produced were of the kind expected. There were no abnormalities. The results produced are in my opinion, reliable and accurate within the limits of the 2D hydraulic modelling (e.g. Section 2.1, FHWA-HIF-19-061 October 2019, Two-Dimensional Hydraulic Modeling for Highways in the River Environment) and standard practice. Standard practice implies that the methodologies applied were in general conformance with HEC-RAS Manual, and Australian Rainfall and Runoff (ARR) document (ARR, Two-Dimensional Modelling in Urban and Rural floodplains, Stage 1 & 2 Report, November 2012). Other references used are within the report.

Inputs

22. The inputs to the model are described at section 2.2, on pages 12 to 16 of the Report.

Peer Review

23. ORC engaged Tom Bassett of Tonkin + Taylor to peer review my modelling work.

BS AH

24. The first version of the Report was sent to Mr Bassett on 25 October 2022.

25. The modelling work was further developed and refined as a result of Mr Bassett's input. An amended version dated 21 November 2022 was sent to Mr Bassett and discussed with him by phone and email to take into account the issues raised by him, before being finalised.

Qualifications, Assumptions and Limitations

26. Inflow boundaries to the HEC-RAS model at Mill Creek railway line and six catchments to the north, were based on catchment analysis completed by ORC, which is the standard practice for ungauged catchments.

27. Mill Creek channel, Mill Creek diversion, and other drainage channels in the floodplain were modelled using LiDAR data, without cross sections.

28. Limitations in accuracy of the LiDAR used to generate terrain for the HEC-RAS model can influence model results.

29. The model is calibrated for one event and validated for three other events, with return period less than 100-yr, comparing modelled water level with the surveyed high-water marks, more specifically debris marks, which is the standard practice. There might be some uncertainty associated with the surveyed high-water marks.

Conclusion

30. The hydraulic modelling was carried out to assess the flood hazard and determine how North Taieri/Gordon Road floodway was impacted during the July 2017 flood event and the 100-yr ARI event. The modelling results confirm that the overtopping of the true right bank of Silverstream below the Gordon Road bridge (also known as Gordon Road Spillway) is the primary contributor to flooding of North Taieri/Gordon Road floodway area. For July 2017 event the depth of flood water is expected to range between less than 0.5m to almost 3m, while for 100-yr ARI event the flood depth is expected to range between less than 0.5m to more than 3m. For both events the velocity is expected to range between 0.5 to 1 m/s in the floodplain.

Sworn at Hamilton this 21st day of December 2022 before me:-)
)
)

Bikesh Shrestha

Andrew Hong
Solicitor
Hamilton

A Solicitor of the High Court of New Zealand

"A"

108 Cambridge Road, Hillcrest, Hamilton 3216
Mobile: 022 4028 026, Email: bikeshs1983@gmail.com, bshrestha@bbo.co.nz

1. NAME:	**BIKESH SHRESTHA**
2. EDUCATION:	▪ **Ph. D in Civil Engineering,** University of Canterbury (UC), New Zealand, 2020. ▪ **Master of Engineering in Water Engineering and Management,** Asian Institute of Technology (AIT), Thailand, 2010. ▪ **B.Sc. in Civil Engineering**, Central Luzon State University, The Philippines, 2005.
3. RELEVANT SKILLS:	▪ **Technical skill:** experience in hydrological investigation, monitoring, analysis and modelling; catchment hydrology; climate change impact assessment; land use change impact assessment; flood hazard risk assessment; sediment modelling; water quality (nitrate and phosphorus) modelling; hydraulic modelling; design of hydraulic structures related to hydropower, irrigation and water supply; water use master planning and integrated catchment management. Auto Cad and ARC GIS trained and experienced with different modeling tools such as, HEC HMS, HEC RAS, HEC Resim, Mike 11, SWAT, EPA SWMM. ▪ **Management skill:** consistently achieved goals using organizational and problem-solving skills. Planning and coordination with clients / local partners. Contract and project management. ▪ **Communication skill:** excellent in spoken English, writing and reading English.
4. ACHIEVEMENTS:	▪ 2019 – Nominated for the ORC Staff Awards in Category Collaboration/ silent achiever – Collaborates well with other, involves others in decision making, demonstrates cooperation and builds good relationships. ▪ 2014 – UC Doctoral Scholarship for Ph. D studies ▪ 2010 – The Chainarong Na Lamphun Prize (Gold Medal) for Master Studies ▪ 2009 – HydroAsia Award: The Excellence Award by University of Incheon, South Korea. ▪ 2008 – The Asian Development Bank–Japan Scholarship Program (ADB–JSP) to pursue Masters at AIT ▪ 2005 – Academic Excellence Award for Bachelor Studies
5. AFFILIATION:	▪ Member – Engineering New Zealand. ▪ Member – New Zealand Hydrological Society ▪ Member – Water New Zealand ▪ Member – Rivers Group

This is the document marked with the letter "A" and referred to in the annexed affidavit of BIKESH SHRESTHA of Hamilton, Water Resources Engineer, sworn at Hamilton this 21st day of December 2022 before me:
Andrew Hong
Solicitor
Hamilton
A Solicitor of the High Court of New Zealand

6. EXPERIENCE:

From: June 2021	– Present
Employer:	Bloxam Burnett and Olliver, New Zealand
Position held:	**Water Resources Engineer**
Responsibilities:	▪ Undertake water engineering design and draughting on projects undertaken by the company. ▪ Carryout hydrological and hydraulic modelling to assess the downstream flood hazard effects for a stormwater discharge consent. ▪ Undertake embankment breach analysis, bridge hydraulics and scour assessment. ▪ Provide technical advice on river hydraulics and river modelling. ▪ Establishing technical requirements.
Project Involved / Client	▪ Rotokauri North Development Stage 1 / Rotokauri North Holdings Limited ▪ Takatimu North Link Stage 1 and 2 / Waka Kotahi New Zealand Transport Agency ▪ Hydraulic Support / Otago Regional Council ▪ Peacocke Waikato River Bridge and Strategic Services / Hamilton City Council
From: February 2017	– May 2021
Employer:	Otago Regional Council, New Zealand
Position held:	**Natural Resources Engineer**
Responsibilities:	▪ To lead and/or participate in hydraulic investigation of flood hazard and flood control and drainage schemes. ▪ Contribute to the development of river morphology and riparian management

strategies setting out river values, management objectives and methods.

- Assist with the investigation and assessment of trends and changes in the morphology of Otago's rivers and coastline.
- To provide technical appraisals and advice on applications and proposals for activities development, District Plan changes and Councils powers and function for dams under the Building Act.
- Lead and/or participate in project teams as assigned.
- Keep up to date with scientific knowledge as required to effectively undertake the responsibilities of the position.
- Assist with the preparation of contract or consultancy brief documentation, the analysis of tenders and the management of external consultants or contractors as may be required.
- Assist with the technical appraisal of proposals/activities as they related to the achievement of the primary objective.
- Provide technical appraisal of bylaw and resource consent applications.
- Participate in flood response and flood forecasting.

Project Involved

- Scheme performance of West Taieri Drain, Lower Taieri.
- Performance review of Clutha flood protection scheme at Alexandra.
- Flood hazard modelling and assessment of Dart River.
- Hydraulic modelling of Lower Taieri and assessment of the performance of flood protection schemes.
- Hydraulic modelling of Silver Stream and assessment of Gordon Road Spillway performance.
- Flood hazard modelling and assessment of Manuherikia River at Ophir and Lauder.
- Flood hazard modelling and assessment of Lowe Waitaki Plain.
- Hydraulic modelling of Water of Leith for Leith Amenities Project (River channel modification for improving amenities downstream of Forth Street Bridge to Harbour).
- Hydraulic modelling of Water of Leith for ITC Bend Modification Project (Shifting of right bank wall due to construction difficulties).
- Hydraulic modelling Water of Leith for Dundas Bridge upgrade (Optimization of additional culvert sizing).
- Physical modelling of Water of Leith for Dundas Bridge upgrade project.
- Morphological assessment of Silver Stream.
- Morphological assessment of Lower Taieri River.

From: January 2015 – January 2017
Employer: University of Canterbury, New Zealand
Position held: **Research Assistant**
Responsibilities:

- Hydrological and water quality modelling.
- Installation and maintenance of water level meters and flow measuring devices such as weir.
- Monitoring of water levels and stream flow measurements
- Conduct training to client to download and manage water level data.
- Analyse and interpret water level and flow data.
- Flow estimation for ungauged basins.
- Communicate findings as appropriate.

Project involved / Client

- Estimation of river flows for alternative potential dam sites in the Xe Kong/ Natural Heritage Institute, USA
- Critical Basin at Risk: Assessing and managing ecosystem pressures from development and climate change in the 3S basin / John D and Catherine T McArthur Foundation, USA. More specifically use of Soil and Water Assessment Tool (SWAT) model for hydrological, ecological assessment, sediment modelling and sediment management.
- Installation and maintenance of water level meters and collection of water level

data at Isaac Conservation and Wildlife reserve / Isaac Conservation and Wildlife Trust, New Zealand
- Installation and maintenance of water level meters and collection of water level data at Montrose / Fish and Games, New Zealand

From: June 2012	– March 2014
Employer:	CMS Engineering Consult, Nepal
Position held:	**Water Resources Engineer / Hydrologist**
Responsibilities:	▪ Hydrological investigation, analysis and modelling; crop water requirement calculation; water balance analysis and assessment of water use patterns in catchments and hydraulic modelling ▪ Design of hydraulic structures related to irrigation schemes. ▪ Supervision of the design and feasibility report preparation; review and check planning, designs and cost estimates of projects prepared by the Irrigation Engineers; and conducting orientation and in-house training to Irrigation Engineers. ▪ Assist in project proposal preparation for project bidden by the company. ▪ Represent company in various water related project while dealing with clients.
Project involved / Client	▪ Community Irrigation Project (CIP) / Government of Nepal and Asian Development Bank ▪ Long Term Vision of Nepal's Water and Energy Sector / Government of Nepal ▪ Formation of Basin/Sub Basin Committees (within Babai and West Rapti) and Preparation of Water Access Mechanism / Government of Nepal and The World Bank
From: January 2011	– May 2012
Employer:	Asian Institute of Technology (AIT), Thailand
Position held:	**Research Associate**
Responsibilities:	▪ Principal Researcher for the Research entitle: "Impact on Sediment Due to Climate Change and Human Activities in the Mekong River Basin: A case study of Nam Ou Basin, LAO PDR". ▪ Communicate research outcome through journal publication, policy document and educational material.
Project involved / Client	PROAcc: Post-doctoral Programme on Climate Change Adaptation in the Mekong River basin / UNESCO-IHE, Netherlands
From: October, 2010	– December, 2010
Employer:	Hydro Solutions, Nepal
Position held:	**Design Engineer**
Responsibilities:	▪ Hydrological and sediment analysis, hydrological modelling, design of hydraulic structure and financial analysis of the project. ▪ Preparation of standard and detail drawings of various hydropower structures.
Project involved / Client	▪ Nyasim Khola Hydropower Project 30 MW / Hydro Solutions, Nepal
From: June, 2010	– August, 2010
Employer:	Asian Institute of Technology (AIT), Thailand
Position held:	**Research Associate**
Responsibilities:	Assist in research projects undertaken by the Institute and communicate findings as appropriate.
From: November, 2005	– July, 2008
Employer:	CEMECA HRA (P.) Ltd, Nepal
Position held:	**Project Engineer / Design Engineer / Civil Engineer**
Responsibilities:	▪ Hydrological investigation and analysis, irrigation and water supply demand estimation. ▪ Plan, survey, design, cost estimate, economic analysis, implementation and monitoring of 50+ conventional as well as non-conventional irrigation projects. ▪ Coordinate with various stake holders of the projects. ▪ Design of water supply schemes. ▪ Preparation of Water Use Master Plan.
Project involved / Client	▪ Local Infrastructure for Livelihood Improvement (LILI) program / HELVETAS Swiss Intercooperation, Nepal

- Rural Village Water Resources Management Project (RVWRMP) / Government of Finland

7. PUBLICATIONS:	▪ **Shrestha, B.**, Cochrane, T.A., Caruso, B.S., Arias, M.E., and Wild, T.B, 2021. Sediment management for reservoir sustainability and cost implications under land use/ land cover change uncertainty. Water Resources Research, 57, e2020WR028351. https://doi.org/10.1029/2020WR028351. ▪ **Shrestha, B.**, Cochrane, T.A., Caruso, B.S., Arias, M.E., 2018. Land use change uncertainty impacts on streamflow and sediment projections in areas undergoing rapid development: A case study in the Mekong Basin. Land Degradation and Development, 29(3): 835-848. DOI:10.1002/ldr.2831 ▪ **Shrestha, B.**, Maskey, S., Babel, M.S., van Griensven, A., Uhlenbrook, S., 2018. Sediment related impacts of climate change and reservoir development in the Lower Mekong River Basin: a case study of the Nam Ou Basin, Lao PDR. Climatic Change, 149(1): 13-27. DOI:10.1007/s10584-016-1874-z ▪ Oeurng, C., Cochrane, T.A., Arias, M.E., **Shrestha, B.**, Piman, T., 2016. Assessment of changes in riverine nitrate in the Sesan, Srepok and Sekong tributaries of the Lower Mekong River Basin. Journal of Hydrology: Regional Studies, 8: 95-111. DOI:10.1016/j.ejrh.2016.07.004 ▪ **Shrestha, B.**, Cochrane, T.A., Caruso, B.S., Arias, M.E., and Piman, T., 2016. Uncertainty in flow and sediment projections due to future climate scenarios for the 3S Rivers in the Mekong Basin. Journal of hydrology, 540 (2016) 1088–1104 ▪ **Shrestha, B.**, Babel, M. S., Maskey, S., van Griensven, A., Uhlenbrook, S., Green, A., and Akkharath, I., 2013. Impact of climate change on sediment yield in the Mekong River basin: a case study of the Nam Ou basin, Lao PDR. Hydrol. Earth Syst. Sci., 17, 1-20. ▪ Babel, M.S., **Shrestha, B.**, Perret, S.R., 2011. Hydrological impact of biofuel production on hydrology: A case study of Khlong Phlo Watershed in Thailand. Agri. Water Mgt., 101, 8-26.
8. REFEREES:	To be provided upon request

"B"

Otago Regional Council

Hydraulic Support for Silver Stream and Gordon Road Floodway Modelling

19 October 2022

This is the document marked with the letter "**B**" and referred to in the annexed affidavit of **BIKESH SHRESTHA** of Hamilton, Water Resources Engineer, sworn at Hamilton this 21st day of December 2022 before me:

Andrew Hong
Solicitor
Hamilton

A Solicitor of the High Court of New Zealand

BLOXAM BURNETT & OLLIVER

Document control

Project identification		
Client	Otago Regional Council	
Client representative	Dr. Jean-Luc Payan, Manager Natural Hazards	
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Job number/s	147460	
Job name	Hydraulic Support for Silver Stream and Gordon Road Floodway Modelling	
Contract numbers	N/A	
Report name and number		
Date / period ending	19 October 2022	
File path	C:\12ds\data\10.7.120.14\147460 - Otago Regional Council Hydraulic Support_5203\07 Water Resources\01 Reports	

Report status			
Status	**Name**	**Signature**	**Date**
Report prepared by	Bikesh Shrestha		19/10/2022
Checked by	Eugene Vodjansky		25/10/2022
Approved for issue (V1)	Scott Bready		25/10/2022

Document history			
Version	**Changes**	**Signature**	**Issue date**
V2	Updated after reviewers' comment		21/11/2022
V3			
V4			

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1. Introduction

1.1 Overview

The Lower Taieri River floodplain comprises mainly farmland, but also includes several townships, the largest being Mosgiel and Outram and the Lower Taieri River floodplain also contains critical infrastructure including Dunedin International Airport (Figure 1). The Lower Taieri River floodplain is exposed to flooding from Taieri River, Silver Stream, Mill Creek, Owhiro Stream, Contour Channel, and runoff from other surrounding hill catchments.

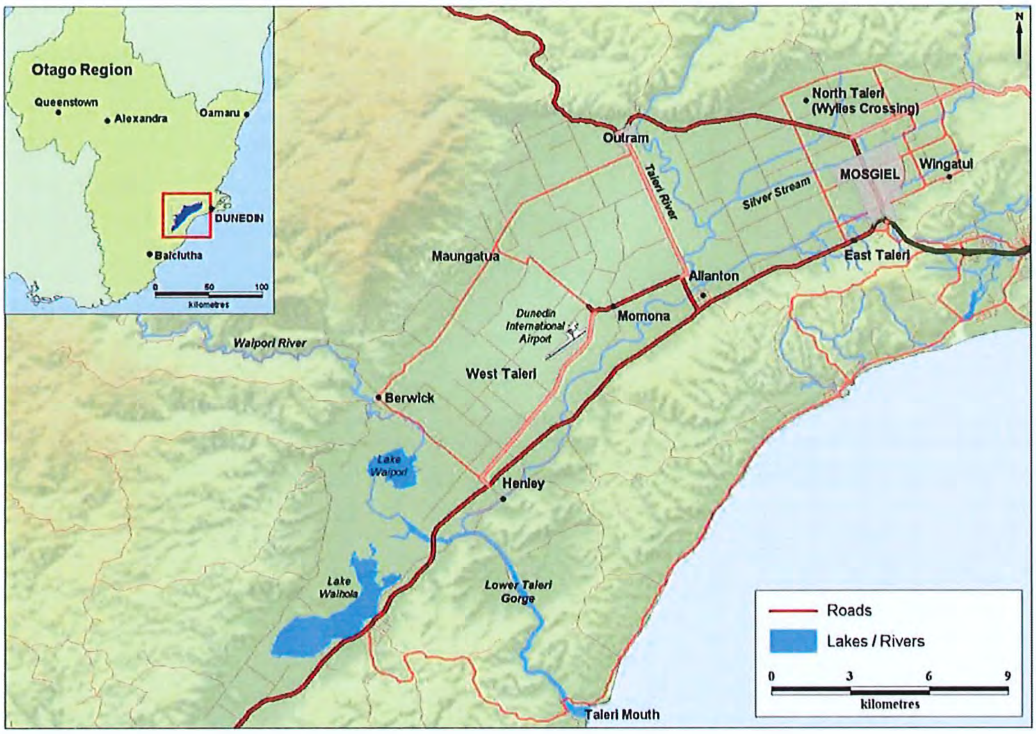

Figure 1. Lower Taieri River floodplain (ORC, 2015).

Otago Regional Council (ORC) initiated the flood-hazard characterization and mapping of the Lower Taieri floodplain in 2006, which was later refined in 2013, 2014 and 2015. The flood hazard map (as presented in Figure 2) was created based on elevation data, historical flood extents, along with flood-extent photos and observations provided by residents, landowners, and ORC field staff during previous flood events.

The North Taieri area is bounded by a range of 300 to 500m high hills to the north, Silver Stream to the south, the East Taieri Upper Pond cut-off bank to the west, and Miners Road to the east. This area is exposed to flooding from Silver Stream, Mill Creek, and small catchments to the north. The Upper Pond cut-off bank is intended to prevent water from the Taieri River from entering this area. ORC has demarked the North Taieri into four hazards areas namely: Area 14A, 14B, 14C, and 14D (Figure 3). Among these four hazard zones, ORC wants to have better understanding of how the North Taieri floodway, also known as Gordon Road floodway (Area 14B), is impacted during flood events.

This report describes the flood hazard assessment carried out to better understand how the North Taieri/Gordon Road floodway is impacted during flood events and details the development of the hydraulic model used to inform the assessment.

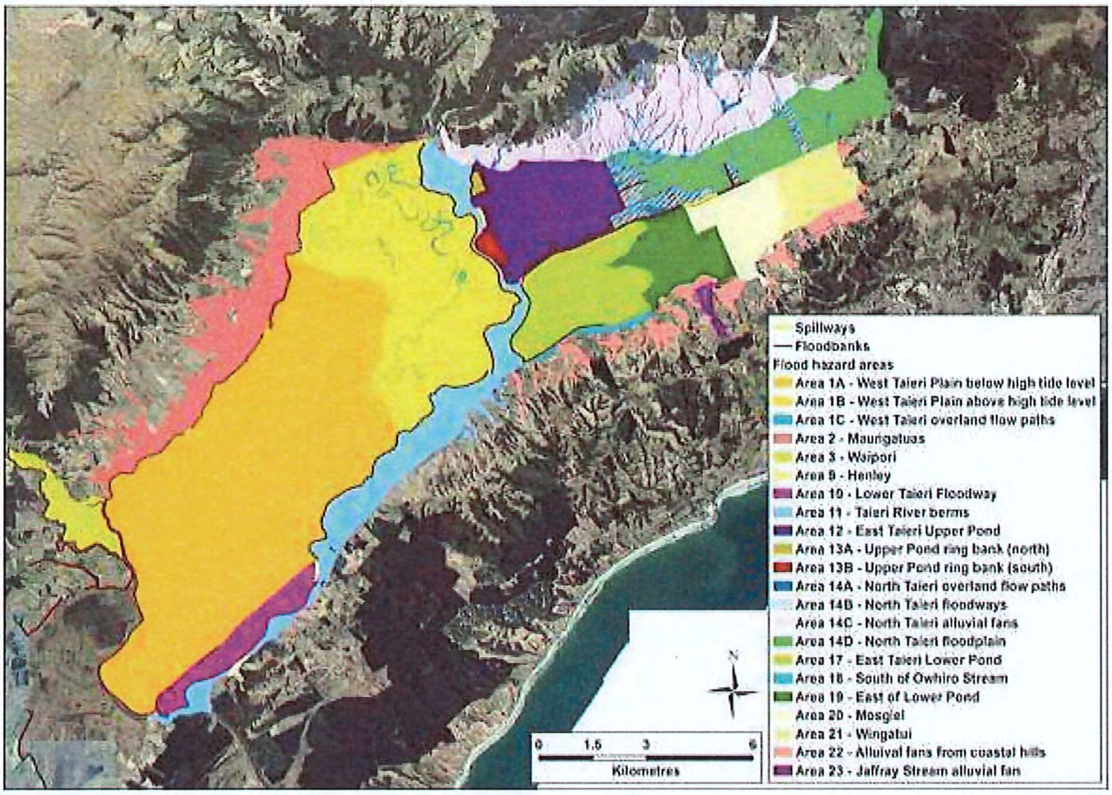

Figure 2. Flood hazard areas of Taieri Floodplain (ORC, 2015).

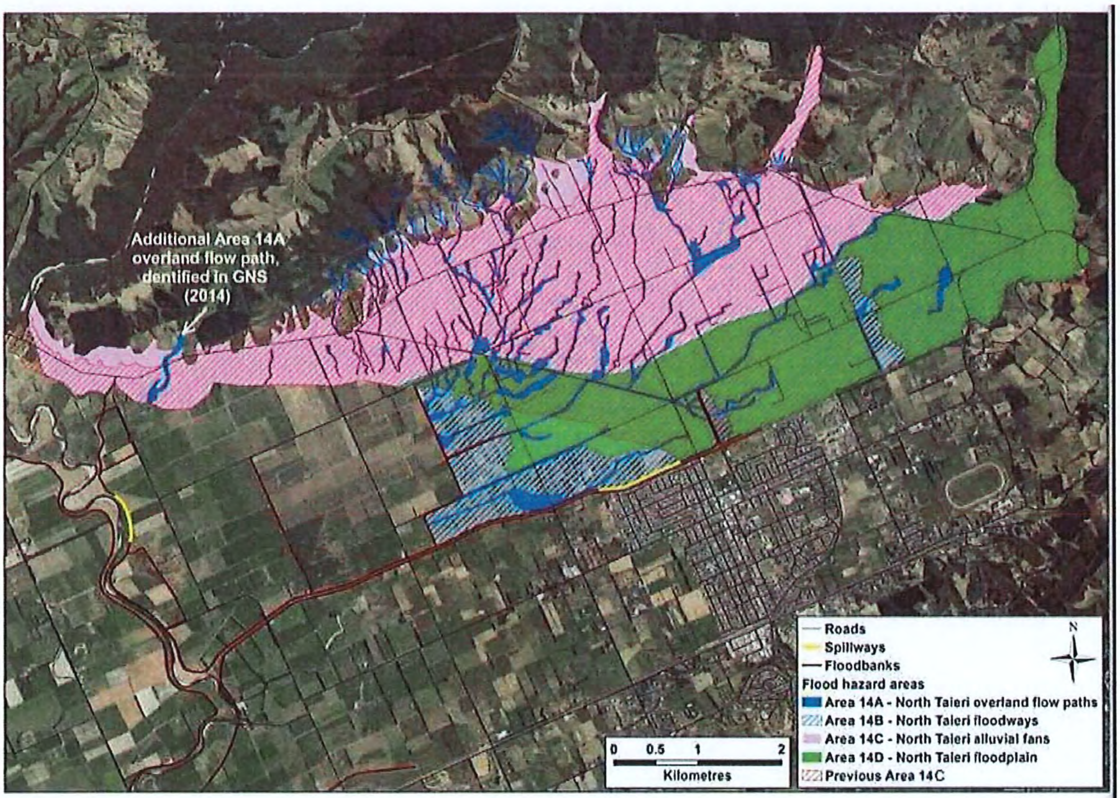

Figure 3. Hazard areas for North Taieri (ORC, 2015).

1.2 Scope

The scope of the investigation was to carry out the flood hazard assessment to determine how North Taieri/Gordon Road floodway, more specifically the area between cut-off banks and State Highway 87, is impacted in flood events using the Taieri hydraulic model previously completed by ORC. The assessment was carried out for July 2017 and 100-yr ARI events.

2. Hydraulic model configuration and hydrological inputs

2.1 Hydraulic model setup

ORC maintains the HEC-RAS (version 5.0.3) 1-Dimensional (1D) / 2-Dimensional (2D) hydraulic model for the Silver Stream, which was created in 2019 to assess the implication of morphological changes of the Silver Stream on the performance of the Gordon Road spillway and recommend possible measures to reduce the impact. The floodplain was modelled as a 2D component, and the Silver Stream was modelled as a 1D component. The 2D flow area elements were connected laterally to the 1D river reach using lateral structures/weirs. 1D and 2D flow area connections in the model primarily represent the existing flood banks which are modelled as broad-crested weirs. For greater accuracy, the station-elevation data for the weir profiles were based on surveyed crest levels, rather than the LiDAR profile. The two bridges over Silver Stream at Gordon Road and Riccarton Road were also modelled using energy equation.

The existing 1D/2D model covers the area between Outram-Mosgiel Road (SH 87) on the east and north, Owhiro River on the south and Taieri River on the west (as presented in Figure 4). The existing model has been setup utilizing 2016 LiDAR data (Figure 5), which has an expected vertical accuracy of +/- 30 cm, along with 23 surveyed cross-sections of the Silver Stream (March 2003, November 2011 and October 2017), and flood bank crest level survey data gathered in July 2017. The cross-section spacing for Silver Stream ranges between 50m – 488m. Land use data (Figure 6) from Landcare Research (LCDB v4.1 - Land Cover Database version 4.1, Mainland New Zealand) was used to set Manning's roughness values for floodplain areas (Table 1). Manning's roughness values for floodplain areas were set based on recommendations made by Chow (1959), Babister and Barton (2012), and previous modelling exercises.

The model has been calibrated using a June 2015 event and validated for May 2006, May 2010, and July 2017 events as presented in Figure 7. The debris data collected for four different flood events (May 2006, May 2010, June 2015, and July 2017) were used for model calibration and validation. It is to be noted that during the calibration period (June 2015) Silver Stream cross-section surveyed in November 2011 was used, while for the validation period of May 2006, May 2010 and July 2017 Silver Stream cross-section surveyed in March 2003, November 2011 and October 2017 were used, respectively. During the calibration process Manning's n roughness value of the Silver Stream channel was changed. The Manning's n of 0.03 was found to be appropriate representation of channel roughness for the Silver Stream. The comparison of modelled water level against the debris mark suggests that the modelled value aligns well with the debris marks.

Table 1. Hydraulic Roughness of the floodplain area.

Surface type	Manning's n
Broadleaved indigenous hardwoods	0.05
Built-up area	0.15
Deciduous hardwoods	0.09
Exotic forest	0.09
Flax land	0.1
Forest-harvested	0.05
Gorse and /or broom	0.2
Gravel or rock	0.02
Herbaceous freshwater vegetation	0.06
High producing grassland	0.05
Indigenous forest	0.09
Lake or pond	0.01
Low producing grassland	0.035
Manuka and/or Kanuka	0.15
Mixed exotic shrubland	0.05
Orchard, vineyard or other perennial crop	0.05
Short-rotation cropland	0.04
Surface mine or dump	0.03
Tall tussock grassland	0.05
Transport infrastructure	0.016
Urban parkland/open space	0.035

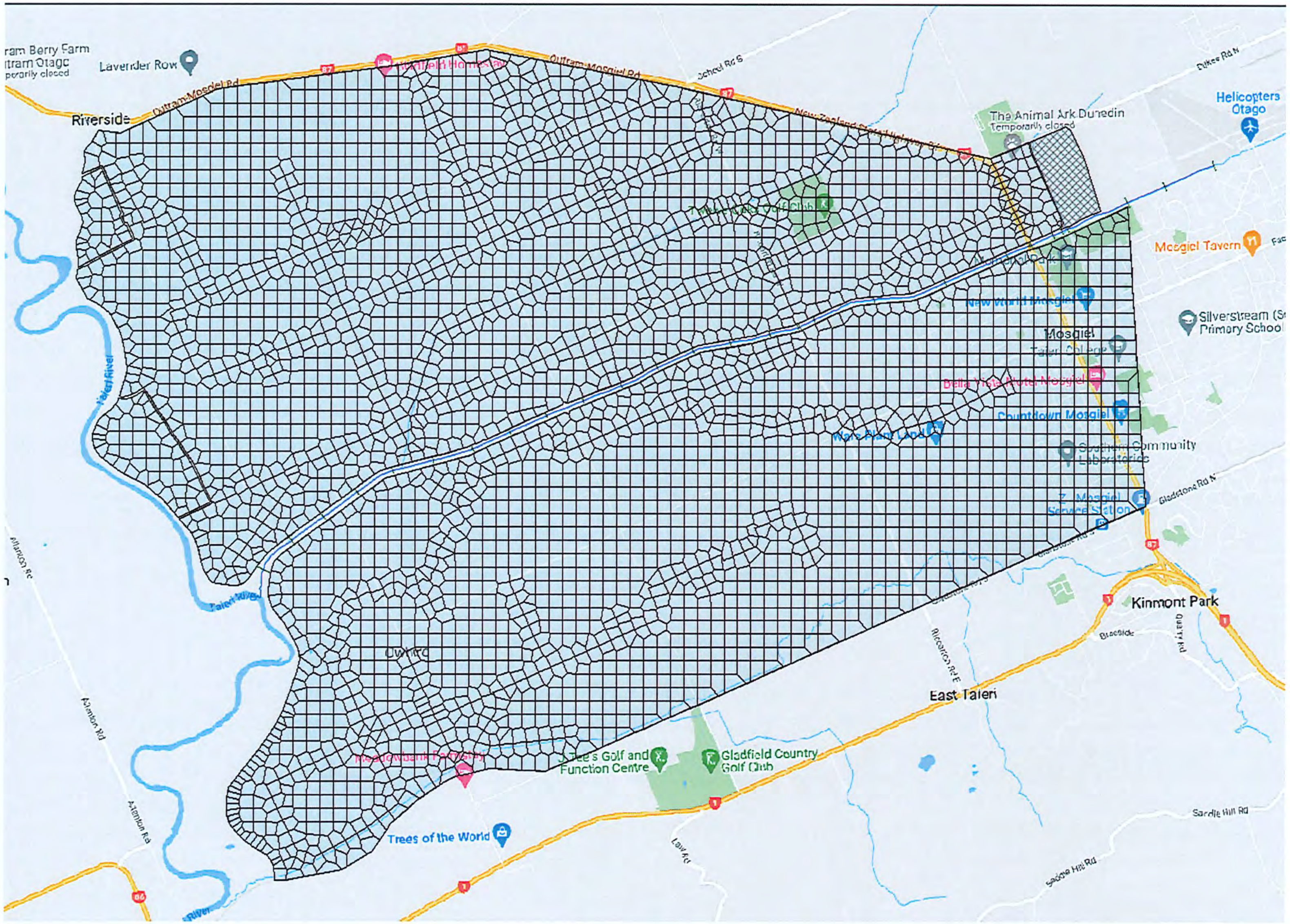

Figure 4. Extent of the 1D/2D hydraulic model of the Silver Stream maintained by ORC.

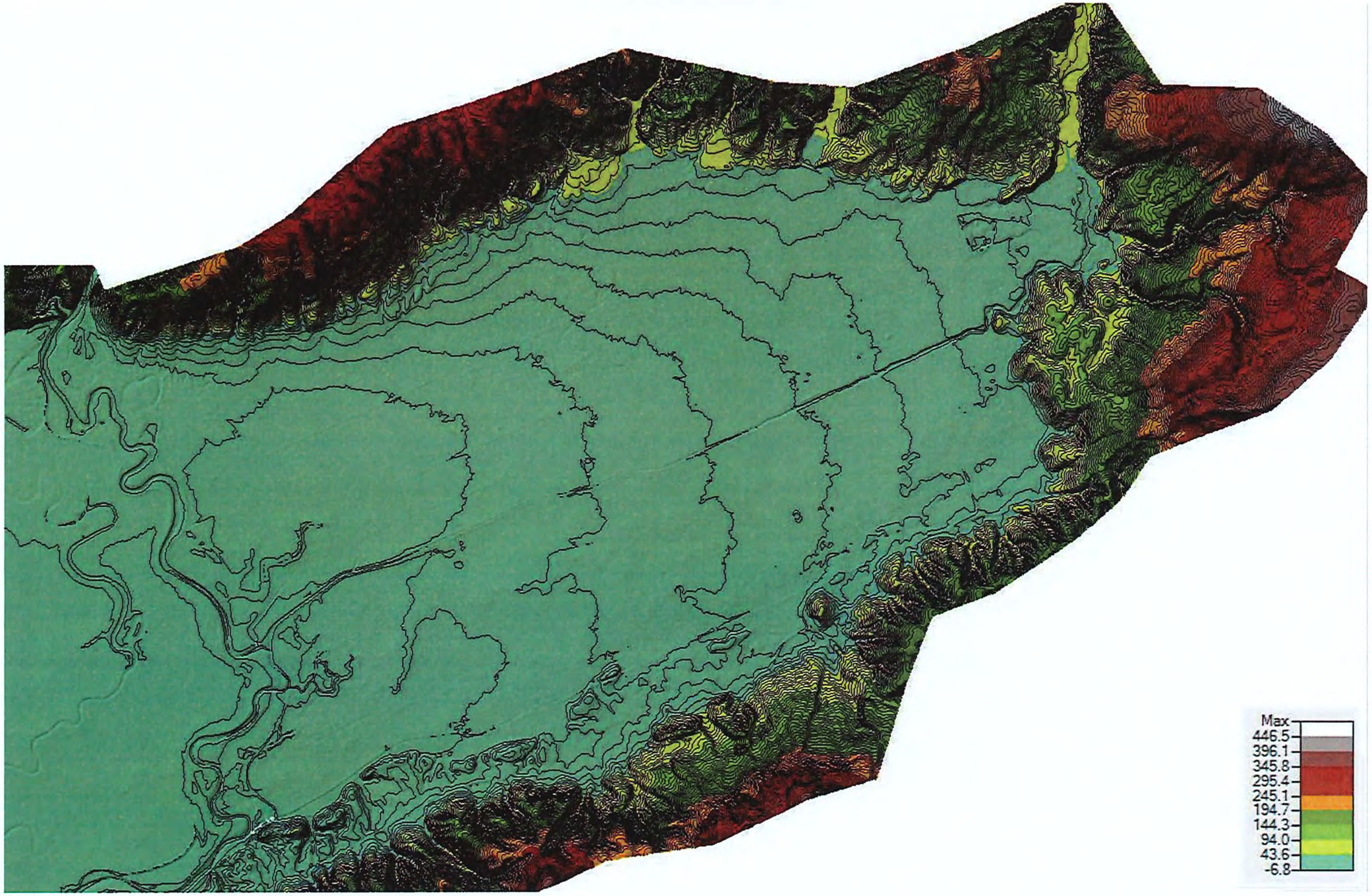

Figure 5. Taieri LiDAR Terrain 2016.

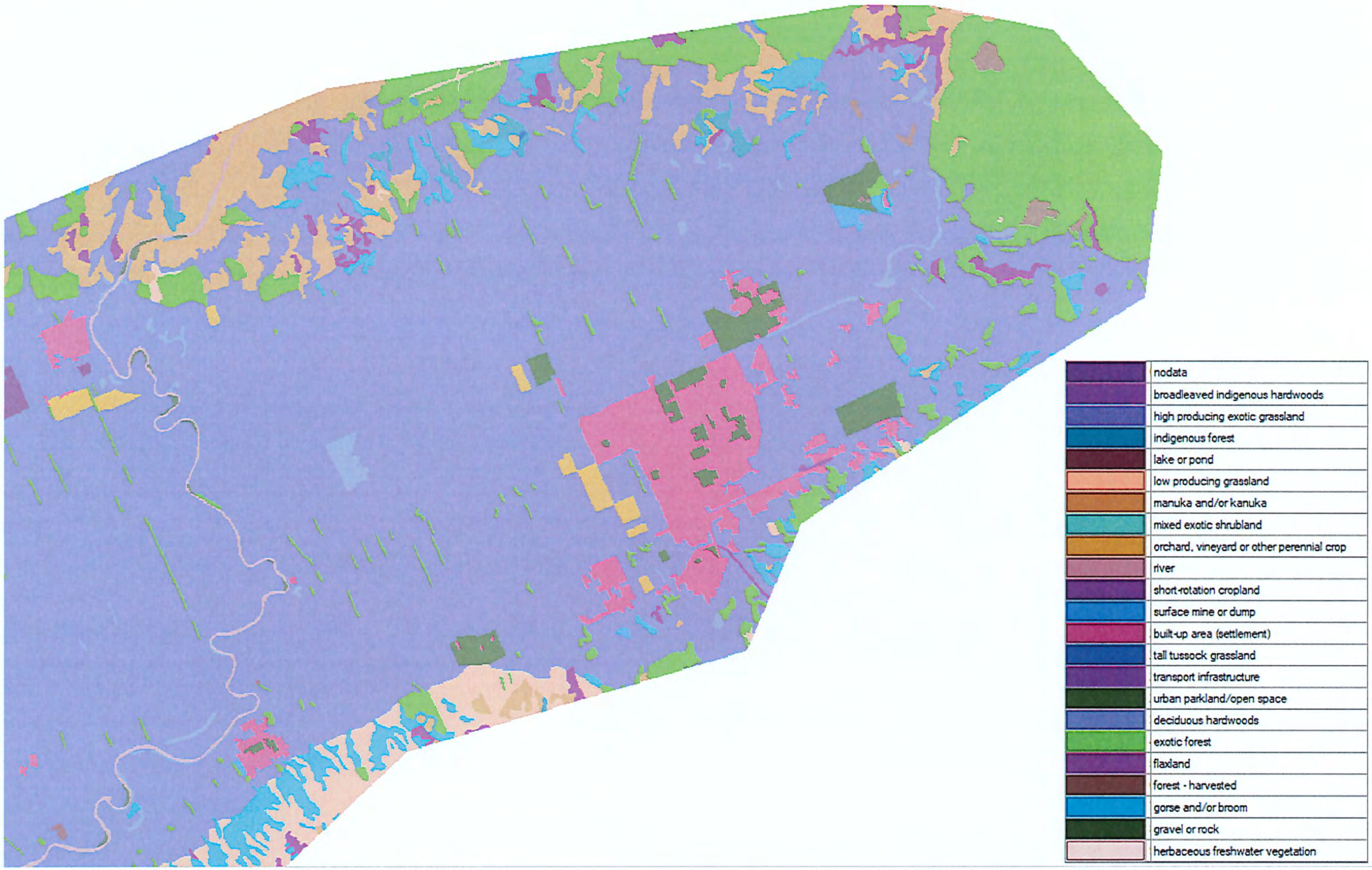

Figure 6. Land use data of Lower Taieri Floodplain.

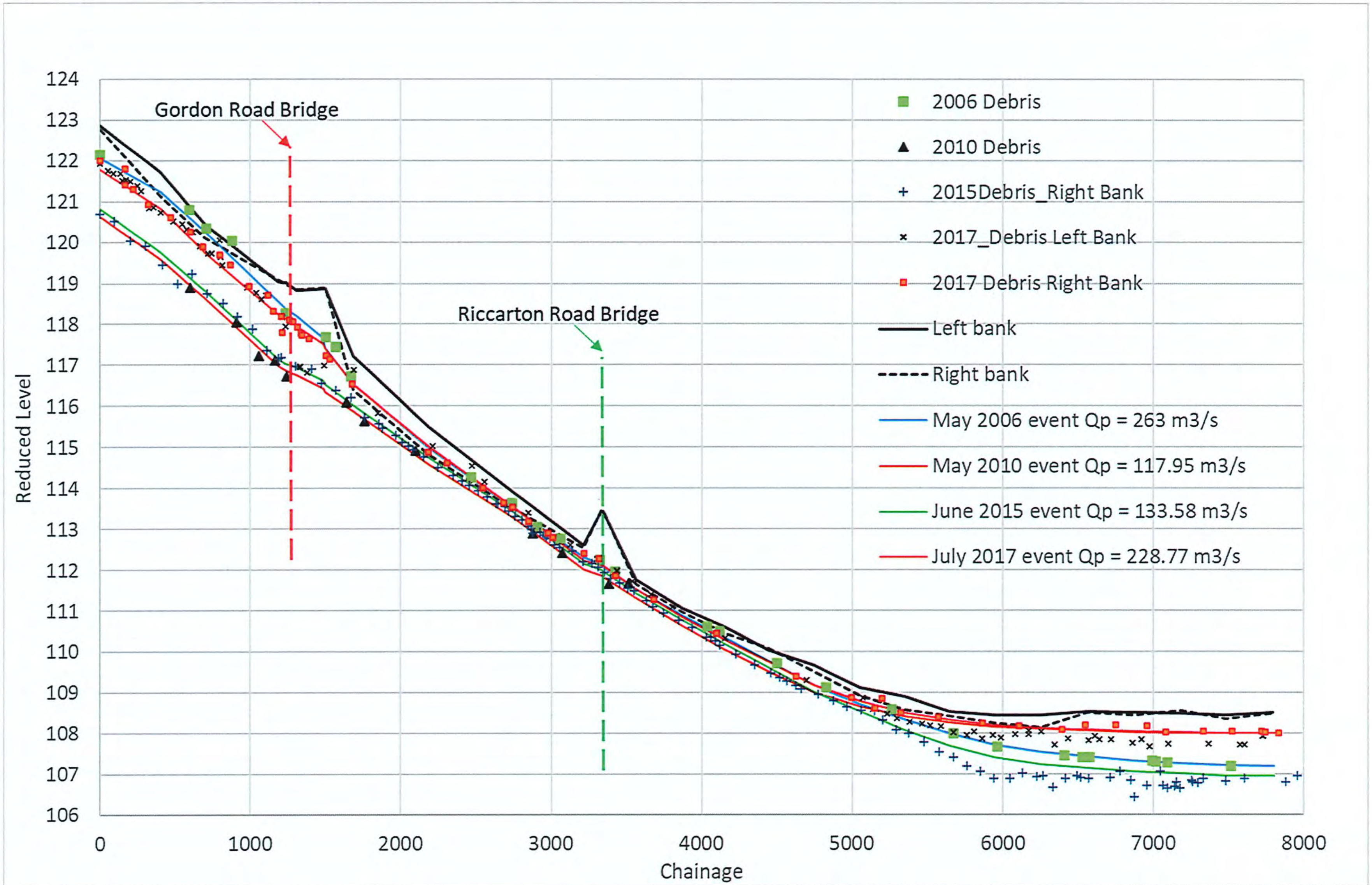

Figure 7. Comparison of observed high water level against modelled water levels for various events.

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For the current assessment several modifications were made to the existing ORC model which are outlined below:

a) The 2D area of the existing model was further extended (area under red boundary as indicated in Figure 8) to include the area between Miner Road on the east, Tirohanga Road on the north, Outram-Mosgiel road on the west and Silver stream on the south. The area between Wingatui road and Outram-Mosgiel road on the Lower Pond area was also included. The 2D area was extended to have better understanding of the contribution of Mill creek, area east of Outram-Mosgiel road and catchments to the north to the flooding of North Taieri/Gordon Road floodway.
b) The grid size of the 2D area was refined from 100m x 100m to 50m x 50m for Lower Pond area and 15m x 15m for Upper Pond and North Taieri area. Break line spacing was further refined to 5m x 5m grid spacing for better representation of cut-off banks.
c) The grid sizes along the major roads and high ground were also refined with break lines using 5m x 5m grid spacing to better represent terrain and avoid leakage in the model.
d) Interpolated cross-sections, with spacing of 50m, for Silver Stream, upstream of Mill Creek diversion and Silver Stream confluence, were added to the model.
e) The terrain was also modified to include the bund erected at 50 Dukes Road (Figure 9).
f) The bridges - at Dukes Road and Hazlett Road were also included in the model and modelled as culvert structure. The Mill Creek channel was modelled only using LiDAR data, without cross sections.
g) Eight culverts with flap gates through the cut-off banks and a bridge at Riccarton Road over the Mill Creek were included in the model. The bridge at Riccarton Road was modelled as culvert structure. The details on culverts through the cut-off banks and a bridge at Riccarton Road are provided in Appendix A.
h) The model was transferred from HEC RAS version 5.0.3 to 5.0.7 and the model parameters including manning's roughness were also transferred.
i) Rain on grid was used as an internal boundary to the Upper Pond and North Taieri area to have a better understanding of the contribution of internal runoff to the flooding of the floodplain.

The hydraulic model simulation uses the full momentum equation set with computation interval of 2 seconds.

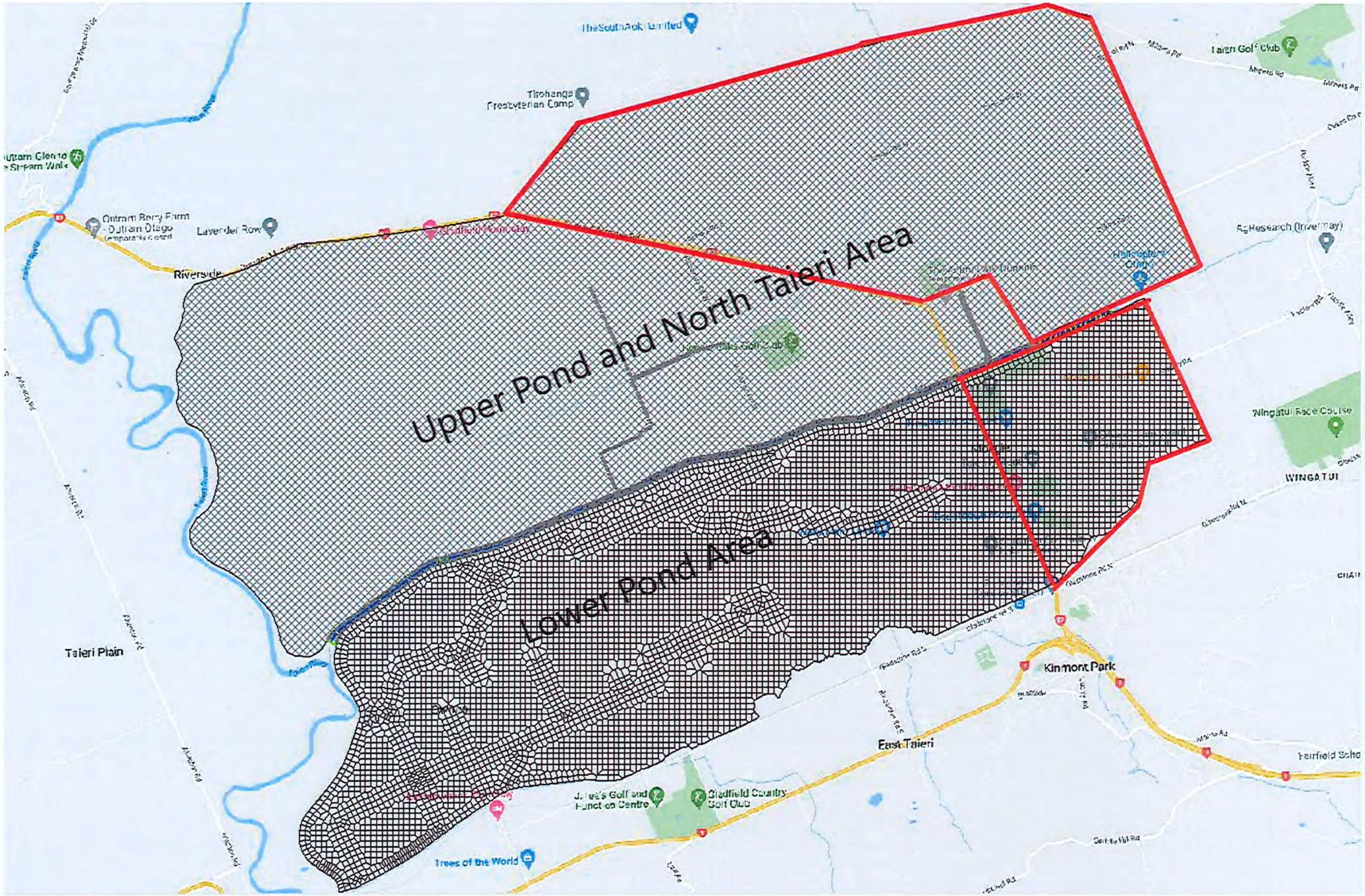

Figure 8. Current Silver Stream hydraulic model extent.

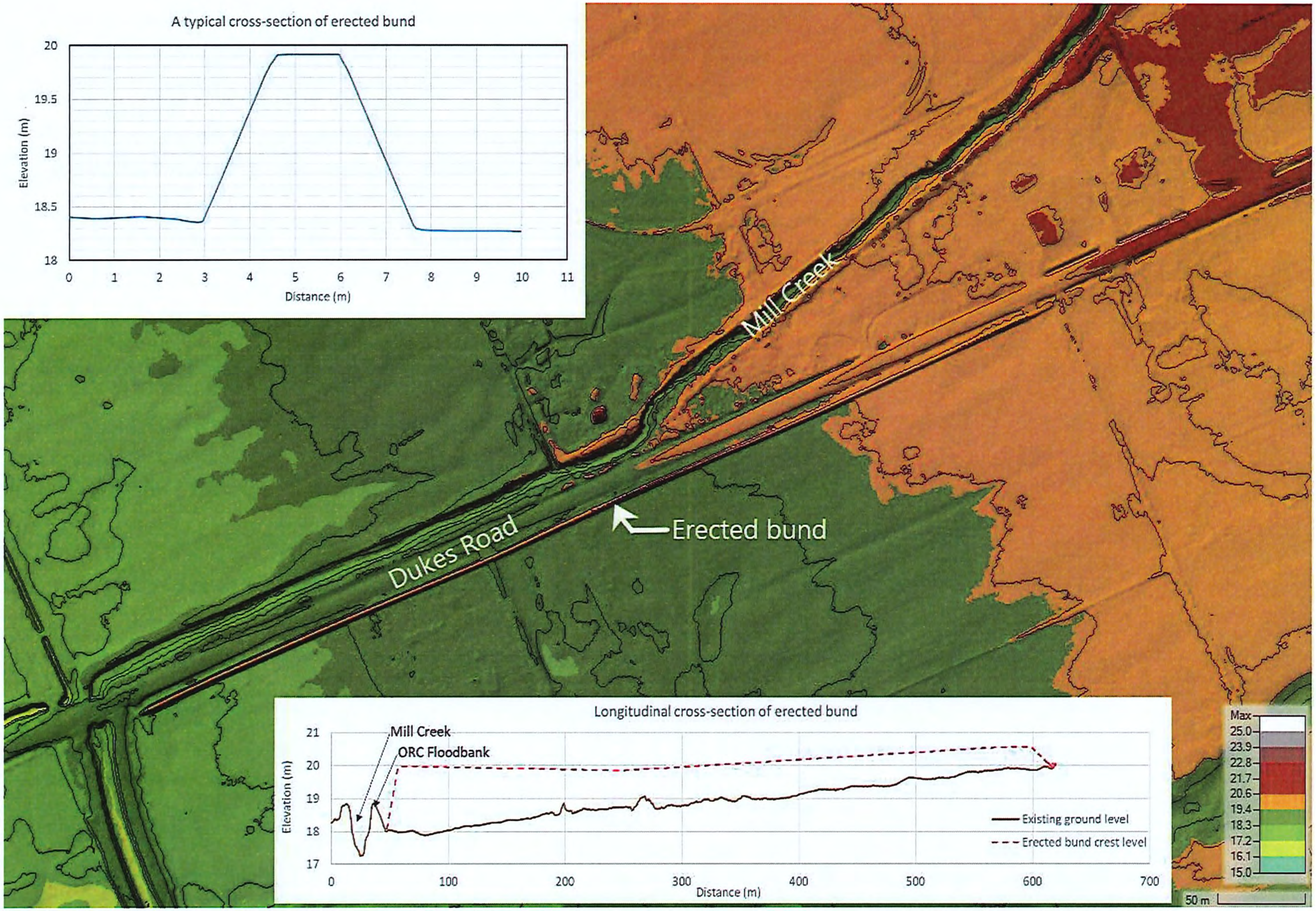

Figure 9. Modified terrain at the Dukes Road and a typical cross-section of erected bund.

TV7

2.2 Hydrological Inputs

There were eleven boundary conditions for the model, namely Mill Creek flow at railway line, flows from six catchments to the north and Silver Stream flow as upstream boundaries, effective precipitation as internal boundary at Upper Pond and North Taieri area, Taieri flow level at the Taieri and Silver Stream confluence as downstream boundary, and overflows from Taieri River via Riverside Spillway to Upper Pond. The flow and precipitation boundaries were provided by ORC, while the Taieri flow level at the Taieri and Silver Stream confluence and overflows from Taieri River via Riverside Spillway to Upper Pond were extracted from the Lower Taieri HEC RAS model. It is to be noted that during the large events the flow from Taieri River enters the East Taieri Upper Pond via Riverside Spillway. The culverts across the cut-off banks are provided with flap gates to prevent flow from the Upper Pond to the Gordon Road Floodway. The operation of the flap gates at culverts across the cut-off banks is affected by Taieri overflows to Upper Pond. Further, the modelling of Lower Taieri by ORC also suggests that during the 100-year event the overflows from Taieri River is likely to overtop the cut-off banks. Hence, the overflows from Taieri River was also included in the model.

ORC gauges the Silver Stream at Gordon Road around 235m downstream of the Mill Creek diversion and Silver Stream confluence. The length of records ranges from 9 July 1975 till date. Frequency analysis of available flow data of the Silver Stream was carried out by ORC utilizing the Partial Duration Series (PDS) approach.

Table 2. Silverstream design flows**.**

Return Period (yrs)	Design Flow (m^3/s)
5	120
10	158
20	196
50	251
100	296
200	345

The flow hydrographs for design event were produced by ORC utilizing the design relative hydrograph (Figure 10) derived based on six significant Silver Stream high flow events.

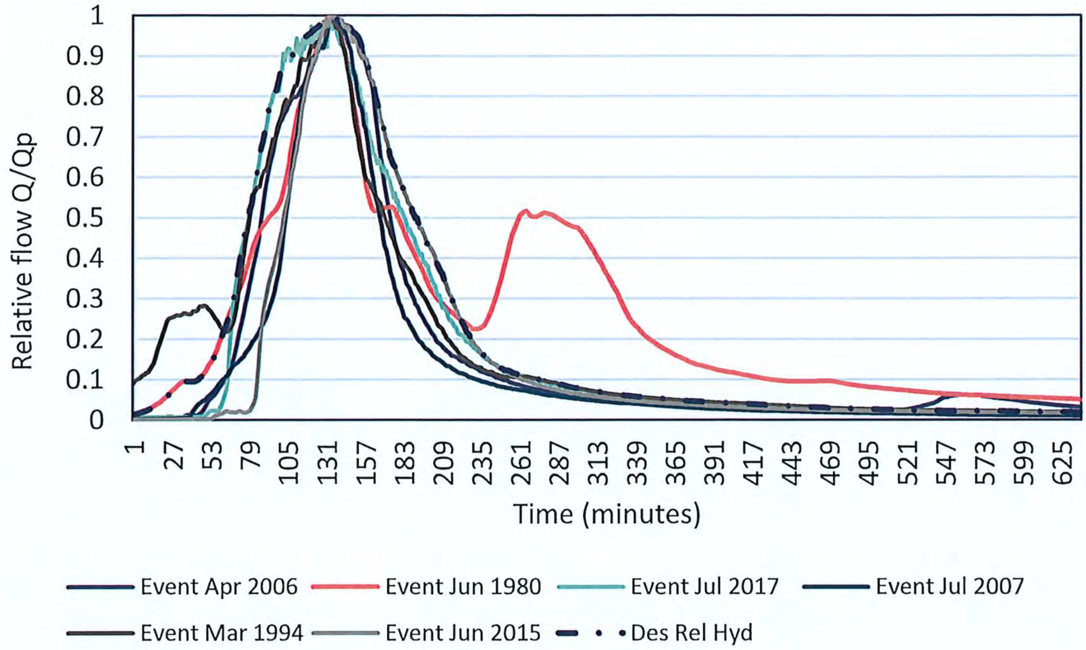

Figure 10. Silver Stream design relative hydrograph (DRH).

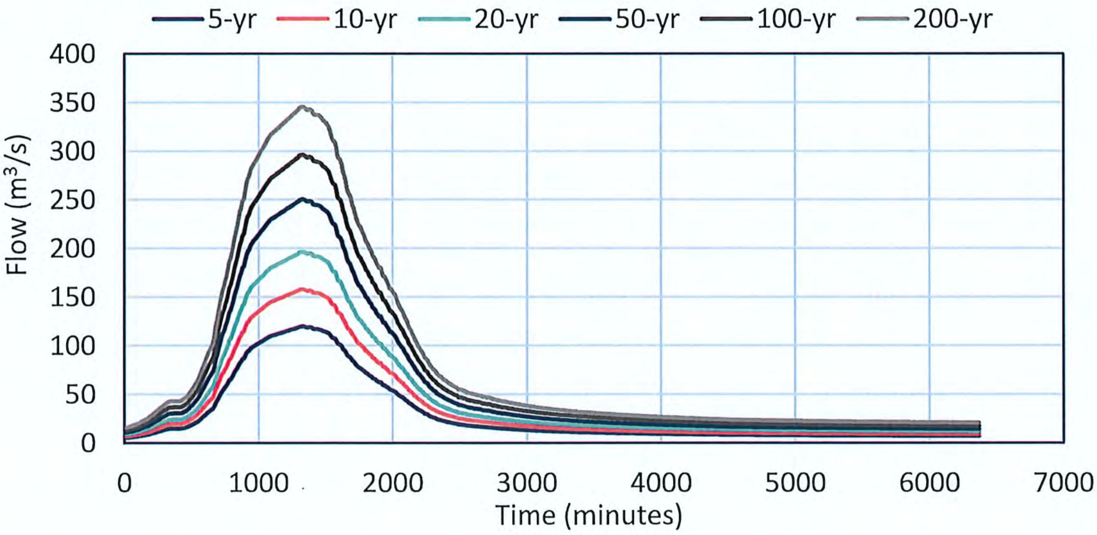

Figure 11. Silver Stream design flow hydrographs for various event.

There are no flow observations for the Mill Creek and catchments to the north (Figure 12) hence, to produce 2017 July event flow and design flows for the Mill Creek catchments upstream of railway line and catchments to the north, a HEC-HMS model was developed by ORC making use of the catchment areas and topographical characteristic, including the initial and constant losses which were estimated for Silver Stream. Design rainfalls were obtained from HIRDS (NIWA High Intensity Rainfall Design System), and these design rainfalls were applied to the developed HEC-HMS model to estimate the design flows (Figure 13) for different return periods.

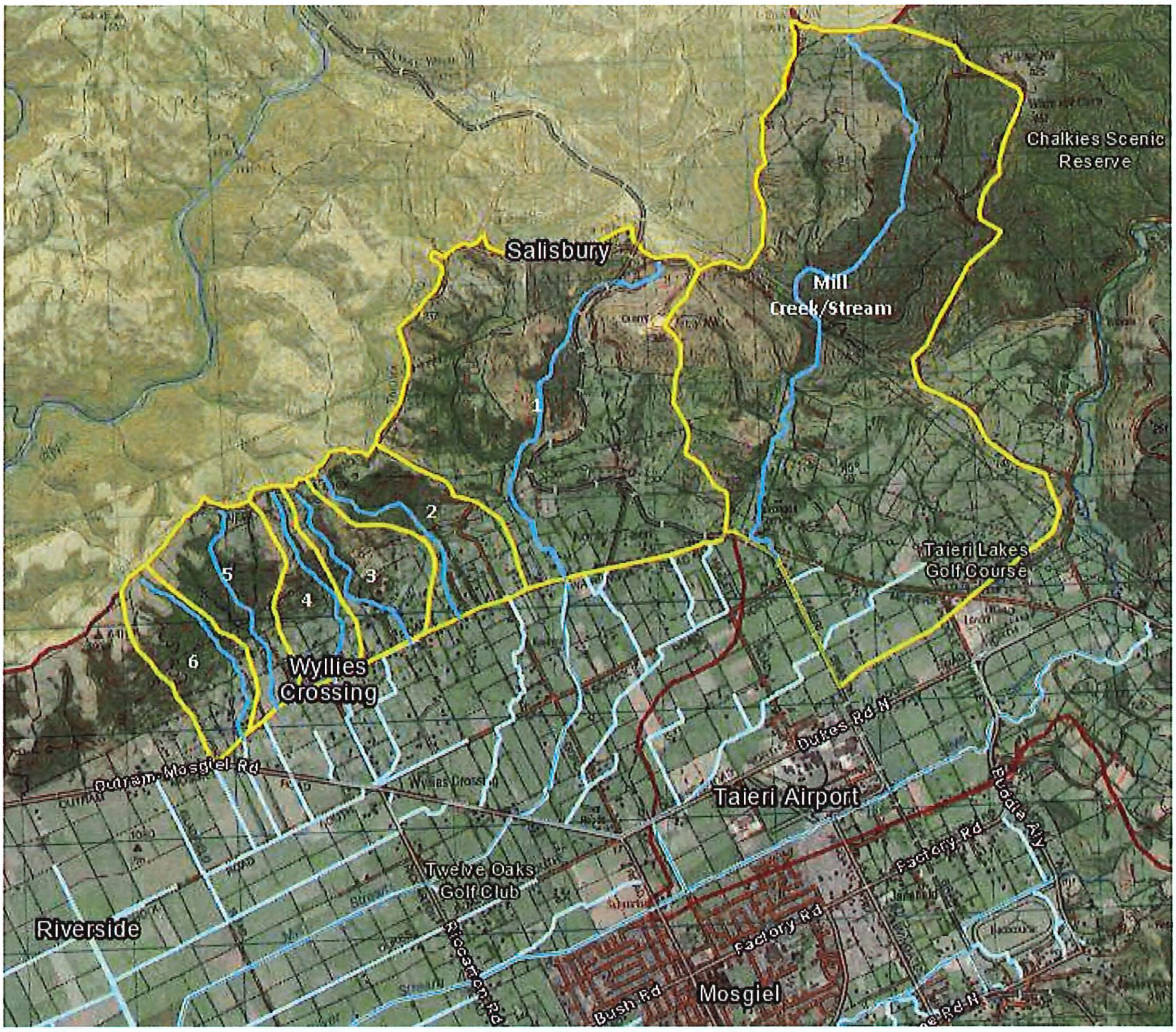

Figure 12. Mill Creek catchment and six catchments to the north.

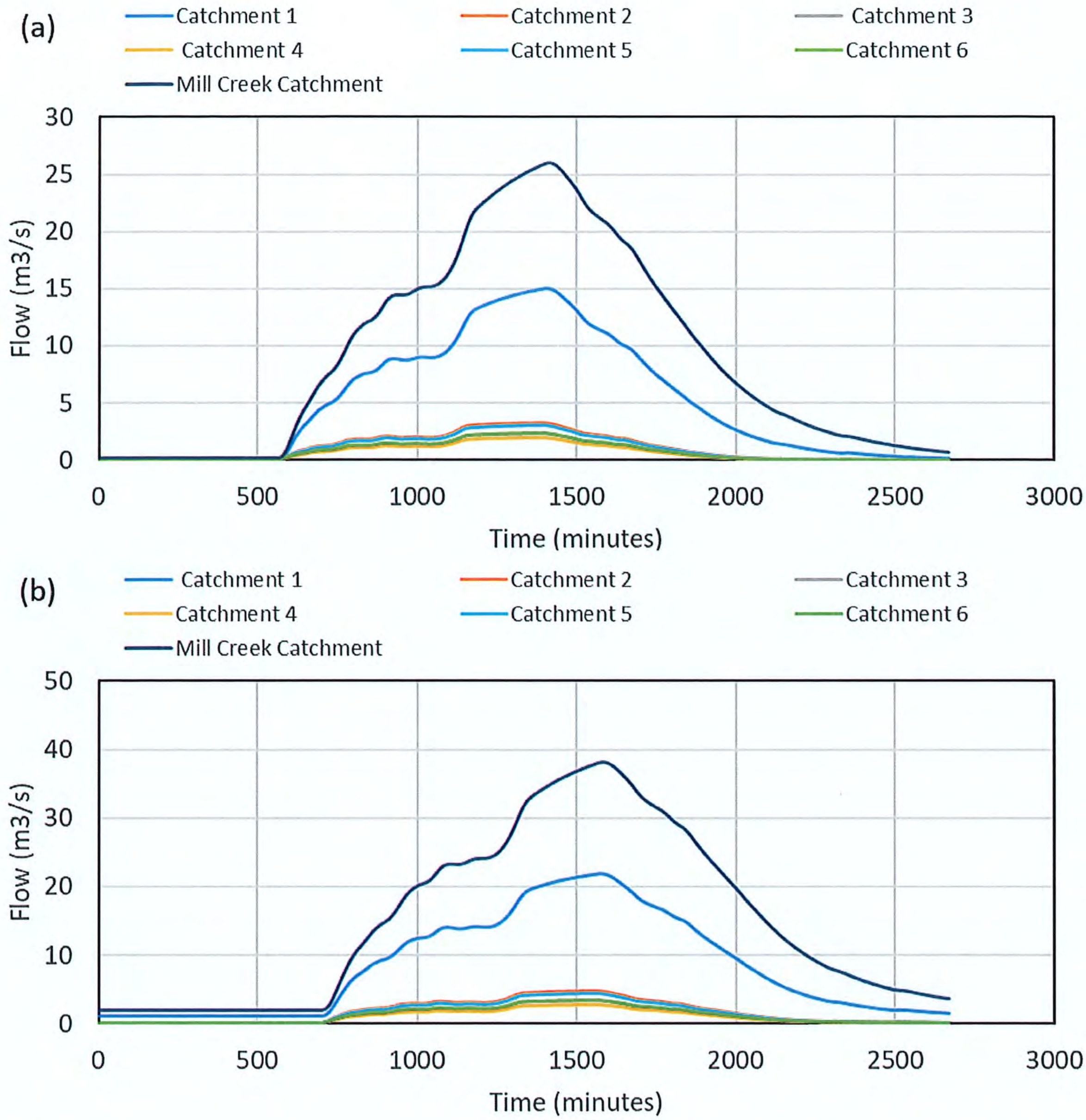

Figure 13. Mill Creek at the railway line and catchments to the north flow hydrographs for (a) July 2017 event and (b) 100-yr ARI event

It is to be noted that the flow boundary for Silver Stream was applied approximately 1200m upstream of the confluence of Mill Creek diversion and Silver Stream. ORC measures flow downstream of the confluence of Mill Creek diversion and Silver Stream which is the combined flow of Silver Stream and Mill Creek diversion (Figure 14). Since Mill Creek is not gauged the flow contribution from Mill Creek diversion is not known. For modelling purposes, the July 2017 observed flow and 100-yr ARI design flow were modified using trial and error approach. The modified hydrographs were applied at the upstream boundary such that the combined flow from Silver Stream upstream of confluence and Mill Creek diversion aligns with the observed and design flows downstream of the confluence.

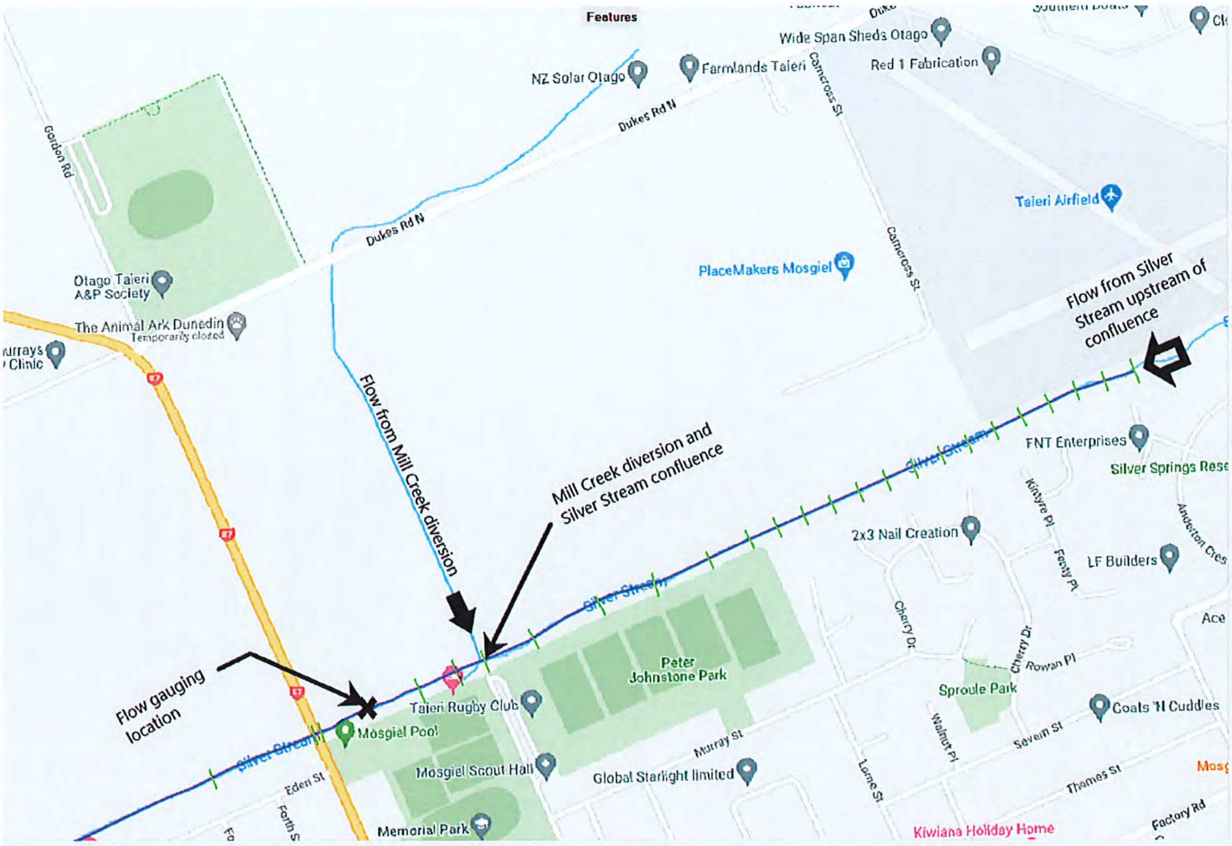

Figure 14. Location of gauging station and upstream flow boundary of Silver Stream.

The peak flow for the 100-yr ARI for Silver Stream at Gordon Road has been estimated as 296m^3/s by ORC based on frequency analysis. However, hydraulic analysis carried out to get the combined flow from the Mill Creek diversion and Silver Stream, upstream of the confluence of Mill Creek diversion and Silver Stream, suggests that the 100-yr ARI peak flow downstream of the Mill Creek diversion and Silver Stream confluence will not reach 296m^3/s because of flow overtopping on the right bank of Silver Stream, upstream of the Mill Creek diversion and Silver Stream confluence. Our analysis suggests that the peak flow for 100-yr ARI flow downstream of the Mill Creek diversion and Silver Stream confluence will be closer to 286m^3/s. Otago Catchment Board (1974) also outlines that the Wingatui Road to Gordon Road bridge reach of Silver Stream was designed to carry flow of 283.17 m^3/s.

3. Hydraulic model results

The original Silver Stream hydraulic model was setup, calibrated, and validated using HEC RAS version 5.0.3. This model was further refined, extended, and transferred to HEC RAS version 5.0.7. The model was re-evaluated against the observed high-water marks for July 2017 event. The results are presented in Figure 15 and Figure 16. The comparison of modelled water level against the debris mark suggests that the modelled value aligns well with the debris marks. In general, the modelled water levels in the floodplain are within the range of +/-250mm (Figure 16), however along the downstream cut-off bank the modelled water levels are more than 500mm higher than the observed data. During the July 2017 event there was overtopping of the cut-off bank at several locations hence the surveyed debris line may not represent the actual water level in the cut-off bank during peak of the event (i.e., during the overtopping of cut-off bank).

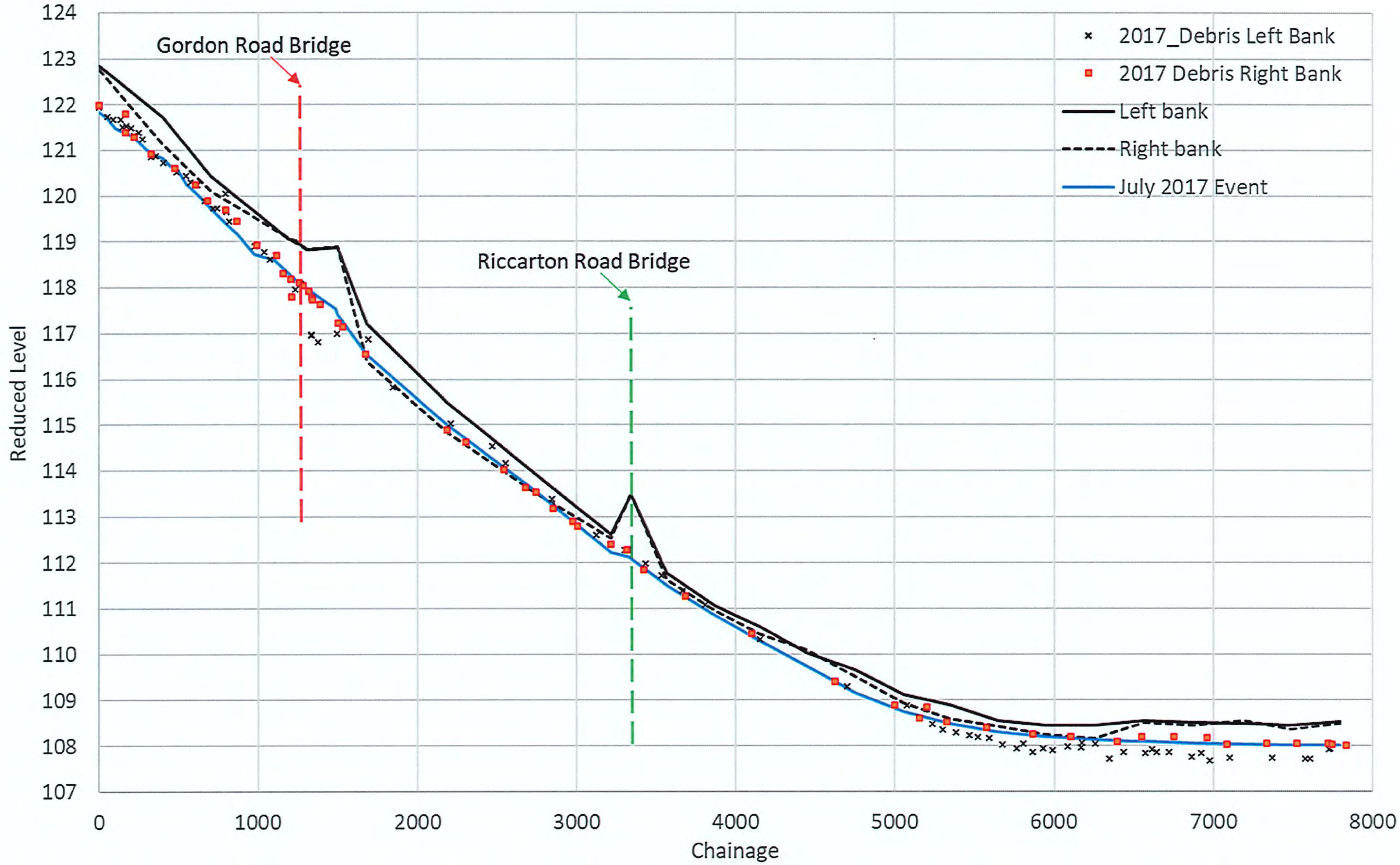

Figure 15. Modelled Silver Stream water level compared against observed high water marks for the July 2017 event.

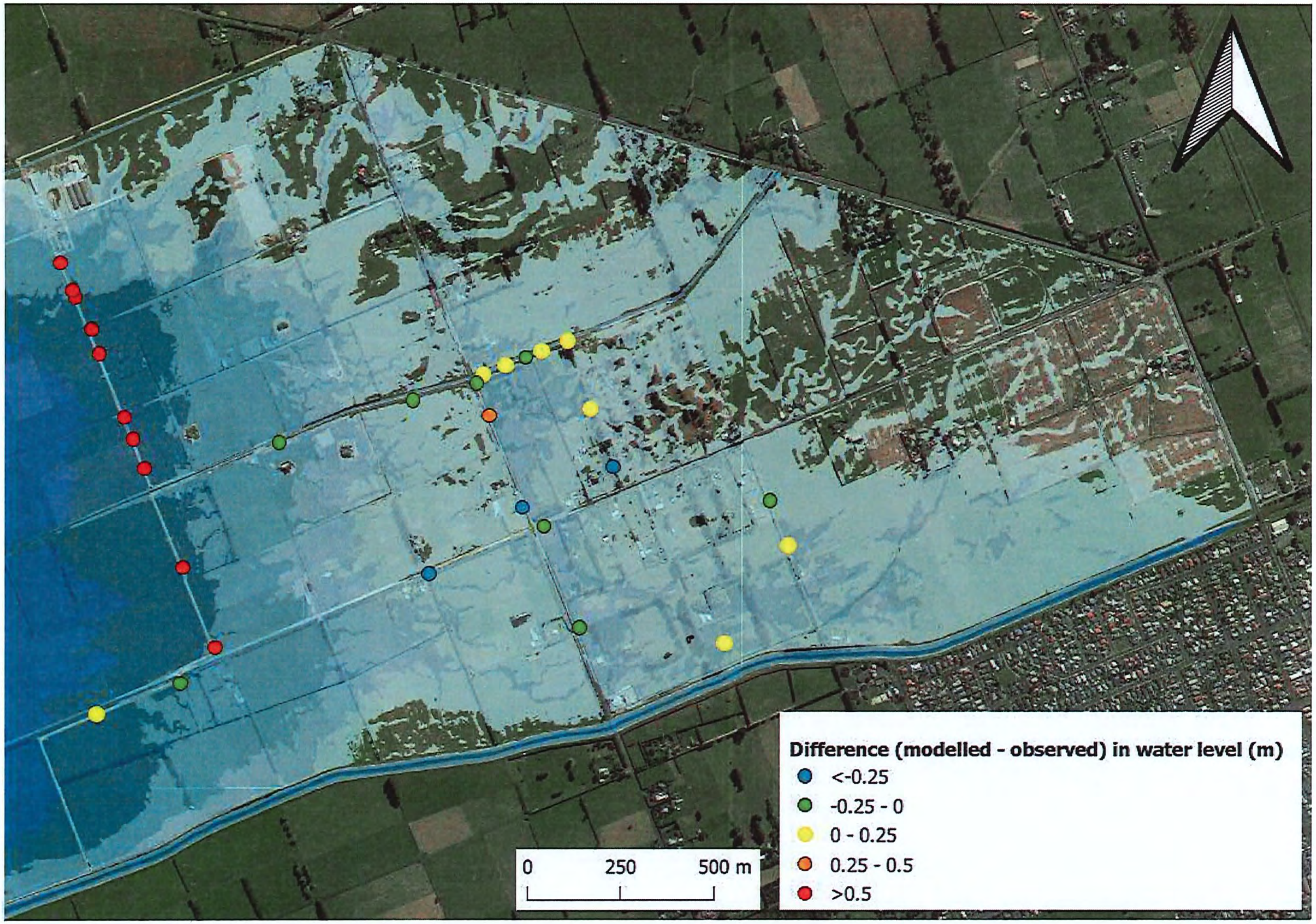

Figure 16. Difference in modelled versus observed debris lines, as an indication of floodplain water level for the July 2017 event.

The modelling result confirms that the overtopping of the true right bank of Silverstream below the Gordon Road bridge (also known as Gordon Road Spillway) is the largest contributor to flooding of North Taieri/Gordon Road floodway. More specifically, the area between the Mill Creek, cut-off bank, and Silver Stream will be flooded primarily due to operation of the Gordon Road Spillway when flow in Silver Stream exceeds 115 m^3/s (Figure 17). Flood water from Mill Creek and runoff from area upstream of Outram-Mosgiel road are the secondary contributors to flooding of the area. The area to the north between Mill Creek, cut-off bank, and Outram-Mosgiel Road is flooded due to runoff from Mill Creek and the area upstream of Outram-Mosgiel Road and internal runoff. For both events (i.e., July 2017 and 100-yr ARI) Dukes Road (between the cut-off bank, and 800m upstream of Riccarton Road), Dukes Road junction, and Riccarton Road are expected to overtop. For July 2017 event the depth of flood water is expected to range between less than 0.5m to almost 3m, while for 100-yr ARI event the flood depth is expected to range between less than 0.5m to more than 3m. For both events the velocity is expected to range between 0.5 to 1 m/s in the floodplain. Higher velocities (greater than 1m/s) are expected in the overtopped portion of Dukes Road and Riccarton Road.

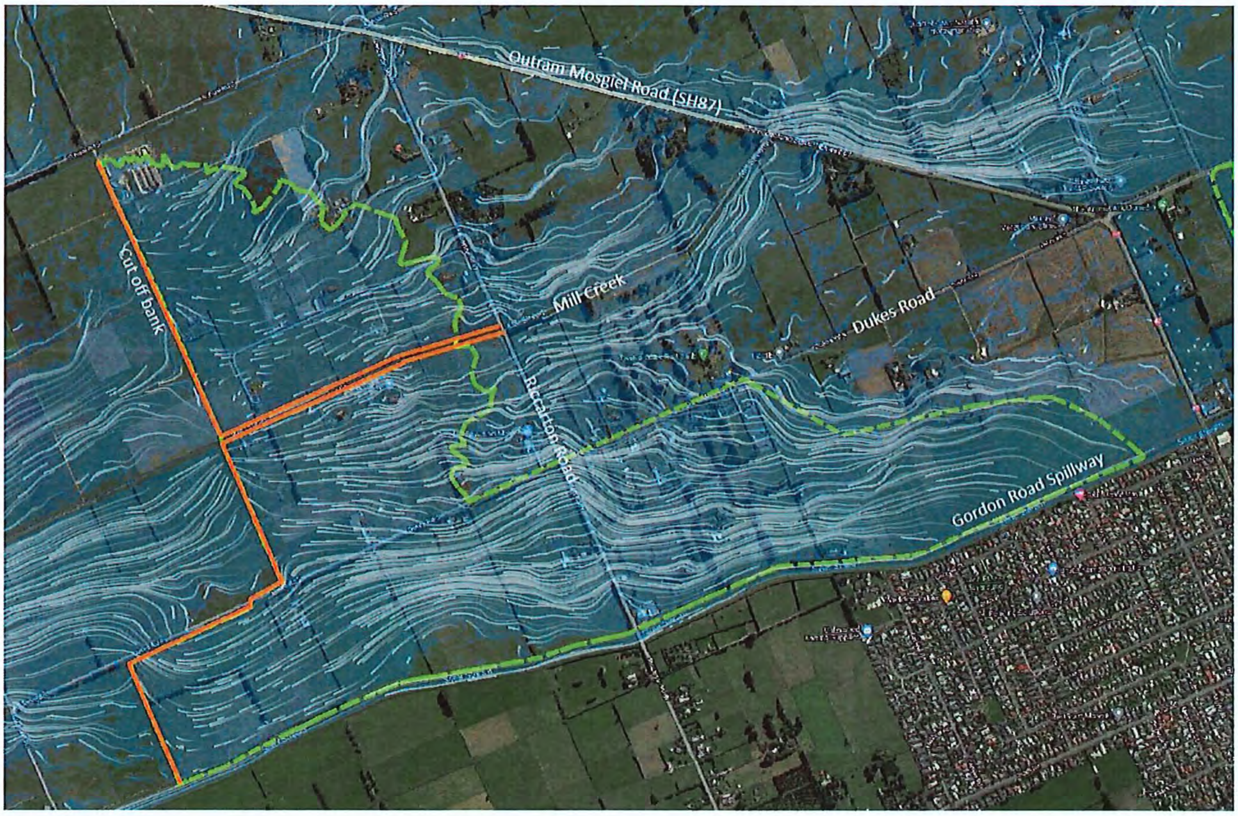

Figure 17. Flood water inundation and particle tracing in North Taieri/Gordon Road floodway.

The depth, velocity, and velocity x depth distribution map for the North Taieri/Gordon Road floodway, more specifically the area between the cut-off banks, and State Highway 87 for July 2017 event and 100-yr ARI events are presented in Figures 18-20, and Figures 21-23 respectively.

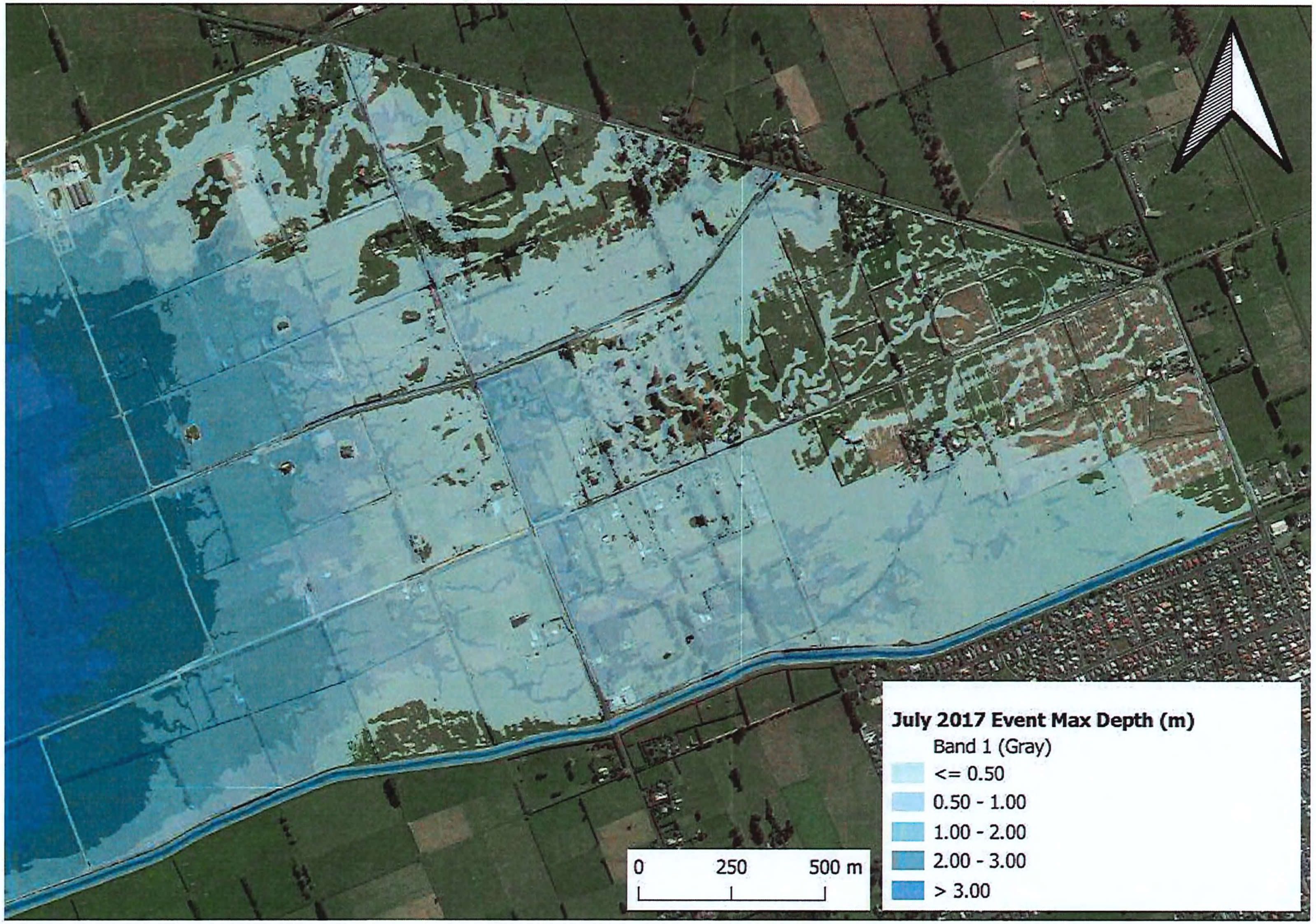

Figure 18. Modelled maximum flood depth distribution map for the July 2017 event.

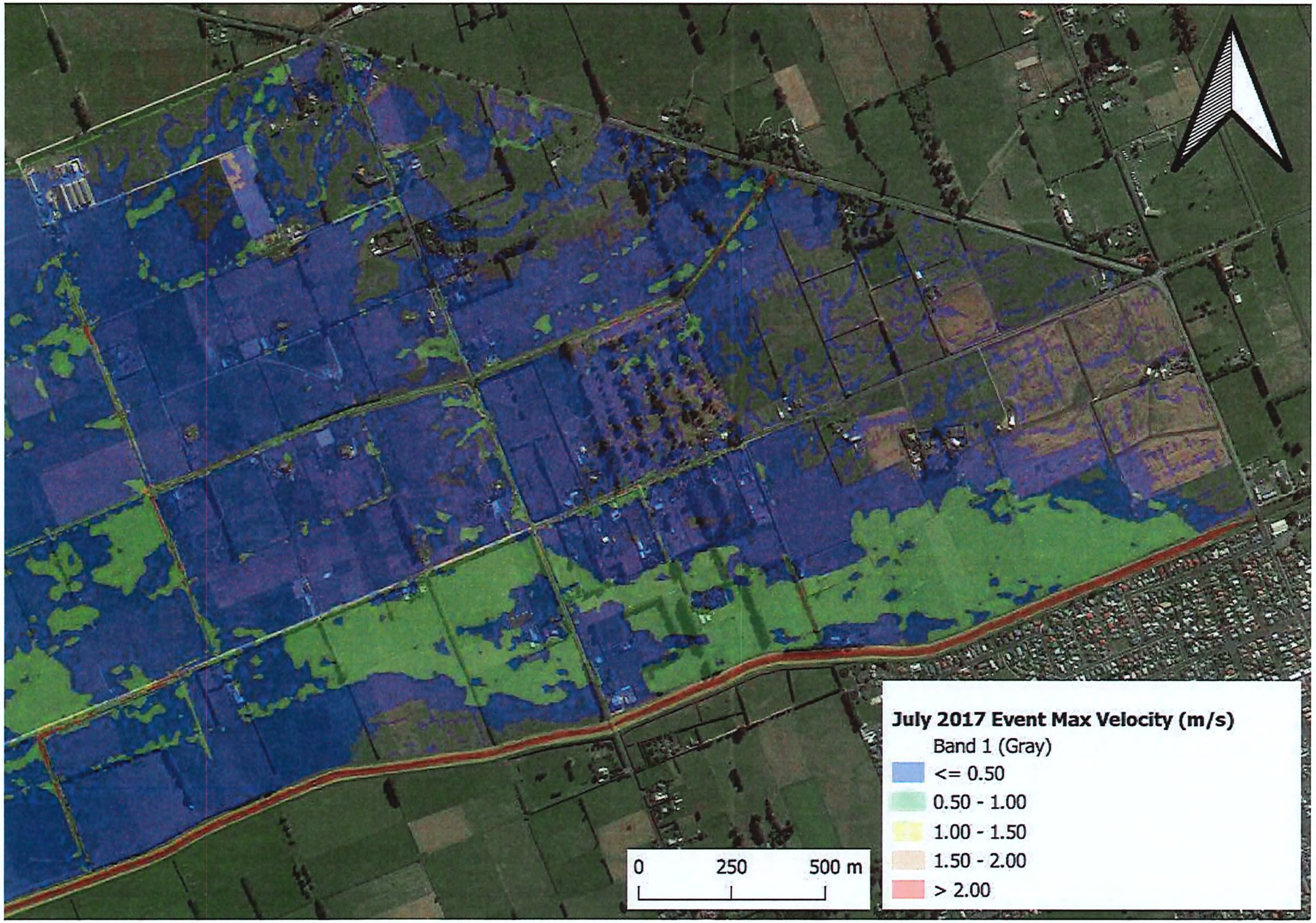

Figure 19. Modelled maximum flood velocity distribution map for the July 2017 event.

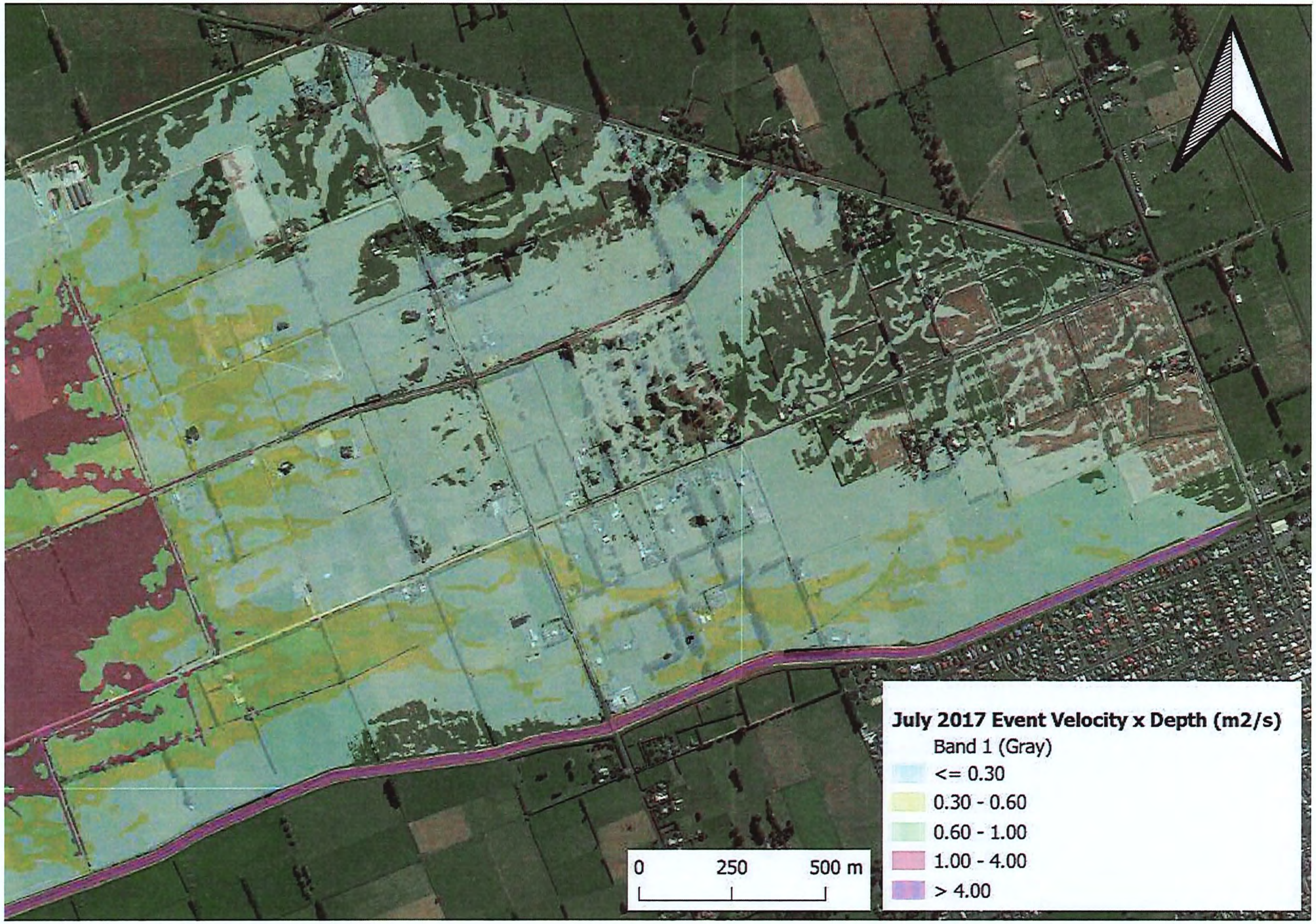

Figure 20. Modelled maximum flood velocity x depth distribution map for the July 2017 event.

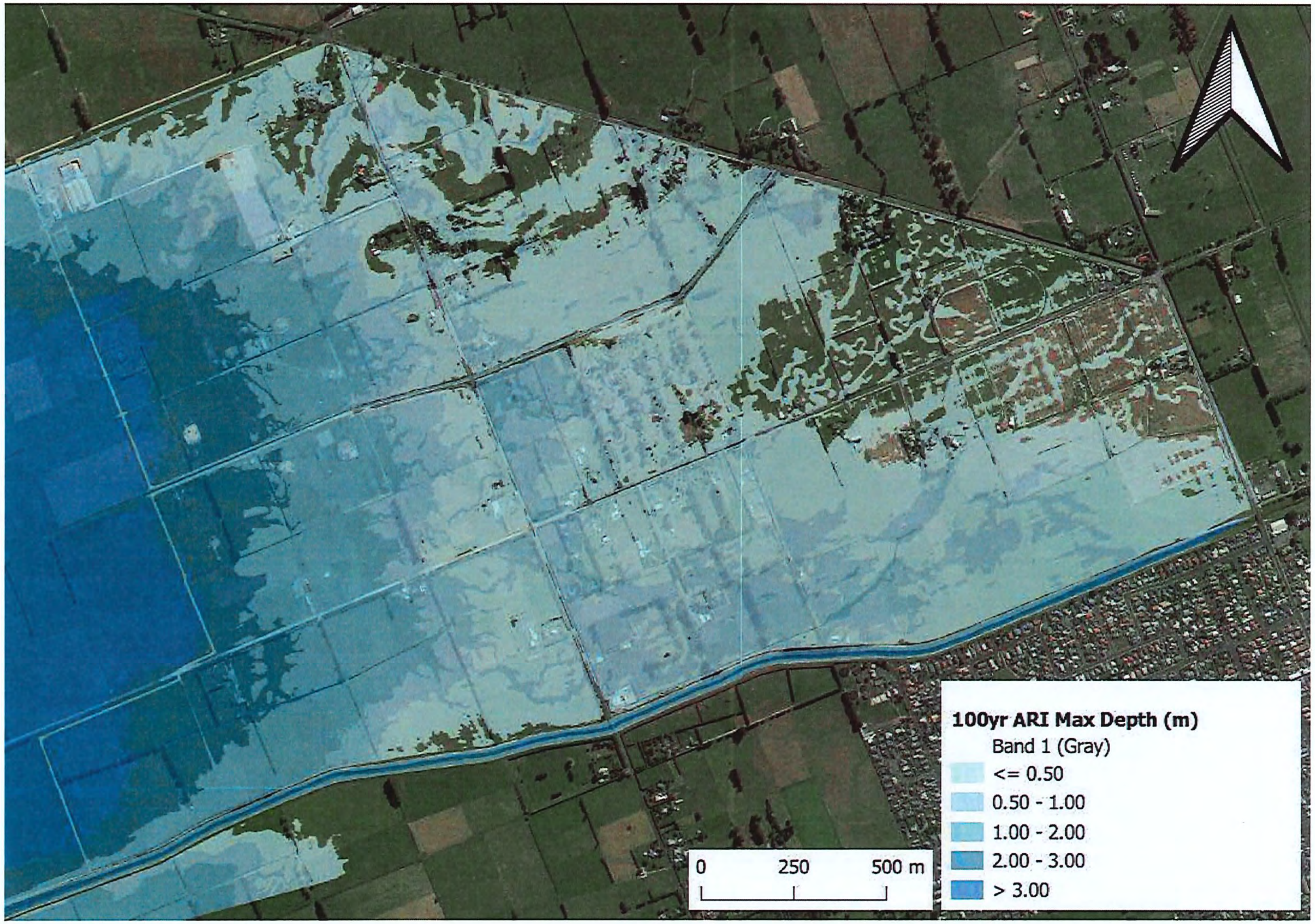

Figure 21. Modelled maximum flood depth distribution map for the 100-yr ARI event.

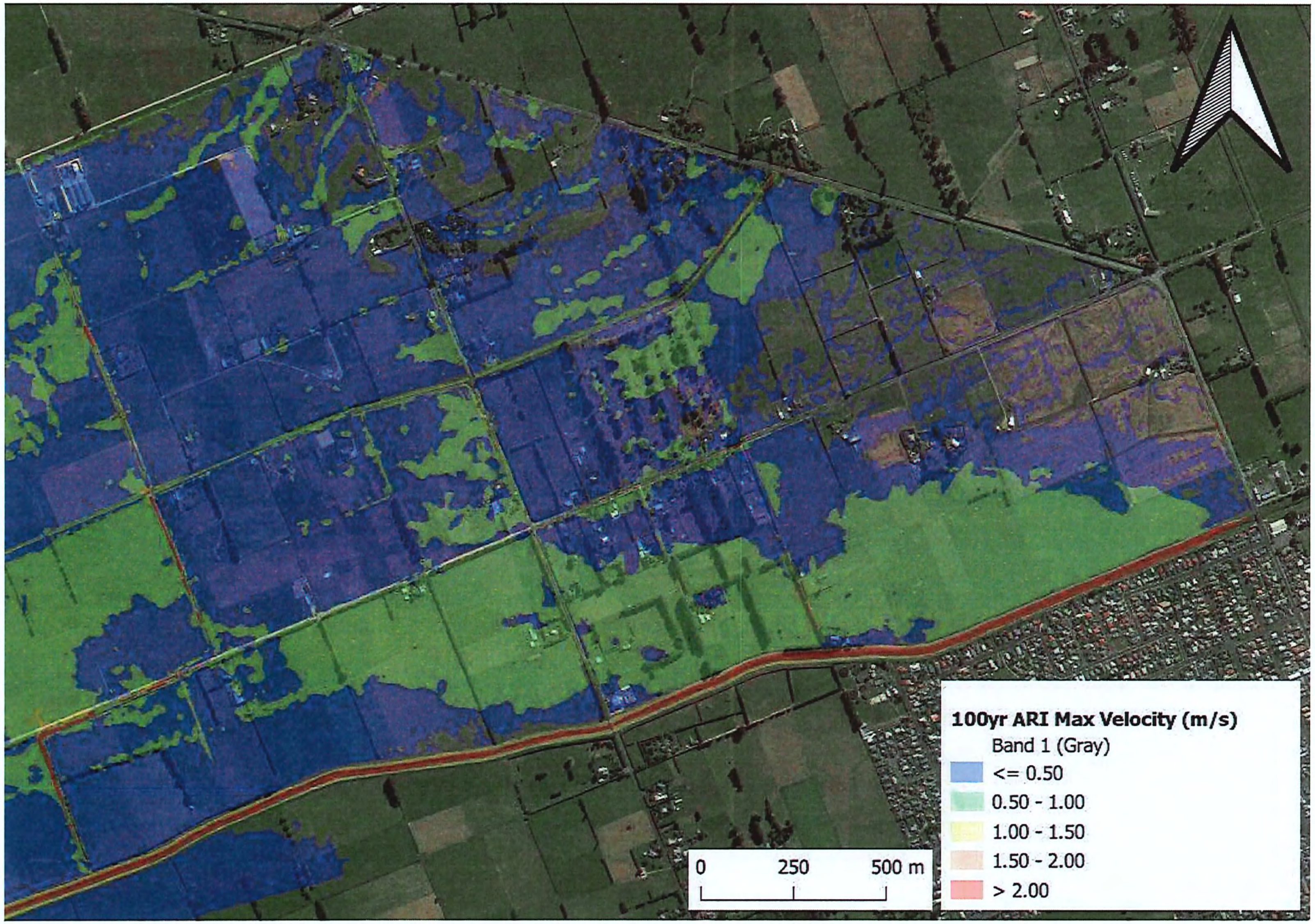

Figure 22. Modelled maximum flood velocity distribution map for the 100-yr ARI event.

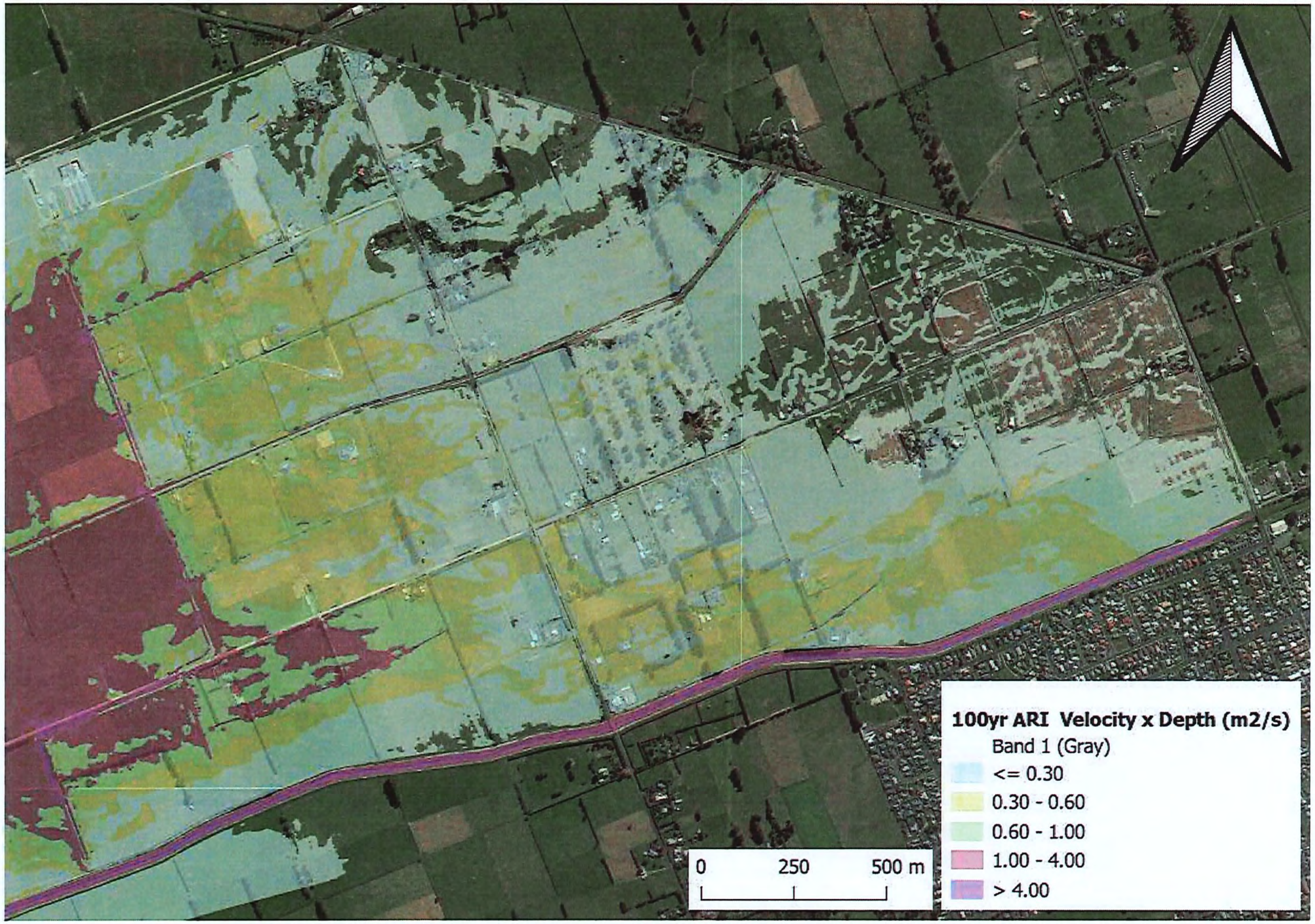

Figure 23. Modelled maximum flood velocity x depth distribution map for the 100-yr ARI event.

4. Conclusion

The hydraulic modelling was carried out to assess the flood hazard and determine how North Taieri/Gordon Road floodway is impacted during the July 2017 flood event and the 100-yr ARI event. The modelling results confirm that the overtopping of the true right bank of Silverstream below the Gordon Road bridge (also known as Gordon Road Spillway) is the primary contributor to flooding of North Taieri/Gordon Road floodway area. For July 2017 event the depth of flood water is expected to range between less than 0.5m to almost 3m, while for 100-yr ARI event the flood depth is expected to range between less than 0.5m to more than 3m. For both events the velocity is expected to range between 0.5 to 1 m/s in the floodplain.

5. Reference

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Appendix A

Appendix Figure 1. Map showing the location of culverts across the cut-off banks and a bridge at Riccarton Road

Appendix Table 1. Details of culverts across the cut-off banks and a bridge at Riccarton Road

	Length (m)	Dimension (m)	Materials	Remarks
Culvert 1	21.70	1.2 m diameter	Concrete	With flap gate
Culvert 2	11.40	2 m (W) x 1m (H)	Concrete	With flap gate
Culvert 3	12.19	1.2 m diameter	Concrete	With flap gate
Culvert 4	16.30	0.6 m diameter	Concrete	With flap gate
Culvert 5	10.70	2 m (W) x 1 m (H)	Concrete	With flap gate
Culvert 6	12.00	2 m (W) x 1 m (H)	Concrete	With flap gate
Culvert 7	15.50	0.6 m diameter	Concrete	With flap gate
Culvert 8	16.50	1.2 m diameter	Concrete	With flap gate
Bridge	9.00	7 m (W) x 2.5 m (H)	Concrete	