BEFORE THE INDEPENDENT HEARING COMMISSIONER APPOINTED BY THE WEST COAST REGIONAL COUNCIL

UNDER	the Resource Management Act 1991 (RMA)
IN THE MATTER	of an application for resource consent under section 88 of the RMA by the West Coast Regional Council for stopbanks in the Waiho River

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STATEMENT OF EVIDENCE OF MATTHEW GARDNER ON BEHALF OF THE WEST COAST REGIONAL COUNCIL (AS APPLICANT)
12 July 2023

PO Box 323 QUEENSTOWN 9348

Tel +64 3 379 7622

Fax +64 3 379 2467

WYNN WILLIAMS

Solicitor: A H Balme

(alice.balme@wynnwilliams.co.nz)

Introduction

1 My full name is Matthew James Gardner. I practice as a consulting engineer specialising in water resources engineering. I am the managing director of Land River Sea Consulting Limited, a Christchurch based engineering consultancy that specialises in flood modelling, geomorphology, river engineering and flood risk management.

Statement of Professional Qualifications and Experience

2 I hold the degree of Bachelor of Engineering (Hons) in Natural Resources Engineering from the University of Canterbury. I am a Chartered Professional Engineer (CMEngNZ, CPEng). I am also a member of the Engineering New Zealand (EngNZ) Rivers Group (a technical subgroup of EngNZ), the New Zealand Hydrological Society and Water New Zealand (the New Zealand Water and Wastes association).

3 I have been working as a professional engineer in the field of water resources engineering, river modelling and floodplain management since early 2006. Included in this experience is close to 4 years with Wellington Regional Council where I was employed in the Flood Protection Department. I have further experience on a range of river flood, sediment transport and urban drainage modelling/engineering projects working for URS New Zealand Ltd as well as with River Edge Consulting Limited.

4 Amongst the projects that I have completed with Land River Sea Consulting since 2012 are those involving a range of major river and floodplain systems in Canterbury, West Coast, the Marlborough District and the Wellington/Wairarapa region.

5 I have carried out detailed hydraulic modelling studies on many major New Zealand rivers, including the Hutt River, Waiohine River, Mangatarere Stream, Waipoua River and Porirua Stream in the Wellington Region, the Wairau River, Omaka River, Fultons Creek in Marlborough, the Buller River, Waiho (Waiau) River, Grey River, Hokitika River, Wanganui River in the West Coast Region as well as a number of other rivers around New Zealand for a range of public and private sector clients.

6 I have been asked by the West Coast Regional Council (**Council**) to provide independent expert evidence on its application for resource consent in relation to stopbanks in the Waiho River. I have been involved in the proposal since mid-2021. In addition to visiting the site specifically for this job, I also have visited the site on numerous occasions for a range of investigations over the previous decade and am very familiar with the surrounding location and the nature of the catchment.

7 I have been involved in many investigations on the Waiho River since 2014 when I was commissioned to build a one-dimensional (1-D) hydraulic model. I have studied the river and catchment processes and provide advice to the council in relation to the management and mitigation of the ongoing flood hazard, primarily due to aggradation of the bed. I have performed studies to evaluate changes in bed levels over time based on historical cross-section and LiDAR surveys since 2012. I have also built multiple versions of a flood model of the river based on these LiDAR datasets.

8 In addition to carrying out work for Council, I have also performed studies of the Waiho River for the Department of Conservation to assess the risk to their assets within the catchment.

9 Although this evidence is prepared for a Council hearing, I have read the code of conduct for expert witnesses contained within the Environment Court Practice Note 2023 and agree to comply with it. Except where I state that I am relying on the specified evidence of another person, my evidence in this statement is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions I express.

Scope of evidence

10 My evidence addresses the following matters:

(a) An explanation of the functional need for the proposed stopbanks in light of the modelling completed;

(b) A description of modelling completed of the Waiho River for the purposes of setting design stopbank heights and assessing the impact of the proposal; and

(c) An explanation of the results of modelling, including an assessment of effects on other structures in the river and the wider floodplain.

11 In preparing this evidence, I have reviewed and relied on the following:

(a) Preliminary Design Report (attached to my evidence as **Appendix 1**);

(b) Design Memorandum (Tetra Tech Coffey, 2021), attached to the evidence of Dr Thomas as Appendix 1;

(c) The evidence of Dr Dai Thomas.

Functional need for the stopbanks

12 The Waiho River is set in a highly geologically active area and is subject to rapid bed aggradation. This aggradation is being exacerbated by the rapidly retreating glacier, which is exposing large volumes of fractured bed rock material which is entering the river in storm events. The Franz Josef township has been developed adjacent to this river and currently receives significant protection from the stopbanks. Without the stopbanks, the existing state highway, wastewater treatment ponds as well as portions of the existing town and adjacent farmland would not be able to exist.

13 If the stopbanks are not raised, then the river will continue to aggrade eventually overtopping the existing banks and creating significant risk and cost to public and private property.

14 It is my understanding that the Council has been actively exploring managed retreat in the area over the past decade, however as no concrete plans are yet in place, the Council has elected to raise the stopbanks on the true right bank in order to protect the town and assets. It is my opinion that due to the severity of the residual risk due to the height of these banks, this is the last raise that should take place. This project should be seen as a short-term solution, purely for the purposes of buying time to implement a more permanent solution, such as managed retreat.

Waiho River flow modelling

15 I have developed a 2-dimensional MIKE21FM hydraulic model of the Waiho River to determine:

(a) the design height of the proposed stopbanks; and

(b) the potential impacts on other assets within the river and the surrounding floodplain.

16 The results from this model have been provided to Dr Dai Thomas who has used the outputs to inform the design requirements of the stopbank. I understand that these outputs were used directly by Dr Dai Thomas, and that his methodology is covered in his evidence.

17 The model was developed using industry best practices. Satellite survey data collected in June 2021 by the University of Otago was used to assign elevations to the river bed portion of the model and LiDAR data collected by New Zealand Aerial Surveys in June 2016 as well as additional data collected in June 2019 by the University of Waikato was used to assign elevations to the floodplain. In June 2021, I performed a ground survey to confirm the elevations of the Church and Helipad stopbanks as well as the main stopbank along the true left side using a survey grade GPS.

18 There are no flow gauges along the Waiho River to develop a flood-frequency curve which is used to estimate the annual exceedance probabilities (e.g., the 100-year flow). Further, there is no reliable measured water-surface elevations to calibrate the model. The adopted model values were carefully selected based on extensive research and sensitivity testing as well as engineering judgement based on my experience in modelling gravel braided river systems around New Zealand.

19 The river bed / stopbank geometry for the hydraulic model was based on 2021 survey data and the Proposed Stopbank alignment. In order to represent scour near the stopbank, I modified the hydraulic model to represent a 2m deep by 30m wide artificial channel along the toe of the true right bank. This provided more conservative hydraulic conditions (i.e. deeper flow and higher velocity) for the scour and riprap sizing analyses undertaken by Dr Thomas and is similar to what occurs during a real flood event. It was necessary to manually burn in this scour channel due to the fact that this model is a fixed bed model and does not replicate live bed movement. The dimensions of the scour channel were based on actual measurements in the field of post flood scour channels in the Waiho River.

20 The design flow of 2500 m^3/s has been based on my 2014 analysis of a range of statistical and empirical techniques for determining design flows in New Zealand Rivers (Gardner, 2014). This flow rate is my best estimate at a 1% Annual Exceedance Probability (AEP) return period flow. This number has been rounded up from 2450 m^3/s due to the significant uncertainty in the catchment as well as the dynamic nature of the bed which is aggrading at a rapid rate. It is my opinion that the rate of aggradation in the catchment and the geomorphological processes are much more significant than the design flow rate. This flow rate however has been adopted by the council for their design since 2014, and has also been used by Waka Kotahi for setting the design heights of their stopbanks on the true left.

21 The alignment of the new section of bank was selected based on an analysis of three potential alignments which were modelled. An analysis of the results showed that Alignment B was likely to have the least impact on channel velocities as it had a more gentle curvature following the natural topography of the river. It was therefore less likely to be prone to severe erosion issues compared to the other options and therefore more resilient. It was also considered to have the least impact of the three options on sediment transport and would be less likely to alter the natural aggradation patterns.

22 The key parameters / model inputs which affect the peak water levels in the model are the design flow and the Manning's *n* roughness coefficient. For this study, I have adopted flow and roughness values which are slightly higher than are derived using standard design formulae / methodologies, however I have been intentionally conservative in selecting these higher values to account for the significant uncertainty and highly dynamic nature of the river.

23 Whilst I have adopted higher roughness values for setting the design height of the stopbanks, when providing the design velocities used by Dr Dai Thomas for the sizing of rock protection as well as for determining scour depth, I have adopted values from sensitivity runs using a lower roughness value which gives higher velocities and deeper scour depths.

24 Due to the dynamic nature of the Waiho River, one of the main drivers of flood risk is ongoing aggradation of the river bed. The model has therefore been used to simulate a range of potential future aggradation scenarios based on average aggradation rates at each surveyed cross-

section, using a range of dates from 1993 to the 2021. The adopted aggradation profile was selected in consultation with Gary Williams (experienced river engineer and a Fellow of Engineering New Zealand) and Dr Dai Thomas (Engineering Geomorphologist) and has been extrapolated for a 20-year time period based on the average aggradation rates since 1993.

25 It must be acknowledged that the processes driving bed level aggradation in the river are complex and there is a lot of uncertainty in future aggradation rates and patterns because they are dependent on future flood events, sediment transport rates and volume of sediment into the river system from other watershed processes including land sliding and glacial processes. If the future aggradation rates are greater than the average rates from 1993 to present, then it is likely that the capacity of the stopbanks will decrease faster than predicted, and the life of the stopbanks will be less than predicted. Conversely, if the future aggradation trends are lower than the historic average, the stopbanks will have a longer lifespan. It is important to note that the banks will still be providing a level of protection from flood, however this level of protection will continue to decrease over time. Because the design life of this bank is only intended to be 20 years, the effects of climate change have not been considered as it is likely that global climate cycles such as the Interdecadal Pacific Oscillation (IPO) will have a greater impact on peak flows and rates of aggradation over this time period than climate change.

26 The Waiho River is a highly dynamic and mobile river. A significant limitation of the model is that it is a fixed bed model. This limitation has been overcome by manually adjusting the terrain to account for both future aggradation as well as changes in braid alignment using our expert engineering judgement, which is based on our experience of observing the behaviour of gravel braided rivers and scientific understanding of the mechanics of fluid and mobile sediment behaviour.

27 Whilst mobile bed models do exist, they are very expensive to set up, require significant computational time and most importantly require significant data for calibration in order to have any confidence in the outputs. In the case of the Waiho data we do not have this data, and therefore a fixed bed model is considered the most appropriate choice

with the results being interpreted by a team of engineering experts who understand the nature of the river in detail.

28 The limitations of the model have also been reduced by performing sensitivity testing of flow, bed levels, braid alignments, roughness, viscosity, computational regime and mesh size.

Modelling results

29 The model was run at the design flow of 2500 m^3/s to predict the design crest levels for the proposed stopbank alignment based on the adopted bed level scenarios allowing for 20 years of aggradation at the average rates since 1993. These design levels are the basis for the stopbank crest levels adopted by Dr Dai Thomas.

30 The model has also been used to provide peak velocities to Dr Dai Thomas along the stopbank alignment to inform the rock sizing specification and scour depths.

31 In addition to providing peak water levels and velocities, the model has been run with and without the proposed stopbanks in place to assess the potential impact of the banks on other assets (such as stopbanks) within the river as well as potential impacts on the floodplain.

32 The results of this modelling and my report on the potential effects is attached to my evidence as **Appendix 2**.

33 The model results show that the proposed stopbank has:

(a) No significant impact on water levels or peak velocities on the true left bank or downstream of the proposed stopbank upgrade for the scenario with the 2021 bed levels with changes in water level adjacent to the stopbank being less than 5cm. No stopbanks are predicted to overtop in this scenario.

(b) No significant impact on water levels or peak velocities on the true left bank or downstream of the proposed stopbank upgrade for the bed aggradation scenarios with increases in water level (i.e. depth of floodwaters) being in the order of 1 to 2 cm on the floodplain, and a very slight increase in the spatial flood extent around the fringes of the flood extent where low elevation land is filled in – this generally results in an increase in spatial extent in the order of 2 to

3 metres. The true left stopbanks upstream of Canavan's Knob are overtopping in this scenario.

Comments on Model Results

34 It may seem counterintuitive that raising the stopbanks on the true right of the river will have no significant impact on the stopbanks on the true left. However, close examination of the topography shows that:

(a) The natural high ground levels on the Church bank (ie immediately downstream of the State Highway Bridge) are significantly higher than the existing true left stopbank and hence the preferential overtopping direction is currently to the south side (i.e. true left), immediately downstream of the bridge. Raising the stopbanks does not alter this.

(b) The existing helipad stopbank is intentionally slightly higher than the true left stopbank to ensure that the true left stopbank overtops before the true right stopbank (Figure 1). Raising the stopbank therefore doesn't change the general behaviour, it just slightly increases the volume of water to overtop the true left bank. Ensuring the river spills to the south first, allows for the preferential protection of the significant assets on the true right of the river including the state highway, wastewater treatment ponds as well as the main urban township which includes hotels, restaurants, accommodation venues as well as educational and health facilities.

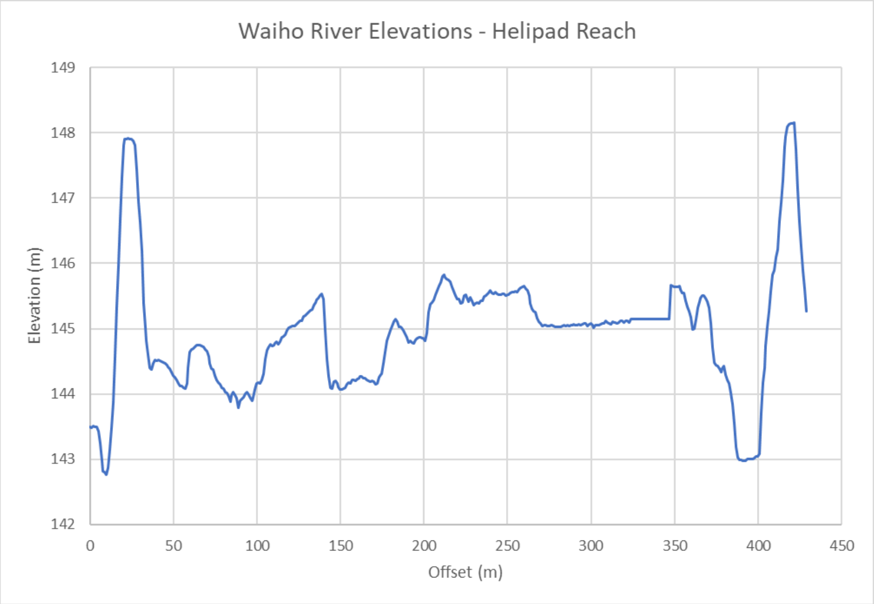

Figure 1 – Cross section highlighting stopbank elevations in the Helipad Reach showing that the true right stopbanks are already slightly higher than the true left

(c) At the downstream end of the new section of stopbank and near the 55km Corner, the true right stopbank is built on the edge of a natural alluvial fan and the true left stopbank has been built down the centre of the alluvial fan. The surface of the fan along the left side of the river is significantly higher than the right side and the stopbanks on the true left are therefore significantly higher in elevation than those on the true right. Even when raised by 2m, the right stop banks are lower compared to the true left side (Figure 2). In addition, the active bed of the river is very wide at this location, expanding to a width of approximately 1km compared to 350m in the Helipad Reach, allowing for significant buffer capacity for the increase in volume to be distributed over a wide area.

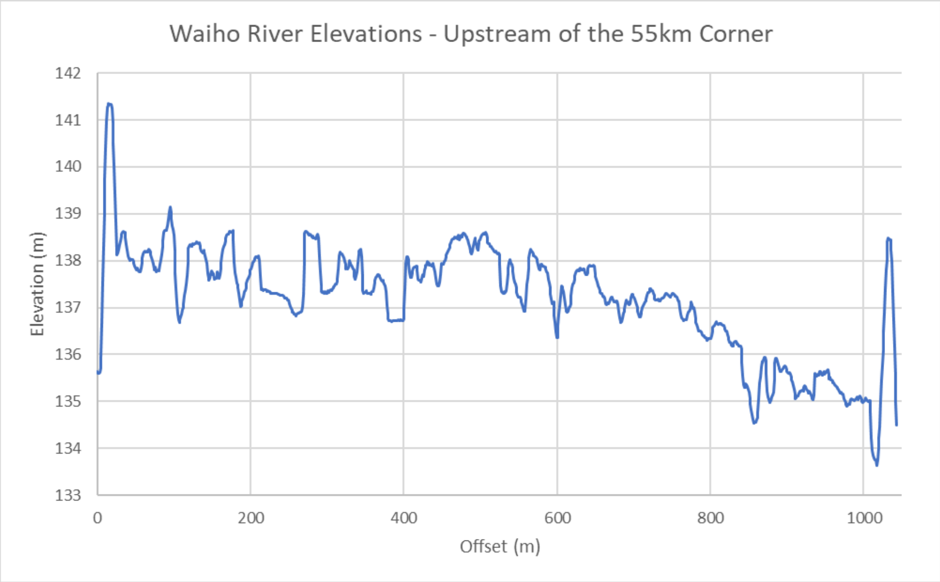

Figure 2 – Cross section highlighting stopbank elevations just upstream from the 55km corner showing that the true right stopbanks are already significantly lower than the true left due to their location of the edge of the alluvial fan surface

Conclusion

35 I was commissioned by the Council to build a 2D hydrodynamic model of the river in order to provide guidance around appropriate design heights and to refine / confirm the proposed alignment.

36 The model has been built using industry best practice techniques and the results have been interpreted in conjunction with Gary Williams and Dr Dai Thomas, who are both engineers with significant experience in geomorphology.

37 Outputs from the model results have been provided to Dr Dai Thomas to be used as the basis of his design for the crest level as well as rock sizing and scour calculations.

38 The model has also been used to assess the effects of the proposal. Results have shown that the proposed banks do not have any significant impact on the scenario with the existing bed levels. For a future bed level scenario accounting for 20 years of potential aggradation, the true left stopbanks overtop. Results show that the proposal has a very minor increase in peak water level. This results in very minor increases in flood extent and increases in level by less than 2cm.

39 Multiple reports commissioned by the Council since the 1980s acknowledge that continually raising stopbanks is not sustainable nor practical in the long term. I have personally been involved in significant

discussions and investigations with the Council around retreating from the river since 2014 (including relocating one motel) and understand that many more discussions have taken place prior to this since the late 1980’s. However, based on my understanding that no concrete plans have yet been put in place for managed retreat, the Council has elected to raise the true right stopbanks to provide time for further investigations and decisions. This ensures that the town can continue to operate in the short term, whilst hard decisions are made in relation to the long-term management of the hazard. I have made it clear in my report that it is my opinion that this is the last time these banks should be raised for safety reasons and that there are significant consequences should the banks fail.

Matthew Gardner

12 July 2023

APPENDIX 1: PRELIMINARY DESIGN REPORT (OCTOBER 2021)

Franz Josef Stopbanks

Preliminary Design Report

OCTOBER 26, 2021

Client: WCRC
Report by: Matthew Gardner
Land River Sea Consulting Ltd
www.landriversea.com

LANDRIVERSEA CONSULTING

THE WEST COAST REGIONAL COUNCIL

FRANZ JOSEF STOPBANKS

REVISION HISTORY

Author:	Matthew Gardner Water Resources Engineer, CMEngNZ, CPEng
Signature:	M Gardner
Date:	26/10/2021
Revision:	2
Authorised by:	Brendon Russ
Signature:	
Organisation:	West Coast Regional Council
Date:	

Land River Sea Consulting Limited
PO Box 27121
Shirley
Christchurch

M: +64 27 318 9527
E: matthew@landriversea.com
W: landriversea.com

LANDRIVERSEA CONSULTING

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1. INTRODUCTION

1.1 BACKGROUND

Land River Sea Consulting Ltd was contracted by the West Coast Regional Council [WCRC] to provide technical advice in regard to raising the stopbanks on the true right bank of the Waiau River (Waiho) adjacent to the town of Franz Josef. Land River Sea Consulting has significant experience working in the Waiau River having been actively involved in a range of technical investigations in the river since 2013 (Gardner, 2014) (Gardner, 2016) (Gardner & Brasington, 2019). Land River Sea Consulting has also engaged Dr. Dai Thomas from Tetra-Tech Coffey (Geomorphologist) as well as Gary Williams from Waterscape (FEngNZ, Water Resources Engineer / Geomorphologist) to provide advice and input into the design process.

Following this stage of the design, Dr. Thomas with input from Gary Williams, will perform rock sizing and scour calculations to check the WCRC design specifications. Following on, Dr. Thomas will develop the stopbank design that will include the alignment and stopbank elevations.

It is our understanding that ongoing high-level discussions are underway with central government in regard to the future of the town with an option of allowing the river to actively reclaim its natural fan on the true left bank of the river. Due to the significant length of time required to make any such option and the significant ongoing channel aggradation, the WCRC considers it necessary to raise the banks now. A proposal had to been put to central government to raise banks on both sides of the river. At this time, funding has only been provided to raise the bank on the true right bank. Any design needs to assume that the true left stopbanks will also be raised. In addition to raising the existing banks, it has been proposed to construct a new section of stopbank joining the existing helipad stopbank to the Havill Wall stopbank that protects the state highway and the treatment ponds. The proposed stopbank is referred to as the NZTA stopbank. This study has investigated three potential alignments for the NZTA stopbank referred to as Alignment A, B & C (Figure 1-1).

The WCRC have indicated they intend to raise the entire length of existing bank by an average of 2m to allow for ongoing aggradation in the river. In addition, the WCRC are proposing to install a rock lined bund to prevent overflows into the Tatare River.

A 3-D visualisation of the area if interest highlighting the different sections of stopbank is presented in Figure 1-1 below.

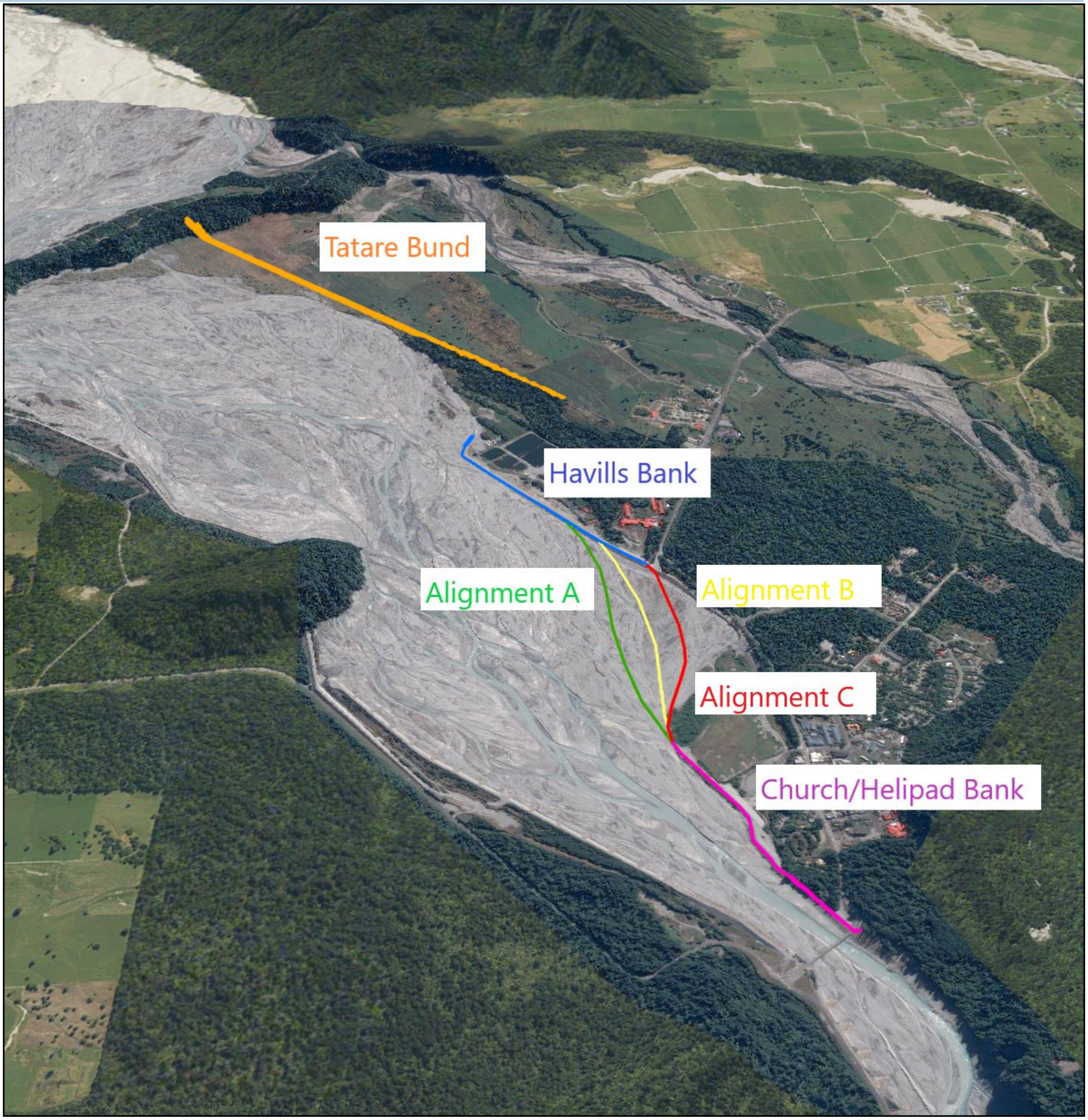


Figure 1-1 – Stopbanks to be raised / constructed

1.2 SCOPE OF PROJECT

Our scope for this project is;

- Review available reports, aerial photography, and time-sequential cross-section surveys of the channel.
- Assess the potential aggradation rates in the Waiho River from the glacier to the Waiho Loop over a 20-year time period.
- Select a design discharge.
- Build a 2D hydraulic model of the river based on the 2019 LiDAR (Brasington, 2019) and the 2021 satellite DEM (Sirguey, 2021). Run the model at the design discharge and use the model output to:
    - Evaluate the 3 proposed alignments and select a design alignment
    - Evaluate the impacts of the aggradation on design levels
- The model output will be used in the following phase of the study to:
    - Perform scour and rock sizing calculations.
    - Develop the design profile for the crest level of the stop banks.

1.3 SITE VISIT

Matthew Gardner has visited the site on numerous occasions over the years, however a project specific site visit was carried out by Matthew Gardner (Land River Sea Consulting) and Dai Thomas (Tetra-Tech Coffey) on the 21st of June 2021. The purpose of the visit was to observe the existing assets on the ground as well as to better visualise the current bed profiles and river set up, to assist in our understanding of river processes.

Crest level survey of the stopbanks was carried out by Matthew Gardner using an RTK GPS system to confirm the existing crest profiles.

Depth and width of historic braids were measured and the bed material was measured using the pebble-count method (Wolman, 1954) to characterise the size of the material. A selection of photos taken during the site visit are presented on the following page.

Figure 1-2 – View downstream of the existing rock on the Havill Wall Bank.

Figure 1-3 – Rock lining on the Church bank

Figure 1-4 –Scour from a recent braid adjacent to the bank

Figure 1-5 – Old bank adjacent to new Havill Wall Bank

2. DATA USED IN THIS STUDY

The main basis of information for this study has been LiDAR data collected in 2016 (NZ Aerial Surveys), 2019 (Brasington, 2019) as well as satellite Digital Elevation Model (DEM) developed by Pascal Sirguey in 2021 using advanced photogrammetry techniques from Pleides Satellite Imagery (Sirguey, 2021). In addition to this, existing stopbank crest levels were surveyed by Matthew Gardner from Land River Sea Consulting on the 21st of June 2021.

In addition to the DEM data, cross sections 13 to 22 were re-surveyed by Coastwide Surveys Ltd in May 2021 (Figure 2-1) The survey data covered the full width of the active channel of the river, but did not include the below water portion due to health and safety reasons, although a few below water points were collected near the edge of the water. As a result, the Mean Bed Levels (MBL) collected in 2021 will slightly overestimate the MBL, in particular in the confined reach between from State Highway bridge and the end of the Helipad Bank.

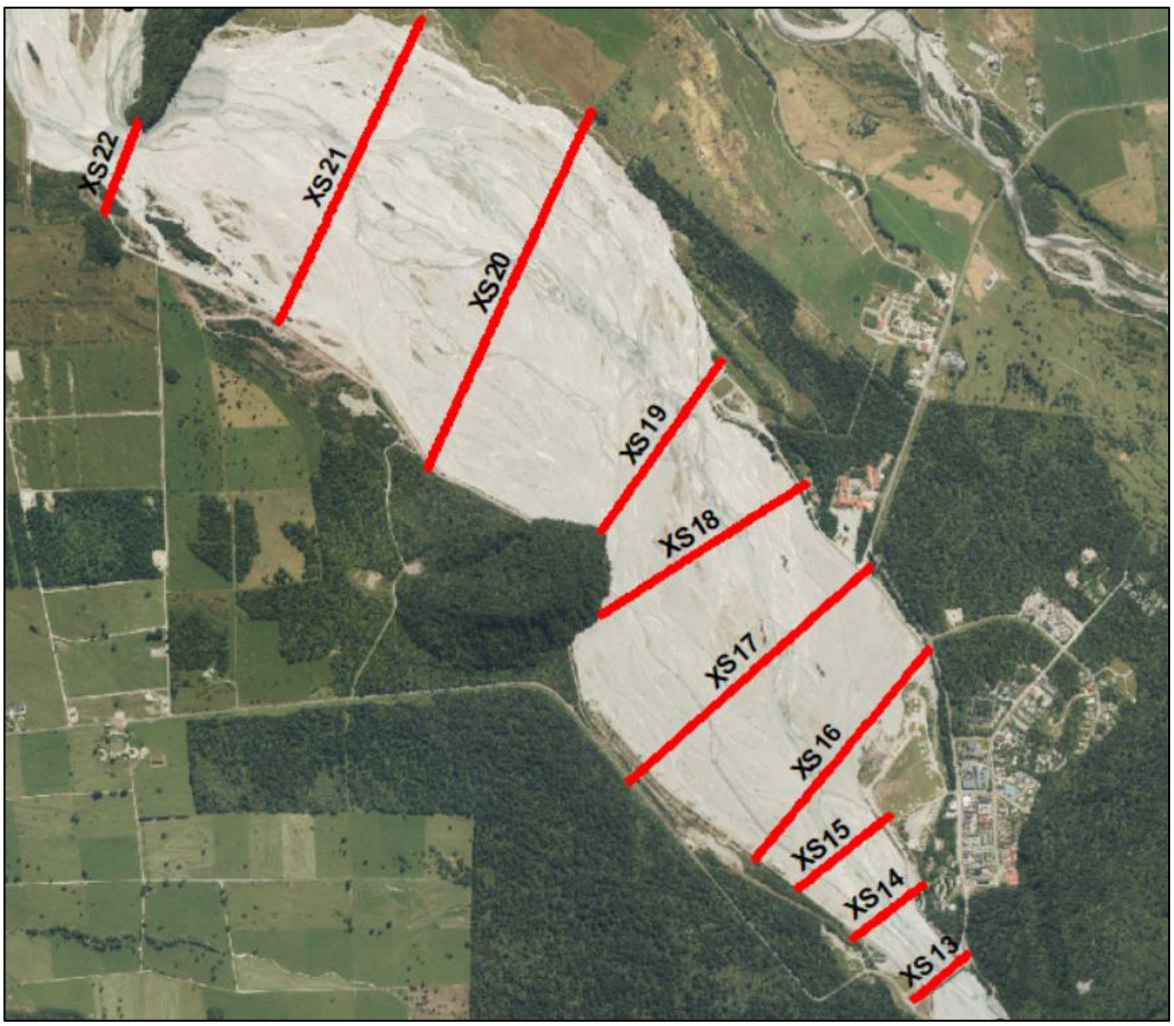


Figure 2-1 – Location of surveyed cross sections surveyed by Coastwide Surveys Ltd in May 2021

Plots of the cross sections compared with cross sections extracted from the 2019 LiDAR is presented in Appendix A.

2.1 ASSESSMENT OF 2021 SATELLITE DEM

On 19 March 2021, Professor Pascal Sirguey from the University of Otago arranged for the Pléiades-1B satellite to acquire a triplet of cloud-free imagery of Franz Josef Glacier and surroundings (ie three overlapping satellite images captured at different angles). The triplet was tied to an existing triangulated photogrammetric image block spanning across the Main Divide to benefit from an existing and extensive network of sub-metre accurate Ground Control Points (GCP). (Sirguey, 2021)

The final output was a 0.5m pixel resolution orthorectified cloud free image of the river valley, as well as a 2m resolution digital surface model (DSM) with a reported residual of 0.47m CE90 (circular error of 90 %) and 0.58m LE90 (linear error of 90 %). These errors are reported based on a comparison with the GCP network, which likely contain points within steep mountain valleys, and therefore increasing the uncertainty. A comparison of the bed levels from the DSM with the cross-section survey data collected between the 13 to 22 of May 2021 show an excellent agreement (Appendix B), with the main differences occurring at the wetted area of the river. Because the survey data was collected approximately 2 months apart, some of the differences in bed levels is due to the aggradation/degradation that occurred between the surveys. A comparison between the datasets at cross section 17 is presented in Figure 2-2.

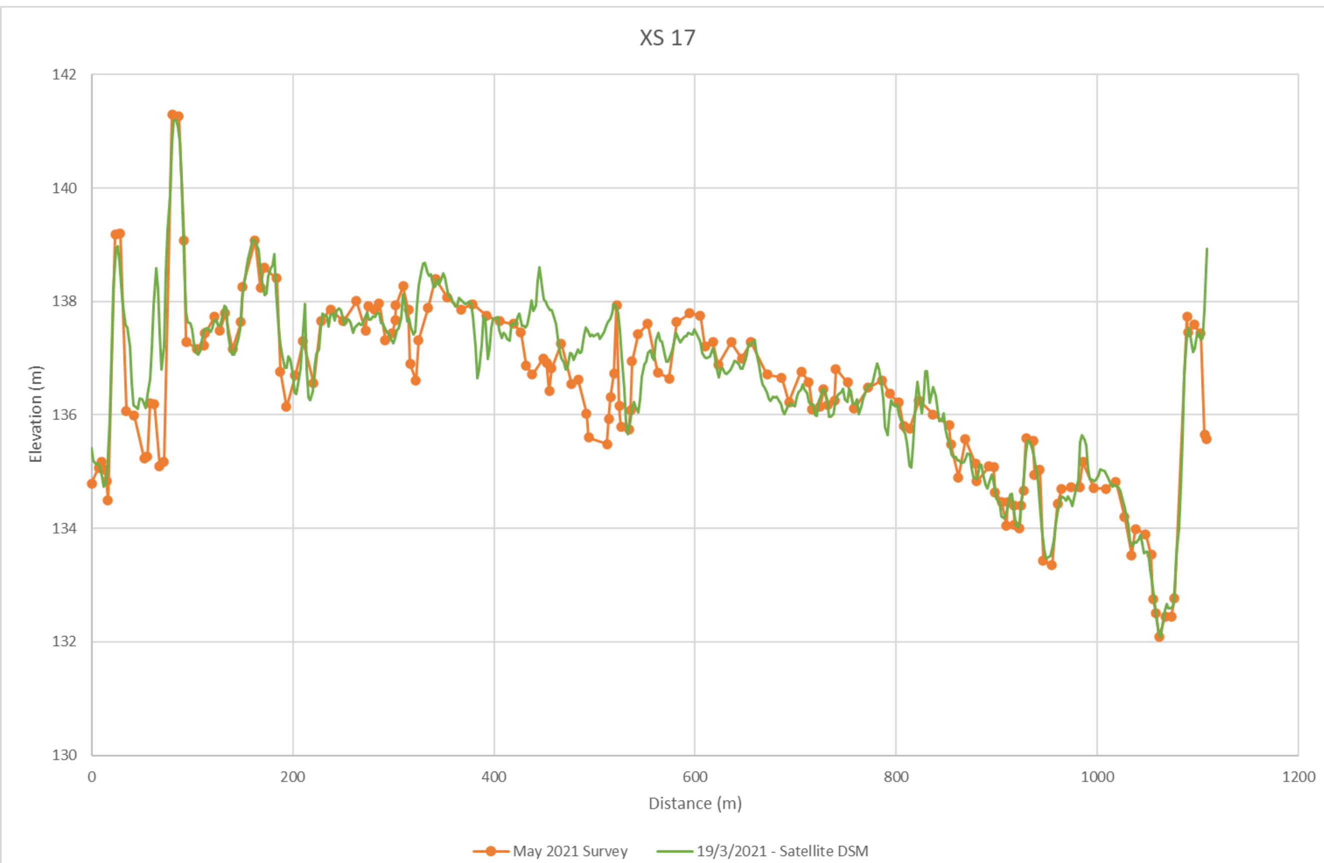


Figure 2-2 – Comparison of May 2021 survey data with the 19 March 2021 Satellite DSM

Overall we conclude that there is an excellent match between the satellite data and actual ground survey.

We conclude that the satellite data is fit for the purposes of representing the active channel in a hydraulic model and can be relied upon for the purposes of sizing stopbanks. Whilst there is greater uncertainty in the ground levels with this data, it must be kept in mind that the Waiau river is very active with constantly changing bed levels. We consider this surface to be more suitable than using the 2019 LIDAR DEM data as it gives a very realistic spatial representation of the overall bed levels / slopes etc and will be more reliable than simply adjusting the 2019 LiDAR using average trends from the latest cross section survey data.

This satellite data can be acquired on a regular basis fairly easily and at a significantly lower cost than a more detailed LiDAR survey. We believe that serious consideration should be given to carrying acquiring regular repeat surveys using these techniques as this would allow ongoing monitoring of the aggradation rates over the entire river area. This would be useful to detect any rapid or unexpected aggradation along the length of the stopbanks which would compromise the safety of the scheme.

3. ASSESSMENT OF POTENTIAL AGGRADATION

The Waiau River valley is set in a highly active geologic area and receives large volumes of sediment from the surrounding catchment which is resulting in ongoing aggradation in the river valley. Cross-section surveys from 1983 to present at the State Highway Bridge show an average rate of aggradation of about 0.18 m/ year. Aggradation trends down the length of the river have been assessed previously and are updated in this report based on the most recently available cross section survey data (May 2021) as well as a comparison of the LiDAR and Satellite DEM data from 2016, 2019 and 2021.

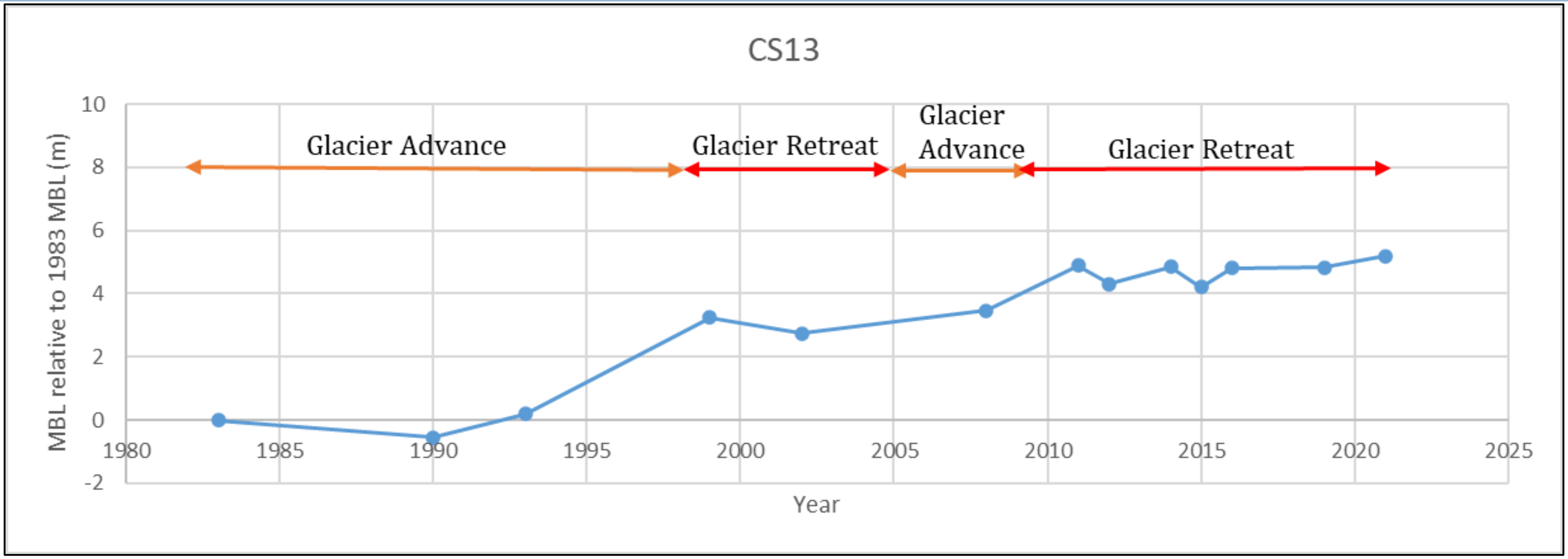
3.1 CROSS SECTION DATA

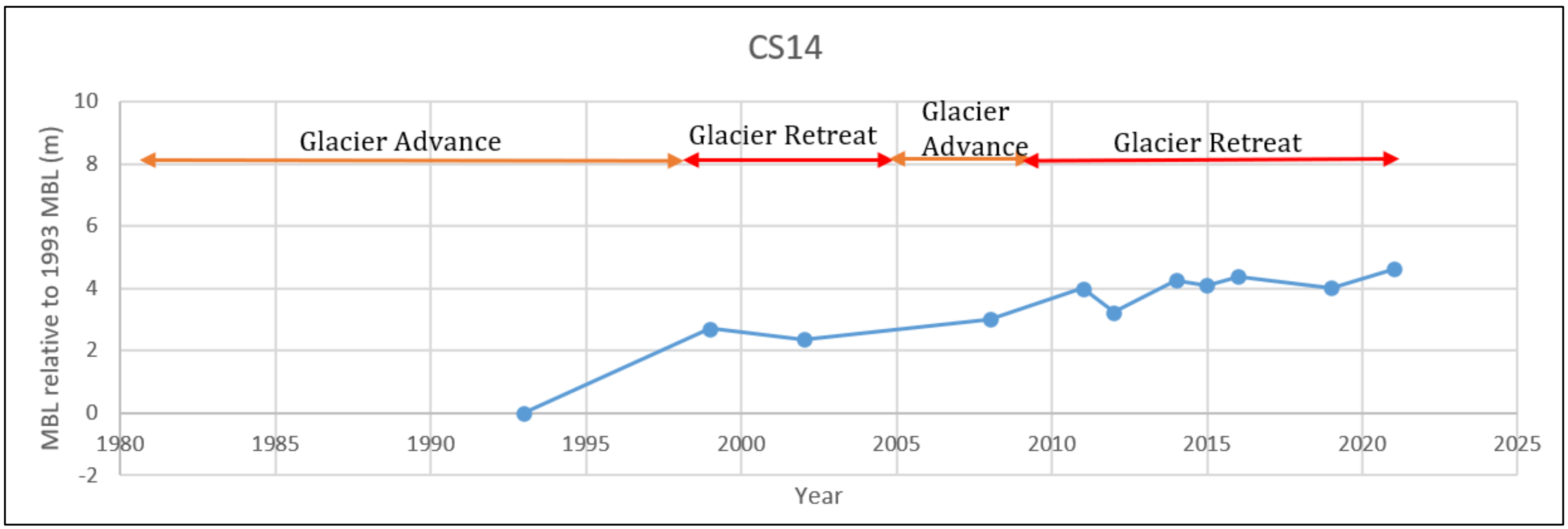
A mean bed level (MBL) assessment from XS13 to XS22 was performed to update the MBL trends presented in the recent 2019 report. It should be highlighted that the 2021 cross section survey did not include a full survey of the wetted channel and the MBL numbers in particular at XS13 to XS15 are likely indicating slightly higher levels of aggradation than has actually occurred when comparing with the historic data.

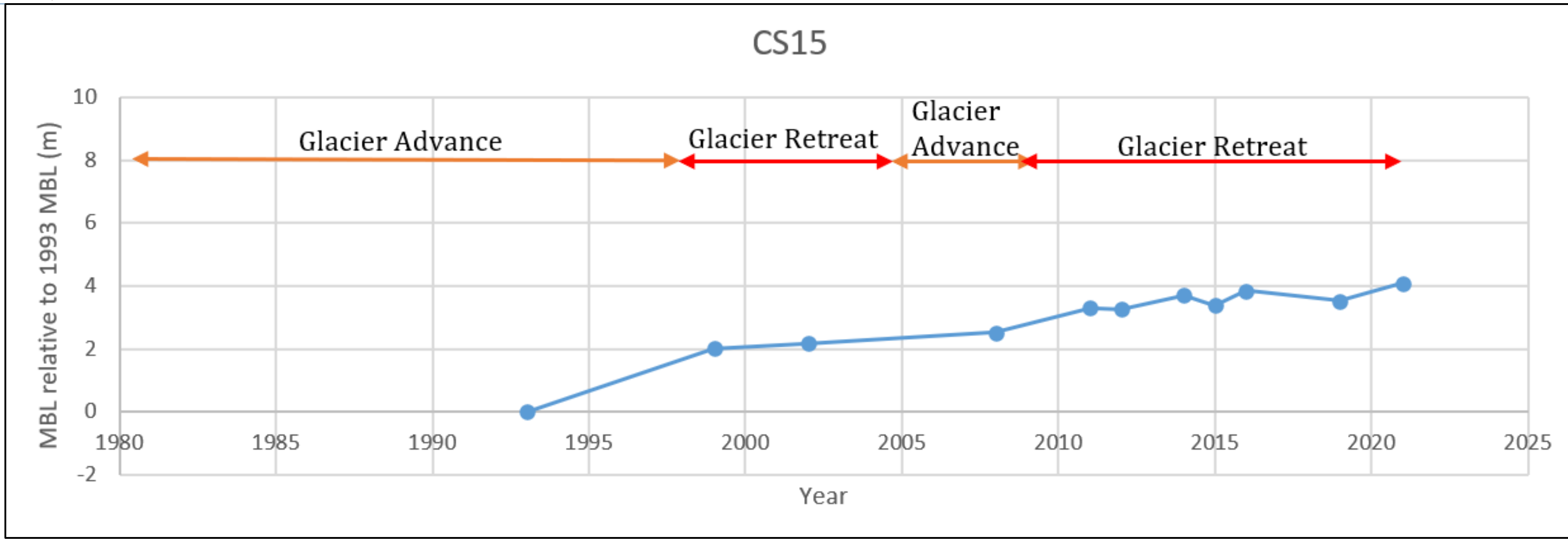
The calculated MBL values for each cross section from XS13 to XS21 is presented in Table 3-1 and plots of the mean bed level trends are presented on the following pages.

Table 3-1 – MBL Calculation (1983 to 2021)

	1983	1990	1993	1999	2002	2008	2011	2012	2014	2015	2016	2019	2021
CS13	145.7	145.1	145.9	148.9	148.4	149.1	150.6	150	150.5	149.9	150.5	150.5	150.87
CS14			143.6	146.3	145.9	146.6	147.6	146.8	147.8	147.7	148	147.6	148.20
CS15			141.2	143.2	143.4	143.7	144.5	144.5	144.9	144.6	145.1	144.7	145.31
CS16			137.7	139.2	139.6	139.8	140.2	140.2	140.5	140.5	140.9	140.9	141.26
CS17			133.1	134.3	134.4	134.6	135.2	135.2	135.6	135.7	136	136.2	136.48
CS18			127.8	128.7	128.9	129.2	129.7	129.7	129.8	129.8	130.1	130.7	130.90
CS19	123.6		124	124.3	124.6	124.8	125.2	125.3	125.2	125.3	125.6	126.5	126.49
CS20	116.9		117.1	117.4	117.4	117.9	118.3	118.4	118.5	118.8	118.7	119.1	117.67
CS21	109.1		109.1	109.2	109.2	109.4	109.5	109.6	109.6	109.7	109.7	109.9	109.88
CS22	101.4		100.9	101	101	101	101	100.8	100.9	101	100.9	101.7	101.86


CS13
Glacier Advance
Glacier Retreat
Glacier Advance
Glacier Retreat
MBL relative to 1983 MBL (m)
10
8
6
4
2
0
-2
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year


CS14
Glacier Advance
Glacier Retreat
Glacier Advance
Glacier Retreat
MBL relative to 1993 MBL (m)
10
8
6
4
2
0
-2
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year


CS15
Glacier Advance
Glacier Retreat
Glacier
Advance
Glacier Retreat
MBL relative to 1993 MBL (m)
10
8
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-2
1980
1985
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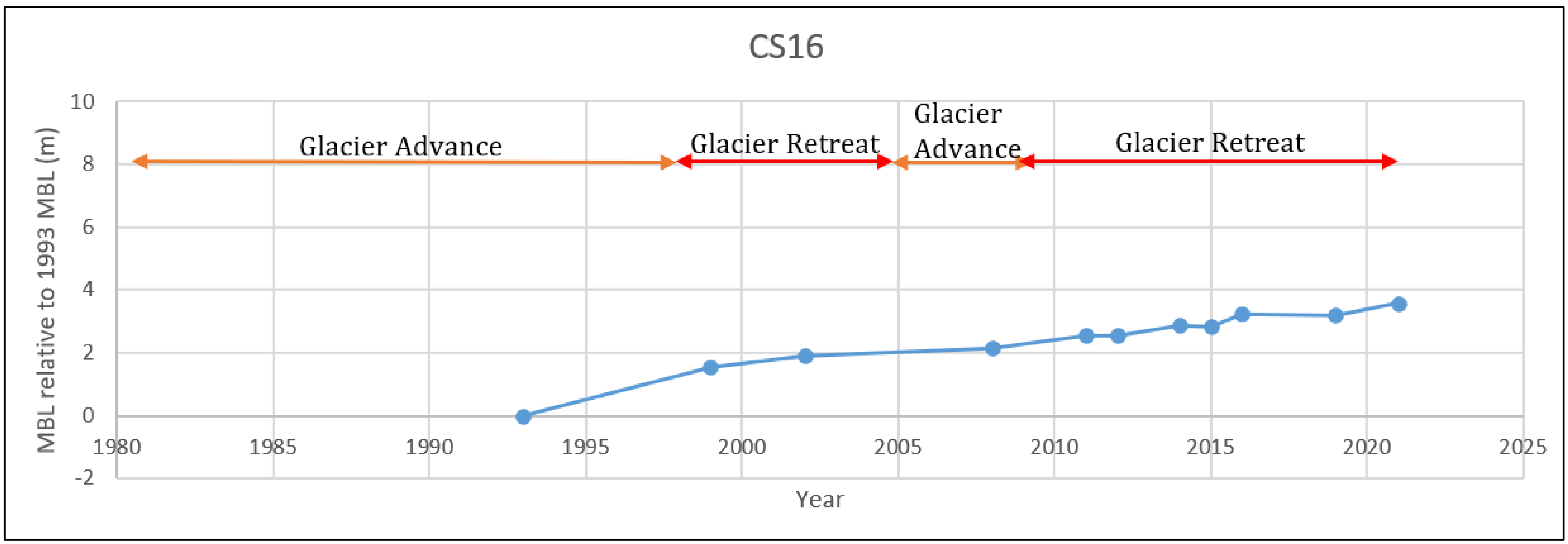
2020
2025
Year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Glacier Advance
Glacier Retreat
Glacier
Advance
Glacier Retreat
MBL relative to 1993 MBL (m)
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8
6
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2
0
-2
1980
1985
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1995
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2005
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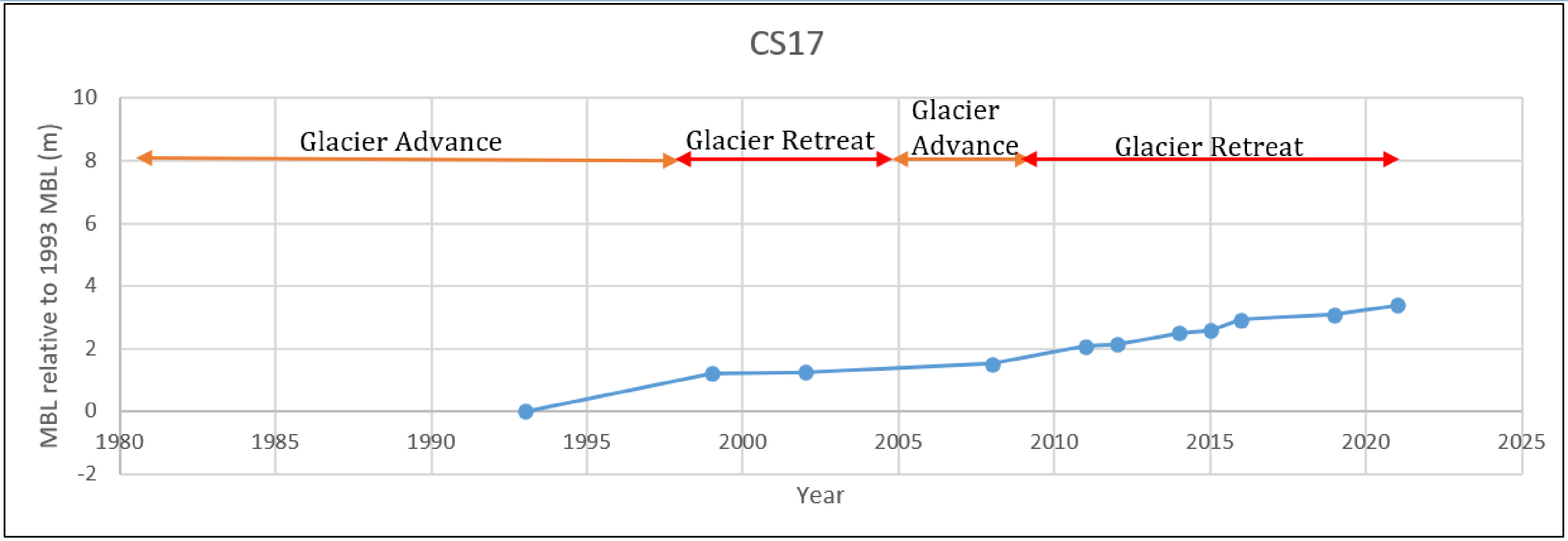
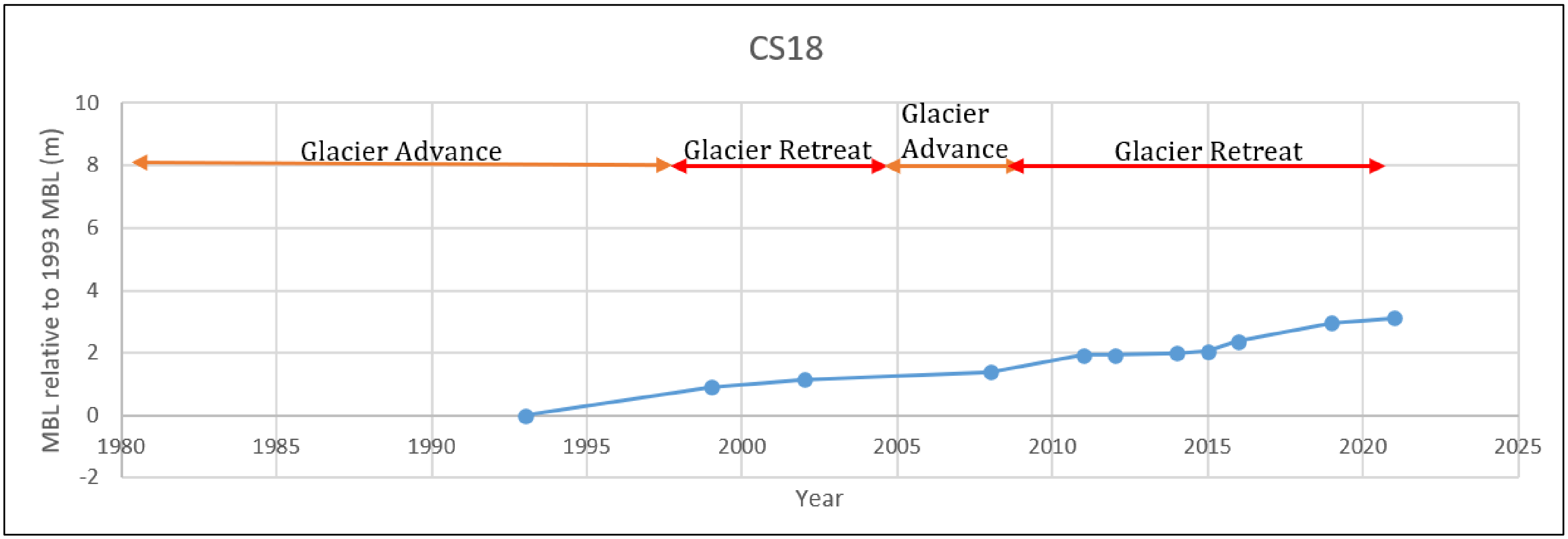
2015
2020
2025
Year





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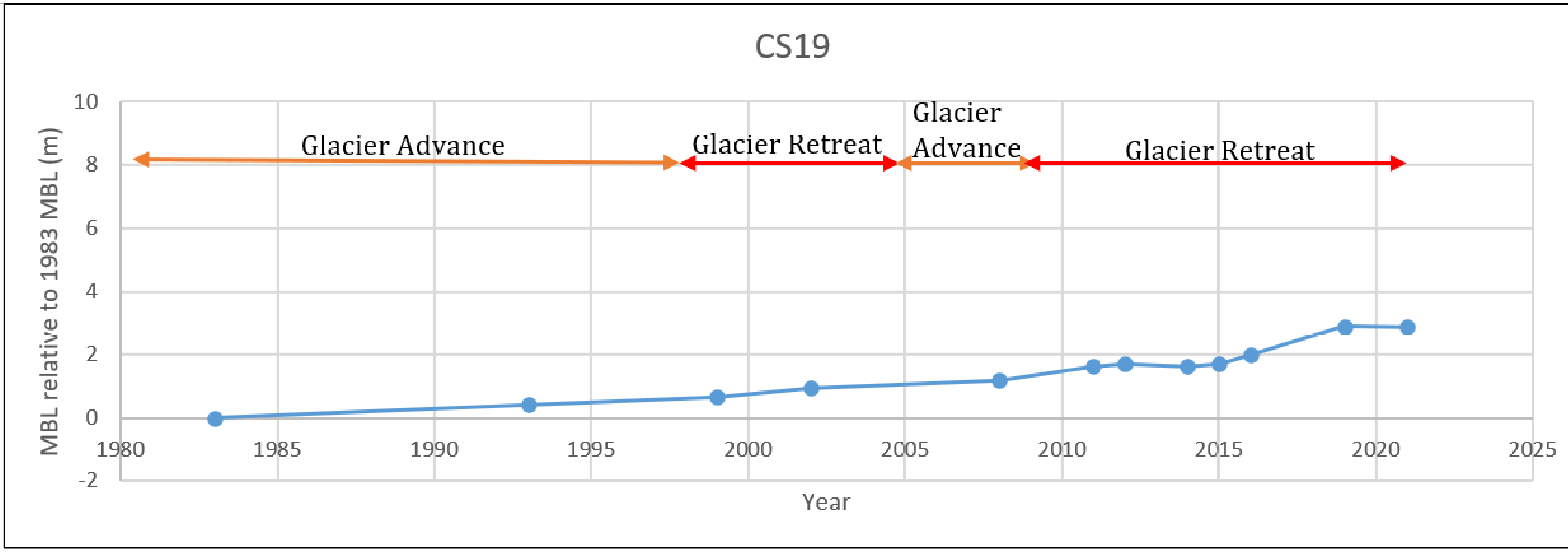
CS19
MBL relative to 1983 MBL (m)
Year
Glacier Advance
Glacier Retreat
Glacier
Advance
Glacier Retreat
10
8
6
4
2
0
-2
1980
1985
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2010
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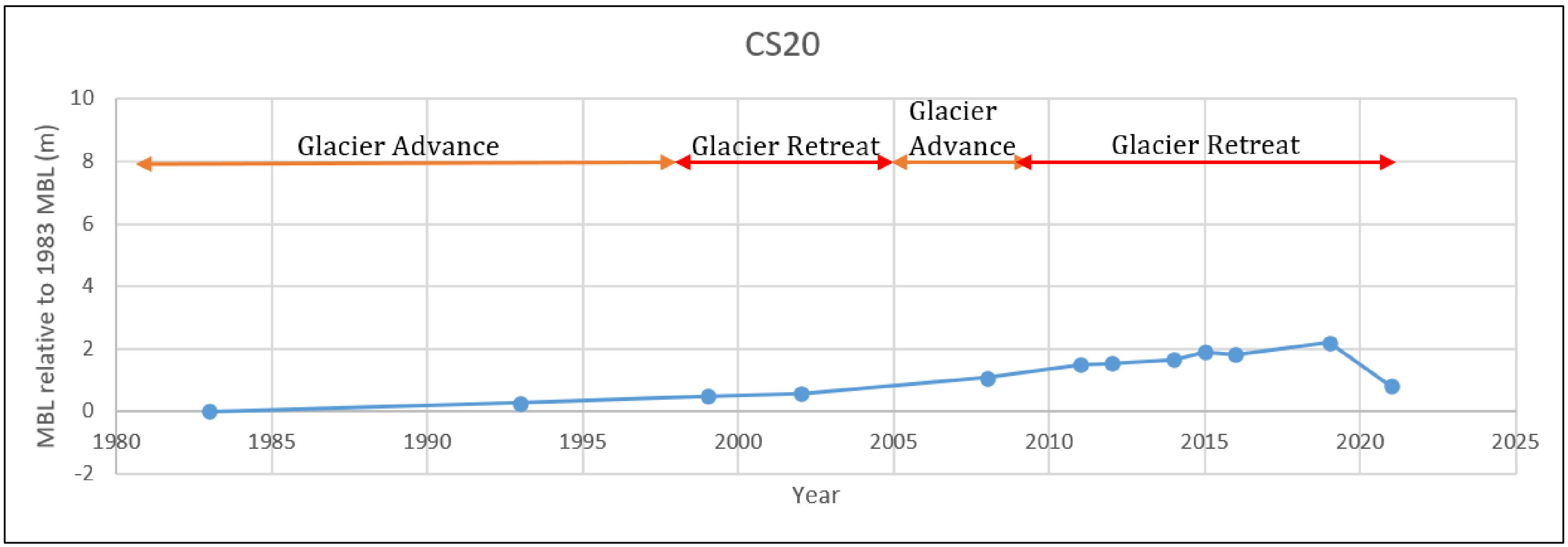
2020
2025


CS20
MBL relative to 1983 MBL (m)
Year
Glacier Advance
Glacier Retreat
Glacier
Advance
Glacier Retreat
10
8
6
4
2
0
-2
1980
1985
1990
1995
2000
2005
2010
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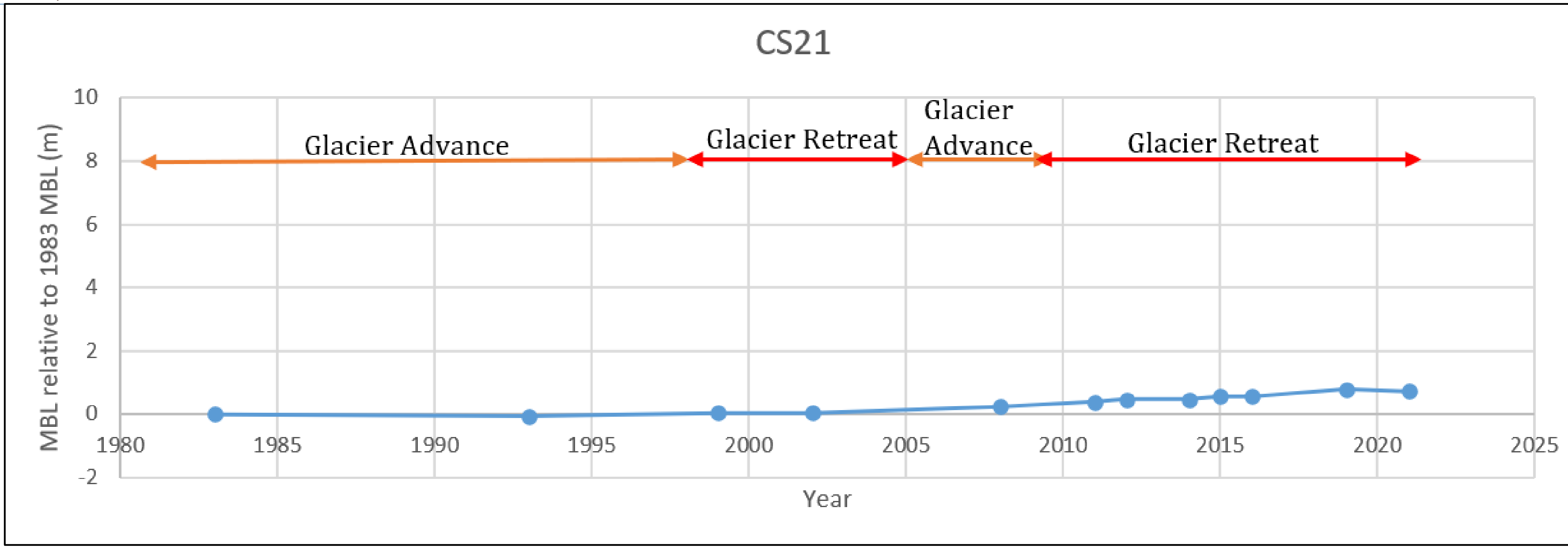
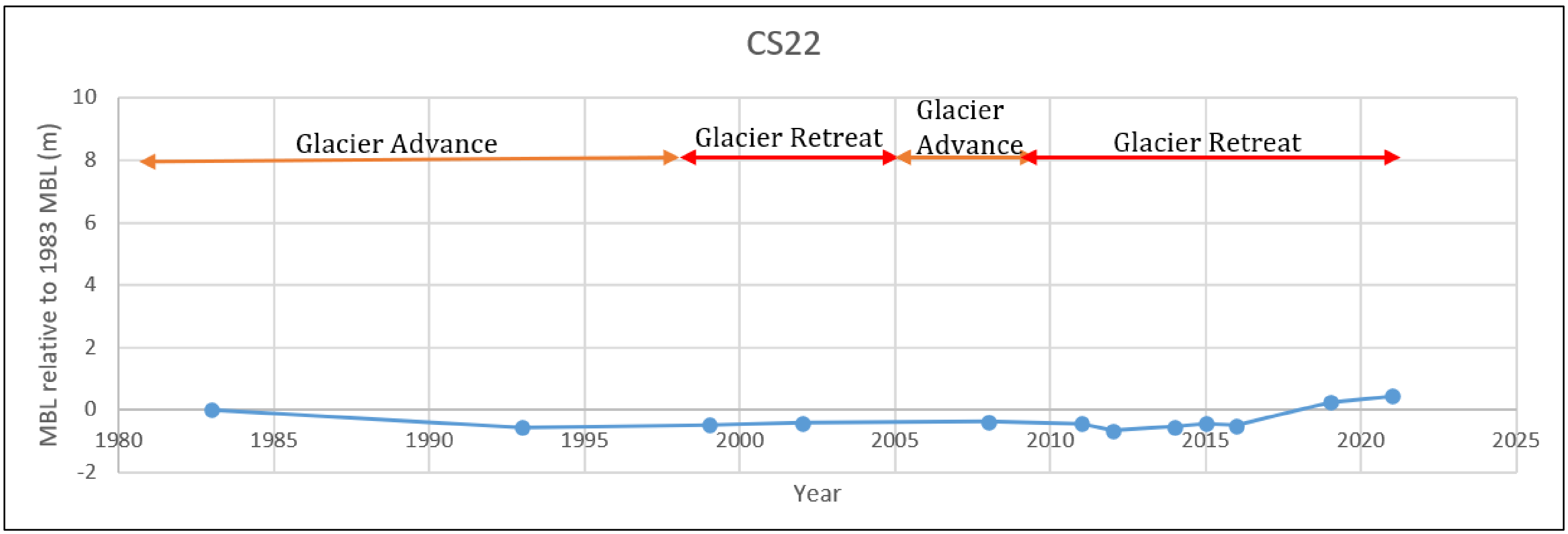
2020
2025


CS21
Glacier Advance
Glacier Retreat
Glacier
Advance
Glacier Retreat
MBL relative to 1983 MBL (m)
Year
10
8
6
4
2
0
-2
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025


CS22
Glacier Advance
Glacier Retreat
Glacier
Advance
Glacier Retreat
MBL relative to 1983 MBL (m)
Year
10
8
6
4
2
0
-2
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

3.2 GCD ANALYSIS

In order to gain a detailed spatial understanding of the dynamics of the system, a change detection analysis (GCD) analysis was performed the using 2021 Satellite DEM and the 2019 LiDAR DEM the area of interest (AOI) is shown on Figure 3-1. The method is the same as applied to the previous study in 2019 which analysed the difference between the 2019 and 2016 LiDAR DEMs (Gardner & Brasington, 2019).

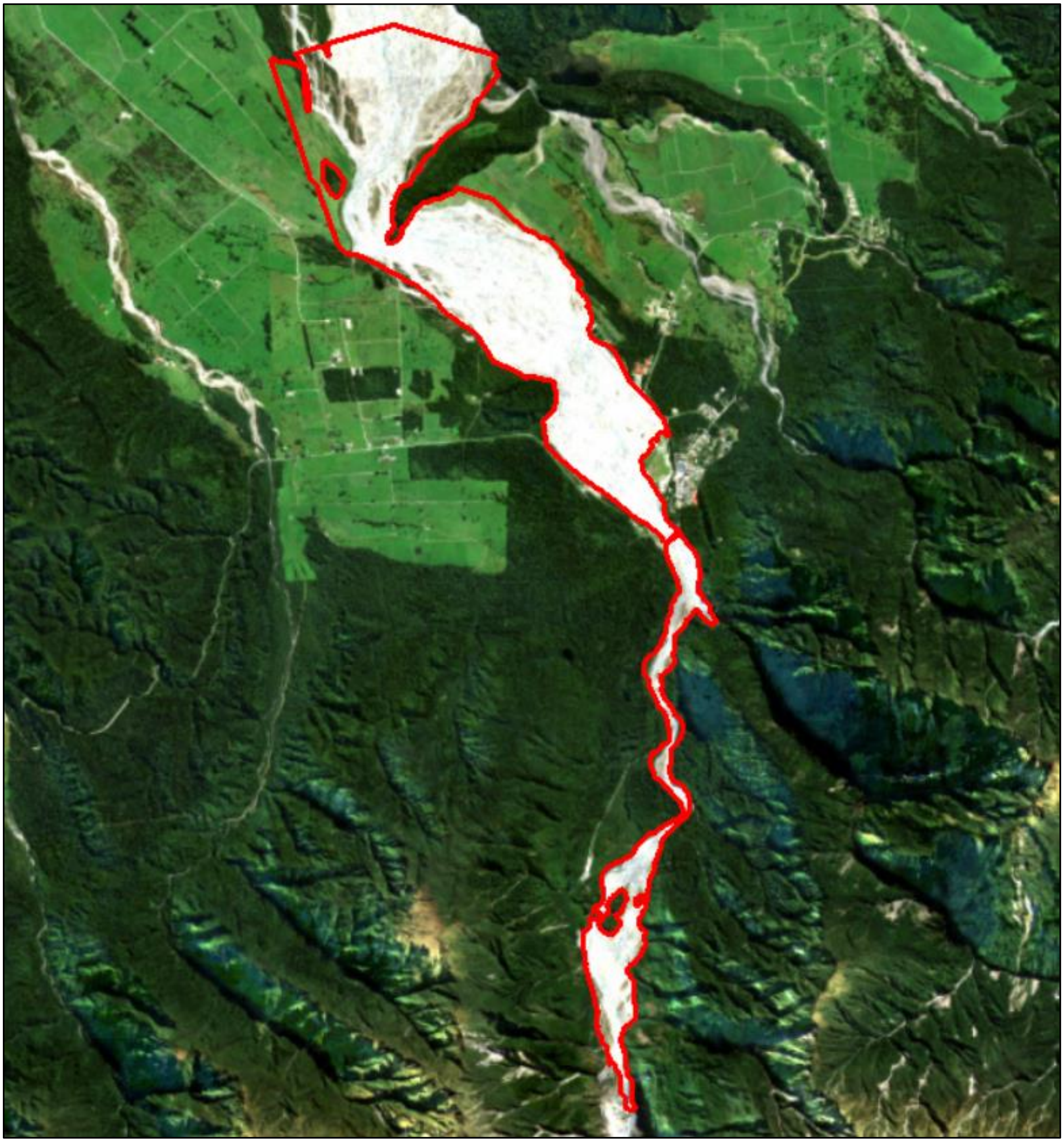


Figure 3-1 – Area of interest for GCD study

Overall the analysis has shown that over the AOI, there has been a build-up of gravel in the system in excess of 1 million cubic metres between April 2019 and March 2021. A summary of volumetric changes for each cross-section reach is presented in Figure 3-2. Of particular note is the significant aggradation in the reach from XS2 to XS4 as well as the degradation from XS0 to XS2. This likely indicates that the material which filled up the valley during the 2019 flood events, is slowly working its way down the system and will be likely to be causing ongoing aggradation for many years to come.

Of further note is the absence of significant change immediately upstream of the State Highway Bridge indicating that in this section, the sediment passes through with little change in channel geometry. Downstream of the bridge the volumetric changes are notable, particularly from XS15 to XS19 where the river widens significantly and there is a reduction in sediment-transport capacity, and an associated increase in sediment deposition that results in fairly rapid aggradation rates.

A visual presentation of the change detection is presented in Figure 3-2a and 3-2b on the following pages.

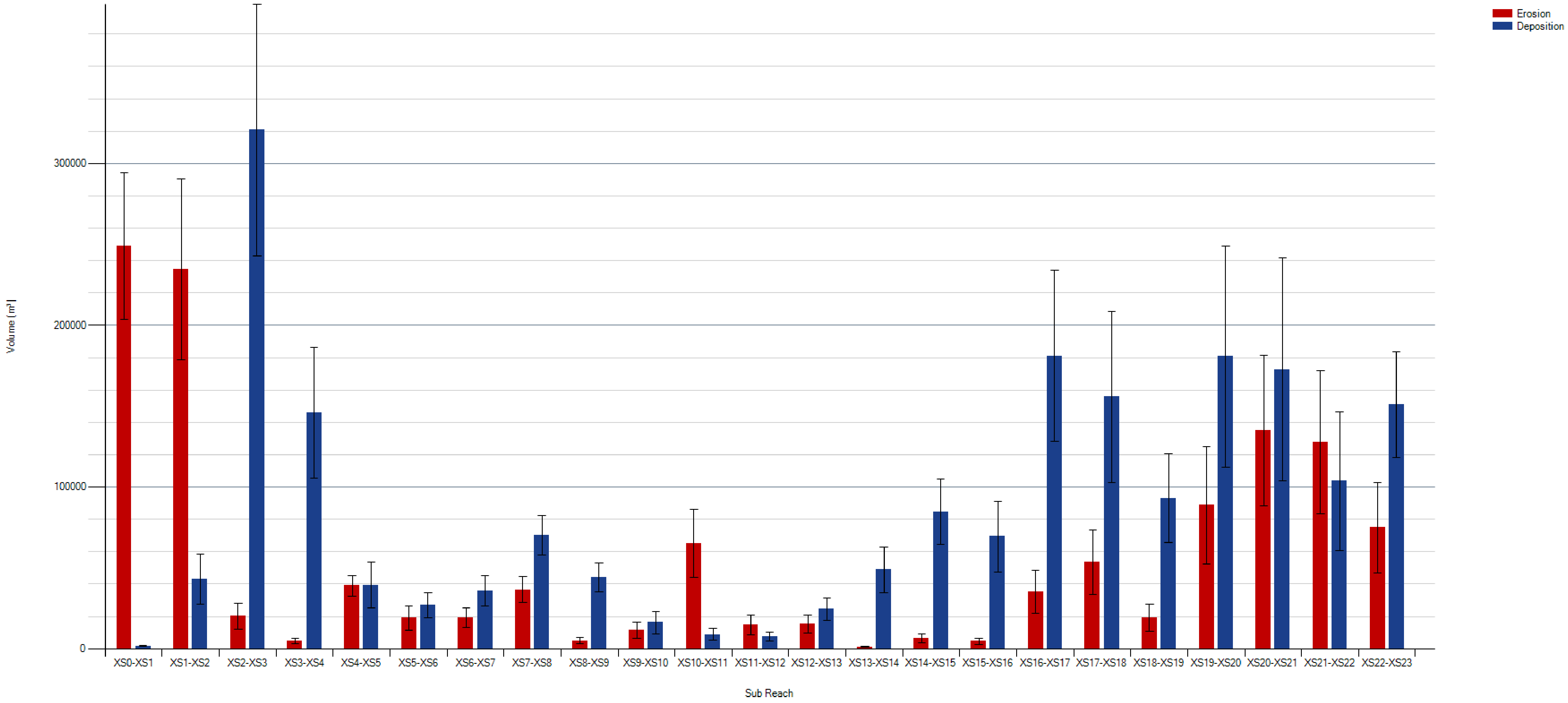
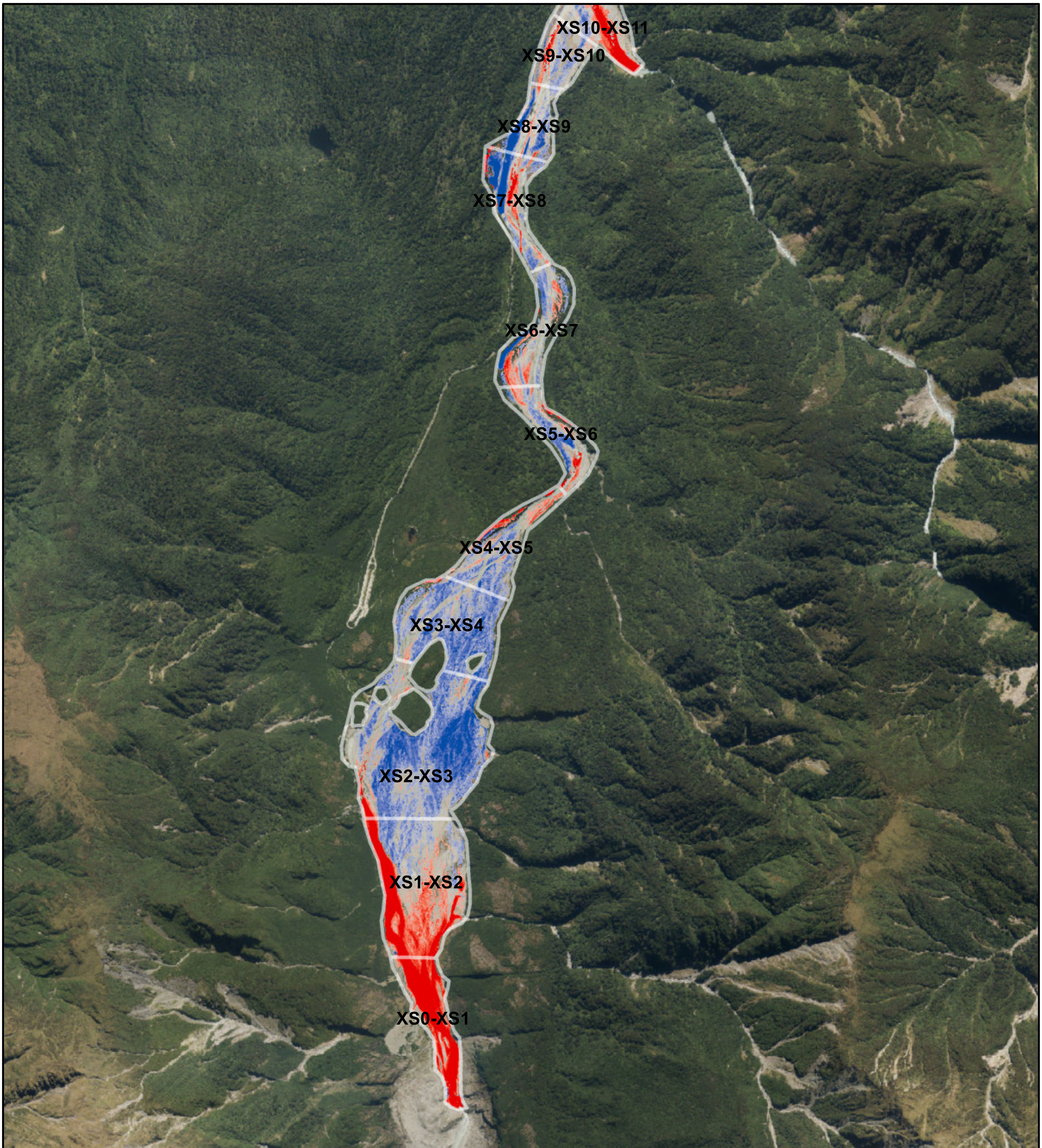


Figure 3-2 – Change in volume for each cross section reach for time period 2019 to 2021 based on 2019 LiDAR DEM and 2021 Satellite DEM



SCALE BAR

0 0.25 0.5 1 km

Legend

XS Budget Cells

Elevation Difference (m)

- < -2.20
- -2.20 to -2.00
- -1.90 to -1.70
- -1.70 to -1.50
- -1.40 to -1.20
- -1.20 to -1.00
- -1.00 to -0.80
- -0.70 to -0.50
- -0.50 to -0.30
- -0.20 to 0.00
- 0.00 to 0.20
- 0.20 to 0.40
- 0.50 to 0.70
- 0.70 to 0.90
- 1.00 to 1.20
- 1.20 to 1.40
- 1.40 to 1.60
- 1.70 to 1.90
- 1.90 to 2.10
- > 2.20

PROJECT

Waiho River Change Detection Analysis

TITLE **Glacier to Callery Confluence**
April 2019 LiDAR to March 2021 Satellite DEM
Map 1 of 2

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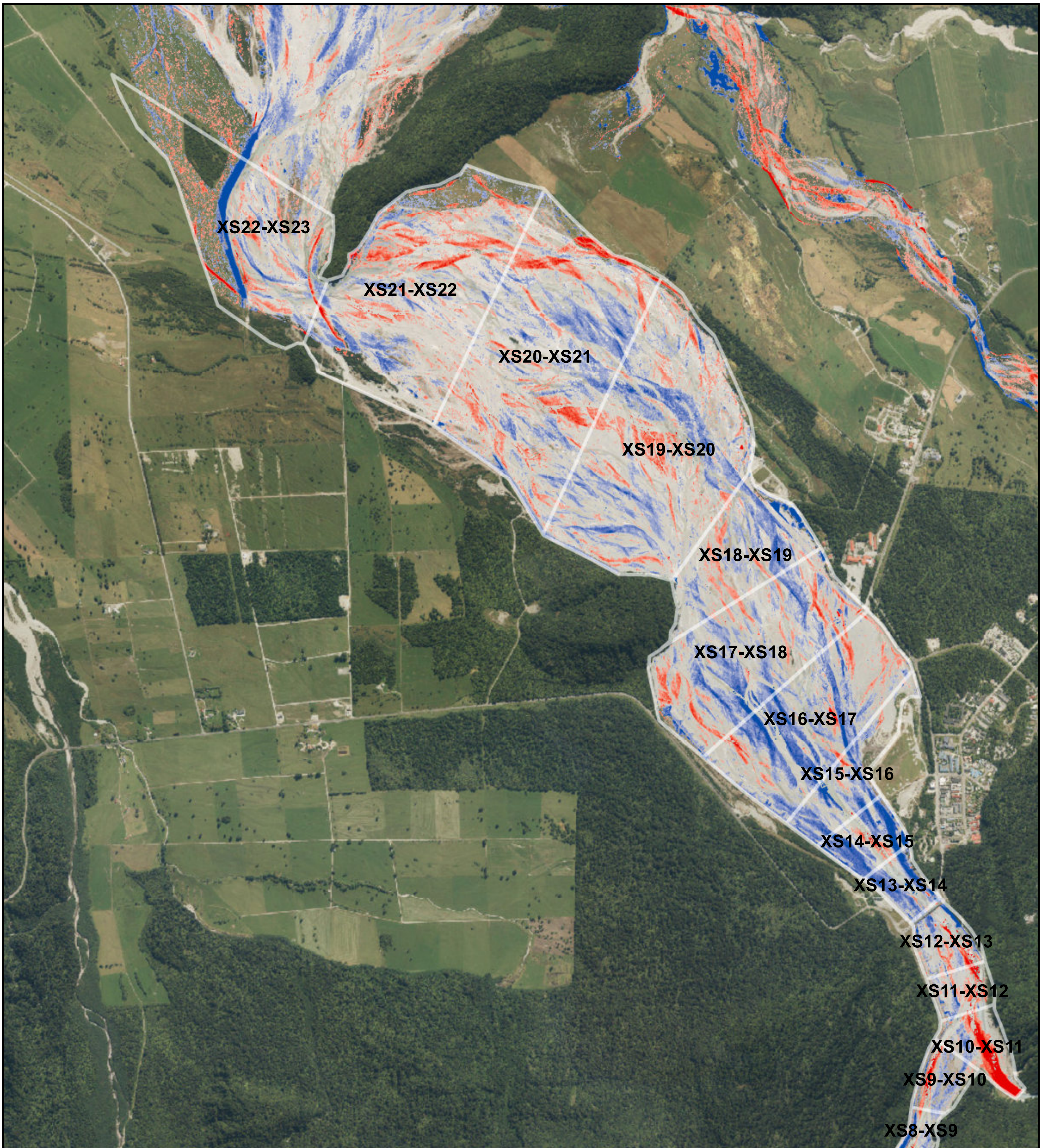
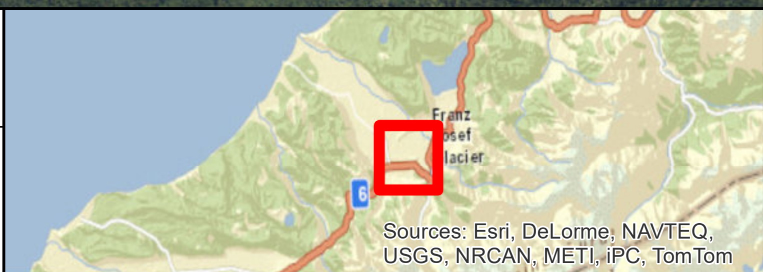
AUTHOR	DATE	JOB CODE	REVISION
Matthew Gardner	1 Oct 2021	WCRC029	01

N



SCALE BAR

0 0.25 0.5 1 km



PROJECT Waiho River Change Detection Analysis

TITLE Glacier to Callery Confluence April 2019 LiDAR to March 2021 Satellite DEM Map 2 of 2

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THE WEST COAST REGIONAL COUNCIL

AUTHOR Matthew Gardner | **DATE** 1 Oct 2021 | **JOB CODE** WCRC029 | **REVISION** 01 | N

In order to further illustrate the significant ongoing aggradation in the river, a cross-section profile was developed across the river in the location of the historic Glacier Gateway motel which was relocated in 2015, after modelling showed that it was at risk of inundation in a 1 in 10 year return period event (Gardner, 2014).

LiDAR is available in this location from 2011, 2016 and 2019 as well the satellite DEM from March 2021. A cross section profile has been extracted from each dataset in the location highlighted in red in Figure 3-3.

Figure 3-3 – Location of extracted cross section

The cross section profiles presented in Figure 3-4 show very clearly that although the stopbanks have been raised on several occasions, the river bed has continued to aggrade along the true left side by over 4m over a 10 year period.

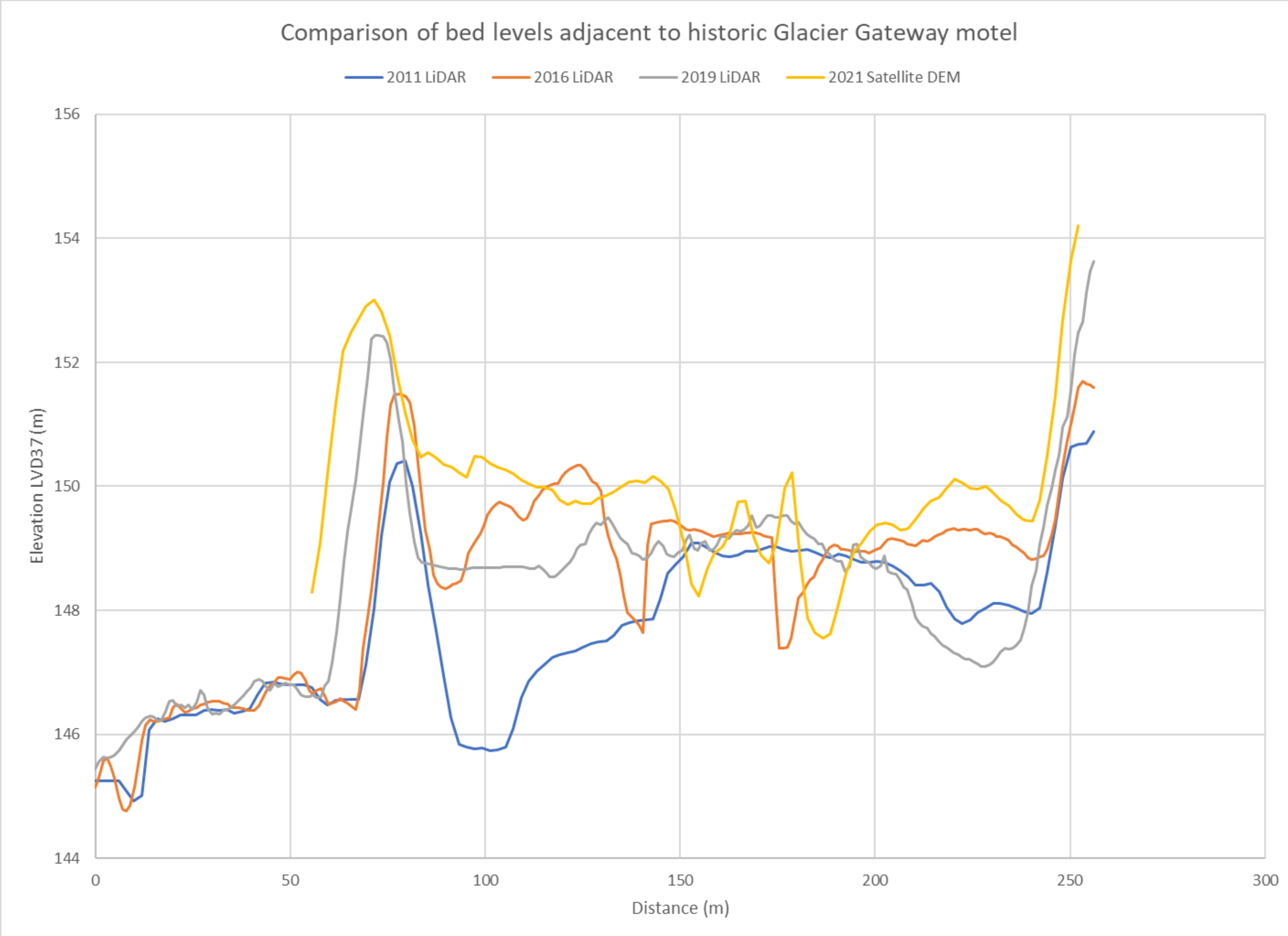

Figure 3-4 – Cross section profile plot adjacent to Glacier gateway hotels

4. POTENTIAL STOPBANK ALIGNMENTS

In late 2014 / early 2015, Gary Williams and I were contracted to provide emergency advice on potential works to prevent a breakout of the river in the vicinity of what is referred to as the 55km corner. We considered a range of options which took into account the likely sedimentation patterns and river dynamics. We recommended the construction of a stopbank that extends from the helipad bank to downstream of the treatment ponds.

Since then, a flood in March 2016 broke out in this location destroying the Scenic Circle Hotel (Mueller) and the treatment ponds. Subsequently a new section of stopbank was built which is referred to as the Havill Wall bank which connects the existing Waka Kotahi (NZTA) section of stopbank and extends the full length to beyond the treatment ponds. The Havill Wall bank is significantly higher and wider than the old bank and sits in front of the previous section of stopbank. As a result, the stopbank design proposed in 2015 will need adjusting in order to be able to tie into the new section of bank.

The preliminary design submitted to the government as part of the application for provincial growth funding has assumed an alternative alignment. A summary of the existing banks is shown as well as the proposed design alignments in Figure 0-1 below.

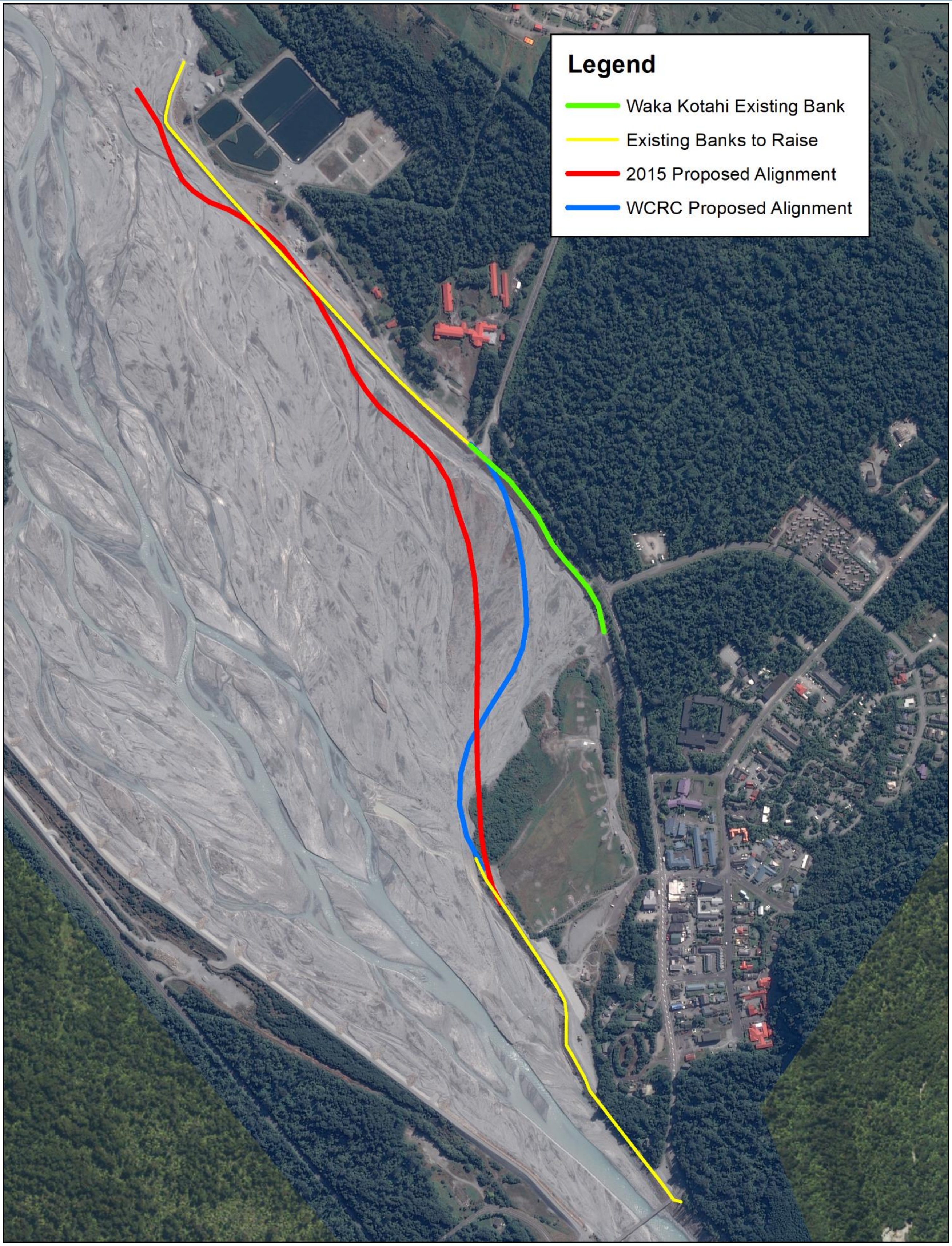

Figure 0-1 – Proposed design alignment for new section of stopbank

FRANZ JOSEF STOPBANKs

On review of the alignment submitted as part of the funding proposal, we have concern that the alignment is less than ideal due to the following reasons:

- The stop bank alignment has a significant expansion with the potential to cause sediment deposition midway along the bend
- The bend alignment will likely cause flow to impact the stopbank at a sharp angle upstream of the hotel and have an associated increase in velocity and shear stress against the bank, with the potential for increased toe scour and bank erosion.
- There is potential to significantly increase the velocity near the stopbank upstream of the hotel
- There is excessive fall towards the 55km corner

Gary, Dai and myself have workshopped a range of potential alignments internally and selected three alignments for further analysis, the results of which were used to select a preferred alignment (Figure 1-1).

4.1 TATARE OVERFLOW BUND

In addition to raising the existing banks, the proposal includes the construction of a rock lined bund to prevent flow into the Tatare River. Due to the aggradation in the Waiho River, there is potential for the Waiho River to avulse into the Tatare River, which could create significant threat to the township as discussed in previous reports (Hall, 2012).Floodwaters have already been spilling over this area in recent flood events, with significant scour and headcutting occurring each time. The construction of a bund to prevent an avulsion at this location is considered to be highly prudent. The location of the proposed bund is presented in Figure 0-2 below.

Figure 0-2 – Location of Tatare overflow bund

5 HYDRAULIC MODEL SETUP

A MIKE21FM hydraulic model of the river was built to evaluate the three stopbank alignments. Elevations were assigned to the model primarily using the March 2021 satellite DEM and supplemented with the raw survey data. The model extends from the confluence with the Callery River downstream of the Waiho Loop.

The model has been constructed using a flexible mesh with variable mesh size ranging from 25m^2 for the main channel to 1000 m^2 near the downstream boundary to provide mesh stability (Figure 5-1).

To ensure stopbank crest elevations are accurately represented, the crest locations have been carefully included in the mesh to allow the elevations to be defined using a 1D dike feature within the software. A schematic of the final mesh is presented in Figure 5-1.

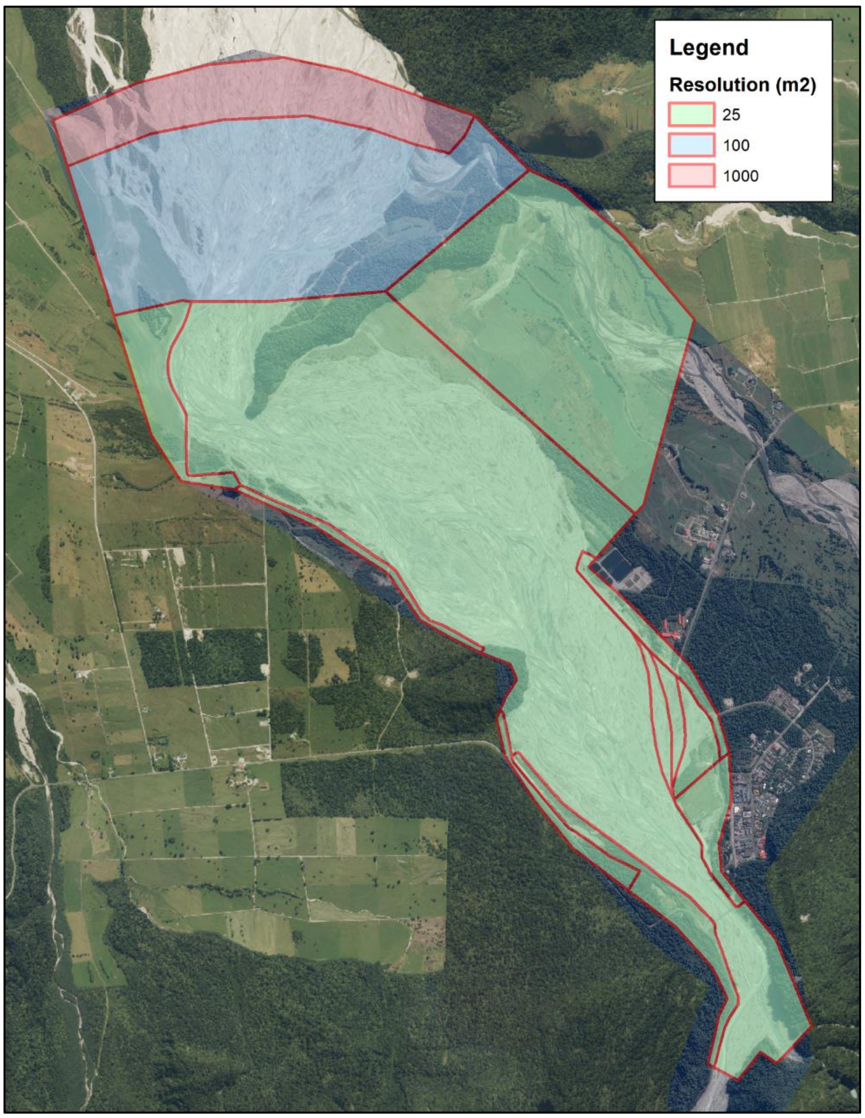

Figure 5-1 – Mesh Extent

It must be highlighted that this is a fixed bed hydraulic model, which does not account for the mobile nature of the bed during flood events nor for ongoing aggradation, and hence needs to be interpreted by a suitably qualified and experienced engineer. The purpose of the model should be seen as a tool to assist in decision making, rather than a definitive model of the river.

4.1 Model Terrain

The model bathymetry has been interpolated using points generated at a 2m grid resolution from the satellite DEM. Because the DEM did not contain the subaqueous portion of the river, the DEM was modified by burning in a 1.5m deep by 18m wide trapezoid channel (Figure 5-2, Figure 5-3, Figure 5-4). The channel edges were designed to tie in with the DEM elevations.

The model was run with the inserted channel braid for the existing conditions, the three braid alignments and the Manning's n-value sensitivity runs.

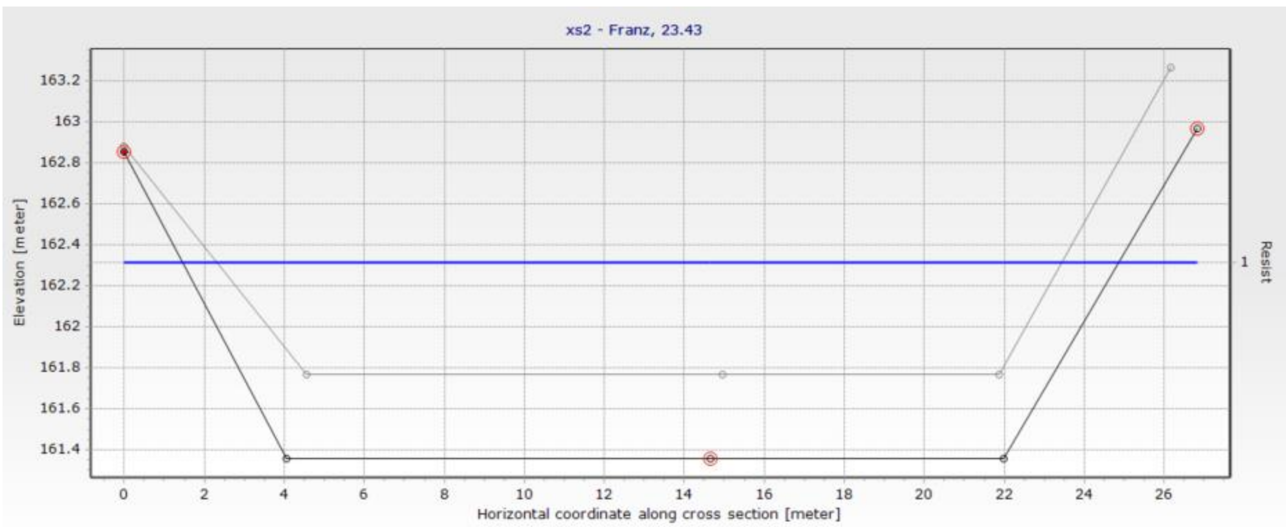

Figure 5-2 – Example of typical trapezoidal channel shape in MIKE Hydro River

Figure 5-3 - Example of cross section locations in relation to main channel

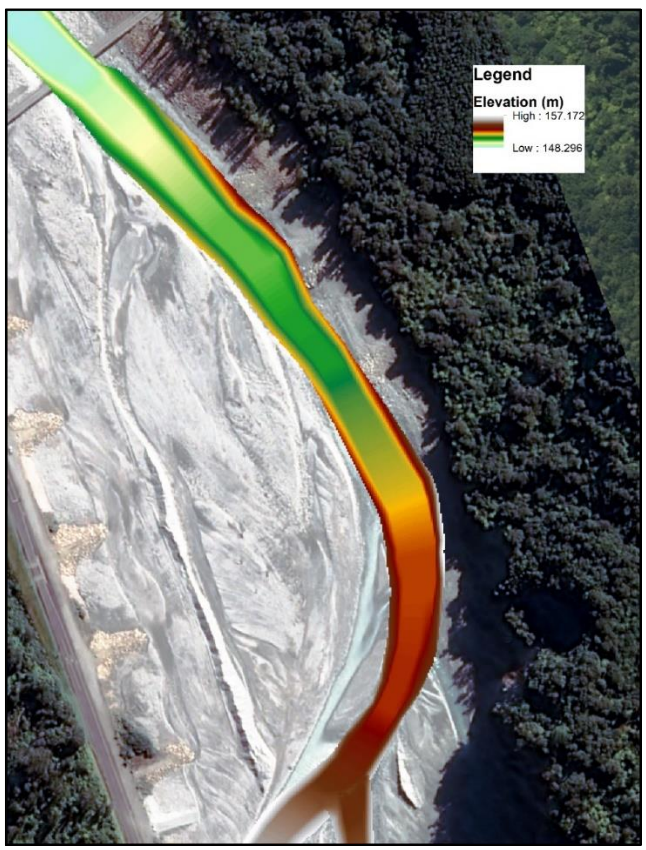

Figure 5-4 - Visualisation of interpolated 2D bathymetry

4.2 Manning's n roughness values.

Based on previous experience with modelling the river (Gardner, 2014 & 2016), a Manning's 'n' value of 0.05 was selected as being representative of the likely roughness characteristics of the channel bed. This is slightly higher than suggested by standard formula for gravel-based rivers based on the grain size distribution (D_{50} = 165 mm, D_{84}=285 mm) however due to the significant turbulence observed during flood events, we consider this value to be suitable. This value is also consistent with assessments carried out by NIWA (2011) and Bob Hall (Hall, 2012)

In addition to the base value of 0.05, the model was run with a Manning's of 0.04 for scour calculations and at 0.06 to evaluate the freeboard.

4.3 Hydrology

Due to the significant mobilisation of the entire bed during high flow events, it is not considered practical to install a flow gauge in the river. There is also only limited rain gauge information in the catchment, hence there is no known relationship between rainfall and runoff available making it difficult to assess flood frequency.

Previous assessments have assessed the 1% Annual Exceedance Probability (AEP) flow in the catchment to be between 2000 to 3000 m^3/s at the State Highway Bridge. A recent assessment was carried out in 2014 and was based on a scaling of flows in the adjacent Whataroa catchment (Gardner, 2014). This assessment placed the 1%AEP flow as 2451 m^3/s and was rounded up to 2500 m^3/s to account for uncertainty.

Whilst it would be possible to undertake a more detailed hydrological assessment, considering the significant uncertainties in the catchment due to a lack of flow and rainfall gauges as well as a continually changing climate, we do not believe that there is significant merit in changing the design flow from 2500 m^3/s, especially considering that any stopbank heights will be controlled more by the ongoing aggradation, rather than flow.

4.4 Stopbank Alignments

In addition to the existing river setup, three potential stopbank alignments (A, B and C) were simulated, The banks were represented in the model using 1D dike features in MIKE21fm. To simulate a likely braid set up at the base of each bank alignment; a 30m wide, 2m deep trapezoidal braid has been burnt into the DEM for each stopbank alignment. These dimensions have been based on site measurements of braids that have clearly formed adjacent to the existing stopbank in the vicinity of the 55km corner. An example of the braid for alignment A is presented in Figure 5-5 below.

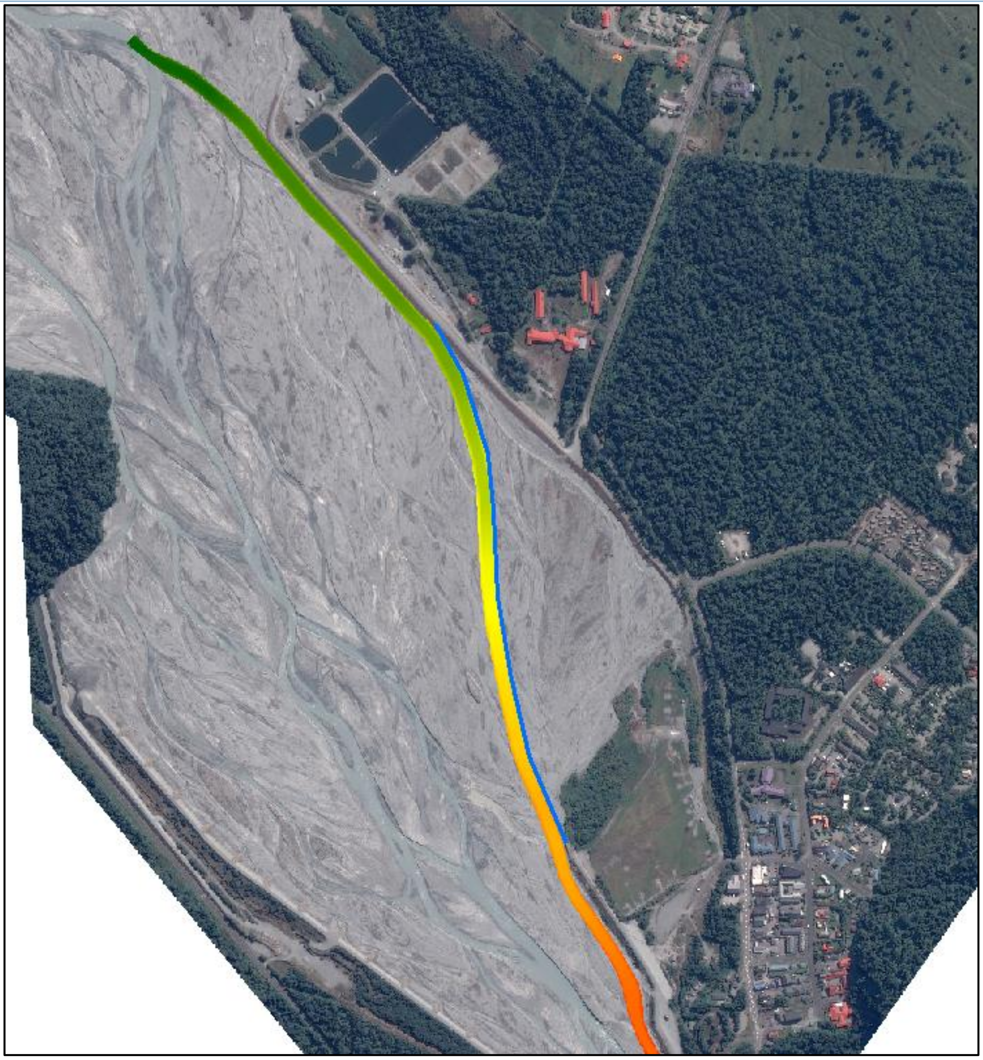

Figure 5-5 – Example of braid channel burnt into terrain for alignment A

4.5 Aggradation Scenarios

To assess the likely aggradation in the vicinity of the stopbanks over a 20-year period, an analysis was performed of the historic aggradation trends at each cross section from 1993 to 2021. When examining the trends presented in section 3, it is apparent that there are three potential pivot points which could be used to assess varying aggradation trends. The average rate of aggradation was calculated for the three following time periods:

- 1993 to 2021
- 1998 to 2021
- 2008 to 2021

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Table 5-1 – Cross sectional average aggradation rates – 1993 to 2021

	Rate (m/year)			Aggradation - 20 year period (m)		
	1993 - 2021	1998 - 2021	2008 - 2021	Rate1	Rate2	Rate3
CS13	0.18	0.09	0.14	3.6	1.8	2.7
CS14	0.16	0.09	0.12	3.3	1.7	2.5
CS15	0.15	0.10	0.12	2.9	1.9	2.5
CS16	0.13	0.09	0.11	2.5	1.9	2.2
CS17	0.12	0.10	0.14	2.4	2.0	2.9
CS18	0.11	0.10	0.13	2.2	2.0	2.6
CS19	0.09	0.10	0.13	1.8	2.0	2.6
CS20	0.02	0.01	-0.02	0.4	0.2	-0.4
CS21	0.03	0.03	0.04	0.6	0.6	0.7
CS22	0.03	0.04	0.07	0.7	0.8	1.3

In order to assess the potential impact on flood levels, an aggradation surface was developed by interpolating an aggradation rate at each cross section, and increasing the bed level at that location by that amount.

6 MODEL SIMULATIONS

A range of simulations have been run through the model in order to assist with the detailed design process. The runs have been decided upon jointly, based upon the needs of the detailed design stage of the project.

Table 6-1 summarises the modelled scenarios.

Table 6-1 – Modelled Scenarios

Scenario	Discharge m^3/s	Alignment	Mannings 'n'	Aggradation Rate
1	500	B	0.05	
2	1000	B	0.05	
3	1500	B	0.05	
4	2000	B	0.05	
5	2500	A	0.05	
6	2500	B	0.05	
7	2500	C	0.05	
8	2500	Existing	0.05	
9	3000	B	0.05	
10	3500	B	0.05	
11	2500	B	0.04	
12	2500	B	0.06	
13	2500	B	0.05	Aggradation Rate 1
14	2500	B	0.05	Aggradation Rate 2
15	2500	B	0.05	Aggradation Rate 3

Model output each run has been provided electronically with long section profiles showing peak elevation as well speed as presented in Appendix C. Maps showing peak speed and flood extent for each modelled scenario are also presented in Appendix D.

Peak water levels for the Tatare Overflow Bund are provided in Appendix E.

7 RESIDUAL RISK

Whilst raising stopbanks may be seen as essential in order to prevent flooding to property and infrastructure, it must also be kept in mind that raising of stopbanks also increases the residual risk and consequences should a stopbank failure occur.

The Waiho River is receiving a large volume of sediment from the upstream catchment which is resulting in rapid rates of aggradation over the entire fan area. It is unlikely that the rate of aggradation will decrease in the near future, and with increased storm intensities predicted with the changing climate, it only seems likely that these rates of aggradation will accelerate.

It is my professional opinion that the further raising of the stopbanks comes with increased risk and should be considered as a short-term solution, purely for the purposes of buying time to allow the implementation of more permanent solutions, such as vacating the true left bank of the river, allowing the river to reclaim its natural floodplain, and hence distribute the sediment inputs over a significantly larger area.

Whilst the exact impact of allowing the river to reclaim its natural floodplain on the true left bank of the river is uncertain, it is in my opinion likely that the overall rate of aggradation will decrease, considering the fact that the river will have the ability to distribute its sediment over a much larger area.

8 CONCLUSIONS

- Based on our analysis we conclude that Alignment B is the most suitable alignment for the construction of the new bank.
- It is very apparent that ongoing aggradation is a very significant issue for the river, and future trends are uncertain. We recommend using Aggradation Scenario 2 for sizing the stopbanks as this gives a fairly uniform trend and provides a realistic profile for design purposes. Based on historic rates of aggradation, we could expect this to provide approximately 20 years of design life for a design flow of 2500 m^3/s. Regular monitoring of aggradation is recommended via LiDAR or satellite technology.
- The consequence of a stopbank breach or failure increases every time that a stopbank is raised. It is not recommended that these stopbanks are raised again after this raise and that serious consideration is given to managed retreat due to the significant nature of the hazard.
- The results of the modelling scenarios used in this preliminary design are appropriate to be used for detailed design.
- The satellite DEM data utilised in this study acquired through the Otago University School of surveying has proven to be extremely useful, reliable and cost effective. Serious consideration should be given to carrying acquiring regular repeat surveys using these techniques.

9 REFERENCES

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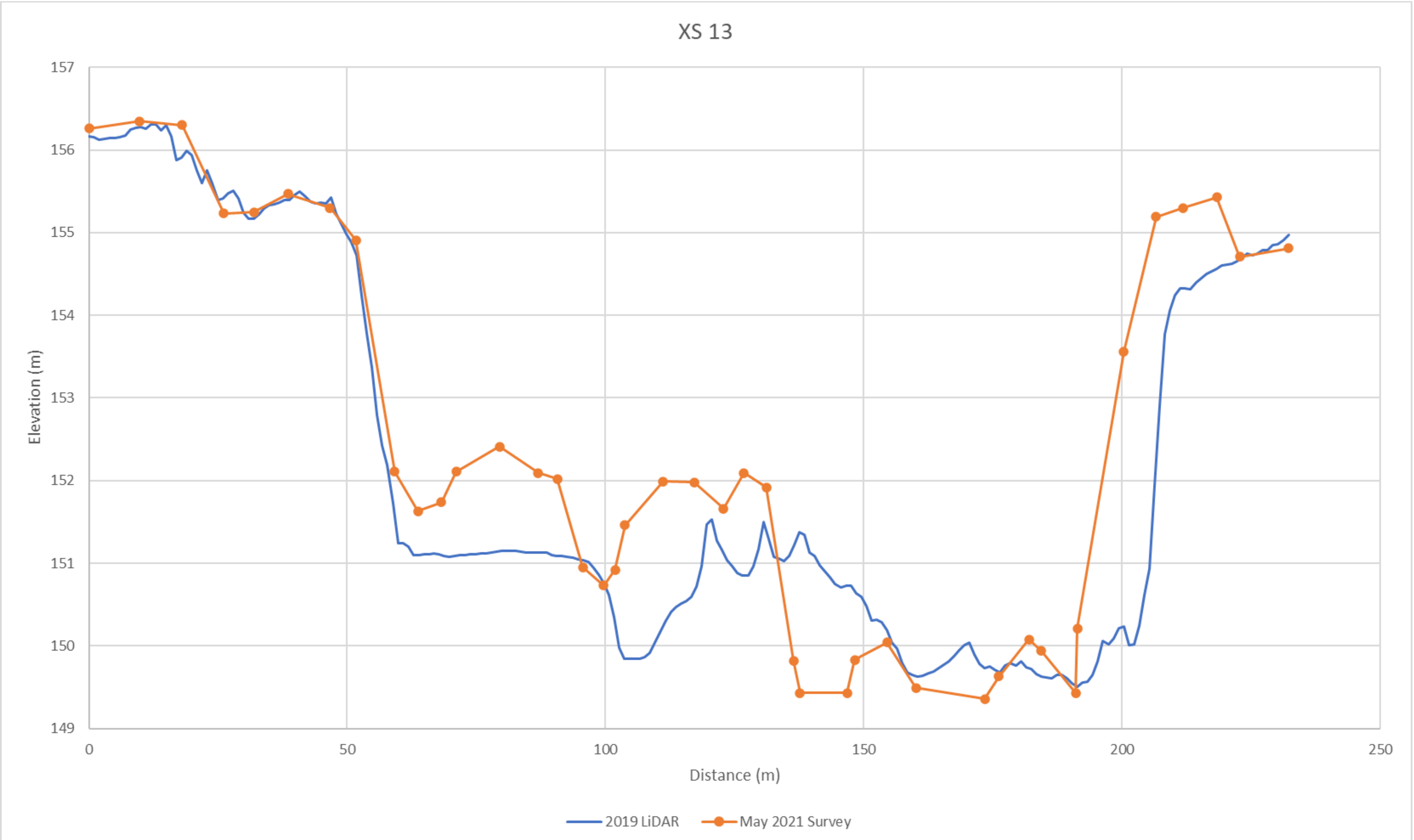
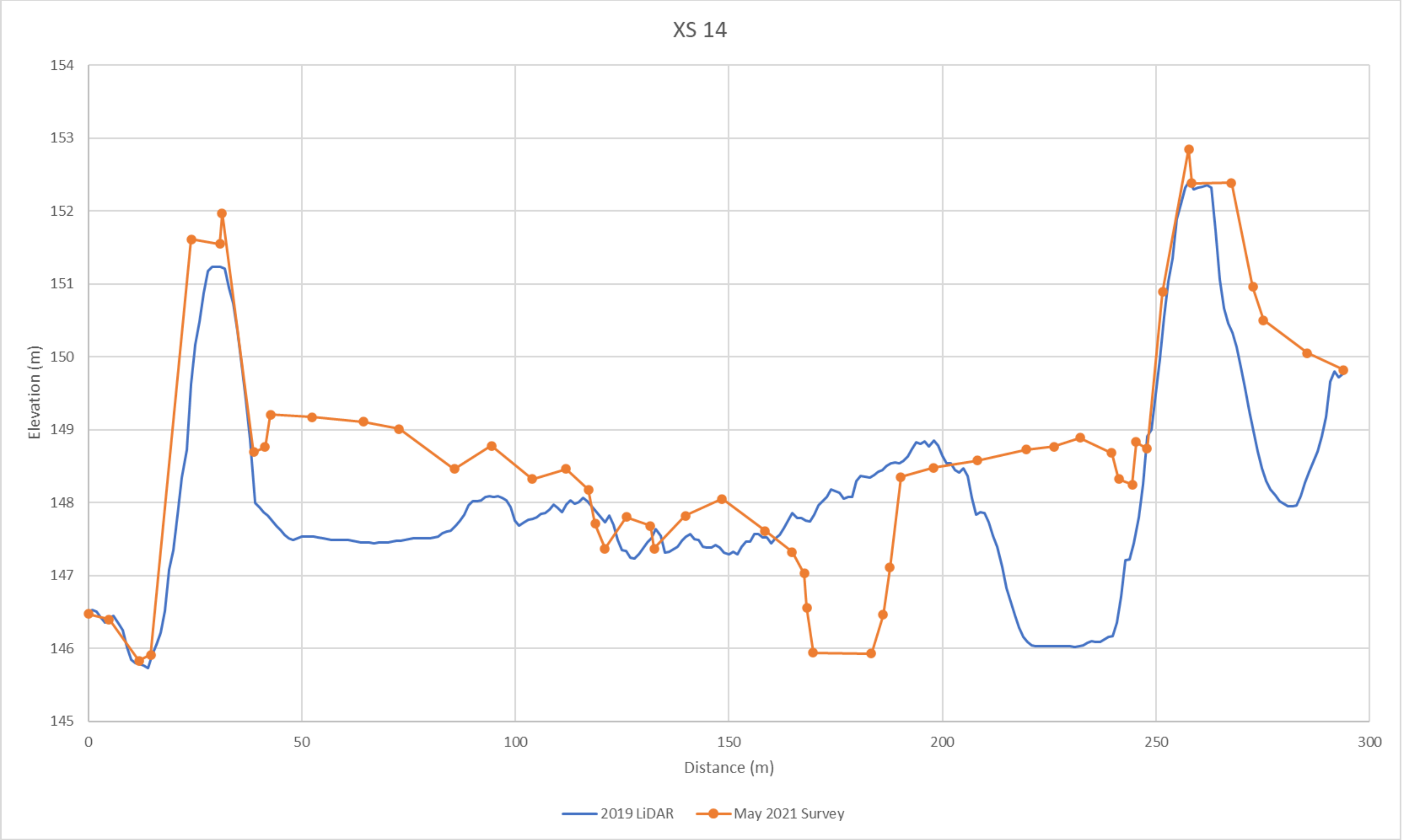
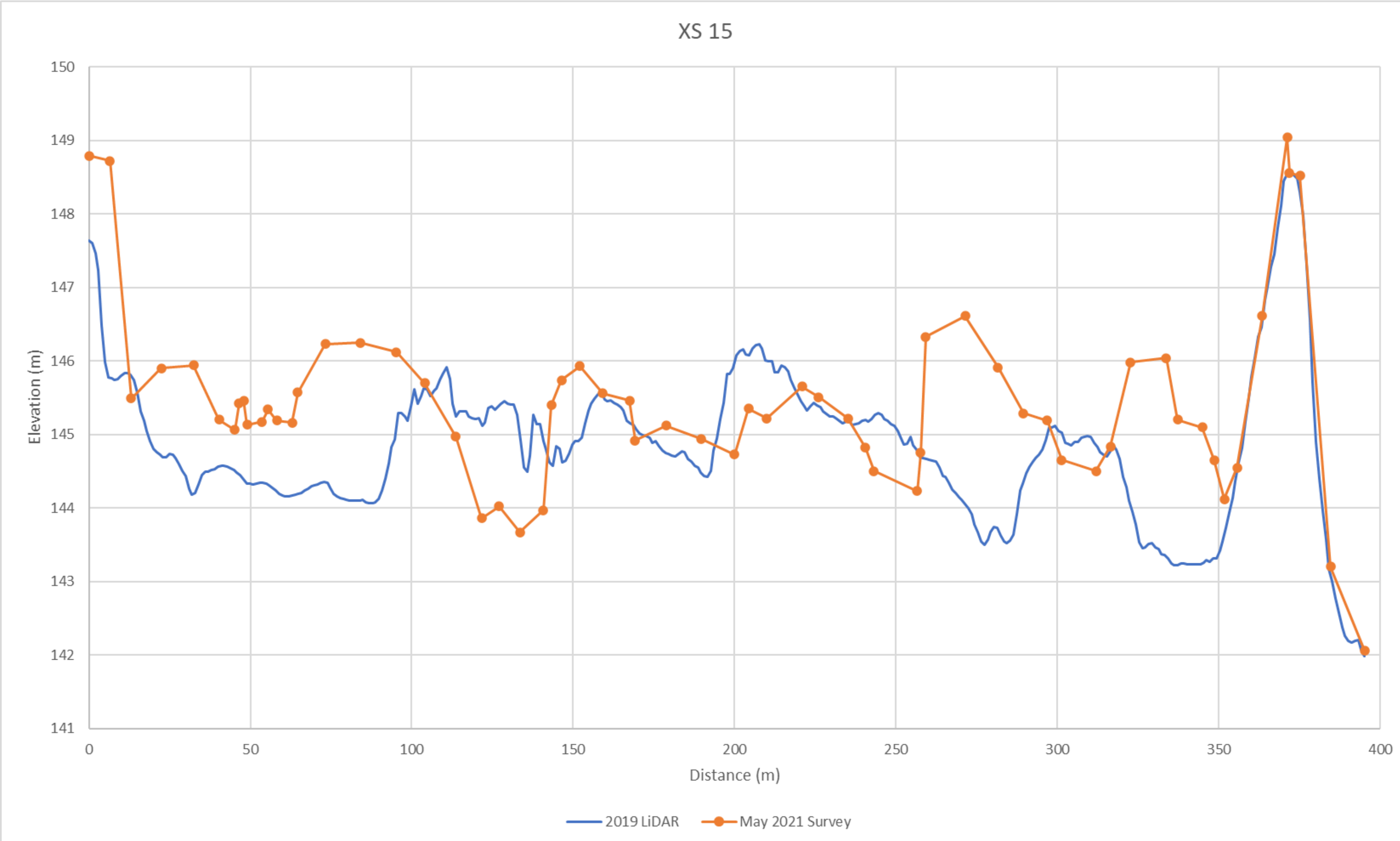
Wolman, M G. 1954. *A method for sampling coarse river bed material. Transactions of American Geophysical Union, v.35 (6), pp. 951-956.* 1954.

APPENDIX A – CROSS SECTION PLOTS


XS 13
157
156
155
154
153
152
151
150
149
Elevation (m)
0
50
100
150
200
250
Distance (m)
2019 LiDAR
May 2021 Survey


XS 14
154
153
152
151
150
149
148
147
146
145
Elevation (m)
0
50
100
150
200
250
300
Distance (m)
2019 LiDAR
May 2021 Survey


XS 15
Elevation (m)
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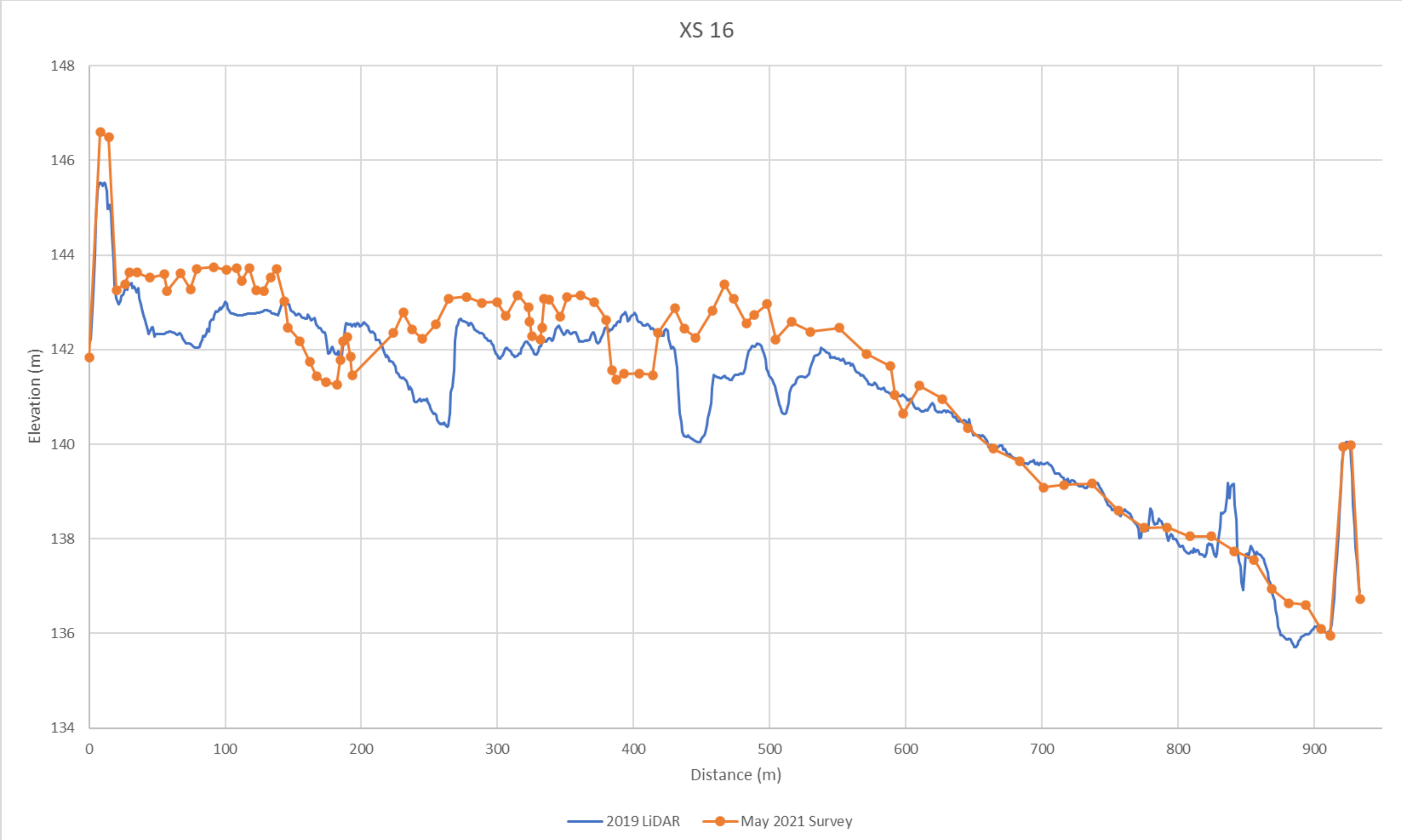
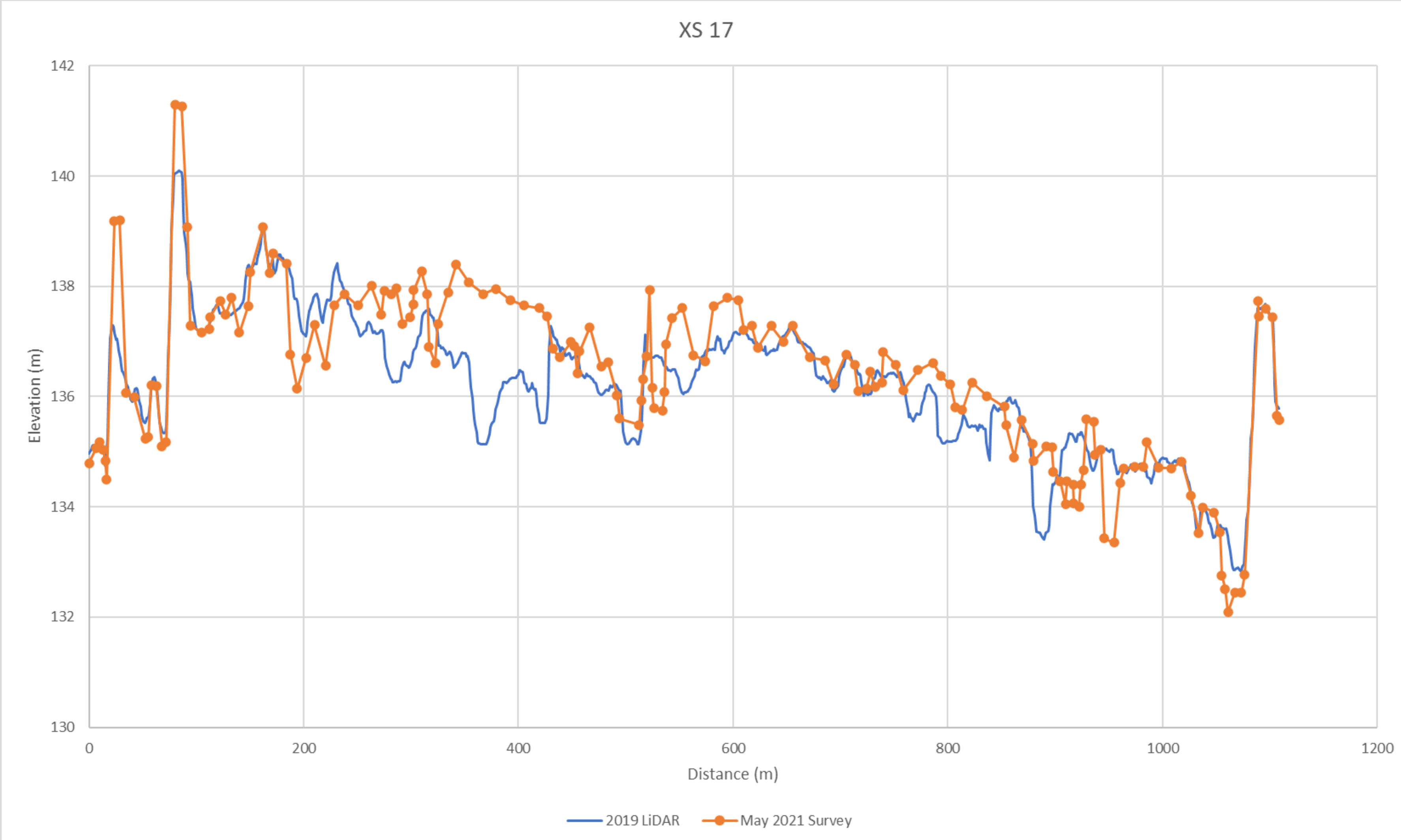
149
148
147
146
145
144
143
142
141
0
50
100
150
200
250
300
350
400
Distance (m)
2019 LiDAR
May 2021 Survey


XS 16
Elevation (m)
148
146
144
142
140
138
136
134
0
100
200
300
400
500
600
700
800
900
Distance (m)
2019 LiDAR
May 2021 Survey


XS 17
Elevation (m)
142
140
138
136
134
132
130
0
200
400
600
800
1000
1200
Distance (m)
2019 LiDAR
May 2021 Survey

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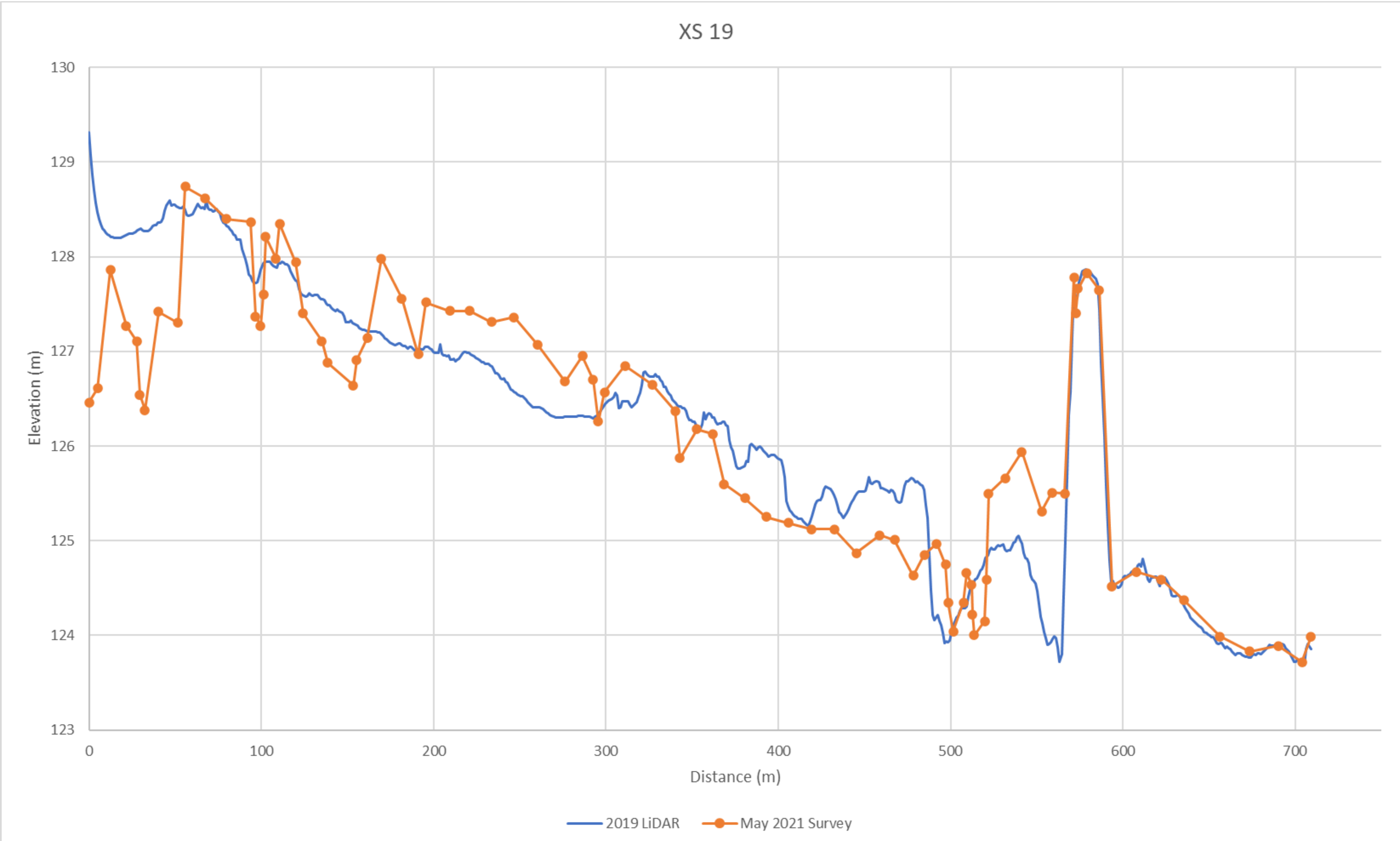
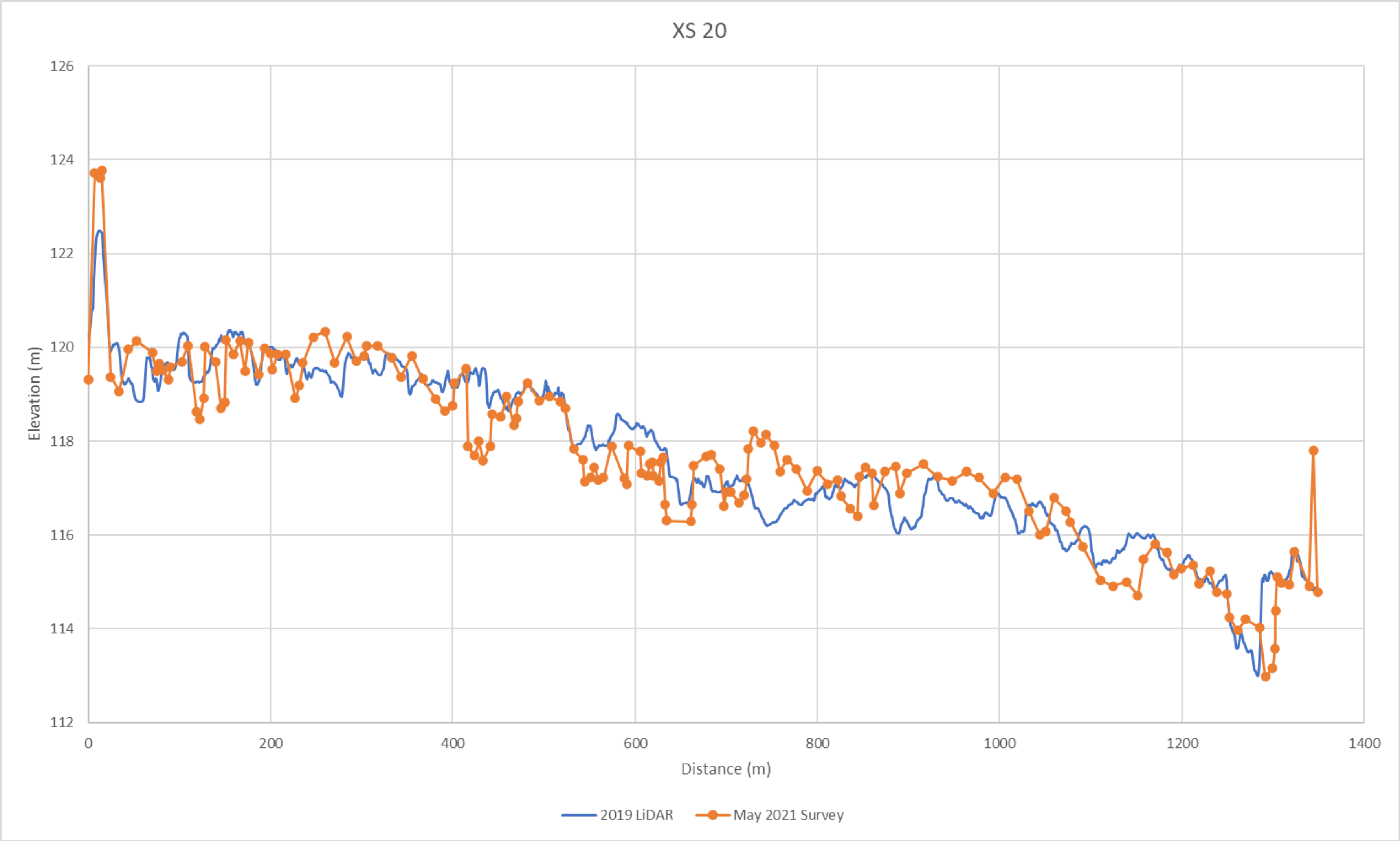
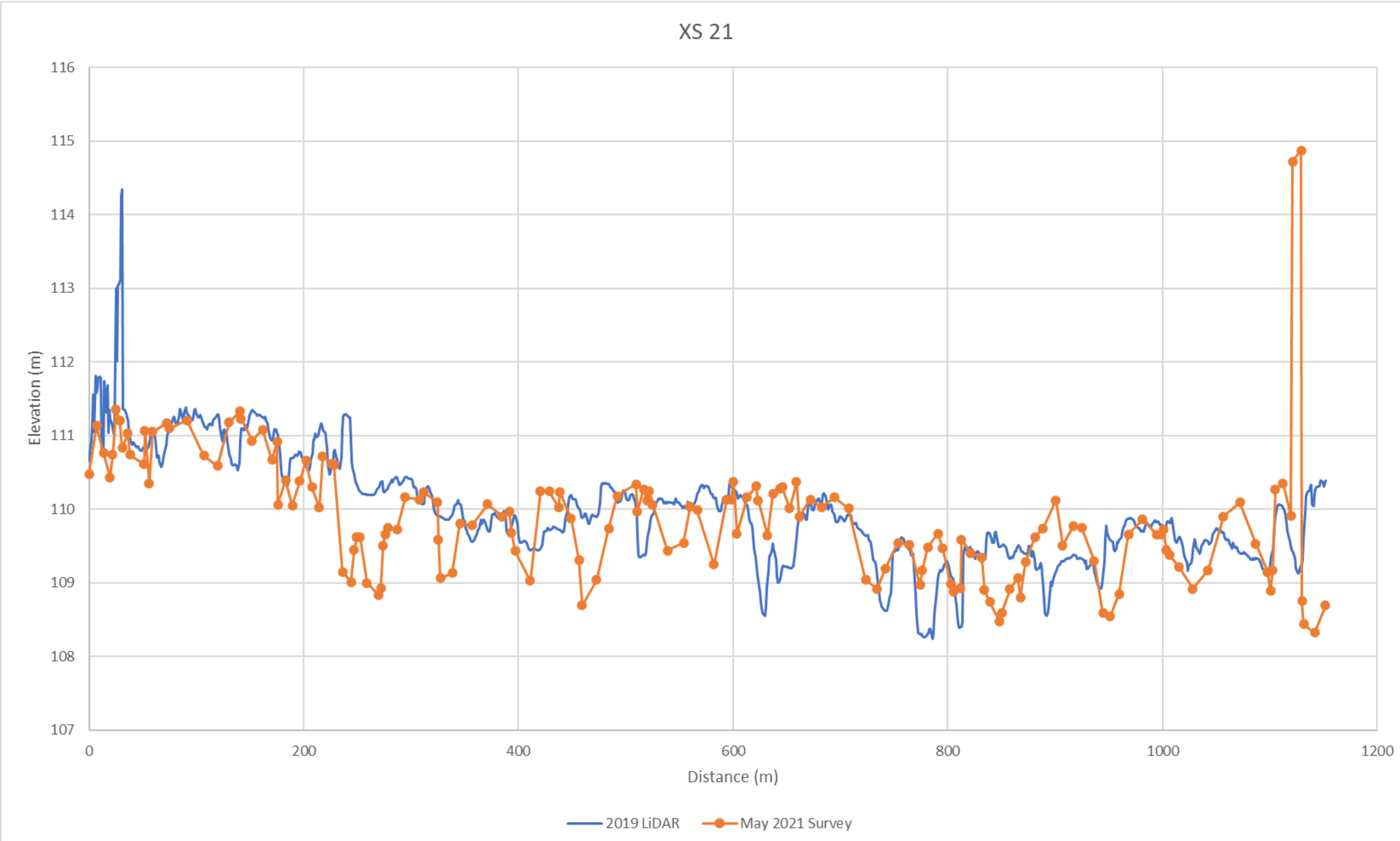
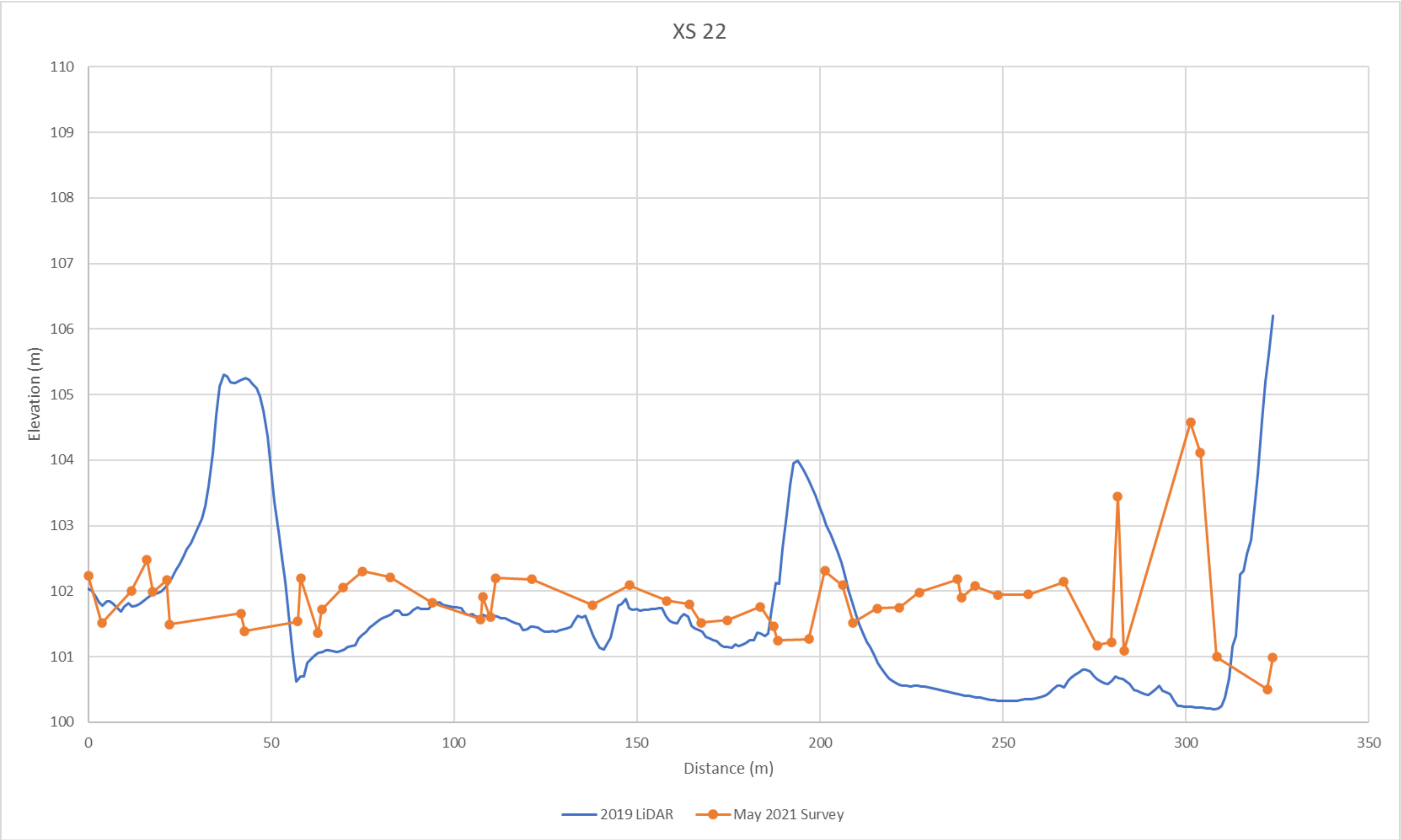

XS 19
130
129
128
127
126
125
124
123
Elevation (m)
0
100
200
300
400
500
600
700
Distance (m)
2019 LiDAR
May 2021 Survey


XS 20
126
124
122
120
118
116
114
112
Elevation (m)
0
200
400
600
800
1000
1200
1400
Distance (m)
2019 LiDAR
May 2021 Survey

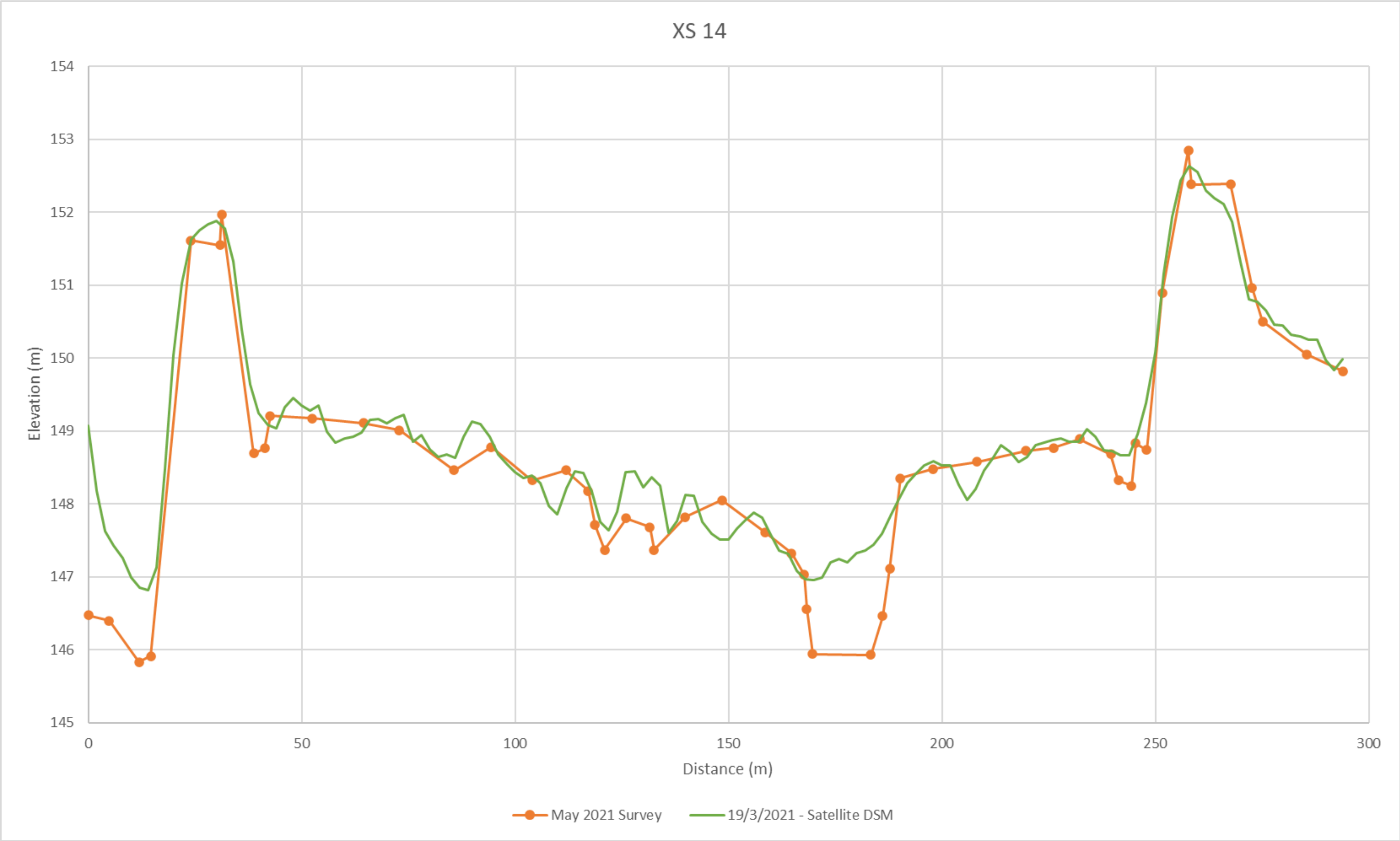

XS 21
116
115
114
113
112
111
110
109
108
107
Elevation (m)
0
200
400
600
800
1000
1200
Distance (m)
2019 LiDAR
May 2021 Survey


XS 22
Elevation (m)
110
109
108
107
106
105
104
103
102
101
100
0
50
100
150
200
250
300
350
Distance (m)
2019 LiDAR
May 2021 Survey

APPENDIX B – COMPARISON OF MAY 2021 CROSS SECTION SURVEY WITH MARCH 2021 SATELLITE DEM

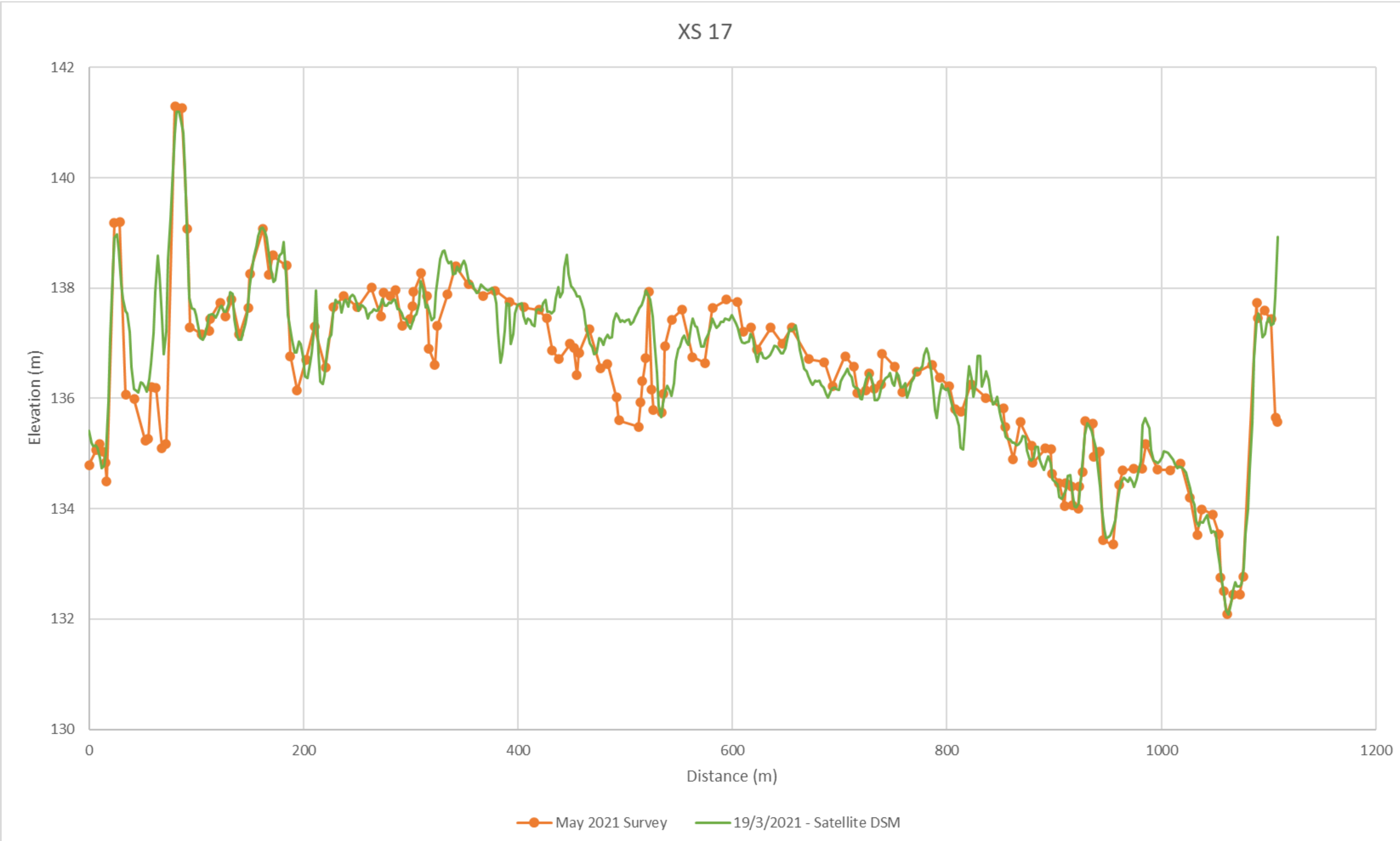
.

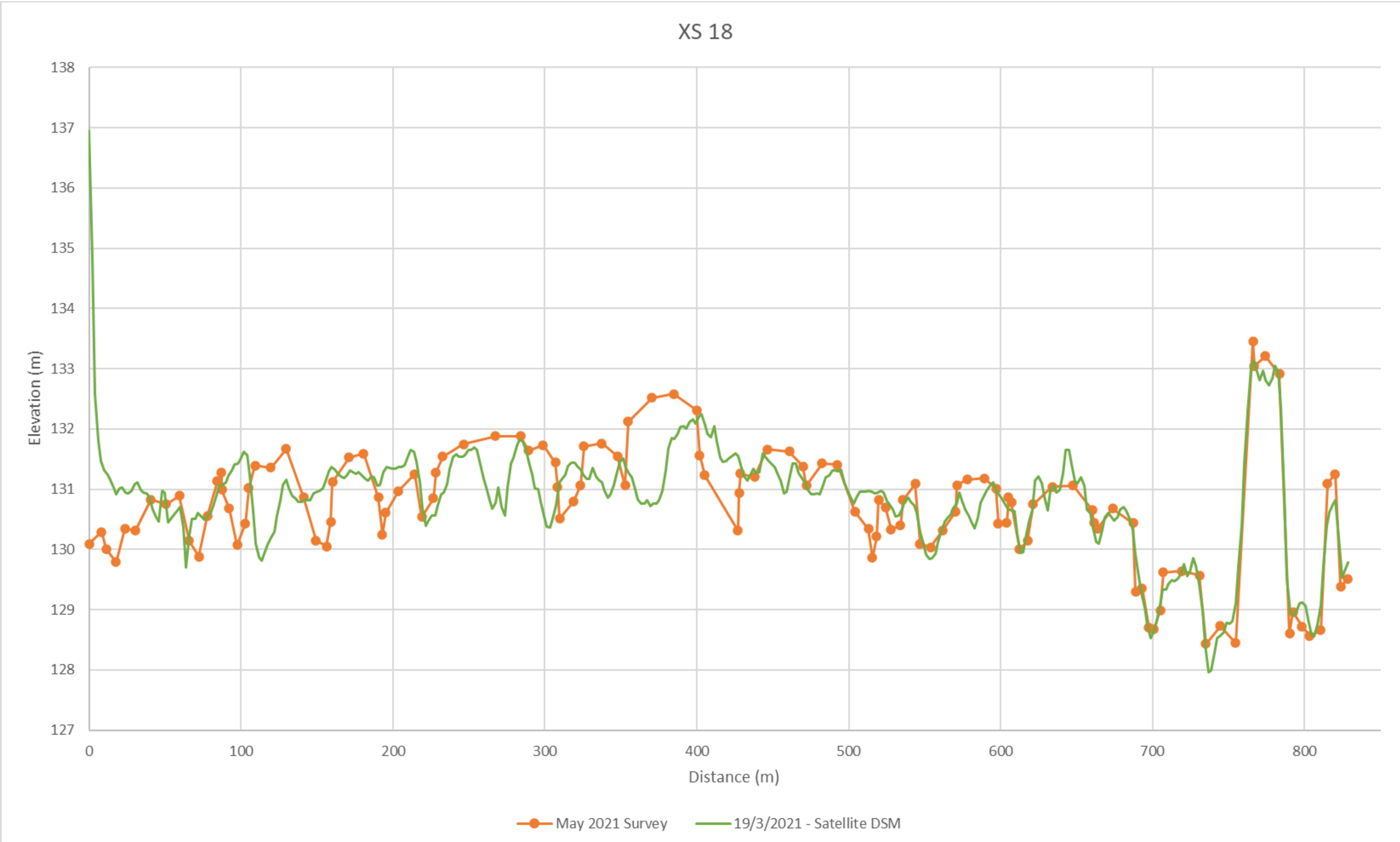

XS 13
Elevation (m)
157
156
155
154
153
152
151
150
149
148
0
50
100
150
200
250
Distance (m)
May 2021 Survey
19/3/2021 - Satellite DSM


XS 14
154
153
152
151
150
149
148
147
146
145
Elevation (m)
0
50
100
150
200
250
300
Distance (m)
May 2021 Survey
19/3/2021 - Satellite DSM


XS 15
150
149
148
147
146
145
144
143
142
141
Elevation (m)
0
50
100
150
200
250
300
350
400
Distance (m)
May 2021 Survey
19/3/2021 - Satellite DSM

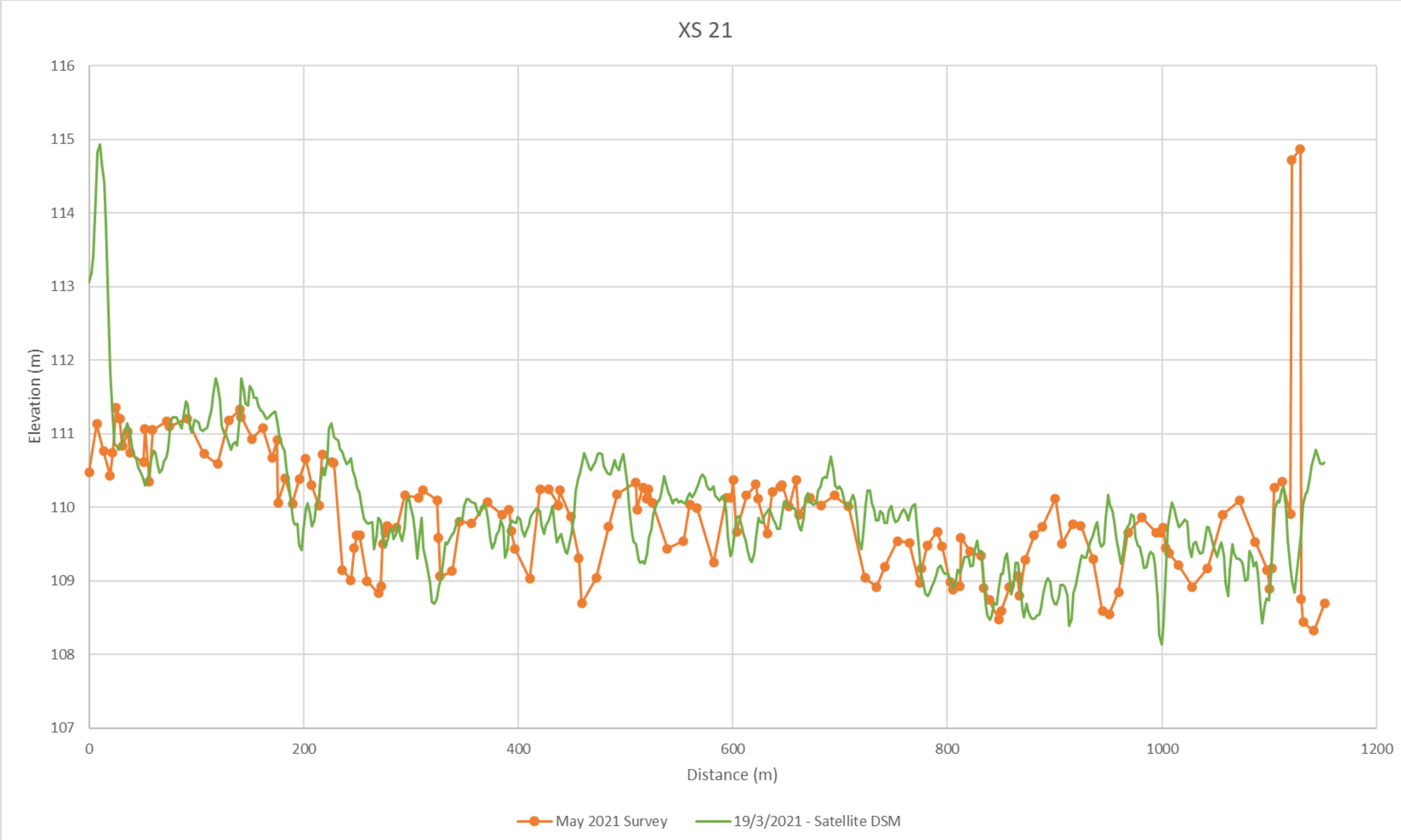

XS 16
148
146
144
142
140
138
136
134
Elevation (m)
0
100
200
300
400
500
600
700
800
900
Distance (m)
May 2021 Survey
19/3/2021 - Satellite DSM


XS 17
Elevation (m)
142
140
138
136
134
132
130
0
200
400
600
800
1000
1200
Distance (m)
May 2021 Survey
19/3/2021 - Satellite DSM


XS 18
Elevation (m)
138
137
136
135
134
133
132
131
130
129
128
127
0
100
200
300
400
500
600
700
800
Distance (m)
May 2021 Survey
19/3/2021 - Satellite DSM


XS 19
130
129
128
127
126
125
124
123
Elevation (m)
0
100
200
300
400
500
600
700
Distance (m)
May 2021 Survey
19/3/2021 - Satellite DSM


XS 20
Elevation (m)
126
124
122
120
118
116
114
112
0
200
400
600
800
1000
1200
1400
Distance (m)
May 2021 Survey
19/3/2021 - Sattelite DSM


XS 21
Elevation (m)
116
115
114
113
112
111
110
109
108
107
0
200
400
600
800
1000
1200
Distance (m)
May 2021 Survey
19/3/2021 - Satellite DSM

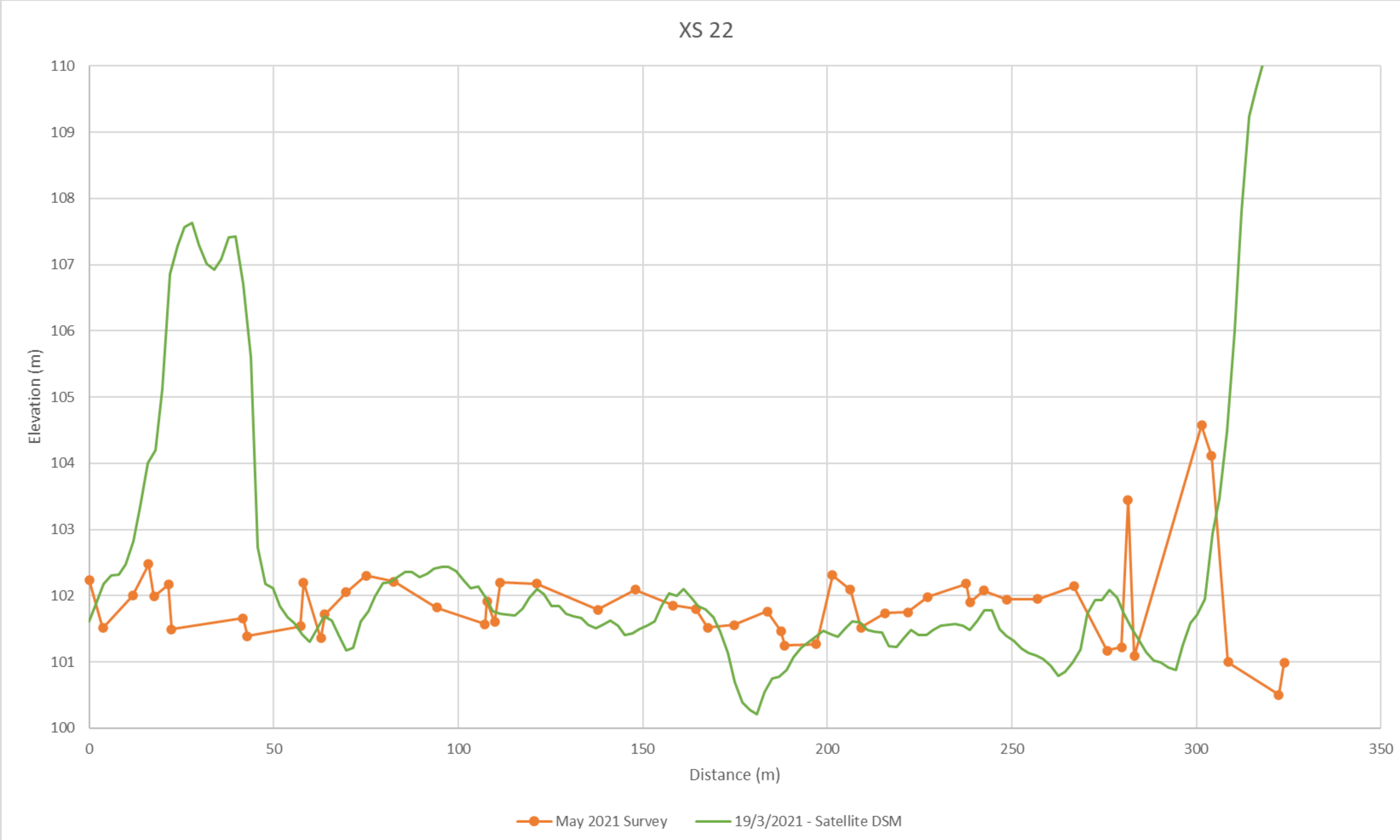

XS 22
Elevation (m)
Distance (m)
110
109
108
107
106
105
104
103
102
101
100
0
50
100
150
200
250
300
350
May 2021 Survey
19/3/2021 - Satellite DSM

Figure 0-1 to Figure 0-5 show the location used for the distance marker for each of the longsection profiles presented in the following pages.

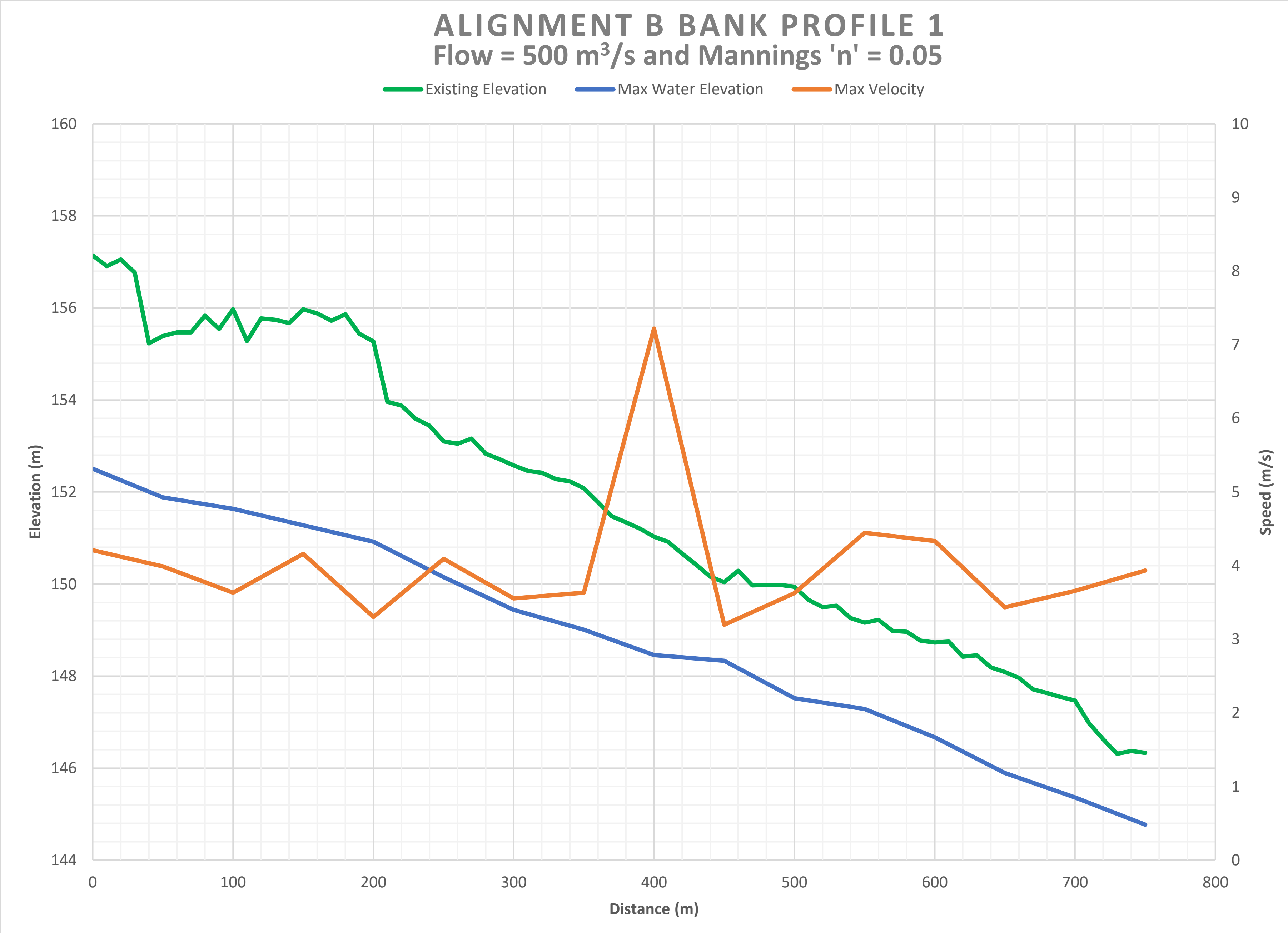
Figure 0-1 – Bank 1 profile distance markers

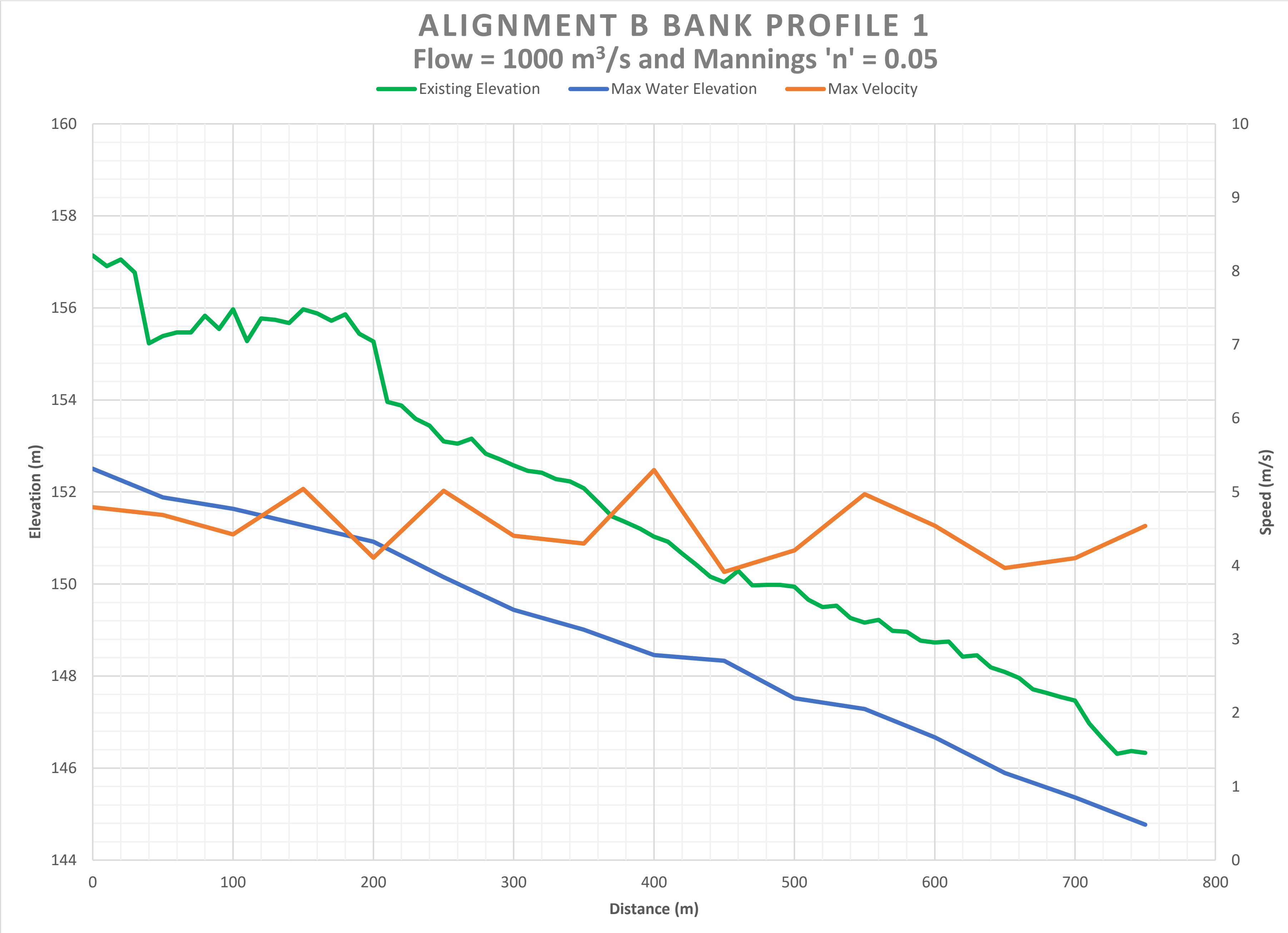
Figure 0-2 – Bank 2, Existing Alignment, distance markers

Figure 0-3 – Bank 2 – Alignment A distance markers

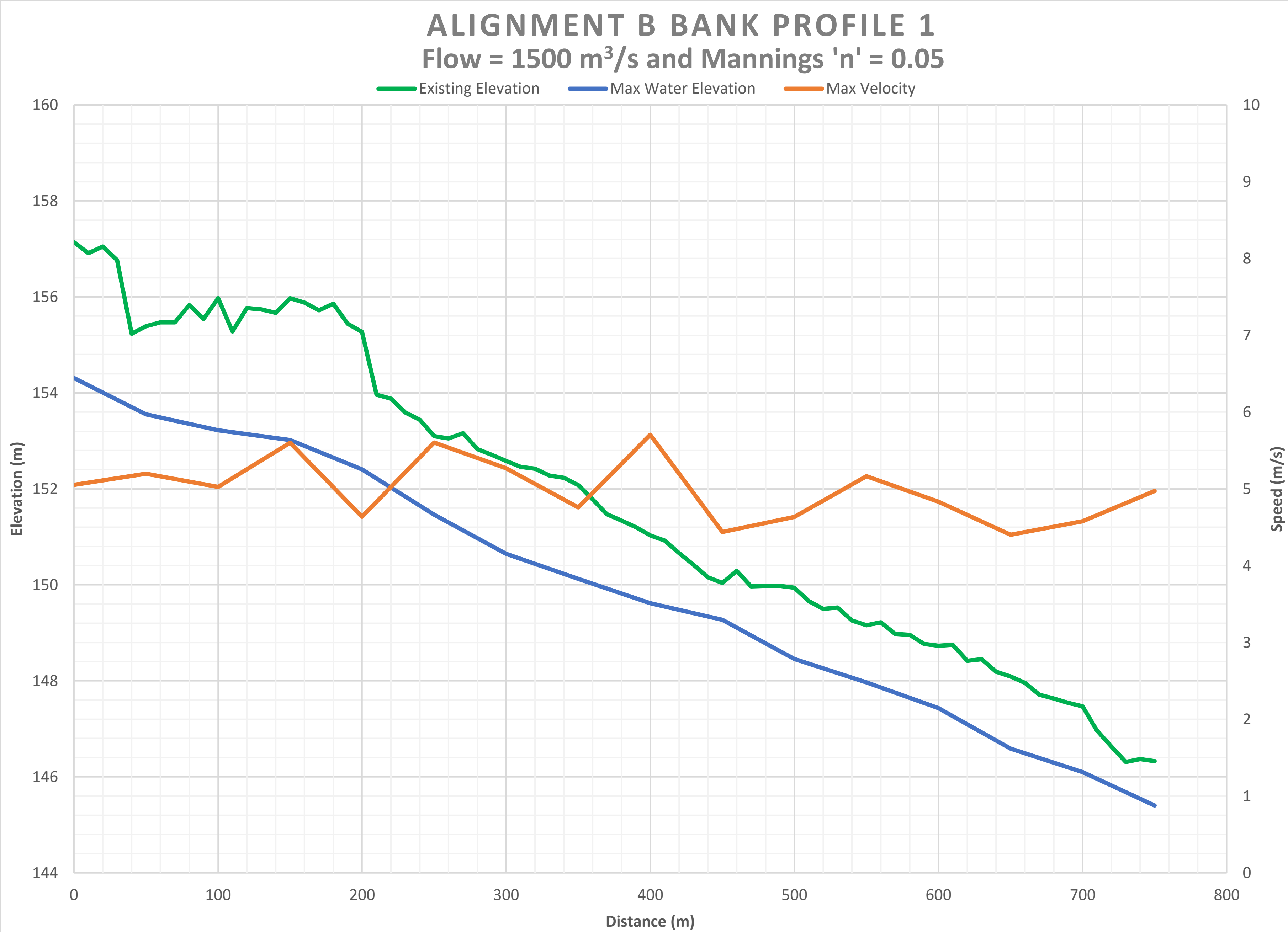
Figure 0-4 – Bank 2 – Alignment B distance marker

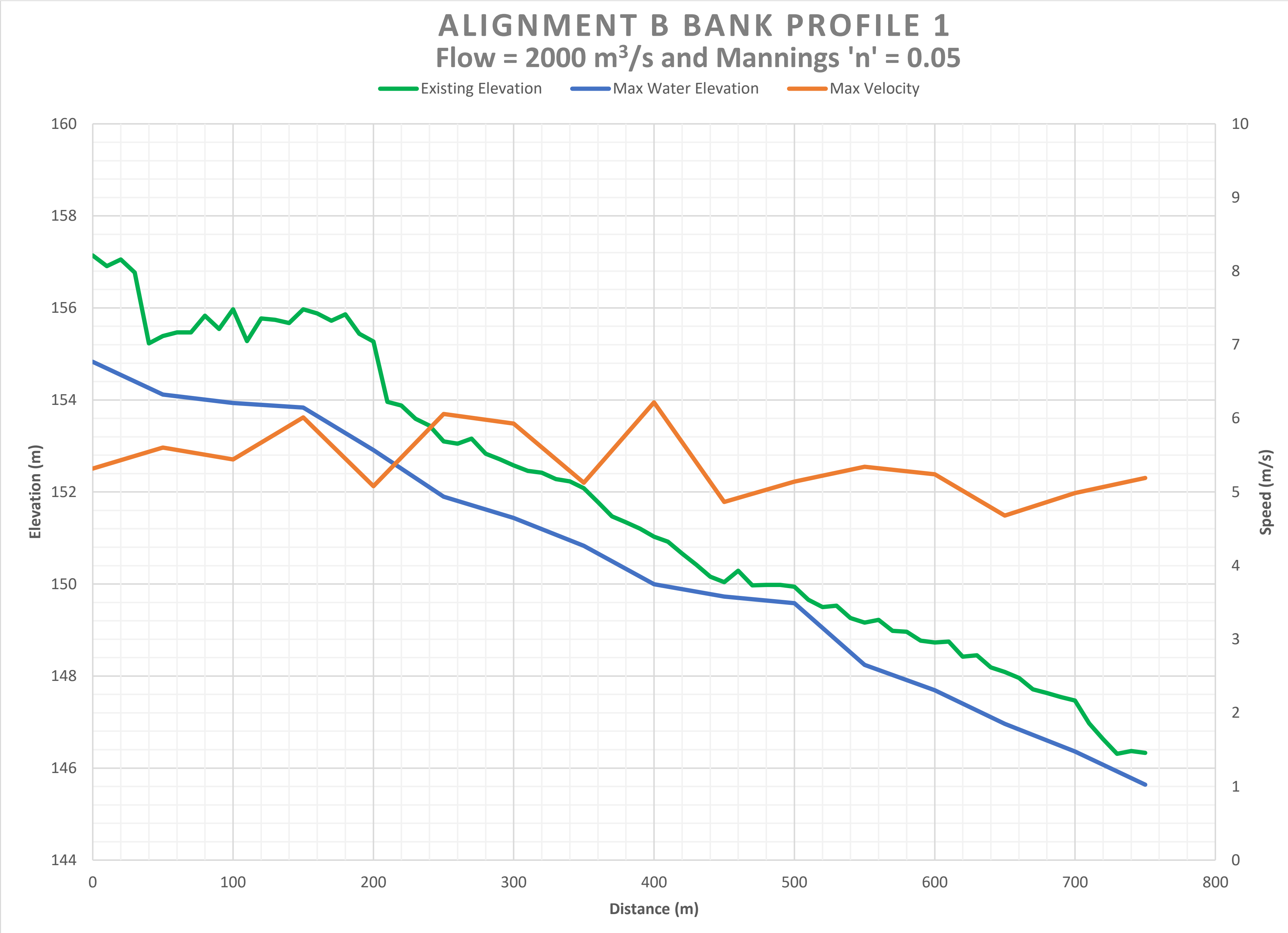
Figure 0-5 – Bank 2 – Alignment C distance markers


ALIGNMENT B BANK PROFILE 1
Flow = 500 m³/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
160
158
156
154
152
150
148
146
144
Speed (m/s)
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800
Distance (m)

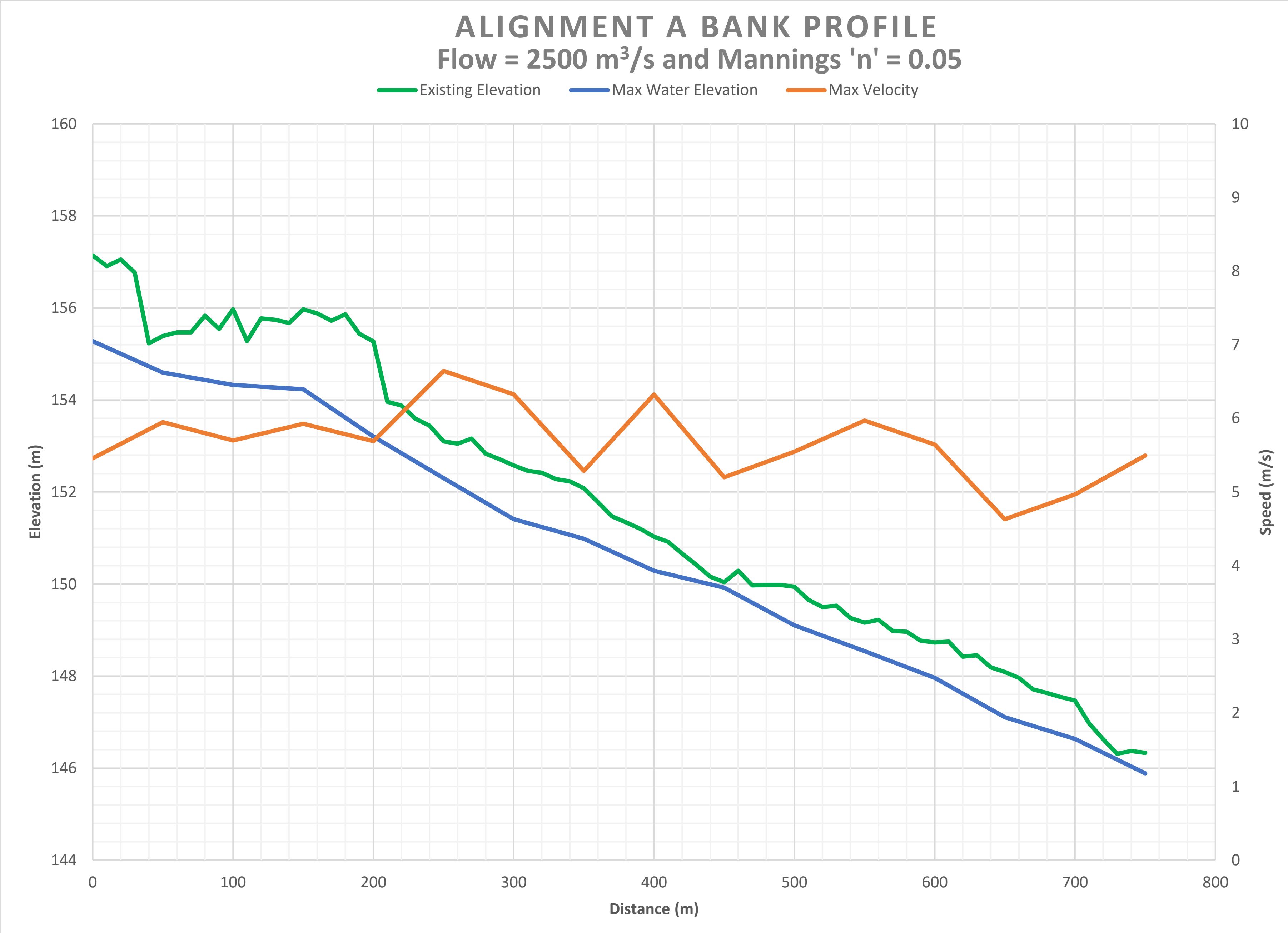


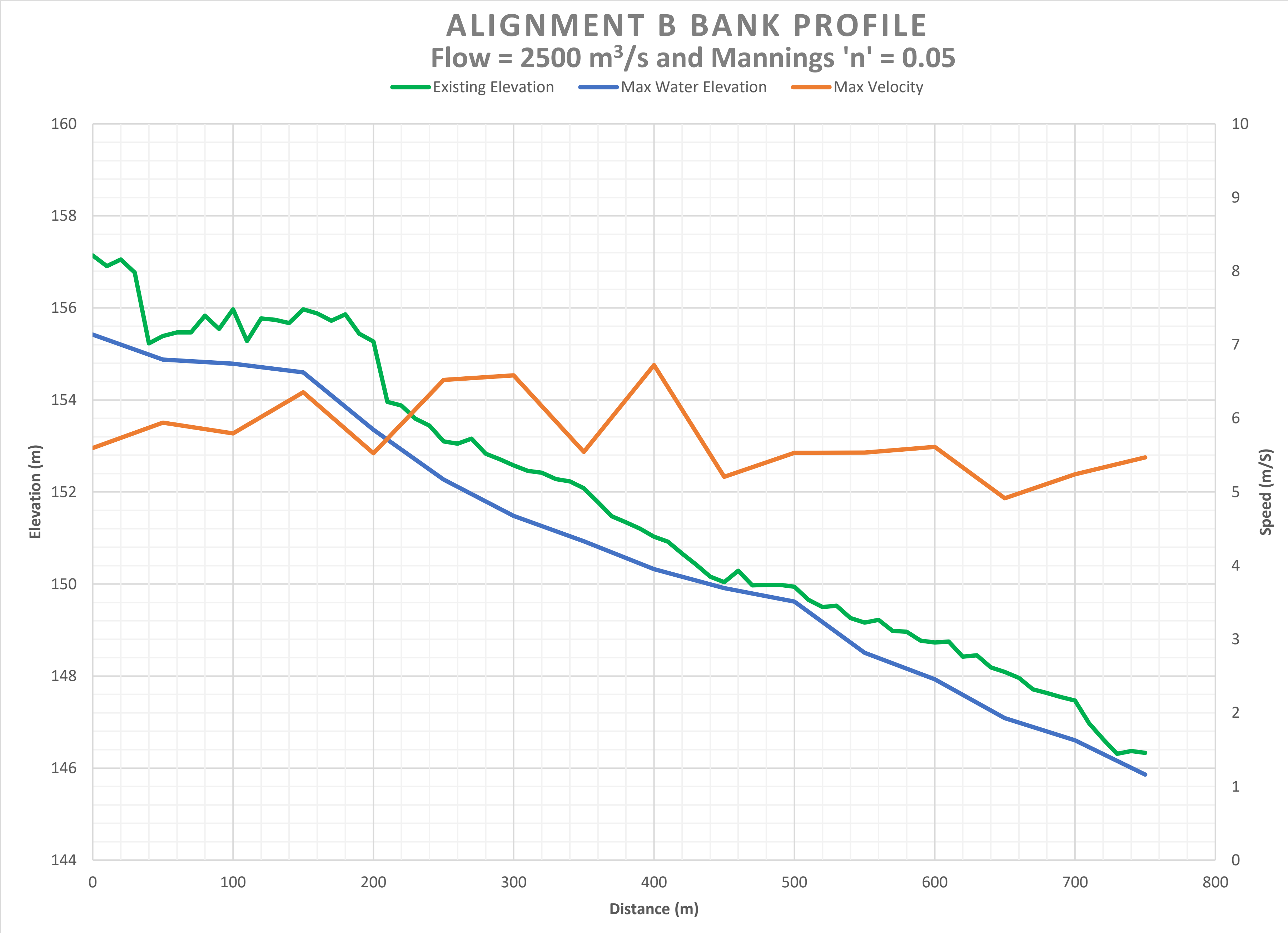
ALIGNMENT B BANK PROFILE 1
Flow = 1000 m³/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

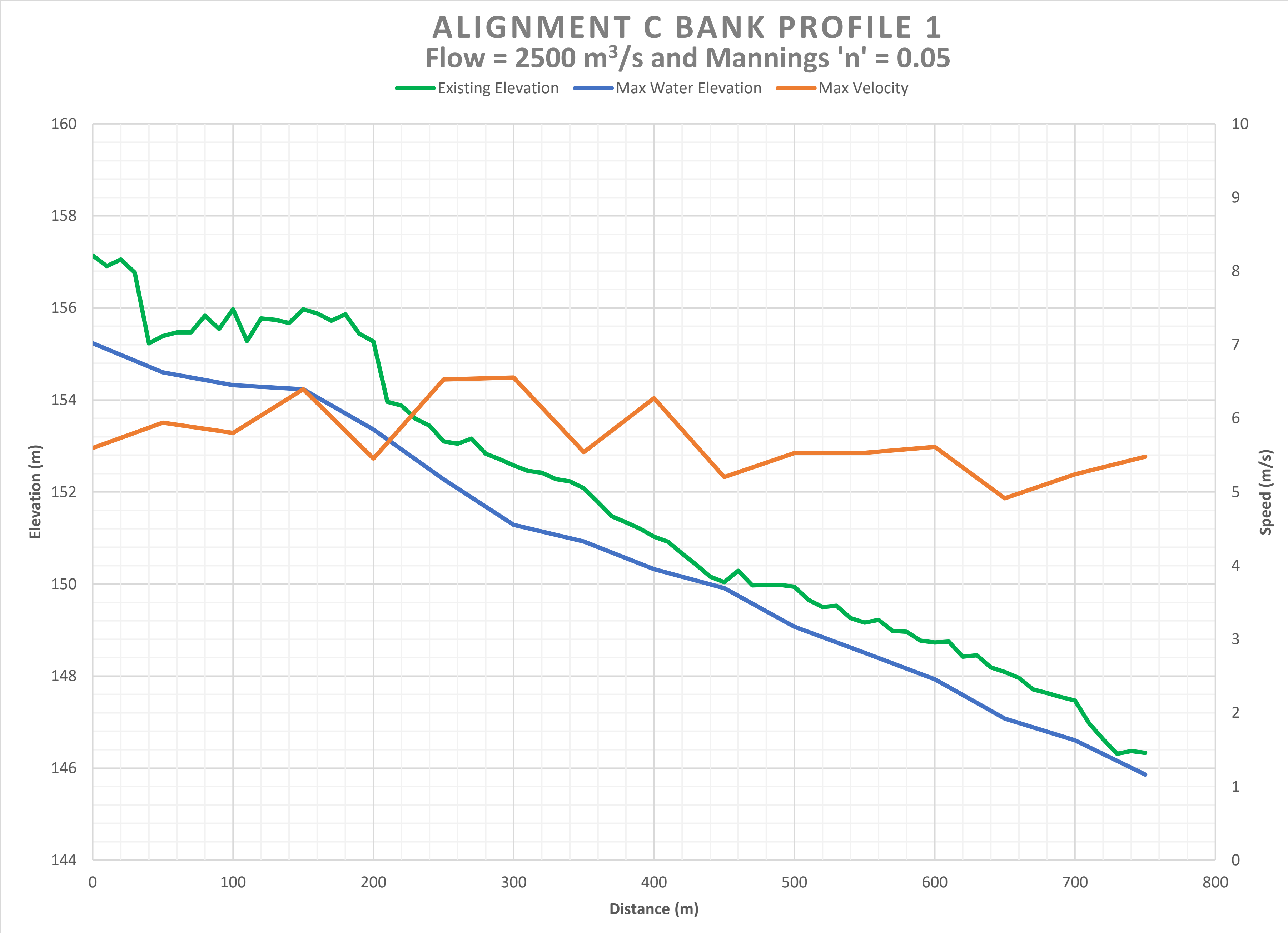

ALIGNMENT B BANK PROFILE 1
Flow = 1500 m³/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800



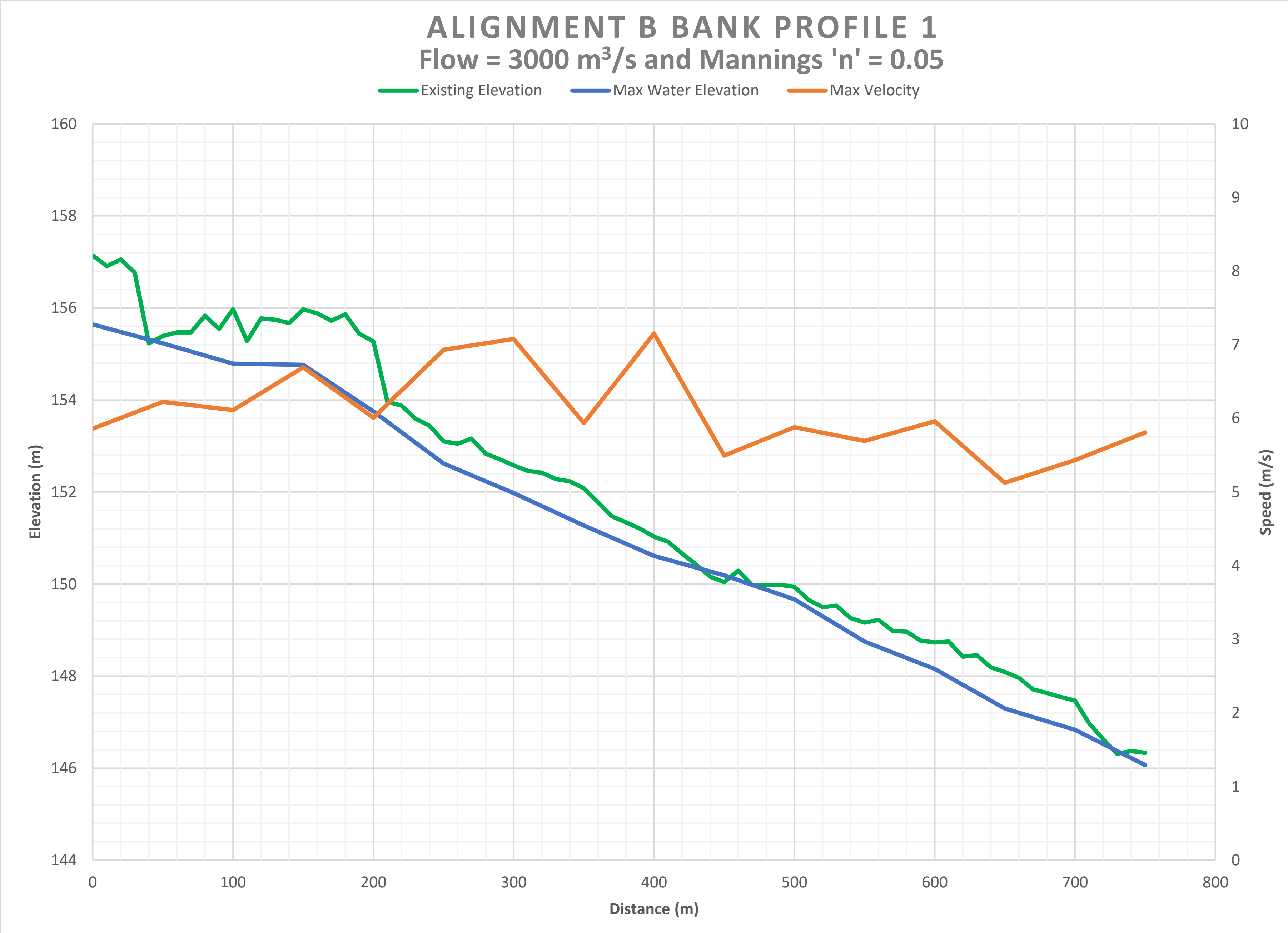
ALIGNMENT B BANK PROFILE 1
Flow = 2000 m3/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800


ALIGNMENT A BANK PROFILE
Flow = 2500 m3/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

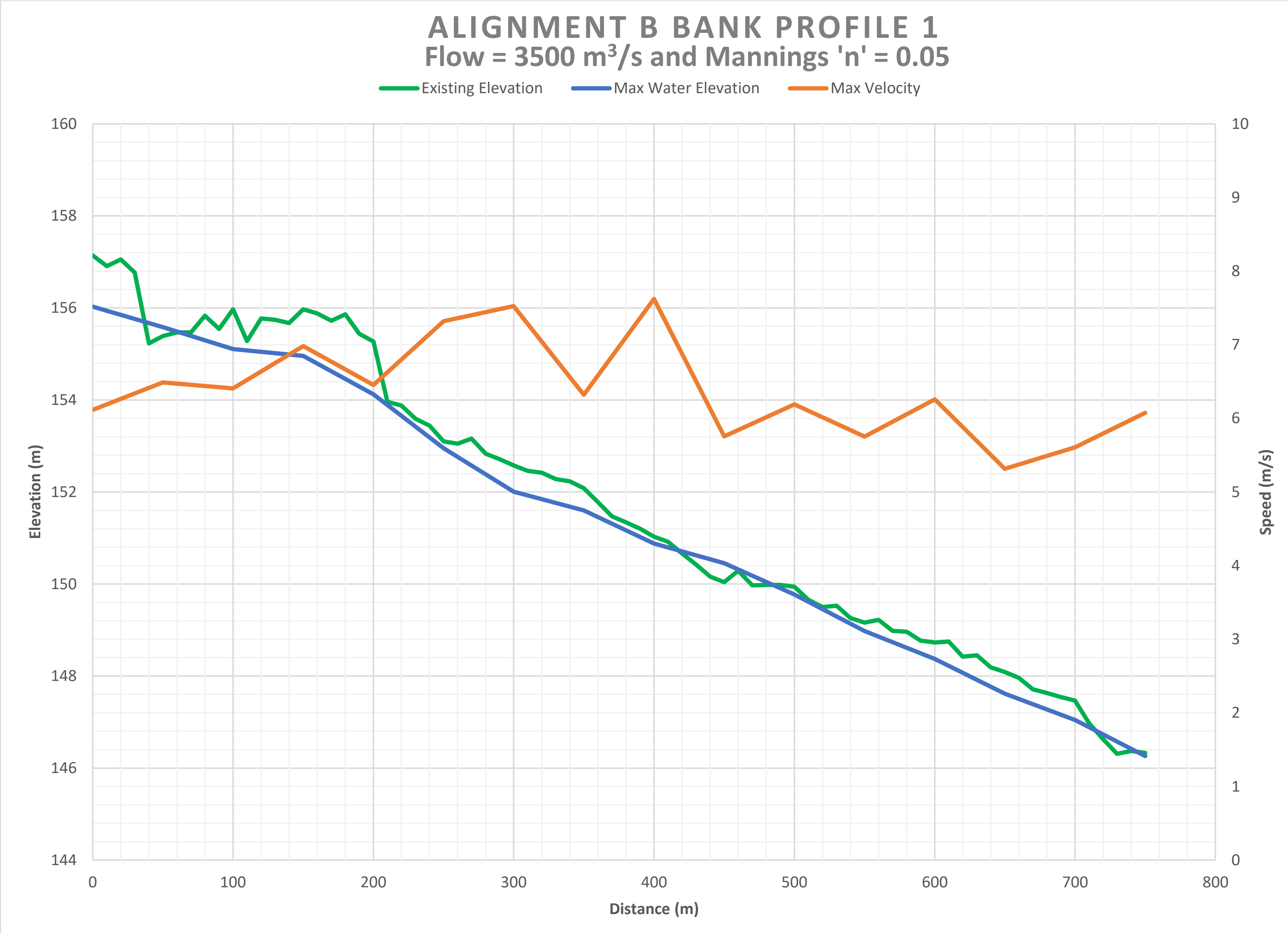

ALIGNMENT B BANK PROFILE
Flow = 2500 m³/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/S)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

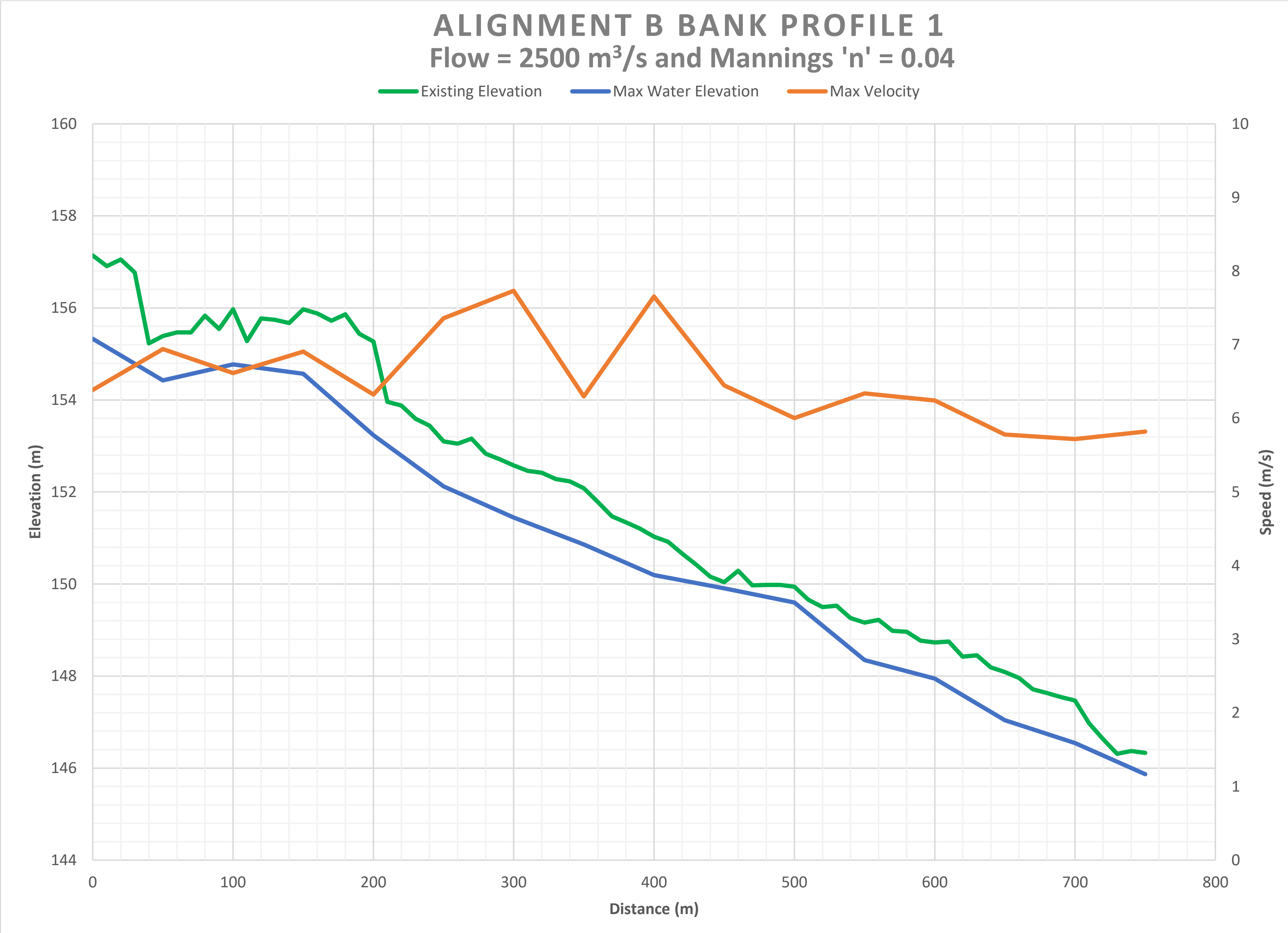

ALIGNMENT C BANK PROFILE 1
Flow = 2500 m³/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

EXISTING ALIGNMENT BANK PROFILE 1
Flow = 2500 m³/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

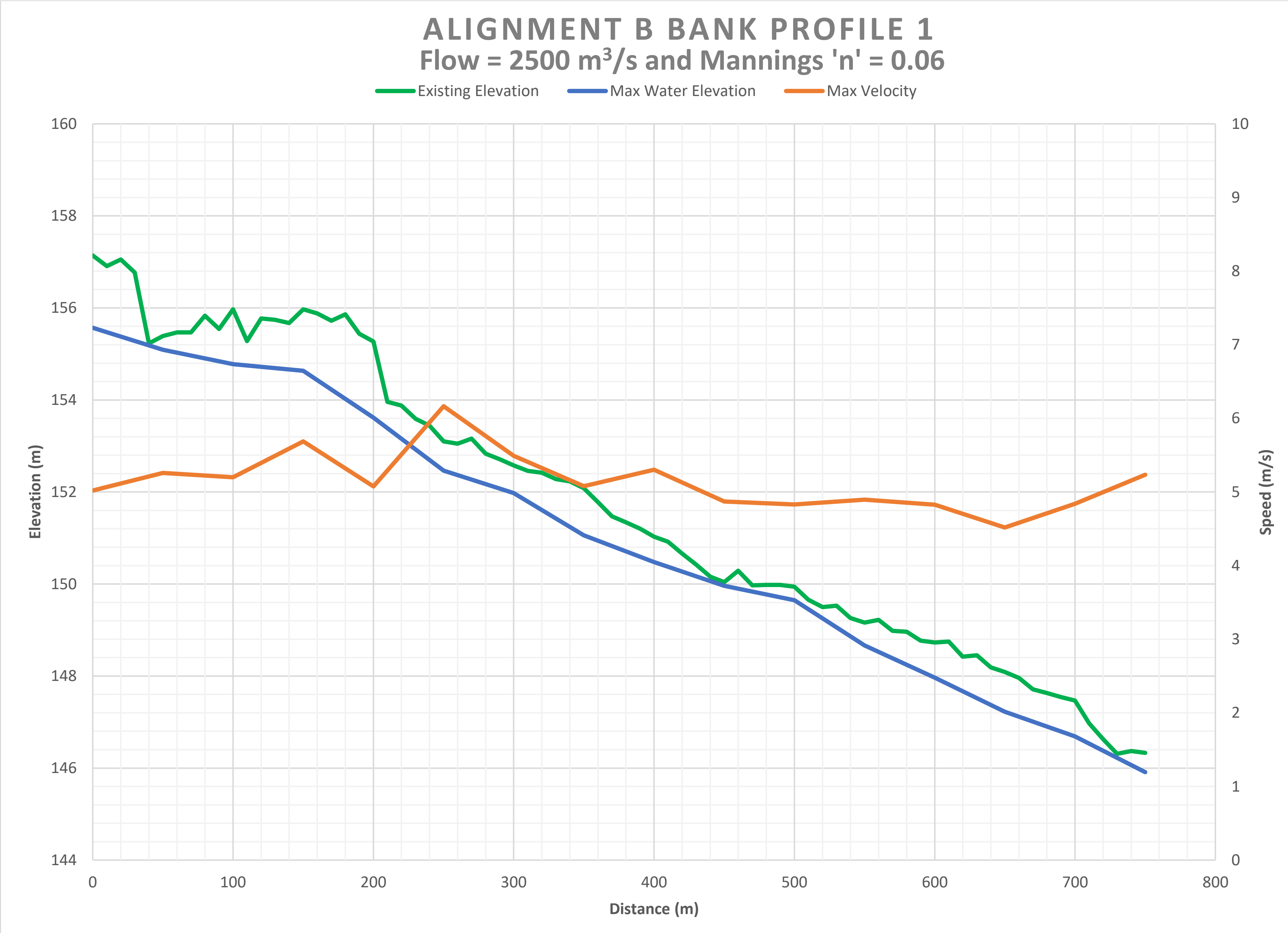


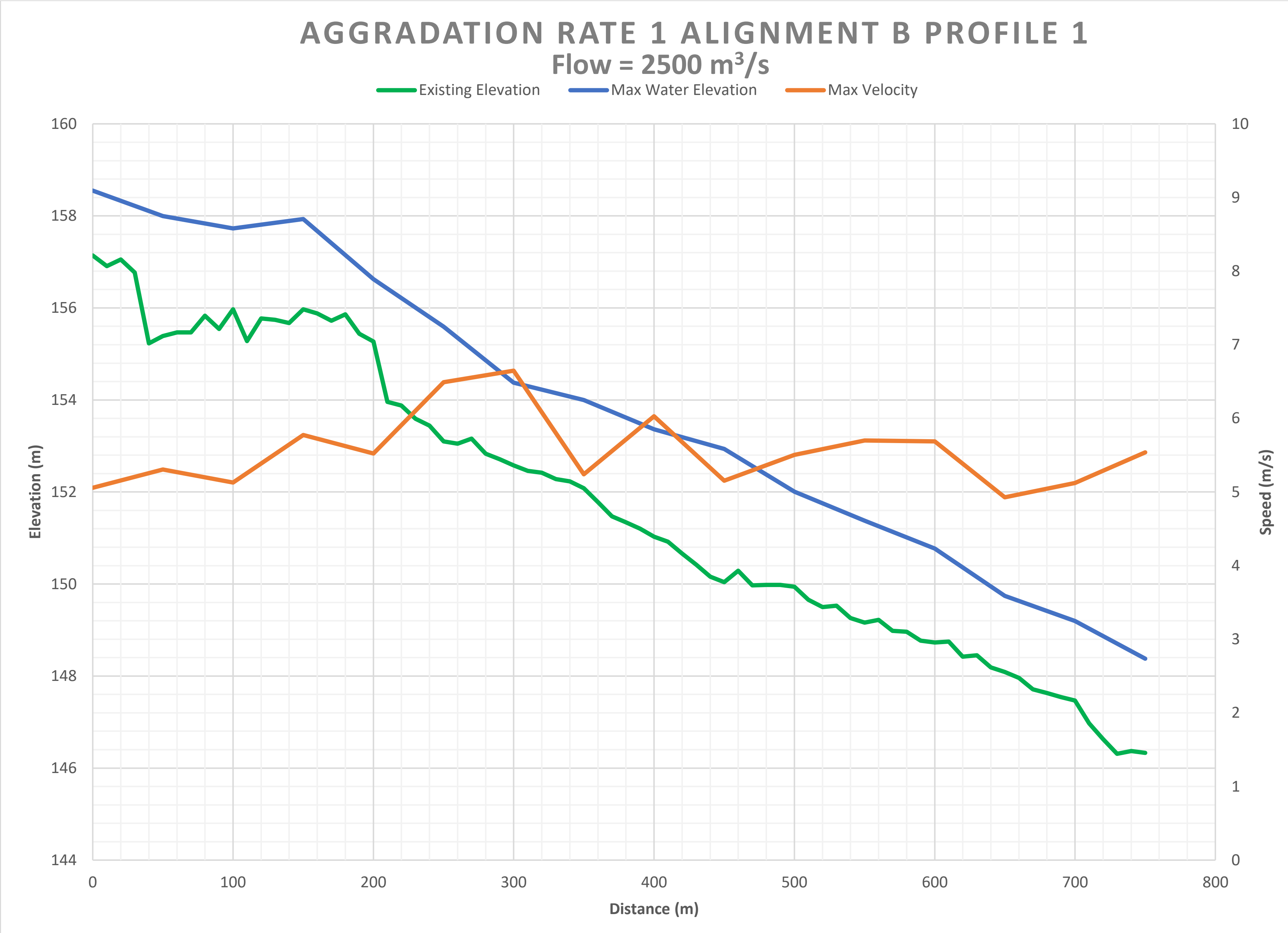
ALIGNMENT B BANK PROFILE 1
Flow = 3000 m3/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800


ALIGNMENT B BANK PROFILE 1
Flow = 3500 m³/s and Mannings 'n' = 0.05
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

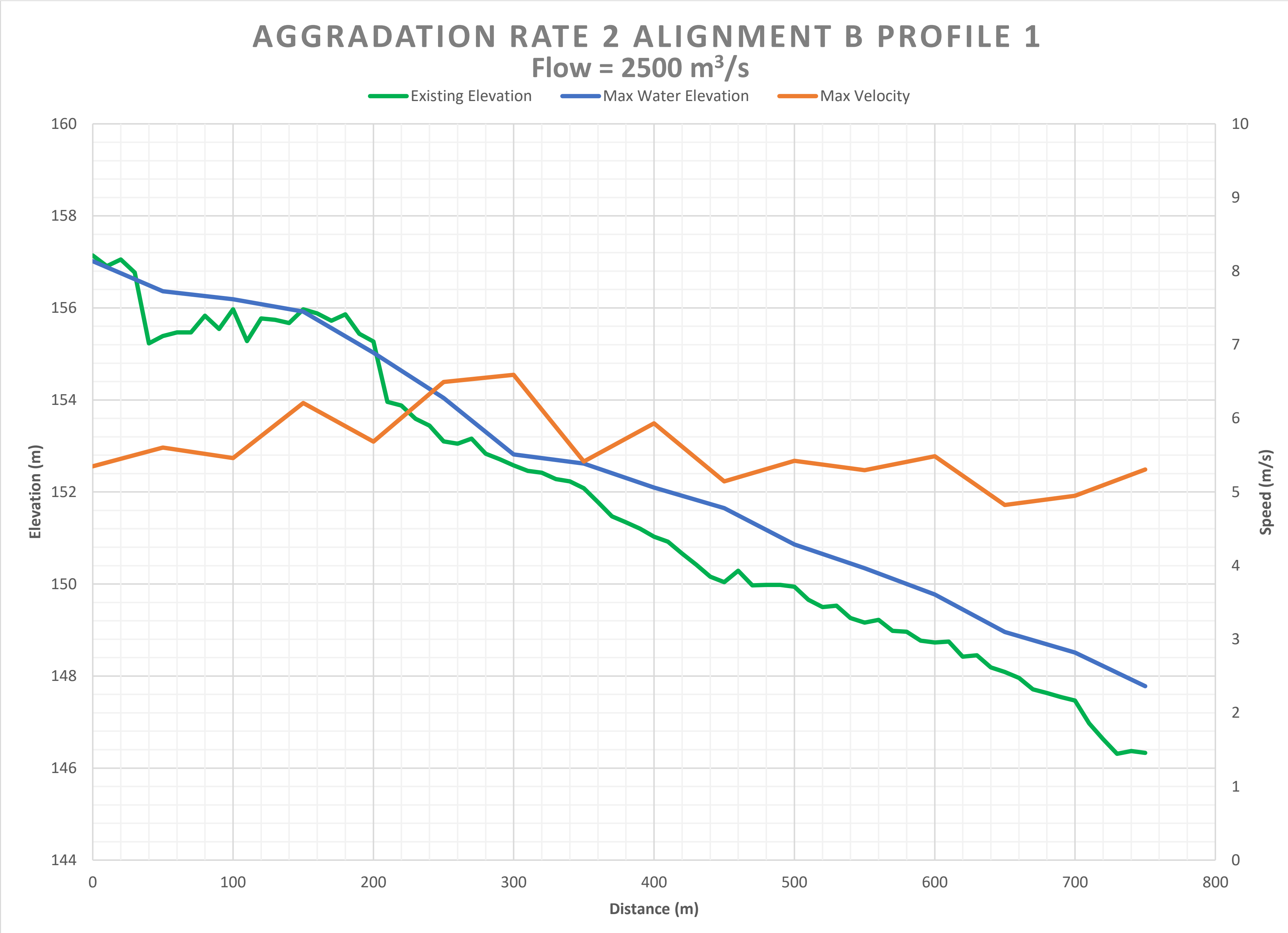


ALIGNMENT B BANK PROFILE 1
Flow = 2500 m³/s and Mannings 'n' = 0.04
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

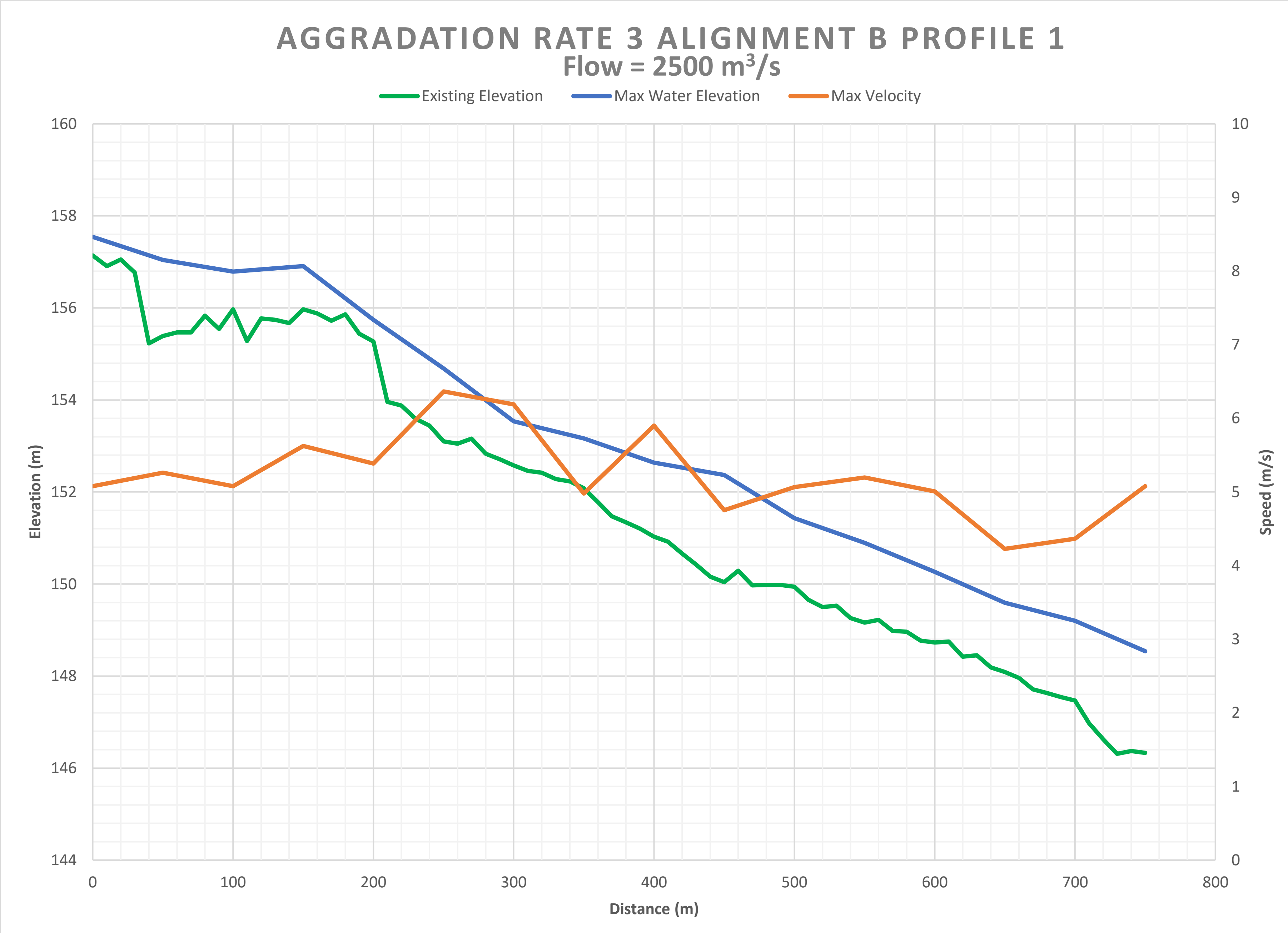

ALIGNMENT B BANK PROFILE 1
Flow = 2500 m3/s and Mannings 'n' = 0.06
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800



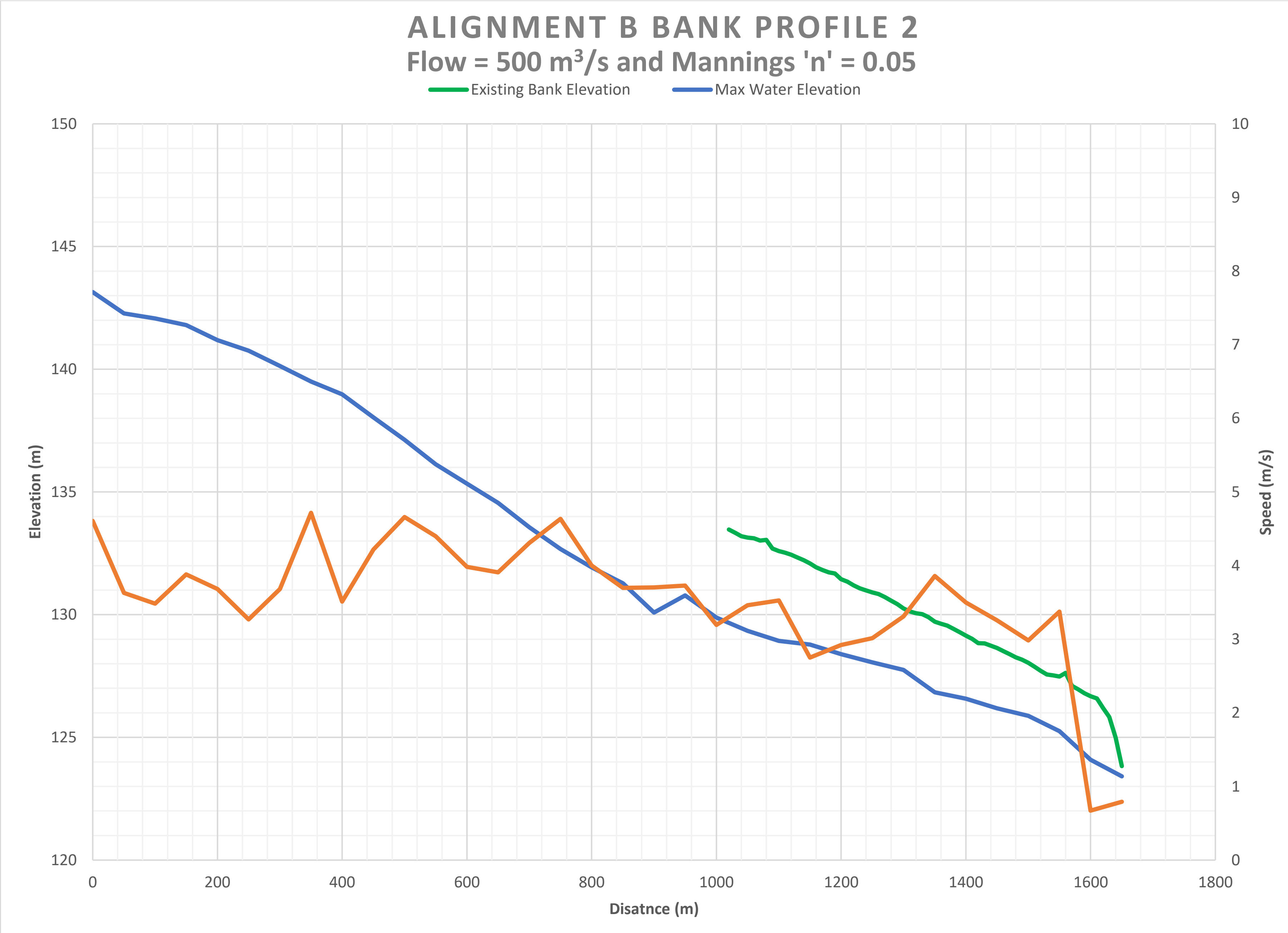
AGGRADATION RATE 1 ALIGNMENT B PROFILE 1
Flow = 2500 m³/s
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

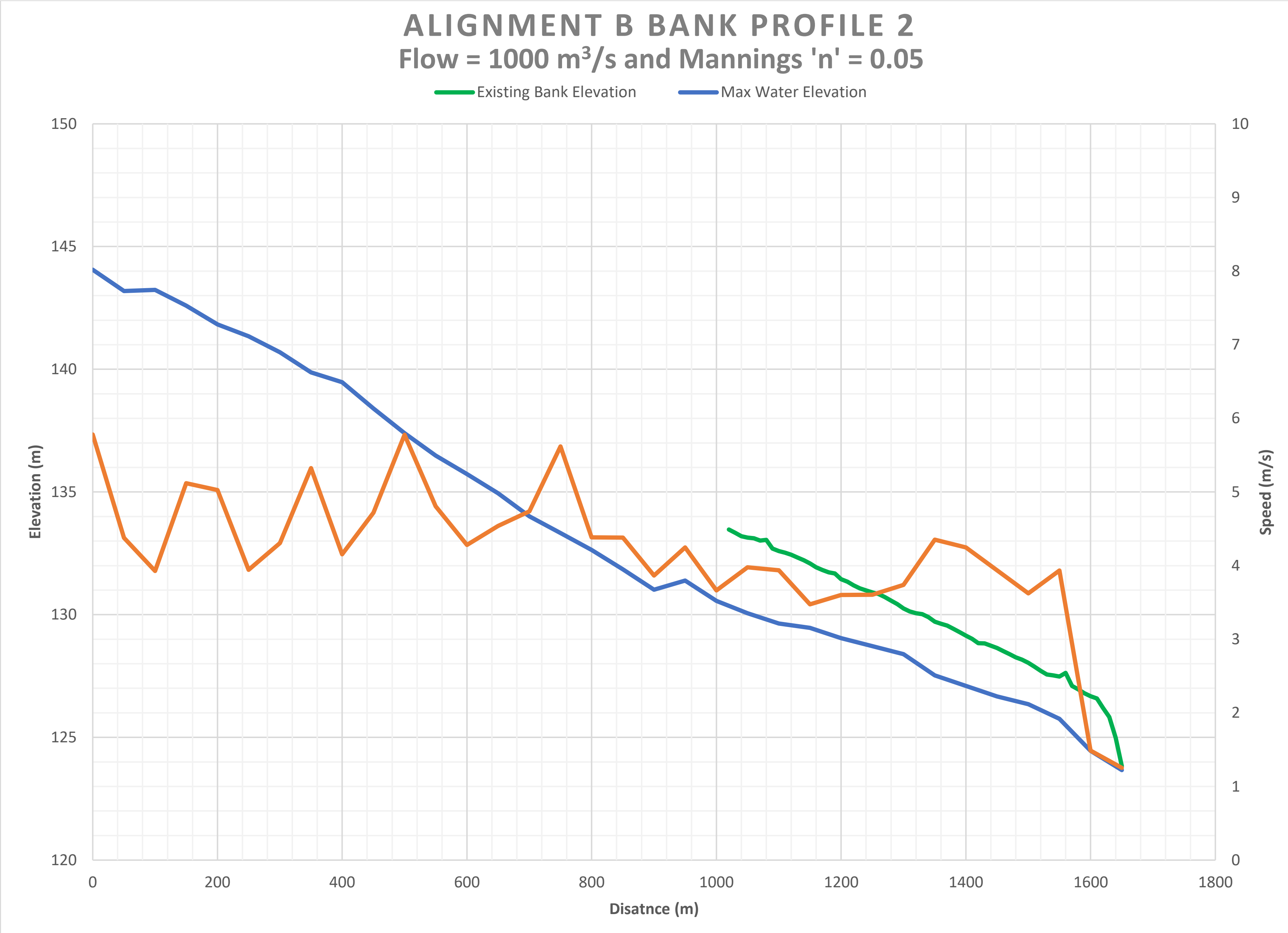


AGGRADATION RATE 2 ALIGNMENT B PROFILE 1
Flow = 2500 m³/s
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

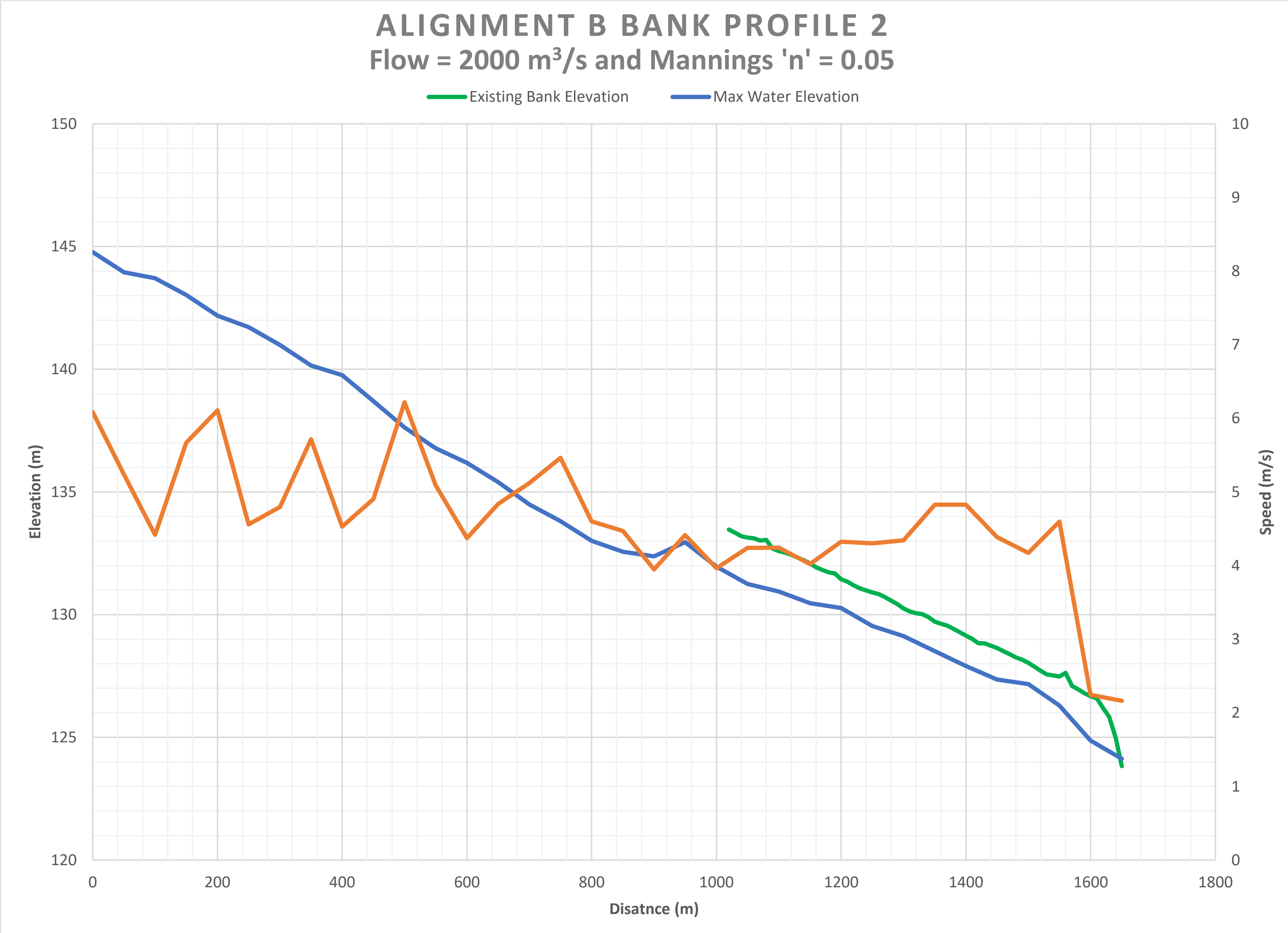


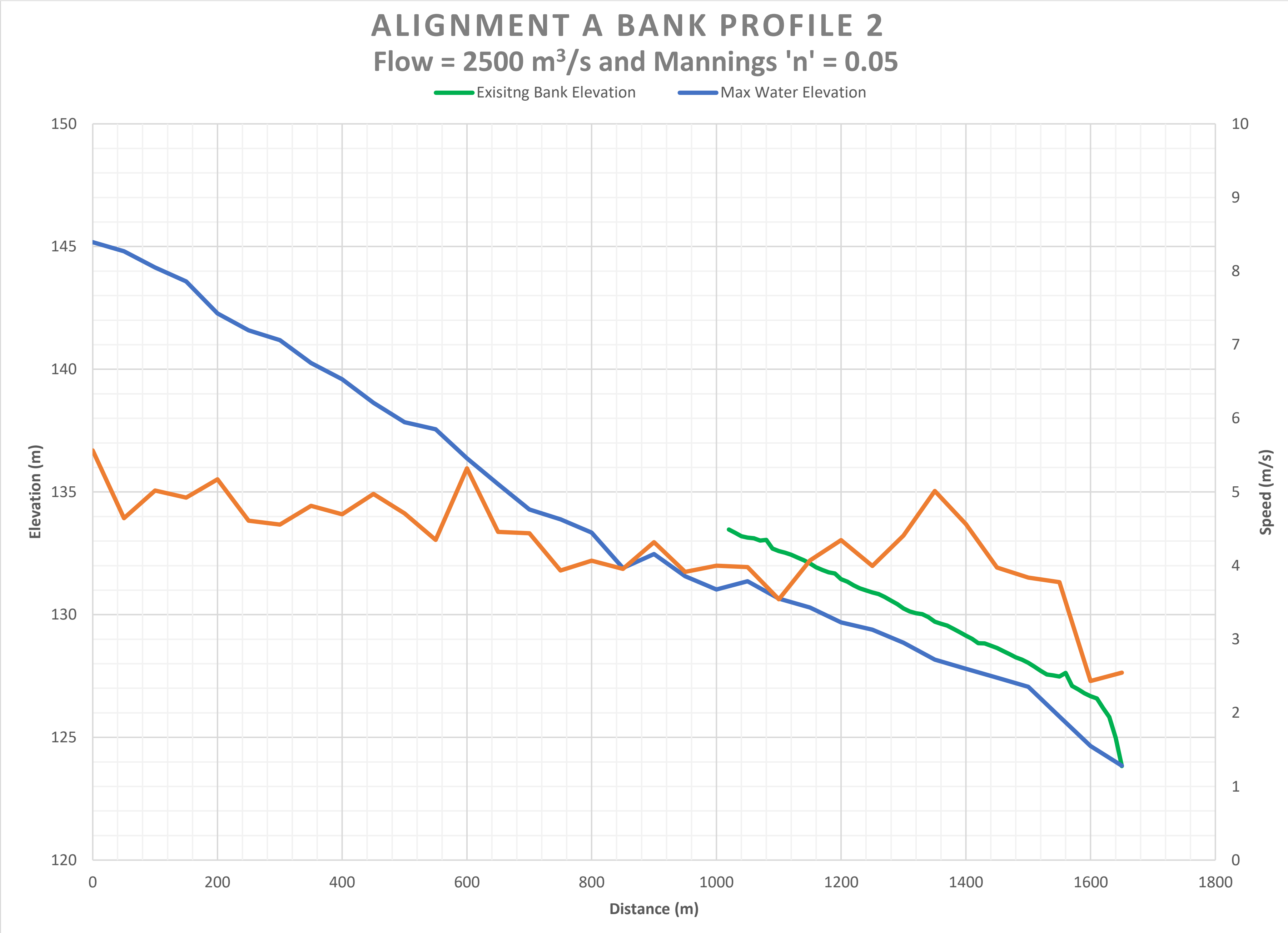
AGGRADATION RATE 3 ALIGNMENT B PROFILE 1
Flow = 2500 m³/s
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
160
158
156
154
152
150
148
146
144
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800

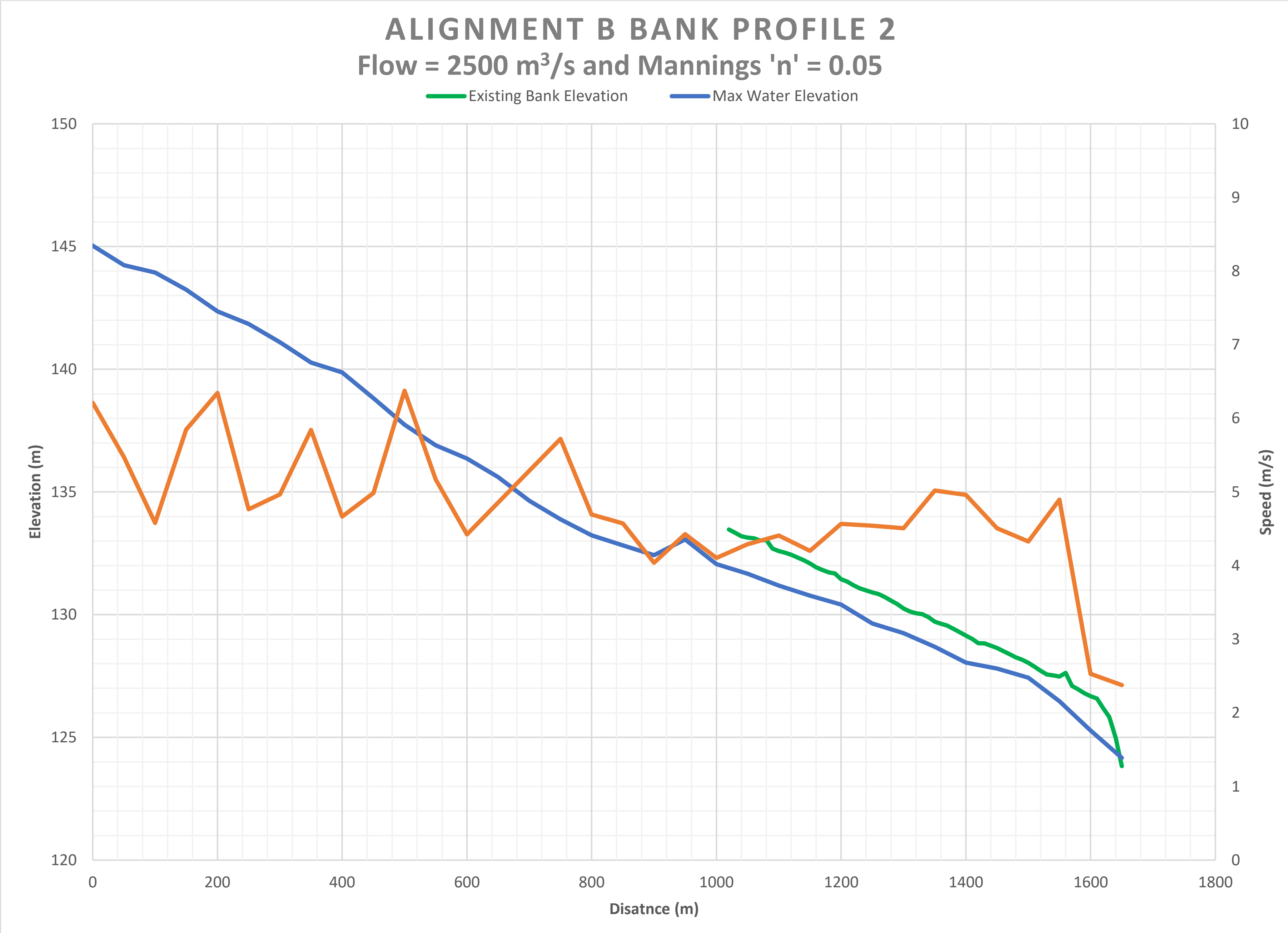

ALIGNMENT B BANK PROFILE 2
Flow = 500 m³/s and Mannings 'n' = 0.05
Existing Bank Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Disatnce (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800

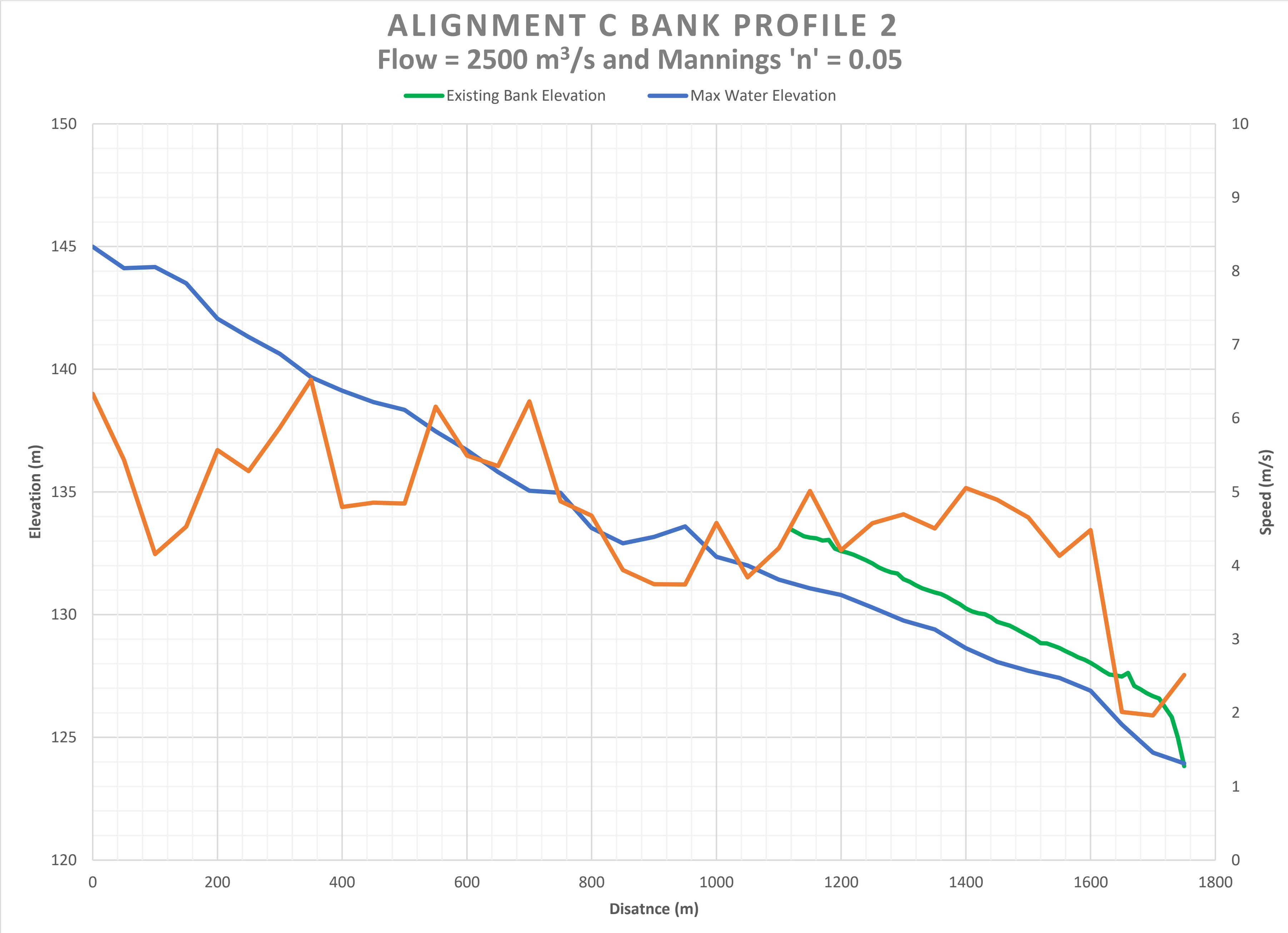


ALIGNMENT B BANK PROFILE 2
Flow = 1000 m³/s and Mannings 'n' = 0.05
Existing Bank Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Disatnce (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800

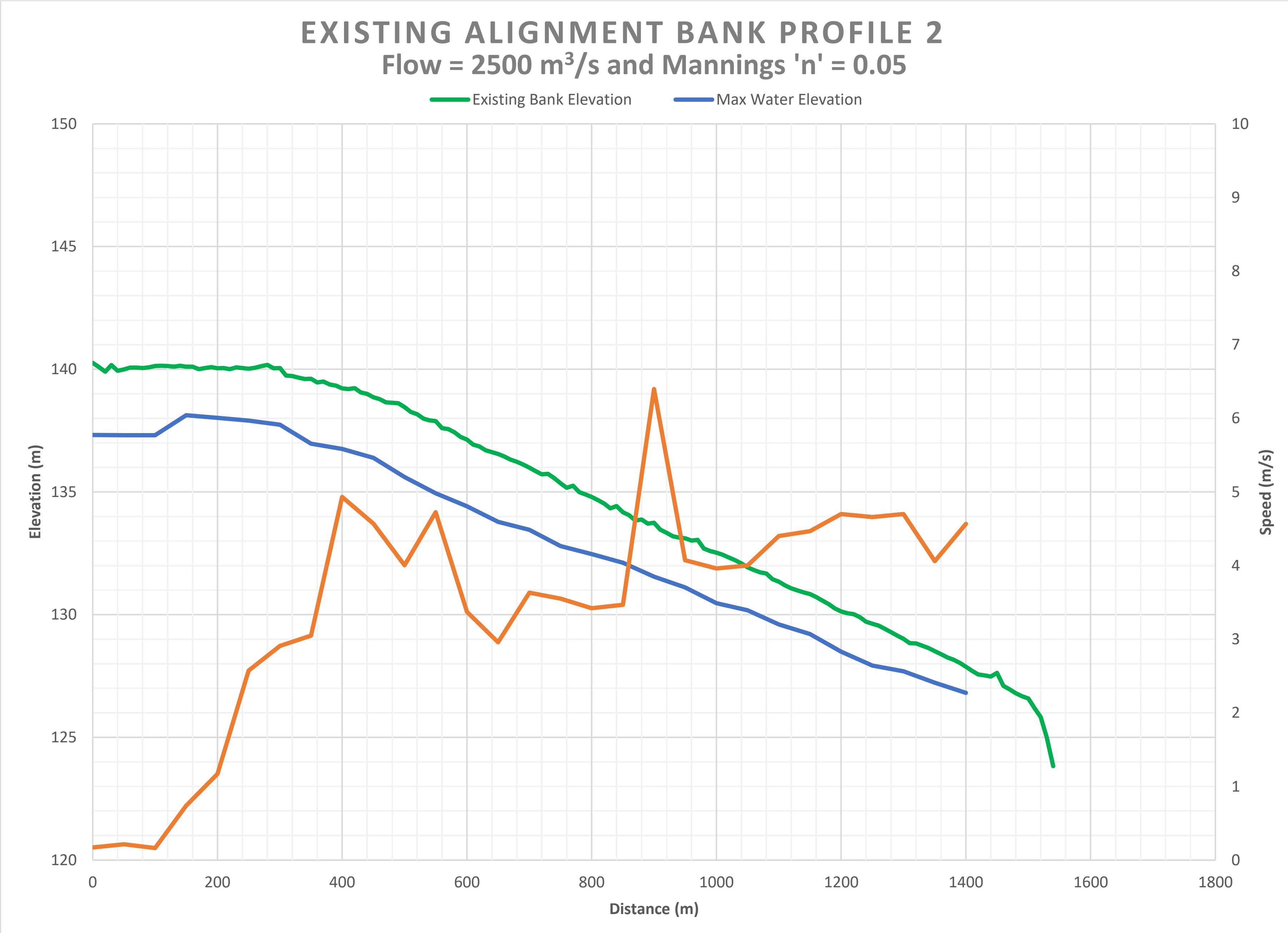

ALIGNMENT B BANK PROFILE 2
Flow = 2000 m³/s and Mannings 'n' = 0.05
Existing Bank Elevation
Max Water Elevation
150
145
140
135
130
125
120
Elevation (m)
10
9
8
7
6
5
4
3
2
1
0
Speed (m/s)
0
200
400
600
800
1000
1200
1400
1600
1800
Disatnce (m)


ALIGNMENT A BANK PROFILE 2
Flow = 2500 m³/s and Mannings 'n' = 0.05
Exisitng Bank Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Distance (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800

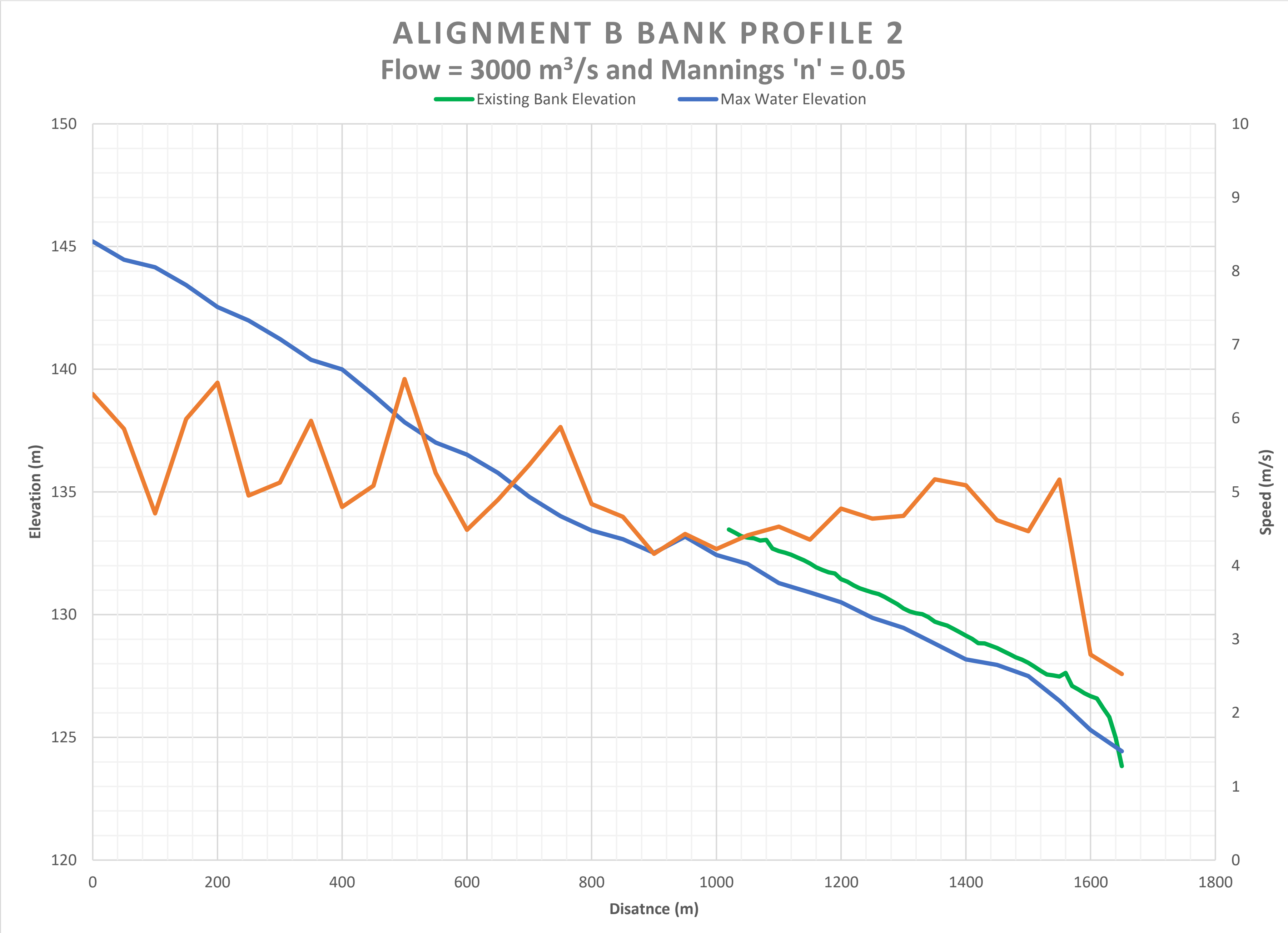

ALIGNMENT B BANK PROFILE 2
Flow = 2500 m³/s and Mannings 'n' = 0.05
Existing Bank Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Disatnce (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800

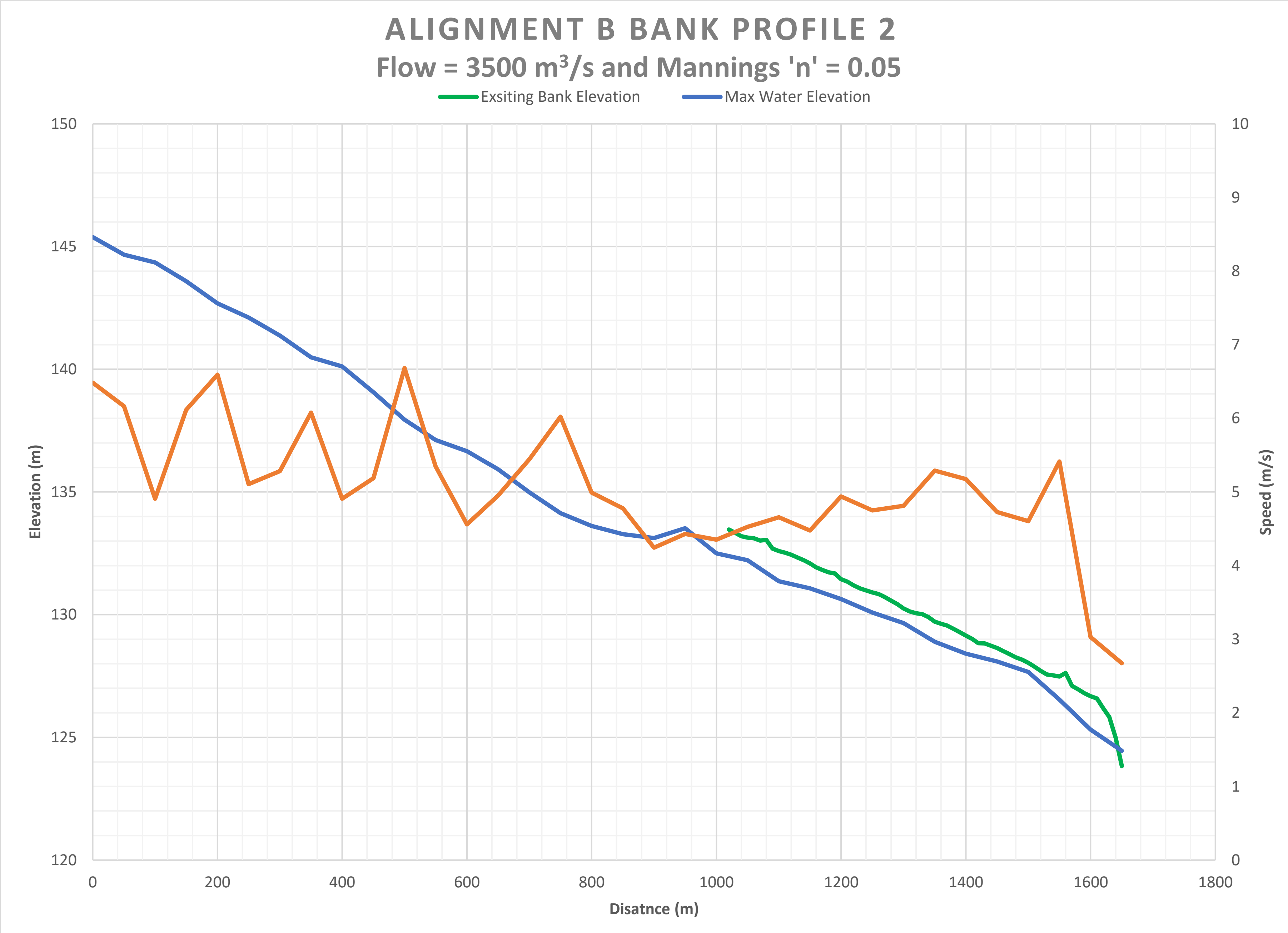


ALIGNMENT C BANK PROFILE 2
Flow = 2500 m³/s and Mannings 'n' = 0.05
Existing Bank Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Disatnce (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800

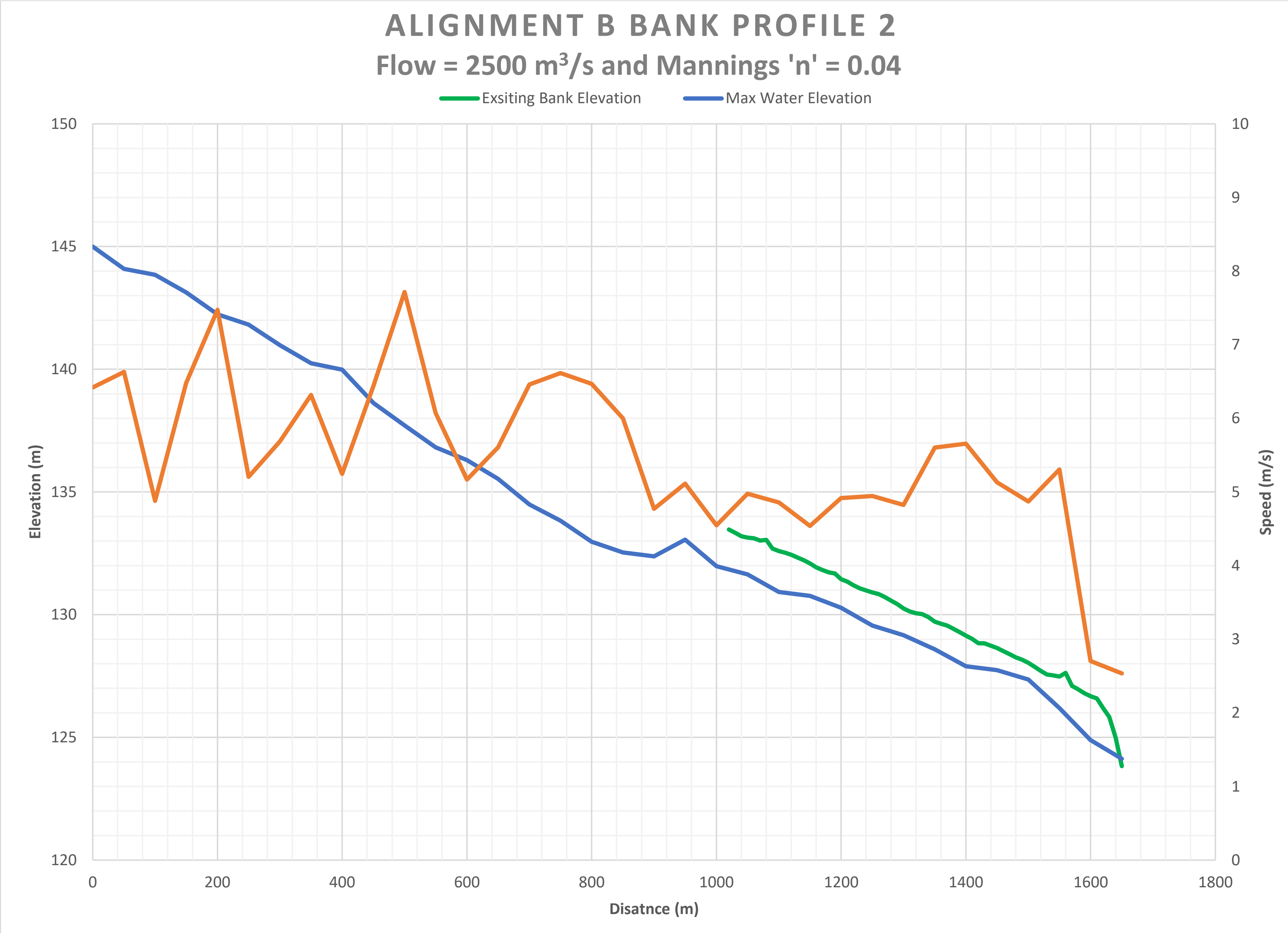


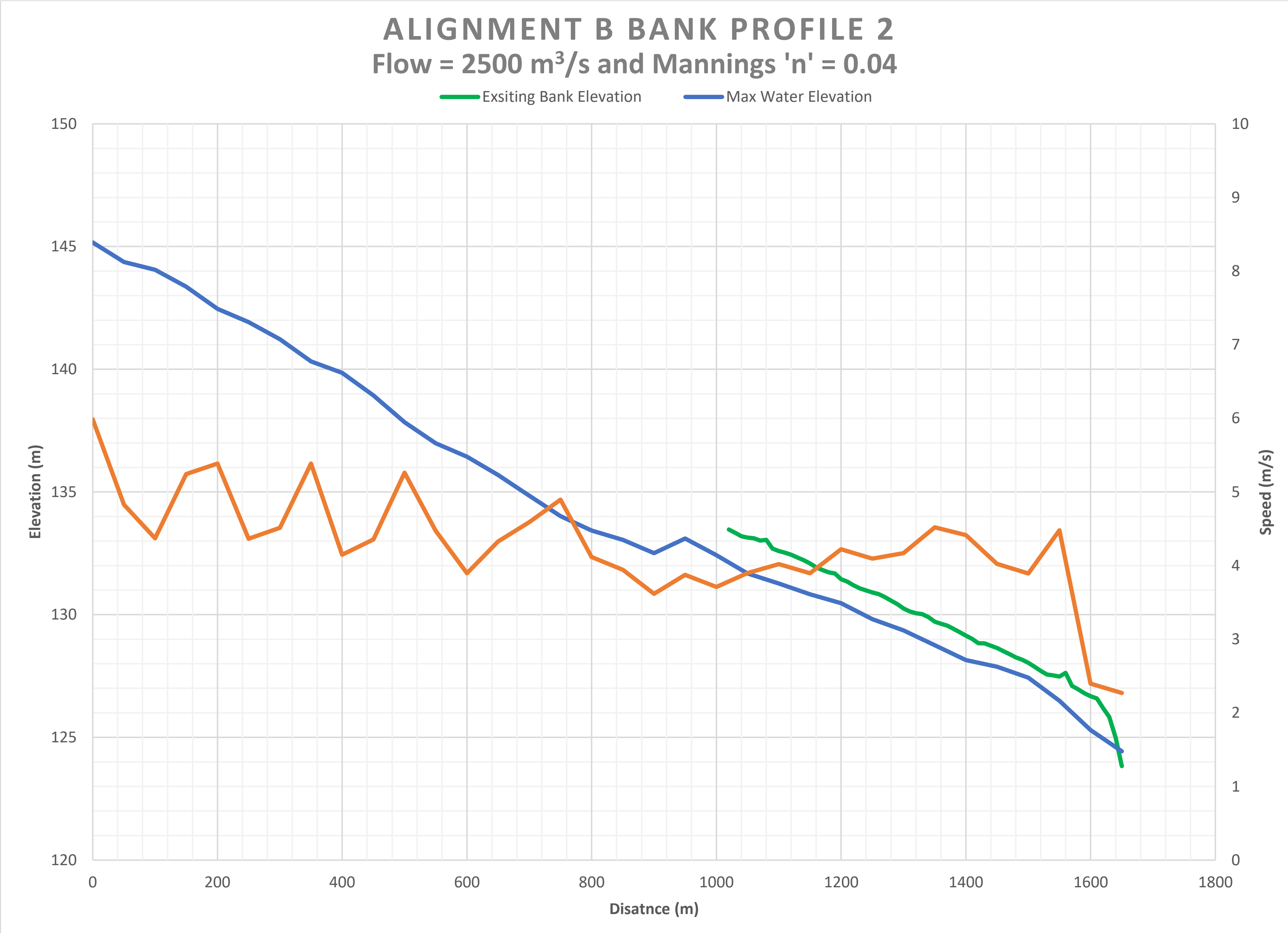
EXISTING ALIGNMENT BANK PROFILE 2
Flow = 2500 m³/s and Mannings 'n' = 0.05
Existing Bank Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Distance (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800

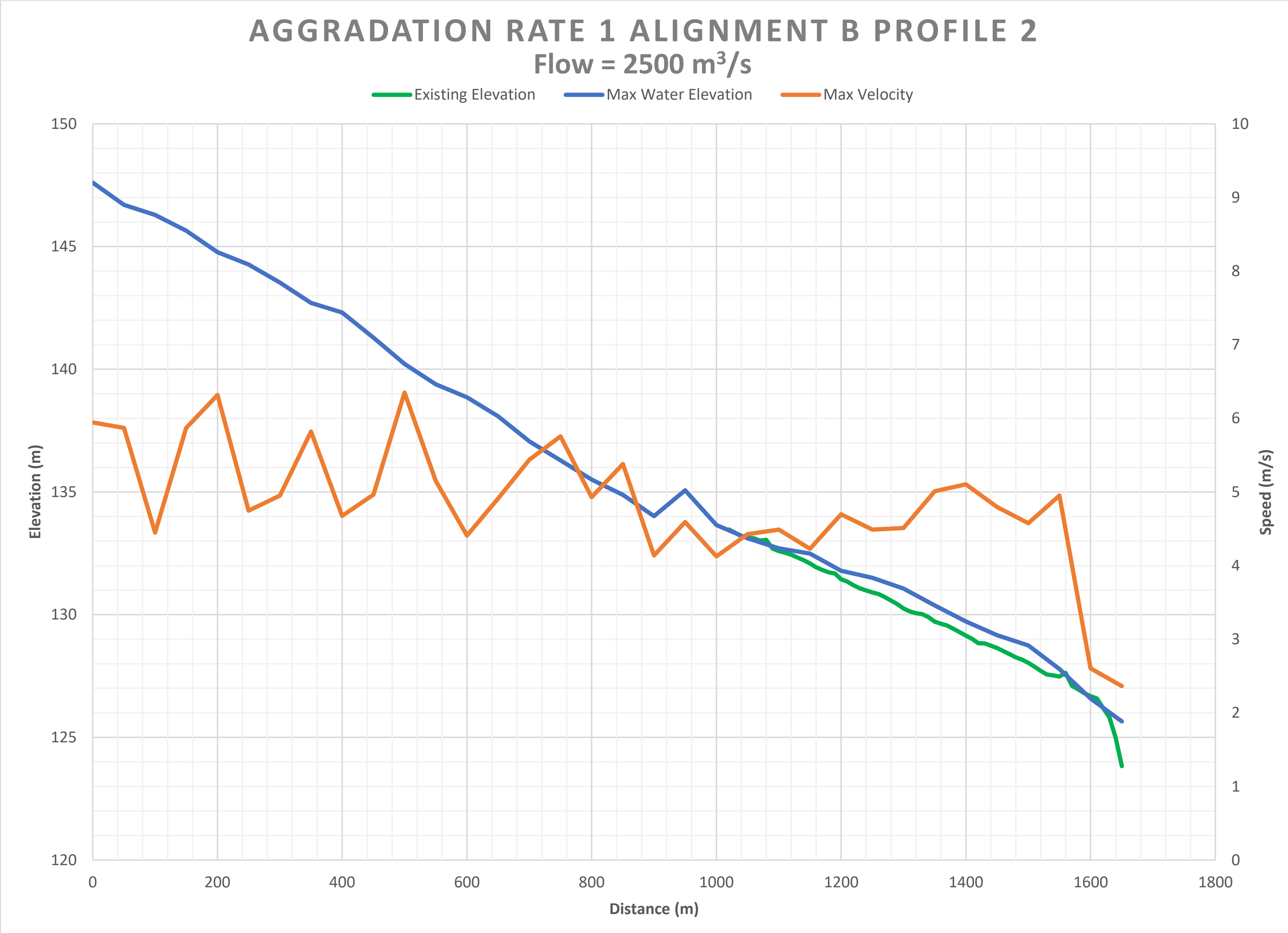

ALIGNMENT B BANK PROFILE 2
Flow = 3000 m³/s and Mannings 'n' = 0.05
Existing Bank Elevation
Max Water Elevation
Elevation (m)
150
145
140
135
130
125
120
Speed (m/s)
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800
Disatnce (m)



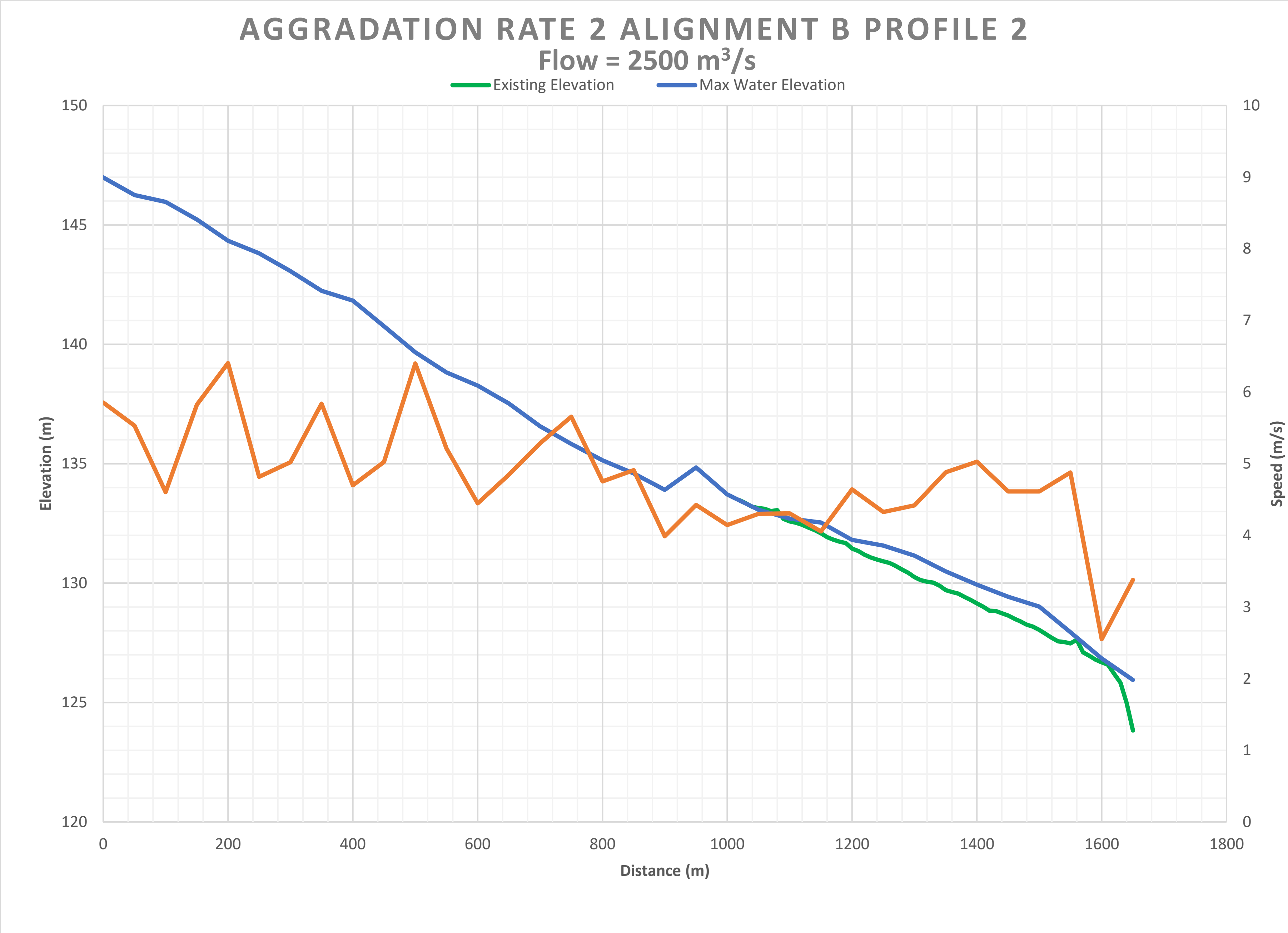
ALIGNMENT B BANK PROFILE 2
Flow = 3500 m3/s and Mannings 'n' = 0.05
Exsiting Bank Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Disatnce (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800


ALIGNMENT B BANK PROFILE 2
Flow = 2500 m³/s and Mannings 'n' = 0.04
Exsiting Bank Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Disatnce (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800

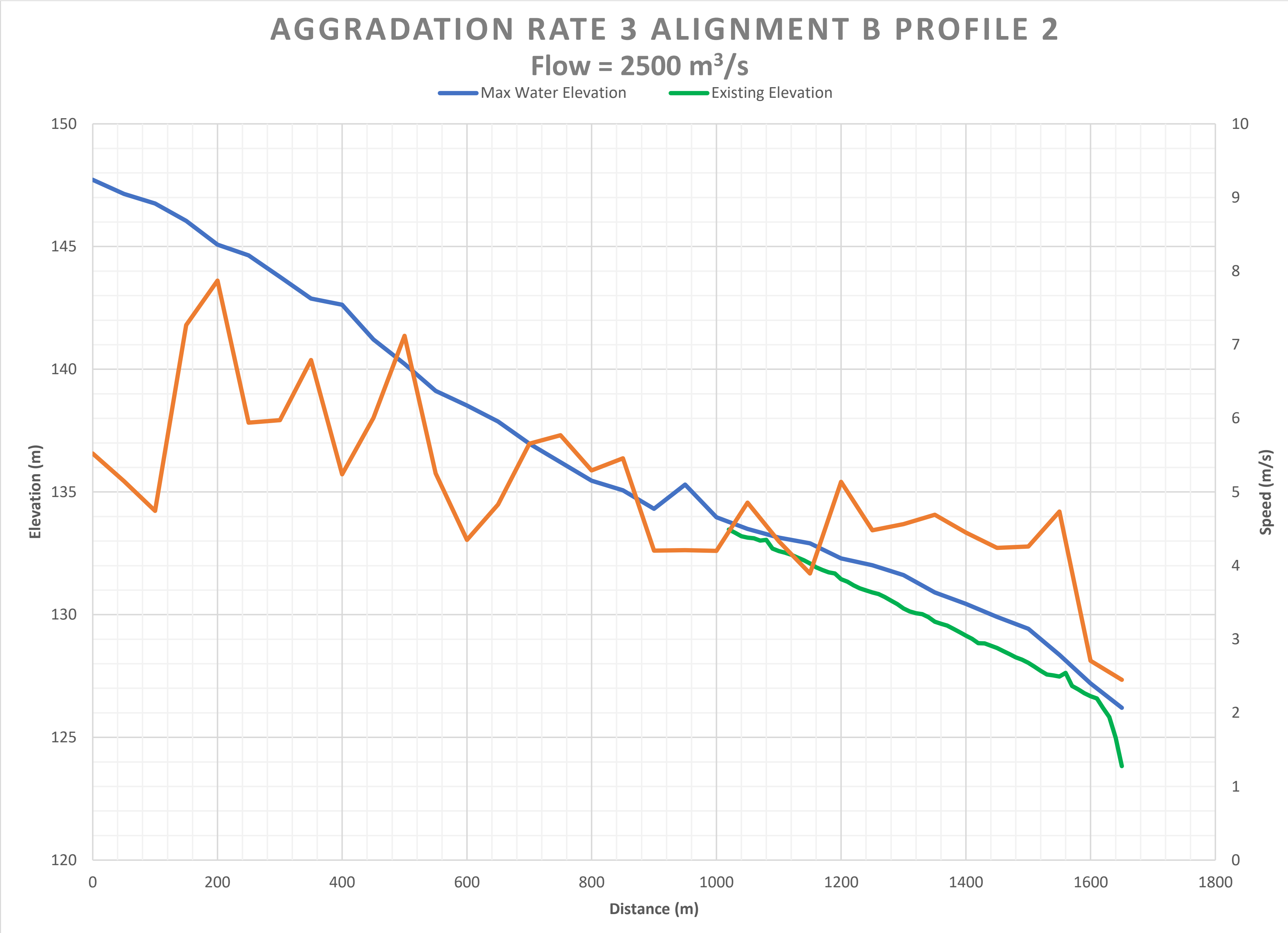

ALIGNMENT B BANK PROFILE 2
Flow = 2500 m³/s and Mannings 'n' = 0.04
Exsiting Bank Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Disatnce (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800



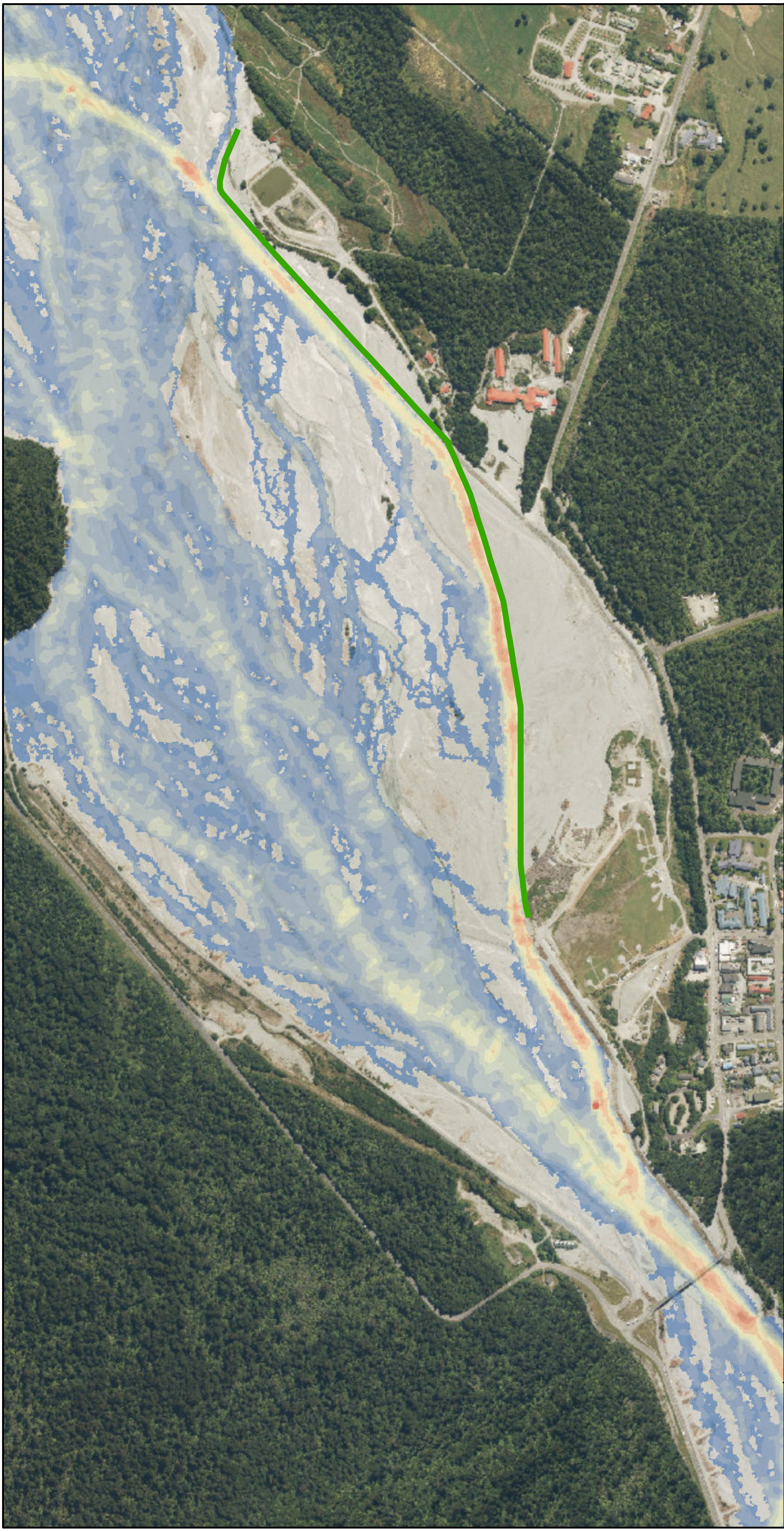
AGGRADATION RATE 1 ALIGNMENT B PROFILE 2
Flow = 2500 m³/s
Existing Elevation
Max Water Elevation
Max Velocity
Elevation (m)
Speed (m/s)
Distance (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800



AGGRADATION RATE 2 ALIGNMENT B PROFILE 2
Flow = 2500 m³/s
Existing Elevation
Max Water Elevation
Elevation (m)
Speed (m/s)
Distance (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800



AGGRADATION RATE 3 ALIGNMENT B PROFILE 2
Flow = 2500 m³/s
Max Water Elevation
Existing Elevation
Elevation (m)
Speed (m/s)
Distance (m)
150
145
140
135
130
125
120
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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THE WEST COAST REGIONAL COUNCIL

PROJECT

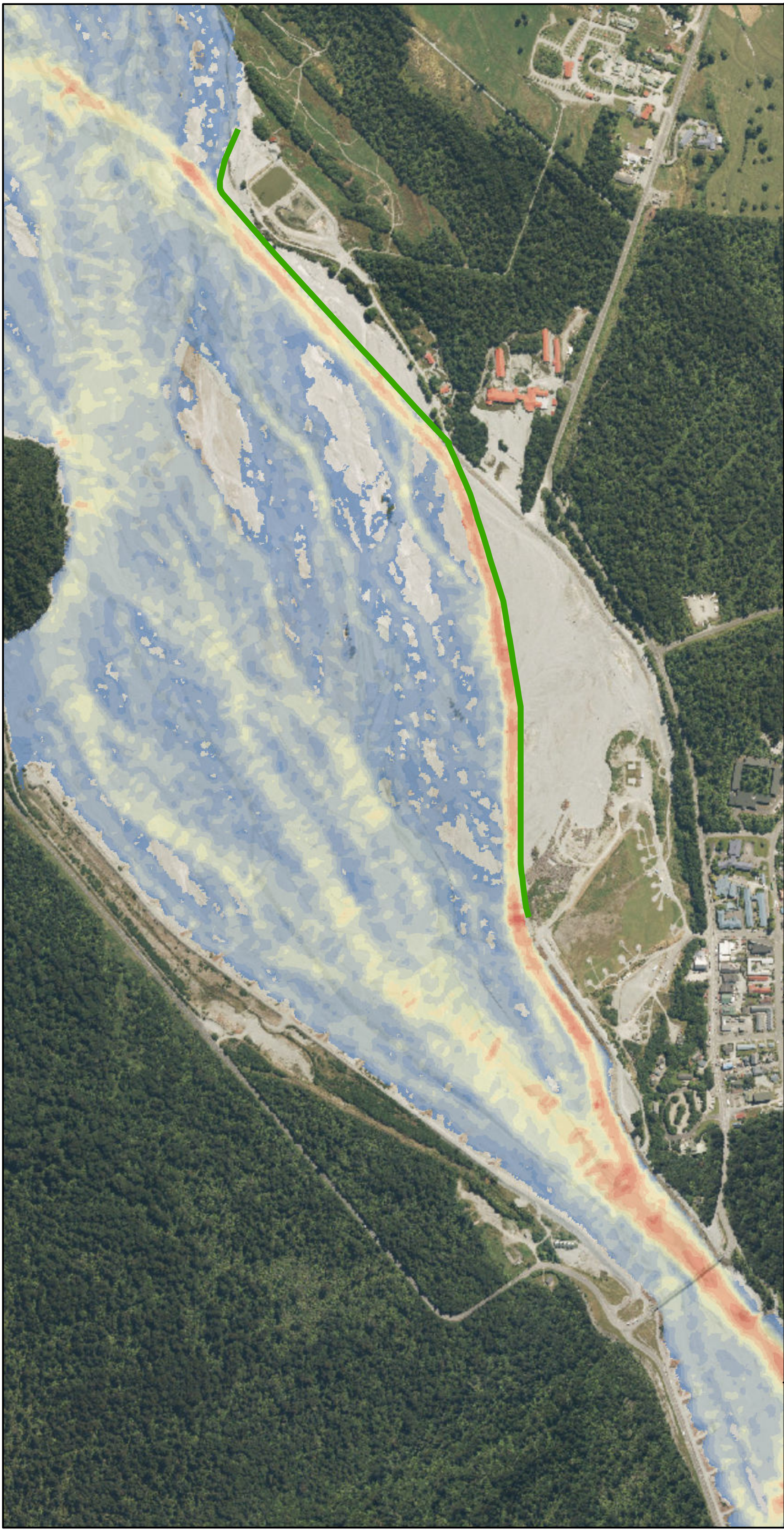
Franz Josef Stopbank Upgrade

MAP TITLE

Peak Speed Map
Bank Alignment B
Q500 m3/s
Mannings 'n' 0.05

REVISION	DATE	
01	19 July 2021	N
A3 SCALE	AUTHOR	
1:10,000	Matthew Gardner	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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PROJECT

Franz Josef Stopbank Upgrade

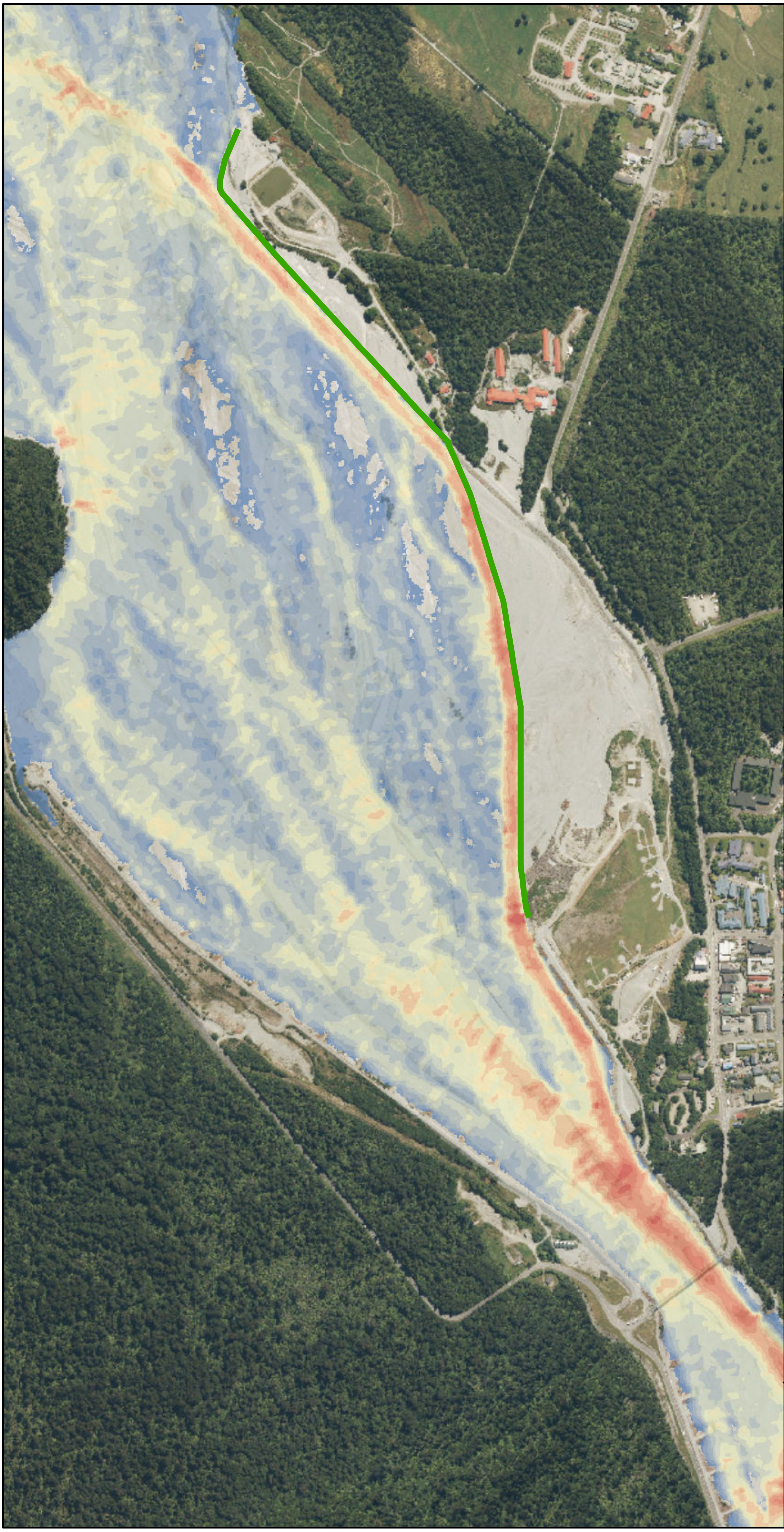
MAP TITLE

Peak Speed Map Bank Alignment B Q1000 m3/s Mannings 'n' 0.05

REVISION	DATE
01	19 July 2021
A3 SCALE	AUTHOR
1:10,000	Matthew Gardner

N

0 0.125 0.25 0.5 Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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PROJECT
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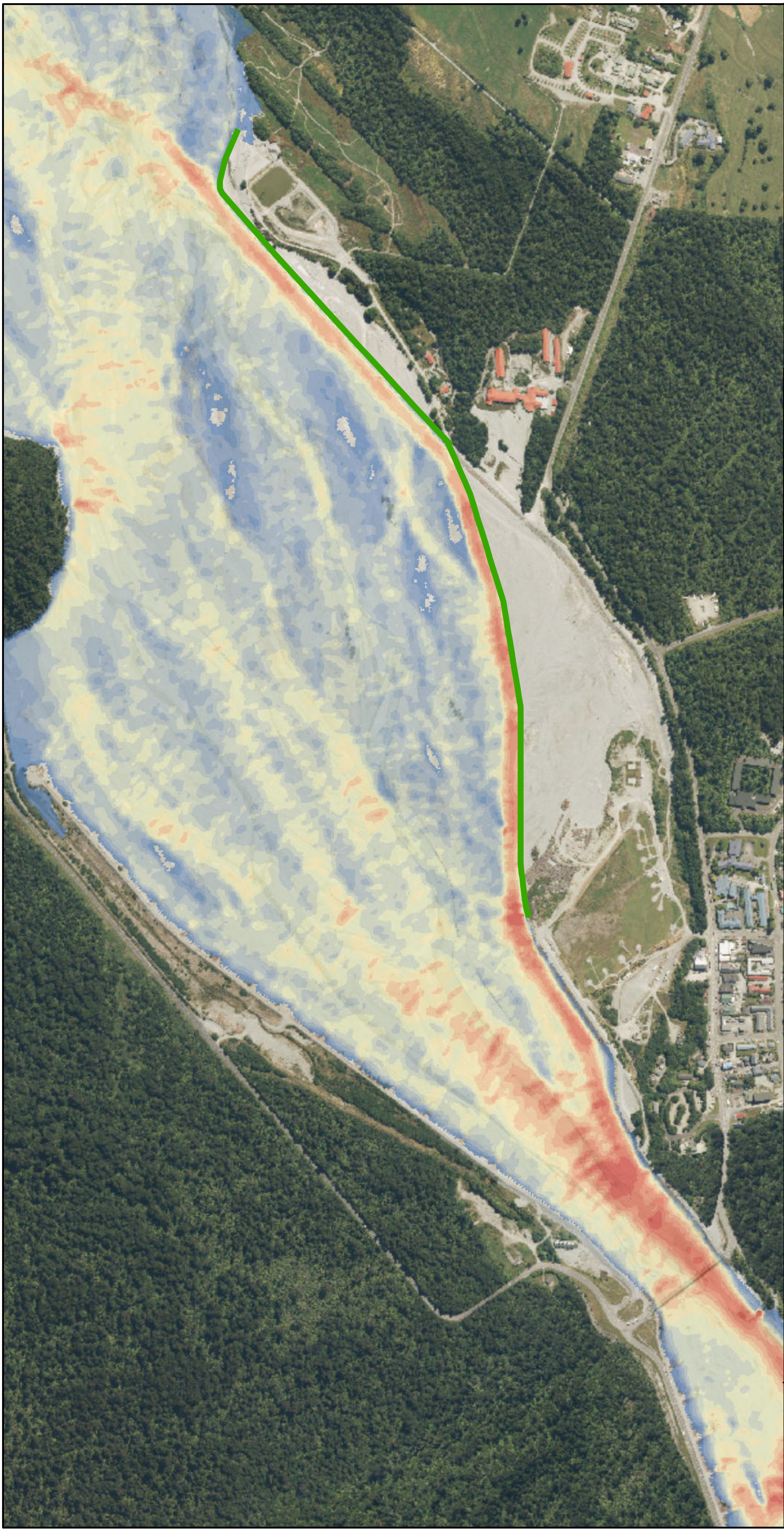
MAP TITLE
Peak Speed Map
Bank Alignment B
Q1500 m3/s
Mannings 'n' 0.05

REVISION	DATE	
01	19 July 2021	N
A3 SCALE	AUTHOR	
1:10,000	Matthew Gardner	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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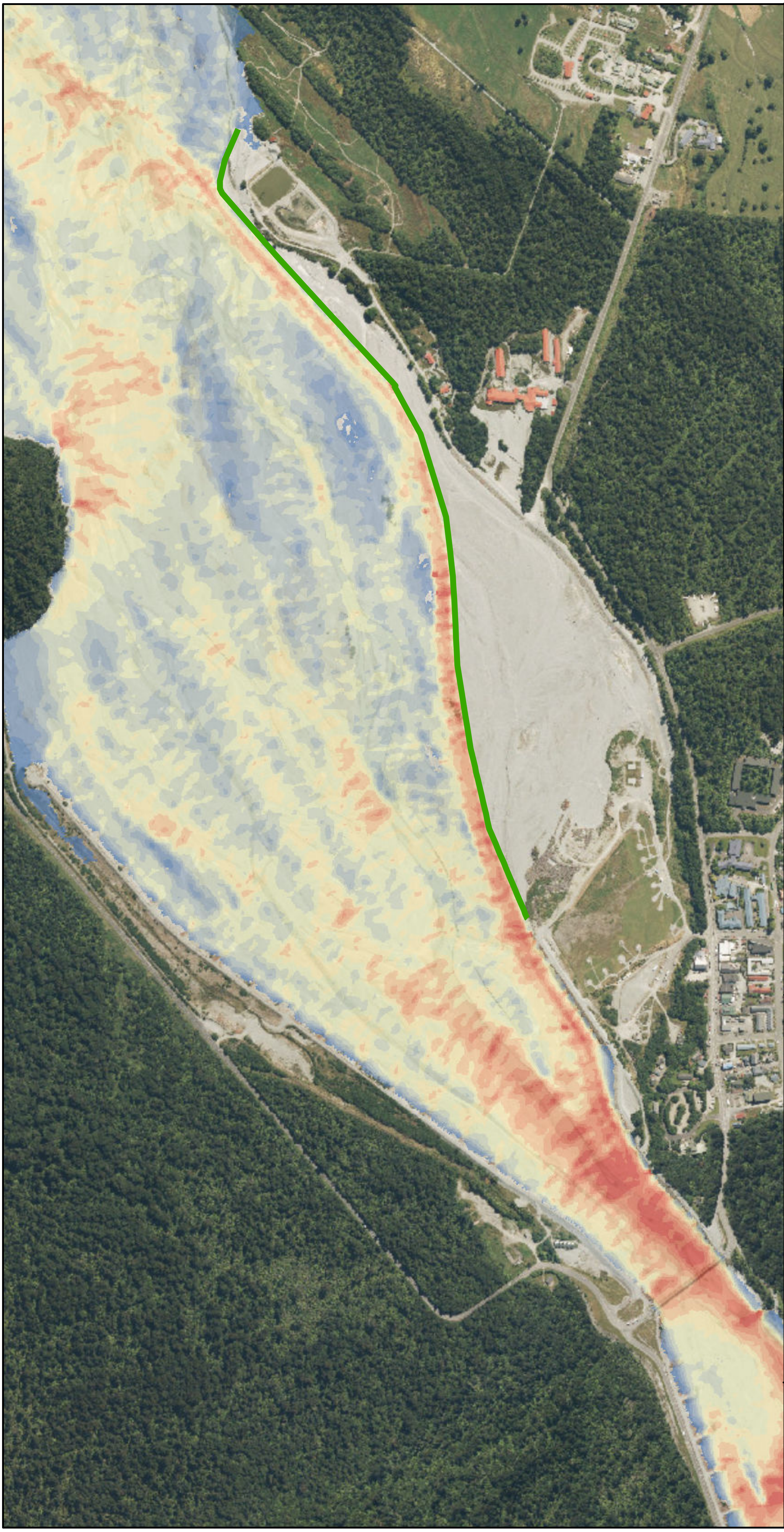
MAP TITLE

Peak Speed Map
Bank Alignment B
Q2000 m3/s
Mannings 'n' 0.05

REVISION	DATE	
01	**19 July 2021**	N
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment A

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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PROJECT

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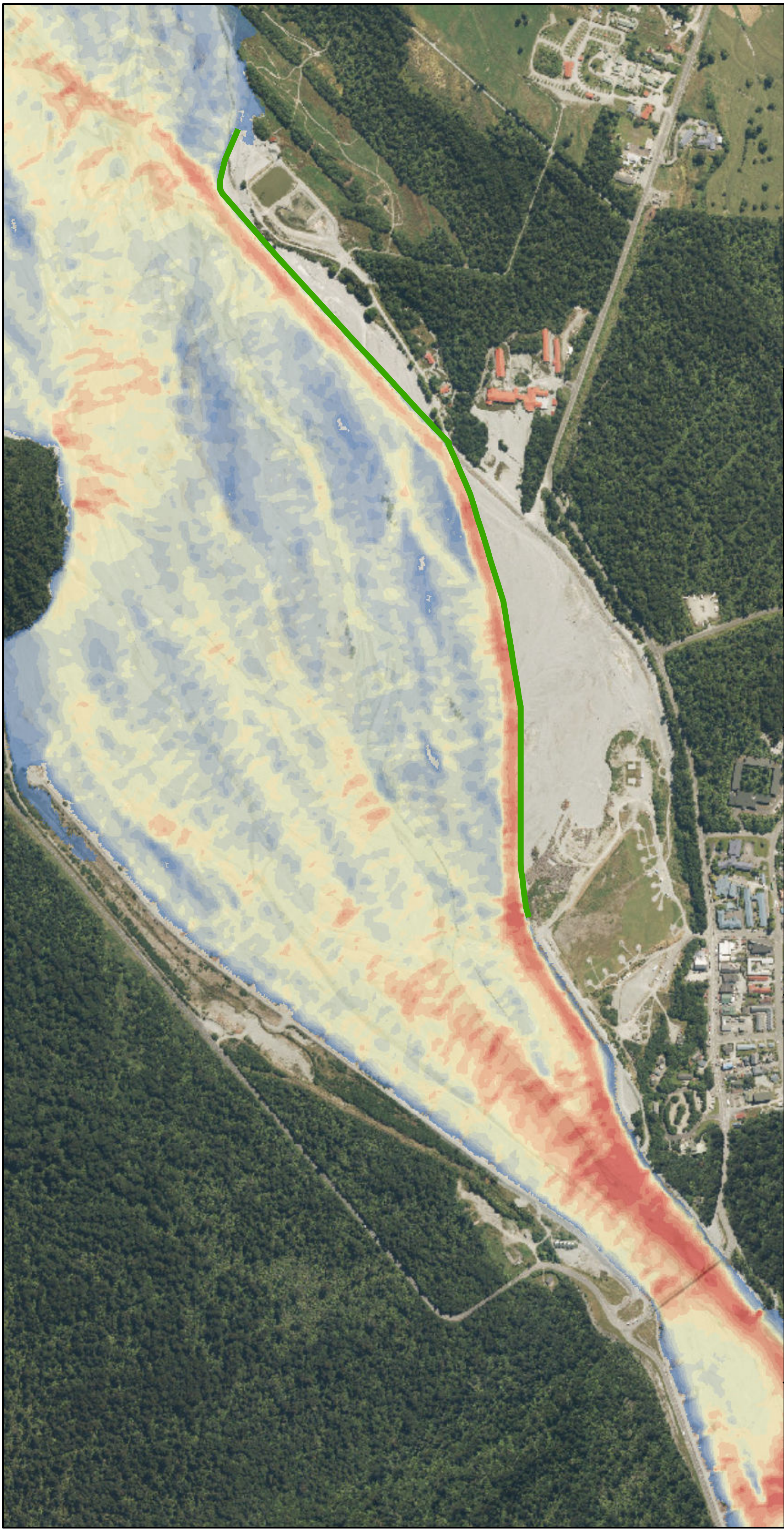
MAP TITLE

Peak Speed Map
Bank Alignment A
Q2500 m3/s
Mannings 'n' 0.05

REVISION	DATE	
01	**19 July 2021**	N
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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PROJECT

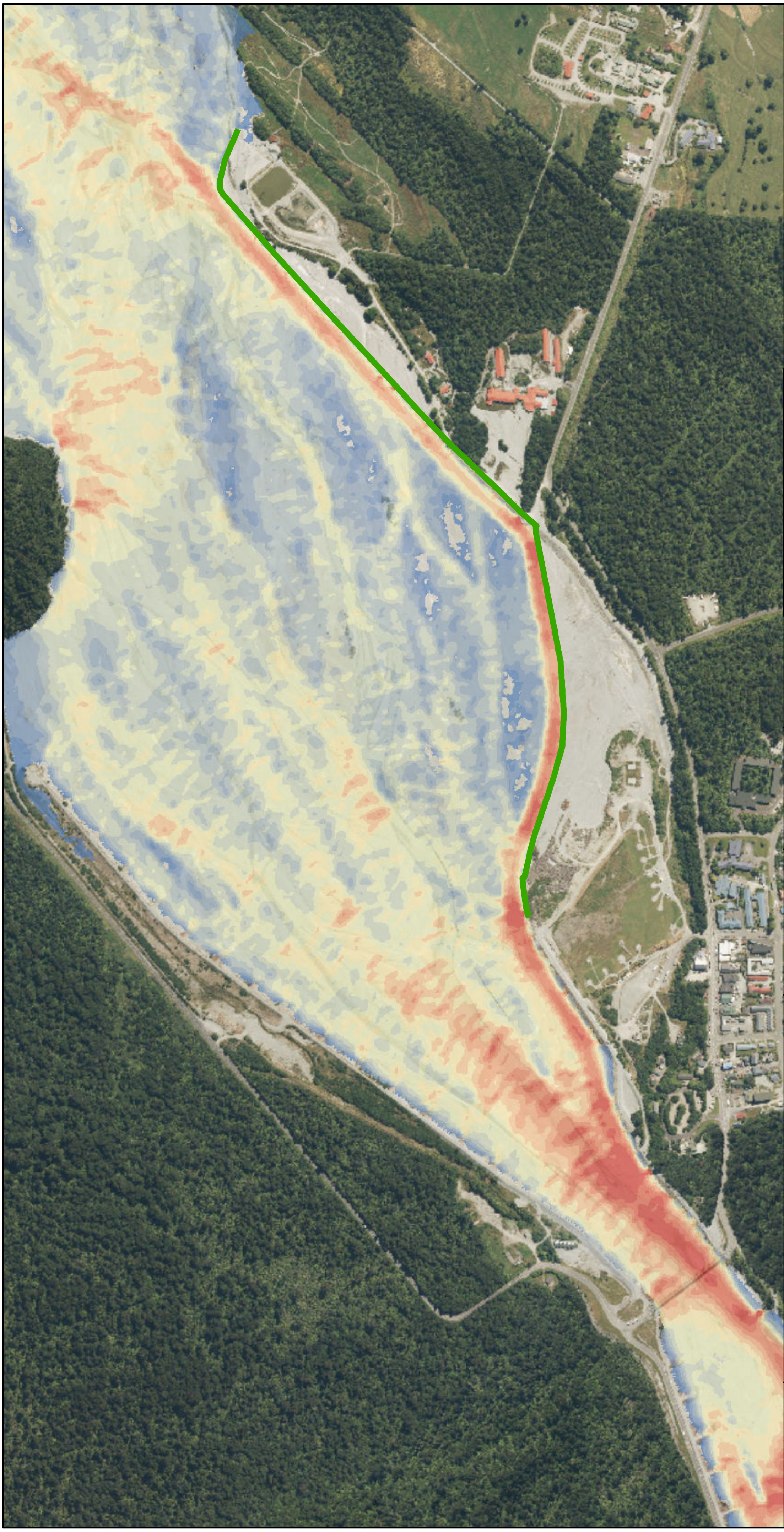
Franz Josef Stopbank Upgrade

MAP TITLE

Peak Speed Map
Bank Alignment B
Q2500 m3/s
Mannings 'n' 0.05

REVISION	DATE	
01	19 July 2021	N
A3 SCALE	AUTHOR	
1:10,000	Matthew Gardner	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment C

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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PROJECT

Franz Josef Stopbank Upgrade

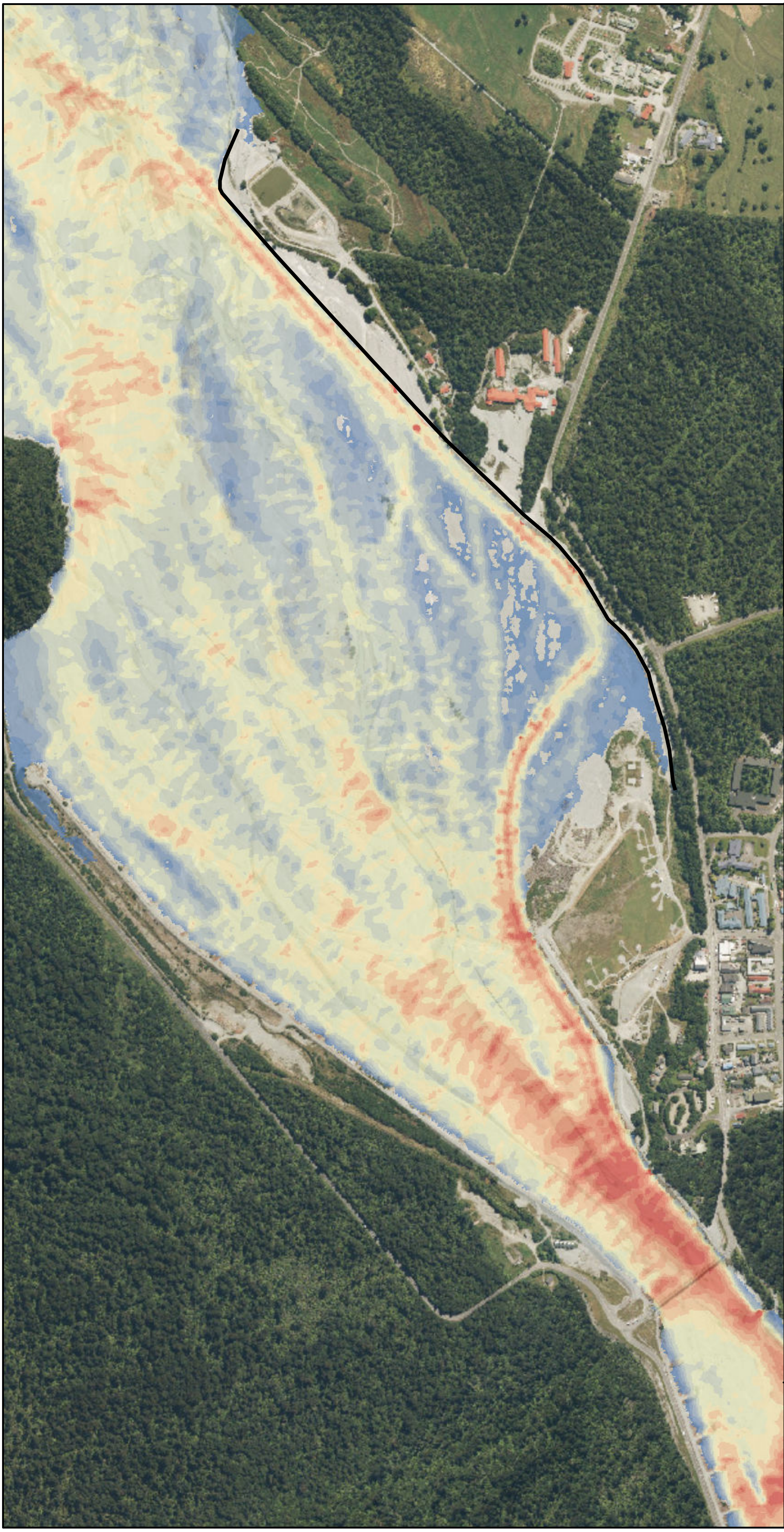
MAP TITLE

Peak Speed Map
Bank Alignment C
Q2500 m3/s
Mannings 'n' 0.05

REVISION	DATE
01	**19 July 2021**
A3 SCALE	AUTHOR
1:10,000	**Matthew Gardner**

N

0 0.125 0.25 0.5
Kilometers

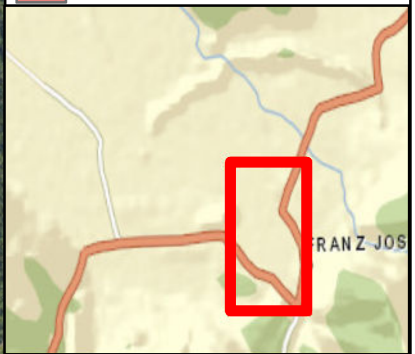


Legend

Existing Dike

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5



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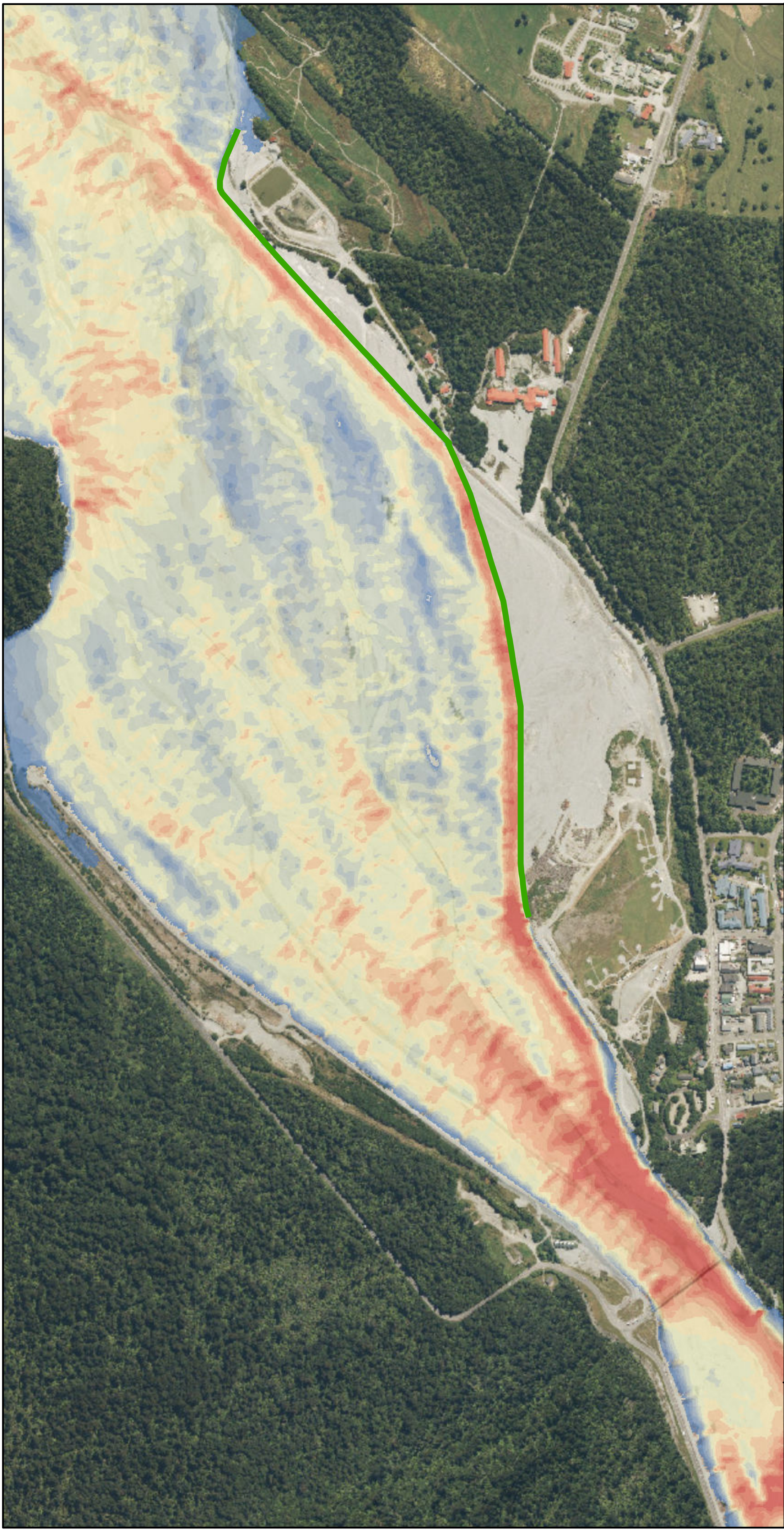
Franz Josef Stopbank Upgrade

MAP TITLE

Peak Speed Map
Existing Dike
Q2500 m3/s
Mannings 'n' 0.05

REVISION	DATE	
01	**19 July 2021**	N
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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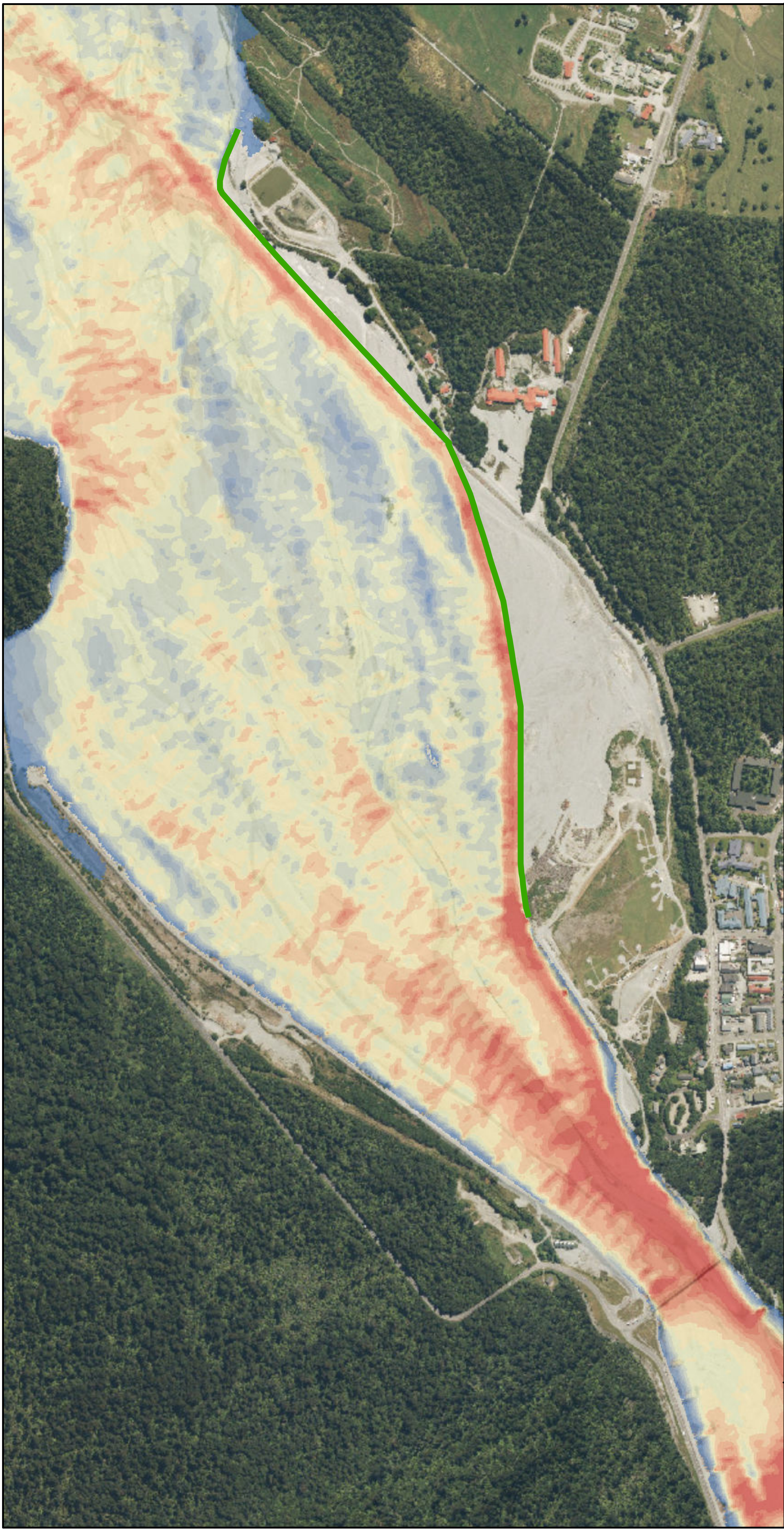
MAP TITLE

Peak Speed Map
Bank Alignment B
Q3000 m3/s
Mannings 'n' 0.05

REVISION	DATE	
01	**19 July 2021**	N
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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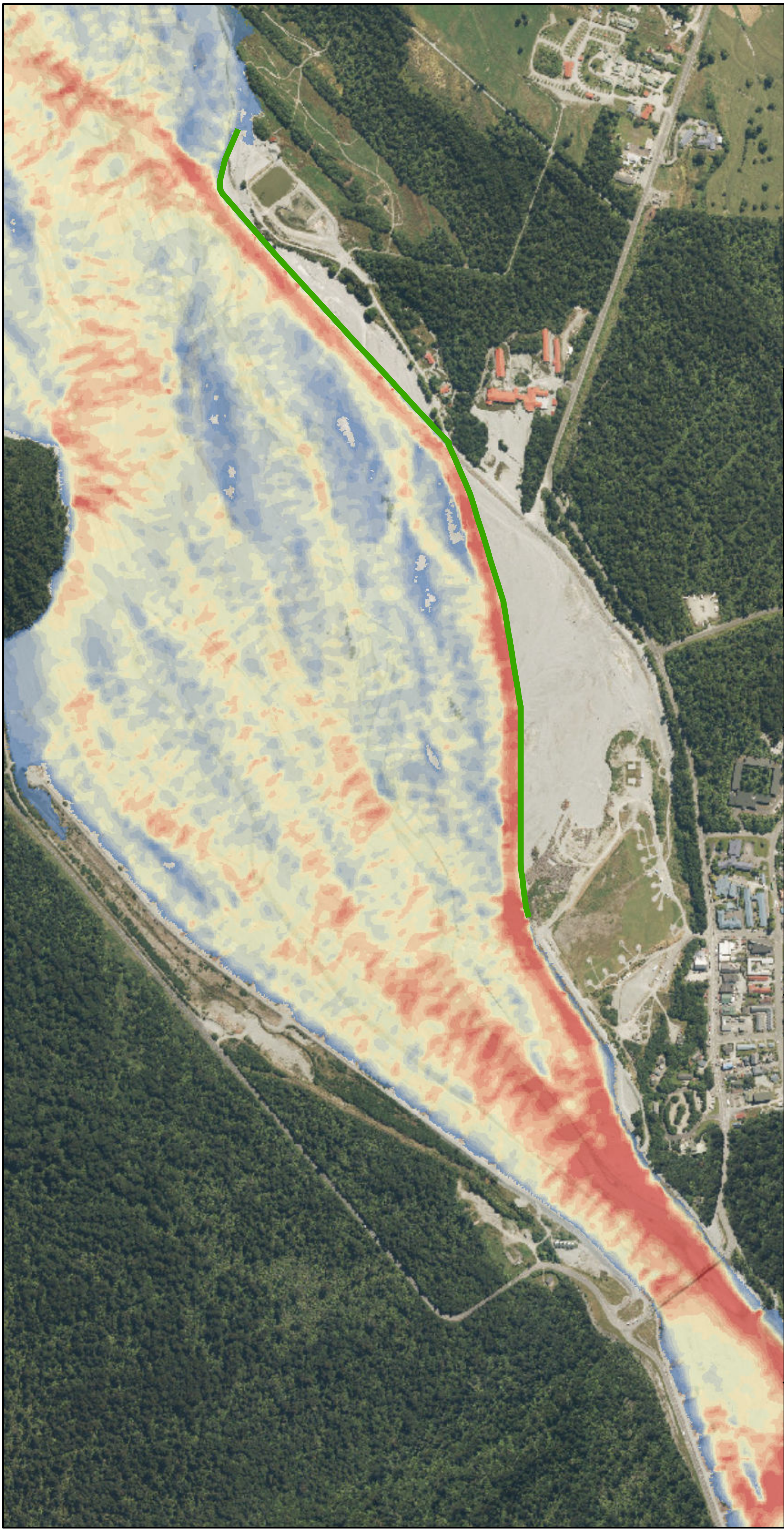
MAP TITLE

Peak Speed Map
Bank Alignment B
Q3500 m3/s
Mannings 'n' 0.05

REVISION	DATE	
01	**19 July 2021**	N
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers

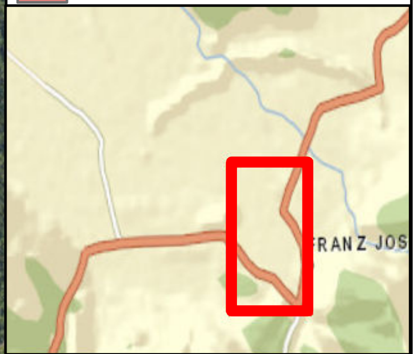


Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5



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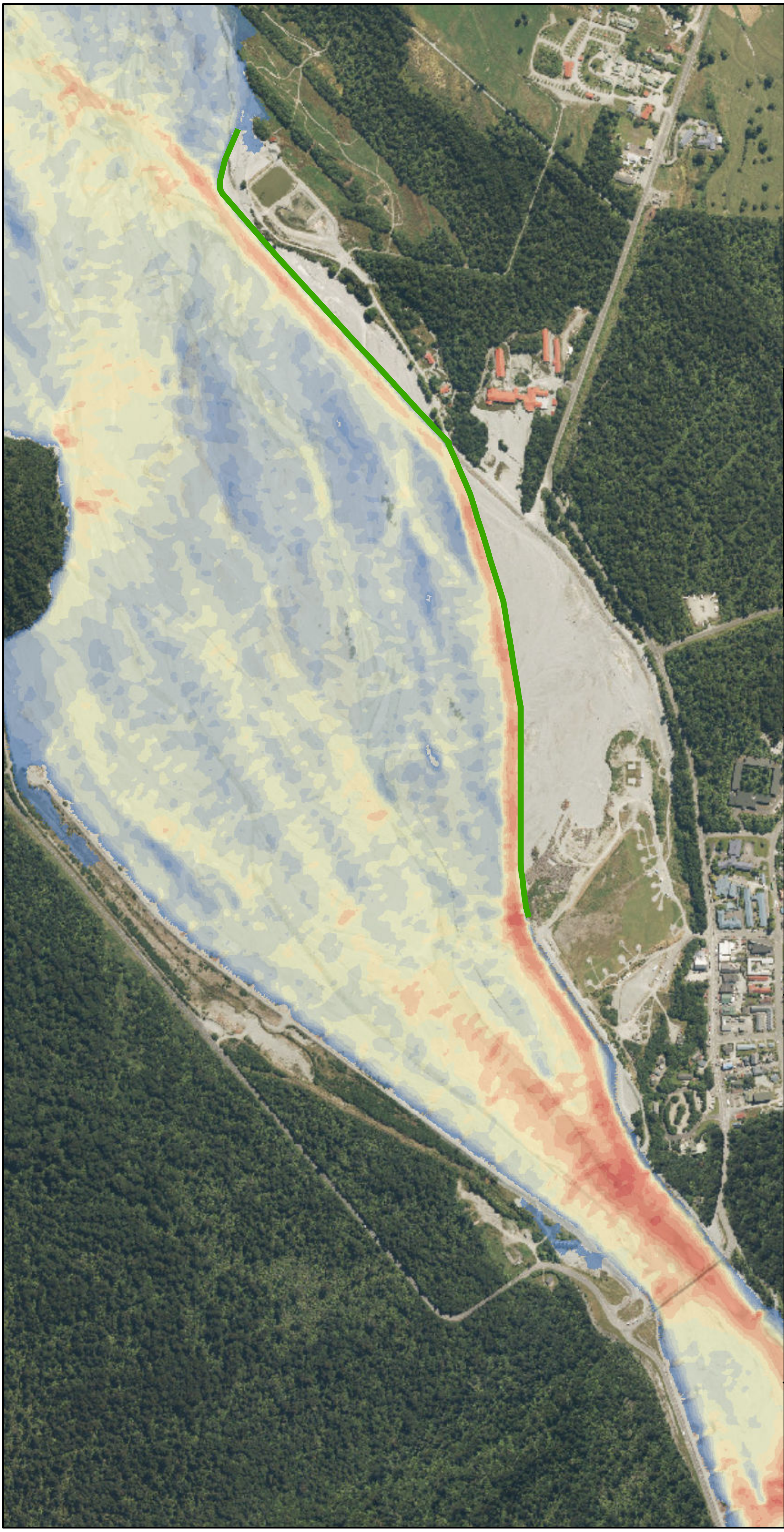
MAP TITLE

Peak Speed Map
Bank Alignment B
Q2500 m3/s
Mannings 'n' 0.04

REVISION	DATE	
01	**19 July 2021**	N
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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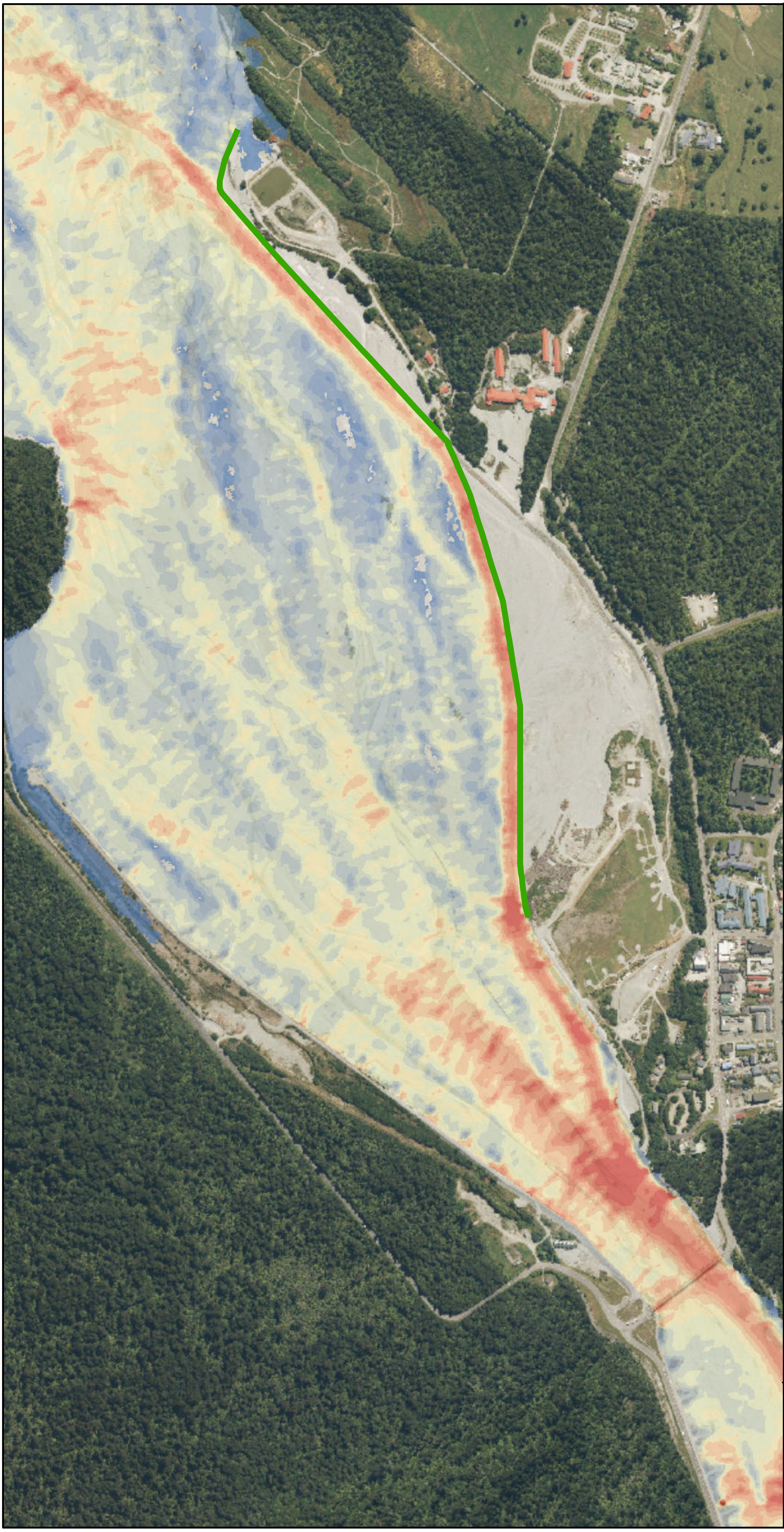
MAP TITLE

Peak Speed Map Bank Alignment B Q2500 m3/s Mannings 'n' 0.06

REVISION	DATE	N
01	**19 July 2021**	
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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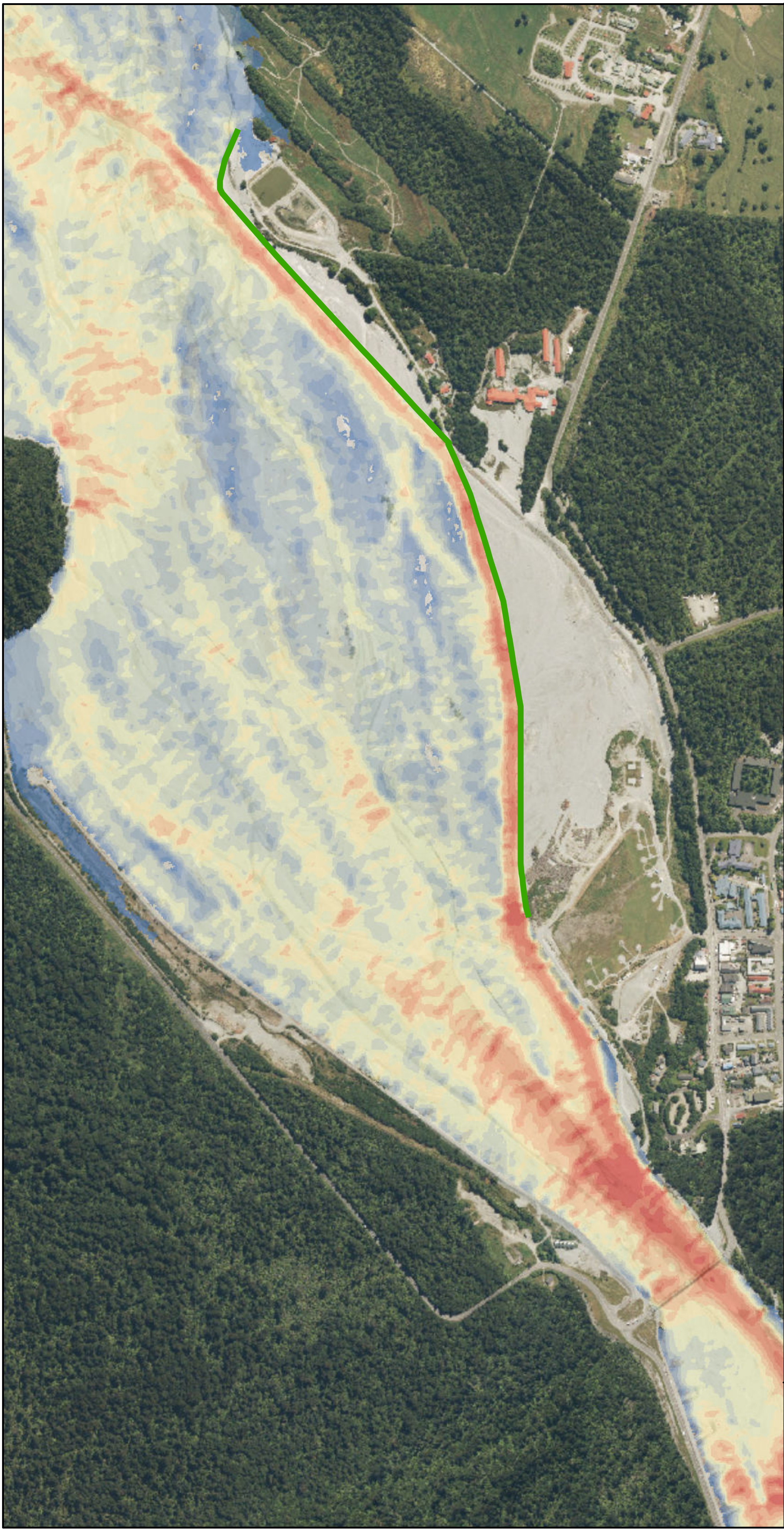
MAP TITLE

Peak Speed Map
Bank Alignment B
Q2500 m3/s
Mannings 'n' 0.05
Aggradation Rate 1

REVISION	DATE	
01	**24 Aug 2021**	N
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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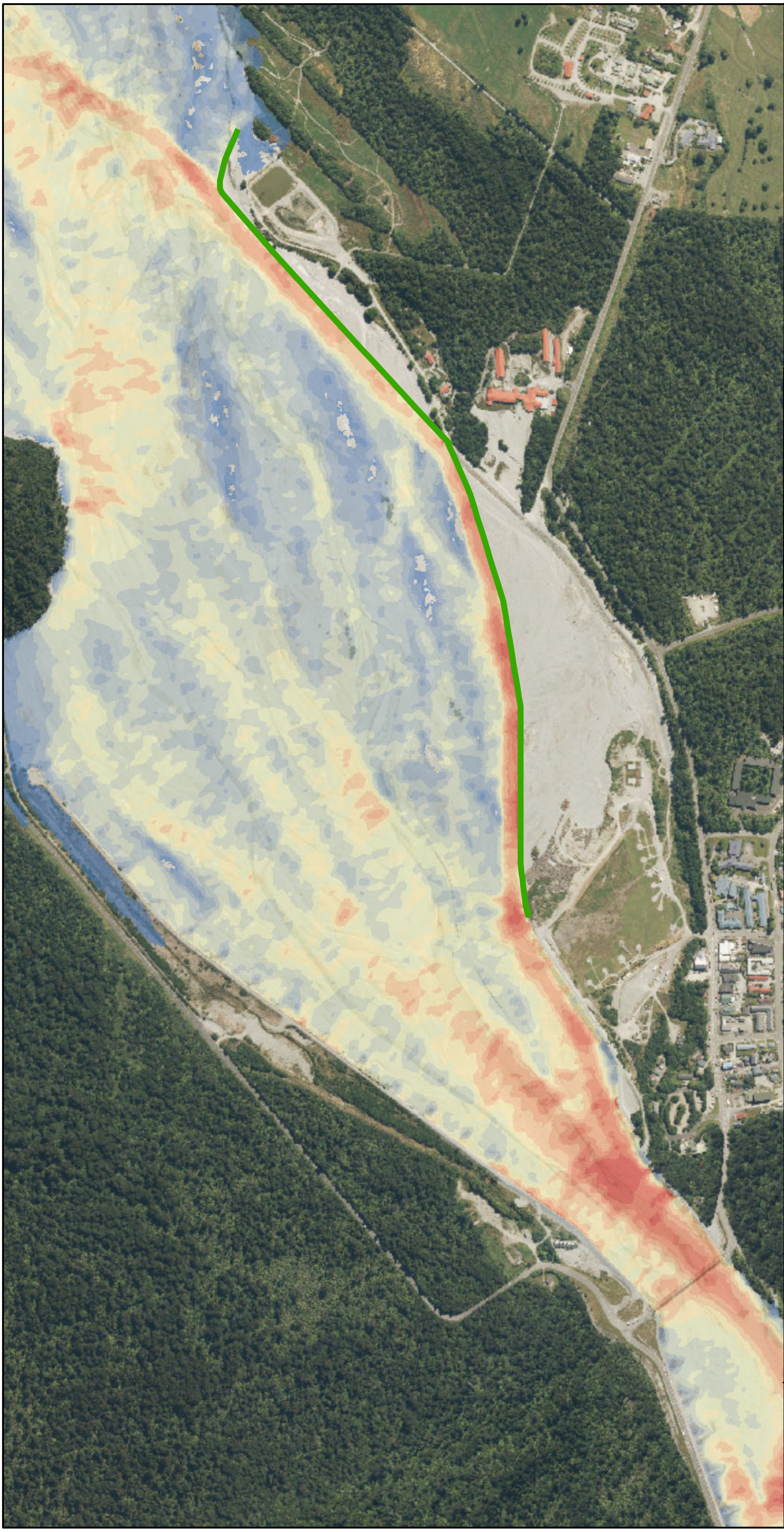
MAP TITLE

Peak Speed Map
Bank Alignment B
Q2500 m3/s
Mannings 'n' 0.05
Aggradation Rate 2

REVISION	DATE	
01	**24 Aug 2021**	N
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers



Legend

Bank Alignment B

Peak Speed (m/s)

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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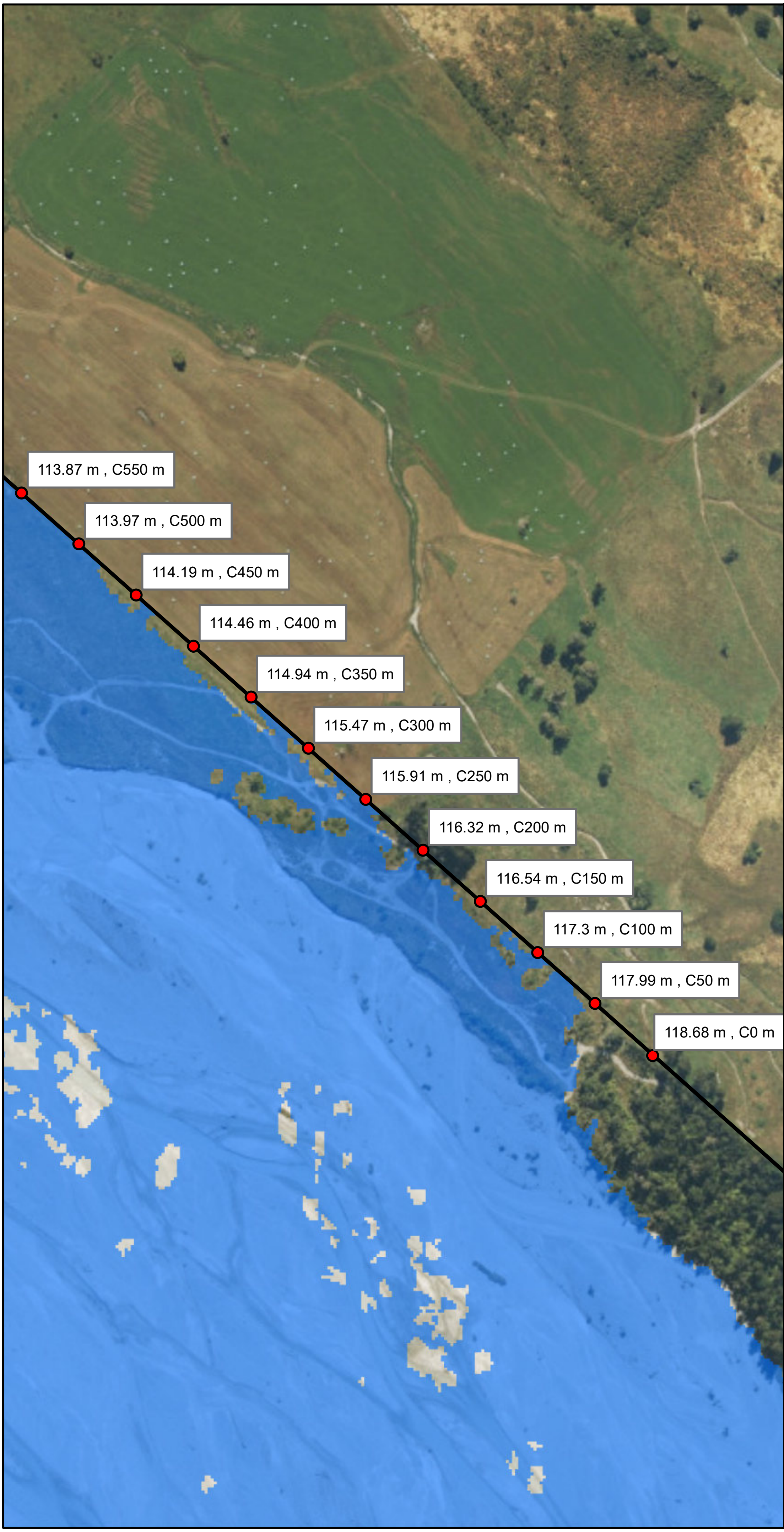
MAP TITLE

Peak Speed Map
Bank Alignment B
Q2500 m3/s
Mannings 'n' 0.05
Aggradation Rate 3

REVISION	DATE	
01	**24 Aug 2021**	N
A3 SCALE	AUTHOR	
1:10,000	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers

APPENDIX E – TATARE OVERFLOW BUND – PEAK WATER LEVELS



Legend

- Water Level Locations
- Tatare Bund Alignment
- Modelled Water Extent

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MAP TITLE

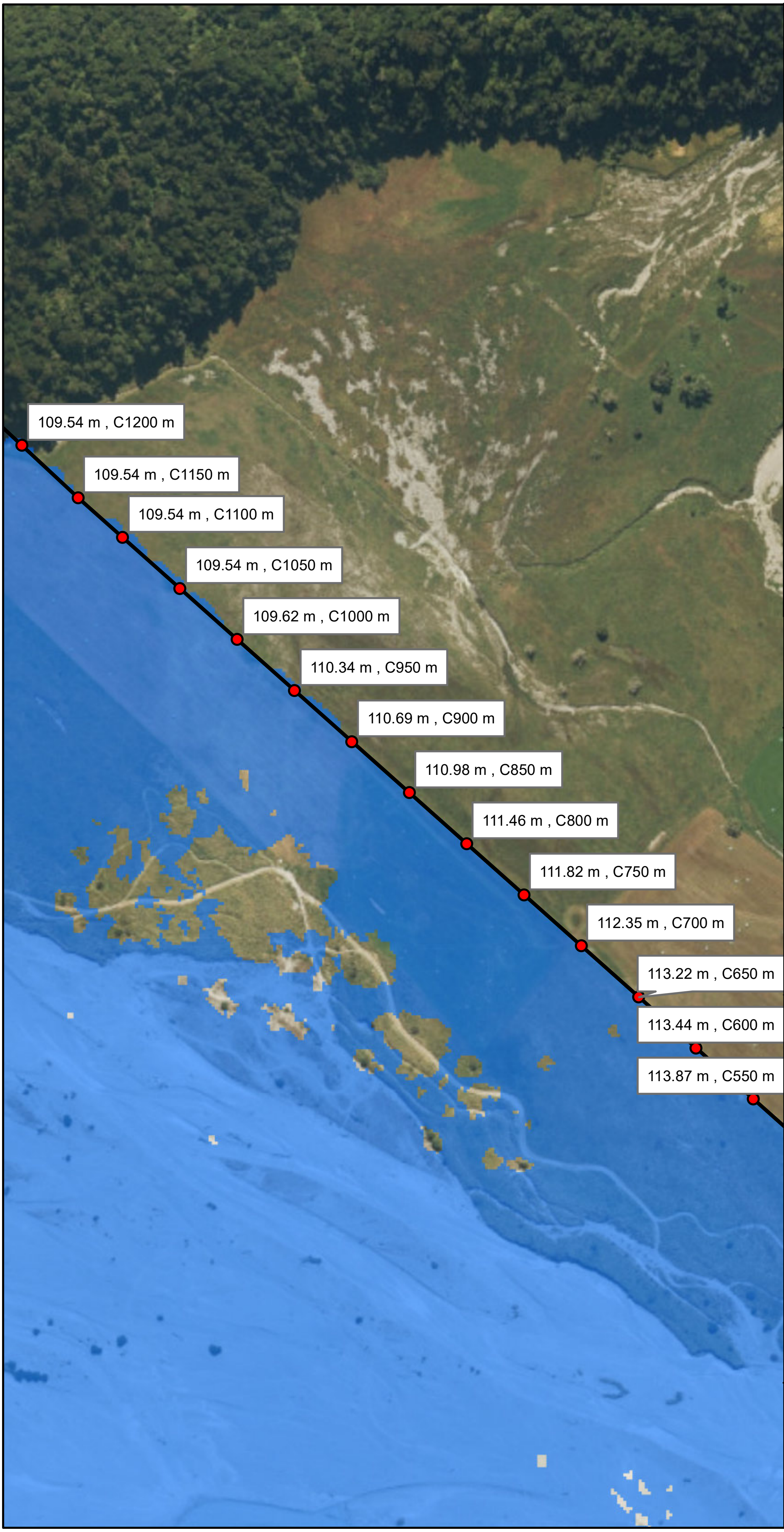
Tatare Bund Location and Peak Water Level

Map 1 of 2

REVISION	DATE
01	**09 Sep 2021**
A3 SCALE	AUTHOR
1:3,500	**Matthew Gardner**

N

0 0.0425 0.085 0.17
Kilometers



Legend

- Water Level Locations
- Tatare Bund Alignment
- Modelled Water Extent

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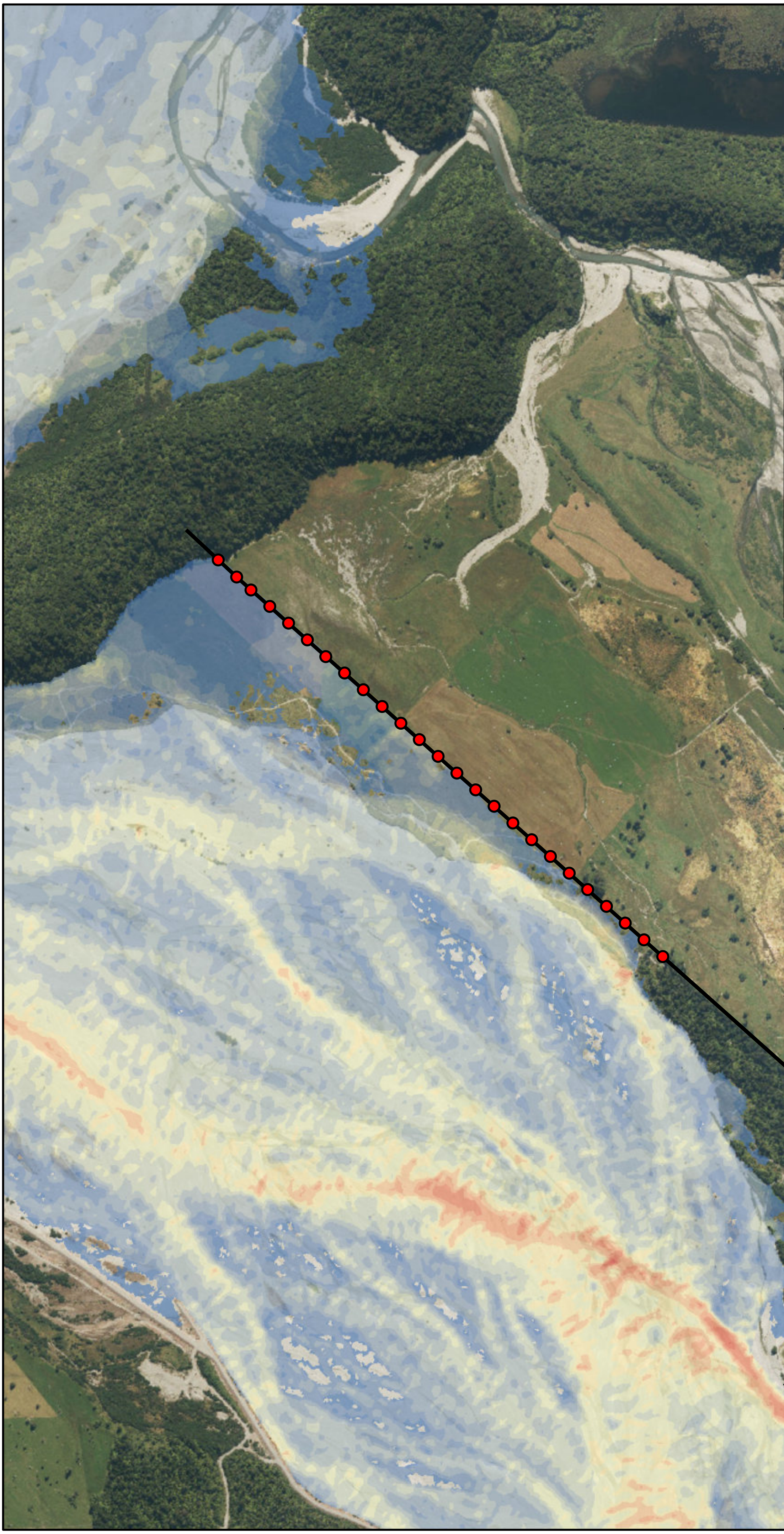
MAP TITLE
Tatare Bund Location and Peak Water Level

Map 2 of 2

REVISION	DATE	
01	**09 Sep 2021**	N
A3 SCALE	AUTHOR	
1:3,500	**Matthew Gardner**	

0 0.0425 0.085 0.17
Kilometers



Legend

- Water Level Locations
- Tatare Bund Alignment

Peak Speed

- <0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 -2.5
- 2.5 -3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 -5
- 5 - 5.5
- >5.5

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MAP TITLE

Tatare Bund Location and Peak Speed Map

REVISION	DATE	
01	**09 Sep 2021**	N
A3 SCALE	AUTHOR	
1:10,741	**Matthew Gardner**	

0 0.125 0.25 0.5
Kilometers

APPENDIX 2: MEMORANDUM REGARDING FURTHER MODELLING RESULTS

Land River Sea Consulting Limited
5/245 St Asaph Street, Christchurch
Tel: +64 27 318 9527
matthew@landriversea.com
www.landriversea.com

30 JUNE 2023

Sam Scott

West Coast Regional Council

Sent via email: sam.scott@wcrc.govt.nz

WAIHO RIVER - ASSESSMENT OF EFFECTS OF NEW STOPBANKS

Since European occupation of the Franz Josef area around the 1890's, the management strategy for the Waiho River and its fan surface, has been one of control through protection structures such as stopbanks, rock gabions, riprap, and groynes. The location of the township of Franz Josef was originally chosen as it was considered safe from flooding, and provided close access to what was believed to be a reasonably safe and stable river crossing, as at the time, the riverbed consisted of very large glacial lag boulders. However, as increased volumes of sediment have entered the river overtime from the upper catchment and the riverbed has aggraded, extensive management of the flood hazard has been required, and stopbanks have been constructed on both the right and left banks of the river.

The present day protection scheme is owned and managed by several organisations including the West Coast Regional Council, New Zealand Transport Agency (Waka Kotahi), Hokitika Airport Authority, Department of Conservation, and Westland District Council (WDC) and is shown in Figure 1.

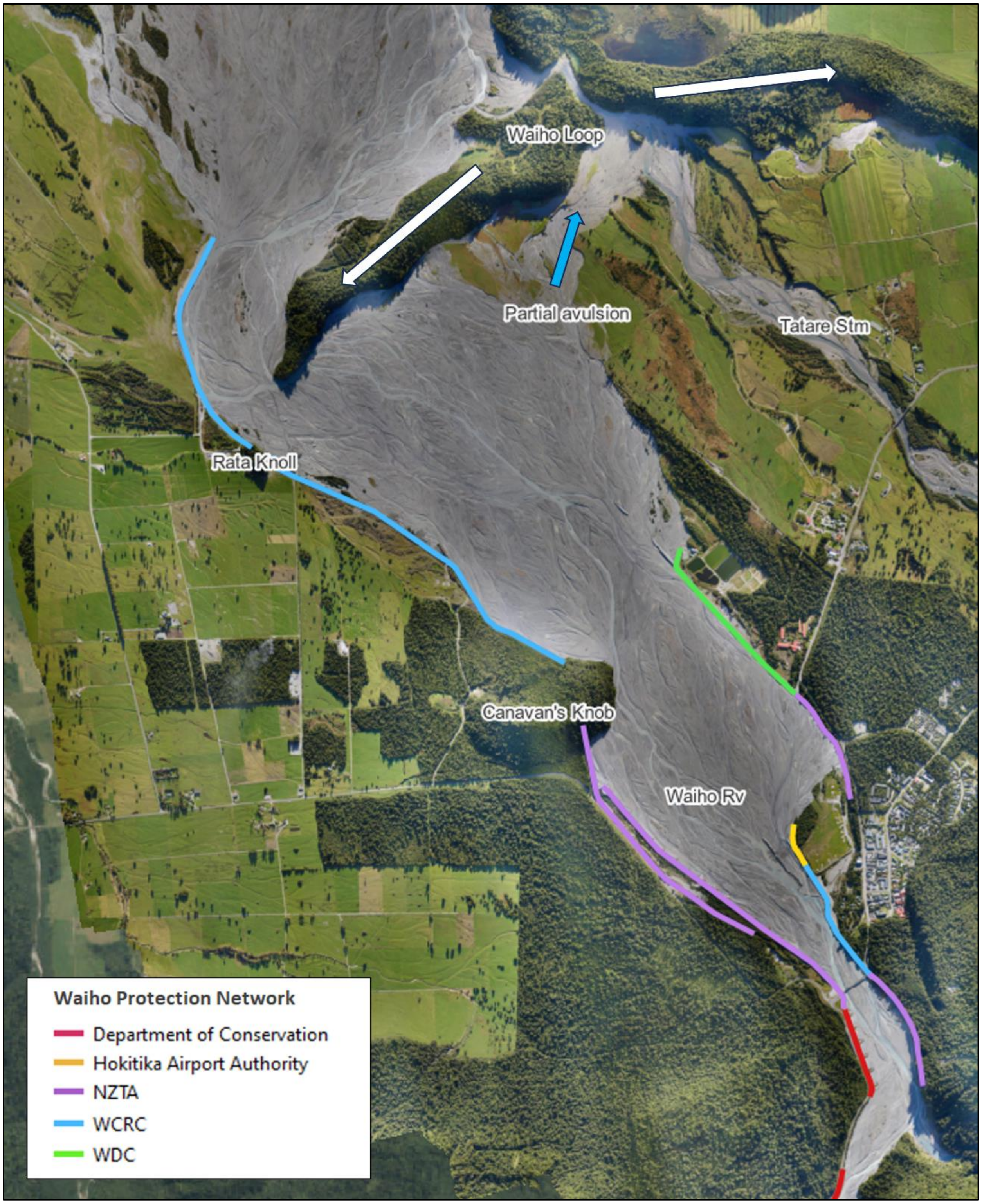


Figure 1 - Present day protection scheme and stopbank ownership

Due to ongoing aggradation and serious threat to the State Highway as well as assets on the true right bank of the river, the council has elected to raise the stopbanks on the true right bank as well as build an additional section of bank connecting the Helipad Bank to the WDC bank. Detailed design has been completed for the raising and construction of the stopbanks on the true right bank based on the alignment as shown in Figure 2. Further details around the design and preferred alignment is presented in the preliminary design report (Gardner, 2021).

Figure 2 – Stopbank locations

In order to assess and quantify the impact of raising and constructing these new banks, the existing hydraulic model has been used to run the model with and without the banks in place for the design flow of 2500 m^3/s. The 2021 model was largely unchanged for the simulations, and so details of the original build can be found in the report "Franz Josef Stopbanks: Preliminary Design Report" (Gardner, 2021). As the 2021 model was only focused on sizing the stopbanks, the floodplain outside of the stopbanks was excluded from the initial model extent and it therefore was not able to simulate overtopping outside of the scheme. This model has therefore been expanded to include the wider floodplain to allow the full flood extent to be mapped (Figure 3).

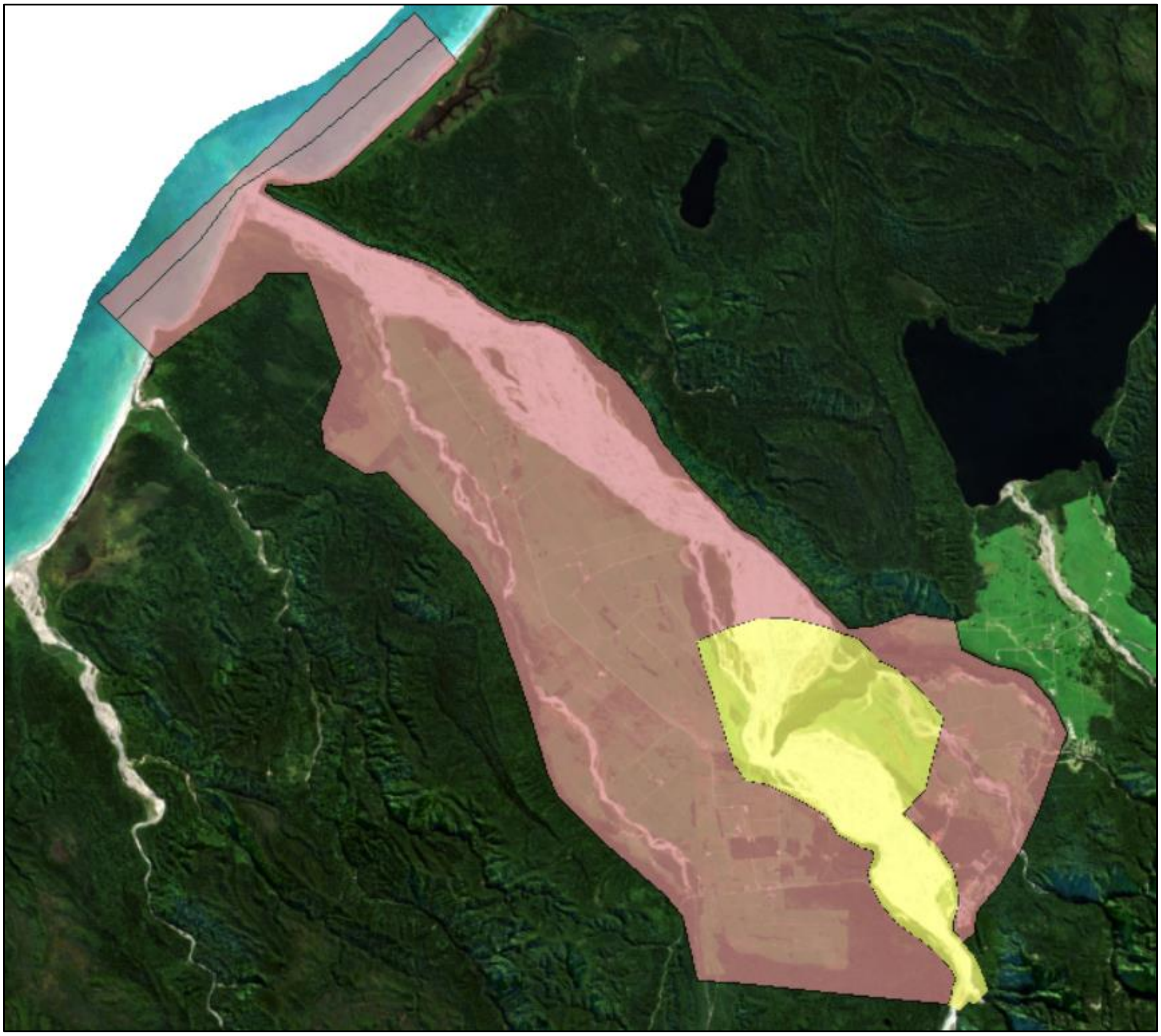


Figure 3 - 2021 model extent shown in yellow, and the expanded extent for the options assessment scenarios shown in pink.

Stopbank Heights

The latest LiDAR data (2019) does not have the current true left stopbank levels as these were raised after the LiDAR was flown in 2020 by Waka Kotahi by an average height of 2m. There have also been modifications to the true right stopbank over the years, particularly in the vicinity of the state highway bridge, therefore the levels differ from that captured by the 2019 LiDAR survey.

Land River Sea Consulting Ltd carried out a survey of the main true left stopbank as well as the Church and Helipad bank in June 2021 and additional survey was commissioned by WSP in May 2023 in order to capture the elevation of the secondary stopbank on the true left. Survey was carried out in the locations shown in Figure 4 below. Additional survey on the right bank as well as downstream of this location was not required as these assets have not changed since the 2019 LiDAR was flown.

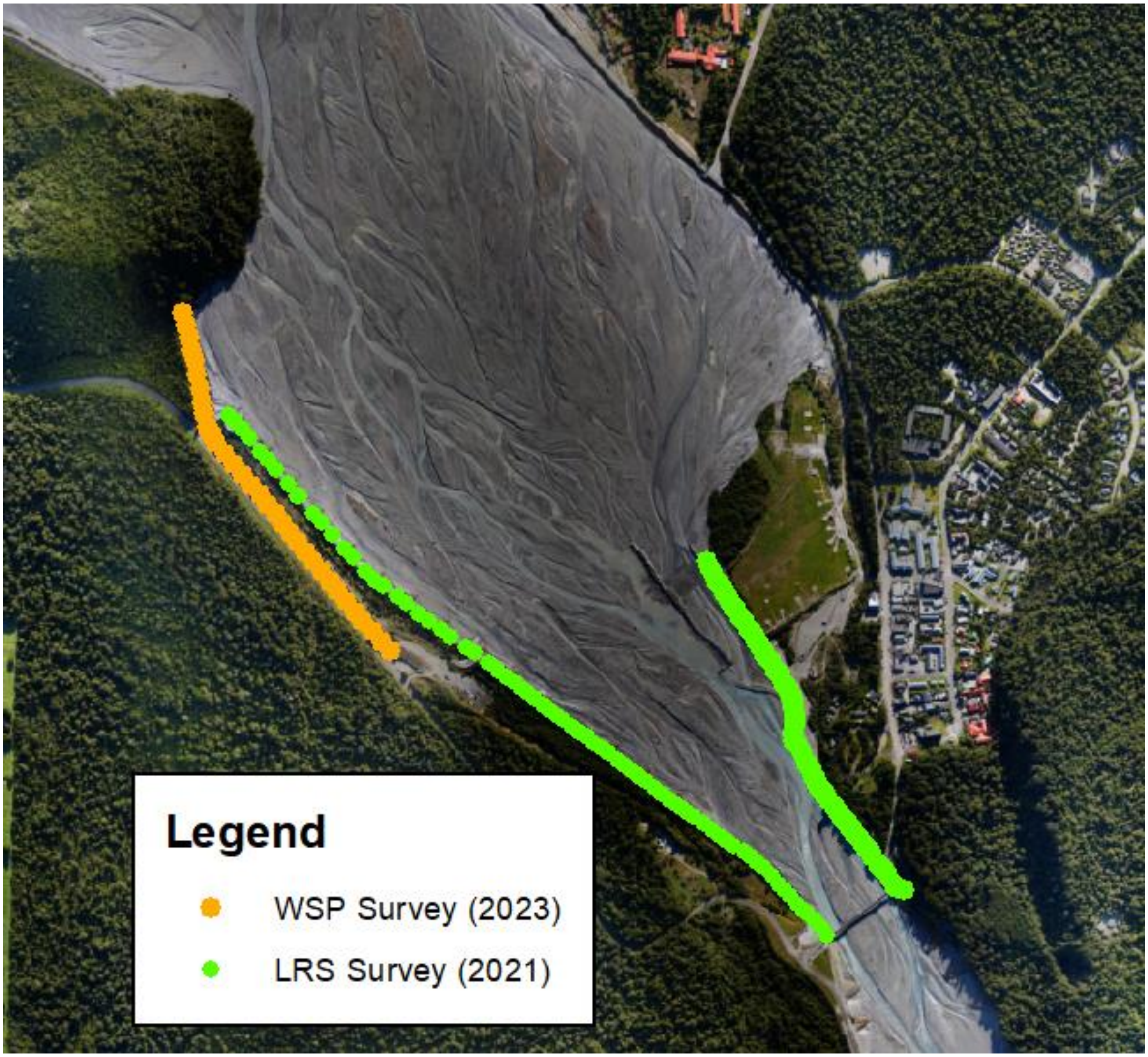


Figure 4 – Location of surveyed banks

Additionally, the proposed and consented – but not yet built – Tatare bund was included in the model. However, the Tatare Bund is located at a significant distance downstream of Canavan's Knob and will not have any noticeable impact on floodwater upstream of this location and associated with the Proposal.

Model Scenarios

The model was run with the existing stopbank levels and then with the new proposed banks in place (as per Figure 2)

- 2021 bed level
- 2021 bed level with increased/decreased manning's 'n'.
- 2021 bed level adjusted with future aggradation scenario B (as per Gardner 2021) to allow for an additional 20 years of aggradation based on average historic rates. Bed levels have been raised based

on the average rate of aggradation at each cross-section location from 1993 to 2021 as detailed in the preliminary design report (Gardner, 2021).

Depth, speed as well as depth and speed difference maps have been produced and are attached at the end of this memo. It does need to be noted that this model is a fixed bed model, and is unable to dynamically simulate any changes in the bed levels. Future aggradation scenarios have been simulated but it is very difficult to predict how the bed may change overtime due to the new stopbanks being in place, however the alignment of the banks have been carefully designed with the geomorphology of the river in mind. It is not expected that the new banks will have a significant impact on the profile of the bed to cause any significant changes to the conclusions of this report.

Results Analysis

Current Bed Levels

Results show that the under the 2021 bed level scenario, the existing stopbanks are not likely to overtop with a peak flow of 2500 m^3/s, however some inundation of the heliport operations is evident due to back flow. As a result of this, results show that the increase in height of the stopbanks will not have any impact on the flood levels or velocities.

Analysis of the depth difference results show that the changes to the stopbanks on the true right bank result in very small increases in flood depth except immediately adjacent to the new section of bank (which is to be expected). Increases in flood level elsewhere however and in particular on the true left stopbanks upstream of Canavans Knob are negligible (ie less than 1cm) and within the tolerances of the model in addition there are no observable change in speed/velocity. Depth difference outputs are shown in Figure 5 below.

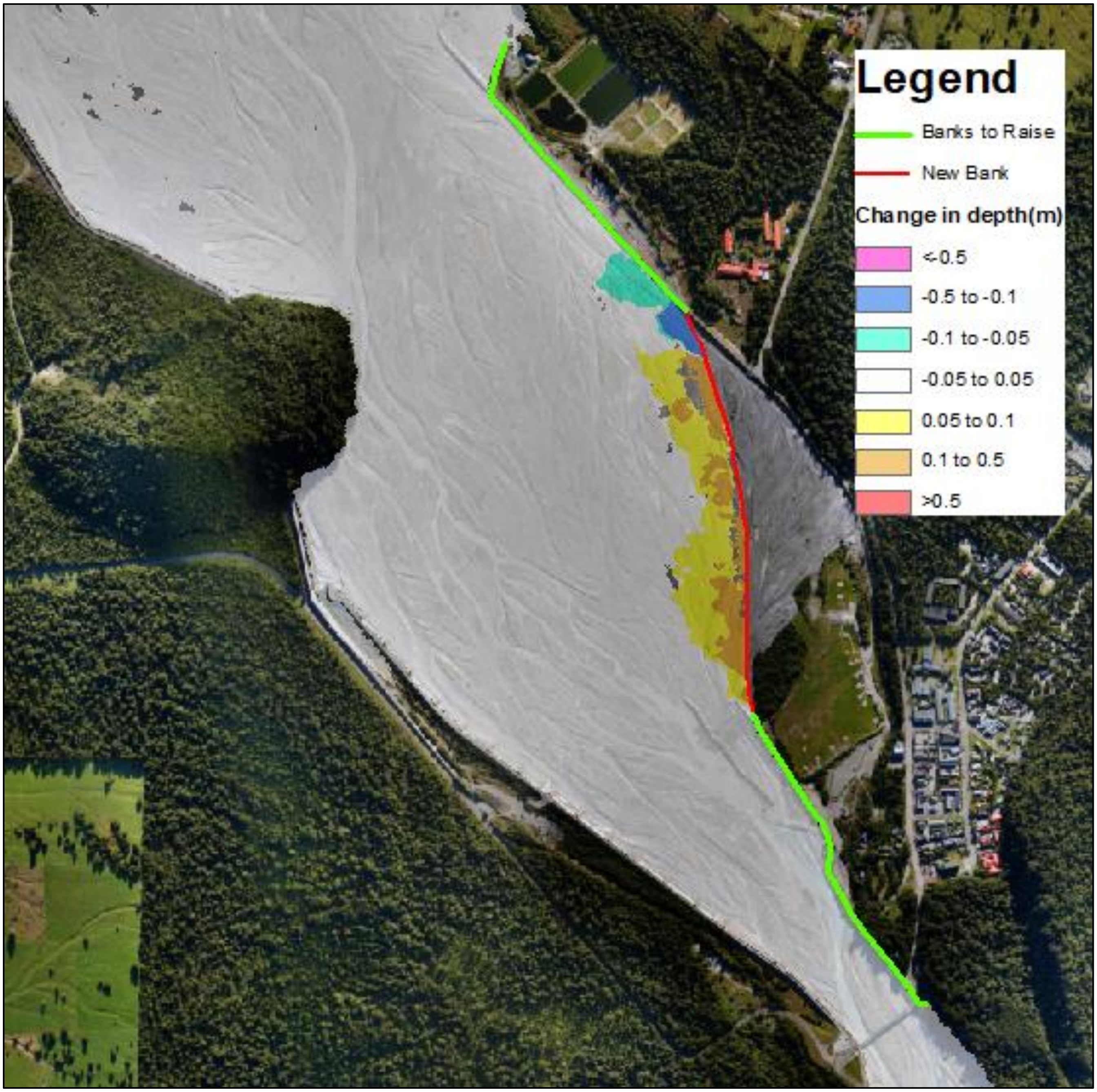


Figure 5 – Depth difference map for 2500 m³/s flow with 2021 bed levels

Future Bed Levels

For the modelled future bed level scenario (which is what the new banks are designed to), the model results show that we can expect significant overflow on both the true left and true right banks. The new stopbanks will prevent all overflow on the true right bank, however overflow on the true left bank will remain.

The difference maps indicate that the increased height of the true right stopbanks result in a small (less than 5cm) increase in flood depths (Figure 6) visible on the true left stopbanks upstream of Canavans Knob, this results in very minor increase in flood extents on the true left bank farmland with increased flood levels being less than 1cm. It is my opinion that this increase is within tolerance levels of the model, and that any increase in flooding would not actually be noticeable on the ground.

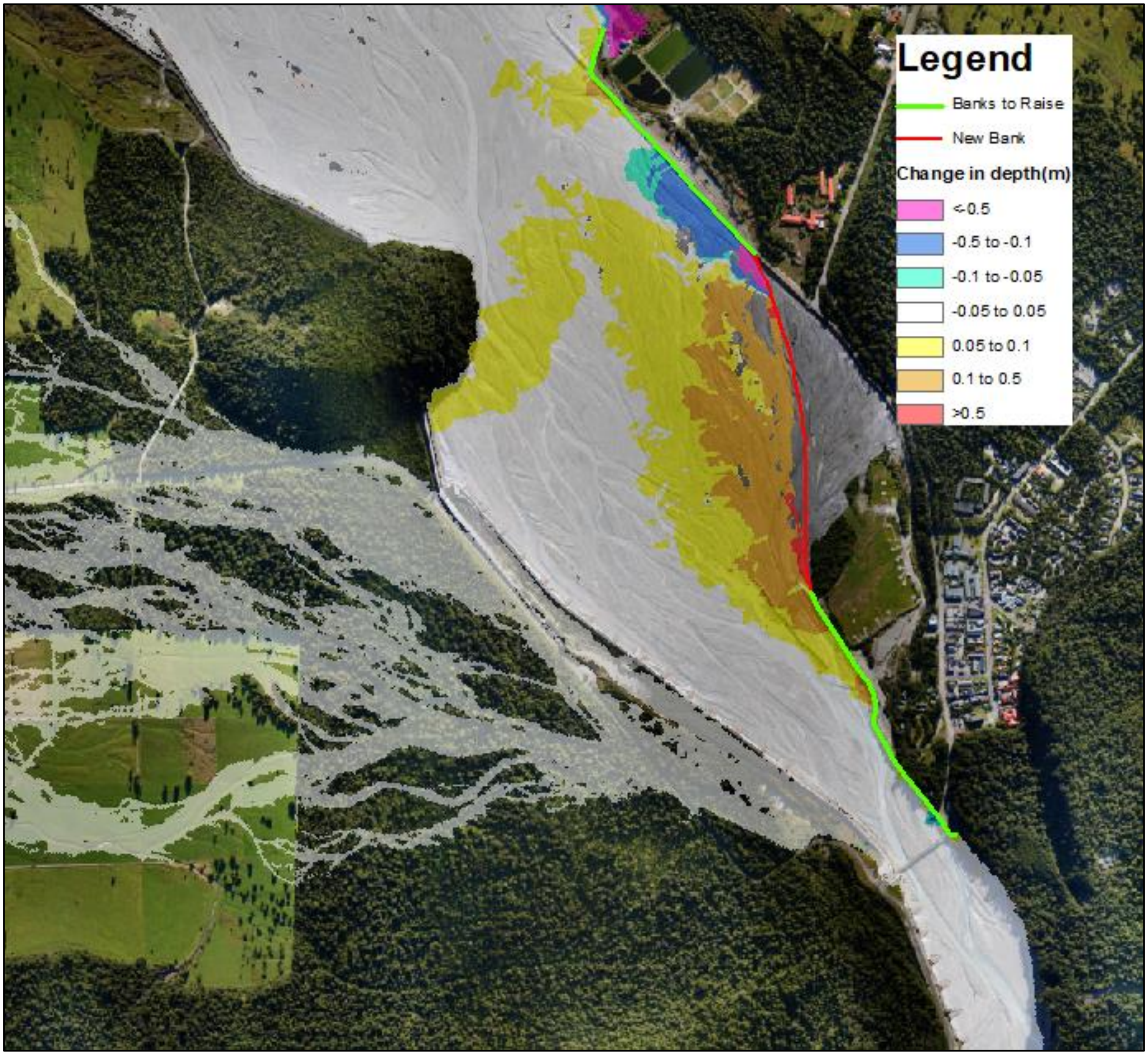


Figure 6 – Difference in depth map for future bed level scenario (allowing for 20 years of aggradation) – Note – white indicates change within a range of +/- 0.05m and is considered within tolerance levels of the model

It may seem counterintuitive that raising the stopbanks on the true right of the river will have no significant impact on the stopbanks on the true left. However, close examination of the topography shows that;

The natural high ground levels on the Church bank (ie immediately downstream of the State Highway Bridge) are significantly higher than the existing true left stopbank and hence the preferential overtopping direction is currently to the south side (i.e. true left), immediately downstream of the bridge. Raising the stopbanks does not alter this.

The existing helipad stopbank is intentionally slightly higher than the true left stopbank to ensure that the true left stopbank overtops before the true right stopbank (Figure 7). Raising the stopbank therefore doesn't change the general behaviour, it just slightly increases the volume of water to overtop the true left bank. Ensuring the river spills to the south first, allows for the preferential protection of the significant assets on the true right of the river including the state highway, wastewater treatment ponds as well as the main urban township which includes hotels, restaurants, accommodation venues as well as educational and health facilities.

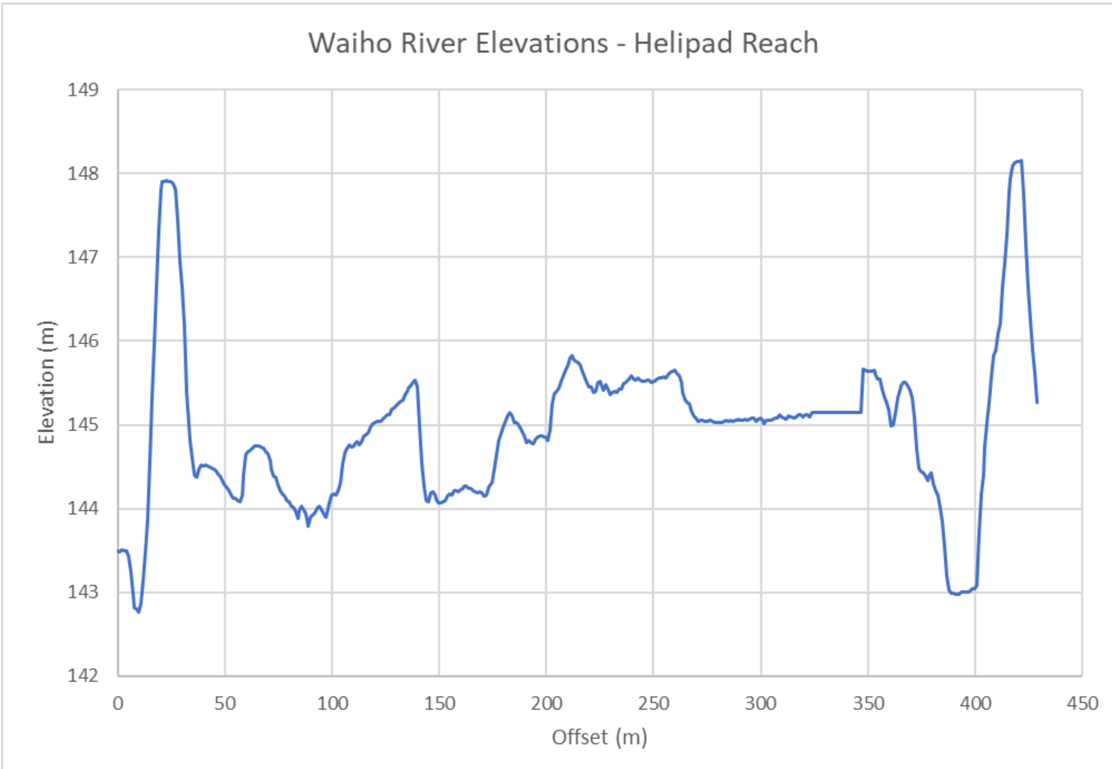


Figure 7 - Cross section highlighting stopbank elevations in the Helipad Reach showing that the true right stopbanks are already slightly higher than the true left

At the downstream end of the new section of stopbank and near the 55km Corner, the true right stopbank is built on the edge of a natural alluvial fan and the true left stopbank has been built down the centre of the alluvial fan. The surface of the fan along the left side of the river is significantly higher than the right side and the stopbanks on the true left are therefore significantly higher in elevation than those on the true right. Even when raised by 2m, the right stop banks are lower compared to the true left side (Figure 8). In addition, the active bed of the river is very wide at this location, expanding to a width of approximately 1km compared to 350m in the Helipad Reach, allowing for significant buffer capacity for the increase in volume to be distributed over a wide area.

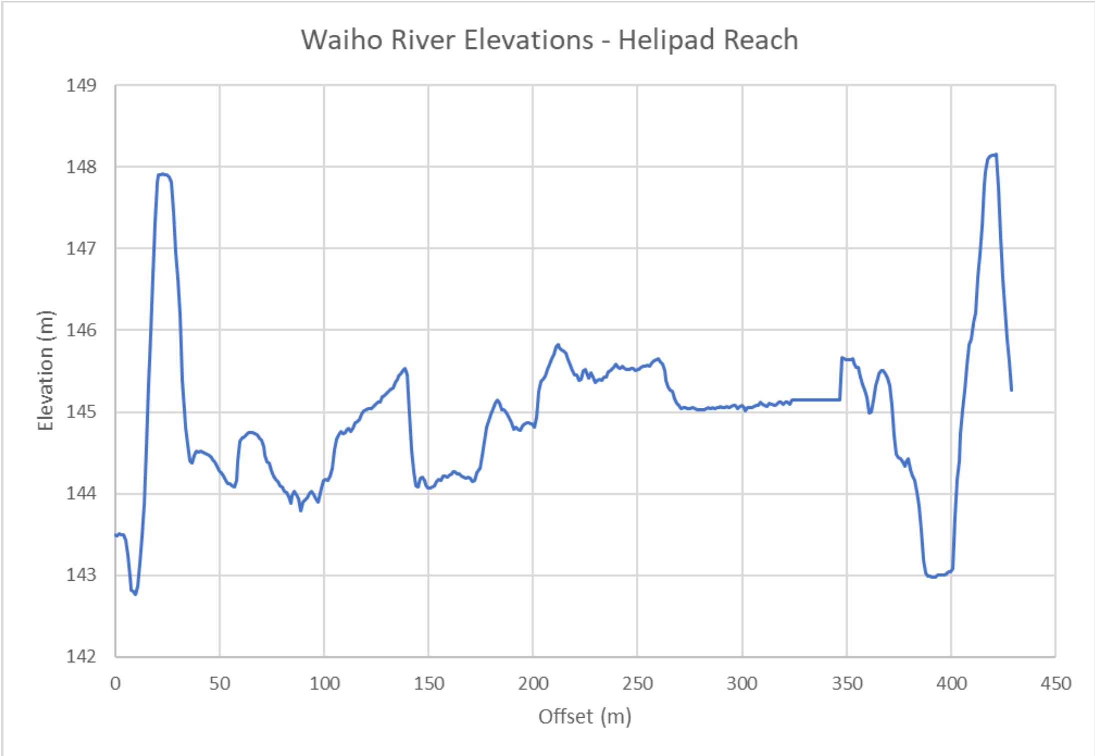


Figure 8 - Cross section highlighting stopbank elevations just upstream from the 55km corner showing that the true right stopbanks are already significantly lower than the true left due to their location of the edge of the alluvial fan surface

We trust this memo meets your requirements, any questions please don't hesitate to make contact.

Kind regards,

Matthew Gardner (CMEngNZ CPEng)

Director, Land River Sea Consulting Ltd

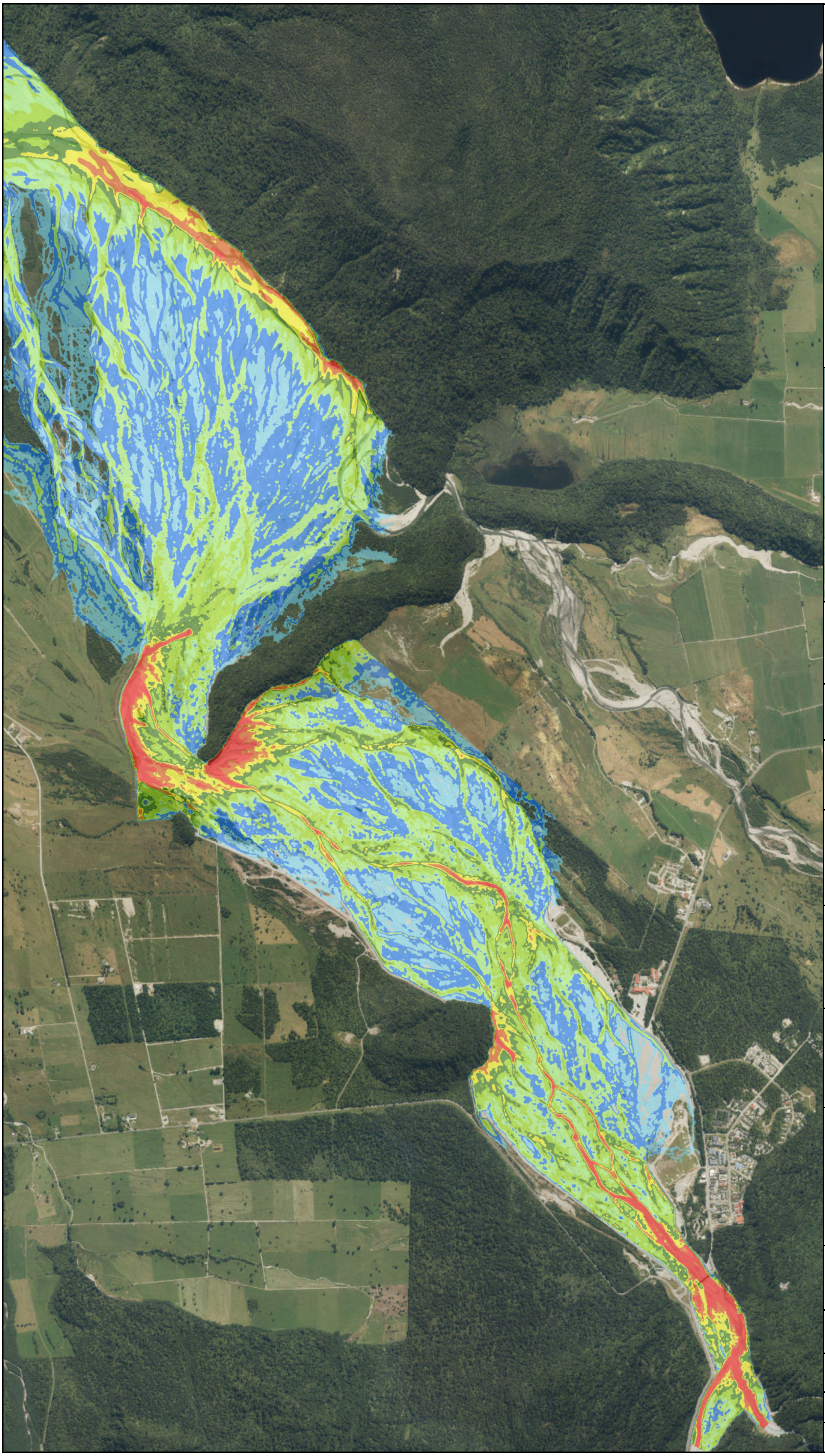
ATTACHMENTS

DEPTH MAPS

DIFFERENCE IN DEPTH MAPS

SPEED MAPS

DIFFERENCE IN SPEED MAPS



Legend

Peak water depth(m)

- 0 - 0.01
- 0.01 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 +

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WEST COAST EMERGENCY MANAGEMENT GROUP

PROJECT

Franz Josef Flood Modelling

TITLE

PEAK DEPTH MAP

Existing Stopbanks
2021 Bed Levels
2500 cumec design flow

Model Information

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New Zealand Transverse Mercator
Vertical Datum: LVD1937
Model Completed: February 2022

0 250 500 1,000
Meters

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REVISION	01	DATE	24/05/2023
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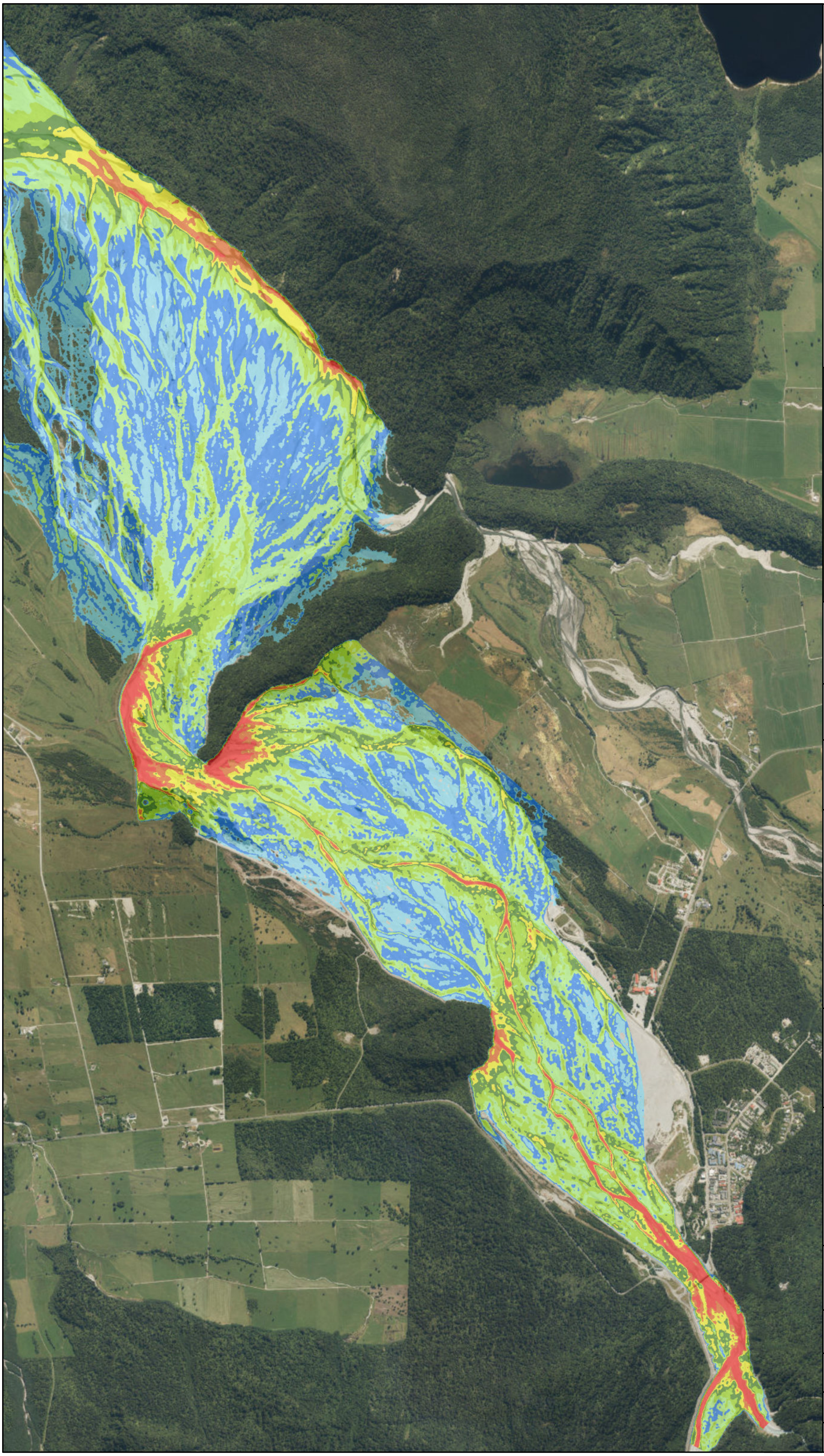
Reviewed By	MG	Matthew Gardner	



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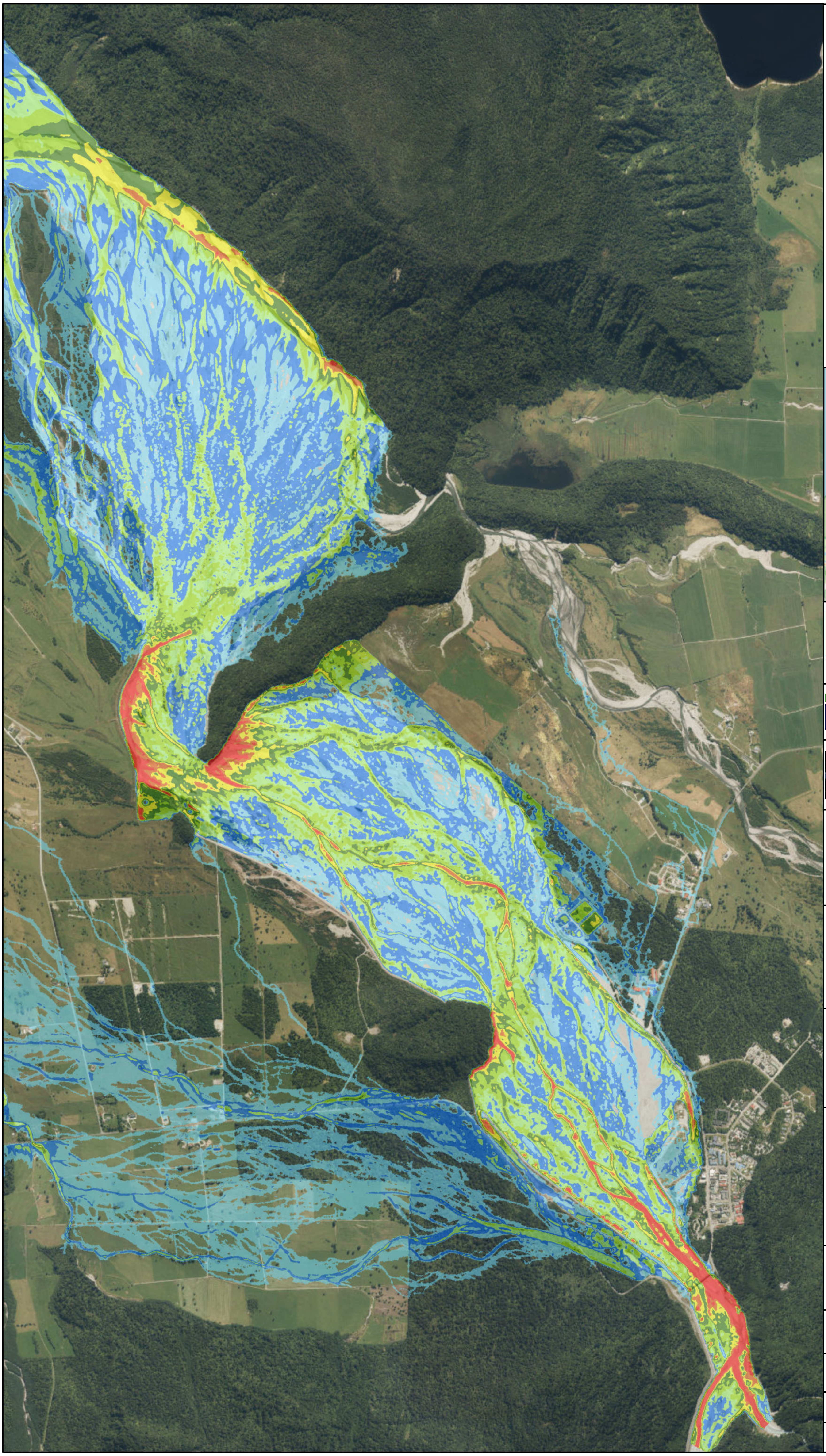

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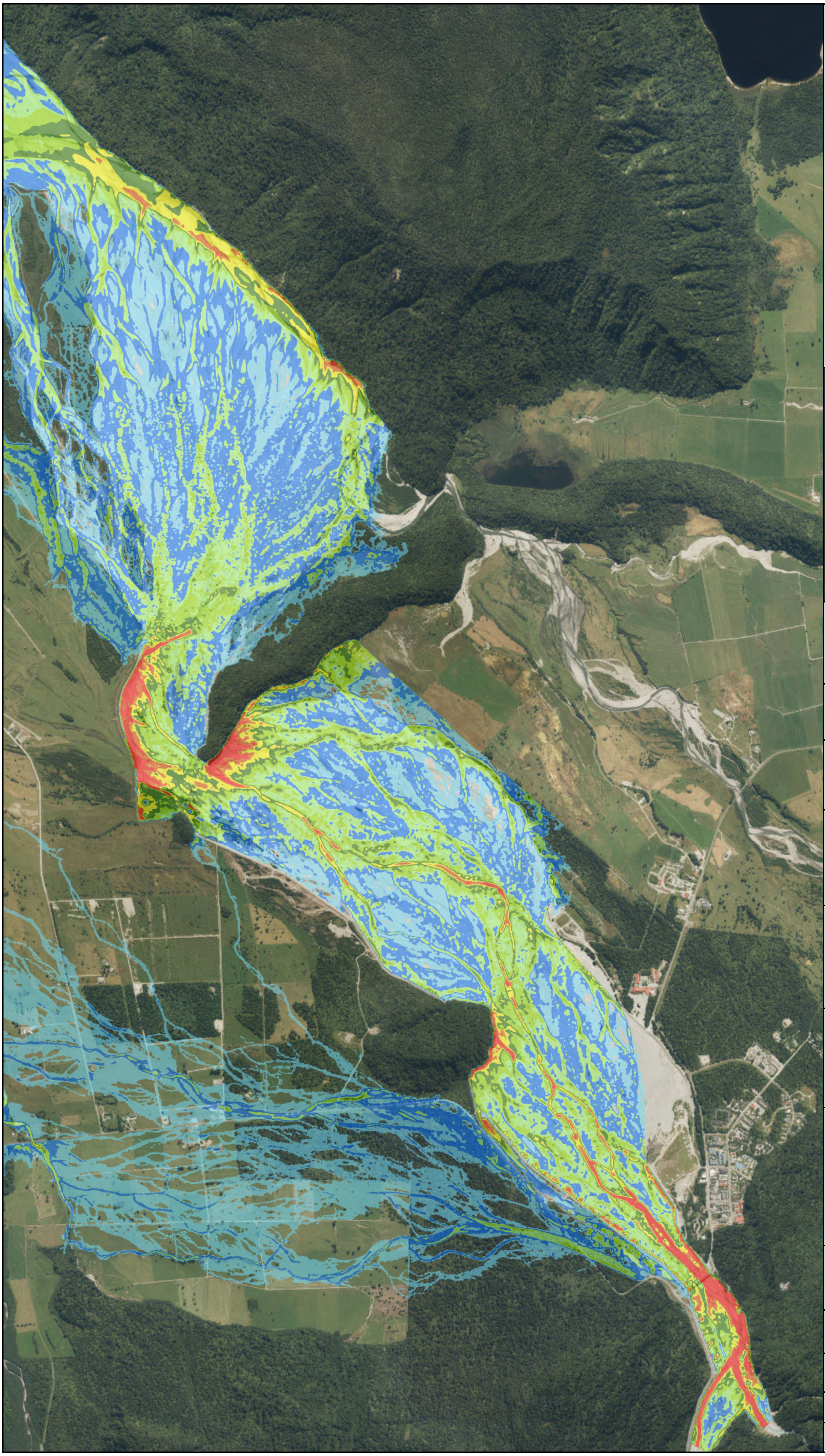

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- <-0.5
- -0.5 to -0.1
- -0.1 to -0.05
- -0.05 to 0.05
- 0.05 to 0.1
- 0.1 to 0.5
- >0.5

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2500 cumec design flow

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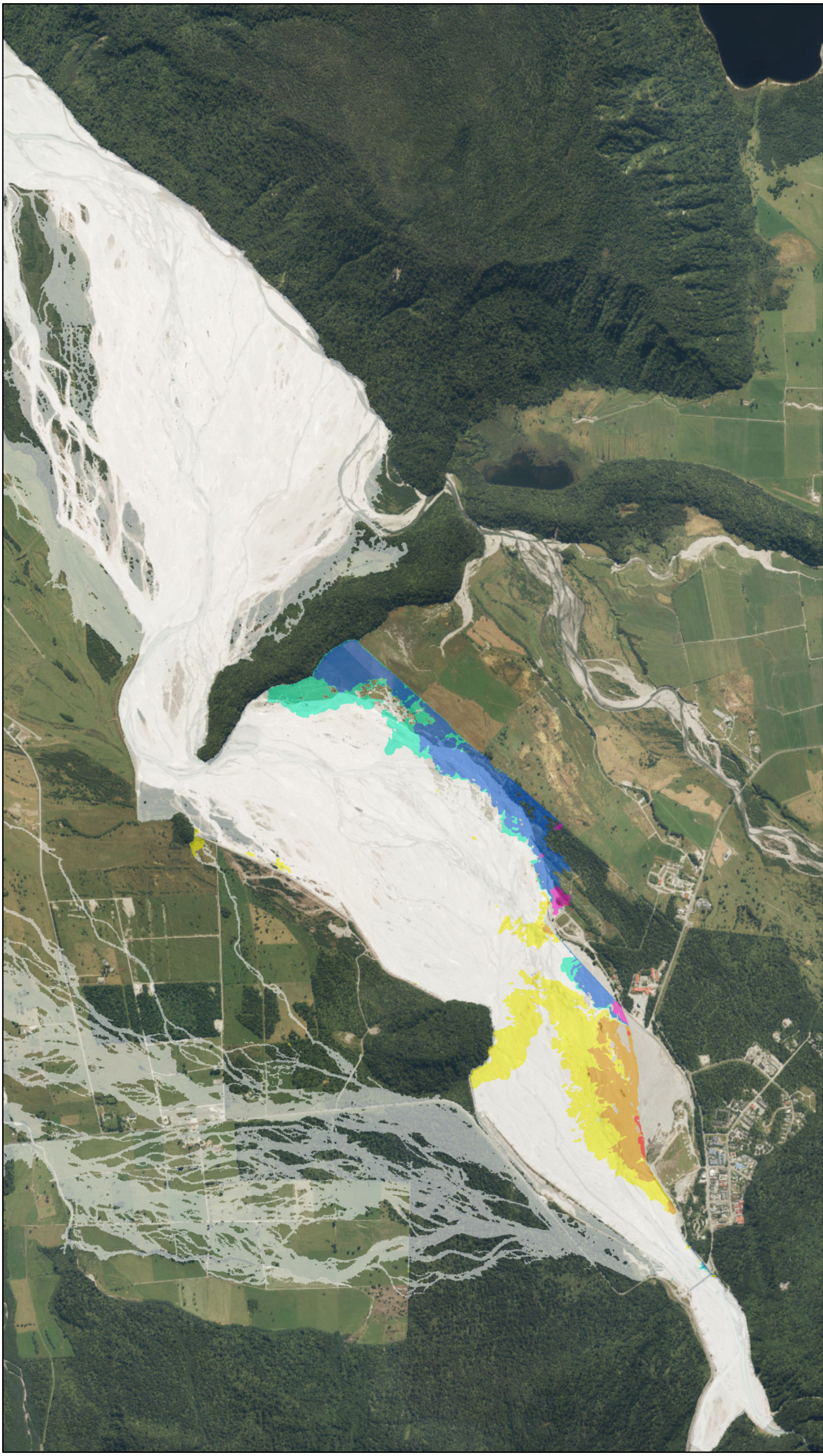

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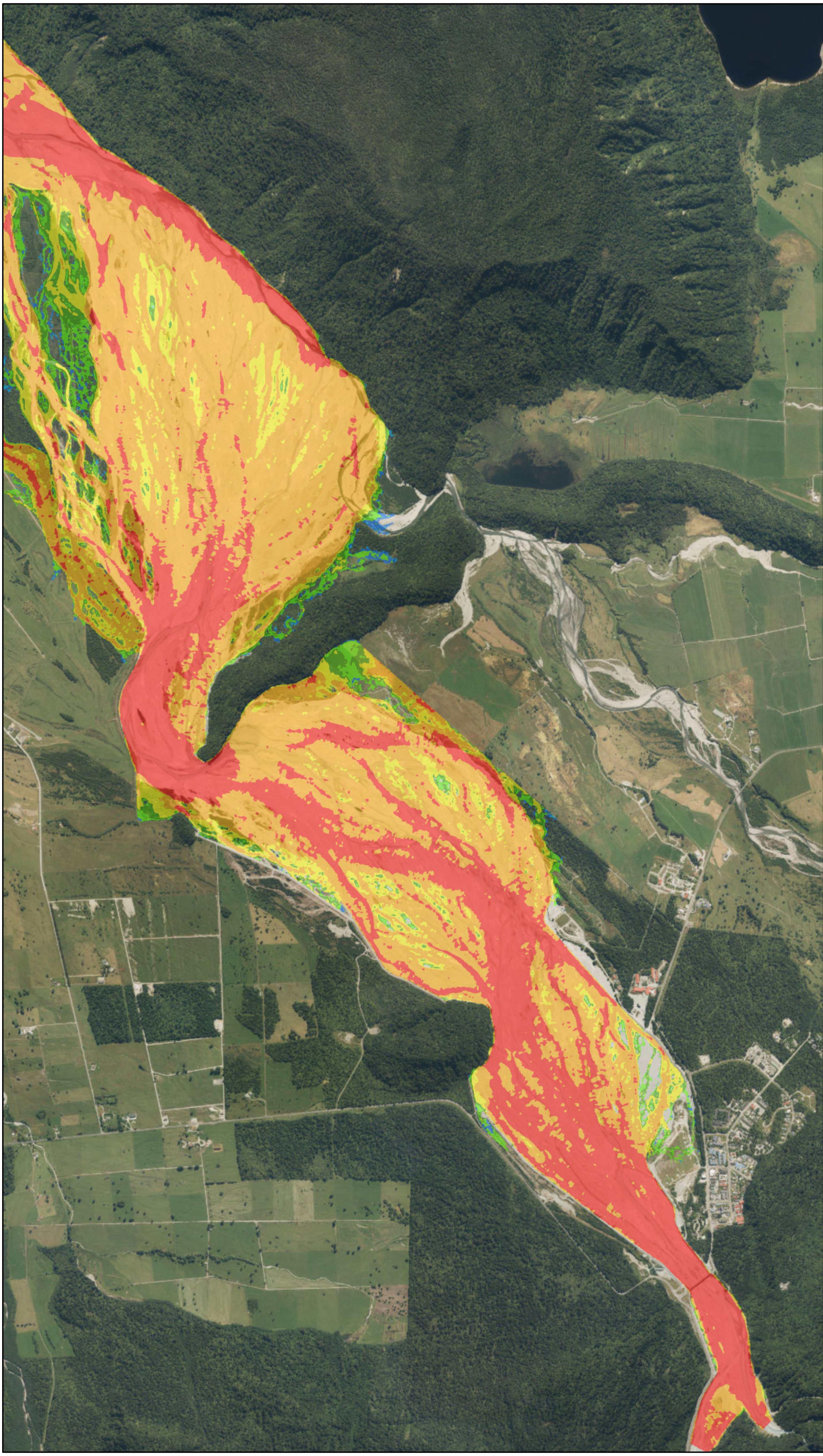

Legend

Peak water speed(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

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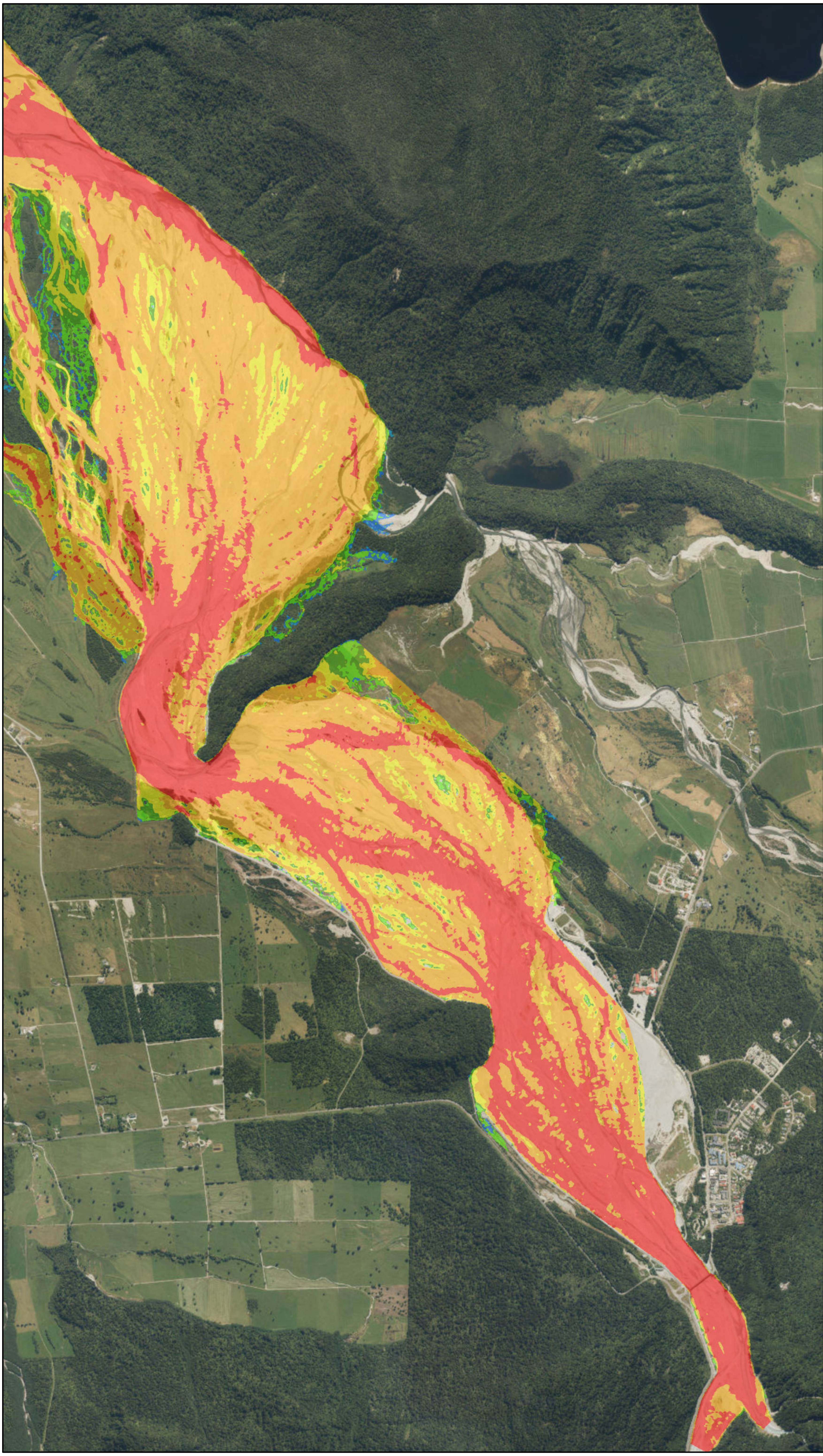

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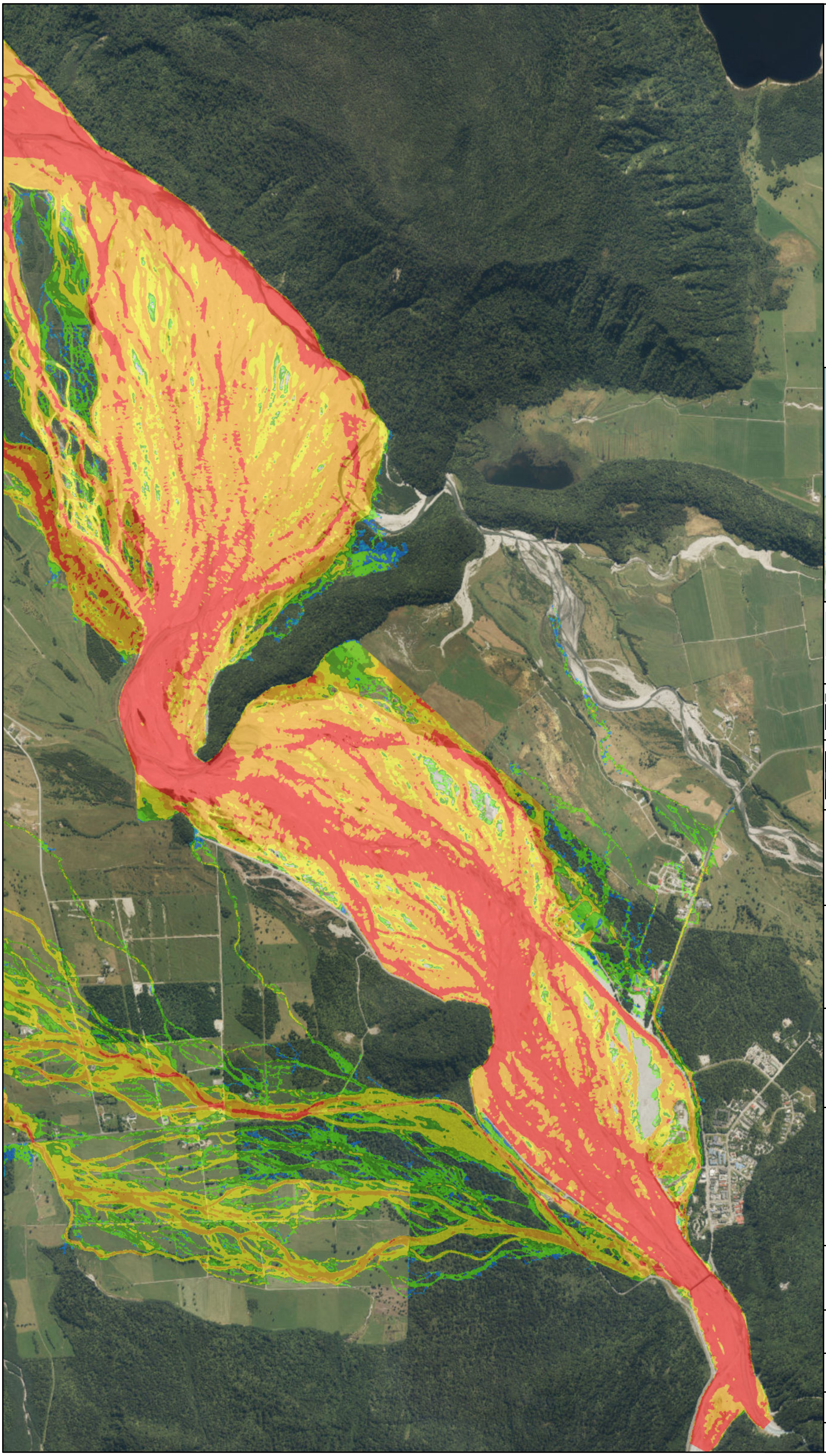

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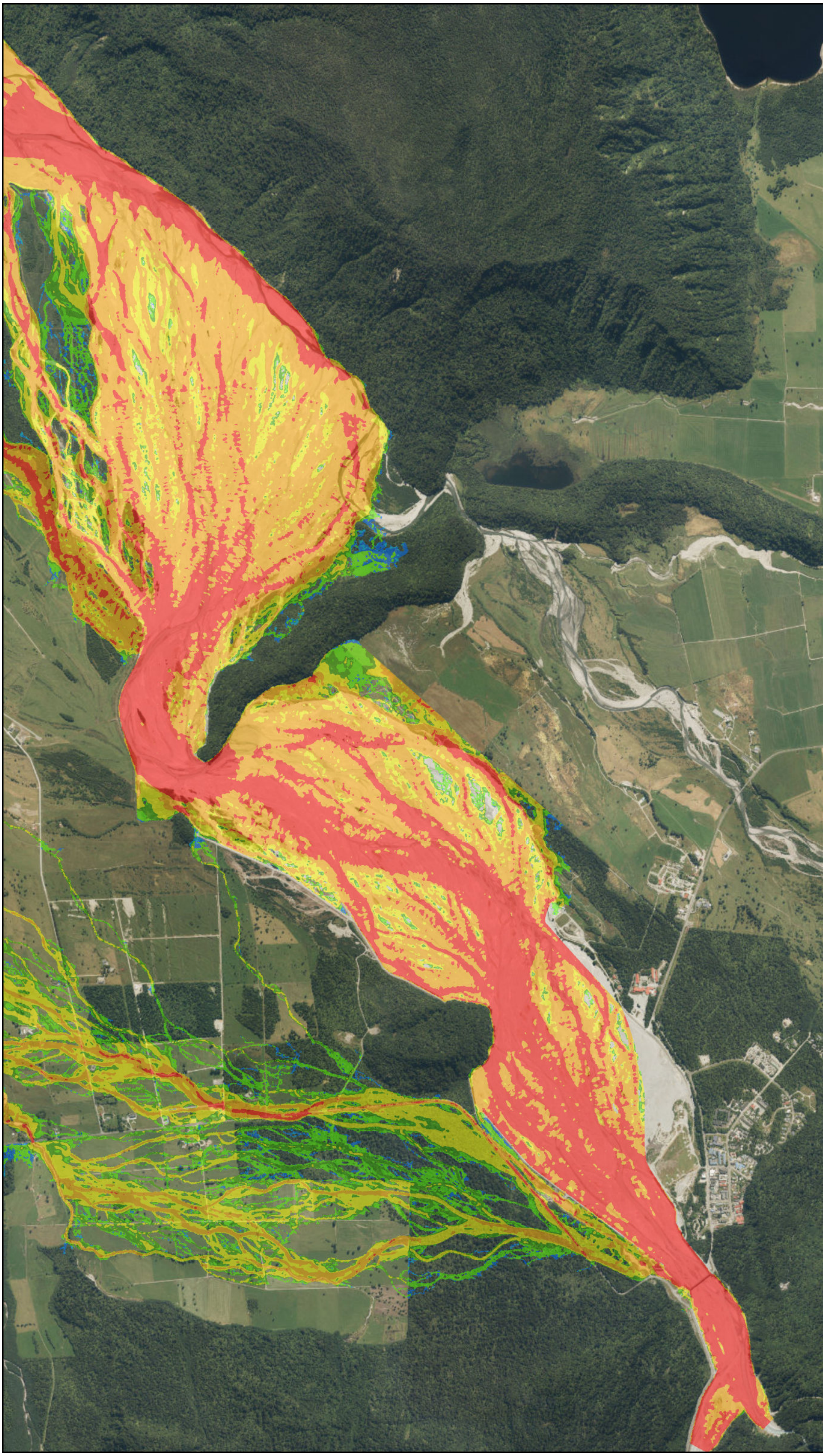

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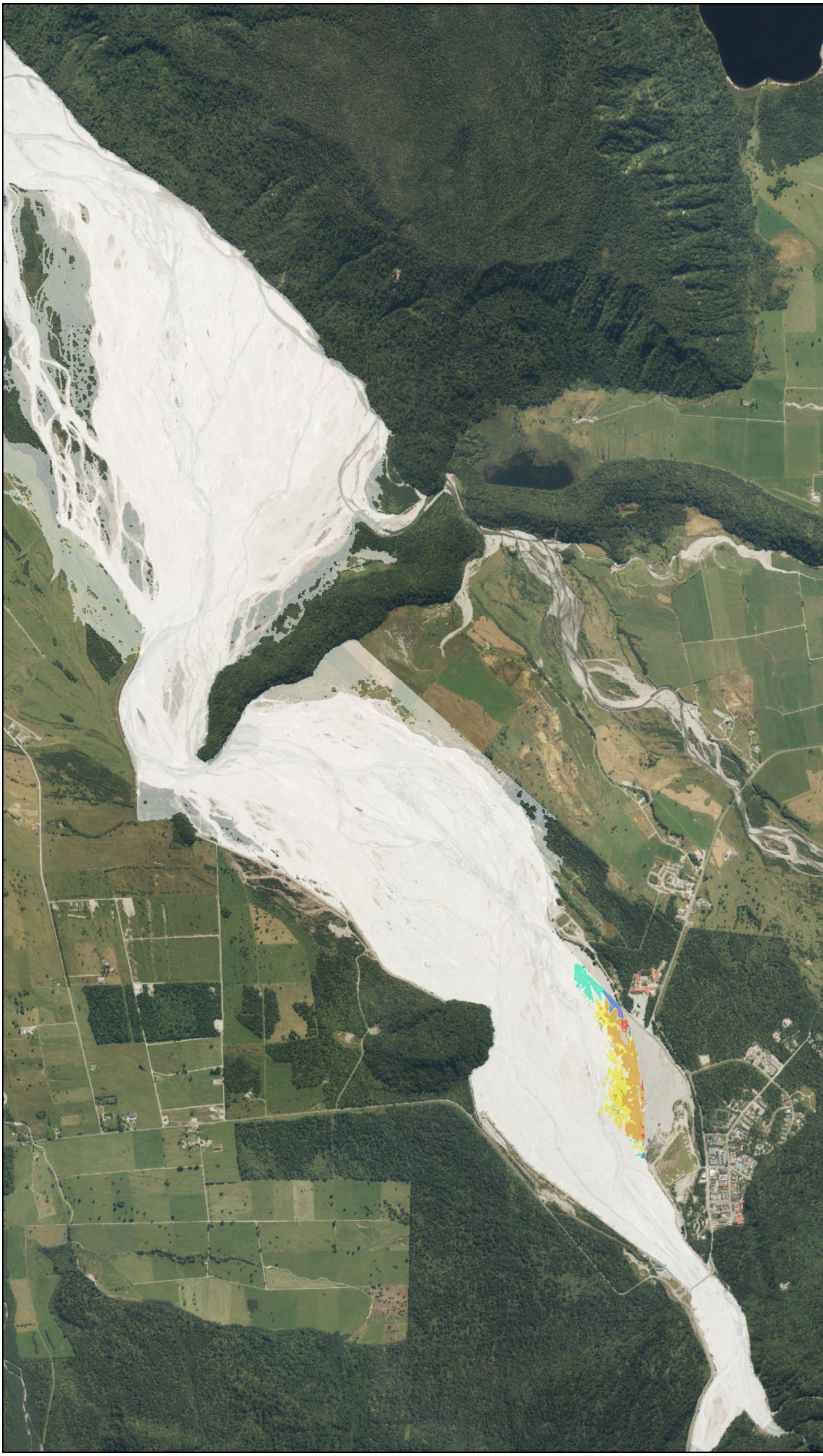

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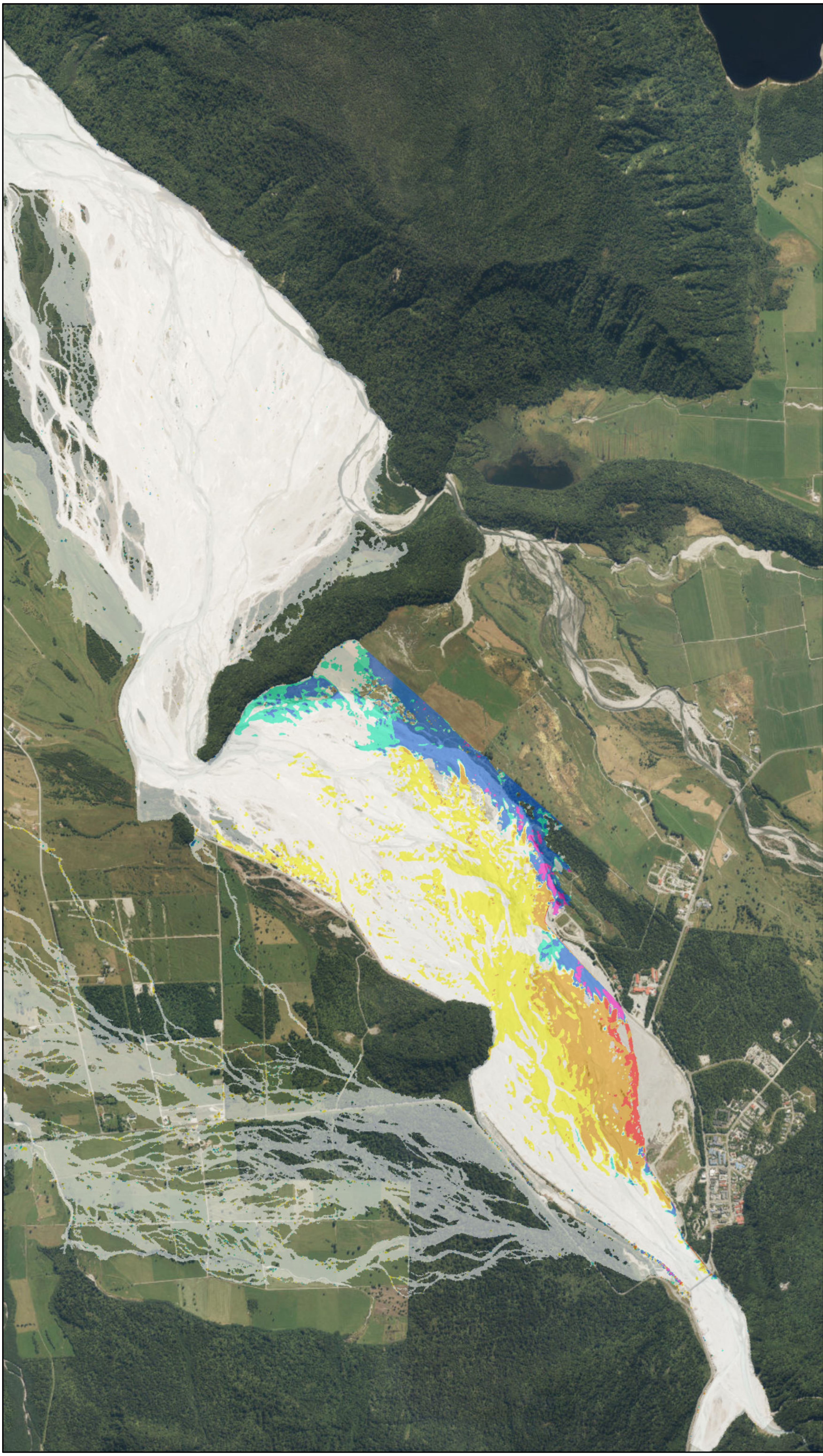

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