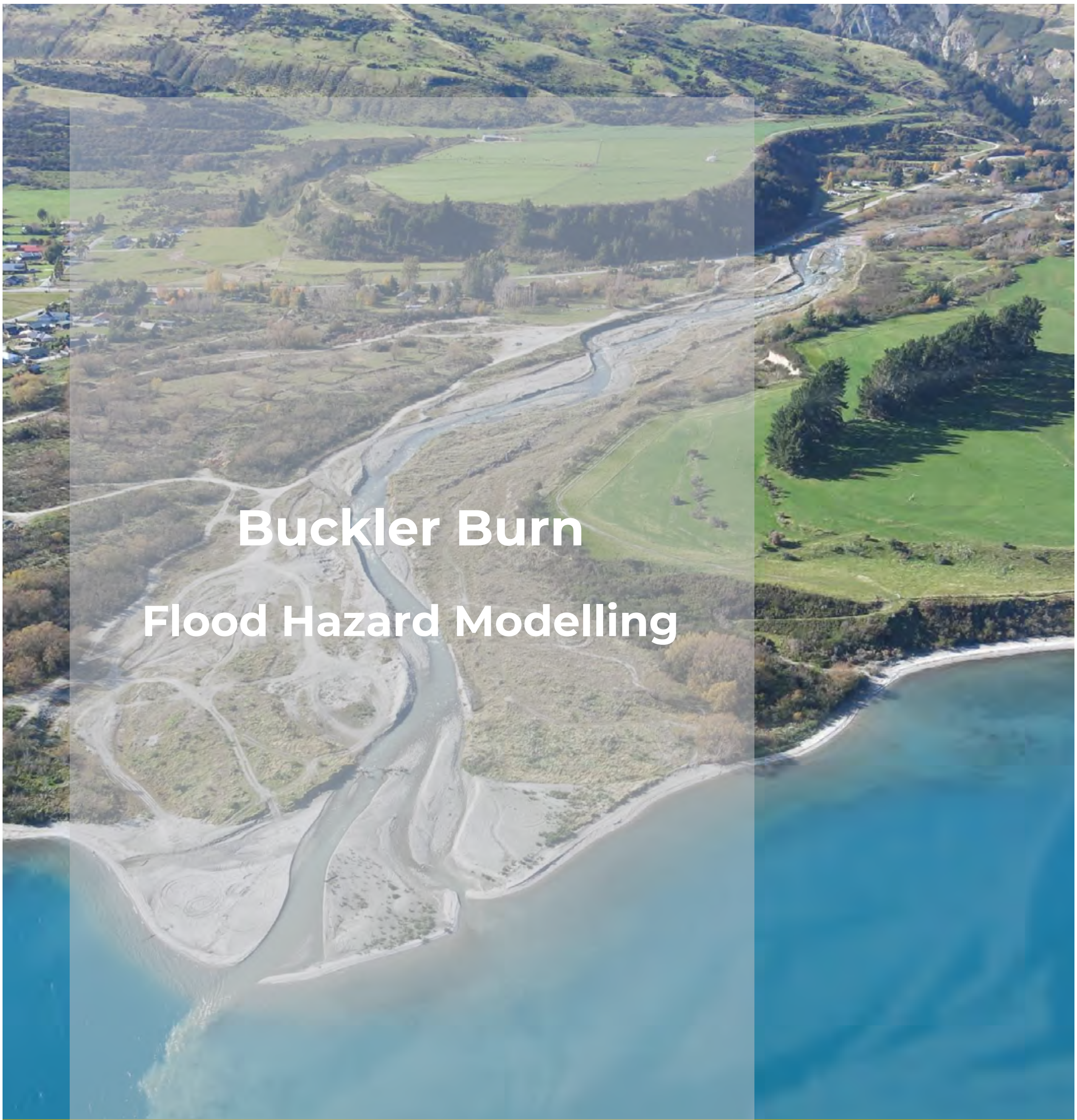

Buckler Burn

Flood Hazard Modelling

7 August 2023
Client: Otago Regional Council
Report by: Matthew Gardner & Rose Beagley
Land River Sea Consulting Limited
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1. INTRODUCTION

1.1. SCOPE

Land River Sea Consulting (LRS) has been contracted by the Otago Regional Council (ORC) to develop a detailed flood model of the Buckler Burn alluvial fan area from the Glenorchy-Queenstown Rd bridge downstream to Lake Wakatipu.

The purpose of the model is to:

- Inform landowners and residents of the potential hazards posed by the Buckler Burn; and
- Provide input into the ongoing Head of Lake Wakatipu Hazards Adaption project, providing a better understanding of hazard and risk characteristics of the Buckler Burn flooding threat.

The area of interest for this project is presented in Figure 1-1 below.

Figure 1-1: Area of interest showing the Buckler Burn, Glenorchy and Campbelltown.

The scope of the project involves:

- Upgrading the LRS 'Dart/Rees Rivers MIKE21FM model' by converting it to HECRAS, and then extending the mesh to include the entire Buckler Burn fan, creating a new roughness layer, and recalibrating it to the February 2020 flood event.
- Simulating a range of design flow scenarios on the fan.
- Simulating a range of simplified aggradation scenarios on the fan.
- Generating peak depth, floodwater elevation, velocity, hazard, and extent maps for the above scenarios.

1.2. PREVIOUS MODELLING

The Buckler Burn and alluvial fan have been modelled previously by both URS NZ Ltd and Land River Sea Consulting Ltd as part of larger projects. Glenorchy Floodplain Flood Hazards for the former, and the Dart-Rees Rivers model for the latter.

In 2007, URS NZ Ltd completed modelling of the Glenorchy floodplain including Buckler Burn(Whyte & Ohlbock, 2007). The modelling was carried out using MIKE11 software with the 1D model based on the limited cross sectional survey (2006). It included an assessment of the hydrology as well as an assessment of the level of service of the Glenorchy stopbank. However, none of the scenarios modelled showed flooding from the Buckler Burn onto the Glenorchy-Queenstown Rd. It is believed that this was due to the bedload transport being a more complex process during a flood than what had been modelled, or under-estimation of the design flows.

In 2022, Land River Sea Consulting Ltd built a detailed MIKE21 hydraulic model of the Dart-Rees Rivers using the 2019 LiDAR data as well as available cross section survey data. The purpose of the model was to provide a better understanding of the potential flood hazard from both rivers to Glenorchy as well as the surrounding rural land for a range of return period events, including the potential impacts of climate change and stopbank failure. The Buckler Burn fan was included in the extent of the model, but no flood hazard assessments were carried out on it.

Debris flow modelling of the Buckler Burn has also been completed by Geosolve Ltd (not publicly available). This was not a comprehensive investigation, rather a test of sensitivity to factors such as failure locations, debris volumes and release mechanisms (van Woerden & Payan, 2022).

In addition, the geomorphology of the Buckler Burn alluvial fan has been documented in several memos and reports prepared by ORC and Massey University. These include:

- URS - Glenorchy area geomorphology and geo-hazard assessment (Mabin, 2007).
- GNS - Otago alluvial fans project: Supplementary maps and information on selected areas of Otago. GNS Science consultancy report 2009/052, prepared for ORC (Barrell et al., 2009).
- ORC - Natural Hazards of Glenorchy (Otago Regional Council, 2010).
- Massey University - Key notes and observations from preliminary assessment of debris flood and flow hazard potential at Glenorchy (Fuller & McColl, 2021).
- ORC - memorandum on the Buckler Burn aggradation scenarios (van Woerden, 2023).

1.3. SITE VISIT

On the 12th and 14th of October 2021 Matthew Gardner visited the Glenorchy area for the Dart-Rees flood model investigation. He was accompanied by Tim van Woerden and Magdy Mohssen on the 12th ofOctober.

The focus of the site visit was to observe the terrain in person which is invaluable for gaining a full appreciation for the characteristics of the site. Key areas for the Dart-Rees model were traversed over the two days with photography captured using both a drone and standard camera.

Special attention was paid to several areas, and those that are relevant to the current Buckler Burn project have been listed below:

- Glenorchy township and potential inundation areas
- Glenorchy stopbank
- Buckler Burn was briefly viewed.

2. LIMITATIONS OF STUDY

This study has been carried out using the information and data made available to the author at the time of this study. There are a number of uncertainties which should be acknowledged which include but are not limited to:

- LiDAR data – whilst there is good coverage, LiDAR data comes with a degree of vertical uncertainty typically considered to be in the range of +/-0.15m.
- The model is a fixed bed model and does not allow for bed mobilisation / gravel transport. This is especially relevant, given we are modelling an alluvial fan which is an inherently dynamic system that experiences significant channel movement and geomorphic change during and outside of flood events.
- Input hydrology data is based on hydrological modelling. There is no physical flow gauge in the Buckler Burn nor raingauge in the catchment.

3. HYDROLOGY

3.1. CATCHMENT

The Buckler Burn is a steep catchment to the south of Glenorchy township, with its active channel belt located just shy of the developed residential area (Figure 3-1). The headwaters begin on the eastern slopes of the 1900m to 2300m high Richardson Mountains - from Mt McIntosh around to Mt Alaska - before the burn drops steeply down to Lake Wakatipu where an active alluvial fan and delta system has formed.

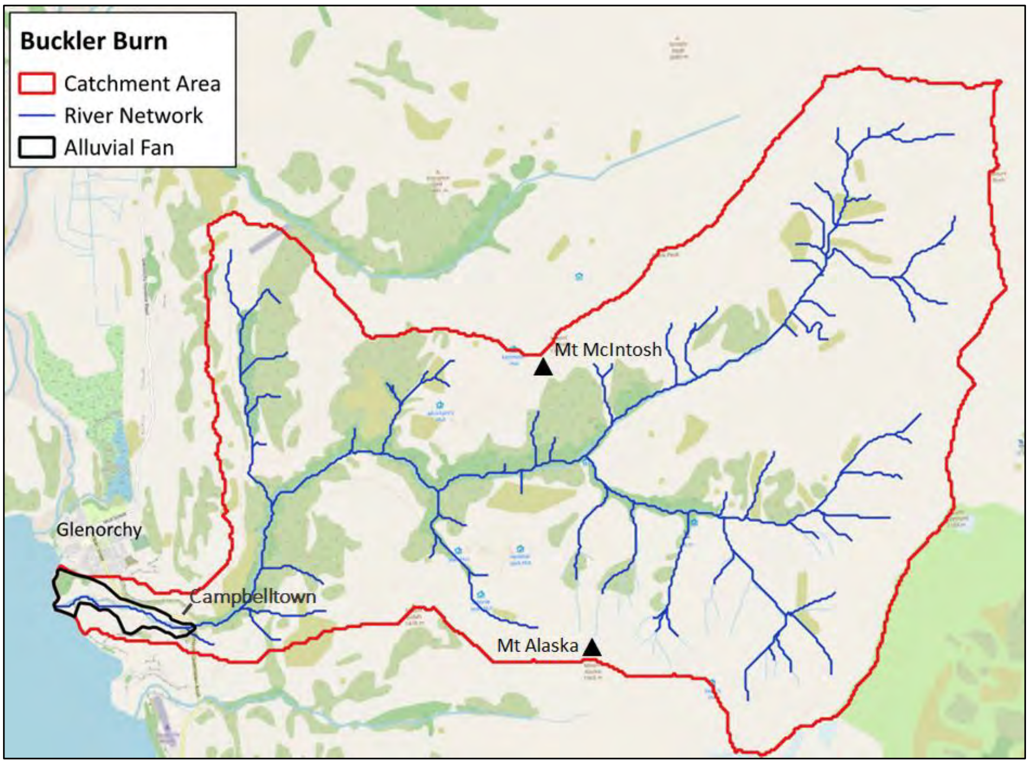

Figure 3-1 – Buckler Burn catchment.

Due to its steep gradient and origin in the Richardson Mountains – largely unvegetated in the tops and schist dominated – the burn has a high bedload, which can be moved downstream during high flow events. These events are largely rainfall-driven, but there is also the risk of dambreak flood occurrence from the upper reaches and/or the gorge. As a result, the alluvial fan at the burn and lake junction undergoes several dynamic processes including avulsion, channel migration and aggradation which pose a threat to the bridge, Glenorchy-Queenstown Rd, Glenorchy, and Campbelltown.

3.2. FLOOD AND FAN HISTORY

3.2.1. FLOOD EVENTS

The Buckler Burn is not monitored for water level or flow, and there are no rainfall gauges within its catchment. Therefore, knowledge of past floods events is based upon the relatively few observations of events, and the NIWA NZ Historic Weather Events Catalogue (Table 3-1).

Table 3-1 – Observations of weather events which have resulted in flooding from the Buckler Burn impacting on Glenorchy and/or Campbelltown (NIWA, 2018a)**.**

Event/Observation	Description	Impact
1937	Buckler Burn flood risk to the Glenorchy School.	The school was forced to relocate.
1970s onwards	Buckler Burn was threatening the southside of Glenorchy and the Glenorchy Queenstown Rd.	Various protection works were built. Gravel was removed from the channel.
1978 - October	4-day weather event with warm rain resulting in snow melt.	1978 - Numerous slips closed the Queenstown Glenorchy Rd.
1979 - December	Torrential rainfall in Central Otago resulting in widespread flooding. Lake Wakatipu rose by 1m.	The Glenorchy dam on the Ox Burn/Twelve Mile Ck (which has a very similar catchment to the Buckler Burn) filled with gravel, rocks and trees and took months to clear. Many bridge approaches in West Otago badly affected. 1978 and 1979 - Several cottages on the southern side of Glenorchy, a few hundred metres upstream of the lake were reported to have flooded. This was also the location of the old school site which had been relocated earlier due to flood hazard.
1994 – January	3-day event with serious flooding occurring in the Queenstown-Lakes district from streams bursting their banks.	400 people evacuated from Glenorchy by boat.
1999 - November	5-day event with an estimated return period of 150 years. The Rees Valley Station recorded 275mm in 4 days (ARI of 100yrs). Lake Wakatipu rose extremely high and flooded its foreshore, peaking at 312.7m asl, 0.5m higher than the previous high record set in 1878. Aggradation of up to 2m occurred in the Buckler Burn channel.	Surface flooding and slips closed roads throughout the region, with civil defence emergencies declared in Otago. It experienced some of its worst flooding in the century. Road washouts isolated Glenorchy and Kinloch. The Buckler Burn inundated a section of the Queenstown-Glenorchy Rd with water and debris.

3.2.2. ALLUVIAL FAN

The Buckler Burn has formed an alluvial fan-delta system between where it departs the confines of the Richardson Mountains and flows into Lake Wakatipu.

Given the steep and mountainous nature of the upstream basin which is dominated by alpine weathering processes, rockfall, and mass movements, the fan has a high sediment supply. As a result, it's a very dynamic system with active geomorphic change. This is readily identified through the available aerial imagery from the last century, and photographs from the 1994 and 1999 events when floodwaters reached close to the southern margin of the Campbelltown and Glenorchy residential areas (Figure 3-1).

Survey datasets have also been used to show channel belt and fan surface changes. The few surveys available in addition to observations during larger flood events have been used to infer that the fan surface is aggrading or may aggrade in the future, and that this is leading to an increasing hazard (Mabin, 2007; Otago Regional Council, 1999, 2022).

In the section below, we will briefly discuss the aerial imagery in relation to the morphological characteristics of the fan, with the focus largely on the 1999 event as this is the most significant flood on record for the burn and is being used to validate the model.

In order to be consistent with any observations or references made to the alluvial fan in the section and the report as a whole, we have used the chainage created by ORC, measured in kilometres from the Glenorchy-Queenstown Rd bridge down the Buckler Burn alluvial fan to Lake Wakatipu (Figure 3-2).

Figure 3-2 – The Buckler Burn fan edge outlined in red, overlain by chainage measured in kilometres downstream from the road bridge.

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Aerial Imagery

The aerial imagery, photographs and observations indicate a very dynamic alluvial fan, with decadal scale fluctuations in activity. Quiescent phases are associated with a contracted active channel belt, whilst active phases are associated with an expanded active channel belt.

In the aerial imagery from the 1930's to the present day (1937, 1966, 2008, 2019), the alluvial fan experiences large-scale geomorphic changes as it shifts from an active phase into increasingly quiescent phases. The active river channel belt significantly narrows with each image, and as the width of the active channel belt changes, so too does the amount of vegetation present on the fan (Figure 3-3), with the amount of vegetation increasing as the belt narrows. This suggests that there are periods of time when flows do not exceed the threshold of the active channel belt frequently enough to inhibit vegetation growth and are therefore the more quiescent phases of the fan's lifecycle.

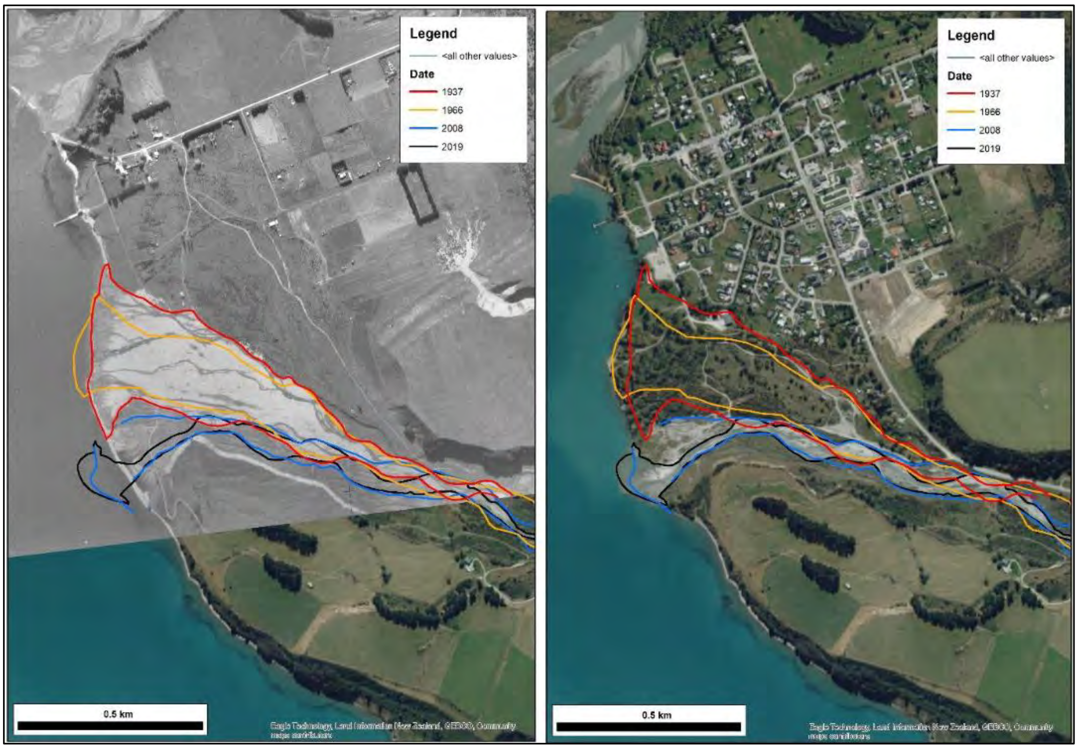

Figure 3-3 - Comparison of aerial imagery at the Buckler Burn in 1937 (left) and 2019 (right), annotated to show approximate extent of the active riverbed at four dates (1937, 1966, 2008, 2019) (ORC, 2022).

The aerial imagery from 1937, 1994, and 1999 (Figure 3-3 and Figure 3-4) suggest a much more active phase of the fan's lifecycle, with wider active channel belts and larger areas of exposed gravel compared to imagery post 2000 through to 2019, and in the 1960s. In these periods it is likely that sediment laden flood events occurred frequently enough to aggrade the fan and force channel changes through processes such as infilling, bifurcation, lateral migration, and avulsion.

Furthermore, in the aerial imagery from the January 1994 flood event, vegetation is still present between the Buckler Burn fan surface and the Queenstown-Glenorchy Rd (0.7 to 0.8km chainage). This vegetation and the road was then inundated with debris and water during the November 1999 flood (Figure 3-4).

Figure 3-4 – January 1994 and November 1999 aerial imagery.

The 1999 flood also generated a far greater active surface upstream of about the 1.15km chainage on the fan than the 1994 flood. This suggests sediment mobilisation and transportation downstream to the fan was likely greater during the 1999 flood, or simply that flooding between the 1994 and 1999 events infilled enough of the channels that by the time the 1999 flood occurred, there was little capacity to handle flows and large amounts of sediment. Thus, in the 1999 flood, the sediment supply exceeded the ability of fan to move it through the system, resulting in aggradation of the fan surface and as a result the overtopping of the Queenstown-Glenorchy Rd (Figure 3-5). This overtopping is a crucial part of the model validation and is discussed further in Section 5.

Figure 3-5 – The Buckler Burn following the November 1999 flood event, showing debris deposition over the Queenstown-Glenorchy Road on the true right bank.

In addition, between 1937 and 2019, the fan experiences progressive lateral migration of the active channel belt to the south, with the present day alignment being at the most southern limit of the fan (Figure 3-3). This indicates that northwards migration should be anticipated, particularly if the fan is to enter a more active phase as experienced in the 1930s, and between the late 1970s to late 1990s.

3.3. INPUT FLOWS AND LAKE LEVELS

Considerable discrepancy exists between the peak flows estimated by different agencies (Table 3-2).

In 2007, URS used the Regional Method (McKercher & Pearson, 1991) to estimate 10, 50, 100 and 150 ARI flows for the Buckler Burn, with a standard error between +\-21 and 29% for each flow. However, these flow values are at least double those estimated by NIWA (2018), indicating that there is considerable uncertainty as to how much water is coming down the Buckler Burn during events.

Land River Sea Consulting Ltd has taken a conservative approach to the flow estimates for the Buckler Burn design runs and used slightly higher flows than those estimated by Whyte and Ohlblock (2007)(Table 3-2). Also, due to the large uncertainty between flow estimates and return periods by URS and NIWA, and those that we have used, we have chosen not to align our flows with any particular return period (Table 3-3).

Table 3-2 –URS, NIWA and Land River Sea Consulting Ltd estimated Buckler Burn flows.

Return Period (ARI)	URS (2007)	NIWA (2018)
10-year	112m^3/s (± 21m^3/s S.E.)	52m^3/s (± 21m^3/s S.E.)
50-year	129m^3/s (± 26m^3/s S.E.)	73m^3/s (± 37m^3/s S.E.)
100-year	170m^3/s (± 28m^3/s S.E.)	82m^3/s (± 45m^3/s S.E.)
150-year	180m^3/s (± 29m^3/s S.E.)	

Table 3-3 – Peak flows used for the Buckler Burn design runs in the Land River Sea Consulting modelling.

Design number	Design flows
1	100m^3/s
2	150m^3/s
3	180m^3/s
4	200m^3/s
5	250m^3/s
6	300m^3/s

The corresponding hydrographs used with these design flows are a scaled down version of those used in the LRS 2022 Dart-Rees model. They have also been shortened to allow for the smaller catchment of the Buckler Burn. Figure 3-6 shows all six of the hydrographs.

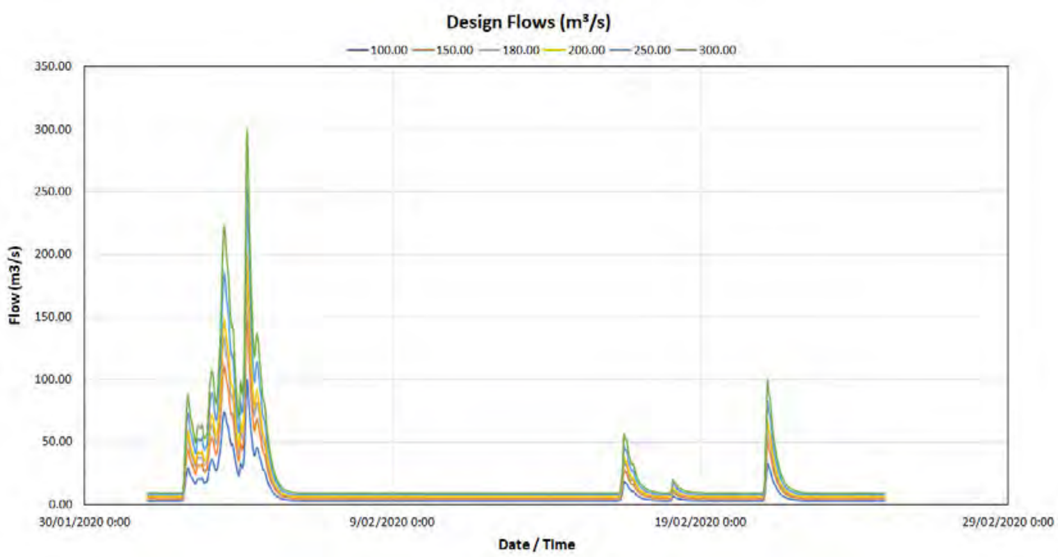

Figure 3-6 - LRS design flow hydrographs for the Buckler Burn.

ORC staff have carried out a detailed lake level frequency analysis based on the available records (Mohssen, 2021). The adopted lake levels based on this analysis are presented in Table 3-4. To put these levels into context, the highest lake level was recorded in November 1999 with a level of 312.78m, whilst the peak level recorded on the 4th of February 2020 was 311.35m. This was 1.43m lower than the 1999 event, but was a part of a significant weather event for the region.

Table 3-4 – Adopted Lake Wakatipu levels.

Return Period	Lake Level – DUN58 (m)
2-year ARI	310.7
10-year ARI	311.5
100-year ARI	312.9

For the Buckler Burn design and aggradation scenario model runs Land River Sea Consulting has used the Lake Wakatipu February 2020 event stage hydrograph. This peaks at 311.35m, which is just under a 10-year ARI.

Given the steepness of the fan, and that the flooding hazard is largely from its upper reach, it is unlikely to be overly sensitive to higher lake levels than that used (5 – 10 year ARI). Therefore, no simulations were run with any higher lake levels.

4. CONVERSION OF MODEL FROM MIKE21 FM TO HECRAS

The Dart-Rees MIKE21FM model has been used as the basis for this study and has first been converted to HECRAS, which is a freely available software package made by the US Army Corp of Engineers and is utilised inhouse at the Otago Regional Council. For details of the Dart-Rees model please refer to the *Dart/Rees Rivers: Flood Hazard Modelling* report, 2022.

The following updates have been made to the model as part of this study.

4.1. MESH

The mesh has been converted to a 10m x 10m rectangular mesh and has been expanded to cover the entire Buckler Burn floodplain.

In order to prevent leakage between the cell faces along linear features and hydraulic controls such as the Glenorchy-Queenstown Rd and Oban St and unrealistic overtopping, break lines have been included in the mesh (Figure 4-1). In addition, to ensure that the crest level of the Glenorchy stopbank (Figure 4-1) is represented in the model, the stopbank crest has been removed from the 2D terrain and has been represented using a 1D DIKE feature based on actual ground survey (Figure 4-1). This ensures the precise crest level is represented in the model.

The computational regime of HEC-RAS also differs significantly from MIKE21FM.

In HEC-RAS the computational cell faces control the flow movement from cell to cell rather than the average elevation of the cell as is the case in MIKE21FM. In HEC-RAS, the terrain and the computational mesh are pre-processed in order to develop detailed elevation/volume relationships for each cell based on the underlying digital elevation model (DEM; which is 1m in this case). This allows for a larger cell resolution to be adopted, however to still utilise the detail of the higher resolution DEM which underlies the model.

A visualisation of the mesh for the Buckler Burn / Glenorchy portion of the model is presented in Figure 4-1.

Figure 4-1 - Visualisation of the mesh with the inclusion of the Glenorchy stopbank (black line) and the Glenorchy-Queenstown Rd and Oban St break line (dark red).

4.2. INPUT DATA

The base DEM for the model build was the 2019 LiDAR utilised in the Dart-Rees flood model (Figure 4-2) which has a vertical accuracy of +\-0.15m. All three of the DEMs used in the aggradation scenarios were developed from this 2019 DEM.

However, additional runs have looked at the impact of recent changes in the Buckler Burn alluvial fan utilising 2022 LiDAR flown by the University of Canterbury (Figure 4-3). The main changes between 2019 and 2022 were:

- Localised aggradation in the lower reach of the fan in the order of 01.m to 1.1.m
- Localised aggradation in the upper fan reach between chainages 0.7 and 0.85km in the order of 0.1m to 0.4m.
- Localised bank erosion in the upper reach of the fan.

 **Figure 4-2 - 2019 LiDAR from the Dart-Rees flood model**	 **Figure 4-3 - 2022 LiDAR for the Buckler Burn alluvial fan**

4.3. FLOODPLAIN RESISTANCE

Floodplain resistance has been represented in the model using a spatially varying Manning's 'n' coefficient.

To account for varying roughness values on the floodplain, a raster of roughness values with a grid size of 1m has been created where each cell has been assigned a Manning's 'n' value based on the land use visible in the latest aerial imagery.

This task has been carried out using a combination of manual and automatic image classification techniques to ensure the most accurate classification of land uses.

- Buildings have been located based on a digitised building footprint shapefile supplied by Land Information New Zealand (LINZ).
- Road centrelines were manually drawn due to discrepancies between the online datasets and the aerial imagery, and a buffer polygon was created around the road centreline since the available GIS datasets did not have sufficient accuracy.

For the manning's 'n' value of the gravel in the active channel belt of the Buckler Burn, we have taken a different approach to the above.

- Despite the grain size of the fan material, evidence presented in international research suggests that the Manning's 'n' value increases significantly in steep, active bed load dominated gravel river systems (Jarrett, 1985) such as is the case for the Buckler Burn.
- Therefore, we have assessed the potential bed roughness using the Jarretts equation (Equation 1) with the required parameters taken from 8 cross sections extracted from the 2019 LiDAR data.

$$n = 0.39 * (S^{0.38}) * (R^{-0.16})$$

Where, n = Manning's 'n', S = Slope and R = Hydraulic radius

Equation 1 – Jarretts Equation

As a result of the above, we have adopted a manning's 'n' value of 0.1 for the gravel in the active channel belt of the Buckler Burn.

The adopted Manning's 'n' values for the entire model build are summarised in Table 4-1, and an example of the Manning's delineation is shown (Figure 4-4 and Figure 4-5).

Table 4-1 – Adopted Manning's 'n' coefficients for the Buckler Burn model.

Landuse	Manning's 'n'
Buildings	2.0
Grass	0.033
Gravel	0.019
Gravel - Buckler Burn	0.10
Lagoons	0.029
Lake	0.01
Road - Concrete	0.02
Road - Unpaved	0.025
Vegetation - Light	0.07
Vegetation - Medium	0.09
Vegetation - Dense	0.12

Figure 4-4 – Aerial imagery

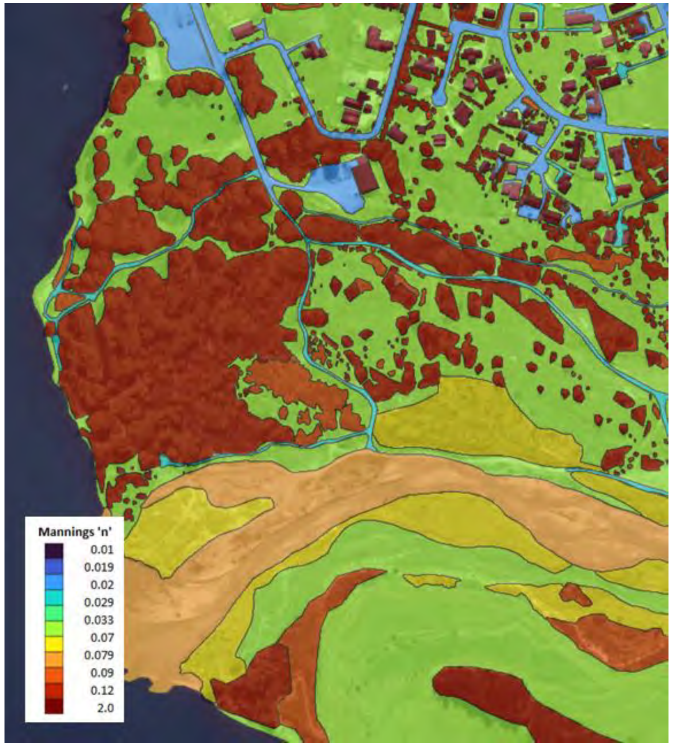

Figure 4-5 – Land use classification.

4.4. MODEL CALIBRATION / VALIDATION

In order to ensure the HEC-RAS model is giving outputs consistent with the original MIKE21FM model, the model has been used to simulate the February 2020 flood event.

Model results have shown that the model gives a very similar flood extent to the calibrated MIKE21 model (Figure 4-6).

Figure 4-6 – Comparison of HEC-RAS results (red) with MIKE21FM results (blue) at Glenorchy

Comparison of peak water levels at key locations show a slight improvement in model calibration:

- Records from the event indicate that the peak water level at the footbridge crossing Lagoon Creek was estimated to be around 312.7 to 312.8m.
- The MIKE21FM model results indicated a water level of 313.0m at this location, however the HEC-RAS model gives a level of 312.96m which shows a marginally improved fit (of 1 decimal place).

However, the HEC-RAS does not show overtopping of the Glenorchy stopbank, likely as a result of interpolating from larger triangles to squares during the conversion from a triangular mesh within MIKE to a rectangular grid for viewing within ArcGIS. Despite this, due to the general similarity in results between the two models, we are comfortable to continue using the HEC-RAS model for simulations within the Buckler Burn catchment.

4.5. ADJUSTMENT OF DEM TO INCORPORATE FAN AGGRADATION

The project scope included investigating how channel bed aggradation impacts on the flood characteristics of the Buckler Burn and resulting flood risk to the Glenorchy township.

To do this, ORC has developed and supplied three aggradation scenarios (A, B, and C), which assume a uniform thickness of aggradation occurs within the more confined upper section of the stream channel (chainage 0 – 1.0km) and then decreases at a consistent rate to zero at the lake margin.

The scenarios increase by 1m steps in elevation above the 2019 fan surface profile in the upper section of the fan (Figure 4-7):

A – 1m increase in elevation

B – 2m increase in elevation

C – 3m increase in elevation

These increases in elevation do not necessarily equate to volumes deposited during an event or consecutive events on the contemporary fan surface. Further study is required into the potential sediment sources available i.e. mass slope failure or landslide dambreak, as well as the connectivity in the catchment, so as to establish realistic supply volumes and therefore aggradation depths across the fan surface.

Furthermore, the main area of aggradation in the modelled scenarios is in the upper fan because this was identified by Ian Fuller in a note to ORC (Fuller & McColl, 2021) as a critical area in which aggradation in the channel could result in an avulsion to the north towards Glenorchy, and therefore was worthy of investigation. However, the scenarios have the aggradation thickness decrease at a consistent rate towards the lake boundary. In reality, the thickness of the deposited sediment in the long profile would vary with abrupt changes in morphology due to the unpredictable and erratic pulse like nature of sediment movement across a fan surface. Though a necessary simplification, this deviation from reality has implications on the modelled inundation, as it smooths out the fan surface, thus removing natural channel formations and processes which create nonlinear flow paths that can direct water beyond the fan's surface.

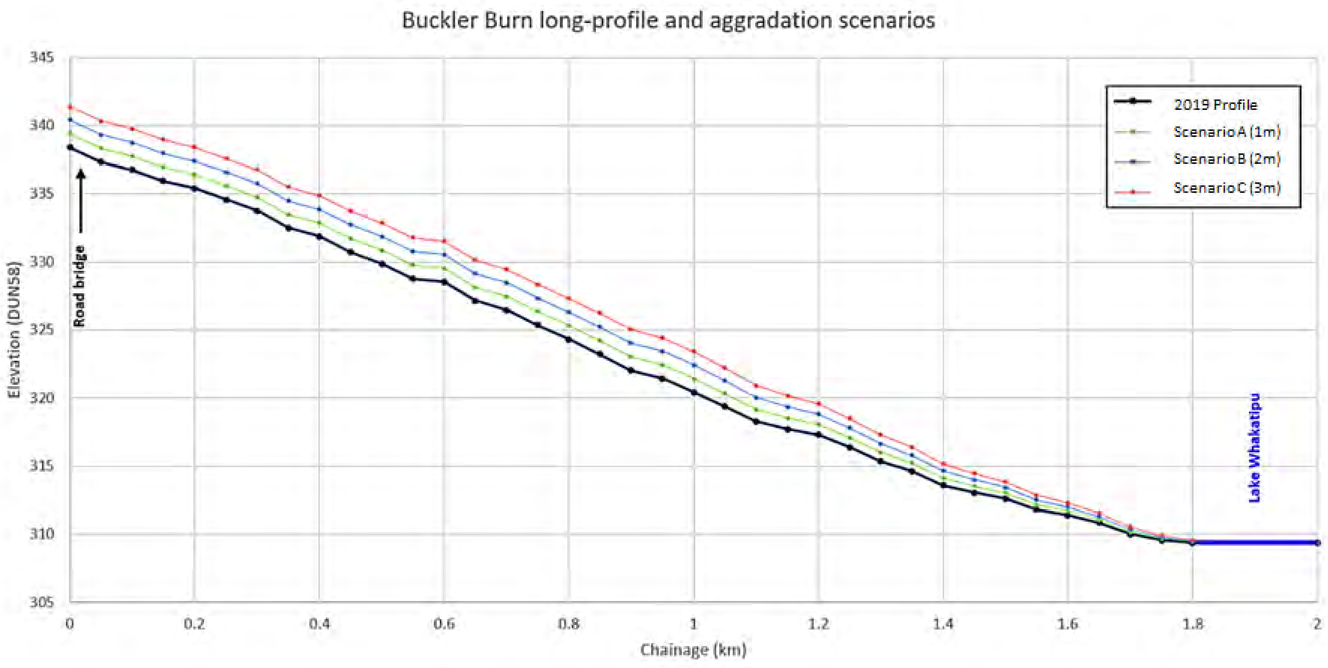

Figure 4-7 – Buckler Burn long profile and aggradation scenarios developed for use in the flood hazard modelling.

Fan Surface Adjustment

In order to model the three scenarios, we generated three DEMs with the fan surface aggraded from the 2019 DEM and based on the aggradation profiles (Figure 4-7).

We have applied these aggradation profiles to the DEM using the following steps:

1. Extract cross sections across the fan at 50m intervals down the centreline.
2. Adjust the cross sections manually to incorporate the desired level of aggradation applying judgement as to how the fan would naturally taper off at the sides (Figure 4-8).
3. Interpolate an adjustment DEM based on the cross sections from step 2.
4. Adjust the DEM using the output from step 3.
5. Interpolate the edges of the fan surface where necessary to ensure it ties in neatly with the surrounding terrain.

An example of an adjusted cross section is shown in Figure 4-8.

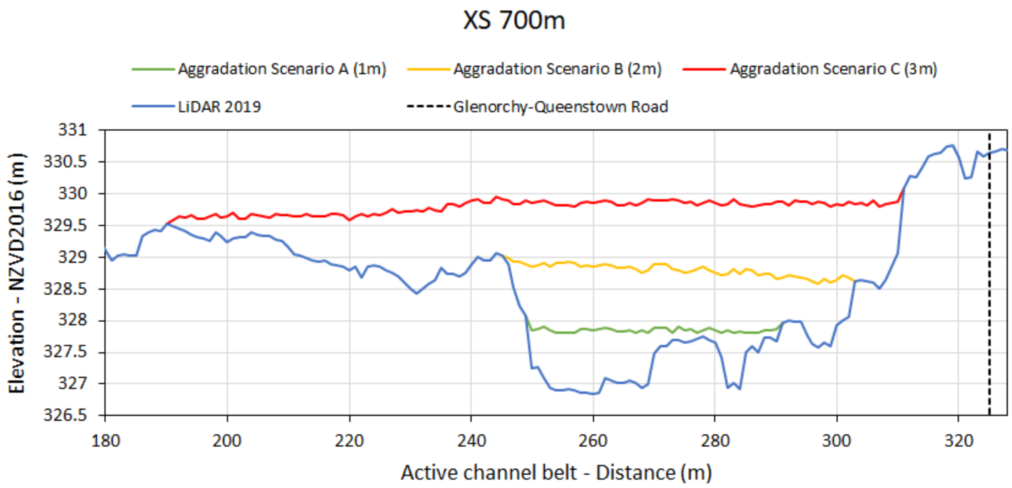

Figure 4-8 – Example of how the bed level of the active channel belt has been adjusted to account for the three aggradation scenarios. Note that the model extent itself extends beyond the active channel belt.

5. MODEL VALIDATION

In order to optimise the model run times, the model has been clipped to cover only the Buckler Burn Fan and Glenorchy township for the remainder of the simulations.

To validate the model behaviour for the Buckler Burn catchment we have compared the results of the simulations with aerial photography and ORC file notes from the 1999 flood event.

The November 1999 flood event is the biggest event on record for Lake Wakatipu, and also has photographic evidence available of the resulting flooding of the Buckler Burn. As there is no flow data available for the Buckler Burn and too little documentation of its past flood events to know what the largest event was or to provide comparison between events, the 1999 event has been used for its known status as a large event.

5.1. NOVEMBER 1999 FLOOD

The 1999 flood occurred in response to a significant weather event that affected the southern part of the South Island. During the event, the Buckler Burn overtopped the Glenorchy-Queenstown Rd on the true right and cut off Glenorchy and Kinloch from Queenstown.

Though there wasn't (and isn't) a flow/water level site on the Buckler Burn, the nearby Dart Rv at Hillocks flow site recorded a double peak; with the first peak in the early hours of the 16th of November, and a second prolonged peak at the end of the 16th and into the early hours of the 17th (Figure 5-1). This double peak is also evident in the rainfall data at the Dart Rv at Hillocks site (Figure 5-1).

We also draw on newspaper articles to describe what was happening during the November 1999 event, though we note that these aren't fact, rather as close as we can get to documentation of what occurred.

An article from the Otago Daily Times on the 18th of November, states that "*slips and debris closed the* [Glenorchy-Queenstown] *road yesterday early morning*".

- Whilst this could be referring to other sections of the road, we have assumed that it was in fact referring to the Buckler Burn and the adjacent Glenorchy-Queenstown Rd, given the debris deposited by the burn onto the road during the event.
- Therefore, ignoring the difference in catchment size, and assuming that the response of the Buckler Burn to the weather event was similar to that of the Dart River, then the article indicates that the Glenorchy-Queenstown Rd was likely overtopped early in the morning on the 17th of November, after a potential second peak from the Buckler Burn.

Additionally, an article from the Oamaru Mail on the 17th of November states that "*excavation was being done on the Buckler Burn at Campbelltown as it was threatening to break its banks*."

- The reach adjacent to Campbelltown (0.2 to 0.6km chainage) is narrow, and if the burn was in flood, then it is likely that the floodwaters would have occupied the entire active channel belt in this reach.
- Therefore the term 'threatening to break its banks" would be referring to the floodwaters spilling out onto the wider expanse of Buckler Burn fan surface.

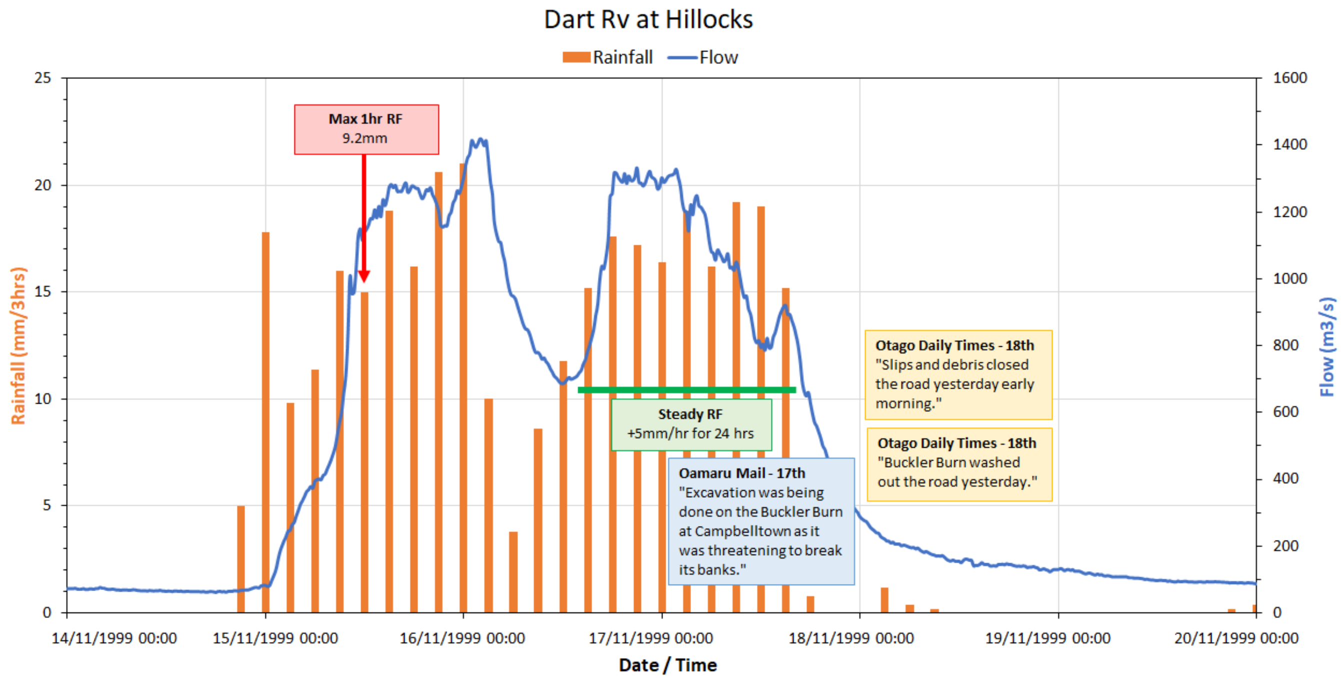

Figure 5-1 - Rainfall and flow data and stats from the nearby Dart Rv at Hillocks monitoring site and newspaper articles from the November 1999 event.

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Land River Sea CONSULTING

5.2. VALIDATION SUMMARY

Previous modelling by URS (Whyte & Ohlbock, 2007) was unable to replicate the November 1999 flood event as none of the scenarios modelled overtopped the Glenorchy-Queenstown Rd.

The current modelling by Land River Sea Consulting Ltd, was also initially unable to show overtopping of the Glenorchy-Queenstown Rd. We had to considerably increase the design flows from those estimated by both URS and NIWA, to produce flooding across the road. However, this flooding is not from the burn in the reach immediately adjacent to the road (0.7 to 0.85km chainages), but from spillover onto the inactive fan surface upstream between the 0.25 and 0.5km chainages adjacent to Campbelltown and then down the Glenorchy-Queenstown Rd. This is where the burn was "*threatening to break its banks*" in the November 1999 event according to the Oamaru Mail article, which suggests that the "success" of the excavation works may have forced more water and sediment downstream, resulting in the overtopping of the burn in the reach adjacent to the road.

Regardless, the design flows do not produce inundation of the road as a result of overtopping from the reach immediately adjacent to it. Therefore, knowing the inherent difficulty in modelling dynamic systems like alluvial fans where sediment movement, dominates during and outside of events, we hypothesise that the difficulties found with reproducing the 1999 event could be in part due to the combined effect of the excavation works as well as:

- The inability to model the complexities of the fan response to a large pulse of sediment which is likely to have occurred during the 1999 event (as also hypothesised by ORC); and
- A difference in the morphological characteristics of the fan between 1999 and recent years which made the fan susceptible to rapid channel infilling and subsequent overtopping, during the 1999 event.

Each of these is discussed further below.

5.2.1. A LARGE PULSE OF SEDIMENT

Alluvial fans are formed and evolve as a result of primary and secondary processes:

- Primary processes are those that transport sediment into the system and are therefore vital in the formation of the fan. These are often events with a high sediment concentration such as debris loaded flood flows and mass movements (Vincent et al., 2022).
- Secondary processes are those that occur during smaller events such as low sediment concentration flood events, or at low flows, and remobilise and rework sediment that has been previously deposited on the fan (Vincent et al., 2022).

Primary processes are likely to involve aggradation of the fan surface, infilling of the main channel, and bifurcation of flow, whilst secondary processes lend towards increased flow channelization and channel incision (Vincent et al., 2022).

The Buckler Burn upper basin is comprised of steep, mountainous terrain dominated by sub-alpine weathering processes (scree generation), as well as instability as rockfall deposits, and some deeper-seated mass movements, which provide a ready supply of sediment to the alluvial fan below (Fuller &

McColl, 2021; NIWA, 2018b). The catchment is therefore likely to be capable of producing flood flows with high sediment concentrations, resulting in primary processes dominating during such events.

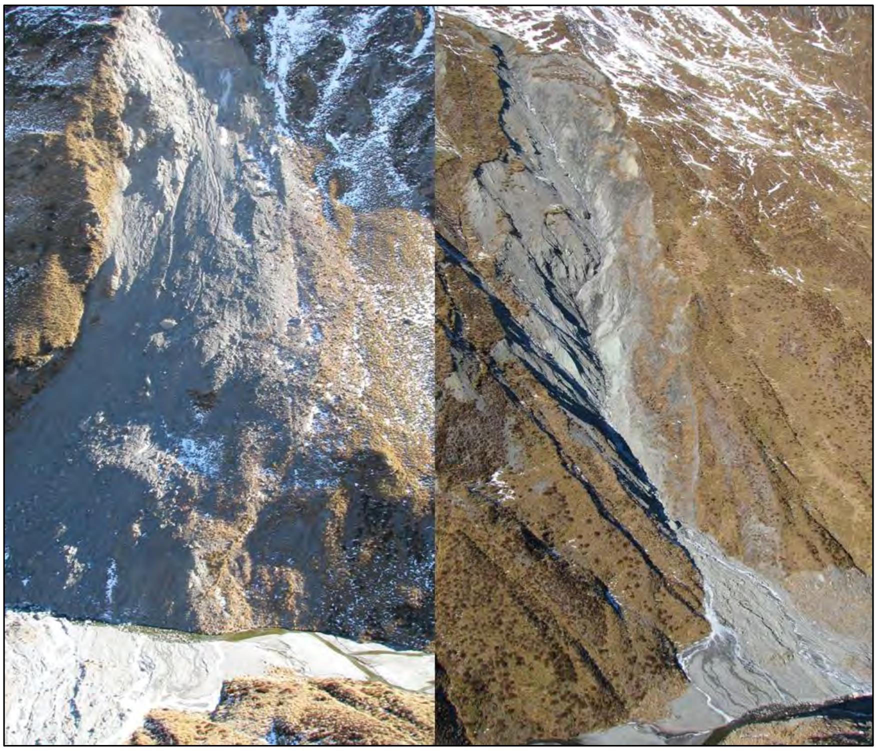

Figure 5-2 – ORC photos showing a large landslide in the upper Buckler Burn catchment on the TR of the channel (left image) and the TL of the channel (right image).

The 1999 event has been reported in the NIWA Historical Weather Events Catalogue as a significant weather event, with widespread slips and flooding across Otago.

- Analysis of the Dart Rv peak flow (~1450m^3/s) for the event suggests an ARI in the range of 5 – 10 years (Mohssen, 2021).
- The Dart at Hillocks rainfall gauge, which is the nearest to the Buckler Burn catchment recorded a 5 day total of 343.2mm, whilst the Rees Valley Station recorded a 4 day total of 275mm which at the time had a return period of a 100 years (NIWA, 2018b). Though these totals relate to different (nearby) catchments they suggest that rainfall in the Buckler Burn was likely prolonged and over several days, which would have resulted in saturated soils and therefore increased likelihood of slope failure and mass movement.

- The maximum hourly rainfall intensity recorded by the Hillocks site during the event was ~9.2mm/hr on the 15th of November (beginning at 12:30pm), though this is not significant in terms of HIRDs statistics for the area, it does indicate heavy rainfall.
- Rainfall eased during the first half of the 16th of November, before falling steadily (+5mm/hr) for a 24 hour period from midday onwards on the 16th, again indicating prolonged rainfall with subsequent effect on soil saturation.
- Photographs from after the 1999 event show a much aggraded upper fan surface, with debris strewn across the Glenorchy-Queenstown Rd (Figure 3-5), whilst aerial imagery shows a far greater area of active fan surface (exposed gravels) compared to the 1994 event (Figure 3-4).

It is highly likely that given the nature of the upper catchment, the probable double peaked nature of the event, and the intensity and duration of the rainfall that a large sediment pulse entered the system during the second part of the event and was distributed across the upper reach of the Buckler Burn fan.

However, the HEC-RAS model does not simulate sediment erosion, transport, and deposition nor channelbifurcation and lateral migration. Therefore, this sediment pulse has been modelled by beginning the run with an already aggraded fan surface (aggradation scenarios A, B, and C), and so is unable to capture theprimary processes of bifurcation, channel infilling, and lateral migration that would have occurred during the 1999 event and contributed to the overtopping of the Glenorchy-Queenstown Rd. However, it does still allow for an understanding of the inundation hazard from the Buckler Burn should the bed aggradein the future.

5.2.2. A DIFFERENCE IN THE MORPHOLOGICAL CHARACTERISTICS OF THE FAN SURFACE

The size, shape and slope of a fan have long been documented to be reflective of the inputs of water and sediment, determined by the upper drainage basin relief, size, and geology, as well as the accommodation space (Harvey et al., 2005; Kochel, 1990; Schumm et al., 1987). However, more recently, experimental fan studies have focussed on how changes in sediment supply can affect alluvial fan morphology, and the resulting effect on flood risk.

The studies have found that sudden increases or decreases in supply, or changes in the frequency between primary and secondary processes result in considerable morphological variation in experimental fans and over decadal, annual, and even monthly timescales of fans in the field, with:

- An increase in supply, or more frequent high supply events resulting in the primary fan-building processes dominating, and therefore less time for the fan to undergo remobilization and reworking under the secondary processes. Thus, experiments found these scenarios produced shorter, steeper, and more "stacked" fans, with numerous braided channels, negligible incision, and mainstem aggradation(Leenman & Eaton, 2022; Leenman & Tunnicliffe, 2020; Vincent et al., 2022).
  The negligible incision was shown to play a key role in flood risk, as it reduces the channel capacity and therefore it takes a smaller amount of flow to overtop the channel and inundate the surrounding fan and land, or trigger an avulsion.

- A decrease in supply, or less frequent high supply events allows for the secondary processes to dominate. In these scenarios, the experimental fans were able to redistribute sediment from the upper to the lower fan, form a fan-head trench (channel incision), centralize flow paths, and develop a telescoping lower fan (Leenman & Eaton, 2022; Vincent et al., 2022).
  Thus, in these scenarios, flood risk is reduced, because as the channel capacity increases it is better able to contain aggradational events (Wasklewicz & Scheinert, 2016) so it will take larger flows to overtop the channel and more time for the channel to infill and trigger an avulsion (Vincent et al., 2022).

The Buckler Burn is nestled in a part of the country where frequency and intensity of weather events appear to be affected by the positive and negative phases of the Interdecadal Pacific Oscillation (IPO) cycles (McKerchar & Henderson, 2003).

The IPO is the long-term oscillation of sea surface temperatures in the Pacific Ocean which affects the strength and frequency of El Niño and La Niña cycles. When in a positive IPO phase, New Zealand receives stronger west to southwest winds which means the southern and western parts of the South Island are wetter than average. So, they experience more extreme rainfall and therefore more frequent flooding than average (Wratt et al., 2022). As a result of the increasing rainfall, sediment supply volume and frequency to river and fan systems increases through mobilization of sediment and an increase in the frequency of mass movement events such as shallow landslides (Jakob & Owens, 2021).

Rainfall data from the longest rainfall record in the area – the Earnslaw gauge in the Rees River catchment – as well as observations, coincide with changes in the IPO (Figure 5-3).

- As the average annual rainfall at Earnslaw increased by more than 500mm between 1950 and 2000 (Otago Regional Council, 2010), the IPO shifted from a negative phase (1950's to the late 1970s) to a positive phase (late 1970s to 21st century).
- Then, since the turn of the century, the Earnslaw site has recorded a decline in average annual rainfall (Otago Regional Council, 2010), corresponding to a return to a negative IPO phase.
- Additionally, between 1950 and 2000 a significant increasing trend in total precipitation, rain days, consecutive wet days, and number of very wet days in the vicinity of Glenorchy have been identified (Otago Regional Council, 2010).

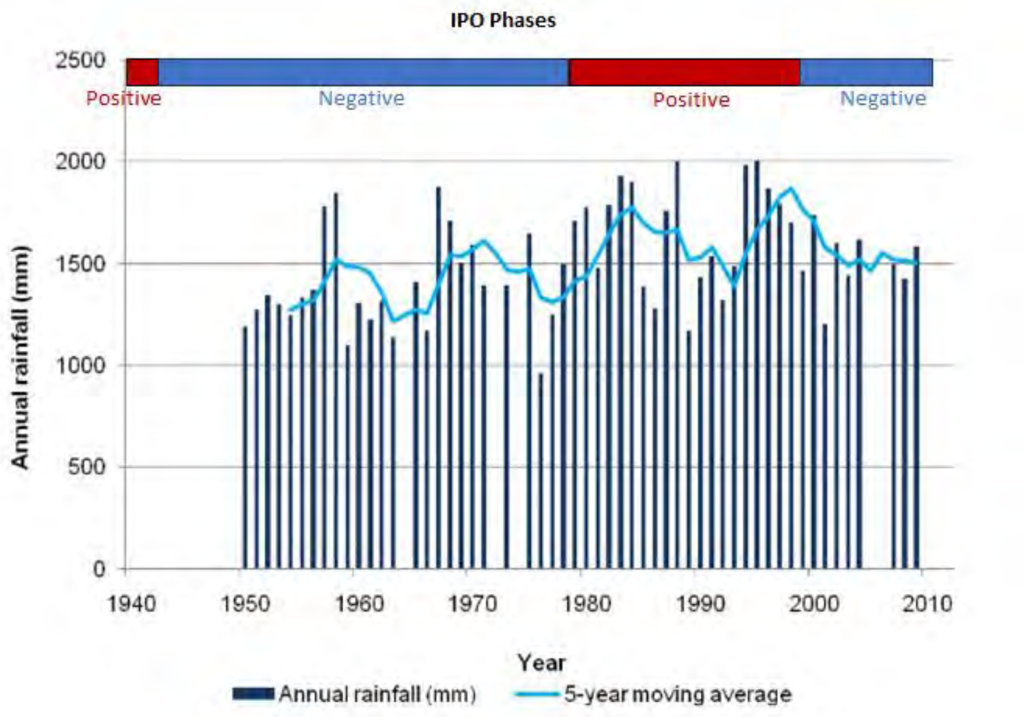

Figure 5-3 – Annual rainfall totals for the Rees at Earnslaw gauge, 1950 to 2009 with the positive and negative IPO phases above. The rainfall data is missing: 1964, 1972, 1974, 2005, and 2006.

The November 1999 event occurred at the end of a ~20 year positive IPO phase, when the average annual rainfall at the Earnslaw gauge was at its highest.

- It is hypothesised that between the late 1970's and 1990's, sediment supply increased with the increased frequency and intensity of weather events, resulting in aggradation at the Buckler Burn fan head, steepening of the fan slope, channel infilling, and a widening of the active channel belt and therefore increase in the active fan surface area.
- Aerial imagery from 2001 (just after the end of a positive IPO) indicates a larger area of exposed gravels compared to the 1966 imagery (negative IPO) (Figure 5-4).
- Satellite imagery in the early 2000's, though of poor quality, also indicates a larger area of exposed gravels compared to imagery from the last few years.

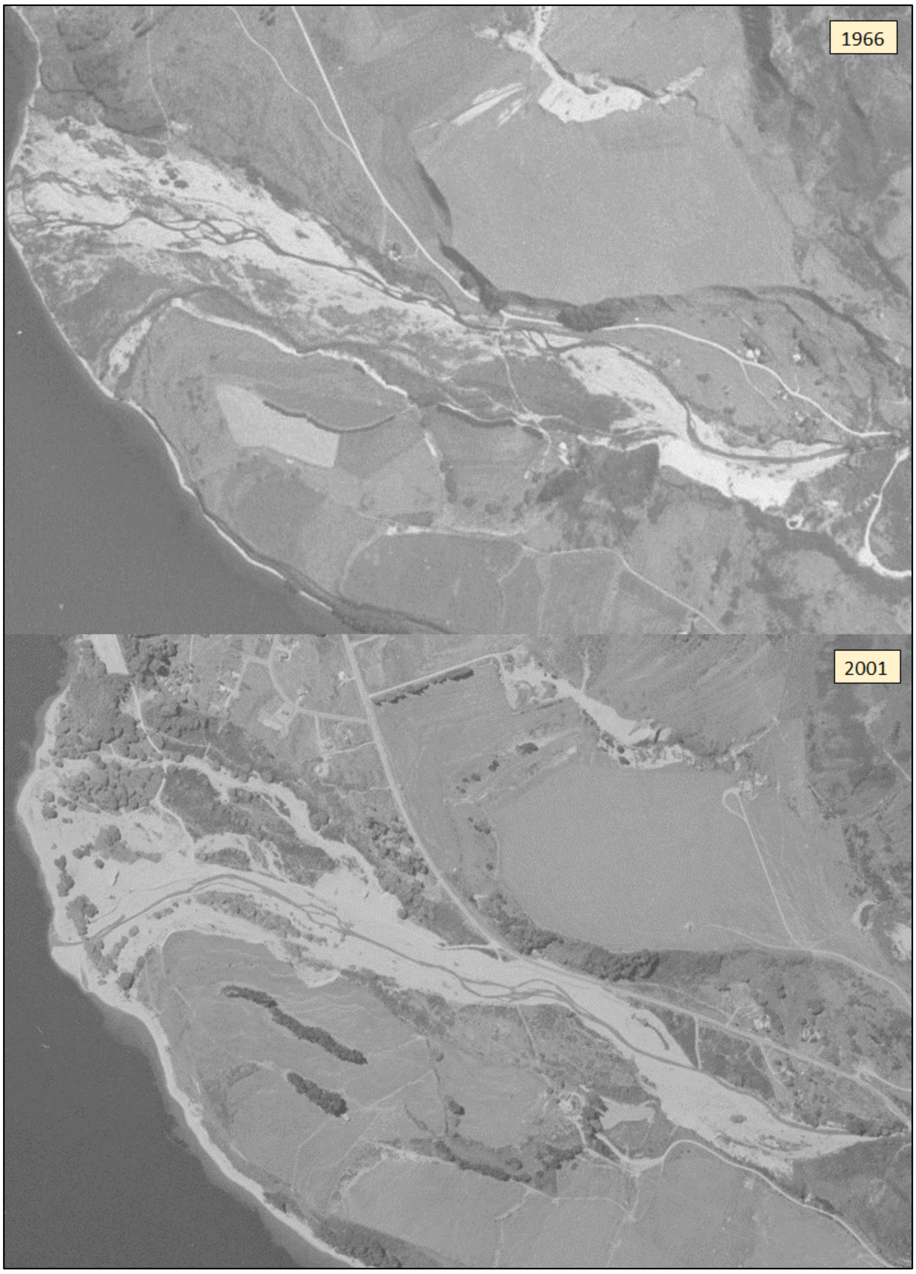

Figure 5-4 - aerial imagery from 1966 and 2001 downloaded from Retrolens.

The IPO has been in a negative phase since the 1999 flood up until 2016.

- With fewer and less intense weather events, sediment supply likely decreased, and secondary processes dominated, reworking the existing sediment through the system.
- As the experiments by Vincent et al (2022) indicate, this could have resulted in a gentler fan slope, progradation of the fan toe, as well as increasing channelization and entrenchment of the main flow.
- The aerial imagery also shows a prograded toe out into Lake Wakatipu in the 1966, 2008 and 2019 imagery (negative phase), compared to the 1937 imagery (positive phase) (Figure 3-3).
- And as noted above, the aerial imagery confirms a narrower active channel belt and decreased active fan area with increasing vegetation growth over this time. The 1966 and 2001 aerial imagery provide an excellent comparison between positive and negative IPO fan surfaces, whilst more recent imagery from 2019 (in the early years of a positive IPO phase) show a narrow and well vegetated active fan surface (Figure 5-5).

Figure 5-5 - 2019 aerial imagery of the Buckler Burn.

Therefore, it seems likely that when the 1999 event occurred, as a result of the increase in sediment supply and frequency from the preceding 20 years of positive IPO, the aggraded and steepened upper Buckler Burn fan surface was closer in elevation to the Glenorchy-Queenstown Rd, and with negligible incision in the main channel, a sediment laden flow or sudden pulse of sediment (as hypothesised) could have rapidly infilled the channel, resulting in the road overtopping. It is possible, that this was assisted by the excavation works forcing more flow and sediment downstream from the fan surface adjacent to Campbelltown.

In terms of the modelling, what this means is that the fan surface during the 1999 event was likely very different to the 2007 and 2023 modelled fan surfaces.

The 2007 model used cross sectional data from 2006, whilst the current HEC-RAS model has used the 2019 LiDAR data.

- Though within seven years of the 1999 event, and so not long into the negative IPO cycle, the 2006 cross sections are sparse, and do not cover the area immediately alongside the road where it overtopped in 1999, but rather above and below the reach of interest, with cross sections at chainage points 0.45km and 1.05km (Figure 5-6). It is therefore unlikely that the generated DEM could have accurately captured the fan surface, the degree of channel incision, and slope at that time.

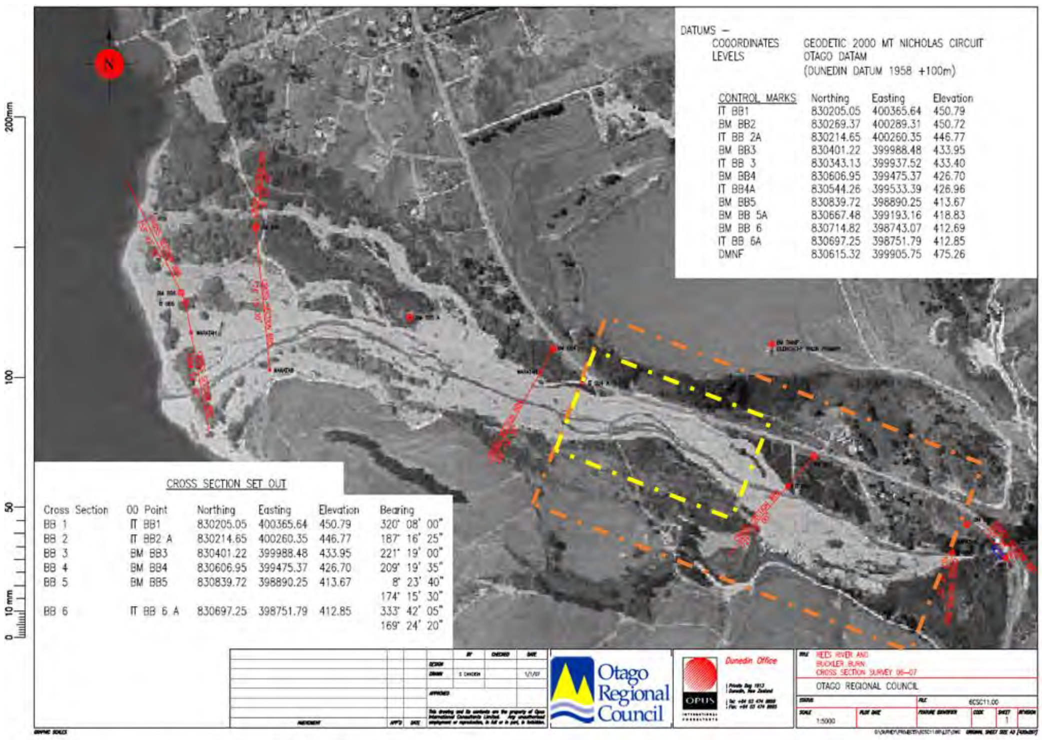

Figure 5-6 – Locations of the 2006 cross sections (red lines) used in the 2007 modelling. The upper reach of the Buckler Burn alluvial fan has been indicated by the dashed orange lines, and the area of interest (where the road overtopped in the 1999 event) by the yellow dashed lines.

- The 2019 and 2022 LiDAR has been taken only a couple of years into the current positive IPO phase. A Geomorphic Change Detection (GCD) analysis shows that the latest 2022 LiDAR has aggraded in the order of 0.1m to 0.4m compared to the 2019 LiDAR in the reach alongside the road (Figure 5-7), as well as eroded the banks of both sides of the main channel at the head of the fan indicating early channel expansion. Thus showing how fan morphology varies over time. However, given it is in the early years of the positive phase, the 2019 and 2022 fan surfaces are unlikely to have reached a similar state to that of 1999 which was at the end of ~20 years of positive IPO.

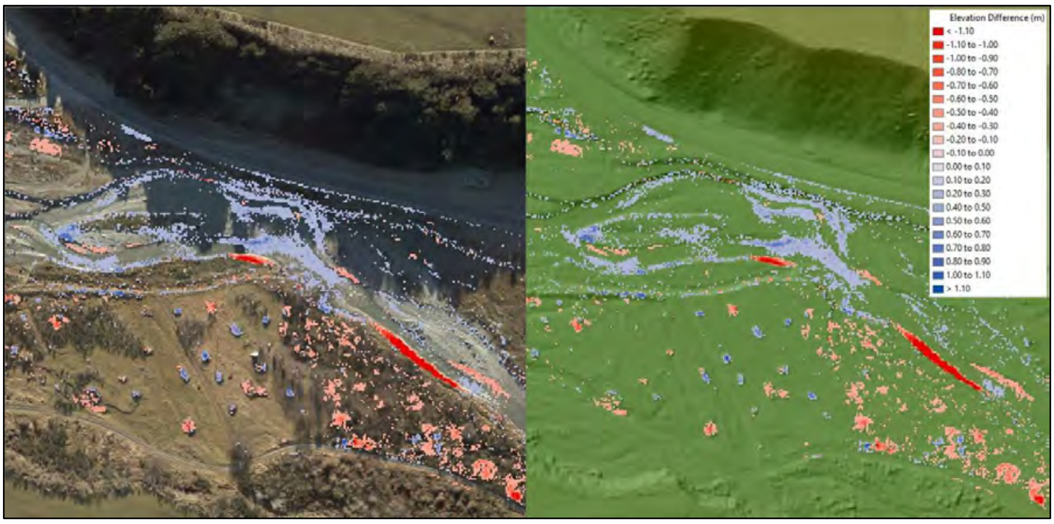

Figure 5-7 – GCD result between the 2019 and 2022 LiDAR, shown on the aerial imagery and hillshade layer.

Thus, the DEMs used in the 2007 and 2023 models would have had:

- a gentler fan slope,
- more incised channels with increased flow capacity,
- and an upper fan surface much lower in elevation compared to the Glenorchy-Queenstown Rd, which therefore prevents overtopping during the model runs, unless the runs begin with aggradation added to the DEM.

6. MODEL RESULTS

Two categories of scenarios have been simulated:

- **Design scenarios** (Table 6-1 and Table 6-2)
  A range of six flows from 100m³/s to 300m³/s were simulated. Each flow was run twice, once with the 2019 LiDAR, and a second time with the 2022 LiDAR. This was because we received the 2022 LiDAR part way through the project, and wanted to utilize the latest data to see if that affected the results. Fan morphology is very dynamic, and we hypothesised that the three years between the two LiDAR surveys would be enough to produce morphological change, and therefore a difference in the resulting inundation.
- **Aggradation scenarios** (Table 6-3)
  In order to test the sensitivity of the Buckler Burn and flood hazard to channel bed aggradation, the six design flows were simulated with each of the three aggradation scenarios. In these scenarios, the channel belt of the Buckler Burn in the 2019 LiDAR was aggraded by 1m, 2m and 3m, creating the three new DEMs used in the simulations.

Table 6-1 The 2019 LiDAR design scenario with each of the six design flows.

Run name	Flow (m³/s)	LiDAR
Design Scenario 2019 – 100 m³/s	100	2019
Design Scenario 2019 – 150m³/s	150	2019
Design Scenario 2019 – 180m³/s	180	2019
Design Scenario 2019 – 200m³/s	200	2019
Design Scenario 2019 – 250m³/s	250	2019
Design Scenario 2019 – 300m³/s	300	2019

Table 6-2- The 2022 LiDAR design scenario with each of the six design flows.

Run name	Flow (m³/s)	LiDAR
Design Scenario 2022 – 100 m³/s	100	2022
Design Scenario 2022 – 150m³/s	150	2022
Design Scenario 2022 – 180m³/s	180	2022
Design Scenario 2022 – 200m³/s	200	2022
Design Scenario 2022 – 250m³/s	250	2022
Design Scenario 2022 – 300m³/s	300	2022

Table 6-3 – Eighteen runs in total, as each of the six design flows was run with each of the three aggradation scenarios.

Run name	Flow (m^3/s)	Aggradation
Aggradation Scenario A – 100m^3/s	100	A (1m)
Aggradation Scenario A – 150m^3/s	150	A (1m)
Aggradation Scenario A – 180m^3/s	180	A (1m)
Aggradation Scenario A – 200m^3/s	200	A (1m)
Aggradation Scenario A – 250m^3/s	250	A (1m)
Aggradation Scenario A – 300m^3/s	300	A (1m)
Aggradation Scenario B – 100m^3/s	100	B (2m)
Aggradation Scenario B – 150m^3/s	150	B (2m)
Aggradation Scenario B – 180m^3/s	180	B (2m)
Aggradation Scenario B – 200m^3/s	200	B (2m)
Aggradation Scenario B – 250m^3/s	250	B (2m)
Aggradation Scenario B – 300m^3/s	300	B (2m)
Aggradation Scenario C – 100m^3/s	100	C (3m)
Aggradation Scenario C – 150m^3/s	150	C (3m)
Aggradation Scenario C – 180m^3/s	180	C (3m)
Aggradation Scenario C – 200m^3/s	200	C (3m)
Aggradation Scenario C – 250m^3/s	250	C (3m)
Aggradation Scenario C – 300m^3/s	300	C (3m)

The design scenario peak depth and velocity, and hazard maps have been presented in appendices A, B and C, whilst the aggradation scenario peak depth and velocity, and hazard maps have been presented in appendices D, E and F.

There are a large number of potential hazard categorisations to use. However, ORC have requested that we use the Australian Rainfall and Runoff guidelines, as we have already used these for the maps created for the Dart-Rees model results, and the council would like to maintain consistency between maps.

The hazard categorisations in the Australian Rainfall and Runoff Guidelines are based on a combination of speed and velocity (Cox, 2016). These have been summarised in Table 6-4 and presented graphically in Figure 6-1. More detailed information on the derivation of the Hazard Categories can be found in the Australian Rainfall and Runoff guidelines which can be accessed online at http://arr.ga.gov.au/arr-guideline (NB. hazard categories are discussed in Chapter 7 of Book 6 – Hydraulics).

We note there is a range of more specific hazard categorisations available which are more specific for evacuation planning etc, however the categories adopted for these maps are the most general and suitable for a wide range of purposes.

Table 6-4 - Description of Hazard Categories

Hazard Vulnerability Classification	*Description*
H1	Generally safe for vehicles, people and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles, children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

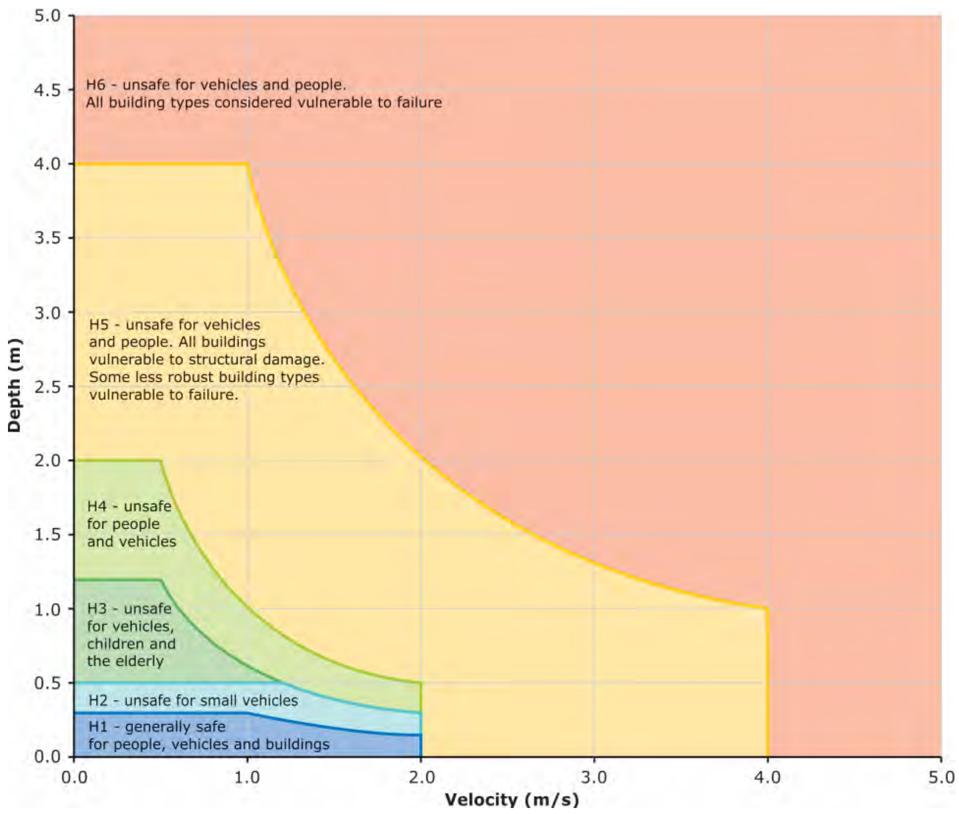

Figure 6-1 - Graphical representation of the Hazard Categories

6.1. RESULTS ANALYSIS – DESIGN RUNS

6.1.1. DESIGN SCENARIO 2019

In none of the 2019 LiDAR design runs does inundation of the Glenorchy-Queenstown Rd alongside chainage 0.7 to 0.85km occur as a result of overtopping from the burn at that location. Instead, in scenarios with peak flows equal to and greater than 150m³/s, floodwaters spilling out over the inactive fan surface between the 0.25 and 0.5km chainages on the true right result in floodwaters running alongside, over, and down the road into the Glenorchy township (Figure 6-2).

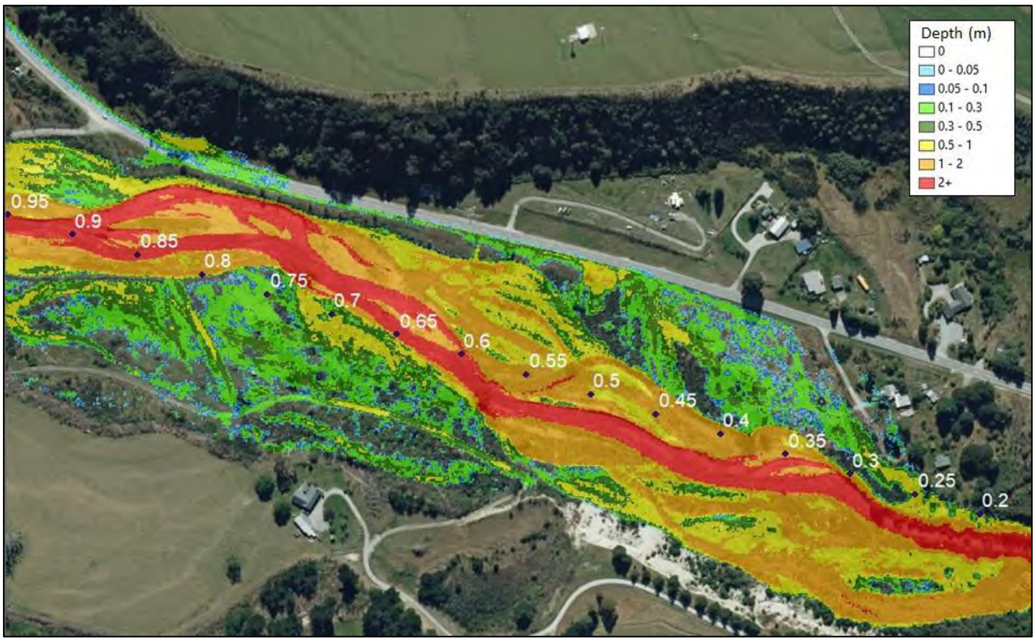

Figure 6-2 – 300m³/s design (2019) run showing the spillover at 0.25km chainage, and the additional breakouts at 0.35 and 0.45 that occur at the higher end design flows.

From the 180m³/s scenario onwards, the flow path from the spillover on the true right of the upper fan results in floodwaters pooling behind the Glenorchy stopbank (that protects the town from the Dart-Rees system) and to the south of the eastern end of Mull St (Figure 6-3), as well as inundation of the Oban St and Shiel St (street names are shown in Figure 1-1).

Figure 6-3 – Floodwaters from the Buckler Burn pooling behind the Glenorchy stopbank and eastern end of Mull St in the 250m^3/s design (2019) run.

Downstream, the vegetated northern end of the lower fan reach is activated in all the 2019 design runs, with inundation extent and depth increasing with each step up in peak flow. This inundation also contributes to pooling of floodwaters behind the Glenorchy stopbank (Figure 6-3) and leads to localised inundation in the western end of Lochburn Ave, with depths up to 1m in a low lying point relative to the surrounding land.

Aside from the upper fan spillovers and northern lower fan surface inundation, the burn remains largely confined to its active fan surface. It does not flow into the larger channel on the true right around chainage point 1.1km, despite this channel being activated in both the 1994 and 1999 floods, as shown by aerial imagery after the events (Figure 3-4). However, this does not mean that it could not access this area under future channel configurations and fan morphology.

Additionally, any inundation within the town (i.e. roads and the buildings on either side) is for the most part classed as hazard category 1 with a few localised spots as high as 6 on some roads. Inundation of the Glenorchy-Queenstown Rd and the southern end of Oban St also results in hazard categories as high as 6 (Figure 6-4). On the active fan surface, the hazard category is either 5 or 6 as result of the steep gradient, and fast flowing deep water.

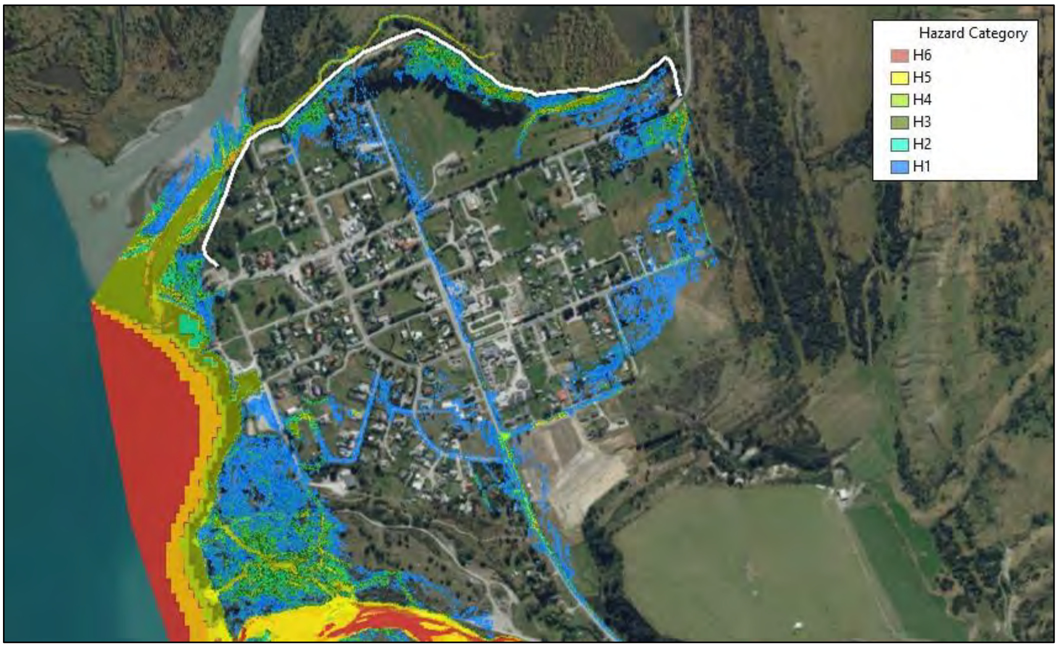

Figure 6-4 – Hazard map for the 300m³/s 2019 design run.

6.1.2. DESIGN SCENARIO 2022

In a similar respect to the 2019 LiDAR design runs, the 2022 LiDAR design runs do not produce inundation of the Glenorchy-Queenstown Rd as a result of overtopping from the burn from chainage 0.7 to 0.85km. Like the 2019 LiDAR, it is the spillover between the 0.25 and 0.5km chainages that produces the inundation of the road. However, the extent at which this inundation occurs in the 150m³/s 2019 LiDAR run, requires a larger flow with the 2022 LiDAR of 250m³/s, this is likely due to an increase in channel capacity in this upper reach due to erosion of the banks as shown by the 2019-2022 GCD analysis (and discussed in sections 5.2.2 and 7.1).

Another difference between the two LiDAR design run sets occurs in the lower fan reach downstream of the 1.4km chainage. The 2022 LiDAR runs results in slightly greater inundation and deeper channelised flows in this location, compared to the 2019 LiDAR runs (Figure 6-5). This becomes more noticeable with each step up in design flow. Additionally in the areas where the bed has aggraded, flow becomes shallower in the 2022 runs.

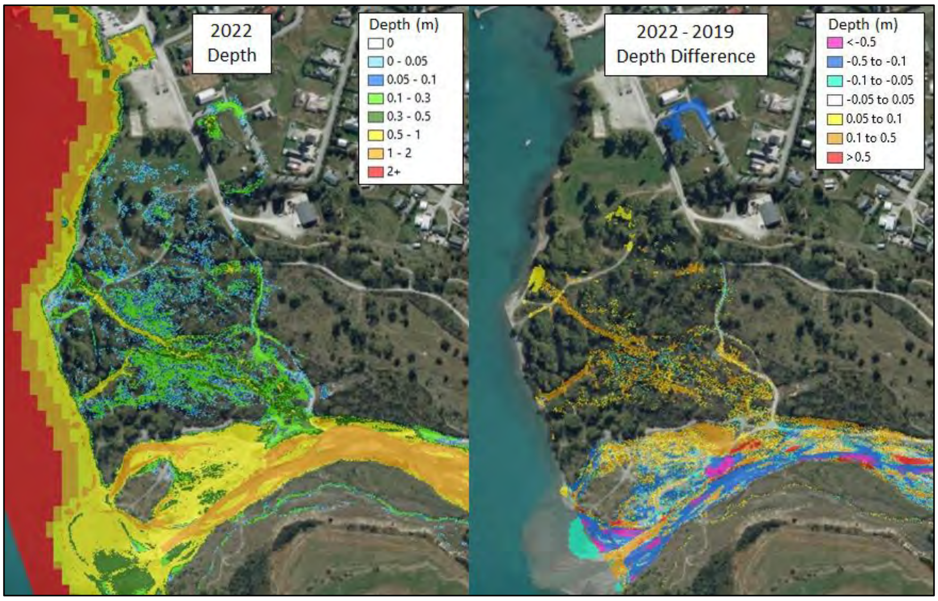

Figure 6-5 – 100m³/s 2022 design run with a depth map to the left and a depth difference map (with the 100m³/s 2019 design run) to the right.

This difference is validated by the fact that the GCD analysis between the 2019 and 2022 shows that the main channel and parts of the fan surface in this lower reach have aggraded by 0.3 to 1.2m between 2019 and 2022 (Figure 6-6). This will have reduced the channel capacity, and therefore resulted in more flow into the northern side of the fan in the 2022 design runs.

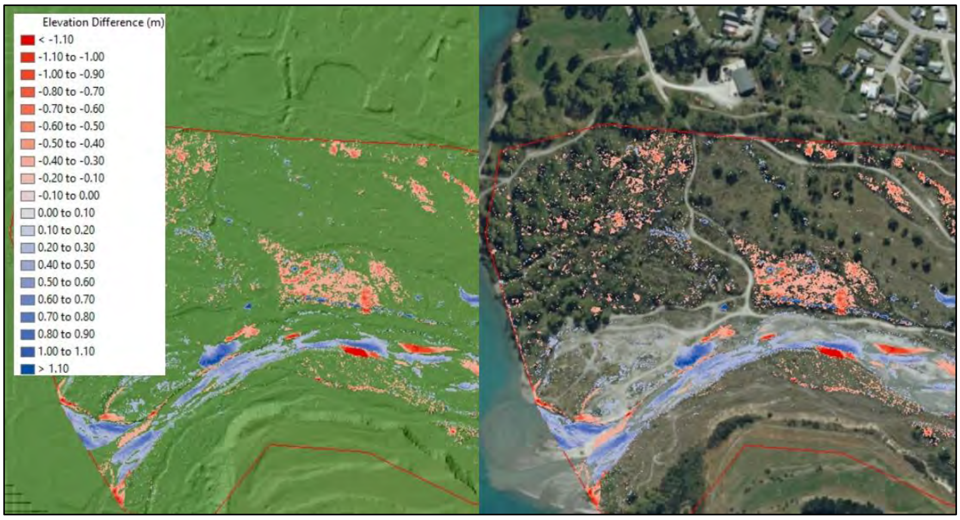

Figure 6-6 – GCD analysis between the 2022 and 2019 LiDAR data sets zoomed in on the lower reach of the Buckler Burn fan-delta system. Two different base layers - hillshade and aerial imagery have been used to better show the elevation difference.

In terms of inundation of the Glenorchy township, in this modelled scenario with the 2022 fan morphology, the western end of Lochburn Ave experiences localised inundation in all of the scenarios. However, unlike the 2019 LiDAR design runs, Glenorchy-Queenstown Rd, Oban St, and Shiel St only become inundated in the 250m^3/s and 300m^3/s scenarios, and even then, this is mostly under 0.3m deep (hazard category 1) with a few localised spots peaking around 1m in depth (hazard category is 4). Additionally, there is not enough spillover from the upper fan and along the Glenorchy-Queenstown Rd to produce pooling behind the Glenorchy stopbank nor at the eastern end of Mull St.

6.2. RESULTS ANALYSIS – AGGRADATION SCENARIOS

In the aggradation scenarios, the fan surface has been aggraded and the main channel infilled, therefore reducing the channel capacity and its ability to handle flood flows. As a result, compared to the design runs, smaller peak flows from the Buckler Burn result in greater activation of the northern side of the lower fan, as well as inundation of the Glenorchy-Queenstown Rd and Glenorchy township itself, relative to the level of aggradation (i.e., A – 1m, B – 2m, and C – 3m).

The results from each of the three aggradation scenarios with the range of peak flows, have been described below. Unless stated otherwise, any comparisons made to the design runs are to the 2019 LiDAR design set.

6.2.1. AGGRADATION SCENARIO A (1M)

100m^3/s

In this smallest of peak flow scenarios, the 1m of aggradation halves the capacity of the burn and fan to handle flood flows, and results in similar inundation of the Glenorchy-Queenstown Rd, behind the Glenorchy stopbank, and Glenorchy township to a slightly smaller extent than that of the 250m^3/s design run (Figure 6-7).

The Glenorchy-Queenstown Rd and Oban St are both inundated with depths under 0.5m, and Lochburn Ave and Shiel St are also inundated, peaking under 1m where there are low lying areas relative to the surrounding land.

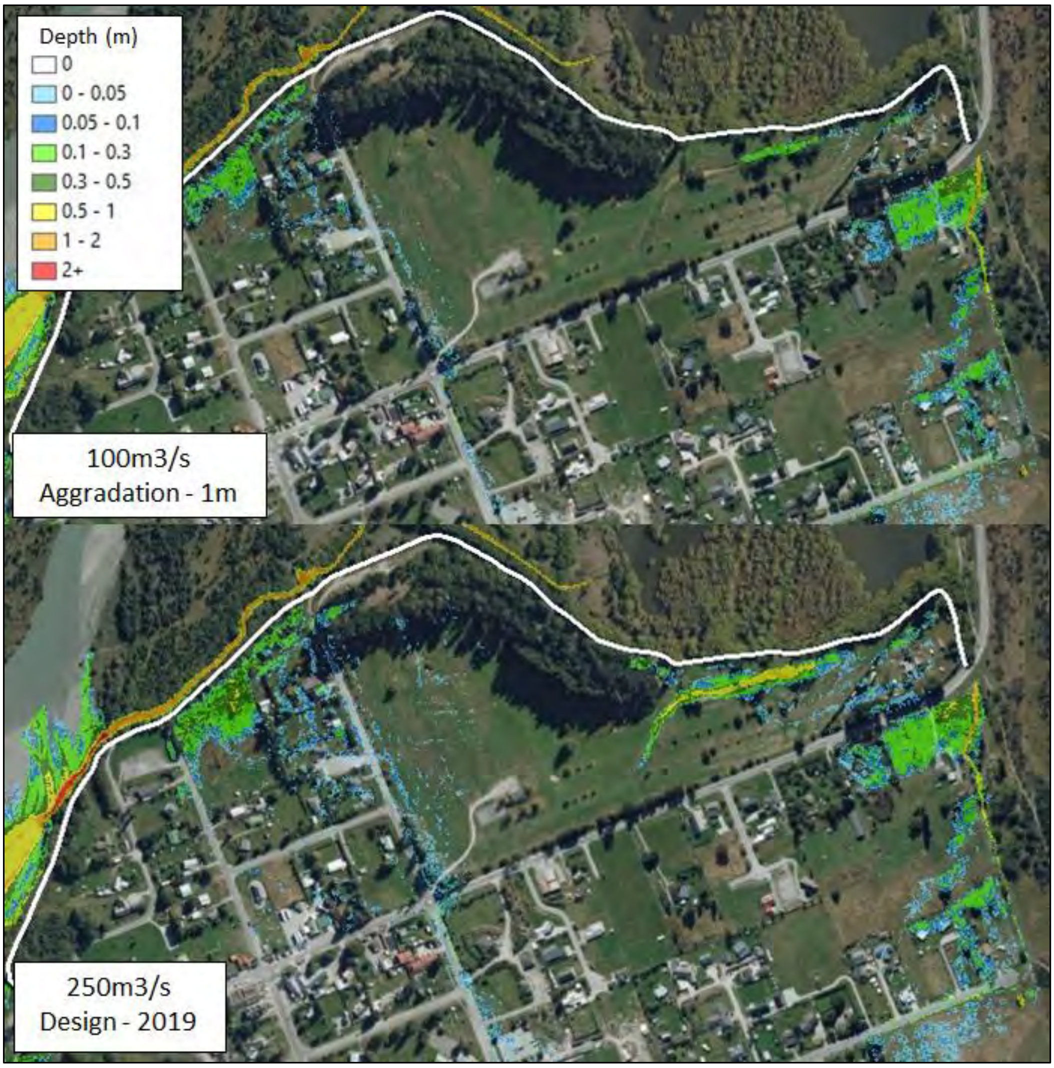

Figure 6-7 - Depth maps for the 250m3/s design 2019 run and the 100m^3/s aggradation (1m) run.

In the active fan surface, compared to the 100m^3/s design run, depths are up to 0.8m shallower in the main channel, notably between chainages 0.1 and 0.6km, and between 0.9 and 1.15km (Figure 6-8), whilst the section from chainage 0.7 to 0.9km where the road overtops, shows depths decreasing by only up to 0.5m. Outside of the main channel – across the active fan surface – flow is up to 0.5m deeper.

Additionally, several small flow paths and patchy inundation develop on the northern side of the fan in the bottom half of the lower reach (downstream of chainage 1.5km). This is similar (though slightly deeper) to the 100m³/s design run (Figure 6-8).

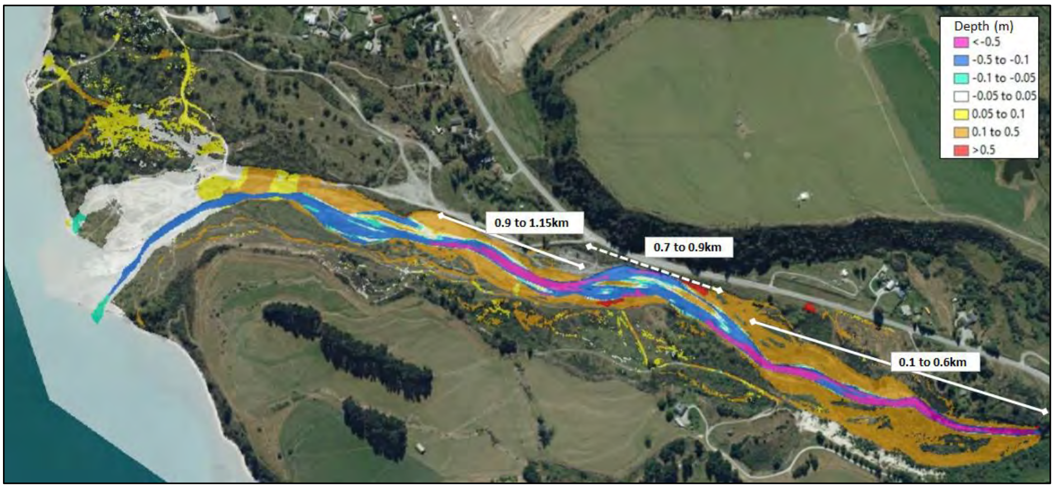

Figure 6-8 – DEM of Difference between the 100m3/s 1m aggradation scenario and the 100m3/s design (2019) run.

150m³/s to 300m³/s

The 1m aggradation scenarios with peak flows between 150m³/s and 300m³/s all result in floodwaters pooling behind the Glenorchy stopbank and at the eastern end of Mull St, with depths slowly increasing with each step up in flow (Figure 6-9). Patchy inundation is also expected along and to the sides of Lochburn Ave, Lancaster Pl, Invincible Dr, Shiel St, and Jetty St, with deeper inundation along the Glenorchy-Queenstown Rd and Oban St (Figure 6-9).

In these five scenarios, flow begins to break out earlier onto the northern side of the lower fan reach with each step up in flow, with flow path depths and inundation of the northern fan surface increasing. However, the breakouts don't quite reach the channel activated in the 1994 and 1999 flood events that begins between chainages 1 and 1.2km.

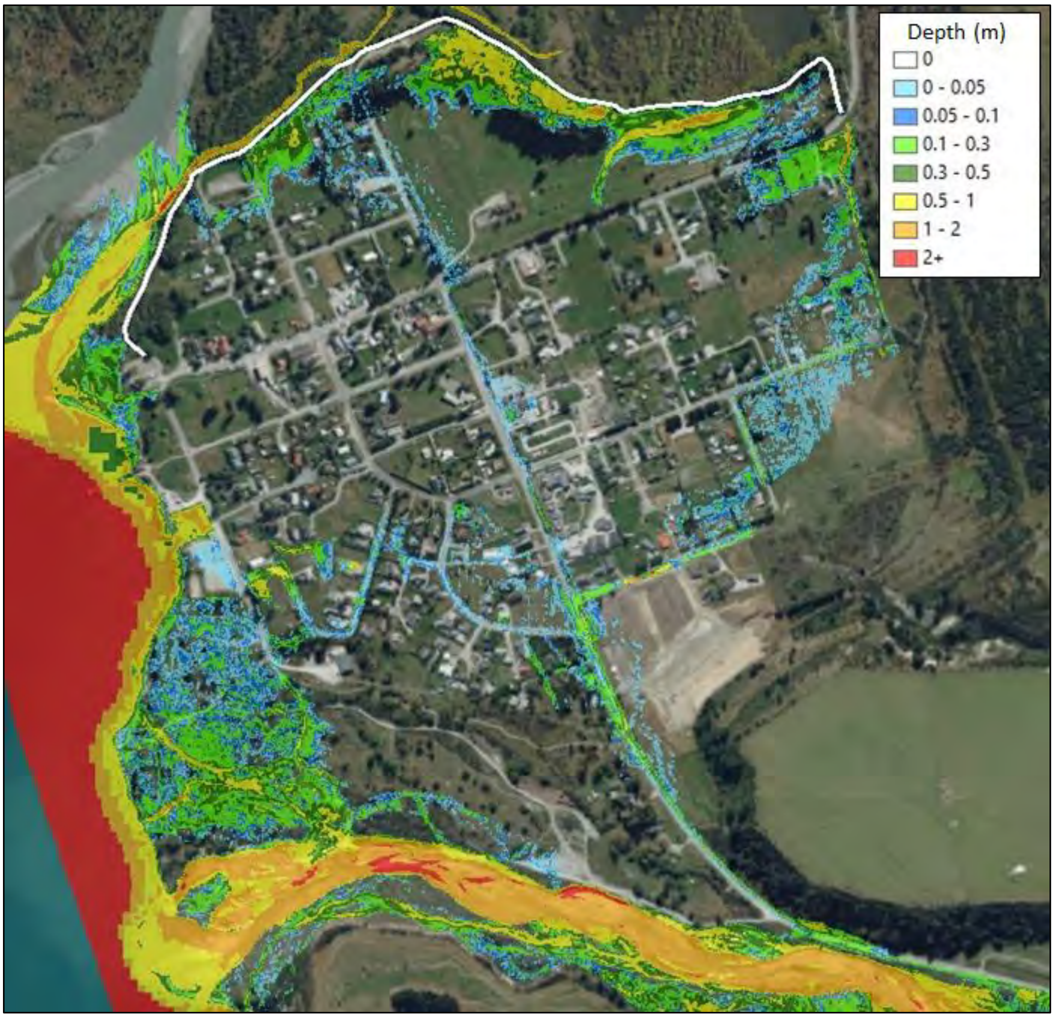

Figure 6-9 – 200m³/s aggradation (1m) inundation depths along the Glenorchy stopbank, with shallower inundation through the township.

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6.2.2. AGGRADATION SCENARIO B (2M)

100m³/s

In the 100m³/s scenario, 2m of aggradation across the fan surface results in greater inundation of the Glenorchy township than the largest of the design scenarios (300m³/s), despite being a much smaller flow (Figure 6-10).

In this scenario most of the flow entering the town comes from the where the burn spills over onto the Glenorchy-Queenstown Rd between chainages 0.25 and 0.5km, and results in the water pooling behind the Glenorchy stopbank and eastern end of Mull St reaching depths as high as 2m.

Figure 6-10 – Depth difference map between the 100m³/s aggradation (2m) and 300m³/s design (2019) runs. Despite the smaller flow, the aggradation scenario produces greater inundation.

The northern side of the lower fan reach does not show significant inundation, with only a few of the small channels activated and patchy inundation through the vegetation of less than 0.3m.

150m³/s to 300m³/s

In the five flow scenarios ranging from 150m³/s to 300m³/s with 2m of aggradation, a similar depth of floodwaters accumulates behind the Glenorchy stopbank and eastern end of Mull St in all of them (Figure 6-11).

However, as flows increase, inundation depths along the Glenorchy-Queenstown Rd and Oban St also increases, peaking around 1.5m, whilst several roads within the Glenorchy township i.e., Lochburn Ave, Lancaster Pl, Invincible Dr, Shiel St, and Jetty St experience increasing inundation with depths largely below 0.3m but in places peaking as high as 1m (Figure 6-11). These results indicate that the spillover from the upper fan does not take the natural flow paths of the bajada that the township is built on, but rather is forced along the roadways, which creates potential inundation of adjacent properties.

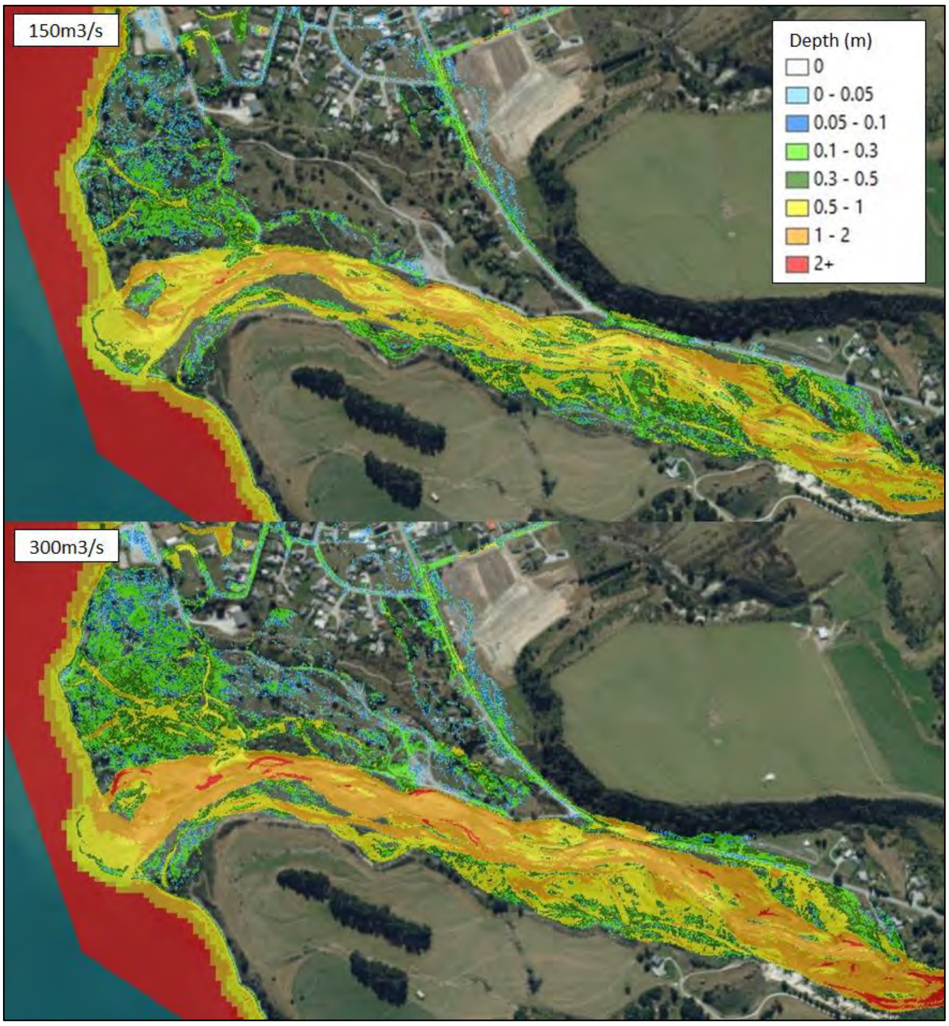

Figure 6-11 – 2m aggradation scenarios showing inundation of the 150m^3/s and 300m^3/s runs.

Where the five runs differ is in the amount of inundation across the northern side of the lower fan reach. In the 150m^3/s this is still patchy, and largely confined to the most downstream part of the fan. However, by the 300m^3/s scenario, there are flow paths across the entire vegetated northern side of the lower fan reach, though depths remain below 1m (Figure 6-11).

In the main fan surface, instream channel depths range between 0.5 and 2m with small places exceeding 2m.

Similar to the design runs and slightly lower aggradation scenario (1m), for the most part inundation within the Glenorchy township is classed as hazard category 1 with small areas up to 4. However, there are localised spots as high as 6 along the Glenorchy-Queenstown Rd and Oban St where flow velocities peak above 2m/s (Figure 6-12), and the floodwaters behind the Glenorchy stopbank, have crept up to category 3.

Again, the main active fan surface is classed as hazard category 5, with flow velocities in the main channel exceeding 1m/s in all scenarios, whilst the northern side of the lower fan reach has velocities largely between 0.5 and 1m/s, with a hazard category of 1.

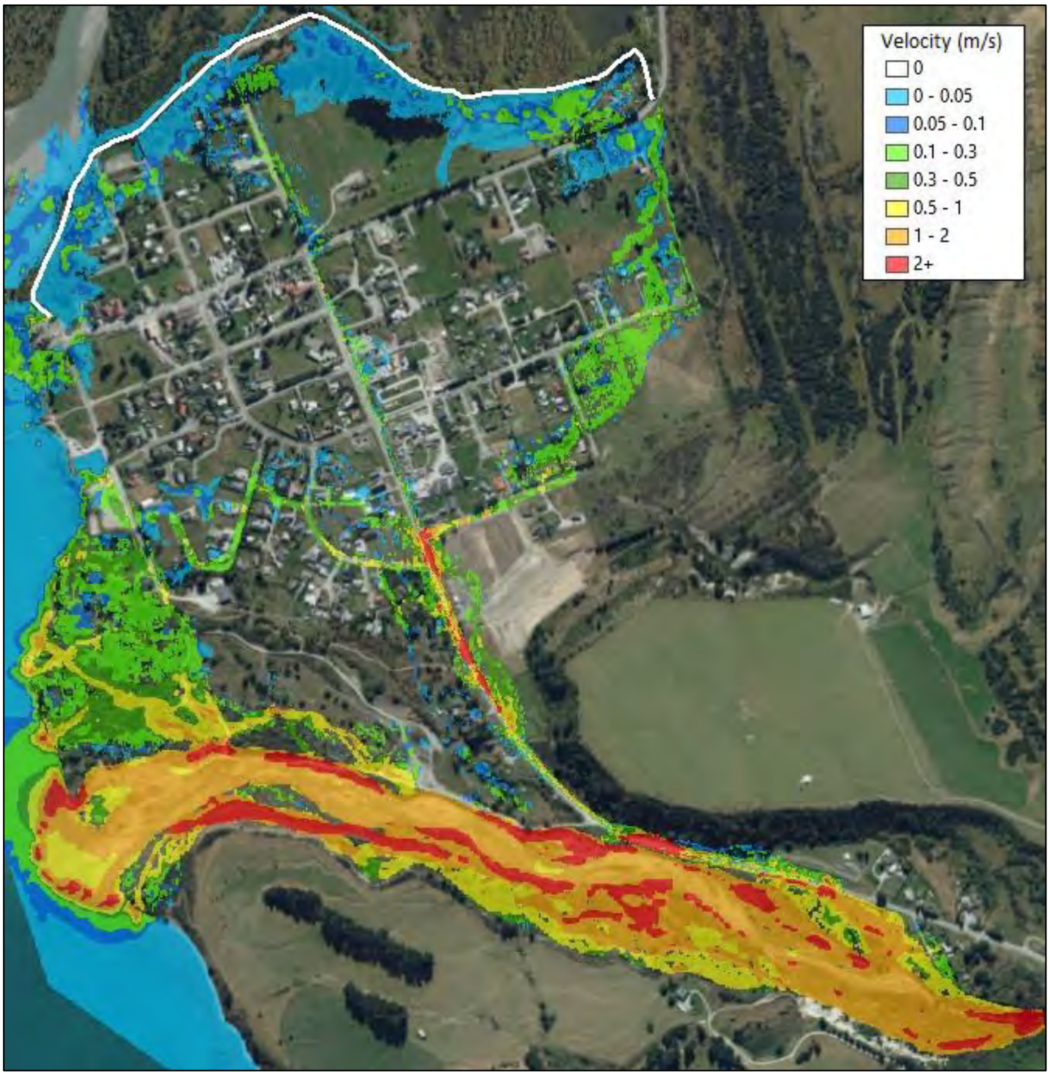

Figure 6-12 – Velocity map for the 200m³/s aggradation (2m) scenario.

AGGRADATION SCENARIO C (3M)

100m³/s

The 100m³/s scenario with 3m of aggradation results in activation of the entire upper fan surface area, with overtopping of the Glenorchy Queenstown Rd, but only patchy inundation of the northern side of the lower fan reach (Figure 6-13).

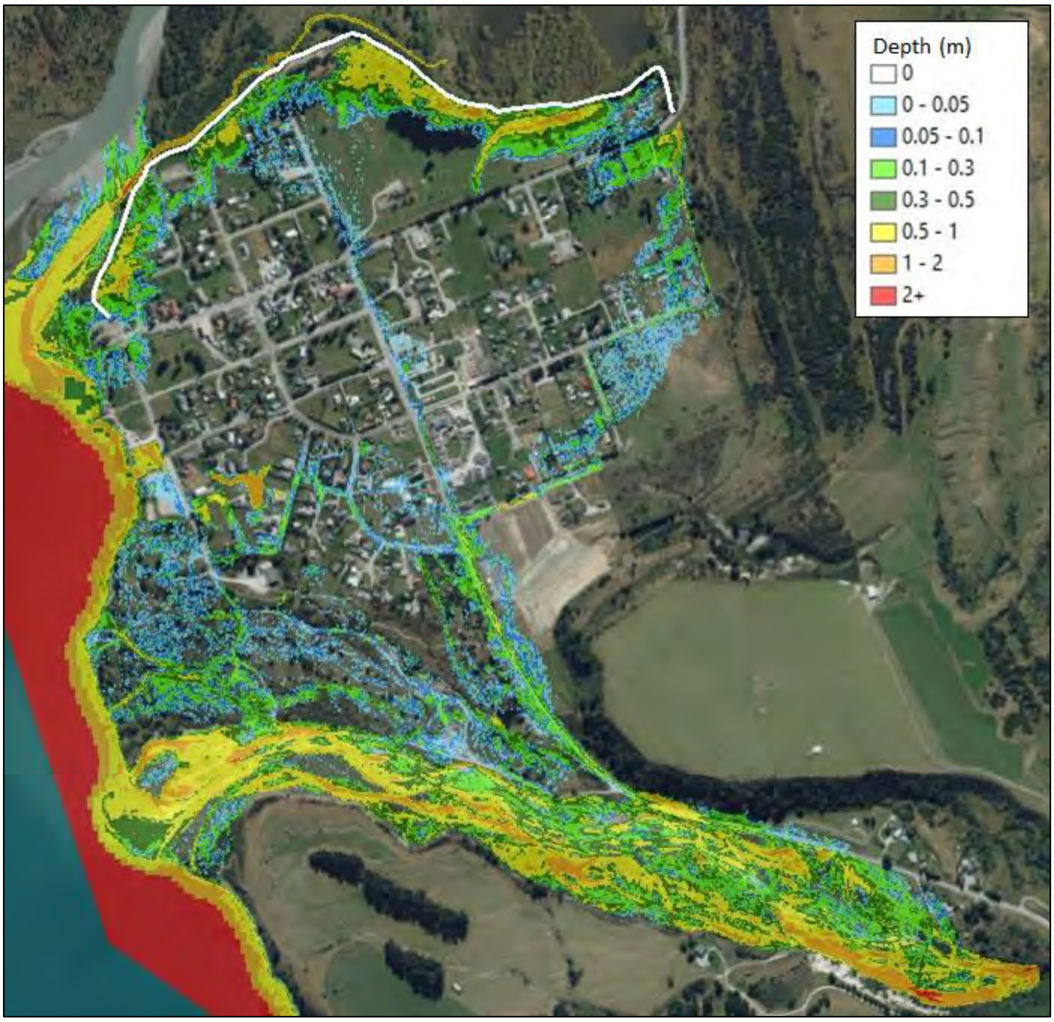

Figure 6-13 – Depth map for the 100m³/s aggradation (3m) scenario.

Inundation in the Glenorchy township is similar to that of 300m³/s flow with 2m aggradation scenario, with flood waters settling behind the Glenorchy stopbank, eastern end of Mull St and in locally low areas on the western side of the township. Most of this inundation is classed as hazard category 1, however there are localised spots reaching as high as category 3, and along Oban St and the Glenorchy-Queenstown Rd, as high as category 6.

150m³/s to 300m³/s

Similar to the 2m aggradation scenarios, in the 3m scenarios, the results for the 150m³/s to 300m³/s peak flows indicate that most of the change in inundation occurs across the northern side of the lower fan surface, and along the Glenorchy-Queenstown Rd.

As flows increase, flow paths and inundation coverage across the northern lower fan surface increases, as do depths along the Glenorchy-Queenstown Rd and Oban St, peaking +2m in depth and +2m/s in velocity, rendering them impassable (Figure 6-14).

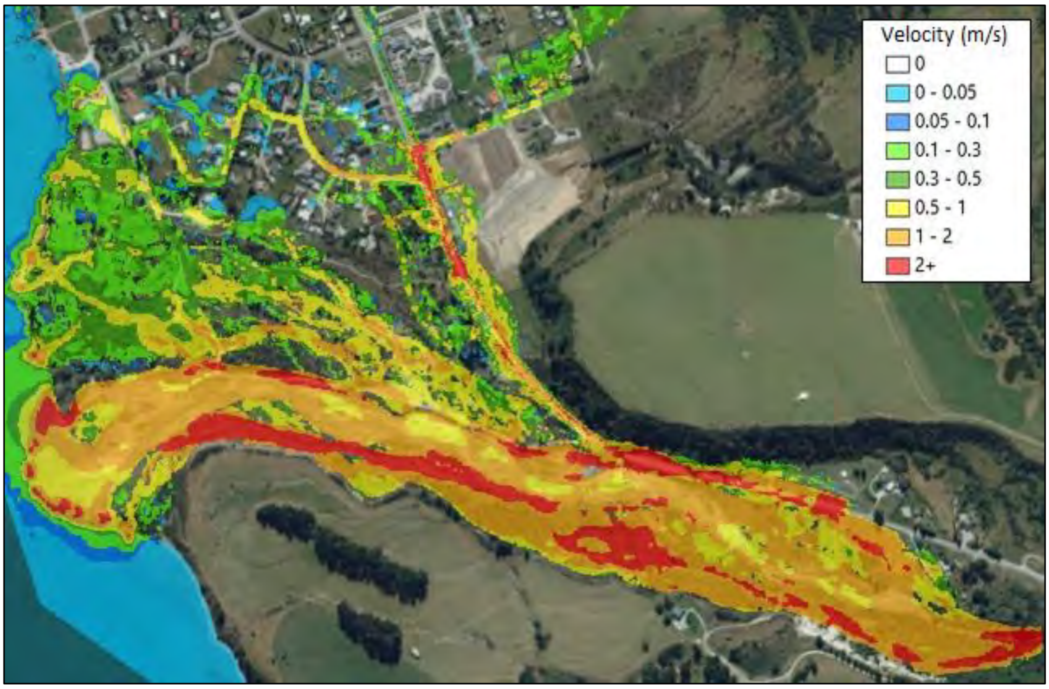

Figure 6-14 – Velocity map for the 200m³/s aggradation (3m) scenario.

Several roads within the Glenorchy township i.e., Lochburn Ave, Lancaster Pl, Invincible Dr, Shiel St, and Jetty St also experience inundation with depths largely below 0.3m but in places peaking as high as 1.5m.

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Properties along these roads may experience some inundation. However, the hazard category for much of the town remain at 1, with only a few areas creeping up to 4, and along the Glenorchy-Queenstown Rd and Oban St, to 6 (Figure 6-15).

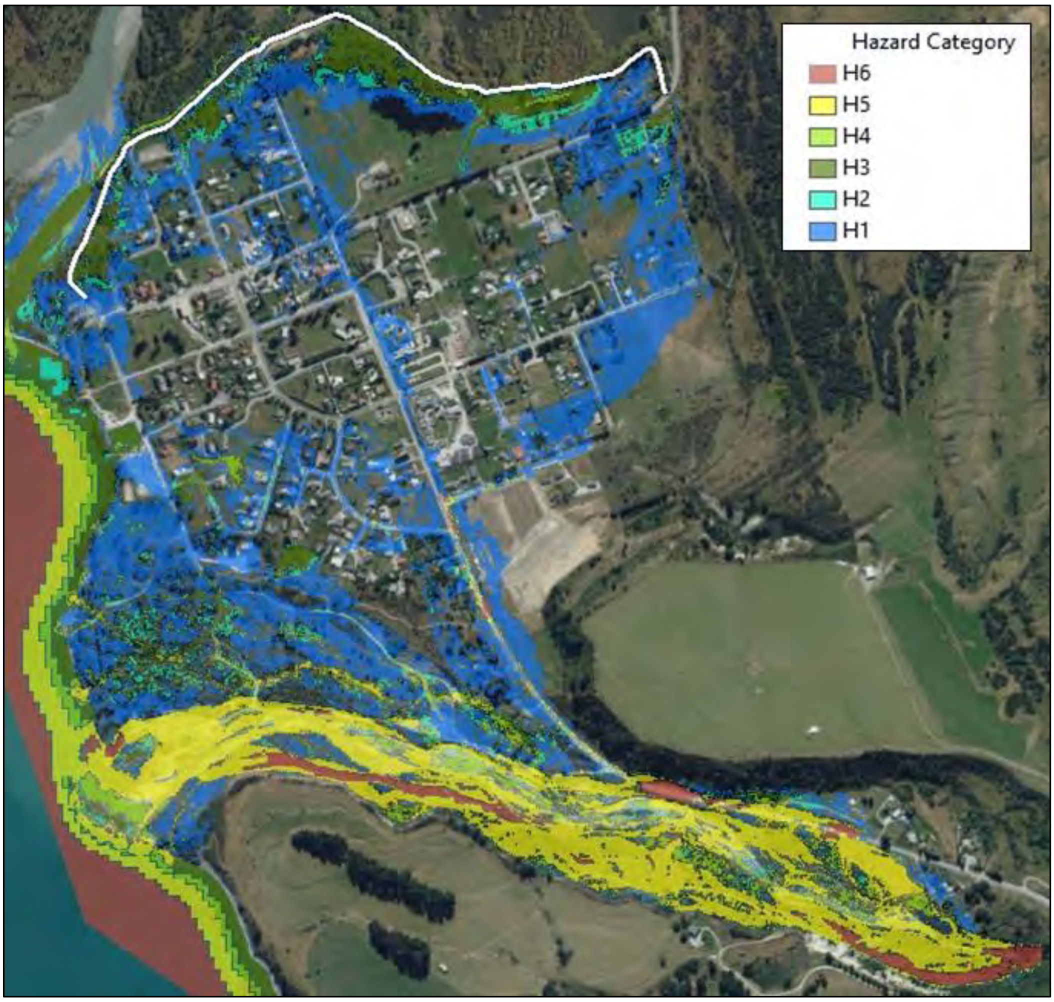

Figure 6-15 – Hazard category map for the 300m³/s aggradation (3m) scenario.

7. RESULTS DISCUSSION

In both sets of design runs and in all three of the aggradation scenarios, the modelling shows that with the fan morphology unique to the DEM of each design run or aggradation scenario, the Glenorchy township and Glenorchy-Queenstown Rd should expect to experience inundation as a result of spillover:

- from the upper fan between 0.25 and 0.5km chainages,
- from the lower fan downstream of the 1.4km chainage,
- and in some of the higher flow aggradation scenarios from adjacent to the road around the 0.7 and 0.85km chainages.

In all situations, the flow (mostly from the upstream spillover) generally follows the natural contouring of the bajada* that has formed from the northern depositional lobe of the Buckler Burn fan and the Bible Stream fan, which the town has been built on, before pooling at the toe of the bajada behind the Glenorchy stopbank.

The flow typically goes:

- Down the apex of the bajada, though given the potential flow paths it could follow this appears to be enforced by Oban St; and
- Down the sides of the bajada – Benmore Pl, Lochburn Ave, Shiel St and the eastern end of Mull St.

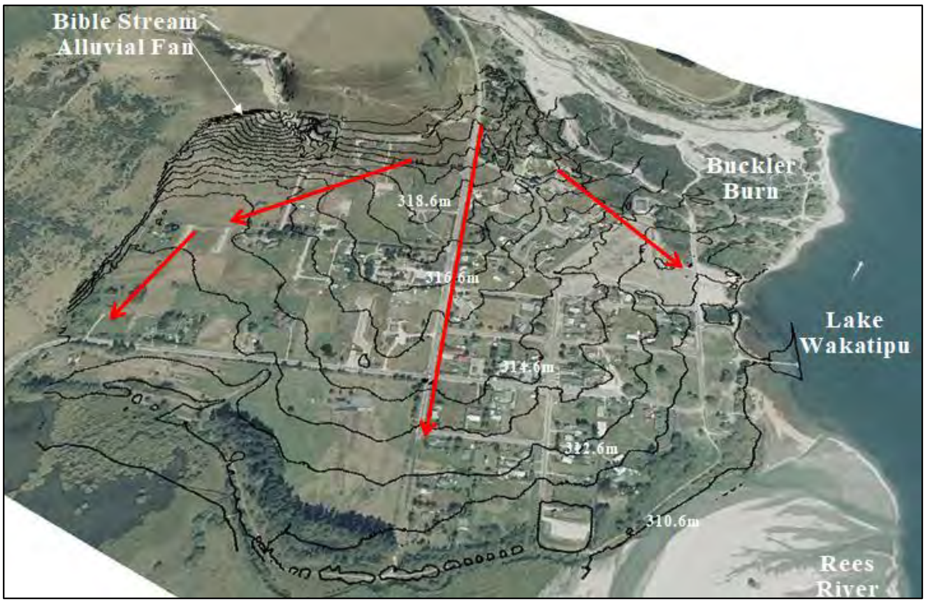

Figure 7-1 - ORC generated image. Land River Sea Buckler Burn model flow paths drawn on in red.

** Bajada: a broad slope of alluvium formed from multiple coalescing alluvial fans* (Fairbridge, 1968).

7.1. DESIGN RUNS

In the design runs, the modelling shows that in both sets (2019 and 2022 LiDAR) the Glenorchy township and access road (Glenorchy-Queenstown Rd) experience increasing inundation with each step up in flow. However, the fan surface has changed between the 2019 and 2022 LiDAR surveys, and as a result the two sets of design runs show differences in inundation, thus highlighting the sensitivity of the model (and therefore the flood hazard to the Glenorchy township) to subtle changes in fan morphology.

- Aggradation in the lower fan reach (below chainage 1.4km) in the 2022 design runs results in slightly greater inundation of the northern side of the lower fan surface compared to the 2019 design runs. This becomes more obvious in the depth difference maps with bigger flows.
- Inundation of the town and Glenorchy-Queenstown Rd from spillover from the upper fan occurs with smaller flows in the 2019 runs (150m^3/s) compared to the 2022 runs (250m^3/s), and as a result floodwaters pool behind the Glenorchy stopbank in the 2019 runs but not in the 2022 runs.

This latter point seems counterintuitive given the hypothesis of an aggrading fan surface under a positive IPO climate, and that the 2022 active fan surface has experienced some aggradation in places compared to the 2019 fan surface. However, a close inspection of the GCD analysis between the 2019 and 2022 LiDAR shows erosion to the banks on both sides of the channel in the upper fan with only small changes in depth, thus increasing the channel capacity in the 2022 LiDAR and model runs (Figure 7-2). Thus, the 2022 design runs require larger flows to spillover the fan boundaries and inundate the Glenorchy township.

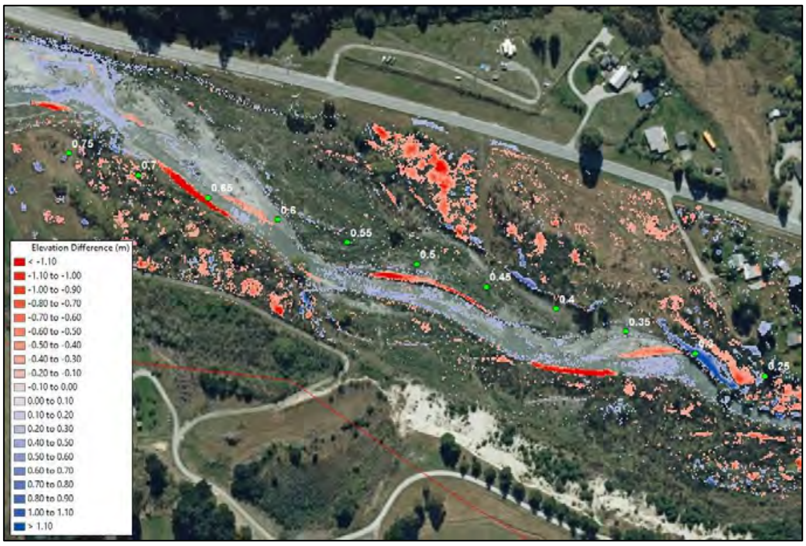

Figure 7-2 – GCD analysis between the 2022 and 2019 LiDAR. The dark red areas along the edges of the active braid plain indicate erosion and widening, whilst the dark blue between 0.25 and 0.3km likely indicates vegetation growth.

Additionally, it should be noted that the classification of ground points and vegetation was not done to as high a quality in the processing of the 2022 LiDAR compared to the 2019 LiDAR. Therefore, vegetation growth such as that between the 0.25 and 0.3km chainage (as shown by the positive change in elevation in the GCD) may have resulted in overflow paths being blocked off in the 2022 model runs thus preventing overtopping in smaller flows (Figure 7-2).

In both design sets, the Glenorchy-Queenstown Rd does not overtop as a result of flooding from the chainage immediately adjacent to the road in any of the design runs (2019 and 2022), but rather from spillover upstream at the 0.25km chainage.

With the modelled fan morphology, inundation, when it does occur in the township is for the most part confined to roads with depths under 1m and has been give the lowest hazard category of 1, with smaller areas up to 4. However, there are a few localised spots as high as 6 where the Glenorchy-Queenstown Rd is inundated and at the southern end of Oban St in the bigger flow design runs.

7.2. AGGRADATION SCENARIOS

In the aggradation scenarios, due to the main channel infilling and therefore reducing the channel capacity, it takes less flow for the channel to fill (shallower depths). Thus there is an increase in spillover beyond the active channel belt and subsequently greater activation of the northern side of the lower fan with depths increasing across the fan surface.

- Inundation of the Glenorchy Queenstown Rd occurs via two mechanisms, flooding from upstream between the 0.25 and 0.5km chainages, and in the 3m aggradation scenarios with flows between 200m^3/s to 300m^3/s, from the fan surface immediately adjacent to the road. However, in these situations the flooded area appears larger than what is inferred on the 1999 photos.
- Velocities in the township vary between 0.1 and 1m/s, but along the southern end of Oban St and the Glenorchy Queenstown Rd, peak above 2m/s.
- Inundated areas in the township are for the most part classed as hazard category 1, with smaller areas getting as high as 4, and up to category 6 along the Glenorchy-Queenstown Rd and Oban St in the 2m and 3m aggradation scenarios.
- The fan surface is categorised as either 5, 6 or a mixture of both, depending on the scenario, as expected given its steep nature.

Additionally, despite the increasing activation of the northern side of the lower fan, the modelled inundation of the township that results from this, is still minimal. This is not necessarily realistic; but more likely an underestimation of the depths and frequency of inundation in the township due to the simplified nature of the elevated fan surface in the aggradation scenarios. Tapering the slope to the lake margin, and smoothing out the fan surface, removes the braided and ‘lumpy’ nature of the lower fan surface, and hence the inability to direct flow to the north (or south) which would result in greater inundation.

7.3. RISK OF AVULSION

Finally, in all of the design and aggradation scenarios, and most notably those with the larger flows (+200m^3/s), there is consistently high velocities along the northern (true right) bank of the Buckler Burn, in the vicinity of the Glenorchy-Queenstown Rd. Though the model assumes a static bed so erosion can't be modelled using this approach, these velocities indicate that erosion of the bank is highly likely in this location with the associated risk of avulsion. The avulsion would likely take a northerly direction, reoccupying former channel pathways (Fuller and McColl, 2021) and may ultimately direct flow into the Glenorchy township with significant consequences.

8. CONCLUSIONS

The following conclusions can be drawn from this study.

- Flood flows have the potential to overtop the active channel belt, spill out across the fan surface and inundate the township. The extent of this inundation depends on the state of the fan surface and alignment of channels. However, should a sizeable event occur, due to the natural contouring of the Buckler and Bible bajada, and forcing of the roadways, the flow generally goes down the apex (Oban St) and the sides of the bajada (Lochburn Ave and Shiel St) with only localised flooding to the buildings alongside the roads in these locations.
- Aggradation across the fan surface and infilling of the active channel belt, leads to a reduction in the amount of flow required to spill out onto the fan surface, which leads to an increase in inundation along the Glenorchy-Queenstown Rd and within the Glenorchy township.
- Flood behaviour is therefore sensitive to aggradation on the fan and the exact nature of a flood will change based on that.
- However, simplification of the aggradation profiles, though necessary, may have resulted in an underestimation of the inundation extents to the north, and warrant further study with greater detail.
- Further, subtle changes in the fan morphology between the 2019 and 2022 LiDAR surveys results in differences in the extent and depth of inundation, and the size of flow required to fill the active channel belt and spillover onto rest of fan surface in the two sets of design runs. This shows that the modelling cannot capture the full range of such a dynamic system, but rather provide only a generalised prediction of behaviour and resulting inundation for these design and aggradation scenarios.
- Given the steep nature of the fan, flood flows across the fan surface are classed as hazard category 5, 6 or a mixture of both, whilst the floodwaters which enter the township, are for the most part given the lowest hazard category of 1, with localised spots there and along the Glenorchy-Queenstown Rd and Oban St as high as 6, rendering these roads impassable and likely damaged should such an extreme event occur.
- High velocities along the true right in the vicinity of the Glenorchy-Queenstown Rd also suggest that rates of erosion would be significant in this location, and therefore there is the risk of avulsion to the north.
- Imagery, cross sections, and past behaviour of the fan, suggest that its surface is actively changing over time with resulting effect on flood risk. For example, the active channel belt is currently aligned at the most southern limit of the fan; therefore northwards migration should be anticipated, with subsequent changes expected in the inundation to the north compared to that which has been modelled. To better understand the relationship between the fan surface morphology and flood risk, the fan would benefit from ongoing monitoring.

9. RECOMMENDATIONS

The following recommendations can be made from this study:

Modelling

Further modelling could be completed to better understand the risk of the hazards posed by the Buckler Burn:

- More detailed aggradation scenarios that have a more realistic distribution of sediment across the entire fan surface could be simulated. As could a scenario where the spillover onto the inactive fan surface between the 0.25 and 0.5km is prevented. This latter scenario will likely force more water down the fan to where the road overtopped in the 1999 flood, and may be a more realistic simulation of what actually happened in the 1999 event.
- Delft 3D could be used to model sediment transport and channel morphology within the Buckler Burn. This would provide further insight into the potential and vulnerability of the Buckler Burn switching channels whilst in a more aggraded state (as opposed to its currently incised state).
- Rapid Mass Movement Simulation (RAMMS) could be used to assess the potential magnitude of near-instantaneous bed aggradation in response to mass flows (debris flows/floods) by investigating the risks posed by slope failures in delivering large volumes of sediment.
- To better determine the risk of flooding to the Glenorchy township, a detailed catchment hydrology review could be completed to determine best-estimate flood frequency flows (annual return intervals) and provide an estimation on future flows under the climate change projection scenarios.

Fan morphology and behaviour

- Annual/biannual cross section monitoring to better understand flood risk from the burn, by keeping track of the change in channel capacity, fan surface elevation, and gradient over time. Periods where the main channel has infilled will result in reduced channel capacity and subsequently susceptibility to rapid infilling and higher flood risk from the burn, during events.
- Annual or significant event-based monitoring using LiDAR or drone survey (photogrammetry) to capture high resolution detail of the fan surface, will allow for GCD analysis to show change in the fan surface and channel topography over time.
- These successive DEMs should then be incorporated into future model runs to better understand changes in risk of inundation as the channel morphology adjusts.
- Document behaviour of the fan (main and subsidiary channels and delta) during and immediately after flood events.

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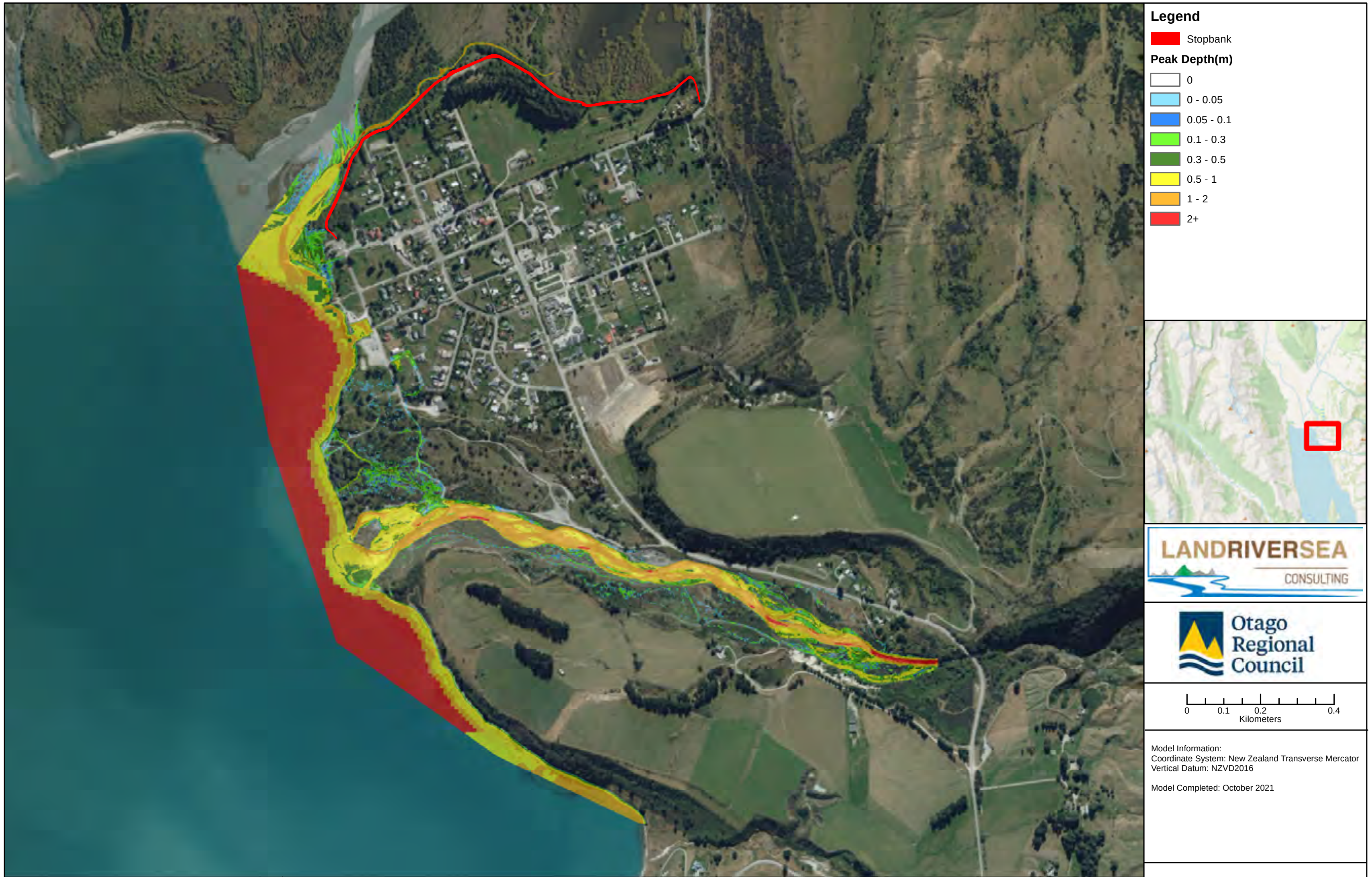
APPENDIX A – DESIGN RUNS – PEAK FLOOD DEPTH MAPS



PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **PEAK DEPTH MAP** **Design Scenario 2019 - Q 100 m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N	

Legend

Stopbank	
Peak Depth(m)	
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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0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 150 m3/s**	02		
		CREATED BY UP	27/07/2023	1:9,000
		REVISED BY	AUTHOR **Matthew Gardner**	N

Legend

Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 180 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 200 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N

Legend

- Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

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0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **PEAK DEPTH MAP** **Design Scenario 2019 - Q 250 m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N

Legend

- Stopbank

Peak Depth(m)

- 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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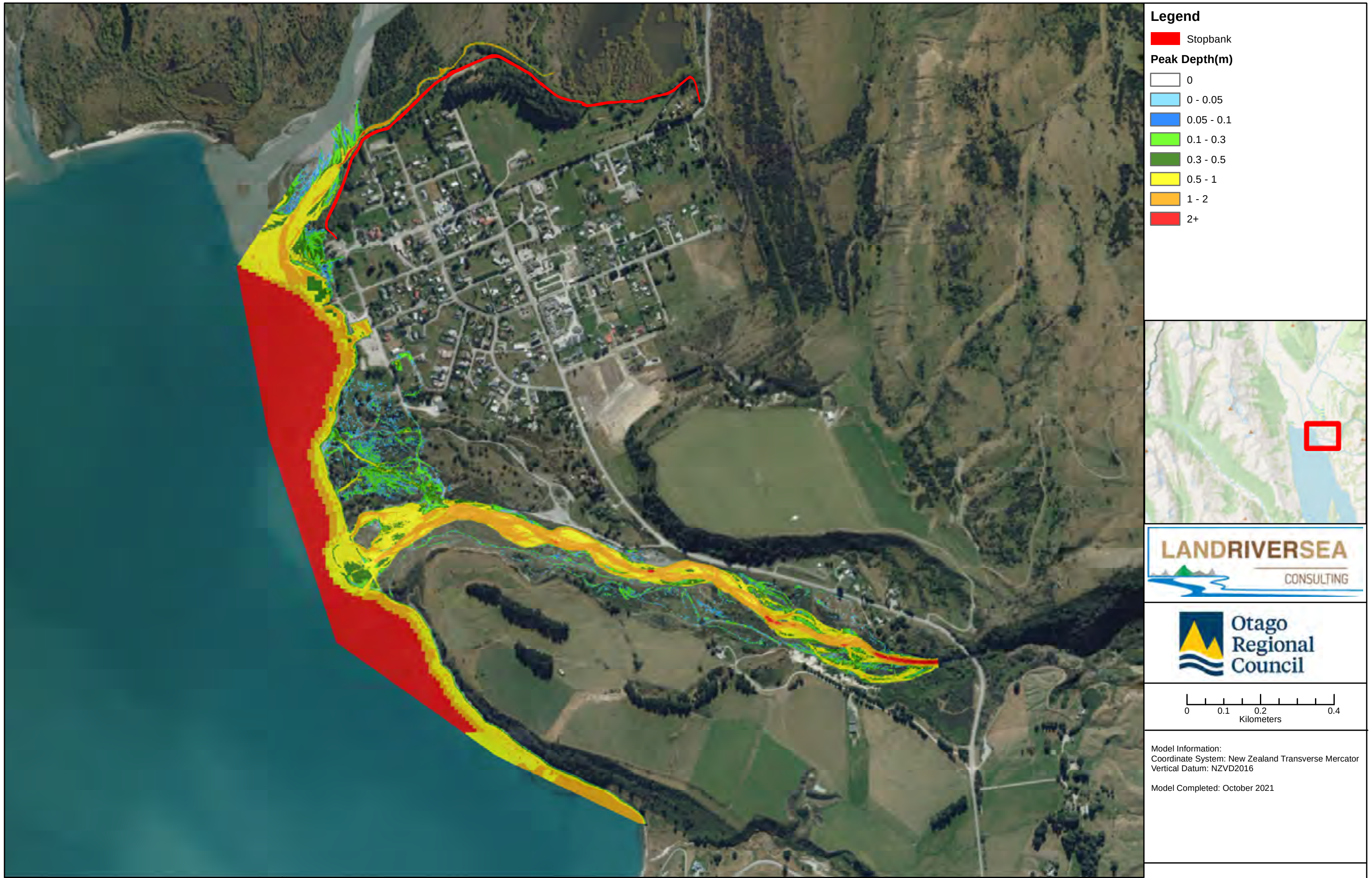
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 300 m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	**27/07/2023** AUTHOR **Matthew Gardner**	**1:9,000**	N



PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 100 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 150 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 180 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 200 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank	
Peak Depth(m)	
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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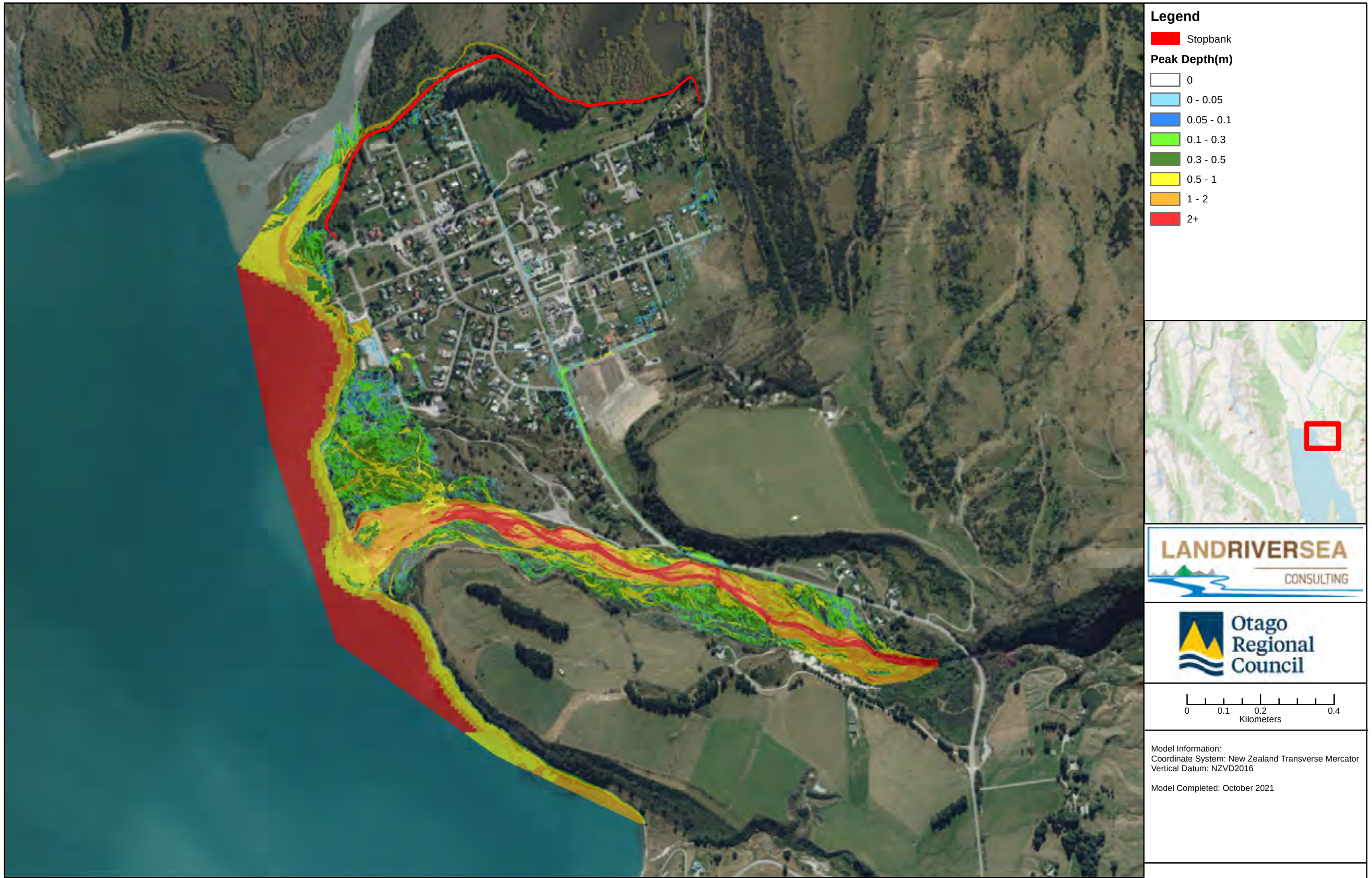
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 250 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 300 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

APPENDIX B – DESIGN RUNS – PEAK SPEED MAPS

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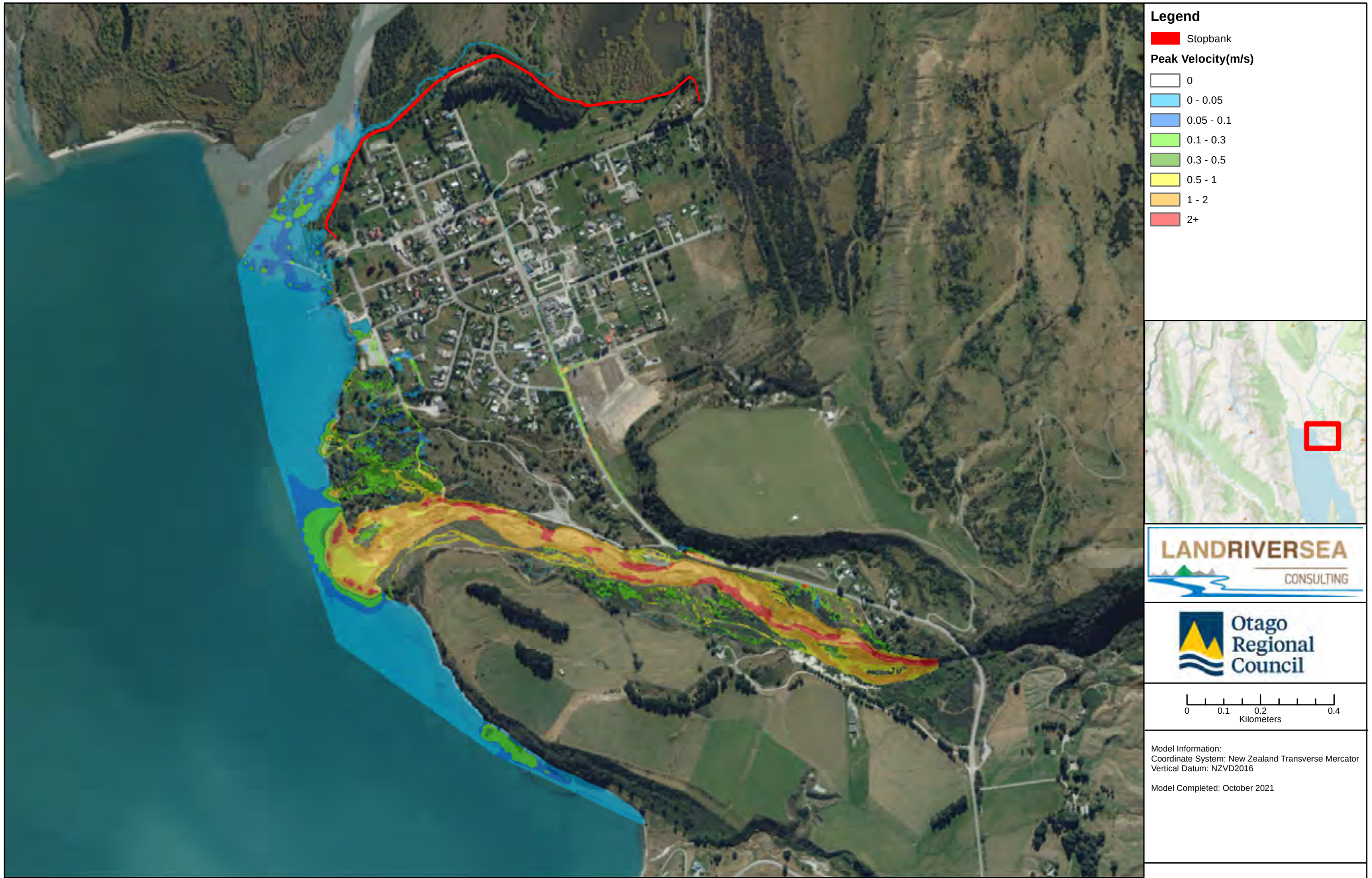
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2019 - Q 100 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

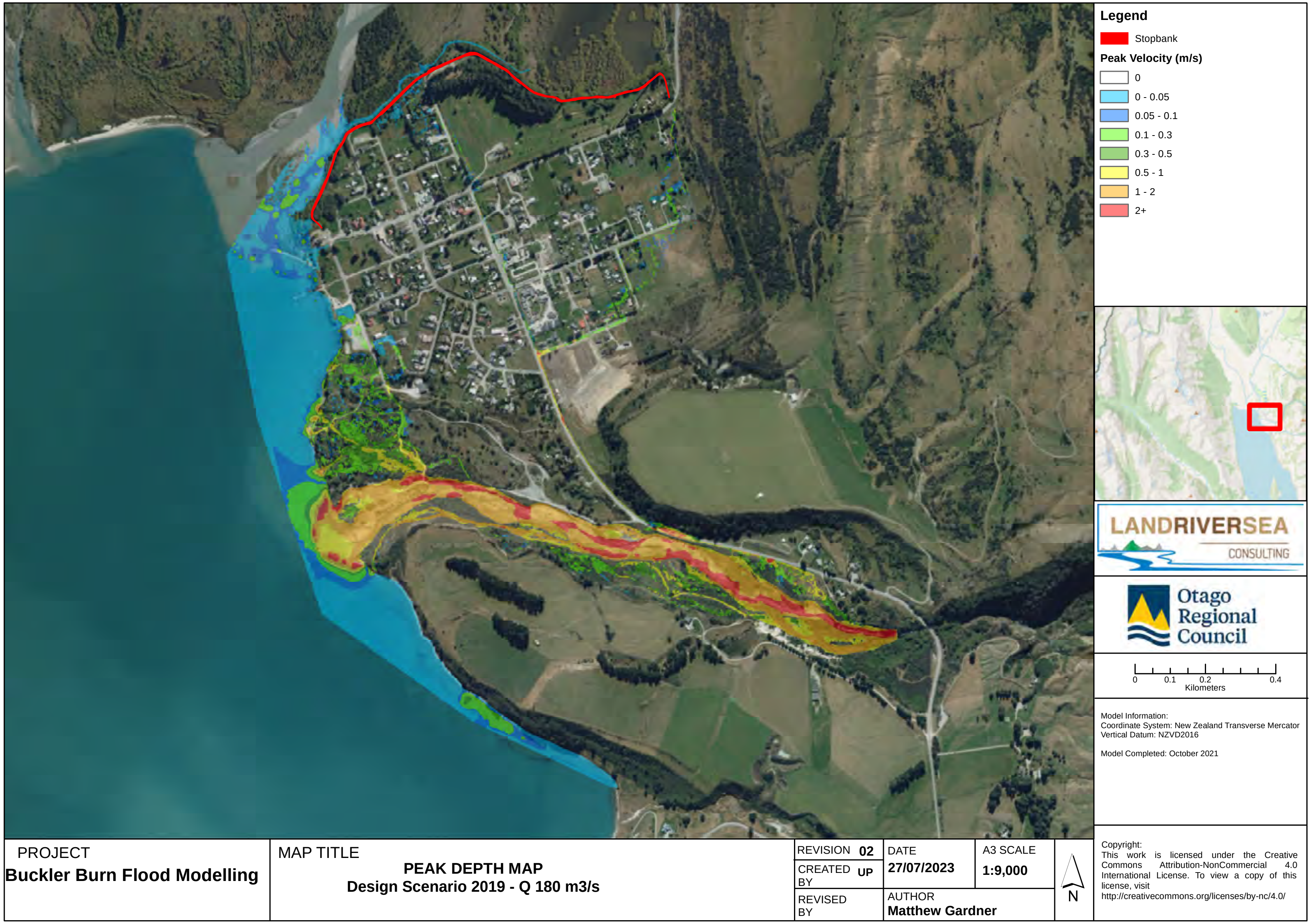
N



Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2019 - Q 150 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		


Legend
Stopbank
Peak Velocity (m/s)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK DEPTH MAP
Design Scenario 2019 - Q 180 m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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Legend

Stopbank

Peak Velocity (m/s)

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

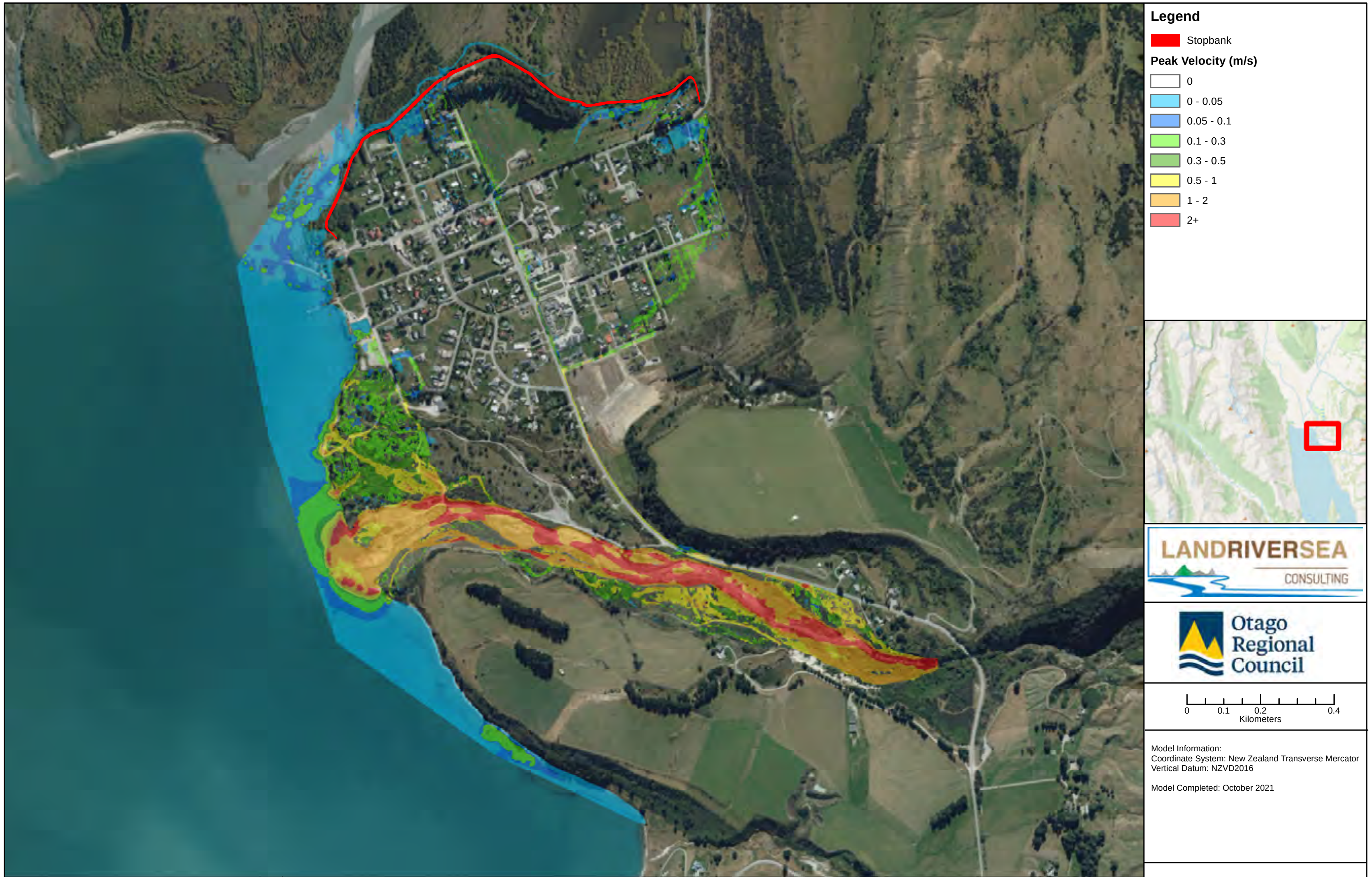
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

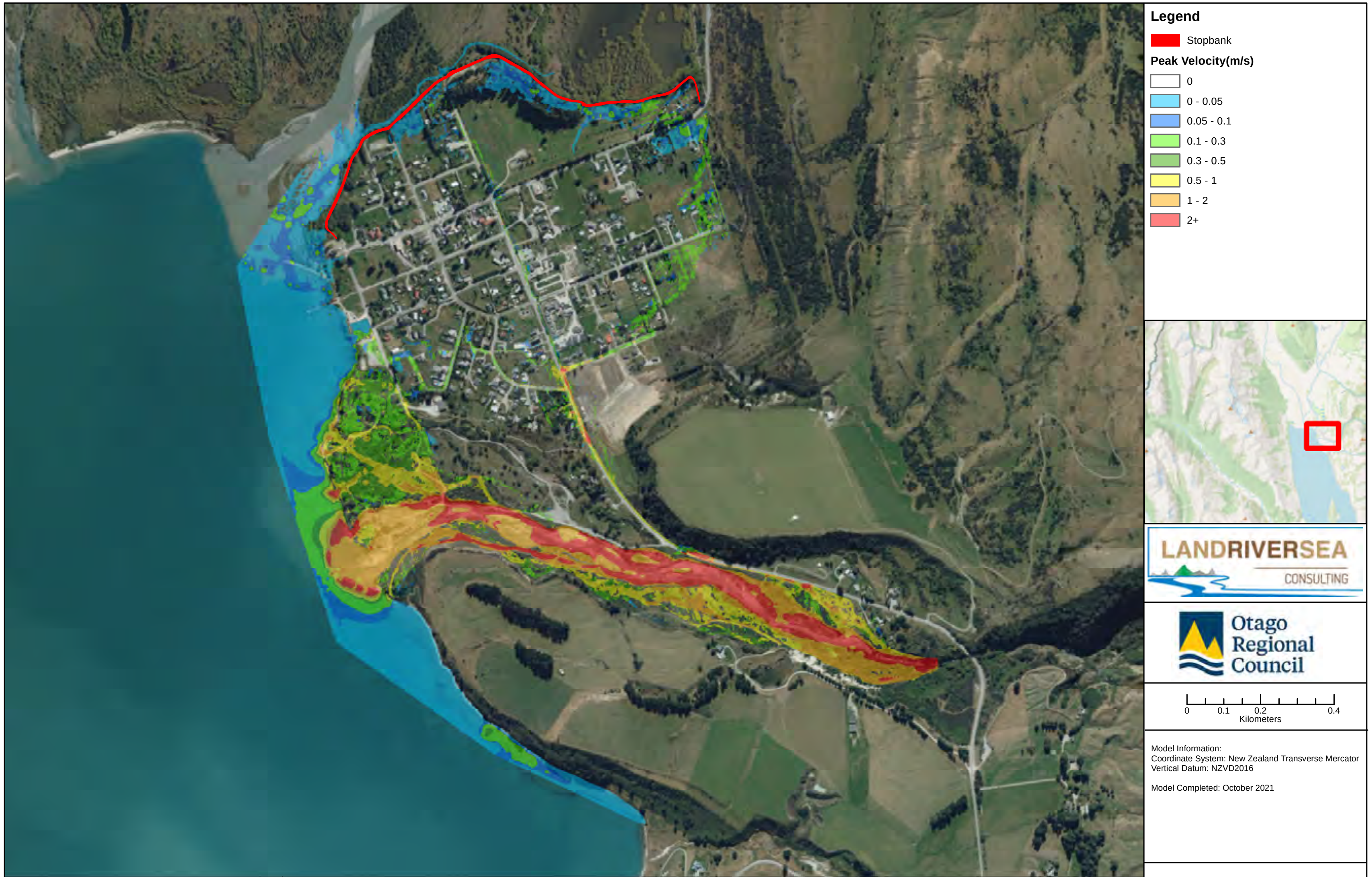
Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 200 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N



PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 250 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 300 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N

Legend

Stopbank

Peak Velocity(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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0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2022 - Q 100 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

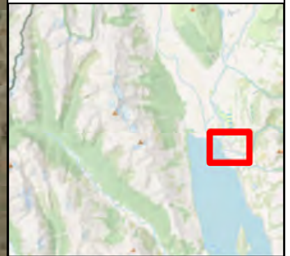
N

Legend

- Stopbank

Peak Velocity(m/s)

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



LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2022 - Q 150 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

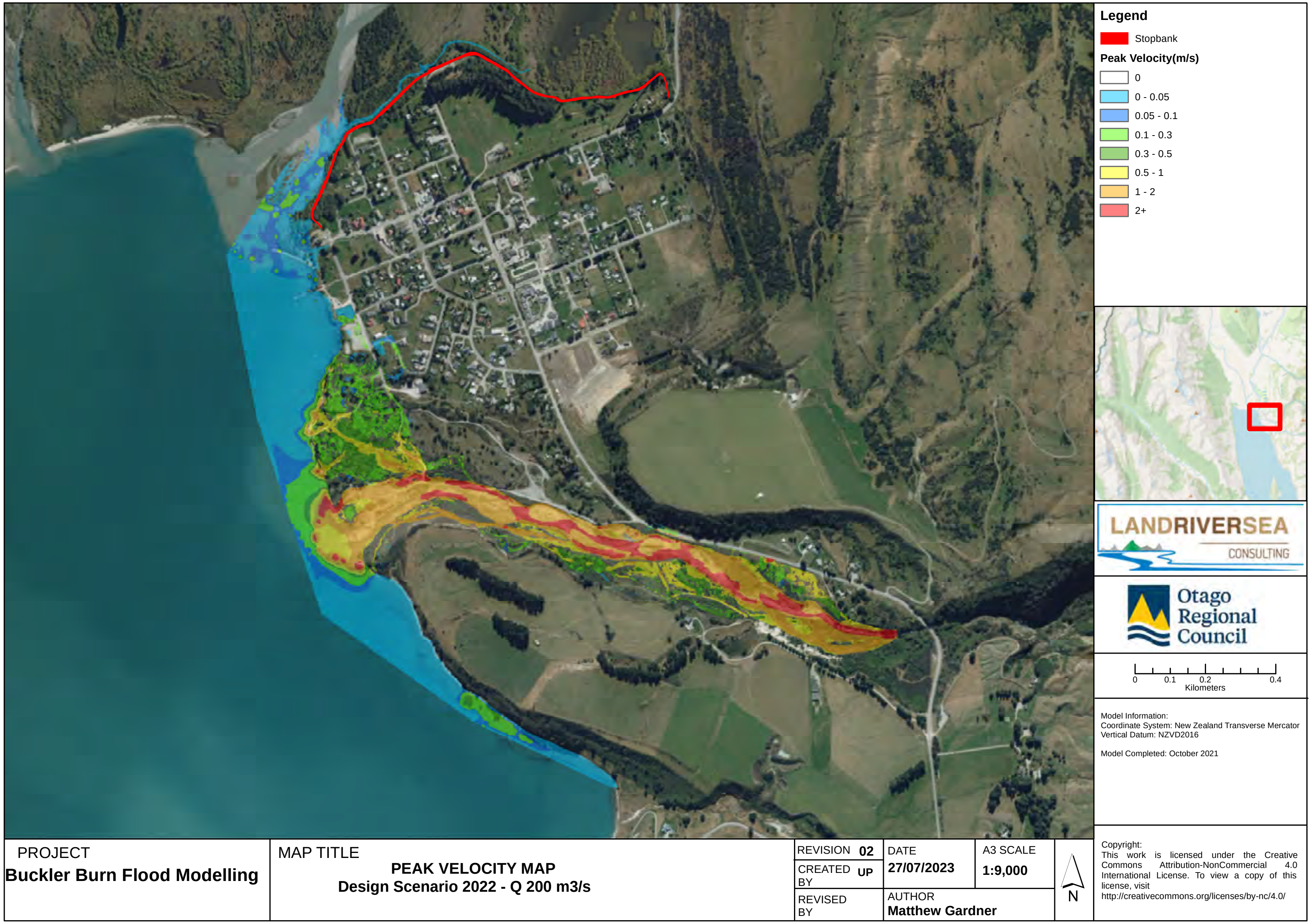
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2022 - Q 180 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		


Legend
Stopbank
Peak Velocity(m/s)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK VELOCITY MAP
Design Scenario 2022 - Q 200 m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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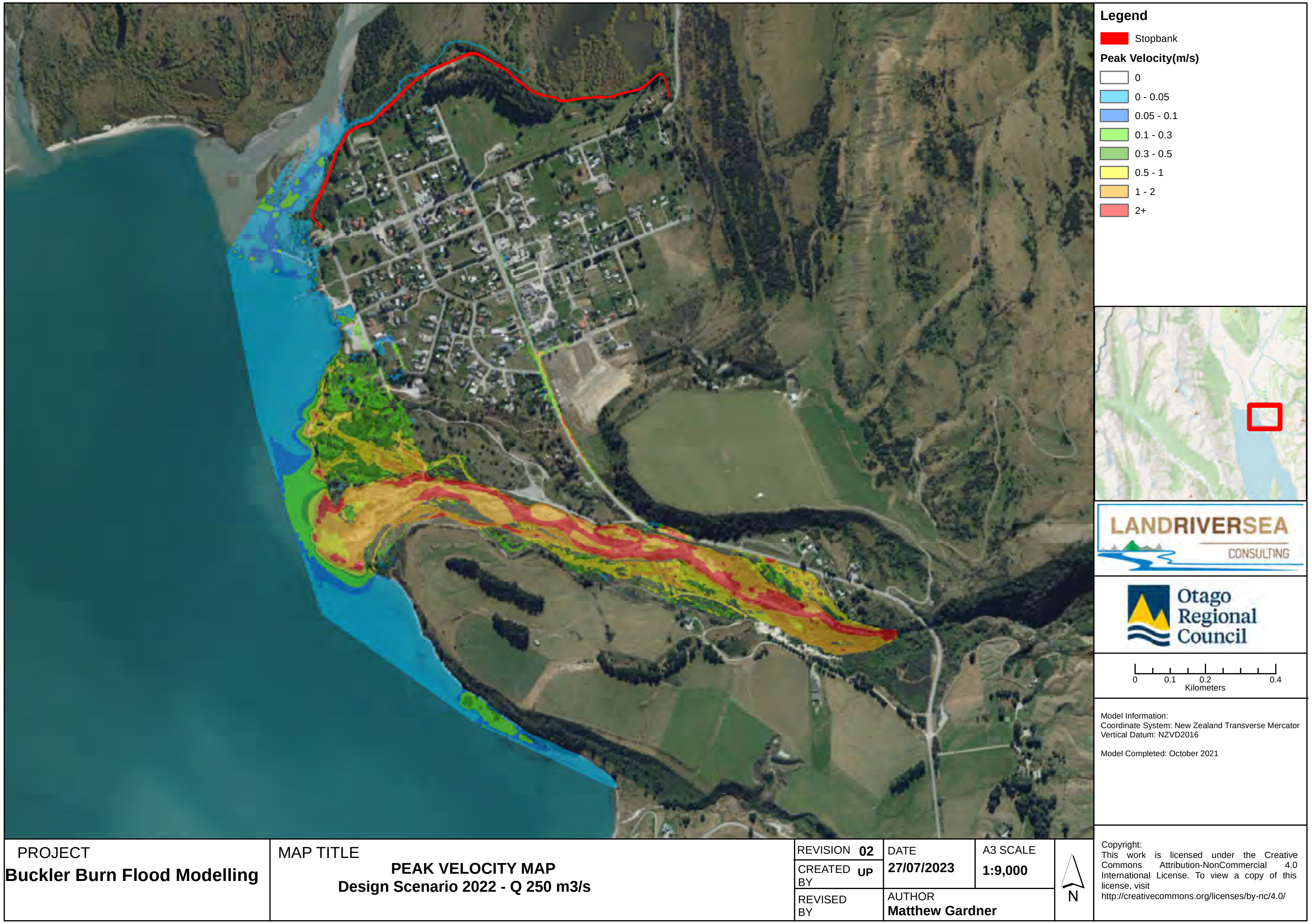
Legend
Stopbank
Peak Velocity(m/s)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK VELOCITY MAP
Design Scenario 2022 - Q 250 m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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Legend

- Stopbank

Peak Velocity(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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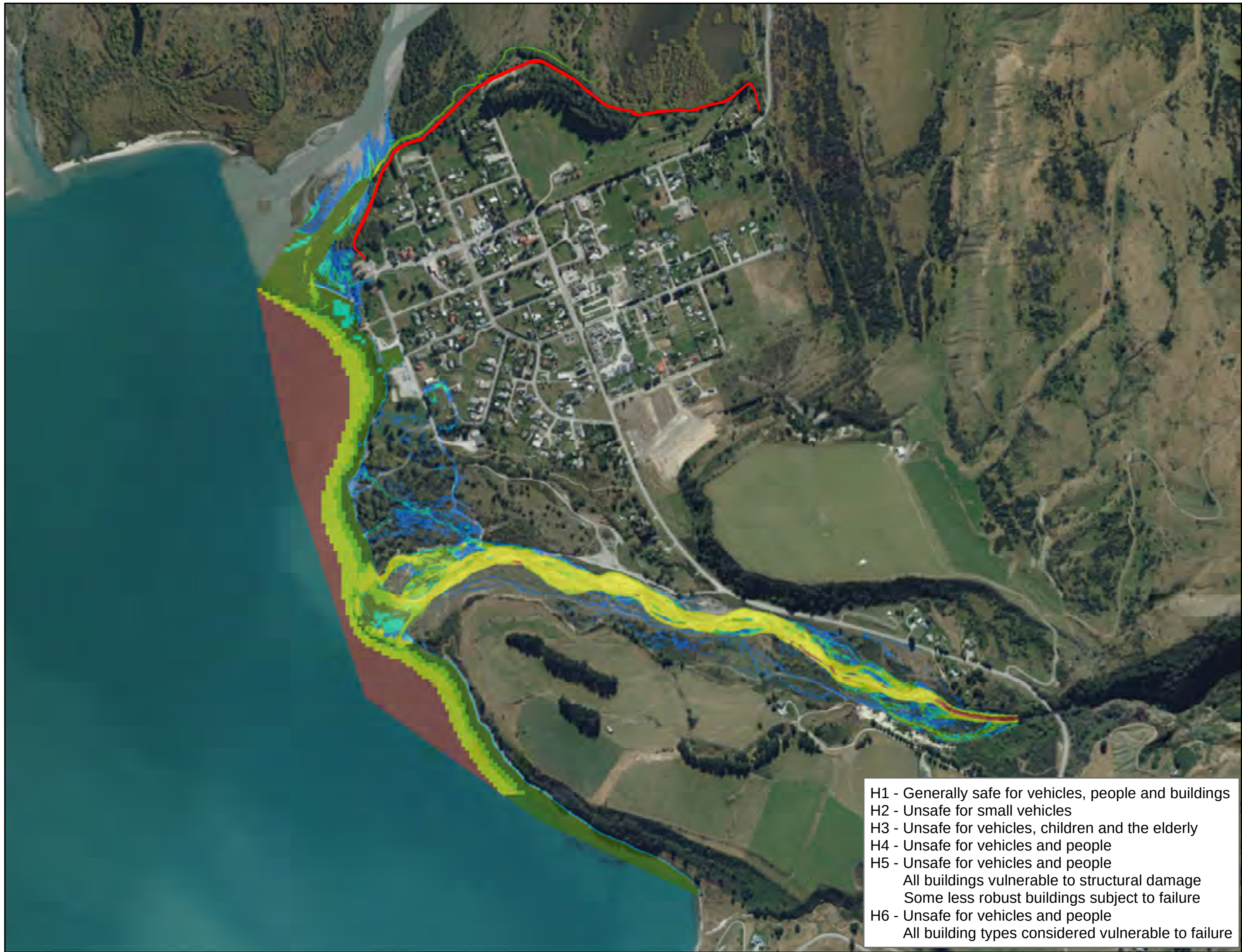
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2022 - Q 300 m3/s**	02	27/07/2023	1:9,000
		CREATED BY: UP	AUTHOR: Matthew Gardner	N
		REVISED BY		

APPENDIX C – DESIGN RUNS – HAZARD MAPS



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

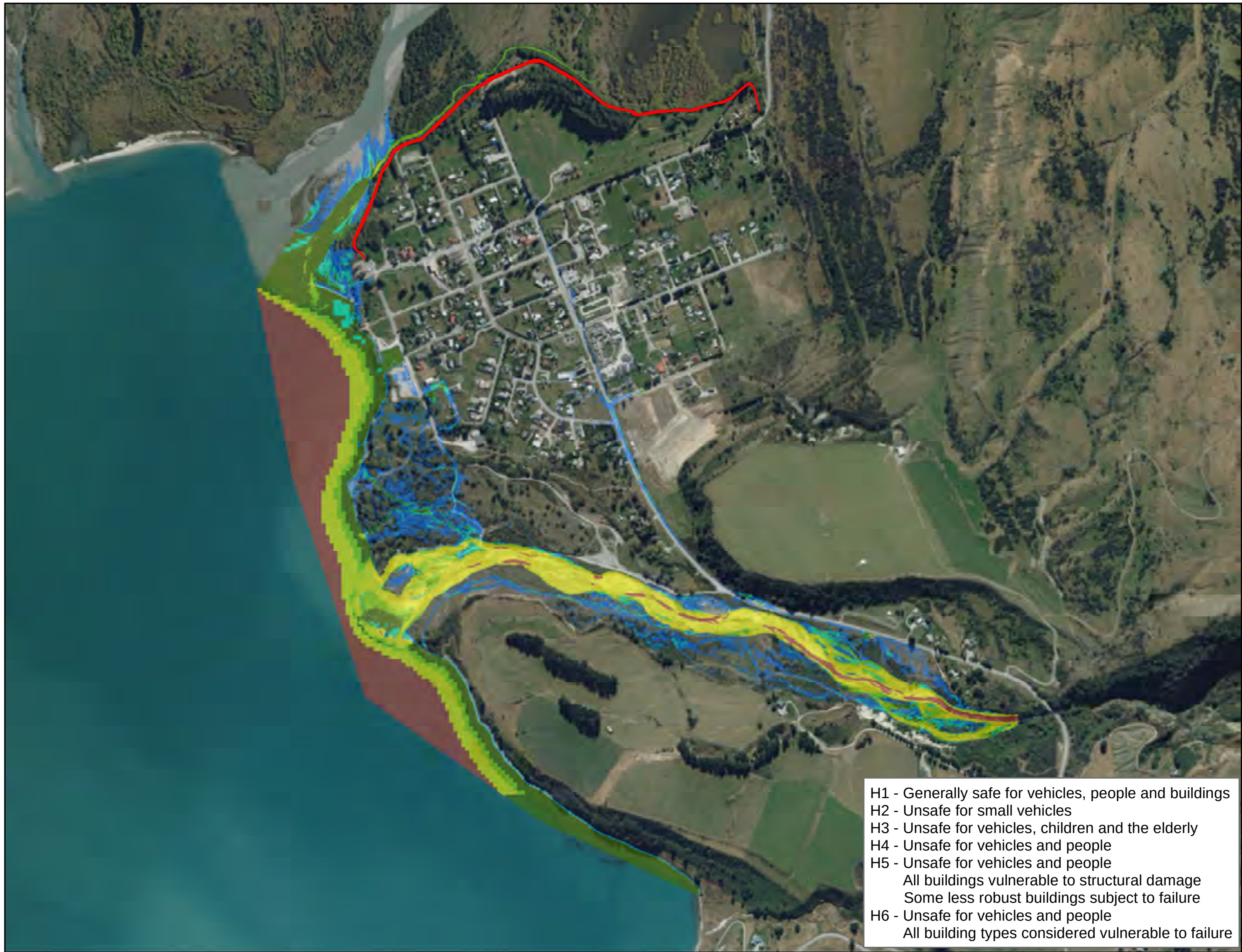
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2019 - Q 100 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

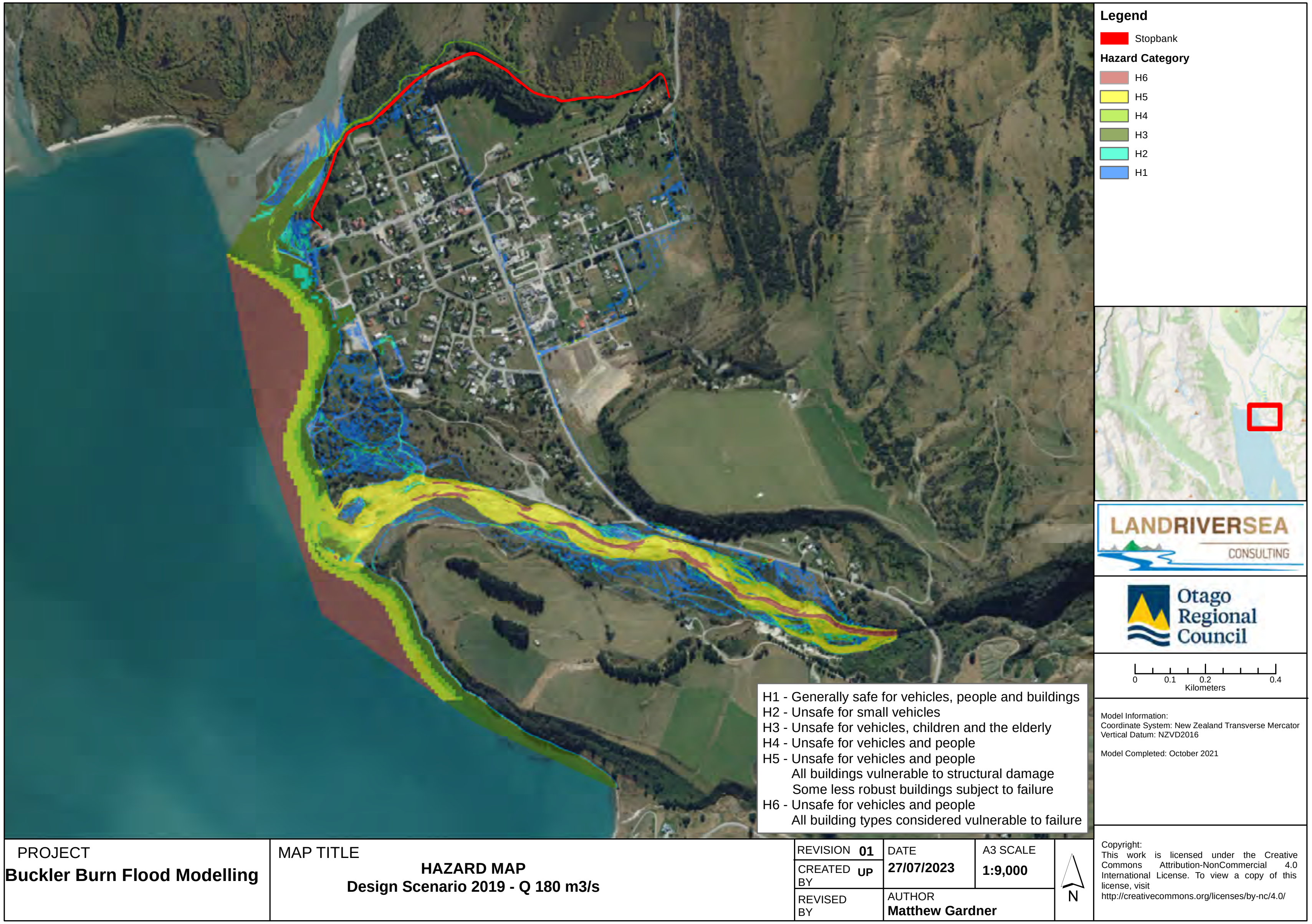
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2019 - Q 150 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		


Legend
Stopbank
Hazard Category
H6
H5
H4
H3
H2
H1
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
H1 - Generally safe for vehicles, people and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for vehicles and people
H5 - Unsafe for vehicles and people
All buildings vulnerable to structural damage
Some less robust buildings subject to failure
H6 - Unsafe for vehicles and people
All building types considered vulnerable to failure
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
HAZARD MAP
Design Scenario 2019 - Q 180 m3/s
REVISION 01
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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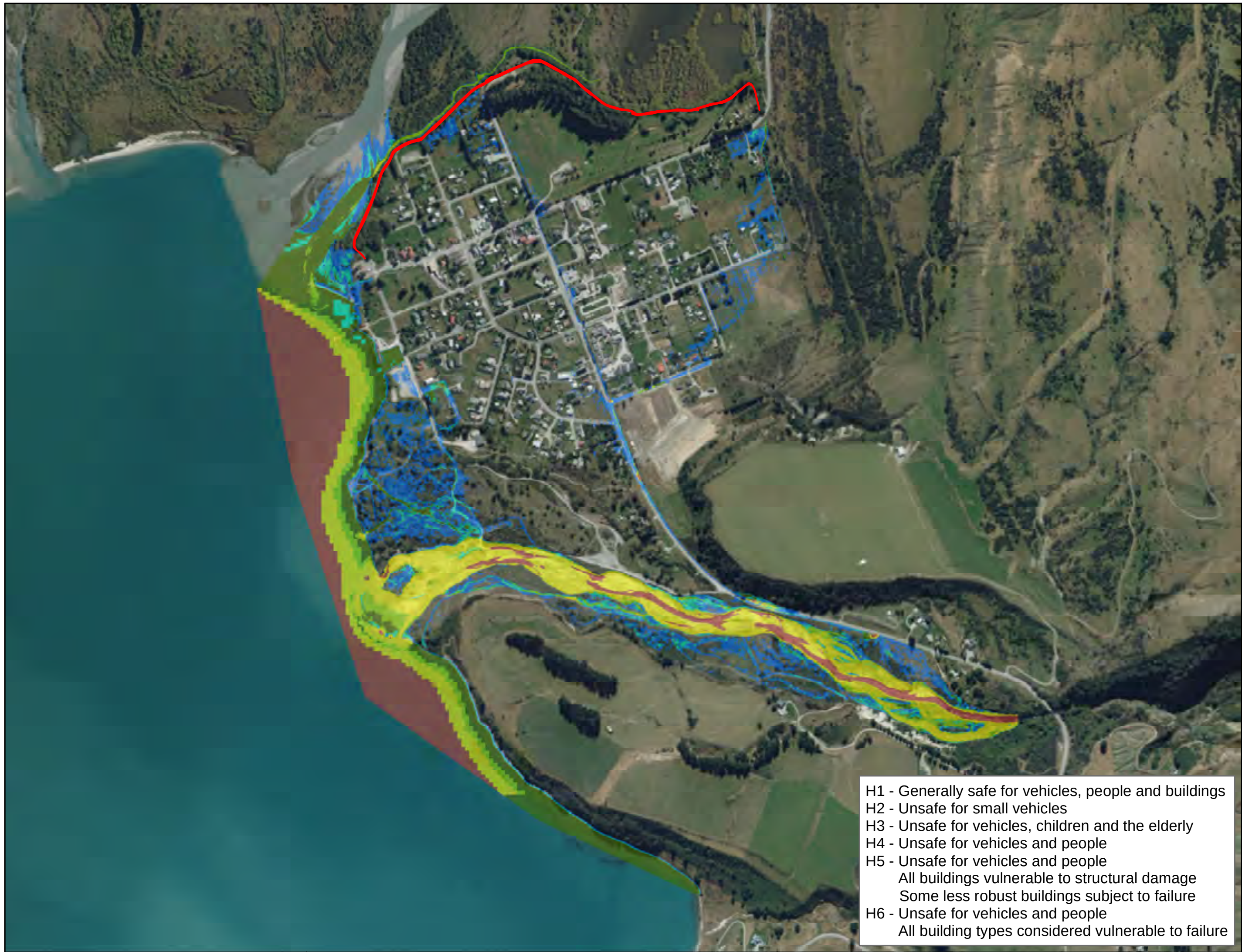


Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

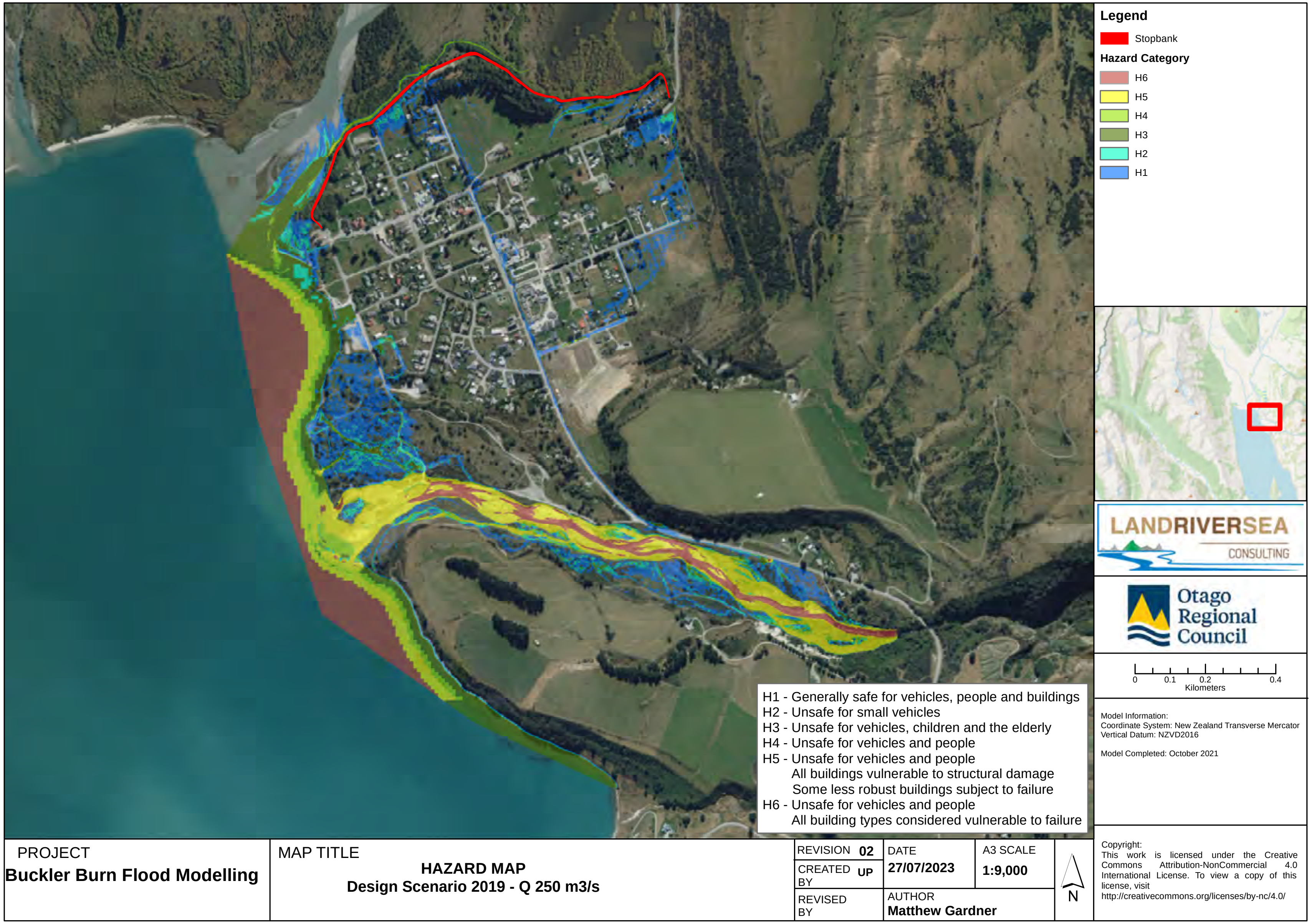
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2019 - Q 200 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N


Legend
Stopbank
Hazard Category
H6
H5
H4
H3
H2
H1
LANDRIVERSEA
CONSULTING
Otago Regional Council
0
0.1
0.2
0.4
Kilometers
H1 - Generally safe for vehicles, people and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for vehicles and people
H5 - Unsafe for vehicles and people
All buildings vulnerable to structural damage
Some less robust buildings subject to failure
H6 - Unsafe for vehicles and people
All building types considered vulnerable to failure
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
HAZARD MAP
Design Scenario 2019 - Q 250 m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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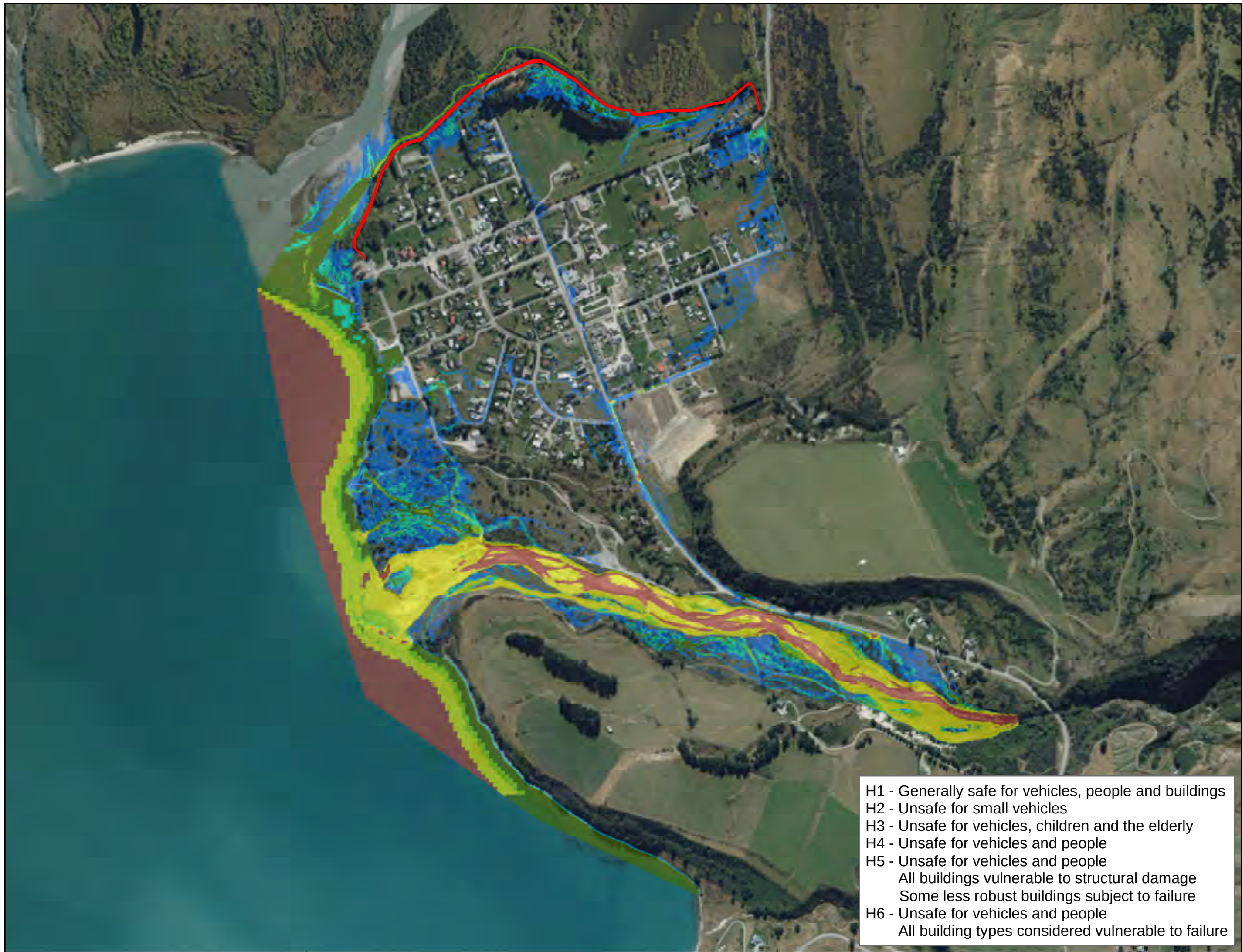


Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

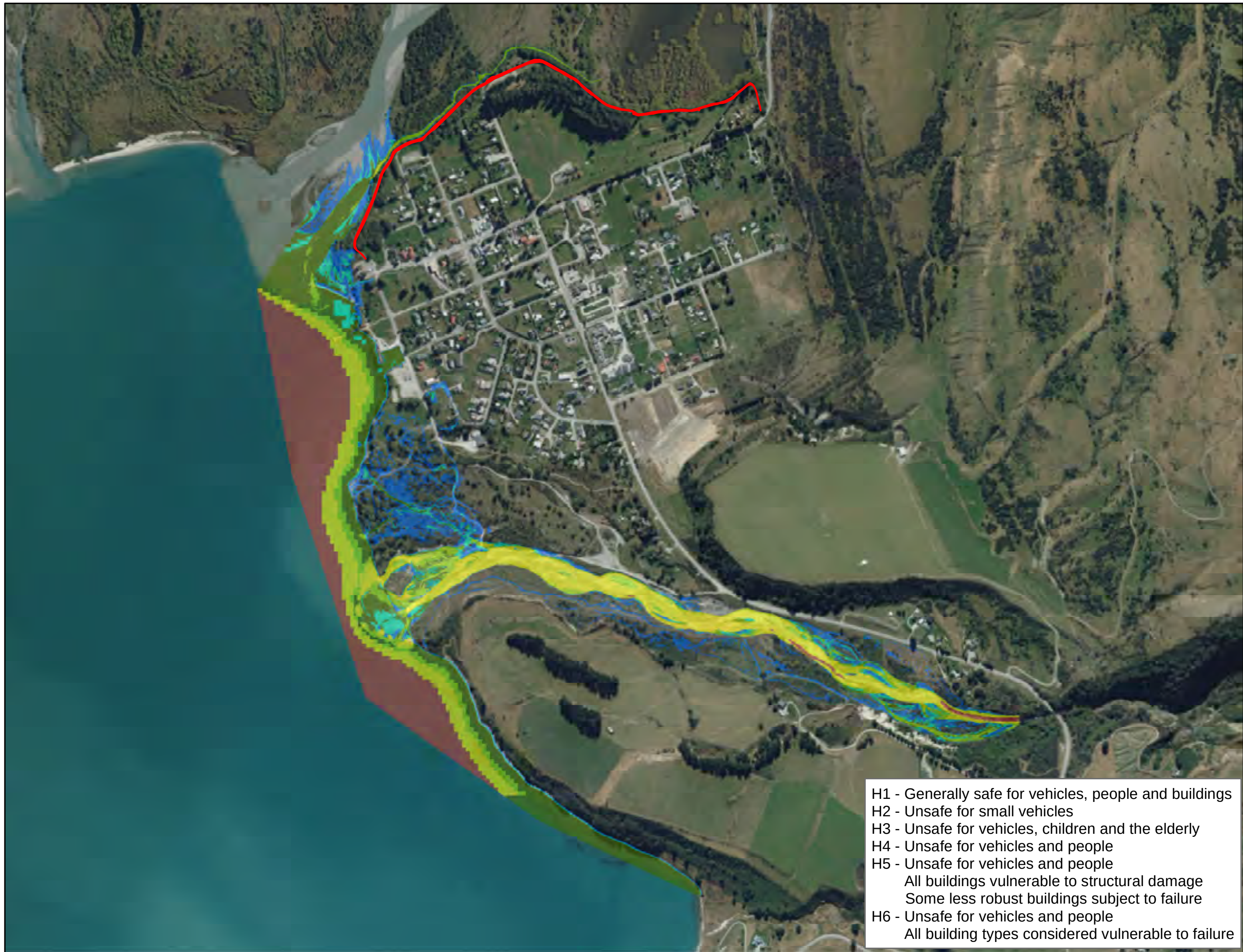
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2019 - Q 300 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

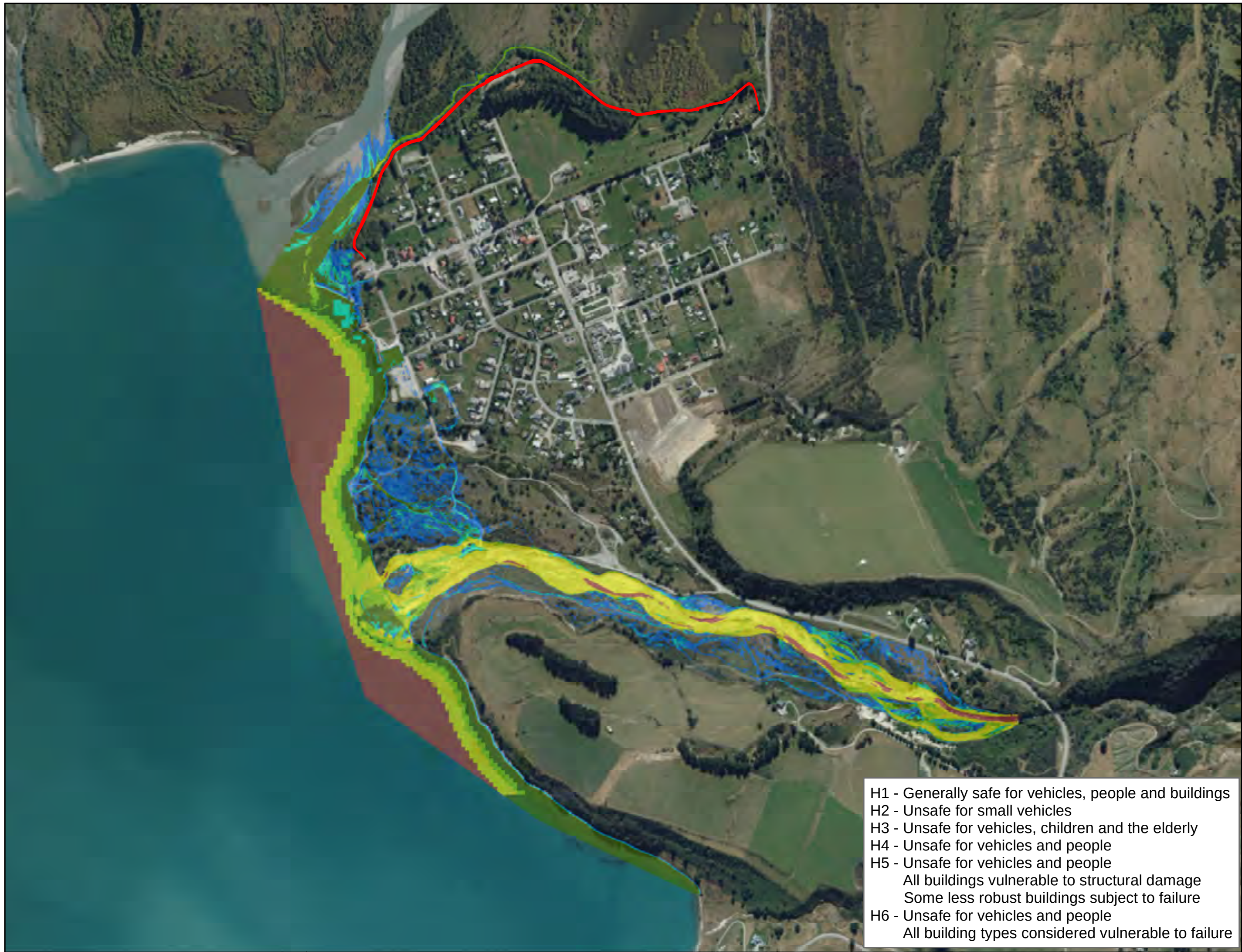
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2022 - Q 100 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

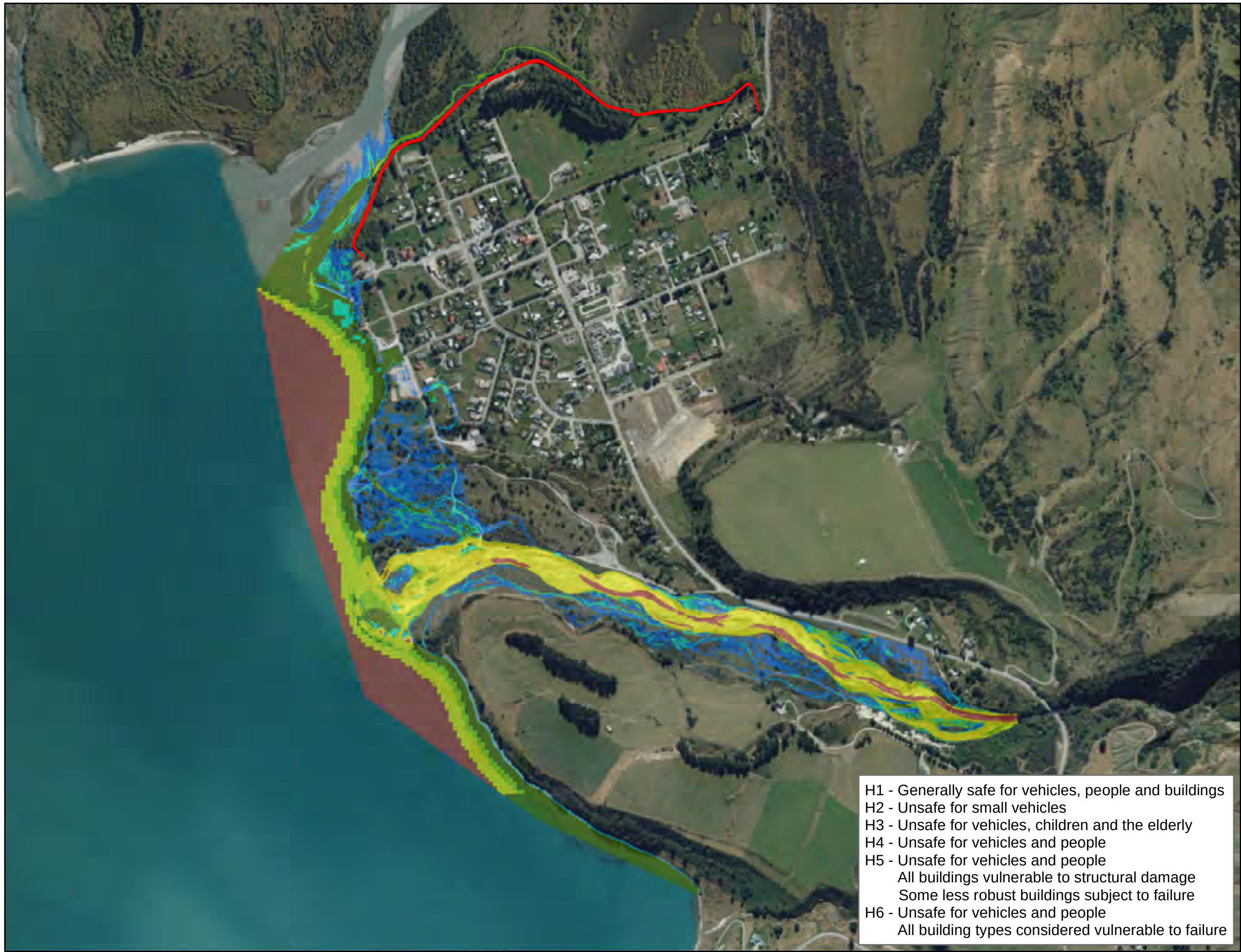
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2022 - Q 150 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

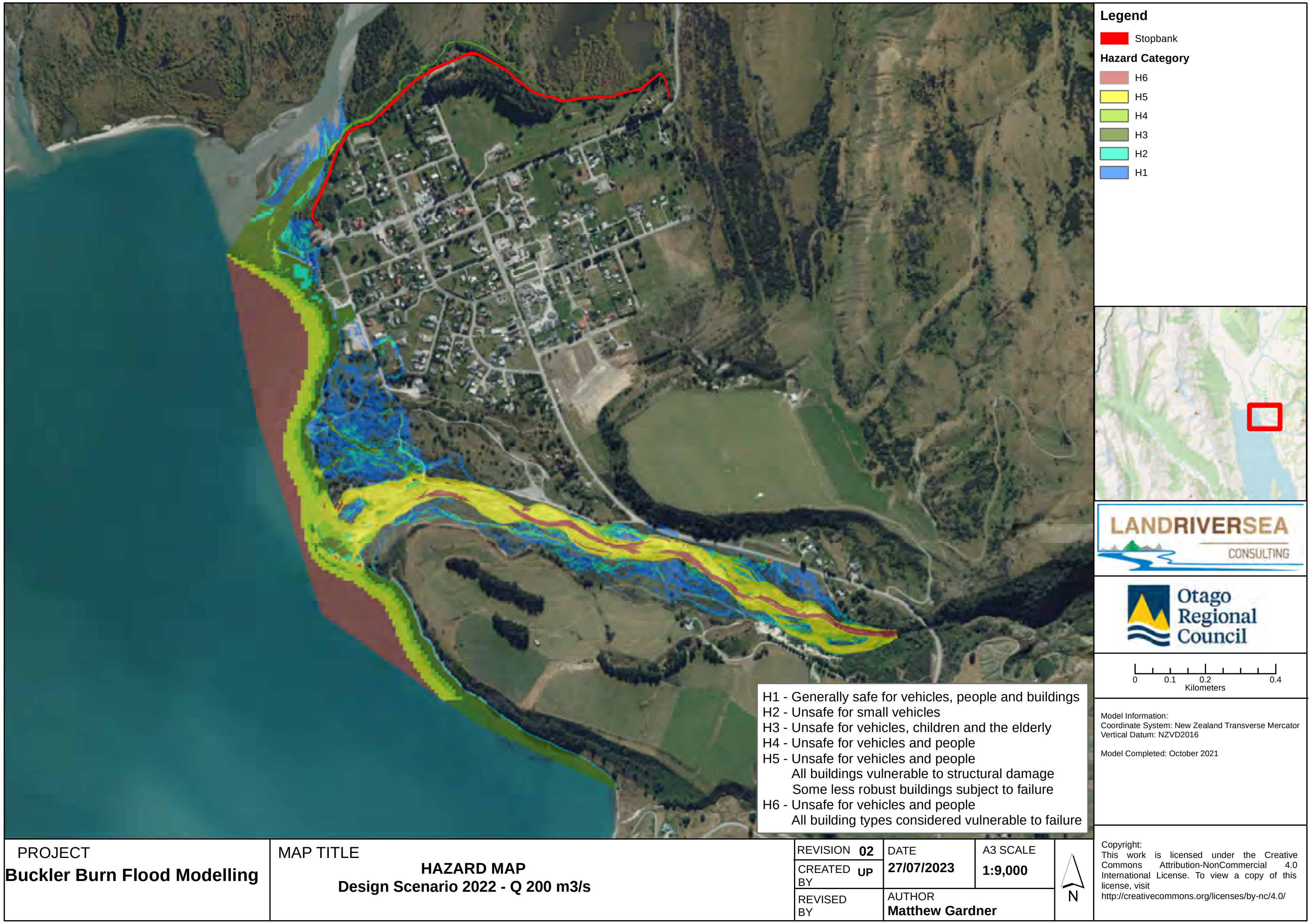
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**HAZARD MAP Design Scenario 2022 - Q 180 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		


Legend
Stopbank
Hazard Category
H6
H5
H4
H3
H2
H1
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
H1 - Generally safe for vehicles, people and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for vehicles and people
H5 - Unsafe for vehicles and people
All buildings vulnerable to structural damage
Some less robust buildings subject to failure
H6 - Unsafe for vehicles and people
All building types considered vulnerable to failure
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
HAZARD MAP
Design Scenario 2022 - Q 200 m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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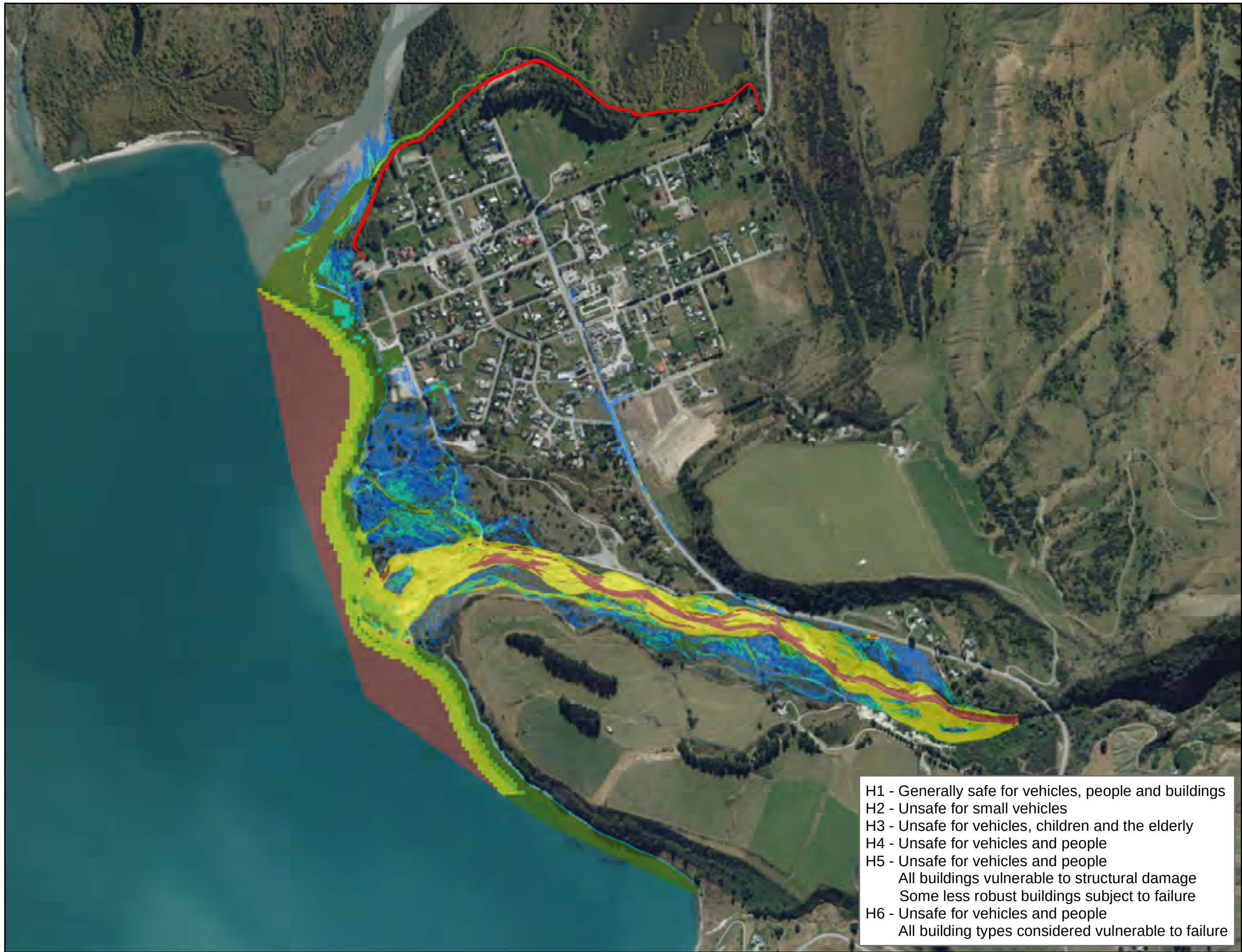
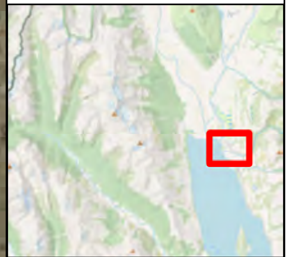


Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1



LANDRIVERSEA CONSULTING

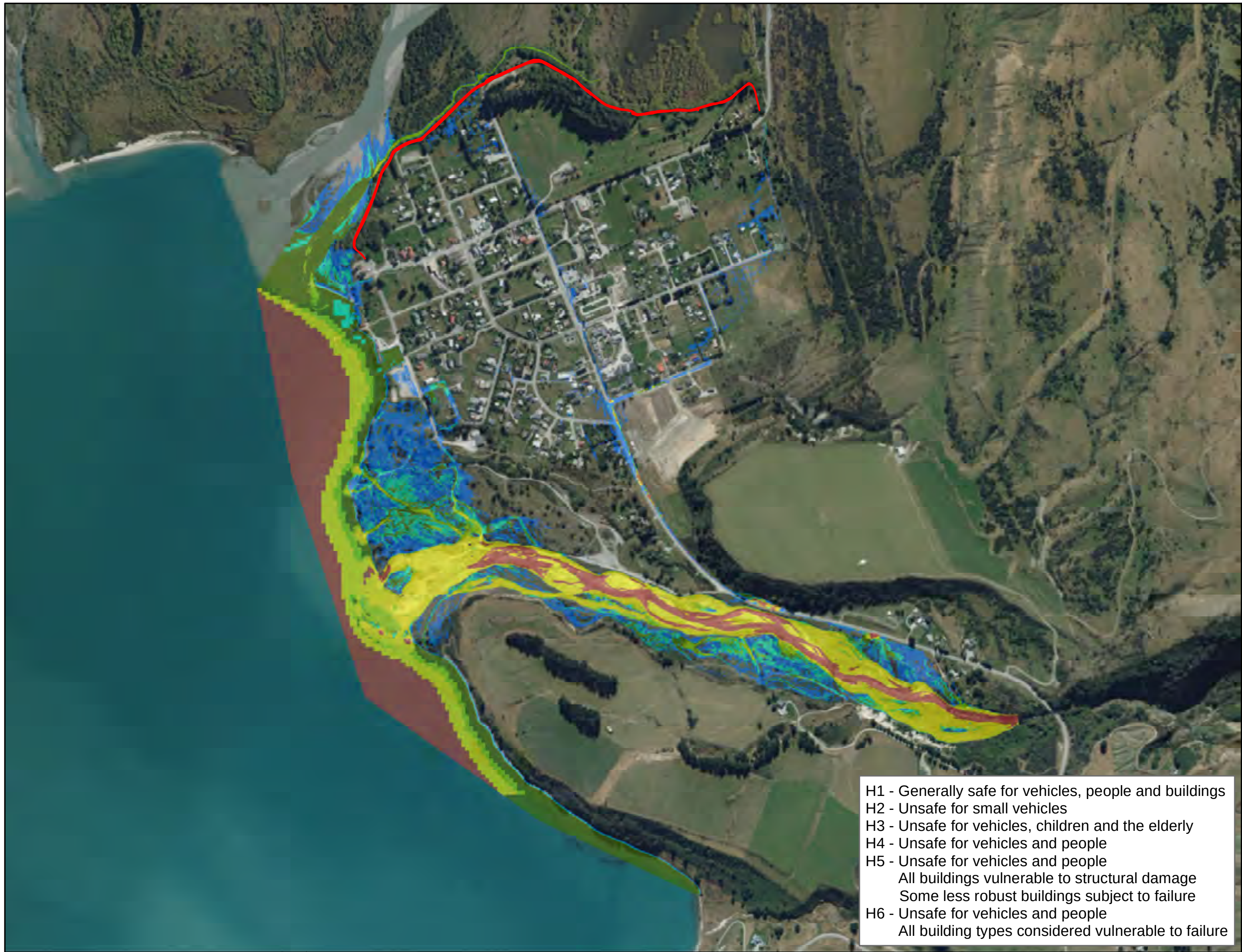
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **HAZARD MAP** **Design Scenario 2022 - Q 250 m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N



Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **HAZARD MAP** **Design Scenario 2022 - Q 300 m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N

APPENDIX D – AGGRADATION SCENARIOS – PEAK FLOOD DEPTH MAPS

Legend

Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

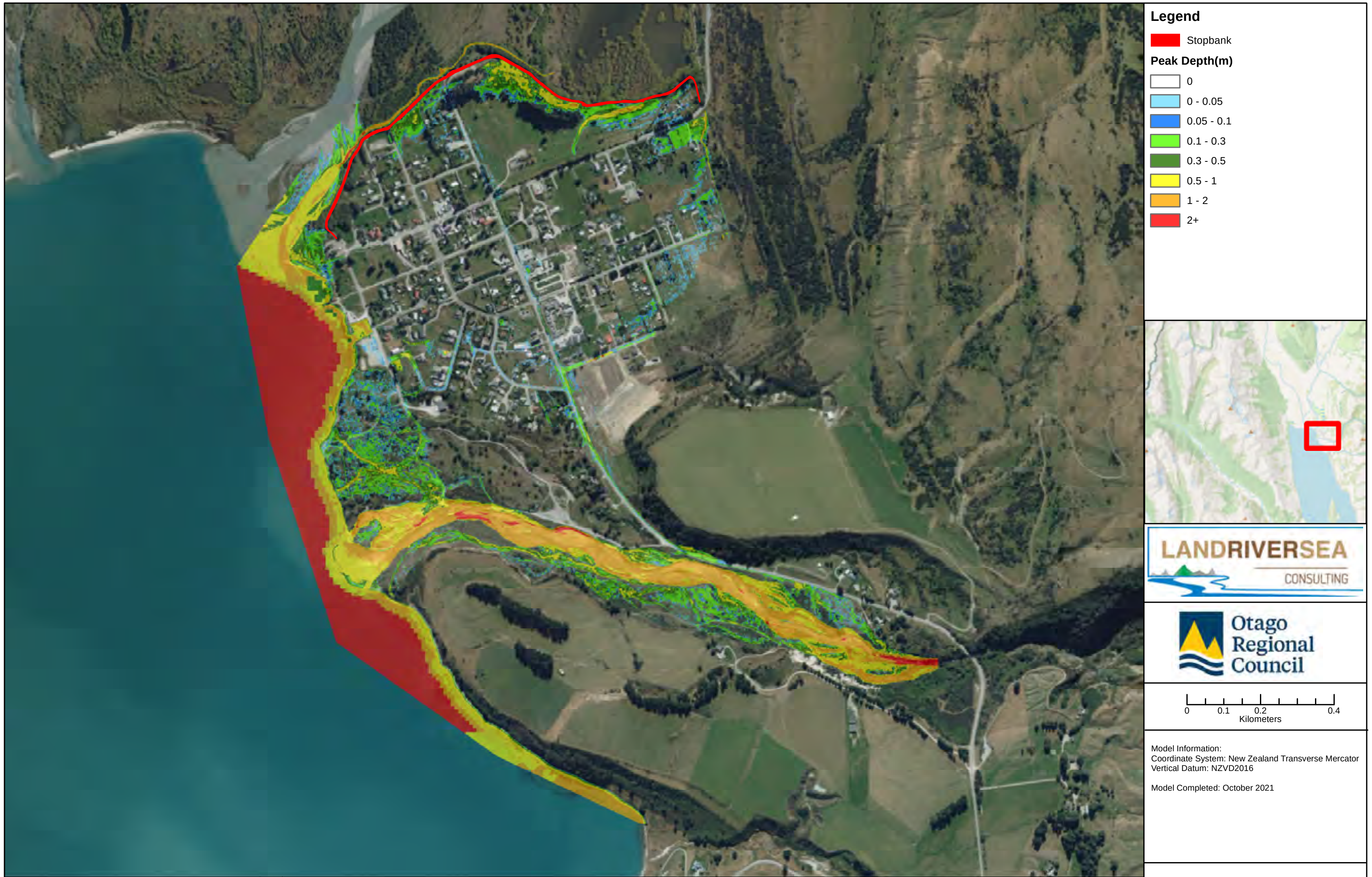
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 100m3/s**	CREATED BY UP	27/07/2023	1:9,000	N
		REVISED BY	AUTHOR **Matthew Gardner**		

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE		
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 150m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N	
		REVISED BY	AUTHOR **Matthew Gardner**			



PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 180m3/s**	CREATED BY UP	27/07/2023	1:9,000	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Depth(m)

- 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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Otago Regional Council

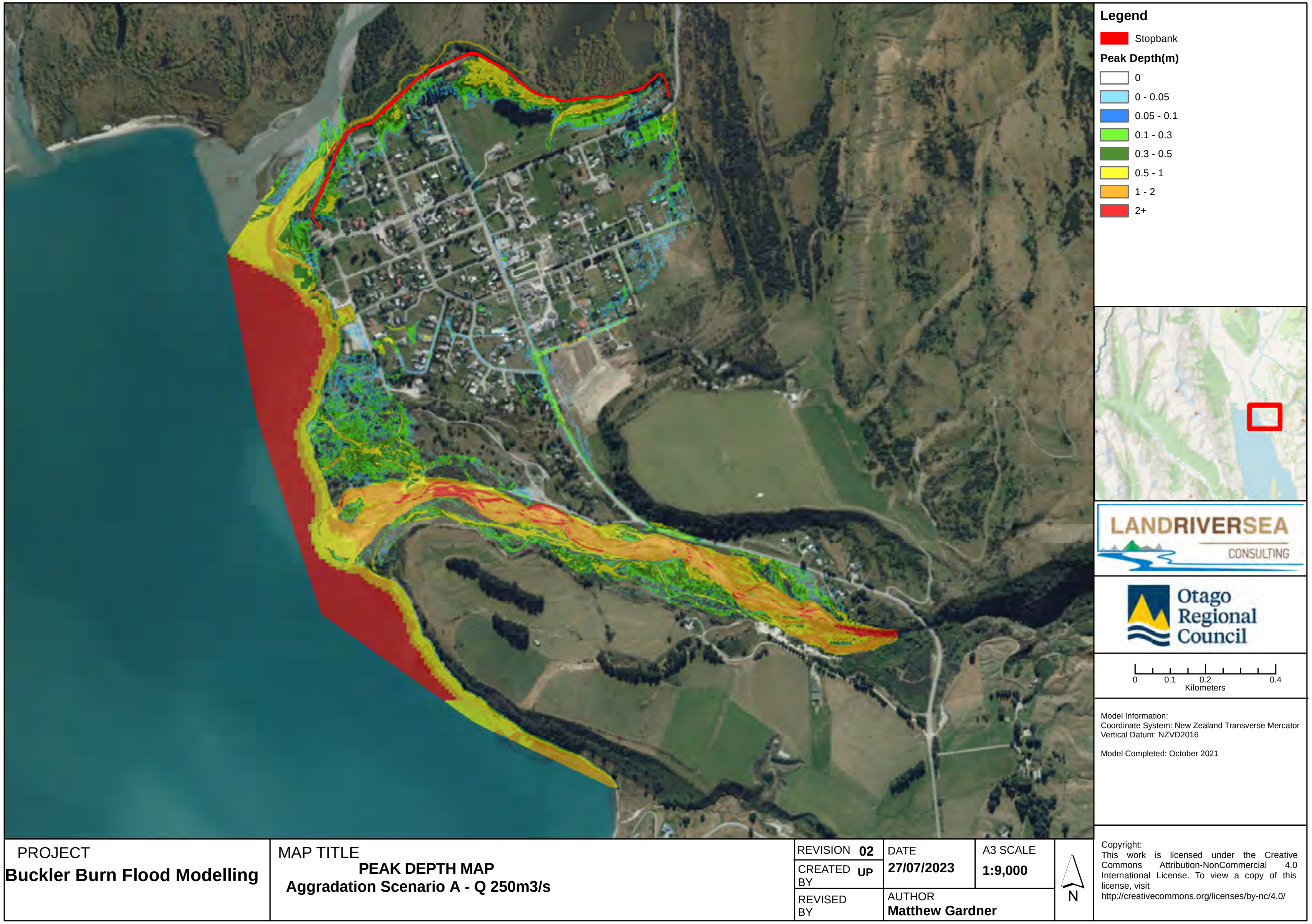
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 200m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N



Legend
Stopbank
Peak Depth(m)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK DEPTH MAP
Aggradation Scenario A - Q 250m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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Legend

- Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 300m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 100m3/s**	CREATED BY UP	27/07/2023	1:9,000	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Depth(m)

- 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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0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

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0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 180m3/s**	CREATED BY UP	27/07/2023	1:9,000	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 200m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 250m3/s**	02	27/07/2023	1:9,000
		CREATED BY UP	AUTHOR	
		REVISED BY	Matthew Gardner	

N

Legend

Stopbank	

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 300m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N

Legend

- Stopbank

Peak Depth(m)

- 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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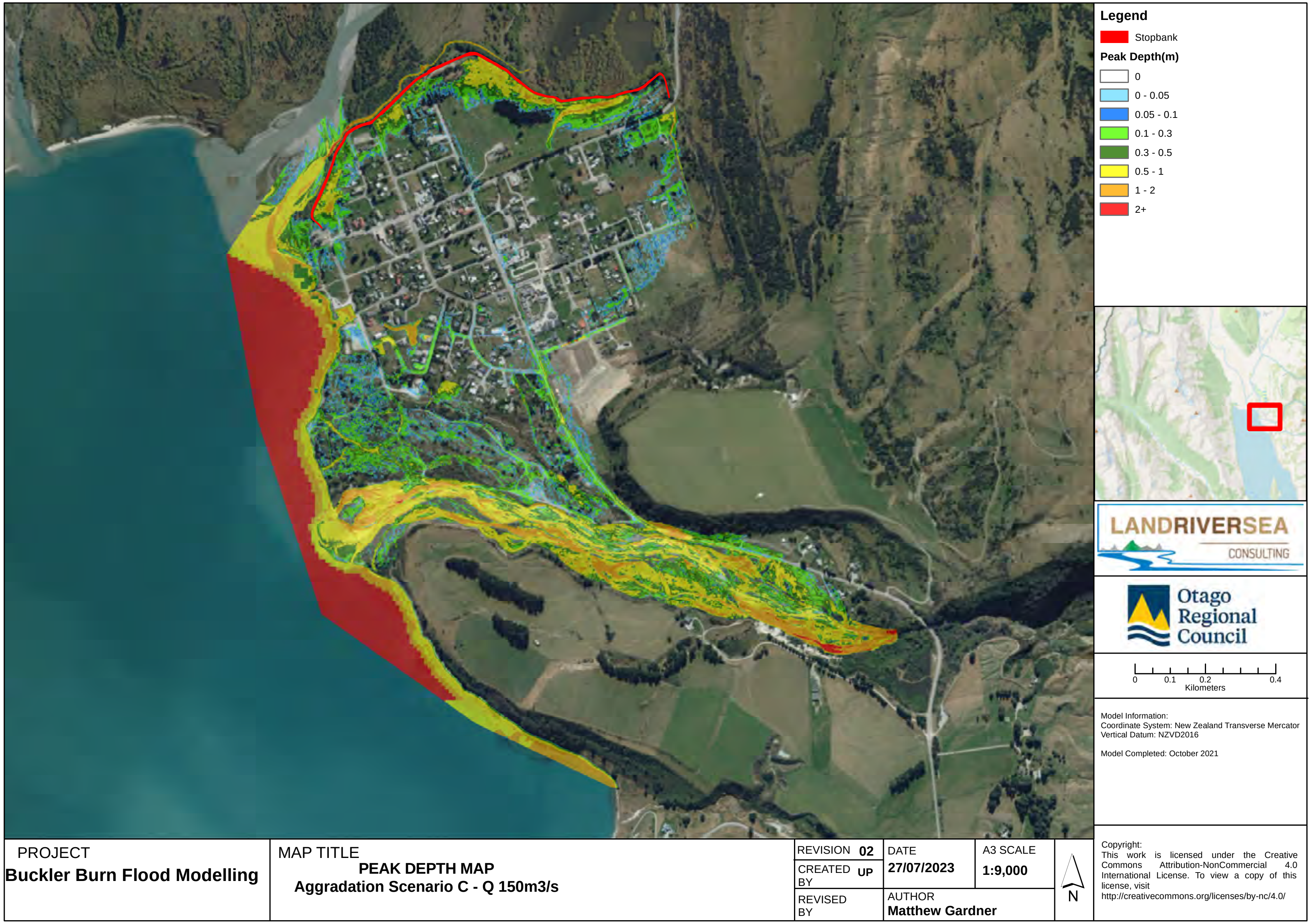
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 100m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		


Legend
Stopbank
Peak Depth(m)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK DEPTH MAP
Aggradation Scenario C - Q 150m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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Legend

- Stopbank

Peak Depth(m)

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

LANDRIVERSEA CONSULTING

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0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 180m3/s**	CREATED BY UP	27/07/2023	1:9,000	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Depth(m)

- 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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0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 200m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

- 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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Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 250m3/s**	CREATED BY UP	27/07/2023	1:9,000	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

- 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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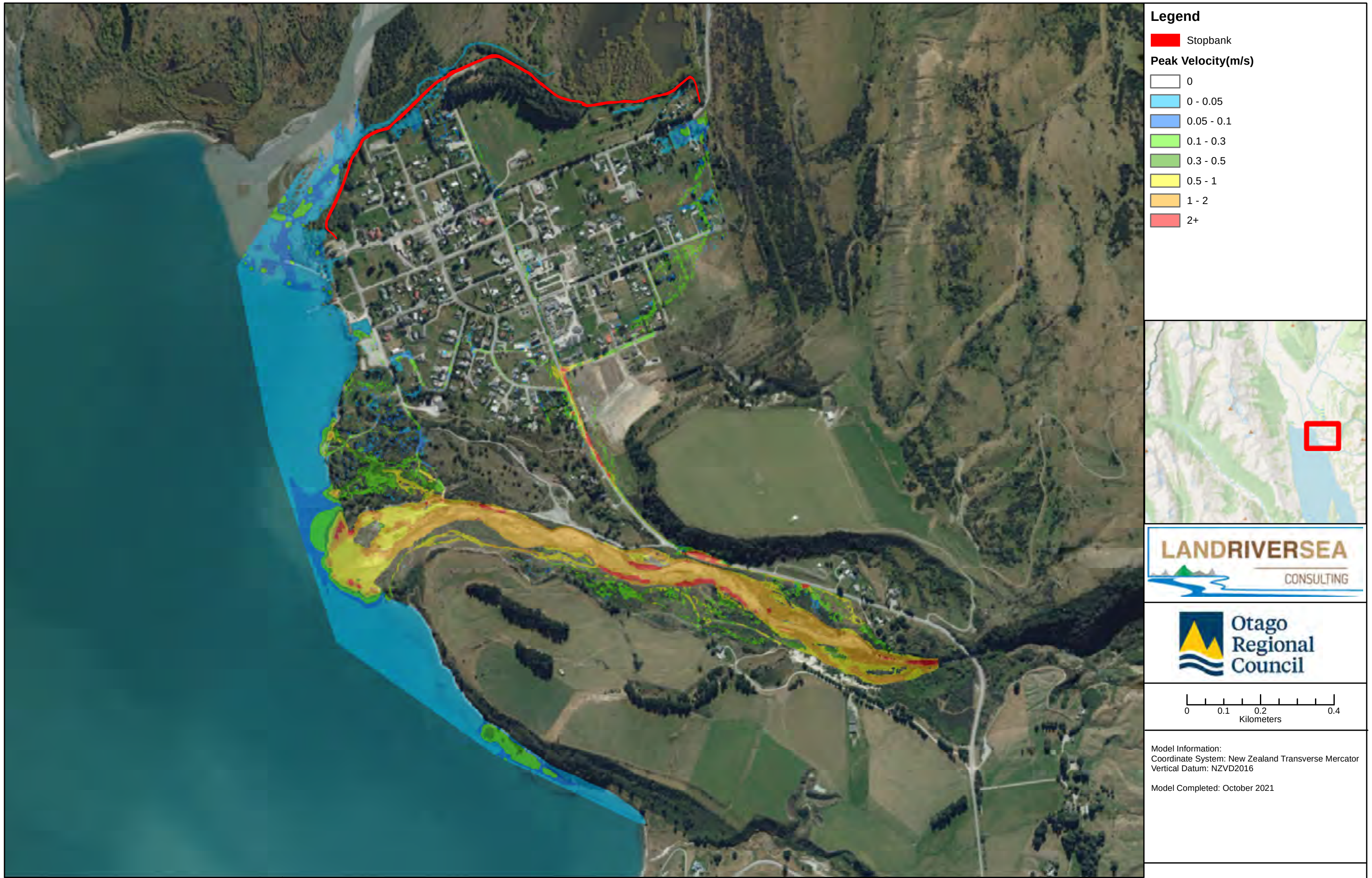
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 300m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

APPENDIX E – AGGRADATION SCENARIOS – PEAK SPEED MAPS



Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

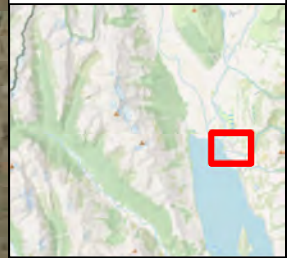
PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario A - Q 100m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

Legend

Stopbank

Peak velocity(m/s)

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



LANDRIVERSEA CONSULTING

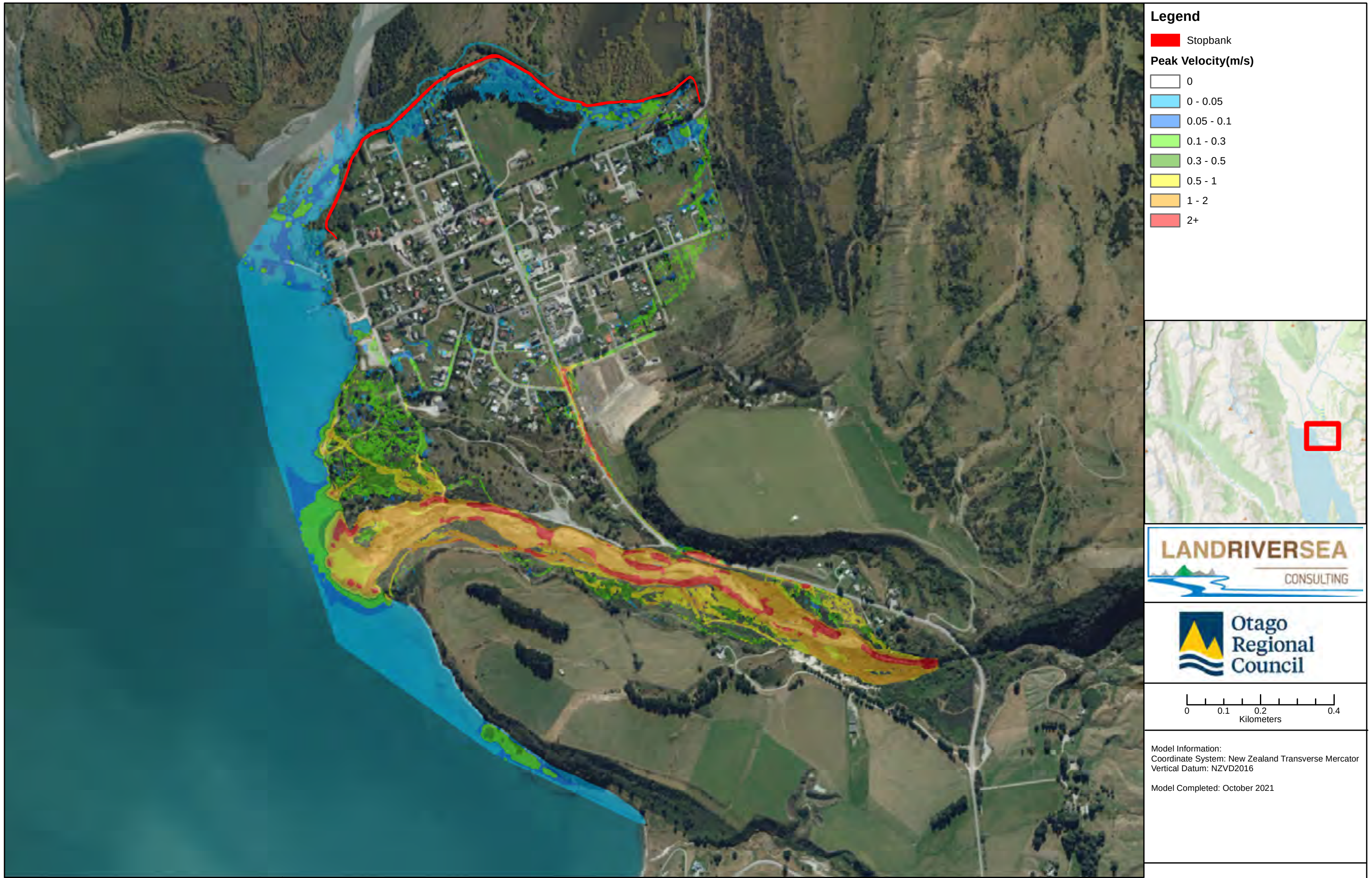
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

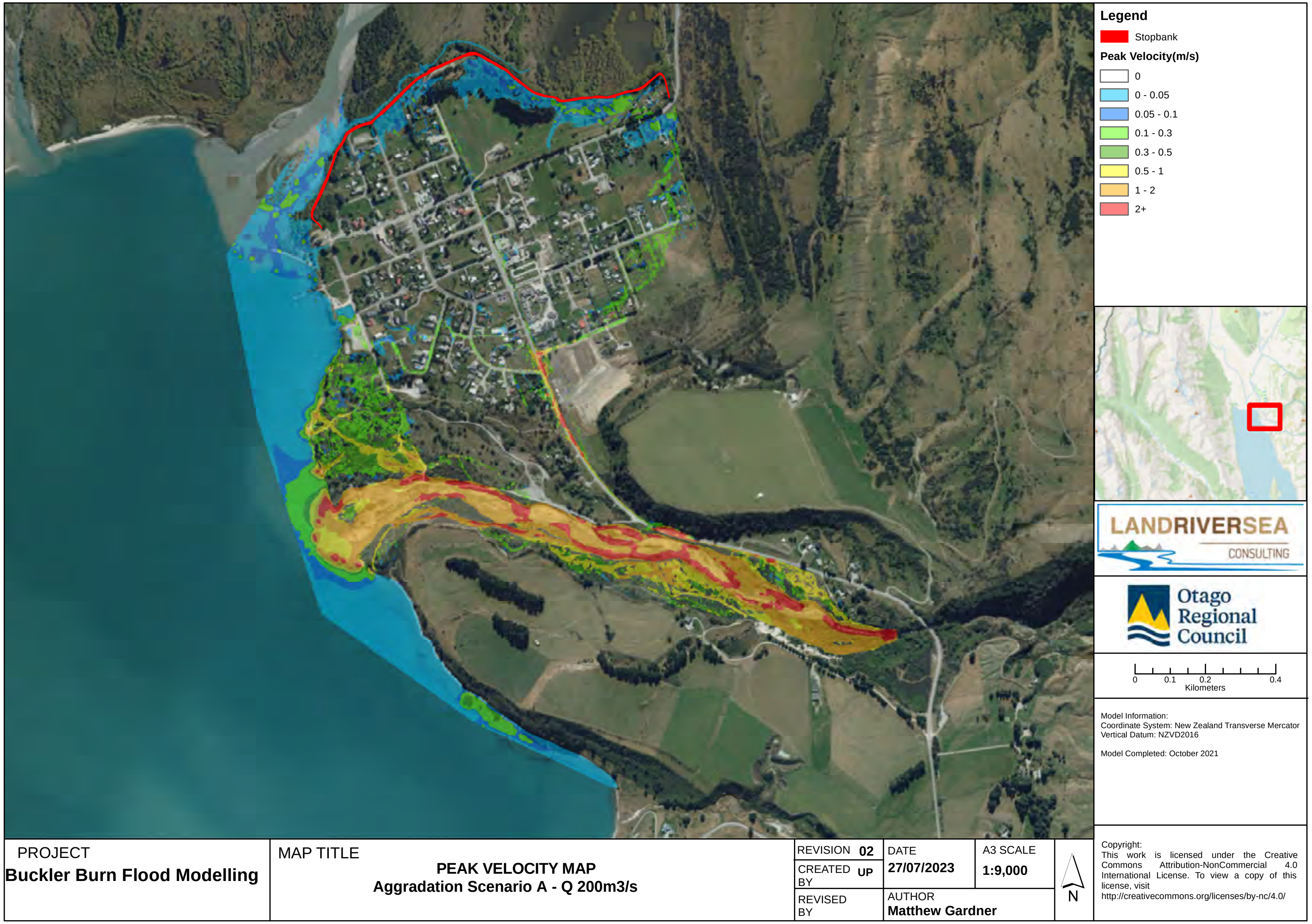
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario A - Q 150m3/s**	02 CREATED BY UP REVISED BY	**27/07/2023** AUTHOR **Matthew Gardner**	**1:9,000**	N



PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	PEAK VELOCITY MAP Aggradation Scenario A - Q 180m3/s	CREATED BY UP	27/07/2023	1:9,000
		REVISED BY	AUTHOR Matthew Gardner	N


Legend
Stopbank
Peak Velocity(m/s)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK VELOCITY MAP
Aggradation Scenario A - Q 200m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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Legend

Stopbank	
Peak Velocity(m/s)	
	0
	0 - 0.05
	0.05 - 0.1
	0.1 - 0.3
	0.3 - 0.5
	0.5 - 1
	1 - 2
	2+

LANDRIVERSEA CONSULTING

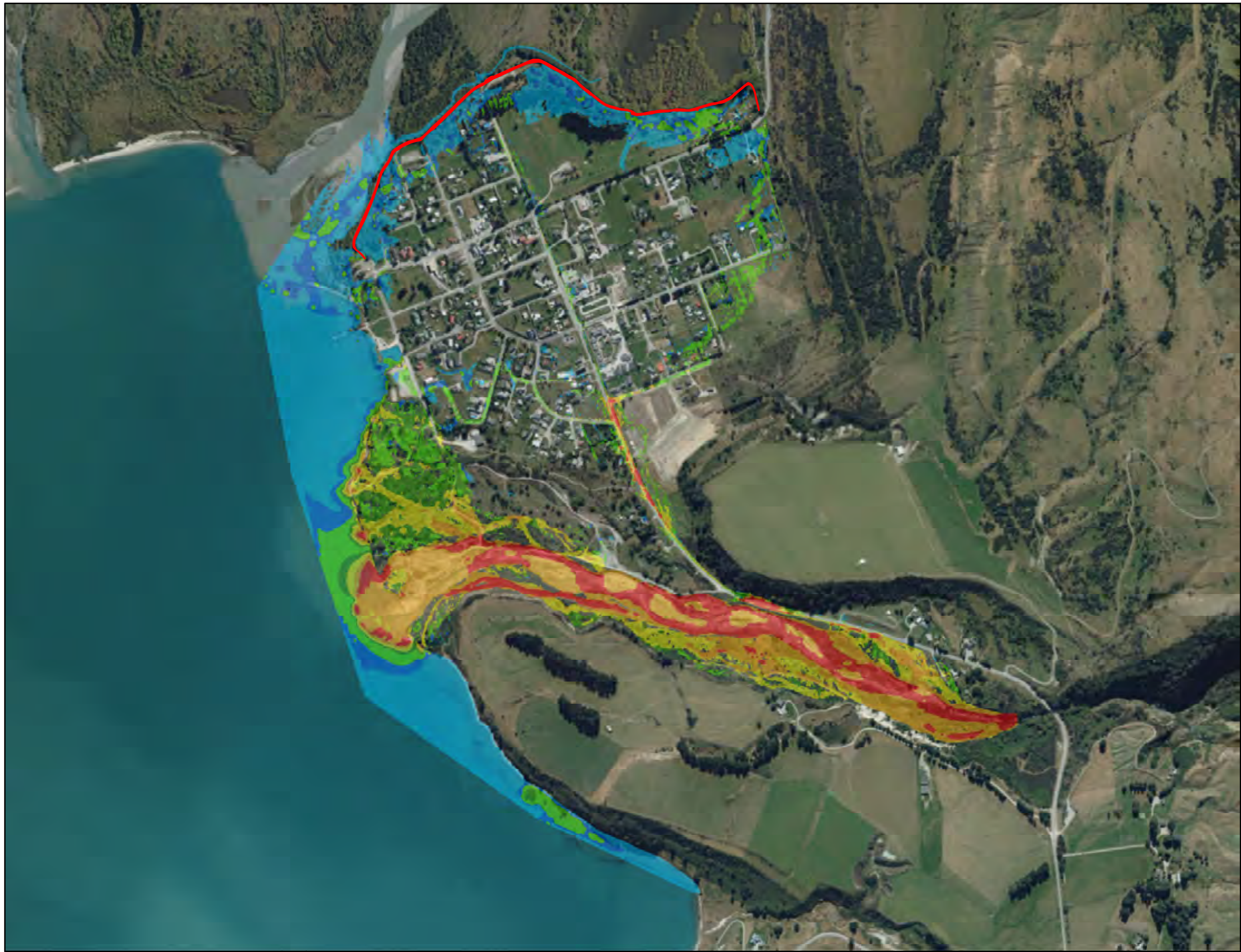
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario A - Q 250m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank	
Peak Velocity(m/s)	
	0
	0 - 0.05
	0.05 - 0.1
	0.1 - 0.3
	0.3 - 0.5
	0.5 - 1
	1 - 2
	2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario A - Q 300m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 100m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

Legend

Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 180m3/s**	02	27/07/2023	1:9,000
		CREATED BY: UP	AUTHOR: Matthew Gardner	
		REVISED BY		

N

Legend

Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

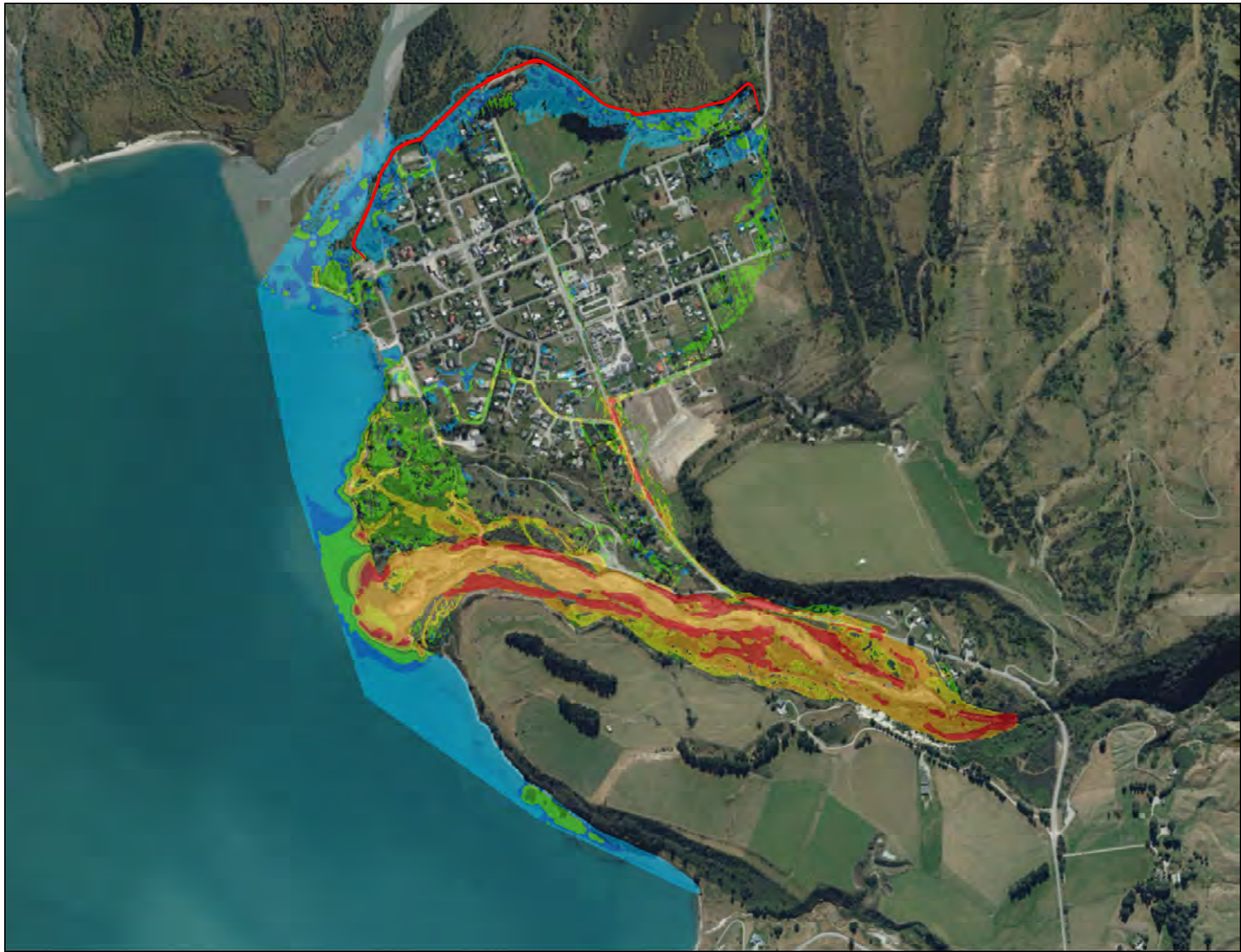
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 200m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

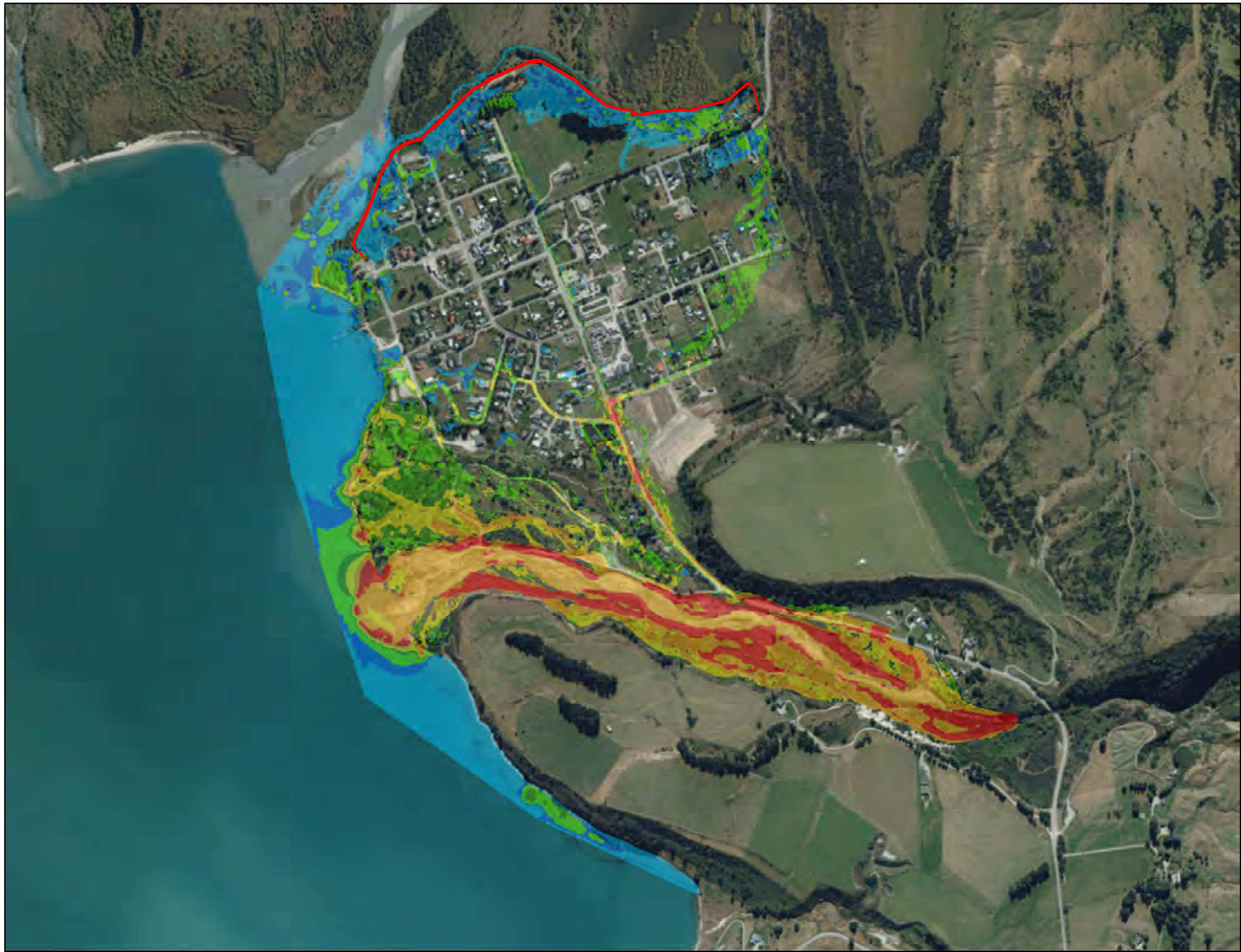
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **PEAK VELOCITY MAP** **Aggradation Scenario B - Q 250m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N



Legend

Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 300m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

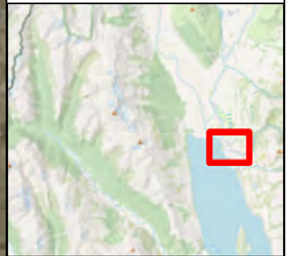
PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 100m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Velocity(m/s)

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



LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 180m3/s**	CREATED BY UP	27/07/2023	1:9,000	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Velocity(m/s)

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

LANDRIVERSEA CONSULTING

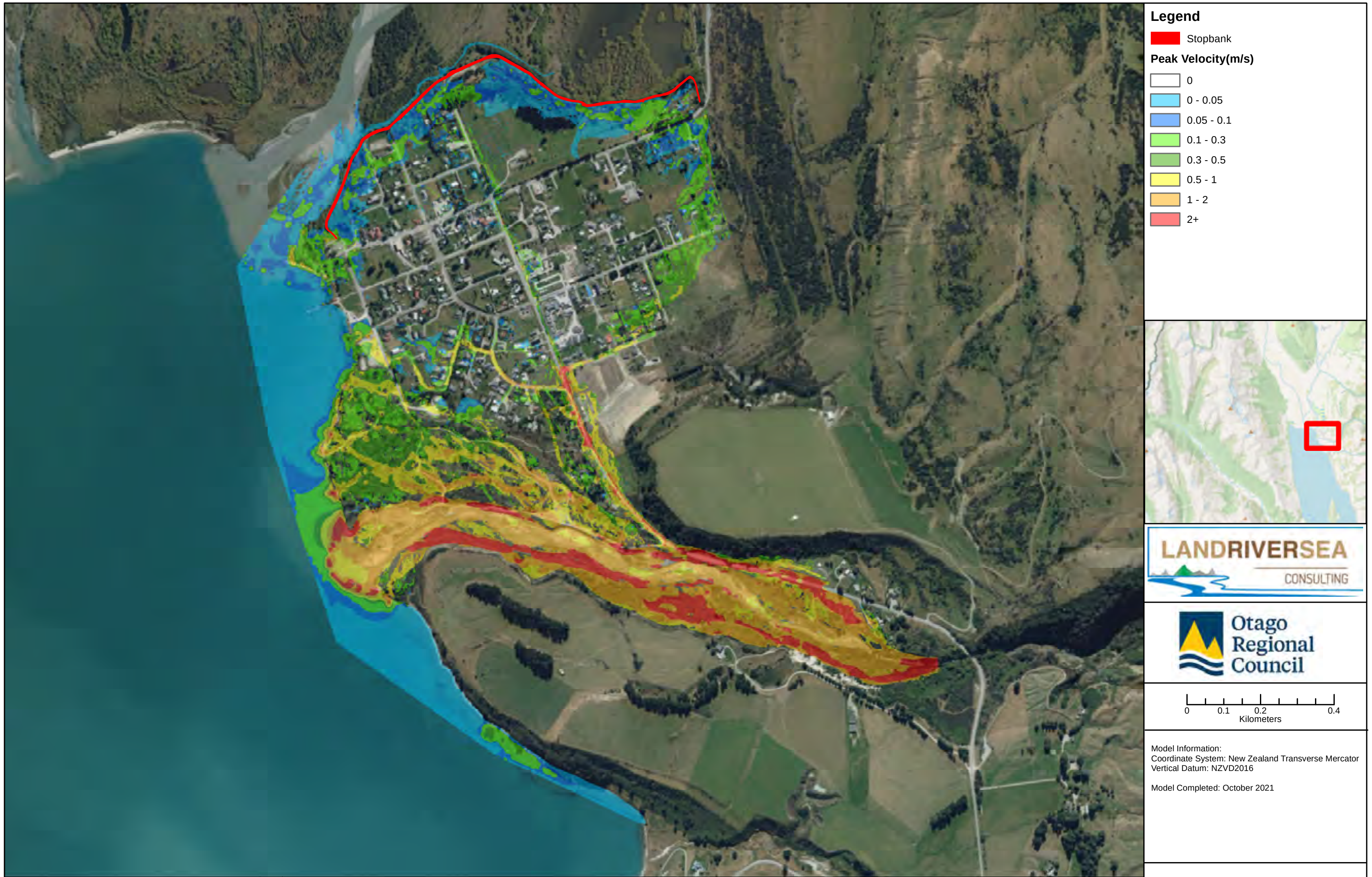
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 200m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 250m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Veloity(m/s)

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

LANDRIVERSEA CONSULTING

Otago Regional Council

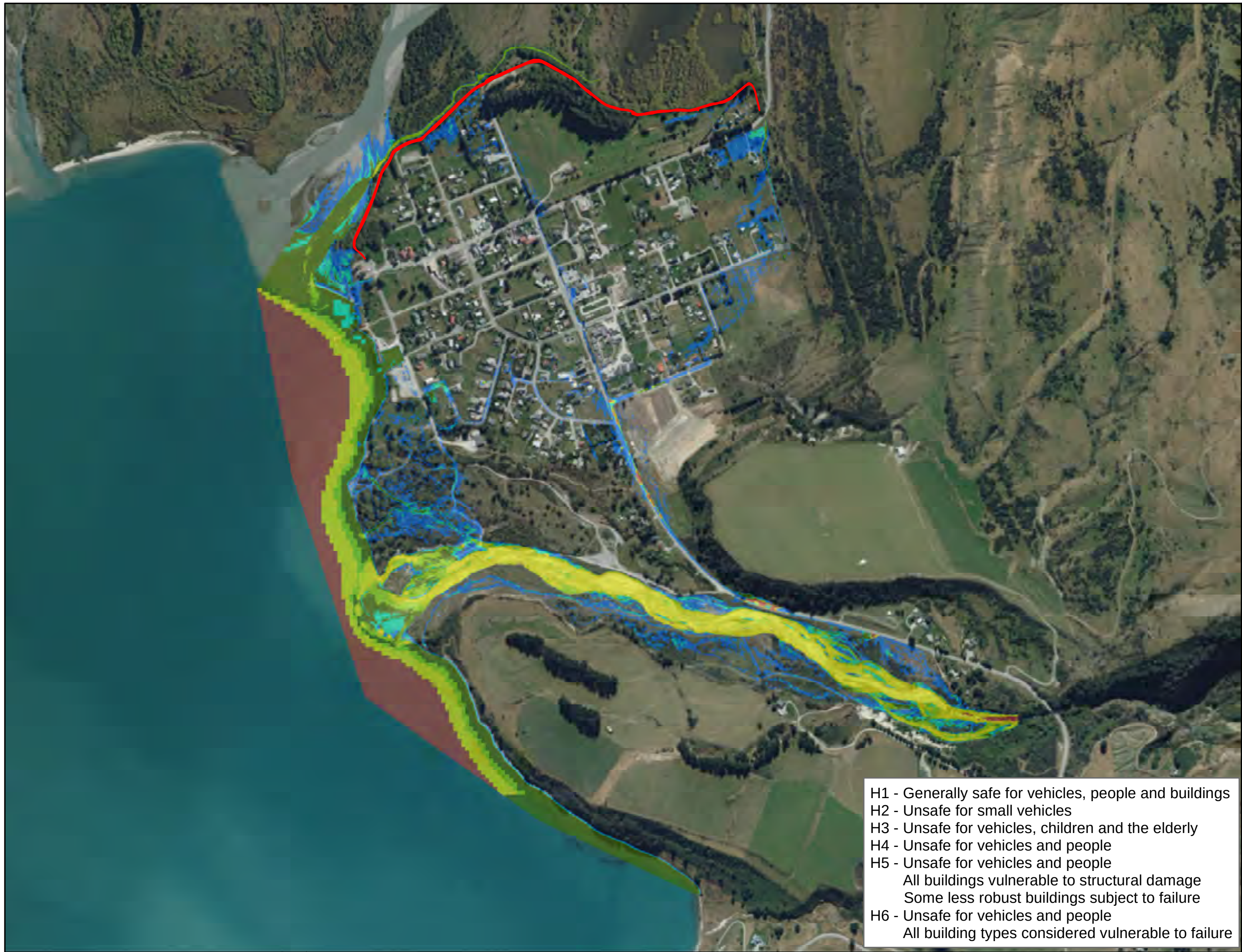
0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 300m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

APPENDIX F – AGGRADATION SCENARIOS – HAZARD MAPS

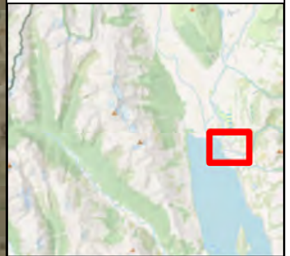


Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1



LANDRIVERSEA CONSULTING

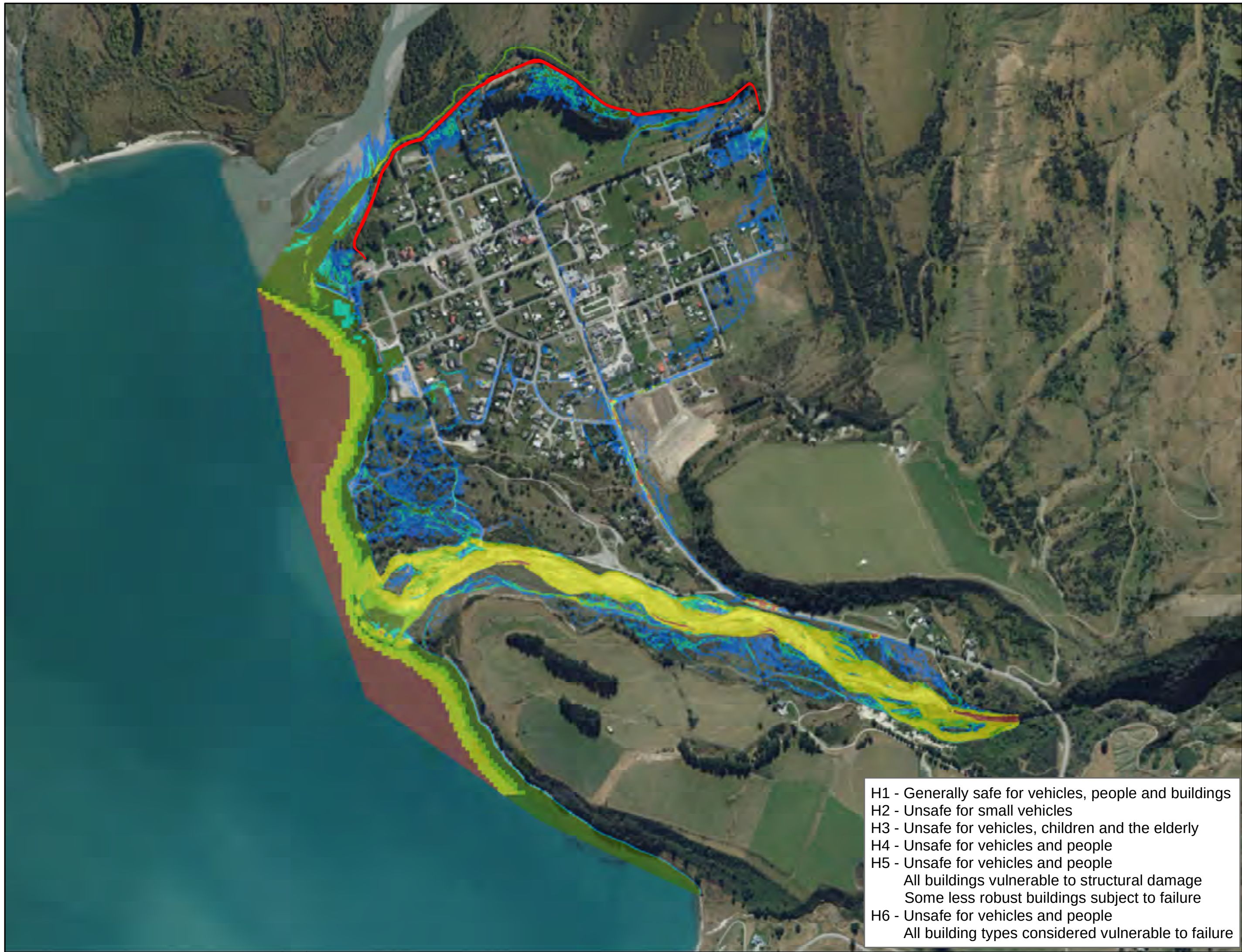
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 100m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

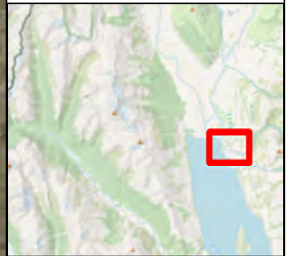


Legend

- Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1



LANDRIVERSEA CONSULTING

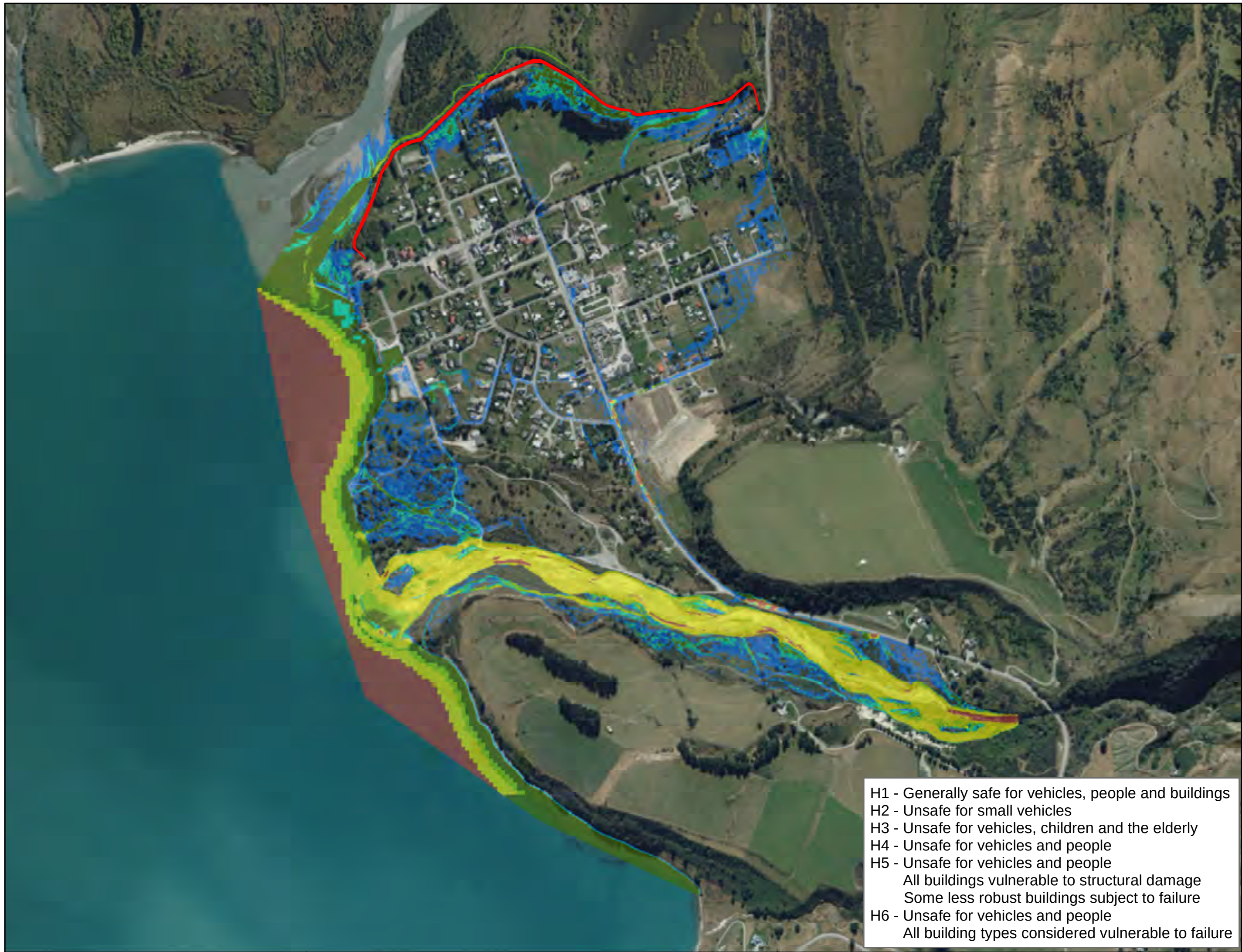
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 150m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

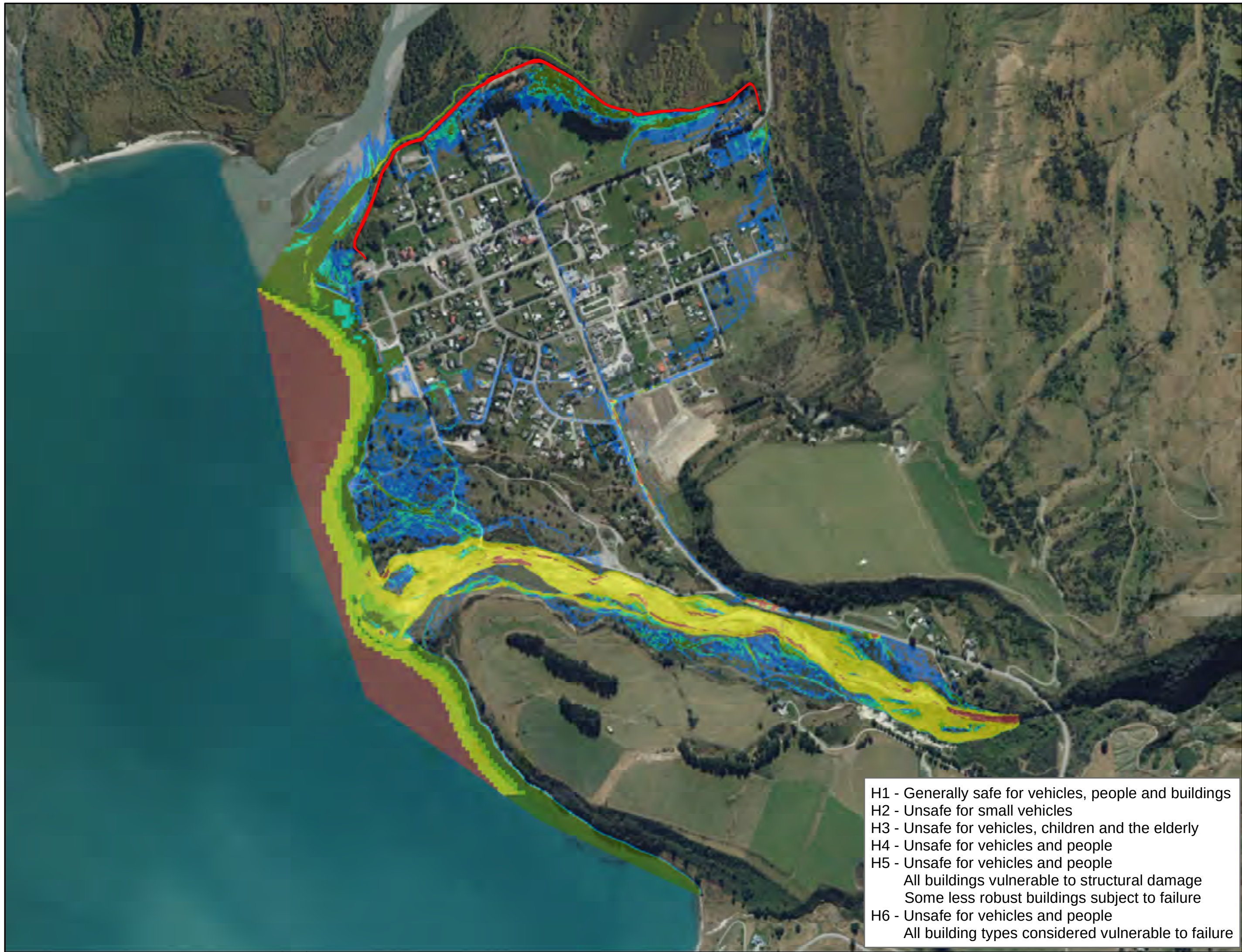
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 180m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



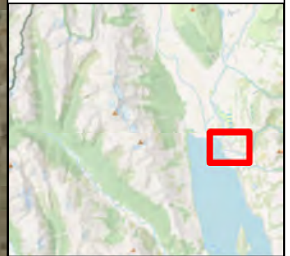
Legend

Stopbank

Hazard_Q200_Gleno...

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1



LANDRIVERSEA CONSULTING

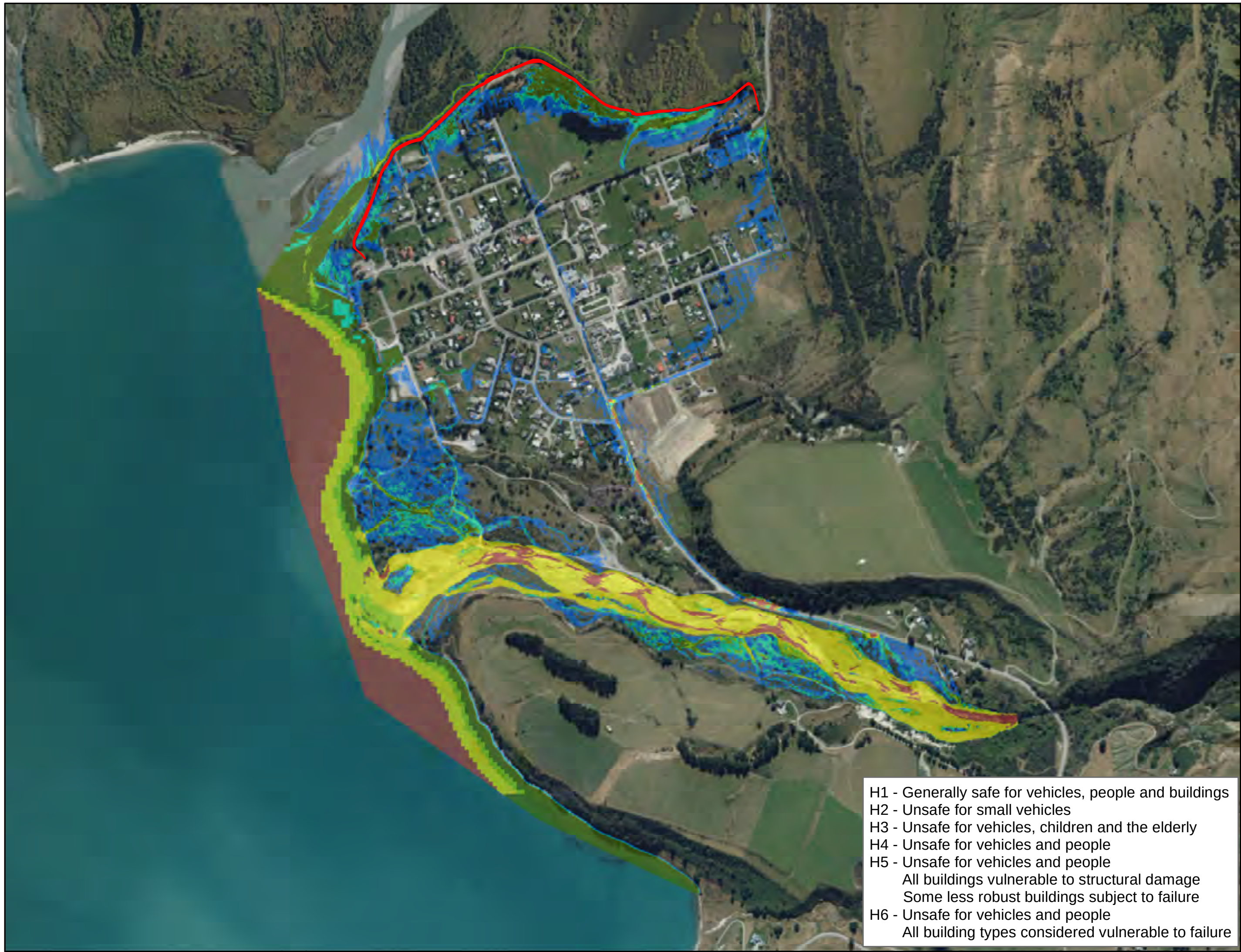
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 200m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

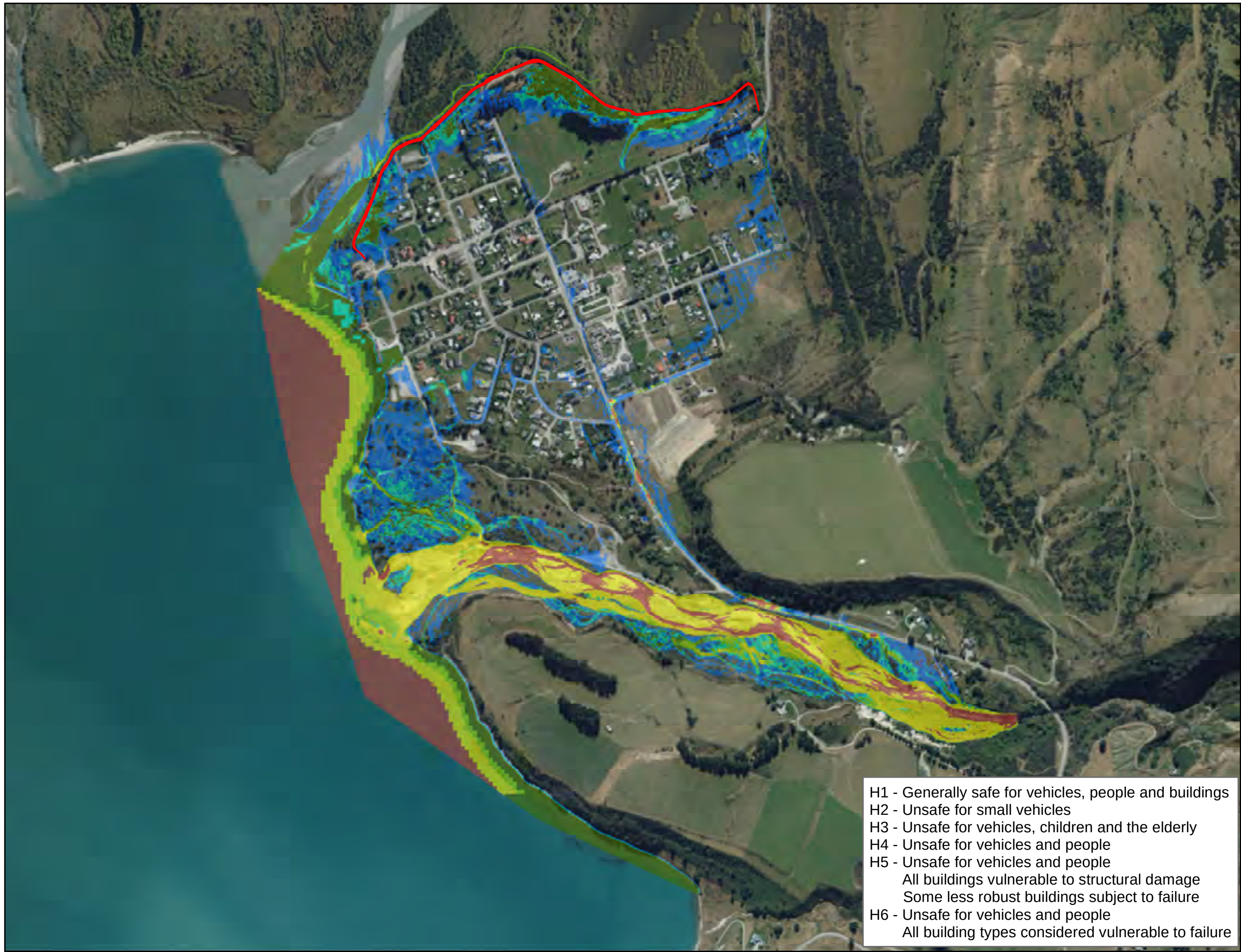
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **HAZARD MAP** **Aggradation Scenario A - Q 250m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

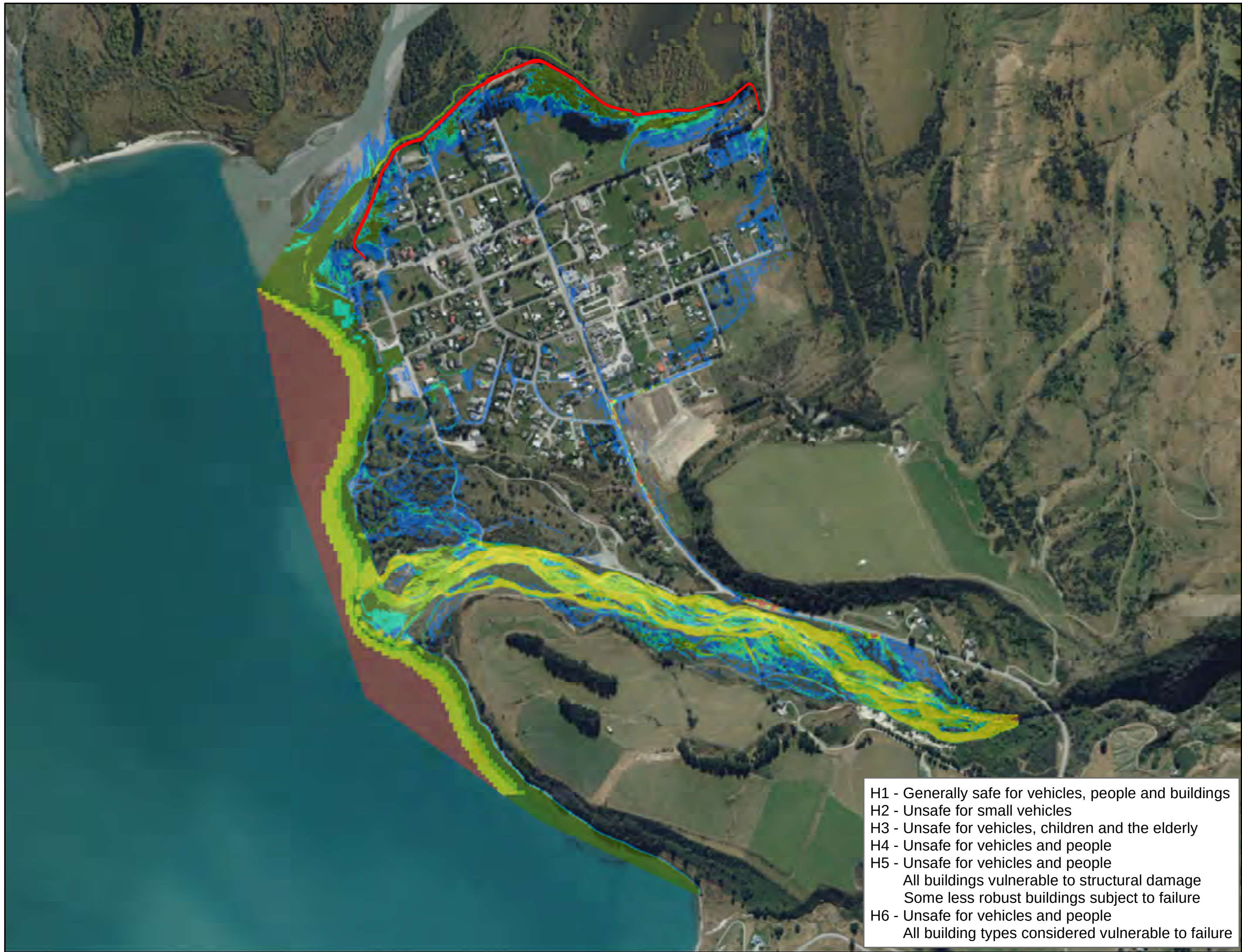
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 300m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

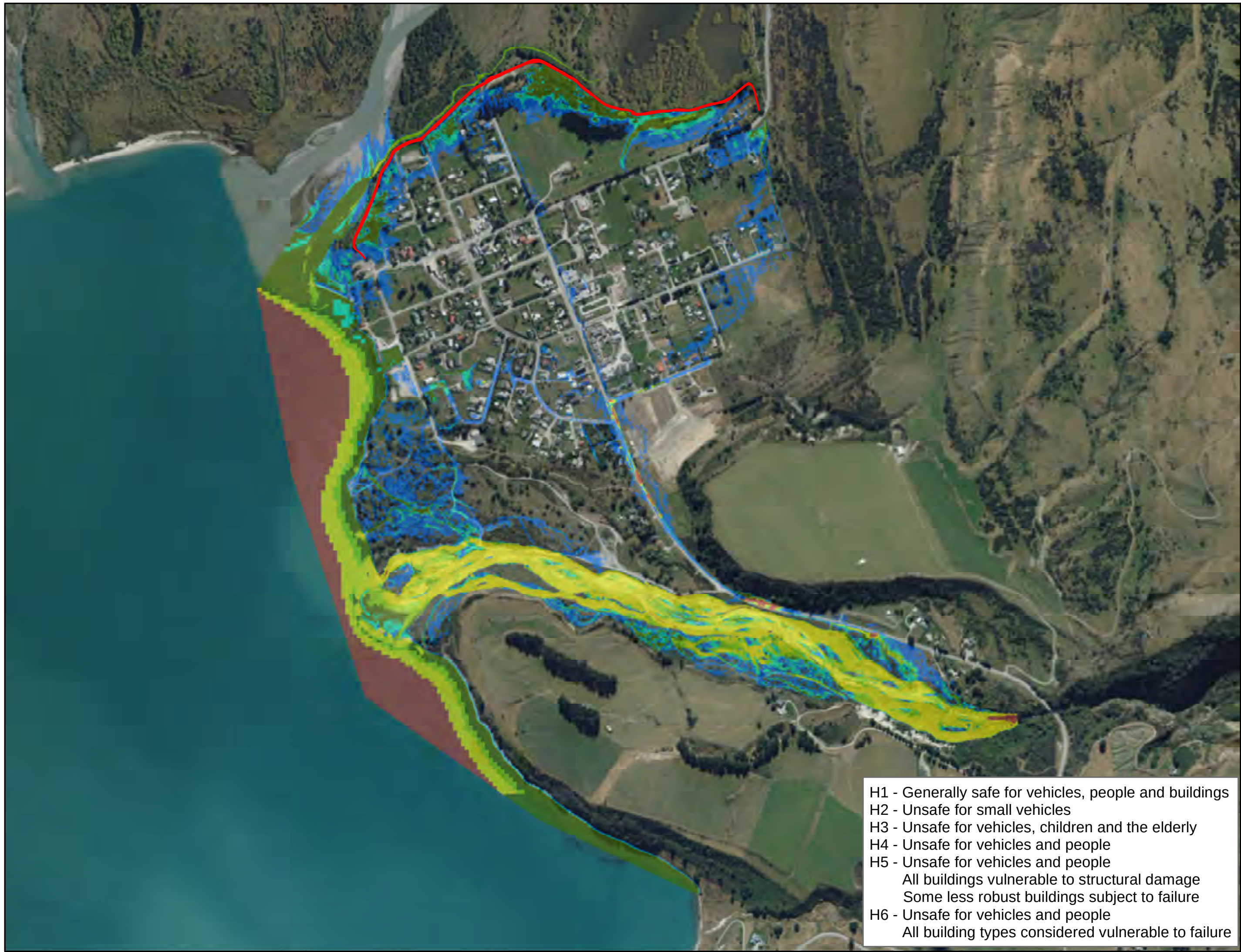
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION **02**	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario B - Q 100m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

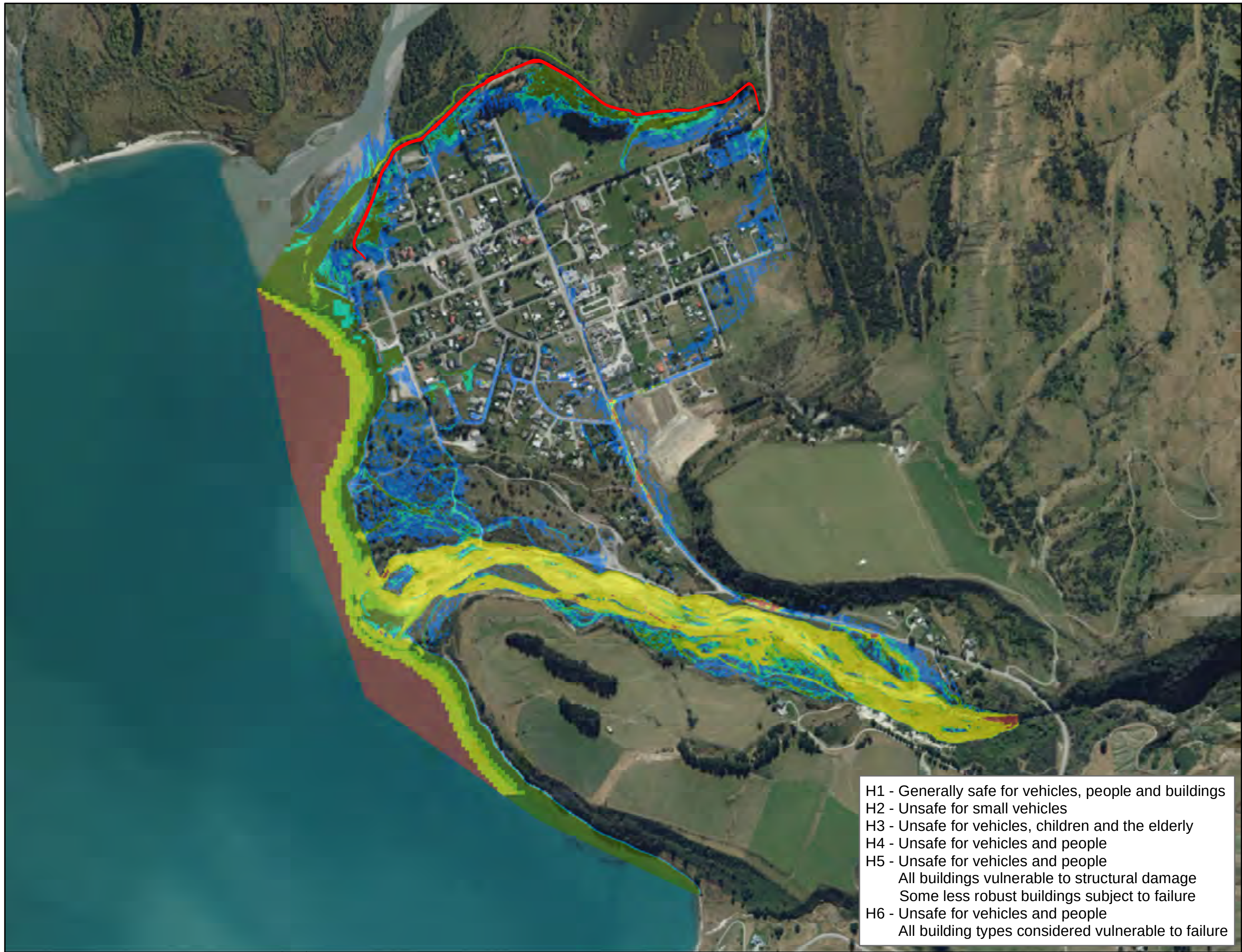
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario B - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

Otago Regional Council

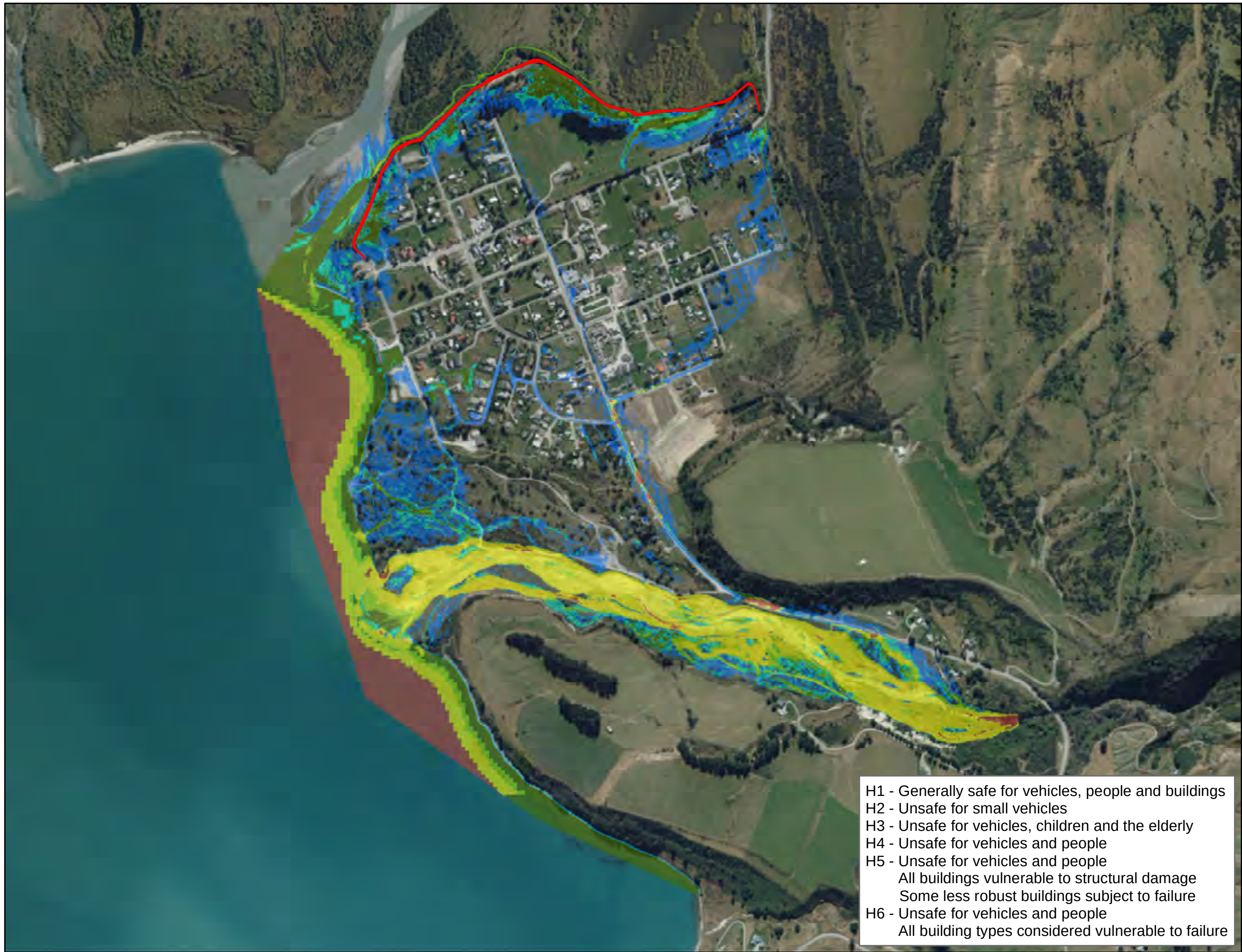
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario B - Q 180m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N



Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

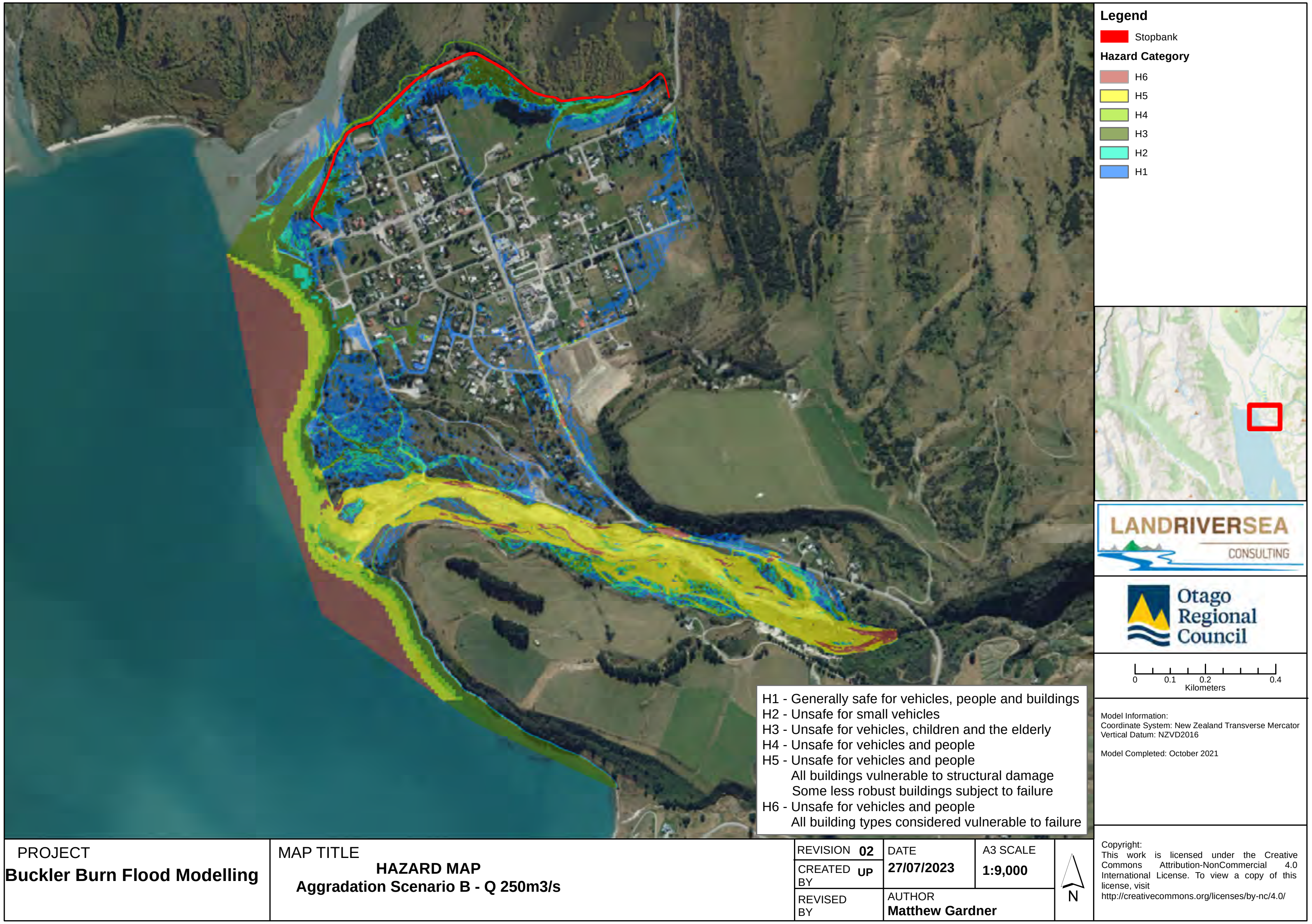
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario B - Q 200m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		


Legend
Stopbank
Hazard Category
H6
H5
H4
H3
H2
H1
LANDRIVERSEA
CONSULTING
Otago Regional Council
0
0.1
0.2
0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
H1 - Generally safe for vehicles, people and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for vehicles and people
H5 - Unsafe for vehicles and people
All buildings vulnerable to structural damage
Some less robust buildings subject to failure
H6 - Unsafe for vehicles and people
All building types considered vulnerable to failure
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
HAZARD MAP
Aggradation Scenario B - Q 250m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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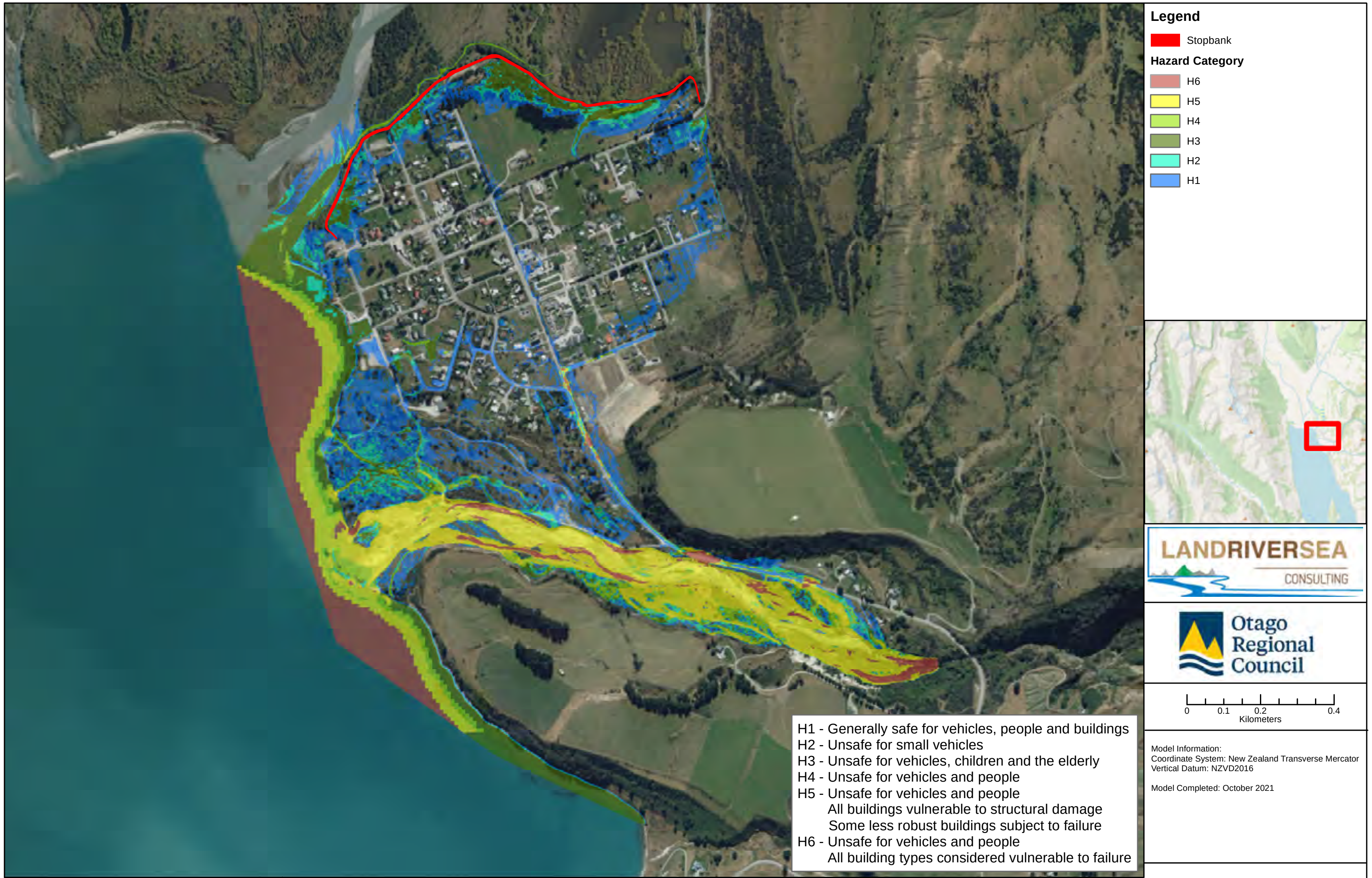
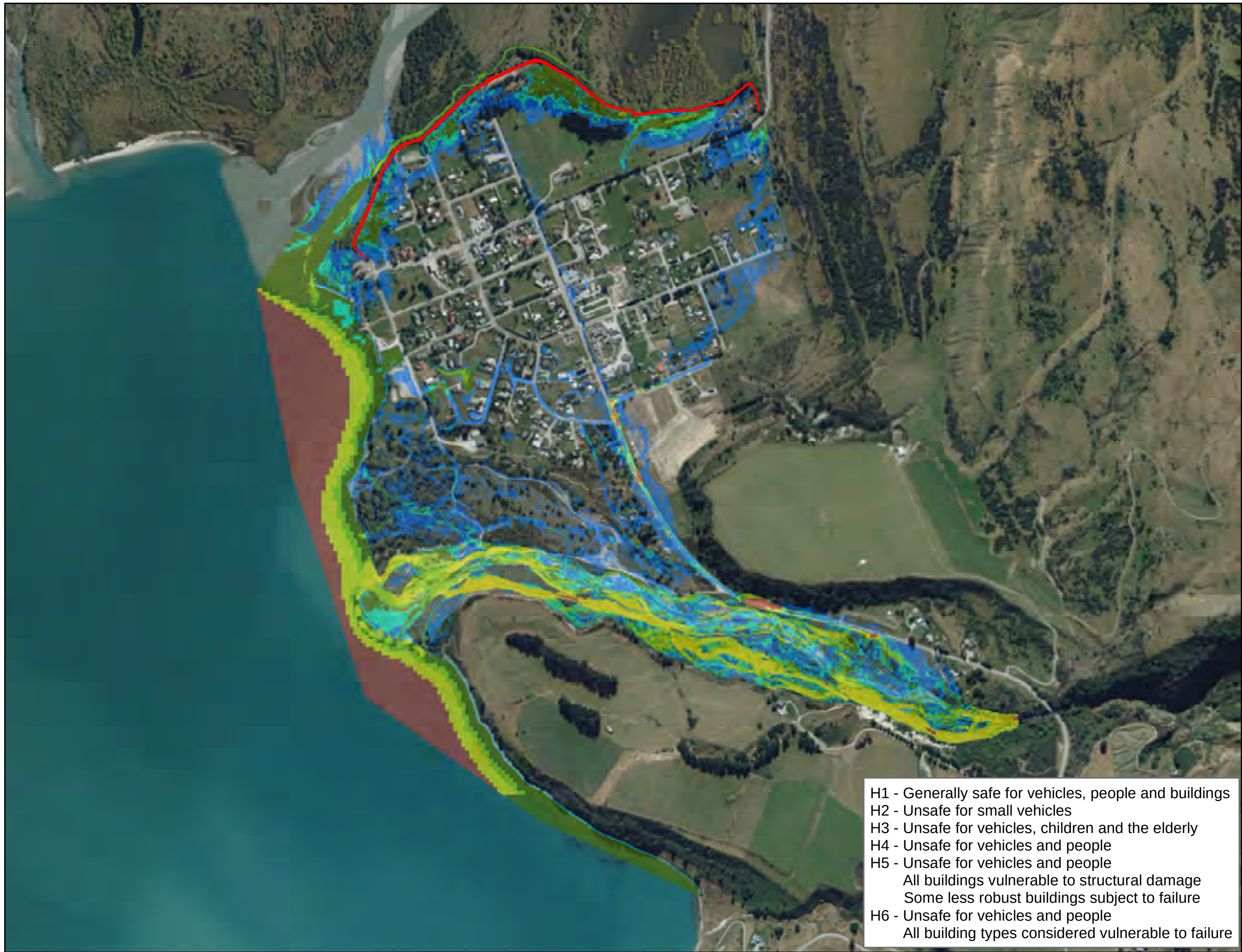


Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **HAZARD MAP** **Aggradation Scenario B - Q 300m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N

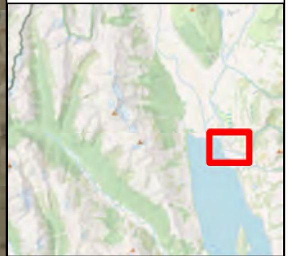


Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1



LANDRIVERSEA CONSULTING

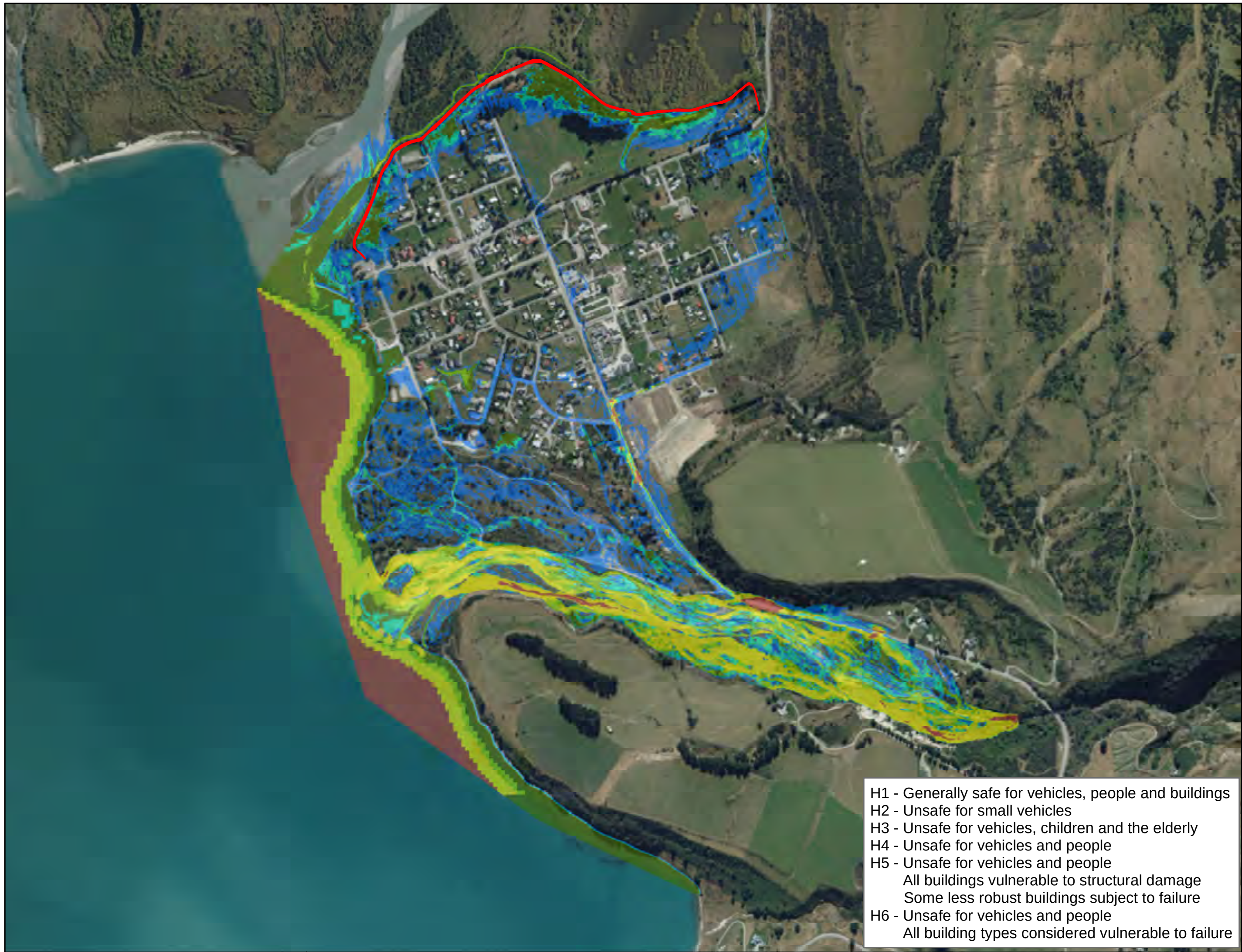
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario C - Q 100m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

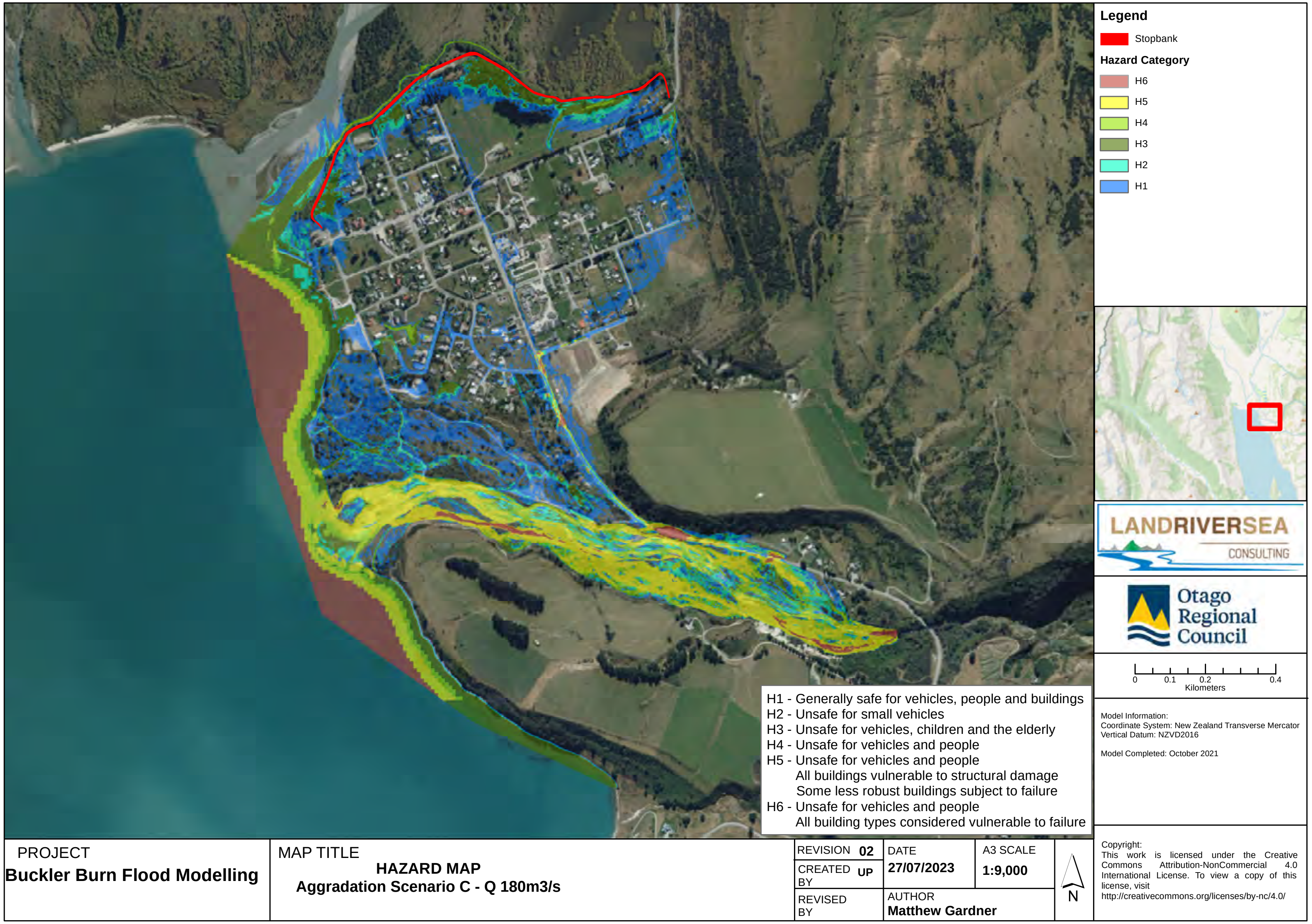
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario C - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N


Legend
Stopbank
Hazard Category
H6
H5
H4
H3
H2
H1
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
H1 - Generally safe for vehicles, people and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for vehicles and people
H5 - Unsafe for vehicles and people
All buildings vulnerable to structural damage
Some less robust buildings subject to failure
H6 - Unsafe for vehicles and people
All building types considered vulnerable to failure
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
HAZARD MAP
Aggradation Scenario C - Q 180m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
AUTHOR
Matthew Gardner
A3 SCALE
1:9,000
N
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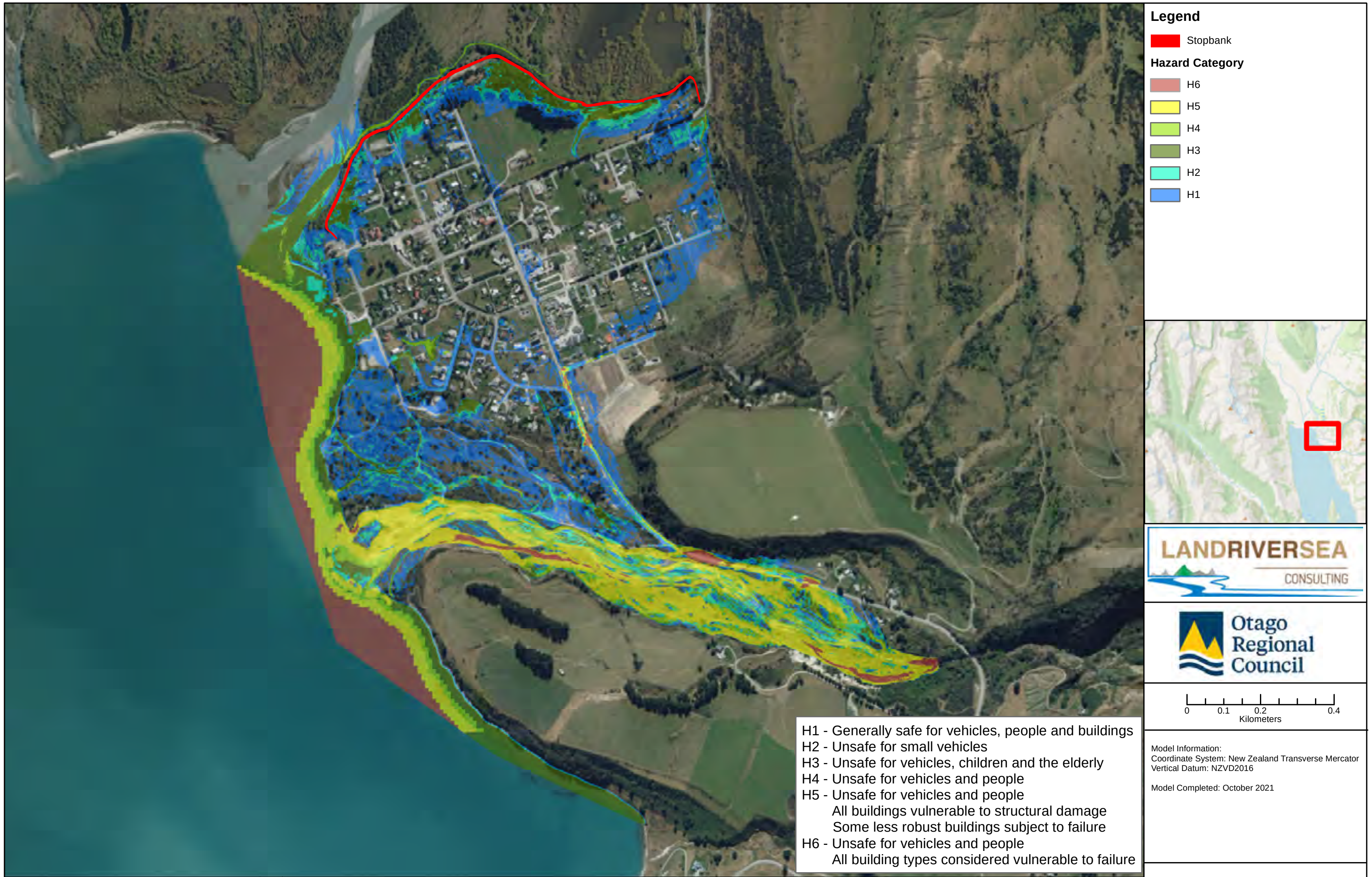
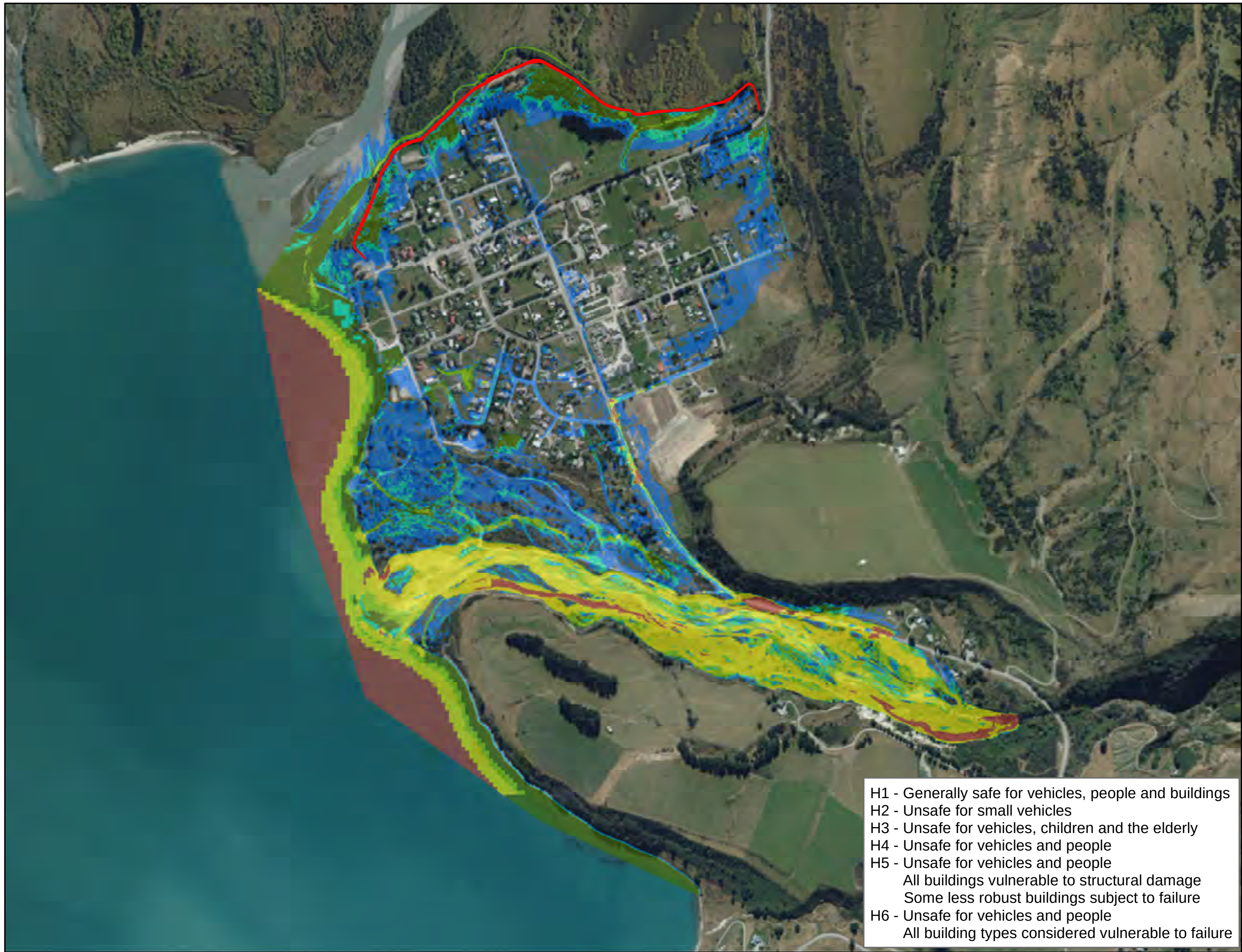


PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario C - Q 200m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

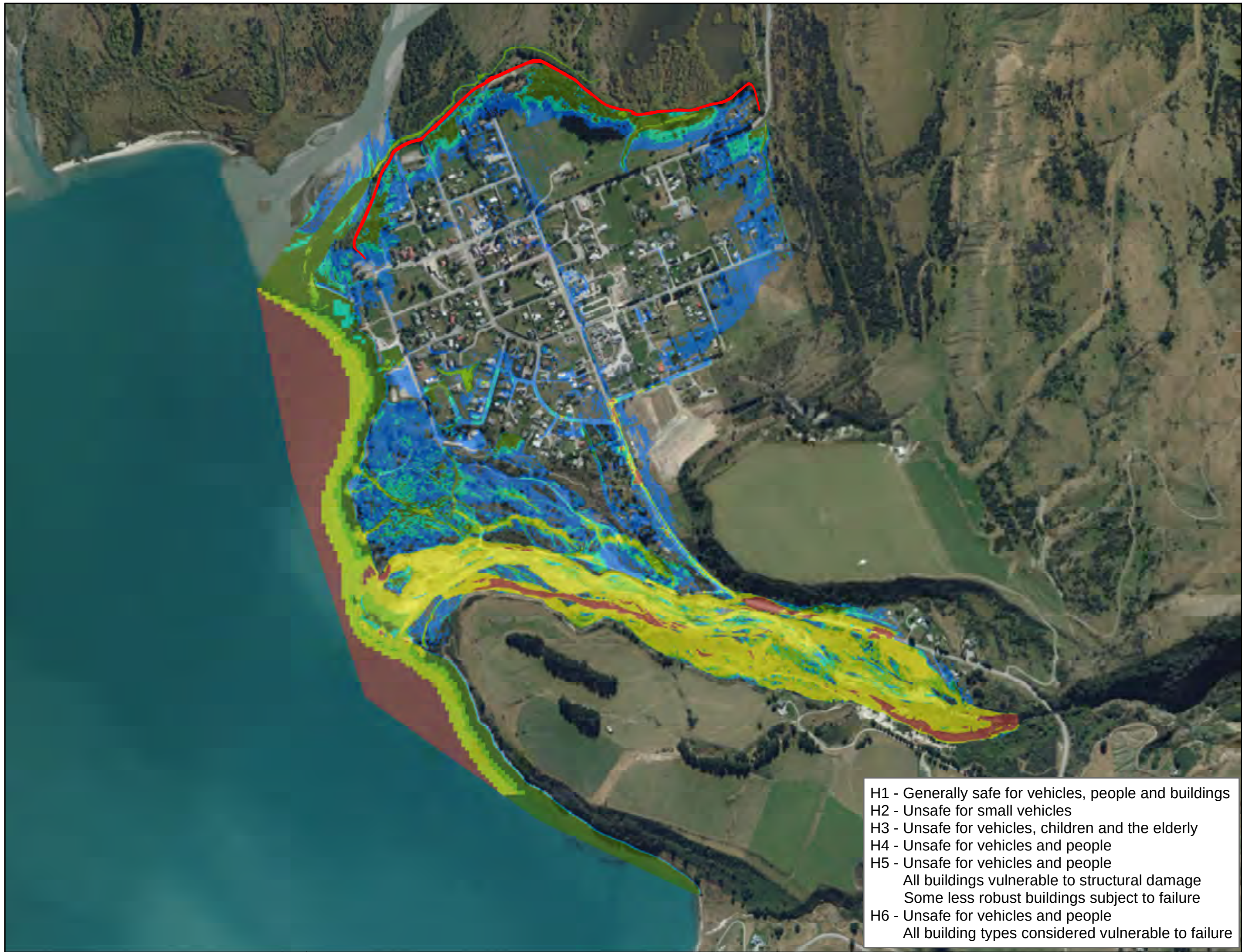
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario C - Q 250m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT
Buckler Burn Flood Modelling

MAP TITLE
HAZARD MAP
Aggradation Scenario C - Q 300m3/s

REVISION **02**	DATE **27/07/2023**	A3 SCALE **1:9,000**	N
CREATED BY **UP**			
REVISED BY	AUTHOR **Matthew Gardner**		