REPORT

Tonkin+Taylor

Taieri Flood Protection Scheme

Floodbank Risk Assessment

Prepared for
Otago Regional Council
Prepared by
Tonkin & Taylor Ltd
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Executive summary

Otago Regional Council (ORC) have engaged Tonkin & Taylor Ltd (T+T) to undertake a high-level risk assessment for the Lower Taieri River Flood Protection Scheme ("the scheme").

<u>The objective of this risk assessment is to understand the relative risks to the community of floodbank failure within the Lower Taieri River Flood Protection Scheme</u>. This will assist the Asset Manager (ORC) in understanding the appropriate level of service and prioritising potential floodbank improvements.

This high-level risk assessment has been commissioned as part of a wider body of work currently being undertaken by ORC assessing the Taieri scheme. This assessment includes all 109 km of floodbanks within the Scheme as shown on Figure 1. The Taieri River reach is bounded by the State Highway 87 bridge at Outram, Henley-Berwick Road Bridge at Waipori and State Highway 1 bridge at Waipori. The Silver Stream reach is bounded by Solway Place and the Taieri River confluence. The Contour Channel and Waipori River/Lake Waipori reaches within the Scheme are included with exception of a private section of floodbank on the Meggat Burn.

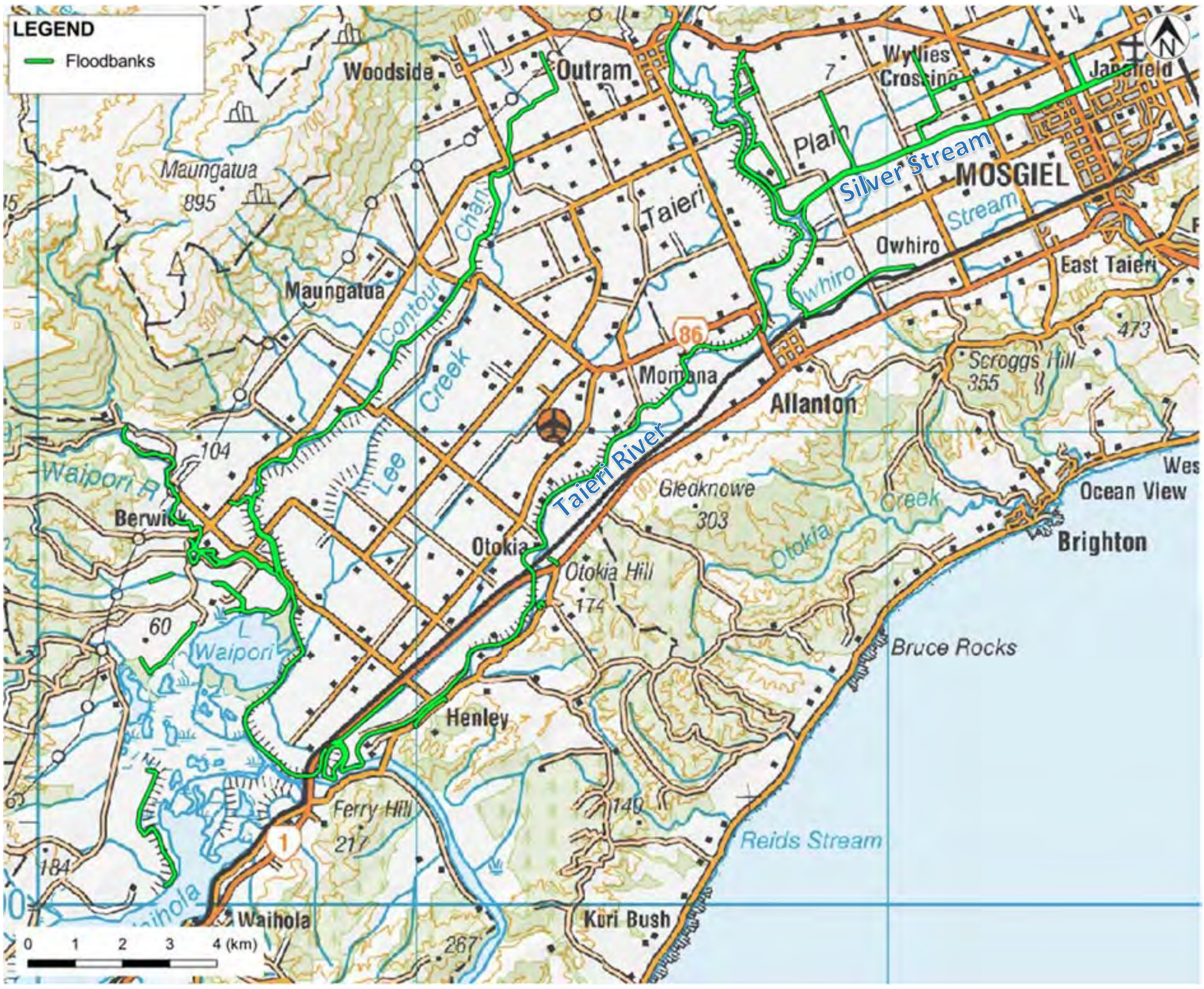


Figure 1: Lower Taieri River Flood Protection Scheme assessed floodbanks, highlighted in green.

The framework adopted for the risk assessment generally follows the methodology described in the NZ River Managers Forum (RMF) Code of Practice document *'Flood Protection Assets Performance Assessment Code of Practice',* March 2015. The RMF Code of Practice provides an Excel spreadsheet tool which estimates the performance score and relative risk rating of each floodbank section.

For this assessment, risk has been defined as the product of likelihood and consequence of failure where:

Likelihood: *The severity of known condition and performance defects that can lead to failure during a design flood event.*

Consequence: *The preliminary assessment of the effect of failure of the floodbanks at select locations.*

The floodbank was delineated into sections based on the findings of a field condition assessment undertaken within the Scheme in 2017/2018, soon after the July 2017 flood event. The 2017/2018 condition assessment recorded 629 field observation points along the Scheme floodbanks at an average distance of 173 m apart. The start and end of each section was set at the mid-point between each field observation point.

To estimate the likelihood of failure at each floodbank section, three failure modes were assessed, comprising field condition (berm, structures, surface condition and other), intrinsic strength (slope instability and seepage/piping), and capacity (e.g. crest height and river channel capacity). A rating of 1 to 5 (very low, low, medium, high, very high) was estimated for each floodbank section to reflect the vulnerability to each of the failure modes. Each of the three failure modes comprise of several components.

Rating for the field condition failure mode at each floodbank section were estimated based on findings from the 2017/2018 condition assessment. Ratings for the intrinsic strength failure modes were estimated using a combination of both semi-quantitative geotechnical analysis and qualitative evaluation incorporating the results of the 2017/2018 condition assessment. The rating for the overtopping failure mode at each floodbank section was estimated by comparing flood levels modelled by ORC (3,000 m^3/s in the Taieri River) to the floodbank crest levels.

To estimate the consequence of failure at each floodbank section, consequence categories were adopted from the International Infrastructure Management Manual including the effect as those consequences felt by social (safety & health, loss of service extent/duration), environment and property inundation damages (buildings, productive farmland and airport). A consequence rating of 1 to 5 (insignificant, minor, moderate, major, catastrophic) at each floodbank section was estimated for each consequence category. An overall consequence rating from 1 to 5 was then calculated for each floodbank section based on the highest rating from each category.

Consequence ratings for the social, environment and property inundation consequence categories were estimated based on high-level floodbank breach 2-dimensional hydraulic modelling and indicative damage assessment.

The likelihood and consequence rating estimates were used to populate the fields within the RMF spreadsheet tool. The tool provides an overall risk rating for each floodbank section as shown in the chart below.

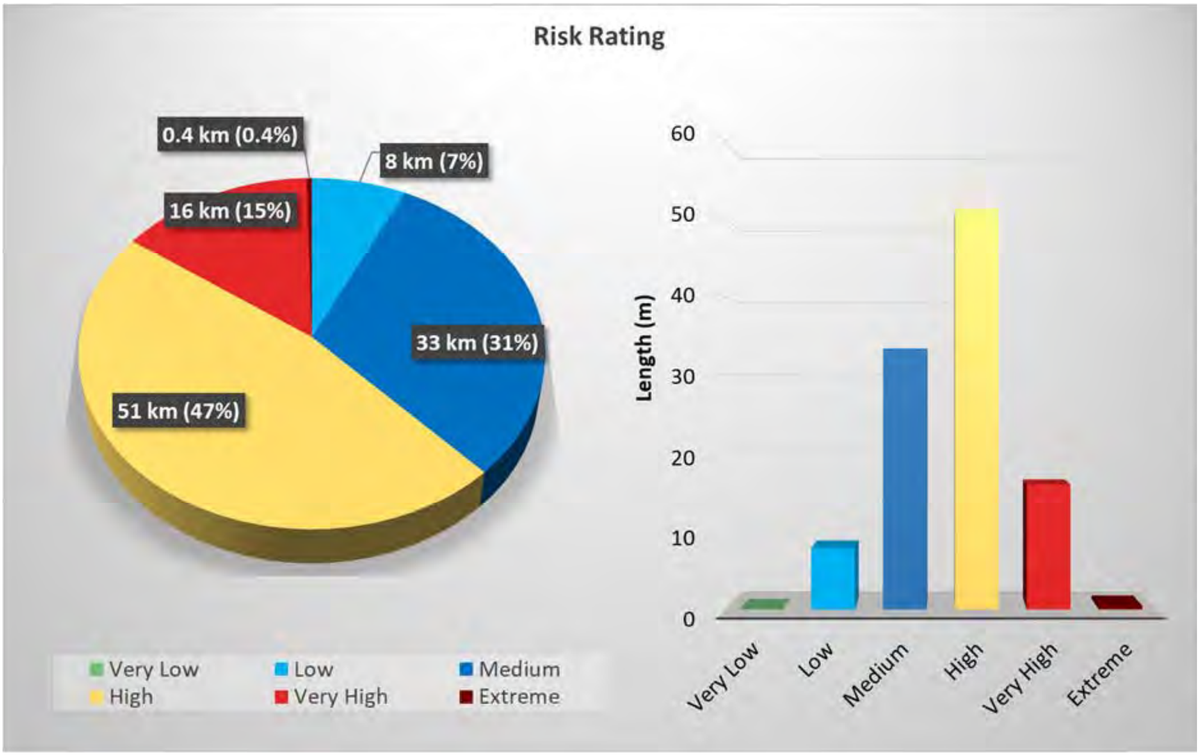


Figure 2: Risk rating summary

Generalisations of the risk rating along the floodbank are summarised in the table following.

Table 1: General reasoning for risk ratings

Risk rating	Floodbank Section	Reasoning
Extreme	Two sections of Waipori downstream Contour Channel	Catastrophic consequence rating due to inundation of airport and PAR >100. Very high likelihood rating due to potential seepage/piping susceptibility. Piping susceptibility in this area is relatively higher than other areas due to the landside elevation being close to, or at a lower elevation than, the normal water level in the adjacent waterway. These two sections have a higher likelihood rating than adjacent sections due to the presence of trees, and associated root systems, located within approximately 5 m of the floodbank.
Very high	Waipori downstream Contour Channel	Catastrophic consequence rating due to inundation of airport and PAR >100. High likelihood rating due to intrinsic strength value. Intrinsic strength values are generally high due to the piping susceptibility rating. Piping susceptibility in this area is relatively higher than other areas due to the landside elevation being close to, or at a lower elevation than, the normal water level in the adjacent waterway.

<table>
<tr><th>Risk rating</th><th>Floodbank Section</th><th>Reasoning</th></tr>
<tr><td rowspan="2"></td><td>Cut-off bank between Riccarton Road West and Gladfield Road</td><td>Major consequence rating due to PAR between 11 and 100. Very high likelihood rating due to capacity/overtopping.</td></tr>
<tr><td>Several sections along Waipori River upstream of Berwick, lower Contour Channel, Taieri River right floodbank upstream of Silver Stream, Silver Stream upstream of SH87, Taieri River left floodbank at Henley.</td><td>Reasons vary but generally major consequences due to PAR and very high likelihood rating due to capacity/overtopping or intrinsic strength.</td></tr>
<tr><td rowspan="6">High</td><td>Waipori River upstream Berwick</td><td>Major consequence rating due to PAR between 11 and 100. High or very high likelihood rating due to intrinsic strength rating. Intrinsic strength values are generally high due to the piping susceptibility rating in these sections.</td></tr>
<tr><td>Silver Stream upstream of Carlye Road</td><td>Catastrophic or major consequence rating due to high PAR (Mosgiel township). Variable likelihood ratings from medium to very high.</td></tr>
<tr><td>Taieri River right floodbank between Outram and Otokia</td><td>Catastrophic consequence rating due to PAR >100. Medium or high likelihood rating caused by field condition and capacity/overtopping.</td></tr>
<tr><td>Taieri River right floodbank downstream of Otokia to Waipori confluence</td><td>Moderate consequence rating due to PAR between 2 and 10. Very high likelihood rating caused by field condition and capacity/overtopping.</td></tr>
<tr><td>Contour Channel downstream Dow Road</td><td>Major consequence rating due to PAR between 11 and 100. Low, medium, high or very high likelihood rating.</td></tr>
<tr><td>Several sections of Taieri River left floodbank upstream of Silver Stream confluence, Silver Stream downstream of Gladfield Road</td><td>Moderate consequence rating due to inundation of McKays Triangle Wetland. High or very high likelihood rating due to overtopping.</td></tr>
<tr><td rowspan="6">Medium
Low
Very low</td><td>Contour Channel upstream of Dow Road</td><td rowspan="6">Reasons vary along sections. Consequence rating either insignificant, minor or moderate. Likelihood rating vary from very low to very high.</td></tr>
<tr><td>Owhiro right floodbank</td></tr>
<tr><td>Various sections at Lake Waipori</td></tr>
<tr><td>Waipori River downstream Berwick</td></tr>
<tr><td>Taieri River left floodbank upstream of SH1</td></tr>
<tr><td>Silver Stream left and right floodbank downstream of Carlye Road</td></tr>
</table>

1 Introduction

Otago Regional Council (ORC) have engaged Tonkin & Taylor Ltd (T+T) to undertake a high-level risk assessment for the Lower Taieri River Flood Protection Scheme.

The objective of this risk assessment is to understand the relative risks of floodbank failure within the Lower Taieri River Flood Protection Scheme. This will assist the asset owner in understanding the appropriate level of service and prioritising potential floodbank improvements.

This high-level risk assessment has been commissioned as part of a wider body of work currently being undertaken by ORC assessing the Taieri scheme. This broader work involves scheme assessments and future planning for the full Taieri Scheme, including the Taieri River primary floodbanks, primary ponding zones, and tributaries including Silver Stream, Contour Canal, Waipori River/Lake Waipori and Owhiro Stream. This project is part of identifying the current state and risks of the scheme to inform scheme requirements for the community both now and into the future. The risk assessment only focuses on floodbanks and not other assets.

ORC has requested that the risk assessment generally follows the methodology described in the NZ River Managers Forum (RMF) Code of Practice document "*Flood Protection Assets Performance Assessment Code of Practice*", March 2015 and the corresponding Flood Protection Assets Performance Assessment Tool V2 (the "RMF Tool").

This report has been prepared for ORC in accordance with the conditions of engagement in dated 11 November 2021, Variation 01.

2 Background

The Lower Taieri Flood Protection Scheme ("the Scheme") comprises approximately 110 km of floodbanks located on the Taieri Plains southwest of Dunedin as shown on Figure 3. The primary floodbanks along the scheme protect surrounding land from river induced flooding from the Taieri River, Silver Stream, Waipori River/Lake Waipori, Contour Channel, as well as several smaller streams. Within the scheme, several ponding areas, cut-off banks, ring banks and surface water pump stations complement the primary flood protection system.

The lower Taieri area is very flat and gravity drainage is very limited. The west Taieri area relies on three pump stations (Waipori, Lake Ascog, Henley) and a network of drains for drainage. The primary role of the pumps is to discharge runoff back into the river during dry conditions and small rainfall events. The pumps are not designed to alleviate flooding during severe flood events. After a severe flood, water that has flowed or fell into the west Taieri area can only be removed by pumping over time after the event. The East Taieri area including the upper and lower ponding areas can drain away under gravity once river levels recede.

Land use within the Scheme area is predominantly rural. Agricultural uses within the area vary but predominantly include cropping, beef, sheep and dairy. Township communities include Mosgiel to the east, Outram to the north, Allanton to the south east and Henley to the South. Of particular significance, the Dunedin International Airport is located within the lower Taieri area between Allanton and Henley. Three State Highways are located within the Scheme including SH1, SH86 and SH87.

The Scheme has been constructed and upgraded in various stages since the late 19th century. A significant flood event occurred in 1980, during which the peak flow recorded at Outram was approximately 2,500 m^3/s. The peak flow recorded during the 1980 flood is the largest to have occurred since records began in the late 19th century. The return period of a 2,500 m^3/s flow was at the time of the flood, estimated to be a 1% Annual Exceedance Probability (AEP) event. The AEP of the 1980 event may now be different due to an additional 43 years of flow data being available.

Another large flood event occurred in July 2017 which recorded a peak flow at Outram of 1,700 m^3/s.

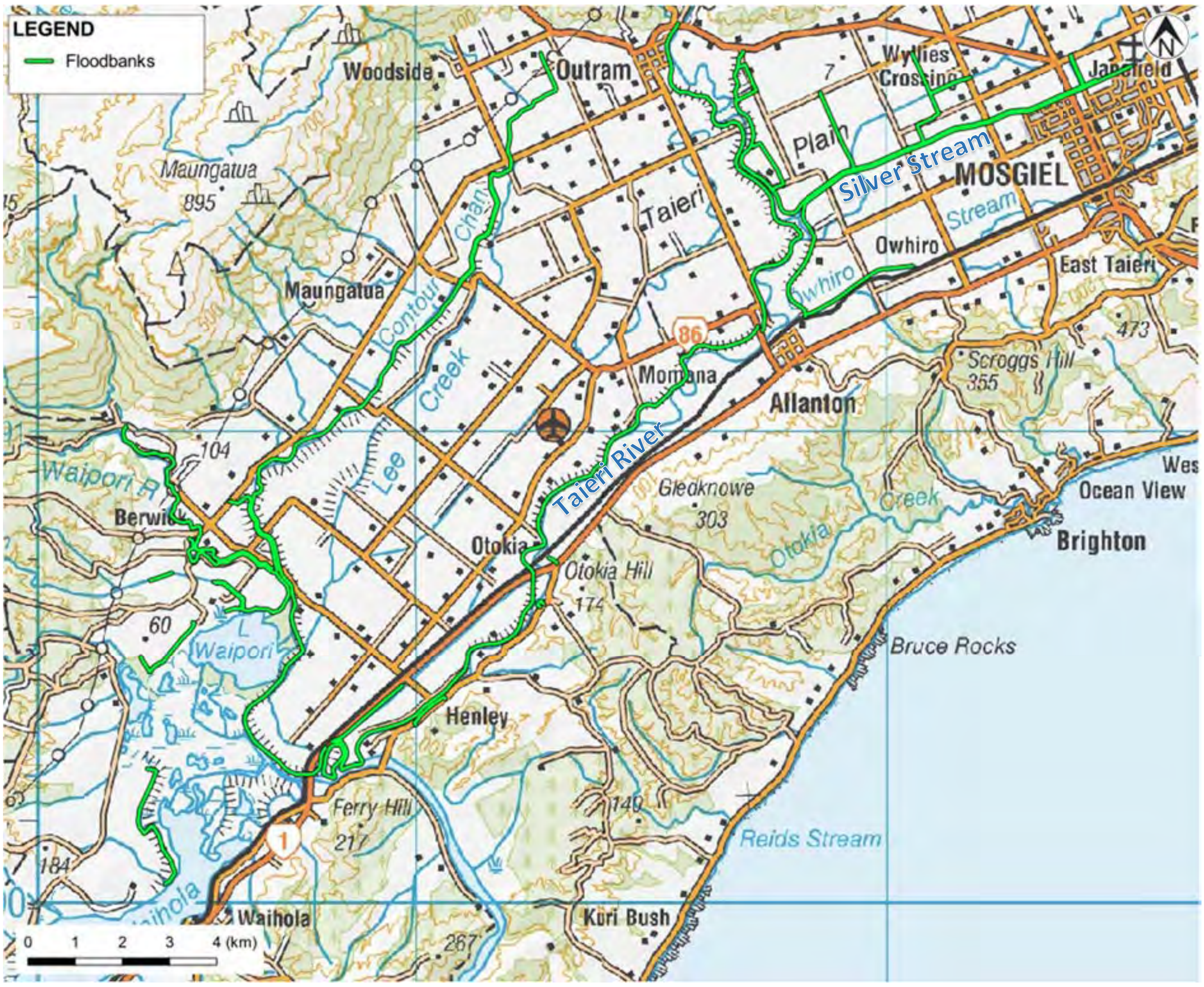


Figure 3: Lower Taieri River Flood Protection Scheme assessed floodbanks

3 Methodology

The following sections summarise the methodology adopted for the risk assessment.

3.1 Framework

The framework adopted for the risk assessment generally follows the methodology described in the NZ River Managers Forum (RMF) Code of Practice document *'Flood Protection Assets Performance Assessment Code of Practice',* March 2015. The method is predicated on observed condition and performance during a design (or near-design) flood event.

The RMF Code of Practice provides a framework for assessing the performance of flood protection assets where the assessment methodology and frequency is aligned to the amount of risk posed to the community. The framework takes the asset owner through the following general methodology to calculate a performance score and relative risk rating for the flood protection asset:

- Defining level of service and design/construction standards (in this instance the level of service is inferred from as-built infrastructure as opposed to a design standard per se);
- Sectioning assets appropriately into suitable scale;
- Identifying failure modes;

- Estimating consequence of failure including social, environmental and property inundation damage;
- Scoring confidence in the information;
- Estimation of the performance score; and
- Assigning a relative risk rating.

Figure 4 shows a graphical representation of the RMF framework methodology adopted for this assessment.

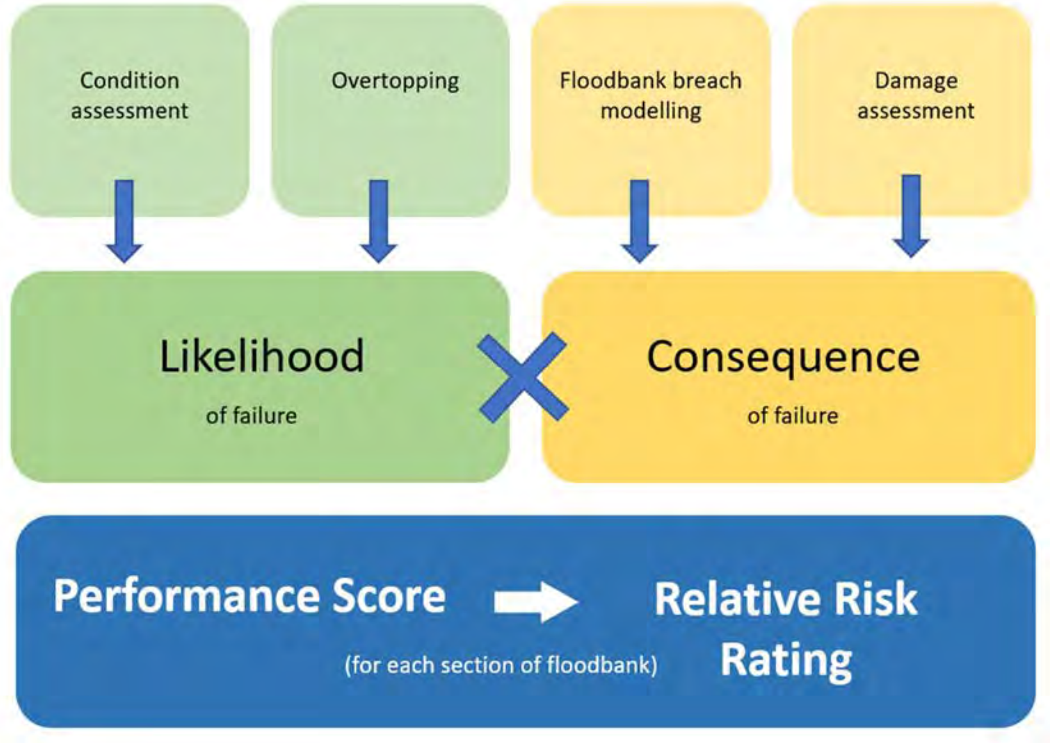


Figure 4: RMF framework methodology

For this assessment, risk has been defined as the product of likelihood and consequence where:

Likelihood: *The severity of known condition and performance defects that can lead to failure during a design flood event.*

Consequence: *The preliminary assessment of the effect of failure of the floodbanks at select locations.*

Further information and background regarding the RMF framework methodology is provided in the RMF Code of Practice.

The RMF Code of Practice provides an Excel spreadsheet tool ("The RMF Tool") which leads the user through the RMF framework methodology, from setting the context of the assessment to estimating the performance score and relative risk rating. The RMF Tool allows for flexibility to customise the parameters specific to each user and flood protection asset.

3.2 Floodbank sectioning

The RMF Tool requires the floodbank to be delineated into representative sections. It is recommended by the RMF Code of Practice that sections are delineated such that local floodbank conditions are suitably reflected depending on the resolution of data held for a particular floodbank reach.

This assessment includes all 109 km of floodbanks within the Scheme as shown on Figure 1. The Taieri River reach is bounded by the State Highway 87 bridge at Outram, Henley-Berwick Road Bridge at Waipori and State Highway 1 bridge at Waipori. The Silver Stream reach is bounded by Solway Place and the Taieri River confluence. The Contour Channel and Waipori River/Lake Waipori reaches within the Scheme are included with exception of a private section of floodbank on the Meggat Burn.

The floodbank was delineated into sections as shown in Appendix A, Figures A1 and A2 based on the findings of a field condition assessment undertaken within the Scheme in 2017/2018. The 2017/2018 condition assessment[1] recorded field observation points along the Scheme floodbanks at intervals ranging from 21 m to 1289 m at an average of 173 m. The start and end of each section was set at the mid-point between each field observation point.

Further information regarding the 2017/2018 condition assessment is provided in Section 3.3.1

3.3 Likelihood of failure

Likelihood: *The severity of known condition and performance defects that can lead to failure during a design flood event.*

To estimate the likelihood of failure at each floodbank section, three failure modes have been assessed as recommended by the RMF Tool, including field condition, intrinsic strength, and capacity.

The standard RMF failure modes have been adjusted based on site specific information, data availability and discussions with ORC[2]. The adopted failure modes are shown in Table 2.

[1] T+T report *"Floodbank condition and structural integrity assessment"* report (May 2018), T+T ref 1001453.v4
[2] Proposed failure mode provided to ORC in document 20220309.saff.proposed rating criteria.v1.docx

Table 2: Likelihood of failure modes

Failure mode	Description
Field condition	
Berm	Undermining of the floodbank from the river during flood conditions.
Structures	Floodbank integrity at structures which penetrate or are within a zone which may potentially affect integrity of the floodbank.
Surface condition	Presence and condition of trees, grass, crossings, stock damage, rabbit burrows and erosion which may potentially affect integrity of the floodbank.
Other	Presence and condition of other factors such as geomorphic features, excavations, evidence of seepage, potentially steep hydraulic gradient, encroachments, factors inhibiting view of floodbank which may potentially affect integrity of the floodbank.
Intrinsic strength	
Slope instability (including foundation)	Presence of slips and/or slumping on the floodbank, based on the 2017/2018 condition assessment.
Seepage/piping	Piping susceptibility based on the hazard assessment summarised in the 2017/2018 condition assessment.
Capacity	
Overtopping	Susceptibility to overtopping during design flood conditions which may potentially lead to erosion/scour of the floodbank

A rating of 1 to 5 (very low, low, medium, high, very high) was estimated for each floodbank section to reflect the vulnerability to each of the failure modes. This is described further in the following sections.

3.3.1 Field condition

Likelihood ratings for the field condition failure modes (berm, structures, surface condition and other) at each floodbank section were estimated based on findings from a field condition assessment undertaken along the Scheme floodbanks in 2017, soon after the July 2017 flood event.

The 2017/2018 condition assessment comprised of walking the crest of the Scheme floodbanks and recoding field observations points for a range of condition criteria. In total, 401 observation points were recorded along the Taieri and Silver Stream reaches as shown in Figure 5. Each field observation point corresponds to a floodbank section as described in Section 3.2.

Figure 5: 2017/2018 condition observation points

Additional field observations collected by ORC staff since the 2017/2018 condition assessment have been provided by ORC[3]. Where overlap existed between the 2017 and additional observations, the more recent observations were adopted. In total, 34 of the 629 observations points were updated with the more recent observations. Output datasets have been given a unique identifier to indicate which observation (2017 or additional ORC) were used in the risk assessment.

Table 3 explains how the likelihood ratings were estimated for the field condition failure modes.

[3] Data package 'Engineering Operations General Backup' sent via email from Ellyse Gore (ORC) to Scott Forster (T+T), 'FW: Field Observations', 16 November 2022

Table 3: Field condition rating

Field condition failure mode	Rating	Description[1]
Berm	1	Wide bench with normal flow distant from floodbank, or well armoured bank
	2	Transition
	3	Moderate width bench between floodbank and river
	4	Minor bench
	5	Floodbank slope extends directly down to river with no bench or armour
Structures	1	No structures in/on stopbank, or structure unlikely to contribute to floodbank vulnerability.
	2	NA
	3	Structure may contribute to floodbank vulnerability.
	4	NA
	5	Potentially significant issue, further assessment and/or monitoring recommended.
Surface condition	1	Hazard rating 1 for criteria trees, grass, crossings, stock damage, rabbit burrows and erosion
	2	Hazard rating 2 for criteria trees, grass, crossings, stock damage, rabbit burrows and erosion
	3	Hazard rating 3 for criteria trees, grass, crossings, stock damage, rabbit burrows and erosion
	4	Hazard rating 4 for criteria trees, grass, crossings, stock damage, rabbit burrows and erosion
	5	Hazard rating 5 for criteria trees, grass, crossings, stock damage, rabbit burrows and erosion
Other	1	Additional observation unlikely to contribute to floodbank vulnerability.
	2	NA
	3	Additional observation may contribute to floodbank vulnerability.
	4	NA
	5	Additional observation noted as a potentially significant issue, further assessment and/or monitoring recommended.

1. Further information regarding descriptions are provided in the T+T report '*Floodbank Condition and Structural Integrity Assessment*', May 2018.

The Riverside Spillway Structure rating was manually adjusted to 5 to reflect observations made during the 2017 flood which resulted in significant scour and erosion of the spillways rock protection.

3.3.2 Intrinsic strength

Likelihood ratings for the intrinsic strength failure modes (slope instability and seepage/piping) at each floodbank section were estimated using a combination of both quantitative geotechnical analysis and qualitative evaluation incorporating the results of the 2017/2018 field condition assessment.

Table 4 explains how the likelihood ratings were estimated for the intrinsic strength failure modes.

Table 4: Intrinsic strength rating

Intrinsic strength failure mode	Rating	Description[1]
Slope instability (including foundation)	1	No slippage
	2	Slippage affecting land surrounding/near floodbank
	3	Minor slipping/slumping not affecting crest, but on lower slopes of floodbank
	4	Extensive developed slippage affecting crest
	5	Severe slips/slumps
Seepage/piping	1	Seepage may occur at or near the floodbank toe. Not expected to result in severe soil strength loss or piping during flood.
	2	Seepage may occur at or near the floodbank toe. Higher seepage rate and potentially erosion may occur at/around ground penetrations such as tree roots or structures and/or other preferential flow paths, mainly on natural ground on landside rather than through floodbank.
	3	Seepage expected to occur at or near floodbank toe. Soil strength loss may result in erosion of soil material.
	4	Significant seepage is expected to occur and may result in erosion of soil material, particularly around penetrations such as tree roots or structures.
	5	Observed locations of seepage and/or piping in previous flood events.

1. Further information regarding descriptions are provided in the T+T report '*Floodbank Condition and Structural Integrity Assessment'*, May 2018.

3.3.3 Overtopping

The likelihood rating for the overtopping failure mode at each floodbank section was estimated by a combination of quantitative water level review, field observation data and engineering judgement.

The quantitative water level review was undertaken by comparing modelled flood levels[4] to the floodbank crest levels[5] Modelled flood levels were based on peak flows of 3,000 m^3/s (estimated as a 1% AEP event[4]) for the Taieri River, 300 m^3/s (1% AEP) flow upstream of the Gordon Road spillway for Silver Stream, 90 - 93 m^3/s (10% AEP) flow for the Contour Channel and 113 m^3/s (approximately 2% AEP) for the Waipori River.

[4] 2-dimensional hydraulic model outputs provided by ORC as described in ORC report 'Lower Taieri River Model Development Report', Preliminary Draft, August 2020. Flood levels from Design Scenario 3 adopted for this assessment.
[5] Floodbank crest levels taken from 2021 LiDAR level survey.

Due to spatial limitations in the design flood level data, 2.5 km of the total 109 km length of floodbank does not have a flood level. For these lengths of floodbank, overtopping rating was assigned based on the nearest available flood level.

Table 5 explains how the likelihood rating was estimated for the overtopping failure mode.

Table 5: Overtopping rating

Rating	Description[1]	
1	More than 0.5 m freeboard predicted.	No overtopping expected. Very low probability of compromise to the integrity of the floodbank by overtopping (i.e. breach).
2	0.5 m freeboard to 0.0 m freeboard predicted, with grass/vegetation, crossing, stock, or erosion rating(s) of 1 or 2 (from field condition assessment).	Minor overtopping may occur (due to variability of crest height, minor flow stalling etc.), and is expected to be sustainable for an extended period with minimal or no scour damage. Low probability of compromise to the integrity of the floodbank (i.e. breach).
3	0.5 m freeboard to 0.0 m freeboard predicted, with grass/vegetation, crossing, stock, or erosion rating(s) greater than 2 (from field condition assessment)	Minor overtopping may occur (due to variability of crest height, minor flow stalling etc.), minor damage may occur over a period of about an hour, or significant damage may occur over greater periods. Low to moderate probability of compromise of the integrity of the floodbank (i.e. breach).
4	0.0 m freeboard to 0.3 m overtopping predicted.	Overtopping expected to occur, resulting in scour damage over a period of several hours. Moderate probability of compromise of the integrity of the floodbank (i.e. breach).
5	More than 0.3 m overtopping predicted.	Severe overtopping expected to occur, resulting in scour damage which affects integrity of the floodbank. High probability of a breach if overtopping lasts for more than a few hours.

1. Further information regarding overtopping descriptions are provided in the T+T report '*Floodbank Condition and Structural Integrity Assessment*', May 2018.

Spillways at Riverside Road, Gordon Road, Henley and two along the Contour Channel are designed to overtop in a design flood event. Therefore, an overtopping rating of 1 was assigned to these sections. This assumes that the spillways are appropriately designed for overtopping.

3.4 Consequence of failure

Consequence: *The preliminary assessment of the effect of failure of the floodbanks at select locations.*

To estimate the effect of failure at each floodbank section, consequence categories were adopted from the International Infrastructure Management Manual (IIMM). The RMF Tool recommends the use of the IIMM categories. The IIMM describes the effect as those consequences felt by social, environmental and economic factors.

The standard IIMM consequence categories have been adjusted based on site specific information, data availability and adopting part of ORC's Natural Hazard Risk Assessment descriptors as agreed with ORC. The adopted categories are shown in Table 6 on the following page.

A rating of 1 to 5 (insignificant, minor, moderate, major, catastrophic) was estimated for each floodbank section based on high-level floodbank breach modelling and damage assessment described in the following sections.

An overall consequence rating from 1 to 5 was calculated for each floodbank section based on the highest rating from each category, this is also known as a "first past the post" approach as agreed with ORC.

Table 6: Consequence of failure categories

		Consequence of failure category					
		Social		Environment	Property inundation damages		
Rating		Safety & health	Loss of service extent/duration		Building damages	Productive farmland damages	Airport damages
1	Insignificant	PAR[1] = 0	Small number of customers experiencing minor service disruption	Negligible impact, no impact to natural state	< 1% of buildings have functionality compromised	< 1% of Productive land area affected	-
2	Minor	PAR = 1	Significant service disruption affecting small number of customers	Material damage, localised impacts and importance, return to natural state within 1 – 3 months	2-10% of buildings have functionality compromised	2-10% of Productive land area affected	-
3	Moderate	PAR = 2 to 10	Significant localised disruption over extended period (two weeks)	Serious damage, localised impacts and importance, return to natural state within 12 months	11-20% of buildings have functionality compromised	11-20% of Productive land area affected	-
4	Major	PAR = 11 to 100	Major localised disruption over extended period (over a month)	Serious damage, national impacts and importance, return to natural state within 5 months	21-49% of buildings have functionality compromised	21-49% of Productive land area affected	-
5	Catastrophic	PAR > 100	Major long-term service disruption affecting rest of region	Serious damage of national importance. Long term remediation/study required. May not return to natural state	> 50% of buildings have functionality compromised	> 50% of Productive land area affected	Catastrophic damages if terminal building flooded

1. PAR: Population at risk - definition: The number of people who would be directly exposed to inundation greater than 0.5m in depth if they took no action to evacuate. Definition from NZSOLD Guidelines 2015.

3.4.1 Floodbank breach modelling

T+T undertook high-level floodbank breach modelling along the Taieri River and Silver Stream floodbank to estimate the flooded extent and water depth resulting from a hypothetical floodbank breach. This information was used to inform the damage assessment for each of the consequence of failure categories; social, environmental and property inundation.

Further information and limitations regarding the breach modelling are provided in the T+T report '*Flood Risk Assessment – Taieri Scheme Review – Floodbank breach modelling*', 1 February 2023, and provided in Appendix B.

A 2-dimensional hydraulic model of the Taieri River and Silver Stream flood scheme area was developed in TUFLOW software (Version 2020-10-AA) to predict the flooded extent during various floodbank breach scenarios.

Fifteen representative locations on the landward side of the floodbanks were selected to apply a hypothetical breach hydrograph as a point source. The locations were selected based on floodbanks with a history of observed locations of seepage in previous flood events, and to broadly cover the scheme area from upstream to downstream. Appendix A, Figure A3 shows the locations of the modelled stopbank breaches. There is potential for floodbanks to breach at any location within the scheme area. Floodbank breaches at other locations would result in different flooded extents. Breaches may form in a different manner to that assumed and breach arrangements different to those assumed will also result in different outcomes. Breaches have been modelled independently. If multiple breaches occur at the same time the flooding extent and depth could be larger.

Each modelled breach result was applied to multiple floodbank sections based on the location of the section in relation to the breach. The length, depth and formation time of each section was based on judgment. In general, breach results apply to floodbank sections downstream of the breach location until it intercepts with another breach location (e.g. Breach 1 and 2). In ponding areas, breach results are also applied to upstream floodbank sections (e.g. Breach 6).

Floodbank breach hydrographs applied to each breach location were estimated using the method described in Zomorodi, 2020. This method provides theoretical equations to estimate the peak discharge from a floodbank breach scenario based on the height and material composition of the floodbank. The failure mode for all the breach scenarios is assumed to be overtopping. Floodbanks may have other failure modes (e.g. piping) however the overtopping failure mode results in the larger and more conservative discharge when using the Zomorodi equations. The equations assume that the water level within the river at the time of the breach is at the crest of the floodbank which would be required for an overtopping failure.

A breach hydrograph shape was estimated based on peak discharge and the river hydrograph shape of the 1980 flood event for the Taieri River and April 2006 event for the Silver Stream. These events were selected due to their significant magnitude. A sensitivity analysis was undertaken with an extended breach duration hydrograph shape. This analysis indicates that although the volume, depth and area of flooding increases with the extended breach duration, the overall consequence rating did not significantly change.

It has been assumed that during a breach of the Taieri River right floodbank downstream of Otokia, SH1 does not breach and therefore, all flooding is contained between SH1 and floodbank.

Figure 6 and Figure 7 shows the derived breach hydrographs.

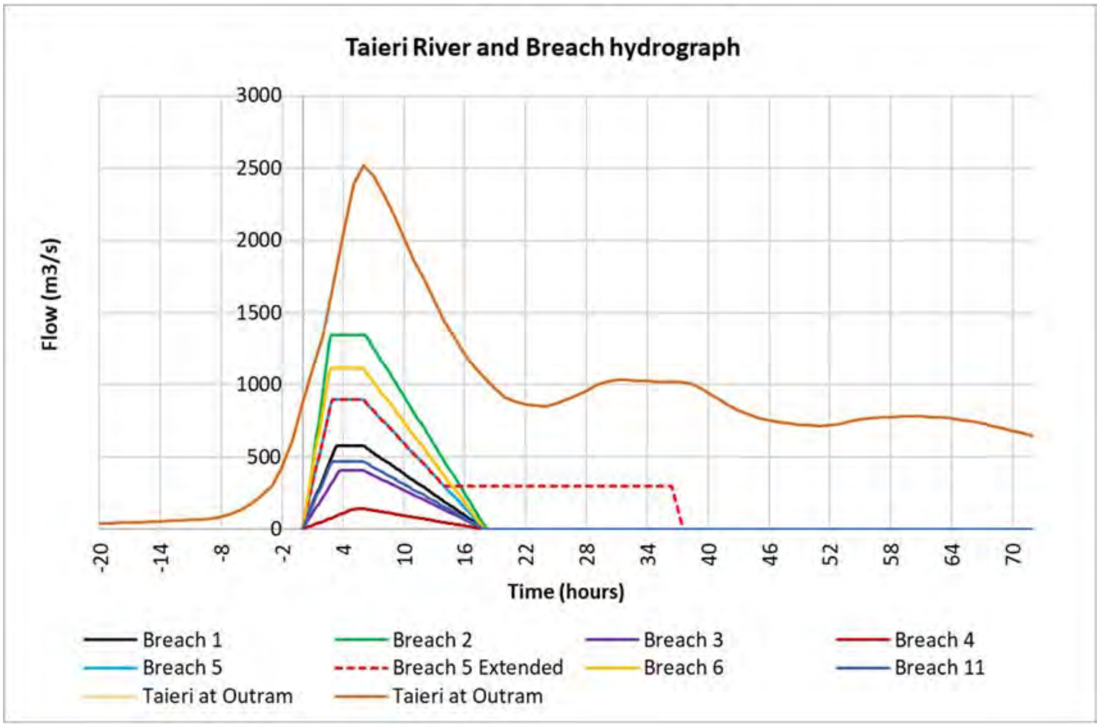


Figure 6: Breach hydrographs Taieri

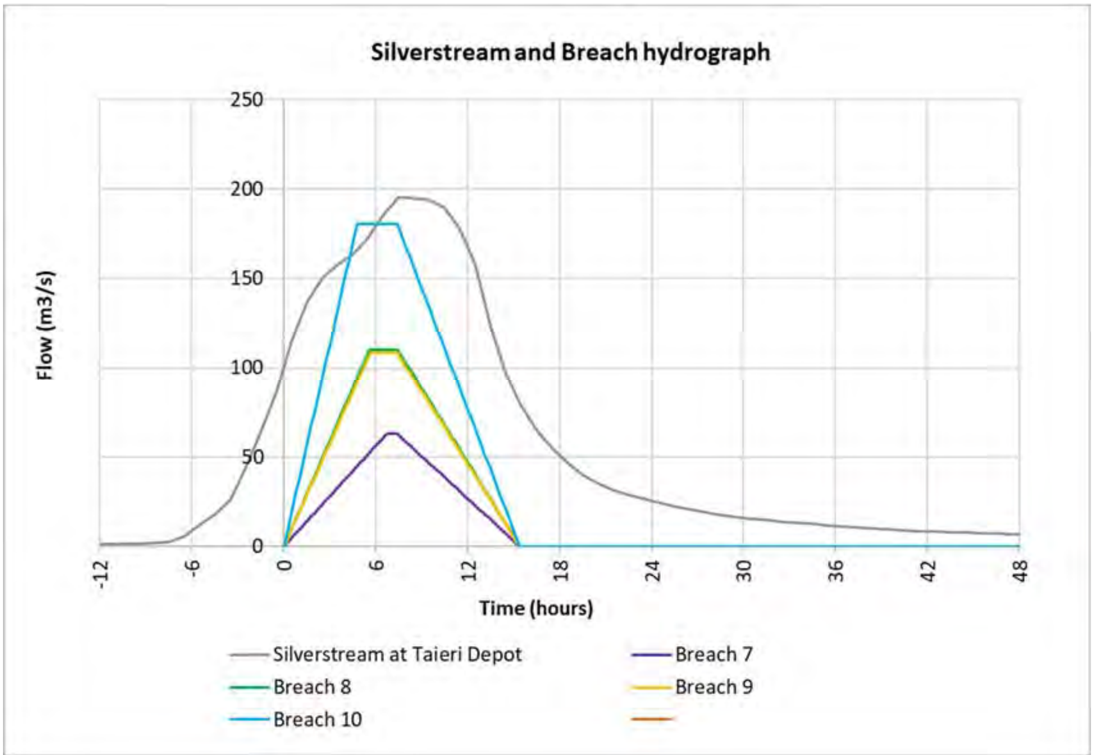


Figure 7: Assumed breach hydrographs Silver Stream

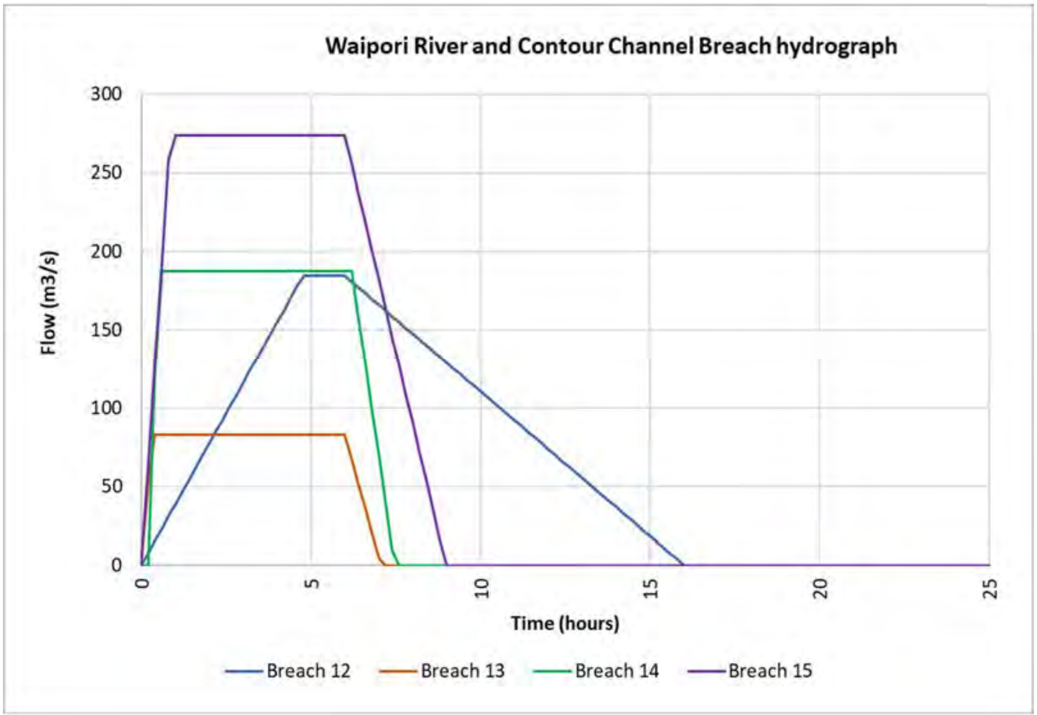


Figure 8: Assumed breach hydrographs Waipori River and Contour Channel

3.4.2 Damage assessment

The flood depth results from the breach modelling were overlaid with asset information to estimate the damage associated with the modelled hypothetical floodbank breach scenarios. The damage estimate is assessed for each of the consequence categories: social, environmental and property flood inundation.

T+T in collaboration with ORC developed the damage criteria for each consequence category as shown in Table 7. This table shows how the breach model flood depth results were used to estimate the damage for each consequence category.

Table 7: Consequence damage

Category	Damage criteria
Social	
Safety & health	Population At Risk[1] (PAR) assumed to 2.7 persons per building[2] if estimated flood depth is 0.5 m or more. PAR > 100 for Dunedin Airport[3] terminal building if estimated flood depth is 0.5 m or more. Other non-permanent itinerants (e.g. schools and other facilities) are excluded from the assessment to avoid double counting PAR within residential dwellings. This does not apply to the Airport as it is assumed that most PAR at the Airport would not be local residents.

Loss of service extent/duration		
Road[4]	SH1	Significant localised disruption over extended period if estimated flood depth is 0.5 m or more.
	SH86 and 87	Significant service disruption affecting a small number of customers if estimated flood depth is 0.5 m or more.
	All other roads	Minor service disruption if estimated flood depth is 0.5 m or more.
Rail[5]		Significant localised disruption over extended period if estimated flood depth is 0.5 m or more.
Dunedin Airport		Major localised service disruption over extended period if runway and/or terminal is flooded by an estimated flood depth of 0.5 m or more.
Power infrastructure		Minor service disruption if one power substations is flooded. Significant localised disruption over extended period if two or more adjacent power substations are flooded.
Environment		Serious damage, localised impacts and importance, return to natural state within 12 months if Henley Swamp, Otokia Swamp, Mckays Triangle Wetland or Mosgiel Waste Water Treatment Plant are flooded by an estimated flood depth of 0.5 m or more.
Property Inundation		
Building damages		Proportion of affected buildings[2] if estimated flood depth is 0.5 m or more
Productive farmland damages		Proportion of affected productive farmland[6] area if estimated flood depth is 0.5 m or more.
Airport damages		Dunedin Airport treated independently, if terminal building is flooded by an estimated flood depth of 0.5 m or more then consequence rating is catastrophic.

1. Population at risk definition: The number of people who would be directly exposed to inundation greater than 0.5m in depth if they took no action to evacuate. Definition from NZSOLD Guidelines 2015. Only permanent population at risk within residential dwellings included. An average of 2.7 people per building.
2. Buildings were identified using the LINZ building spatial data (Building outlines derived from LINZ Building Outline layer, sourced 16/1/2023). LINZ building information does not different between use (e.g. residential commercial, utility etc). Building areas less than $50m^2$ were removed from the data. For PAR estimates, only one flooded building per land parcel was counted. (e.g. if 5 buildings within one land parcel are flooded, only one building counted towards PAR).
3. Highest PAR rating category from NZSOLD Guidelines 2015 Section 3.1.
4. Roads alignments identified using the LINZ Roads spatial data, sourced 16/1/2023.
5. Rail alignment identified using the LINZ Rail spatial data, sourced 16/1/2023.
6. Landuse sourced from Land Cover Database (LCDB) GIS layer. Productive farmland defined as High Producing Exotic Grassland, Perennial Crops and Short-rotation Cropland.

A location map of the consequence categories is shown in Appendix A, Figure A4.

3.5 Performance score and risk rating

The performance score and risk rating are determined by multiplying the likelihood rating by the consequence rating.

Table 8 shows the performance score and risk rating matrix adopted from the RMF Tool.

Table 8: Performance score and risk rating matrix

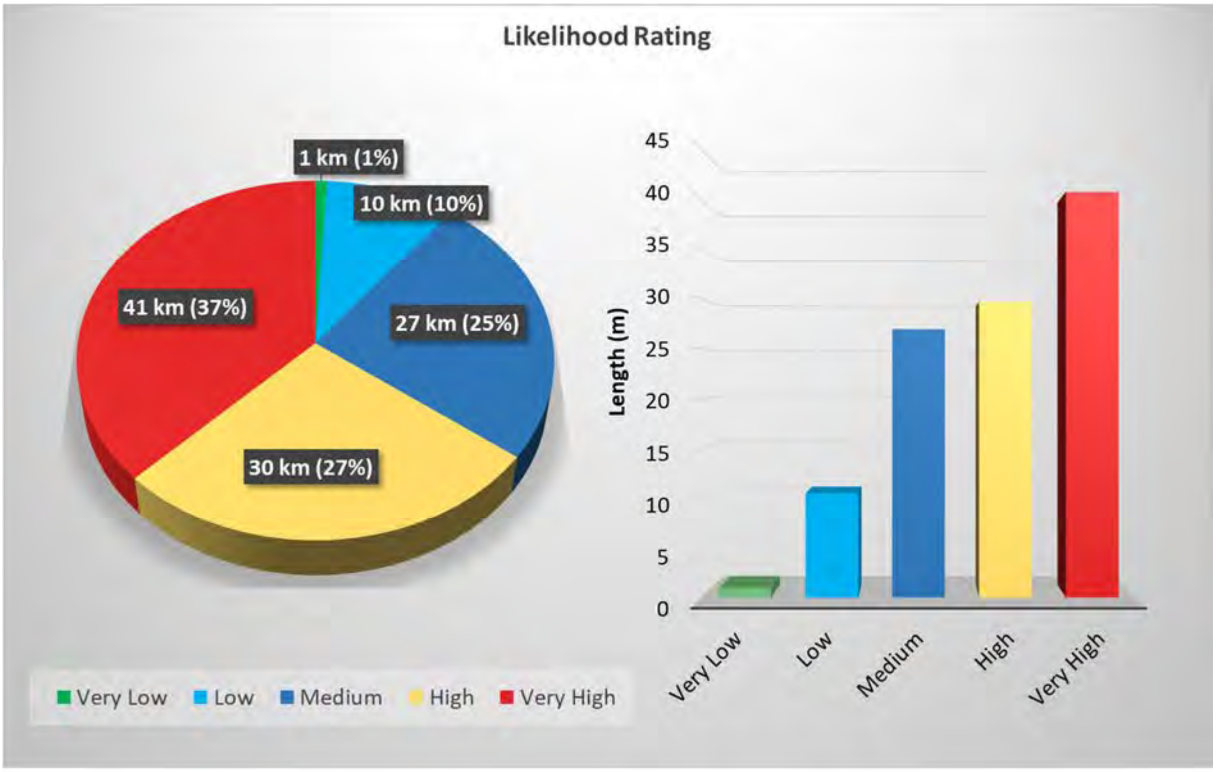
			Consequence				
			1	2	3	4	5
			Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	1	Very low	(1) very low	(2) very low	(3) low	(4) medium	(5) medium
	2	Low	(2) very low	(4) low	(6) low	(8) medium	(10) high
	3	Medium	(3) very low	(6) low	(9) medium	(12) high	(15) high
	4	High	(4) low	(8) medium	(12) medium	(16) high	(20) very high
	5	Very High	(5) medium	(10) medium	(15) high	(20) very high	(25) Extreme

4 Risk assessment results

The following sections present the results from the risk assessment.

4.1 Likelihood of failure rating

Figure 9 shows a summary of the overall likelihood rating.



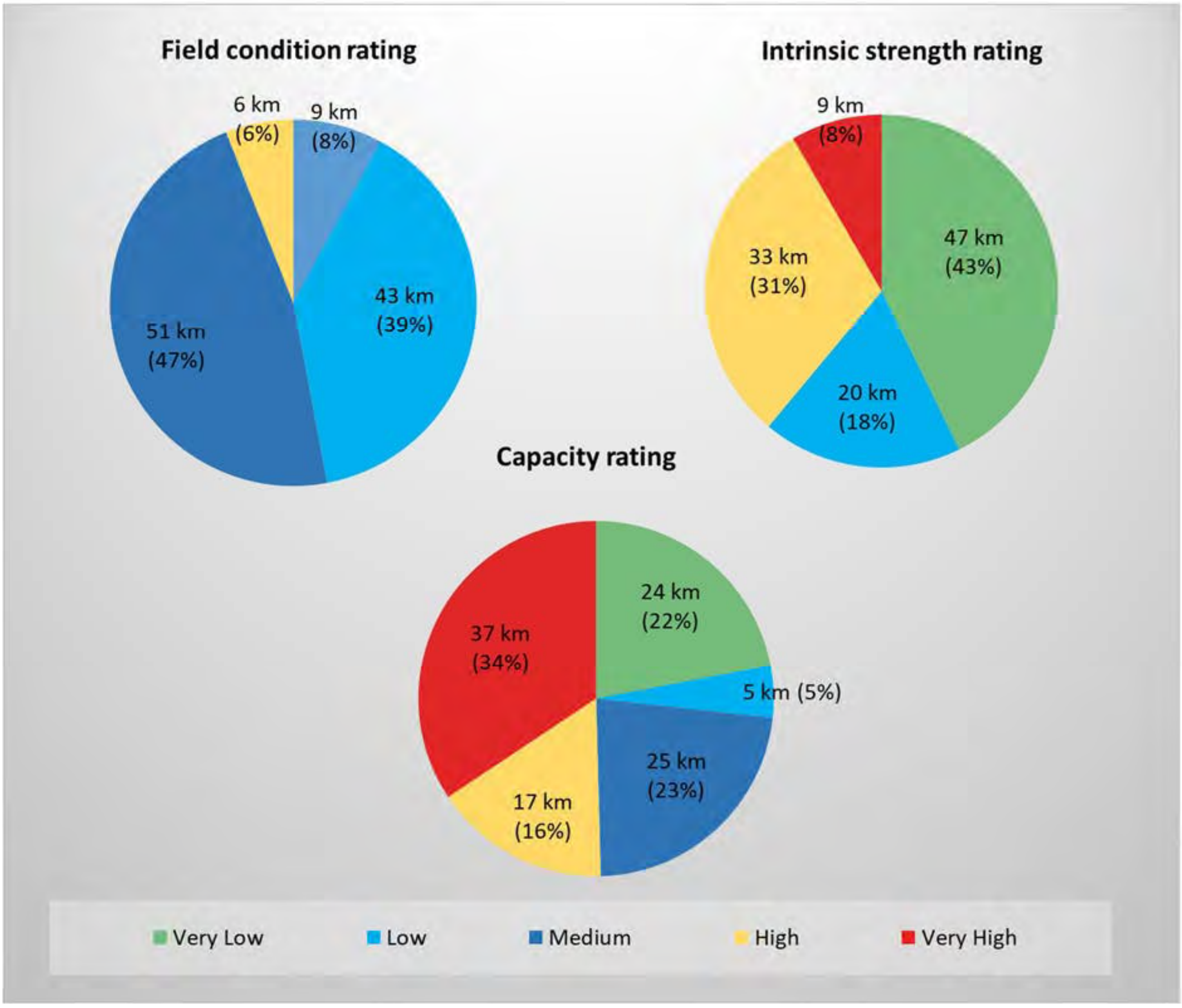
Likelihood of failure modes		
Field condition	Intrinsic strength	Capacity

Figure 9: Likelihood rating summary

Appendix C provides maps showing the likelihood rating for each floodbank section.

Figure 9 shows that 71 km (64%) has a high or very high likelihood rating. This means that based on the three failure modes (field condition, intrinsic strength, and capacity), the likelihood of failure is high or very high during the specified design flood event. The remaining floodbank sections have a medium or lower likelihood rating.

The reasons for the different likelihood ratings along the floodbank vary. Figure 10 shows the likelihood rating for the three failure modes.



Likelihood of failure modes							
Failure mode	Field condition				Intrinsic Strength		Capacity
Components	Berm	Structures	Surface condition	Other	Slope instability	Seepage/piping	Overtopping

Figure 10: Likelihood rating summary breakdown

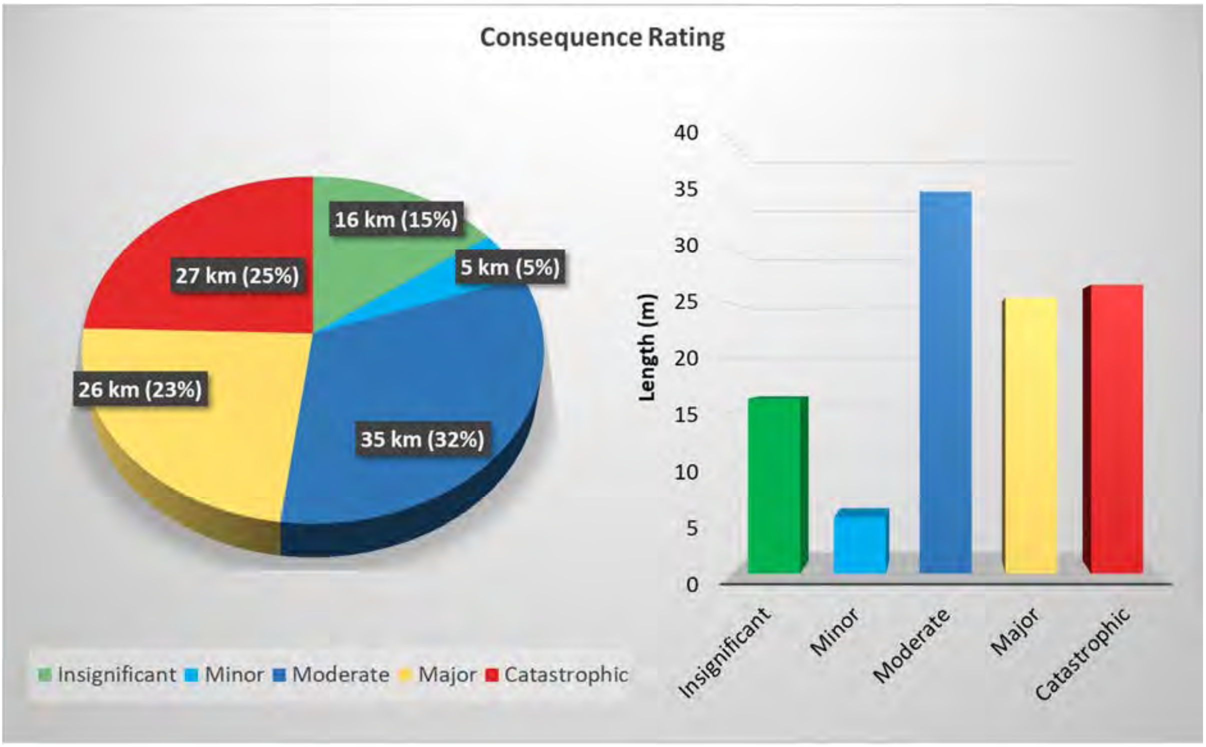
The general reasons for different likelihood ratings along the floodbank are summarised in Table 9.

Table 9: General reasoning for likelihood of failure ratings

Likelihood rating	Floodbank Sections	Reasoning
Very high	Several sections of Taieri River left floodbank upstream Silver Stream confluence	Generally due to capacity/overtopping rating with more than 0.3m overtopping
	Silver Stream downstream Gladfield Road	
	Cut-off bank	
	Owhiro right floodbank	
	Taieri River left floodbank at Henley	
	Several sections at Lake Waipori	
	Several sections of Waipori River	Due to intrinsic strength values, which are generally high due to the piping susceptibility rating.
	Lower Contour Channel	Due to intrinsic strength values and/or capacity/overtopping. Intrinsic strength values are generally high due to the piping susceptibility rating.
	Taieri River downstream Otokia	Due to intrinsic strength values and/or capacity/overtopping. Intrinsic strength values are generally high due to the piping susceptibility rating.
High	Several sections of Taieri River right floodbank downstream of Outram.	Due to overtopping rating with 0.0 m to 0.3 m overtopping.
	Several sections of Taieri River left floodbank downstream of Silver Stream confluence.	
	Several sections of Silver Stream upstream of SH87	
	Several sections of Waipori River	Due to intrinsic strength values, which are generally high due to the piping susceptibility rating.
	Lower Contour Channel	
	Waipori downstream of Contour Channel	
Medium & Low	Taieri River right floodbank from Outram to Otokia	Generally due to field condition rating higher than intrinsic strength and capacity/overtopping ratings. Field condition rating incorporates numerous inputs and difficult to draw broad conclusions, noting that field condition primarily relates to floodbank surface condition and berm/bench width.
	Contour Channel	
	Silver Stream upstream Gladfield Road	Due to field condition and capacity/overtopping ratings being slightly higher than intrinsic strength.
Very low	Isolated sections along Taieri River and Silver Stream	Due to field condition, intrinsic strength and capacity/overtopping ratings being favourable.

4.2 Consequence of failure rating

Figure 11 shows a summary of the overall consequence rating.



Consequence of failure category						
Category	Social		Environmental	Property inundation		
Component	Safety & health	Loss of service extent/duration	Environment	Building damages	Productive farmland damages	Airport damages

Figure 11: Consequence rating summary

Appendix C provides maps showing the consequence rating for each floodbank section.

Figure 11 shows that 38 km (35%) of the assessed floodbank sections have a catastrophic consequence rating, and 26 km (23%) of the sections have a major consequence rating. The remaining sections have a moderate or lower consequence rating.

Table 10 shows the damage estimates for each modelled breach scenario.

Table 10: Damage estimate and overall consequence rating

Breach scenario	Consequence of failure category						Rating
	Social		Environment	Property inundation damages			
	Safety & health (PAR)	Loss of service extent/duration		Building damages	Productive farmland damages	Airport damages	
1	794	Major localised disruption over extended period (over a month)	Negligible impact, no impact to natural state	2-10% of buildings have functionality compromised	21-49% of Productive land area affected	-	5
2	1180	Major localised disruption over extended period (over a month)	Negligible impact, no impact to natural state	11-20% of buildings have functionality compromised	21-49% of Productive land area affected	Airport terminal flooded > 0.5m	5
3	0	Small number of customers experiencing minor service disruption	Serious damage, localised impacts and importance, return to natural state within 12 months	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	3
4	0	Small number of customers experiencing minor service disruption	Negligible impact, no impact to natural state	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	2
5	329	Major localised disruption over extended period (over a month)	Negligible impact, no impact to natural state	2-10% of buildings have functionality compromised	21-49% of Productive land area affected	-	5
6	413	Major localised disruption over extended period (over a month)	Negligible impact, no impact to natural state	2-10% of buildings have functionality compromised	21-49% of Productive land area affected	Airport terminal flooded > 0.5m	5
7	419	Significant service disruption affecting small number of customers	Serious damage, localised impacts and importance, return to natural state within 12 months	2-10% of buildings have functionality compromised	2-10% of Productive land area affected	-	5
8	19	Small number of customers experiencing minor service disruption	Serious damage, localised impacts and importance, return to natural state within 12 months	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	4
9	5	Small number of customers experiencing minor service disruption	Negligible impact, no impact to natural state	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	3

10	0	Small number of customers experiencing minor service disruption	Serious damage, localised impacts and importance, return to natural state within 12 months	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	3
11	30	Small number of customers experiencing minor service disruption	Serious damage, localised impacts and importance, return to natural state within 12 months	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	4
12	32	Small number of customers experiencing minor service disruption	Negligible impact, no impact to natural state	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	4
13	3	Small number of customers experiencing minor service disruption	Negligible impact, no impact to natural state	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	3
14	11	Small number of customers experiencing minor service disruption	Negligible impact, no impact to natural state	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	4
15	38	Small number of customers experiencing minor service disruption	Negligible impact, no impact to natural state	< 1% of buildings have functionality compromised	2-10% of Productive land area affected	-	4

The general reasons for different consequence ratings along the floodbank are summarised in Table 11.

Table 11: General reasoning for consequence of failure ratings

Consequence rating	Floodbank Sections	Estimated consequences
Catastrophic	Taieri River right floodbank upstream of Otokia and Waipori left floodbank downstream Contour Channel	PAR > 100 Damage and PAR associated with flood depths > 0.5 m within Outram township, Airport, rural residential properties and productive farmland Significant productive farmland and building inundation Major loss of service at Airport, local roads, and SH86/87 Inundation of Henley Swamp and Otokia Swamp Inundation of Outram substation
	Silver Stream left floodbank upstream of Carlyle Road	PAR > 100 Potential inundation of WWTP Significant building inundation
Major	Cut-off bank between Riccarton Road and Gladfield Road	PAR = 30 Inundation of McKays Triangle Wetland
	Silver Stream right floodbank upstream of Riccarton Road West	PAR = 19 Inundation of McKays Triangle Wetland
	Contour Channel downstream Dow Road	PAR = 11 to 38
	Waipori River upstream of Berwick	PAR = 32
	Taieri River left floodbank at Henley	PAR > 11
Moderate	Contour Channel upstream of Dow Road	PAR = 3
	Silver Stream right floodbank downstream of Riccarton Road West	Inundation of McKays Triangle Wetland
	Silver Stream left floodbank downstream of Carlyle Road	PAR = 5
	Taieri River left floodbank upstream of the Silver Stream confluence	Inundation of McKays Triangle Wetland
	Taieri River right floodbank downstream of Otokia to Waipori confluence	PAR = 6

Minor	Taieri River left floodbank downstream of the Silver Stream confluence	Some productive farmland inundation in ponding area
	Owhiro right floodbank	Some productive farmland inundation in ponding area
Insignificant	Various sections at Lake Waipori, left bank lower Contour Channel, lower floodbanks Waipori River	N/A

4.3 Risk rating

Figure 12 shows a summary of the risk rating.

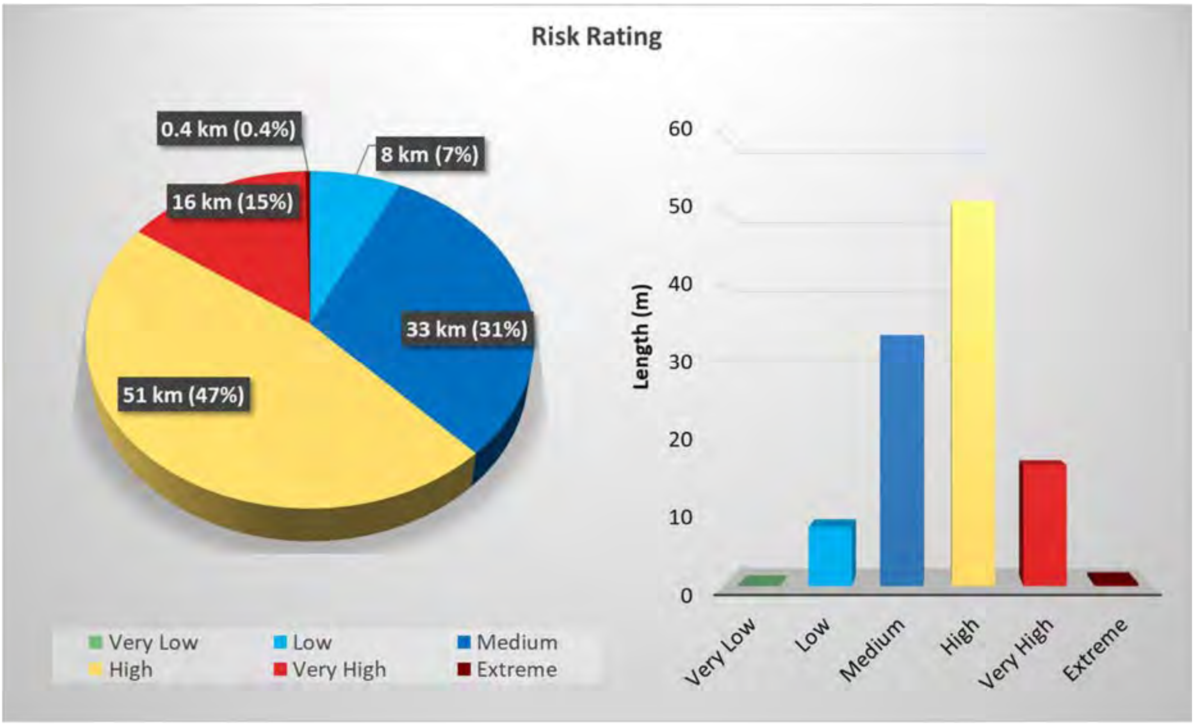


Figure 12: Risk rating summary

Appendix C provides maps showing the risk rating for each floodbank section.

Figure 12 shows that 0.4 km (0.4%) of the assessed floodbank sections have an extreme risk rating, and 16 km (15%) have a very high risk rating. 51 km (47%) have a high risk rating. The remaining sections have a medium or lower risk rating.

It is difficult to make generalisations of the risk rating along the floodbank as the reasons are section specific. However, some generalisations have been made as summarised in Table 12.

Table 12: General reasoning for risk ratings

Risk rating	Floodbank Section	Reasoning
Extreme	Two sections of Waipori downstream Contour Channel	Catastrophic consequence rating due to inundation of airport and PAR >100. Very high likelihood rating due to potential seepage/piping susceptibility. Piping susceptibility in this area is relatively higher than other areas due to the landside elevation being close to, or at a lower elevation than, the normal water level in the adjacent waterway. These two sections have a higher likelihood rating than adjacent sections due to the presence of trees, and associated root systems, located within approximately 5 m of the floodbank.

Very high	Waipori downstream Contour Channel	Catastrophic consequence rating due to inundation of airport and PAR >100. High likelihood rating due to intrinsic strength value. Intrinsic strength values are generally high due to the piping susceptibility rating. Piping susceptibility in this area is relatively higher than other areas due to the landside elevation being close to, or at a lower elevation than, the normal water level in the adjacent waterway.
	Cut-off bank between Riccarton Road West and Gladfield Road	Major consequence rating due to PAR between 11 and 100. Very high likelihood rating due to capacity/overtopping.
	Several sections along Waipori River upstream of Berwick, lower Contour Channel, Taieri River right floodbank upstream of Silver Stream, Silver Stream upstream of SH87, Taieri River left floodbank at Henley.	Reasons vary but generally major consequences due to PAR and very high likelihood rating due to capacity/overtopping or intrinsic strength.
High	Waipori River upstream Berwick	Major consequence rating due to PAR between 11 and 100. High or very high likelihood rating due to intrinsic strength rating. Intrinsic strength values are generally high due to the piping susceptibility rating in these sections.
	Silver Stream upstream of Carlye Road	Catastrophic or major consequence rating due to high PAR (Mosgiel township). Variable likelihood ratings from medium to very high.
	Taieri River right floodbank between Outram and Otokia	Catastrophic consequence rating due to PAR >100. Medium or high likelihood rating caused by field condition and capacity/overtopping.
	Taieri River right floodbank downstream of Otokia to Waipori confluence	Moderate consequence rating due to PAR between 2 and 10. Very high likelihood rating caused by field condition and capacity/overtopping.
	Contour Channel downstream Dow Road	Major consequence rating due to PAR between 11 and 100. Low, medium, high or very high likelihood rating.
	Several sections of Taieri River left floodbank upstream of Silver Stream confluence, Silver Stream downstream of Gladfield Road	Moderate consequence rating due to inundation of McKays Triangle Wetland. High or very high likelihood rating due to overtopping.
Medium Low Very low	Contour Channel upstream of Dow Road	Reasons vary along sections. Consequence rating either insignificant, minor or moderate. Likelihood rating vary from very low to very high.
	Owhiro right floodbank	
	Various sections at Lake Waipori	
	Waipori River downstream Berwick	
	Taieri River left floodbank upstream of SH1	
	Silver Stream left and right floodbank downstream of Carlye Road	

5 Conclusions and recommendations

The objective of this risk assessment was to understand the relative risks to the community of floodbank failure within the Lower Taieri River Flood Protection Scheme.

The framework adopted for the risk assessment generally follows the methodology described in the NZ River Managers Forum (RMF) Code of Practice document *'Flood Protection Assets Performance Assessment Code of Practice',* March 2015. For this assessment, risk was defined as the product of the likelihood and consequence of failure estimates. For the purpose of this assessment, likelihood was based on the severity of known condition and performance defects that could lead to failure during a flood event. Consequence was based on the preliminary assessment of the effect of failure of the floodbanks.

This assessment includes 109 km of floodbanks within the scheme area. The floodbanks were delineated into 629 separable sections based on a field condition assessment undertaken by T+T within the Scheme in 2017/2018.

Each floodbank section was assigned a risk rating based on the RMF framework method. A summary of the resulting risk rating estimates within the scheme area is provided below. Refer to Table 12 for further breakdown of the general reasoning for each floodbank.

Extreme risk: Two separate sections of the Waipori floodbank downstream of Contour Channel. These sections have an extreme risk due to a catastrophic consequence rating caused by a PAR >100, combined with a very high likelihood rating influenced by high seepage/piping susceptibility. These two sections have a higher likelihood rating than adjacent sections due to the presence of trees, and associated root systems, located within approximately 5 m of the floodbank.

Very High risk: Waipori floodbank downstream of the Contour Channel, and cut-off bank between Riccarton Road West/Gladfield Road. Several sections along the Waipori River upstream of Berwick, the lower Contour Channel, Taieri River right floodbank upstream of Silver Stream and Silver Stream upstream of SH87. These floodbanks have a very high risk rating generally due to a catastrophic or major consequence caused by a high PAR, combined with a very high likelihood rating influenced by capacity/overtopping and/or intrinsic strength (which includes seepage/piping susceptibility and/or slope instability) issues.

The following floodbank risk ratings are high, medium or low due to several different combinations of consequence and likelihood ratings. Refer to Table 12 for a further breakdown of the general reasoning for each floodbank.

High risk: Waipori River upstream of Berwick, Silver Stream upstream of Carlye Road, Taieri River right floodbank downstream of Outram and Contour Channel downstream of Dow Road. Several sections in the Taieri River left floodbank upstream of Silver Stream and Silver Stream downstream of Gladfield Road.

Medium risk: Contour Channel upstream of Dow Road, Taieri River left floodbank between Silver Stream/Owhiro Stream, Silver Stream between SH87/Gladfield Road. Several sections in the Waipori area and Taieri River left floodbank upstream of Silver Stream.

Low risk: Several sections of the Contour Channel near Dow Road, Taieri River left floodbank between Silver Stream/Owhiro Stream, Silver Stream downstream of Riccarton Road West and various sections in the Waipori area.

The consequence rating for the floodbanks is based on assessing potential damage that could result from a floodbank breach. However, the rating does not consider other aspects such as ingress and egress during a breach event. Safe escape may be extremely difficult from some areas of the scheme due to the limited amount of warning time (e.g. ring banks). It is recommended that a review is undertaken to assess ingress and egress which impact the consequence and therefore overall risk rating for some areas.

Given the significant length of high and very high-risk rating (driven by largely catastrophic consequences) along the floodbank, it is recommended that a review is undertaken to assess whether the current requirement for the scheme level of service (currently assessed against a performance measure of 2,500 m^3/s) coincident with embankment crest level (i.e. nil freeboard) provides "adequate" performance for the scheme and the community relying on the scheme.

This assessment has been carried out on the basis of the inputs, assumptions and limitations stated in this report. Limitations are provided in the following Section 6.

6 Limitations

The following limitations apply to this assessment:

1. All inputs into the risk assessment rely on judgement based on our previous work, as well as information provided by ORC, and there is uncertainty associated with the estimated values. The inherent uncertainty in the inputs will result in uncertainty in the calculated risk estimate. It is likely that the results of this assessment will identify areas of uncertainty associated with various inputs into the risk calculation, which in itself may identify areas where further work is required to better understand the contributions to the risk level.
2. This assessment relies on the 2017/2018 condition assessment and supplemental information from ORC. The condition of floodbanks may have changed since this information was collected.
3. Buildings were identified using the LINZ building spatial data. Building areas less than 50 m^2 were removed from the data. Furthermore, for the PAR estimate only one flooded building per land parcel was counted. (e.g. if 5 buildings within one land parcel are flooded, only one was counted). This approach has several limitations including:
   - There may be properties which contain more than one residential dwelling within each land parcel (e.g. farm worker accommodation).
   - There are likely to be several non-residential buildings (such as sheds, commercial facilities). Incorporating a building use type would improve the accuracy of this analysis. We understand ORC do not hold any such information currently. LINZ is currently working on developing this dataset for the country.
   - Floor levels of buildings have not been assessed. It is possible that many of the buildings identified as being flooded > 0.5m have raised foundations (e.g. piles). This would reduce the actual depth of flooding.
4. An estimate of the population at risk (PAR) was completed based on the NZSOLD 2015 Guidelines which includes buildings flooded by 0.5 m or more of flood depth. For this assessment, only permanent population at risk within residential dwellings was included. There may be other populations at risk (e.g. recreational users, commercial workers etc) not included in this assessment.
5. Likelihood failure modes and consequence categories have been assessed based on agreed categories with ORC. There may be other modes of failure and consequences which have not been assessed in this assessment.
6. More comprehensive techniques are available to help identify and quantify the likelihood of the failure mechanism(s) and consequences e.g. event tree, fault tree, etc. However, such techniques require information and data inputs that are currently unavailable and out of scope for this assessment.
7. There are several inputs and assumptions into this assessment which are limited by data availability and accuracy. Some of these inputs and assumptions weigh more heavily on the risk rating than others. For example, the consequences or likelihood of airport operation, including what other factors may impact the airport's ability to function, and the potential for incremental damages under different circumstances which are relevant.

7 Applicability

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

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by:

....

Richard Brunton
Water Resource Engineer

Authorised for Tonkin & Taylor Ltd by:

....

Tim Morris
Project Director

RIBR
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Appendix A Figures

- Figure A1: Floodbank sectioning - east
- Figure A2: Floodbank sectioning - west
- Figure A3: Floodbank breach locations
- Figure A4: Consequence categories

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NOTES:
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REV	DESCRIPTION	GIS	CHK	DATE
0	First version	RIBR	SAFF	14/11/2023


LOCATION PLAN

PROJECT No.	1001453.0153	
DESIGNED	RIBR	NOV.23
DRAWN	KTHA	NOV.23
CHECKED	TGM	NOV.23
APPROVED	TGM	23/11/23

CLIENT OTAGO REGIONAL COUNCIL
PROJECT FLOODBANK RISK ASSESSMENT
TITLE FLOODBANK SECTIONS - EAST
SCALE (A3) 1:40,000 FIG No. FIGURE A1 REV 0

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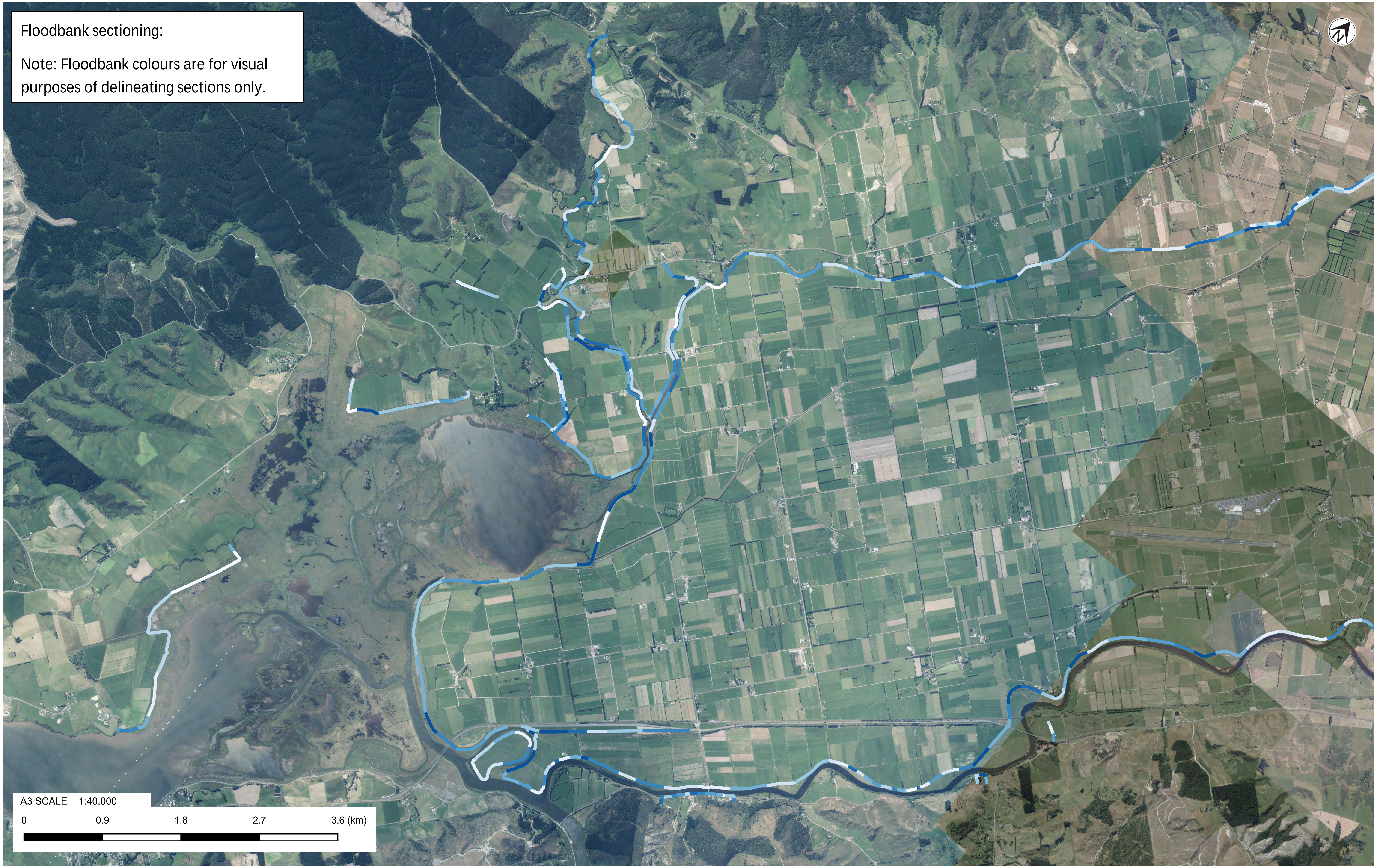

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LOCATION PLAN

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DESIGNED	RIBR	NOV.23
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CHECKED	TGM	NOV.23
APPROVED	TGM	23/11/23

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PROJECT FLOODBANK RISK ASSESSMENT
TITLE FLOODBANK SECTIONS - WEST
SCALE (A3) 1:40,000 FIG No. FIGURE A2 REV 0

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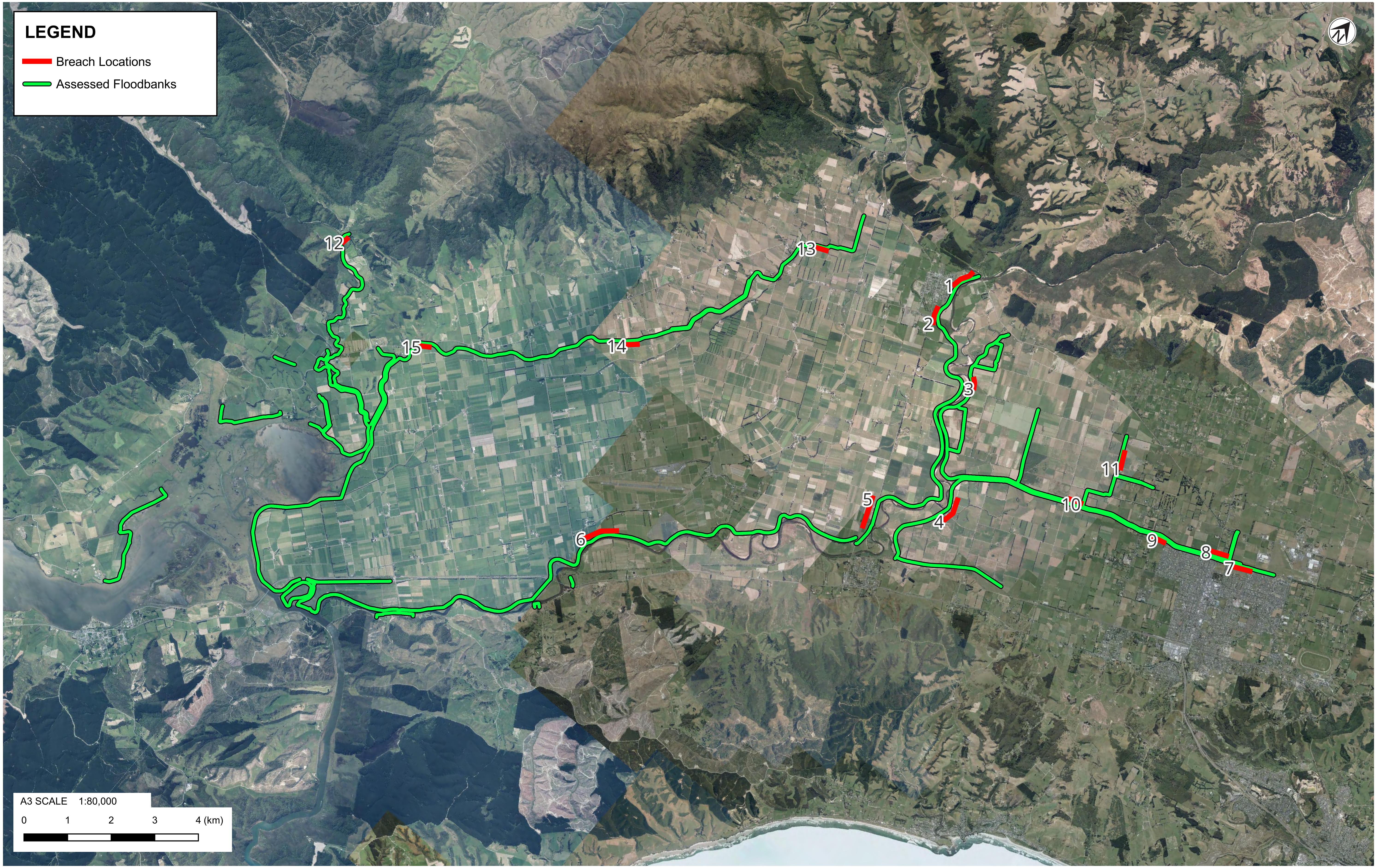

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LOCATION PLAN

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CHECKED	TGM	NOV.23
APPROVED	TGM	23/11/23

CLIENT OTAGO REGIONAL COUNCIL

PROJECT FLOODBANK RISK ASSESSMENT

TITLE FLOODBANK BREACH LOCATIONS

SCALE (A3) 1:80,000 FIG No. FIGURE A3 REV 0

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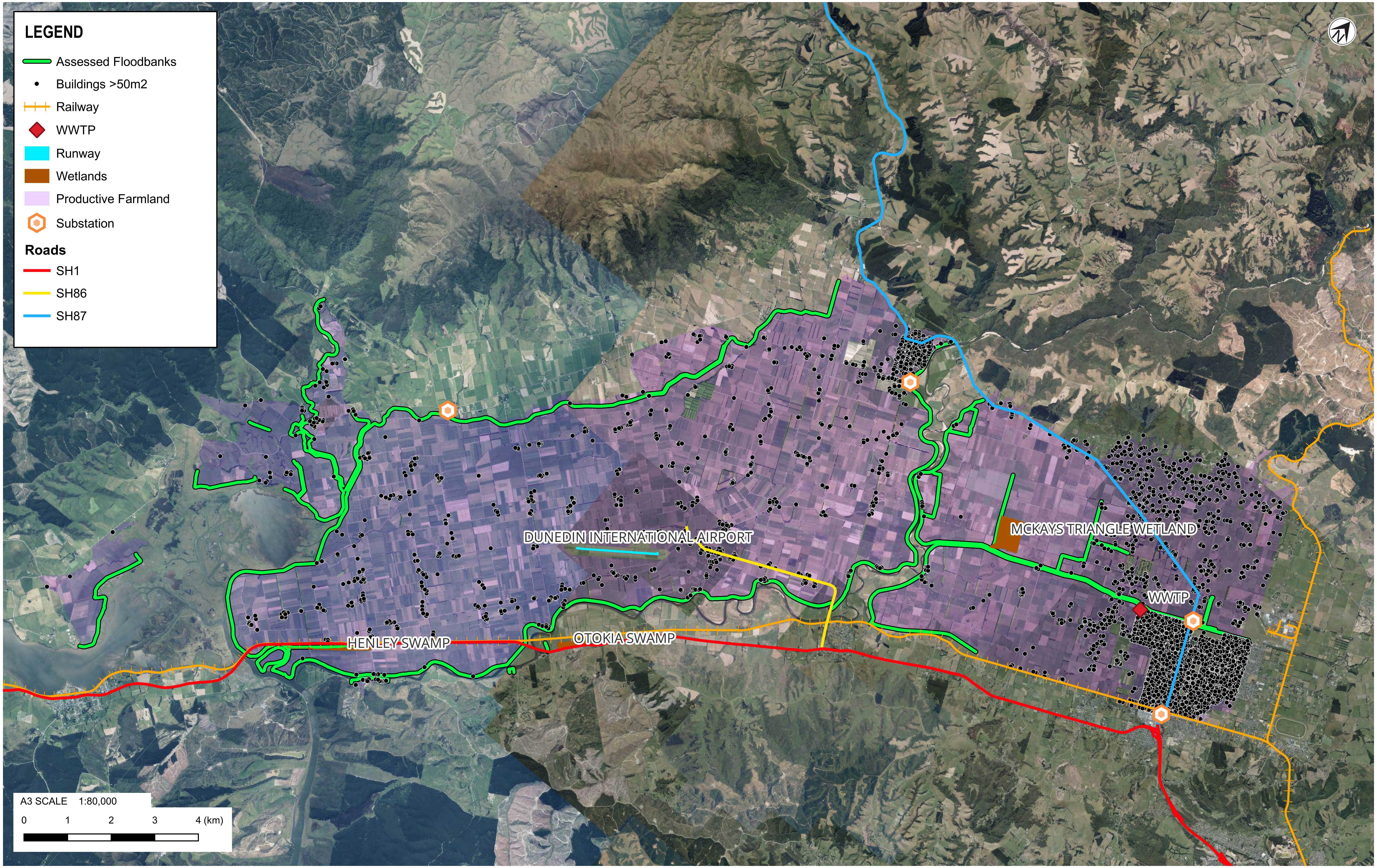

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REV	DESCRIPTION	GIS	CHK	DATE
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LOCATION PLAN

PROJECT No.	1001453.0153	
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DRAWN	KTHA	NOV.23
CHECKED	TGM	NOV.23
APPROVED	TGM	23/11/23

CLIENT OTAGO REGIONAL COUNCIL

PROJECT FLOODBANK RISK ASSESSMENT

TITLE CONSEQUENCE CATEGORIES

SCALE (A3) 1:80,000   FIG No. FIGURE A4   REV 0

Appendix B Floodbank breach model report

Job No: 1001453.0153
23 November 2023

Otago Regional Council
70 Stafford Street
Private Bag 1954
Dunedin 9054

Attention: Brett Paterson & Ellyse Gore

Dear Brett & Ellyse

Floodbank Risk Assessment

Floodbank breach modelling

Otago Regional Council (ORC) have engaged Tonkin & Taylor Ltd (T+T) to undertake high-level floodbank breach modelling at select locations to inform the consequence portion of the risk assessment being carried out as part of a wider body of work currently being undertaken by ORC assessing the Taieri scheme.

This work has been prepared for ORC in accordance with the conditions of engagement in dated 13 April 2022, Variation 03 and 27 June 2023, Variation 04.

1 Introduction

Our scope of work included developing a high-level breach model to estimate the flooded extent resulting from a hypothetical potential floodbank breach at various locations along the Taieri River, Silver Stream, Waipori River and Contour Channel. The results of this work will be used to inform the consequence portion of the risk assessment being carried out for the flood protection scheme review. Our scope of work included:

- Develop a high-level hydraulic model of the Taieri Plains to predict the flooded extent during various floodbank breach scenarios.
- Develop a high-level breach hydrograph at 15 representative points along the existing floodbank.
- Inundation mapping using the hydraulic model results to estimate the population at risk and area of productive farmland located within the flooded extent.

2 Hydraulic model

A 2-dimensional hydraulic model of the Taieri River and Silverstream flood scheme area was developed in TUFLOW software (Version 2020-10-AA) to predict the flooded extent during various floodbank breach scenarios.

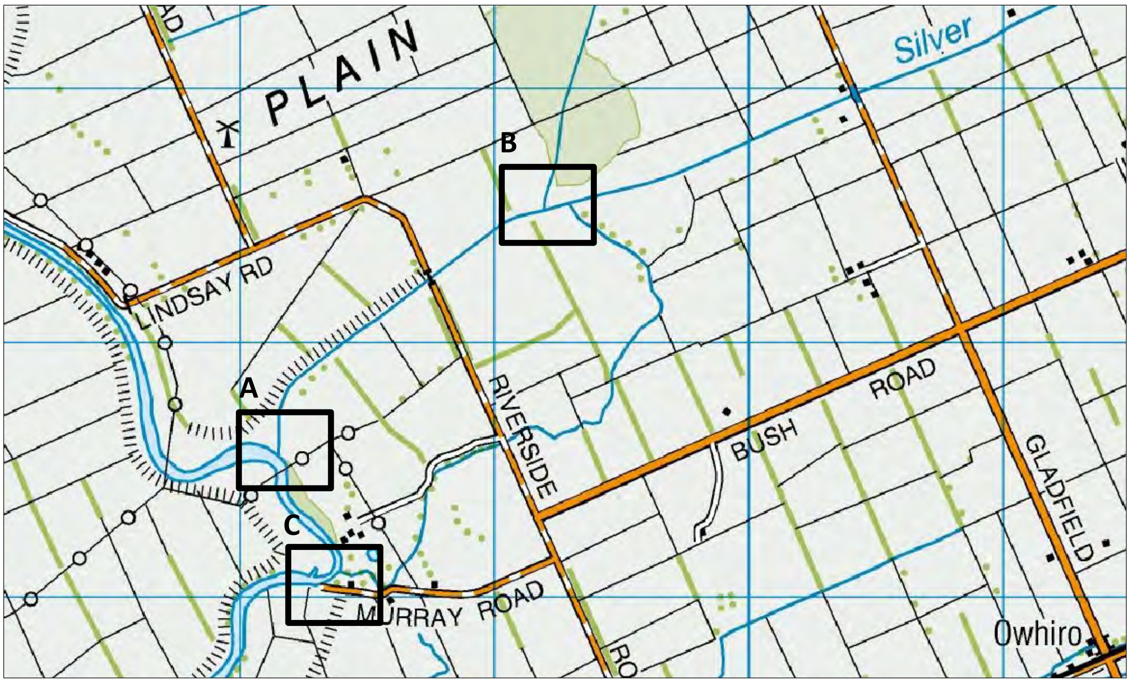
Representative locations on the landward side of the floodbanks within the model domain were selected to apply a hypothetical breach hydrograph as a point source. The locations were selected based on floodbanks with a history of susceptibility and to broadly cover the scheme area from upstream to downstream. Appendix A, Figure A1 shows the locations of the modelled stopbank breaches.

It is important to note that there is potential for floodbanks to breach at any location within the scheme area. Floodbank breaches at other locations would result in different flooded extents.

A static downstream boundary condition has been assumed for the model. A water level of -5 mRL was assumed which effectively removes any effect of a tidal boundary. Tide and breach hydraulic interactions are complex, with breach duration and flow likely to be affected at different rates as the tide fluctuates over the duration of the breach. A detailed assessment of tide conditions is out of scope for this work.

Model topography was represented in the model using 2021 LiDAR survey data[1]. 2016 LiDAR survey data was used to cover a small area in the eastern side of the model domain not covered by the 2021 LiDAR. The computational grid size for the floodplain area is 20 x 20m. So that the crest levels of existing stopbanks are better represented in the model, the grid size was reduced to 1.25 m x 1.25 m along and 10 m either side of floodbank alignments[2].

Corrections were made to the model topography at three locations shown on Figure 2 including the A1 gate outfall, Silverstream pumpstation and Mill Creek pumpstation. At these locations, the LiDAR incorrectly represents actual ground levels, allowing water to artificially enter the ponding areas from the river. Correction involved increasing the ground level to match the floodbank level either side. For the A1 Gate Outfall, it is assumed that the water level within the Taieri River during the breach is high enough that water is prevented from flowing out of the upper ponding area via the flap gates.



[1] DEM for LiDAR data from the Otago Region captured in 2021, sourced from LINZ Data Service November 2022

[2] ORC_Assett_Floodbank shapefile provided by ORC

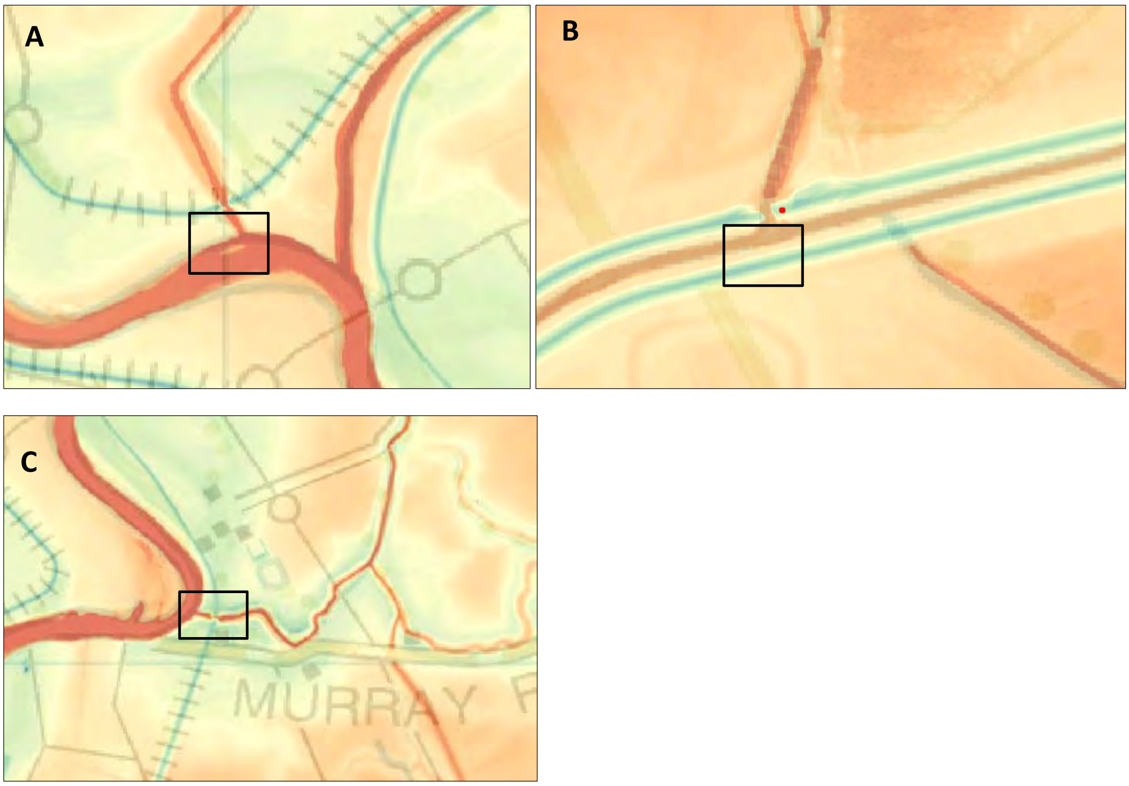


Figure 2: Model topography corrections

3 Breach hydrograph

Floodbank breach hydrographs applied at each breach location have been estimated using the method described in Zomorodi[3], 2020. This method provides theoretical equations to estimate the peak discharge (Q_{peak}) from a floodbank breach scenario based on the height and material composition of the floodbank. The failure mode for all the breach scenarios is assumed to be overtopping. Floodbanks may have other failure modes (e.g. piping) however the overtopping failure mode results in the larger and more adverse discharge when using the Zomorodi equations.

The equation for Q_{peak} from Zomorodi, 2020:

$$Q = \frac{2}{3} C_D W_b \sqrt{2g}\, H^{\frac{3}{2}} \qquad (19)$$

Where

Q = Peak discharge (m^3/s),

C_D = Discharge coefficient,

W_b = Final breach dimension in the direction of flow (m),

G = Gravity acceleration= 9.81 (m/S^2),

H = Elevation head, which is equivalent to the height of water measured from levee base (could be approximated by levee height), ignoring any depth of erosion hole at the levee base (m).

[3] K. Zomorodi (September 2020), *Empirical equations for levee breach parameters based on reliable international data.*

The equations assume that the water level within the river at the time of the breach is at the crest of the floodbank which would be required for an overtopping failure. If the floodbank breaches at the lower river water level (i.e. via piping failure) the peak discharge Q_{peak} would be lower. There are a range of uncertainties for the method such as:

- Scour hole formation.
- How fast water spreads out relative to the breach size and thus the available head to drive the breach discharge.
- The extent to which water levels build up prior to the breach forming (e.g. depending upon duration of overtopping, the nature of grass cover and embankment slope).

Factors such as these will affect how a particular breach will form.

For levees of height 0.5 m to 10 m and comprised of cohesive material, the equation for W_b from Zomorodi, 2020:

$W_b = 22 \times H_b$

The height (H_b) has been estimated from existing 2021 LiDAR data and is the height from the riverbank crest to ground level on the landward side of the riverbank.

A breach hydrograph shape was estimated based on Q_{peak} and the river hydrograph shape of the 1980 flood event for the Taieri River and April 2006 for the Silverstream. These events were selected due to their significant magnitude. The following assumptions were made in the derivation of the breach hydrograph:

- Breach start time: Initialised approximately halfway up the rising limb of the flood hydrograph.
- Breach development time: Estimated from Equation 13 of Zomorodi, 2020.For each breach location Q_{peak} has been set at a constant flow rate from the time of full breach development to the end of the river flood peak flow. Q_{peak} varies for each breach location due to the variation in floodbank crest heights which is an input into the Zomorodi equation.
- Breach end time: Set approximately at the bottom of the falling limb of the river flood hydrograph. At this point the water level in the river is likely to fall below the invert of the breach cut and breach flow will cease. A sensitivity analysis on the beach end time is provided further in this letter.

Figure 3 and Figure 4 shows the breach hydrographs.

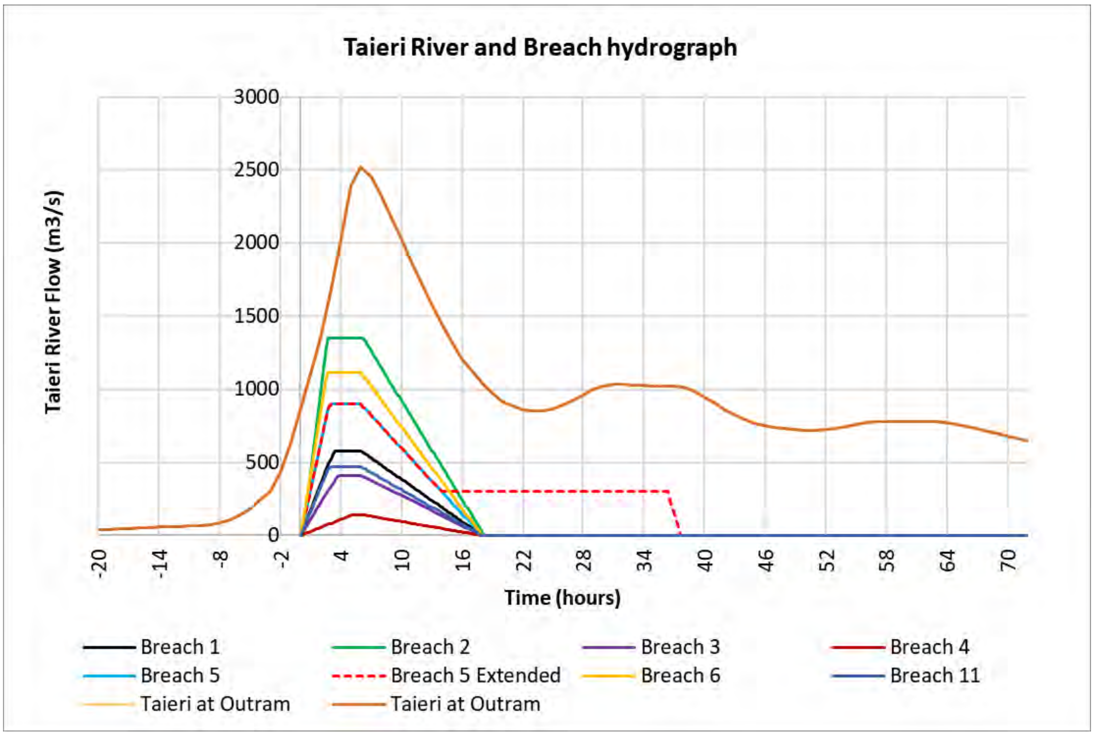


Figure 3: Breach hydrographs Taieri River

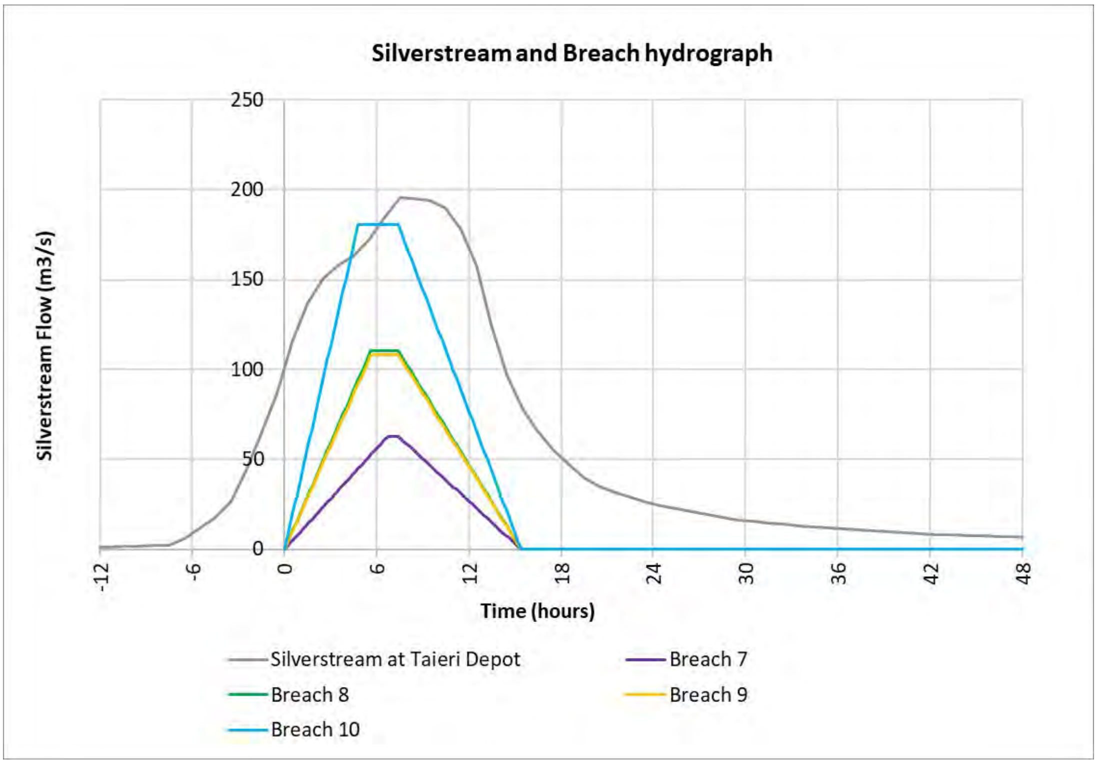


Figure 4: Breach hydrographs Silverstream

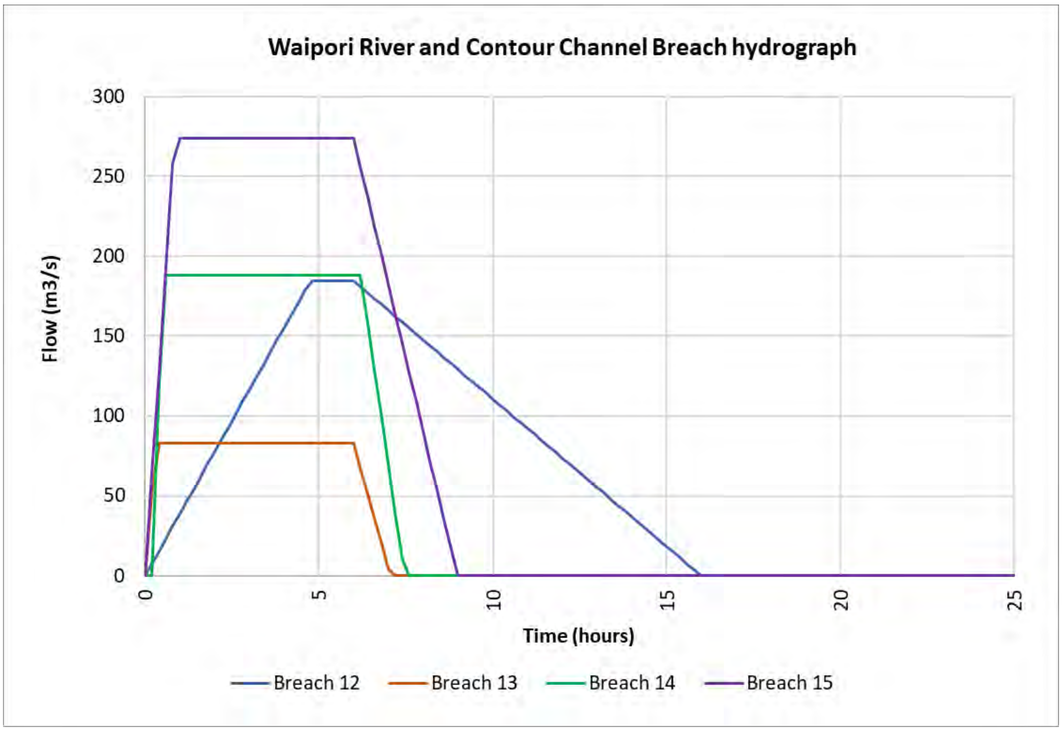


Figure 5: Breach hydrographs Waipori River and Contour Channel

Breach 11 (cut-off floodbank) assumes that the lower ponding area is filled to the top of the floodbank when a breach occurs. This scenario is conservative as it assumes that the entire ponding area is filled with water before a breach occurs.

Due to the height of the Contour Channel stopbanks, the estimated peak flows for breaches 12, 13 and 14 were found to be unrealistically high relative to the maximum flow capacity of the Contour Channel. Therefore, breach flows were capped to the combined 50-year flow rates from each Contour Channel sub-catchment as estimated by ORC. Peak flows were assumed to be coincident.

There are many factors which could influence the start and end time of a breach, such as the failure type (overtopping vs piping), river conditions (flood hydrograph shape and duration), variable tailwater levels and interventions. A detailed sensitivity analyses has not been undertaken in this assessment as it is out of scope.

The 1980 Taieri River flood featured a double peak which could extend the duration of a breach if the water level in the river remains above the invert of the breach cut. This water level is likely to vary along the floodbank depending on the relative river water level and geometry of the river channel and floodbanks. A sensitivity analysis was undertaken for Breach 5 assuming the double peak continues to force water through the breach cut. Although the volume, depth and area of flooding increases with the extended breach duration, the overall consequence rating does not change. As the overall consequence rating does not change with the extended breach duration, the original breach hydrographs were adopted for the final consequence assessment.

4 Mapping

The hydraulic model depth results were overlaid with the Building Outline GIS layer from LINZ[4] to estimate the number of buildings inundated by floodwater. Buildings with areas less than 50 m^2 were removed. Furthermore, only one flooded building per land parcel was counted for the PAR estimate. (e.g. if 5 buildings within one land parcel are flooded, only one was counted as contributing towards PAR). This approach adopted for PAR is simplistic because:

- There may be properties which contain more than one residential dwelling within each land parcel (e.g. farm worker accommodation).
- There are likely to be several non-residential dwellings (such as farm sheds, commercial facilities) remaining in the dataset. Incorporating a building use type would improve the accuracy of this analysis. We understand ORC do not hold any such information at this time. LINZ is currently working on developing this dataset for the country however the release date is currently unknown.

An estimate of the population at risk (PAR) was then completed based on the NZSOLD 2015 Guidelines which includes buildings flooded ≥ 0.5 m depth. For this assessment, only permanent population at risk within residential dwellings was included. An average of 2.7 people per building was assumed to estimate PAR. There may be other populations at risk (e.g. recreational users, commercial workers etc) not included in this assessment.

Table 1 shows the number of buildings flooded ≥ 0.5 m deep and the resulting PAR for the breach scenarios modelled.

The hydraulic model depth results were overlaid with the Land Cover Database[5] (LCDB) GIS layer to estimate the area of productive farmland flooded during the breach scenarios. Productive farmland was assumed to include High Producing Exotic Grassland, Perennial Crops and Short-rotation Cropland defined by the LCDB and as shown in Figure 6.

[4] Building outlines, sourced from LINZ Data Service April 2022
[5] LCDB Version 5 – https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/ - downloaded November 2022.

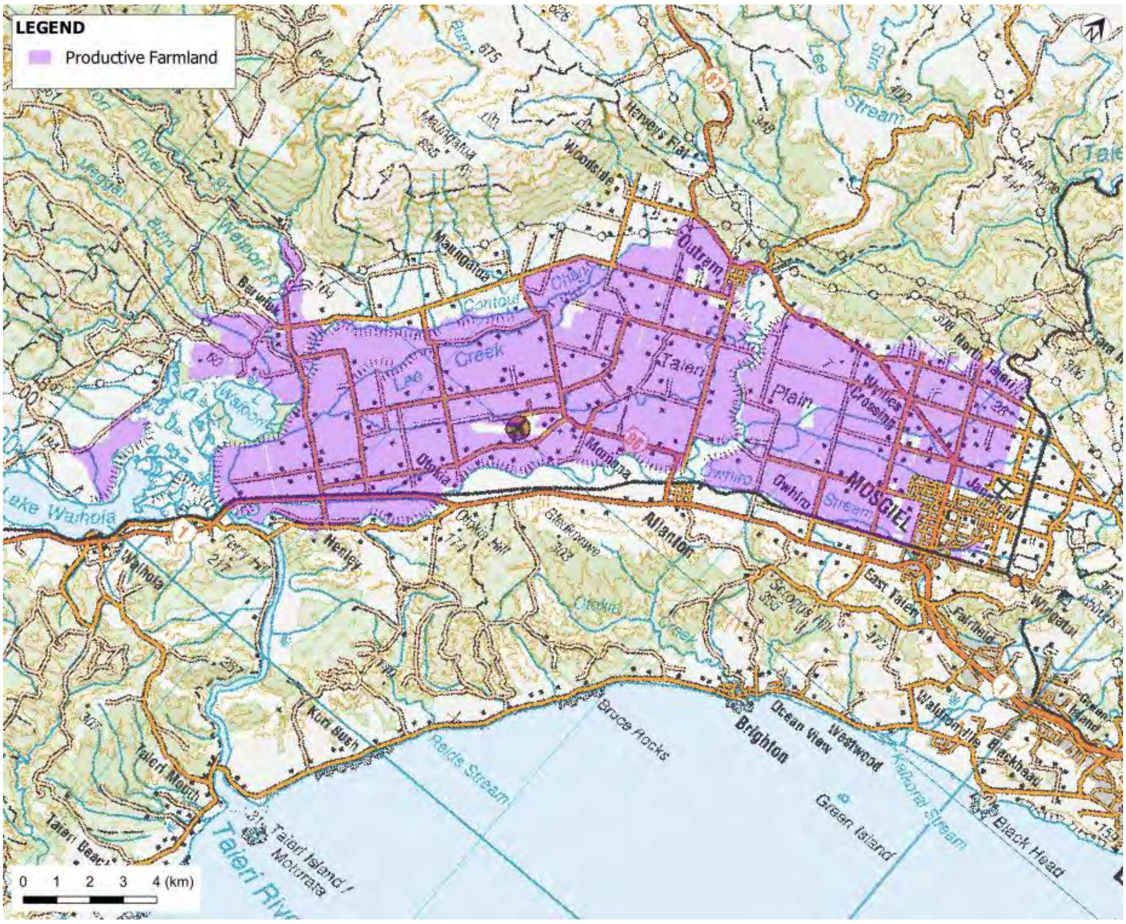


Figure 6: Farmland derived from LCDB

Farmland may be susceptible to varying degrees of damage from a combination of factors, typically including flood depth, velocity and duration. It has been assumed for this assessment that farmland will be damaged at depths ≥ 0.5 m. Table 1 shows the area of farmland flooded ≥ 0.5 m deep for the breach scenarios modelled.

Dunedin Airport is a significant asset located within the scheme area and will have a large weighting on the consequence portion of the risk assessment. The operation of the airport during a breach scenario will depend on a combination of factors. It has been assumed for this assessment that the airport would be inoperative if the runway is flooded at any depth. The rows highlighted in red within Table 1 indicate which breach scenarios result in flooding of the runway.

Table 1: Estimates of PAR, flooded farmland and airport operation during breach scenarios (red highlight = impact to airport)

Breach location	Number of buildings flooded ≥ 0.5m	Number of PAR buildings flooded ≥ 0.5m	PAR based on 2.7 people per dwelling (average)	Area of farmland flooded ≥ 0.5m (ha)
1	460	294	794	3194
2	781	400	1180	5823
3	0	0	0	665
4	0	0	0	356
5	280	122	329	4373
6	322	116	413	3892
7	167	155	419	220
8	12	7	19	338
9	5	2	5	371
10	0	0	0	395
11	17	11	30	809
12	15	12	32	298
13	1	1	3	226
14	4	4	11	521
15	25	14	38	763

The results show that during several of the breach scenarios the PAR is larger than 100. Based on the proposed consequence criteria[6] the Consequence of Failure for these scenarios is Catastrophic.

The modelling results indicate the airport is potentially flooded during Breach scenarios 1, 2, 5 and 6. Due to flooding on the runway (at any depth) it is likely that the runway would be unusable during all four of these Breach scenarios. The airport terminal is flooded ≥ 0.5 m deep only in Breach scenario 2. It is likely that the airport would be at risk of flooding due to a breach in the stopbank along any location along the right bank between Henley and Outram.

5 Conclusion

The results of this assessment (estimated population at risk, flooded farmland, and airport operation) will be used to estimate the consequence portion of the risk assessment for the flood protection scheme.

The results indicate that several of the breach scenarios will likely result in a Catastrophic Consequence of Failure due to the high estimated PAR. It is recommended that consideration is given to this when deciding upon future performance standards of the scheme. We consider this conclusion valid irrespective on uncertainties with the model inputs as described in preceding sections.

[6] Memo 'Proposed consequence criteria for ORC comment' dated 17 June 2022

6 Model Limitations

The purpose of the breach model is to estimate and provide a general perspective on the number of buildings and area of farmland that may be flooded during a theoretical breach from the floodbank at defined locations. For example:

- In order to inform this estimate, the modelling undertaken has been based on theoretical equations for breach discharge which make several assumptions.
- The model does not assess the probability of a floodbank breach.
- Breaches may occur at locations other than the locations modelled.
- The model does not include any structures, drainage features or pumpstations which may affect the flow path of the breach other than those represented within the LiDAR surface.
- The model is not suitable for assessing flooding on individual properties.
- The method used to identify buildings is simplistic.
- The flooded depth threshold of 0.5 m for buildings and farmland has been adopted for this assessment. In reality, buildings and farmland may be susceptible to varying degrees of damage from a combination of factors, typically including flood depth, velocity and duration. These combined factors have not been assessed.

7 Applicability

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

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

Report prepared by:

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Water Resources Engineer

Authorised for Tonkin & Taylor Ltd by:

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Tim Morris
Project Director

RIBR
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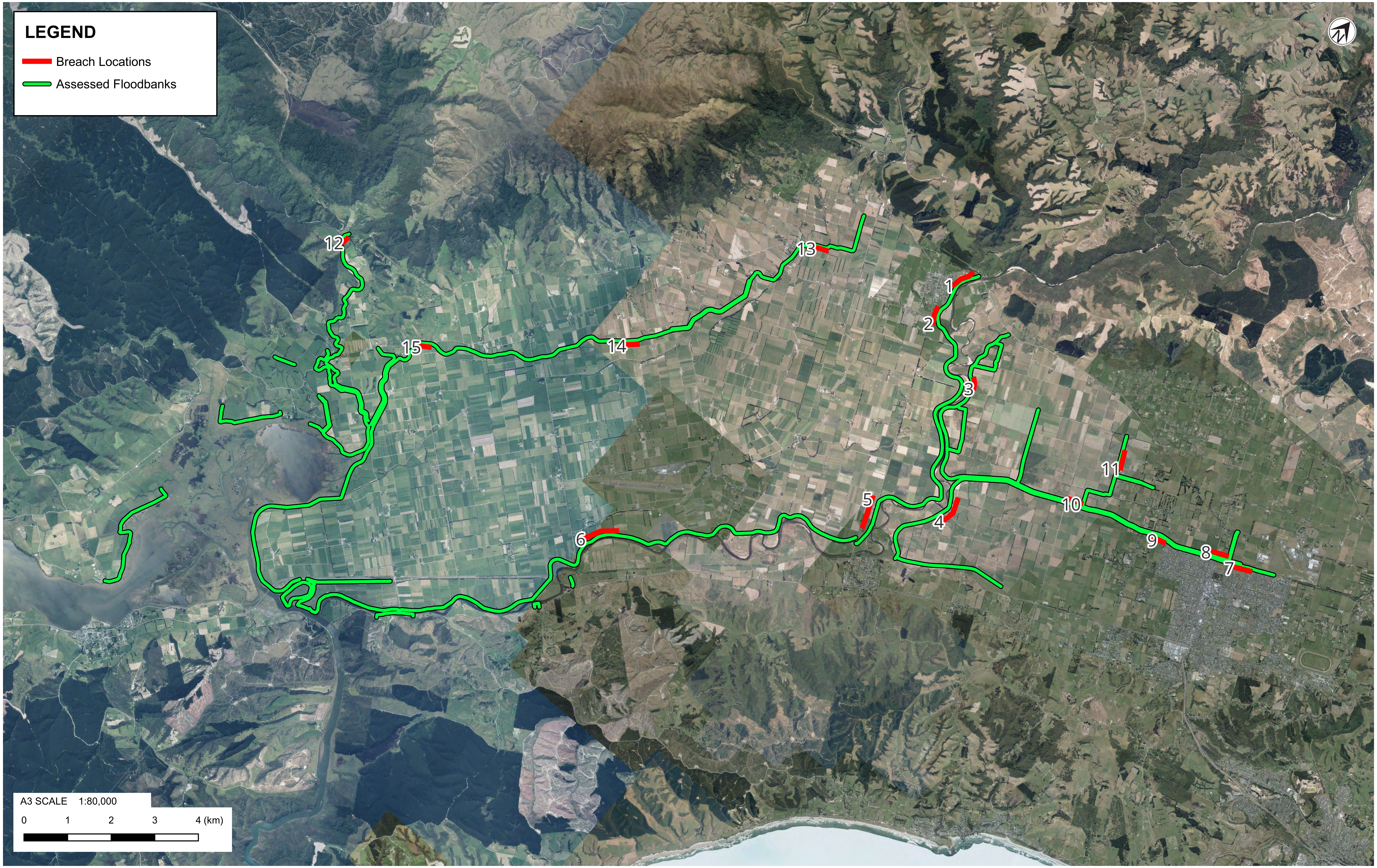

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NOTES:

To be read in conjunction with T+T report Taieri Scheme Review - Floodbank Risk Assessment, dated Nov 2023

REV	DESCRIPTION	GIS	CHK	DATE
0	First version	RIBR	SAFF	14/11/23

LOCATION PLAN

PROJECT No.	1001453.0153	
DESIGNED	RIBR	NOV.23
DRAWN	KTHA	NOV.23
CHECKED	TGM	NOV.23
APPROVED	TGM	23/11/23

CLIENT: OTAGO REGIONAL COUNCIL

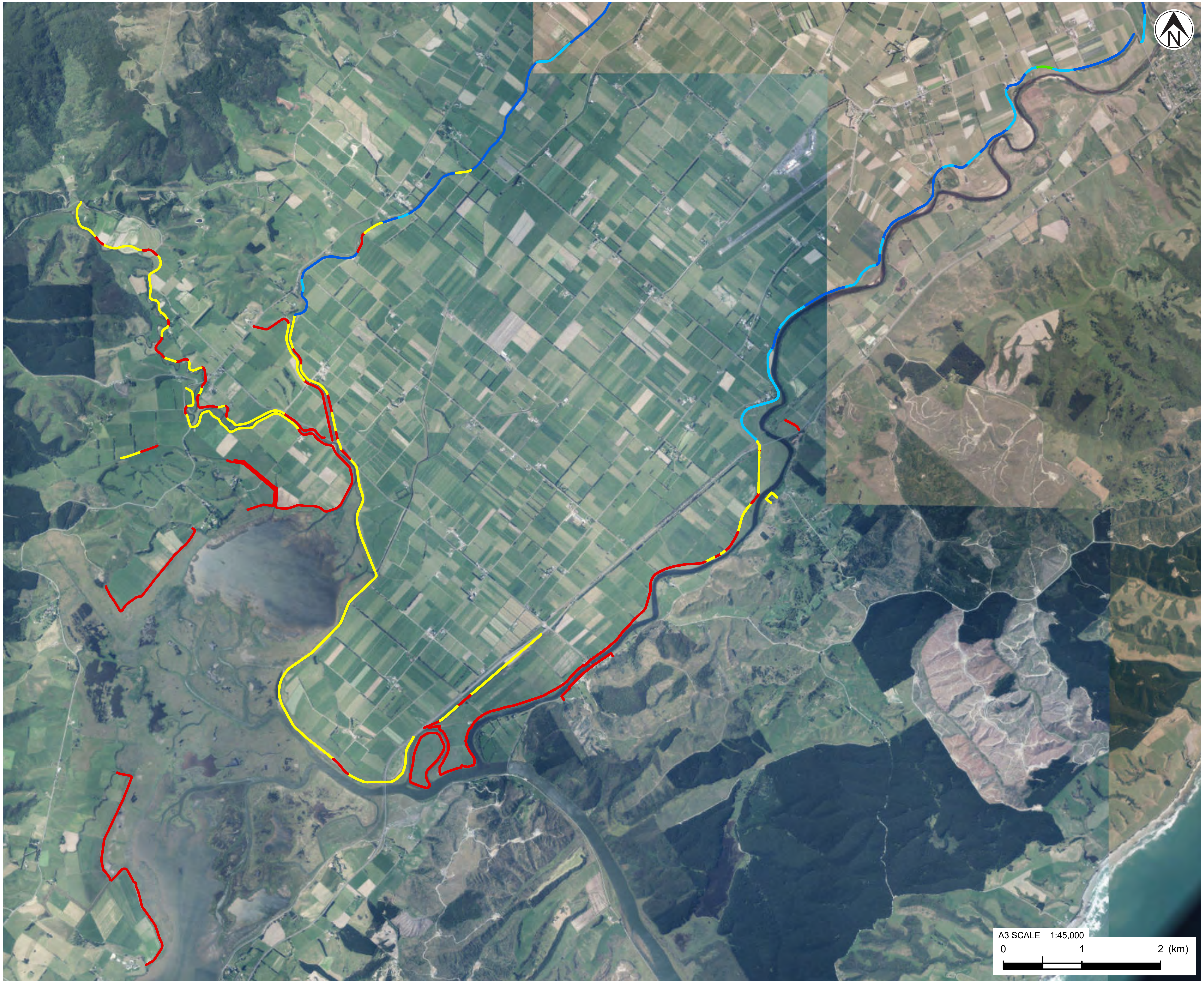
PROJECT: FLOODBANK RISK ASSESSMENT

TITLE: FLOODBANK BREACH LOCATIONS

SCALE (A3): 1:80,000   FIG No. FIGURE A1   REV 0

Appendix C Risk rating result maps

- Likelihood Rating: Figures C1.1 and C1.2
- Consequence Rating: Figures C2.1 and C2.2
- Risk Rating: Figures C3.1 and 3.2



LEGEND

Floodbank Section Rating

Likelihood Rating

- Very Low
- Low
- Medium
- High
- Very High

NOTES

Basemap: NZ Navigation Map: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors. NZ Imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

LOCATION PLAN

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TAIERI SCHEME REVIEW - FLOODBANK RISK ASSESSMENT

LIKELIHOOD RATING - WEST

PROJECT No.	1001453.0153
FIG No.	FIGURE C1.1
SCALE (A3)	1:45,000
REV	0

LEGEND

Floodbank Section Rating

Likelihood Rating

- Very Low
- Low
- Medium
- High
- Very High

NOTES

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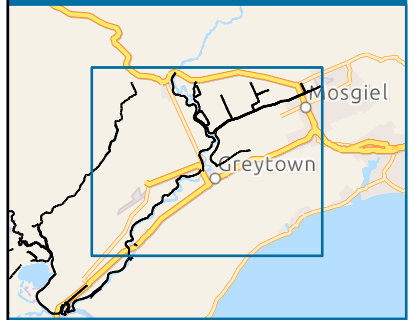

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TAIERI SCHEME REVIEW - FLOODBANK RISK ASSESSMENT

LIKELIHOOD RATING - EAST

PROJECT No.	1001453.0153
FIG No.	FIGURE C1.2
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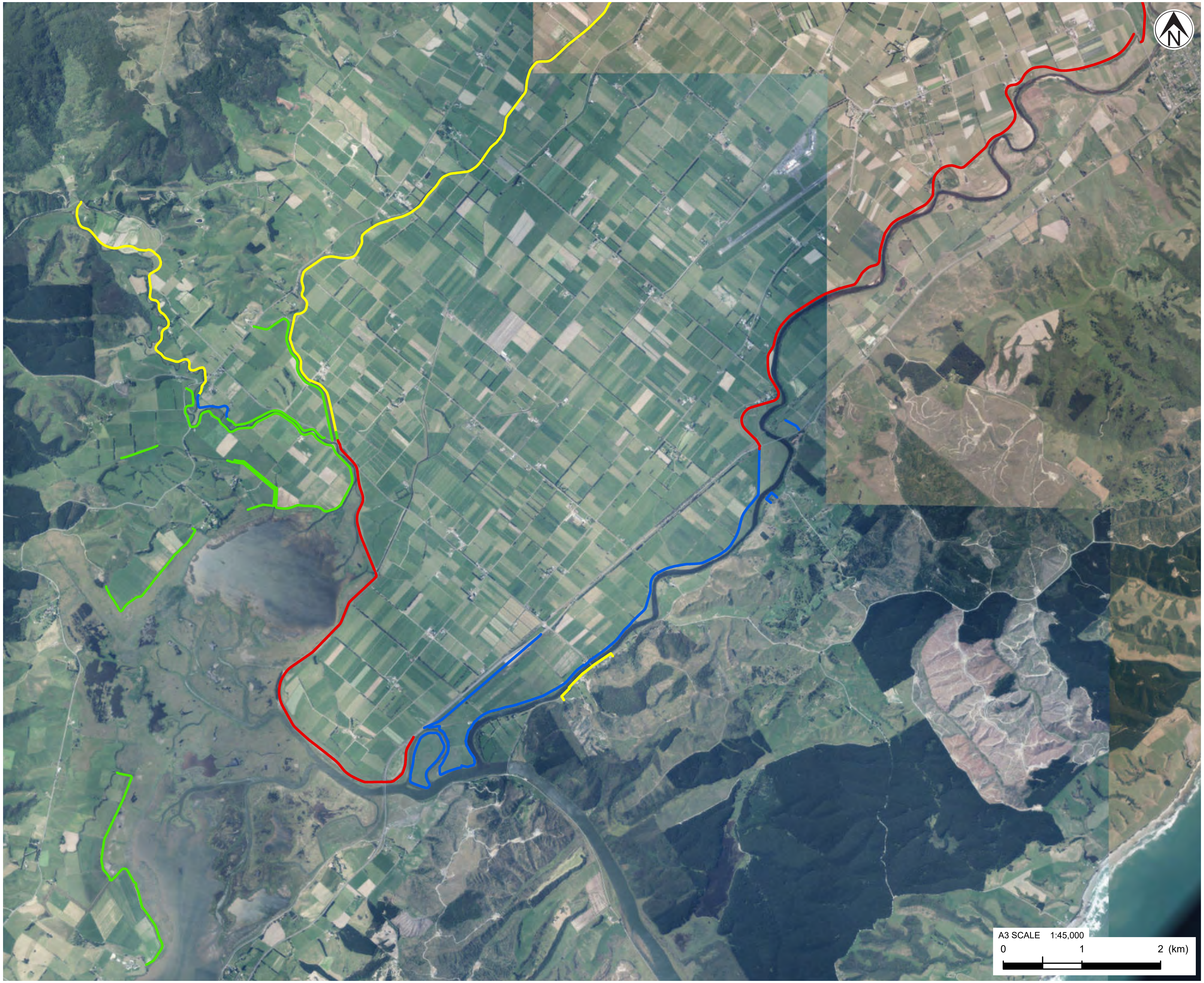

LEGEND

Floodbank Section Rating

Consequence Rating

- Insignificant
- Minor
- Moderate
- Major
- Catastrophic

NOTES

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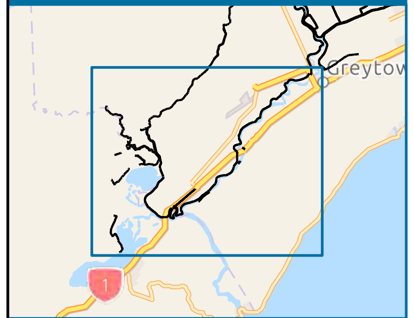
LOCATION PLAN



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TAIERI SCHEME REVIEW - FLOODBANK RISK ASSESSMENT

CONSEQUENCE RATING - WEST

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FIG No.	FIGURE C2.1
SCALE (A3)	1:45,000
REV	0

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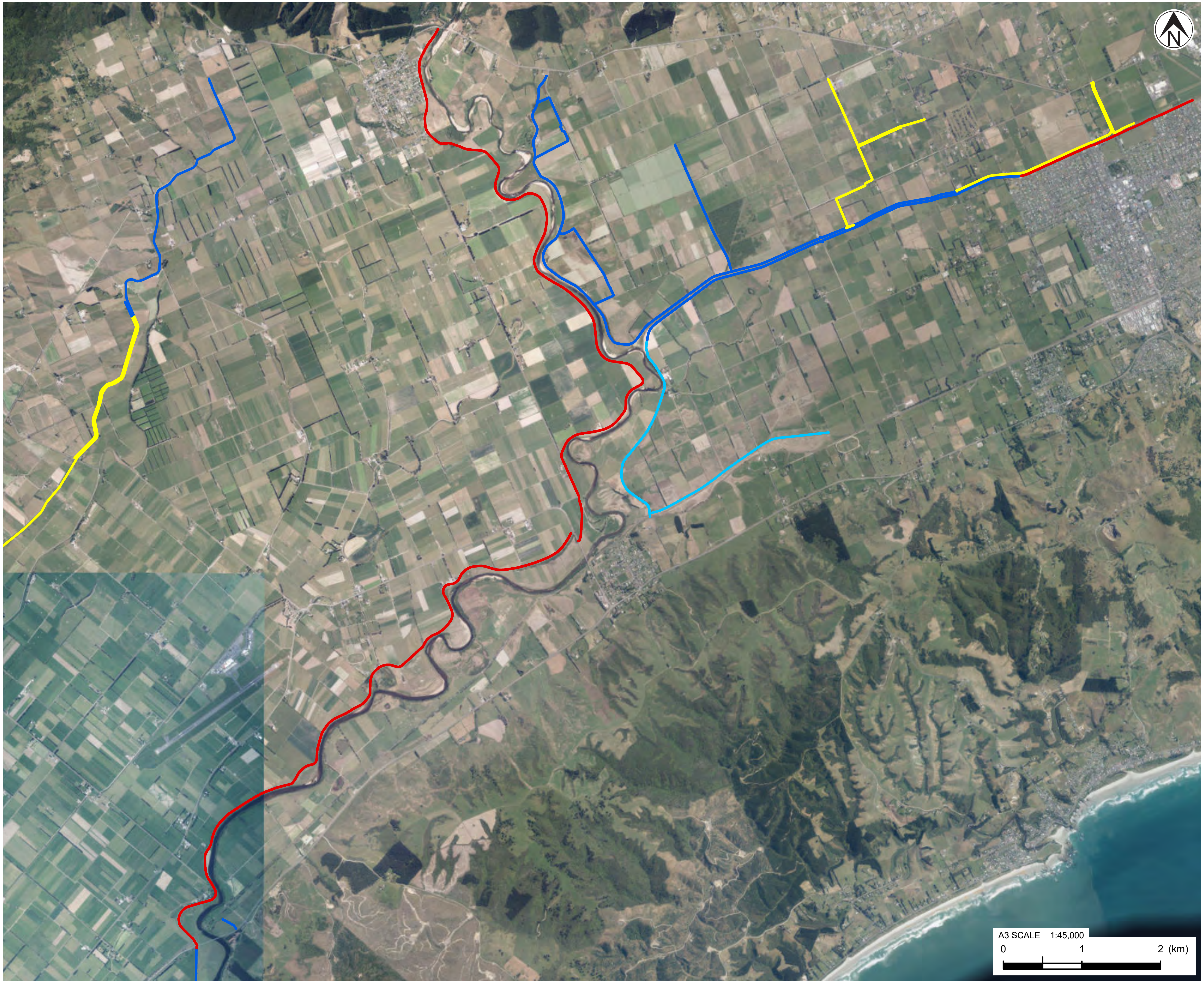

LEGEND

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- Minor
- Moderate
- Major
- Catastrophic

NOTES

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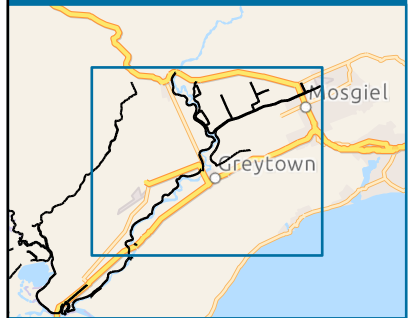

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CONSEQUENCE RATING - EAST

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FIG No.	FIGURE C2.2		
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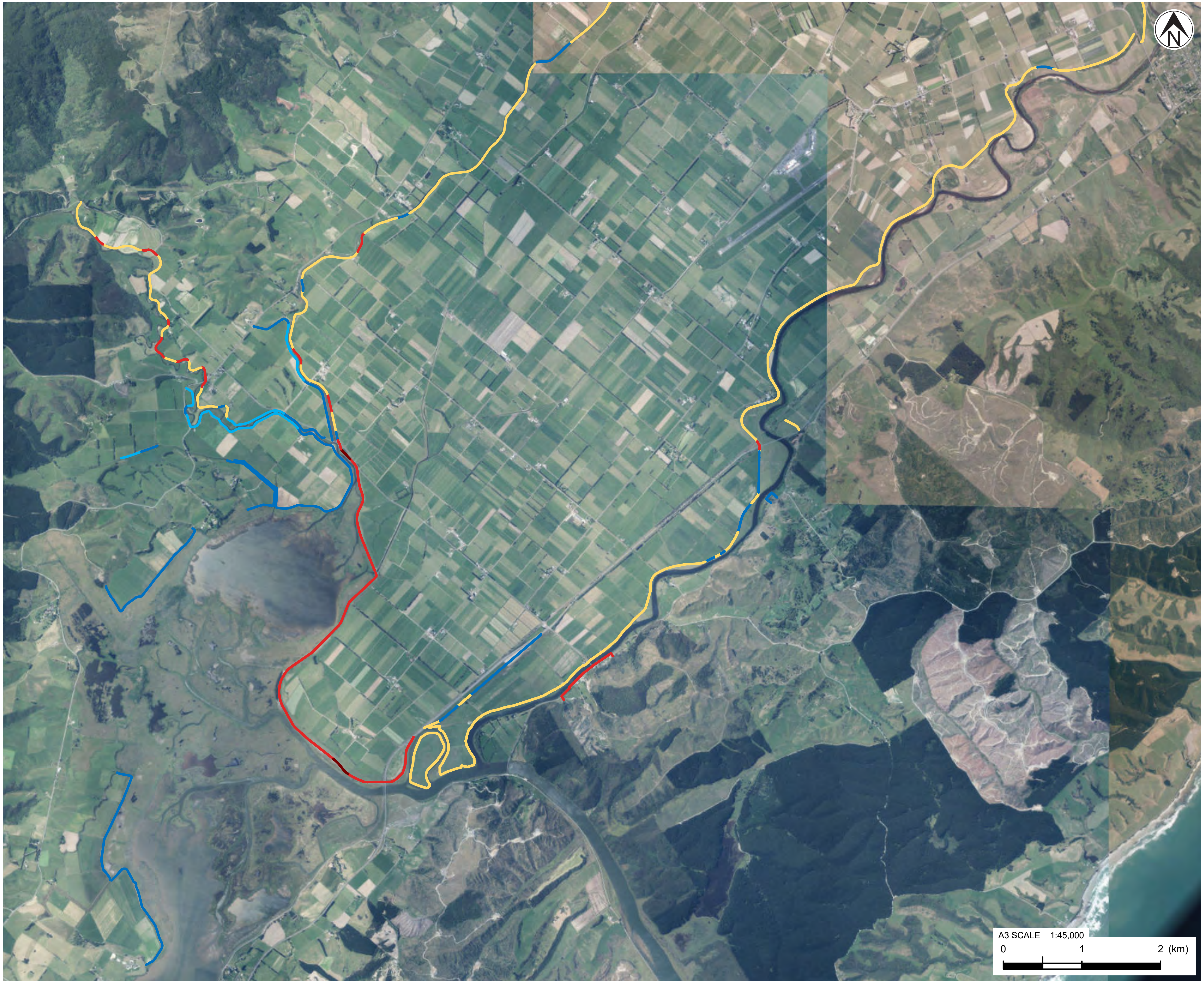

LEGEND

Floodbank Section Rating

Risk Rating

- Low
- Medium
- High
- Very High
- Extreme

NOTES

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TAIERI SCHEME REVIEW - FLOODBANK RISK ASSESSMENT

RISK RATING - WEST

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FIG No.	FIGURE C3.1
SCALE (A3)	1:45,000
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LEGEND

Floodbank Section Rating

Risk Rating

- Low
- Medium
- High
- Very High
- Extreme

NOTES

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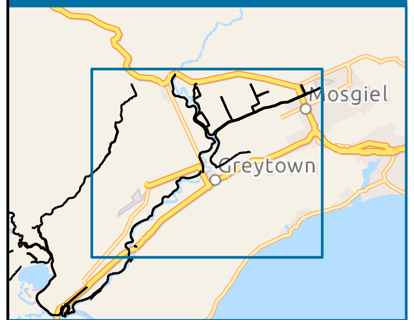
LOCATION PLAN



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RISK RATING - EAST

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FIG No.	FIGURE C3.2
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