Clutha Delta flood hazard study

NIWA Client Report: CHC2005-146
November 2005

NIWA Project: ORC05504

Clutha Delta flood hazard study

Graeme Smart
Maurice Duncan
Jochen Bind

Prepared for

Otago Regional Council

NIWA Client Report: CHC2005-146
November 2005

NIWA Project: ORC05504

National Institute of Water & Atmospheric Research Ltd
10 Kyle Street, Riccarton, Christchurch
P O Box 8602, Christchurch, New Zealand
Phone +64-3-348 8987, Fax +64-3-348 5548
www.niwa.co.nz

Contents

Reviewed by:

Jeremy Walsh

Approved for release by:

D M Hicks

Murray Hicks

Summary

This report describes investigations into flooding and erosion hazards in the Lower Clutha Delta region. Flooding is represented by inundation depths and erosion hazard by flow velocities. Flood sizes ranging from 2,900 m^3/s to 6,600 m^3/s are modelled in conjunction with three sea level scenarios and seven floodbank breach scenarios. A finer resolution model is used to investigate flooding of Balclutha township. The model runs indicate that a 50 yr ARI flood will inundate the Barnego Flats, the Balclutha aerodrome, the river loop west of Chicory Rd floodway, the Matau river loop at Mosley's Road and areas from opposite Kaitangata downstream. There will be low overtopping of floodbanks on the Koau NE of Otanomomo and on the Matau at Raumati. A 500 yr ARI flood will inundate most of the Clutha Delta including parts of Balclutha township. Without catastrophic floodbank failure, model results indicate that large floods will enter Balclutha from the downstream side. The level at which floods enter Balclutha depends on whether Koau Branch floodbanks breach or not. For floods around 100 yr ARI (or greater) damage to Balclutha town could be reduced by manually breaching the floodbanks south of Finegand.

Caution

Particularly alongside Balclutha showgrounds and in the Lower Koau branch, the Clutha River bed, as surveyed in 2005, must undergo considerable vertical scouring during the rising stage of a large flood in order to pass floods such as the 1999 flood which was used to calibrate the models. Should future flood scouring evolve in a different manner to that indicated by the models, inundation levels different from those predicted by the models could result. Also, in several locations significant velocities occur against the stopbanks. While these locations are identified, failure of stopbanks from lateral scouring has not been considered in the present model runs and such failures could markedly change the predicted inundation extent. Results of the modelling investigation may become invalid if modifications are made to existing floodbanks. Finally, in consideration of the following report, it must be borne in mind that such model studies are simplifications of physical reality and consequently they cannot accurately represent all possible eventualities.

1. Introduction

This project is to produce inundation information to identify and quantify flooding and erosion hazards due to relevant river and coastal processes on the Lower Clutha Delta. Eight flood sizes are modelled and three scenarios combining sea level rise and storm surge are investigated. In addition various floodbank breach scenarios are examined. Hazards such as coastal erosion and tsunami are not included in this study. All elevations refer to the Dunedin Vertical Datum 1958.

Specific Project tasks were:

1. **To carry out a topographic survey of the Lower Clutha River bed, berms and floodbanks**
    - A re-survey of existing river cross-sections where the bench marks for these sections could be found.
    - A bathymetric survey of the Lower Clutha riverbed.

2. **To analyse and adaptat LiDAR data for the purpose of flood mapping**
    - LiDAR and bathymetric data are combined to give a Digital Elevation Model (DEM) of the Lower Clutha Delta.

3. **To assess and report on the impact of sea level rise and storm surge**
    - Inundation of the low lying coastal areas.
    - Boundary conditions for hydraulic model.

4. **To hydraulically model the Clutha River Delta and develop flood hazard maps**
    - The 2D hydraulic model includes three combinations of sea level rise and storm surge, three floodbank breach scenarios prescribed by Otago Regional Council (ORC) staff and eight design flow hydrographs specified by ORC.

5. **To hydraulically model inundation of Balclutha Township**
    - The model defines the potential extent and depths of flooding and velocities of floodwater flows in the Balclutha township for eight floods as specified above, associated with four different scenarios of floodbank breaching at

locations prescribed by ORC staff, and different degrees of floodwater overtopping of the floodbanks.

6. **Output files**

- All coordinate information is in the New Zealand Transverse Mercator (NZTM) Projection and New Zealand Geodetic Datum 2000 (NZGD2000).
- The 106 maps derived from modelling are in Map Info compatible format. accompany this report on a CD

2. Implementation

2.1. Design hydrographs

Eight design flow hydrographs were specified by ORC. The hydrographs are identified by their Average Recurrence Interval (ARI) or peak flow as follows:

- 500 year ARI flood event
- 200 year ARI flood event
- 100 year ARI flood event
- 50 year ARI flood event
- 20 year ARI flood event and
- 10 year ARI flood event
- 5600 m^3/s
- 4000 m^3/s

These hydrographs are shown on Figure 1.

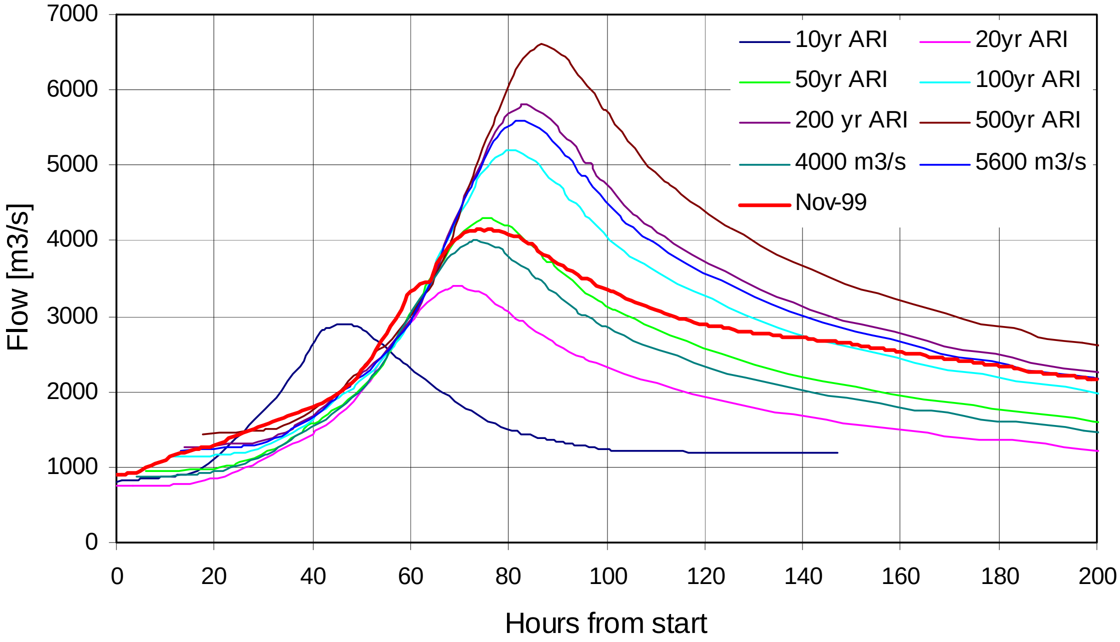


Figure 1: **Hydrographs used in inundation modelling.**

2.2. Sea level scenarios

Three different sea level scenarios were considered as shown in Table 1. The M2 tide is the lunar semi-diurnal tide. Tides calculated with this tidal component alone give a mean tide. When the S2 solar semi-diurnal tide is added to the M2 tide, tidal values for spring tides are obtained.

Table 1: **Sea levels used in inundation modeling**

Scenario	Mean sea level used (m.a.s.l.)	Tide (amplitude)	Resulting max. water level
1	Present Mean Sea Level (0.12 m)	Standard M2 tide (0.77 m)	0.89 m
2	Sea Level in year 2100 (0.62 m)	Spring tide M2+S2 (0.89 m)	1.51 m
3	100 yr Storm Surge (0.9 m) + Present MSL (0.12 m) **Or other combinations** such as: 10 yr SS (0.7 m)+ 40yr SL (0.32 m)	Spring tide M2+S2 (0.89 m)	1.91 m

Note. Scenario 1: Present mean sea level has risen to 0.12 m above the m.s.l. datum.

Scenario 3: Different combinations of sea level rise and storm surge that add to 1.02 m are equivalent in terms of their downstream hydraulic effect on the model.

These sea level scenarios were implemented as dynamic downstream boundary conditions for the hydraulic model runs. Tides and hydrographs were synchronised so that high tide occurred at the time a flood peak reached the coast.

2.3. Topography

Topography for the model is derived from LiDAR scanning of the project area carried out on September 6-11 2004. The raw data were interpolated to a 10m grid **D**igital **E**levation **M**odel for the greater delta area and a 4m grid DEM for the Balclutha township area (Figure 2). Care was taken to preserve floodbank crest levels and flow paths in the data interpolation process. Some uncertainties over the accuracy of the geoid model have been expressed by ORC (a geoid model is used by the LiDAR mapping company to calibrate the LiDAR elevations to orthometric heights above the datum). As inundation levels are dependent on topography, any bias or trend in the LiDAR data will have an influence on the inundation results reported below.

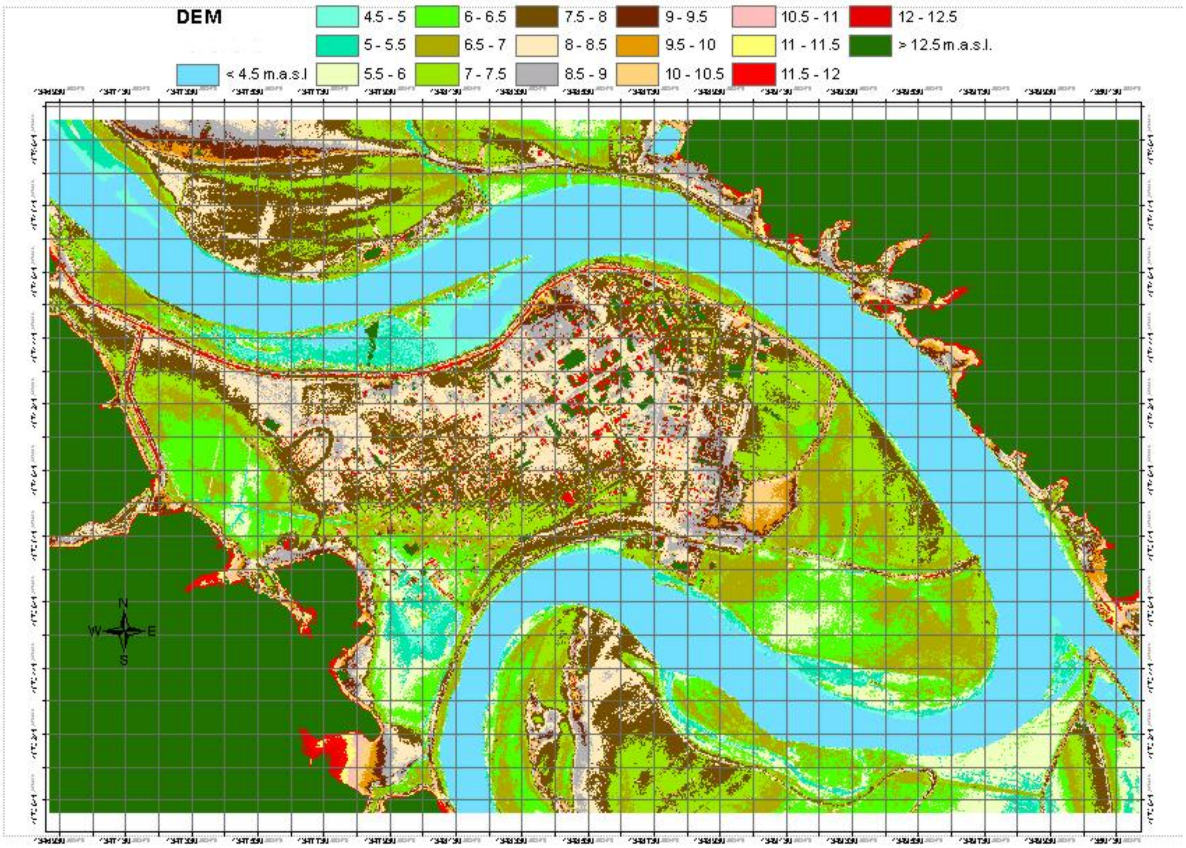


Figure 2: **Digital Elevation Model of Balclutha area topography.**

2.3.1. Bathymetry

Riverbed topography in April 2005 was surveyed by GPS-located echo soundings as part of this investigation. An example of the bathymetry, interpolated to the modelling grid, is shown for the Balclutha region in Figure 3. Model runs of the 18 November 1999 calibration flood, which peaked at 4167 m^3/s, showed that it was not possible for the river to pass the 1999 flood with the bed levels surveyed in 2005. An investigation of the 1999 flood showed that bed shear stress levels indicated by the model were sufficiently high during this flood to cause substantial scouring of the channel bed and the model bed topography was consequently modified to encompass scouring. Scouring was deemed to be representative of the 1999 bed conditions during the flood when bed shear stress fell below levels required for entrainment of the larger bed particles and when peak water levels matched peak levels measured during the 1999 flood. Bed scouring in the vicinity of Balclutha is likely to be more accurate in the smaller Balclutha model because of the finer resolution.

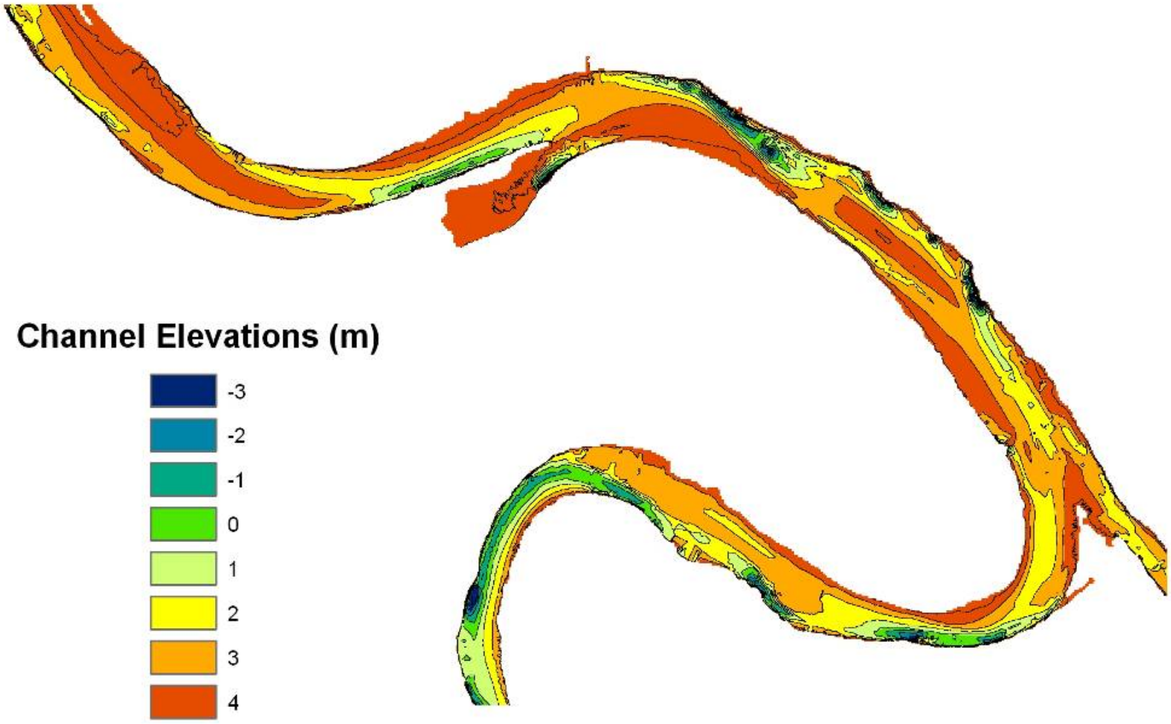


Figure 3: **Digital Elevation Model of river bed levels near Balclutha (surveyed in April 2005).**

2.3.2. Cross-sections

During the 2005 bathymetric survey, cross-sections were surveyed at locations of historic measurements. These data are supplied in associated files. An example of a cross section survey is given in Figure 4.

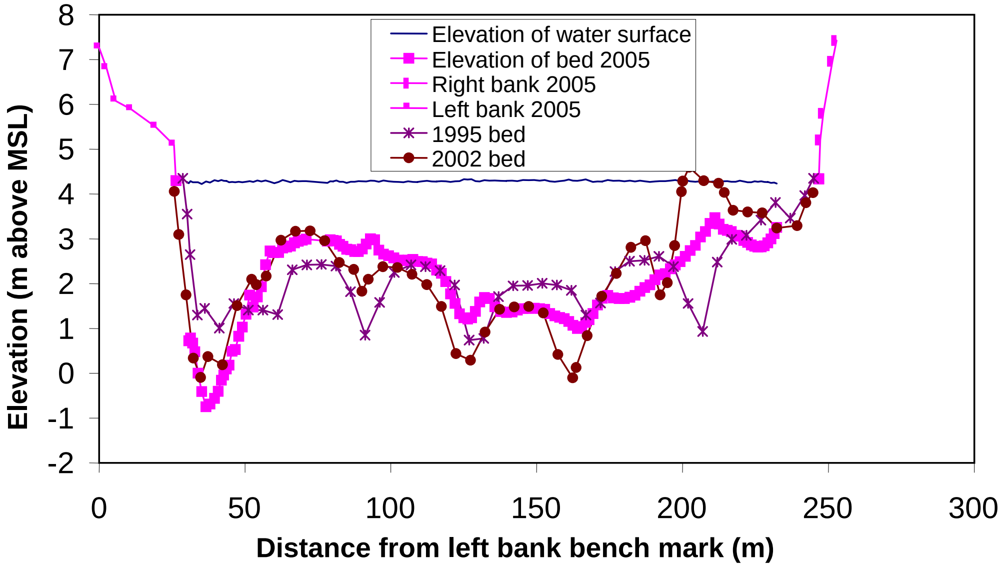


Figure 4: 2005 survey of a Clutha River cross section at the railway bridge compared to earlier measurements at the same location.

2.3.3. Breach scenarios

For the Balclutha Delta region four breach scenarios were investigated. On the Koau, two breakout locations were permitted, #1 near the Finegand freezing works and #2 NE of Otanomomo near E 1350 000, N4869 000. The locations are shown on Figure 5. These two locations were combined as one scenario with breaching occurring wherever water depth over the prescribed locations exceeded 150 mm. This scenario was termed *Koau.* On the Matau Branch, breakouts were permitted near Mosley bend (#3) and at Lawsons (#4). These scenarios were termed *Mosley* and *Lawson.* Breaching occurred wherever water depth over the prescribed locations exceeded 115 mm. Breaching reduces floodbank levels to local ground level at a rate governed by the Meyer-Peter Mueller sediment transport formula.

Some uncertainty surrounds final inundation depth and extent following a breach (when a river is spilling out of its usual course) because steps would normally be taken

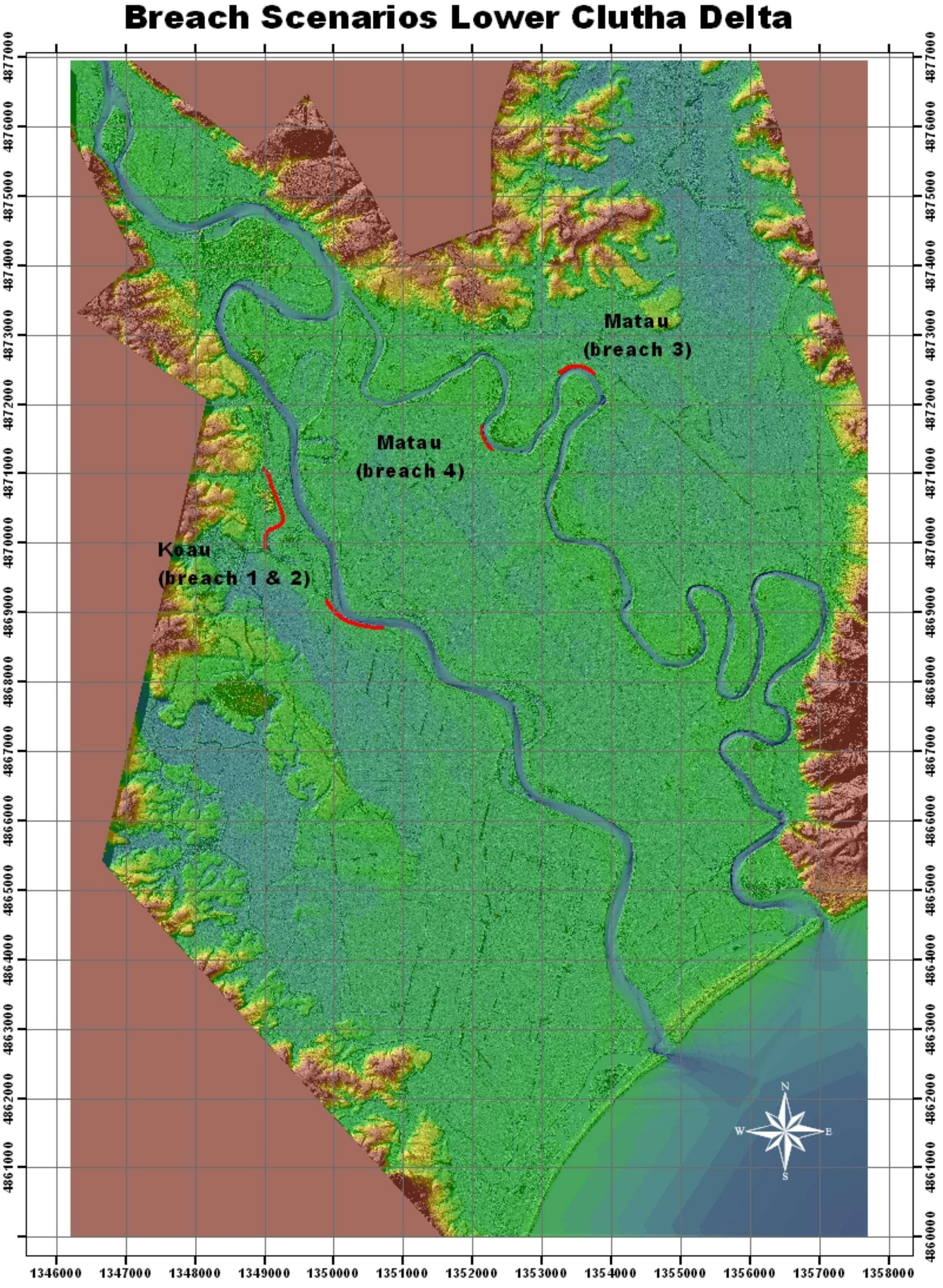


Figure 5: **Locations on the Clutha Delta where breaching was invoked on stopbank overtopping**

to plug a floodbank breach. For modelling of floods that took many days to recede (floods in excess of 5500 m^3/s), breaches were assumed to be repaired on a falling flood when inflows fell below 3800 m^3/s (rising floods overtop stopbanks at around 4300 m^3/s).

For the Balclutha town model several scenarios for breaching were investigated. The proposed scenarios were initially: No Breach (1), Breach upstream of Balclutha on the bank protecting the Barnego flats (2), Breach opposite Balclutha on the bank protecting the Barnego flats (3), and Breach on the floodbank protecting the north of Balclutha town (4). Initial modeling runs showed that the Barnego flats were inundated during all floods greater than a 50 yr ARI and breaches in the surrounding banks only affected the rate at which Barnego flats were flooded and had little effect on maximum inundation depths. Modelling also showed that during high floods, Balclutha was back-flooded from the downstream southern side. It was decided that useful information would be achieved by modelling the following breach scenarios:

O. No breach,

A. North Balclutha overtopping leading to breach,

B. North Balclutha piping (a forced breach whereby a 28 m long section of stopbank was assumed to fail suddenly at the 100 yr ARI flood peak 5200 m^3/s), and

C. South Balclutha overtopping breach (stopbank removed on the downstream side of Balclutha town when it was overtopped by flow at least 150 mm deep).

These locations are shown on the Balclutha model domain in Figure 6. For the prescribed range of flood hydrographs, modelling showed that the banks on the north side of Balclutha were never overtopped and scenarios O and A gave the same result.

2.4. Numerical model description

The computational model used was *Hydro 2de*. It was developed by Dr Cornel Beffa of Fluvial.ch, Switzerland. *Hydro 2de* is a non-interactive program that solves the depth-averaged shallow water equations on a cell-centred rectangular grid using a finite volume discretisation. It allows wet and dry domains; sub- and super-critical flow conditions, the specification of variable bed topography, variable hydraulic roughness, and dynamic boundary conditions. The salient features of *Hydro2de* are:

- explicit time integration (1st or 2nd order) with variable time stepping
- zero-equation turbulence models

- grid independent input (simulation on different grid sizes with the same input data)
- culvert flow (inlet- and outlet controlled)
- computational stability.

The *Hydro 2de* model is internationally recognised and has previously been used for flood and habitat studies on a wide range of New Zealand rivers.

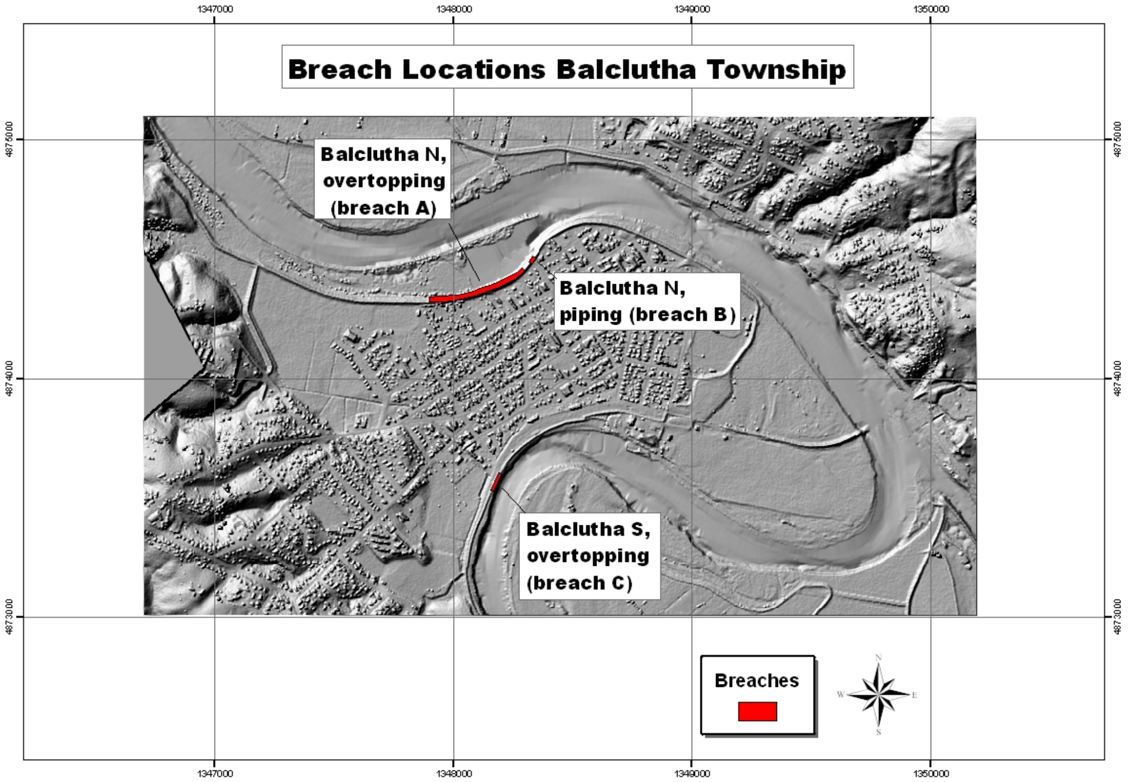


Figure 6: **Locations North and South of Balclutha where floodbank breaching was possible.**

2.5. Model assumptions and approximations

- Flow depths and velocities are calculated from the equations of depth-averaged shallow water flow as incorporated in the model. The inputs to the equations are derived from the supplied flow hydrographs, model boundary conditions, digitised topography elevations and the surface roughness. A log-law flow resistance equation is used to help overcome the problem of resistance coefficients changing with depth, as occurs with Manning’s type equations (Smart 2002, 2004).

- Water depths calculated to be less than 50 mm are considered to be dry.

- Except at inflow boundaries, no assumptions are made on flow paths. The direction and velocity of flow are determined by bed topography, flow-resistance and the laws of hydrodynamics.

- The calibrated model provides mean water depth and depth-averaged velocities for each model cell. As these values are means for a cell, parameters for features smaller than the cell dimensions may not be accurately estimated. In the Clutha Delta model the cell size is 10m x 10m. In the Balclutha sub model the cell size is 4m x 4m. There are a total of 1.95 million cells in the Clutha Delta model and 461,000 cells in the Balclutha sub model.

- The model is a fixed bed model and any scour or deposition must be manually edited into the topography.

- Spillway gates were modelled as open above flows of 2710 m^3/s (ORC, May 2000).

- The model results are only as good as the data on which they are based. Potential causes of error include: topographical and roughness measurement errors, insufficient model resolution to represent small scale hydraulic effects, changes in topography and ground roughness between the calibration period and the time of a future flood, three-dimensional flow effects not represented in a 2-D model and morphodynamic effects such as unexpected scour and deposition in the river channel.

2.6. Model calibration

The flood used to calibrate the model occurred during November 1999 with a peak flow of 4167 m^3/s at Balclutha. This flood is close to the 4300 m^3/s magnitude of the prescribed ARI 50 year event and was the third highest event in 136 years of record (ORC, March 2000). The November 1999 flood was well reported with photographs taken on the day following the flood peak and maximum flood levels recorded at 28 locations within the model domain. The photographs and 23 more or less reliable levels provided an excellent basis for model calibration. Another factor aiding calibration was the knowledge that although the 1999 flood peak was estimated at 4167 m^3/s and the design flood for the majority of the stop banks was 4000 m^3/s, none of the floodbanks were significantly overtopped during the flood.

Boundary conditions used for calibration were the DEM measured in 2004, the 1999 flood hydrograph measured at the Balclutha water-level recorder and the ocean tide at the time, calculated using the NIWA NZ tidal model. There was no significant storm surge for the duration of the calibration flood. Hydraulic resistance of the channels was estimated from gauging records made in the Clutha, Koau and Matau channels. Out of channel (floodplain) roughness was based on interpretation of ground cover and, once classified, was not adjusted for calibration purposes. The surface roughnesses used are shown in Figure 7.

An initial attempt to calibrate the model gave predicted levels that were too high, even when the channel flow resistance was reduced within plausible limits. It was evident that locations of poor fit were typically associated with regions of very high bed shear stress. These bed stresses were sufficient to entrain large quantities of bed material and consequently the bed was artificially scoured (the DEM bathymetry was edited) at locations where scouring was indicated by the model. This technique was applied iteratively until bed shear reduced and the predicted peak water levels approached the field measured levels. The results of calibration for the Clutha Delta are shown at locations of measured flood marks in Figure 8. Considering that some flood marks can be imprecise and that the stated accuracy of the LiDAR derived elevations is ~ 0.15 m, the fit was judged to be satisfactory and most modelled water-levels were within 0.2 m of measured levels. A comparison of model-predicted water levels and an aerial photograph of the 1999 flood at the same location is given in Figure 9.

Various fixed bed conditions were consequently used for the different sized floods. For the Delta model:

- 10 yr ARI - River bed topography as surveyed in April 2005.
- 20 yr ARI - April 2005 bed scoured according to bed shear stress.
- Calibration flood – Scoured to match water levels measured in the flood.
- 50 yr ARI and bigger – As for calibration flood (main channel shear does not increase significantly once floodbanks are overtopped).

For the high resolution Balclutha model the surveyed bed topography was used for the 10 yr and 20 yr ARI floods (a conservative assumption). The bed was scoured according to shear stress for the calibration flood and this bed was used for higher floods.

Figure 7: **Roughness length scales used for hydraulic modelling.**

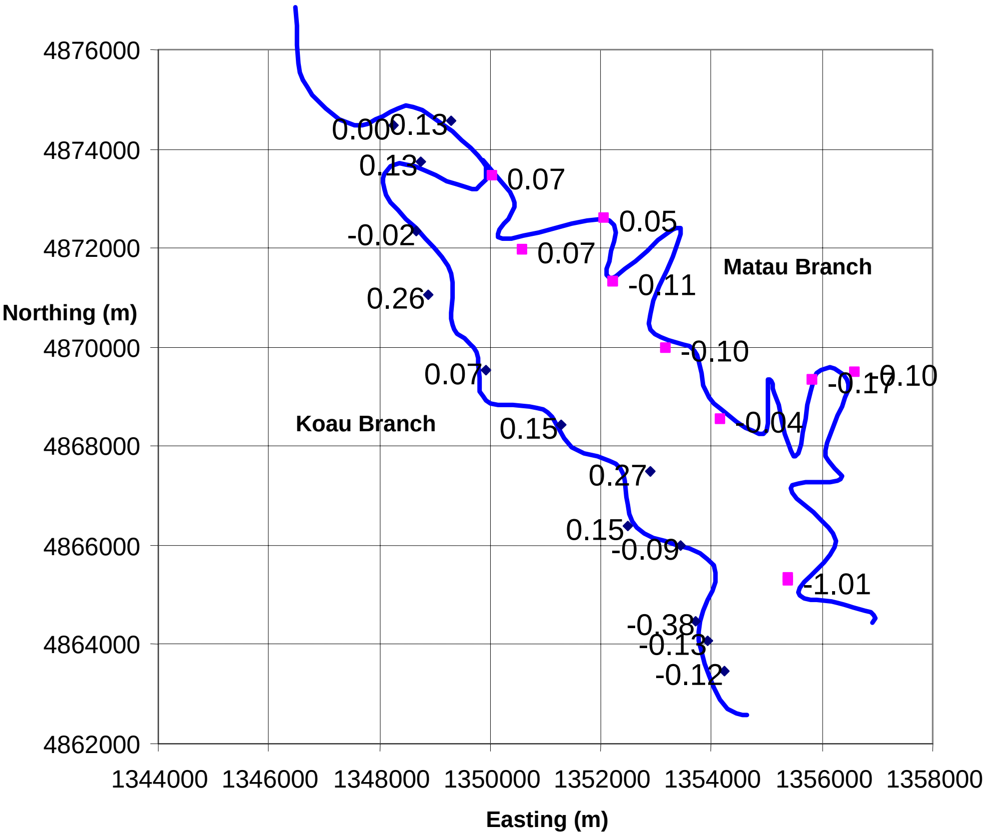


Figure 8: **Comparison of predicted water levels with flood marks measured after 1999 flood. Negative numbers indicate the model prediction is too low. Accuracy of the bottom right flood mark is suspect.**

2.7. Model runs

Modelling runs were carried out as prescribed in the contract and are listed in Appendix 1. For each of the runs there were two files produced, one containing maximum water depths (D) in metres and one containing maximum water velocity (V) in metres/second. Maximum depth and maximum velocity may have occurred at different times during the course of a flood.

Note: Flood depths from the model should be used only in conjunction with the corresponding DEM topography files supplied. Calculation of flood levels by adding model flood depths to other topographic measurements such as field R.L. measurements may produce erroneous results. To supply or export data for other uses, add local model depths to local ground levels from the model DEM (at the same resolution) and provide third parties with local flood levels.

Figure 9: Comparison of 1999 flood photo (top) with model predicted water levels (below) for the Balclutha area.

3. Model results

As requested in the contract, output from the 106 hydraulic modelling runs has been provided for further analysis by the Council as MapInfo compatible files. Examples of the files are presented in this report to give an overview of results.

3.1. 2100 Sea Level with no flood event

Effects of a spring tide with the predicted 2100 sea level are shown in Figure 10. The floodbanks contain the inundation within the river channel, with minor out of channel flooding on the Matau Branch near the coast. Ponding behind floodbanks due to inadequate drainage could be extensive under these conditions but is not shown in this study.

3.2. 10 yr ARI flood event

In all scenarios no overtopping of floodbanks occurred.

3.3. 20 yr ARI flood event

In all scenarios no overtopping of floodbanks occurred.

3.4. 4000 m^3/s event

In all scenarios no overtopping of floodbanks occurred.

3.5. 50 yr ARI flood event

This event occurring at normal sea levels with no breaches is shown in Figure 11. There will be low overtopping of floodbanks on the Koau Branch NE of Otanomomo and on the Matau Branch at Raumati. This flood inundates the Barnego Flats, the Balclutha aerodrome, the river loop west of Chicory Road floodway, the Matau river loop at Mosley’s Road and areas from opposite Kaitangata downstream. With a 100 yr storm surge affecting tide levels, stopbank overtopping NE of Otanomomo inundates the land between the Koau Branch and Kaka Point Rd and, if this floodbank breaches, the inundation extends inland to the Greenall Rd junction and south to the coast.

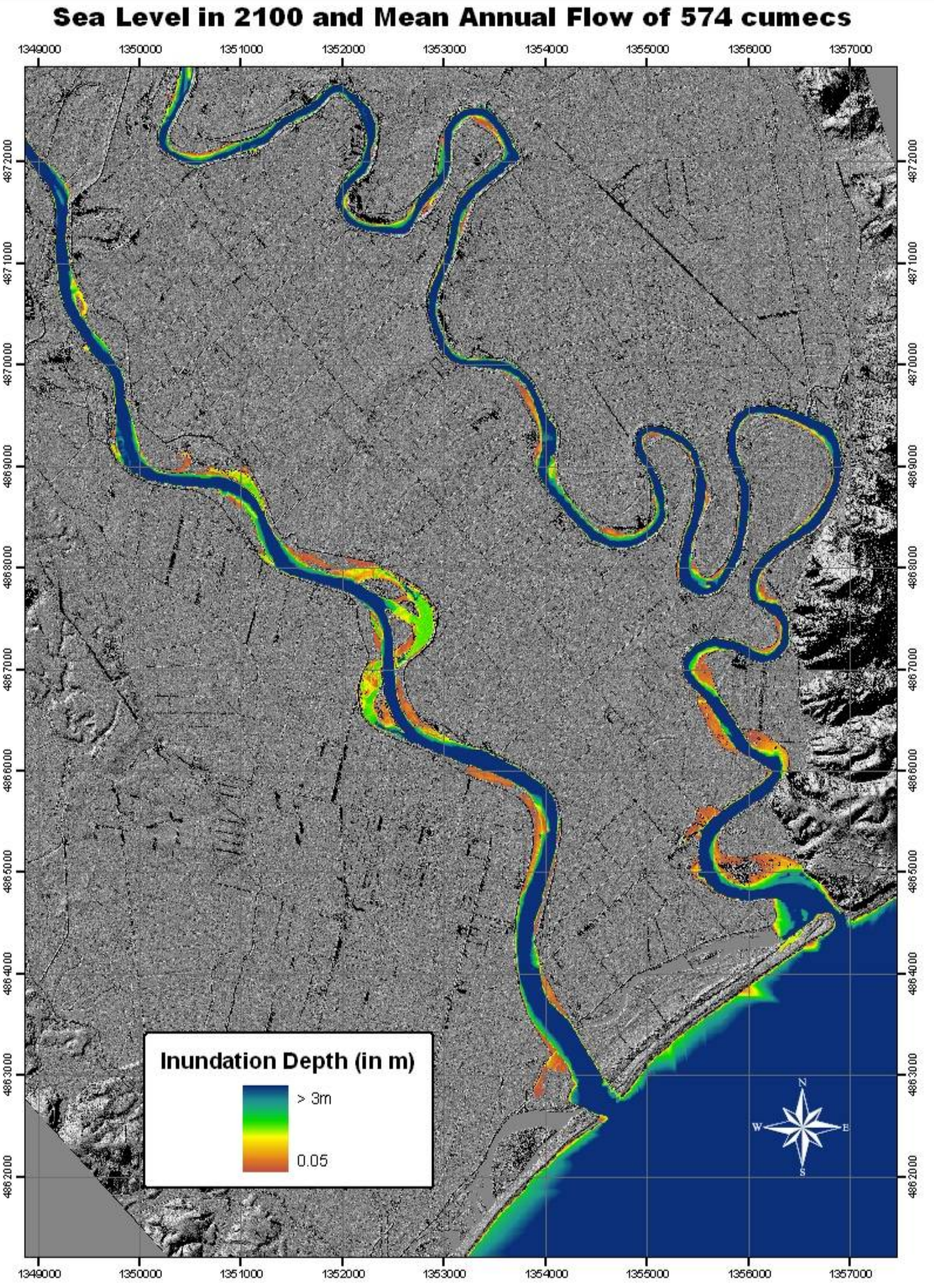


Figure 10: Inundation for a spring tide, average river flow and anticipated 2100 sea level.

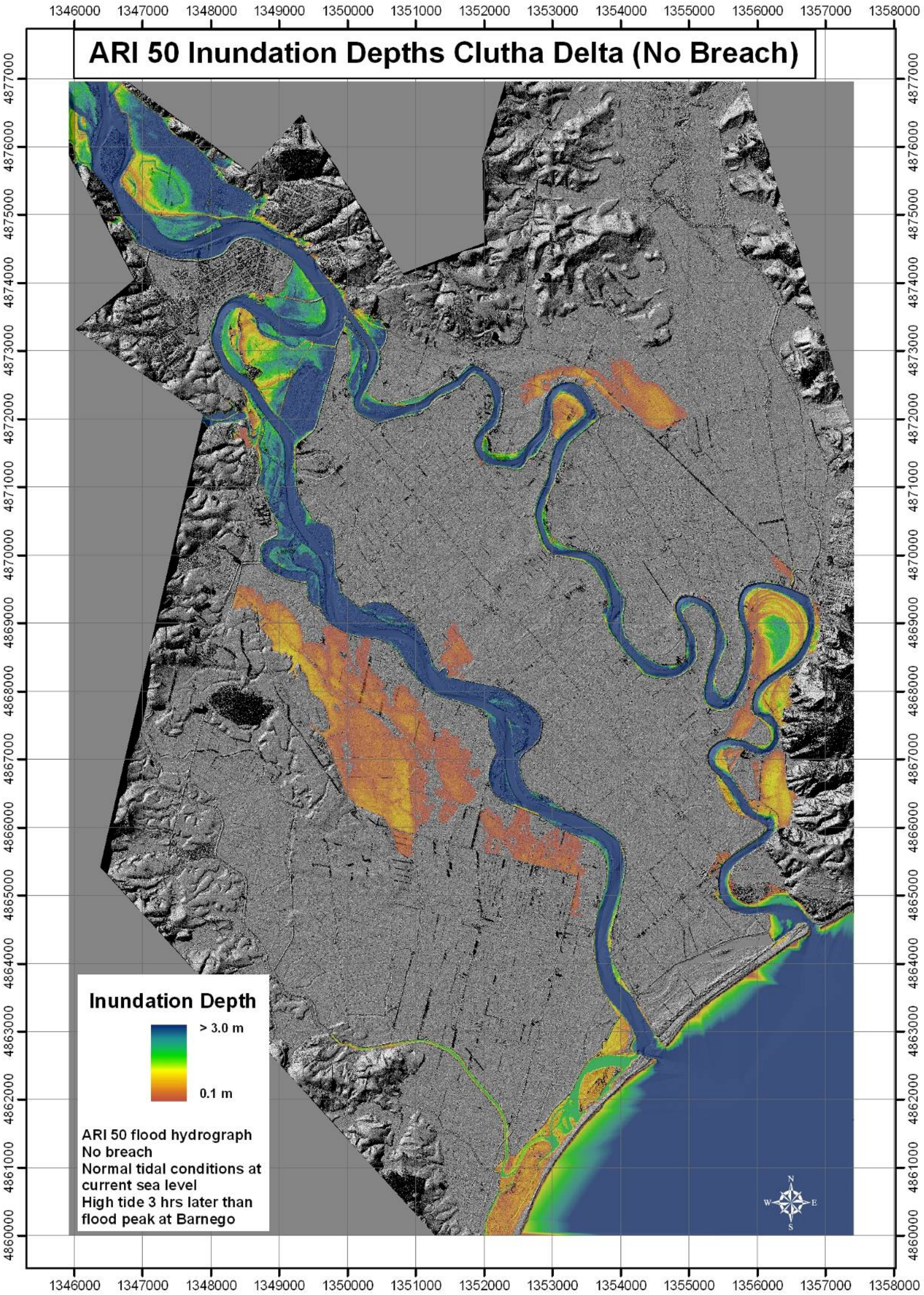


Figure 11: **Inundation depths resulting from a 50yr ARI flood with no stopbank failure.**

3.6. 100 yr ARI flood event

The results indicate that the 5200 m^3/s 100-yr flood may overtop the Balclutha floodbanks which were designed to contain a 5600 m^3/s flood. Three possible explanations are suggested as to why the model predictions of water levels are higher than the design levels:

1. The stopbank design was made on the basis of a 1-D model which does not incorporate water level changes across cross-sections or momentum effects on the outside of curves and/or other 2-dimensional flow effects which have been incorporated in the present inundation models.

2. Greater channel capacity may have been anticipated during the 5200 m^3/s 100-yr flood than is indicated by the 4167 m^3/s calibration flood. Greater scour would produce water levels lower than those indicated herein.

3. Floodbanks may not yet have been constructed on the Koau Branch or breaches of the Koau floodbank may have occurred during floods used to guide the design of the Balclutha floodbanks (see following).

The overtopping of the Balclutha floodbanks does not occur if breaches occur on the Koau floodbanks downstream of Balclutha as shown in Figure 12. When the downstream floodbanks are intact, overtopping of Balclutha floodbanks occurs on the downstream side of Balclutha as shown in Figure 13. Breaches of the Koau floodbanks downstream of Balclutha also prevent inundation of much of Inch Clutha between the Koau and the Matau Branches (compare Figures 12 and 13).

3.7. 5600 m^3/s event

Results are similar to the 200 yr ARI flood described below. For specific details on local water depths and velocities see the accompanying Map Info compatible files

3.8. 200 yr ARI flood

The situation with no floodbank breaches is shown in Figure 14. Serious inundation occurs over most of the Clutha Delta. Figure 15 shows that breaching of the Koau floodbanks no longer protects Balclutha from inundation. Details of inundation within Balclutha are best represented by results of the Balclutha sub model runs. The higher resolution of these models allows flow paths to be more accurately defined and inundation depths differ slightly from the 10m model predictions. An example from the Balclutha sub model is given in Figure 16, which shows inundation depths in the town during a 200 yr ARI flood with no downstream floodbank breaches.

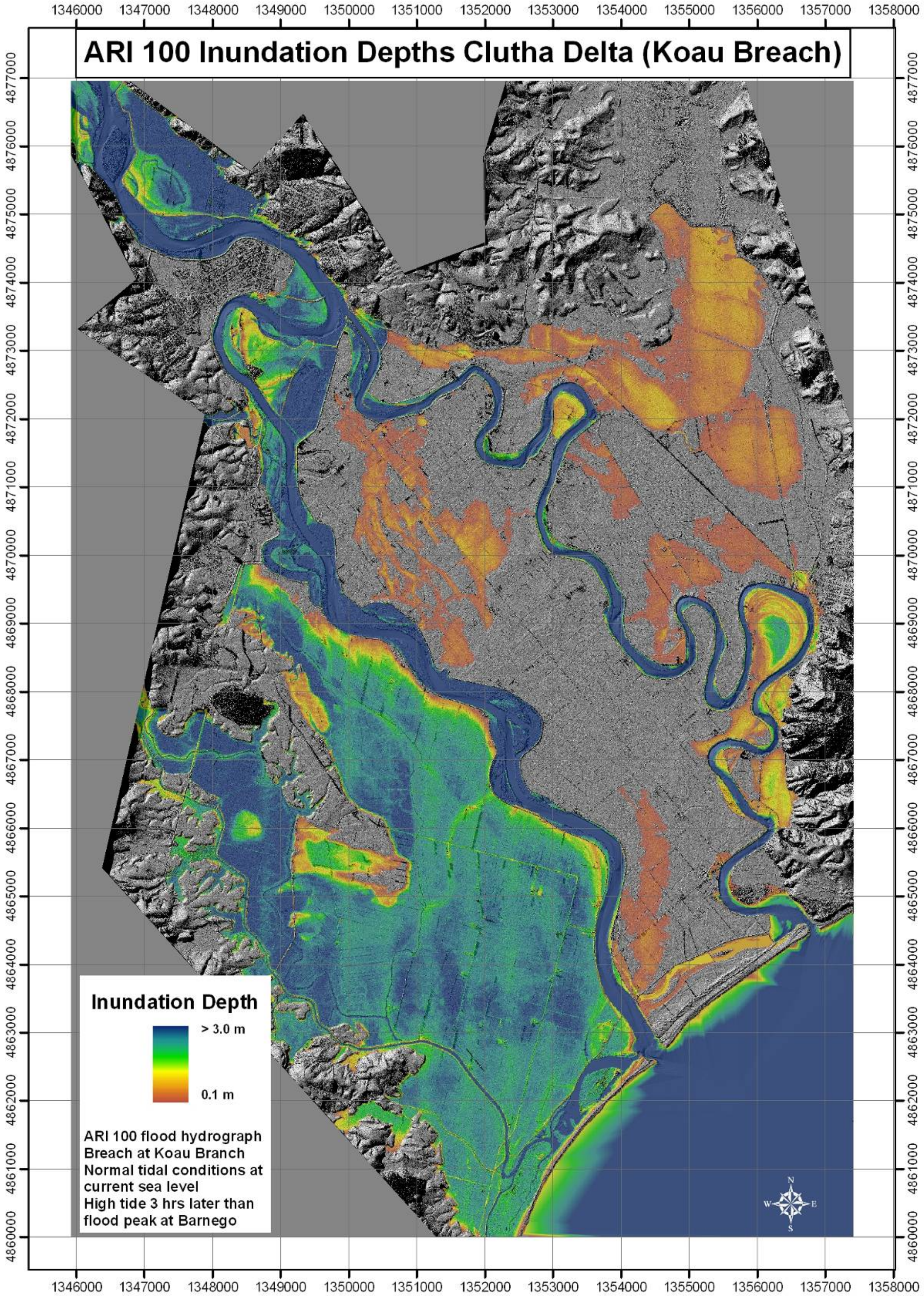


Figure 12: **Inundation depths resulting from a 100yr ARI flood with breaching on the Koau branch.**

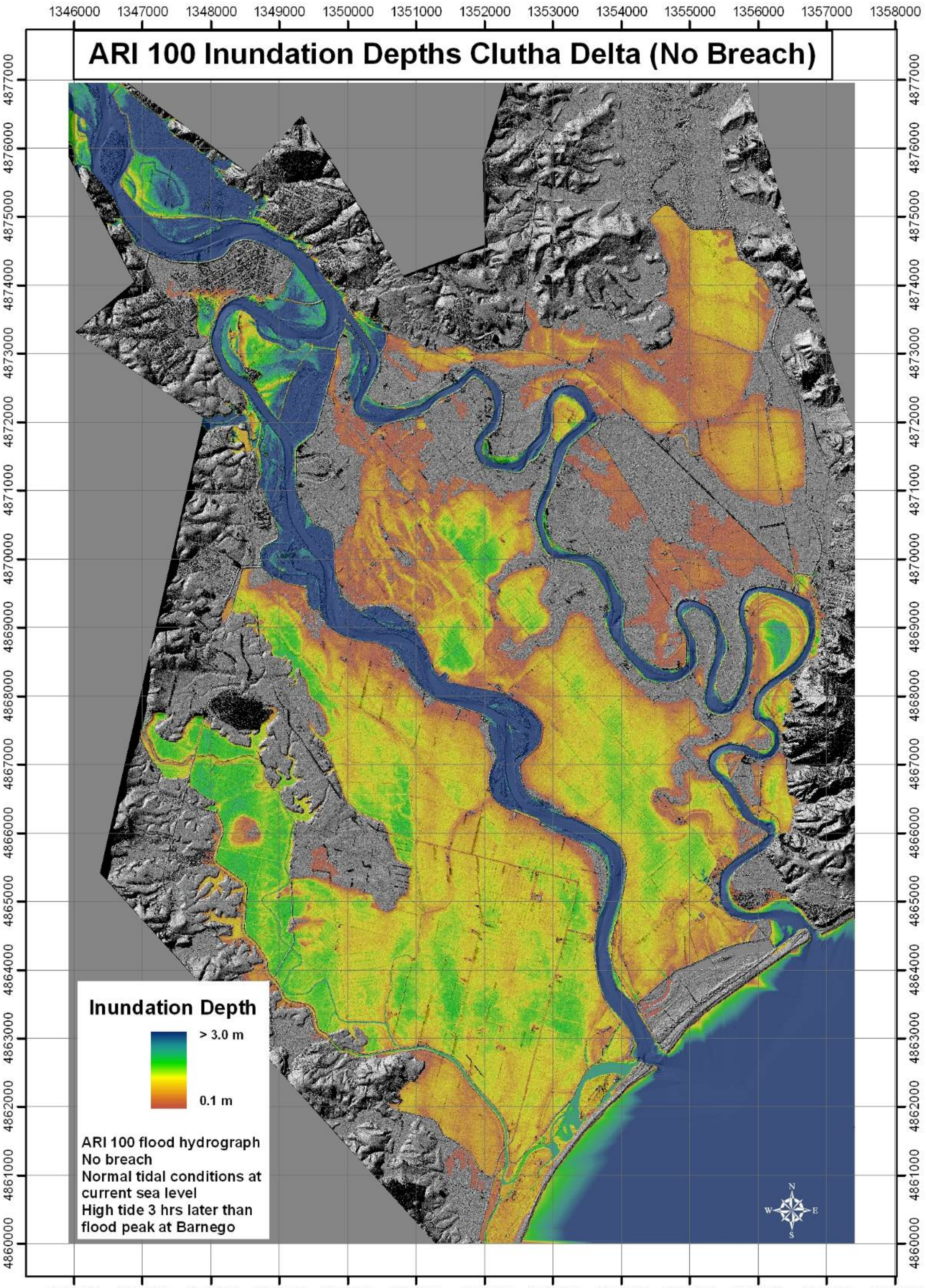


Figure 13: Inundation depths resulting from a 100 yr ARI flood with no breaching permitted.

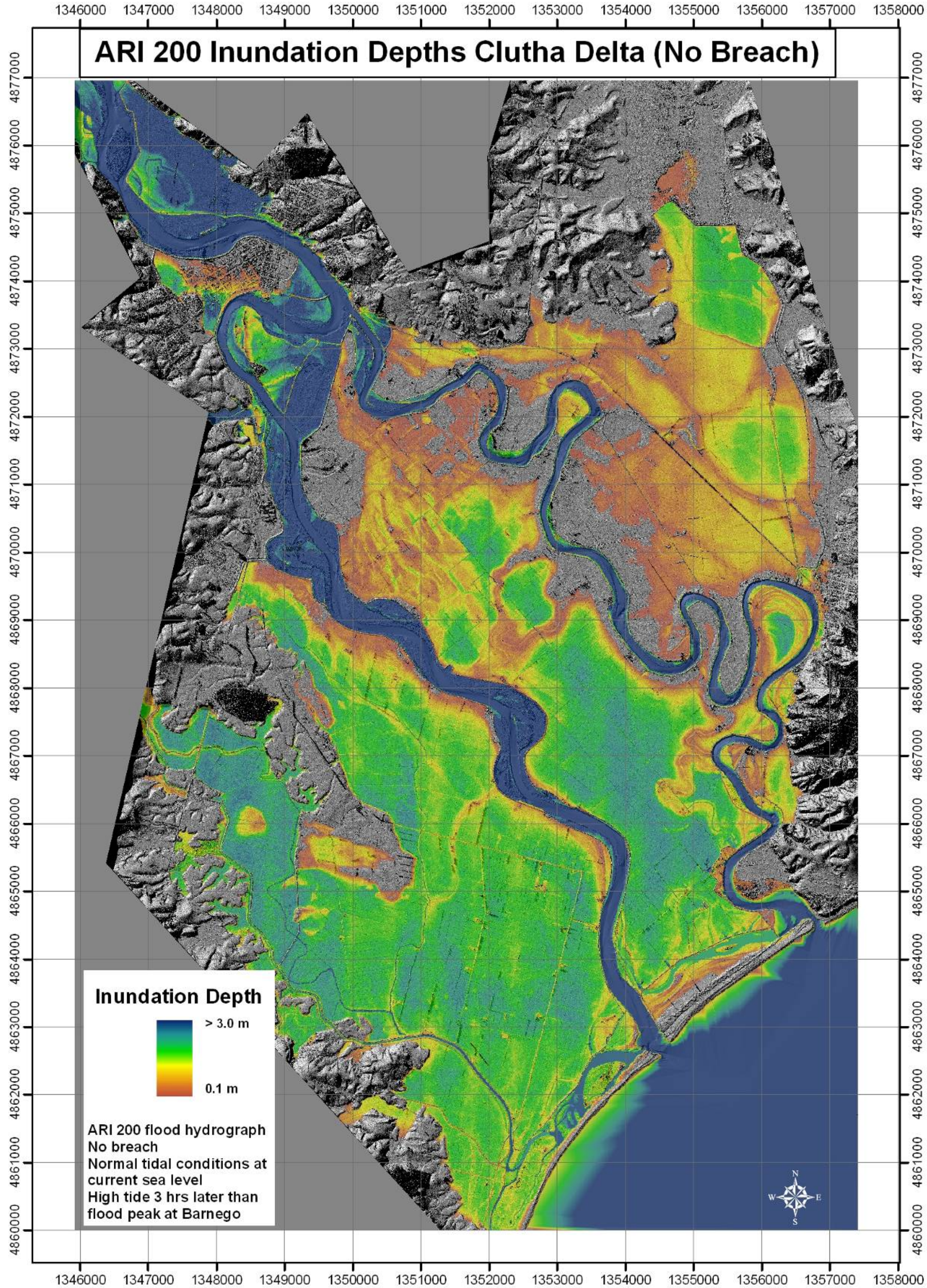


Figure 14: Inundation depths resulting from a 200yr ARI flood with no floodbank failure.

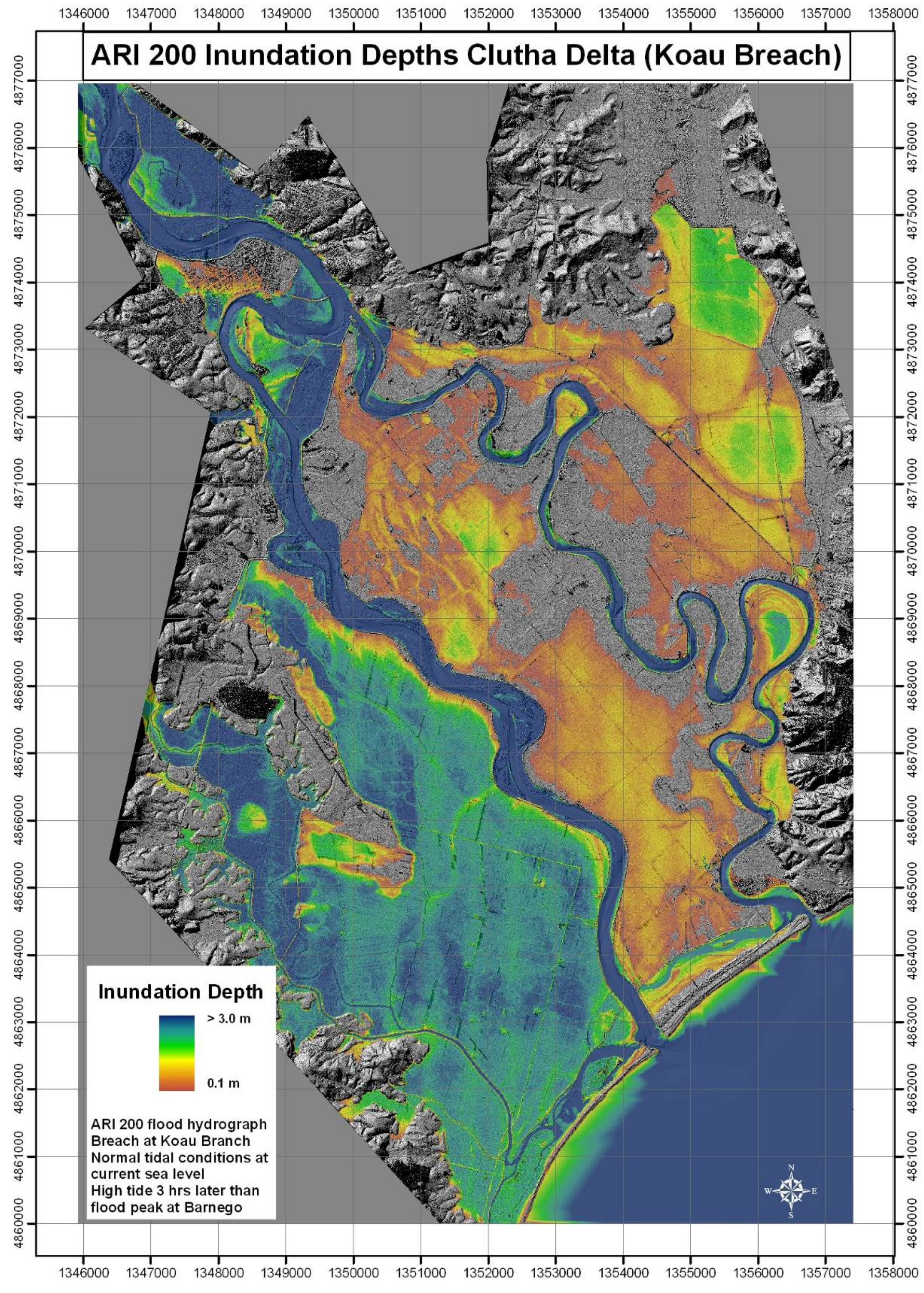


Figure 15: Inundation depths resulting from a 200yr ARI flood with breaching on the Koau branch.

3.9. 500 yr ARI flood event

Except for some high ground beside the rivers and along the coastal strip, the entire Clutha Delta is inundated, including that part of Balclutha that is on the flat. The modelled 500 yr ARI flood overtopped floodbanks slightly later than the 200 yr ARI flood due to its slower early rate of rise. More specific details on local water depths and maximum velocities during the 500 yr ARI flood event are given in the accompanying Map Info compatible files.

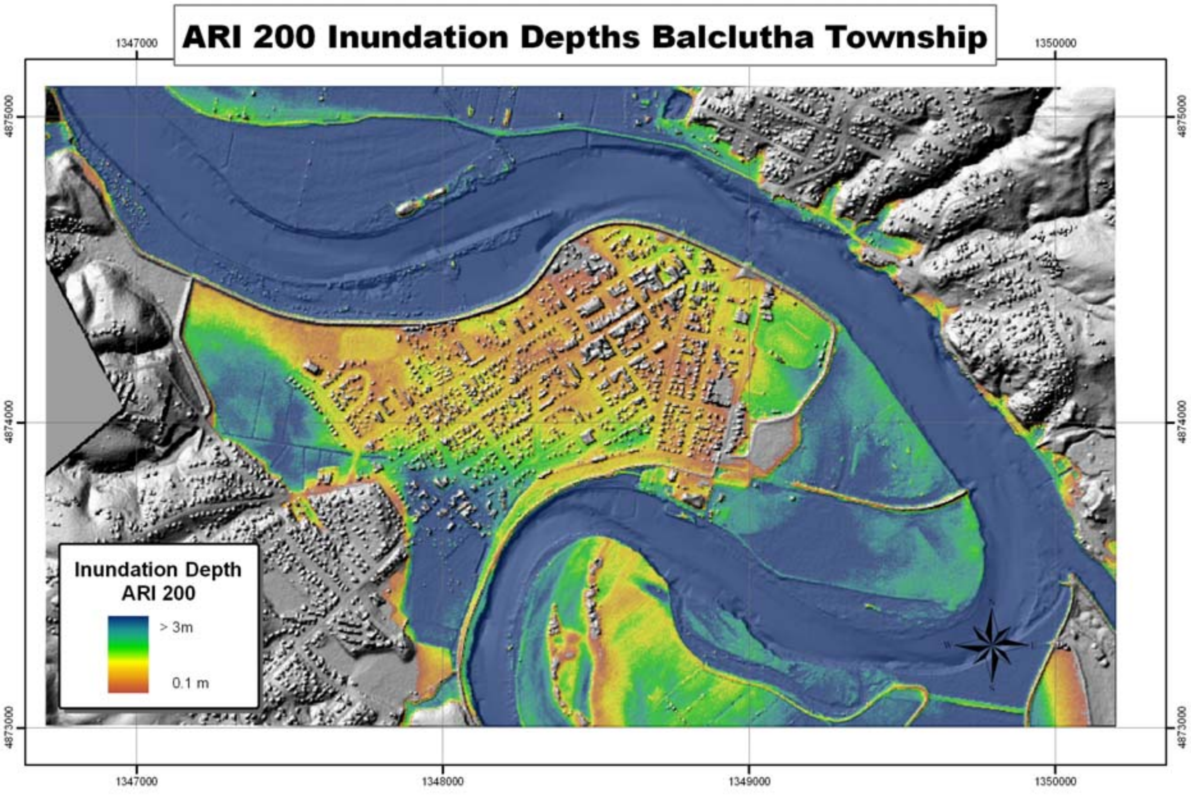


Figure 16: Balclutha inundation predicted during a 200 yr ARI flood with no floodbank breaches.

4. Hazard evaluation

A potential hazard exists if floodbanks do not meet the specifications of the project design. While it was not possible to check the original design specifications, low points in the present floodbanks have been detected at several locations. These are given in Table 2.

Table 2: Location of low points in the present floodbanks indicated by the LiDAR survey

Balclutha Floodbanks:
E1348150 N4873510 to E1348245 N4873670

Matau Floodbanks:
E1352155 N4872440 to E1352140 N4872470
E1352815 N4870550 to E1352820 N4870620
E1352990 N4870060 to E1352900 N4870215
E1354115 N4869040 to E1354115 N4869100

Koau Floodbanks:
E1350000 N4868870 to E1349950 N4868890
E1349530 N4869300 to E1349520 N4869320
E1349925 N4869690 to E1349905 N4869765
E1351480 N4868330 to E1351510 N4868335
E1349915 N4868910 to E1349870 N4868950

Floodbank failure at the last of these locations prevents a 100 yr ARI flood from backing up into Balclutha township because the floodbank failure reduces upstream flood water levels. If the floodbank is resilient at this location or if it was raised, thus preventing a breach, the models indicate that parts of Balclutha would be flooded in a 100 yr ARI event.

Flood depths, velocities and consequential hazard are available at any point in the modelled domain by delving into the output files that have been supplied to the Council. As it is not possible to report on all 106 model variants, the 100 yr ARI flood with present mean sea level is used as an example to illustrate the locations of potential hazards.

4.1. Hazard due to water depth

Different degrees of water depth hazard are illustrated on Figure 17 for the 100 yr ARI flood. It is considered that water in the 0.3 – 0.6 range would enter many buildings and stall common modes of transportation. Water depths in the 0.6 – 0.9 m range would present some risk of drowning and water levels deeper than 0.9 m would cause serious damage to dwellings and present a higher risk of loss of life.

4.2. Velocity hazard

Areas with high water velocities are shown on Figure 18. Velocities greater than 1 m/s present a risk to unsecured pedestrians, particularly if the water is deep. Velocities greater than 3 m/s indicate a strong likelihood of scouring of unprotected structures.

In several locations (usually on the outside of bends), significant velocities occur against the stopbanks. Failure of stopbanks from lateral scouring has not been considered in the present model runs and such failures could markedly change the inundation extent.

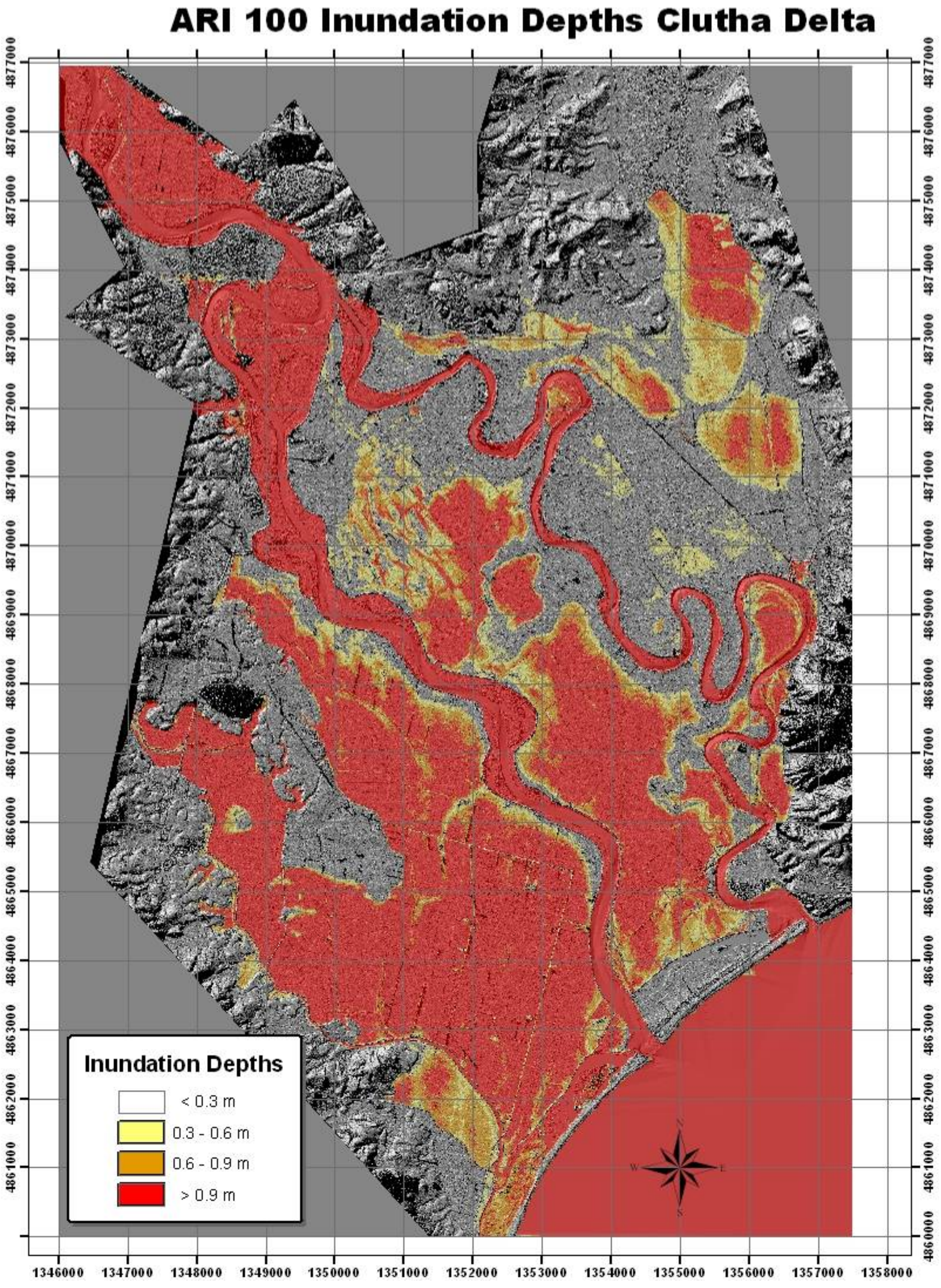


Figure 17: **Hazardous locations due to water depth during a 100 yr ARI flood with present sea level.**

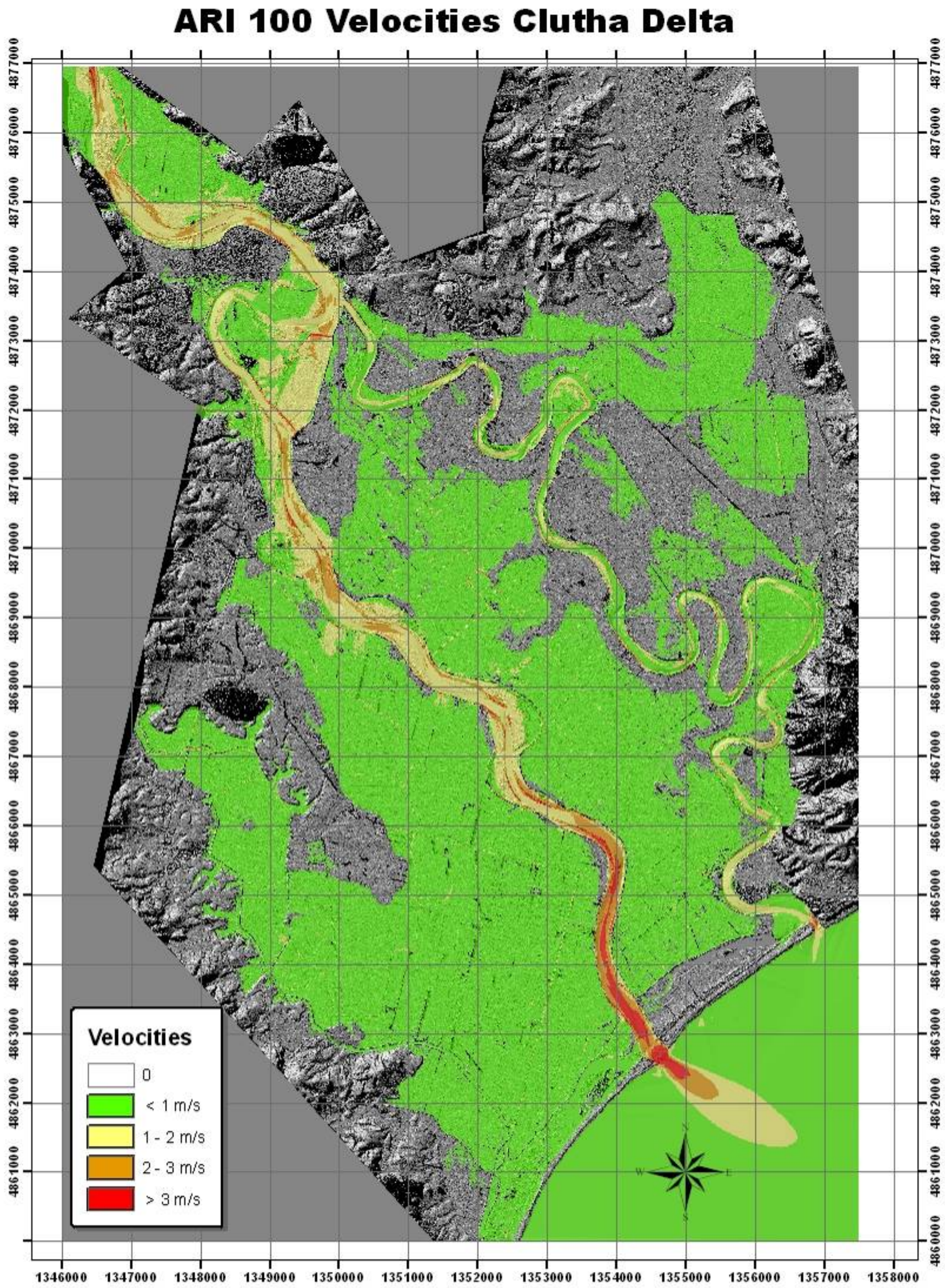


Figure 18: **Hazard due to water velocities during an ARI 100 yr flood at present sea level**

5. Summary and Conclusions

A 10 m grid model of the greater Clutha Delta region and a 4 m grid model of the Balclutha township were developed and evaluated using the *Hydro 2de* numerical hydraulic model in conjunction with 8 design flood hydrographs, 3 sea-level scenarios and various floodbank breach scenarios.

The results show that overtopping of sections of the present floodbanks occurs from around a 50 yr ARI flood.

Depending on downstream conditions, a 100 yr ARI flood may or may not flood into Balclutha township from the downstream side. A breach of the Koau floodbanks downstream of Balclutha can help protect the township and also prevent inundation of much of Inch Clutha. A piping failure of the stopbank on the North side of Balclutha township would be catastrophic and cause great loss of life if the township were not evacuated. Details of local flood depths and velocities may be found in the Map Info compatible files supplied in conjunction with this report.

The bed, as surveyed in 2005, must undergo considerable vertical scouring to pass floods such as the 1999 calibration flood. Should future scouring not occur, or should it evolve in a different manner to that indicated by the models, inundation levels different from those predicted by the models could result.

6. References

Otago Regional Council (March 2000). Clutha River Catchment Updated Flood Frequency Analyses Following the November 1999 Flood Event. ISBN: 1-877265-02-0, 20 p.

Otago Regional Council (May 2000). Lower Clutha Flood Control and Drainage Scheme, Operation and Maintenance Manual. 42 p.

Smart, G.M.; Duncan, M.J.; Walsh, J. (2002). Relatively Rough Flow Resistance Equations. *Journal of Hydraulic Engineering, ASCE 128(6)*: 568-578.

Smart, G.M. (2004). An Improved Flow Resistance Formula. Proceedings of River Flow 2004, A2-15, Balkema, Netherlands: 259-263.

Appendix 1: Clutha Delta model and Balclutha model

Clutha Delta Model (10m resolution)

File name	Flood	Sea level	Breach	Constraints
Calibration1999.zip	1999	actual	nil	Calibration flood
MeanFlowSL2100.zip	Mean flow	2	nil	2100 sea level, no flood
ARI10br12.zip	ARI 10	1	Koau	2005 bed bathymetry
ARI20br12.zip	ARI 20	1	Koau	2005 bed bathymetry
ARI50br12.zip	ARI 50	1	Koau	Scoured bed used
ARI100br12.zip	ARI 100	1	Koau	Scoured bed used
ARI200br12.zip	ARI 200	1	Koau	Scoured bed used
ARI500br12.zip	ARI 500	1	Koau	Scoured bed used
4000br12.zip	4000 m^3/s	1	Koau	Scoured bed used
5600br12.zip	5600 m^3/s	1	Koau	Scoured bed used
ARI10SL2100br12.zip	ARI 10	2	Koau	2005 bed bathymetry
ARI20SL2100br12.zip	ARI 20	2	Koau	2005 bed bathymetry
ARI50SL2100br12.zip	ARI 50	2	Koau	Scoured bed used
ARI100SL2100br12.zip	ARI 100	2	Koau	Scoured bed used
ARI200SL2100br12.zip	ARI 200	2	Koau	Scoured bed used
ARI500SL2100br12.zip	ARI 500	2	Koau	Scoured bed used
4000SL2100br12.zip	4000 m^3/s	2	Koau	Scoured bed used
5600SL2100br12.zip	5600 m^3/s	2	Koau	Scoured bed used
ARI10SSbr12.zip	ARI 10	3	Koau	2005 bed bathymetry
ARI20SSbr12.zip	ARI 20	3	Koau	2005 bed bathymetry
ARI50SSbr12.zip	ARI 50	3	Koau	Scoured bed used
ARI100SSbr12.zip	ARI 100	3	Koau	Scoured bed used
ARI200SSbr12.zip	ARI 200	3	Koau	Scoured bed used
ARI500SSbr12.zip	ARI 500	3	Koau	Scoured bed used
4000SSbr12.zip	4000 m^3/s	3	Koau	Scoured bed used
5600SSbr12.zip	5600 m^3/s	3	Koau	Scoured bed used
ARI10br3.zip	ARI 10	1	Mosley	2005 bed bathymetry
ARI20br3.zip	ARI 20	1	Mosley	2005 bed bathymetry
ARI50br3.zip	ARI 50	1	Mosley	Scoured bed used
ARI100br3.zip	ARI 100	1	Mosley	Scoured bed used
ARI200br3.zip	ARI 200	1	Mosley	Scoured bed used
ARI500br3.zip	ARI 500	1	Mosley	Scoured bed used
4000br3.zip	4000 m^3/s	1	Mosley	Scoured bed used
5600br3.zip	5600 m^3/s	1	Mosley	Scoured bed used
ARI10SL2100br3.zip	ARI 10	2	Mosley	2005 bed bathymetry
ARI20SL2100br3.zip	ARI 20	2	Mosley	2005 bed bathymetry

File name	Flood	Sea level	Breach	Constraints
ARI50SL2100br3.zip	ARI 50	2	Mosley	Scoured bed used
ARI100SL2100br3.zip	ARI 100	2	Mosley	Scoured bed used
ARI200SL2100br3.zip	ARI 200	2	Mosley	Scoured bed used
ARI500SL2100br3.zip	ARI 500	2	Mosley	Scoured bed used
4000SL2100br3.zip	4000 m^3/s	2	Mosley	Scoured bed used
5600SL2100br3.zip	5600 m^3/s	2	Mosley	Scoured bed used
ARI10SSbr3.zip	ARI 10	3	Mosley	2005 bed bathymetry
ARI20SSbr3.zip	ARI 20	3	Mosley	2005 bed bathymetry
ARI50SSbr3.zip	ARI 50	3	Mosley	Scoured bed used
ARI100SSbr3.zip	ARI 100	3	Mosley	Scoured bed used
ARI200SSbr3.zip	ARI 200	3	Mosley	Scoured bed used
ARI500SSbr3.zip	ARI 500	3	Mosley	Scoured bed used
4000SSbr3.zip	4000 m^3/s	3	Mosley	Scoured bed used
5600SSbr3.zip	5600 m^3/s	3	Mosley	Scoured bed used
ARI10br4.zip	ARI 10	1	Lawson	2005 bed bathymetry
ARI20br4.zip	ARI 20	1	Lawson	2005 bed bathymetry
ARI50br4.zip	ARI 50	1	Lawson	Scoured bed used
ARI100br4.zip	ARI 100	1	Lawson	Scoured bed used
ARI200br4.zip	ARI 200	1	Lawson	Scoured bed used
ARI500br3.zip	ARI 500	1	Lawson	Scoured bed used
4000br4.zip	4000 m^3/s	1	Lawson	Scoured bed used
5600br4.zip	5600 m^3/s	1	Lawson	Scoured bed used
ARI10SL2100br4.zip	ARI 10	2	Lawson	2005 bed bathymetry
ARI20SL2100br4.zip	ARI 20	2	Lawson	2005 bed bathymetry
ARI50SL2100br4.zip	ARI 50	2	Lawson	Scoured bed used
ARI100SL2100br4.zip	ARI 100	2	Lawson	Scoured bed used
ARI200SL2100br4.zip	ARI 200	2	Lawson	Scoured bed used
ARI500SL2100br4.zip	ARI 500	2	Lawson	Scoured bed used
4000SL2100br4.zip	4000 m^3/s	2	Lawson	Scoured bed used
5600SL2100br4.zip	5600 m^3/s	2	Lawson	Scoured bed used
ARI10SSbr4.zip	ARI 10	3	Lawson	2005 bed bathymetry
ARI20SSbr4.zip	ARI 20	3	Lawson	2005 bed bathymetry
ARI50SSbr4.zip	ARI 50	3	Lawson	Scoured bed used
ARI100SSbr4.zip	ARI 100	3	Lawson	Scoured bed used
ARI200SSbr4.zip	ARI 200	3	Lawson	Scoured bed used
ARI500SSbr4.zip	ARI 500	3	Lawson	Scoured bed used
4000SSbr4.zip	4000 m^3/s	3	Lawson	Scoured bed used
5600SSbr4.zip	5600 m^3/s	3	Lawson	Scoured bed used

Balclutha Model (4 m resolution)

File name	Flood	Breach	Constraints
BalARI10.zip	ARI 10	No breach	2005 bed bathymetry
BalARI20.zip	ARI 20	No breach	2005 bed bathymetry
BalARI50.zip	ARI 50	No breach	Scoured bed used, no breaches of delta banks
BalARI100.zip	ARI 100	No breach	Scoured bed used, no breaches of delta banks
BalARI200.zip	ARI 200	No breach	Scoured bed used, no breaches of delta banks
BalARI500.zip	ARI 500	No breach	Scoured bed used, no breaches of delta banks
Bal4000.zip	4000 m^3/s	No breach	Scoured bed used, no breaches of delta banks
Bal4000.zip	5600 m^3/s	No breach	Scoured bed used, no breaches of delta banks
BalARI10breachA.zip	ARI 10	Barnego Island	2005 bed bathymetry
BalARI20breachA.zip	ARI 20	Barnego Island	2005 bed bathymetry
BalARI50breachA.zip	ARI 50	Barnego Island	Scoured bed used, piping breach
BalARI100breachA.zip	ARI 100	Barnego Island	Scoured bed used, piping breach
BalARI200breachA.zip	ARI 200	Barnego Island	Scoured bed used, piping breach
BalARI500breachA.zip	ARI 500	Barnego Island	Scoured bed used, piping breach
Bal4000breachA.zip	4000 m^3/s	Barnego Island	Scoured bed used, piping breach
Bal5600breachA.zip	5600 m^3/s	Barnego Island	Scoured bed used, piping breach
BalARI10breachB.zip	ARI 10	Barnego Road	2005 bed bathymetry
BalARI20breachB.zip	ARI 20	Barnego Road	2005 bed bathymetry
BalARI50breachB.zip	ARI 50	Barnego Road	Scoured bed used, potential overtopping breach
BalARI100breachB.zip	ARI 100	Barnego Road	Scoured bed used, potential overtopping breach
BalARI200breachB.zip	ARI 200	Barnego Road	Scoured bed used, potential overtopping breach
BalARI500breachB.zip	ARI 500	Barnego Road	Scoured bed used, potential overtopping breach
Bal4000breachB.zip	4000 m^3/s	Barnego Road	Scoured bed used, potential overtopping breach
Bal5600breachB.zip	5600 m^3/s	Barnego Road	Scoured bed used, potential overtopping breach
BalARI10breachC.zip	ARI 10	Town NW bank	2005 bed bathymetry
BalARI20breachC.zip	ARI 20	Town NW bank	2005 bed bathymetry
BalARI50breachC.zip	ARI 50	Town NW bank	Scoured bed used, potential downstream breach

File name	Flood	Breach	Constraints
BalARI100breachC.zip	ARI 100	Town NW bank	Scoured bed used, potential downstream breach
BalARI200breachC.zip	ARI 200	Town NW bank	Scoured bed used, potential downstream breach
BalARI500breachC.zip	ARI 500	Town NW bank	Scoured bed used, potential downstream breach
Bal4000breachC.zip	4000 m^3/s	Town NW bank	Scoured bed used, potential downstream breach
Bal5600breachC.zip	5600 m^3/s	Town NW bank	Scoured bed used, potential downstream breach

Appendix 2: River Cross Sections Supplied.

Clutha River file names	**Koau Branch file names**	**Matau Branch file names**
C1.xls	K9.xls	M5.xls
C2.xls	K10.xls	M6.xls
C3.xls	K10A.xls	M7.xls
C5.xls	K11.xls	M8.xls
C6.xls	K12.xls	M9.xls
C7.xls	K13.xls	M10.xls
C8.xls	K48.xls	M11.xls
C9.xls	K54.xls	M12.xls
C10.xls	K64.xls	M94.xls
C11.xls	K67.xls	M99.xls
C12.xls	K84.xls	M128.xls
C13.xls		M140.xls
		M147.xls
		M154.xls
		M195.xls
		M202.xls
		M223.xls

Clutha River Flood Hazard Assessment - Mt Cooee Landfill

M.J. Goldsmith

GHC Consulting Report 2023/03

Original Version March 2023
Updated 14 April and 17 May 2023

DISCLAIMER

This report has been prepared by GHC Consulting Limited exclusively for and under contract to the Clutha District Council. Unless otherwise agreed in writing, GHC Consulting Limited accepts no responsibility for any use of, or reliance on any contents of this Report by any person other than the Clutha District Council and shall not be liable to any person other than Clutha District Council, on any ground, for any loss, damage or expense arising from such use or reliance.

CONTENTS

FIGURES

EXECUTIVE SUMMARY

Flood hazard in the vicinity of the Mt Cooee landfill has been assessed. The landfill is located near Balclutha, at the upper end of the Clutha Delta. The landfill has been developed in the valley of a small creek which flowed into the Clutha River/Matau-Au. This creek was previously exposed to flooding from the Clutha River during large events.

With significant infilling due to landfill activity, only the berm area between the front face of the landfill and the main river channel is now exposed to flooding. This includes the stormwater sedimentation ponds which lie on this berm area. The depth of inundation across this berm area will vary depending on the magnitude of the flood event, but previous modelling (NIWA, 2005) suggests it will not exceed 1.0 metres.

Deposition of silt across all or part of the berm area would be expected during an extreme flood event, and this would require removal post the event. Erosion of the front face of the landfill due to an extreme flood event is unlikely, due to the low velocity of floodwater and the construction methods used to cap the landfill.

1.0 INTRODUCTION

GHC Consulting were engaged by Clutha District Council to undertake a simple flood hazard[1] assessment at the Mt Cooee landfill near Balclutha (Figure 1-1). The assessment relates to potential flood impacts from the Clutha River/Mata-Au only.

Figure 1-1 View of the Mt Cooee area from the Kaitangata Highway, showing the river and berm area to the right, and the landfill face to the left (through the trees). Source: Google Maps.

As noted in a previous Otago Regional Council (ORC) report relating to natural hazards on the Clutha Delta,[2] "Land use decisions in the future will need to take the complex hazard setting … into consideration to ensure that proposed and existing activities are compatible with the hazard exposure and the residual risks posed by a range of natural hazards." This report is intended to assist Clutha District Council understand flood hazard in the vicinity of the Mt Cooee landfill.

2.0 ENVIRONMENT SETTING

The Mt Cooee landfill is located near Balclutha, at the upper end of the Clutha Delta (Figure 2-1). The Clutha Delta is a low lying alluvium-filled basin, approximately 130 km^2 in size, surrounded by low hills to the north, east and west, and Molyneux Bay to the southeast (ORC, 2016). The delta has gently sloping topography, with the central part of Balclutha lying at about 10m above sea level, despite being almost 13 km from the Pacific Ocean. The delta has been formed by the Clutha River/Mata-au (New Zealand's largest river, in terms of catchment size and flow volume).

---

[1] *Hazard*: An unavoidable danger or threat to property and human life, resulting from naturally occurring events.

[2] *Natural Hazards on the Clutha Delta, Otago.* (May 2016). Hornblow, S., Payan, J.L., Sims, A., O'Sullivan, K. Reviewed by Goldsmith, M. & Palmer, G.

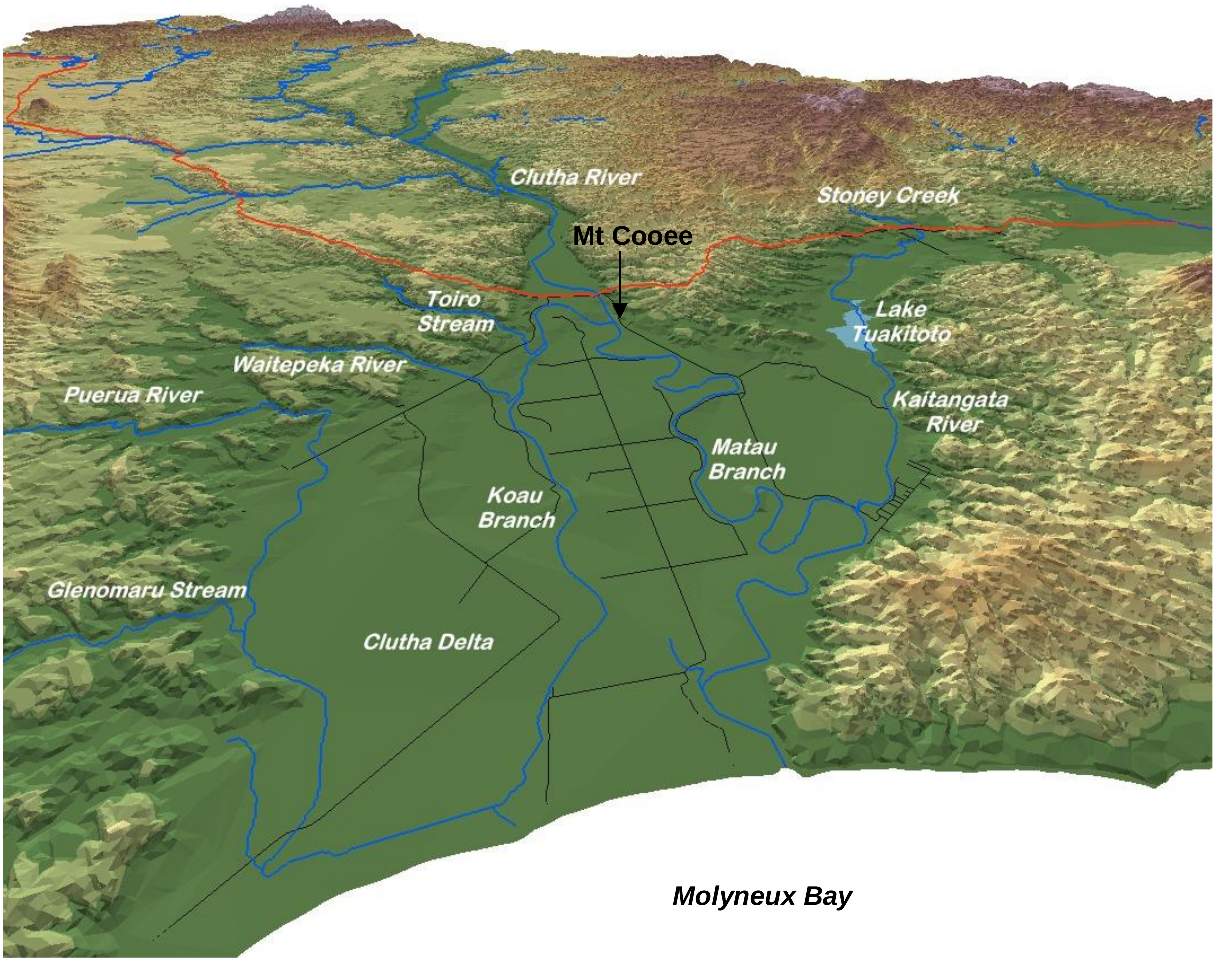


Figure 2-1 Digital Elevation Model of the Clutha Delta, looking towards the northwest, with 3 times vertical exaggeration. Source: ORC 2016.

There are a range of natural hazards present on the Clutha Delta, and this assessment draws on information from previous ORC reports, as well as information available through the Otago Natural Hazards Portal (link). Flooding is the most recognised hazard on the Clutha Delta due to its frequency of occurrence and has always been a fact of life for those living on the delta. A number of significant floods have occurred since early European settlement began in the mid-19th century, with the most notable in recent times occurring in October 1978, December 1995, November 1999, and February 2020 (Figure 2-2).

2.1 MT COOEE LANDFILL

The Mt Cooee landfill is the only Class 1 landfill in the Clutha District that accepts municipal solid waste. The landfill receives waste from council’s kerbside waste collections, commercial waste from private waste operators, and waste from the public. Council also operates rural transfer stations throughout the district, and waste from these transfer stations is disposed of at Mt Cooee.

The landfill lies near the bifurcation, where the main stem of the clutha River/Mata-au splits into the Koau and Matau branches (Figure 2-3). The landfill has been created by infilling of a small creek which previously flowed into the Clutha River just upstream of the bifurcation. Water from this catchment has now been diverted away from the landfill, along the northern side of the South Island Main Trunk Line.

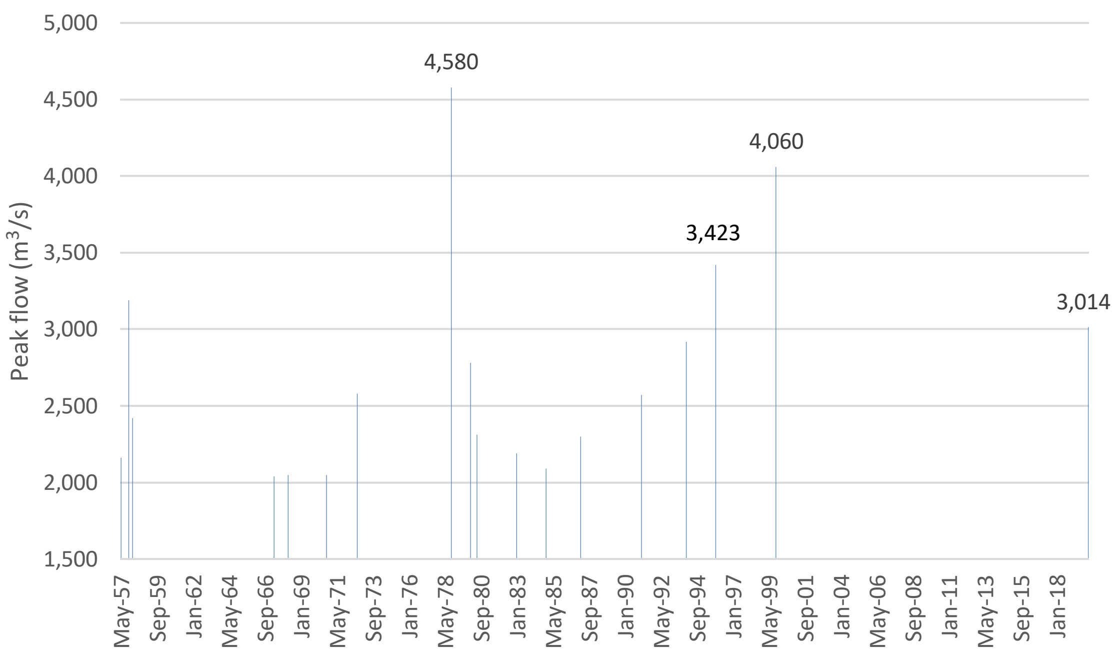


Figure 2-2 Flood peaks above 2,000 m3/s in the Clutha River at Balclutha, from 1950 to 2023. The peak flood flows in the 1978, 1995, 1999 and 2020 floods are labelled. Data sourced from NIWA.

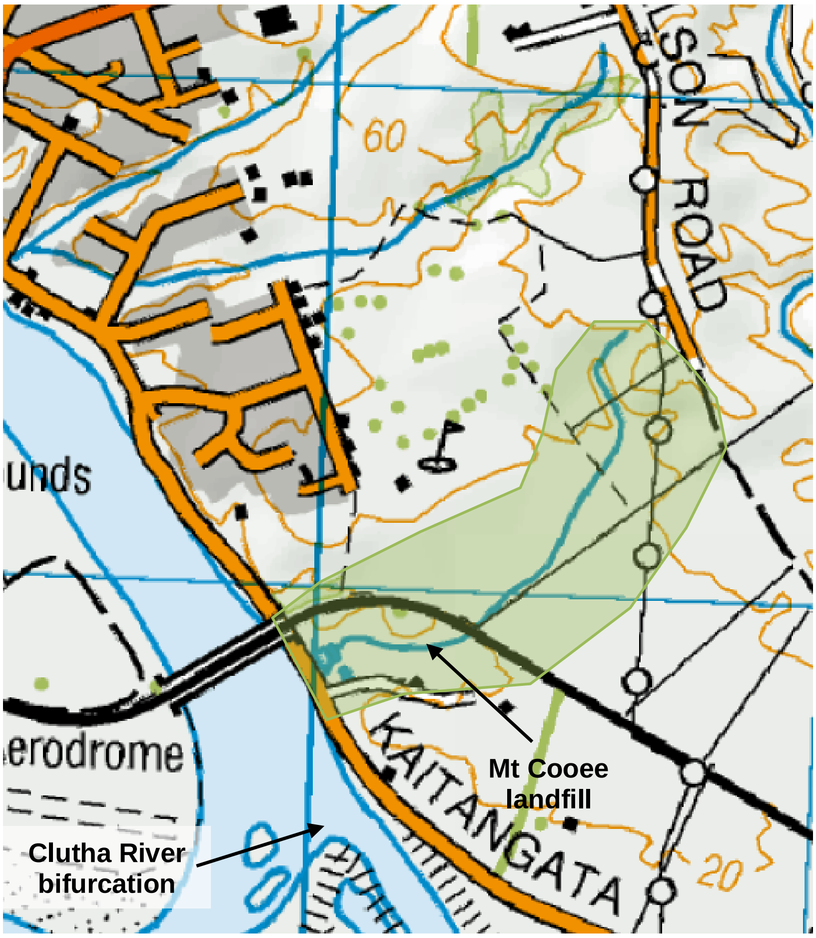


Figure 2-3 A 1:50,000 topographic map of the Mt Cooee area. The approximate extent of the small creek where the landfill has been developed is shaded in green. Source: LINZ Topomap.

3.0 FLOOD HAZARD

The ORC's 2016 assessment of natural hazards on the Clutha Delta divides the area into 22 geographical areas, based on their flood-hazard characteristics. The Mt Cooee landfill lies within or adjacent to Area A1. The following items are paraphrased from the description of Area 1A in the ORC report and are generally relevant to the study area.

- *Area A1 comprises the immediate flood berms of the Clutha River including the river channel. The berm areas are directly exposed during the early stages of flooding.*
- *The land is generally flat and is used primarily for agricultural activities and other facilities (aerodrome, silos, saleyards) with few dwellings.*
- *There is no, or very limited direct flood protection. The area is bounded by higher ground in the absence of flood banks. It includes low-lying areas of North Balclutha (on the true left side of the river).*
- *The area plays a crucial role in the conveyance of floodwater, and in the mitigation of flood hazard for other parts of the delta. It is the main flow path during high river flows, and modifications to this area could affect the safe and effective operation of the Lower Clutha Flood Protection Scheme.*
- *Flooding would be widespread over the area in a 1:100-year flood event, with the depth of water likely to exceed 3 m on the berm areas and the water velocity could exceed 2 m/s at some locations.*
- *The potential hazard (expressed as a combination of the depth of inundation and of the water velocity) to people and buildings in this area is considered to be extremely high.*

3.1 FLOOD HAZARD PRIOR TO LANDFILL DEVELOPMENT

A map of the 1A flood hazard area is not available through the ORC's Natural Hazards Portal. However, the extent of this area appears to be based on an earlier flood hazard assessment prepared by ORC in 1999[3] which in turn is based on the mapped extent of the May 1957 flood. The mapped extent of this flood in the vicinity of Mt Cooee is shown in Figure 3-1.

A larger flood occurred in October 1978 and an aerial view of the area is shown in Figure 3-2. The extent of flooding during this flood is similar to the mapped hazard area shown in Figure 3-1, although it is noted that infilling of the creek (due to landfill development) had not occurred at that time.

---

[3] *Clutha District Floodplain Report* (1999). Report prepared by Melanie Stevenson, Engineer.

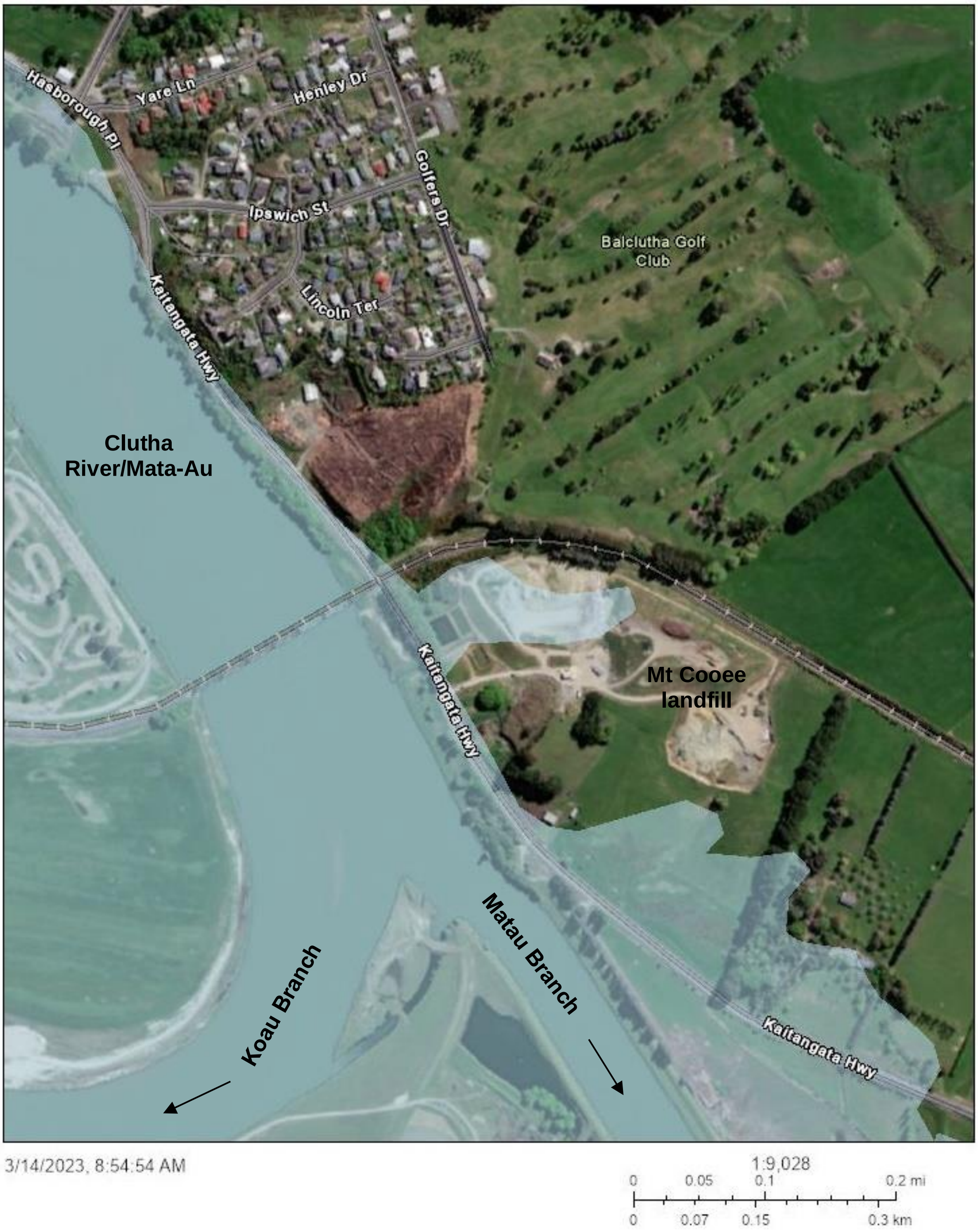


Figure 3-1 Lower Clutha Flood hazard area in the vicinity of the Mt Cooee landfill. Flood hazard area is based on the estimated extent of the May 1957 flood (2,160 m^3/s). Source: ORC Natural Hazards Portal.

Figure 3-2 The October 1978 flood event, looking upstream towards Balclutha. The current site of the Mt Cooee landfill is circled in red. The photo was not necessarily taken at the peak of the flood. Source: ORC.

3.2 FLOOD HAZARD POST LANDFILL DEVELOPMENT

The current flood hazard area mapped by ORC (Figure 3-1) extends well up into the landfill and does not take into account the infilling of the small catchment which has occurred as the landfill has been formed over the last few decades. This area is now considerably higher (Figure 1-1) and the landfill itself is therefore less likely to be inundated during a flood event of the magnitude seen during the last 70 years (Figure 2-2).

A general view of the Clutha Delta during the November 1999 flood is shown in Figure 3-3. This photo helps to confirm the description of flood hazard on the Clutha Delta, with the landfill lying on the margins of a broad floodplain, with more elevated land to the northeast.

An aerial view of the landfill site during the November 1999 flood is shown in Figure 3-4 and Figure 3-5. Although not necessarily taken at the peak of the flood, these photos show that flooding was limited to the berm area, including the Kaitangata Highway, and the area around the stormwater sedimentation ponds. Although the landfill was only partly developed at this time, the photos show evidence of landfill activity underway, and that this area was not affected by flooding from the Clutha River. Additional infilling has occurred since this time, particularly at the front face (Figure 1-1).

Figure 3-3 The November 1999 flood event, looking downstream across Balclutha. Photo not necessarily taken at the peak of the flood. The study area is circled in red. Source: ORC.

Figure 3-4 View of the Mt Cooee landfill looking north during the November 1999 flood. Source: ORC.

Figure 3-5 View of the Mt Cooee landfill looking south during the November 1999 flood. Source: ORC.

Modelling undertaken by NIWA[4] of an extreme flood (a 1:200-year event, peaking at 5,800 m^3/s) indicates that flooding to a depth of 0.5 m - 1.0 m could occur on the berm area between the Kaitangata Highway and the front face of the landfill (Figure 3-6 and Figure 3-7).[5]

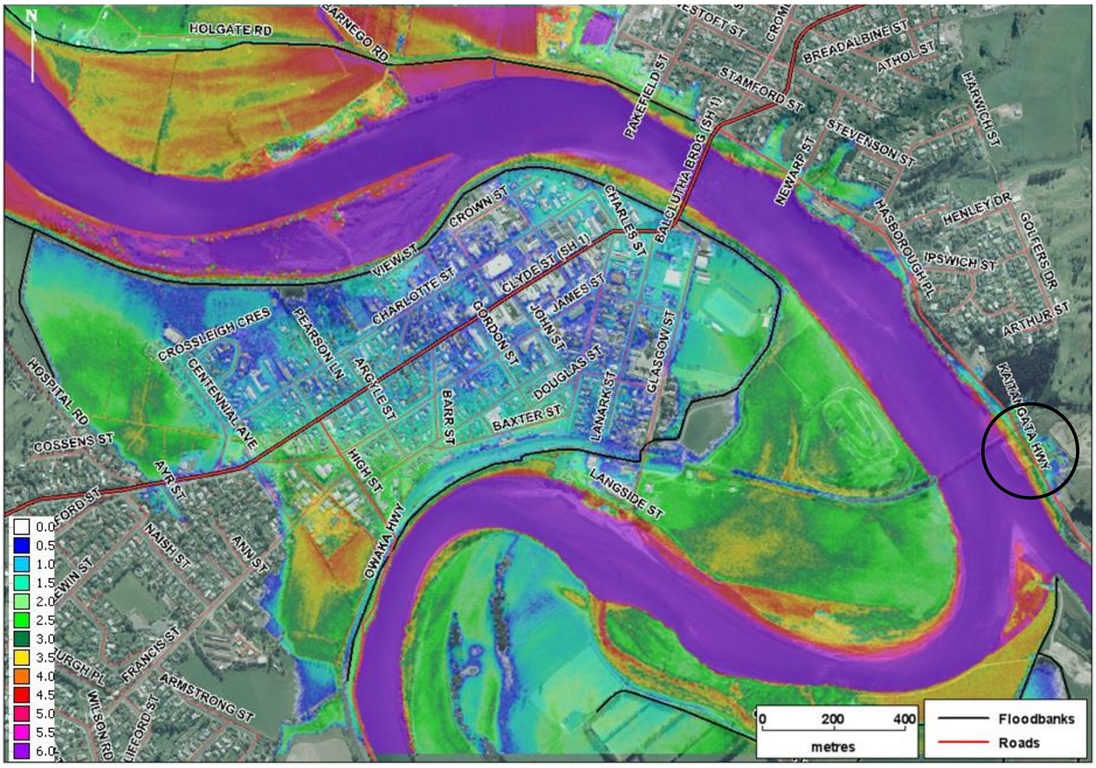
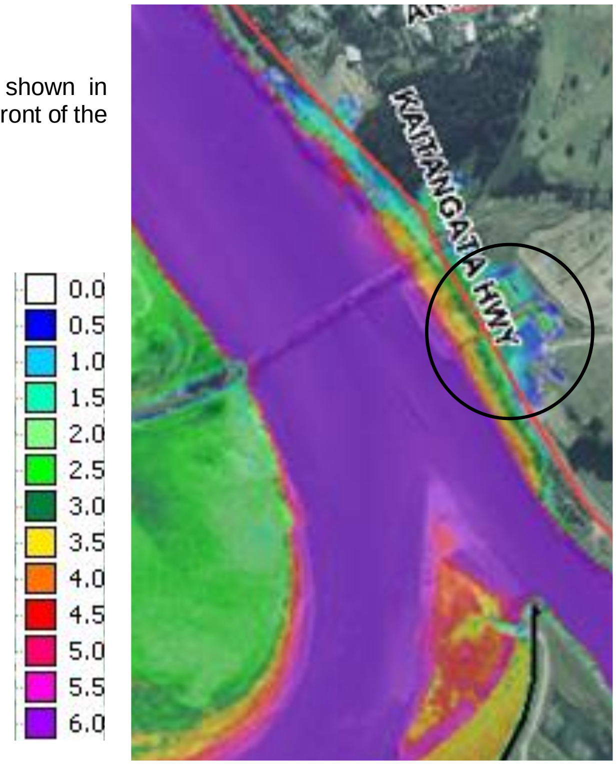


Figure 3-6 Estimated flood depth in Balclutha associated with a 1:200-year flood (peaking at 5,800 m3/s at Balclutha). Depth is in meters.

Figure 3-7 A close-up image of the modelling shown in Figure 3-6, showing the berm area in front of the Mt Cooee landfill (circled in black).



---

[4] NIWA (2005) *Clutha Delta flood hazard study,* Prepared for the Otago Regional Council.

[5] This would be a extreme flood event, and the NIWA modelling shows overtopping of the flood bank at the southern end of Balclutha could result in widespread flooding of up to 1.5 m in the town.

The velocity of floodwater during this event (as modelled by NIWA) is shown in Figure 3-8 and Figure 3-9. This shows velocities of no more than 0.4 m/s on the eastern side of the Kaitangata Highway. Velocity near the front face of the landfill and the landfill access road are generally no more than 0.2 m/s.

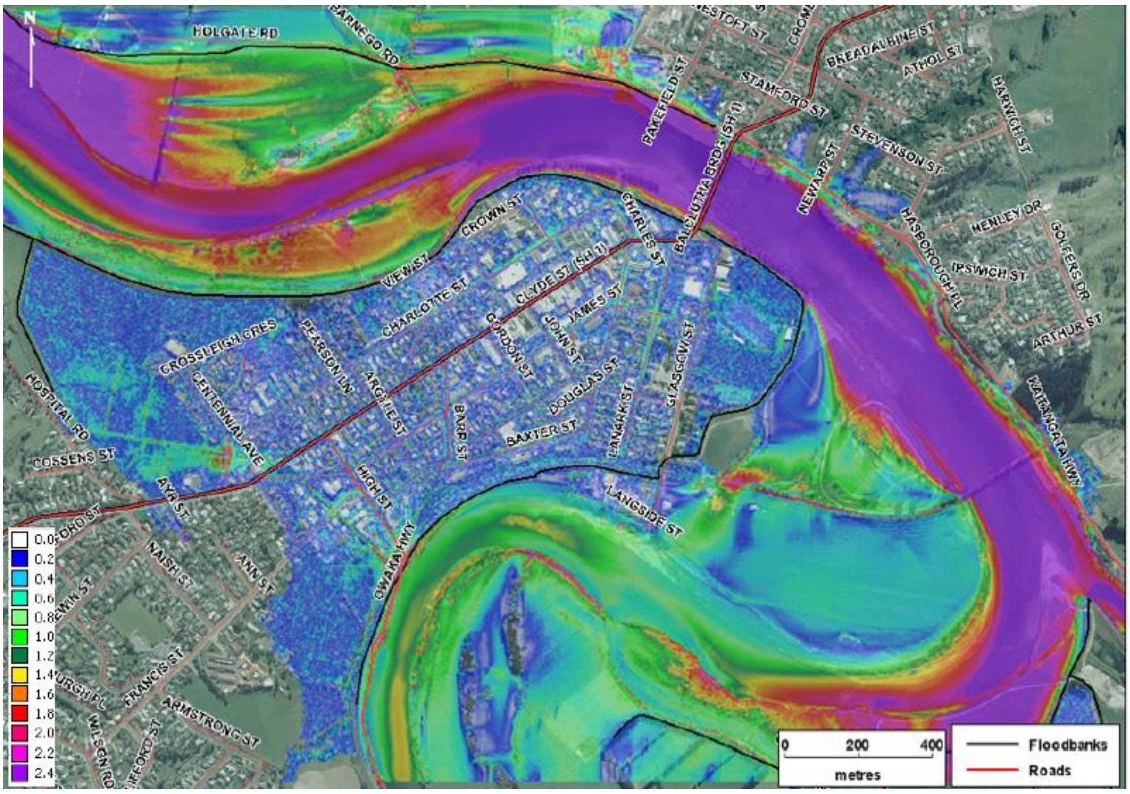
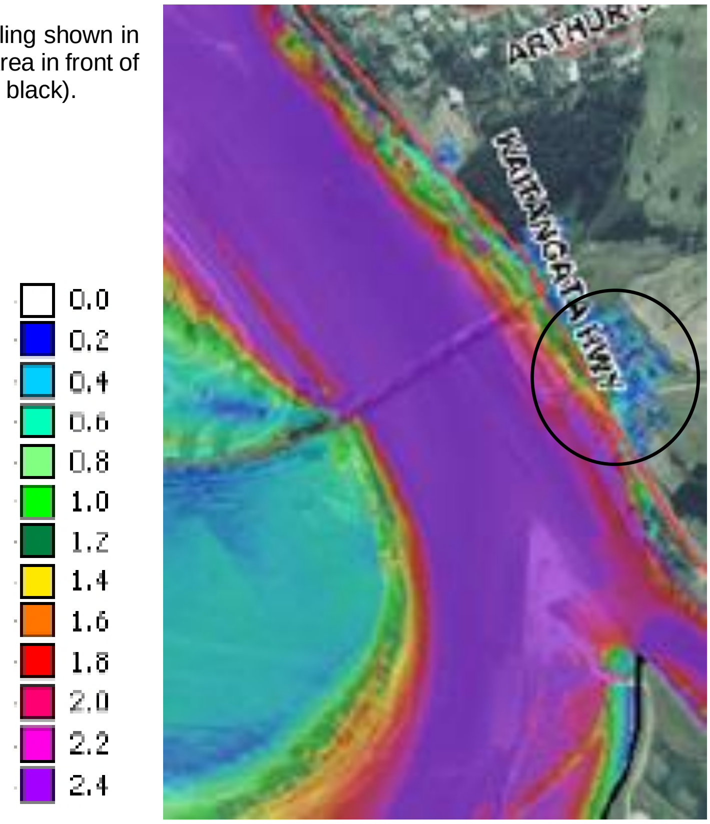


Figure 3-8 Estimated flood velocity in Balclutha associated with a 1:200-year flood (peaking at 5,800 m3/s at Balclutha). Velocity is in m/s.

Figure 3-9 A close-up image of the modelling shown in Figure 3-8, showing the berm area in front of the Mt Cooee landfill (circled in black).



3.3 CURRENT FLOOD RISK

3.3.1 Flood extent

Using currently available information, the floodplain (or berm) area that may be affected by flooding in the vicinity of the Mt Cooee landfill was mapped by GHC Consulting, and this is shown in Figure 3-10. A geomorphological approach[6] was used by GHC as the basis for identifying this area – i.e., it includes flat to gently sloping land which may be affected if water overtops the main channel, and subsequently flows or extends out across the floodplain.

The mapped area shown in Figure 3-10 is based on the photos and other information described above, a site visit in March 2023, and contour information held by CDC (Box 1). The landward extent of the mapped area follows the base of the terrace risers and embankments that border the floodplain. It does not follow a particular contour, but generally lies between the eight and ten metre contours. Land that lies well above potential break-out points has been excluded.

The depth and extent of flooding on this berm area will depend on the magnitude of the flood event, but is unlikely to extend beyond the mapped area, unless major changes in the topography of this area occur in the future. A photo showing the topography of this berm area is shown in Figure 3-11.

Subsequent work by WSP for the Clutha District Council refined the mapping undertaken by GHC to take account of the earthworks around the sediment ponds. WSP identified a flood boundary which is provided as Figure 3-12, and which shows “potential for flooding up to 1.1m above the Kaitangata Highway centreline”.[7]

Box 1: Technical specifications

The contours shown on Figure 3-10 are derived from LiDAR, collected by LINZ in January 2020. LiDAR vertical accuracy is +/- 0.12m, horizontal accuracy is +/- 0.57m. Vertical datum is NZVD2016. The contours do not represent any changes in topography which may have occurred since 2020.

The base layer is an urban aerial photo collected by CDC in 2023.

---

[6] Rather than other methods such as 2D modelling.

[7] R. Latham, email communication to CDC, 13 April 2023.

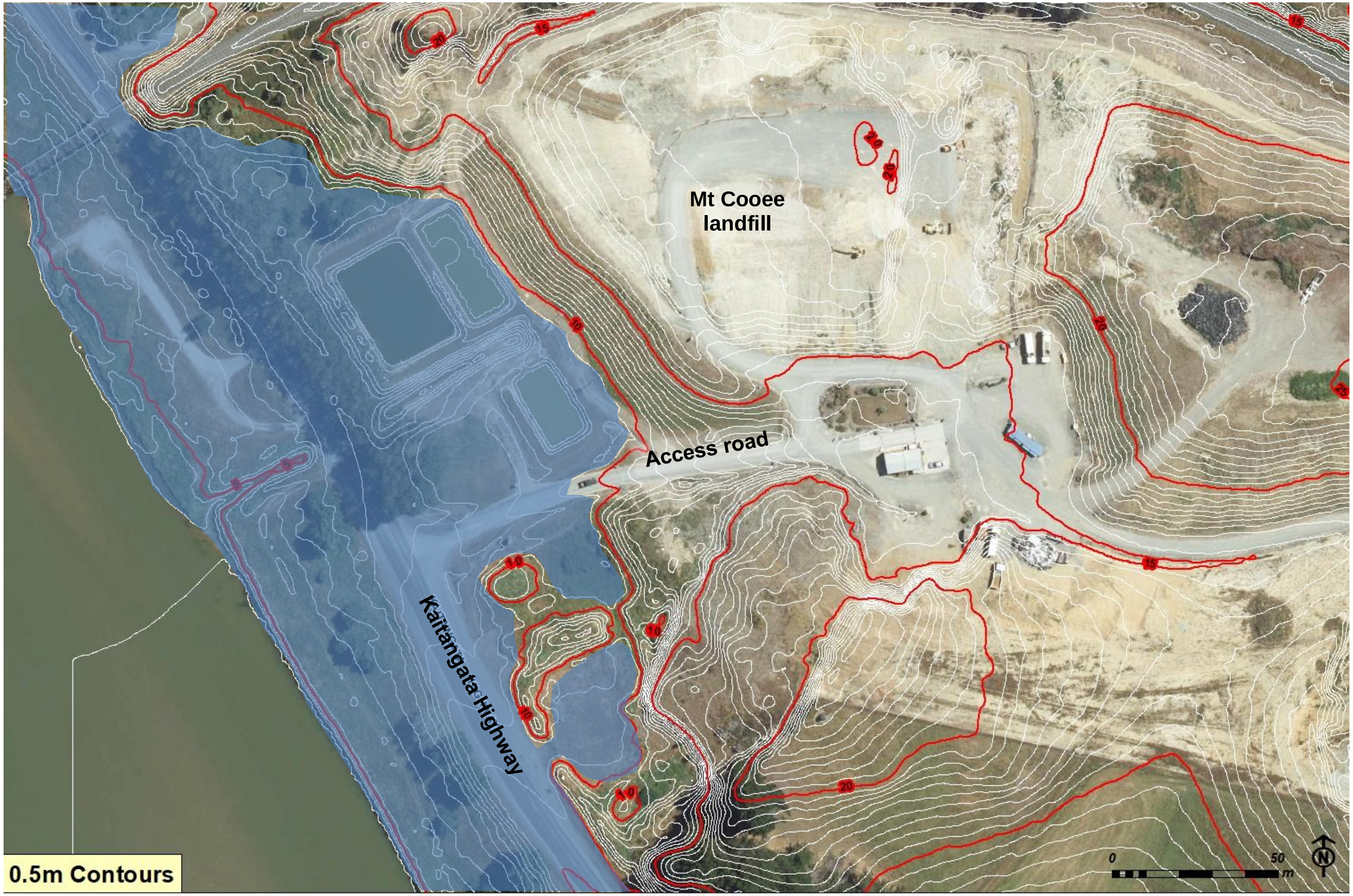


Figure 3-10 The approximate extent of the floodplain in front of the Mt Cooee landfill.

Figure 3-11 Top: view of the berm area and ponds in front of the Mt Cooee landfill. Bottom: showing the boundary of the berm area mapped by GHC.

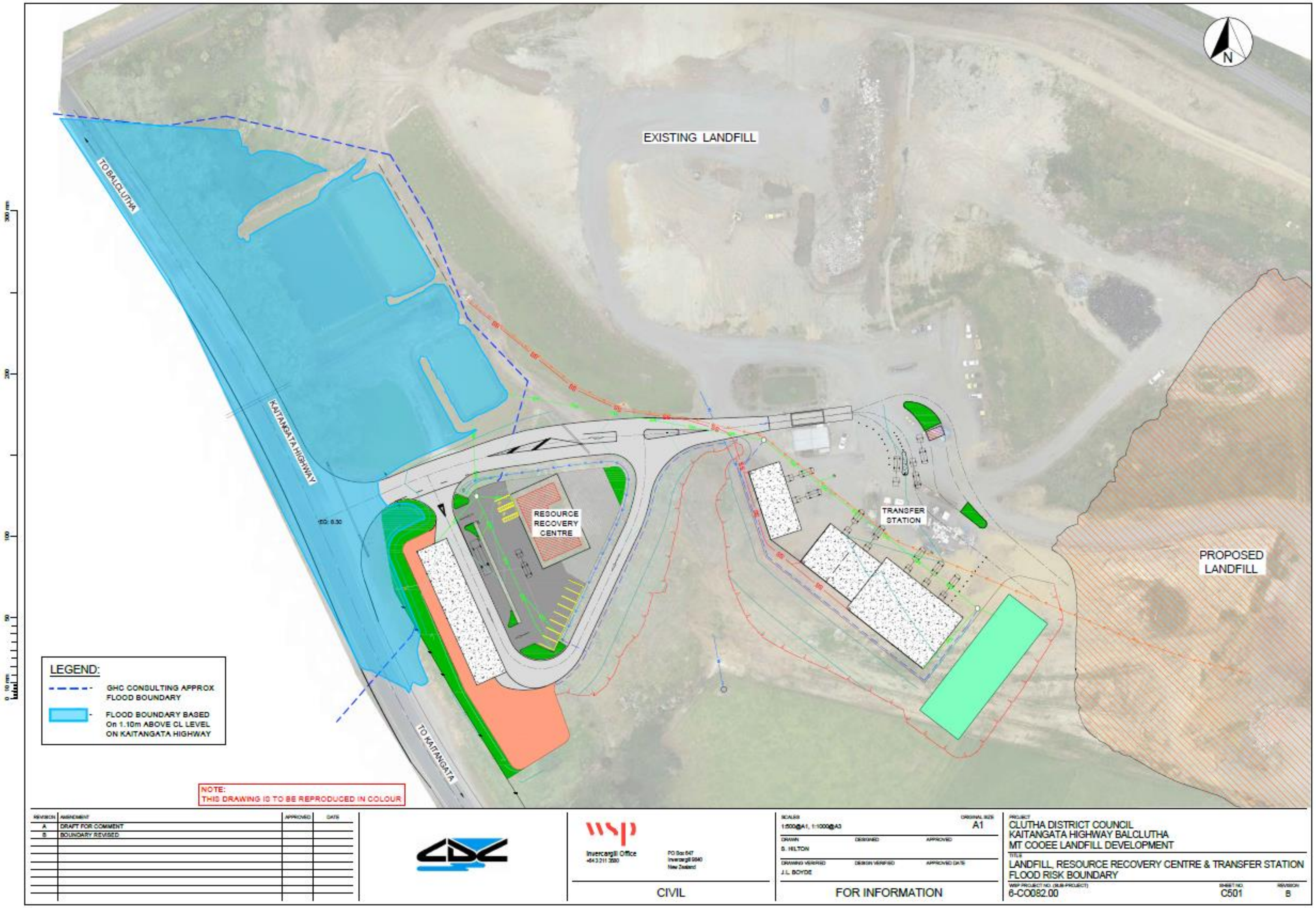


Figure 3-12 Flood boundary (shaded blue) based on 1.1m above centreline of the Kaitangata Highway, as mapped by WSP for CDC.

3.3.2 Flood hazard characteristics

The velocity of flood water on the berm area in front of the Mt Cooee landfill and near the proposed resource recovery centre[8] would be relatively slow (<0.4 m/s), even during extreme flood events (NIWA, 2005). The trees which border the site may also help to reduce velocity in the backwater which would form in front of the landfill face (noting that these trees may not always be present in the future). Significant erosion in this area due to an extreme flood event is therefore less likely, due to lower velocities and minimal depth of floodwater. The landfill face has a 3:1 slope and is constructed of a clay cap over the waste, which in turn is covered with a geosynthetic fabric liner, 300mm of topsoil and shallow rooting plants (predominantly native grass species). The cap is designed to stop water penetrating the landfill, whether this be rainfall, stormwater flowing down the face, or inundation from floodwater.

Under very high water levels, the stormwater sedimentation and leachate ponds may be inundated by flood water. The effect of this on the river during a major flood event is outside the scope of this report but would likely depend on the characteristics of any contaminants in the pond, the ability of the flood flows to remove these from the area, and how they were subsequently diluted within the river. The pond rims are elevated eight to ten metres above normal river level. For context, the water level of the Clutha River at Balclutha hydro site[9] rose up to five metres above normal during the November 1999 and February 2020 floods.

Deposition of silt across all or part of the berm area would be expected during an extreme flood event, and this would require removal post the event. The Kaitangata Highway is also affected during major flood events (Figure 3-4).

---

[8] As shown on the map prepared by WSP (Figure 3-12)

[9] located 0.9 km upstream of Mt Cooee