AECOM

Hawea Dam Break Update
Contact Energy Limited
30 September 2011

Hawea Lake Control Dam

Dam Break Analysis Update Report

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Prepared for

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Executive Summary

Contact Energy has engaged AECOM to undertake a hydraulic modelling study investigating potential consequences that could result from a failure of the Lake Hawea Control Dam. This report and accompanying flood maps document the results. A previous dam break study was undertaken in 1990, but in the last twenty years there has been significant development around Wanaka town requiring updated flood maps.

Potential Failure Scenarios and Breach Parameters

Two possible failure scenarios have been modelled; an earthquake induced piping failure under normal operating and inflow conditions (termed the 'sunny day event') and a piping failure induced by high lake levels following a Probable Maximum Flood (PMF) event in the catchment (termed the 'rainy day event').

A sunny day failure scenario was modelled in the 1990 study and has been repeated in this study using the same breach parameters. These being a single failure of the east dam only with a base breach width of 30m and breach invert of RL 326.00m. The starting water level was RL 346.00m, which is the maximum normal operating level.

A rainy day event was considered because the of New Zealand Society on Large Dams (NZSOLD) guideline requirement to model both fair weather and design flood scenarios. For the Hawea Dam the design flood is the PMF. The most recent PMF study for the Clutha catchment (Opus 2000) suggests that following a PMF event the level of Lake Hawea would be higher than the dam core for more than ten days. A piping failure was modelled with the same breach dimensions as the sunny day event, but with a starting lake level of RL 350.24m.

An analysis of a failure of the Gladstone Gap stopbank was outside the scope of this work and is not considered in this study. A Gladstone Gap failure event has previous been modelled by Opus (2007).

Breach Outflows

The peak breach outflow from Lake Hawea was estimated to be 14,500m^3/s and 21,300m^3/s for the sunny and rainy day failure events respectively. Because of the very large volume of water stored in Lake Hawea the breach discharge would continue for several weeks with the outflow gradually reducing as the lake level dropped until the lake was fully drawn down to a water level of RL 326.00m.

Flood Wave Hydraulic Modelling

The dam breach and downstream flood wave have been modelled simultaneously using HEC-RAS (version 4.1.0). Because of the deeply entrenched nature of the Hawea and Clutha Rivers a one-dimensional modelling approach was appropriate.

The model was developed using cross sections of the Clutha River supplied by Contact. These sections are a mix of ground survey for the river channel and LiDAR survey for the floodplain. The Hawea River was represented in the model using cross sections extracted from LiDAR data supplied by Contact.

Lakes Hawea, Wanaka and Dunstan were all represented using level-pool storage nodes. The Hawea and Clyde Dams were included in the model with stage-discharge curves based on Contact's Clutha flood rules.

Sensitivity Analyses

A wide range of sensitivity analyses were conducted to test the effects on the initial breach discharge and the downstream flood wave propagation. The peak discharge was found to be insensitive to changes in breach formation time, with formation times ranging between 30mins and 3hrs giving a change of less than 2%. The model is not sensitive to breach formation time because of the large storage volume and the time required to draw down the lake.

Both the sunny and rainy day models were run with a starting water level of RL 277.20m in Lake Wanaka. This is the median lake level for the period 1930-2007 (Opus 2009) and results in minimal inundation through Wanaka town. For a rainy day event it is likely that Lake Wanaka would have a higher initial level so a model was also run with a 100yr ARI starting level of RL 280.87m. This gives a peak lake level of RL 283.45m and significantly increases the inundation and damage through Wanaka town. Peak flood levels also increase in Albert Town.

The model did not include any allowance for sediment or debris transport, instead a sensitivity analysis was run using higher Manning's n values. Using a coefficient of 0.060 for both the floodplain and the channel decreases peak discharge by approximately 4% and increases peak water levels by an average 4% (with a range -2.2% to

+10%). The entrenched river channels mean this increased water level does not correspond to an increase in flood extent.

The model uses the Clyde Dam as the downstream boundary with a discharge rule based on Contact's Clutha flood rules. With these operational rules the dam would be overtopped in both a sunny and rainy day event. A sensitivity analysis considered an alternative scenario where the spillway gates are opened fully when water level in Lake Dunstan exceeds RL 195.10m. This gives negligible reductions in peak water level and discharge for both sunny and rainy day events.

Flood Inundation Extent

Although the Hawea River is deeply incised in its upper reaches, the depth of flood water following a breach means there would be some inundation onto the Hawea Flats downstream of the Hawea oxidation ponds. The bridge at Camp Hill Road would likely be destroyed by the initial flood wave, 40mins after maximum breach formation. With the constrained channel and the high peak discharge there would likely be severe bed and bank erosion along the Hawea River.

Albert Town is located at the confluence of the Hawea and Clutha Rivers and would experience widespread inundation and damage following a failure of Hawea Dam. The low lying area around the confluence would act as a flood storage area and there would be negative flow up both the Clutha and Cardrona Rivers. The flood peak would arrive at Albert Town 2.50 hours after the initiation of a breach at Hawea with the peak water level occurring 1.50 hours later (4.00 hours after breach initiation). The SH6 bridge would likely be destroyed, either by the initial flood wave or by erosion and slope instability on the south bank.

With an initial water level of RL 277.20m in Lake Wanaka and a peak flood level of RL 286.65m (for the sunny day event) in Albert Town, the normal flow direction would be reversed upstream of Albert Town. Water would spill into Lake Wanaka, which would experience a water level rise of 2.02m for the sunny day event and 2.98m for the rainy day event. Lake Wanaka has a surface area of approximately $193km^2$ and this large storage capacity means the lake would act as a flood detention basin following a breach of Hawea Dam. The peak inflow to the lake is $4,076m^3/s$ during a sunny day event and $6,500m^3/s$ during a rainy day event.

The large storage volume means the peak lake level would not occur for 3 days after a Hawea failure. When flood levels in the Clutha begin the drop, Lake Wanaka would then discharge the flood water back into the Clutha River. This increases the total duration of the flood event downstream of Albert Town, but significantly attenuates the peak discharge.

The sensitivity analyses show that if Lake Wanaka had a higher initial water level (close to the 100 year ARI of RL 280.87m) there would be extensive inundation and damage through Wanaka town. The lake level rises by 2.58m to a peak of RL 283.45m. Approximately 90 buildings, including several hotels, numerous cafes and a supermarket would all be inundated.

Downstream of Albert Town the peak flood discharge would be attenuated by both the ponding through Albert Town and the negative flow upstream to Lake Wanaka. The Clutha River is deeply incised and the flood wave would be contained within the channel. State Highway 8A crosses the Clutha River at Luggate, approximately 30km downstream of the Hawea Dam and the bridge would likely be destroyed in both a sunny and rainy day event.

The peak water levels in Lake Dunstan are controlled by discharge from the Clyde Dam. During a sunny day event and assuming Contact's flood rules were followed and the initial lake level was RL 194.00m, Lake Dunstan would rise by 3.74m to a peak of RL 197.74m. The corresponding figures for a rainy day event are 5.59m and RL 199.59m. The crest level of Clyde Dam is RL 196.75m, but the dam has been designed to withstand overtopping so a cascade failure is unlikely

The population at risk (PAR) following a failure of Hawea Dam is estimated to be 2,040 for the sunny day event and 2,280 for the rainy day event. If a rainy day event were to occur in coincidence with a high water level in Lake Wanaka, the PAR could increase to 2,620.

1.0 Introduction

1.1 Overview

The primary objective of this study was to identify the potential impacts and consequences of a flood wave in the Hawea and Clutha Rivers resulting from a hypothetical failure of Lake Hawea Control Dam. This includes analysis of both sunny day and rainy day failure events and production of detailed flood inundation maps.

A previous dam break study was undertaken in 1990, but in the last twenty years there has been significant development in Wanaka and Albert Town requiring updated and more detailed flood maps.

1.2 Description of Dam and River Reach

The Hawea Lake Control Dam is a zoned earth fill dam blocking the outlet of Lake Hawea. The dam has a height of 25m and is constructed in two parts, east and west separated by a central rock island. The east dam blocks the original outlet channel and contains the outlet structure, which comprises four low level sluice gates each with a maximum discharge capacity of $141m^3/s$ (Worley, 1998). The west dam is smaller and blocks a diversion channel that was used during construction of the dam.

Lake Hawea has an operating range of 8m with a normal maximum operating level of RL 346.00m. At this elevation the lake has a storage volume of $2{,}531Mm^3$ and a surface area of approximately $149km^2$. Lake Hawea is an old glacial lake and the Hawea Dam is a short extension of the long natural barrier formed by post glacial action (Opus 2009).

In addition to the control dam a smaller stopbank has been constructed 3km to the east of the control dam. The stopbank is known as the Gladstone Gap and has a crest elevation of RL 350.49m. The stopbank could be deliberately breached during a large flood to increase discharge from the lake and relieve pressure on the control dam. A stopbank breach would inundate large sections of the Hawea flats and would only reduce the lake level to RL 349.00m (the minimum stopbank level). Table 1 gives the key parameters for the Hawea and Clyde Dams.

Table 1 Hawea and Clyde Dam Parameters

	Hawea Dam	Clyde Dam
Dam type	Earth fill	Concrete gravity
Dam height (m)	25	100
Dam crest level (m RL)	351.40	196.75
Dam core level (m RL)	349.65	-
Minimum normal operating lake level (m RL)	338.00	193.50
Maximum normal operating lake level (m RL)	346.00	194.50
Storage volume at maximum operating level (Mm^3)	2,531	387
Design flood level (m RL)	349.05	195.10

Downstream of the control dam the Hawea River is deeply entrenched for most of its 14km length to the confluence with the Clutha River at Albert Town. The geology of the Hawea River is old fluvioglacial deposits that could be susceptible to erosion during high large flood events.

The Clutha River drains from Lake Wanaka, 5km upstream of the Hawea confluence. Lake Wanaka has a surface area of $193km^2$ and live storage volume of $309Mm^3$ at RL 277.0m. At RL 272.0m the lake outlet is only 3m higher than the channel bed at Albert Town.

Downstream of Albert Town the Clutha continues to be deeply entrenched as far as the confluence with the Lindis River. Downstream of the confluence the river valley widens and the river has a wide braided bed. As the river approaches Lake Dunstan there are several small islands in the river formed by sediment deposition at the head of the lake.

The Clutha River flows into the Clutha arm of Lake Dunstan, which is impounded behind the Clyde Dam. The Clyde Dam is a 100m high concrete gravity dam and is located 94km downstream of the Hawea dam. The lake has a 1.0m operating range with a maximum normal operating level of RL 194.50m and a total storage volume of 387Mm^3.

1.3 Previous Studies

The previous Hawea dam break study was undertaken by Works Consultancy Services in 1990. The objective of the study was to identify the impact of a failure of Hawea dam on Clyde Dam, which was under construction at the time. The study considered a sunny day failure resulting from an earthquake induced piping failure; a rainy day failure was excluded from the analysis on the basis that the large storage volume in the lake meant it was very unlikely the dam would be overtopped.

The 1990 study used the USBR DAMBRK software program to model the breach outflow hydrograph with the downstream flood wave modelled using a water balance approach.

The results of the 1990 study are summarised and compared to the results of this study in Section 6.7.

2.0 Consideration of Potential Failure Scenarios

When assessing the potential consequences of a dam failure it is standard practice, both within New Zealand and worldwide to consider two hypothetical scenarios, which are often termed "sunny day" and "rainy day" failures. The potential failure scenarios considered in this section relate specifically to embankment dams only.

Dam break modelling is standard practice for all dams and is undertaken for emergency planning purposes. Dam break modelling is an analysis of a hypothetical event and is not indicative of any actual concerns at Hawea Dam. In New Zealand it is an NZSOLD requirement to determine potential inundation areas for emergency planning purposes.

A sunny day event represents a dam breach under normal flow and operating conditions, which may occur as a result of internal piping through the embankment, embankment instability or leakage from internal structures (e.g. conduits through the structure). These failure mechanisms could result from structural damage following seismic events. Overtopping failures are typically not considered during a sunny day analysis but could occur as a result of prolonged blockage of the outlet structures.

A rainy day failure represents a dam breach resulting from a flood event, which would most likely occur due to overtopping of the structure either as a result of spillway blockage or lack of capacity. Flood events in excess of the design event (for example, a probable maximum flood) are considered and failure is modelled at the maximum reservoir level.

The following sections discuss hypothetical sunny and rainy day failure mechanisms for the Hawea Dam.

2.1 Sunny Day Failure

Several potential sunny day failure scenarios were outlined in the 1990 study. These have been reviewed as part of this study and are considered to remain valid. They are summarised in the following paragraphs.

- A large earthquake reactivating the Mt Maude slide, with the subsequent slide movement squeezing the west part of the dam, cracking the dam fill and initiating a piping failure.
- A large nearby earthquake imposing a shearing action on the east part of the dam, cracking the dam fill and initiating a piping failure.
- An earthquake causing a rupture of the irrigation pipe running through the east part of the dam with the internal seepage causing a piping failure. This scenario would require a high lake level to develop a serious failure.

The 1990 study concluded that a piping failure through the east dam as a result of an earthquake would produce the largest breach size and potentially the most severe consequences. This hypothesis is still valid and has been used in this study as a sunny day failure mechanism.

2.2 Rainy Day Failure

The 1990 study concluded that there is sufficient discharge capacity through the dam and storage capacity in the lake that an overtopping failure had a lesser probability than a piping failure by an order of magnitude. On this basis the 1990 study did not consider a rainy day failure event. However the NZSOLD guideline now requires that a rainy day event is modelled.

The Clutha Hydro Dams PMF Update (Opus 2000) modelled a Probable Maximum Flood (PMF) event in the Hawea catchment using three different starting lake levels. This confirmed that even with an initial lake level of RL 346.00m (the normal maximum operating level) there is sufficient storage volume in the lake that neither the dam nor the Gladstone Gap stopbank would be overtopped. For the worst case scenario the lake level peaks at RL 350.37m, which is 1.03m below the dam crest but 0.72m above the core level. With the modelled lake level remaining higher than the core level for at least ten days there is the possibility that a seepage induced failure could occur under PMF conditions.

The core level has a higher elevation than the rock island separating the east and west dams, so seepage induced failure could occur on either side of the dam. A failure of both the east and west dams was not considered, on the basis that both would not fail simultaneously and once one side of the dam failed the downstream flood wave and increased tail water level would equalise the hydrostatic pressure on the remaining dam, reducing the possibility of complete failure. As the east dam is the larger of the two and would produce the largest breach size (and hence the largest peak discharge), only a failure of the east dam was modelled.

A rainy day failure resulting from a PMF in the wider Clutha catchment was not considered because peak water levels in Lake Hawea would not exceed core level.

3.0 Breach Outflow Estimates

The dam breach and downstream flood wave have been modelled simultaneously using HEC-RAS (version 4.1.0) hydraulic modelling software. HEC-RAS is developed by the US Army Corps of Engineers (USACE) and is a one-dimensional hydraulic modelling package. The software has the capability to dynamically model both the dam breach and the resulting downstream flood wave.

3.1 Breach Parameters

The breach parameters have been considered with reference to the 1990 study and published literature. Table 2 shows the breach parameters estimated using equations from eight published studies referenced in USBR (1998), all considering embankment dam failures. These parameters have been estimated for a failure of the eastern dam following a rainy day event.

Both the sunny and rainy day events have been modelled as piping failures with the same maximum breach dimensions.

Table 2 Rainy Day Breach Parameters (estimated from USBR Literature)

Parameter			MacDonald and Langridge-Monopolis (1984)	USBR (1988)	Von Thun and Gillette (1990)	Froehlich (1995b)	National Weather Service (1992)	National Weather Service Simplified Method	Walder and O'Connor (1997)	Webby (1996)
Average breach width	B	(m)	-	73.11	115.83	275.44	166.68	76.11	-	-
Upper breach width	B_{top}	(m)	-	97.97	155.21	374.80	223.35	-	-	-
Lower breach width	B_{bottom}	(m)	-	48.25	76.44	176.28	110.01	-	-	-
Breach depth	h_b	(m)	25.37	25.37	25.37	25.37	25.37	25.37	-	-
Breach formation time	tf	(hrs)	4.1	0.8	0.7	-	7.4	8.1	-	-
Volume removed	V_{er}	(m^3)	3,103,710	-	-	-	-	-	-	-
Side slope ratio		$(1h\ xv)$	2.00	1.00	1.00	0.90	1.00	-	-	-
Peak discharge	Q_p	(m^3/s)	-	-	-	15,566	-	-	18,360	26,885

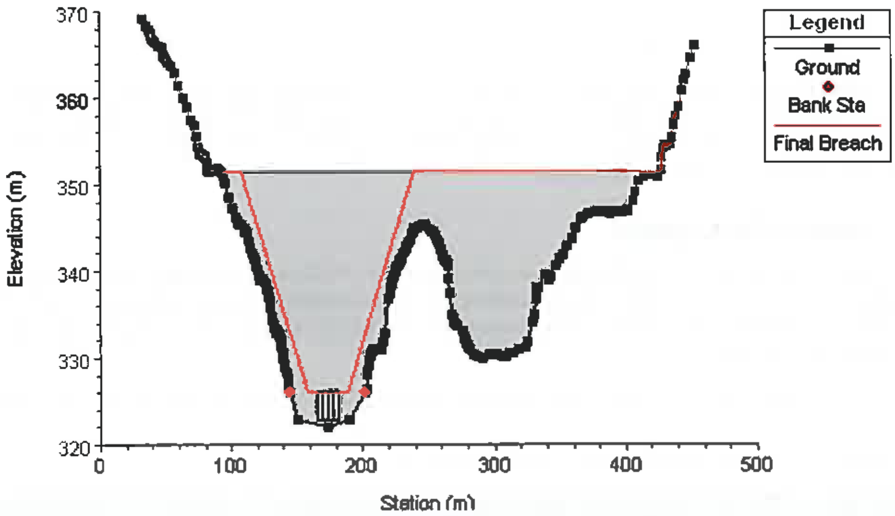
Of these, the key parameter in the case of Hawea Dam is the breach formation time, which has a range from 42 minutes to 8 hours. Other parameters, such as maximum breach width and breach depth are constrained by the geometry of the east dam, as shown on Figure 1. The minimum breach elevation of RL 326.00m is just above the top of the sluices. A bottom breach width of 30m was used.

The parameters used in the modelling are shown in Table 3. The base case breach models use a breach formation time of 1.0 hours, but a sensitivity analysis was also done using a range between 30mins and 3 hours (see Section 5.1.1).

Table 3 Modelled Breach Parameters

Parameter		Sunny Day	Rainy Day
Initial Lake Level	m RL	346.00	350.24
Peak Inflow to Lake	m^3/s	50	5,440
Failure Method		Piping	Piping
Time to Maximum Breach Formation	hrs	1.0	1.0
Final Breach Invert	m RL	326.00	326.00
Initial Piping Elevation	m RL	326.00	349.65

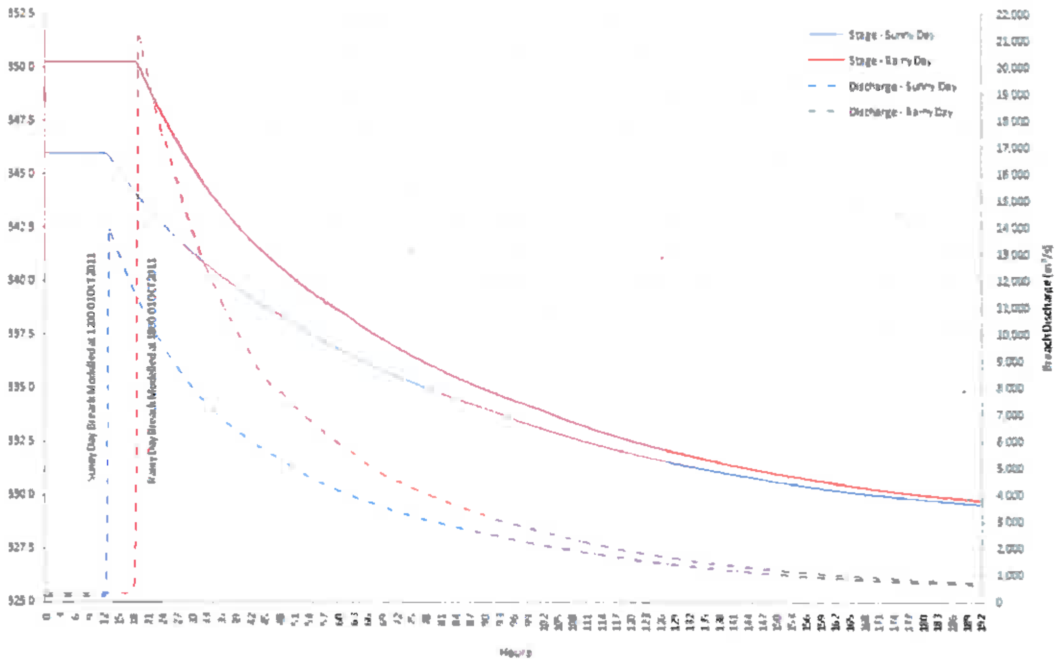
Figure 1 Final Breach Dimensions, Hawea Dam (looking downstream)



3.2 Breach Outflow

The modelled breach hydrographs for both a sunny and rainy day failure are shown in Figure 2. The peak discharge is 14,500m^3/s and 21,300m^3/s for the sunny and rainy day events respectively.

Figure 2 Modelled Breach Outflow and Stage Hydrographs, Lake Hawea



4.0 Flood Wave Hydraulic Modelling

4.1 Methodology

The hydraulic model has been built to include lakes Hawea, Wanaka and Dunstan with the three main river reaches connecting them (the Hawea River, Clyde River upstream of Albert Town and Clyde River downstream of Albert Town). The model was developed using GIS data and the HEC-GeoRAS extension. The extents of the three lakes, river alignments, cross section locations and extents and structure (Hawea and Clyde Dams and Albert Town bridge) locations were all created using HEC-GeoRAS and exported into HEC-RAS.

A Digital Terrain Model (DTM) of the Hawea and Clutha rivers was built using LiDAR data supplied by Contact. This DTM was used to extract cross sections of the Hawea River and to map the flood extents.

The model was initially run without a dam breach for both the sunny and rainy day (PMF) events. These base case model runs were used to verify the modelling parameters, particularly channel and floodplain friction coefficients and boundary conditions (both external boundaries and internal conditions at structures).

Because of the inherent uncertainties involved in dam break modelling, a thorough sensitivity analysis was conducted for both the sunny and rainy day breach models. The model parameters that were considered during the sensitivity analysis included breach formation time, breach progression type, hydraulic roughness (Manning's n) and initial lake levels. A detailed discussion of the sensitivity analysis is provided in Section 5.0.

Flood inundation extents for the sunny and rainy day events were generated in Arc-GIS (version 9.3) using the GIS based Hec-GeoRAS post-processing tools.

4.1.1 Model Extents

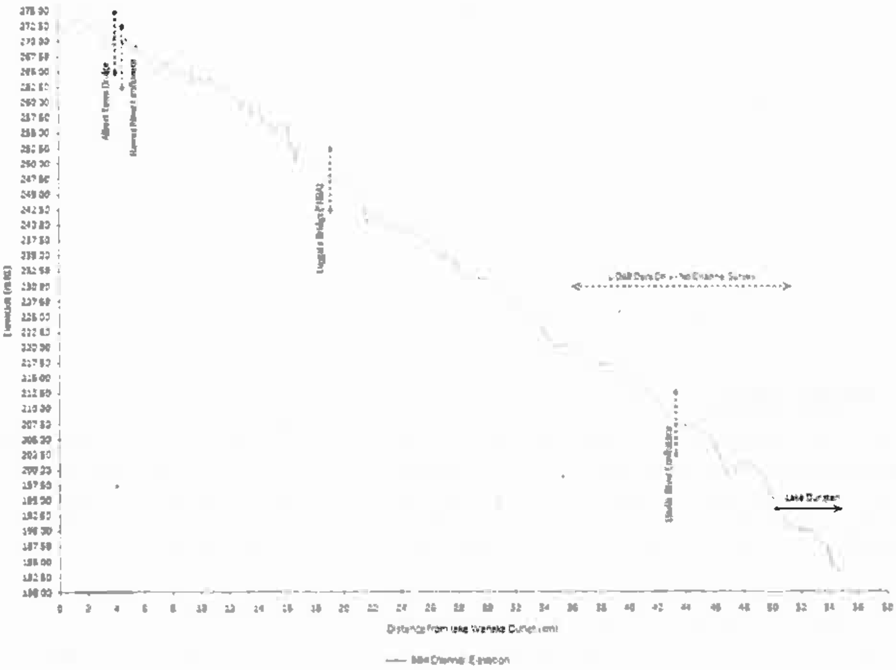
The bounding extents of the hydraulic model are Lakes Hawea and Wanaka at the upstream extents and the Clyde Dam at the downstream extent. The extent of the model (including cross section locations) is shown in the Figure in Appendix C.

4.1.2 Topographic Data

The model was developed using a mix of surveyed cross sections and LiDAR survey. Cross sections for the Clutha River between Lake Wanaka and Lake Dunstan were supplied by Contact and comprised surveyed channel sections with floodplain extents represented using LiDAR survey. The channel and LiDAR survey was supplied in DHI MIKE11 export format along with a cross section coordinate file so the cross sections could be geo-referenced in HEC-RAS. In total 114 cross sections were used to represent the Clutha River. A profile of the Clutha River is shown in Figure 3

No channel survey was available for the Hawea River. The Hawea River cross sections use LiDAR survey only and were created in GIS using the Hec-GeoRAS tools. The LiDAR survey was supplied by Contact and was flown in May 2009. Because no channel survey was available the Hawea River sections do not include any elevation data below the water line on the day the LiDAR was flown. Given the large discharge and water depths resulting from a dam breach the lack of channel survey is not considered a significant issue with regard to the modelled flood extents.

Figure 3 Upper Clutha Long Section



4.1.3 Structures

In addition to the two dams (Hawea and Clyde) there are also three road bridges within the model extents. These are the Camp Hill Road bridge crossing the Hawea River, the SH6 bridge at Albert Town crossing the Clutha River and the Church Road bridge at Luggate crossing the Clutha. All three of these bridges were visited during the site visit and are summarised in Table 4.

The Camp Hill Road bridge is a clear span, single lane structure with a deck elevation of RL 317.65m (estimated from the LiDAR survey). Clearance from the bridge soffit to the channel bed is estimated to be approximately 7m, based on an approximate bed level of RL 310.40m (taken from NIWA gauging data at the bridge). This bridge was not included in the modelling as it is considered highly likely the bridge would be destroyed by the initial flood wave.

The SH6 road bridge at Albert Town has four bridge piers (570mm diameter), a deck elevation of RL 279.80m and a soffit elevation of RL 278.10m (structure depth 1.70m). The bridge has a clearance of approximately 7.20m to the channel bed, however there is also an extensive floodplain on the left bank of the river and secondary flow could be expected when water levels exceed RL 277.00m. The bridge is located immediately upstream of the Clutha-Hawea confluence and although the bridge would be overtopped during a breach, peak velocities would be low. Therefore the bridge was included in the model using cross section data supplied by Contact.

The Church Road bridge at Luggate is a single lane truss structure. The bridge has two large diameter (estimated 1.0m+) piers, one adjacent to each bank. The bridge deck elevation is estimated to be RL 257.90m with a clearance of approximately 8.0m (both estimated from the LiDAR survey). This bridge is located on a bend of the Clutha River and there is a flow constriction. The bridge was not included in the modelling as it was considered highly likely it would be destroyed by the initial flood wave.

Table 4 Bridges on the Hawea and Clutha Rivers

River	Structure	Distance from Hawea Dam (km)	Deck Elevation (m RL)	Clearance to Channel Invert (m)	Included in Model
Hawea	Camp Hill Road bridge	5	317.60	7.00	No
Clutha	SH6 Albert Town bridge	15	279.80	7.20	Yes
Clutha	Church Road bridge	29	257.90	8.00	No

4.1.4 Hydraulic Roughness

The model was initially set up using roughness (Manning's n) values of 0.030 for the channel and 0.045 for the floodplain. These values were used throughout the model and were modified during the calibration process.

The model does not explicitly account for sediment and debris that would be transported during a dam break flood. Instead a sensitivity analysis was undertaken using a higher 0.060 roughness value (see Section 5.1.4).

4.2 Boundary Conditions

The boundary conditions for the sunny and rainy day models are discussed in the following sections and summarised in Table 5.

Table 5 Initial boundary Conditions

Boundary	Sunny Day Failure		Rainy Day Failure	
	Lake Level (m RL)	Inflow (m^3/s)	Lake Level (m RL)	Inflow (m^3/s)
Lake Hawea	346.00	50	350.24	307
Lake Wanaka	277.20	170	277.20	170
Lake Dunstan	194.00	220	194.00	220

4.2.1 Lake Hawea

Lake Hawea forms the upstream boundary of the Hawea reach of hydraulic model and is represented using a storage node upstream of the dam structure. The storage volume was input as a stage-volume curve using volumes obtained from the Electricity Authority NZ website (volumetric storage data sets prepared by Opus, 2010). This stage-storage data covers the lake range RL 338.09m to 347.24m and was extrapolated to RL 351.00m to match the dam crest level. Figure 4 shows the live storage volume and discharge curves for the lake and control structure.

The Hawea control dam was included in the model as an inline structure with a crest elevation of RL 351.40m. The geometry of the sluice gates was included in the representation of the dam, however for the dynamic model runs discharge from the structure was controlled using a rule curve supplied by Contact in their Clutha Flood Rules document. In the model this rule curve overwrites the gate operation rules.

For the sunny day model runs the initial lake level was set at RL 346.00m. This is the normal maximum operating level of the lake and is the same initial condition as used in the 1990 study.

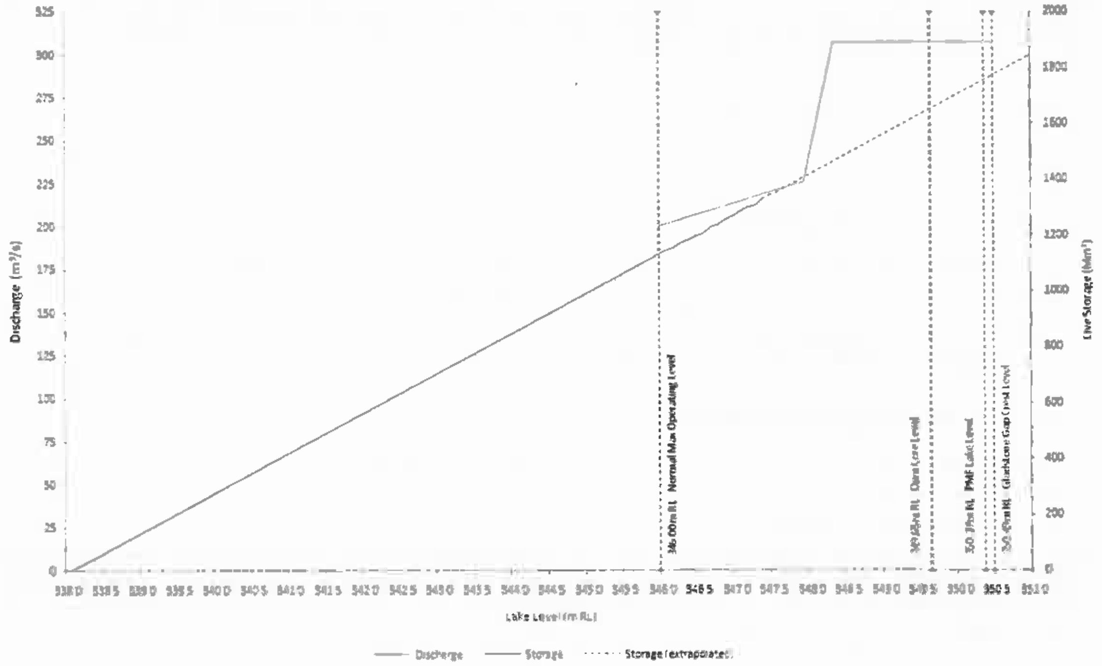
For the rainy day model runs the initial lake level was set at RL 350.24m. This was the peak lake level modelled during the PMF (no breach) model runs and was read into the breach models using a restart file. This starting level is discussed further in Section 4.3.1.

Inflows to Lake Hawea were set at a constant $50m^3/s$ for the sunny day model runs. This is the same value as used in the 1990 study and corresponds to the median lake inflow over the period 1960-2007 (Opus 2009).

For the rainy day model runs the Opus (2000) Case 3, 72 hour PMF hydrograph was used as the inflow condition. Because the breach models were run using a restart file from the PMF (no breach) model run corresponding to the time of peak lake level, only the last 18 hours of the PMF hydrograph were input directly into the breach runs, giving a peak inflow of 307m^3/s (which occurs at hour 87 of the full PMF inflow hydrograph).

For the PMF (no breach) model run the full Opus (2000) PMF hydrograph was used as the inflow condition, with a peak inflow of 5,440m^3/s.

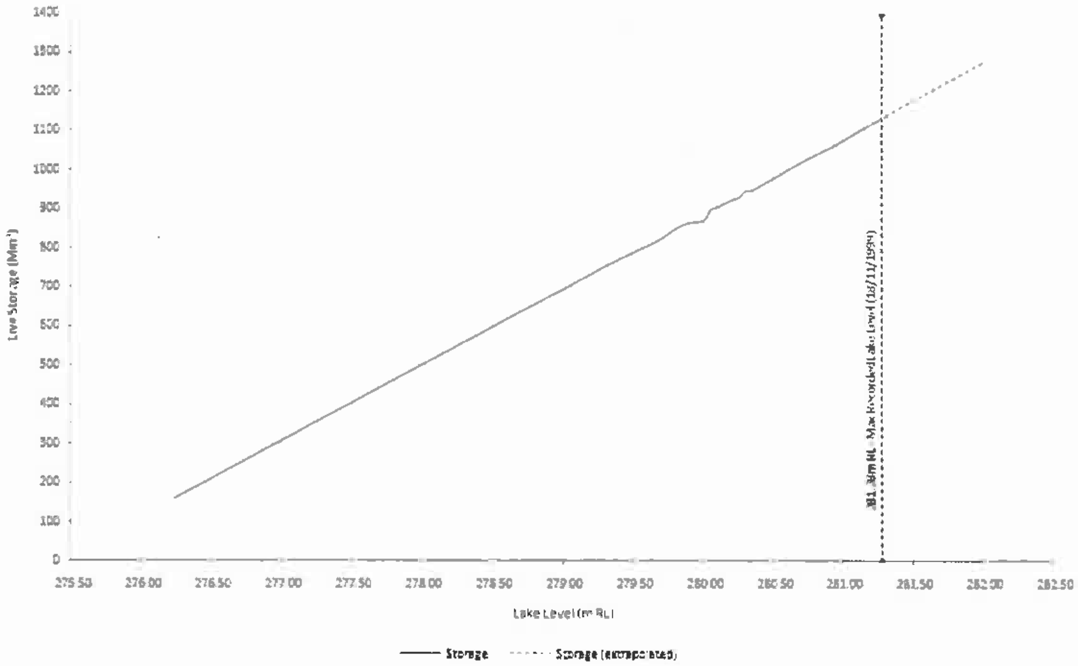
Figure 4 Lake Hawea Stage-Discharge and Live Storage Curves



4.2.2 Lake Wanaka

Lake Wanaka forms the upstream boundary of the Clutha reach of the hydraulic model and is represented using a storage node. The storage volume was input as a stage-volume curve using volumes obtained from the same Electricity Authority NZ (Opus 2010) data set as Lake Hawea. The stage-storage data covers the lake range RL 276.23m to 281.28m and the years 1990-2008. The highest recorded lake level is RL 281.28m, which occurred on 18th Nov 1999; the lake storage has been extrapolated above this level to a maximum of RL 282.00m, as shown in Figure 5.

Figure 5 Lake Wanaka Storage Curve



The initial lake level has been set at RL 277.20m for both the sunny and rainy day breach model runs. This lake level is the same as was used in the 1990 study and corresponds to the median lake level for the period 1930-2007 (Opus 2009). An analysis of the lake record confirms this to be the median level and is considered an appropriate assumption for the initial condition.

Although the rainy day model used a lake level of RL 277.20m as the initial condition, the sensitivity of this assumption was checked using a higher initial lake level of RL 280.87m. This corresponds to the 100yr ARI lake level and is discussed in detail in Section 5.1.3.

Inflows to Lake Wanaka were set at a constant 170m^3/s for both the sunny and rainy day model runs. Again, this is the same value used in the 1990 study and has been exceeded 30% of the time over the period 1930-2007 (Opus 2009). The sensitivity of inflows to Lake Wanaka was not considered as the direct inflow volume is small when compared to the inflow volume from a failure of Hawea Dam.

4.2.3 Lake Dunstan and Clyde Dam

Lake Dunstan forms the downstream boundary of the Clutha reach of the hydraulic model and is represented using a storage node upstream of an inline structure representing the Clyde Dam. The storage volume of the lake was input using data supplied by Contact covering the range RL 140.00m to 197.00m. The supplied stage-storage curve extends 0.25m above the dam crest and was extrapolated up to a level of RL 200.00m for use in the hydraulic model.

Lake Dunstan has a normal operating range of 1.0m, between RL 193.50m and 194.50m. The initial lake level was set at RL 194.00m for both the sunny and rainy day model runs.

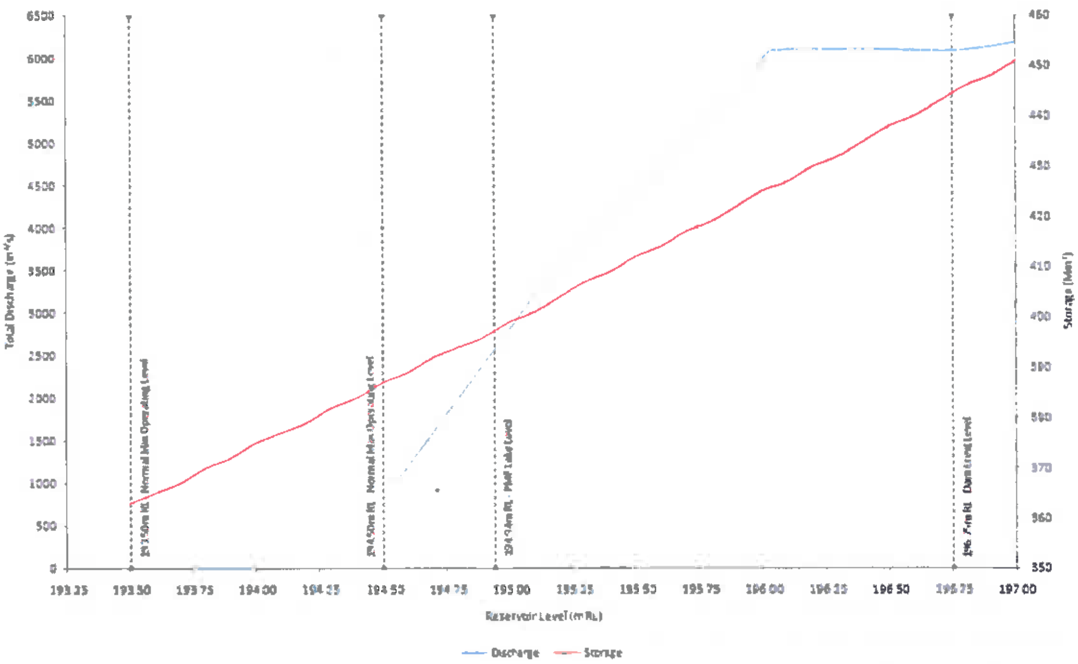
The downstream boundary of the hydraulic model is the Clyde Dam, which has been included as an inline structure with a crest elevation of RL 196.75m. The geometry of the spillway and dewatering gates was included in the representation of the dam, however for the dynamic model runs discharge from the structure was controlled using a rule curve supplied by Contact in their Clutha Flood Rules document. This rule curve overwrites the spillway gate opening rules in the model.

The Lake Dunstan storage curve and Clyde Dam flood discharge rule curve are shown in Figure 6.

The Lake Dunstan storage node has a constant inflow of 220m^3/s for both the sunny and rainy day events, representing inflow from the Kawarau River and tributaries discharging into the Upper Clutha. With the 190m^3/s discharge from Lake Wanaka and 200m^3/s discharge from Lake Hawea (based on the Contact flood discharge rules for the Hawea Dam), this gives a total steady state inflow of 610m^3/s to the lake. This is higher than the mean inflow of 472m^3/s (Opus 2007) but is considered a reasonable assumption.

During the PMF (no breach) model run the peak discharge from Hawea Dam is 307m^3/s, which increases the total Lake Dunstan inflow to 717m^3/s.

Figure 6 Clyde Dam Stage-Discharge and Reservoir Storage Curves



4.3 Model Calibration

The hydraulic model has been calibrated using records from two NIWA stage recorders, located at Camp Hill Bridge on the Hawea River (gauging station number 75287, Mar/68 – Apr/11) and downstream of the Cardrona confluence on the Clutha River (gauging station number 75282, Apr/92 – Apr/11). Additional flood history information has been supplied by Contact (Opus 2000).

The model was calibrated using the three largest events on record at the Cardrona gauge, which occurred on 24th Jan 1994, 13-14th Dec 1995 and 17-18th Nov 1999 and the corresponding water levels in Lakes Wanaka and Hawea. The peak water levels and discharges are shown in Table 6. Lake Hawea discharge information was taken from the ECNZ dataset (Opus, 2010) and is the mean daily discharge.

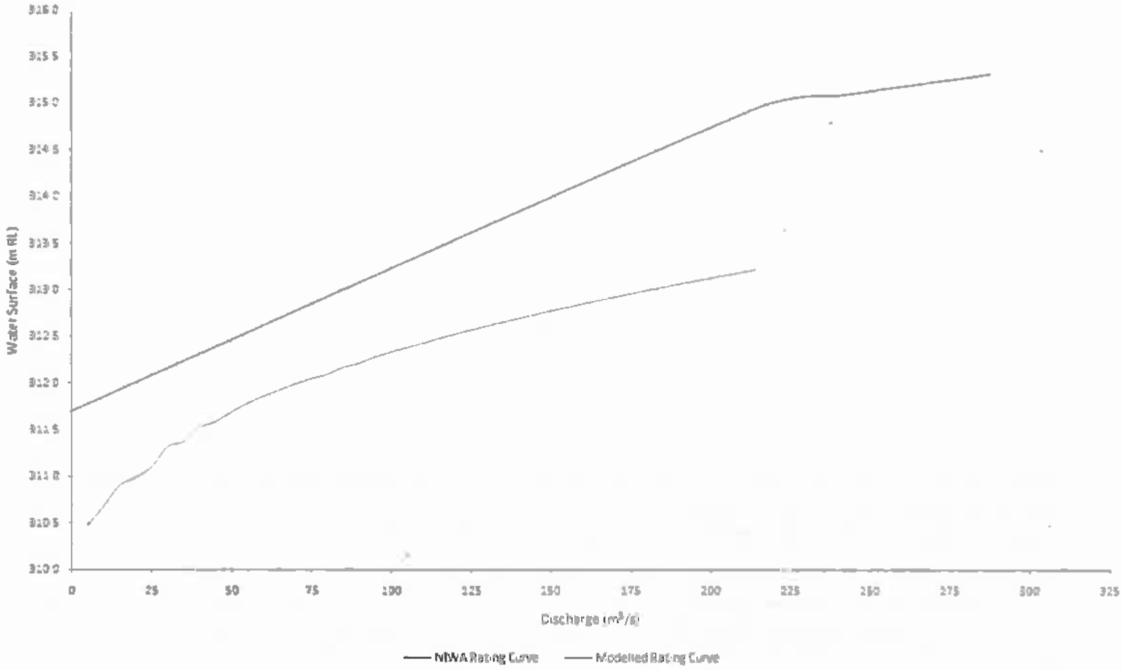
Table 6 Recorded Peak Discharge and Water Levels (NIWA Gauges)

Date	Lake Wanaka	Lake Hawea		Clutha @ Cardrona	
	Peak Level (m RL)	Discharge (m^3/s)	Peak Level (m RL)	Peak Discharge (m^3/s)	Peak Level (m RL)
24th Jan 1994	279.72	289	346.07	1,092	274.59
13th Dec 1995	279.88	303	346.06	1,263	275.07
14th Dec 1995	280.31	322	347.00	1,155	274.77
17th Nov 1999	280.91	225	344.31	1,620	275.95
18th Nov 1999	281.28	241	344.74	1,528	275.72

These flood events were modelled in steady state to develop modelled rating curves at the two gauging sites. A composite inflow was added to the model at the Cardrona confluence to compensate for the inflow from the Cardrona River (which is not included in the model). The model was calibrated by adjusting the channel and floodplain roughness coefficients, with the final modelled rating curves compared to the NIWA curves shown on Figure 7 and Figure 8.

It should be noted that only the current NIWA rating curves have been used in the model calibration. These curves are valid for all three of the calibration events.

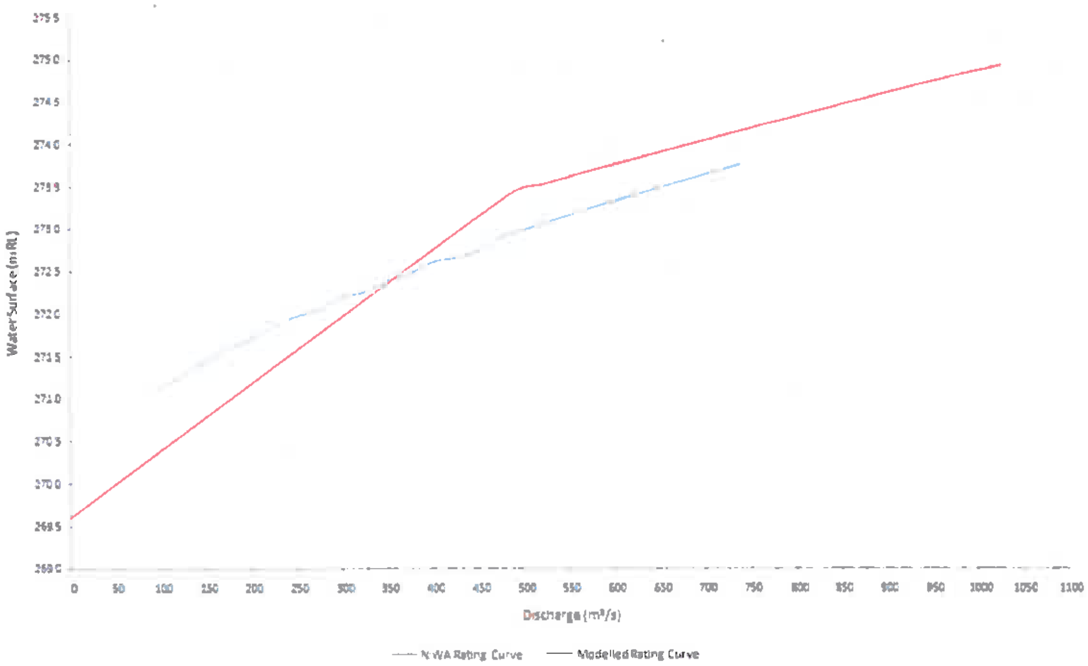
Figure 7 Model Calibration Results – Hawea @ Camphill Gauge



As shown on Figure 7, it was not possible to achieve a good calibration against the Camp Hill Road gauge, with a water level difference of over 1.50m at the high end of the NIWA rating curve. This is due to the lack of channel survey for the Hawea River, with the LiDAR survey not giving any elevations below the water line. The minimum elevation of the LiDAR cross section is RL 311.70m, however the minimum elevation on the NIWA rating curve is RL 310.40m with a rated discharge of 60m^3/s below the minimum LiDAR elevation.

The calibration against the Cardrona gauge gave a better result, however the model is under-predicting water levels at the lower end of the rating curve and over-predicting at the higher end. The difference in water levels is 600mm at the high end of the rating curve.

Figure 8 Model Calibration Results – Clutha @ Cardrona Gauge



Although the model calibration has not given a satisfactory result, it was decided not to change the roughness coefficients significantly in order to improve the calibration. Based on the observed channel and floodplain roughness at the two gauge sites, the roughness values are of the right order.

The peak gauged flow at Camp Hill Road is only 1% of the rainy day breach discharge. At the Clutha @ Cardrona gauge the peak gauged flow is only 12% of the rainy day breach discharge. At both gauges the peak rainy day breach water level is approximately 17m higher than the top of the gauge staff. Although a calibration of the model has been attempted, the differences between the gauged and modelled rating curves are not considered significant. Instead the influence of roughness coefficient was assessed during the sensitivity analysis (see Section 5.1.4).

4.3.1 PMF (No Breach) Event

The rainy day breach model uses the 72 hour probable maximum flood hydrograph as the inflow to Lake Hawea. In their PMF update report Opus (2000) estimated a peak inflow to Lake Hawea of 5,440m^3/s and a peak lake level of RL 350.37m. To confirm the peak lake level (at which time the dam failure will be initiated in HEC-RAS) the PMF event has been modelled without any breach.

For this model run the PMF inflow hydrograph was scaled from Figure 5.15 (page 56) of the Opus report. When the hydrograph was routed through Lake Hawea using the stage-storage and discharge curves shown on Figure 4 the maximum water level in Lake Hawea was RL 350.24m. This is a difference of -130mm against the Opus report. Given that this lake level falls within the extrapolated section of the Lake Hawea storage curve, this is not considered to be a significant difference.

A restart file was created for the PMF event at the time of peak lake level. This restart file was then used to define the initial conditions for the rainy day breach model runs. This reduced model run times and file sizes without impacting on model accuracy.

5.0 Sensitivity Analyses

Because of the inherent uncertainties involved in dam break modelling, the sensitivity of the model has been tested against several parameters.

5.1.1 Breach Formation Time

The base case model runs used a breach formation time of 1.0 hour for both sunny and rainy day failures. Three sensitivity analyses were undertaken for each failure event, using formation times of 30mins, 2 hours and 3 hours. The peak discharges are shown in Table 7.

Table 7 Impact of Breach Formation Time on Peak Discharge

Breach Formation Time (hrs)	Sunny Day Event		Rainy Day Event	
	Peak Discharge (m^3/s)	Change from Base Case (%)	Peak Discharge (m^3/s)	Change from Base Case (%)
0.5	14,472	-0.14	21,359	+0.33
1.0 (base case)	14,492	-	21,289	-
2.0	14,384	-0.75	21,114	-0.82
3.0	14,267	-1.55	20,881	-1.92

As the table shows, changing the breach formation time parameter has no significant impact on the peak discharge from Lake Hawea, with a maximum change of less than 2%. This is likely due to the very large storage volume in the lake; the modelled hydrographs show it would take over a week to fully draw down the lake and nearly five hours from full breach formation to draw the lake down by 1m.

5.1.2 Breach Progression Type

HEC-RAS has the functionality to model breach progression as either a linear or sinusoidal process, based on a user specified time to peak (breach formation time). For the base case model runs the breach progression was modelled as a linear process with a sinusoidal progression modelled as a sensitivity analysis.

Table 8 shows the breach progression type has no impact on the peak discharge, with a maximum change of less than 1% for the sunny day event. As with the breach formation time, this is likely due to the large storage volume and the amount of time required to draw the lake down.

Table 8 Impact of Breach Progression Type on Peak Discharge

Breach Progression Type	Sunny Day Event		Rainy Day Event	
	Peak Discharge (m^3/s)	Change (%)	Peak Discharge (m^3/s)	Change (%)
Linear Progression (T_b 1hr)	14,492	-	21,289	-
Sinusoidal Progression (T_b 1hr)	14,358	-0.92	21,246	-0.20

5.1.3 Initial Lake Levels

The base case models use an initial water level of RL 277.20m for Lake Wanaka. While this is considered appropriate for the sunny day event, a sensitivity analysis has been done for the rainy day event using a higher initial level of RL 280.87m. This level corresponds to a 100yr ARI event based on an analysis of mean daily lake level records from 1933-2011 (data supplied by NIWA).

The Lake Wanaka PMF level (RL 282.84m, Opus 2000) was not used as the joint probability of PMF events in both the Hawea and Wanaka catchments combined with a failure of Hawea Dam would be extremely low. This combination of events was considered overly conservative, so the 100yr ARI lake level was used.

The effect of a higher initial lake level is a 200m^3/s increase in the peak flow from Albert Town into Lake Wanaka, peaking at 6,730m^3/s. The maximum lake level increases to RL 283.45m, a rise of 2.58m. This result is the opposite of what would be expected; the higher lake level would be expected to result in a smaller peak flow from Albert Town. However, a lake level of RL 280.87m gives a discharge of 1,100m^3/s from Lake Wanaka meaning water levels in Albert Town are already elevated prior to arrival of the dam breach flood wave. This in turn increases the hydraulic fall between Albert Town and Lake Wanaka from 2.36m to 3.78m (at the time the flood wave arrives in Albert Town), resulting in a higher peak discharge into Lake Wanaka.

The higher initial water level in Lake Wanaka significantly increases the flood extent, number of properties inundated and the population at risk. This is discussed in Section 6.3.

5.1.4 Hydraulic Roughness

The sensitivity of the model to the hydraulic roughness coefficient was tested by increasing the floodplain roughness from the base case values (0.044 on the Clutha reaches and 0.048 on the Hawea) to 0.060 throughout the model, an increase of 25-36%.

The roughness sensilivity was necessary because the model calibration did not give satisfactory results and also to consider potential effects of debris transport. During the site visit it was observed that many sections of the Clutha and Hawea rivers have heavily wooded banks that would have a higher roughness coefficient than 0.048, but the calibration results suggested a lower coefficient was required. Bearing in mind the modelled flow depths (which in many areas would results in trees being submerged or washed away) a value of 0.060 was used.

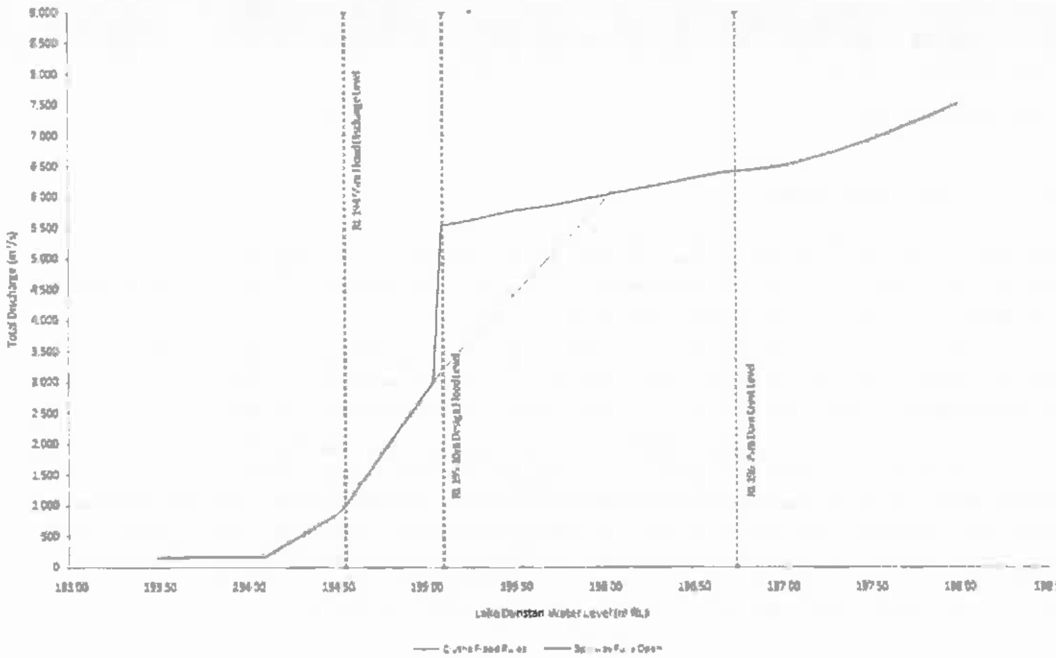
A full tabulation of the sensitivity results is shown in Appendix A. On the Hawea and Clutha Rivers the increased roughness gives a peak flow reduction of 4.0 – 4.4% compared to the base case runs, while the peak water depth increases by an average 4% (with a range between -2.2% and +10.9%). The most significant water level changes occur around the Church Road bridge at Luggate and on the upper Clutha River near the Lake Wanaka outlet.

5.1.5 Clyde Dam Discharge

The base case sunny and rainy dam breach models have been run using the stage-discharge relationship given in Contact's Clutha Flood Rules document, as shown in Figure 9. An alternative scenario has also been modelled, which uses Contact's flood rules while the Lake Dunstan water level is below RL 195.10m (which equates to the design flood level); once lake levels start rising above this level the spillway gates are opened fully and the machines are shut down. This stage-discharge curve is also shown on Figure 9. This alternative scenario is similar to that modelled in the 1990 study.

The objective of these model runs was to determine if overtopping of the Clyde Dam could be avoided if the peak discharge was increased earlier during the flood event. As the flood wave would have a travel time of seven hours from Lake Hawea to the upstream extent of Lake Dunstan, plus the breach formation time (in this case 1 hour) there would be plenty of warning time to start increasing discharge from the Clyde Dam and lowering the level of Lake Dunslan.

Figure 9 Modelled Stage-Discharge Curves for Clyde Dam



The peak discharge from the Clyde Dam and water level in Lake Dunstan are similar under both discharge scenarios. The Clyde Dam would be overtopped in both a sunny and rainy day event regardless of the spillway operation, with the depth of overtopping reduced by only 0.07m and 0.02m for the sunny and rainy day events respectively, as shown in Figure 11.

Table 9 Lake Dunstan Water Levels and Clyde Dam Overtopping Durations

	Sunny Day Event			Rainy Day Event		
	Peak Water Level (m RL)	Overtopping Duration (hrs)	Peak Discharge (m^3/s)	Peak Water Level (m RL)	Overtopping Duration (hrs)	Peak Discharge (m^3/s)
Clutha Flood Rules	197.74	16	7,195	199.59	26	9,585
Spillway Fully Open	197.67	15	7,105	199.57	26	9,527
Change	-2%	-6%	-1%	-	-	-

Note: The change in peak water level is relative to the minimum operating level of RL 193.50m

Figure 10 Lake Dunstan Time Series – Sunny Day Failure

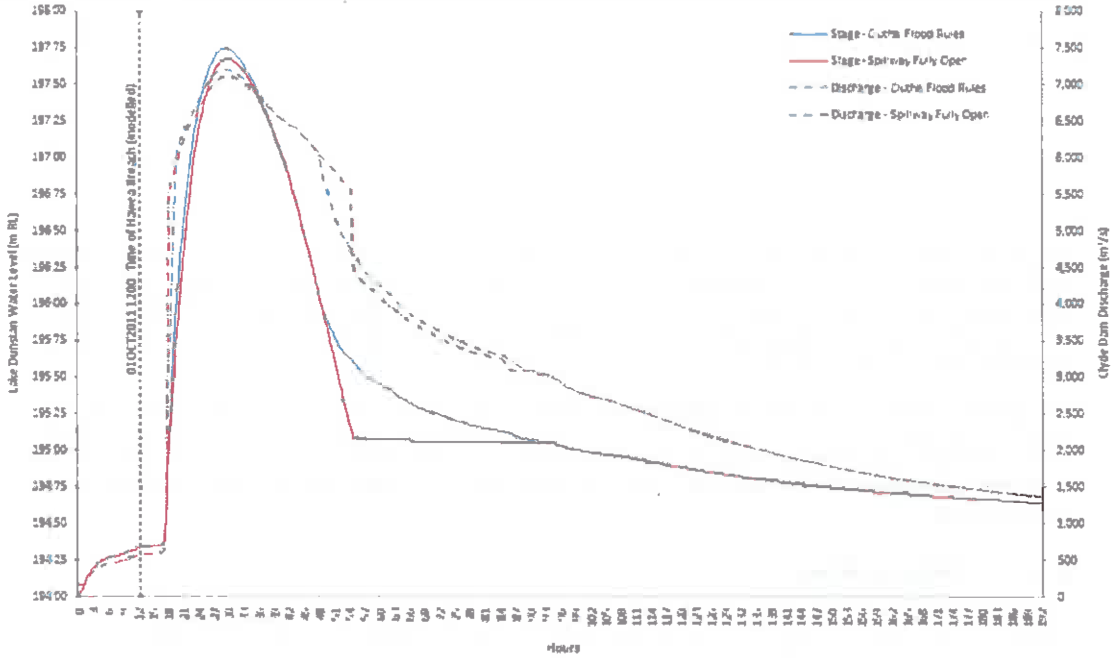
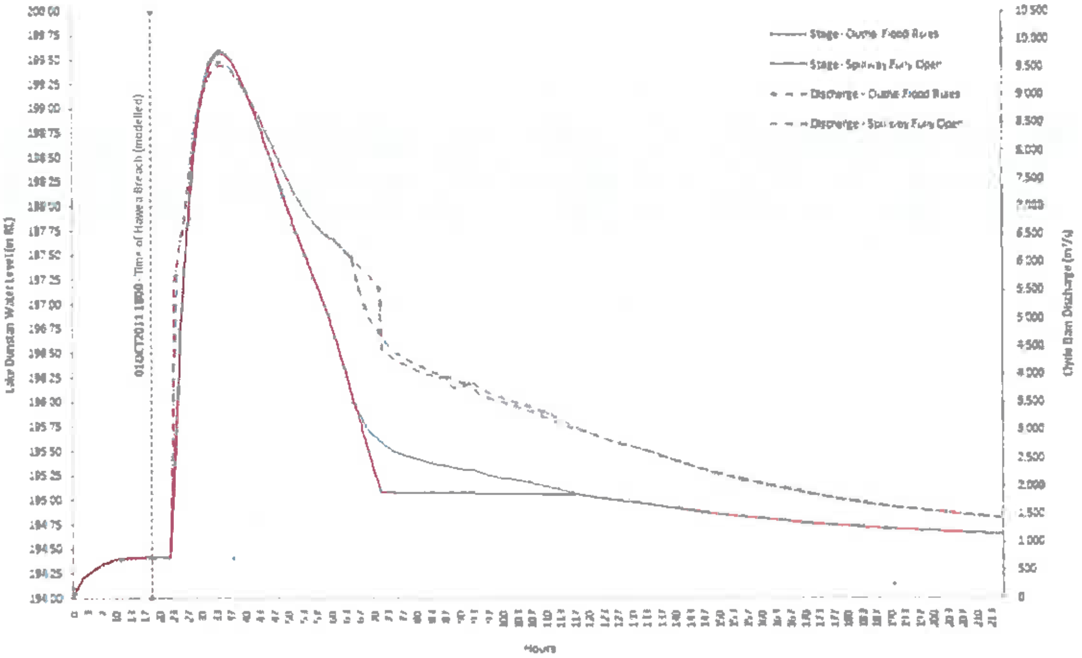


Figure 11 **Lake Dunstan Time Series – Rainy Day Failure**



6.0 Damage Assessment

The modelling results for the sunny and rainy day breach models are discussed in the following sections, with the flood inundation maps shown in Appendix D. It should be noted that travel times refer to the time taken for the flood wave to travel from the Hawea Dam to a particular location. With a one hour breach formation time, the warning time (the temporal lag between breach imitation and arrival of the flood wave) at any particular location will be the travel time plus one hour.

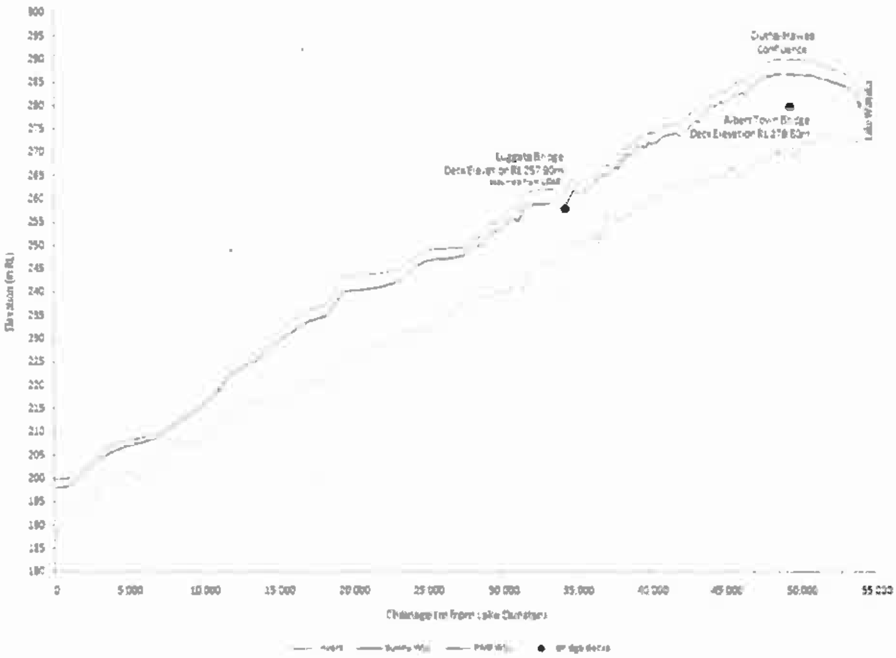
The Hawea Dam is a well monitored structure and it is assumed that flood warnings could be issued within 15 minutes of initiation of a sunny day breach (this assumes there would be staff on site following the hypothetical event that initiates the failure). For a rainy day breach there is a lag time of several days between when the start of the flood event and when the lake level exceeds the dam core, so it is again assumed that early flood warnings could be issued.

6.1 Hawea River

Although the Hawea River is deeply incised in its upper reaches, the depth of flood water following a breach means there would be inundation onto the Hawea Flats downstream of the Hawea oxidation ponds.

The only road crossing of the Hawea River is at Camp Hill Road, 5.0km downstream of Hawea Dam. The flood wave would reach the bridge 1.40 hours after initiation of the breach (40mins after maximum breach formation). As shown on Figure 12 the bridge would be submerged under 10m of water. With the increased local velocities through the bridge site (the bridge is at a constriction in the river giving average velocities of 11m/s) it is likely that the bridge would be destroyed.

Figure 13 Water Surface Profiles, Clutha River



6.3 Lake Wanaka

With an initial water level of RL 277.20m in Lake Wanaka and a peak flood level of RL 286.65m (for the sunny day event) in Albert Town, the normal flow direction would be reversed upstream of Albert Town. Water would spill into Lake Wanaka, which would experience a water level rise of 2.02m for the sunny day event and 2.98m for the rainy day event. Between Lake Wanaka and Albert Town the Clutha River is deeply incised with steep banks constraining the flood extent.

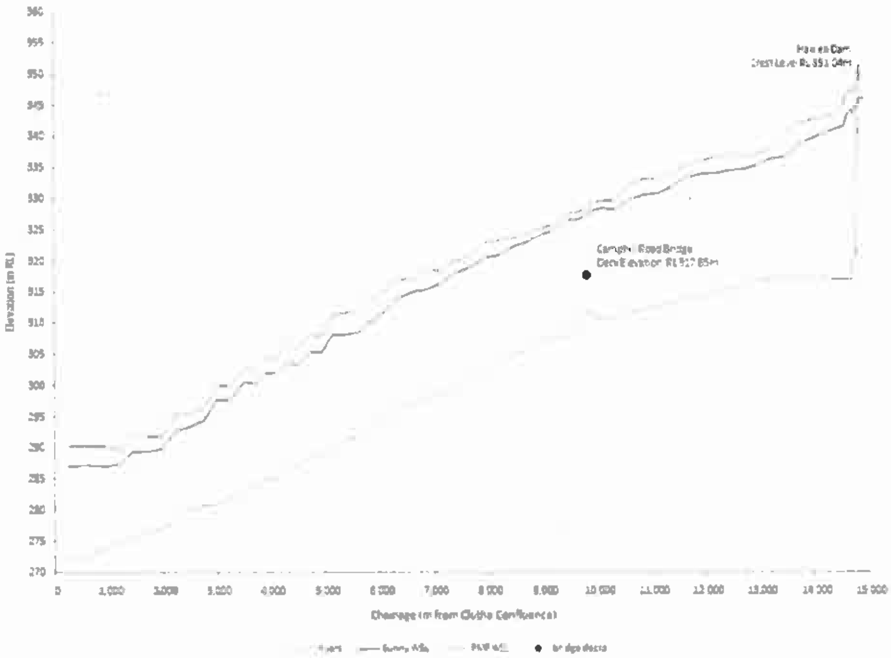
Lake Wanaka has a surface area of approximately 193km^2 and this large storage capacity means the lake would act as a flood detention basin following a breach of Hawea Dam. The peak inflow to the lake is 4,076m^3/s during a sunny day event and 6,500m^3/s during a rainy day event. The large storage volume means the peak lake level would not occur for 3 days after a Hawea failure.

When flood levels in the Clutha begin to drop, Lake Wanaka would then discharge the flood water back into the Clutha River. This increases the total duration of the flood event downstream of Albert Town, but significantly attenuates the peak discharge.

At Roys Bay the flood extents have been plotted using 1m interval contour data and aerial photography (see drawing 60221308-SD-08). This shows that during the sunny day event there would be minimal damage in Wanaka town (the peak water level in Lake Wanaka only raises to RL 279.22m). During a rainy day event the peak level would be slightly higher at RL 280.18m, causing surface flooding across Ardmore Street and inundation of three properties on the corner of Ardmore and Dungarvon Streets. Outside of Roys Bay the flood mapping has used 20m interval contour data and 1:25,000 topographic maps; these only provide a large scale indication of the potential flood extent at other areas around the lake shore.

The sensitivity analyses show that if the lake had a higher initial water level (close to the 100 year ARI of RL 280.87m) there would be extensive inundation and damage through Wanaka town. The lake level rises by 2.58m to a peak of RL 283.45m. The flood extent (also shown on drawing 60221308-SD-01) shows a large part of the town centre would be inundated between Ardmore and Brownston Streets to the north-south and Helwick and Dungarvon Streets to the east-west. From the aerial photographs, approximately 60 buildings, including several hotels, numerous cafes and a supermarket would all be inundated. Pembroke Park and Wanaka Recreational Reserve would also be inundated. On the north side of the town, Lakeside Drive would be flooded between the

Figure 12 Water Surface Profiles, Hawea River



Downstream of the bridge there would be extensive inundation on the right bank. On the left bank Newcastle Road would be inundated for a length of 2.80km.

Around Horseshoe Bend the flood extent would be constrained by bluffs on both banks of the river, however there are several properties in this area that would all be flooded. The flood wave would reach these properties at Horseshoe Bend around 2.50 hours after initiation of the breach.

As the Hawea River approaches the confluence with the Clutha River the floodplain widens and the flood extent increases. There is a camp site and kayak slalom course located 1.50km upstream of the confluence. Peak flood depths at this location would be in the order of 14m with a travel time of 1.50 hours from the dam (2.50 hours after breach initiation).

There is a Department of Conservation (DOC) campsite located to the west of SH6 at the Hawea-Clutha confluence. The depth of inundation at the camp site would be in the region of 16m. The SH6 road would also be inundated for a distance of 800m on the northern approach to the SH6 Albert Town bridge.

6.2 Albert Town

Albert Town is located at the confluence of the Hawea and Clutha Rivers and would experience widespread inundation and damage following a failure of Hawea Dam. The low lying area around the confluence would be inundated and there would be negative flow up the Cardrona River.

The flood peak would arrive at Albert Town 2.5 hours after the initiation of a breach at Hawea with the peak water level occurring 1.5 hours later (4.0 hours after breach initiation).

With a peak water level of RL 286.62m during the sunny day event and RL 289.90m during the rainy day event the SH6 bridge would be overtopped and remain submerged for 48 hours. The flood water would start to overtop the bridge 3.5 hours after the breach initiation. Secondary flow would occur around the north (true left) of the bridge, however there is also the possibility of erosion and slope instability on the south abutment.

The northern and eastern areas of Albert Town would be inundated during both a sunny and rainy day event, however the central section of the town (immediately north of State Highway 6) would only be inundated during a rainy day event.

intersections of Ardmore and Beacon Point Roads, but no properties are within the flood extent. Approximately 30 other properties located between Eely Point and Beacon Point would also be inundated.

6.4 Upper Clutha River

Downstream of Albert Town the peak flood discharge would be attenuated by both the ponding through Albert Town and the negative flow upstream to Lake Wanaka. The peak discharge downstream of Albert Town would be 9,125m^3/s and 12,830m^3/s for the sunny and rainy day events respectively, giving attenuation of approximately 30% for both events.

Downstream of Albert Town the Clutha River is deeply incised and the flood wave would be contained within the channel. State Highway 8A crosses the Clutha River at Luggate, approximately 30km downstream of the Hawea Dam. The deck elevation of the bridge has been estimated from the LiDAR survey but would be submerged and likely destroyed in both a sunny and rainy day event (see Figure 13). The flood wave would arrive at the bridge 4.50 hours after initiation of the Hawea breach.

The town of Luggate is above the peak flood level and is not at risk of inundation. Downstream of Luggate the Clutha River continues to be incised with only isolated areas of out-of-bank flooding. One of these areas is at Sandy Point (41km downstream of Hawea Dam) where the Aoturoa Farmstead is located. The farm buildings are located at the outer extent of the flood envelope and would only be inundated during a rainy day event, which would also result in some spill across SH6. The peak rainy day flood level at Aoturoa is RL 249.11m as the flood wave would arrive 5.50 hours after initiation of the Hawea breach.

Approaching the confluence with the Lindis River the channel starts to widen with the Clutha being braided downstream of the confluence. The channel expansion and resulting energy losses give significantly lower peak velocities and water depths downstream of the Lindis confluence. The flood would have an extent of 1.30 – 2.20km wide in these lower reaches of the Clutha. The farm properties at Willowbank and Bendigo would be inundated, as would a 1.60km length of SH8. The flood wave would arrive at these properties between 6.50 and 7.00 hours after initiation of the breach at Hawea.

6.5 Lake Dunstan and Clyde Dam

The peak water levels in Lake Dunstan are controlled by the operating rules for the Clyde Dam. The stage-discharge curve that would be used in the event of a major flood is shown on Figure 6. Because Lake Dunstan has been modelled as a storage node the reservoir is treated as a level pool, so the results do not show the hydraulic gradient through the lake that would occur in reality. The LiDAR survey does not cover Lake Dunstan and the flood envelopes have been created using 20m interval contours, so this modelling approach is considered to be acceptable.

During a sunny day event and assuming Contact's flood rules were followed and the initial lake level was RL 194.00m, Lake Dunstan would rise by 3.74m to a peak of RL 197.74m. The corresponding figures for a rainy day event are 5.59m and RL 199.59m. Because of the low resolution of the contour data used around Lake Dunstan it is difficult to state with confidence if any properties will be inundated along the lake front. However, the subdivision at the intersection of SH6 and Clarke Road (27km upstream of the Clyde Dam) is within both the sunny and rainy day flood envelopes, as is the Pisa Range Cromwell Hotel.

The flood envelopes also show some minor flooding around Cromwell during the rainy day event, but more detailed contour information is required to confirm this. The extent shown around Cromwell is not considered realistic as Cromwell has an elevation of RL 210m, putting it 10m clear of the peak lake level.

State Highway 6 on the western side of Lake Dunstan is within both the sunny and rainy day flood envelopes between Clarke Road and Lowburn with further isolated inundation south of Lowburn.

Downstream of Cromwell the flood waters would be contained within the Cromwell gorge. Some minor inundation of SH8 may occur.

The peak lake level would occur 17-18 hours after initiation of the Hawea breach.

The crest level of the Clyde Dam is RL 196.75m. As shown on Figure 10 and Figure 11, if the dam were operated using the existing Clutha flood rules the structure would be overtopped by 0.72m during a sunny day event and 2.84m during a rainy day event. These are the maximum modelled water depths above the crest, although the total duration that the dam would be overtopped is 26hrs for a rainy day event and 16hrs for a sunny day event. The dam has been designed to withstand overtopping.

6.6 Population at Risk

The population at risk (PAR) from a hypothetical sunny or rainy day failure of Hawea Dam has been estimated by exporting the flood inundation extents in KMZ format and using Google Earth to determine the number of properties lying within the flood boundary. The number of inundated properties in each area is shown in Table 10. The rainy day figures are for an initial level of RL 280.87m in Lake Wanaka.

Table 10 Number of Inundated Properties

	Properties	Hotels	Camp Sites
Sunny Day Event			
Hawea River	18	-	1
Lake Wanaka	-	-	1
Clutha u/s Albert Town	-	-	-
Albert Town	158	2	1
Clutha d/s Albert Town	4	-	-
Lake Dunstan	55	1	-
Sunny Day Total	235	3	3
Rainy Day Event			
Hawea River	22	-	1
Lake Wanaka	95	3	1
Clutha u/s Albert Town	-	-	-
Albert Town	230	2	1
Clutha d/s Albert Town	5	-	-
Lake Dunstan	68	1	-
Rainy Day Total	420	3	3

The average number of people per dwelling has been estimated at 2.3, based on NZ Government census data for Wanaka and Hawea. Campsite populations have been estimated using 2.5 people per tent site with 180 sites per campground. Hotel populations have been estimated using occupancy of 50 people per hotel. The campsite occupancy figures appear conservative as they assume that a Hawea breach would occur during the peak summer period, however given the three largest floods on record in the Clutha have occurred between November and January, the assumption is not unreasonable.

The above figures give a total PAR of 2,040 for the sunny day event and 2,280 for the rainy day event. If a rainy day event were to occur in coincidence with a high water level in Lake Wanaka, the PAR could increase to 2,620.

6.7 Comparison with the 1990 Study

A short comparison of results against the 1990 study is included in Table 11. These results are for the sunny day failure only, assuming a failure time of 3 hours and that the Clyde Dam spillway gates are open fully when Lake Dunstan reaches RL 195.10m.

Table 11 Comparison against 1990 Results

	1990 Study	2011 Study
Peak outflow from Hawea (m^3/s)	12,300	14,267
Peak water level Albert Town (m RL)	284.50	286.65
Peak water level Lake Wanaka (m RL)	280.80	279.22

	1990 Study	2011 Study
Peak inflow to Lake Wanaka (m^3/s)	6,510	4,076
Peak discharge downstream of Albert Town (m^3/s)	5,360	9,139
Peak water level Lake Dunstan (m RL)	195.90	197.67
Peak inflow to Lake Dunstan (m^3/s)	4,580	8,906

The results show that peak discharge and water level estimates are generally higher in this study than in the 1990 study, the exception being Lake Wanaka. Reasons for the differences in results could include the modelling methodology, topographic data used (i.e. cross sections), and extrapolation of lake storage curves.

Although the 1990 study was a very comprehensive report, the results of this study are considered to be more accurate because of the better quality ground survey data used and the improvements in modelling software that have occurred over the last 20 years.

7.0 Conclusion

Failures of earth fill dams such as the lake Hawea Control Dam are extremely rare but have occurred in the past, either as a result of internal erosion or overtopping. In this study a failure resulting from internal erosion was assumed for both the sunny and rainy day events. The sunny day event considered an earthquake induced failure during normal operating conditions, with the rainy day event considering failure following high lake levels and internal erosion resulting from seepage above the dam core.

With a maximum PMF lake level of RL 350.24m an overtopping failure was not considered, particularly as the Gladstone Gap stopbank could be breached in the event of lake levels approaching RL 351.00m. Consequences resulting from a breach of the Gladstone Gap were not considered in this study.

The peak discharge from the breach is estimated to be 14,500m^3/s for the sunny day event and 21,300m^3/s for the rainy day event.

There would be extensive damage through Albert Town and all three bridges across the Hawea and Clutha rivers would likely be destroyed, leaving the SH8 bridge at Cromwell as the only remaining crossing of the Clutha. Depending on the initial water levels in Lake Wanaka there could also be extensive damage through Wanaka town.

The Hawea and Clutha Rivers are entrenched in old fluvioglacial deposits and severe bed and bank erosion could be expected, although the locations and extent of such erosion have not been considered in this study. The banks of the rivers are heavily wooded and large debris flows (comprising trees, eroded bank material, material from the Hawea Dam etc) could also be expected. Some of this material could be deposited around Albert Town where velocities would be lower due to ponding.

The population at risk following a breach of Hawea Dam is estimated to be in the range of 2,040 to 2,620 people, mostly centred in Albert Town and Wanaka. The actual PAR would depend on the time of the year, with the figure being highest in the summer months, particularly around the Christmas period. The travel time of the flood wave is estimated to be two hours to Albert Town, with a one hour breach formation time giving a total warning time of three hours (assuming detection on initiation of the breach). Peak water levels in Lake Wanaka would occur two days after a breach of Hawea, giving sufficient time for Wanaka town to be evacuated if necessary.

8.0 References

CADAM (2000), Dambreak Modelling Guidelines and Best Practice

Contact Energy Clutha Flood Rules

Environment Agency UK (2011), Reservoir Flood Maps Guide

New Zealand Society on Large Dams (2000), New Zealand Dam Safety Guidelines

Opus (2000). Flood History in the Clutha Catchment

Opus (2000), Clutha Hydro Dams – PMF Update

Opus (2007), Contact Energy Limited: Station Hydraulic Data

Opus (2009), Hawea Dam – Review of 1990 Dam Break Analysis

Opus (2010), Lake Generation Potential History (volumetric storage data sets prepared for Electricity Commission)

USACE (2010), HEC-RAS River Analysis System User's Manual, Version 4.1

USBR (1998), Prediction of Embankment Dam Breech Parameters, Dam Safety Research Report DSO-98-004

Works Consultancy Services (1990), Hawea Lake Control Dam; Report on Dam Break Analysis

Appendix A

Tabular Results

Appendix A Tabular Results

Table A1 – Base case model results for the sunny and rainy day events

Table A2 – Sensitivity results with increased hydraulic roughness for sunny and rainy day events

	River	Reach	Cross Section	Chainage	Channel Invert (m RL)	Sunny Day Failure: Peak WSL (m RL)	Peak EGL (m RL)	Avg Velocity (m/s)	Peak Discharge (m^3/s)	Top Width (m)	PMF Failure (Low Wanaka Level): Peak WSL (m RL)	Peak EGL (m RL)	Avg Velocity (m/s)	Peak Discharge (m^3/s)	Top Width (m)	PMF Failure (High Wanaka Level): Peak WSL (m RL)	Peak EGL (m RL)	Avg Velocity (m/s)	Peak Discharge (m^3/s)	Top Width (m)
	Hawea	Hawea	14908.58 Lake Hawea	14909	322.00	346.00	346.00	0.10	200	261.83	350.24	350.24	0.11	307	313.3	350.24	350.24	0.11	337	313.3
Lake Hawea	Hawea	Hawea	14871.62 Lake Hawea	14872	322.00	346.00	346.00	0.10	200	261.83	350.26	350.26	0.00	0	313.3	350.26	350.26	0	0	313.3
Hawea Dam	Hawea	Hawea	14848.66 Hawea Dam	14849	322.00	346.00		Hawea Dam			350.26		Hawea Dam			350.26		Hawea Dam		
	Hawea	Hawea	14719.37	14719	320.05	343.83	349.11	8.14	14,433	224.33	346.85	350.15	9.58	21,296	285.9	346.85	350.15	9.68	21,296	285.9
	Hawea	Hawea	14678.95	14679	317.05	344.33	345.80	6.26	14,443	239.05	347.61	349.81	7.54	21,307	311.1	347.61	349.81	7.64	21,304	311.1
	Hawea	Hawea	14606.49	14606	317.05	343.42	348.01	8.76	14,410	214.95	346.64	350.07	10.32	21,301	257.6	346.64	350.06	10.32	21,298	257.6
	Hawea	Hawea	14557.05	14557	317.05	341.59	346.64	12.01	14,402	197.62	345.03	350.54	13.16	21,300	222.3	345.03	350.53	13.15	21,284	222.3
	Hawea	Hawea	14344.56	14345	317.05	341.04	345.51	11.79	14,396	177.64	343.41	349.63	14.20	21,249	187.4	343.41	349.63	14.20	21,245	187.4
	Hawea	Hawea	14055.05	14055	317.35	339.89	344.26	11.34	14,378	228.42	342.61	347.74	12.79	21,205	237.8	342.61	347.74	12.79	21,204	237.8
	Hawea	Hawea	13753.46	13753	317.05	338.86	342.89	11.17	14,380	268.50	342.26	346.11	11.52	21,188	285.4	342.26	346.11	11.52	21,192	285.4
	Hawea	Hawea	13486.47	13486	317.54	338.64	342.42	12.82	14,385	227.18	340.51	345.52	12.60	21,157	325.2	340.49	345.54	12.64	21,194	325.0
	Hawea	Hawea	13163.89	13164	316.85	336.21	339.63	10.92	14,379	232.25	337.90	344.53	14.97	21,187	332.4	337.90	344.54	14.99	21,199	332.3
	Hawea	Hawea	12938.93	12939	317.05	335.38	339.01	11.03	14,314	305.58	337.05	342.23	13.58	21,019	359.7	337.00	342.26	13.71	21,118	356.6
	Hawea	Hawea	12687.94	12688	316.05	334.81	337.74	11.06	14,239	385.14	336.84	340.17	12.00	20,955	435.3	336.60	340.13	12.29	20,795	430.6
	Hawea	Hawea	12451.29	12451	315.30	334.50	336.42	9.63	14,238	468.81	335.98	338.88	10.06	20,976	529.3	335.75	338.74	10.27	20,841	521.3
	Hawea	Hawea	12196.54	12197	315.40	334.11	335.40	8.93	14,238	475.06	335.57	337.96	9.37	20,973	535.1	335.32	337.77	9.52	20,824	518.7
	Hawea	Hawea	11929.78	11930	314.06	333.85	334.79	8.03	14,235	502.99	335.17	337.40	7.07	20,965	592.6	335.31	337.65	7.31	20,841	812.9
	Hawea	Hawea	11633.93	11634	313.64	333.23	334.42	8.91	14,232	482.66	335.16	337.18	9.48	20,960	695.1	335.18	337.38	9.94	20,829	784.4
	Hawea	Hawea	11402	11402	313.05	331.97	334.20	10.12	14,222	424.12	334.14	336.49	10.75	20,946	523.0	334.49	336.53	10.26	20,831	970.2
	Hawea	Hawea	11117.02	11117	312.55	330.81	333.25	8.64	14,208	506.49	333.13	335.37	9.86	20,928	565.4	332.65	335.98	11.79	20,833	785.7
	Hawea	Hawea	10830.69	10831	312.05	330.55	332.25	8.37	14,210	656.89	333.06	334.44	8.09	20,933	744.1	332.37	334.40	9.59	20,832	963.7
	Hawea	Hawea	10573.85	10574	311.55	329.78	331.67	8.31	14,209	509.21	332.20	334.08	8.77	20,933	604.3	331.02	333.72	10.21	20,371	598.1
	Hawea	Hawea	10323.65	10324	310.80	328.06	331.35	10.64	14,202	324.27	329.67	334.00	12.69	20,933	329.3	328.99	334.29	14.12	20,968	327.3
	Hawea	Hawea	10085.94	10086	310.30	328.39	330.15	7.73	14,206	291.19	329.63	332.56	10.05	20,933	296.8	328.66	332.24	11.04	20,902	292.1
Camp Hill Road Bridge	Hawea	Hawea	9876.887	9877	311.70	327.95	329.58	9.91	14,203	548.00	329.29	331.42	11.98	20,933	617.7	328.72	331.34	12.83	20,931	590.9
	Hawea	Hawea	9807.301	9807	311.70	327.25	329.43	11.37	14,199	522.86	328.34	331.38	13.65	20,932	569.4	327.82	331.52	14.98	20,931	543.2
	Hawea	Hawea	9656.099	9656	309.05	326.67	328.30	8.55	14,186	677.42	327.82	329.94	10.11	20,904	732.3	327.11	330.03	11.64	20,681	696.4
	Hawea	Hawea	9426.82	9427	308.05	326.93	327.30	7.76	14,190	818.74	327.74	328.75	8.50	20,889	834.5	327.03	328.36	10.05	20,894	821.6
	Hawea	Hawea	9195.49	9196	307.55	324.68	327.55	10.43	14,185	850.15	325.71	329.11	12.08	20,531	964.1	326.44	328.72	10.43	20,867	1488.9
	Hawea	Hawea	8928.076	8928	305.61	324.07	326.22	8.55	14,183	1081.53	325.13	327.55	8.74	20,938	1107.2	324.34	328.02	12.75	20,893	1312.4
	Hawea	Hawea	8603.418	8603	305.54	323.09	325.38	9.57	13,918	1058.30	323.95	326.66	11.38	20,033	1145.3	323.92	326.81	11.31	20,662	1144.9
	Hawea	Hawea	8463.057	8463	305.05	322.29	324.20	9.69	14,175	1218.55	323.70	325.19	9.45	20,870	1308.1	323.73	325.22	9.48	21,011	1309.5
	Hawea	Hawea	8200.776	8201	303.20	320.86	322.72	8.98	13,783	984.66	323.29	324.38	8.04	20,794	1559.7	323.33	324.40	8.62	20,035	1560.1
	Hawea	Hawea	7946.528	7947	302.05	320.53	321.68	7.12	12,486	1041.78	322.00	323.91	7.44	20,794	1126.7	322.04	323.94	7.44	20,927	1127.4
	Hawea	Hawea	7673.591	7674	301.05	318.90	323.55	11.36	14,154	397.47	320.65	325.68	12.90	20,787	879.4	320.67	325.90	12.91	20,920	870.7
	Hawea	Hawea	7390.548	7391	299.05	318.08	321.00	9.79	14,162	479.25	320.00	322.99	10.54	20,789	530.6	320.03	323.02	10.56	20,901	531.1
	Hawea	Hawea	7129.821	7130	296.80	318.43	320.58	12.73	14,123	461.61	318.35	322.28	13.27	20,705	495.8	318.38	322.28	13.26	20,746	496.1
	Hawea	Hawea	6864.788	6865	298.05	315.45	319.12	10.81	14,105	612.57	318.67	320.62	8.99	20,698	697.8	318.69	320.64	8.98	20,740	698.7
	Hawea	Hawea	6635.919	6636	297.05	315.03	317.78	10.18	14,092	187.28	317.14	320.13	11.06	20,612	422.7	317.18	320.18	11.11	20,741	423.4
	Hawea	Hawea	6323.218	6323	296.30	313.96	316.53	6.67	14,093	533.56	316.08	319.07	8.74	20,624	721.0	317.00	319.20	8.91	20,711	855.6
	Hawea	Hawea	6067.44	6067	294.55	311.73	317.14	13.77	14,095	273.97	315.13	318.83	12.58	20,625	468.3	315.15	318.85	12.58	20,711	468.8
	Hawea	Hawea	5805.812	5806	290.35	310.08	316.27	12.33	14,094	188.99	313.44	319.95	13.35	20,568	753.4	313.46	319.96	13.35	20,712	753.5
	Hawea	Hawea	5610.217	5610	292.05	308.60	314.21	12.80	14,093	148.18	311.97	318.43	14.26	20,567	461.1	312.00	322.21	17.85	20,638	592.5
	Hawea	Hawea	5374.761	5375	291.05	308.07	310.35	8.56	14,083	238.33	311.77	313.83	8.63	20,671	552.6	311.68	313.87	8.78	20,939	552.6
	Hawea	Hawea	5133.99	5134	282.95	308.10	309.66	7.51	14,085	254.66	311.23	313.18	8.47	20,712	335.2	311.19	313.14	8.50	20,679	335.2
	Hawea	Hawea	4930.127	4930	289.05	305.37	309.89	12.59	14,087	185.53	308.94	313.99	14.51	20,706	175.5	308.91	313.96	14.51	20,655	175.3
	Hawea	Hawea	4685.188	4685	283.05	305.29	308.34	9.98	14,085	199.02	308.25	312.04	11.25	20,614	203.2	308.22	312.03	11.23	20,579	203.2
	Hawea	Hawea	4485.775	4486	287.05	302.92	309.70	15.67	14,087	219.78	305.80	312.15	15.67	20,496	232.5	305.82	312.03	15.49	20,311	232.5
	Hawea	Hawea	4313.439	4313	286.75	303.91	304.77	5.11	14,087	301.26	307.13	308.22	5.93	20,722	301.3	307.13	308.21	5.93	20,709	301.3
	Hawea	Hawea	4122.169	4122	285.00	302.00	304.67	9.32	14,087	228.54	304.67	308.08	10.66	20,710	228.5	304.68	308.08	10.65	20,579	228.5
	Hawea	Hawea	3898.204	3898	284.60	301.97	303.93	8.09	14,087	196.05	304.24	307.35	9.93	20,720	196.5	304.24	307.34	9.92	20,708	196.5
	Hawea	Hawea	3687.526	3688	283.80	300.25	303.57	9.87	14,086	220.21	302.22	306.04	11.93	20,695	225.7	302.23	306.05	11.93	20,707	225.7
	Hawea	Hawea	3485.256	3485	283.05	300.58	302.67	8.38	14,087	257.73	302.90	305.74	9.88	20,707	264.8	302.90	305.74	9.88	20,706	264.8
	Hawea	Hawea	3238.418	3238	281.60	297.87	302.57	12.47	14,086	234.26	299.81	305.84	14.19	20,709	247.3	299.81	305.84	14.18	20,706	247.3
	Hawea	Hawea	2980.743	2981	280.80	297.69	299.50	8.47	14,086	335.19	299.87	302.16	9.61	20,701	339.0	299.88	302.16	9.61	20,705	339.0
	Hawea	Hawea	2749.738	2750	280.55	294.44	299.95	13.24	14,086	251.91	296.25	302.93	14.94	20,702	264.7	296.25	302.93	14.94	20,705	264.7
	Hawea	Hawea	2469.01	2469	280.05	293.40	295.44	8.63	14,085	495.04	295.54	297.83	9.26	20,696	414.9	295.33	297.83	9.27	20,702	414.9
	Hawea	Hawea	2230.207	2230	278.55	292.61	294.28	8.31	14,085	507.54	295.26	296.75	7.85	20,521	517.3	295.26	296.76	7.84	20,696	517.3
	Hawea	Hawea	1978.029	1978	275.80	289.60	296.08	14.50	14,085	190.23	291.76	299.58	16.29	20,192	190.2	291.75	299.59	16.31	20,194	190.2
	Hawea	Hawea	1711.625	1712	278.49	289.30	291.03	8.42	14,084	411.96	291.75	293.43	8.23	19,753	412.0	291.69	293.41	8.31	19,808	412.0
	Hawea	Hawea	1433.145	1433	275.55	289.40	290.27	5.50	14,082	506.98	292.00	292.90	5.61	19,765	513.7	291.96	292.90	5.74	20,149	513.0
	Hawea	Hawea	1210.233	1210	274.50	287.48	289.25	8.51	14,077	230.70	289.38	292.63	9.76	19,478	230.7	289.28	292.59	9.83	19,454	230.7
	Hawea	Hawea	940.6125	941	273.81	287.03	288.75	7.97	13,223	752.70	290.18	291.09	6.24	19,471	777.8	290.06	291.02	6.40	19,572	777.4
	Hawea	Hawea	700.1266	700	273.05	287.12	287.75	5.29	13,225	944.37	290.27	290.58	4.41	19,465	975.1	290.16	290.59	4.50	19,566	973.9
	Hawea	Hawea	608.228	608	272.63	287.09	287.58	4.39	13,225	947.97	290.25	290.61	4.07	19,513	1012.3	290.13	290.51	4.15	19,565	1011.4
	Hawea	Hawea	474.077	474	272.07	287.05	287.41	4.39	13,225	972.70	290.23	290.52	3.96	19,512	1079.8	290.11	290.42	4.03	19,562	1079.0
	Hawea	Hawea	398.3899	398	272.38	287.00	287.34	3.95	13,225	857.23	290.17	290.50	3.93	19,510	1032.8	290.05	290.39	4.01	19,560	1031.9
	Hawea	Hawea	246.9318	247	271.55	287.04	287.23	2.57	13,227	995.53	290.20	290.41	2.70	19,533	1165.0	290.09	290.30	2.74	19,658	1165.0
Lake Wanaka	Clutha	Wanaka	54038.55 Lake Wanaka	54039	272.20	279.22	279.23	0.43	120	126.73	280.18	280.19	0.41	156	131.7	283.45	283.45	0.19	134	143.3
	Clutha	Wanaka	53996.52	53997	272.20	280.33	280.78	-10.18	-4,078	132.33	284.28	284.38	-8.22	-6,498	145.6	283.45	283.48	0.21	151	143.3
	Clutha	Wanaka	53870.66	53871	272.20	281.24	283.52	8.38	4,680	135.96	284.93	286.72	7.61	6,528	147.3	283.45	283.48	0.21	151	143.4
	Clutha	Wanaka	53764.1	53764	272.20	282.29	283.78	-7.05	-4,092	139.14	285.33	286.96	-7.26	-6,539	148.4	283.85	285.44	7.14	-5,326	144.5
	Clutha	Wanaka	53677.87	53678	272.20	282.63	284.00	-6.57	-4,095	140.65	285.61	287.14	-7.05	-6,562	149.2	284.51	286.64	-6.30	-6,753	145.2
	Clutha	Wanaka	53554.82	53556	272.20	283.06	284.26	-6.13	-4,096	142.08	285.95	287.38	-6.80	-6,563	150.2	285.14	286.97	-7.70	6,778	147.8
	Clutha	Wanaka	53320.66 1_255550	53321	272.20	283.70	284.69	-5.60	-4,096	144.69	286.51	287.77	-6.42	-6,569	152.0	285.97	287.48	-7.00	-6,779	150.2
	Clutha	Wanaka	52899.14 2_255150	52899	271.00	284.26	285.22	-4.71	-4,096	125.17	286.96	288.05	-5.81	-6,577	134.0	286.59	288.18	-6.20	-6,779	132.8
	Clutha	Wanaka	52522.18 3_254700	52522	271.60	284.67	285.58	-4.52	-4,096	124.84	287.41	288.77	-5.58	-6,574	135.3	287.14	288.66	-5.69	6,779	133.8
	Clutha	Wanaka	52121.41 4_254370	52121	272.60	285.08	285.99	-4.64	-4,096	122.66	287.87	289.23	-5.72	-6,578	120.6	287.68	289.17	-6.01	-6,780	132.7
	Clutha	Wanaka	51646.21 5_254100	51646	273.90	285.58	286.18	-3.58	-4,096	145.21	288.55	289.42	-4.37	-6,578	155.3	288.41	289.36	-4.55	-6,780	154.7
	Clutha	Wanaka	51547.32 6_253810	51547	273.70	285.87	286.38	-3.80	-4,096	145.84	288.71	289.64	-4.53	-6,579	197.0	288.59	289.60	-4.72	-6,780	196.4
	Clutha	Wanaka	51093.01 7_253340	51093	272.60	286.11	286.59	-3.23	-4,096	172.31	289.17	289.86	-3.92	-6,580	175.9	289.15	289.84	-3.96	-6,780	285.5
	Clutha	Wanaka	50638.91 8_252900	50639	271.80	286.45	286.59	-2.09	-4,097	474.64	289.59	289.80	-2.51	-6,579	328.8	289.61	289.78	-2.28	-6,781	478.6
	Clutha	Wanaka	50310.9 9_252510	50311	272.60	286.57	286.62	-1.44	-4,097	730.00	289.85	289.92	-1.54	-6,580	577.7	289.79	289.79	-1.55	-6,782	780.5
	Clutha	Wanaka	49932.44 10_252170	49932	269.50	286.60	286.62	-0.63	-4,097	1453.56	289.91	289.91	0.68	-6,578	1524.6	289.76	289.79	-0.71	-6,783	1524.2
	Clutha	Wanaka	49456.66 13_251680	49457	269.40	286.65	286.65	-1.19	-4,096	520.24	289.95	289.94	-1.61	-6,578	853.4	289.75	289.83	-1.09	-6,785	853.1
	Clutha	Wanaka	49357.42 11	49357	270.90	286.62	286.66	-1.23	-4,097	789.48	289.90	289.94	-1.32	-6,580	967.1	289.79	289.82	-1.38	-6,785	964.2
	Clutha	Wanaka	49241.42	49241	270.94	286.62	286.66	-1.27	-4,096	737.75	289.89	289.93	-1.36	-6,580	974.4	289.76	289.83	-1.42	-6,785	965.4
	Clutha	Wanaka	49327.46	49327	270.94	286.62	286.66	-1.20	-4,096		289.90	289.95	-1.30	-6,580		289.76	289.82		-6,785	
Albert Town Bridge	Clutha	Wanaka	49326.16 Bridge 1	49326	270.94	286.62	286.65	-1.19	4,097	737.81	289.90	289.94	1.28	6,579	974.5	289.79	289.82	-1.34	-6,786	965.5
	Clutha	Wanaka	49276.38 14_251450	49276	270.60	286.64	286.65	-0.86	-4,097	1427.16	289.93	289.94	-0.85	-6,581	1435.8	289.80	289.82	-0.90	-6,786	1567.1
	Clutha	Wanaka	49114.52 15_251280	49115	271.00	286.64	286.65	-0.68	-4,096	1544.39	289.93	289.94	-0.69	-6,582	1567.3	289.81	289.82	-0.72	-6,788	1566.5
	Clutha	Wanaka	49038.66 16_251200	49039	270.60	286.65	286.66	-0.78	-4,097	1137.61	289.93	289.95	-0.88	-6,591	1345.6	289.81	289.83	-0.92	-6,794	1338.0
	Clutha	Upper Clutha	48797.55 17_251000	48798	271.00	286.64	286.78	2.46	9,126	989.15	289.86	289.97	2.23	12,829	1049.8	289.81	289.92	2.24	12,764	1049.5
	Clutha	Upper Clutha	48717.5 19_250880	48718	269.40	286.68	286.75	1.87	9,126	953.95	289.88	289.96	1.86	12,829	1036.9	289.83	289.90	1.87	12,763	1036.7
	Clutha	Upper Clutha	48589.99 18_250780	48590	270.70	286.68	286.74	1.50	9,125	1130.62	289.89	289.94	1.49	12,829	1165.0	289.84	289.89	1.49	12,762	1165.0
	Clutha	Upper Clutha	48492.13 20_250690	48492	269.40	286.64	286.73	1.93	9,125	761.52	289.84	289.94	1.98	12,828	765.6	289.79	289.89	1.98	12,761	765.5
	Clutha	Upper Clutha	48388.98 21_250570	48389	270.60	286.64	286.72	1.95	9,125	941.39	289.85	289.93	2.00	12,828	1121.2	289.80	289.88	2.00	12,761	1118.2
	Clutha	Upper Clutha	48287.97 22_250490	48288	270.20	286.65	286.70	1.46	9,125	909.34	289.86	289.92	1.54	12,828	924.7	289.81	289.86	1.54	12,761	924.5
	Clutha	Upper Clutha	48186.38 23_250300	48186	269.60	286.56	286.71	2.42	9,125	531.56	289.75	289.92	2.57	12,828	542.8	289.70	289.87	2.57	12,760	542.6
	Clutha	Upper Clutha	48074.78 24_250220	48075	268.80	286.34	286.71	3.52	9,124	312.74	289.49	289.94	3.86	12,828	320.5	289.44	289.88	3.86	12,760	320.4
	Clutha	Upper Clutha	47950.68 25_250120	47951	268.80	286.28	286.68	3.58	9,124	310.45	289.43	289.91	3.92	12,828	320.3	289.38	289.85	3.92	12,760	320.1
	Clutha	Upper Clutha	47756.36 26_249920	47756	269.40	286.22	286.61	3.36	9,124	318.96	289.38	289.84	3.70	12,827	330.3	289.33	289.79	3.69	12,760	330.1
	Clutha	Upper Clutha	47587.41 27_249740	47587	268.00	286.03	286.56	3.67	9,124	240.82	289.12	289.80	4.17	12,827	250.9	289.07	289.75	4.17	12,760	250.7
	Clutha	Upper Clutha	47374.09 28_249500	47374	268.00	285.50	286.52	5.01	9,123	189.12	288.48	289.79	5.74	12,827	206.3	288.43	289.73	5.73	12,759	206.1
	Clutha	Upper Clutha	46912.94 29_249070	46913	266.90	284.31	286.24	6.83	9,123	149.70	287.05	289.53	7.86	12,826	160.5	287.00	289.47	7.84	12,759	160.4
	Clutha	Upper Clutha	46430.39 30_248570	46430	265.00	282.35	285.70	8.81	9,122	135.53	284.77	289.01	10.13	12,826	144.7	284.74	288.96	10.10	12,758	144.6
	Clutha	Upper Clutha	46097.42 31_248220	46097	265.20	282.82	284.80	6.97	9,122	151.90	285.39	287.96	8.07	12,826	164.3	285.35	287.91	8.05	12,758	164.1
	Clutha	Upper Clutha	45844.95 32_247960	45845	266.40	282.43	284.41	6.69	9,122	143.58	284.85	287.54	7.69	12,826	154.7	284.81	287.49	7.66	12,758	154.5
	Clutha	Upper Clutha	45651.9 33_247770	45652	266.40	282.28	284.14	6.53	9,122	167.15	284.79	287.22	7.57	12,826	167.2	284.75	287.16	7.55	12,757	167.1
	Clutha	Upper Clutha	45291.43 34_247390	45291	268.30	281.43	283.64	7.10	9,122	138.00	283.61	286.68	8.45	12,825	144.2	283.58	286.63	8.43	12,757	144.1
	Clutha	Upper Clutha	44979.54 35_247080	44980	264.60	280.68	283.18	7.84	9,121	152.97	282.79	286.15	9.25	12,824	167.7	282.76	286.10	9.22	12,754	167.5
	Clutha	Upper Clutha	44662.9 36_246760	44663	264.80	280.78	282.50	6.45	9,121	183.91	283.06	285.31	7.46	12,822	196.5	283.05	285.27	7.44	12,753	196.4
	Clutha	Upper Clutha	44388.17 37_246470	44388	264.60	279.78	282.17	7.51	9,121	159.11	281.71	284.99	8.93	12,823	169.3	281.68	284.94	8.90	12,747	169.2
	Clutha	Upper Clutha	44097.73 38_246150	44098	265.30	280.01	281.55	5.90	9,121	166.86	282.03	284.22	7.07	12,818	173.9	282.01	284.18	7.04	12,747	173.8
	Clutha	Upper Clutha	43906.46 39_245950	43906	265.40	279.05	281.45	7.47	9,120	208.69	281.18	284.09	8.44	12,811	232.2	281.16	284.05	8.42	12,751	232.0
	Clutha	Upper Clutha	43685.27 40_245750	43685	263.40	278.13	281.01	7.99	9,120	180.22	280.49	283.66	8.73	12,806	340.2	280.47	283.62	8.72	12,744	339.3
	Clutha	Upper Clutha	43325.14 41_245380	43325	264.00	276.55	280.34	9.00	9,120	147.62	279.44	283.46	9.56	12,825	421.1	279.43	283.41	9.52	12,740	421.0
	Clutha	Upper Clutha	42990.62 42_245050	42991	263.50	276.68	278.62	6.64	9,120	214.33	278.81	281.41	7.64	12,788	573.2	278.78	281.41	7.86	12,769	572.9
	Clutha	Upper Clutha	42774.48 43_244690	42774	263.00	275.92	278.24	7.51	9,119	194.27	278.40	281.00	8.16	12,769	633.0	278.37	280.98	8.17	12,730	627.3
	Clutha	Upper Clutha	42634.77 44_244690	42635	263.80	275.74	277.88	6.94	9,119	329.93	278.58	280.15	6.48	12,773	795.7	278.53	280.12	6.49	12,699	795.4
	Clutha	Upper Clutha	42490.43 45_244550	42490	263.80	274.86	277.61	7.65	9,117	203.55	277.24	280.26	8.19	12,697	240.6	277.23	280.23	8.17	12,643	240.4
	Clutha	Upper Clutha	42091.23 47_244100	42091	262.50	273.39	276.40	8.29	9,113	235.72	276.00	278.70	8.11	11,872	863.9	275.99	278.61	7.99	11,649	863.8
	Clutha	Upper Clutha	41897.83 48_244000	41898	262.30	273.53	275.40	7.59	9,110	401.95	275.78	277.63	8.04	12,945	907.2	275.76	277.60	7.99	12,807	907.0
	Clutha	Upper Clutha	41757.64 49_243850	41758	263.20	273.98	274.79	5.05	9,111	488.83	275.93	276.91	5.81	12,806	919.1	275.90	276.90	5.85	12,801	918.9
	Clutha	Upper Clutha	41166.23 50_243460	41166	262.00	273.66	274.14	3.62	9,111	360.79	275.53	276.17	4.21	12,809	574.0	275.51	276.15	4.22	12,825	573.8
	Clutha	Upper Clutha	40786.6 51_243170	40787	260.60	273.26	273.97	4.69	9,110	433.65	275.15	275.97	5.13	12,788	465.1	275.12	275.95	5.15	12,795	464.8
	Clutha	Upper Clutha	40447.2 52_243000	40447	260.00	272.09	273.88	7.11	9,108	459.68	274.26	275.79	7.03	12,790	604.3	274.20	275.70	7.07	12,724	604.0
	Clutha	Upper Clutha	40417.61 53_242900	40418	259.10	272.12	273.60	6.20	9,109	424.34	274.15	275.73	6.72	12,790	605.4	274.09	275.70	6.76	12,724	605.0
	Clutha	Upper Clutha	40115.77 54_242740	40116	260.60	271.92	273.07	5.42	9,108	420.38	274.07	275.19	5.58	12,790	434.8	274.01	275.14	5.59	12,724	484.7
	Clutha	Upper Clutha	39826.48 55_242500	39826	258.80	272.06	272.65	3.82	9,109	313.50	274.01	274.81	4.52	12,790	345.4	273.96	274.77	4.53	12,751	345.2
	Clutha	Upper Clutha	39669.77 56_242260	39670	257.80	270.92	272.82	7.23	9,107	373.30	273.13	275.05	7.63	12,789	636.4	273.09	274.90	7.44	12,722	625.9
	Clutha	Upper Clutha	39351.16 57_242050	39351	258.60	271.24	272.01	4.66	9,108	420.82	273.31	274.27	5.59	12,785	533.8	273.28	274.24	5.60	12,737	593.7
	Clutha	Upper Clutha	39176.36 58_241940	39176	259.20	271.02	271.85	4.62	9,108	486.23	273.19	274.07	5.19	12,784	618.8	273.14	274.03	5.21	12,734	618.5
	Clutha	Upper Clutha	38763.83 59_241500	38764	256.50	269.31	271.42	7.37	9,108	204.93	271.06	273.79	8.50	12,780	210.5	271.01	273.75	8.51	12,722	210.3
	Clutha	Upper Clutha	38399.87 61_241150	38400	257.00	269.49	270.62	5.47	9,108	277.64	271.50	272.89	6.12	12,765	285.9	271.44	272.83	6.14	12,730	285.7
	Clutha	Upper Clutha	38220.92 62_241000	38221	256.75	268.14	270.48	7.54	9,107	197.80	269.68	272.90	8.95	12,765	209.6	269.61	272.85	8.98	12,701	209.3
	Clutha	Upper Clutha	38072.87 63_240850	38073	255.50	267.89	270.10	7.35	9,106	202.01	269.38	272.40	8.71	12,733	217.7	269.29	272.34	8.75	12,669	216.6
	Clutha	Upper Clutha	37828.97 64_240610	37829	265.40	266.36	270.04	10.11	9,107	232.99	267.88	272.12	11.13	12,691	241.7	267.78	272.14	11.28	12,675	241.1
	Clutha	Upper Clutha	37696.5 65_240500	37697	256.50	266.95	267.81	4.76	9,107	335.82	268.44	269.60	5.57	12,884	341.3	268.39	269.53	5.53	12,716	341.2
	Clutha	Upper Clutha	37543.21 67_240380	37543	256.20	266.60	267.64	5.38	9,107	359.70	268.05	269.38	6.15	12,789	371.0	268.02	269.35	6.14	12,713	370.7
	Clutha	Upper Clutha	37183.1 68_240100	37183	257.10	265.38	266.90	6.14	9,103	420.98	267.19	268.67	6.22	12,783	432.2	267.16	268.63	6.22	12,709	432.0
	Clutha	Upper Clutha	36916.55 69_239940	36917	252.80	264.96	266.31	7.17	9,102	451.34	267.03	268.18	6.85	12,784	472.5	267.00	268.15	6.85	12,710	472.3
	Clutha	Upper Clutha	36692.88 70_239660	36693	253.10	264.76	265.71	5.10	9,102	290.88	266.54	267.79	5.90	12,784	306.1	266.50	267.75	5.88	12,706	305.9
	Clutha	Upper Clutha	36512.22 71_239550	36512	250.30	264.21	265.53	6.43	9,101	257.75	265.86	267.59	7.45	12,781	263.5	265.83	267.55	7.43	12,702	263.4
	Clutha	Upper Clutha	36357.27 72_239250	36357	252.60	263.74	265.19	5.95	9,100	268.87	265.33	267.25	6.94	12,775	333.4	265.31	267.21	6.92	12,700	331.7
	Clutha	Upper Clutha	35280.32 72_238990	35280	250.80	260.93	264.48	9.43	9,093	317.57	262.92	266.07	9.36	12,748	355.4	262.88	266.03	9.37	12,679	354.1
	Clutha	Upper Clutha	34764.54 75_238850	34765	249.80	261.75	262.08	2.88	9,084	422.24	264.17	264.57	3.20	12,758	432.4	264.13	264.53	3.19	12,689	432.3
Church Road Bridge	Clutha	Upper Clutha	34224.77 us_Luggate_Bridg	34225	247.94	258.29	262.08	9.26	9,072	173.16	260.41	264.83	10.24	12,727	202.6	260.37	264.80	10.24	12,677	202.4
	Clutha	Upper Clutha	34179.21 ds_Luggate_Bridg	34179	247.94	258.04	262.79	10.47	9,068	160.77	260.17	265.49	11.31	12,747	173.6	260.14	265.44	11.28	12,674	173.4
	Clutha	Upper Clutha	34105.69 74_238510	34106	247.60	257.60	260.87	8.72	9,064	189.12	260.24	263.76	9.24	12,710	273.4	260.20	263.63	9.12	12,641	272.8
	Clutha	Upper Clutha	33451.54 76_237820	33452	246.80	259.14	259.39	2.27	9,063	441.39	262.07	262.36	2.47	12,713	462.9	262.02	262.31	2.46	12,648	462.7
	Clutha	Upper Clutha	32844.19 77_237420	32844	245.80	258.94	259.21	3.01	9,062	585.05	261.95	262.21	2.96	12,713	600.4	261.90	262.16	2.96	12,647	600.1
	Clutha	Upper Clutha	31848.27 78_237040	31848	244.00	258.60	258.92	2.89	9,061	422.94	261.64	261.99	3.10	12,712	456.5	261.59	261.94	3.09	12,647	456.2
	Clutha	Upper Clutha	31504.62 79_236640	31505	240.40	257.91	258.86	5.10	9,061	218.01	260.82	261.96	5.65	12,711	227.9	260.77	261.91	5.64	12,646	227.8
	Clutha	Upper Clutha	31071.99 80_236220	31072	242.00	255.11	258.44	8.49	9,061	124.03	257.30	261.72	9.88	12,711	129.6	257.26	261.67	9.86	12,646	129.6
	Clutha	Upper Clutha	30732.29 82_235870	30732	240.80	255.68	257.57	6.59	9,061	168.06	258.37	260.70	7.41	12,711	181.6	258.33	260.64	7.39	12,646	181.4
	Clutha	Upper Clutha	30567.9 81_235700	30568	240.70	255.61	257.30	6.14	9,061	155.48	258.22	260.42	7.08	12,711	164.3	258.18	260.37	7.04	12,648	164.1
	Clutha	Upper Clutha	30218.81 83_235335	30219	239.80	254.05	256.94	8.24	9,061	132.03	256.26	260.11	9.63	12,711	139.9	256.22	260.06	9.61	12,646	139.8
	Clutha	Upper Clutha	29812.53 84_234925	29813	240.20	253.08	255.83	7.61	9,061	130.50	254.95	258.85	9.12	12,711	136.8	254.92	258.80	9.10	12,645	136.7
	Clutha	Upper Clutha	29316.57 85_234400	29317	238.80	252.66	254.77	6.68	9,061	155.22	254.66	257.56	8.12	12,711	162.2	254.63	257.51	8.10	12,645	162.0
	Clutha	Upper Clutha	28910.32 86_233985	28910	239.00	250.98	253.82	8.44	9,060	168.88	252.73	256.48	9.83	12,710	174.7	252.69	256.44	9.81	12,645	174.6
	Clutha	Upper Clutha	28569.06 87_233670	28569	239.20	250.05	252.75	7.59	9,050	161.21	251.58	255.39	9.07	12,710	167.0	251.56	255.35	9.05	12,644	167.0
	Clutha	Upper Clutha	28143.47 88_233205	28143	238.90	249.85	251.30	5.80	9,059	257.91	251.53	253.39	6.67	12,682	265.3	251.51	253.37	6.67	12,643	265.2
	Clutha	Upper Clutha	27950.62 89_233005	27951	238.40	249.30	250.92	5.97	9,059	239.85	250.79	253.00	7.04	12,682	246.8	250.76	252.97	7.04	12,639	246.7
	Clutha	Upper Clutha	27445.48 90_232475	27446	237.20	247.76	249.36	7.22	9,032	407.94	249.47	251.16	7.71	12,609	474.1	249.44	251.13	7.70	12,539	472.7
	Clutha	Upper Clutha	26614.34 92_231600	26614	235.70	247.31	247.61	3.41	9,023	689.05	249.37	249.68	3.48	12,621	678.7	249.34	249.64	3.47	12,548	678.5
	Clutha	Upper Clutha	26474.51 93_231475	26475	234.70	247.30	247.51	3.82	9,023	905.39	249.41	249.60	3.54	12,622	917.8	249.37	249.56	3.54	12,548	917.5
	Clutha	Upper Clutha	26174.48 94_231185	26174	235.60	247.01	247.36	3.70	9,019	600.92	249.13	249.49	3.78	12,622	618.5	249.09	249.45	3.78	12,549	618.2
	Clutha	Upper Clutha	25879.05 95_230900	25879	234.60	247.00	247.17	2.85	9,020	681.52	249.14	249.34	3.01	12,622	692.3	249.10	249.30	3.00	12,549	692.1
Aoturoa farm	Clutha	Upper Clutha	25522.93 96_230530	25523	234.40	246.95	247.07	2.16	9,019	787.73	249.11	249.25	2.34	12,622	944.6	249.07	249.21	2.34	12,548	941.5
	Clutha	Upper Clutha	25235.16 97_230255	25235	233.10	246.85	247.01	2.78	9,020	627.82	248.99	249.19	3.02	12,622	641.3	248.96	249.16	3.01	12,547	641.1
	Clutha	Upper Clutha	24908.77 98_229920	24909	231.80	246.67	246.88	3.22	9,020	491.27	248.80	249.07	3.56	12,621	498.4	248.76	249.03	3.55	12,544	498.3
	Clutha	Upper Clutha	24213.23 99_229220	24213	231.40	245.41	246.20	4.66	9,019	318.65	247.44	248.41	5.21	12,616	326.0	247.41	248.37	5.19	12,543	325.8
	Clutha	Upper Clutha	23155.6 100_228140	23156	231.00	242.34	243.10	5.49	9,021	323.75	244.89	245.70	5.59	12,557	332.8	244.85	245.66	5.59	12,496	332.7
	Clutha	Upper Clutha	21965.62 101_226940	21966	228.75	241.12	241.69	4.32	8,983	377.57	244.10	244.66	4.29	12,549	385.5	244.05	244.61	4.29	12,485	385.4
	Clutha	Upper Clutha	20727.1 102_225830	20727	227.00	240.58	240.82	2.85	8,980	401.25	243.73	244.00	3.06	12,549	411.5	243.68	243.95	3.08	12,485	411.3
	Clutha	Upper Clutha	19371.97 103_224440	19372	224.30	240.15	240.49	3.17	8,979	311.21	243.29	243.71	3.52	12,548	323.3	243.24	243.65	3.51	12,485	323.1
	Clutha	Upper Clutha	18356.45 104_223450	18356	220.00	234.94	240.83	11.41	8,978	85.44	237.48	245.16	13.15	12,548	92.8	237.45	245.09	13.12	12,485	92.7
	Clutha	Upper Clutha	17004.33 DTM1	17004	220.80	233.68	236.27	7.52	8,977	140.19	235.87	239.28	8.73	12,546	149.3	235.84	239.23	8.71	12,483	149.1
	Clutha	Upper Clutha	15247.65 DTM2	15248	217.50	230.04	232.40	7.33	8,976	151.10	231.95	235.18	8.65	12,545	158.3	231.92	235.13	8.63	12,482	158.2
	Clutha	Upper Clutha	14149.73 DTM3	14150	217.13	226.52	229.64	8.56	8,976	176.73	227.86	232.20	10.19	12,545	185.1	227.84	232.16	10.16	12,481	184.9
Queensbury	Clutha	Upper Clutha	12961.14 DTM4	12961	215.54	224.37	225.80	6.38	8,970	368.55	225.61	227.48	7.41	12,544	415.7	225.59	227.44	7.40	12,480	415.5
	Clutha	Upper Clutha	11812.85 DTM5	11813	213.10	222.24	222.95	4.62	8,968	554.31	223.23	224.41	6.18	12,543	638.8	223.21	224.39	6.17	12,480	637.2
	Clutha	Upper Clutha	10859.49 DTM6	10859	211.80	218.03	219.32	6.81	8,967	1538.18	218.64	219.92	7.19	12,542	1688.7	218.63	219.91	7.18	12,479	1687.7
	Clutha	Upper Clutha	9438.206 DTM7	9438	207.28	214.16	214.40	3.95	8,964	1557.05	214.78	215.09	4.36	12,539	1592.9	214.77	215.07	4.35	12,476	1592.2
	Clutha	Upper Clutha	8258.471 DTM8	8258	207.29	211.99	212.36	4.27	8,964	1642.17	212.54	212.99	4.62	12,538	1649.3	212.53	212.98	4.62	12,476	1649.2
	Clutha	Upper Clutha	7169.452 DTM9	7169	205.09	209.06	209.38	3.22	8,957	1443.96	209.81	210.18	3.44	12,516	1452.1	209.80	210.17	3.44	12,455	1452.0
	Clutha	Upper Clutha	5918.831 2 Bendigo	5919	199.90	207.72	207.88	2.21	8,946	1558.88	208.65	208.82	2.43	12,497	1569.5	208.64	208.81	2.43	12,441	1569.4
Willowbank	Clutha	Upper Clutha	4628.777 DTM11	4629	201.73	206.81	206.96	2.14	8,941	1477.60	207.81	207.99	2.32	12,488	1486.5	207.80	207.98	2.32	12,433	1486.4
	Clutha	Upper Clutha	3262.424 DTM12	3262	199.08	204.71	205.13	4.25	8,939	842.31	205.99	206.44	4.47	12,485	952.3	205.97	206.42	4.47	12,430	951.5
Bendigo	Clutha	Upper Clutha	2170.135 3 Bendigo	2170	193.97	201.59	204.27	9.91	8,939	248.55	202.68	206.21	11.33	12,484	248.6	202.67	206.18	11.31	12,429	248.6
	Clutha	Upper Clutha	1241.768 4 Bendigo	1242	193.08	198.92	199.30	3.92	8,938	948.71	200.10	200.34	3.14	9,709	948.7	200.14	200.39	3.12	9,744	948.7
	Clutha	Upper Clutha	701.3322	701	191.11	197.89	198.12	2.90	7,051	1021.74	199.70	199.87	2.47	9,431	1025.6	199.75	199.92	2.45	9,454	1025.6
	Clutha	Upper Clutha	475.7226	476	190.11	197.82	197.93	1.93	7,014	943.87	199.66	199.76	1.89	9,401	957.9	199.71	199.82	1.89	9,445	958.3
	Clutha	Upper Clutha	295.6647	296	189.73	197.78	197.90	1.98	6,993	701.03	199.61	199.74	2.07	9,381	707.2	199.68	199.80	2.07	9,425	707.4
	Clutha	Upper Clutha	133.198	133	187.63	197.74	197.85	2.06	6,980	798.09	199.59	199.70	2.09	9,369	812.8	199.64	199.76	2.08	9,413	813.0
Lake Dunstan	Clutha	Lower Clutha	69.04708 Lake Dunstan	69	140.00	197.74	197.75	0.42	7,195	521.34	199.59	199.60	0.53	9,583	533.5	199.64	199.66	0.53	9,626	533.9
Lake Dunstan	Clutha	Lower Clutha	48.00178 Lake Dunstan	48	140.00	197.74	197.75	0.42	7,195	521.34	199.59	199.60	0.53	9,583	533.5	199.64	199.66	0.53	9,626	533.9
Clyde Dam	Clutha	Lower Clutha	40 Clyde Dam	40	140.00	197.74		Clyde Dam			199.59		Clyde Dam			199.64		Clyde Dam		
	Clutha	Lower Clutha	21.10445	21	140.00	145.87	164.73	19.35	7,195	72.94	146.33	172.99	22.90	9,583	74.4	146.34	173.15	22.97	9,626	74.5
	Clutha	Lower Clutha	7.231917	7	140.00	143.16	210.30	36.30	7,195	67.24	144.20	208.56	35.54	9,583	69.7	144.22	208.52	35.53	9,626	69.8

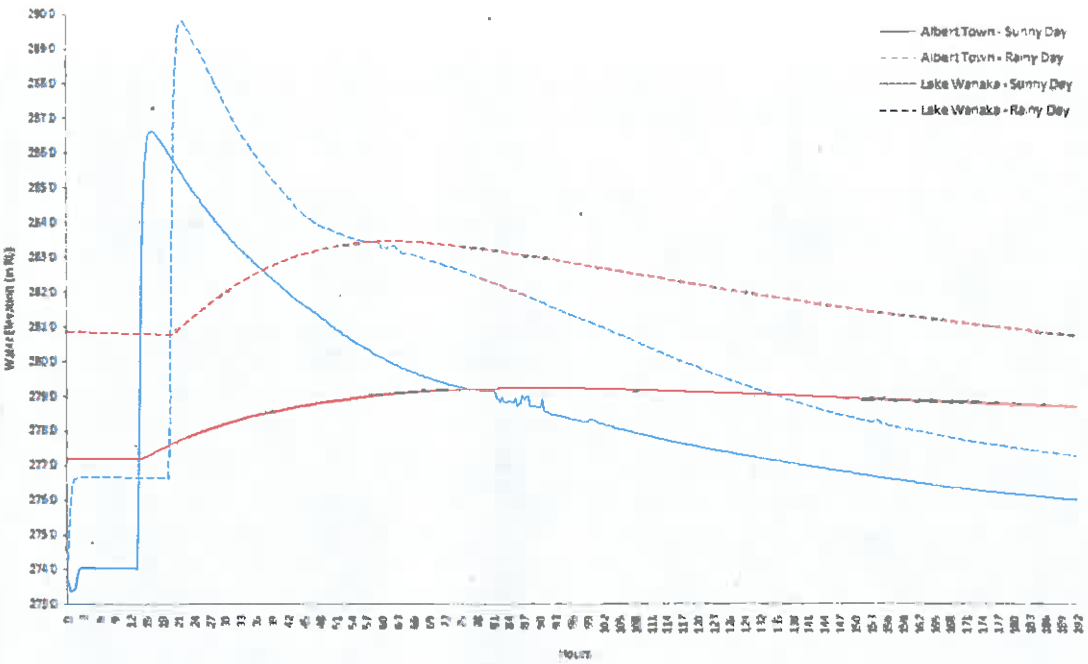
	River	Reach	Cross Section	Chainage	Channel Invert (m RL)	Sunny Day Event: Base Case Peak WSL (m RL)	Base Case Peak Discharge (m³/s)	Roughness +20% Peak WSL (m RL)	Roughness +20% Peak Discharge (m³/s)	Change WSL (%)	Change Discharge (%)	Rainy Day (PMF) Event: Base Case Peak WSL	Base Case Peak Discharge (m³/s)	Roughness +20% Peak WSL (m RL)	Roughness +20% Peak Discharge (m³/s)	Change WSL (%)	Change Discharge (%)
	Hawea	Hawea	14908.58 Lake Hawea	14909	322.00	346.00	200	346.00	200	0.00	0.00	350.24	307	350.24	307	0.00	0.00
Lake Hawea	Hawea	Hawea	14871.62 Lake Hawea	14872	322.00	346.00	200	346.00	200	0.00	0.00	350.26	0	350.26	0	0.00	0.00
Hawea Dam	Hawea	Hawea	14848.86 Hawea Dam	14849	322.00	346.00		Hawea Dam				350.26		Hawea Dam			
	Hawea	Hawea	14719.37	14719	320.05	343.63	14,433	344.17	13,861	2.29	-3.96	346.85	21,298	347.58	20,713	2.72	-2.74
	Hawea	Hawea	14678.95	14679	317.05	344.33	14,443	344.70	13,874	1.36	-3.94	347.61	21,307	348.20	20,802	1.93	-2.37
	Hawea	Hawea	14606.49	14606	317.05	343.42	14,430	343.92	13,859	1.90	-3.96	346.64	21,301	347.33	20,713	2.33	-2.76
	Hawea	Hawea	14557.05	14557	317.05	341.59	14,402	342.74	13,841	4.69	-3.89	345.03	21,300	346.28	20,696	4.47	-2.84
	Hawea	Hawea	14344.56	14345	317.05	341.04	14,398	341.91	13,838	3.63	-3.91	343.41	21,240	344.54	20,665	4.29	-2.71
	Hawea	Hawea	14055.06	14055	317.35	339.89	14,378	340.91	13,834	4.53	-3.79	342.61	21,205	343.80	20,652	4.71	-2.61
	Hawea	Hawea	13753.46	13753	317.05	338.86	14,380	340.08	13,835	5.59	-3.79	342.26	21,188	343.20	20,659	3.73	-2.50
	Hawea	Hawea	13486.47	13486	317.54	336.64	14,385	338.17	13,820	8.01	-3.93	340.51	21,157	342.03	20,622	6.62	-2.53
	Hawea	Hawea	13163.89	13164	316.85	336.21	14,379	336.80	13,728	3.05	-4.53	337.90	21,187	339.29	20,225	6.60	-4.54
	Hawea	Hawea	12938.63	12939	317.05	335.38	14,314	336.19	13,698	4.42	-4.30	337.05	21,019	338.76	20,159	8.55	-4.09
	Hawea	Hawea	12687.94	12688	316.05	334.61	14,239	335.56	13,673	6.12	-3.97	336.84	20,955	338.49	20,157	7.94	-3.81
	Hawea	Hawea	12451.29	12451	315.30	334.53	14,238	335.20	13,667	3.48	-4.01	336.98	20,976	338.27	20,153	5.95	-3.92
	Hawea	Hawea	12196.54	12197	315.46	334.11	14,238	334.59	13,655	2.57	-4.10	336.57	20,973	337.72	20,140	5.45	-3.97
	Hawea	Hawea	11929.76	11930	314.06	333.83	14,235	334.50	13,660	3.39	-4.04	336.17	20,965	337.63	20,142	6.60	-3.92
	Hawea	Hawea	11633.93	11634	313.84	333.23	14,232	333.70	13,653	2.42	-4.07	335.16	20,960	335.59	20,110	6.71	-4.06
	Hawea	Hawea	11402	11402	313.05	331.97	14,222	332.67	13,644	3.70	-4.07	334.14	20,946	335.23	20,075	5.17	-4.16
	Hawea	Hawea	11117.02	11117	312.55	330.81	14,208	331.61	13,633	4.38	-4.04	333.13	20,928	333.96	20,064	4.03	-4.13
	Hawea	Hawea	10830.69	10831	312.05	330.55	14,210	331.05	13,630	2.70	-4.08	333.08	20,933	333.34	20,061	1.24	-4.17
	Hawea	Hawea	10573.65	10574	311.55	329.78	14,209	330.20	13,628	2.30	-4.09	332.20	20,933	331.99	20,057	-1.02	-4.18
	Hawea	Hawea	10323.65	10324	310.80	[illegible]	[illegible]	328.64	13,617	3.36	[illegible]	329.67	[illegible]	330.50	[illegible]	[illegible]	[illegible]
	Hawea	Hawea	10085.94	10086	310.30	328.39	14,206	328.40	13,617	0.06	-4.15	329.63	20,933	329.79	20,053	0.83	-4.21
Camp Hill Road Bridge	Hawea	Hawea	9876.667	9877	311.70	327.95	14,205	327.99	13,618	0.25	-4.13	329.29	20,933	329.53	20,056	1.36	-4.19
	Hawea	Hawea	9807.301	9807	311.70	327.25	14,199	327.05	13,612	-1.29	-4.13	328.34	20,932	328.43	20,056	0.54	-4.18
	Hawea	Hawea	9656.099	9656	309.05	326.67	14,186	326.67	13,608	0.00	-4.09	327.82	20,904	327.87	20,055	0.27	-4.06
	Hawea	Hawea	9426.82	9427	308.05	326.53	14,190	326.19	13,602	-1.84	-4.14	327.74	20,889	327.29	20,053	-2.29	-4.01
	Hawea	Hawea	9195.49	9195	307.55	324.68	14,185	325.33	13,600	3.79	-4.13	325.71	20,631	326.71	20,052	5.51	-2.33
	Hawea	Hawea	8928.076	8928	306.61	324.07	14,183	323.69	13,589	-2.18	-4.19	325.13	20,938	324.88	19,990	-1.35	-4.52
	Hawea	Hawea	8693.418	8693	305.54	323.00	13,918	323.23	13,592	1.32	-2.34	323.95	20,933	324.73	19,999	4.24	-4.46
	Hawea	Hawea	8463.057	8463	305.05	322.29	14,175	322.78	13,556	2.84	-4.37	323.70	20,820	324.37	19,993	3.69	-3.97
	Hawea	Hawea	8200.776	8201	303.29	320.86	13,763	321.64	13,503	4.44	-1.89	323.29	20,794	323.96	19,988	3.35	-3.88
	Hawea	Hawea	7946.526	7947	302.05	320.53	12,486	321.35	13,509	4.44	8.19	322.90	20,794	323.51	19,985	2.93	-3.89
	Hawea	Hawea	7673.591	7674	301.05	318.90	14,154	319.30	13,508	2.24	-4.56	320.65	20,787	321.21	19,977	2.86	-3.89
	Hawea	Hawea	7390.548	7391	299.05	318.08	14,152	318.61	13,504	2.79	-4.58	320.00	20,780	320.70	19,974	3.34	-3.88
	Hawea	Hawea	7129.821	7130	298.80	316.43	14,123	317.23	13,497	4.54	-4.43	318.36	20,705	319.47	19,957	5.67	-3.61
	Hawea	Hawea	6864.788	6865	298.05	315.45	14,105	315.98	13,498	8.79	-4.30	318.67	20,698	319.38	19,959	3.44	-3.57
	Hawea	Hawea	6635.919	6636	297.05	315.03	14,092	316.05	13,496	5.67	-4.23	317.14	20,612	318.05	19,946	4.53	-3.23
	Hawea	Hawea	6323.218	6323	296.30	313.96	14,093	315.35	13,493	7.93	-4.26	316.98	20,624	317.68	19,946	3.38	-3.29
	Hawea	Hawea	6067.44	6067	294.55	311.73	14,095	313.26	13,482	8.91	-4.35	315.13	20,625	316.19	19,934	5.15	-3.35
	Hawea	Hawea	5805.812	5806	293.36	310.08	14,094	311.03	13,484	5.68	-4.32	313.44	20,568	315.10	19,929	6.27	-3.11
	Hawea	Hawea	5610.217	5610	292.05	308.60	14,090	309.50	13,484	5.44	-4.32	311.97	20,587	312.76	19,932	3.97	-3.09
	Hawea	Hawea	5374.761	5375	291.05	308.07	14,083	309.55	13,480	8.70	-4.28	311.72	20,671	313.28	19,930	7.55	-3.58
	Hawea	Hawea	5133.99	5134	289.96	308.10	14,085	309.31	13,481	6.67	-4.29	311.23	20,712	312.69	19,930	6.66	-3.77
	Hawea	Hawea	4930.127	4930	289.05	305.37	14,087	306.68	13,481	8.03	-4.30	308.04	20,708	309.08	19,930	5.48	-3.76
	Hawea	Hawea	4685.168	4685	288.05	305.29	14,085	306.35	13,474	6.15	-4.34	308.21	20,614	308.89	19,930	3.37	-3.32
	Hawea	Hawea	4485.775	4486	287.05	302.92	14,087	303.74	13,042	5.17	-7.42	305.80	20,498	306.00	19,929	1.07	-2.78
	Hawea	Hawea	4313.439	4313	286.75	303.91	14,087	304.48	13,568	3.32	-3.69	307.13	20,722	307.79	19,929	3.24	-3.83
	Hawea	Hawea	4122.169	4122	285.00	302.00	14,087	302.90	13,435	5.29	-4.20	304.67	20,719	305.74	19,929	5.44	-3.82
	Hawea	Hawea	3898.204	3898	284.80	301.87	14,087	302.50	13,488	3.69	-4.25	304.24	20,720	305.04	19,928	4.12	-3.82
	Hawea	Hawea	3687.526	3688	283.80	300.25	14,086	301.22	13,483	5.90	-4.28	302.22	20,695	303.53	19,928	7.11	-3.71
	Hawea	Hawea	3485.256	3485	283.05	300.58	14,087	301.16	13,482	3.31	-4.29	302.90	20,707	303.66	19,928	3.83	-3.76
	Hawea	Hawea	3238.416	3238	281.80	297.67	14,086	298.15	13,480	3.02	-4.30	299.81	20,709	300.16	19,928	1.94	-3.77
	Hawea	Hawea	2980.743	2981	280.80	297.69	14,096	298.17	13,480	2.84	-4.30	299.87	20,701	300.56	19,927	3.62	-3.74
	Hawea	Hawea	2749.736	2750	280.55	294.44	14,086	294.56	13,479	0.86	-4.31	296.25	20,702	296.47	19,927	1.40	-3.74
	Hawea	Hawea	2469.01	2469	280.05	293.40	14,085	293.96	13,479	4.19	-4.30	295.54	20,698	296.36	19,910	5.29	-3.81
	Hawea	Hawea	2230.207	2230	278.55	292.61	14,085	293.08	13,479	3.34	-4.30	295.29	20,521	295.91	19,905	3.70	-3.00
	Hawea	Hawea	1976.029	1976	276.80	289.80	14,085	290.02	13,406	1.63	-4.82	291.76	20,192	292.21	19,456	3.01	-3.64
	Hawea	Hawea	1711.625	1712	276.49	289.30	14,084	289.95	13,017	5.07	-7.58	291.75	19,753	292.83	19,080	7.08	-3.41
	Hawea	Hawea	1433.145	1433	275.55	289.40	14,082	289.78	13,012	2.74	-7.59	292.00	19,765	292.84	19,084	5.11	-3.44
	Hawea	Hawea	1210.233	1210	274.80	287.48	14,077	288.28	12,847	6.31	-8.74	289.38	19,478	290.75	18,790	9.40	-3.54
	Hawea	Hawea	940.8125	941	273.81	287.03	13,223	287.99	12,697	7.26	-3.98	290.18	19,471	291.15	18,836	5.93	-3.27
	Hawea	Hawea	700.1266	700	273.05	287.12	13,225	287.87	12,681	5.33	-4.11	290.27	19,465	291.13	18,832	4.99	-3.25
	Hawea	Hawea	608.228	608	272.63	287.09	13,225	287.82	12,681	5.05	-4.11	290.25	19,513	291.10	18,832	4.82	-3.49
	Hawea	Hawea	474.077	474	272.07	287.05	13,225	287.76	12,680	4.74	-4.12	290.23	19,512	291.06	18,831	4.57	-3.49
	Hawea	Hawea	398.3899	398	272.38	287.00	13,225	287.70	12,680	4.79	-4.12	290.17	19,510	291.01	18,830	4.72	-3.49
	Hawea	Hawea	246.9318	247	271.55	287.04	13,227	287.70	12,680	4.26	-4.13	290.20	19,533	291.01	18,827	4.34	-3.61
Lake Wanaka	Clutha	Wanaka	54038.55 Lake Wanaka	54039	272.20	279.22	129	279.33	165	1.57	28.35	280.18	158	280.28	167	1.25	5.81
	Clutha	Wanaka	53996.52	53997	272.20	280.33	-4,076	281.20	-3,941	10.70	-3.31	284.28	-6,498	286.17	-6,239	15.65	-3.98
	Clutha	Wanaka	53870.66	53871	272.20	281.24	-4,080	282.52	-3,955	14.16	-3.07	284.93	-6,528	286.52	-6,251	12.49	-4.25
	Clutha	Wanaka	53764.1	53764	272.20	282.20	-4,092	283.05	-3,955	8.50	-3.34	285.33	-6,539	286.79	-6,258	11.12	-4.29
	Clutha	Wanaka	53677.87	53678	272.20	282.63	-4,095	283.37	-3,956	7.09	-3.41	285.61	-6,552	286.98	-6,264	10.22	-4.40
	Clutha	Wanaka	53554.82	53555	272.20	283.08	-4,096	283.75	-3,956	6.16	-3.42	285.95	-6,563	287.24	-6,271	9.38	-4.46
	Clutha	Wanaka	53320.66 1_255550	53321	272.20	283.70	-4,096	284.33	-3,957	5.48	-3.39	286.51	-6,569	287.69	-6,282	8.25	-4.38
	Clutha	Wanaka	52899.14 2_255150	52899	271.00	284.28	-4,096	284.92	-3,958	4.82	-3.38	286.96	-6,572	288.13	-6,290	7.33	-4.29
	Clutha	Wanaka	52522.18 3_254790	52522	271.60	284.67	-4,096	285.35	-3,958	5.20	-3.38	287.41	-6,574	288.56	-6,297	7.27	-4.22
	Clutha	Wanaka	52121.41 4_254370	52121	272.80	285.08	-4,096	285.78	-3,958	5.70	-3.38	287.87	-6,578	289.02	-6,302	7.63	-4.20
	Clutha	Wanaka	51846.21 5_254100	51846	273.90	285.56	-4,096	286.23	-3,958	5.76	-3.38	288.55	-6,578	289.55	-6,307	6.83	-4.13
	Clutha	Wanaka	51547.32 6_253810	51547	273.70	285.87	-4,096	286.37	-3,958	5.85	-3.37	288.71	-6,579	289.75	-6,309	6.93	-4.11
	Clutha	Wanaka	51093.01 7_253340	51093	272.80	286.11	-4,096	286.79	-3,958	5.11	-3.38	289.17	-6,579	290.21	-6,311	6.35	-4.08
	Clutha	Wanaka	50838.91 8_252900	50839	271.80	286.46	-4,097	287.10	-3,958	4.37	-3.38	289.59	-6,579	290.54	-6,312	5.34	-4.07
	Clutha	Wanaka	50310.9 9_252510	50311	272.60	286.57	-4,097	287.20	-3,958	4.51	-3.38	289.85	-6,580	290.64	-6,312	4.58	-4.07
	Clutha	Wanaka	49932.44 10_252120	49932	269.50	286.62	-4,097	287.24	-3,958	3.62	-3.38	289.91	-6,578	290.67	-6,312	3.72	-4.04
	Clutha	Wanaka	49456.66 13_251680	49457	269.40	286.60	-4,096	287.23	-3,958	3.66	-3.37	289.88	-6,578	290.66	-6,312	3.81	-4.05
	Clutha	Wanaka	49357.42 11	49575	270.90	286.62	-4,097	287.25	-3,958	4.01	-3.38	289.90	-6,580	290.68	-6,313	4.11	-4.06
	Clutha	Wanaka	49341.42	49341	270.94	286.62	-4,096	287.25	-3,958	4.02	-3.38	289.90	-6,580	290.68	-6,313	4.11	-4.06
Albert Town Bridge	Clutha	Wanaka	49327.46	49327	270.94	286.62		Bridge				289.90		Bridge			
	Clutha	Wanaka	49325.16 Bridge 1	49325	270.94	286.62	-4,097	287.25	-3,958	4.02	-3.38	289.90	-6,579	290.68	-6,313	4.11	-4.04
	Clutha	Wanaka	49276.38 14_251450	49276	270.80	286.64	-4,097	287.27	-3,958	3.98	-3.38	289.93	-6,581	290.70	-6,313	4.03	-4.07
	Clutha	Wanaka	49114.52 15_251280	49115	271.00	286.64	-4,096	287.27	-3,958	4.03	-3.37	289.93	-6,582	290.70	-6,313	4.07	-4.08
	Clutha	Wanaka	49038.68 16_251200	49039	270.60	286.65	-4,097	287.28	-3,959	3.93	-3.37	289.93	-6,591	290.70	-6,316	3.98	-4.17
	Clutha	Upper Clutha	48797.55 17_251000	48798	271.00	286.64	9,126	287.28	8,720	4.09	-4.45	289.86	12,829	290.70	12,505	4.45	-2.53
	Clutha	Upper Clutha	48717.5 19_250880	48718	269.40	286.68	9,126	287.30	8,720	3.59	-4.45	289.88	12,829	290.71	12,505	4.05	-2.53
	Clutha	Upper Clutha	48589.99 18_250780	48590	270.70	286.68	9,125	287.30	8,719	3.88	-4.45	289.89	12,829	290.72	12,504	4.33	-2.53
	Clutha	Upper Clutha	48492.13 20_250690	48492	269.40	286.64	9,125	287.26	8,719	3.60	-4.45	289.84	12,828	290.68	12,504	4.11	-2.53
	Clutha	Upper Clutha	48388.98 21_250570	48389	270.60	286.64	9,125	287.25	8,719	3.80	-4.44	289.85	12,828	290.68	12,504	4.31	-2.53
	Clutha	Upper Clutha	48287.97 22_250480	48288	270.20	286.65	9,125	287.26	8,719	3.71	-4.44	289.86	12,828	290.68	12,504	4.17	-2.53
	Clutha	Upper Clutha	48186.38 23_250300	48186	269.60	286.56	9,125	287.18	8,719	3.66	-4.45	289.75	12,828	290.59	12,504	4.17	-2.53
	Clutha	Upper Clutha	48074.78 24_250220	48075	268.80	286.34	9,124	287.00	8,719	3.76	-4.44	289.49	12,828	290.36	12,503	4.20	-2.53
	Clutha	Upper Clutha	47950.08 25_250120	47951	268.80	286.26	9,124	286.94	8,719	3.78	-4.44	289.43	12,828	290.30	12,503	4.22	-2.53
	Clutha	Upper Clutha	47756.36 26_249920	47756	269.40	286.22	9,124	286.87	8,719	3.66	-4.44	289.38	12,827	290.24	12,503	4.30	-2.53
	Clutha	Upper Clutha	47587.41 27_249740	47587	268.00	286.03	9,124	286.69	8,719	3.66	-4.44	289.12	12,827	290.00	12,503	4.17	-2.53
	Clutha	Upper Clutha	47374.09 28_249500	47374	268.00	285.50	9,123	286.23	8,719	4.17	-4.44	288.48	12,827	289.44	12,502	4.69	-2.53
	Clutha	Upper Clutha	46912.94 29_249070	46913	266.90	284.31	9,123	285.17	8,718	4.94	-4.44	287.05	12,826	288.17	12,502	5.56	-2.53
	Clutha	Upper Clutha	46430.39 30_248570	46430	265.00	282.35	9,122	283.84	8,717	7.44	-4.44	284.77	12,826	286.39	12,501	8.19	-2.53
	Clutha	Upper Clutha	46097.42 31_248220	46097	265.20	282.82	9,122	283.71	8,717	5.05	-4.44	285.39	12,826	286.54	12,501	5.70	-2.53
	Clutha	Upper Clutha	45844.95 32_247960	45845	266.40	282.43	9,122	283.28	8,717	5.30	-4.44	284.85	12,826	285.97	12,501	6.07	-2.53
	Clutha	Upper Clutha	45651.9 33_247770	45652	266.40	282.28	9,122	283.10	8,717	5.16	-4.44	284.79	12,826	285.83	12,501	5.66	-2.53
	Clutha	Upper Clutha	45291.43 34_247390	45291	266.30	281.43	9,122	282.27	8,717	5.55	-4.44	283.61	12,825	284.71	12,501	6.36	-2.53
	Clutha	Upper Clutha	44979.54 35_247080	44980	264.60	280.68	9,121	281.55	8,716	5.41	-4.44	282.79	12,824	283.81	12,501	5.61	-2.52
	Clutha	Upper Clutha	44662.9 36_246760	44663	264.80	280.78	9,121	281.44	8,716	4.13	-4.44	283.08	12,822	283.86	12,501	4.27	-2.51
	Clutha	Upper Clutha	44388.17 37_246470	44388	264.80	279.76	9,121	280.55	8,715	5.07	-4.45	281.71	12,823	282.61	12,501	5.28	-2.52
	Clutha	Upper Clutha	44097.73 38_246150	44098	265.30	280.01	9,121	280.52	8,715	3.47	-4.44	282.03	12,818	282.59	12,501	3.35	-2.47
	Clutha	Upper Clutha	43906.46 39_245950	43906	265.40	279.05	9,120	279.77	8,715	5.27	-4.45	281.18	12,811	281.84	12,501	4.18	-2.43
	Clutha	Upper Clutha	43685.27 40_245750	43685	263.40	278.13	9,120	278.98	8,715	5.77	-4.44	280.49	12,806	281.23	12,500	4.33	-2.39
	Clutha	Upper Clutha	43325.14 41_245380	43325	264.00	276.55	9,120	277.13	8,715	4.62	-4.44	279.44	12,825	279.60	12,500	1.04	-2.54
	Clutha	Upper Clutha	42990.62 42_245050	42991	263.50	276.68	9,120	277.18	8,714	3.79	-4.45	278.81	12,788	279.21	12,494	2.61	-2.30
	Clutha	Upper Clutha	42774.48 43_244890	42774	263.00	275.92	9,119	276.57	8,713	5.03	-4.46	278.40	12,769	278.62	12,452	1.43	-2.48
	Clutha	Upper Clutha	42634.77 44_244690	42635	263.60	275.74	9,119	276.34	8,713	5.03	-4.46	278.58	12,773	278.83	12,430	1.69	-2.69
	Clutha	Upper Clutha	42490.43 45_244550	42490	263.80	274.86	9,117	275.62	8,712	6.87	-4.44	277.24	12,697	277.37	12,169	0.97	-4.16
	Clutha	Upper Clutha	42091.23 47_244100	42091	262.50	273.39	9,113	274.36	8,710	5.91	-4.42	276.00	11,872	276.37	12,471	2.74	5.04
	Clutha	Upper Clutha	41897.83 48_244000	41898	262.30	273.53	9,110	274.44	8,710	8.10	-4.39	275.78	12,945	276.72	12,475	6.97	-3.63
	Clutha	Upper Clutha	41757.64 49_243850	41758	263.20	273.98	9,111	274.61	8,710	5.84	-4.40	275.93	12,806	276.70	12,475	6.05	-2.58
	Clutha	Upper Clutha	41168.23 50_243460	41166	262.00	273.66	9,111	274.16	8,710	4.29	-4.40	275.53	12,809	276.18	12,472	4.80	-2.63
	Clutha	Upper Clutha	40786.6 51_243170	40787	260.60	273.26	9,110	273.79	8,709	4.19	-4.40	275.15	12,788	275.80	12,471	4.47	-2.48
	Clutha	Upper Clutha	40447.2 52_243000	40447	260.00	272.09	9,108	272.69	8,709	6.62	-4.39	274.28	12,790	275.17	12,468	6.38	-2.52
	Clutha	Upper Clutha	40417.81 53_242900	40418	259.10	272.12	9,109	272.84	8,709	5.53	-4.39	274.15	12,790	275.08	12,468	6.18	-2.52
	Clutha	Upper Clutha	40115.77 54_242740	40116	260.60	271.92	9,108	272.55	8,708	5.57	-4.39	274.07	12,790	274.84	12,467	5.72	-2.53
	Clutha	Upper Clutha	39826.48 55_242500	39826	259.80	272.08	9,109	272.52	8,708	3.75	-4.40	274.01	12,790	274.66	12,467	4.57	-2.53
	Clutha	Upper Clutha	39660.77 56_242260	39670	257.80	270.92	9,107	271.74	8,708	6.25	-4.39	273.13	12,789	274.07	12,465	6.13	-2.54
	Clutha	Upper Clutha	39351.18 57_242050	39351	258.60	271.24	9,108	271.78	8,708	4.27	-4.39	273.31	12,785	274.01	12,465	4.76	-2.61
	Clutha	Upper Clutha	39176.38 58_241940	39176	259.20	271.02	9,108	271.52	8,707	4.23	-4.40	273.19	12,784	273.89	12,465	5.00	-2.49
	Clutha	Upper Clutha	38763.83 59_241500	38764	256.50	269.31	9,108	270.04	8,707	5.70	-4.40	271.06	12,780	271.98	12,464	6.32	-2.47
	Clutha	Upper Clutha	38399.87 61_241150	38400	257.00	269.49	9,108	269.96	8,707	3.76	-4.40	271.50	12,765	272.09	12,465	4.07	-2.36
	Clutha	Upper Clutha	38220.92 62_241000	38221	256.75	268.14	9,107	268.81	8,707	5.68	-4.40	269.68	12,765	270.53	12,464	6.57	-2.36
	Clutha	Upper Clutha	38072.87 63_240850	38073	255.50	267.89	9,108	268.51	8,708	5.00	-4.39	269.38	12,733	270.13	12,463	5.40	-2.12
	Clutha	Upper Clutha	37828.97 64_240610	37829	255.40	266.36	9,107	266.53	8,709	1.55	-4.38	267.88	12,691	268.09	12,460	1.68	-1.82
	Clutha	Upper Clutha	37696.5 65_240500	37697	256.50	266.95	9,107	267.38	8,709	4.11	-4.37	268.44	12,884	269.12	12,454	5.70	-3.33
	Clutha	Upper Clutha	37543.21 67_240380	37543	256.20	266.60	9,107	267.04	8,708	4.23	-4.38	268.05	12,789	268.79	12,452	6.24	-2.63
	Clutha	Upper Clutha	37183.1 68_240100	37183	257.10	265.38	9,103	266.07	8,707	6.33	-4.36	267.19	12,783	268.05	12,446	8.52	-2.64
	Clutha	Upper Clutha	36916.55 69_239940	36917	252.80	264.96	9,102	265.63	8,706	5.51	-4.35	267.03	12,784	267.80	12,444	5.41	-2.66
	Clutha	Upper Clutha	36692.88 70_239660	36693	253.10	264.76	9,102	265.28	8,706	4.46	-4.35	266.54	12,784	267.25	12,438	5.28	-2.70
	Clutha	Upper Clutha	36512.22 71_239550	36512	250.30	264.21	9,101	264.77	8,705	4.03	-4.35	265.86	12,781	266.63	12,431	4.95	-2.74
	Clutha	Upper Clutha	36357.27 72_239250	36357	252.60	263.74	9,100	264.33	8,705	5.30	-4.34	265.33	12,775	266.03	12,415	5.50	-2.82
	Clutha	Upper Clutha	35280.32 72_238990	35280	250.80	260.93	9,093	261.39	8,696	4.54	-4.37	262.92	12,748	264.18	12,381	10.40	-2.88
	Clutha	Upper Clutha	34764.54 75_238850	34765	249.80	261.75	9,084	262.15	8,697	3.35	-4.27	264.17	12,758	264.73	12,393	3.90	-2.87
Church Road Bridge	Clutha	Upper Clutha	34224.77 us_Luggate_Bridg	34225	247.94	258.29	9,072	259.09	8,685	7.73	-4.27	260.41	12,727	261.57	12,329	9.30	-3.13
	Clutha	Upper Clutha	34179.21 ds_Luggate_Bridg	34179	247.94	258.04	9,068	258.38	8,695	3.37	-4.12	260.17	12,747	260.57	12,359	3.27	-3.05
	Clutha	Upper Clutha	[illegible]	34106	247.60	[illegible]	[illegible]	259.69	[illegible]	10.90	-4.42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.91
	Clutha	Upper Clutha	[illegible]	33452	[illegible]	259.14	9,062	259.72	8,677	4.70	-4.25	262.07	12,713	262.62	[illegible]	4.91	-2.77
	Clutha	Upper Clutha	[illegible]	33844	[illegible]	[illegible]	9,062	259.51	8,677	4.34	-4.25	[illegible]	12,713	262.68	[illegible]	4.52	-2.77
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	9,061	259.14	8,676	3.79	-4.25	261.64	12,712	262.35	[illegible]	4.02	-2.77
	Clutha	Upper Clutha	[illegible]	[illegible]	240.40	[illegible]	9,061	[illegible]	[illegible]	3.48	-4.25	[illegible]	[illegible]	261.61	[illegible]	[illegible]	-2.77
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	9,061	[illegible]	[illegible]	9.00	-4.25	[illegible]	[illegible]	258.77	[illegible]	[illegible]	-2.77
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.17	-4.25	[illegible]	[illegible]	259.30	[illegible]	[illegible]	-2.77
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8,676	4.56	-4.25	[illegible]	12,711	259.04	[illegible]	4.66	-2.77
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	254.05	9,061	254.99	8,676	6.60	-4.25	[illegible]	12,711	257.45	[illegible]	7.23	-2.77
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	253.08	9,061	253.97	[illegible]	6.91	-4.25	[illegible]	12,711	256.16	12,358	8.26	-2.77
	Clutha	Upper Clutha	29316.57 85_[illegible]	29317	[illegible]	252.66	9,061	253.28	[illegible]	4.47	[illegible]	[illegible]	12,711	255.50	12,358	5.30	[illegible]
	Clutha	Upper Clutha	28910.32 86_[illegible]	28910	[illegible]	250.98	[illegible]	251.83	[illegible]	7.10	[illegible]	252.73	12,710	253.85	12,357	[illegible]	[illegible]
	Clutha	Upper Clutha	28589.06 87_[illegible]	28589	[illegible]	[illegible]	[illegible]	[illegible]	8,671	[illegible]	[illegible]	[illegible]	[illegible]	252.53	[illegible]	7.67	[illegible]
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8,671	[illegible]	-4.29	[illegible]	[illegible]	252.17	[illegible]	[illegible]	[illegible]
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.13	-4.31	[illegible]	[illegible]	251.43	12,344	5.17	[illegible]
	Clutha	Upper Clutha	[illegible]	[illegible]	237.20	[illegible]	9,032	[illegible]	[illegible]	[illegible]	-4.21	[illegible]	[illegible]	[illegible]	12,294	7.42	[illegible]
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	9,023	247.77	[illegible]	3.96	-4.24	[illegible]	[illegible]	[illegible]	12,278	4.32	-2.71
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8,640	3.49	-4.25	[illegible]	[illegible]	249.97	[illegible]	[illegible]	-2.72
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8,637	3.94	-4.23	[illegible]	[illegible]	249.70	[illegible]	4.21	-2.76
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	247.46	8,636	3.23	[illegible]	[illegible]	[illegible]	249.67	[illegible]	[illegible]	-2.75
[illegible]	Clutha	Upper Clutha	[illegible]	[illegible]	234.40	[illegible]	[illegible]	247.33	8,637	3.03	[illegible]	[illegible]	[illegible]	249.62	[illegible]	[illegible]	-2.75
	Clutha	Upper Clutha	[illegible]	[illegible]	233.10	[illegible]	[illegible]	247.23	[illegible]	2.76	[illegible]	[illegible]	[illegible]	[illegible]	12,276	[illegible]	-2.75
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	246.67	[illegible]	247.03	[illegible]	3.42	-4.27	[illegible]	[illegible]	[illegible]	12,268	[illegible]	[illegible]
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.21	-4.29	[illegible]	[illegible]	247.67	12,247	[illegible]	[illegible]
	Clutha	Upper Clutha	[illegible]	23156	[illegible]	242.34	[illegible]	[illegible]	8,602	6.53	-4.65	244.89	[illegible]	245.89	12,198	[illegible]	[illegible]
	Clutha	Upper Clutha	[illegible]	21966	228.75	[illegible]	[illegible]	241.66	8,590	5.98	-4.38	244.18	[illegible]	245.01	12,189	[illegible]	[illegible]
	Clutha	Upper Clutha	[illegible]	[illegible]	227.09	[illegible]	8,960	241.21	8,586	4.64	-4.39	243.73	[illegible]	[illegible]	12,185	[illegible]	[illegible]
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	8,979	240.74	[illegible]	3.72	-4.37	243.29	[illegible]	[illegible]	12,184	[illegible]	-2.90
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	8,978	235.84	[illegible]	6.02	-4.38	237.48	[illegible]	[illegible]	12,183	[illegible]	-2.91
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	8,977	234.54	8,585	6.68	-4.37	235.87	[illegible]	[illegible]	[illegible]	[illegible]	-2.92
	Clutha	Upper Clutha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	230.79	8,584	5.98	-4.37	231.95	[illegible]	[illegible]	[illegible]	[illegible]	-2.92
	Clutha	Upper Clutha	[illegible]	14150	[illegible]	[illegible]	8,976	227.33	8,583	8.63	-4.37	227.86	[illegible]	[illegible]	[illegible]	[illegible]	-2.92
Queensbury	Clutha	Upper Clutha	[illegible]	12961	[illegible]	[illegible]	8,970	224.96	[illegible]	6.68	[illegible]	[illegible]	12,544	[illegible]	12,177	7.05	[illegible]
	Clutha	Upper Clutha	[illegible]	11813	[illegible]	[illegible]	[illegible]	222.49	[illegible]	[illegible]	[illegible]	[illegible]	12,543	[illegible]	[illegible]	3.65	[illegible]
	Clutha	Upper Clutha	[illegible]	10859	211.80	[illegible]	8,967	[illegible]	[illegible]	4.49	[illegible]	[illegible]	12,542	[illegible]	12,175	4.97	-2.93
	Clutha	Upper Clutha	[illegible]	9438	207.28	[illegible]	8,964	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12,172	3.73	[illegible]
	Clutha	Upper Clutha	8258.471 DTM8	8258	207.29	211.99	8,984	212.20	8,578	4.47	-4.30	212.54	12,538	212.85	12,170	5.90	-2.94
	Clutha	Upper Clutha	7169.452 DTM9	7169	205.09	209.08	8,957	209.36	8,565	7.66	-4.38	209.81	12,516	210.22	12,136	8.69	-3.04
	Clutha	Upper Clutha	5918.831 2 Bendigo	5919	199.90	207.72	8,946	208.05	8,549	4.22	-4.45	208.65	12,497	209.09	12,114	5.03	-3.07
Willowbank	Clutha	Upper Clutha	4628.777 DTM11	4629	201.73	206.81	8,941	207.14	8,541	6.50	-4.47	207.81	12,488	208.24	12,103	7.07	-3.08
	Clutha	Upper Clutha	3262.424 DTM12	3262	199.08	204.71	8,939	205.08	8,539	6.57	-4.48	205.99	12,485	206.46	12,099	6.80	-3.09
Bendigo	Clutha	Upper Clutha	2170.135 3 Bendigo	2170	193.97	201.59	8,939	201.90	8,539	4.07	-4.48	202.68	12,484	202.88	12,099	2.30	-3.09
	Clutha	Upper Clutha	1241.766 4 Bendigo	1242	193.08	198.92	8,938	199.15	8,538	3.94	-4.48	200.10	9,709	200.15	9,638	0.71	0.73
	Clutha	Upper Clutha	701.3322	701	191.11	197.89	7,051	197.75	6,806	-2.06	-3.47	199.70	9,431	199.54	9,168	-1.86	-2.79
	Clutha	Upper Clutha	476.7226	476	190.11	197.82	7,014	197.58	6,724	-3.11	-4.14	199.66	9,401	199.46	9,107	-2.09	-3.12
	Clutha	Upper Clutha	295.6647	296	189.73	197.78	6,993	197.53	6,698	-3.11	-4.23	199.61	9,381	199.40	9,088	-2.13	-3.12
	Clutha	Upper Clutha	133.198	133	187.63	197.74	6,980	197.46	6,672	-2.77	-4.42	199.59	9,369	199.36	9,065	-1.92	-3.24
Lake Dunstan	Clutha	Lower Clutha	69.04708 Lake Dunstan	69	140.00	197.74	7,195	197.46	6,887	-0.48	-4.28	199.59	9,583	199.36	9,281	-0.39	-3.16
Lake Dunstan	Clutha	Lower Clutha	48.00178 Lake Dunstan	48	140.00	197.74	7,195	197.46	6,887	-0.48	-4.28	199.59	9,583	199.36	9,281	-0.39	-3.16
Clyde Dam	Clutha	Lower Clutha	40 Clyde Dam	40	140.00	197.74		Clyde Dam				199.59		Clyde Dam			
	Clutha	Lower Clutha	21.10445	21	140.00	145.67	7,195	144.78	6,887	-15.70	-4.28	146.33	9,583	145.37	9,281	-15.17	-3.16
	Clutha	Lower Clutha	7.231917	7	140.00	143.16	7,195	143.63	6,887	14.87	-4.28	144.20	9,583	144.88	9,281	16.19	-3.16

Appendix B

Model Hydrographs

Appendix B Model Hydrographs

Figure B1 Stage Hydrographs at Albert Town and Lake Wanaka



Note – the rainy day hydrographs shown on this figure are for an initial Lake Wanaka level of RL 280.87m

Figure B2 Discharge Hydrographs at Selected Locations (Sunny Day Event)

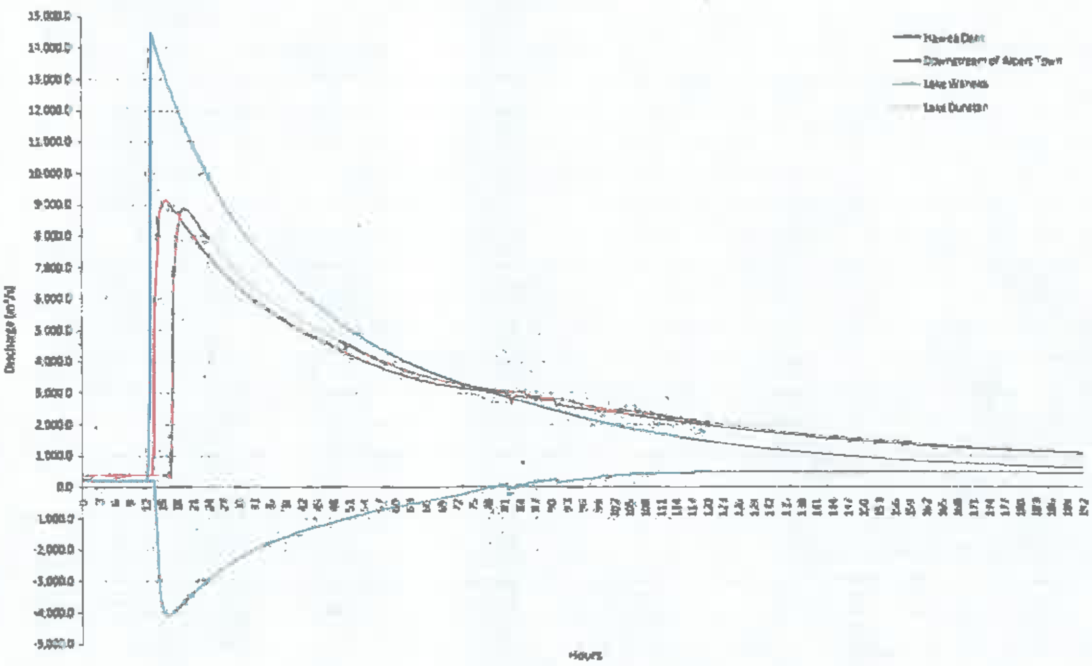


Figure B3 Profile of Peak Discharge in the Clutha River

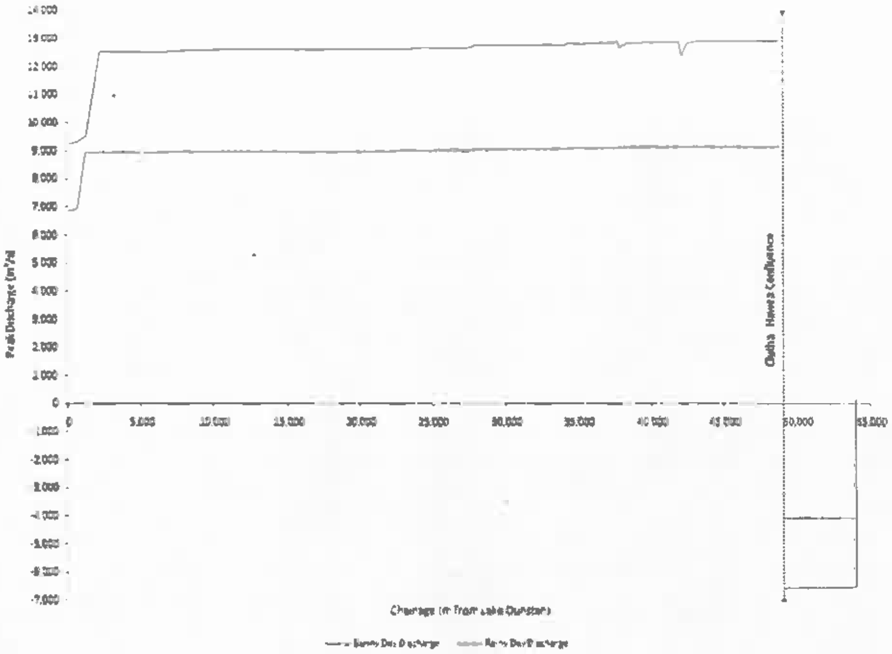
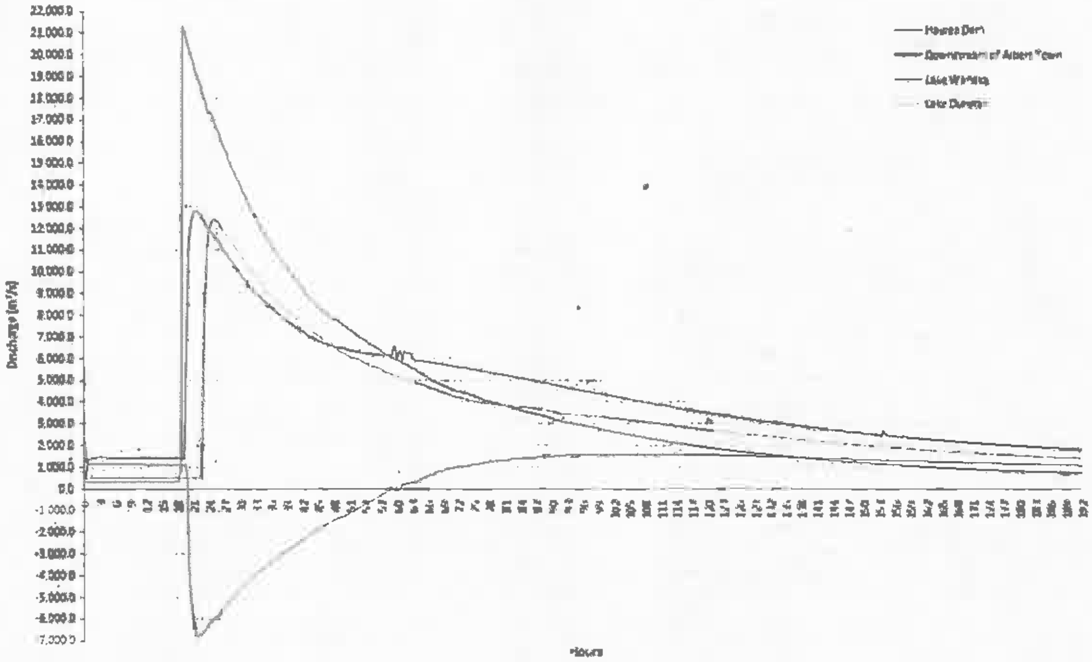


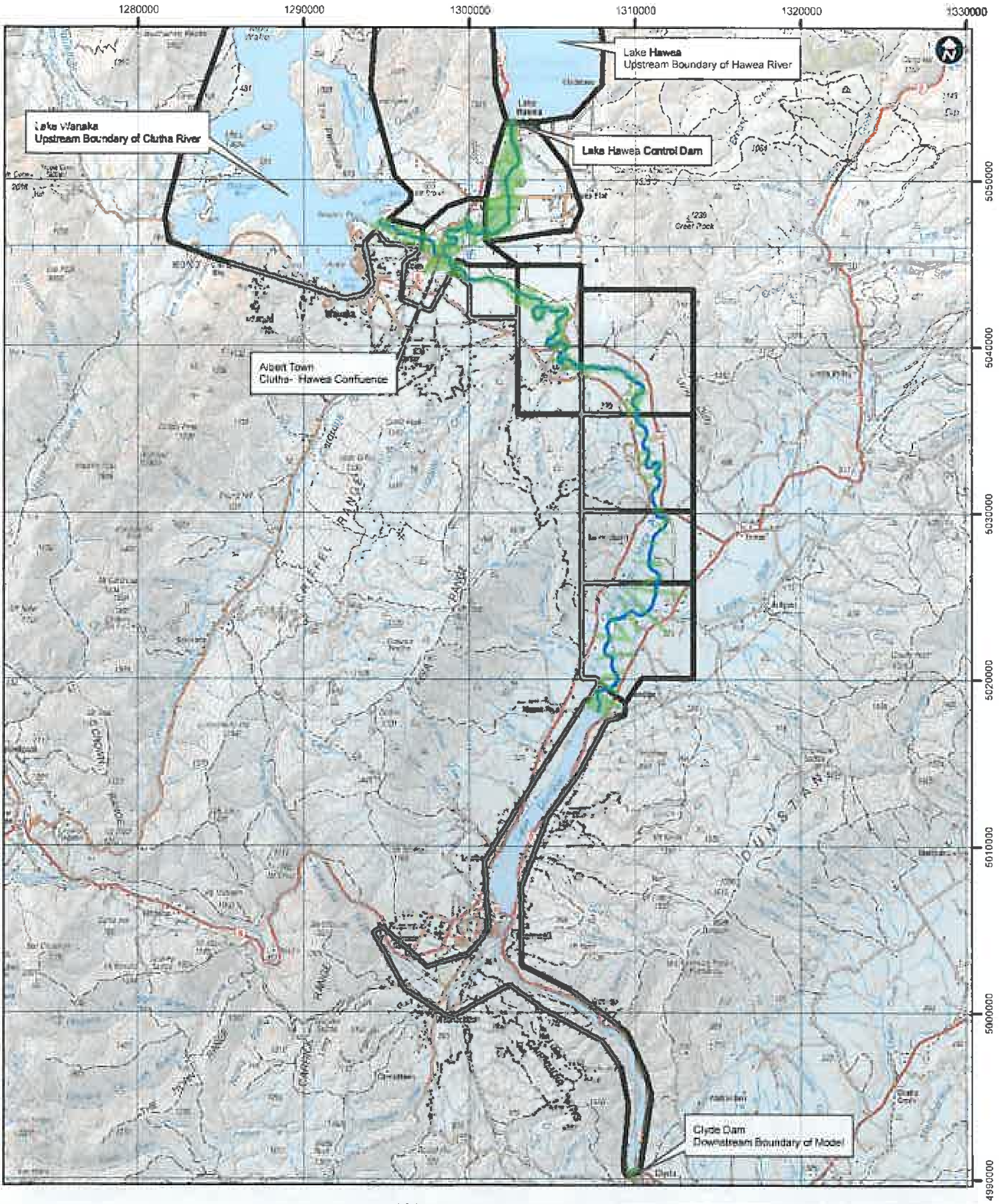
Figure B4 Discharge Hydrographs at Selected Locations (Rainy Day Event)



Note – rainy day hydrographs shown on this figure are for an initial Lake Wanaka level of RL 280.87m

Appendix C

Model Extents



Notes:

Map features depicted in terms of NZTM projection

Data Sources
NZ Topographic Datasets, LINZ 2005
NZ CRS Database, LINZ 2007

Legend:

- Model Cross Sections
- River Centerlines
- DTM and Model Extents

AECOM

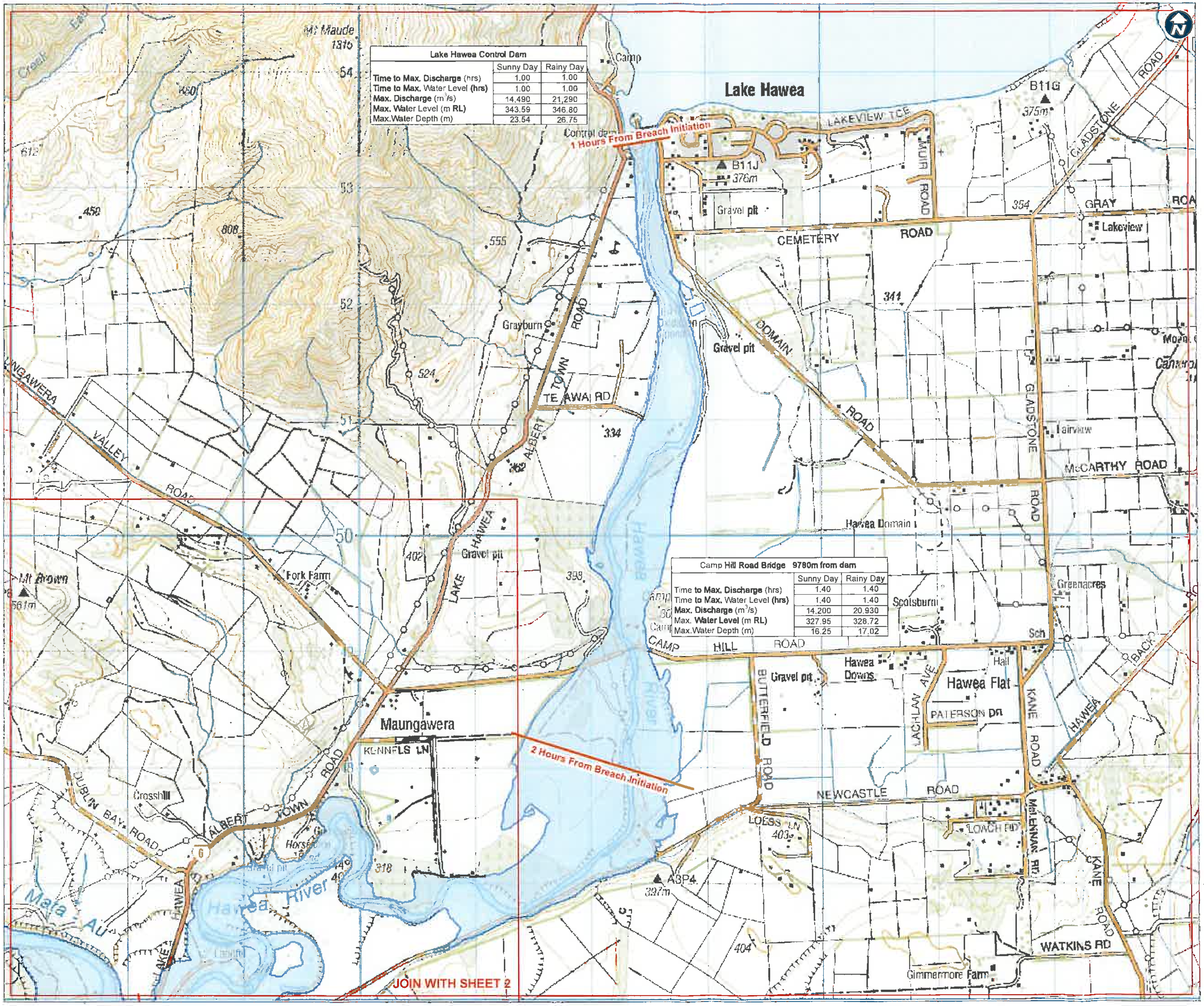
Ref No: **Figure C.1**

Scale: **1:300,000** (A4 size)

Project: LAKE HAWEA CONTROL DAM
Dam Break Update Study
Hydraulic Model Extents

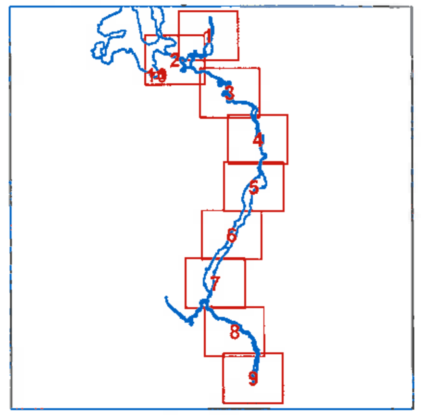
Appendix D

Flood Inundation Maps



Lake Hawea Control Dam		
	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	1.00	1.00
Time to Max. Water Level (hrs)	1.00	1.00
Max. Discharge (m^3/s)	14,490	21,290
Max. Water Level (m RL)	343.59	346.80
Max.Water Depth (m)	23.54	26.75

Camp Hill Road Bridge 9780m from dam		
	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	1.40	1.40
Time to Max. Water Level (hrs)	1.40	1.40
Max. Discharge (m^3/s)	14,200	20,930
Max. Water Level (m RL)	327.95	328.72
Max.Water Depth (m)	16.25	17.02



Key Map:

Legend

- Sunny Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes:
The inundated area shown is based on an hypothetical sunny day failure of the Hawea control structure.
Time of peak discharge and water level have been rounded to the nearest 20mins
Flood extents have been derived using LiDAR data supplied by Contact Energy with a vertical accuracy of +/- 250mm
All levels are to MSL Dunedin Datum
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Project
Lake Hawea Control Dam
Dam Break Update Study

Sheet No	Project No	Issue
1	60221308	Rev

Title:
Sunny Day Failure Inundation Map
Sheet 1 of 10

Scale 1:30,000 (A3 size)

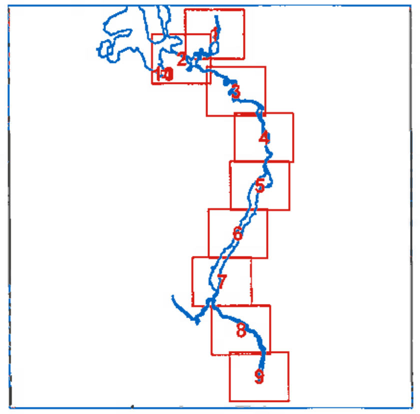
		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-SD-01.mxd		
Printed			

Lake Wanaka 19,900m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	4.00	3.40
Time to Max. Water Level (hrs)	75.00	43.00
Max. Discharge (m^3/s)	4,075	6,775
Max. Water Level (m RL)	279.22	283.45
Max. Water Level Rise (m)	2.02	2.58

Albert Town Upstream of Hawea Confluence	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	3.00	3.00
Time to Max. Water Level (hrs)	4.00	3.40
Max. Discharge (m^3/s)	4,380	6,950
Max. Water Level (m RL)	286.61	289.78
Max. Water Level Rise (m)	15.67	18.84

Hawea-Clutha Confluence 14,700m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	2.20	2.40
Time to Max. Water Level (hrs)	4.00	3.40
Max. Discharge (m^3/s)	13,640	19,975
Max. Water Level (m RL)	287.03	290.09
Max. Water Level Rise (m)	15.48	18.54

Clutha River Downstream of Albert Town	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	3.20	3.20
Time to Max. Water Level (hrs)	4.00	3.40
Max. Discharge (m^3/s)	9,140	12,790
Max. Water Level (m RL)	286.64	289.81
Max. Water Level Rise (m)	15.64	18.81



Key Map:

Legend

- Sunny Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes

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Time of peak discharge and water level have been rounded to the nearest 20mins
Maximum water levels shown assume an initial water level in Lake Wanaka of RL 277.20m for the sunny day event and RL 280.87m for the rainy day event
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Sheet No	Project No.	Issue
2	60221308	Rev

Title:
Sunny Day Failure Inundation Map
Sheet 2 of 10

Scale 1:30,000 (A3 size)

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Drawn	PJC	GB	
Approved	Approved	Status	Final
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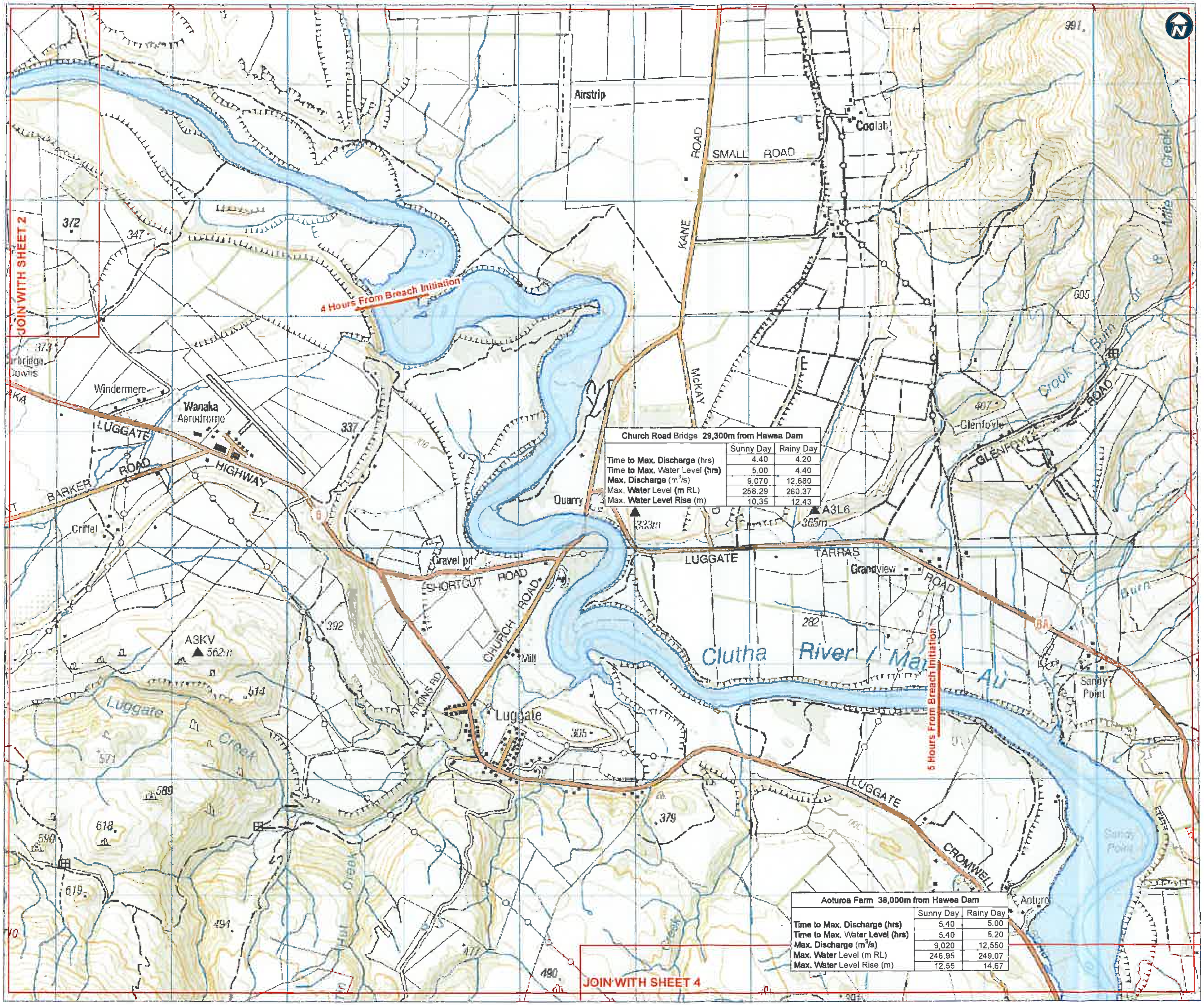
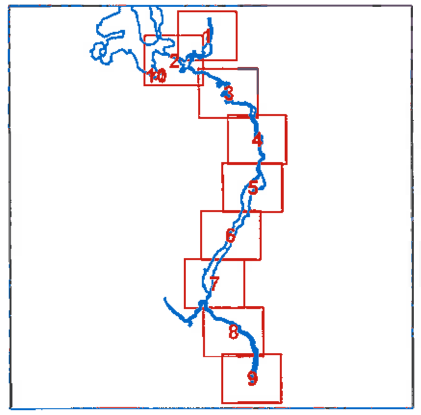
Printed			



Church Road Bridge 29,300m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	4.40	4.20
Time to Max. Water Level (hrs)	5.00	4.40
Max. Discharge (m^3/s)	9,070	12,680
Max. Water Level (m RL)	258.29	260.37
Max. Water Level Rise (m)	10.35	12.43

Aoturoa Farm 38,000m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	5.40	5.00
Time to Max. Water Level (hrs)	5.40	5.20
Max. Discharge (m^3/s)	9,020	12,550
Max. Water Level (m RL)	246.95	249.07
Max. Water Level Rise (m)	12.55	14.67



Key Map:

Legend

- Sunny Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes

The inundated area shown is based on an hypothetical sunny day failure of the Hawea control structure.
Time of peak discharge and water level have been rounded to the nearest 20mins
Maximum water levels shown assume an initial water level in Lake Wanaka of RL 277.20m for the sunny day event and RL 280.87m for the rainy day event
Flood extents have been derived using LiDAR data supplied by Contact Energy with a vertical accuracy of +/- 250mm
All levels are to MSL Dunedin Datum

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Sheet No	Project No.	Issue
3	60221308	Rev

Title
Sunny Day Failure Inundation Map
Sheet 3 of 10

Scale 1:30,000 (A3 size)

		Checked	Date
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Drawn	PJC	GB	
Approved	Approved	Status	Final
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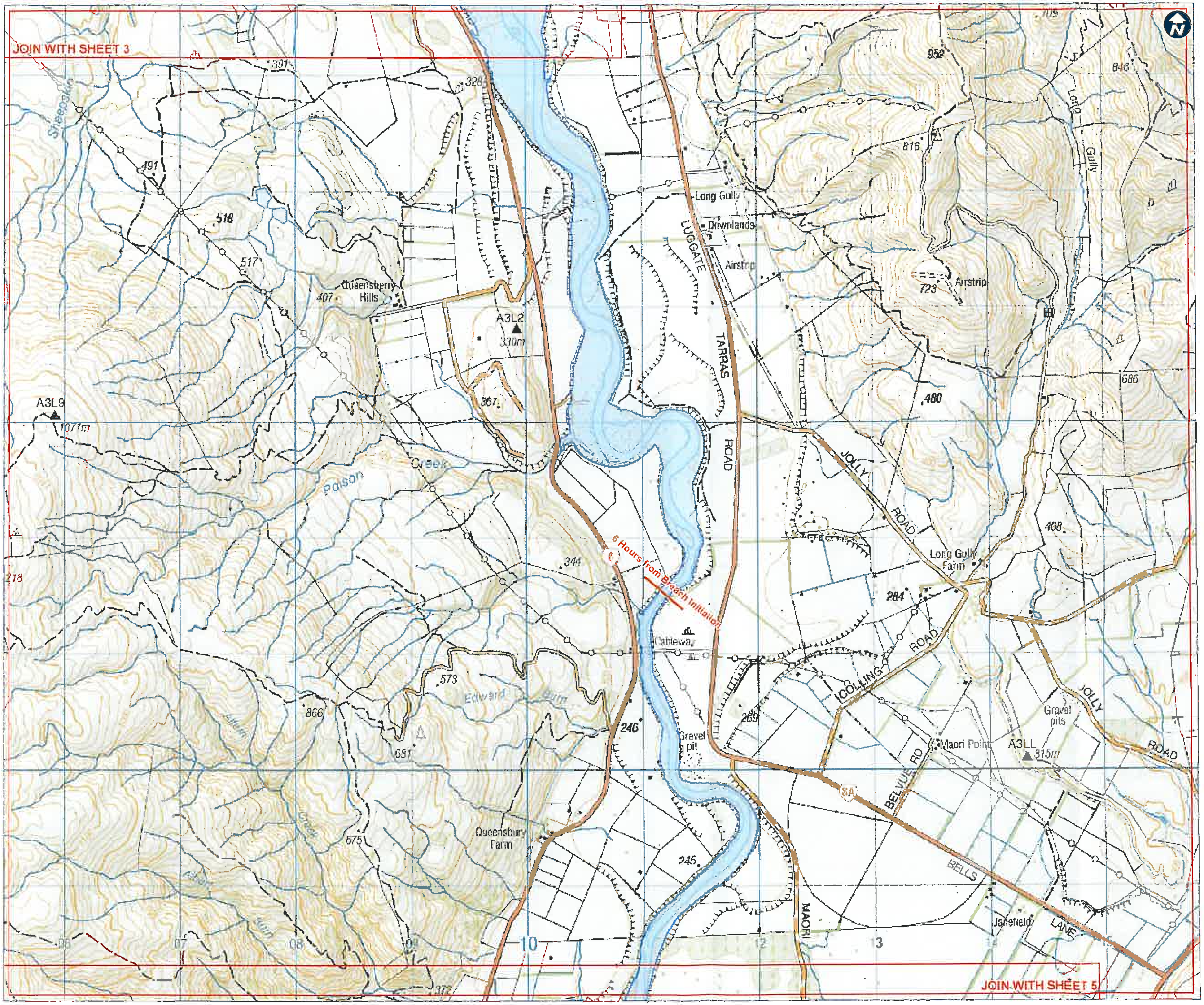

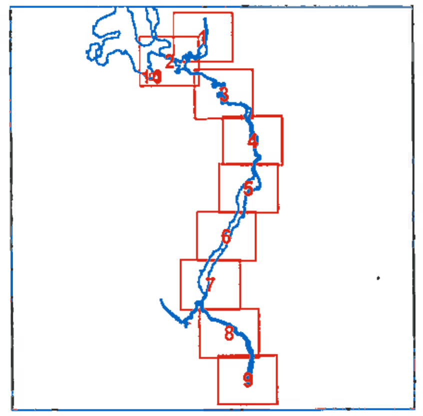

Legend

- Sunny Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes
The inundated area shown is based on an hypothetical sunny day failure of the Hawea control structure.
Time of peak discharge and water level have been rounded to the nearest 20mins
Maximum water levels shown assume an initial water level in Lake Wanaka of RL 277.20m for the sunny day event and RL 280 87m for the rainy day event
Flood extents have been derived using LIDAR data supplied by Contact Energy with a vertical accuracy of +/- 250mm
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Lake Hawea Control Dam
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Sheet No	Project No	Issue
4	60221308	Rev

Title
Sunny Day Failure Inundation Map
Sheet 4 of 10

Scale: 1:30,000 (A3 size)

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Drawn	PJC	GB	
Approved	Approved	Status	Final
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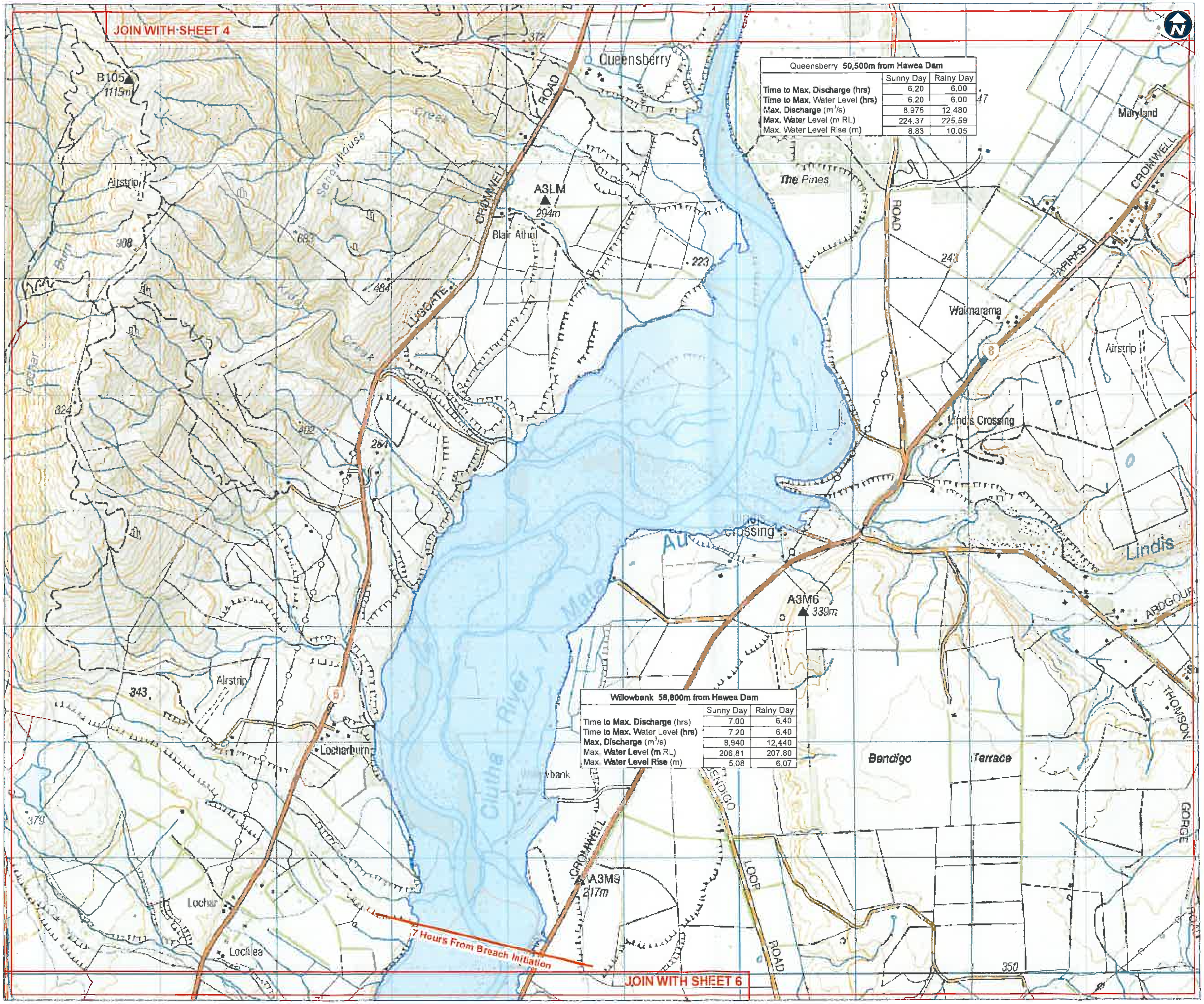
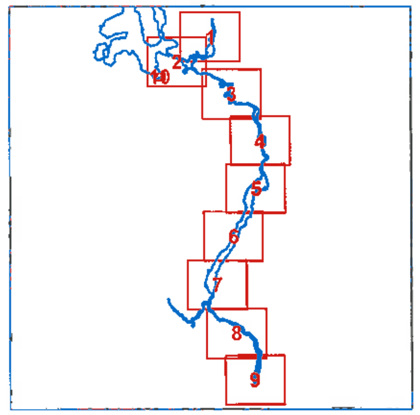


Queensberry 50,500m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	6.20	6.00
Time to Max. Water Level (hrs)	6.20	6.00
Max. Discharge (m^3/s)	8,975	12,480
Max. Water Level (m RL)	224.37	225.59
Max. Water Level Rise (m)	8.83	10.05

Willowbank 58,800m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.00	6.40
Time to Max. Water Level (hrs)	7.20	6.40
Max. Discharge (m^3/s)	8,940	12,440
Max. Water Level (m RL)	206.81	207.80
Max. Water Level Rise (m)	5.08	6.07



Key Map:

Legend

- Sunny Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes
The inundated area shown is based on an hypothetical sunny day failure of the Hawea control structure.
Time of peak discharge and water level have been rounded to the nearest 20mins
Maximum water levels shown assume an initial water level in Lake Wanaka of RL 277.20m for the sunny day event and RL 280.87m for the rainy day event
Flood extents have been derived using LIDAR data supplied by Contact Energy with a vertical accuracy of +/- 250mm
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Project: Lake Hawea Control Dam Dam Break Update Study

Sheet No: 5 | Project No: 60221308 | Issue: Rev

Title: Sunny Day Failure Inundation Map Sheet 5 of 10

Scale 1:30,000 (A3 size)

		Checked	Date
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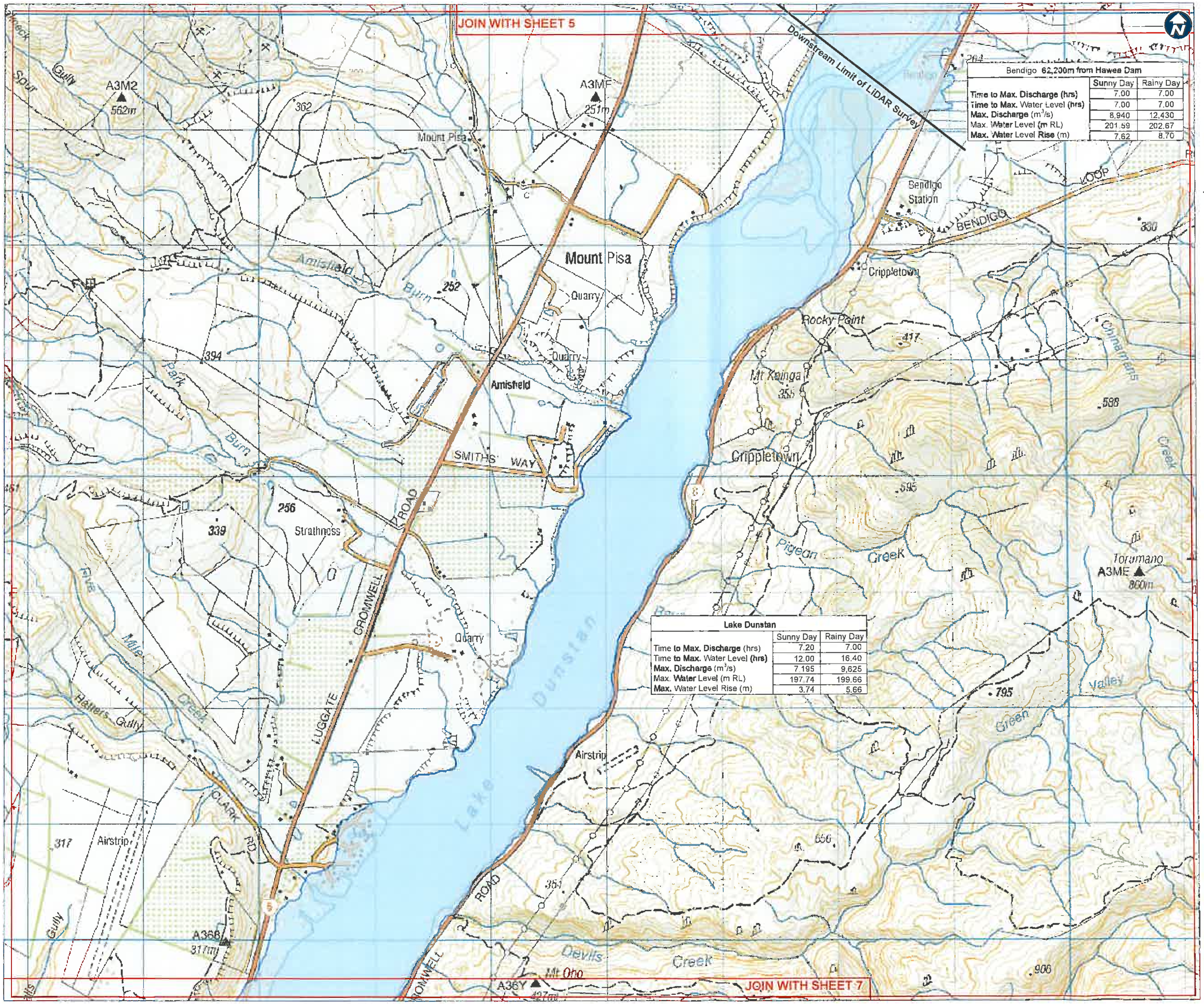
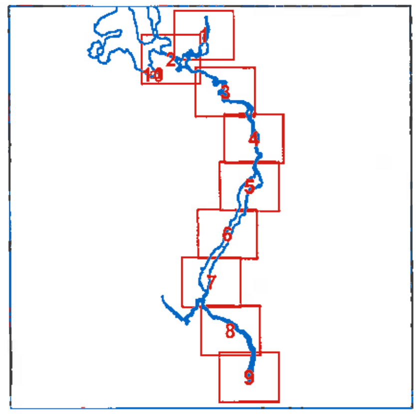
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-SD-05.mxd		
Printed			



Bendigo 62,200m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.00	7.00
Time to Max. Water Level (hrs)	7.00	7.00
Max. Discharge (m^3/s)	8,940	12,430
Max. Water Level (m RL)	201.59	202.67
Max. Water Level Rise (m)	7.62	8.70

Lake Dunstan	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.20	7.00
Time to Max. Water Level (hrs)	12.00	16.40
Max. Discharge (m^3/s)	7.195	9,625
Max. Water Level (m RL)	197.74	199.66
Max. Water Level Rise (m)	3.74	5.66



Key Map:

Legend

- Sunn yDay Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes

The inundated area shown is based on an hypothetical sunny day failure of the Hawea control structure.
Time of peak discharge and water level have been rounded to the nearest 20mins
Maximum water levels shown assume an initial water level in Lake Wanaka of RL 277.20m for the sunny day event and RL 280.67m for the rainy day event
Maximum water levels for Lake Dunstan assume the Clyde Dam is operated as per Contact's Clutha flood rules
Flood extents at Lake Dunstan have been derived using contour data with a vertical interval of 20m, obtained from LINZ
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Dam Break Update Study

Sheet No	Project No	Issue
6	60221308	Rev

Title
Sunny Day Failure Inundation Map Sheet 6 of 10

Scale 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-SD-06.mxd		
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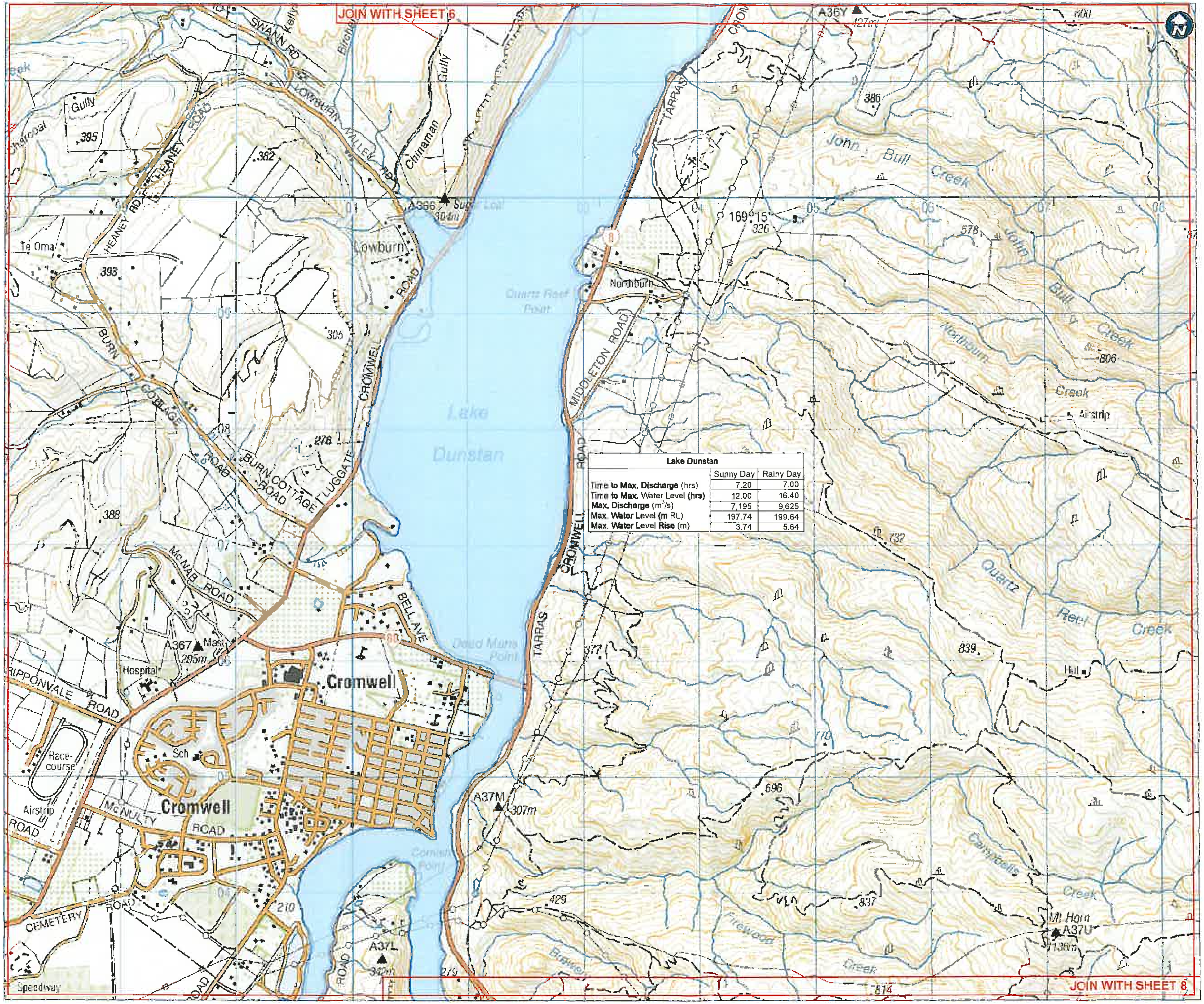
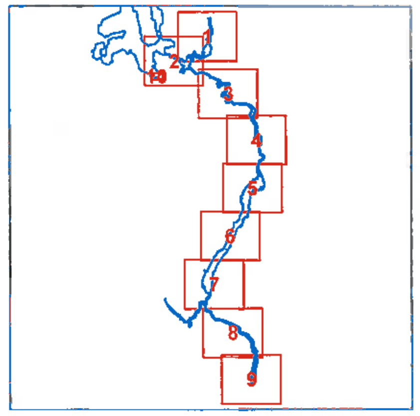


Lake Dunstan	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.20	7.00
Time to Max. Water Level (hrs)	12.00	16.40
Max. Discharge (m^3/s)	7,195	9,625
Max. Water Level (m RL)	197.74	199.64
Max. Water Level Rise (m)	3.74	5.64



Key Map:

Legend
Sunny Day Flood Extent
Flood Wave Travel Time
Map Sheets

Notes

The inundated area shown is based on an hypothetical sunny day failure of the Hawea control structure.
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Maximum water levels shown assume an initial water level in Lake Wanaka of RL 277.20m for the sunny day event and RL 280.87m for the rainy day event.
Maximum water levels for Lake Dunstan assume the Clyde Dam is operated as per Contact's Clutha flood rules.
Flood extents at Lake Dunstan have been derived using contour data with a vertical interval of 20m, obtained from LINZ.
All levels are to MSL Dunedin Datum.

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Sheet No	Project No.	Issue
7	60221308	Rev

Title
Sunny Day Failure Inundation Map Sheet 7 of 10

Scale 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-SD-07.mxd		
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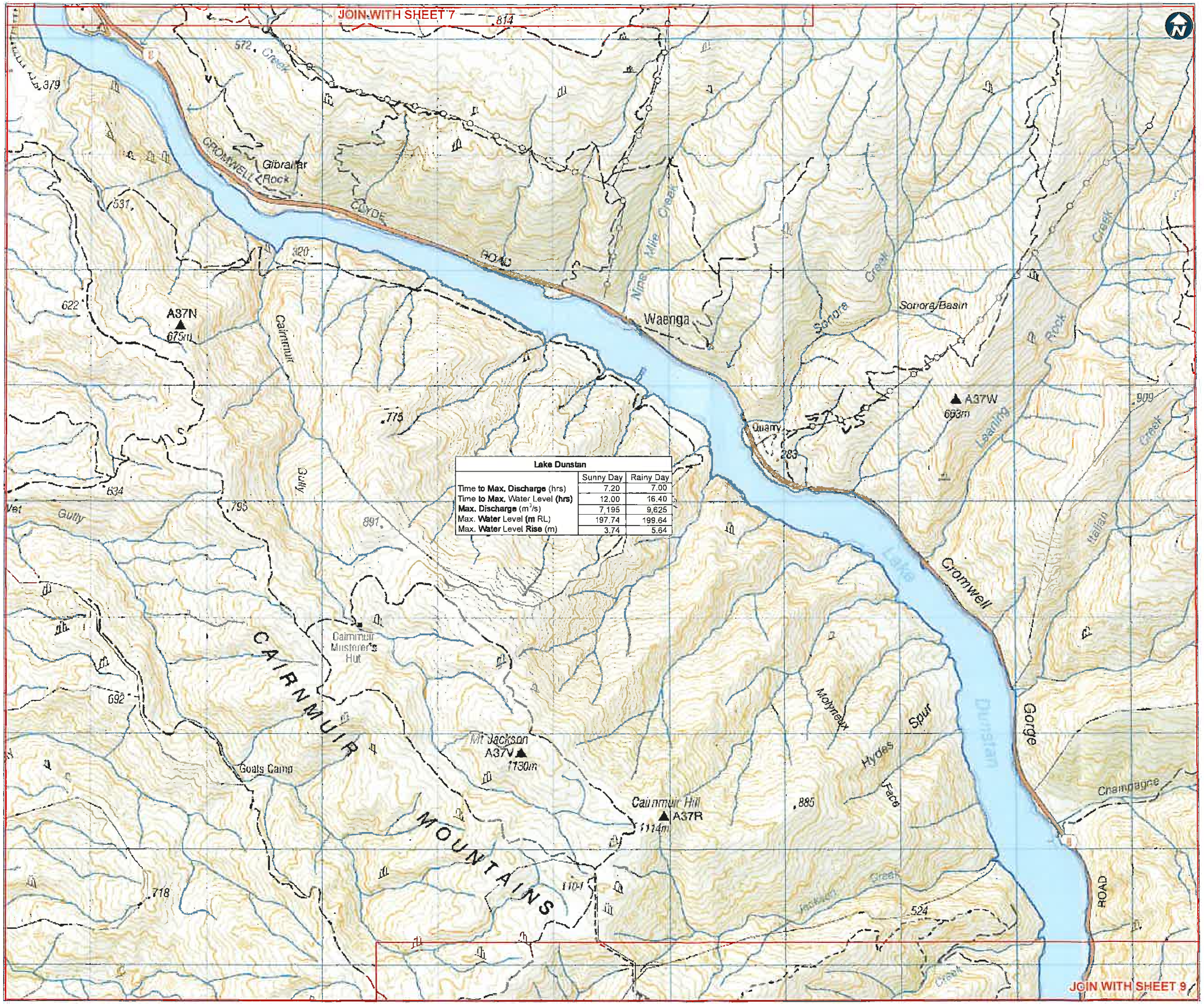
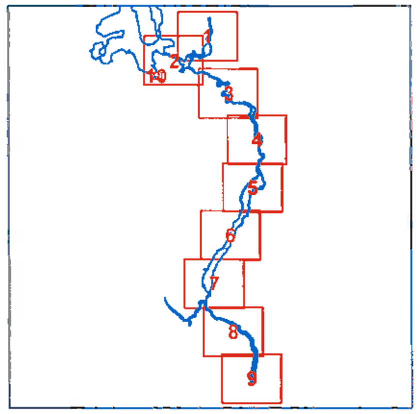


Lake Dunstan		
	Sunny Day	Rainy Day
Time to **Max. Discharge** (hrs)	7.20	7.00
Time **to Max.** Water Level **(hrs)**	12.00	16.40
Max. Discharge (m^3/s)	7,195	9,625
Max. **Water** Level **(m** RL)	197.74	199.64
Max. **Water** Level **Rise** (m)	3.74	5.64



Key Map:

Legend

Notes

The inundated area shown is based on an hypothetical sunny day failure of the Hawea control structure.
Time of peak discharge and water level have been rounded to the nearest 20mins
Maximum water levels shown assume an initial water level in Lake Wanaka of RL 277.20m for the sunny day event and RL 280.87m for the rainy day event
Maximum water levels for Lake Dunstan assume the Clyde Dam is operated as per Contact's Clutha flood rules
Flood extents at Lake Dunstan have been derived using contour data with a vertical interval of 20m, obtained from LINZ
All levels are to MSL Dunedin Datum

AECOM

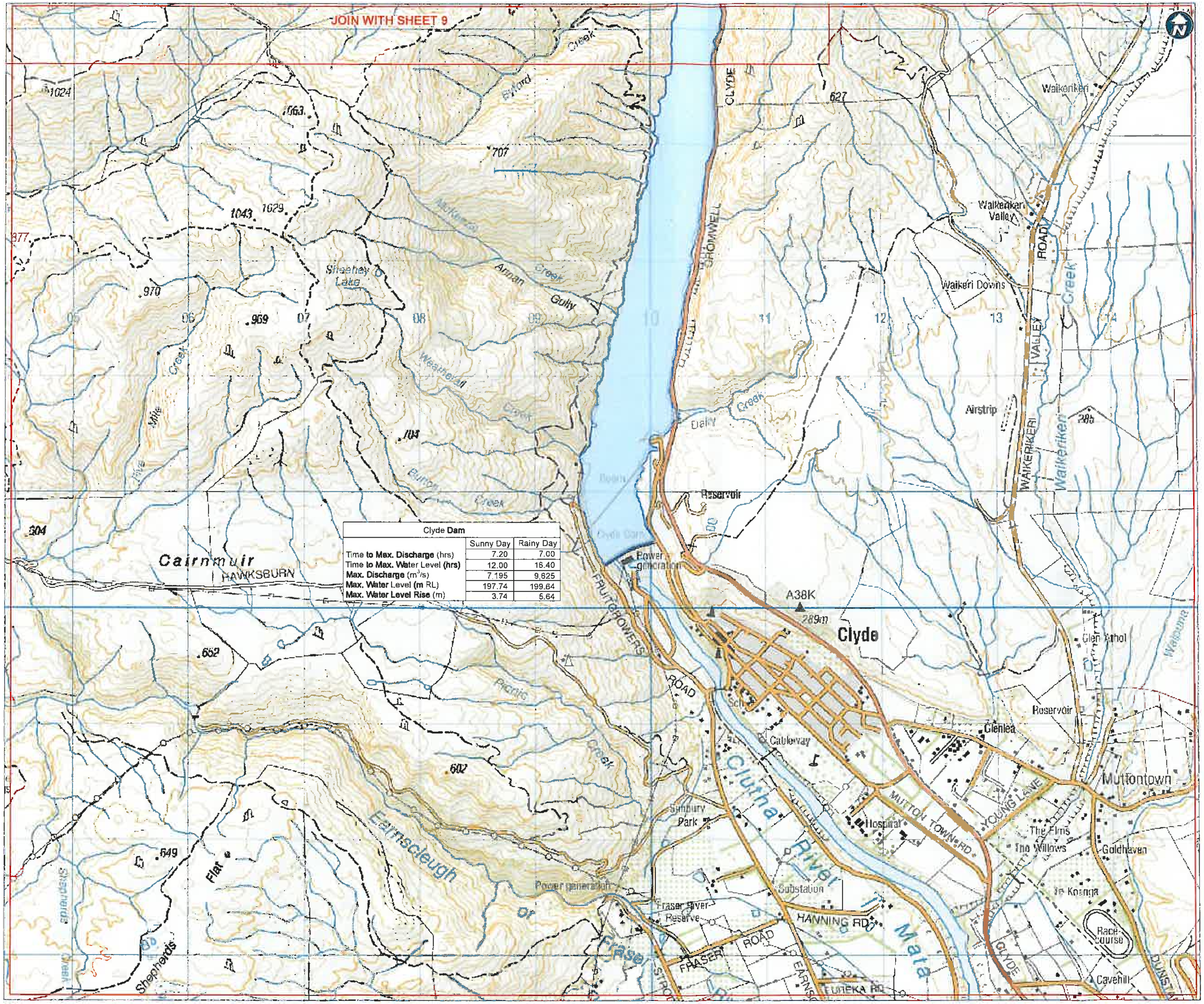
Client
Contact Energy
Project
Lake Hawea Control Dam
Dam Break Update Study

Sheet No	Project No	Issue
8	60221308	Rev

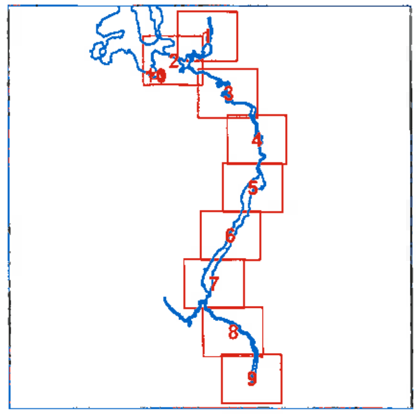
Title
Sunny Day Failure Inundation Map
Sheet 8 of 10

Scale 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-SD-08.mxd		
Printed			



Clyde Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.20	7.00
Time to Max. Water Level (hrs)	12.00	16.40
Max. Discharge (m^3/s)	7,195	9,625
Max. Water Level (m RL)	197.74	199.64
Max. Water Level Rise (m)	3.74	5.64



Key Map:

Legend

- Sunny Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes

The inundated area shown is based on **an hypothetical sunny day** failure of the Hawea control structure.
Time of peak discharge and water level **have been rounded to the** nearest 20mins
Maximum water levels shown assume **an initial water level in Lake** Wanaka of RL 277.20m for the sunny **day event and RL 280.87m** for the rainy day event
Maximum water levels for Lake Dunstan assume **the Clyde Dam is** operated as per Contact's Clutha flood rules
Flood extents at Lake Dunstan have been derived using contour data with a vertical interval of 20m, obtained from LINZ
All levels are to MSL Dunedin Datum
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Client
Contact Energy
Project
Lake Hawea Control Dam
Dam Break Update Study

Sheet No	Project No.	Issue
9	60221308	Rev

Title
Sunny Day Failure Inundation Map Sheet 9 of 10

Scale 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-SD-09.mxd		
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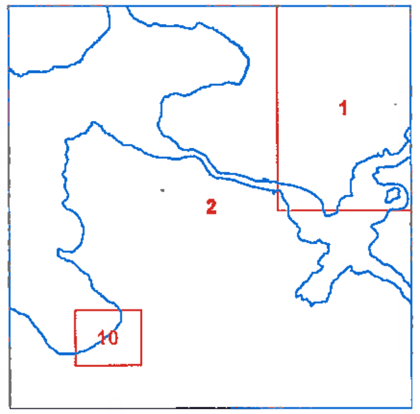
	Sunny Day	Rainy Day	
Initial Lake Level (m RL)	277.20	277.20	280.87
Time to Max. Inflow (hrs)	4.00	4.00	3.40
Time to Max. Water Level (hrs)	75.00	79.00	43.00
Max. Inflow (m^3/s)	4,075	6,640	6,775
Max. Water Level (m RL)	279.22	280.20	283.45
Max. Water Level Rise (m)	2.02	3.00	2.58



Key Map:

Legend

- Sunny Day Flood Extent
- Rainy Day Flood Extent (Initial Lake Level 277.20m)
- Rainy Day Flood Extent (Initial Lake Level 280.87m)
- Map Sheets

Notes

The inundated area shown is based on an hypothetical sunny day failure of the Hawea control structure.
Time of peak discharge and water level have been rounded to the nearest 20mins
Flood extents have been derived using contour data supplied by Queenstown Lakes District Council at a vertical interval of 1.0m
All levels are to MSL Dunedin Datum
Background image sourced from Queenstown Lakes District Council

AECOM

Client
Contact Energy

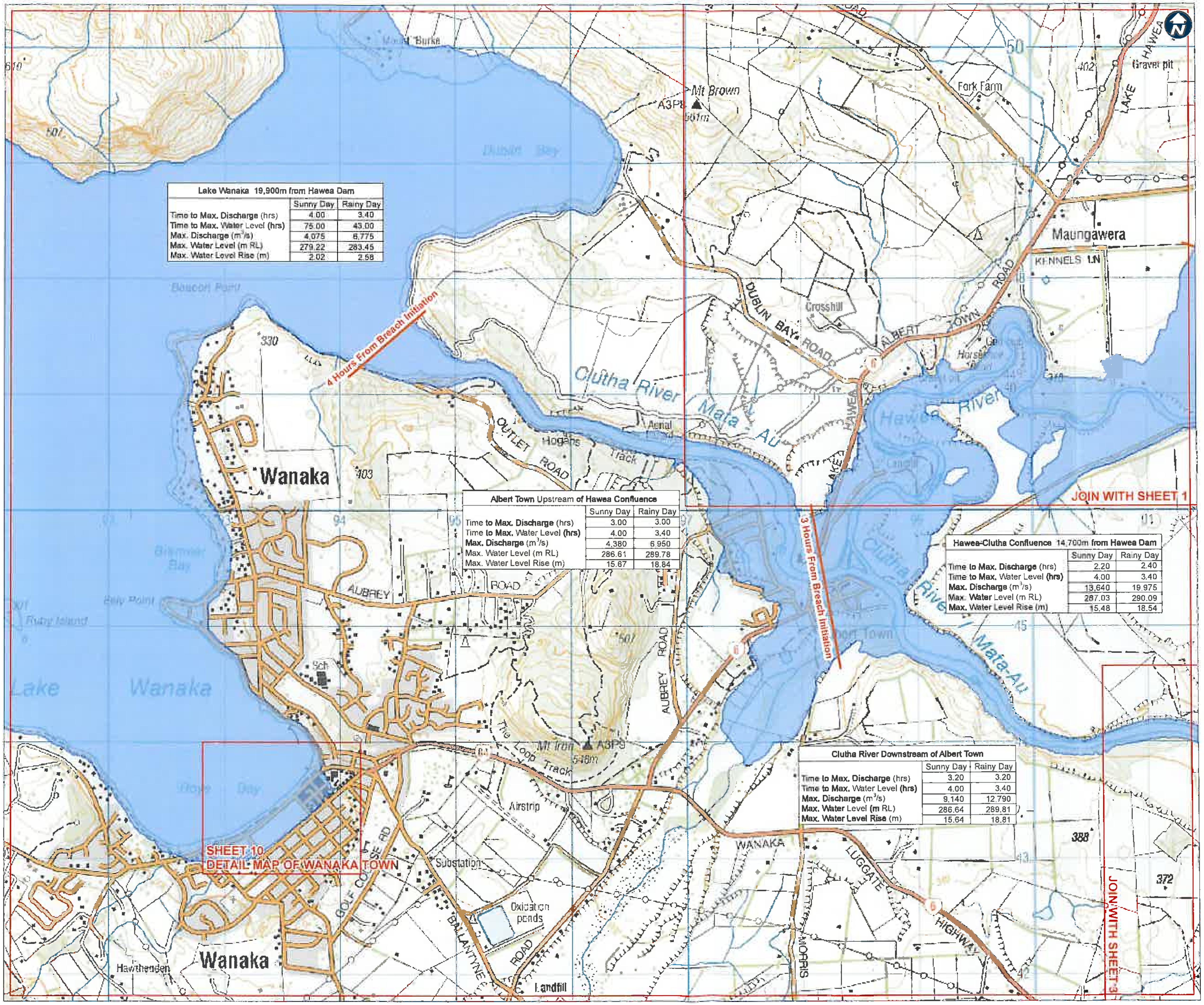
Project
Lake Hawea Control Dam
Dam Break Update Study

Sheet No	Project No	Issue
10	60221308	Rev

Title
Wanaka Town Flood Inundation Map
Sunny and Rainy Day Failure Events

Scale 1:4,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-SD-10.mxd		
Printed			



Lake Wanaka 19,900m from Hawea Dam

	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	4.00	3.40
Time to Max. Water Level (hrs)	75.00	43.00
Max. Discharge (m^3/s)	4,075	6,775
Max. Water Level (m RL)	279.22	283.45
Max. Water Level Rise (m)	2.02	2.58

Albert Town Upstream of Hawea Confluence

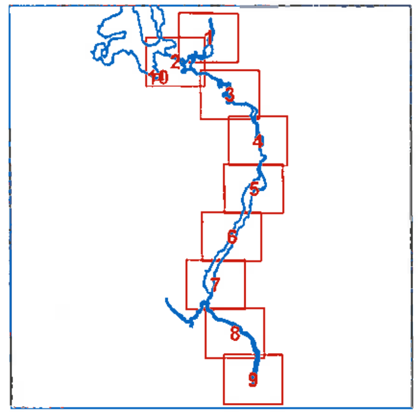
	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	3.00	3.00
Time to Max. Water Level (hrs)	4.00	3.40
Max. Discharge (m^3/s)	4,380	6,950
Max. Water Level (m RL)	286.61	289.78
Max. Water Level Rise (m)	15.67	18.84

Hawea-Clutha Confluence 14,700m from Hawea Dam

	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	2.20	2.40
Time to Max. Water Level (hrs)	4.00	3.40
Max. Discharge (m^3/s)	13,640	19,975
Max. Water Level (m RL)	287.03	290.09
Max. Water Level Rise (m)	15.48	18.54

Clutha River Downstream of Albert Town

	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	3.20	3.20
Time to Max. Water Level (hrs)	4.00	3.40
Max. Discharge (m^3/s)	9,140	12,790
Max. Water Level (m RL)	286.64	289.81
Max. Water Level Rise (m)	15.64	18.81



Key Map:

Legend
- Rainy Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes
The inundated area shown is based on an hypothetical rainy day failure of the Hawea control structure.
Time of peak discharge and water level have been rounded to the nearest 20mins
Maximum water levels shown assume an initial water level in Lake Wanaka of RL 277.20m for the sunny day event and RL 280.87m for the rainy day event
Flood extents have been derived using LIDAR data supplied by Contact Energy with a vertical accuracy of +/- 250mm
All levels are to MSL Dunedin Datum
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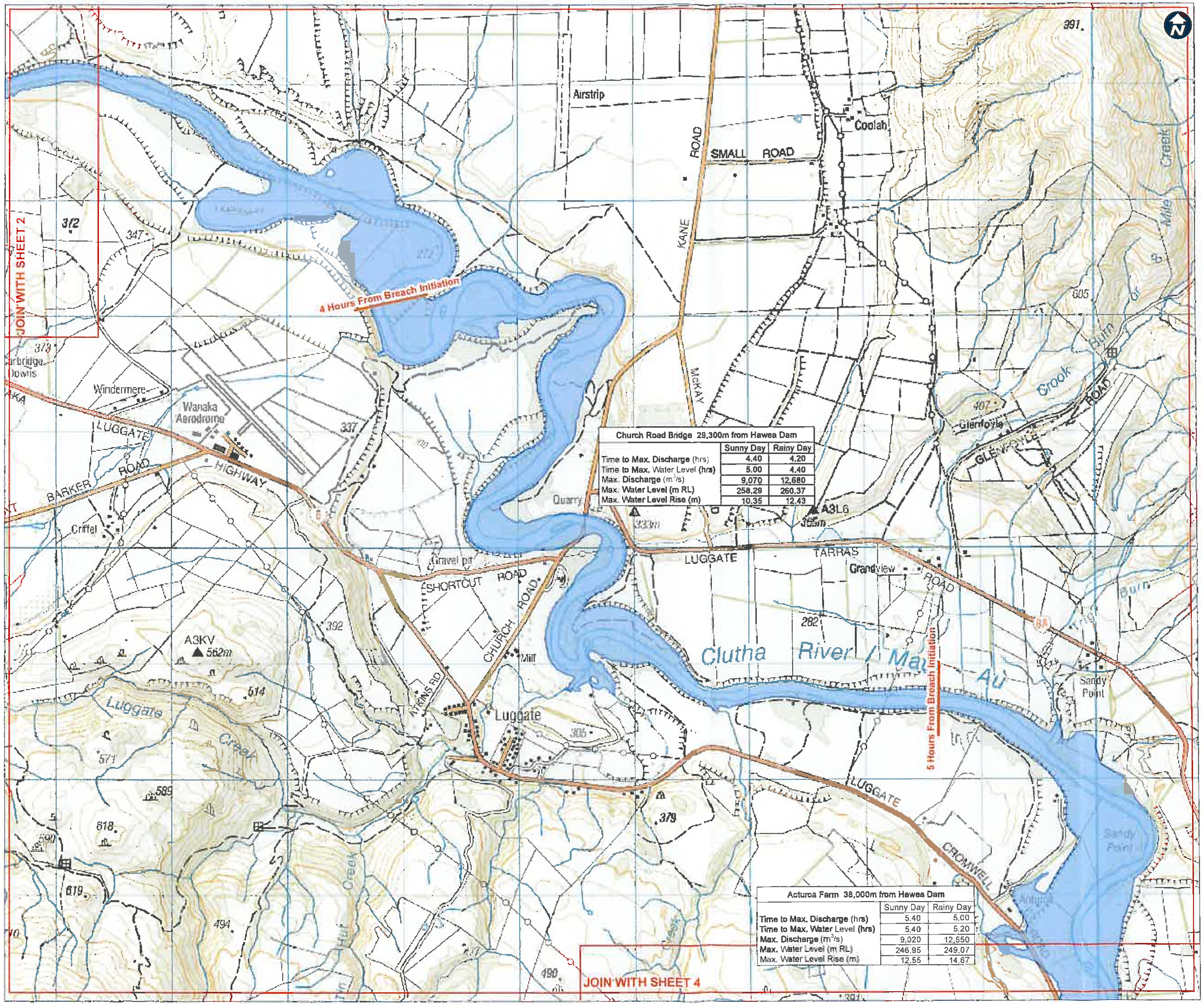
Client: Contact Energy
Project: Lake Hawea Control Dam Dam Break Update Study

Sheet No	Project No	Issue Rev
2	60221308	

Title: Rainy Day Failure Inundation Map Sheet 2 of 9

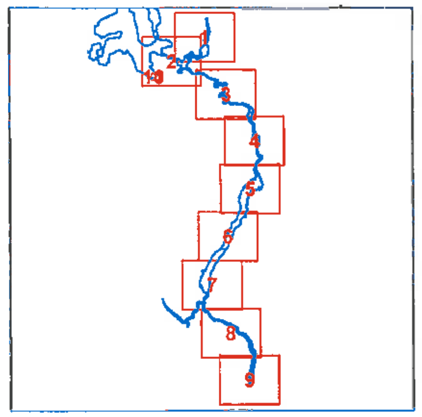
Scale 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved		Status	Final
File Ref.	60221308-RD-02.mxd		
Printed			



Church Road Bridge 29,300m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	4.40	4.20
Time to Max. Water Level (hrs)	5.00	4.40
Max. Discharge (m^3/s)	9,070	12,680
Max. Water Level (m RL)	258.29	260.37
Max. Water Level Rise (m)	10.35	12.43

Acturoa Farm 38,000m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	5.40	5.00
Time to Max. Water Level (hrs)	5.40	5.20
Max. Discharge (m^3/s)	9,020	12,550
Max. Water Level (m RL)	246.95	249.07
Max. Water Level Rise (m)	12.55	14.67



Key Map:

Legend

- Rainy Day Failure Extent
- Flood Wave Travel Time
- Map Sheets

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Client
Contact Energy

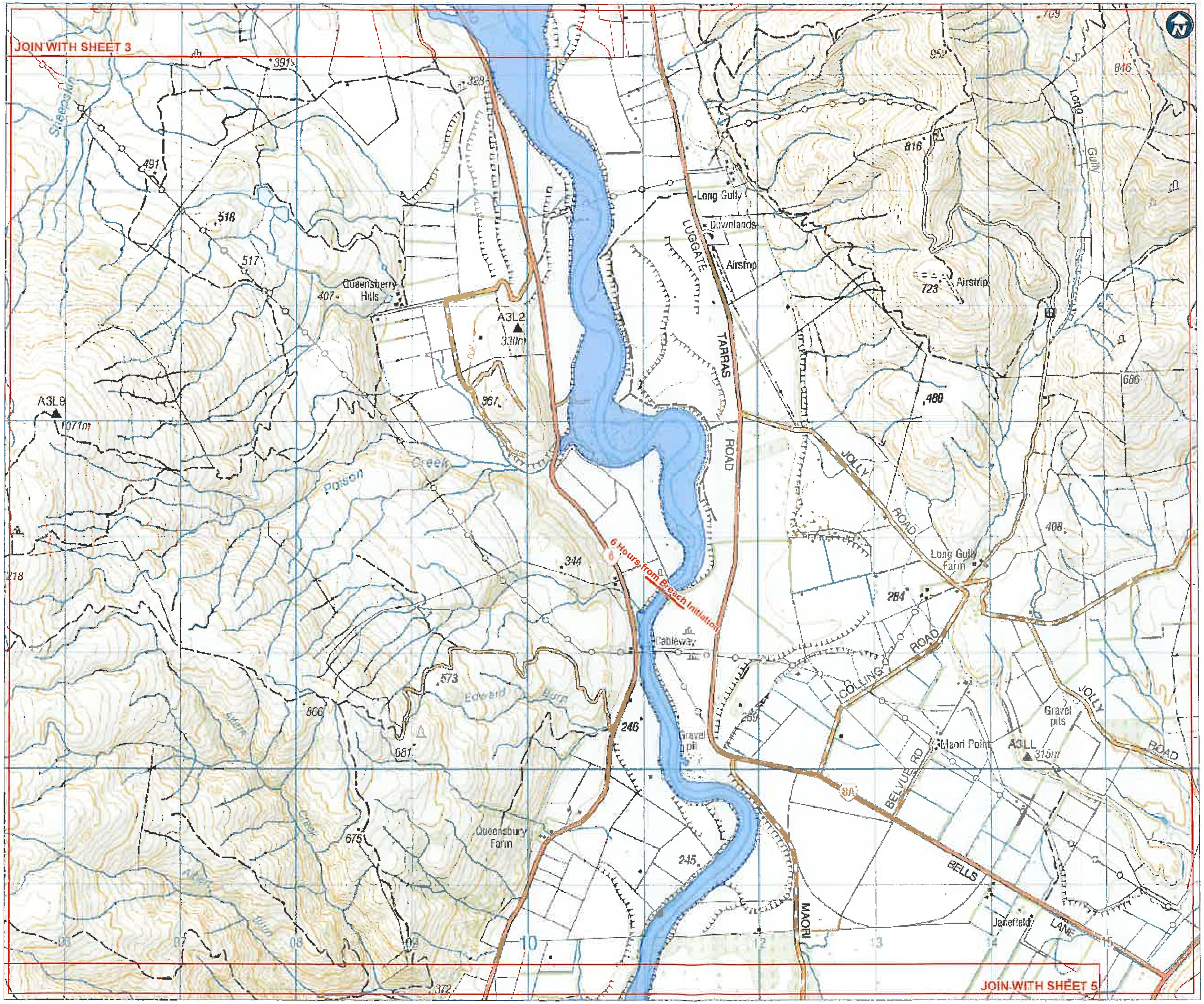
Project
Lake Hawea Control Dam
Dam Break Update Study

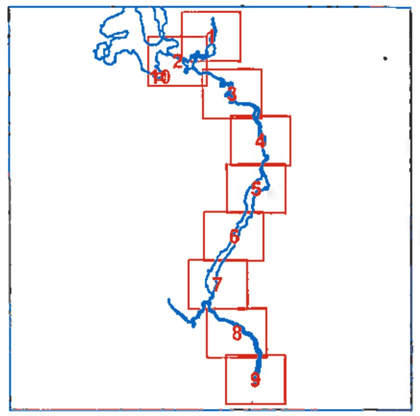
Sheet No	Project No	Issue
3	60221308	Rev

Title
Rainy Day Failure Inundation Map
Sheet 3 of 9

Scale 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-RD-03.mxd		
Printed			





Key Map:

Legend

- Rainy Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes
The inundated area shown is based on an hypothetical rainy day failure of the Hawea control structure.
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Client
Contact Energy

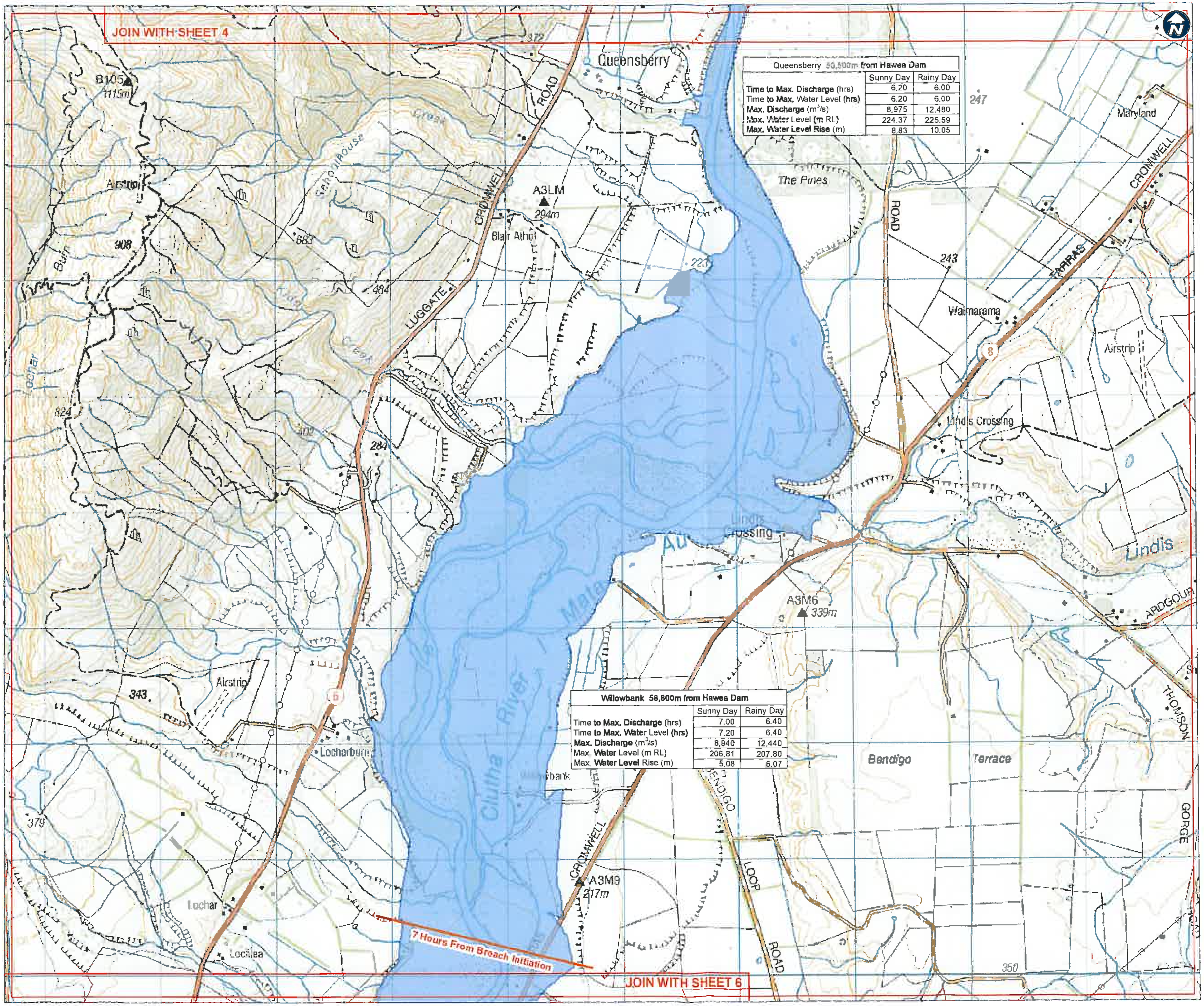
Project
Lake Hawea Control Dam
Dam Break Update Study

Sheet No	Project No.	Issue
4	60221308	Rev

Title
Rainy Day Failure Inundation Map
Sheet 4 of 9

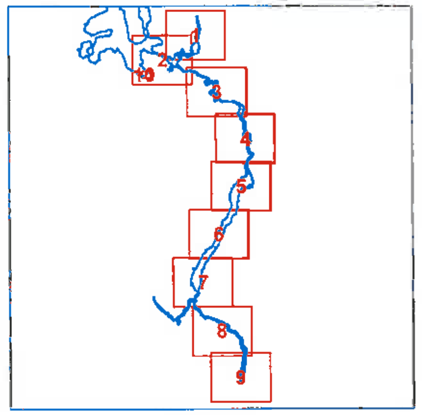
Scale 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-RD-04.mxd		
Printed			



Queensberry 50,500m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	6.20	6.00
Time to Max. Water Level (hrs)	6.20	6.00
Max. Discharge (m^3/s)	8,975	12,480
Max. Water Level (m RL)	224.37	225.59
Max. Water Level Rise (m)	8.83	10.05

Willowbank 58,800m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.00	6.40
Time to Max. Water Level (hrs)	7.20	6.40
Max. Discharge (m^3/s)	8,940	12,440
Max. Water Level (m RL)	206.81	207.80
Max. Water Level Rise (m)	5.08	6.07



Key Map:

Legend

- Rainy Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes

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Client
Contact Energy

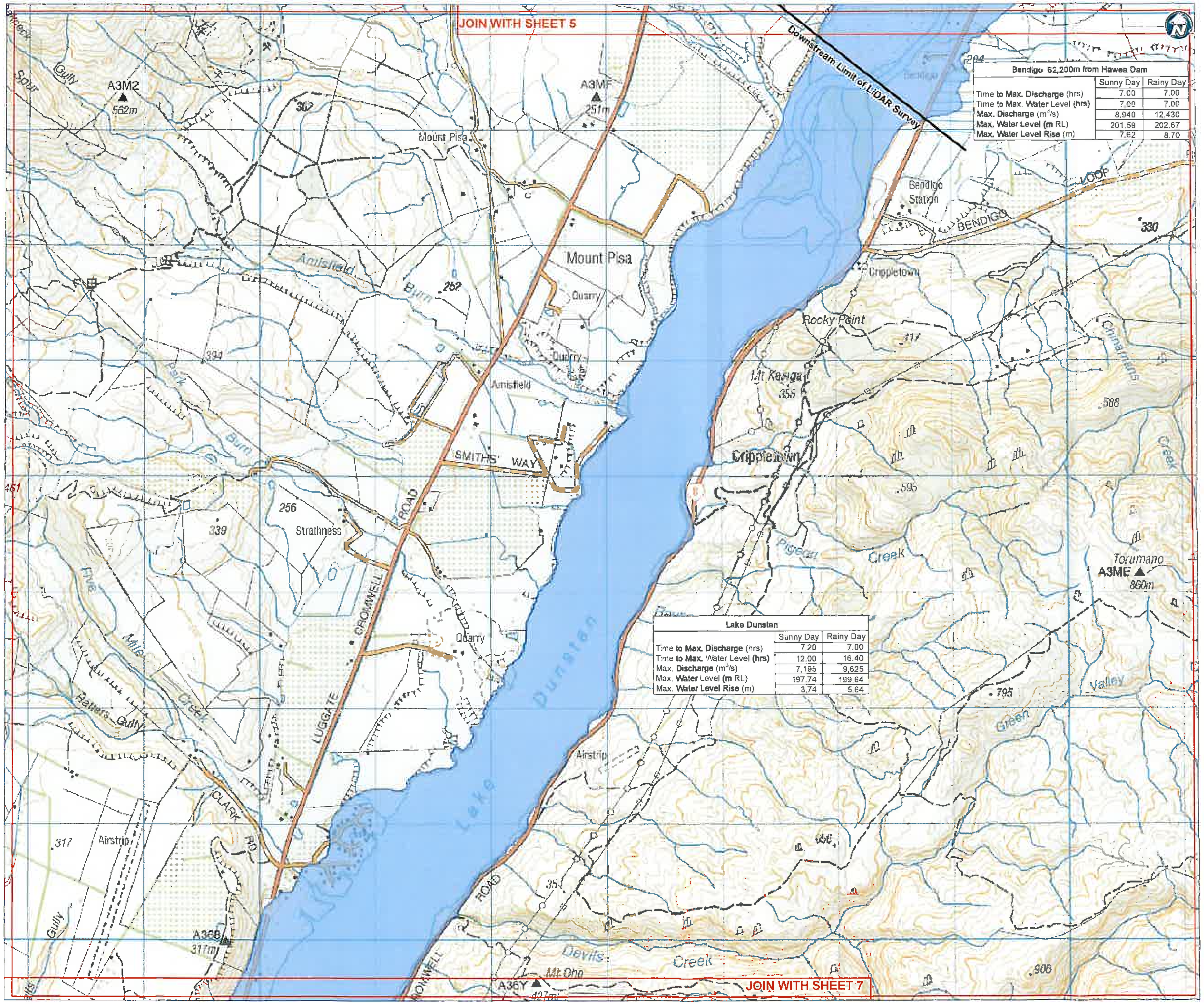
Project
Lake Hawea Control Dam
Dam Break Update Study

Sheet No	Project No.	Issue
5	60221308	Rev

Title
Rainy Day Failure Inundation Map
Sheet 5 of 9

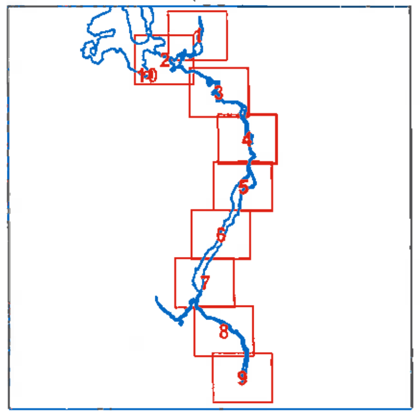
Scale: 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref	60221308-RD-05.mxd		
Printed			



Bendigo 62,200m from Hawea Dam	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.00	7.00
Time to Max. Water Level (hrs)	7.00	7.00
Max. Discharge (m^3/s)	8,940	12,430
Max. Water Level (m RL)	201.59	202.67
Max. Water Level Rise (m)	7.62	8.70

Lake Dunstan	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.20	7.00
Time to Max. Water Level (hrs)	12.00	16.40
Max. Discharge (m^3/s)	7,195	9,625
Max. Water Level (m RL)	197.74	199.64
Max. Water Level Rise (m)	3.74	5.64



Legend

- Rainy Day Flood Extent
- Flood Wave Travel Time
- Map Sheets

Notes

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Maximum water levels for Lake Dunstan assume the Clyde Dam is operated as per Contact's Clutha flood rules
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Client: **Contact Energy**

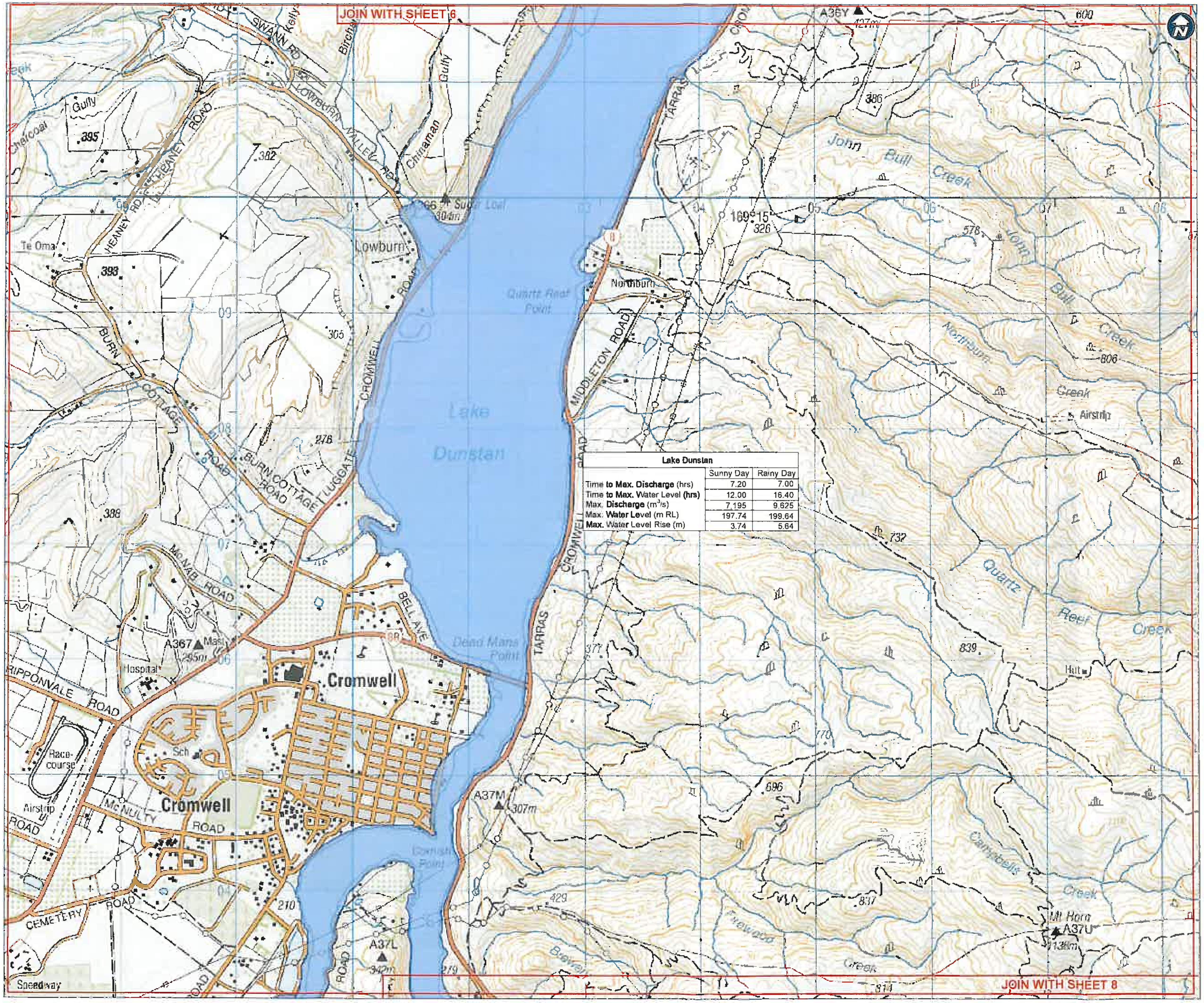
Project: **Lake Hawea Control Dam Dam Break Update Study**

Sheet No: 6 | Project No: 60221308 | Issue: Rev

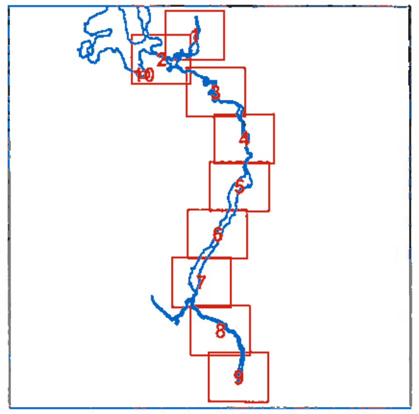
Title: **Rainy Day Failure Inundation Map Sheet 6 of 9**

Scale 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-RD-06.mxd		
Printed			



Lake Dunstan		
	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.20	7.00
Time to Max. Water Level (hrs)	12.00	16.40
Max. Discharge (m^3/s)	7,195	9,625
Max. Water Level (m RL)	197.74	199.64
Max. Water Level Rise (m)	3.74	5.64



Key Map:

Legend

Notes

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Client
Contact Energy

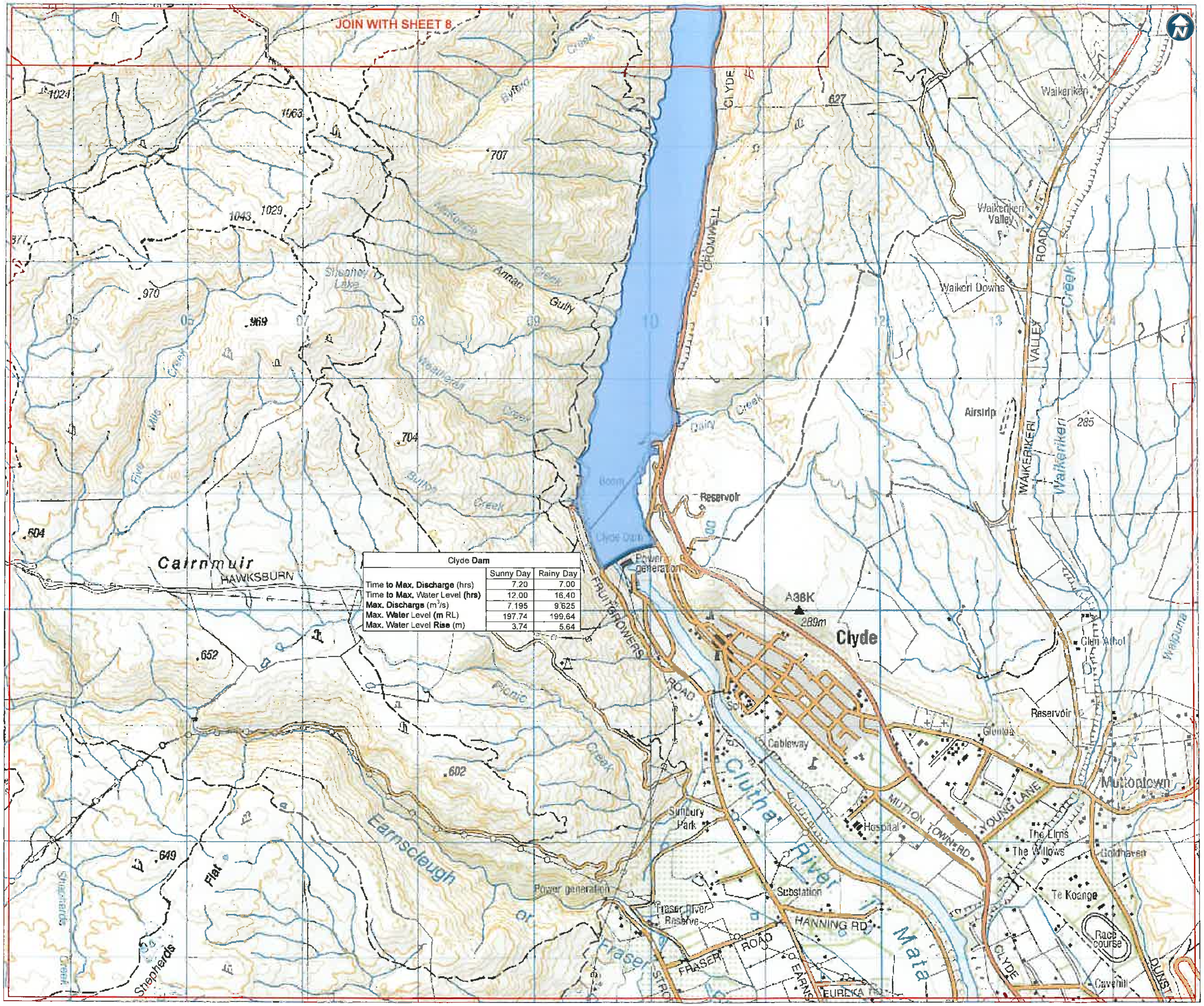
Project
Lake Hawea Control Dam
Dam Break Update Study

Sheet No	Project No	Issue
7	60221308	Rev

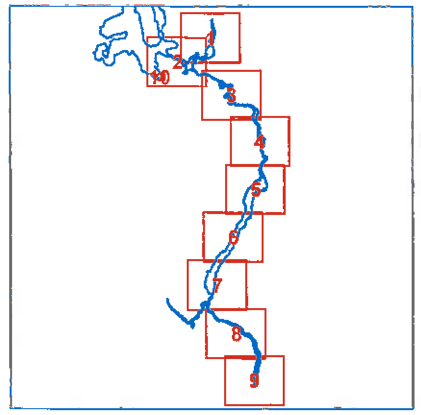
Title
Rainy Day Failure Inundation Map
Sheet 7 of 9

Scale 1:30,000 (A3 size)

		Checked	Date
Design	PJC	GB	28 Sep 11
Drawn	PJC	GB	
Approved	Approved	Status	Final
File Ref.	60221308-RD-07.mxd		
Printed			



Clyde Dam		
	Sunny Day	Rainy Day
Time to Max. Discharge (hrs)	7.20	7.00
Time to Max. Water Level (hrs)	12.00	16.40
Max. Discharge (m^3/s)	7.195	9.625
Max. Water Level (m RL)	197.74	199.64
Max. Water Level Rise (m)	3.74	5.64



Key Map:

Legend

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Client
Contact Energy

Project
Lake Hawea Control Dam
Dam Break Update Study

Sheet No	Project No	Issue
9	60221308	Rev

Title
Rainy Day Failure Inundation Map Sheet 9 of 9

Scale 1:30,000 (A3 size)

		Checked	Date	
Design	PJC	GB	28 Sep 11	
Drawn	PJC	GB		
Approved	Approved		Status	Final
File Ref.	60221308-RD-09.mxd			
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