Appendix E. Hydrology and Hydraulic Assessment Report

RILEY CONSULTANTS

HYDROLOGY AND HYDRAULIC ASSESSMENT
ARATAPU WATER STORAGE RESERVOIR, DARGAVILLE

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HYDROLOGY AND HYDRAULIC ASSESSMENT
ARATAPU WATER STORAGE RESERVOIR, DARGAVILLE

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Report reference: 200240-D

Date: 1 September 2020

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Issue:	Details:	Date:
1.0	Hydrology and Hydraulic Assessment	1 September 2020

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HYDROLOGY AND HYDRAULIC ASSESSMENT
ARATAPU WATER STORAGE RESERVOIR, DARGAVILLE

1.0 Introduction

This preliminary hydrology and hydraulic assessment has been prepared by Riley Consultants Ltd (RILEY), at the request of Te Tai Tokerau Water Trust. This report details the assessment and is intended to support a resource consent application for the construction a large dam.

The scope of the assessment was as follows:

- Estimation of inflow hydrographs for a range of design events in general accordance with the New Zealand Dam Safety Guidelines (New Zealand Society on Large Dams (NZSOLD), 2015) (NZSOLD Guidelines).
- A sunny day Potential Impact Classification (PIC) assessment in general accordance with the NZSOLD Guidelines.
- Preliminary design of the spillway arrangement to provide adequate protection to the dam during the design flood event.
- Preliminary design of the temporary flood diversion works during construction.

2.0 Background

The proposed Aratapu Water Storage Reservoir is located on the Aratapu Creek, on the Pouto Peninsula, to the south of Dargaville. The creek discharges to the tidal reaches of the Wairoa River. The Okapakapa Stream confluences with the Aratapu Creek some distance downstream of the dam. The dam location, relative to other identifying features, is presented on RILEY Dwg: 200240/2-200. The site was previously referred to as K13.

The creek at the proposed dam site consists of a modified channel (i.e. a farm drain), located within a 60m to 70m wide low lying valley. The creek is located to the true-right side of the valley at the dam site. The main channel is approximately 2.0m wide and 1.2m deep. Various other channels are also located within the valley floor to act as drainage system for the surrounding low-lying farmland which is used for grazing dairy cattle. There are also various farm culverts within the channel to aid access across the channel.

Photo 1: View of valley – looking downstream. Main channel is located to right side of valley.

Photo 2: Aratapu Creek at approximate dam site. View looking upstream to a farm culvert. The creek is significantly modified to act as drainage for the surrounding farmland.

3.0 Downstream Effects and Potential Impact Classification

It is normal practice in engineering design to address the potential consequences of a structure failing, by applying design standards appropriate to those consequences. For example, a house has higher design standards applied than a garden shed. Similarly, a hospital has higher design standards than a house. Dam design adopts the same principle of applying increasing design rigour to dams that have a higher consequence if they fail. In dam design jargon this is call assigning a Potential Impact Classification or PIC.

A PIC assessment considers the consequences of an uncontrolled release of the reservoirs' contents as a result of a dam breach. PIC assessments are independent of the likelihood of a failure, which, for a suitably designed, constructed and operated dam, should be very low.

A comprehensive PIC assessment involves determining dam breach characteristics, and hydraulic modelling downstream of the dam.

Module 2 of the NZSOLD Dam Safety Guidelines (2015) outlines the consequence assessment and dam classification framework adopted in New Zealand. It considers three principal components, being:

1. Damage level.
2. Population at risk.
3. Potential loss of life.

Dams are categorised as low, medium, or high PIC based on these components.

The NZSOLD Guidelines provide design criteria, construction and operation requirements for each PIC, with a high PIC dam having the highest criteria. Such a classification system ensures the dam performance requirements are appropriate for the hazard posed by the reservoir.

4.0 Dam Breach Hydraulic Assessment

4.1 Hydraulic Methodology

We have used HEC-RAS (v5.07) to simulate a breach of the dam. The full momentum equation set has been used. HEC-RAS is a software package widely used in the dam and water resources industry to undertake hydraulic analysis.

4.2 Terrain

A 5m Digital Elevation Model (DEM) was provided by Northland Regional Council. A DEM provides elevation information required for the hydraulic analysis. We understand through communications with Northland Regional Council that the DEM was created from a LiDAR survey undertaken in 2017. The DEM covers the full catchment area to the proposed dam and the full floodplain downstream of the dam to the Wairoa River. The vertical datum and horizontal projections used are NZVD 2016, and NZTM 2000, respectively. We have used the same vertical datum and horizontal projections within this assessment. We understand that site specific survey information is not available at this time.

RILEY did not make any modifications to the terrain as part of the dam breach hydraulic assessment.

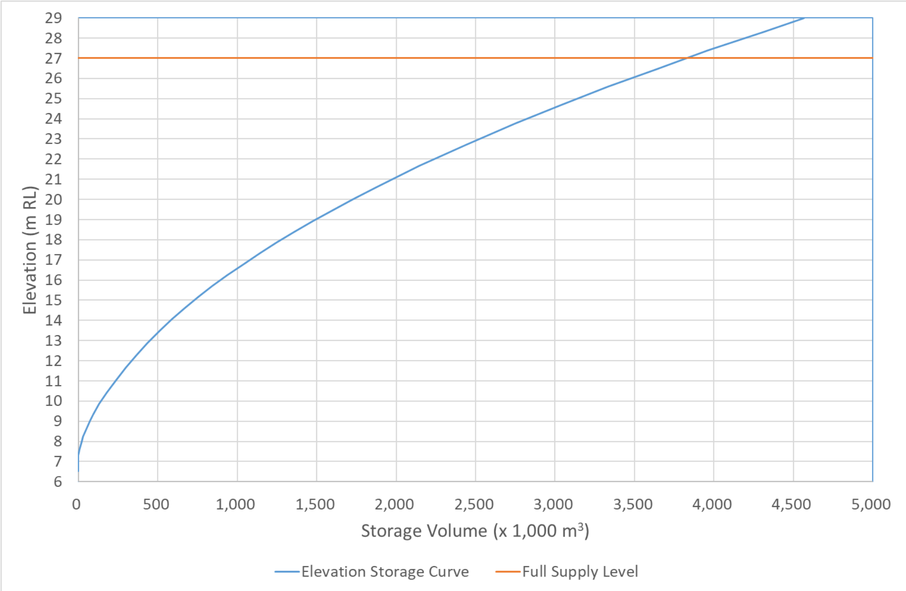
4.3 Breach Scenarios

For the purposes of this preliminary design we have assessed a sunny day piping scenario. A sunny day scenario involves considering a dam failure during normal flow conditions within the stream or river system. A rainy day scenario will also need to be considered during detailed design. A rainy day scenario involves considering a dam failure when the stream or river system is already in flood.

4.4 Geometry

The reservoir has been modelled as a 2D flow area. The elevation-storage relationship (derived from the storage area extent within the HEC-RAS model) is presented within Figure 1.

Figure 1: Elevation Storage Relationship



The area downstream of the dam has been modelled as a 2D flow area, with a 10m x 10m grid, and a global manning's n value of 0.06. The 2D flow area extends the full width of the floodplain and downstream to the confluence with the Wairoa River.

A break line was used along the Wairoa River stopbank. There are two locations, along the Wairoa River stopbank, where the terrain is lower than the mean high water springs (MHWS) level (RL 1.582m) used as the model downstream boundary condition (refer to Section 4.6). Two small weir connections (with an invert of RL 1.6m) have been used to separate the Wairoa River from the low-lying land around Aratapu as we consider it most likely that the stopbank is higher than the MHWS. We consider that this approach is conservative, as the dam breach flood level must overcome a slightly higher threshold before flowing into the Wairoa River, potentially increasing upstream flood levels.

Break lines were also used along Notorious East Road, Redhill Road and Pouto Road embankments.

The dam has been modelled as a connection between the reservoir storage area and the downstream 2D flow area. The dam has a proposed full supply level of RL 27.0m with an indicative crest elevation of RL 29.0m. The downstream dam toe will have a conservative elevation of RL 6.0m.

We have conservatively assumed that all bridges/culverts downstream are blocked forcing all flow out on to the floodplain.

4.5 Breach Parameters

The NZSOLD Guidelines reference Wahl 1998 for the estimation of breach parameters. Wahl 1998 does not provide a specific method for estimating breach parameters. However, it summarises numerous methods/equations derived by others. Typically, these equations use the depth of water (or height of dam) and reservoir volume as input parameters. The main parameters used to derive the breach parameters are presented within Table 1.

Table 1: Input Parameters for Breach Parameter Estimation

Parameter	Value	Source
Dam Toe Elevation (m RL)	6.0	LiDAR (conservative)
Service Spillway Crest (m RL)	27.0	Design Value
Dam Crest (m RL)	29.0	Interim Design Value
Retained Volume Service Spillway Crest (m^3)	3,900,000	LiDAR (conservative)
Final Breach Invert Level (m RL)	7.0	Slightly above downstream terrain
Height of water above breach invert (m)	20.0	Breach invert subtracted from spillway crest
Average embankment width (m)	75	LiDAR
Approach flow width (m)	210	LiDAR

Table 2 presents the dam breach parameters calculated using the methods outlined in Wahl 1998. Froehlich (1995) is the most recent method for estimating dam breach parameters (within Wahl 1998) and it uses the largest number of case studies in the development of its empirical equations. The Froehlich (2016) method has been developed in the time since the NZSOLD Guidelines were published. Furthermore, both Froehlich methods recognise the differences in breach characteristics of an overtopping or piping failure (only the piping failure parameters are presented in Table 2 as this is most appropriate to a sunny day dam breach). We, therefore, gave greater weighting to the Froehlich 2016 method.

Table 2: Dam Breach Parameters

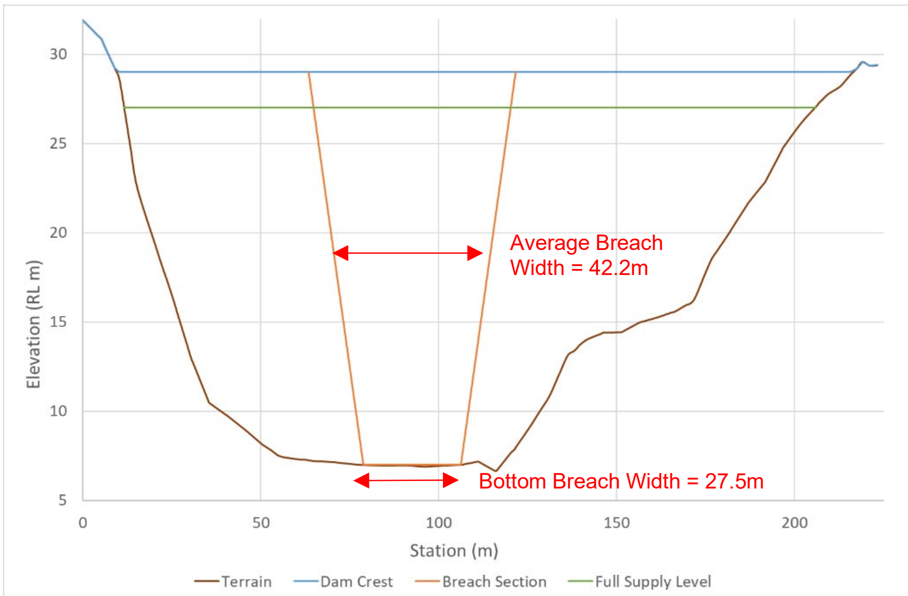
Method	Average Breach Width, B (m) [1]	Formation Time, t_f (minutes)	Z (H:V)
Johnson & Illes (1976)	11.0 – 66.0	n/a	n/a
Singh & Snorrason (1982, 1984)	44.0 – 110.0	15-60[2]	n/a
MacDonald & Langridge-Monopolis (1984)	n/a	46	n/a
FERC (1987)	44.0 – 88.0	6-60[2]	0.25-1.00[2]
USBR (1988)	60.0	40	n/a
Froehlich (1995) – Piping	40.7	32	1.4
Froehlich (2016) – Piping	42.2	31	0.7

Notes:
1 Range shown if applicable
2 Range provided by method without any calculation

The larger the dam breach width (B) and shorter the formation time (t_f), the larger the peak outflow will be. The side slope of the breach shape is of secondary importance.

HEC-RAS uses a bottom breach width, not the average breach width (as derived using the Froehlich methods). We have used a bottom breach width of 27.5m for the piping breach scenario (with an average breach width of 42.2m and side slopes of 0.7). A cross section of the breach profile is presented in Figure 2.

Figure 2: Sunny Day Piping Breach Cross Section



4.6 Downstream Boundary Condition

We have used a static downstream boundary condition to represent a high tide within the Wairoa River. A report titled Coastal Flood Hazard Zones for Select Northland Sites (T+T 2017) presents mean high-water springs (MHWS) levels for Dargaville. The levels are presented in terms of One Tree Point 1964 vertical datum (RL 1.72m) and have been converted to NZVD 2016 using the LINZ New Zealand Coordinate Conversion Tool. The resulting value of RL 1.582m has been used in the model.

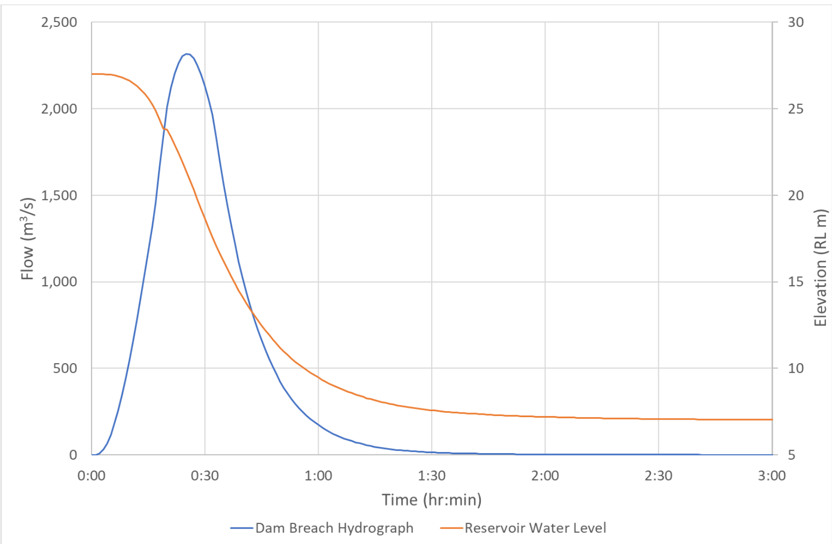
4.7 Initial Condition

We have used an initial condition of RL 27.0m for the reservoir storage area.

4.8 Results

Figure 3 presents the reservoir level and outflow hydrograph immediately downstream of the dam.

Figure 3: Dam Breach Hydrograph and Reservoir Water Level



The HEC-RAS model derives a peak breach outflow of 2,318m^3/s at the dam connection. For comparison, the predicted peak breach outflows by the Froehlich methods are presented in Table 3. Overall, there is a range in results but the predicted flow from HEC-RAS is similar to the flow derived by empirical formulation of Froehlich (2016).

Table 3: Comparison of Peak Breach Outflows

Method	Peak Outflow (m^3/s)
Froehlich (1995)	2,180
Froehlich (2016) – Empirical	1,357
Froehlich (2016) – Semi-theoretical	1,542
HEC-RAS Model	2,318

Froehlich 2016 also presents 42 dams that have failed, which have measured peak discharges. The four dams that are most similar in size and breach characteristics to the proposed dam are presented in Table 4.

Table 4: Failed Dams of Similar Size to Aratapu Water Storage Reservoir

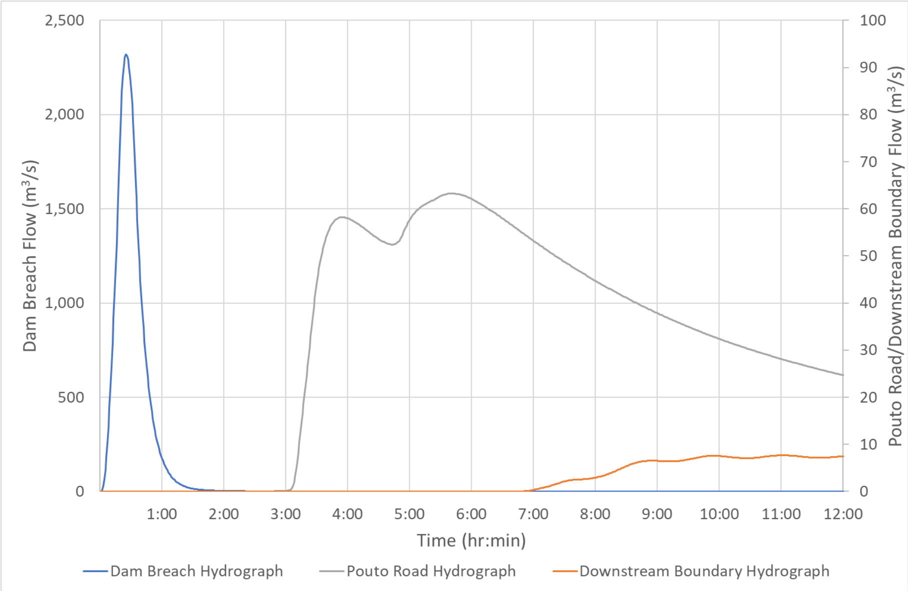
Dam Name and Location	Volume (m^3)	Height of Water Above Breach (m)	Measured Peak Discharge (m^3/s)
Aratapu Water Storage Reservoir	3,900,000	20.0	2,318
Castlewood, Colorado	6,170,000	21.6	3,570
Bradfield (Dale Dyke), England	3,200,000	28.0	2,370
Little Deer Creek, Utah	1,360,000	22.9	1,330
French Landing, Michigan	3,870,000	8.5	929

The predicted peak flow derived from the HEC-RAS model for the proposed dam is most similar to the measured peak discharge of Bradfield Dam, which has the most similar volume to the proposed dam.

Figure 4 presents the dam breach and downstream boundary hydrographs on the left and right axis, respectively. The results indicate that significant attenuation occurs within the floodplain, with a peak flow of less than 8m^3/s within the Wairoa River. The road embankments and the Wairoa River stopbank provide significant storage.

We note that a large culvert or bridge is located near the Aratapu Creek mouth. The embankment/bridge is included within the terrain provided, and we have conservatively assumed that the conveyance system blocks. The model results indicate that the area does not overtop in the modelled dam breach event.

Figure 4: Dam Breach and Downstream Boundary Hydrographs



For the purposes of this assessment, we consider that the predicted peak flow derived from the HEC RAS model is suitable for assessing the PIC.

4.9 Drawings

The drawings within Appendix A and summarised in Table 5, present the model results.

Table 5: Drawing Summary

Drawing Number	Drawing Name
200240/2-200	Downstream Floodplain Overview
200240/2-201 to -202	Sunny Day Breach - Peak Levels (Areas 1 and 2)
200240/2-203 to -204	Sunny Day Breach - Peak Depth (Areas 1 and 2)
200240/2-205 to -206	Sunny Day Breach - Peak Depth Velocity Product (Areas 1 and 2)

5.0 Damage Level Assessment

5.1 General

The damage level assessment requires the assessment of individual specified categories, as outlined in the following sections. The damage level is taken as the highest damage level from each of the categories. The damage levels from lowest to highest damage are Minimal, Moderate, Major, and Catastrophic.

5.2 Residential Houses

The NZSOLD Guidelines define destroyed as rendered uninhabitable but does not define uninhabitable. We note that the NZSOLD Guidelines make references to the following publications with regards to damage to residential houses:

- RESCDAM (2010) – includes test data on the performance of buildings in flowing water as a function of building type, flood depth, and velocity.

- National Institute of Weather and Atmosphere (NIWA, 2010) – provides potential damage curves as a function of building type and flood depth, based on observed data from floods and tsunamis in New Zealand.

NIWA (2010) provides a graph (Figure 5), that presents curves for the damage threshold and the total destruction threshold of timber/weatherboard buildings, based on the depth and velocity of flood waters. The figure indicates that at flood depths less than 3m, velocity damage occurs when the product of depth and velocity (D x V) is 1.5m^2/s and total destruction occurs when D x V is greater than 3m^2/s, as shown in Table 6.

Figure 5: Inundation Depth and Velocity Thresholds for:
(a) Onset of Damage due to Water Velocity; and
(b) Total Destruction, of Timber/Weatherboard Buildings (NIWA, 2010).

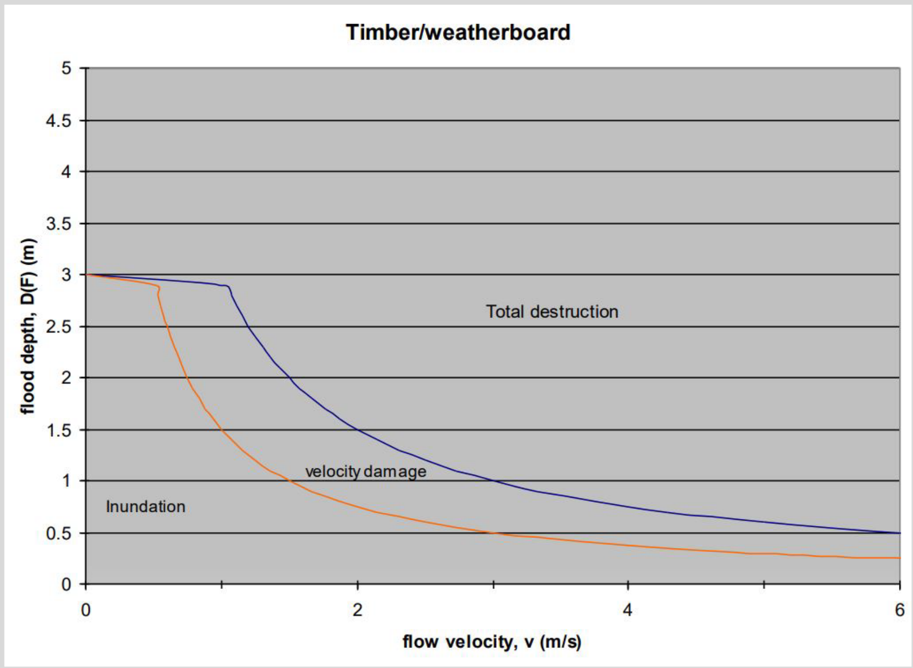


Table 6: Depths and Velocity Points from Curves Presented in Figure 5

Scenario	Depth (m)	Velocity (m/s)	D x V
Velocity Damage Threshold (orange line)	1.5	1.0	1.5
	1.0	1.5	1.5
	0.5	3.0	1.5
Total Destruction Threshold (blue line)	2.0	1.5	3.0
	1.5	2.0	3.0
	1.0	3.0	3.0

An alternative conservative approach is to consider the number of houses that are surrounded by greater than 0.5m of water (above surrounding ground levels). Such inundation could render a house uninhabitable (and therefore destroyed) due to static water damage.

We have used the latest building outline information from LINZ and aerial imagery to assess the number of residential houses affected. We have used our best judgment on whether buildings are residential in nature (i.e. excludes commercial/industrial and non-habitable sheds etc.). Affected houses are highlighted on the drawings. The residential houses affected are predominately located in the community of Aratapu.

Table 7 presents a summary of the residential house assessment. We have not undertaken an inspection of the houses likely to be affected. Overall, we consider that a Moderate damage level is appropriate for the residential houses, as highlighted within Table 8.

Table 7: Residential House Summary

Scenario	Depth > 0.5m	1.5 m^2/s < D x V < 3.0 m^2/s	D x V > 3.0m^2/s
Sunny Day Piping	4	0	0

Table 8: Residential Houses Damage Level

Damage Level	Residential Houses
Catastrophic	More than 50 houses destroyed.
Major	Four to 49 houses destroyed, and a number of houses damaged.
Moderate	One to three houses destroyed and some damaged.
Minimal	Minor damage.

5.3 Critical or Major Infrastructure

The NZSOLD Guidelines state that critical or major infrastructure includes:

(a) lifelines (power supply, water supply, gas supply, transportations systems, wastewater treatment, telecommunications (network mains and nodes rather than local connections)); and

(b) emergency facilities - (hospitals, police, fire services); and

(c) large industrial, commercial, or community facilities, the loss of which would have a significant impact on the community; and

(d) the dam, if the service the dam provides is critical to the community and that service cannot be provided by alternative means.

We have not identified any critical or major infrastructure downstream of the dam, via a review of aerial photography. We note that roads and power lines are located downstream of the dam, however, these are local connections.

We consider that a Minimal damage level is appropriate for critical or major infrastructure, as highlighted within Table 9.

Table 9: Critical or Major Infrastructure Damage Level

Damage Level	Critical or Major Infrastructure
Catastrophic	Extensive and widespread destruction and damage to several major infrastructure components.
Major	Extensive destruction and damage to more than one major infrastructure component.
Moderate	Significant damage to at least one major infrastructure component.
Minimal	Minor damage to major infrastructure components.

5.4 Time to Restore Operation to Critical or Major Infrastructure

We consider any damage to critical or major infrastructure is likely to take up to one week to restore operation. Therefore, a Minimal damage level is appropriate to restore operation to critical or major infrastructure, as highlighted within Table 10.

Table 10: Time to Restore Operation to Critical or Major Infrastructure

Damage Level	Critical or Major Infrastructure
Catastrophic	More than one year
Major	Up to 12 months
Moderate	Up to three months
Minimal	Up to one week

5.5 Natural Environment

The effects of a dam breach on the natural environment downstream may include deposition of sediment and scour within the downstream watercourses, potentially impacting water quality and fish habitat.

We consider that the damage to the natural environment downstream of the dam is likely to be significant but recoverable damage. Therefore, we considered that a Moderate damage level is appropriate for the natural environment, as highlighted within Table 11.

Table 11: Natural Environment Damage Level

Damage Level	Natural Environment
Catastrophic	Extensive and widespread damage.
Major	Heavy damage and costly restoration.
Moderate	Significant but recoverable damage.
Minimal	Short-term damage.

5.6 Community Recovery Time

We consider the community could take months to recover from the dam breach, as the flooding would have significant impacts on the farming community. Therefore, we consider that a Moderate damage level is appropriate for the community recovery time, as highlighted within Table 12.

Table 12: Community Recovery Time Damage Level

Damage Level	Community Recovery Time
Catastrophic	Many years
Major	Years
Moderate	Months
Minimal	Days to weeks

5.7 Damage Level Summary

Table 13 summarises the selected damage levels for each of the categories. The highest damage level from the five categories is Moderate and therefore, the damage level for the dam is Moderate.

Table 13: Damage Level Summary

Category	Damage Level
Residential Houses	Moderate
Critical or Major Infrastructure	Minimal
Time to Restore Operation to Critical or Major Infrastructure	Minimal
Natural Environment	Moderate
Community Recovery Time	Moderate

6.0 Population at Risk

6.1 General

The Population at Risk (PAR) is defined as the number of people likely to be incrementally affected by inundation greater than 0.5m if a dam breach occurs. When evaluating PAR, the potential evacuation of people is not considered. The NZSOLD Guidelines require the PAR to be determined as one of the following:

- 0
- 1 to 10
- 11 to 100
- Greater than 100

The PAR will vary with time of day, week, and year. The NZSOLD Guidelines state that the most critical situation should be used to determine the PAR. The PAR does not take into account exposure times, except for temporary populations on designated routes.

The following sections provide an outline of the assessed PAR. In general, the model results indicate that significant areas experience flooding greater than 0.5m depth upstream of the lower Redhill Rad crossing. Further downstream, 0.5m flooding depths are generally confined to upstream of the Pouto Road embankment, and within a historical river channel associated with the Wairoa River.

6.2 Residential Houses

As presented within the residential house damage level assessment, there are four residential houses that appear to be located in areas where inundation depths are predicted to exceed 0.5m (above surrounding ground levels). These houses are highlighted within the flood drawings (RILEY Dwgs: 200240/2-202 and -203). We note that a specific floor level survey has not been undertaken. If such a survey was undertaken, the number of houses meeting the threshold may reduce. We have allowed for a range of 2.5 to 5 people within each household. Therefore, we consider the PAR associated with residential houses to be between 10 to 20.

6.3 Community Facilities

We have not identified any community facilities, such as schools/halls/hospitals etc. that will be affected by at least 0.5m depth of water.

6.4 Business Areas

The Aratapu Tavern is located on the corner of Pouto Road and Heawa Road and there appears to be various other business on Pouto Road. However, model results indicate that flood depths do not exceed 0.5m in the area.

6.5 Recreational Users

We note that there are two small parcels of public land near the Aratapu Creek mouth. However, review of aerial photography indicates that no public facilities appears to be provided in the area. Recreational users of the Wairoa River are unlikely to be affected. Overall, we have not identified any recreational areas that are affected by flood waters greater than 0.5 depth.

6.6 Road Crossings

The dam breach floodplain crosses a number of roads, with the upstream Redhill Road crossing the most significantly affected. Considering exposure times, the PAR associated with road crossings is likely to be low. We consider the PAR associated with road crossings is likely to be less than two.

6.7 Discussion

The PAR may vary considerably depending on the time of day and day of week of a breach. We consider Table 14 provides an appropriate summary of the PAR.

We consider that the assessing the PAR to be in the 11-100 category is conservative. We note the PAR may increase in the future due to development downstream of the dam.

Table 14: PAR Summary

Type	PAR
Residential Houses	10 - 20
Community Facilities	0
Business Areas	0
Recreational Users	0
Road Crossings	2
Total	**12 - 22**

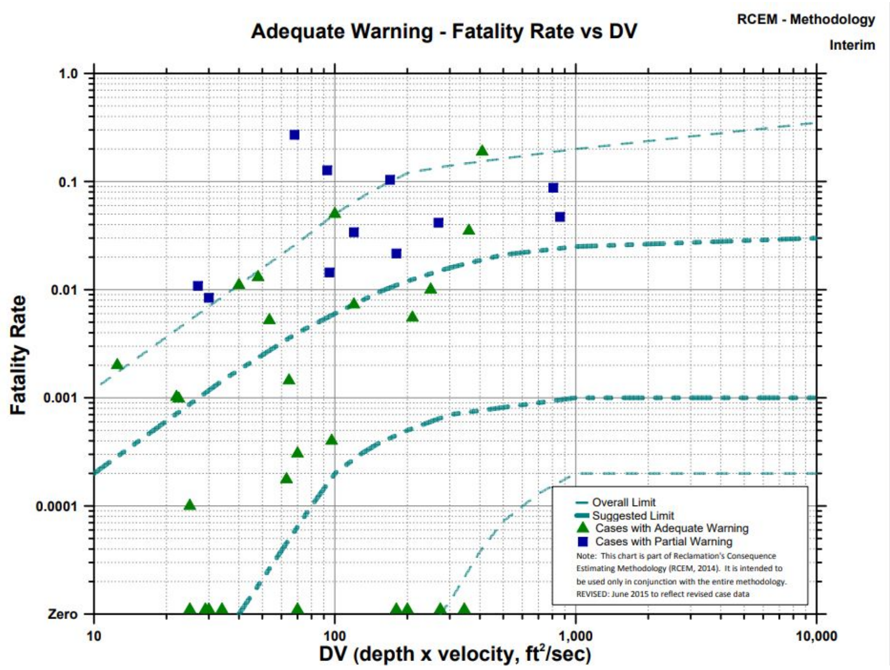
7.0 Potential Loss of Life (PLL)

The NZSOLD Guidelines require that a High PIC is used if two or more lives are highly likely to be lost or a Medium PIC if a life is highly likely to be lost. The NZSOLD Guidelines do not provide a definition of highly likely or guidance on the weighting of the different potential dam breach scenarios (unlike the PAR where the guidelines clearly state that the most critical situation should be used). The PLL takes the potential for evacuation into account.

In 2014, the United States Bureau of Reclamation developed a methodology for estimating PLL entitled Reclamation's Consequences Estimation Methodology (RCEM). RCEM provides a graphical approach giving the fatality rate as a function of the D x V and amount of warning time (based on measured fatality rates in actual dam breach events).

Figure 6 presents the RCEM 2014 fatality rate, for adequate warning. We consider that this approach is conservative, given the dam breach flood takes approximately 3.5 hours to reach the affected PAR after the breach. The figure uses the empirical units of ft^2/s. The important feature of the figure, in this case, is that a D x V product of $10ft^2/s$ (or $1m^2/s$) has a low fatality rate of approximately 0.0002 (at the upper conservative end of the suggested limit).

Figure 6: RCEM 2014 Fatality Rate, Adequate Warning



The flood drawings (200240/2-201 to -206) present the D x V results. The DxV in the vicinity of the PAR is less than 1m^2/s, therefore, using a fatality rate of 0.0002 and assuming PAR of 22, the statistical PLL is 0.0044, and thus, loss of life is highly unlikely. Overall, the risk of loss of life appears low if adequate evacuation plans are in place.

8.0 Potential Impact Classification

The PIC assessment is summarised within Table 15 (as taken from the NZSOLD Guidelines). Given that the damage level is Moderate, the PAR is in the range from 11 to 100, and a low likelihood of loss of life, the table indicates that the dam should have a Medium PIC.

It is recognised that the dam will be used for irrigation of crops and horticulture. This land use will at times during the year potentially increase the PAR within the floodplain below the dam. Given the very low anticipated fatality rate, there would need to be a very large increase in PAR before the PLL reached a level that might indicate an increase in PIC rating for the dam.

Table 15: Determination of Dam Classification

Assessed Damage Level	Population at Risk (PAR)			
	0	1 to 10	11 to 100	More than 100
Catastrophic	High	High	High	High
Major	Medium	Medium/High[4]	High	High
Moderate	Low	Low/Medium/High[3,4]	Medium/High[4]	Medium/High[2,4]
Minimal	Low	Low/Medium/High[1,3,4]	Low/Medium/High[1,3,4]	Low/Medium/High[2,3,4]

Notes:
1 With a PAR of five or more people, it is unlikely that the potential impact will be low.
2 With a PAR of more than 100 people, it is unlikely that the potential impact will be medium.
3 Use a medium classification if it is highly likely that a life will be lost.
4 Use a high classification if it is highly likely that two or more lives will be lost.

9.0 Flood Design Criteria

The PIC assessment classifies the dam as Medium PIC. The NZSOLD guidelines recommend that a Medium PIC dam has an Inflow Design Flood (IDF) of 10,000-year flood event, if the PAR is 11 to 100, as outlined in Table 16.

Table 16: Recommended Minimum Inflow Design Floods (NZSOLD, 2015)

PIC	PAR	PLL	IDF
Low	0 to 10	0	100 to 1,000
Medium	0 to 10	0	1,000
	0 to 10	1	2,500
	11 to 100	0 to 1	10,000
High	No limits	0 to 1	10,000
	No limits	>10	PMF

We consider that the minimum IDF for the dam should be the 10,000-year flood event.

The adopted design criteria is summarised in Table 17 and is consistent with those indicated in the NZSOLD guidelines.

Table 17: Design Criteria

Element	Criteria
Service Flood	100-year flood event to be passed with very low-probability of erosion.
Design Flood	10,000 year flood event to be passed with adequate freeboard to the dam or wave wall crest. Freeboard the greater of 900mm or the sum from the wind set up and wave run up from the 10% annual exceedance probability (AEP) wind.
Construction Diversion	Less than 2% probability of the partially completed dam being overtopped.

10.0 Hydrology

10.1 Methodology

NZSOLD (2015) recommends that two or more methods are used to determine the inflow design flood. For this assessment we have:

1. Developed a rainfall-runoff model using HEC-HMS.
2. Undertaken a regional based flood frequency assessment.

We have not undertaken a flood frequency analysis on nearby flow gauges, noting that both the NIWA portal and Northland Regional Council (NRC) website show no flow gauges on Pouto Peninsula.

We note that there are large uncertainties in estimating flood events in excess of the 100-year event. We have therefore used a conservative approach as suggested by NZSOLD (2015) in determining the appropriate inflow design flood. We also note that the hydrological hazards (as well as the understanding of) can change with time, and therefore a conservative approach may also reduce the need for future upgrade works to the spillway facilities. We have not specifically allowed for climate change as recommended by NZSOLD (2015).

The NZSOLD Guidelines recommend that the PMF should be determined using Thompson and Tomlinson (1991) (and Campbell et al (1994)). However, this document was superseded by an article in the Journal of Hydrology (Volume 31 No. 2), also by Thompson and Tomlinson in 1993, for rainfall durations from 0.5 hours to six hours in length. The 1993 method has been used to determine total rainfall depths for a range of rainfall durations.

We have elected to undertake an assessment of the following design events:

- Mean annual flood event
- 100-year flood event
- 1,000-year flood event
- 10,000-year flood event
- Probable Maximum Flood (PMF)

10.2 Catchment Area

RILEY Dwg: 200240-210 presents the derived catchment boundary derived from the 5m DEM previously detailed. A catchment area of 3.21km^2 was determined.

10.3 Infiltration

A number of methods are available to allow for soil infiltration (i.e. precipitation loss) during rainfall events. Soil infiltration is typically categorised/influenced by soil types and ground cover.

We note that NRC does not appear to have a preferred method for soil infiltration allowance. The Soil Conservation Service (SCS) method is commonly used however and is specified by Auckland Council within TP108. The SCS method categorises soil types into four groups (Group A, B, C or D) based on soil types.

We anticipate that the soils within the catchment mainly consist of Group A soils, as based on RILEY Dwg: 200240/2-211. Group A soils are described within SCS Technical Release 55 (1986) as:

> Soils that have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 7mm/hr).

The majority of the catchment is covered in pasture. Group A soils with pasture cover in good condition have a CN of 39, in accordance with SCS Technical Release 55 (1986).

The SCS method also requires the selection of the Initial Abstraction (Ia). Ia represents the initial precipitation loss at the start of a rainfall event. We note that TP108 recommends the use of Ia = 5mm in the Auckland region. We have conservatively used Ia = 0mm.

We consider significant uncertainty is associated with the selected CN, due to the potential for high infiltration rates within the catchment. For the purposes of this assessment we have used the SCS method, with a Curve Number (CN) of 39 for previous surfaces. We have not allowed for any impervious surfaces (including the proposed reservoir) within the catchment at this preliminary stage. During the detailed design stage further investigations should be undertaken.

10.4 Transform

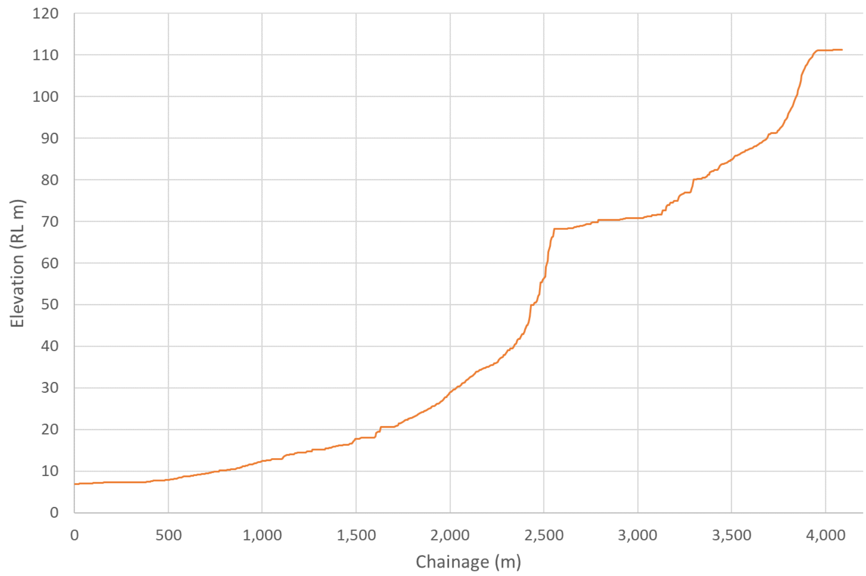
A number of methods are available to model the transformation of excess precipitation to runoff. We note that NRC does not appear to have a preferred method for the region, however the Priority Rivers Modelling Report (URS, 2011) used the SCS Unit Hydrograph method, and it is also used with TP108.

For the purposes of this assessment we have used the SCS Unit Hydrograph method, along with a Peak Rate Factor of 484 (PRF 484). PRF 484 is the standard factor used. Other factors are available which result in peakier or flatter runoff hydrographs. Without any observed events to calibrate to for the catchment, we consider that a PRF of 484 is the most appropriate to use.

10.5 Time of Concentration

Figure 7 presents a long section along the longest flow path to the dam site from the upstream reaches of the watercourse. The maximum elevation with the catchment is RL 130m. The figure demonstrates that the upper reaches of the catchment have a gradient of 5% to 10%, while the lower reaches are in the order of 1.0% to 1.5%.

Figure 7: Longest Flow Path Long Section



Note: Chainage as measured upstream from the dam location

We have used various methods to estimate the time of concentration as presented within Table 18. The methods generally use flow path length, catchment area and elevation change as input parameters. The TP108 method was specifically derived for Auckland catchments.

Table 18: Time of Concentration (Minutes)

Method	Value
Ramser Kirpich	56
Bransby Williams	109
TP108	96

The Bransby Williams and TP108 methods provide similar results. We consider that the use of a time of concentration of 90 minutes is appropriate. The SCS unit hydrograph method uses lag time as the input parameter instead of time of concentration, where the lag time is equal to two thirds of the time of concentration. Therefore, a lag time of 60 minutes has been used within the assessment.

10.6 Rainfall Depth

10.6.1 Design Rainfall Depths

HIRDS (V4) was used to source rainfall information up to and including the 250-year event (highest return period available within HIRDS). We have selected one location within the catchment (at approximately mid elevation) to be representative of the rainfall within the entire catchment area, as presented within RILEY Dwg: 200240/2-210. Since the catchment area is relatively small, we have not allowed for spatial distribution of rainfall within the catchment.

Table 19 presents the HIRDS information for a range of durations. Both the rainfall depths and 6 to 1 hour ratios are low relative to other areas in Northland and New Zealand as a whole. We consider this effect is mainly due to the proposed dam site location, which is in close proximity to the west coast, and therefore the effect of high intensity cyclonic rainfall events from an easterly direction are reduced.

We note that Auckland Council's TP108 rainfall charts extend to the South Head peninsula of the Kaipara Harbour i.e. relatively close to the dam site. The TP108 24-hour rainfall depths are similar to those presented in Table 19 (i.e. 80mm for the 2-year event and 150mm to 190mm for the 100-year event).

Table 19: HIRDS Rainfall

Rainfall Event	Duration (hours)									6 to 1 Hour Ratio
	1	2	3	4	5	6	24	48	72	
2.33-Year	21	29	34	38	42	45	74	92	103	2.1
100-Year	47	63	75	85	93	100	166	206	231	2.1
250-Year	53	72	85	96	105	113	188	234	263	2.1
1,000-Year[1.]	62	84	100	113	124	133	221	276	310	2.1
10,000-Year[1.]	78	105	125	141	155	166	277	346	388	2.1

Note:

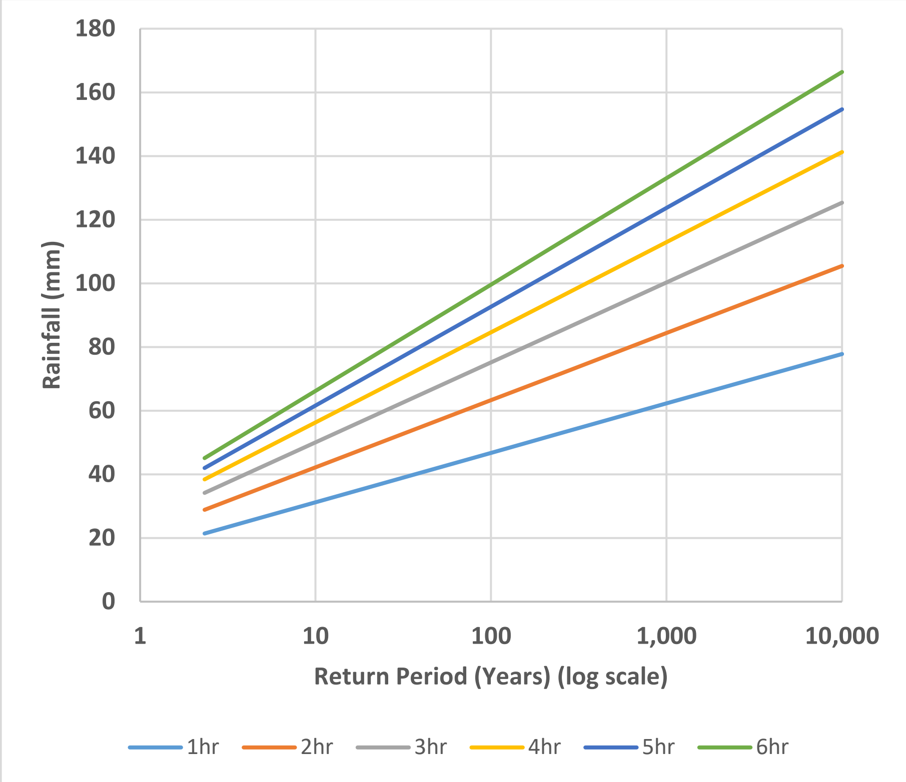
1. Extrapolated on a log scale

At the detailed design stage, a rainfall frequency analysis for appropriate nearby rainfall gauges should be undertaken to compare to the HIRDS data. We note that NRC operates at least one rain gauge in the area (Okoraka at Ngatawhiti Road). As recommended by the NZSOLD Guidelines, comparisons to G Griffiths et al (2014) should also be made.

The NZSOLD Dam Safety Guidelines (2015) recommend a conservative approach is used for estimating design flood events. At detailed design stage further review of design rainfall depths will be undertaken, including a sensitivity analysis.

Figure 8 provides a summary of the HIRDS rainfall depths for the full range of rainfall durations from 1 to 6 hours.

Figure 8: Design Rainfall Depths



10.6.2 Probable Maximum Precipitation

Although the 10,000-year rainfall event has been selected at the design event, we have undertaken an assessment of the PMP rainfall depths, as a sensitivity analysis using the PMP rainfall depths could be considered as part of the detailed design process.

Thompson and Tomlinson (1993) provides a methodology for estimating PMP depths for rainfall durations from 0.5-hour through to six hours. It uses a baseline point value of 220mm for rainfall durations of one-hour and allowances are subsequently made for catchment area, catchment elevation, moisture potential (values generally reduce from north to south in New Zealand). We determined a one-hour PMP of 203mm, based on a catchment area of 3.21km^2 and without any adjustments for catchment elevation and moisture potential. Using the Thompson and Tomlinson (1993) methodology, the one-hour PMP depth is factored to other durations by selecting an appropriate six-hour to one-hour ratio. We have conservatively selected a ratio of 2.5, noting that the HIRDS information indicates an approximate ratio of 2.1. Table 20 presents the PMP depths used within the assessment, along with the ratios used as recommended by Thompson and Tomlinson (1993).

Table 20: Probable Maximum Precipitation Depths

Duration (hour)	Ratio to 1 Hour Duration	PMP (mm)	New Zealand Record (mm)[1.]	Australian Record (mm)[2.]
1	1.00	203	134	230
2	1.42	288	-	-
3	1.75	355	-	-
4	2.03	412	-	-
5	2.27	461	-	-
6	2.50	508	-	589
12	-	-	566	-

Note:
1. Sourced from NIWA (up until 31 December 2016)
2. Sourced from Australian Government Bureau of Meteorology

The predicted PMP rainfall depths compare favourably with the New Zealand records. We have also included some Australian records for comparison. One of the largest recorded flood events in the Northland Region is the 1981 Kerikeri flood. Approximately 450mm of rainfall occurred in approximately eight hours. We note that this event was not included within the dataset for Thompson and Tomlinson (1993). The determined six-hour PMP rainfall depths compare favourably with this event.

10.7 Temporal Distribution

There are a number of options available for the temporal distribution of the design rainfall depths as outlined below:

1. NRC Priority Rivers Hyetograph.
2. HIRDs Standard Project Storm Hyetograph.
3. Hyetograph from locally recorded rainfall events.

Figure 9 provides a comparison of the derived temporal distributions from the Priority Rivers method and the HIRDs method. We note that Thompson and Tomlinson (1993) does not provide a method for the temporal distribution of the total rainfall depth.

The HIRDS Method has been derived hyetographs shapes for different regions within New Zealand. The area of interest is located in the north of the North Island region. Parameter values are provided for use within a formula's for different durations. The two most relevant durations for this catchment are the one and six-hour durations. The NRC Priority Rivers hyetograph was developed in 2010/2011 and uses a 12-hour duration event as a basis. We understand that a recent draft review for NRC has recommended that the HIRDS hyetograph be used in the short term as a replacement for the Priority Rivers hyetograph.

For the purposes of this assessment we consider that the HIRDS hyetograph is the preferred approach, noting that it has been developed on a regional basis for specific durations in the order of those that will be critical for this catchment (i.e. one to six hours). HIRDS provides different parameters for the one-hour and six-hour events. Figure 9 presents the different distribution for the one-hour and six-hour events. The critical events for the catchment are likely to be somewhere between the one and six-hour event, however we have elected to use the six-hour parameters for all assessed durations, as we consider that the critical duration events are likely to be closer to six hours.

Figure 9: Temporal Distribution Comparisons

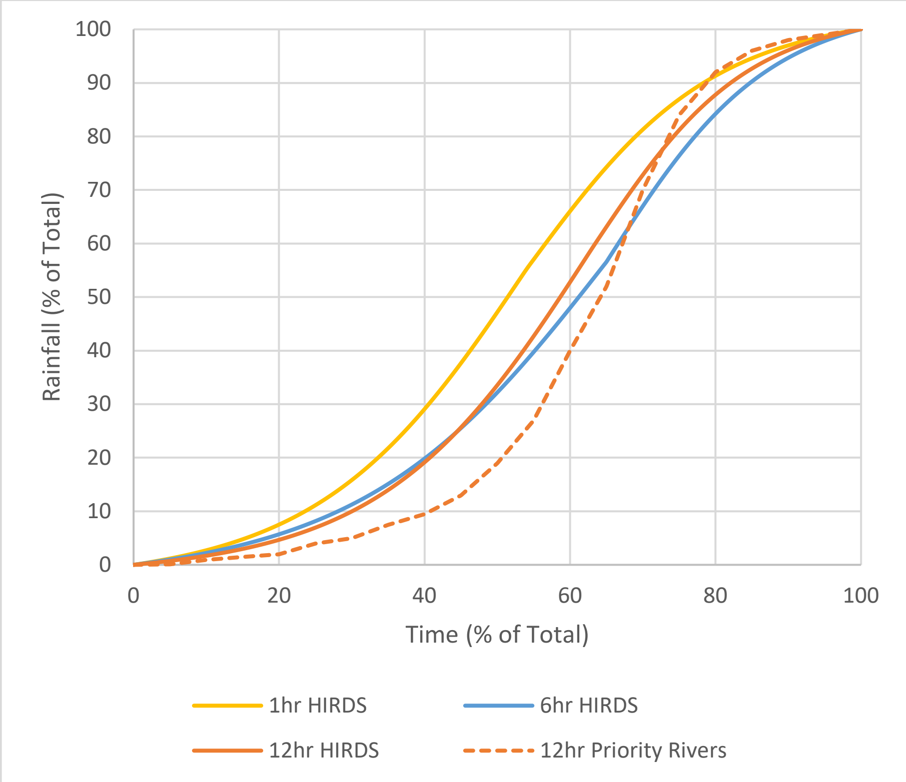
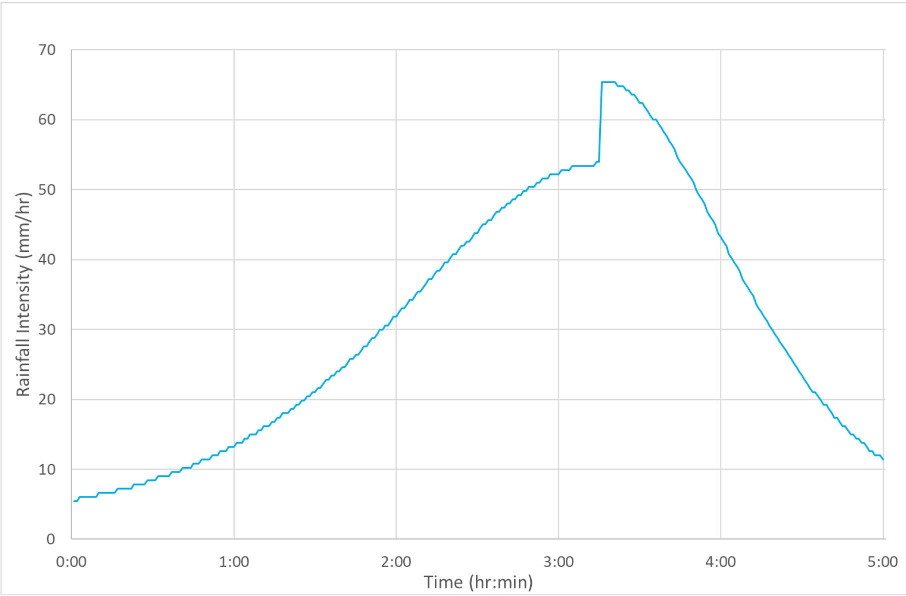


Figure 10 presents the design 10,000-year five-hour rainfall hyetograph.

Figure 10: 10,000 Year Five-Hour Rainfall Hyetograph



10.8 Inflow Design Hydrographs

The HMS rainfall-runoff model has been developed with a single sub-basin utilising the input parameters detailed in the previous sections. The model results are presented within Table 21, with the critical durations highlighted in red.

Table 21: Rainfall-Runoff Model Peak Inflow Results

Rainfall Event	Duration (hr)							
	4	5	6	7	8	24	48	72
2.33-Year	1.3	1.5	1.5	1.5	1.5	-	-	-
100-Year	6.3	6.4	6.5	6.4	-	-	-	-
10,000-Year	15.4	15.7	15.5	-	-	11.4	10.5	8.4

10.9 Regional Methods

McKercher and Pearson (1989) did not include any flow gauges on the Pouto Peninsula within the assessment. Table 22 presents relevant McKerchar and Person Regional Method values.

Table 22: McKerchar and Person Regional Method

Value	Dam Site
$Q_{2.33}/A^{0.8}$	1.0
$Q_{2.33}$ (m^3/s)	2.5
q_{100}	2.2
Q_{100}	5.5

A revised regional method is the New Zealand River Flood Statistics GIS portal. The information indicates that the mean annual flood slightly downstream of the proposed dam site (4.13km^2 catchment) is 1.7m^3/s with a 100-year flow of 3.3m^3/s (a Q_{100}:$Q_{2.33}$ ratio of 2.0).

10.10 Observed Flood Events

We have not reviewed observed flood events specifically at the site as it is outside the scope of the assessment.

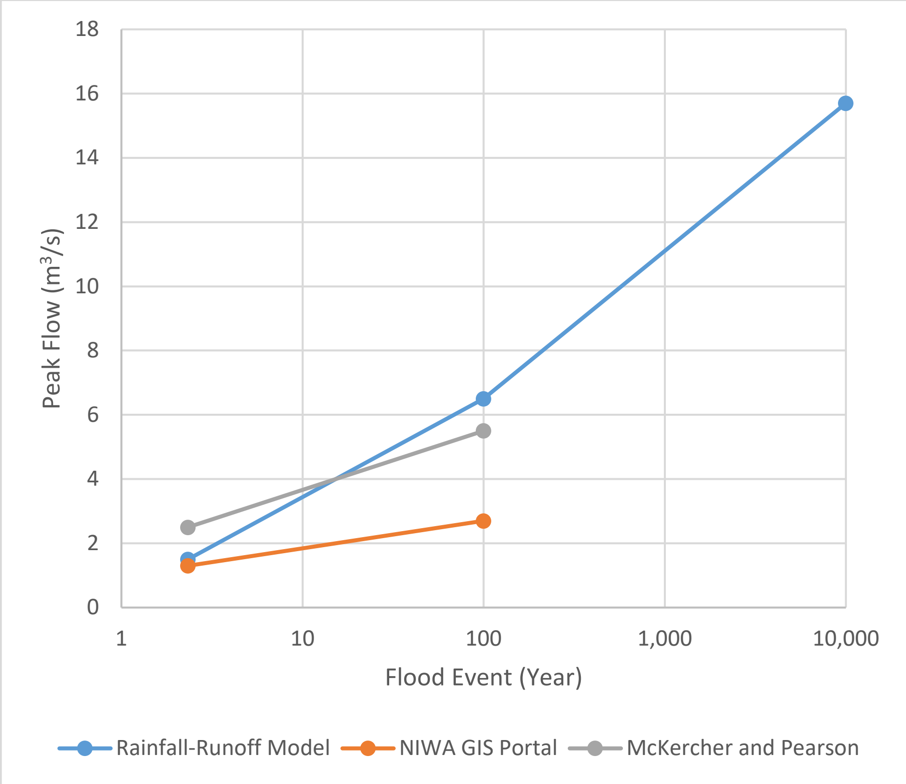
10.11 Summary

Table 23 presents a summary of the peak inflows derived using the various methods. Figure 11 also presents the results (with a log scale).

Table 23: Peak Flow Results (m^3/s)

Method	2.33-Year	100-Year	10,000-Year	Q_{100}:$Q_{2.33}$ Ratio
Rainfall-Runoff Model	1.5	6.5	15.7	4.3
Regional Method NIWA GIS Portal (factored to catchment area of 3.21 km2)	1.3	2.7	-	2.0
Regional Method McKercher and Pearson (1989)	2.5	5.5	-	2.2

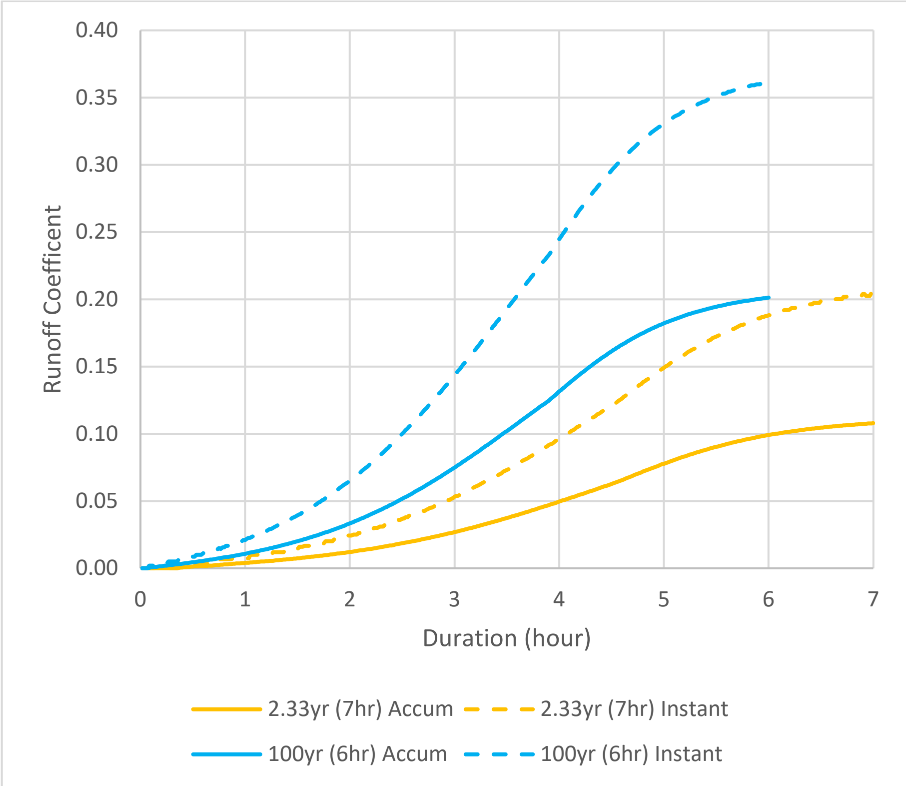
Figure 11: Peak Flow Results



The relatively low mean annual flood flows are reflected in the size of the creek channel at the dam site.

We note that the Q_{100}:$Q_{2.33}$ ratio for the rainfall-runoff model is significantly higher than the regional methods. Figure 12 presents the effective runoff coefficient for the critical mean annual and 100-year rainfall events. The figure demonstrates that the effective runoff coefficient for the 100-year event is almost twice of the mean annual event.

Figure 12: Effective Runoff Coefficient



We anticipate that the ratio is closer to 2.0, however, in the context of this preliminary assessment we consider that the rainfall-runoff model provides conservative results, particularly for extreme flood events.

For the proposes of this assessment, we consider that the rainfall-runoff model provides appropriate inflow design hydrographs.

11.0 Spillway Design

11.1 Methodology

We have used HEC-RAS (v5.07) to simulate the hydraulic performance of the reservoir and spillway.

11.2 Geometry and Spillway Design

Like the dam beach model, the reservoir has been modelled as a 2D flow area. The reservoir 2D flow area is connected to a downstream 2D flow area via a connection.

For the purposes of the preliminary design we have assumed that there is a single overflow spillway. During detailed design, a dual spillway arrangement will be considered, with a primary and an auxiliary spillway. The primary spillway will be designed to have a low risk of erosion during more frequent and smaller magnitude flood events. The spillways will be located entirely within natural ground.

The preferred spillway location is on the right abutment, with the spillway discharging to an adjacent side valley. The preliminary spillway has been designed with a sill elevation of RL 27.0m and a sill length of 20m. The spillway design was incorporated into the 5m DEM described previously.

The downstream 2D flow area extends from the spillway crest to a point approximately 600m downstream of the dam. A refinement region with a grid size of 1m x 1m has been used along the spillway and immediately downstream.

We have conservatively used a Manning's 'n' value of 0.03 to reflect a grassed lined spillway. Future detailed design may consider the use of a concrete chute spillway or a combination of a concrete chute and grassed lined. Erosion protection at the downstream toe of the chute will also need to be considered. We envisage that riprap lining will be adequate.

Photo 3: Proposed spillway will discharge to the head of this valley, near the tree at the centre of the photo.

11.3 Initial Condition

We have used an initial condition of RL 27.0m for the reservoir storage area.

11.4 Upstream Boundary Condition

The results from the HEC-HMS model have been used as inflow hydrographs to the reservoir 2D flow area.

11.5 Downstream Boundary Condition

We have used the normal depth calculation method a with friction slope of 0.002, to correspondence with the general longitudinal gradient of the terrain in the region of the downstream boundary location.

We do not consider the downstream boundary condition is critical to the assessment as the boundary location is sufficiently downstream of the area of interest at the downstream toe of the dam.

11.6 Reservoir Results

The peak reservoir level results are presented in Table 24. The critical duration event (from a peak reservoir level perspective) is significantly longer than the critical event for peak inflows due to the significant storage available within the reservoir.

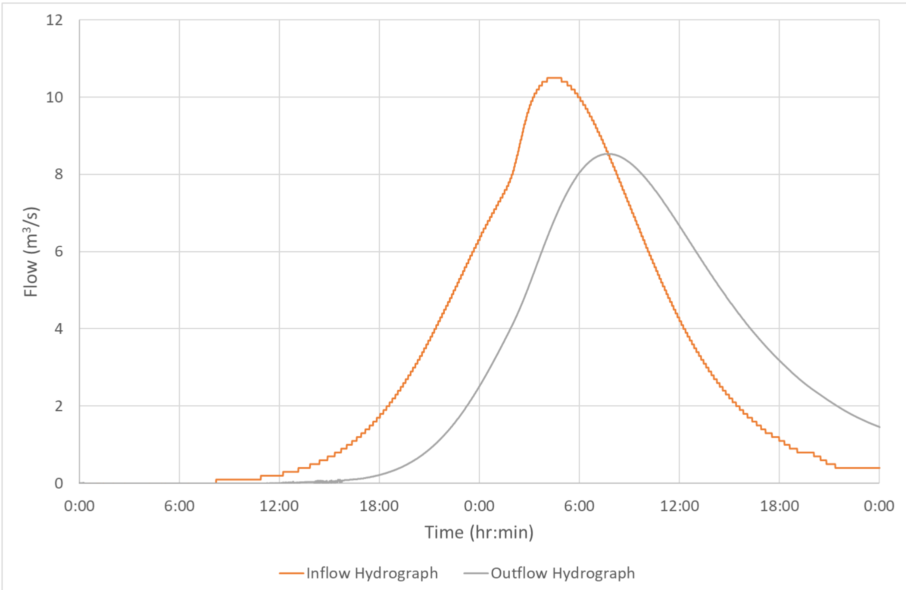
Table 24: Peak Reservoir Level Results (m RL)

Event	24-Hour	48-Hour	72-Hour
10,000-Year	27.43	27.45	27.41

The proposed dam crest level is RL 29.00m. The model results indicate that the dam will have over 900mm freeboard during the design events. We consider that such freeboard is adequate. During future detailed design, the spillway arrangement and dam crest level may be able to be optimised further. Sensitivity analysis should also be undertaken including assessing the available freeboard. We note that settlement of the dam embankment may also influence freeboard considerations.

The reservoir inflow and outflow hydrographs are presented below in Figure 13. The peak inflow of 10.5m^3/s is attenuated by the reservoir to a peak outflow 8.6m^3/s. The attenuation of peak flows by the reservoir reduces downstream flooding and is discussed further in Section 12.0.

Figure 13: 10,000-Year 48-Hour Reservoir Hydrographs



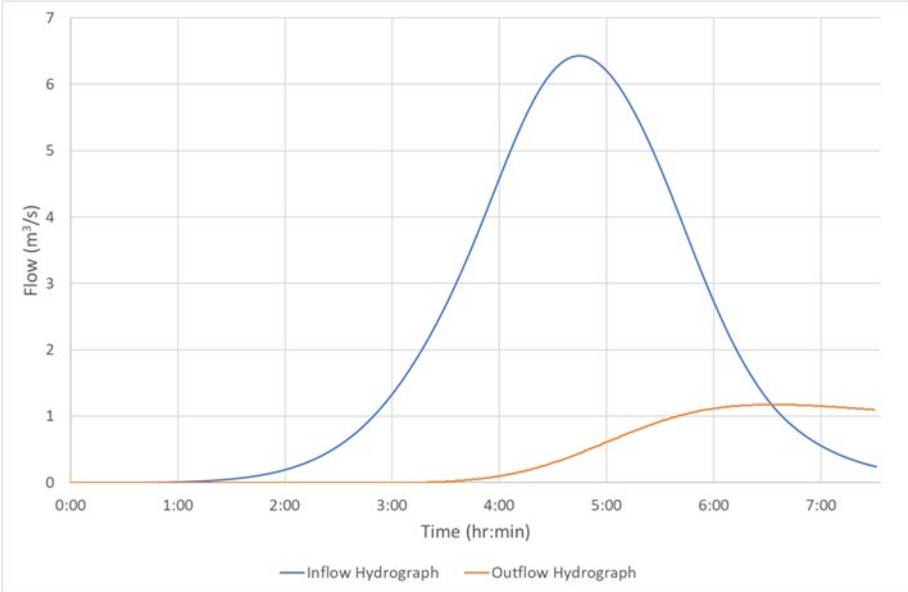
11.7 Velocity Considerations

Preliminary results indicate that velocities within the spillway chute may reach 4m/s depending on the final longitudinal profile, during the 10,000-year flood event. During detailed design erosion protection details will need be considered.

12.0 Flood Attenuation

A secondary objective of the proposed dam design is the capacity to attenuate peak flows discharging from the catchment. The effect of this is a reduction in the flooding experienced by the downstream community. The most relevant events to assess when considering flood attenuation are events in the order of the 100-year event, as larger events are less relevant to communities. The attenuation provided during the critical 5 hour duration 100-year event is presented within Figure 14.

Figure 14: 100 Year Flow Hydrographs



The peak inflow of 6.4m^3/s is attenuated by the reservoir to a peak outflow of 1.2m^3/s. The reduction of peak flow through the spillway is approximately 18% of the inflow which will significantly reduce the downstream flooding. We note that if the reservoir level was below the full supply level prior to the rainfall event, the attenuation provided by the dam would be increased, further reducing downstream flooding.

13.0 Diversion During Construction

The creek needs to be diverted during construction to provide a dry working area during construction and also to prevent the overtopping of a partially formed embankment. We have taken a risk based approach to the diversion design as recommended by the NZSOLD Guidelines i.e. at lower dam heights the likelihood over overtopping is higher, however the downstream consequence an embankment breach is lower. The construction cost risk has not been specifically considered, as it is intended that the Contractor's construction insurance will cover the cost in this event. There is no public safety risk from a breach during foundation works.

The design intent is to construct the diversion culvert offline from the existing creek. When the culvert is completed, the creek will be diverted into the culvert, and the upstream shoulder of the dam will be preferentially constructed ahead of the downstream area, to form a cofferdam.

The NZSOLD Guidelines do not provide specific guidance on acceptable risk, however it does state that "if the incremental consequences of a dam failure during construction include no potential for the loss of life downstream of the dam, a return period of 50 years may be appropriate for the sizing of the diversion works". Given appropriate monitoring and warning systems will be in place, we consider that the potential for loss of life is minimal.

Preliminary calculations indicate that a 1,200mm-diameter culvert will have sufficient capacity to pass the 50-year flood. Further assessments will be required at detailed design stage.

14.0 Intake Details and Fish Passage

The following section includes details of the intakes and approach to fish passage.

Puhoi Stour completed an Assessment of Ecological Effects at the proposed Aratapu Water Storage Reservoir. Key issues that were identified and need to be considered in the design of the dam in regard to fish passage include:

- Migration of eels (elvers) upstream during peak migration periods (summer). Shortfin elver were found at the site. These elvers are <200mm in size (typically 100mm) and are good climbers even with minor flows.
- Excluding upstream passage for Gambusia, an exotic pest which is present at the site.
- Consideration for downstream movement of migrant eels should, however, be included in spillway design to minimise the potential for injuries to occur.
- From the proposed Regional Plan water intakes will need screens with 3mm mesh and velocities into the screen of less than 0.12m/s based on Canterbury Guidelines.

We note that inanga, a native At-Risk and migratory species, were found in the downstream extent of the site. They were not found in the upstream extent of the site and Puhoi Stour have assessed that any modification of access to the headwaters will not affect their lifecycle.

14.1 Upstream Migration of Elvers

The principal challenge with upstream passage is that the reservoir will have a large operating level range across the irrigation season. When the reservoir is full the barrier is 20m high for the elvers to climb to and the range from full to empty is challenging to design for. An elver pass may be feasible with a floating intake to operate in the upper few metres of the range but is not considered feasible for the entire operating level of the dam. When the reservoir water level is below the operating level of the elver pass then a trap and transfer system could be utilised to manage the upstream migration of eel.

Alternatively, a trap and transfer of elver could be undertaken without the construction of an elver pass. This involves a trap installed near the downstream toe of the embankment, within which the elvers enter via a short crawling medium into a holding tank. These are then physically transported and released over the dam. This would be located with a pass a minimal distance above the downstream water level to maximise the reservoir water level range it would operate over. The concept is the flow down the crawling medium attracts the elvers and excludes other unwanted species. If this approach were adopted the source of water could be via the dam and into the trap via the residual flow. The trap and transfer may only operate over peak migration, but adaptive management approach could be used in developing an efficient programme. This option has been used successfully on other large dam projects and therefore provides the greatest chance of success. An example of the elver trap used at Matahina Dam is shown in Figure 15.

Figure 15: Matahina Elver Trap

Another option is a trap pass system with a crawling medium all the way up to the dam crest. The system would enable the elvers to pass without intervention and a schematic is presented in Figure 16. Resting pools would be required at regular intervals up the slope, and a climbing medium would need to span the elver pass to allow elvers to attach. An open channel or frictionless chute such as a plastic pipe would then deliver the elvers to the reservoir and avoid elvers climbing back up. Figure 17 presents some indicative details. A continuous water supply would need to be pumped from the reservoir, albeit this would likely be small.

Figure 16: Schematic of trap pass

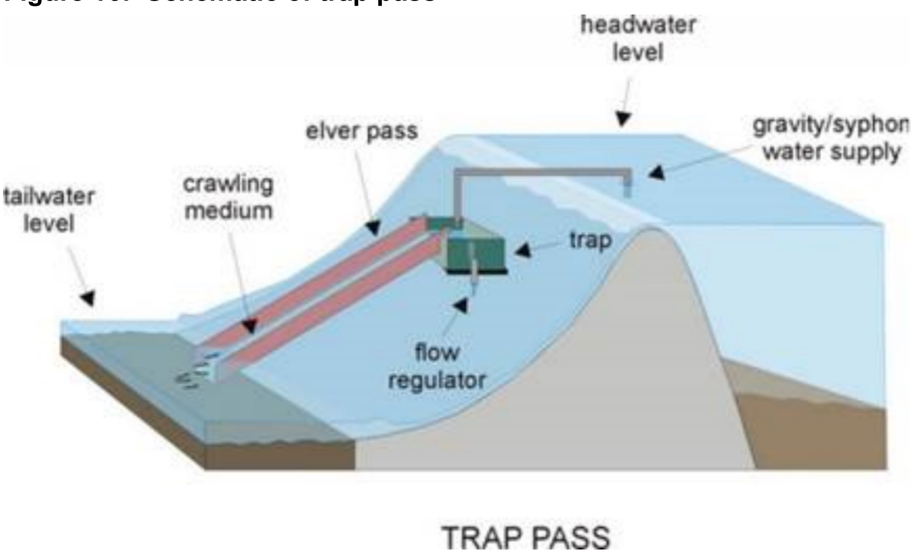
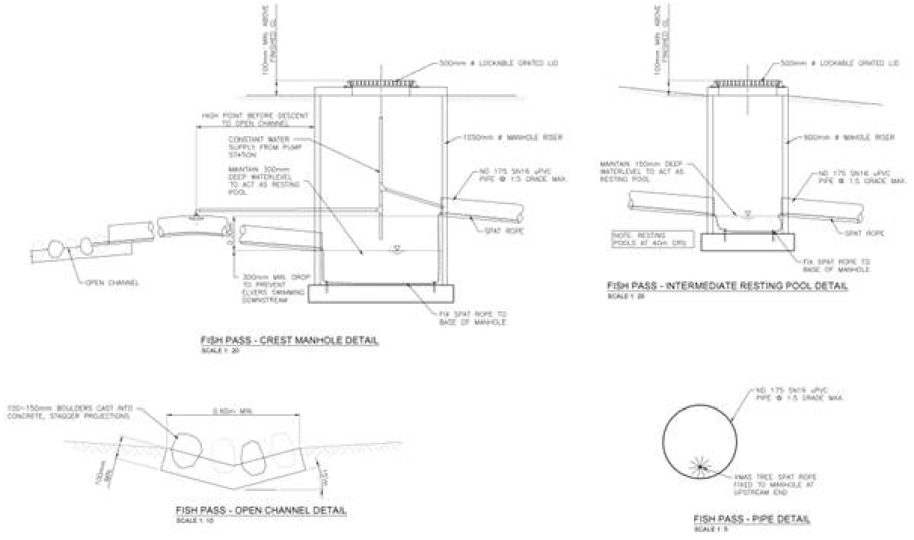


Figure 17: Typical details of trap pass



The nature of both an elver pass and trap and transfer are challenging, and it is likely that some modifications to the pass or the trap and transfer process will be required during operation. Monitoring of the effectiveness will need to be undertaken and where required modifications to resolve any issues implemented

14.2 The Exclusion of Gambusia

This is relatively straight forward as either an elver pass or the trap and transfer of elver can ensure any unwanted species of fish cannot migrate upstream of the dam.

14.3 Spillway Design for Downstream Adult Eel Migration

The shaping of a spillway channel and downstream structures that are part of the spillway will consider what is required to minimise damage to eel. This will relate to depth of flows and any structures with the flow channel downstream and back to the river.

14.4 Intake and Screens

The dam will operate with both a residual flow requirement and an irrigation supply requirement. This will likely involve two separate smaller pipes housed within a larger pipe that also acts as temporary flood diversion during dam construction. Both smaller pipes will require a valve and flow meter to control and measure the flows released. The larger pipe will be provided with a gate to enable emergency dewatering of the reservoir. The intake will need to include a screen to comply with proposed regional plan to keep fish in the stream and also to avoid impingement onto the screen. This includes a requirement of a 3mm mesh screen. Given the small gaps in the screen there is a risk of the screen blocking and therefore, likely that a cleaning system will also be required. If the intake is a single intake located at the invert of the pond, then a rotary or retrievable screen may be used to ensure the screen is kept clean. Specific safety measures will be included that enable the reservoir level to be controlled and maintained in future.

15.0 Summary

The main findings and recommendations contained within this report are summarised as follows:

- A hydraulic model of a sunny day dam breach scenario and a subsequent PIC assessment indicates that the proposed dam has a Medium PIC. A rainy day scenario should be considered at detailed design stage.
- The potential for loss of life as a result of a dam breach is considered to be highly unlikely.
- We consider that the design flood event should be the 10,000-year flood event.
- A preliminary spillway design has been prepared to ensure that adequate freeboard to the dam crest is maintained during the design flood event. Sensitivity analysis should be considered at detailed design stage.
- The spillway arrangement may be optimised further during detailed design. Erosion protection will also be considered further.
- The dam will provide significant flood attenuation for flood events up to and including the 100-year flood event.
- Stream diversion during construction will be managed through the preferential construction of the upstream shoulder of the dam to form a cofferdam.
- Preliminary calculations indicate that a 1200mm dimeter culvert will have sufficient capacity to pass the 50-year flood during construction. Further assessments will be required at detailed design stage.
- Methods to allow for fish passage upstream and downstream of the dam have been outlined. Further assessments to identify the most appropriate method will be required at detailed design stage.

16.0 Limitation

This report has been prepared solely for the benefit of Te Tai Tokerau Water Trust as our client with respect to the brief and Northland Regional Council in processing the consent(s). The reliance by other parties on the information or opinions contained in the report shall, without our prior review and agreement in writing, be at such parties' sole risk.

The hydrological and hydraulic analyses and recommendations contained in this report are based on our understanding and interpretation of the available information. The recommendations are therefore subject to the accuracy and completeness of the information available at the time of the study. Should any further information become available, the analyses and findings of this report should be reviewed accordingly.

APPENDIX A

HEC-RAS Summary

HEC-RAS Model Overview: K-13

Version	5.0.7
Projection	New Zealand Transverse Mercator 2000
Geometry Files	Breach
Terrain	Kaipara 5m DEM
	Spillway v1
Unsteady Flow Files	Sunny Day
	10,000Y 24hr
	10,000Y 48hr
	10,000Y 72hr

Model File Location:
T:\2020 Jobs\200240 Northland WSUP Feasibility Study\4.0 DESIGN-INVEST\4.3 Wat\Dam Break modelling\K-13\HEC-RAS

Modelled by:	GL
Checked by:	VM

Plans	Plan	Unsteady Flow Files	Geometry Files
1	Sunny Day Breach	Sunny Day	Sunny Day Breach
2	10,000Y 24hr Spillway V2	10,000Y 24hr	Spillway V2
3	10,000Y 48hr Spillway V2	10,000Y 48hr	Spillway V2
4	10,000Y 72hr Spillway V2	10,000Y 72hr	Spillway V2

Model Input Details

Geometry Files

Geometry File:	Sunny Day Breach		Spillway V2	
Storage Area/2D Flow Areas:				
Name:	Reservoir K13	DS 2D Area - K13	Reservoir K13	Spillway DS Area
Mannings n:	0.06	0.06	N/A	0.06
Mannings n layer:	N/A		N/A	Yes - on Spillway
Mannings n layer value:	N/A		N/A	0.03
Grid Size:	10m x 10m	10m x 10m	E-V Curve	10m x 10m
Terrain Association:	Kaipara 5m DEM		Spillway v1	

Connections:

Name:	DAM - K13	Spillway Connection
Weir Width (m):	195.68	25.84
Weir Coefficient:	1.43	1.7
Weir Crest Shape:	Broad Crested	Broad Crested
Overflow Computation Method:	Use Weir Equation	Use Weir Equation
Structure Type:	Weir, Gates, Culverts, Outlet RC and Outlet TS	Weir, Gates, Culverts, Outlet RC and Outlet TS
Embankment Station/Elevation Table:	Generated from DEM -Variable Elevation	Generated from DEM -Variable Elevation
Weir Level:	29.00	Clipped from terrain
Dam Breach:	Yes	N/A
Final Bottom Width:	55	-
Final Bottom Elevation:	19	-
Side Slope (V:H):	1:0.7	-
Breach Weir Coefficient:	1.7	-
Breach Formation Time (Minutes):	50	-
Failure Mode:	Piping	-
Piping Coefficient:	0.3	-
Initial Piping Elevation:	40	-
Trigger Failure At:	Set Time	-
Starting Date and Time:	06Apr2120 00:01	-

Unsteady Flow Files

Unsteady Flow Files:	Sunny Day		10,000Y 24hr, 48hr & 72hr	
Storage/2D Flow Areas:	Reservoir K13	DS 2D Area - K13	Reservoir K13	Spillway DS Area
Initial Elevation:	27.00	N/A	27	N/A
Boundary Condition:	N/A	DS BC K-13	US BC	DS BC
Type:	N/A	Stage Hydrograph	Flow Hydrograph	Normal Depth
Enter Table:	N/A	✓	✓	N/A
Use Simulation Time:	N/A	✓	✓	-
Data Time Interval:	N/A	12 hour	1 min	-
EG/Friction Slope:	N/A	N/A	0.001	0.002
Data:	N/A	Constant MHWS	HMS results	Ground Slope
Initial Elevation /Value:		1.49	Respective event	-

Plans

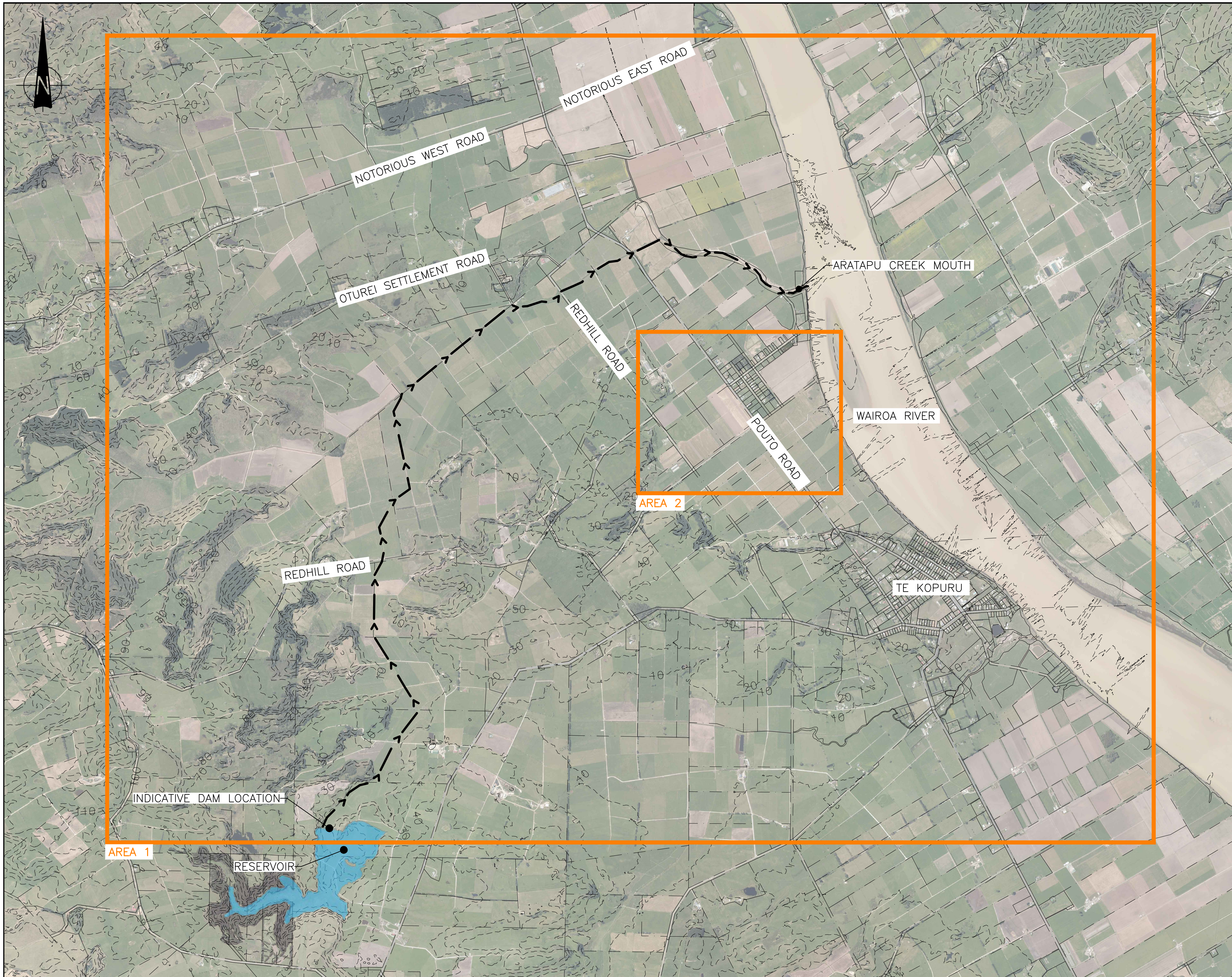
Plan:	Sunny Day Breach	10,000Y 24hr Spillway V2	10,000Y 48hr Spillway V2	10,000Y 72hr Spillway V2
Geometry Preprocessor:	✓	✓	✓	✓
Unsteady Flow Simulation:	✓	✓	✓	✓
Post Processor:	✓	✓	✓	✓
Starting Date:	26/11/2100	26/11/2100	26/11/2100	26/11/2100
Starting Time:	0:00	0:00	0:00	0:00
Ending Date:	26/11/2100	27/11/2100	28/11/2100	29/11/2100
Ending Time:	12:00	0:00	0:00	0:00
Computational Interval:	2 second	Adjust TS based on Courant no.	Adjust TS based on Courant no.	Adjust TS based on Courant no.
Mapping Output Interval:	1 minute	1 minute	1 minute	1 minute
Hydrograph Output Interval:	1 minute	1 minute	1 minute	1 minute
Detailed Output Interval:	1 minute	1 minute	1 minute	1 minute
Equation Set:	Full Momentum	Diffusion Wave	Diffusion Wave	Diffusion Wave

Model Output Details

Plan:	Sunny Day - Piping			10,000Y 48hr Spillway V2		
Layer Name:	WSE	Depth	D * V	WSE	Depth	Velocity
Type:	Water Surface Elevation	Depth	Depth * Velocity	Water Surface Elevation	Depth	Velocity
Unsteady Profile:	Maximum	Maximum	Maximum	Maximum	Maximum	Maximum
Stored (saved to disk):	Raster Based on Terrain	Raster Based on Terrain	Raster Based on Terrain	Raster Based on Terrain	Raster Based on Terrain	Raster Based on Terrain
Item:	Kaipara 5m DEM	Kaipara 5m DEM	Kaipara 5m DEM	Spillway v1	Spillway v1	Spillway v1

APPENDIX B

RILEY Drawings



LEGEND

- PROPERTY BOUNDARY
- INDICATIVE RESERVOIR EXTENT
- INDICATIVE WATERCOURSE ALIGNMENT
- GROUND CONTOURS (10m)

REFERENCE NOTES:

1. AERIAL PHOTO AND PROPERTY BOUNDARIES SOURCED FROM LINZ.

300 0 600 1200m

SCALE 1:30000

FOR CONSENT

REV	DATE	ISSUE	BY
1		FOR CONSENT	GL

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GL	GL	D TATE
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DATE DRAWN: AUG. 2020		ISSUE DATE: 01 / 09 / 20

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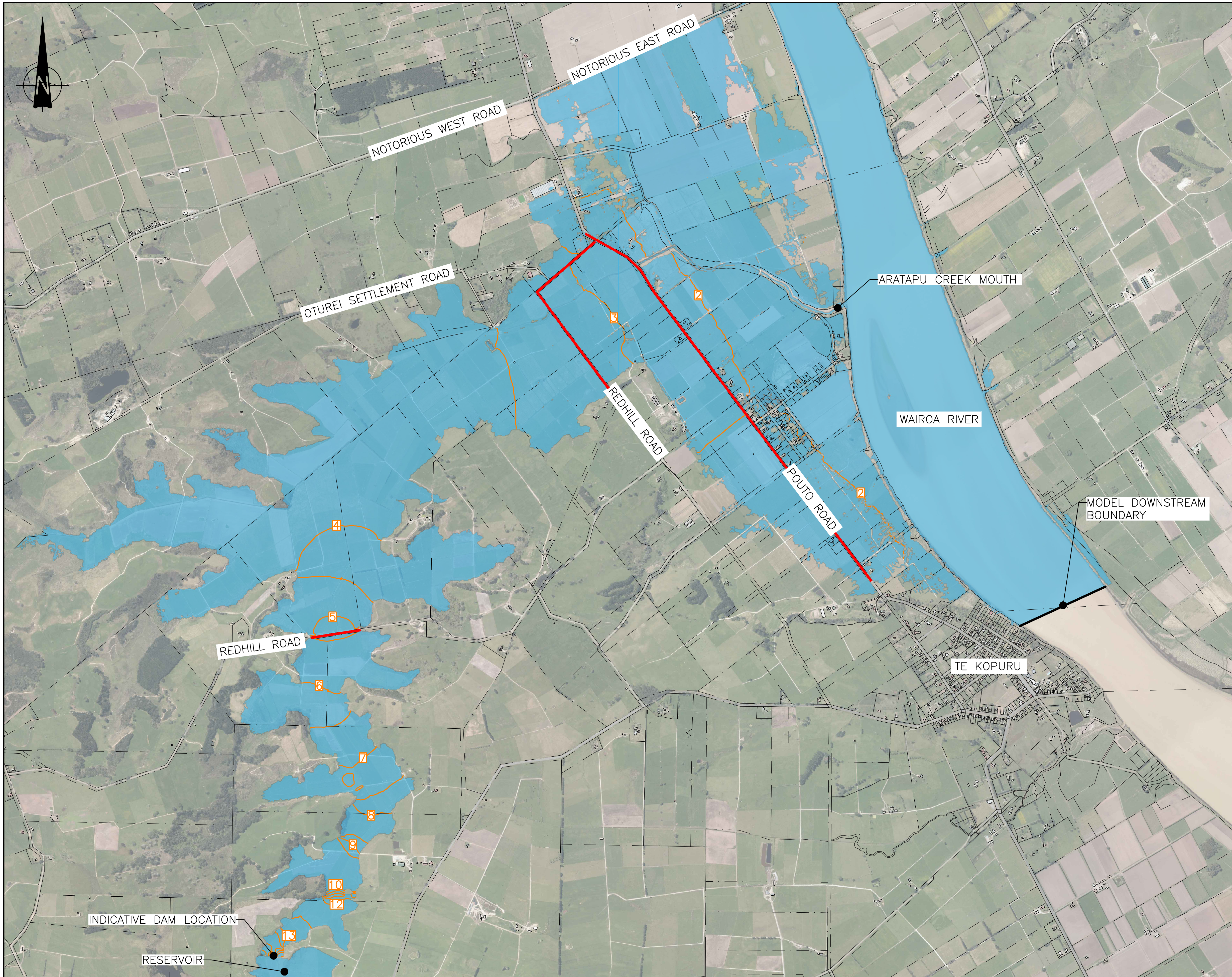
ADDRESS	NORTHLAND
PROJECT	ARATAPU WATER STORAGE RESERVOIR
SHEET TITLE	DOWNSTREAM FLOODPLAIN OVERVIEW

ACENZ

ISO CERTIFIED

CADFILE	200240_2-200.dwg
SCALE (A3): 1:30000	ORIG. SHEET SIZE: A3
DRAWING No.: 200240/2-200	REV.: 1



LEGEND

	INUNDATION EXTENT
2	WATER LEVEL CONTOURS (0.5m)
	PROPERTY BOUNDARY
	BUILDING OUTLINES

REFERENCE NOTES:

1. AERIAL PHOTO, PROPERTY BOUNDARIES AND BUILDING OUTLINES SOURCED FROM LINZ.

250 0 500 1000m

SCALE 1:25000

FOR CONSENT

REV	DATE	ISSUE	BY
1		FOR CONSENT	GL

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GL	GL	D TATE
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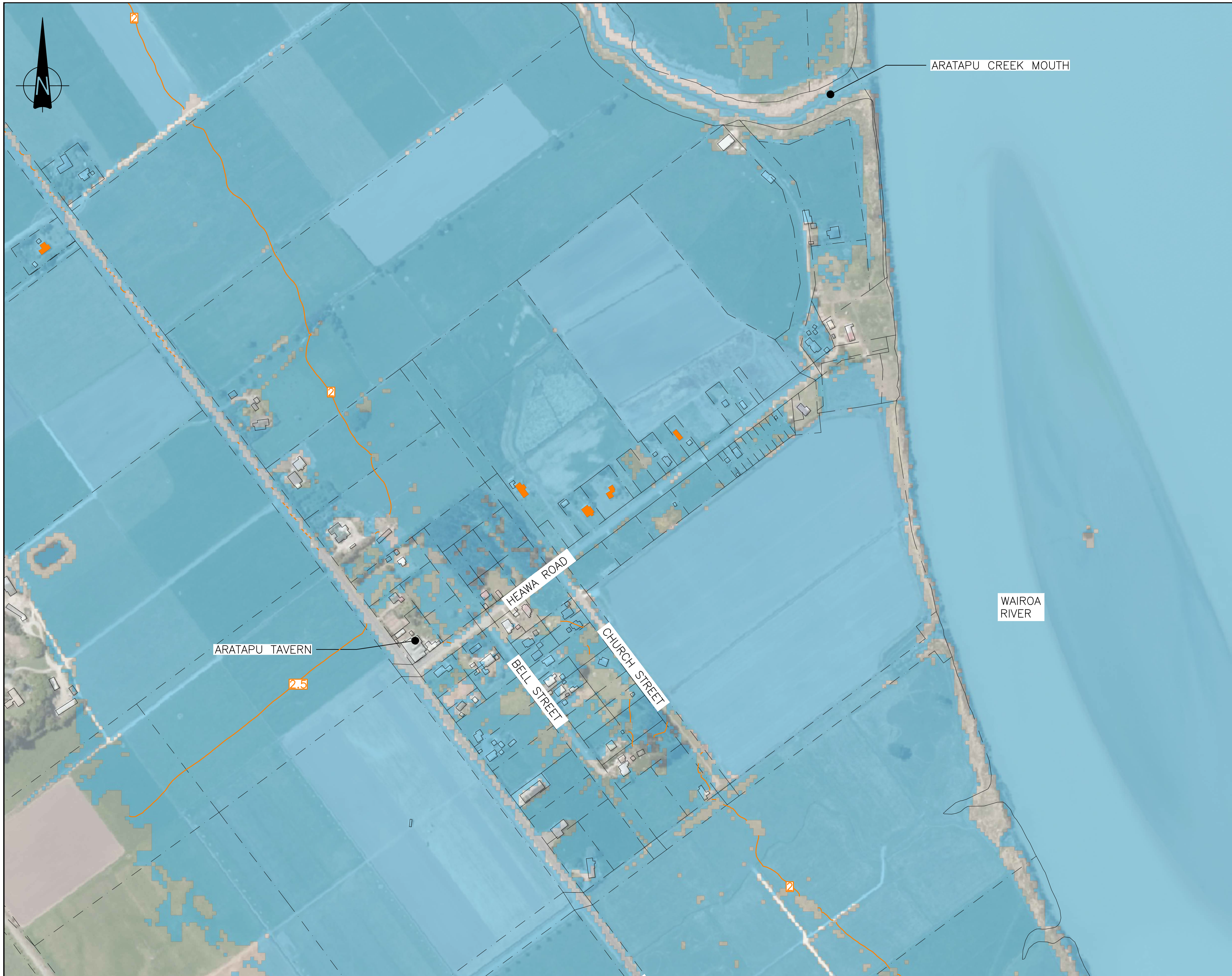
SHEET TITLE	SUNNY DAY BREACH - PEAK LEVELS (AREA 1)

CADFILE	200240_2-201.dwg
SCALE (A3)	1:25000
ORIG. SHEET SIZE	A3
DRAWING No.	200240/2-201
REV.	1



LEGEND

INUNDATION EXTENT
WATER LEVEL CONTOURS (0.5m)
PROPERTY BOUNDARY
BUILDING OUTLINES
RESIDENTIAL HOUSE INUNDATED BY DEPTHS >0.5m

REFERENCE NOTES:

1. AERIAL PHOTO, PROPERTY BOUNDARIES AND BUILDING OUTLINES SOURCED FROM LINZ.

50 0 100 200m
SCALE 1:5000

FOR CONSENT

REV	DATE	ISSUE	BY
1		FOR CONSENT	GL

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DRAWN	CAD CHECK	
GL	JM	
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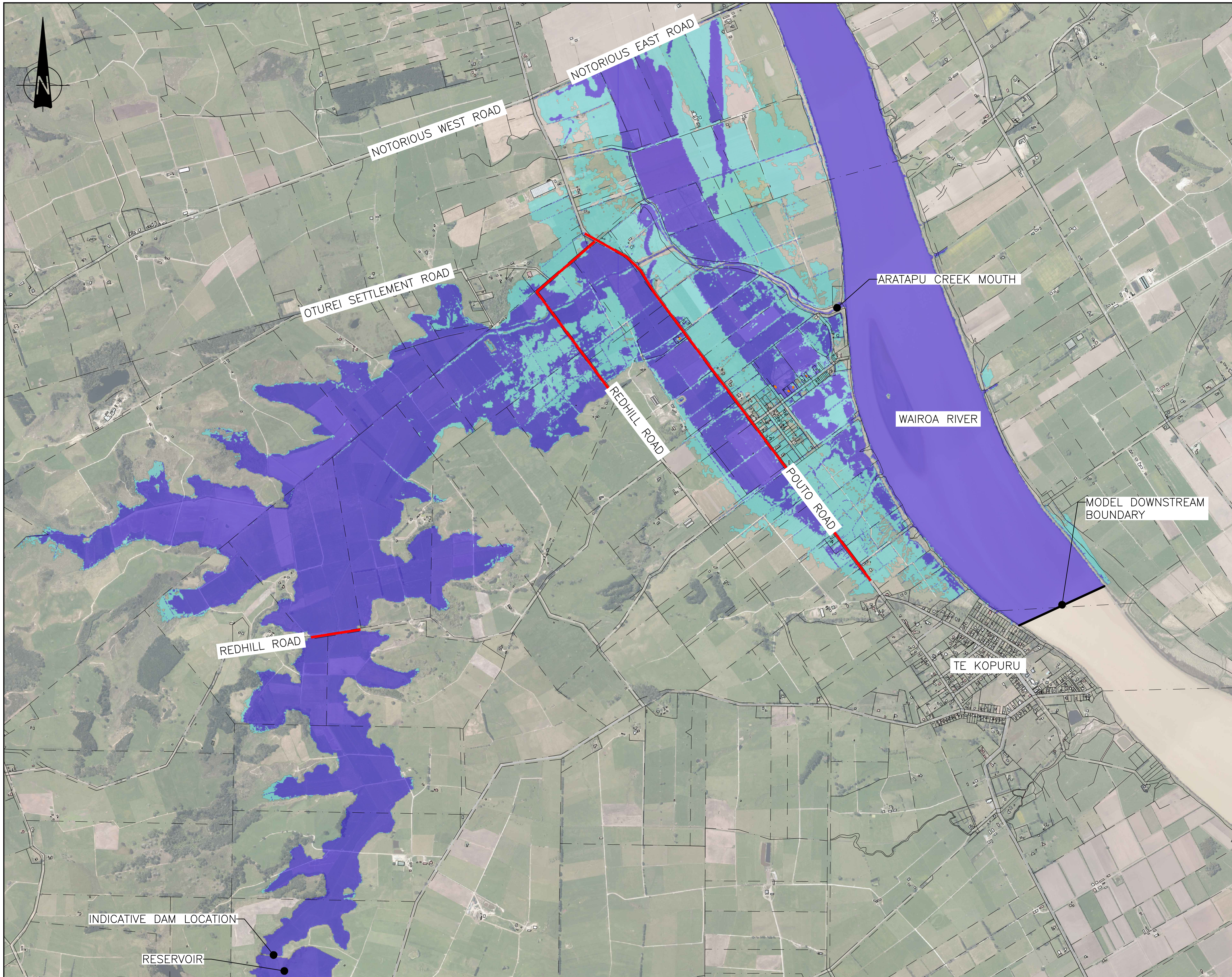
SHEET TITLE	SUNNY DAY BREACH - PEAK LEVELS (AREA 2)

CADFILE	200240_2-202.dwg
SCALE (A3)	1:5000
ORIG. SHEET SIZE	A3
DRAWING No.	200240/2-202
REV.	1



LEGEND

FLOOD DEPTHS
- 0m TO 0.5m
- >0.5m

- PROPERTY BOUNDARY
- BUILDING OUTLINES
- RESIDENTIAL HOUSE INUNDATED BY DEPTHS >0.5m
- SIGNIFICANT ROAD INUNDATED BY DAM BREACH FLOOD

REFERENCE NOTES:
1. AERIAL PHOTO, PROPERTY BOUNDARIES AND BUILDING OUTLINES SOURCED FROM LINZ.

250 0 500 1000m
SCALE 1:25000

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REV	DATE	ISSUE	BY
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SHEET TITLE	SUNNY DAY BREACH - PEAK DEPTHS (AREA 1)

CADFILE	
200240_2-203.dwg	
SCALE (A3)	ORIG. SHEET SIZE
1:25000	A3
DRAWING No.	REV.
200240/2-203	1

LEGEND

FLOOD DEPTHS
- 0m TO 0.5m
- >0.5m
- PROPERTY BOUNDARY
- BUILDING OUTLINES
- RESIDENTIAL HOUSE INUNDATED BY DEPTHS >0.5m

REFERENCE NOTES:
1. AERIAL PHOTO, PROPERTY BOUNDARIES AND BUILDING OUTLINES SOURCED FROM LINZ.

50 0 100 200m
SCALE 1:5000

FOR CONSENT

REV	DATE	ISSUE	BY
1		FOR CONSENT	GL

DESIGN	DES CHECK	APPROVED FOR ISSUE
GL	GL	D TATE
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GL	JM	
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SHEET TITLE	SUNNY DAY BREACH - PEAK DEPTHS (AREA 2)

CADFILE	200240_2-204.dwg
SCALE (A3)	1:5000
ORIG. SHEET SIZE	A3
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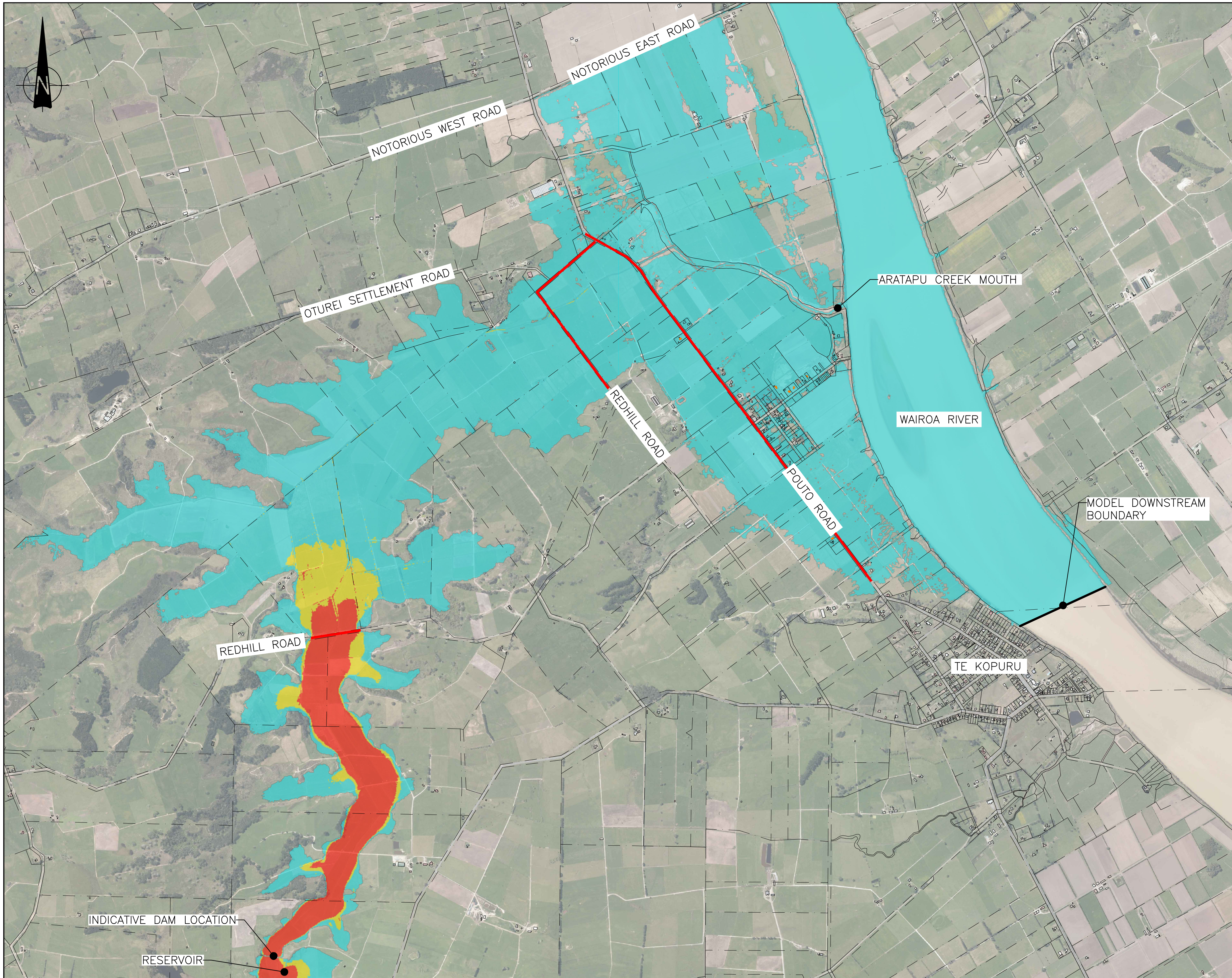
REV.	1



LEGEND

FLOOD DEPTH VELOCITY PRODUCT (DxV)

- $0m^2/s$ TO $1.5m^2/s$
- $1.5m^2/s$ TO $3m^2/s$
- $>3m^2/s$
- PROPERTY BOUNDARY
- BUILDING OUTLINES

REFERENCE NOTES:

1. AERIAL PHOTO, PROPERTY BOUNDARIES AND BUILDING OUTLINES SOURCED FROM LINZ.

250 0 500 1000m

SCALE 1:25000

FOR CONSENT

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REV	DATE	ISSUE	BY

DESIGN	DES CHECK	APPROVED FOR ISSUE
GL	GL	D TATE
DRAWN	CAD CHECK	
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PROJECT	ARATAPU WATER STORAGE RESERVOIR
SHEET TITLE	SUNNY DAY BREACH - PEAK DEPTH VELOCITY PRODUCT (AREA 1)

ACENZ

ISO CERTIFIED GCS

CADFILE	
200240_2–205.dwg	
SCALE (A3)	ORIG. SHEET SIZE
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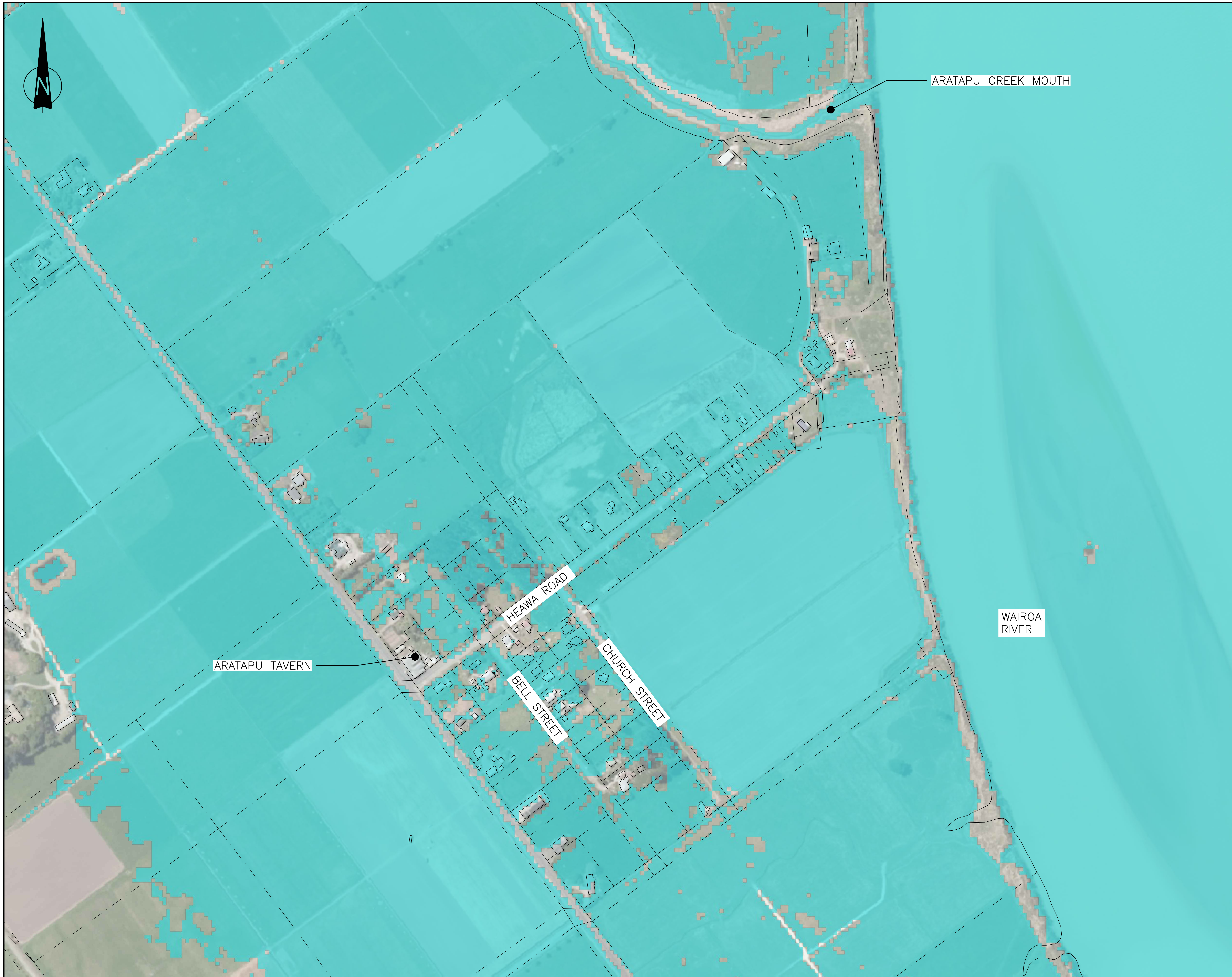
DRAWING No.	REV.
200240/2-205	1



LEGEND

FLOOD DEPTH VELOCITY PRODUCT (DxV)

- $0m^2/s$ TO $1.5m^2/s$
- $1.5m^2/s$ TO $3m^2/s$
- $>3m^2/s$
- PROPERTY BOUNDARY
- BUILDING OUTLINES

REFERENCE NOTES:

1. AERIAL PHOTO, PROPERTY BOUNDARIES AND BUILDING OUTLINES SOURCED FROM LINZ.

50 0 100 200m

SCALE 1:5000

FOR CONSENT

REV	DATE	ISSUE	BY
1		FOR CONSENT	GL

DESIGN	DES CHECK	APPROVED FOR ISSUE
GL	GL	D TATE
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GL	JM	
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ADDRESS: NORTHLAND

PROJECT: ARATAPU WATER STORAGE RESERVOIR

SHEET TITLE: SUNNY DAY BREACH - PEAK DEPTH VELOCITY PRODUCT (AREA 2)

ACENZ

ISO GCS

CADFILE	
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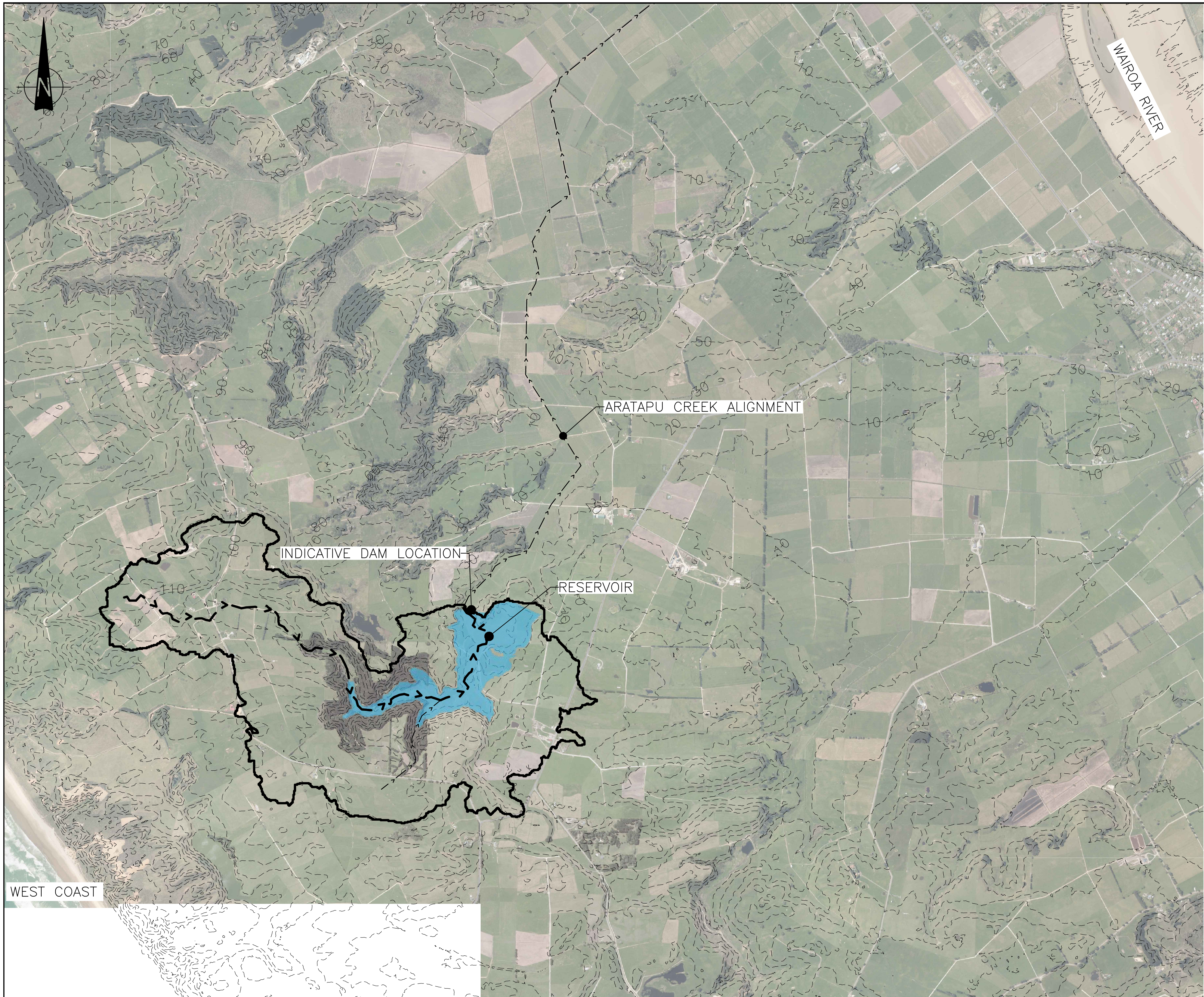
DRAWING No.	REV.
200240/2-206	1



LEGEND

- CATCHMENT BOUNDARY
- LONGEST FLOW PATH
- INDICATIVE WATERCOURSE
- 10m CONTOURS
- INDICATIVE RESERVOIR EXTENT

REFERENCE NOTES:

1. AERIAL PHOTO SOURCED FROM LINZ.
2. CONTOURS EXTRACTED FROM 2017 LIDAR

250 0 500 1000m

SCALE 1:25000

FOR CONSENT

REV	DATE	ISSUE	BY
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DESIGN	DES CHECK	APPROVED FOR ISSUE
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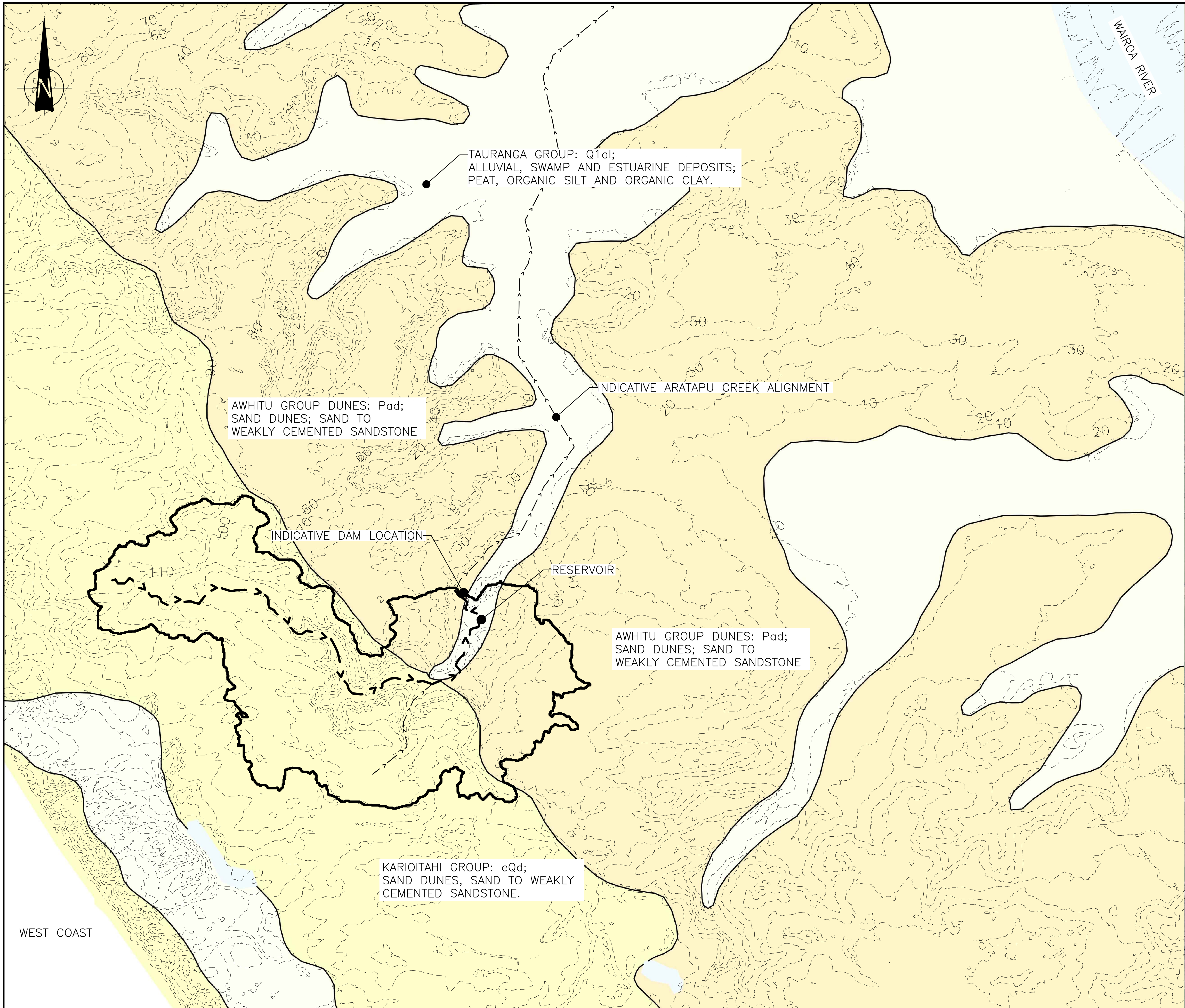
PROJECT	ARATAPU WATER STORAGE RESERVOIR
SHEET TITLE	CATCHMENT PLAN - AERIAL BACKGROUND

ACENZ

ISO CERTIFIED GCS

CADFILE	200240_2-210.dwg
SCALE (A3)	1:25000
ORIG. SHEET SIZE	A3
DRAWING No.	200240/2-210
REV.	1



LEGEND

- CATCHMENT BOUNDARY
- LONGEST FLOW PATH
- INDICATIVE WATERCOURSE
- 20 — 10m CONTOURS

REFERENCE NOTES:

1. GEOLOGY MAP SOURCED FROM GNS SCIENCE (2013)
2. CONTOURS EXTRACTED FROM 2017 LIDAR

250 0 500 1000m

SCALE 1:25000

FOR CONSENT

REV	DATE	ISSUE	BY
1		FOR CONSENT	GL

DESIGN	DES CHECK	APPROVED FOR ISSUE
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ADDRESS	NORTHLAND
PROJECT	ARATAPU WATER STORAGE RESERVOIR
SHEET TITLE	CATCHMENT PLAN - GEOLOGY BACKGROUND

ACENZ

CADFILE	200240_2-211.dwg
SCALE (A3)	1:25000
ORIG. SHEET SIZE	A3
DRAWING No.	200240/2-211
REV.	1

LEGEND

- INUNDATION EXTENT
- 27 WATER LEVEL CONTOURS (1m)
- +27.45 WATER LEVEL SPOT HEIGHT
- PROPOSED GROUND LEVEL CONTOURS (1m)
- INDICATIVE EARTHWORKS EXTENT

REFERENCE NOTES:

1. AERIAL PHOTO SOURCED FROM LINZ.
2. GROUND CONTOURS ARE EXTRACTED FROM 2017 LIDAR AND HAVE BEEN MODIFIED WITHIN THE PROPOSED EARTHWORKS EXTENT.

20 0 40 80m

SCALE 1:2000

FOR CONSENT

REV	DATE	ISSUE	BY
1		FOR CONSENT	GL

DESIGN	DES CHECK	APPROVED FOR ISSUE
GL	GL	D TATE
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GL	JM	
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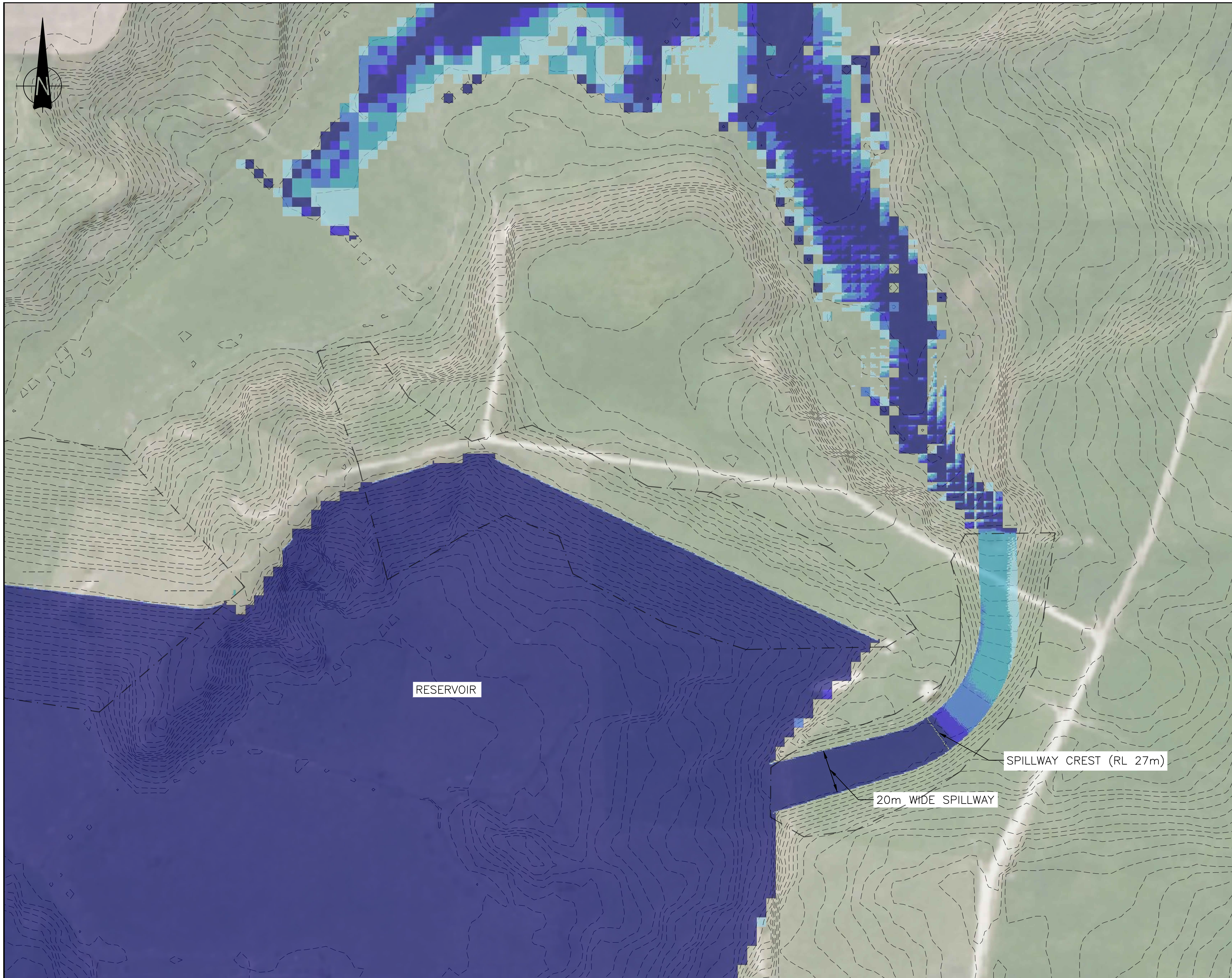
CLIENT	TE TAI TOKERAU WATER TRUST
ADDRESS	NORTHLAND
PROJECT	ARATAPU WATER STORAGE RESERVOIR
SHEET TITLE	10,000 YEAR DESIGN FLOOD - PEAK LEVELS

ACENZ

ISO CERTIFIED GCS

CADFILE	200240_2-220.dwg
SCALE (A3)	1:2000
ORIG. SHEET SIZE	A3
DRAWING No.	200240/2-220
REV.	1



LEGEND

- 0mm TO 100mm
- 100mm TO 150mm
- 150mm TO 200mm
- 200mm TO 250mm
- >250mm
- PROPOSED GROUND LEVEL CONTOURS (1m)
- INDICATIVE EARTHWORKS EXTENT

REFERENCE NOTES:

1. AERIAL PHOTO SOURCED FROM LINZ.
2. GROUND CONTOURS ARE EXTRACTED FROM 2017 LIDAR AND HAVE BEEN MODIFIED WITHIN THE PROPOSED EARTHWORKS EXTENT.

20 0 40 80m

SCALE 1:2000

FOR CONSENT

REV	DATE	ISSUE	BY
1		FOR CONSENT	GL

DESIGN	DES CHECK	APPROVED FOR ISSUE
GL	GL	D TATE
DRAWN	CAD CHECK	
GL	JM	
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CLIENT	TE TAI TOKERAU WATER TRUST
ADDRESS	NORTHLAND
PROJECT	ARATAPU WATER STORAGE RESERVOIR
SHEET TITLE	10,000 YEAR DESIGN FLOOD - PEAK DEPTHS

ACENZ

ISO CERTIFIED QCS

CADFILE	200240_2-221.dwg
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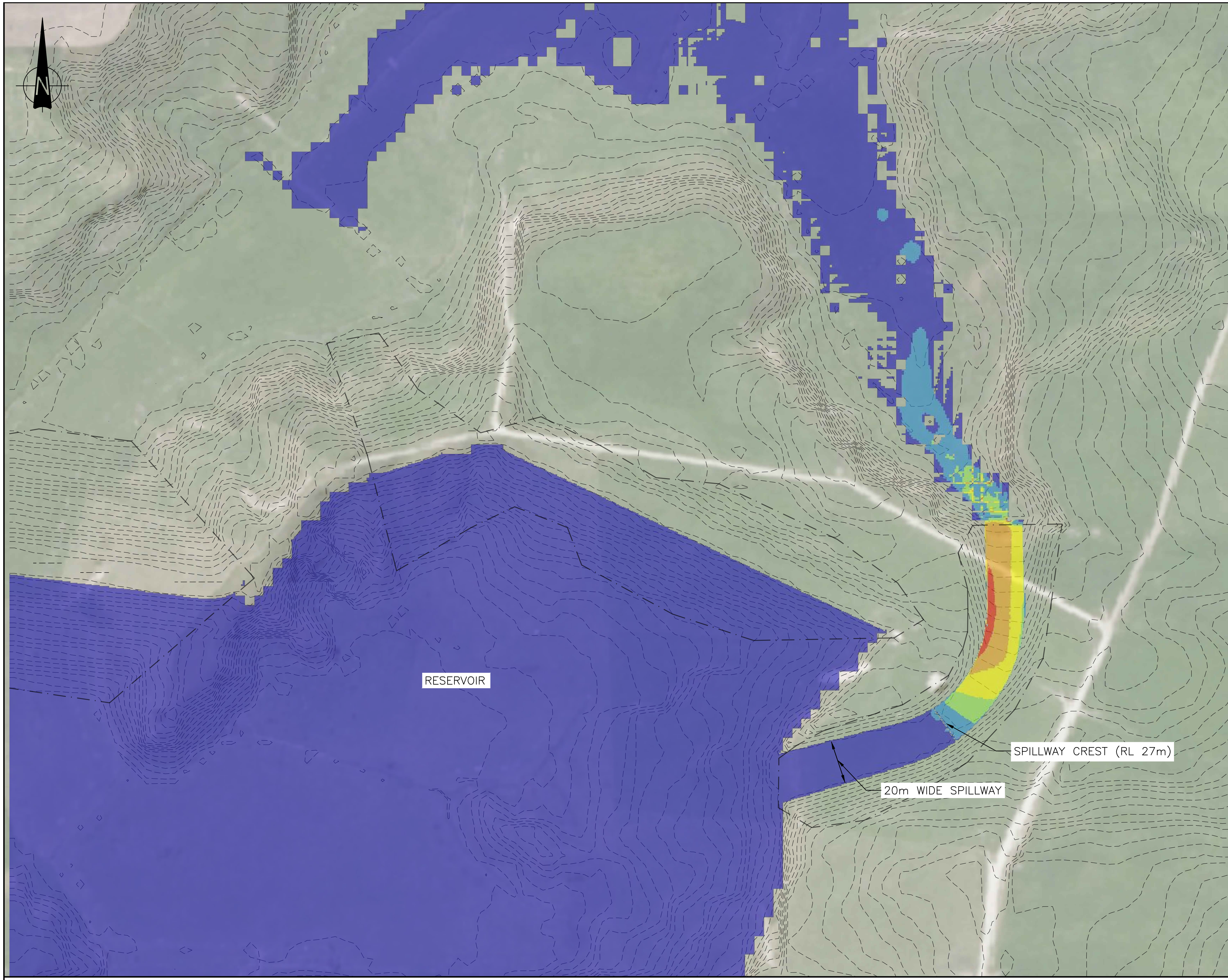
ORIG. SHEET SIZE	A3
DRAWING No.	200240/2-221
REV.	1



LEGEND

- 0m/s TO 1m/s
- 1m/s TO 2m/s
- 2m/s TO 2.5m/s
- 2.5m/s TO 3m/s
- 3m/s TO 3.5m/s
- 3.5m/s TO 4m/s
- PROPOSED GROUND LEVEL CONTOURS (1m)
- INDICATIVE EARTHWORKS EXTENT

REFERENCE NOTES:

1. AERIAL PHOTO SOURCED FROM LINZ.
2. GROUND CONTOURS ARE EXTRACTED FROM 2017 LIDAR AND HAVE BEEN MODIFIED WITHIN THE PROPOSED EARTHWORKS EXTENT.

20 0 40 80m

SCALE 1:2000

FOR CONSENT

REV	DATE	ISSUE	BY
1		FOR CONSENT	GL

DESIGN: GL | DES CHECK: GL | APPROVED FOR ISSUE: D TATE
DRAWN: GL | CAD CHECK: JM
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CLIENT: TE TAI TOKERAU WATER TRUST
ADDRESS: NORTHLAND
PROJECT: ARATAPU WATER STORAGE RESERVOIR
SHEET TITLE: 10,000 YEAR DESIGN FLOOD - PEAK VELOCITIES

ACENZ

ISO CERTIFIED

CADFILE: 200240_2-222.dwg
SCALE (A3): 1:2000 | ORIG. SHEET SIZE: A3
DRAWING No.: 200240/2-222 | REV.: 1