REPORT

Tonkin+Taylor

Flood modelling of the Makirikiri Stream

Model build and results report

Prepared for
Horizons Regional Council

Prepared by
Tonkin & Taylor Ltd

Date
December 2022

Job Number
1019994 v2

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Document control

Title: Flood modelling of the Makirikiri Stream					
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December 2022	2	Final	A White	M Pennington	P Cochrane

Distribution:

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1 Introduction

Tonkin & Taylor Ltd (T+T) was engaged by Horizons Regional Council (HRC) to undertake flood modelling of the Makirikiri Stream and catchment, shown in Figure 1.1. This hazard assessment has been undertaken by developing and making use of hydrological and hydraulic models, which enable identification of likely flood conditions within the catchment.

Figure 1.1: Makirikiri Catchment

2 Available information

The hydraulic and hydrological modelling made use of the following publicly available data:

- Land Information New Zealand (LINZ) data service:-
  - 2015/2016 Aerials.
  - Building outlines.
  - River Centrelines.
  - Whanganui 2015/2016 1 m DEM.
- Land Resource Information System (LRIS) portal:-
  - Soil Types.
  - Land cover data base V5.0 (LCDB) Land Use.

HRC provided the following information which we have used for the model:

- Turakina Mike 11 Model result files (actual model files were not available) and accompanying report, dated May 2010.
- Redmayne drop gate construction drawings, dated 2015.
- Diversion cross section survey, located in the Makirikiri Flood Scheme, dated 2015.

3 Model purpose and limitations

3.1 Model selection

The purpose of the modelling was to provide Horizons Regional Council (Horizons) with a means to achieve a greater understanding of flood hazard in the area of the Makirikiri catchment. The outputs were required to be suitable to inform regional scale flood hazard advice within the Makirikiri catchment.

To achieve the model purpose, the model was used to simulate flood events with Annual Exceedance Probability (AEP) as shown in Table 3.1. The model was simulated for both present day and climate change scenarios. The climate change scenarios (using RCP6.0) were for a 2120 future time horizon.

Table 3.1: Model runs

Output number	AEP	ARI	Climate	Outputs
1	5%	20-Year	2022 (present day)	Depth, velocity, extents
2	2%	50-Year	2022 (present day)	Depth, velocity, extents
3	1%	100-Year	2022 (present day)	Depth, velocity, extents
4	0.5%	200-Year	2022 (present day)	Depth, velocity, extents
5	1%	100-Year	2120 (future, RCP6.0)	Depth, velocity, extents
6	0.5%	200-Year	2120 (future, RCP6.0)	Depth, velocity, extents

The adopted model selection approach is shown in Figure 3.1, and resulted in selection of a "2D+" model as meeting the project needs. This was described in our offer of service to HRC which was accepted.

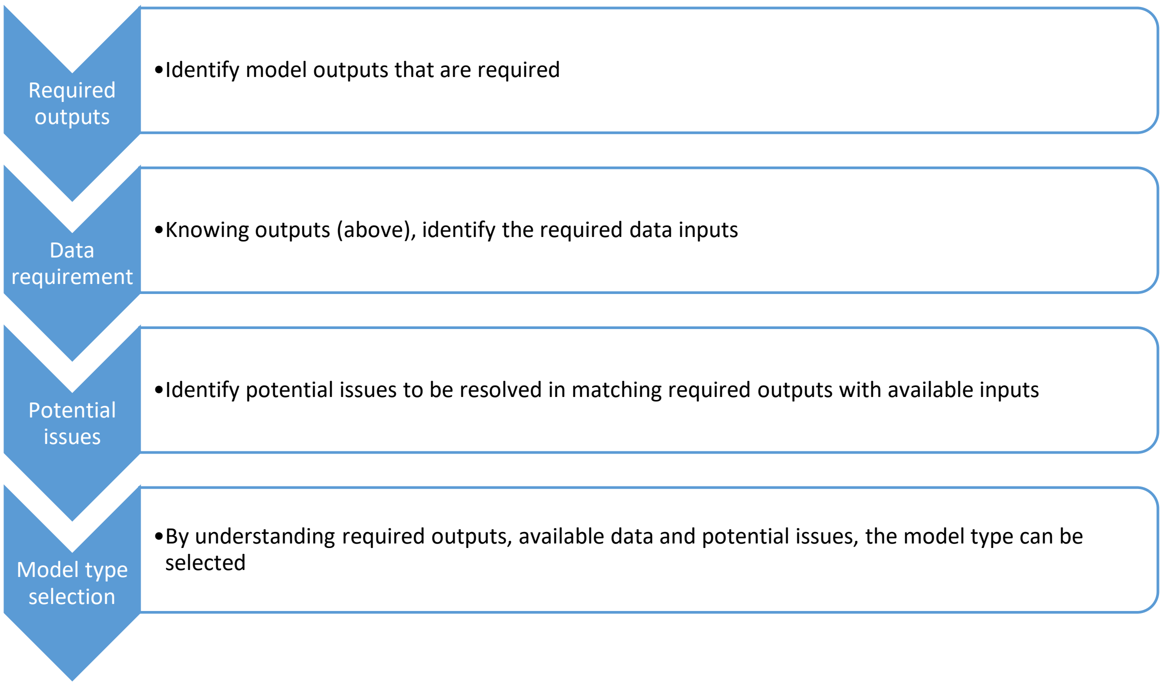


Figure 3.1: Model selection flow chart

The 2D+ approach involves development of a 2D model (only, i.e., no 1D parts) with hydraulic representation of stormwater pipes. In development of the model, it was found that addition of several discrete 1D elements was required to achieve suitable representation. This is described in Section 4.7.

3.2 Model accuracy

Accuracy of model outputs is naturally limited to the quality and availability of data inputs to the model. If flood levels are to be considered for design and consenting purposes, field verification is required. This is particularly the case where a minor degree of flooding (both in depth and in extent) has been predicted on a parcel which, given accuracy limitations in the approach, may or may not be real. The principal reason for this recommendation is that the model has been built of remote-sensed data (LiDAR terrain) which can often miss surface features that are either obstructed at the time of survey or are small relative to the sampling undertaken. The processing of LiDAR data into a DEM often involves smoothing and site-scale features may not be represented in the final model surfaces. An example of such features is small retaining walls which can have a significant impact on surface flooding patterns at local scale, yet are often not picked up in LiDAR surveys. Field verification will confirm the presence or absence of any such structures and will be essential for individual property scale model outputs.

For areas where a high degree of accuracy in design flood level is required, or where there is a significant consequence associated with flood level assessment or where ground levels are known to have changed since the survey capture date, the recommended approach remains a site-specific assessment instead of the catchment scale modelling that has been undertaken as part of this scope of work.

4 Hydraulic model

4.1 Model solver and model domain

The model has been built and run using the latest 2020 TUFLOW Quadtree solver and utilises recently released quadtree nesting[1] and sub-grid-sampling technology[2]. The hydraulic model build has included the following elements:-

- A direct-rainfall hydrological approach with the use of calibrated design rainfall.
- A digital elevation model (DEM) derived from LiDAR sources, applied to TUFLOW as a 1 m x 1 m (1 m^2) grid referenced to the New Zealand Vertical Datum 2016 (NZVD2016). Despite the model cell size being larger (8 m x 8 m), TUFLOW's sub-grid sampling technology samples the underlying topography at a finer resolution.

[1] Quadtree nesting allows variable cell sizes across a 2D domain, allowing higher resolution in areas of interest
[2] Sub grid sampling takes the underlying DEM cell elevations to determine a water surface elevation vs volume relationship for each grid cell. The result is that the full array of information in the DEM is still being utilised within the 2D hydraulic modelling improving the representation of the underlying topography and accuracy of simulated results.

Model build details for the TUFLOW model are summarised in Table 4.1.

Table 4.1: Model Build Summary

Model Element	**Report Section**	**Description**
Model Software	-	2020-10-AB TUFLOW HPC Solver
Time Step	-	The TUFLOW HPC model applies an adaptive time step, based on maintenance of a Courant condition.
Datums	-	Horizontal: New Zealand Transverse Mercator (NZTM) Vertical: New Zealand Vertical Datum 2016 (NZVD2016)
Model Extent	Section 4.2	The model has a total area of about 85 km^2. The model area was determined by delineating the Makirikiri and Kahuraponga Catchments.
Model Topography	Section 4.3	There are two sources of model topography:- A 1 m x 1 m (1 m^2) DEM dated 2015 A 20 m x 20 m (20 m^2) DEM, provided by HRC as part of the Turakina Mike model.
Model Cell Size	Section 4.4	A grid size of 8 m x 8 m was chosen for the final outputs, following cell size convergence testing, Quadtree nesting was included around the major streams and Turakina township, at a 2 m x 2 m resolution.
Hydrology	Sections 5-7	Rainfall inputs were developed based on published data.
Model boundaries	Section 4.6	The downstream boundary is applied as a tailwater boundary, sourced from the Turakina model.
Land use and soil infiltration	Section 4.5.1	Infiltration parameters were derived using the calibrated hydrological model and applied as an initial and constant loss. Initial loss: 5 mm Constant Loss: 1 mm/h
Hydraulic structures	Section 4.7	No hydraulic element information was able to be sourced from the local council, except for survey information for the Redmayne drop structure, which was not included in the model.

4.2 Model domain

The model domain, as shown in Figure 4.1, consists of the Makirikiri and Kahuraponga stream catchments, and a section of the Turakina River. Historical observations showed that there is some hydraulic interaction between the Turakina River and Kahuraponga Stream with the Makirikiri Stream, thus they have been included in the model. These catchments were delineated using the 2015 DEM.

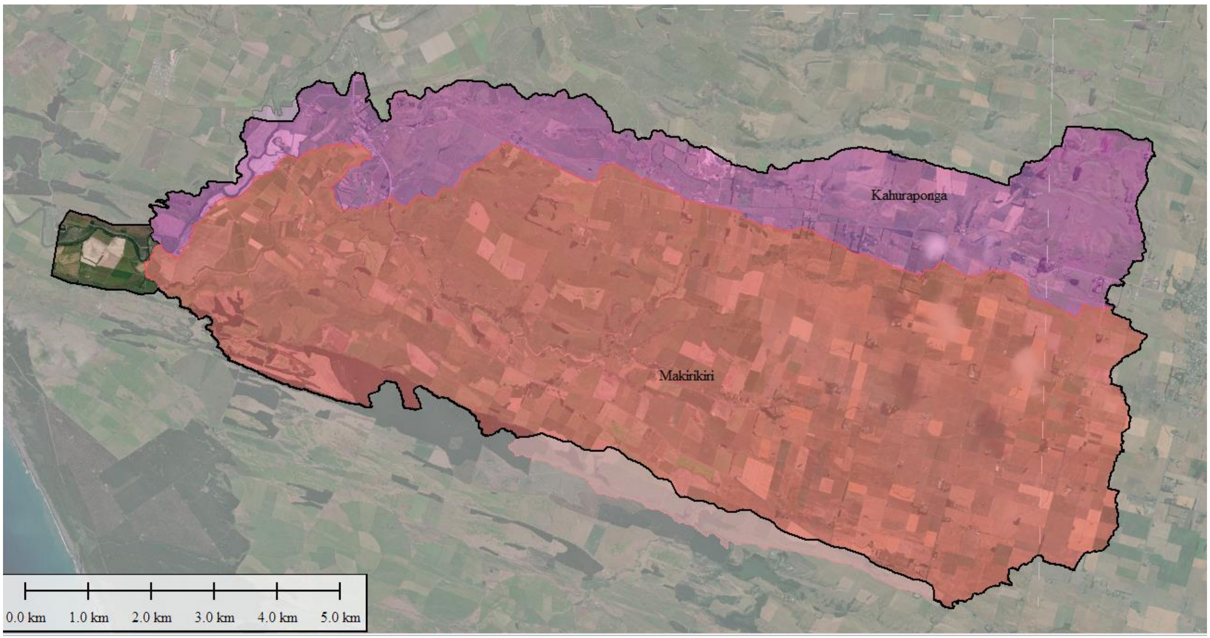


Figure 4.1: Model extent showing the Makirikiri catchment in red, and the Kahuraponga catchment in purple

4.3 Elevation data

There were two sources of elevation data for the model:

- Manawatu – Whanganui LiDAR 1 m DEM, 2015-2016 (2015 1 m DEM).
- Turakina 20 m DEM, used in the Turakina River Model built by Hydro Tasmania Consulting in 2010. This DEM was supplied to us as a .dfs2 file as part of the Turakina model results, and was manually reprojected and rotated for use in our model.

The 2015 1 m DEM covered the majority of the model extent. Where there was a gap in the DEM, a small section of the Turakina DEM was incorporated into the model, as shown in Figure 4.1.

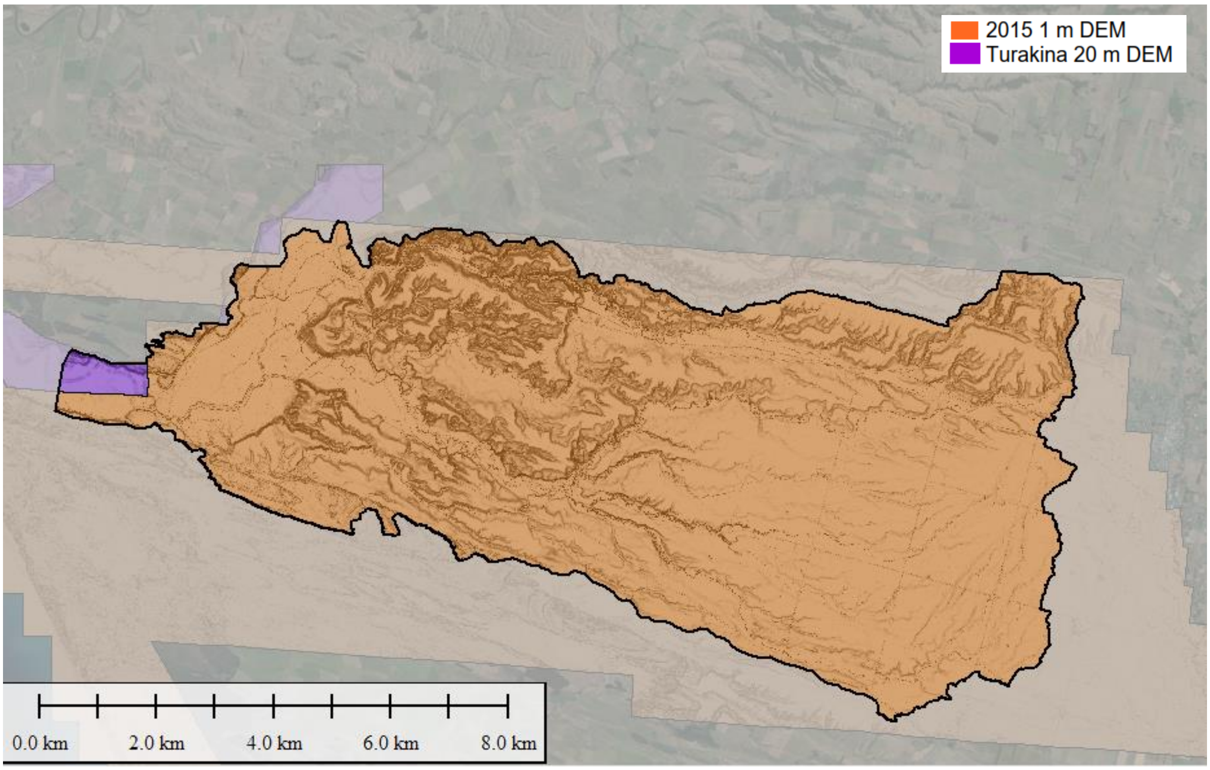


Figure 4.2: Elevation data

4.3.1 DEM continuity

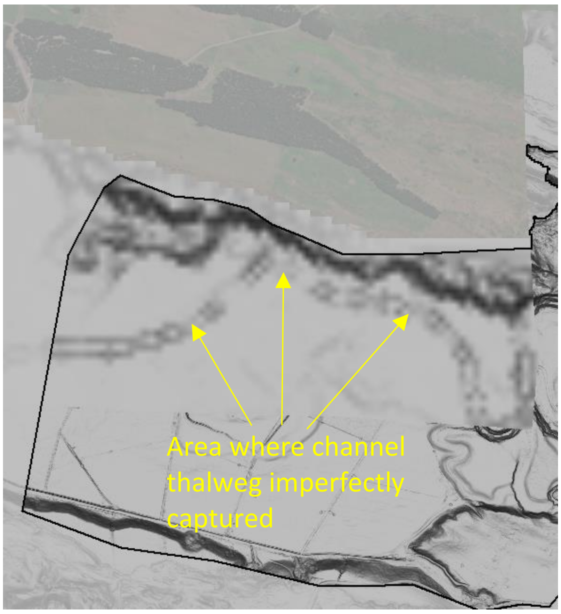
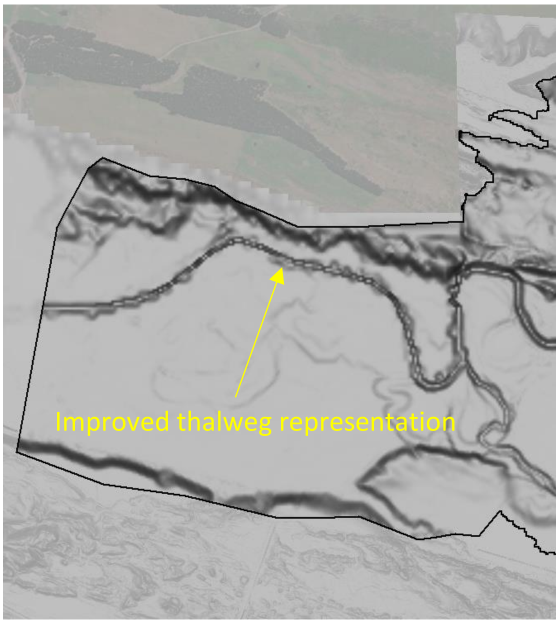
As the two elevation data sources had different grid sizes and were derived in different years, checks were done to confirm acceptable continuity between the 2015 1m DEM and the 20 m DEM. Specific checks were done to determine the following;

- There were no extreme changes in elevation at the boundary of the two DEMs.
- The Turakina River was adequately represented in the 20 m DEM.

It was found that generally, the continuity between the 2015 1 m and Turakina 20m DEMs was acceptable around all areas except for the channels. The thalweg of the Turakina River in the 20m DEM was, on average, around 1 m higher than the 2015 DEM. This is expected as a 1 m resolution is much more likely to pick up low points within the channel.

Because of this, the 20 m DEM was artificially lowered in the model to match the level of the 2015 DEM upstream and downstream of the 20 m extent. That is, thalweg level at the upstream end was linearly interpolated to the thalweg level at the downstream end with corresponding deepening of the 20 m DEM being applied. This is shown in the cmparative plots in Table 4.2.

Table 4.2: Turakina River DEM Modifications

Downstream of Turakina without DEM modifications	Downstream of Turakina with DEM modifications
	

4.3.2 LiDAR data

The 2015 DEM shown above was derived from LiDAR survey data flown in 2015. The source LiDAR data was made available to verify data quality and to ensure no hydrological features were falsely removed from the model.

LiDAR data in the area of interest as shown in Figure 4.3 was analysed, paying particular attention to the representation of the Makirikiri Stream. Particular attention was paid to the stopbanks in the Makirikiri Flood Scheme, to determine that crest level was appropriately picked up, and that the stopbanks are adequately represented by the DEM. This area was checked to determine that all buildings and above ground features were correctly removed in post-processing of the raw LiDAR data, and there were no data gaps that would compromise the quality of the data. In general:

- There are no obvious gaps in the data where they should not be. There are no obvious errors in the data and there are plenty of data points.
- Above ground features are correctly picked up by the LiDAR and the points have been correctly processed to form the DEM.

Figure 4.3 shows the catchment boundary (in red) together with waterways (in blue). The purple box shows the location of the area specifically investigated with respect to LiDAR DEM accuracy, with detail of these checks being shown in Table 4.3.

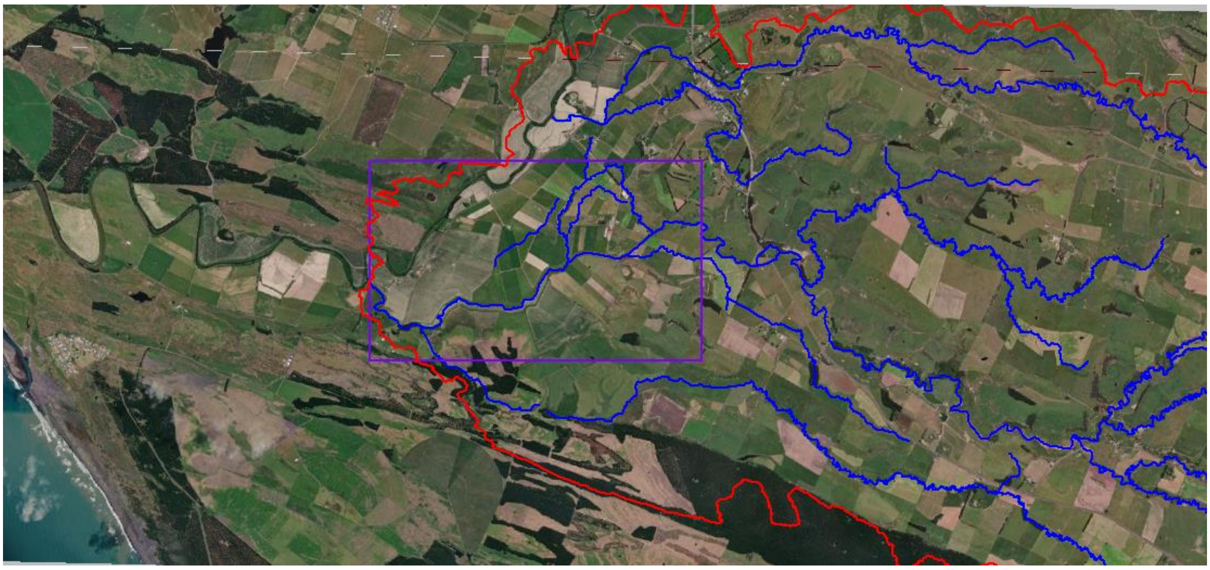
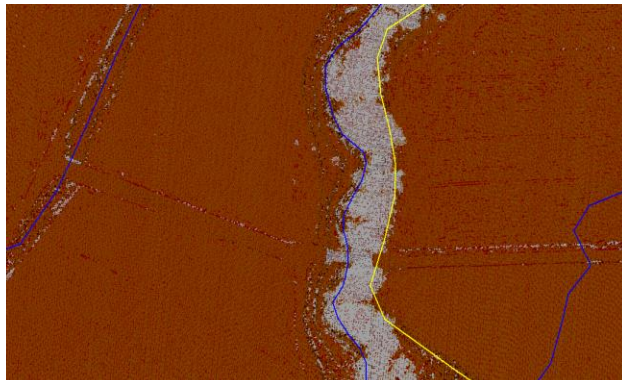
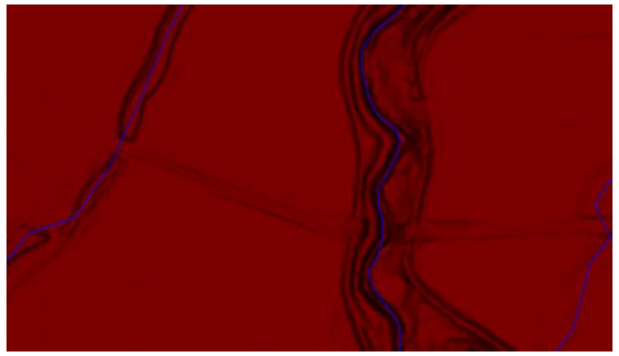
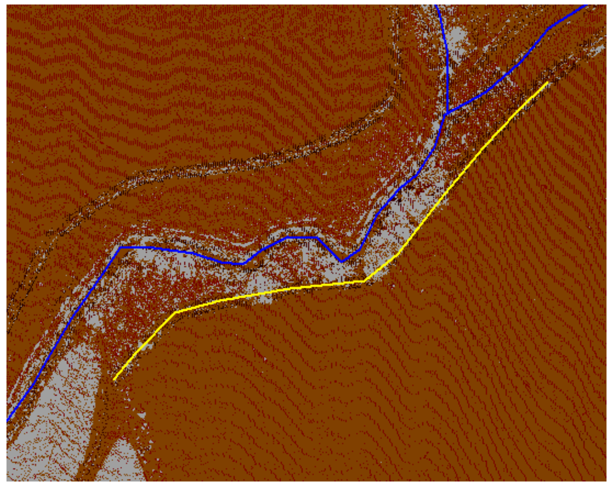
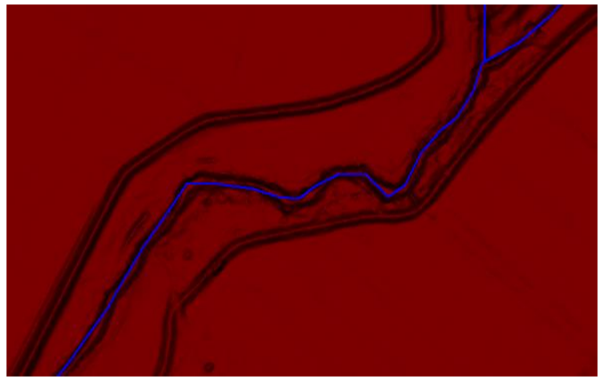
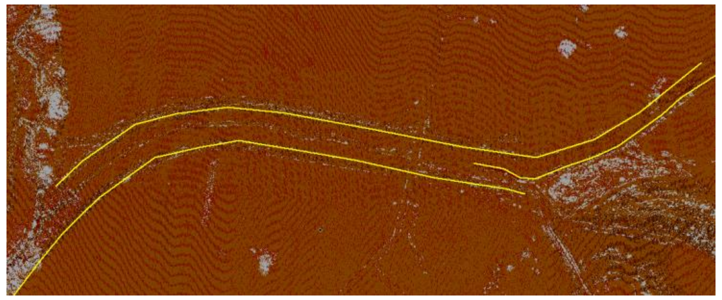
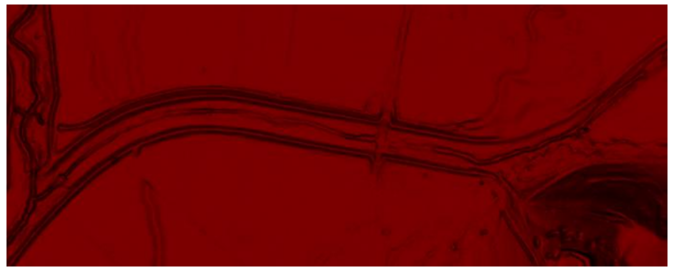


Figure 4.3: LiDAR check locations

Table 4.3: LiDAR checks

Area	LiDAR (stopbank crest in yellow)	DEM	Comments
Area 1: Right Stopbank along the western reach of the Makirikiri Flood Scheme			There is dense tree cover along this stopbank. Despite a lack of ground points, the stopbank is still present in the model.
Area 2: At the confluence of the two tributaries of the Flood Scheme			Despite the dense vegetation cover, there is still adequate ground points picking up the stopbanks, which translates into the DEM
Area 3: Typical Section (covered by 2015 survey)			Plenty of LiDAR points, seems to have picked up the stopbanks well

4.3.3 2015 Survey cross sections

Fifteen cross sections surveyed in 2015 were supplied by HRC as shown in Figure 4.4 below. These were compared to the 2015 DEM, and it was found that:-

- From the survey, it appears that the stopbank crests were represented well by the DEM.
- Majority of the cross sections matched the DEM.

Example cross sections are shown Figure 4.5.

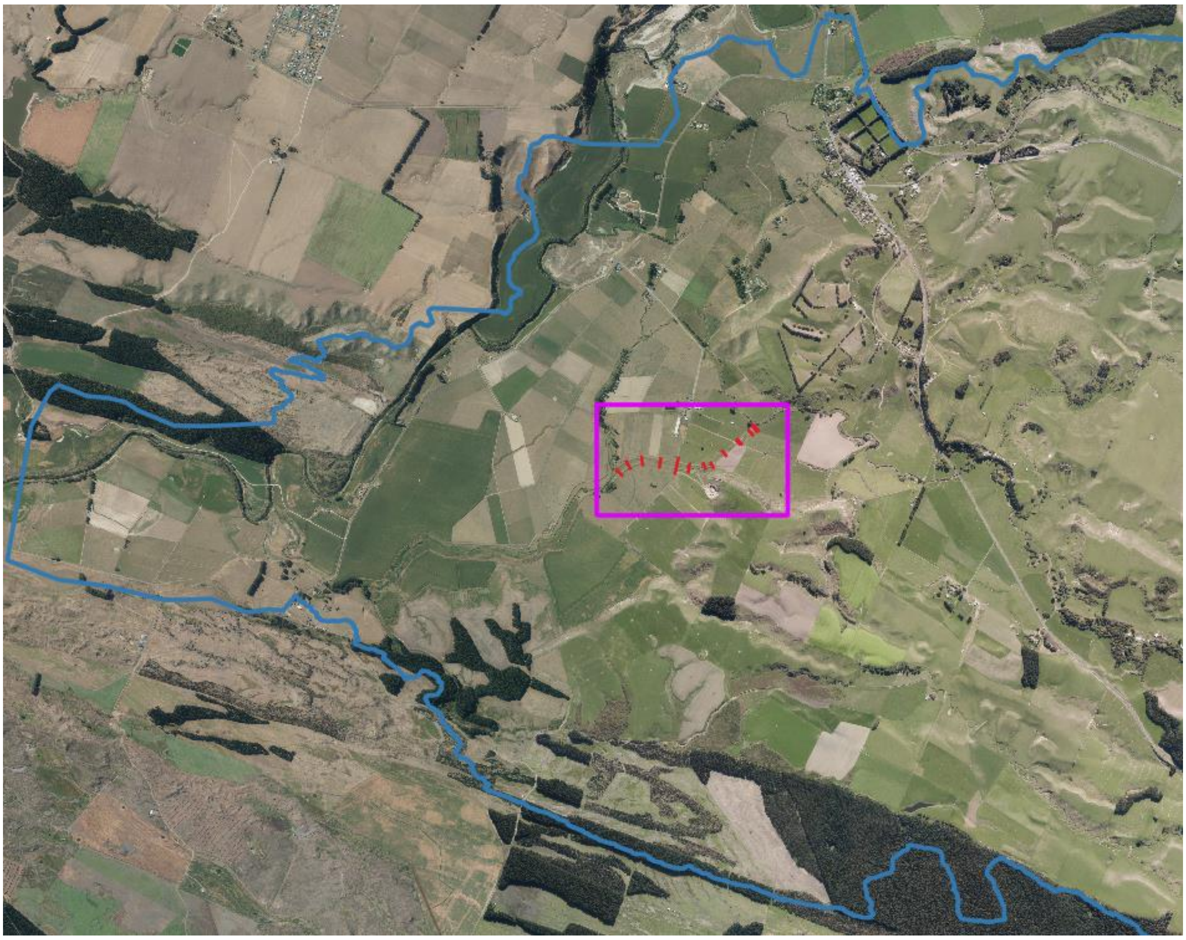
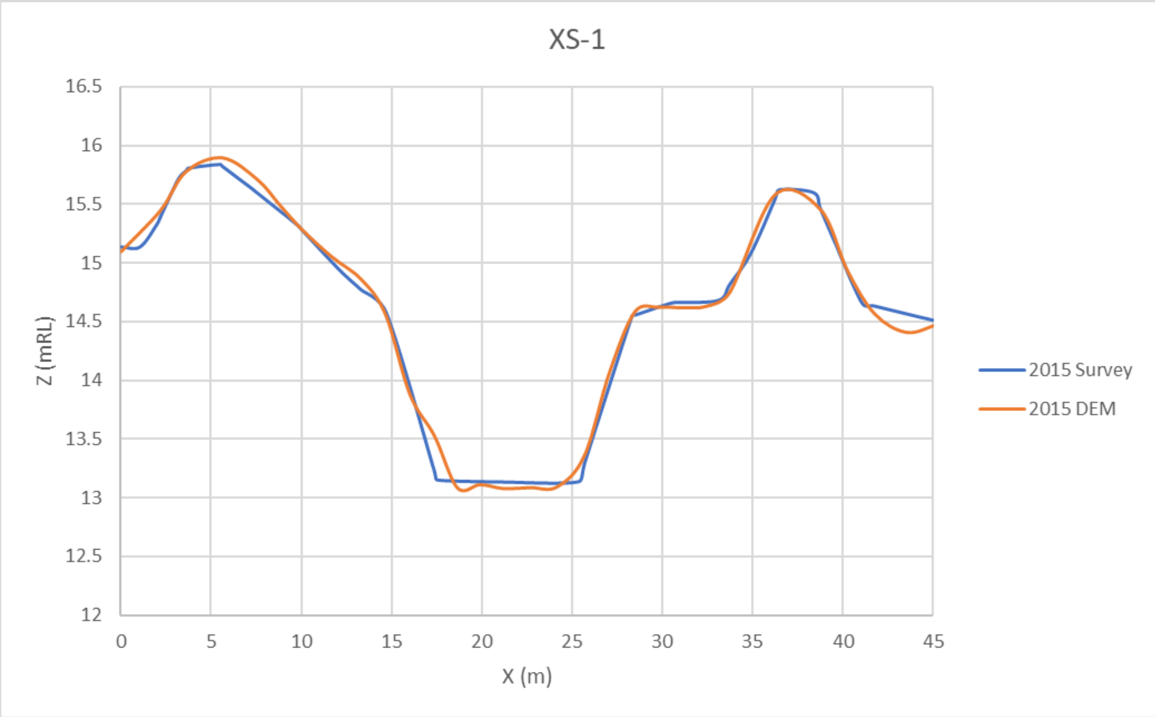


Figure 4.4: 2015 Survey cross sections



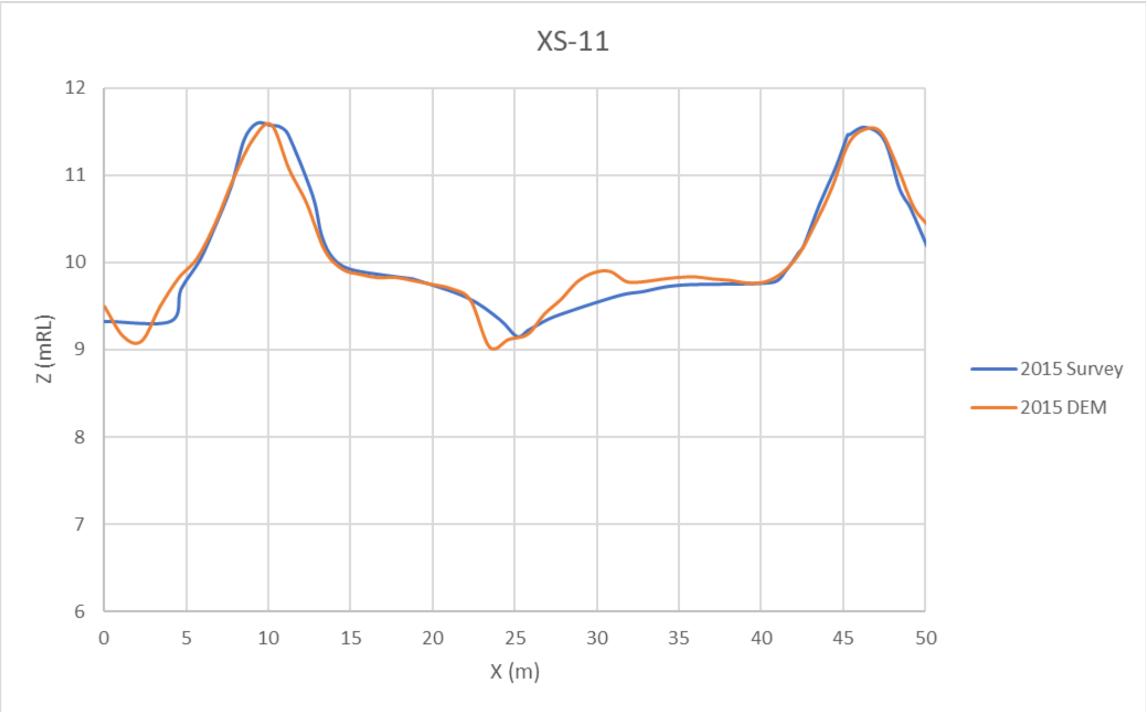


Figure 4.5: Surveyed Cross Sections vs 2015 DEM

The checks carried out confirmed that the DEM provided adequate representation of the channel for which cross section survey was provided. The DEM was accepted for 2D model use on this basis.

4.4 Cell size

Computational speed of hydraulic models is influenced by the grid size used. There is a desire to ensure adequate model accuracy while maintaining run-time efficiency, so the largest grid size is sought that still provides adequate accuracy. To do this a particular model scenario is run for a range of different grid sizes, to check results convergence, as described below.

With the sub-grid sampling function turned on, a 200-YearARIevent was simulated using a range of grid sizes, from 16 m to 4 m. The purpose of this was to establish whether model computational grid size influenced model results. Figure 4.6 shows the locations at which model results were compared for different grid sizes. The selected locations were within the lower reaches of the Makirkiri Stream.

Main observations were the following:-

- Typically, there was a minimal flood level difference of up to 100 mm across the flood plains.
- The flood plain extent changed minimally across the different cell sizes.

For mapping purposes, the 8 m cell size was chosen as it had good convergence with the 4 m grid.

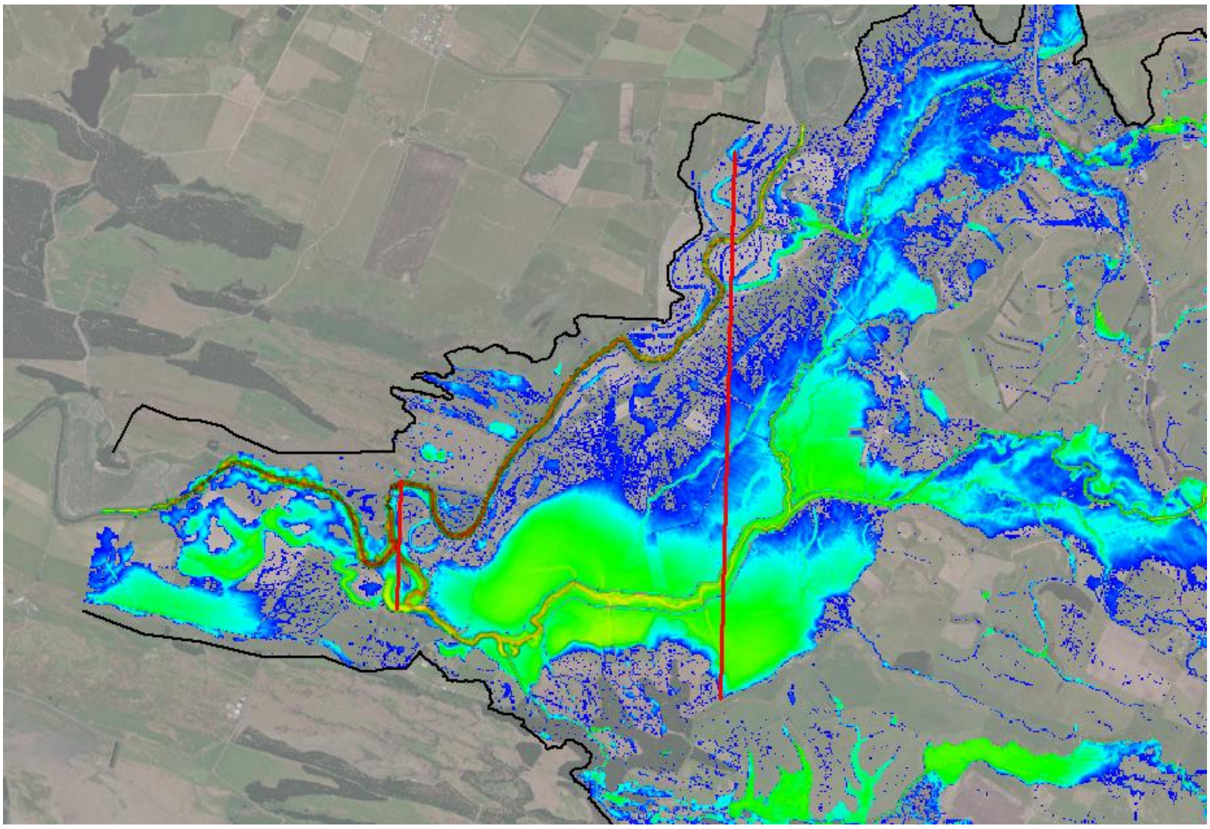


Figure 4.6: Profile locations for Figure 4.7: and Figure 4.8: from left to right

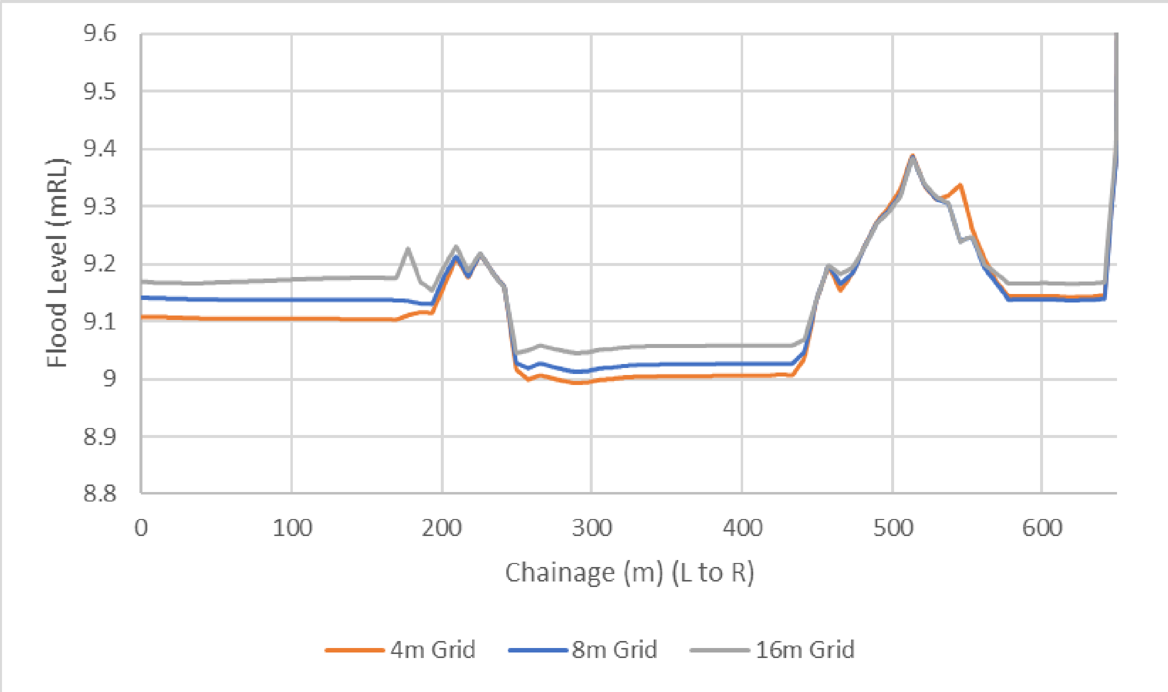


Figure 4.7: Flood level profile for the 4 m, 8 m and 16 m grids, at the confluence of the Makirikiri Stream and Turakina River

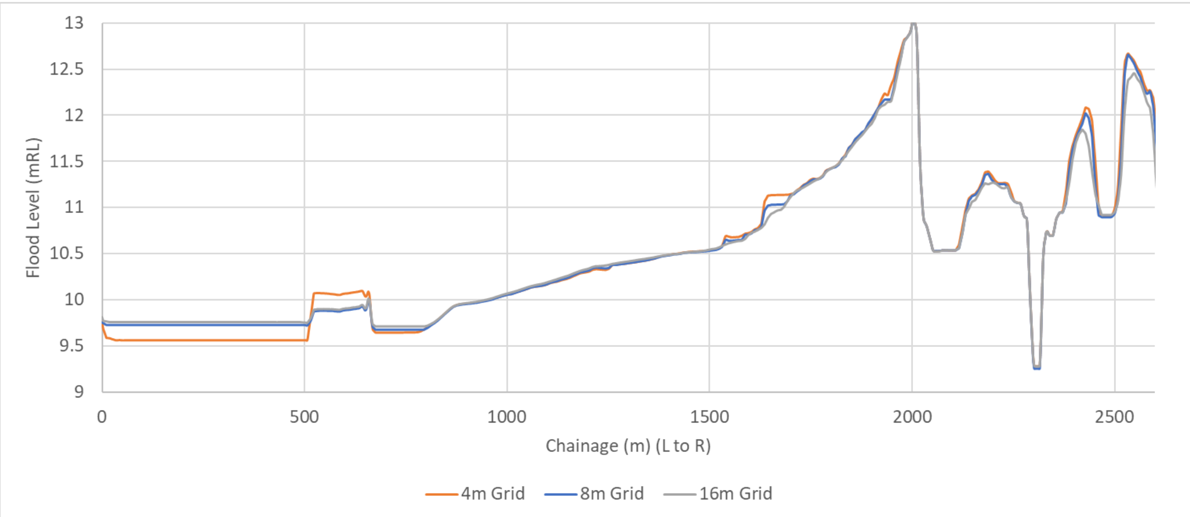


Figure 4.8: Flood level profile for the 4 m, 8 m and 16 m grids, across the Makirikiri flood scheme

4.4.1 Quadtree extent

The quadtree function in TUFLOW allows a variable cell size across a model domain, and thus allows a higher model resolution in areas of interest.

A cell size of 2 m was chosen for the extent shown in Figure 4.9 below, which included:

- Makirikiri and Kahuraponga streams, buffered 50 m each side.
- Turakina River, buffered 50 m each side.

- Turakina township, including the town and surrounding rural areas
- The Makirikiri flood scheme assets

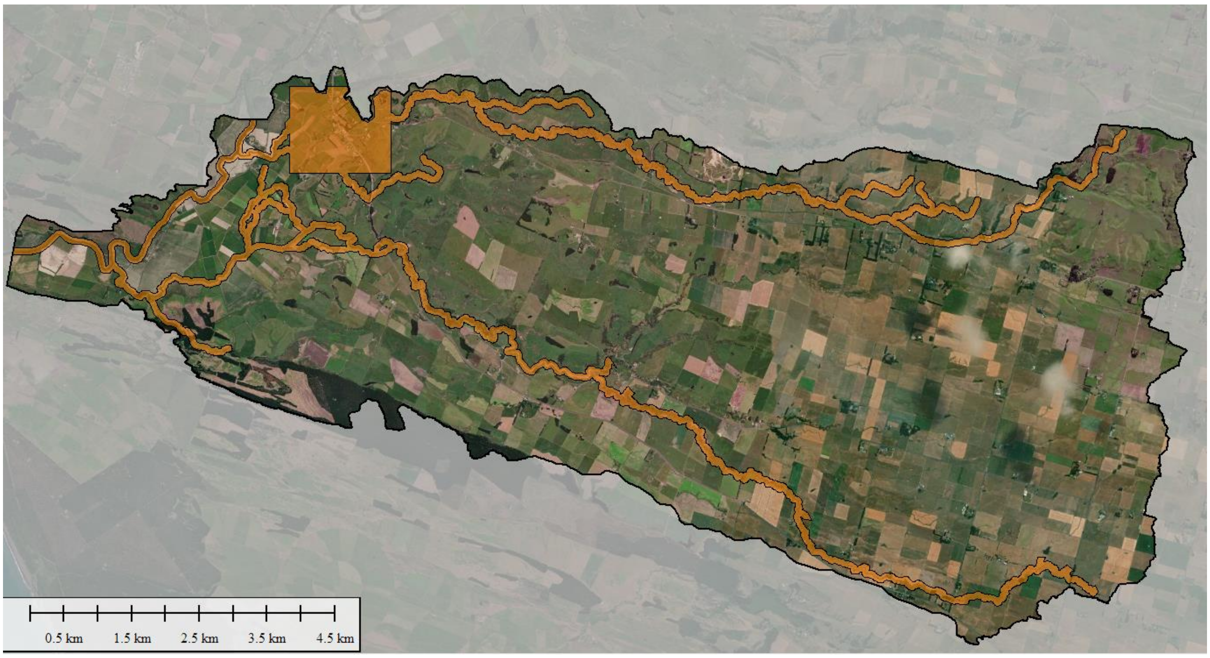


Figure 4.9: Quadtree extent shown in orange

Higher resolution model outputs are available in the areas shown in orange in Figure 4.9.

While areas of higher model resolution have been shown, this should not be confused with model accuracy described in Section 3.2.

4.5 Hydraulic parameters

4.5.1 Land use and roughness

Roughness coefficient is a hydraulic calibration parameter, which should be derived by matching model performance to observed performance. In the absence of suitable calibration data, roughness is often estimated using “look-up” tables that document ranges of calibrated roughness that have been found on other surface water systems. Due to a lack of calibration data available in this instance, “look-up” values were first applied to the model as a starting point and adjusted to test model results sensitivity.

In this model, land use is used to set the hydraulic roughness that is applied to the DEM. The spatial distributions of various land use used for the model was sourced from Land Cover Database version 5.0 (LCDB). This data is relatively coarse and does not differentiate micro scale roughness changes. For this reason, land use was refined manually using 2015 – 2017 aerial imagery sourced from LINZ (refer to Figure 4.10). Land use manual refinement does not include separate delineation for different types of pasture, vegetation, or the inclusion of buildings. This is consistent with the model scale and level of detail required for the model.

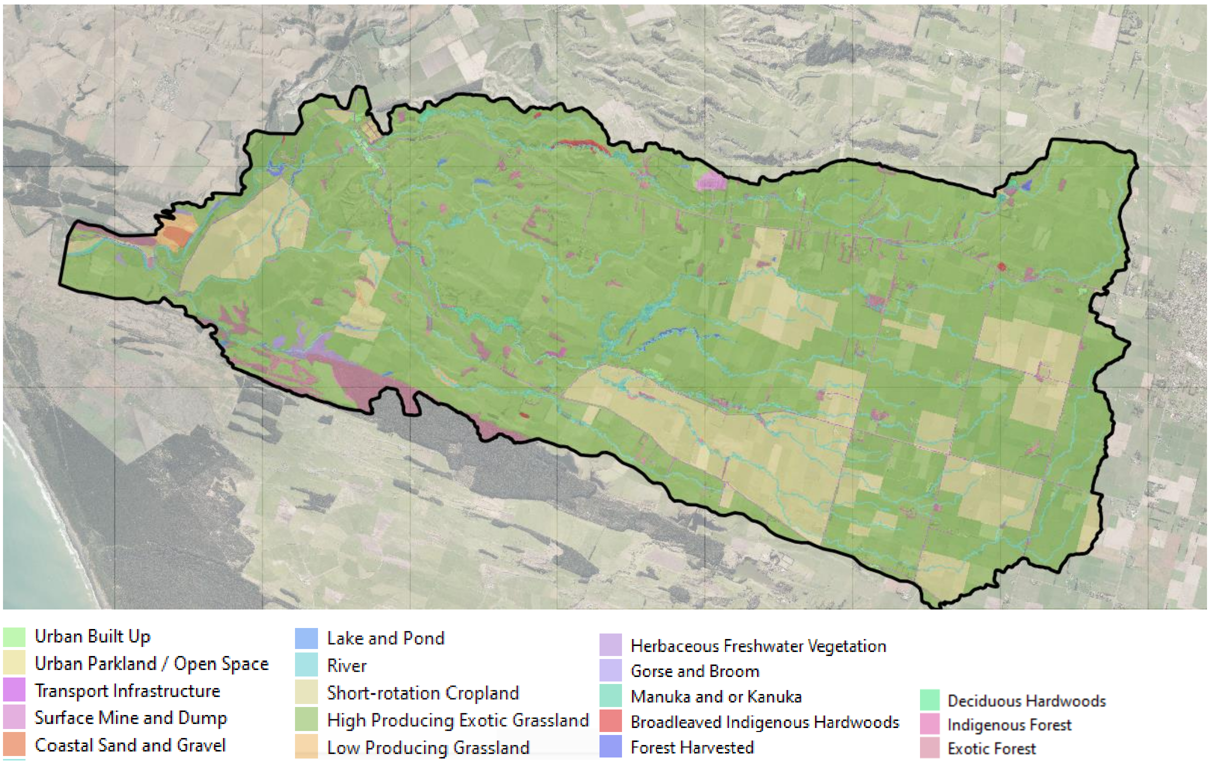


Figure 4.10: Land use

The roughness parameter applied to a direct rainfall model is often used to account for processes other than hydraulic friction loss at the rigid boundary. In some models, roughness is used to also account for turbulence losses, for bend losses and for losses through structures.

For the modelling undertaken, Manning 'n' is the roughness parameter that has been selected. It is recognised that the Manning equation gives reliable results in fully developed, rough, turbulent flow (which generally occurs at high Reynolds number). This means that modelled behaviour may be closer to reality under high Reynolds number conditions (high combination of velocity and depth) and may be less accurate at lower Reynolds number. In this way, calibration is able to be achieved to peak flows (during conditions when Reynolds number is high) but is more challenging if using constant roughness at lower Reynolds number. Thus, if calibration seeks to match peaks only, then constant Manning 'n' is a reasonable approximation. However, if calibration seeks to match an entire recorded hydrograph, there may be deviation in modelled performance at lower Reynolds number if constant Manning 'n' was used. At lower Reynolds number, effective roughness will be higher than at high Reynolds number.

It should be noted that 2D roughness values do not necessarily equate to traditional 1D Manning's n roughness values used for open channel hydraulics, such as those published by Chow (1949). There are multiple reasons for this, which have been recognised in publications such as Australian Rainfall and Runoff (ARR 2019). A major difference occurs where the 2D shallow Water Equations (used in the TUFLOW solver) approximate hydraulic radius with flow depth in a cell. This simplification suits wide, shallow flows but gives differences in incised channel areas.

Model result sensitivity to changes in roughness is reported on in Section 8.

Table 4.4: Manning 'n' values

Land Use Type	Manning 'n' value
Urban built up	0.1
Urban Parkland/ Open Space	0.033
Transport Infrastructure	0.016
Surface Mine and Dump	0.028
Coastal Sand and Gravel	0.025
Lake and Pond	0.02
River	0.035
Short-rotation Cropland	0.1
High Producing Exotic Grassland	0.05
Low Producing Grassland	0.09
Herbaceous Freshwater Vegetation	0.1
Gorse and Broom	0.125
Manuka and or Kanuka	0.1
Broadleaved Indigenous Hardwoods	0.1
Forest Harvested	0.16
Deciduous Hardwoods	0.125
Indigenous Forest	0.15
Exotic Forest	0.15

4.6 Turakina river boundaries

The lower reach of the Makirikiri stream is located on flat plains before it reaches the confluence with the Turakina River. Historical observations showed that in large flood events, the Turakina river spilled into the plains and into the Makirikiri and Kahuraponga stream. As such, it was difficult to model only the Makirikiri and Kahuraponga streams using boundaries from the Turakina model.

To assess the influence of the Turakina River flows on the Makirikiri Catchment, around 5.5 km of the Turakina river was included in the model. HRC provided a modelling report for the Whangaehu and Turakina Rivers[3] and the accompanying model results for the 100-year and 200-year scenarios. This event was run over 60 hours.

To incorporate the Turakina Model results into the hydraulic model, the following boundaries were applied:-

- An upstream flow hydrograph (discharge versus time)1
- A downstream stage hydrograph (water level versus time).

The location of these boundaries is shown in Figure 4.11.

[3] Hydro Tasmania Consulting (2010), *Whangaehu and Turakina Rivers – Flood and Hazard Mapping*

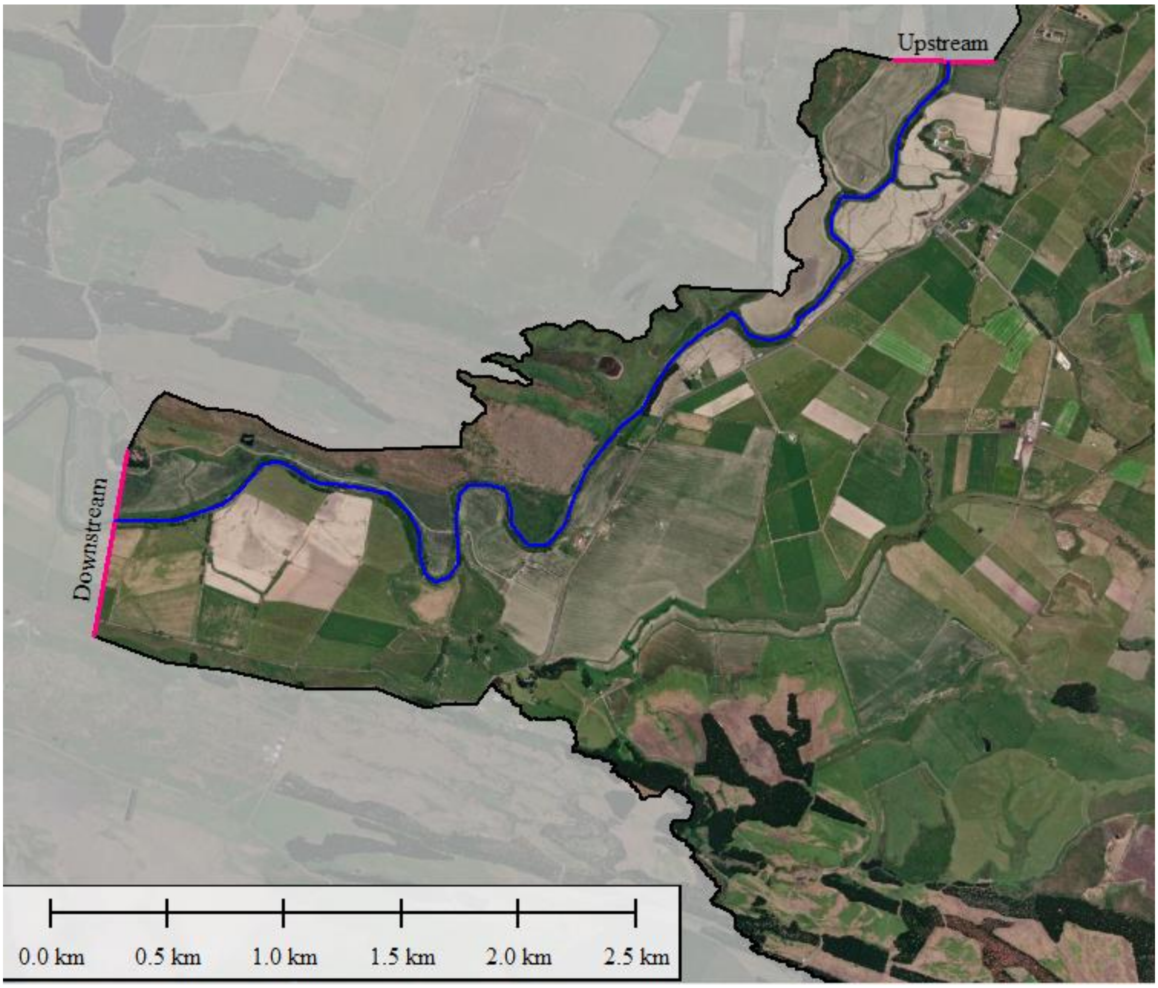


Figure 4.11: Turakina river boundaries

4.6.1 Downstream boundary

The downstream Turakina boundary was taken from the Mike 11 model. It was chosen at a location where the water level along the cross section of the stream and banks was relatively level so that a stage hydrograph could be applied. The maximum water level sits at around 8.2 m in the 200-year event, and 8.1 mRL in the 100-year event. As the Mike 11 results were not spatially referenced, the terrain cross section from the results was used to locate the equivalent location in the model, which became the downstream boundary.

The Mike11 results used for the boundaries were not modified in any way from the results as provided. Thus, the sea level scenario that was simulated in the provided Mike11 results was effectively propagated for use in this model.

Figure 4.12 shows the stage hydrograph extracted from the Mike 11 results. Notably this shows an extended duration for the peak flows which spans some 20 hours.

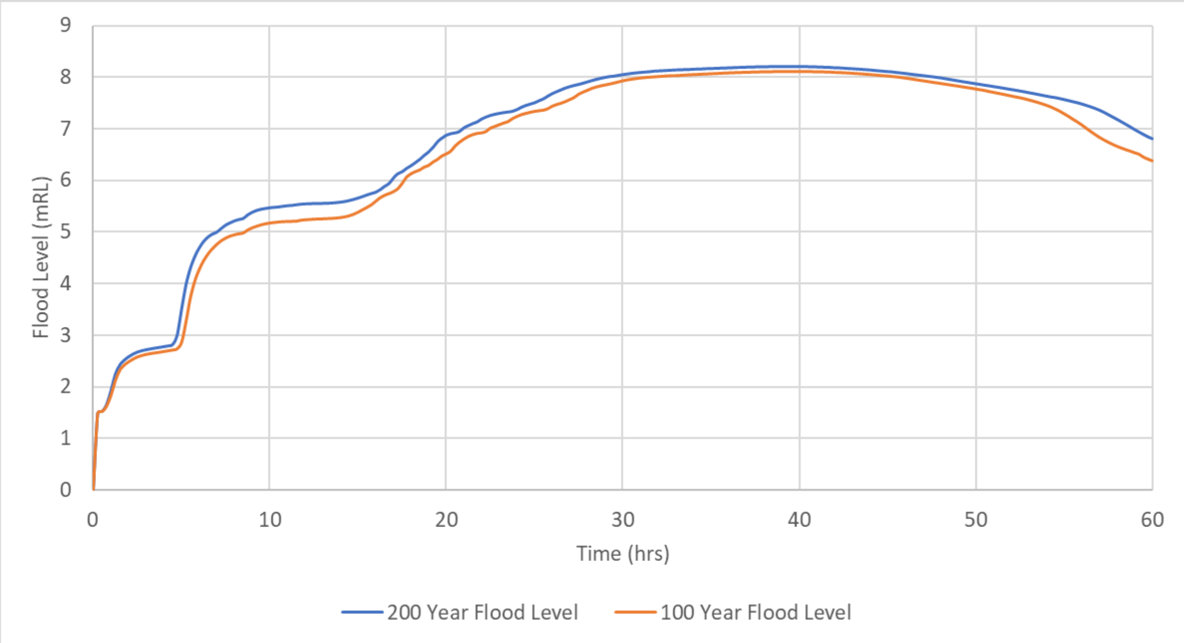


Figure 4.12: Stage hydrographs for the Turakina downstream boundary

4.6.2 Upstream boundary

The upstream boundary of the Turakina River is a time-flow boundary. This was applied at the edge of the 2015 DEM extent, using the flow hydrograph from the closest cross section from the Mike 11 model.

The flow hydrograph was scaled up to the reference flow of 690 m^3/s for the 200-year event, and 566 m^3/s for the 100-year event. The reference flow is based on a flood frequency analysis on gauged data from the O'Neils Bridge gauge site in the Turakina River, done by Hydro Tasmania Consulting.

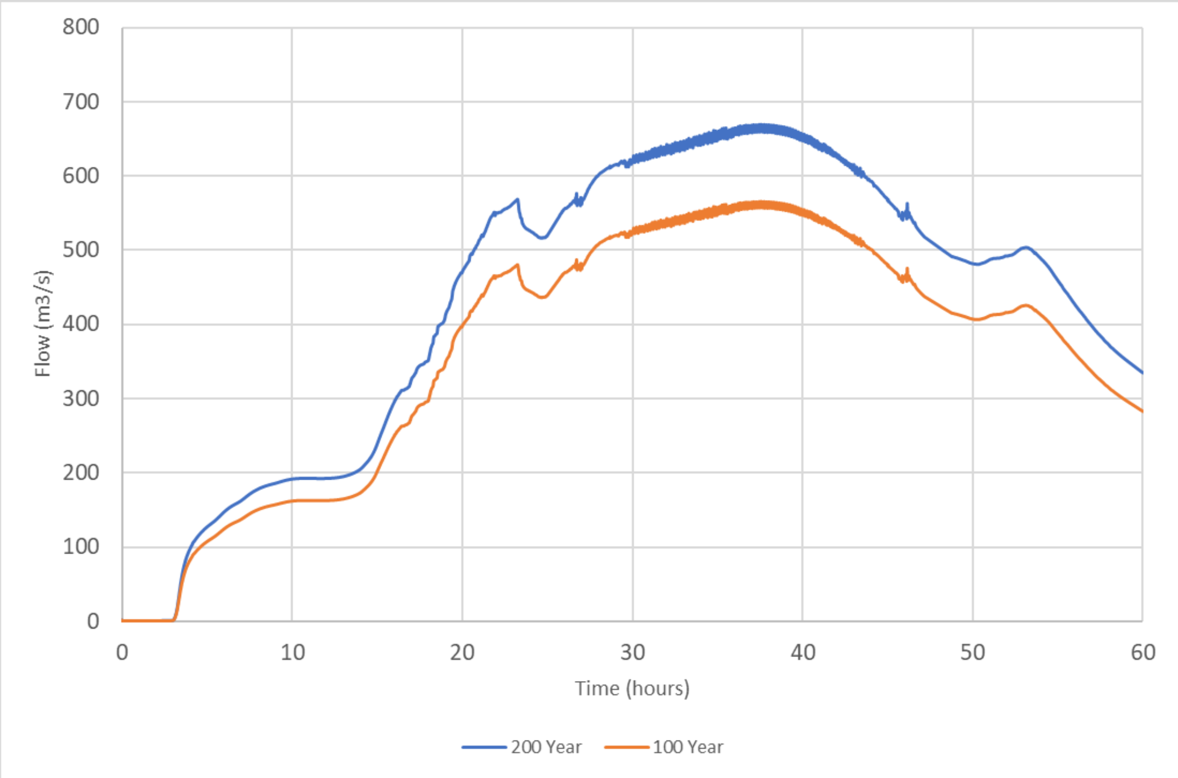


Figure 4.13: Flow hydrographs for the Turakina upstream boundary

Note that for both boundaries described above, the peaks occur some 30 hours after the start of the simulation. For the purpose of the Makirikiri Stream model, it was necessary to ensure that the simulation start time (i.e., time = 0) did not match the simulation start time of the Turakina model as this would not be representative of flood conditions.

4.7 Hydraulic structures

There was no publicly available information on hydraulic structures within the catchment. One surveyed flap gate was included in the model, provided by HRC.

4.7.1 Bridges

Four bridges were included in the model, as shown in Figure 4.14. These bridges were considered critical to the assessment, while bridges further up the catchment were not included and were instead burned in as channels (as discussed in Section 4.7.2).

As survey information on the bridges was not available, assumptions had to be made on bridge dimensions using site photographs and Google Street view. It was assumed that the top of the bridge deck was level with the road at the ends of the bridge. Estimated bridge dimensions are detailed in Table 4.5.

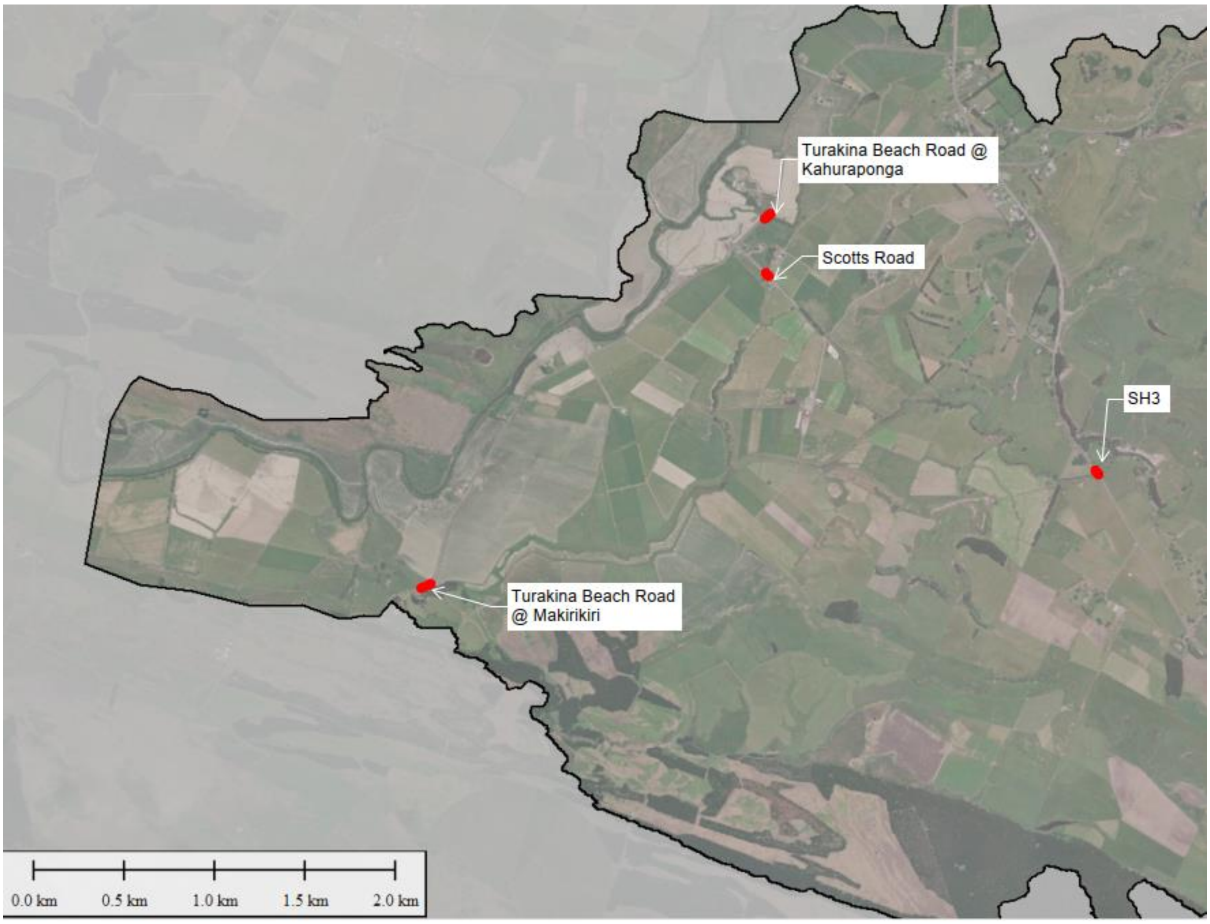


Figure 4.14: Bridge Locations

Table 4.5: Modelled bridge details

Bridge Name	Photo	Comments/Assumptions
SH3		No photos of the bridge, information only obtained through Google Street view. **<u>Modelled geometry</u>** Width: 12 m, same as the road Bridge deck thickness: 0.7 m Railing height: 0.4 m
Turakina Beach Road @ Kauraponga		No photos of the bridge, information only obtained through Google Street view. **<u>Modelled geometry</u>** Width: 10 m, slightly less than road width Bridge deck thickness: 0.3 m Railing: 0.8 m
Turakina Beach Road @ Makirikiri		Details estimated through site photos **<u>Modelled geometry</u>** Width: 14 m, relative to road and verified by photographs Bridge deck thickness: 0.5 m Railing: 1 m
Scotts Road		Details estimated through site photos **<u>Modelled geometry</u>** Width: 12 m Bridge deck thickness: 0.4 m Railing: 0.8 m

4.7.2 Culverts

As there was no publicly available culvert data, locations along the channels where there are bridges or culverts read in as “blockages” in the DEM as the area underneath these features is not captured by LiDAR. Blockages in the watercourses in the model were manually removed using TUFLOW layers, assumed to be one cell width wide (5 m for the design scenario), with invert levels interpolated from the DEM. The location of the resulting channel modifiers is shown in red in Figure 4.15.

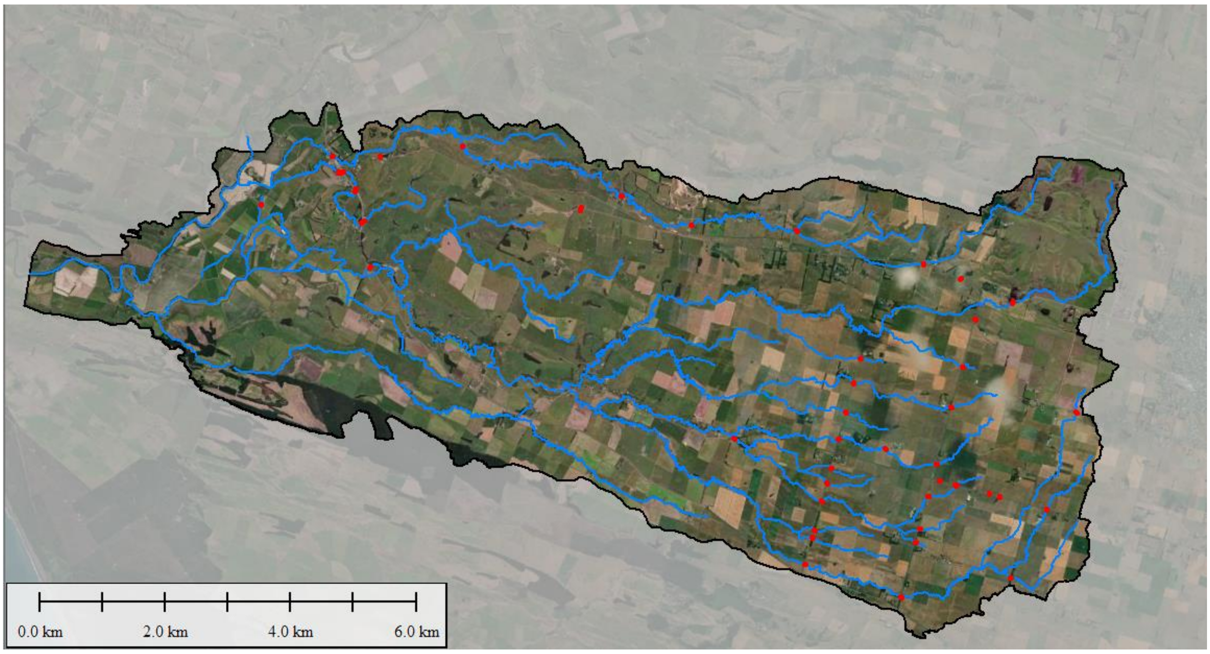


Figure 4.15: Culvert locations

4.7.3 Makirikiri Flood Scheme structures

As there was limited survey information on structures such as stopbanks, flapgates or culverts within the Makirkiri Flood Scheme, these structures were not represented in the model.

Site observations showed that several hydraulic structures exist within the flood scheme. LiDAR checks and comparisons to the 2015 survey showed that the stopbanks seemed to be represented adequately by the LiDAR.

The lack of surveyed data should be noted when considering model results.

One surveyed culvert was included in the model, located at Redmayne Drop Gate, surveyed in 2015. Survey information was provided by HRC.

5 Hydrometeorological data

This section outlines the hydrological analyses carried out to estimate model parameters for input to a rain-on-grid flood model of the 85 km^2 Makirikiri Catchment.

Flows are not measured in the Makirikiri Stream, so parameters had to be estimated based on calibrated rainfall-runoff models for nearby streamflow gauges.

Tasks included:-

- Identifying and collecting available streamflow and rainfall station data.
- Characterising the Makirikiri and gauged catchments.
- Obtaining design rainfall from the HIRDS database for the Makirikiri and gauged catchments.
- Setting up and calibrating rainfall-runoff models for the gauged catchments.
- Transposing parameters to the Makirikiri Catchment.

5.1 Streamflow data

The location of streamflow gauges and their respective record lengths were identified using NIWA's Station Information Management System (SIMS). The gauge listed in Table 5.1 as identified, based on land use and catchment area, as potentially suitable for calibrating a rainfall-runoff model to estimate parameters for the Makirikiri Catchment.

Table 5.1: Streamflow data used to calibrate rainfall-runoff models

Gauge ID	Gauge name	Catchment area (km^2)	Period of record		Number of years record
			Start	End	
32735	Rangitawa at Halcombe	62.4	25 March 1969	7 October 1980	12

5.2 Rainfall data

Rainfall stations in and around the gauged catchments were identified using NIWA's SIMS. The list of rainfall stations was refined to include only those that potentially could provide rainfall data to calibrate an event-based rainfall-runoff model for the Rangitawa streamflow gauge. These rainfall stations are summarised in Table 5.2 and their locations are shown in Figure 5.1.

Table 5.2: List of rainfall stations considered for catchment rainfall

Name	Start date	End date	Identifier	Comment
Motu Kowhai	1 January 1933	31 December 2012	3171	Daily only
Greatford	31 January 1978	31 July 2016	3189	Daily only
Rangitawa at Stanway	29 July 1968	10 December 1980		Sub daily from October 1973

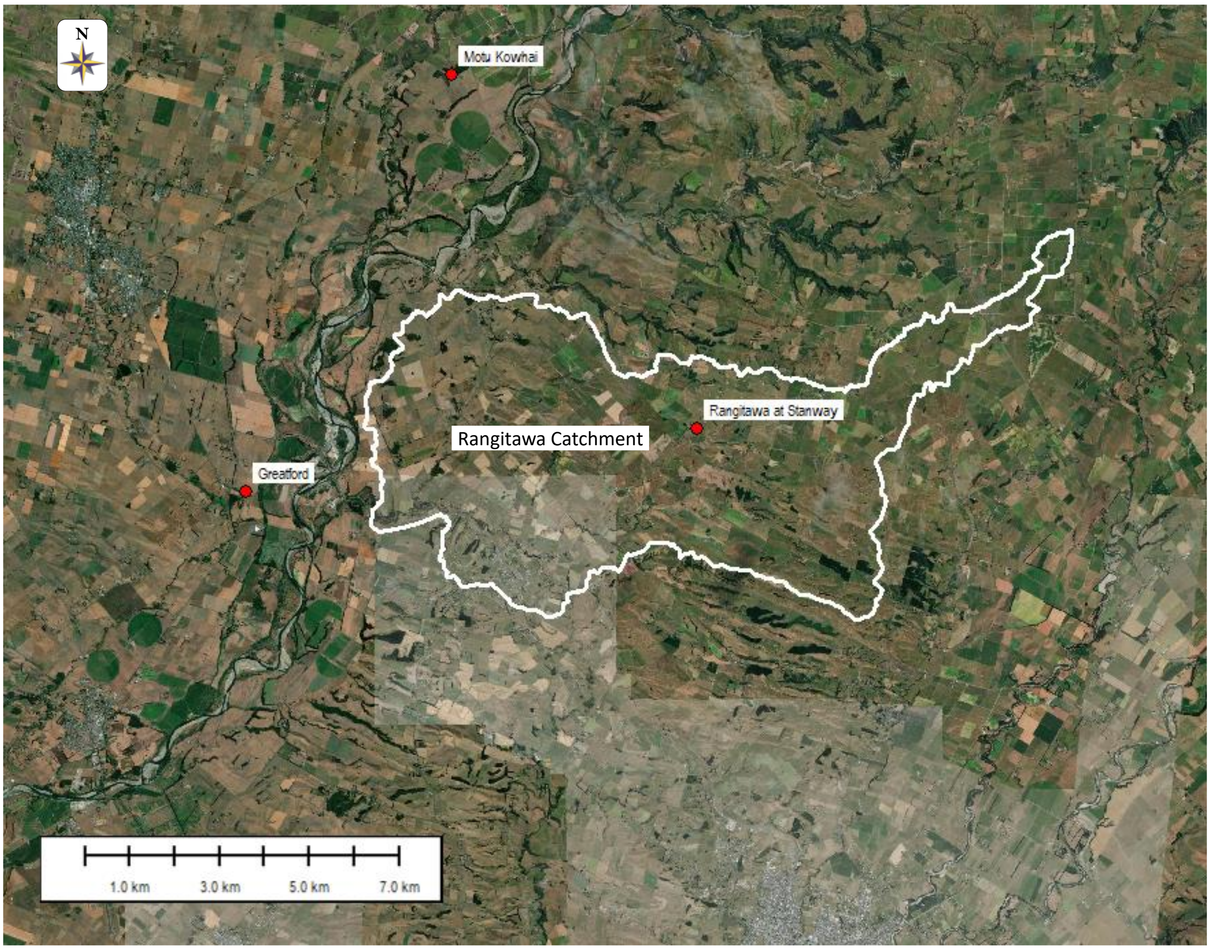


Figure 5.1: Location of rainfall stations

NIWA confirmed that only the Rangitawa at Stanway has sub-daily rainfall data.

The Rangitawa gauged catchment and the Makirikiri Catchment together with the locations of the HIRDS rainfall data, used in the analyses, are shown in Figure 5.2.

The HIRDS rainfall depths shown in Table 5.3 to Table 5.4 are after applying an aerial reduction factor (ARF) calculated using the formula in the HIRDS version 4 document.

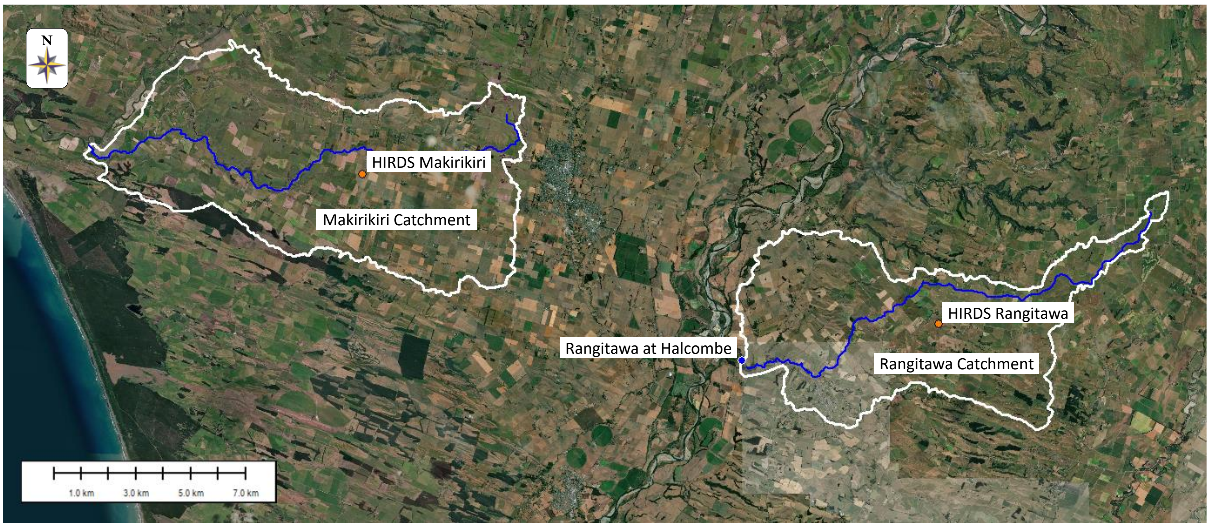


Figure 5.2: Catchment map showing HIRDS data locations and streamflow gauge

Table 5.3: Makirikiri Catchment: Design rainfall depths

Longitude 175.292

Latitude -40.072

ARI	Rainfall depth (mm) for storm duration (hours) (HIRDS version 4 ARF applied)					
	1-hour	2-hour	3-hour	6-hour	12-hour	24-hour
Present day						
20	22.8	32.7	39.6	53.6	70.3	89.1
50	27.3	39.0	47.2	63.7	83.2	105.1
100	30.9	44.2	53.4	71.9	93.7	117.9
200	34.6	49.5	59.9	80.4	104.4	131.0
Projected climate change: RCP 6.0 2120						
100	41.1	58.3	70.0	92.1	116.7	142.6
200	46.1	65.4	78.2	102.9	130.1	158.4

Table 5.4: Rangitawa Catchment: Design rainfall depths - present day

Longitude 175.540

Latitude -40.116

ARI	Rainfall depth (mm) for storm duration (hours) (HIRDS version 4 ARF applied)					
	1-hour	2-hour	3-hour	6-hour	12-hour	24-hour
20	25.9	34.9	40.9	52.9	67.3	84.5
50	31.1	41.8	48.9	63.0	79.7	99.6
100	35.4	47.4	55.4	71.1	89.7	111.5

6 Catchment characteristics

The streams and catchment boundaries shown in Figure 5.2 were delineated using the Ministry for Environment (MfE) rivers and catchment shape files.

The equal area slopes along the longest water courses were calculated using an elevation grid generated from the 20 m contours from the 1:50,000 topographical map. These slopes were input to the USBR formula to estimate time of concentration (Tc) for the catchments.

The Landcare Research permeability map with the two catchments delineated is shown in Figure 6.1.

The Makirikiri and Rangitawa catchments predominantly comprise “Slow” and “Moderate over slow” draining soils. The area of “Slow” draining soils in the Makirikiri Catchment is larger than in the Rangitawa Catchment (62% versus 46%) and the area of “Moderate over slow” smaller (33% versus 54%). These differences indicate that overall infiltration losses in the Makirikiri Catchment will be lower than in the Rangitawa Catchment. Considering that approximately 4% of the Makirikiri Catchment is classified as “Rapid” draining and the difference in infiltration rate between “Slow” and “Moderate over slow” soils is likely to be small, especially during a flood event, the continuing loss in these catchments is expected to be similar.

Characteristics of the two catchments are summarised in Table 6.1. The Clark unit hydrograph storage coefficient was initially estimated at approximately 1.5 times Tc.

Table 6.1: Catchment characteristics

Characteristic	Rangitawa at Halcombe	Makirikiri at Turakina confluence
Catchment area (km^2)	62.4	85
Equal area slope (m/m)	0.010	0.006
Time of concentration (Tc) (hrs)	4.6	5.6
Clark storage coefficient (hrs)	7	9

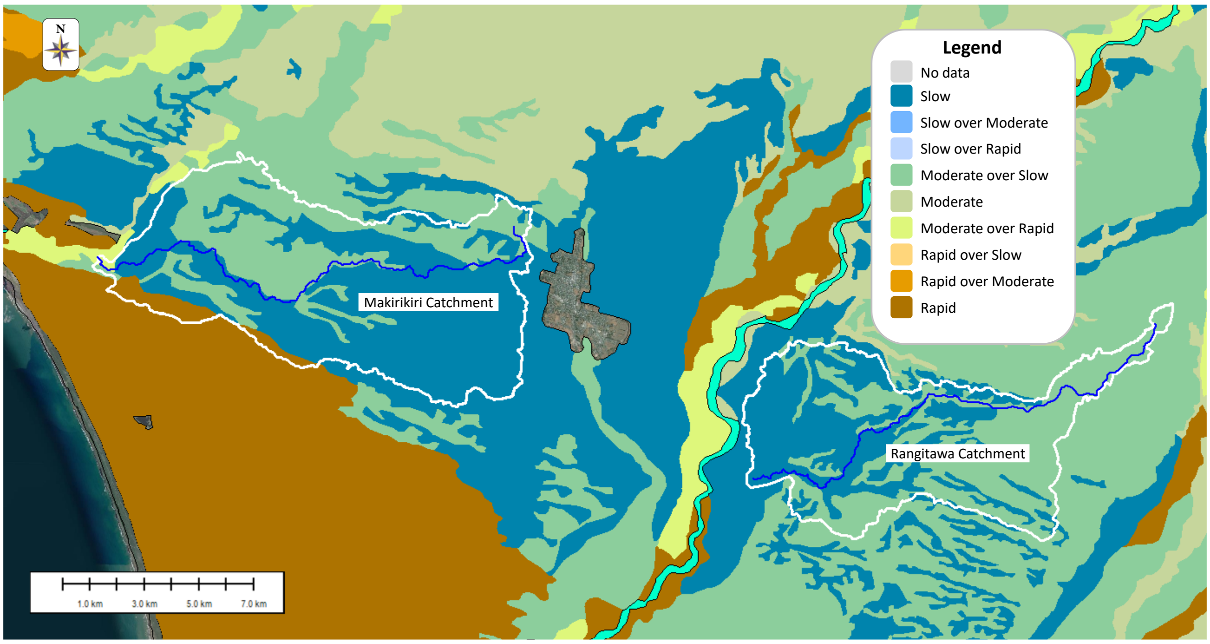


Figure 6.1: Permeability map (Landcare Research)

7 Rainfall-runoff model calibration

The preferred method of calibrating an event-based rainfall-runoff model is to select several observed events for which catchment rainfall data is available and adjust the model parameters so that simulated and observed hydrographs for these events are similar. There is one rainfall station in the Rangitawa Catchment with sub-daily rainfall data that could be used as input to calibrate an event-based rainfall-runoff model. An alternative approach is to calibrate the rainfall-runoff model to simulate flood peaks for a range of annual exceedance probability (AEP) using frequency rainfall for the catchment. Both approaches were followed because parameters derived from the event calibrations were not conclusive.

7.1 Event based rainfall-runoff model calibration

Rainfall data from Rangitawa at Stanway were used as input to a HEC-HMS initial and constant loss model to simulate the annual maximum events recorded at the Rangitawa at Halcomb streamflow gauge from 1974 to 1980 (the events with sub-daily rainfall data available). For each event the initial loss (Ia), constant loss (CL), time of concentration (Tc) and Clark unit hydrograph storage parameter (S) were adjusted to improve the comparisons between observed and simulated flows.

The selected parameters together with the observed and simulated hydrograph peaks are summarised in Table 7.1 and plots showing the comparisons between the observed and simulated hydrographs are included as Appendix A.

Table 7.1: Event based calibration parameters

Event	Ia (mm)	CL (mm/hr)	Tc (hours)	S (hours)	Peak discharge (m^3/s)		Comment
					Simulated	Observed	
17 July 1974	5	1	4.6	7	29.5	30.1	Excellent
28 August 1975	5	1	3	5	24.1	33.4	Good
29 June 1976	5	1.5	3	5	81.5	80.8	Excellent
19 September 1977	5	0.8	3	5	19.2	19.9	Moderate
20 July 1978	5	1.5	4.6	7	23.8	23.1	Excellent
25 August 1979	5	1	3	5	63.6	64.9	Good
27 August 1980	5	1	3	5	32.9	33.8	Excellent

The observed flow record for the 1975 event shows four peaks. The simulation also shows four peaks with one before the first observed peak and without the fourth observed peak. The plot shows that the rainfall station did not see any rainfall that caused the fourth peak and that the temporal distribution of actual rainfall on the catchment was not the same as observed at the gauge.

The 1977 event simulates the peak reasonably well. However, the plot shows that the gauge saw rainfall at the beginning of the storm that was not representative of catchment rainfall.

The rest of the plots show very good comparison between simulated and observed flows. However, the model parameters varied with Tc for 1974 and 1978 set to the USBR estimate, but for the other events Tc needed to be reduced from 4.6 to 3 to simulate the observed hydrograph shapes. The constant loss also needed to be adjusted for the 1976 and 1978 events to reduce the hydrograph peaks.

The model parameters from the event-based calibration show variability that is likely due to the rainfall station data not being fully representative of catchment rainfall.

7.2 Calibration to simulate frequency analysis results

The annual maxima from the Rangitawa record from 1969 to 1980 were input to frequency analysis. The record is too short for reliable frequency analysis but was used because the catchment is hydrologically similar to the Makirikiri Catchment (in terms of land use and permeability) and there is no other suitable catchment. Consideration was given to excluding the 1969 maximum from the analysis because it is from an incomplete year of data and just more than half the next lowest value. However, the nearby Porewa record supports a low value for 1969 so it was included in the frequency analysis.

The fitted frequency distributions are shown in Figure 7.1.

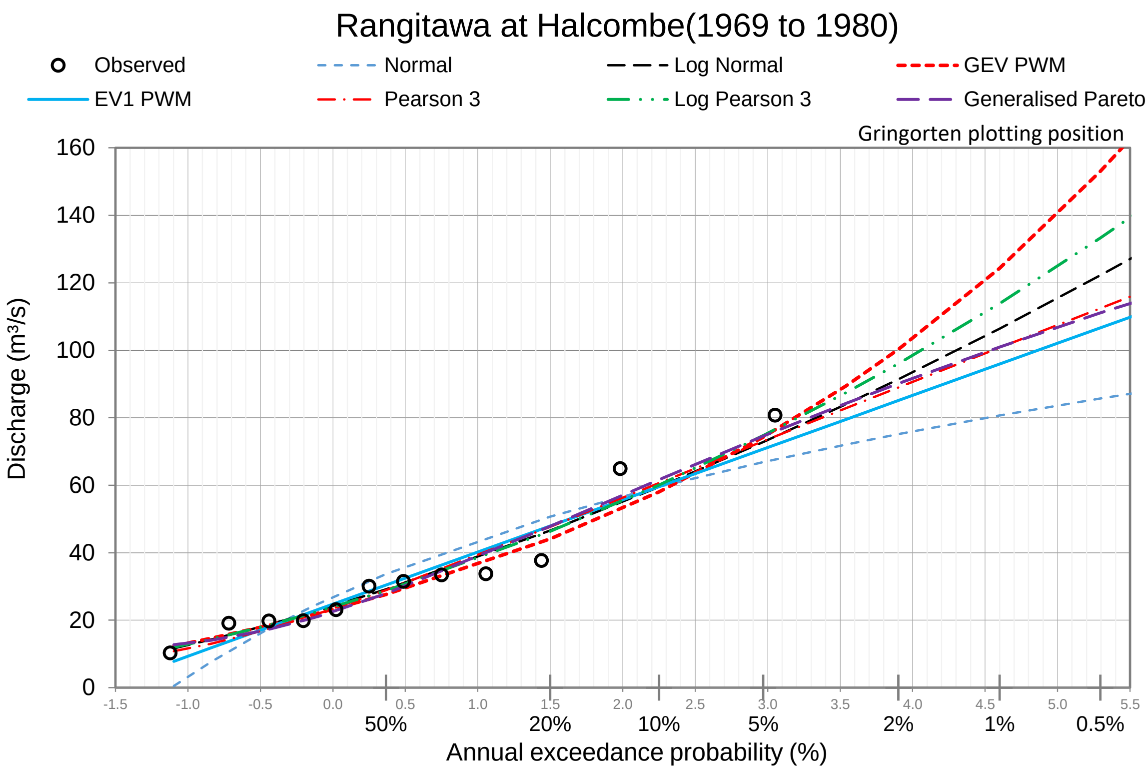


Figure 7.1: Frequency plot: Rangitawa at Halcombe (1969 to 1980)

7.2.1 Rainfall-runoff model calibration

A HEC-HMS Clark unit hydrograph model with losses simulated using the initial and continuing loss model and the rainfall data summarised in Table 5.4 was set up for the Rangitawa gauged catchment. Model calibration assumed that the AEP of rainfall is the same as the AEP of the peak discharge. The HIRDS rainfall data for storm durations of 1, 6, 12, 24 and 48 hours were input to HEC-HMS as hyetographs using the HIRDS temporal distributions.

Model parameters were adjusted so that the flood peaks agreed suitably with the frequency analysis results. The model parameters together with the simulated flood peaks are listed in Table 7.2 and the simulated maxima are plotted together with the frequency distribution results in Figure 7.2.

The simulated maxima show that for AEP from 10% to 2% the 12-hour storm is critical and that a 24-hour storm is critical for the 1% AEP event.

Table 7.2: Rangitawa Catchment: Model parameters and simulated flood peaks

Parameters	Ia 5 mm	CL 1.0 mm/hr	Tc 4.6 hrs	Clark S 7 hrs	
AEP	**Simulated peak discharge- (m³/s) for storm duration (hours)**				
	1	6	12	24	48
10%	30	60	**63**	56	47
5%	37	71	**74**	67	55
2%	46	87	**91**	81	68
1%	53	54	100	**104**	93

Figure 7.2 shows that the simulated flood peaks for the Rangitawa Catchment fit well with the Log Normal distribution, which also fits the observed data well as shown in Figure 7.1.

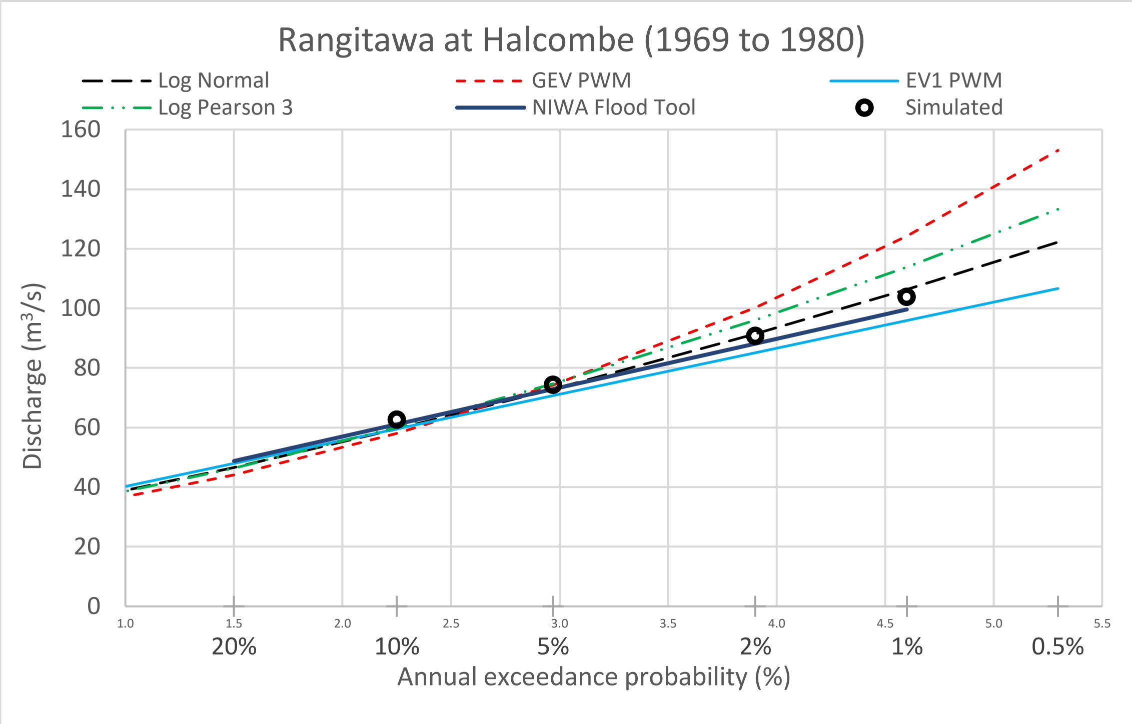


Figure 7.2: Rangitawa Catchment: frequency distributions and simulated flood peaks

The Rangitawa flow record is only 12-years long, which is too short for confidence in the frequency analysis results. However, the CL values determined from the event-based calibrations support a value of 1 mm/hour for the catchment.

Based on catchment similarity discussed in Section 6, the Rangitawa loss parameters (Ia 5 mm and CL 1.0 mm/hr), Tc calculated using the USBR formula and the Clark storage coefficient set to approximately 1.5 times Tc were adopted for the Makirikiri Catchment.

Simulated flood peaks in the Makirikiri Stream at the confluence with the Turakina River together with the Henderson-Collins frequency estimates from New Zealand River Flood Statistics and flood peaks transposed from the Rangitawa Catchment using the ratio of catchment areas raised to the power 0.8, are shown in Figure 7.3.

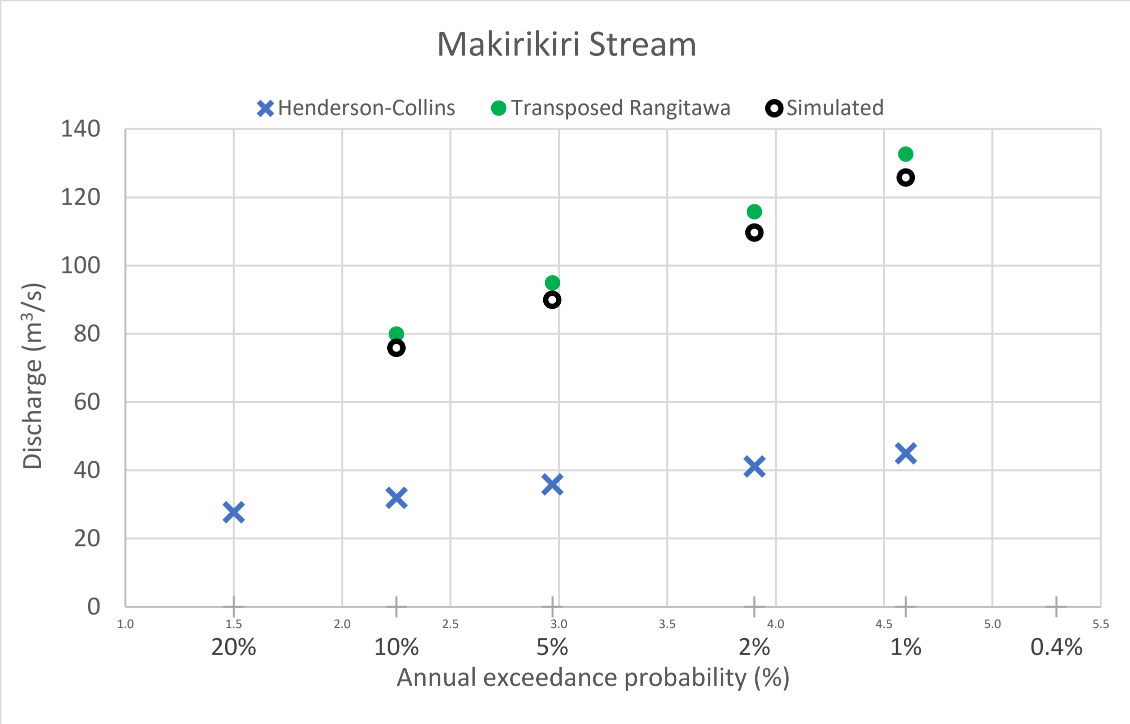


Figure 7.3: Makirikiri at Turakina confluence: comparison of flood peaks

The flood peaks plotted in Figure 7.3 show that the simulated flood peaks from the Makirikiri Catchment are similar to those transposed from the Rangitawa catchment, with the small difference attributed to differences in catchment response times. The reason for the very much lower flood peaks estimated from the Henderson-Collins method is uncertain but likely due to regional model parameters not reflecting the low permeability in the Makirikiri and Rangitawa catchments.

7.3 Simulated hydrographs

The simulation results for the Makirikiri catchment are summarised in Table 7.3. The hydrographs for the critical storm duration (12-hours) are shown in Figure 7.4 and Figure 7.5 for the historic and projected RCP 6.0 2120 scenarios respectively.

Table 7.3: Makirikiri Catchment: Simulated peak discharge for a range of AEP and storm durations

ARI	**Peak discharge (m^3/s) for storm duration**			
	1-hour	**6-hour**	**12-hour**	**24-hour**
Present day				
20	34	80	**90**	85
50	43	98	**110**	104
100	50	113	**126**	119
200	57	128	**142**	135
Projected climate change: RCP 6.0 2120				
100	70	148	**161**	148
200	79	168	**182**	167

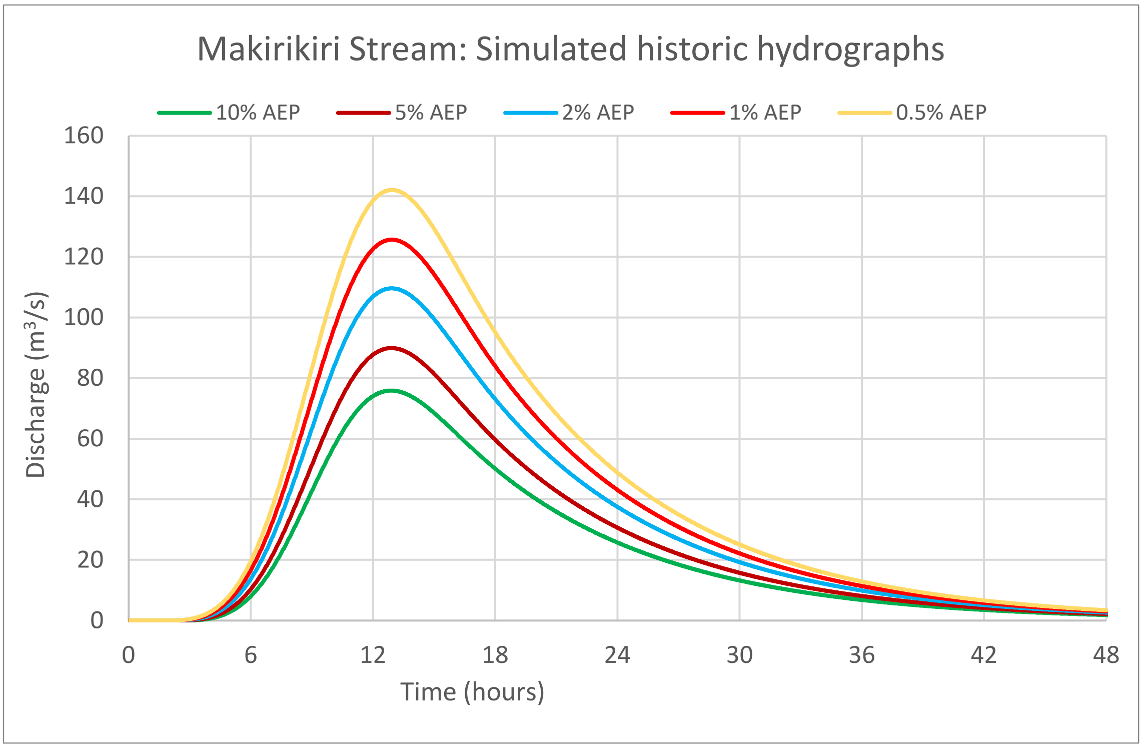


Figure 7.4: Makirikiri Stream: Simulated hydrographs for 12-hour storms – historic rainfall

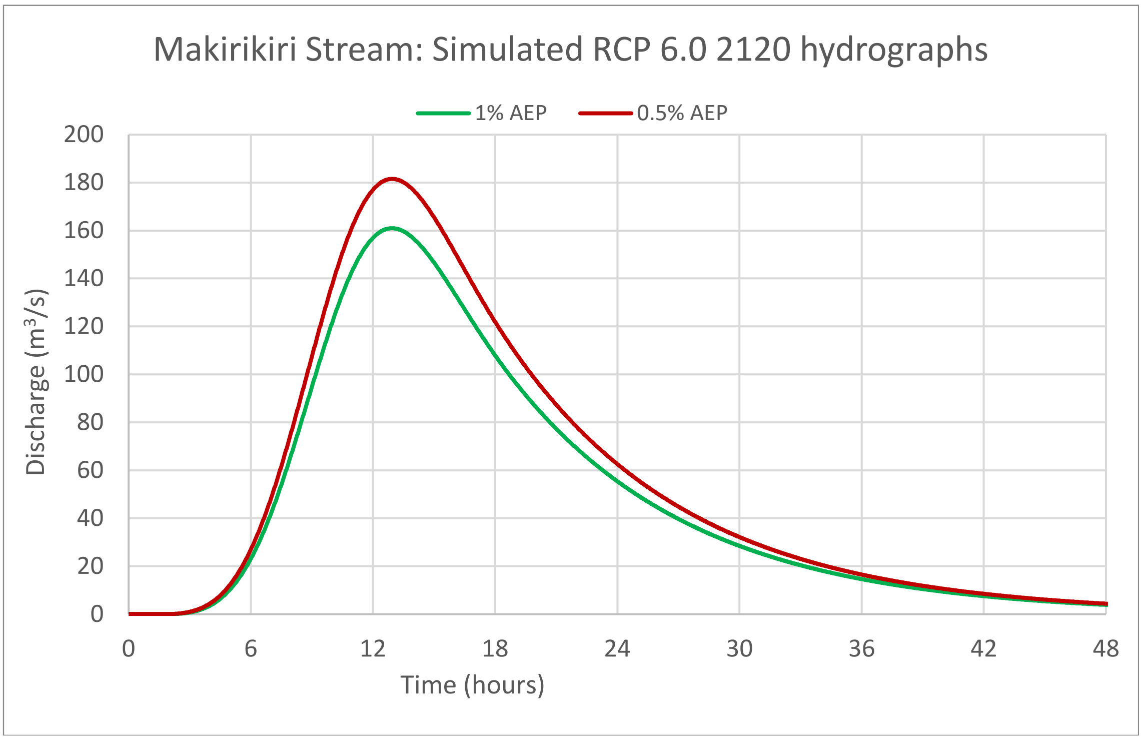


Figure 7.5: Makirikiri Stream: Simulated hydrographs for 12-hour storms – projected RCP 6.0 2120 rainfall

7.4 Validation of 2D model hydrology

The hydraulic and hydrological results for the 200-year ARI, 12-hour present day event were compared to ensure convergence between the two models. Flow hydrographs were extracted from the model at the location shown in Figure 7.6 below. The flow hydrograph from the hydrological model is taken from the base of the Makirikiri catchment.

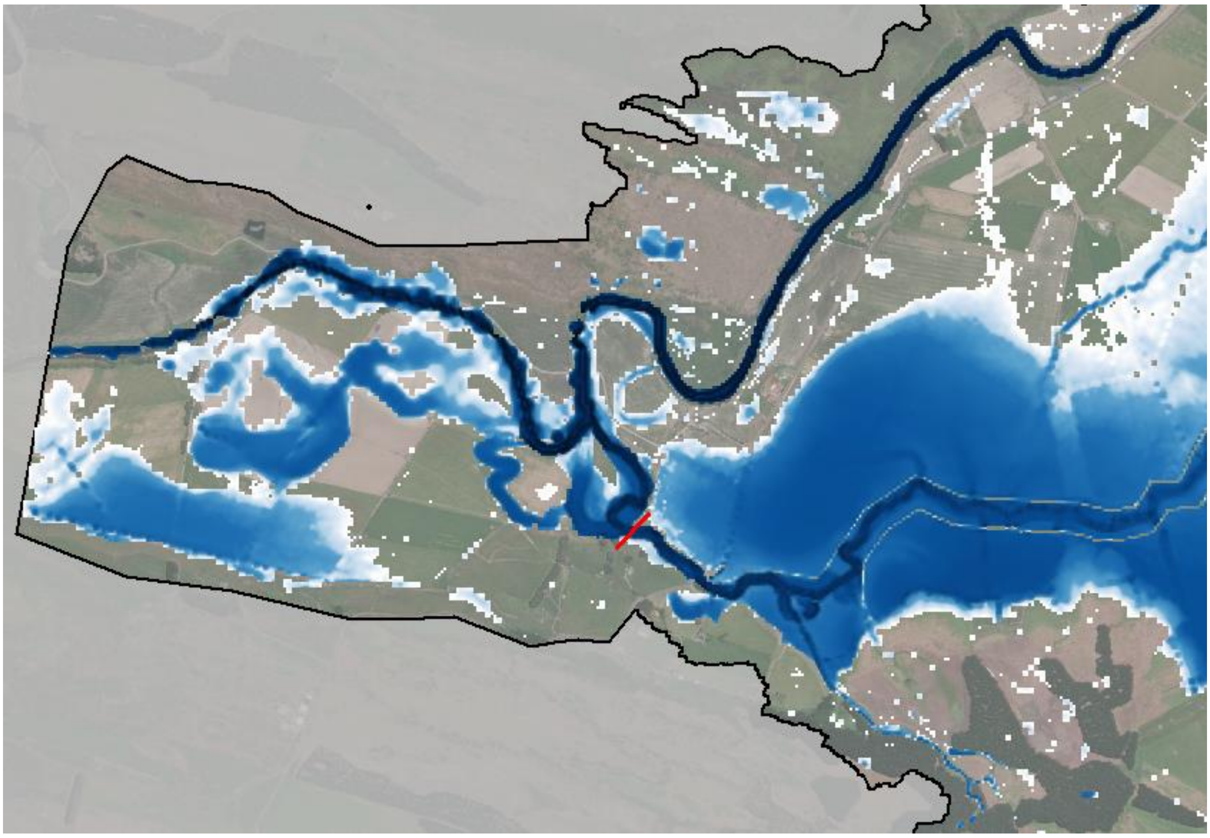


Figure 7.6: Flow hydrograph extraction location

Figure 7.7 shows the two hydrographs from the hydraulic and hydrological models, at the same point along the catchment. The graph shows good convergence between the two models, giving confidence with the hydraulic model results.

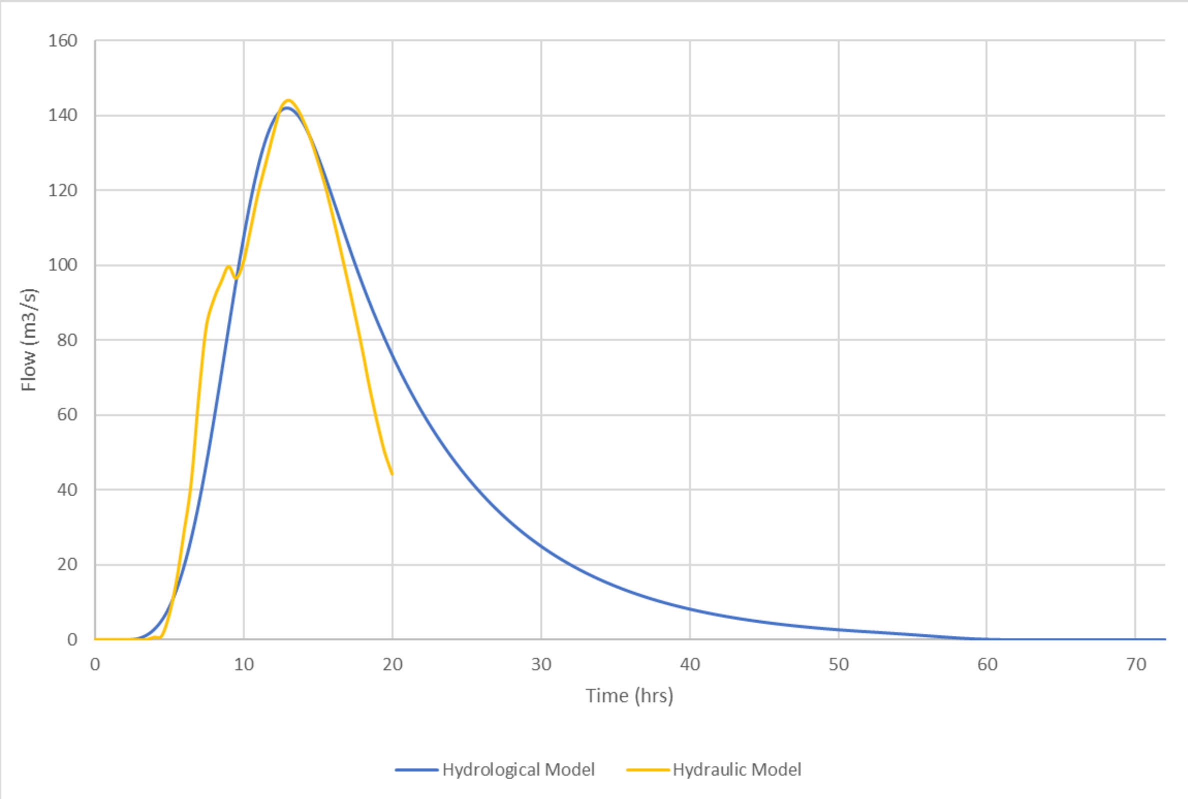


Figure 7.7: Hydraulic vs hydrological hydrograph at confluence of the Makirikiri Stream

8 Model sensitivity

To gain confidence in the outputs from the model, certain elements of the model were changed to see the resultant effects on model outputs such as flood levels, flows and flood plain extent. All sensitivity tests were compared to a 'baseline' event, which was the 200-Year, 12-hour present day climate event.

8.1 Channel lowering

Given that LiDAR is notorious for not necessarily capturing stream invert levels, these were all lowered by 0.5 m and 1 m (in two separate runs) to test the resultant change in flooding effects. It was found that lowering of channel inverts decreased flood levels by up to 100 mm, and flood extent decreased around the lower reaches of the Makirikiri stream.

8.2 Increasing rainfall

Rainfall uncertainty is driven by potential spatial variation, and to test sensitivity rainfall depths were increased by 25% from the 200-year, 12-hour present day event. This is meant to signify an extreme rainfall event, and resultant increases in flood levels and extent were checked.

Flood levels increased by a maximum of 250 mm, and flood extent increased slightly in the lower reaches of the Makirikiri Stream and surrounding inundated farmland.

8.3 Roughness

Manning's roughness values as presented in Section 4 were changed by ± 20% (i.e., two additional runs) to observe resultant changes in results. Increasing roughness increased flood levels by around 50 mm, and decreasing roughness decreased flood levels by around 80 mm. This represents a sensitivity range for this variable, which is comparable to the DEM vertical accuracy range.

8.4 Infiltration

Infiltration in soil is a process that affects the runoff generation from the catchment. The original scenario included the calibrated infiltration from the hydrological model, with an initial loss of 5 mm and a constant loss of 1 mm/h. These infiltration values were changed by ± 20% to see the resultant change in results.

When infiltration was reduced, there was a resultant 40 mm increase in flood levels in the areas with the most ponding (i.e., lower reaches of the Makirikiri Stream), where you would expect to see the highest level of difference. Flood level difference across other areas were negligible. Flood extent did not change.

8.5 Pre-filling dams

There were 31 dams identified within the model extent, as shown in Figure 8.1. These were pre-filled to the crest level at the start of the model simulation. A sensitivity run found that there was negligible difference in flood levels when these dams were not pre-filled.

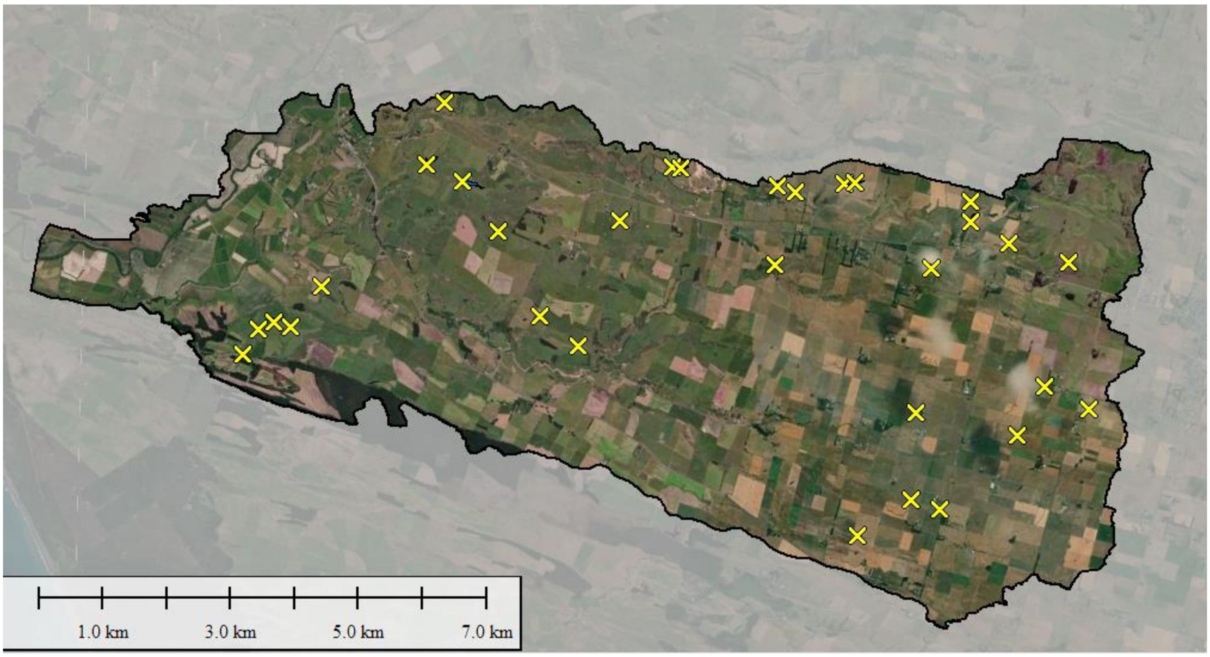


Figure 8.1: Identified dam locations

8.6 Turakina hydrograph inflows

As outlined in Section 4.6, a part of the Turakina river was included in the model to determine the effect on flooding in the Makirikiri catchment. This was done because it is difficult to separate the two waterways, especially under flood flow conditions. Flood flow timing between Turakina and Makirikiri therefore is an introduced model complexity. To ensure a compatible approach, the Makirikiri model was initially run with no tailwater contribution from the Turakina. This was done to determine flood flow timing relative to rainfall event start time.

The 200-year results are shown in this section, and both the 100-year and 200-year events are mapped in Appendix B for all Turakina River inflow scenarios discussed in this section.

Initial model runs without flows in the Turakina River showed that the maximum flood levels, and flow in the lower reaches of the Makirikiri Stream occurred at around 13 hours from event start, as shown in Figure 7.7 and Figure 8.2. Noting that the maximum flow in the Turakina from the Mike11 model occurred at 37 hours from the start of that model simulation. It was thus necessary to adjust boundary time to correspond with the Makirikiri model.

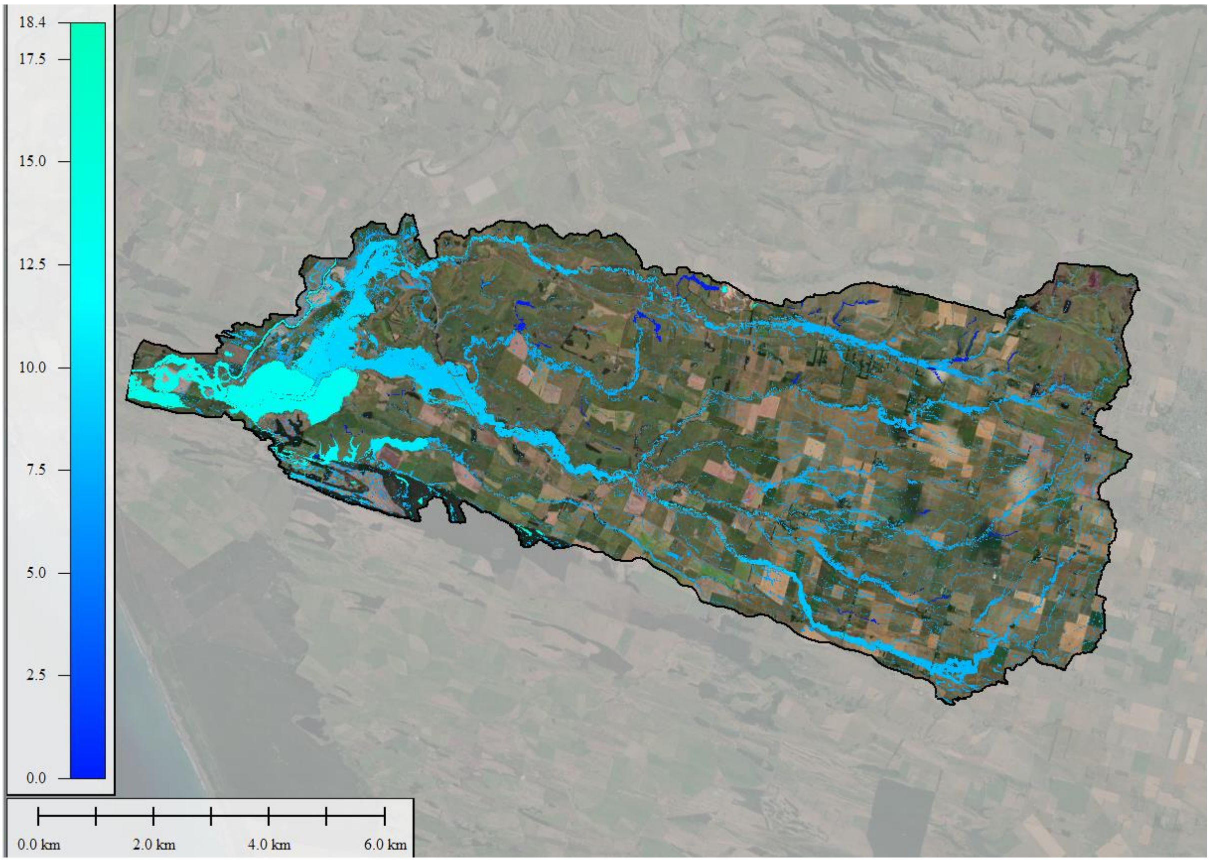


Figure 8.2: Time of peak flood level (hours)

The following scenarios, as shown in Figure 8.3 were run to determine the sensitivity of the Makirikiri Stream to inflows from the Turakina River:-

- No flows in Turakina River.
- Unadjusted Hydrograph: Turakina inflow hydrograph from Mike 11 results, starting at t=0 hrs.
- Shifted Back 12 Hours: Turakina inflow hydrograph from Mike 11 results, starting at t=12 hrs.
- Shifted Back 24 Hours: Turakina inflow hydrograph from Mike 11 results, starting at t=24 hrs (Aligning peaks).

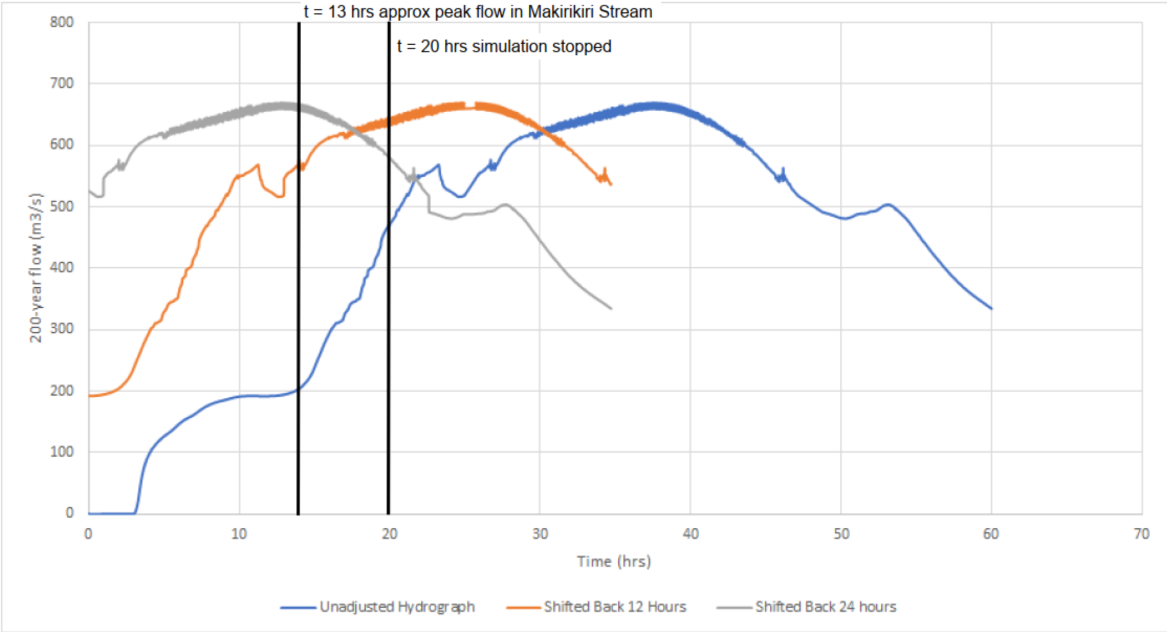


Figure 8.3: 200-year Turakina River inflow hydrograph

Figure 8.4 shows the flood extents of the four scenarios mentioned above. The influence of the Turakina River on the Makirikiri catchment extends up to the flood scheme and towards the Kahuraponga Stream but does not influence flooding past this area. The largest influence on flood extent is around the northern end of the flood plain. Flood depth increases by up to 1 m across the affected area.

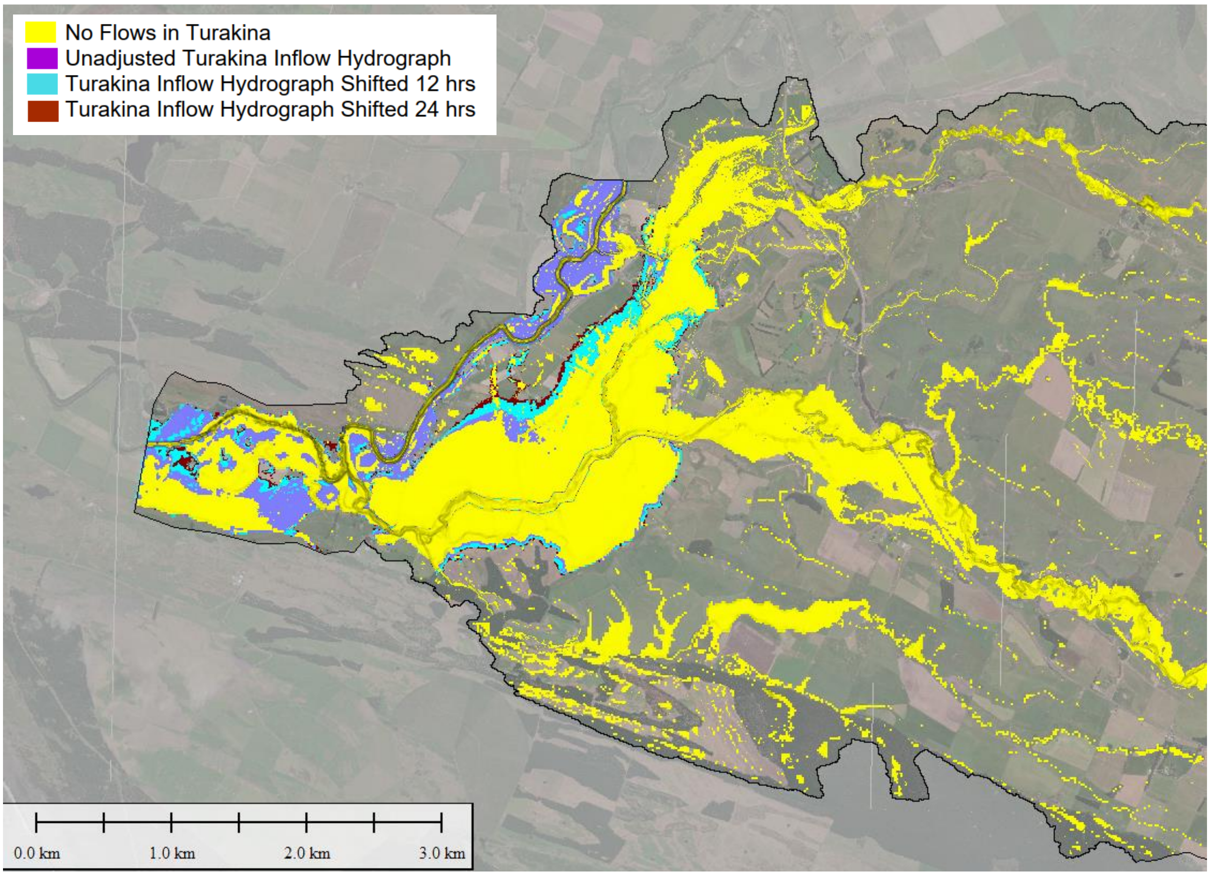


Figure 8.4: Flood extents for different Turakina inflow hydrographs

From Figure 8.4: it can be seen that the largest flood extent in the Makirikiri catchment occurs when the inflow and tailwater boundaries are shifted by 24 hours from the Mike11 model start time. Also evident from Figure 8.4 is that the effect of this is relatively small, meaning that this part of the modelling is not of critical significance to the results.

There was significant discussion on how real this relative catchment peak timing may be. Given the fairly flat hydrograph peak in the Turakina, it was found that timing has small effect as long as the Makirikiri hydrograph peaks at some time during the higher flow part of the Turakina hydrograph.

9 Results

9.1 Flood depths

Appendix B shows flood depth maps for the model extent shown in Figure 1.1. Results are shown for the scenarios ticked in Table 9.1. Hydrological analysis showed that the 12-hour rainfall event was critical for the Makirikiri catchment. Climate change scenario was chosen to be RCP6.0 with future climate horizon of 2120.

Table 9.1: Model Run matrix

Storm Duration	ARI	Climate change scenario	No Turakina Inflows	Turakina Inflow Hydrograph, shifted 24 hrs ('aligning peaks')
12 Hour	20-Year	Present day	✓	×
		With Climate Change	×	×
	50-Year	Present day	✓	×
		With Climate Change	×	×
	100-Year	Present day	✓	✓
		With Climate Change	✓	×
	200-Year	Present day	✓	✓
		With Climate Change	✓	×

Flood depth maps for the 20-year, 50-year and 100-year ARI events have no inflows from the Turakina river, as shown in Appendix B1. This is because only 200-year ARI, present day climate inflows were set up for the model as per Section 4.6. 200-year results, with and without inflows from the Turakina River, are shown in Appendix B2.

9.2 Sensitivity

Model sensitivity was assessed as described in Section 8. Model results of all sensitivity runs were amalgamated in to a "fuzzy" map. This representation indicates the frequency of individual cells in the model being shown to be flooded over all sensitivity runs. For example, if a particular model cell is flooded for all sensitivity runs, there is a high degree of confidence that this cell is flood prone. Conversely, if another cell is only inundated for one of the sensitivity runs, there is lower confidence in this cell being flooded.

Appendix D shows the resultant sensitivity fuzzy map. Cells coloured red are those which did not flood for many of the sensitivity runs, while those coloured blue were flooded across all sensitivity runs.

9.3 Results limitations

Listed below are a summary of limitations to the modelling work that HRC should consider when interpreting and using model results. Many of these factors have been considered through the sensitivity testing described above, and we recommend using the fuzzy map as a confidence overlay to the reported results.

- Digital Elevation Model (DEM) derived from remotely sensed LiDAR survey captured in 2015/16. The limitations of accuracy of LiDAR data are well understood, and these limitations will apply to the model results obtained. In particular, LiDAR survey data and the resulting DEM will have lower accuracy in areas such as incised waterways, heavily vegetated areas, places where above-ground features have been removed and water bodies. Furthermore, where ground levels have been changed since the LiDAR survey was captured, the DEM and hence the model will not recognise these changes (and will be out of date).
- With the adopted approach of removing constrictions offered by bridges and culverts where information is not available, it is possible that flood extents upstream of such structures may be under-estimated. This is especially the case where the lack of capacity through such structures is a major contributor to surface flooding.
- Rainfall was applied globally following a calibrated temporal profile of 12-hour duration. While this gave the most severe results in the lower parts (the areas generally most prone to flooding), this will not be the critical duration for flooding in smaller waterways upstream, and as such the results presented may not globally capture a potential worst case for the given frequency event.
- Roughness applied to the model has been developed through other modelling studies and not through the preferred approach of detailed site-specific calibration. In keeping with the intended purpose of this modelling, this approach can be applied globally but will lack site specific detail.
- A direct rainfall approach has been applied to this model, which can highlight accuracy deficiencies in input data by showing small "puddles" in predicted flooding. It is usual with flood depth results from this kind of modelling approach that the results be "cleaned" by removing puddles before publication. T+T has presented raw model results in this report, in anticipation of HRC undertaking "cleaning" of model results before publication and further use.
- It is worth noting that the modelling undertaken as part of this study simulates the flood related effects of an extreme 200-year ARI rainfall event that is based on future climate predictions. The severity of such an event is above that which has been experienced in most areas within living memory (i.e., the results may look very severe relative to recent observations).
- We are aware that New Zealand experiences Vertical Land Movement that varies spatially. This can affect flood model results in areas where sea level has influence. This has not been considered for this work, yet it arguably should be considered given the minimum 200-year future timeframe being considered.
- We are aware that, given the large spatial extent in this exercise, there may be overlapping results from other models within the model results in the future. It is likely that these other models will have been developed using finer-scale inputs and more detail in the representation of key drainage infrastructure. In all such areas we recommend giving consideration to such other models, with a general approach of preferring the results from models of reduced extent over the results produced in this project.

10 Conclusions

A TUFLOW HPC model has been built for the Makirikiri Catchment to determine flood risk within the catchment. The model utilised rain-on-grid hydrology. The model has been run for 2, 50, 100 and 200-year ARI events using both present day and RCP6.0 (with future climate horizon of 2120) scenarios. The 12 – hour storm duration has been identified as critical through hydrological analysis.

Maximum flood depth maps have been derived from model results.

11 Applicability

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

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Alex White Water Resources Engineer	Peter Cochrane Project Director

Technical Review by Mark Pennington.

ALWH
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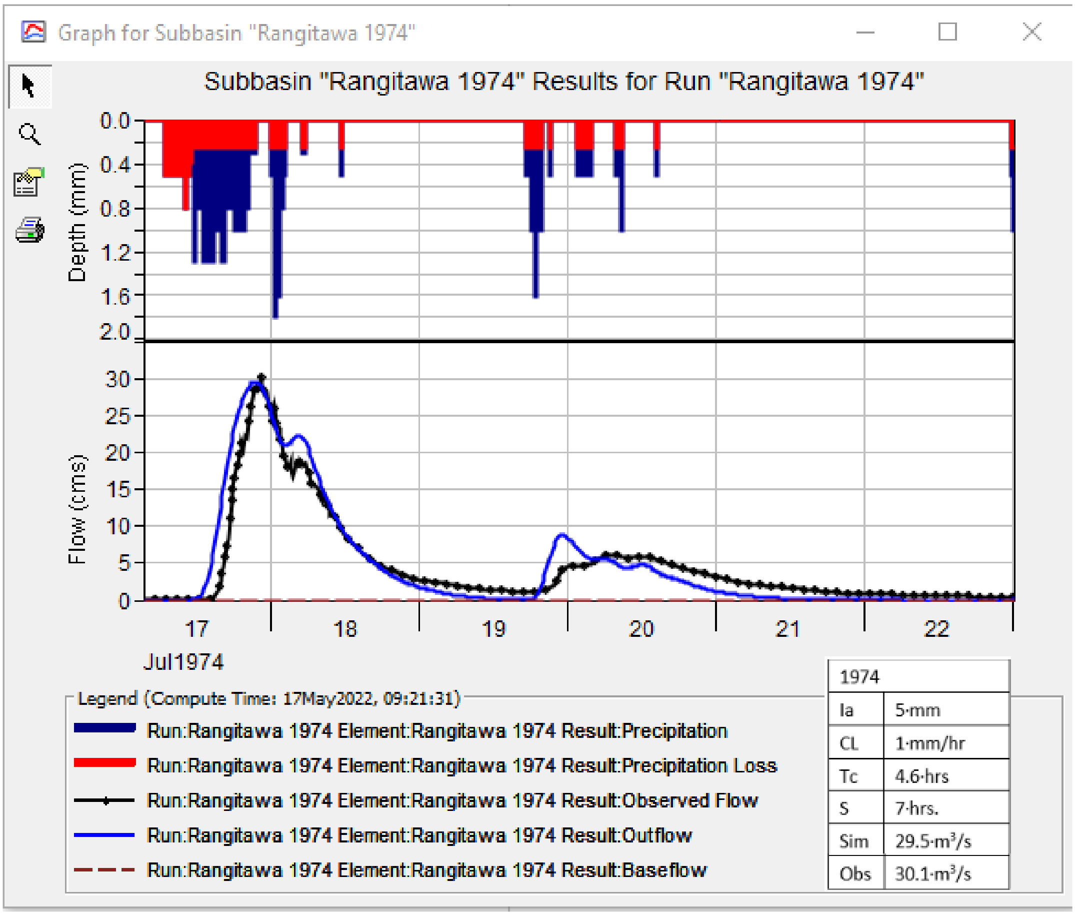
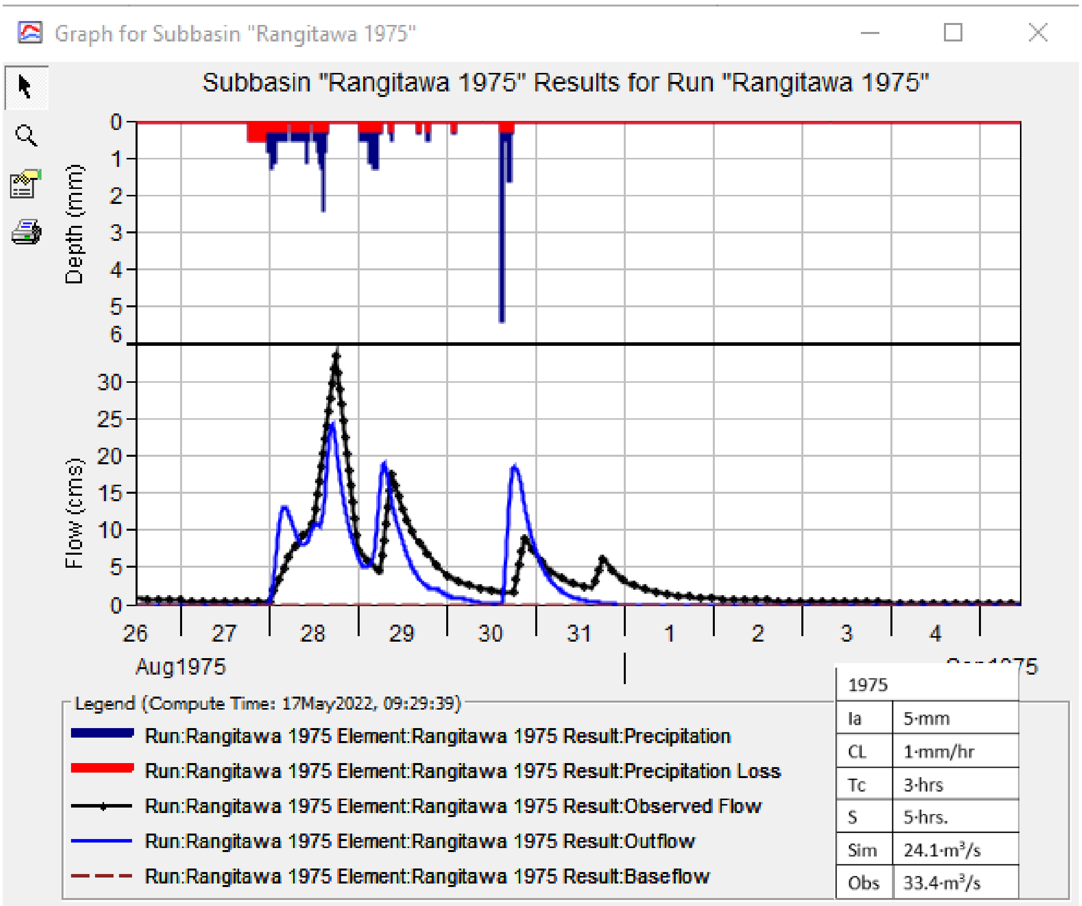
Appendix A Hydrological model calibration: Rangitawa at Halcomb

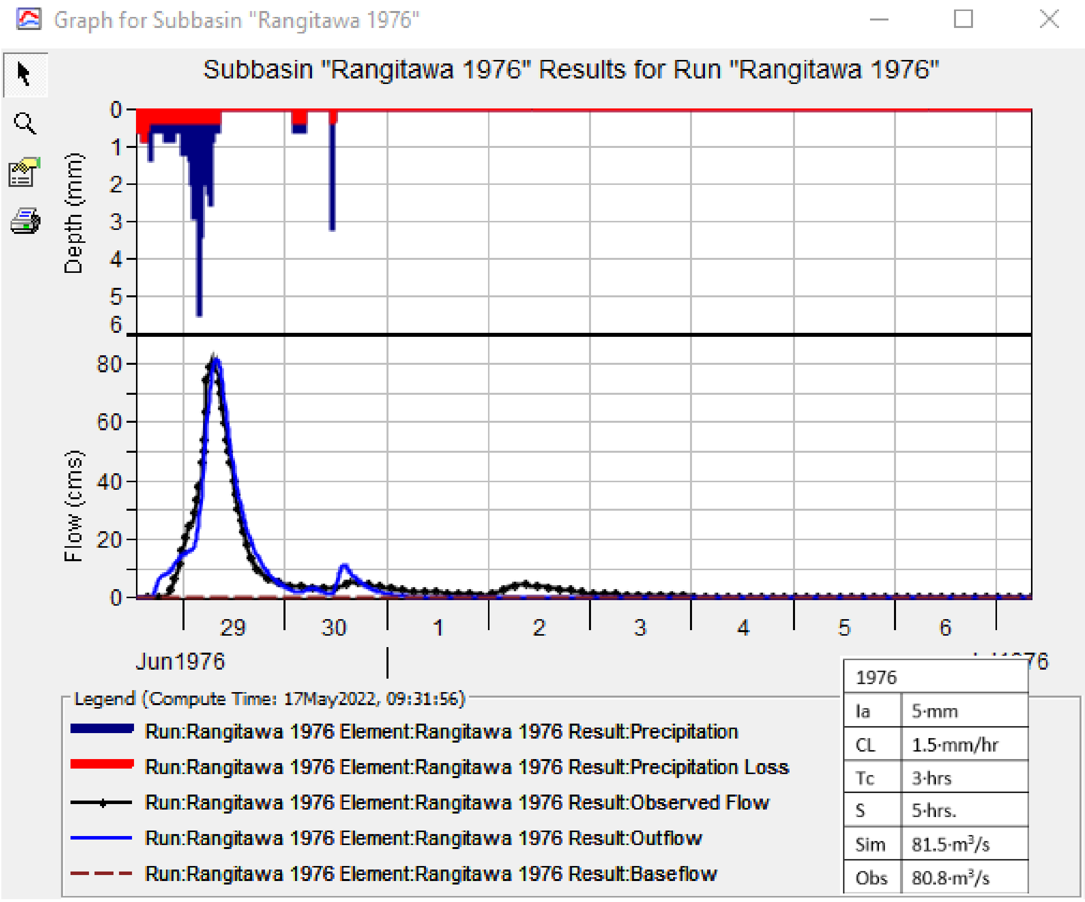
- **17 July 1974**
- **28 August 1975**
- **29 June 1976**
- **19 September 1977**
- **20 July 1978**
- **25 August 1979**
- **27 August 1980**

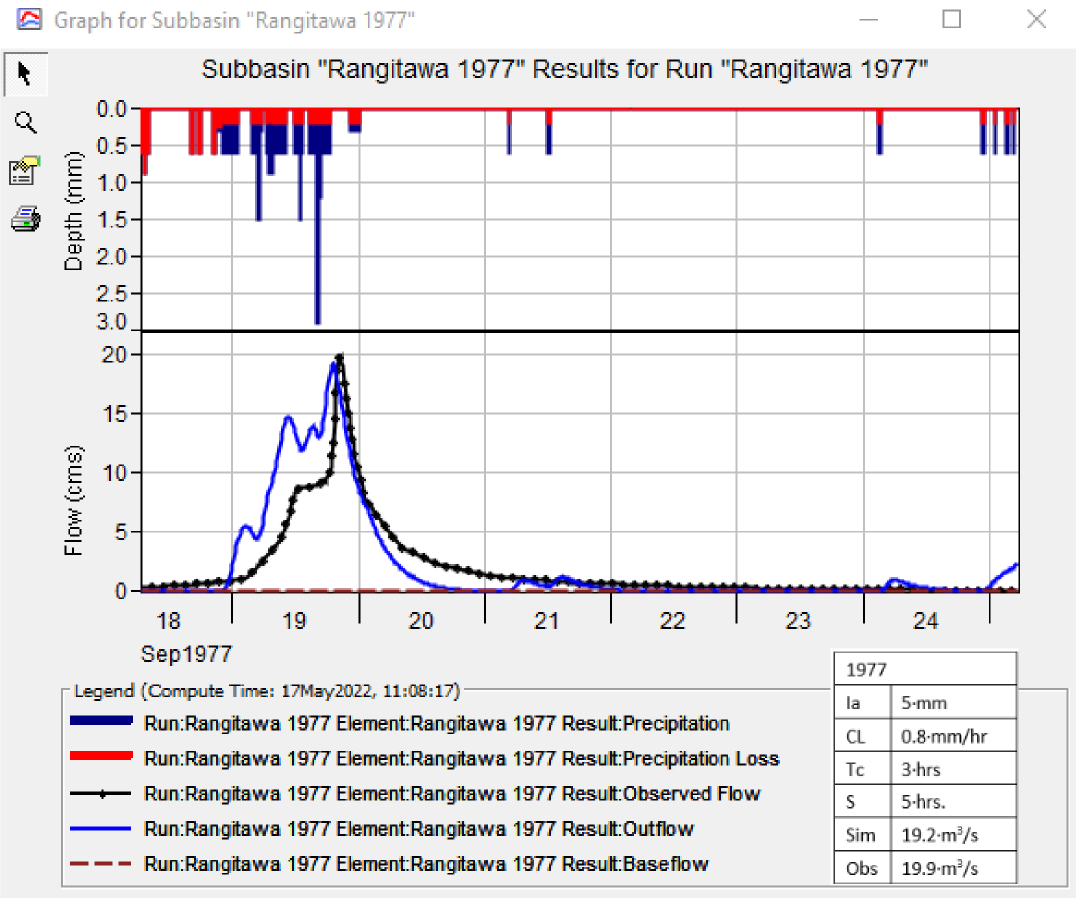


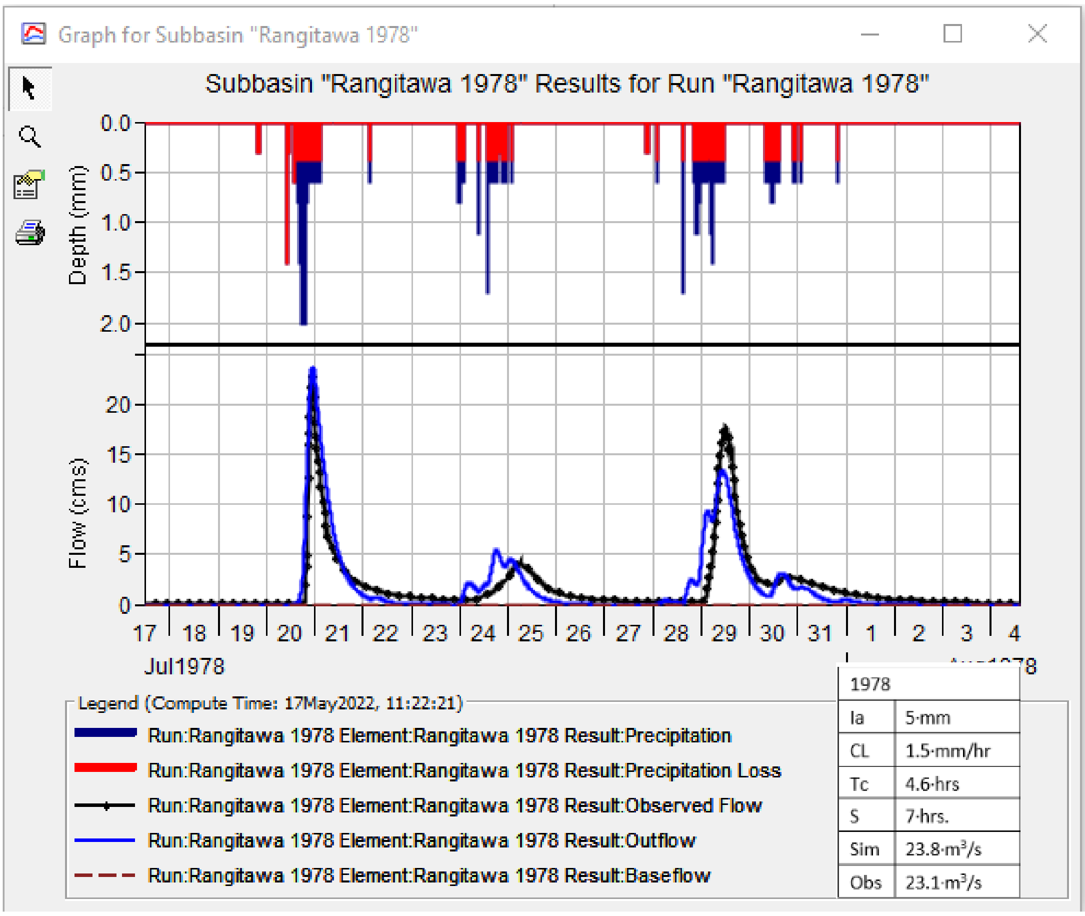
Graph for Subbasin "Rangitawa 1974"
Subbasin "Rangitawa 1974" Results for Run "Rangitawa 1974"
Depth (mm)
0.0
0.4
0.8
1.2
1.6
2.0
Flow (cms)
30
25
20
15
10
5
0
17
18
19
20
21
22
Jul1974
Legend (Compute Time: 17May2022, 09:21:31)
Run:Rangitawa 1974 Element:Rangitawa 1974 Result:Precipitation
Run:Rangitawa 1974 Element:Rangitawa 1974 Result:Precipitation Loss
Run:Rangitawa 1974 Element:Rangitawa 1974 Result:Observed Flow
Run:Rangitawa 1974 Element:Rangitawa 1974 Result:Outflow
Run:Rangitawa 1974 Element:Rangitawa 1974 Result:Baseflow
1974
Ia 5 mm
CL 1 mm/hr
Tc 4.6 hrs
S 7 hrs.
Sim 29.5 m³/s
Obs 30.1 m³/s

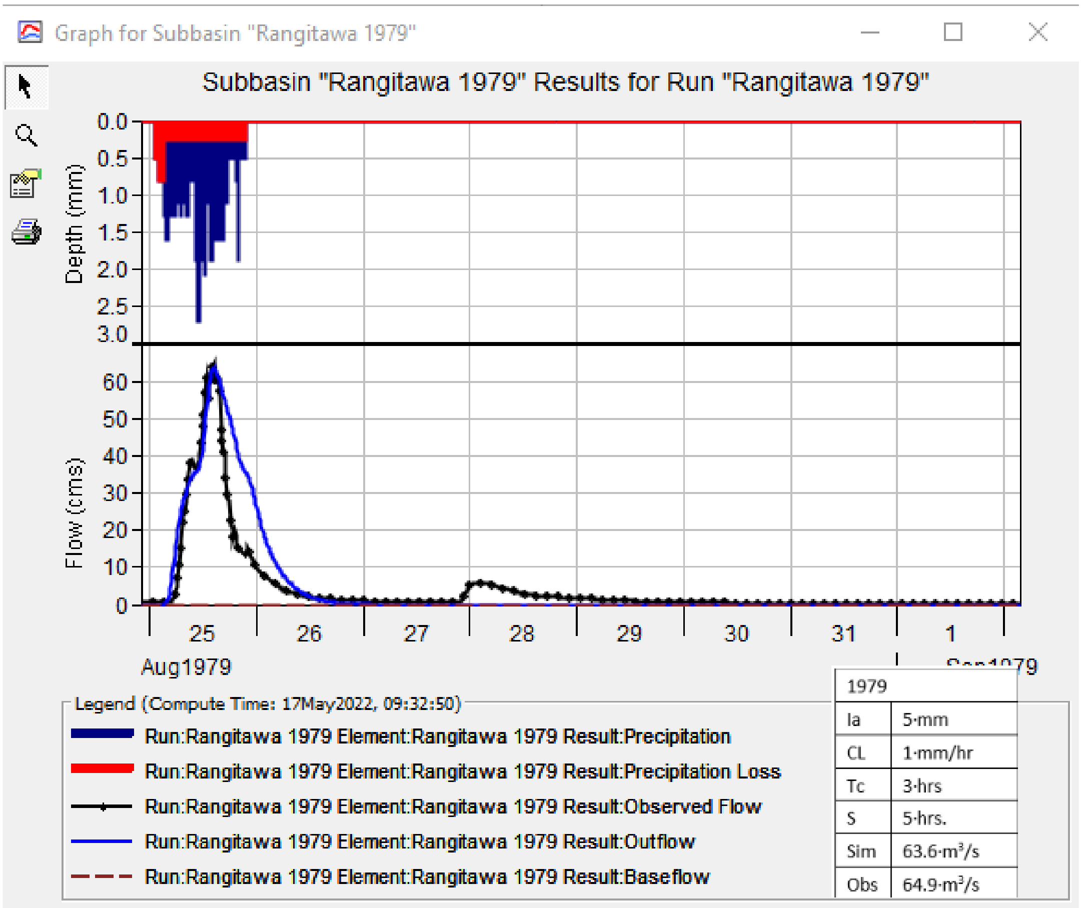


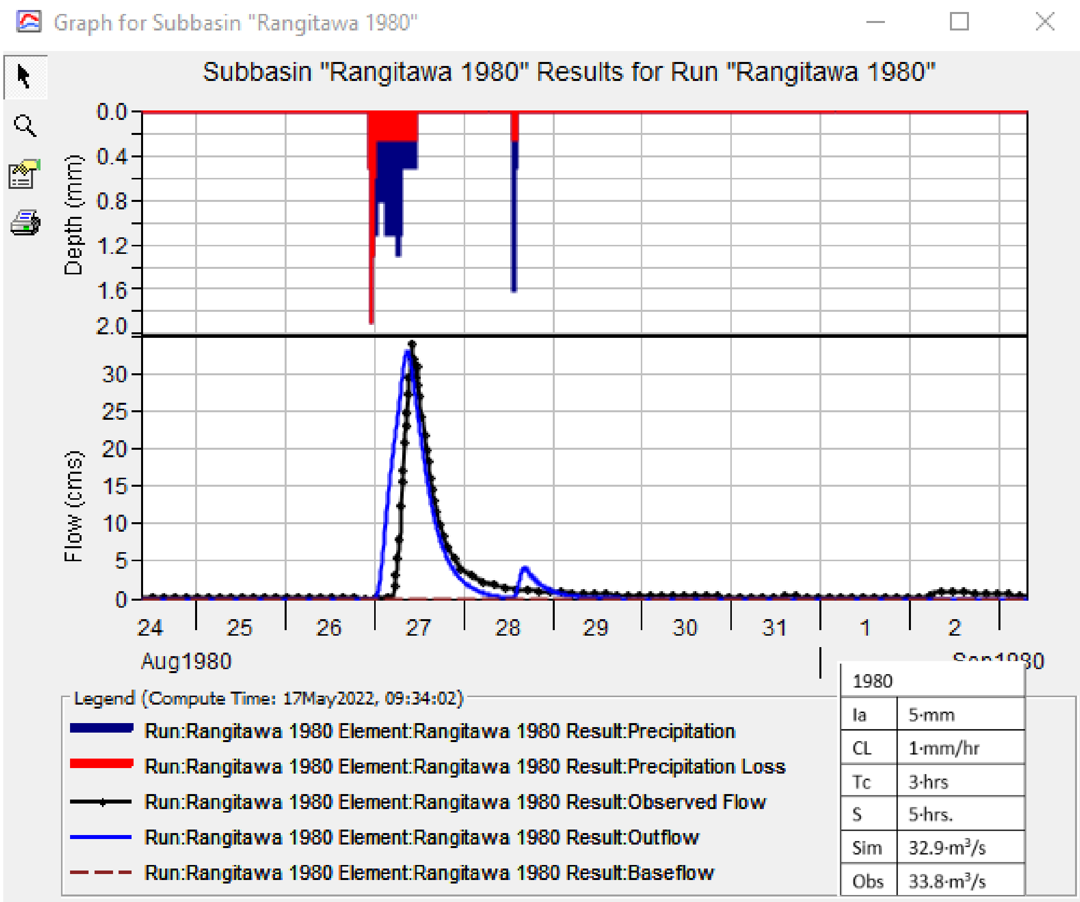
Graph for Subbasin "Rangitawa 1975"
Subbasin "Rangitawa 1975" Results for Run "Rangitawa 1975"
Depth (mm)
0
1
2
3
4
5
6
Flow (cms)
30
25
20
15
10
5
0
26
27
28
29
30
31
1
2
3
4
Aug1975
Legend (Compute Time: 17May2022, 09:29:39)
Run:Rangitawa 1975 Element:Rangitawa 1975 Result:Precipitation
Run:Rangitawa 1975 Element:Rangitawa 1975 Result:Precipitation Loss
Run:Rangitawa 1975 Element:Rangitawa 1975 Result:Observed Flow
Run:Rangitawa 1975 Element:Rangitawa 1975 Result:Outflow
Run:Rangitawa 1975 Element:Rangitawa 1975 Result:Baseflow
1975
Ia 5 mm
CL 1 mm/hr
Tc 3 hrs
S 5 hrs.
Sim 24.1 m³/s
Obs 33.4 m³/s


Graph for Subbasin "Rangitawa 1976"
Subbasin "Rangitawa 1976" Results for Run "Rangitawa 1976"
Depth (mm)
Flow (cms)
Jun1976
Legend (Compute Time: 17May2022, 09:31:56)
Run:Rangitawa 1976 Element:Rangitawa 1976 Result:Precipitation
Run:Rangitawa 1976 Element:Rangitawa 1976 Result:Precipitation Loss
Run:Rangitawa 1976 Element:Rangitawa 1976 Result:Observed Flow
Run:Rangitawa 1976 Element:Rangitawa 1976 Result:Outflow
Run:Rangitawa 1976 Element:Rangitawa 1976 Result:Baseflow
1976
Ia 5 mm
CL 1.5 mm/hr
Tc 3 hrs
S 5 hrs.
Sim 81.5 m³/s
Obs 80.8 m³/s


Graph for Subbasin "Rangitawa 1977"
Subbasin "Rangitawa 1977" Results for Run "Rangitawa 1977"
Depth (mm)
Flow (cms)
Sep1977
Legend (Compute Time: 17May2022, 11:08:17)
Run:Rangitawa 1977 Element:Rangitawa 1977 Result:Precipitation
Run:Rangitawa 1977 Element:Rangitawa 1977 Result:Precipitation Loss
Run:Rangitawa 1977 Element:Rangitawa 1977 Result:Observed Flow
Run:Rangitawa 1977 Element:Rangitawa 1977 Result:Outflow
Run:Rangitawa 1977 Element:Rangitawa 1977 Result:Baseflow
1977
Ia 5 mm
CL 0.8 mm/hr
Tc 3 hrs
S 5 hrs.
Sim 19.2 m³/s
Obs 19.9 m³/s


Graph for Subbasin "Rangitawa 1978"
Subbasin "Rangitawa 1978" Results for Run "Rangitawa 1978"
Depth (mm)
Flow (cms)
Jul1978
Aug1978
Legend (Compute Time: 17May2022, 11:22:21)
Run:Rangitawa 1978 Element:Rangitawa 1978 Result:Precipitation
Run:Rangitawa 1978 Element:Rangitawa 1978 Result:Precipitation Loss
Run:Rangitawa 1978 Element:Rangitawa 1978 Result:Observed Flow
Run:Rangitawa 1978 Element:Rangitawa 1978 Result:Outflow
Run:Rangitawa 1978 Element:Rangitawa 1978 Result:Baseflow
1978
Ia 5 mm
CL 1.5 mm/hr
Tc 4.6 hrs
S 7 hrs.
Sim 23.8 m³/s
Obs 23.1 m³/s


Graph for Subbasin "Rangitawa 1979"
Subbasin "Rangitawa 1979" Results for Run "Rangitawa 1979"
Depth (mm)
Flow (cms)
Aug1979
Sep1979
Legend (Compute Time: 17May2022, 09:32:50)
Run:Rangitawa 1979 Element:Rangitawa 1979 Result:Precipitation
Run:Rangitawa 1979 Element:Rangitawa 1979 Result:Precipitation Loss
Run:Rangitawa 1979 Element:Rangitawa 1979 Result:Observed Flow
Run:Rangitawa 1979 Element:Rangitawa 1979 Result:Outflow
Run:Rangitawa 1979 Element:Rangitawa 1979 Result:Baseflow
1979
Ia 5 mm
CL 1 mm/hr
Tc 3 hrs
S 5 hrs.
Sim 63.6 m³/s
Obs 64.9 m³/s


Graph for Subbasin "Rangitawa 1980"
Subbasin "Rangitawa 1980" Results for Run "Rangitawa 1980"
Depth (mm)
Flow (cms)
Aug1980
Legend (Compute Time: 17May2022, 09:34:02)
Run:Rangitawa 1980 Element:Rangitawa 1980 Result:Precipitation
Run:Rangitawa 1980 Element:Rangitawa 1980 Result:Precipitation Loss
Run:Rangitawa 1980 Element:Rangitawa 1980 Result:Observed Flow
Run:Rangitawa 1980 Element:Rangitawa 1980 Result:Outflow
Run:Rangitawa 1980 Element:Rangitawa 1980 Result:Baseflow
1980
Ia 5 mm
CL 1 mm/hr
Tc 3 hrs
S 5 hrs.
Sim 32.9 m³/s
Obs 33.8 m³/s

Appendix B Flood depth maps

B1 20 Year, 50 Year, 100 Year ARI Peak Flood Depth Maps

- **Figure B1: 20-Year ARI, 12 Hour duration, Present-Day Climate - Flood Depth**
- **Figure B2: 50-Year ARI, 12 Hour duration, Present-Day Climate - Flood Depth**
- **Figure B3: 100-Year ARI, 12 Hour duration, Present-Day Climate - Flood Depth**
- **Figure B4: 100-Year ARI, 12 Hour duration with Climate Change - Flood Depth**
- **Figure B5: 100-Year ARI, 12 Hour duration, Present-Day Climate and Unadjusted Turakina Boundary - Flood Depth**
- **Figure B6: 100-Year ARI, 12 Hour duration, Present-Day Climate and Turakina Boundary Shifted Back 12hrs- Flood Depth**
- **Figure B7: 100-Year ARI, 12 Hour duration, Present-Day Climate and Turakina Boundary Shifted Back 24hrs- Flood Depth**

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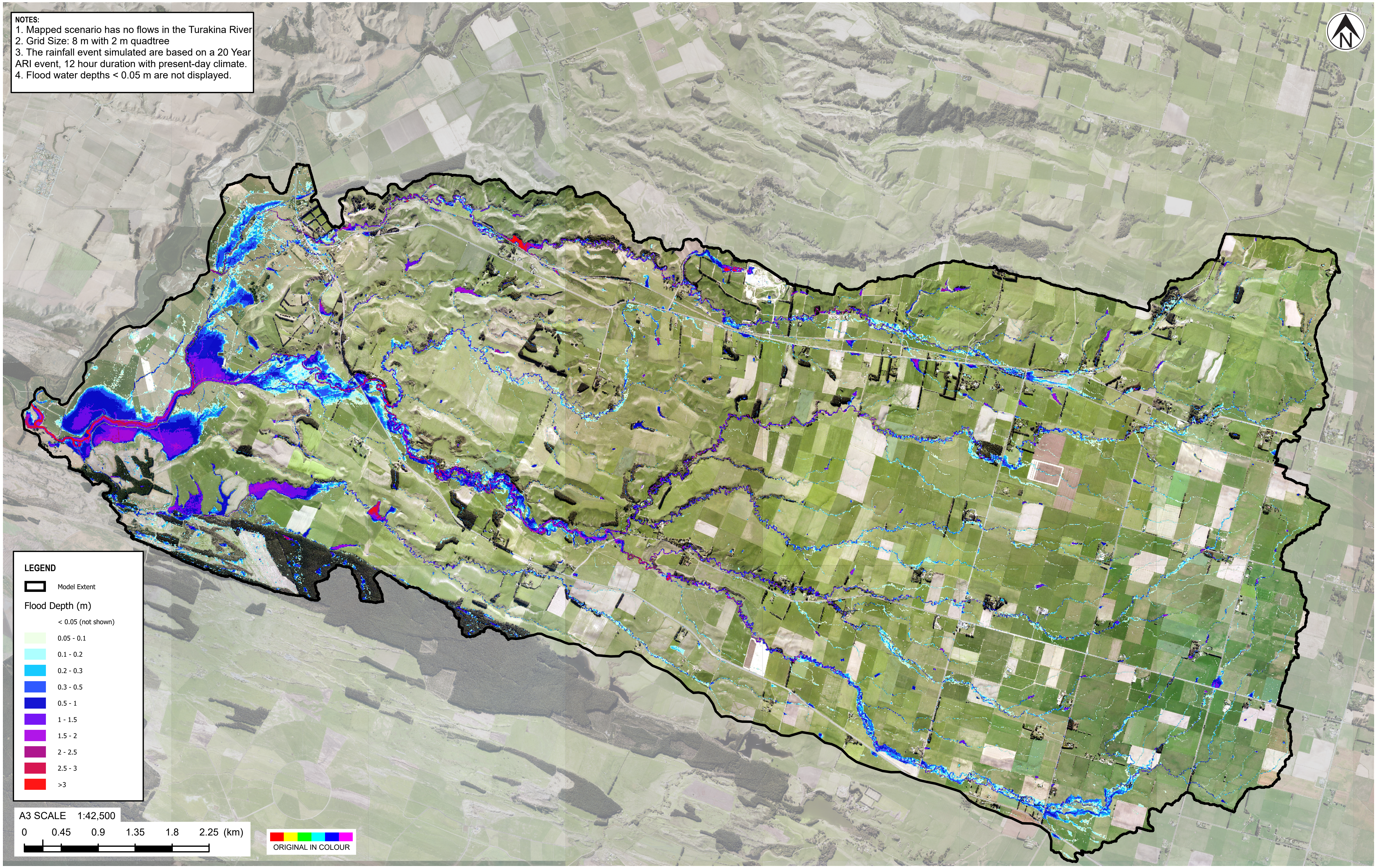
T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx Layout: 20 Year PD Full Extent 2022-Sep-07 1:08 pm Drawn by ALWH



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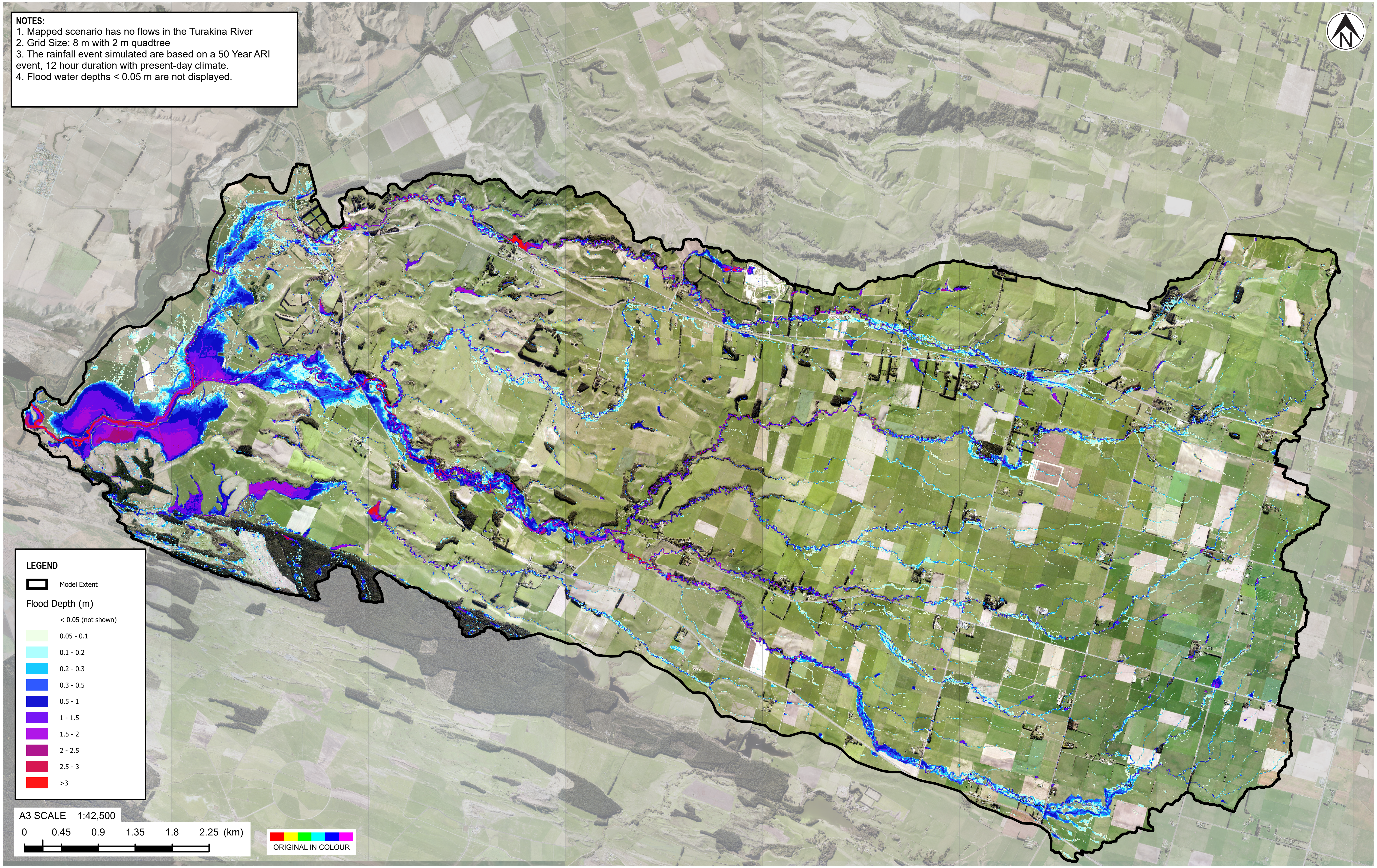
PROJECT **MAKIRIKIRI STREAM MODELLING**

TITLE 20 YEAR ARI 12 HOUR DURATION PRESENT DAY PEAK FLOOD DEPTH

SCALE (A3) 1:42,500 FIG No. FIGURE B1. REV 0

T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx Layout: 50 Year PD Full Extent 2022-Sep-07 1:08 pm Drawn by ALWH



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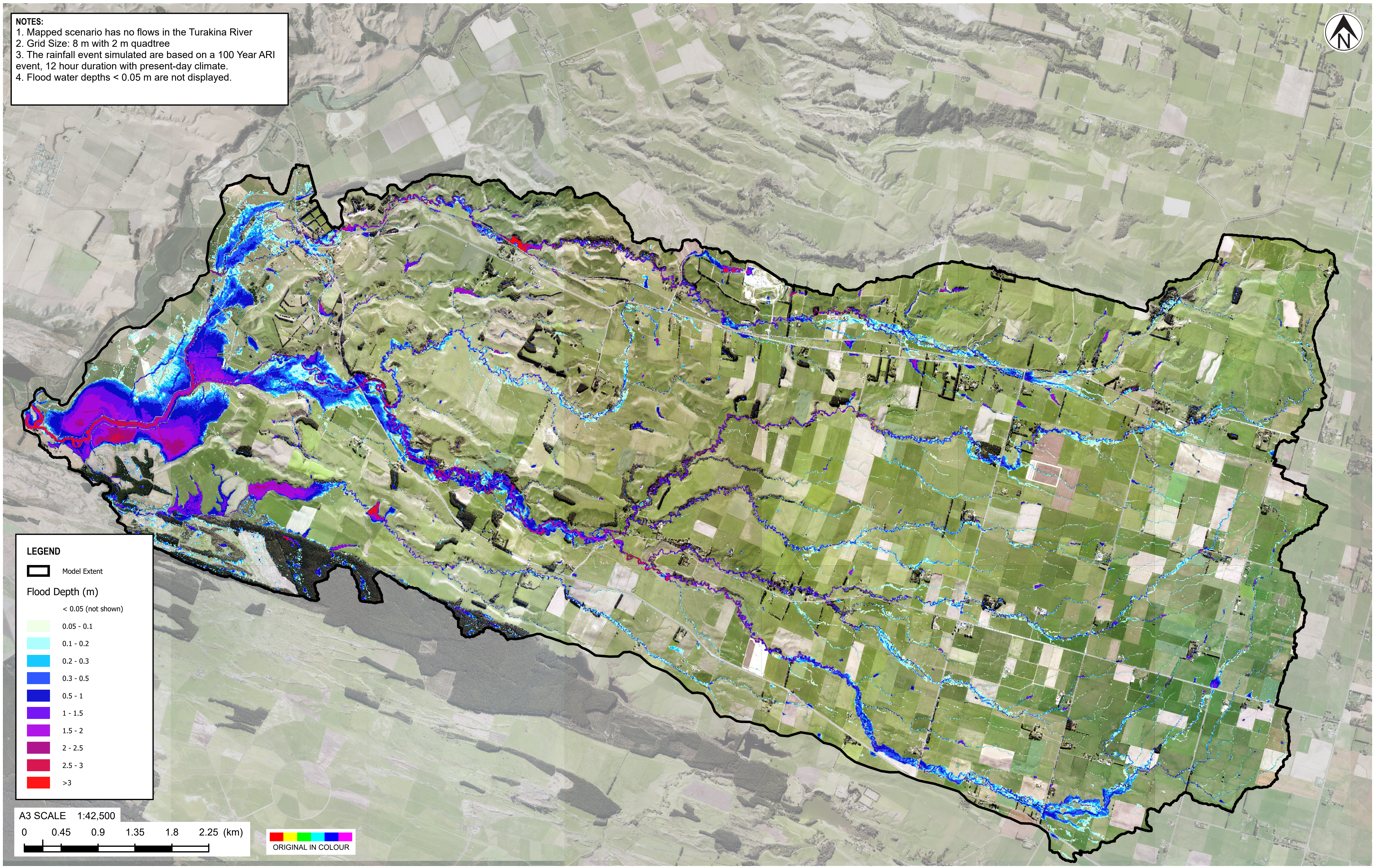
TITLE 50 YEAR ARI, 12 HOUR DURATION, PRESENT-DAY CLIMATE PEAK FLOOD DEPTH

SCALE (A3) 1:42,500 FIG No. FIGURE B2. REV 0

T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx   Layout: 100 Year PD Full Extent   2022-Sep-07 4:12 pm   Drawn by ALWH



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PROJECT: MAKIRIKIRI STREAM MODELLING

TITLE: 100 YEAR ARI 12 HOUR DURATION PRESENT DAY PEAK FLOOD DEPTH

SCALE (A3): 1:42,500   FIG No. FIGURE B3.   REV 0

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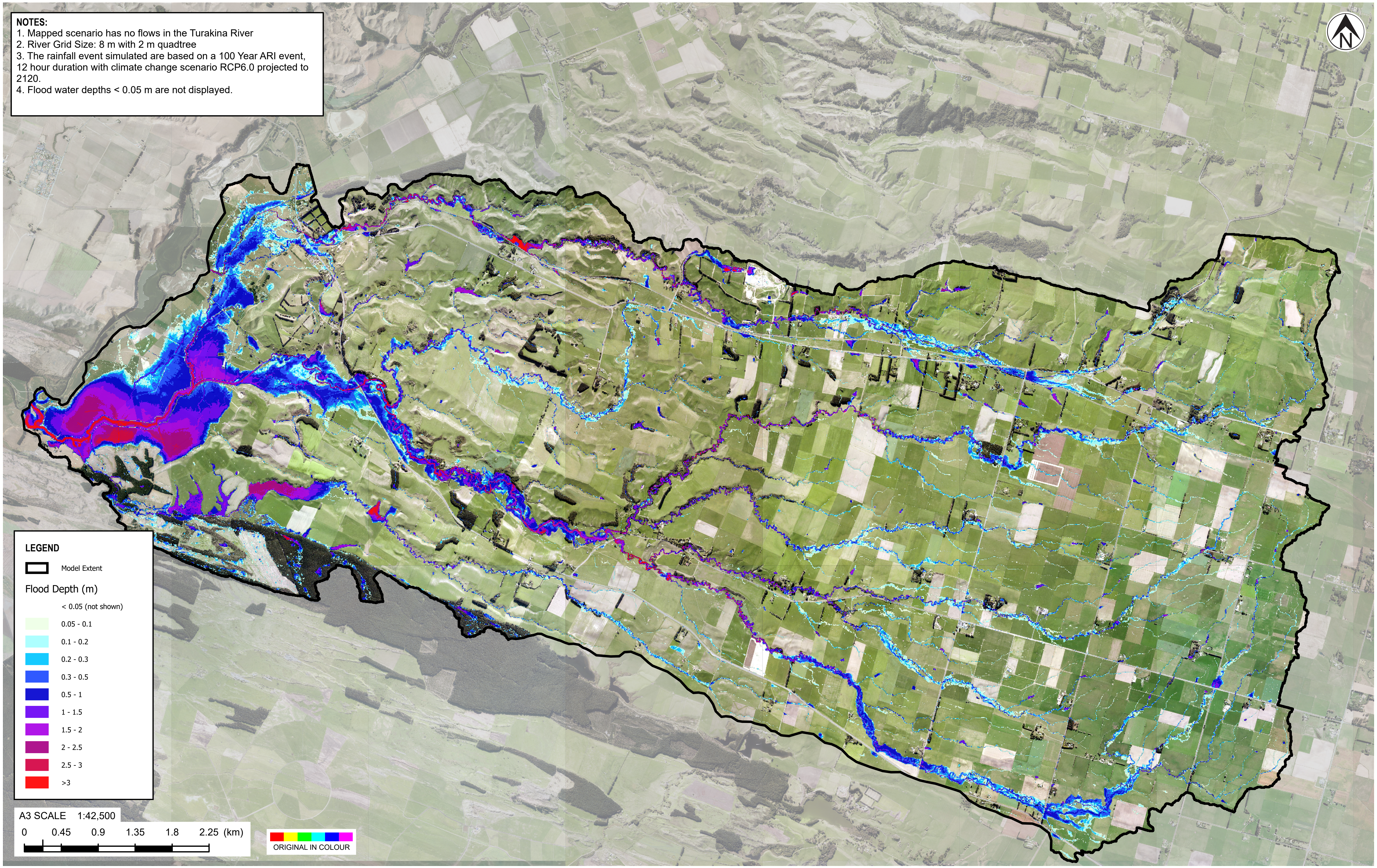

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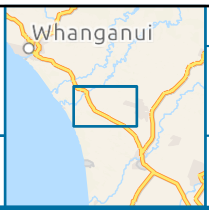

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TITLE 100 YEAR ARI 12 HOUR DURATION WITH CLIMATE CHANGE (RCP6.0, 2120) PEAK FLOOD DEPTH
SCALE (A3) 1:42,500 FIG No. FIGURE B4. REV 0

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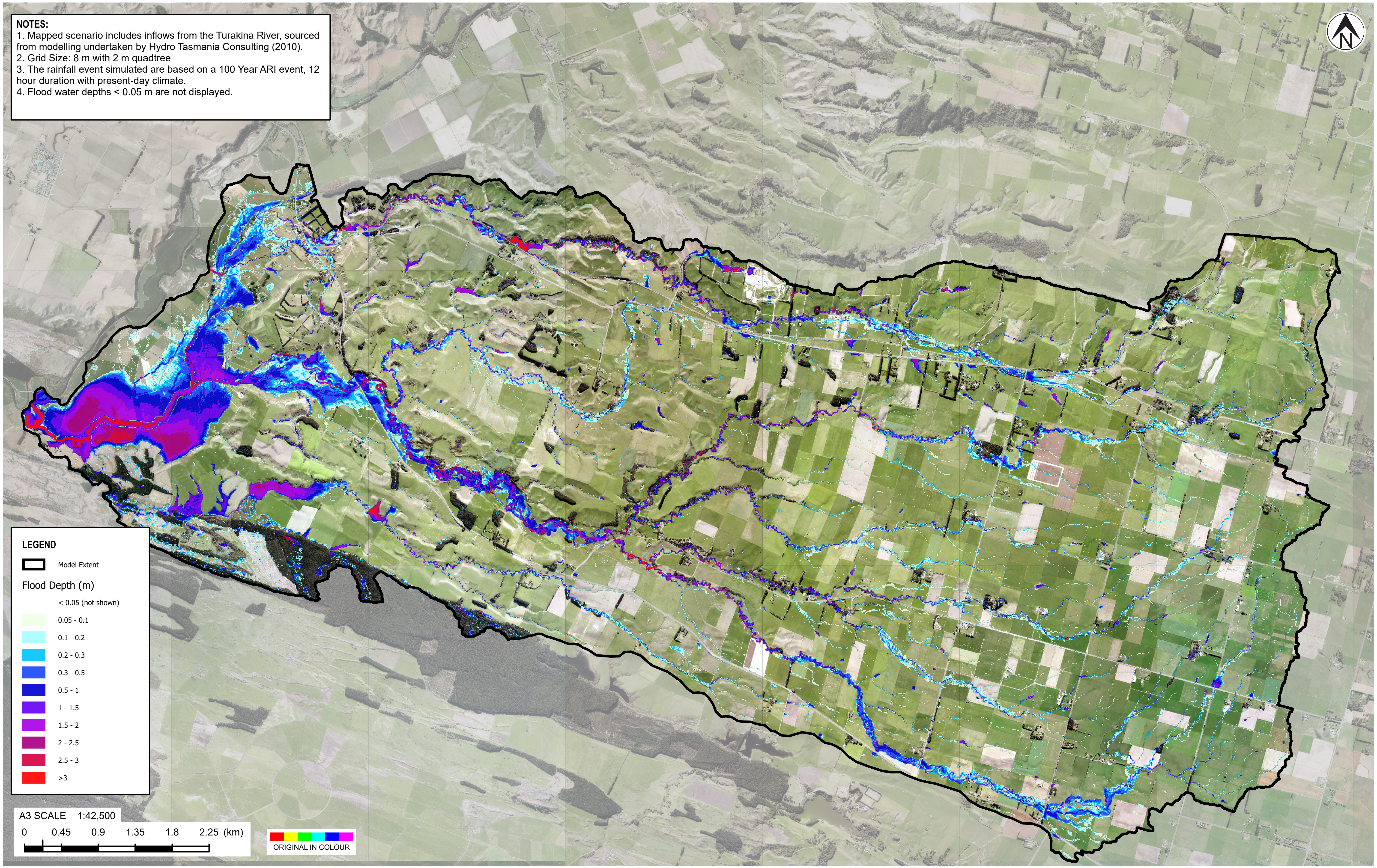
NOTES:
1. Mapped scenario includes inflows from the Turakina River, sourced from modelling undertaken by Hydro Tasmania Consulting (2010).
2. Grid Size: 8 m with 2 m quadtree
3. The rainfall event simulated are based on a 100 Year ARI event, 12 hour duration with present-day climate.
4. Flood water depths < 0.05 m are not displayed.



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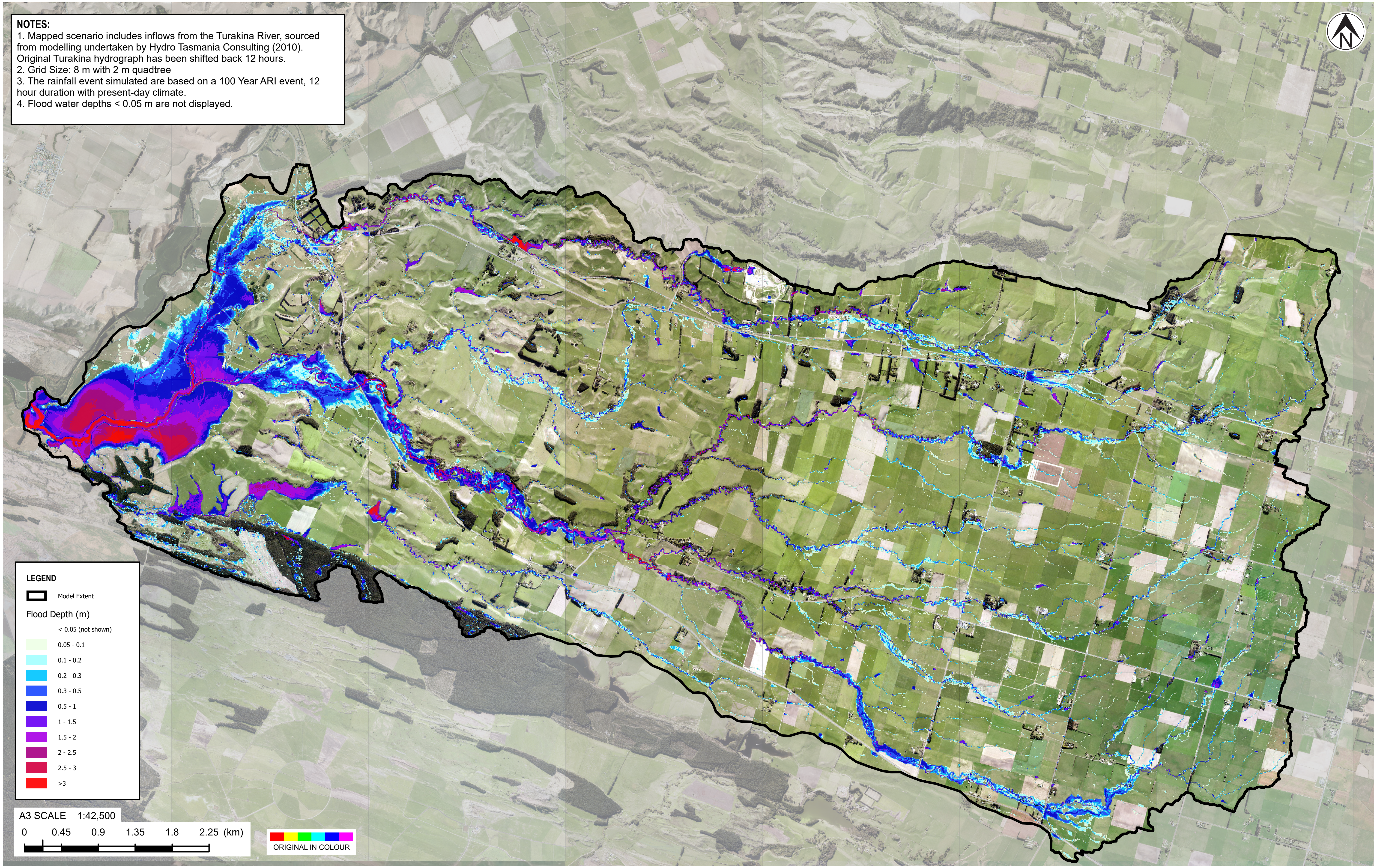
TITLE: 100 YEAR ARI, 12 HOUR DURATION, PRESENT-DAY CLIMATE AND UNADJUSTED TURAKINA BOUNDARY PEAK FLOOD DEPTH

SCALE (A3) 1:42,500 FIG No. FIGURE B5. REV 0

T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx Layout: 100 Year PD 12hr shift Turakina Full Extent 2022-Sep-07 6:09 pm Drawn by ALWH



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TITLE: 100 YEAR ARI, 12 HOUR DURATION, PRESENT-DAY CLIMATE AND TURAKINA BOUNDARY SHIFTED BACK 12HRS PEAK FLOOD DEPTH

SCALE (A3) 1:42,500   FIG No. FIGURE B6.   REV 0

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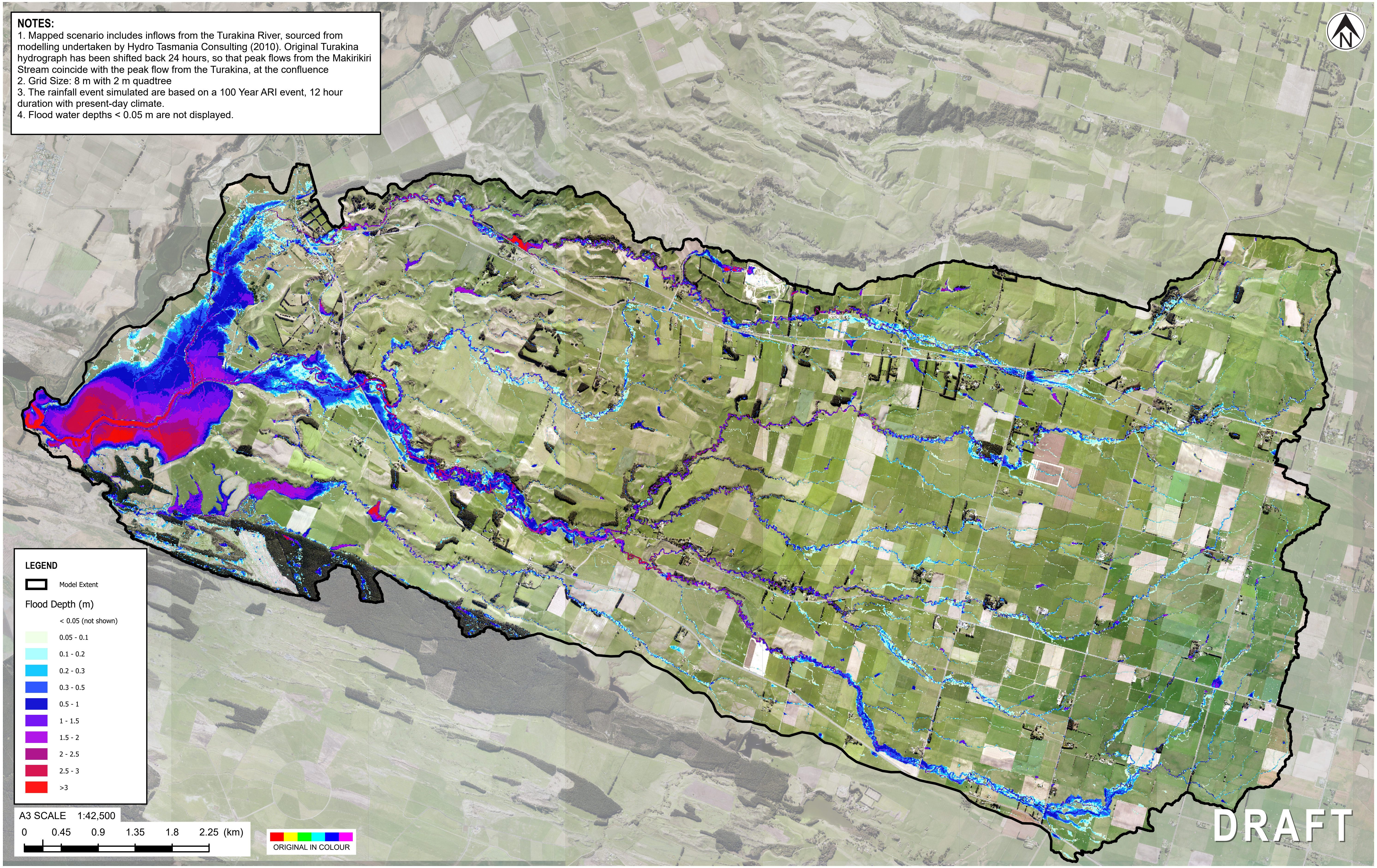
NOTES:
1. Mapped scenario includes inflows from the Turakina River, sourced from modelling undertaken by Hydro Tasmania Consulting (2010). Original Turakina hydrograph has been shifted back 24 hours, so that peak flows from the Makirikiri Stream coincide with the peak flow from the Turakina, at the confluence
2. Grid Size: 8 m with 2 m quadtree
3. The rainfall event simulated are based on a 100 Year ARI event, 12 hour duration with present-day climate.
4. Flood water depths < 0.05 m are not displayed.



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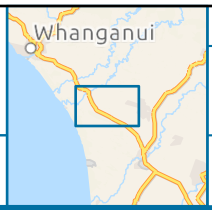

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TITLE 100 YEAR ARI, 12 HOUR DURATION, PRESENT-DAY CLIMATE AND TURAKINA BOUNDARY SHIFTED BACK 24HRS PEAK FLOOD DEPTH

SCALE (A3) 1:42,500   FIG No. FIGURE B7.   REV 0

B2 200 Year ARI Peak Flood Depth Maps

- **Figure B8: 200-Year ARI, 12 Hour duration, Present-Day Climate - Flood Depth**
- **Figure B9: 200-Year ARI, 12 Hour duration with Climate Change - Flood Depth**
- **Figure B10: 200-Year ARI, 12 Hour duration, Present-Day Climate and Unadjusted Turakina Boundary - Flood Depth**
- **Figure B11: 200-Year ARI, 12 Hour duration, Present-Day Climate and Turakina Boundary Shifted Back 12hrs- Flood Depth**
- **Figure B12: 200-Year ARI, 12 Hour duration, Present-Day Climate and Turakina Boundary Shifted Back 24hrs- Flood Depth**

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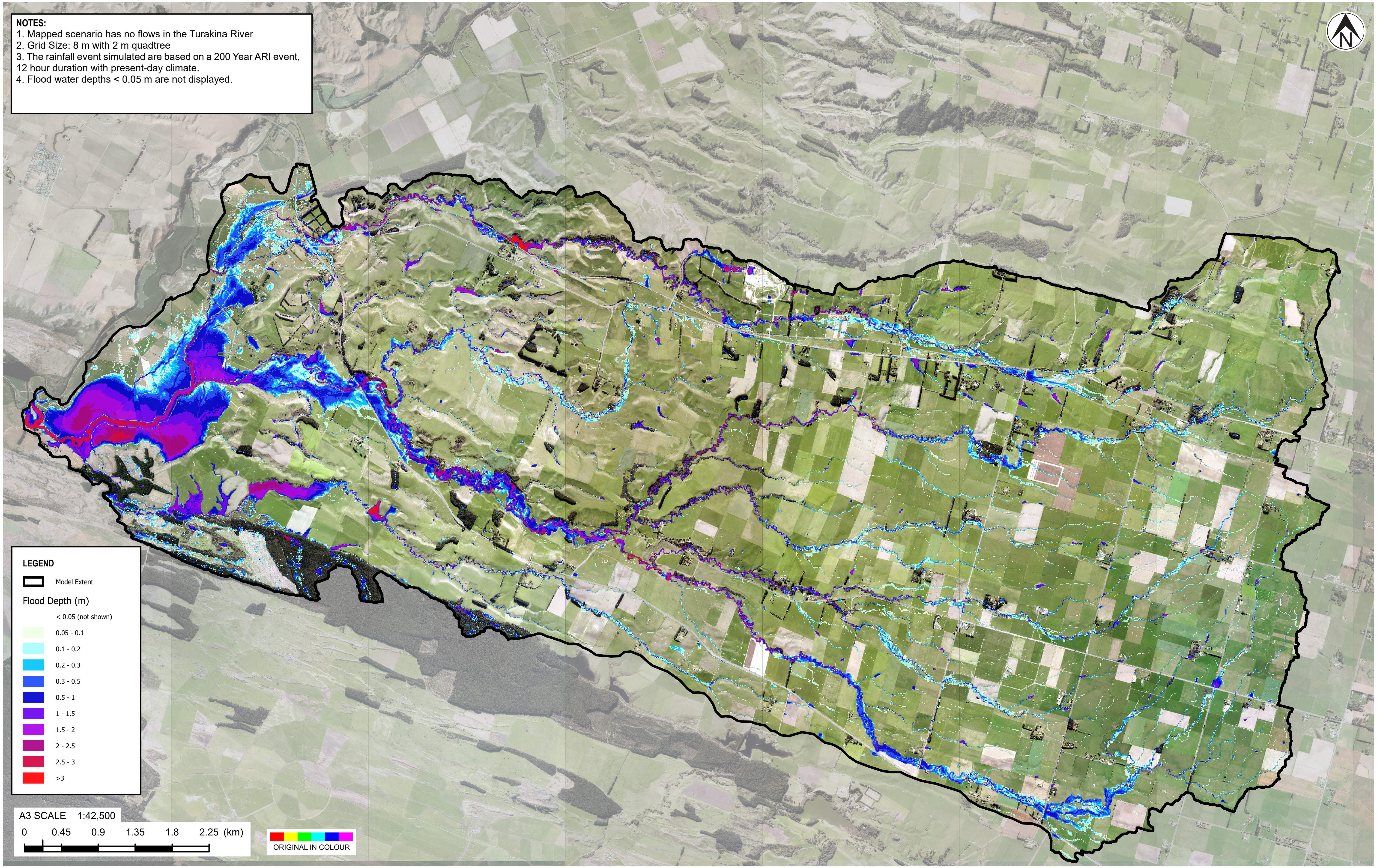

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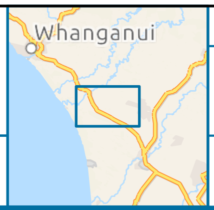

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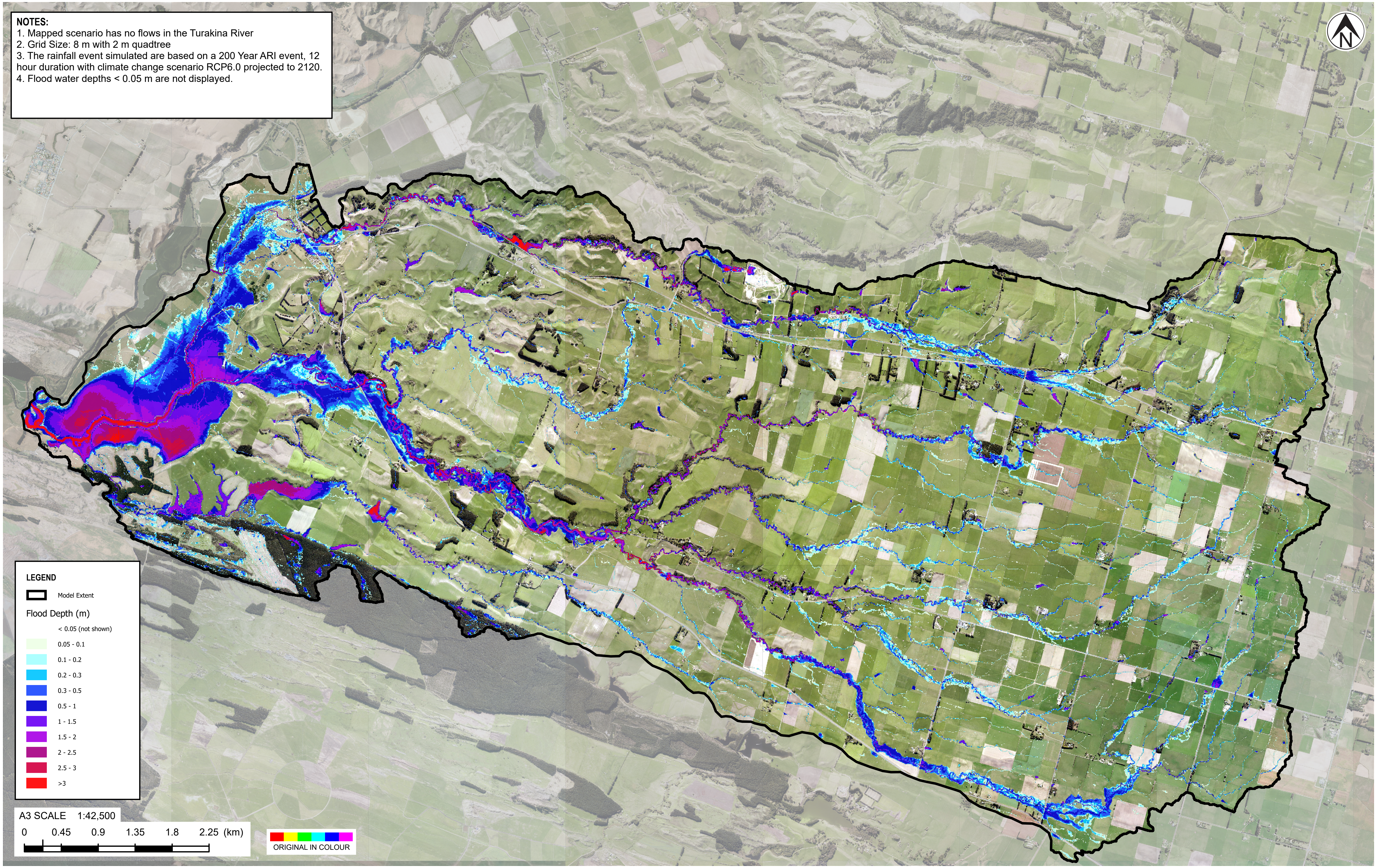
TITLE 200 YEAR ARI, 12 HOUR DURATION, PRESENT-DAY CLIMATE PEAK FLOOD DEPTH

SCALE (A3) 1:42,500 FIG No. FIGURE B8. REV 0

T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx   Layout: 200 Year CC Full Extent   2022-Sep-07 1:08 pm   Drawn by ALWH

NOTES:
1. Mapped scenario has no flows in the Turakina River
2. Grid Size: 8 m with 2 m quadtree
3. The rainfall event simulated are based on a 200 Year ARI event, 12 hour duration with climate change scenario RCP6.0 projected to 2120.
4. Flood water depths < 0.05 m are not displayed.



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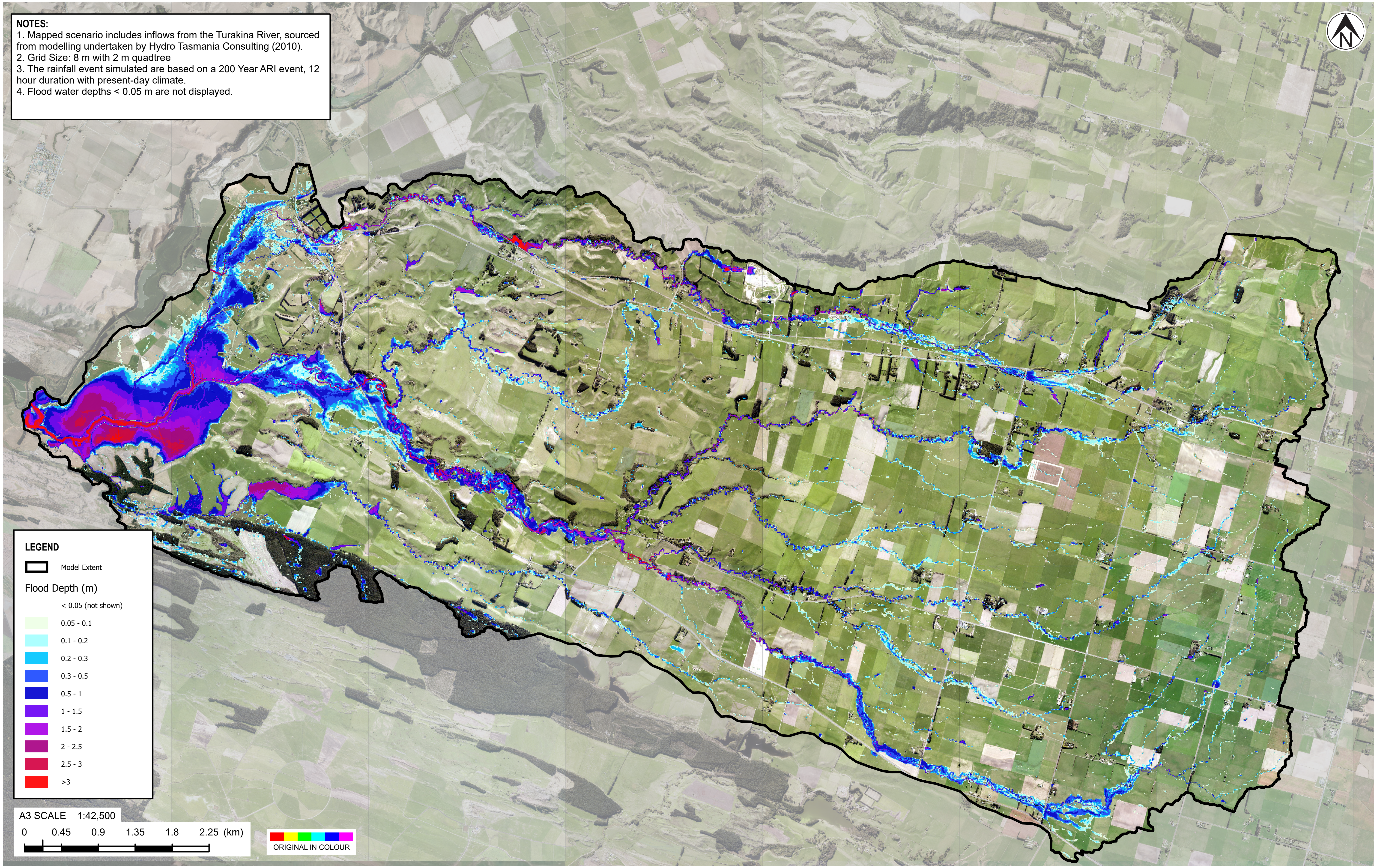
CLIENT: **HORIZONS REGIONAL COUNCIL**
PROJECT: **MAKIRIKIRI STREAM MODELLING**
TITLE: 200 YEAR ARI 12 HOUR DURATION WITH CLIMATE CHANGE (RCP6.0, 2120) PEAK FLOOD DEPTH
SCALE (A3): 1:42,500   FIG No. FIGURE B9.   REV 0

T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx Layout: 200 Year PD Unadjusted Turakina Full Extent 2022-Sep-07 1:08 pm Drawn by ALWH

NOTES:
1. Mapped scenario includes inflows from the Turakina River, sourced from modelling undertaken by Hydro Tasmania Consulting (2010).
2. Grid Size: 8 m with 2 m quadtree
3. The rainfall event simulated are based on a 200 Year ARI event, 12 hour duration with present-day climate.
4. Flood water depths < 0.05 m are not displayed.



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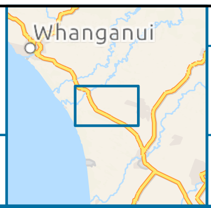

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CLIENT **HORIZONS REGIONAL COUNCIL**
PROJECT **MAKIRIKIRI STREAM MODELLING**
TITLE 200 YEAR ARI, 12 HOUR DURATION, PRESENT-DAY CLIMATE AND UNADJUSTED TURAKINA BOUNDARY PEAK FLOOD DEPTH
SCALE (A3) 1:42,500 FIG No. FIGURE B10. REV 0

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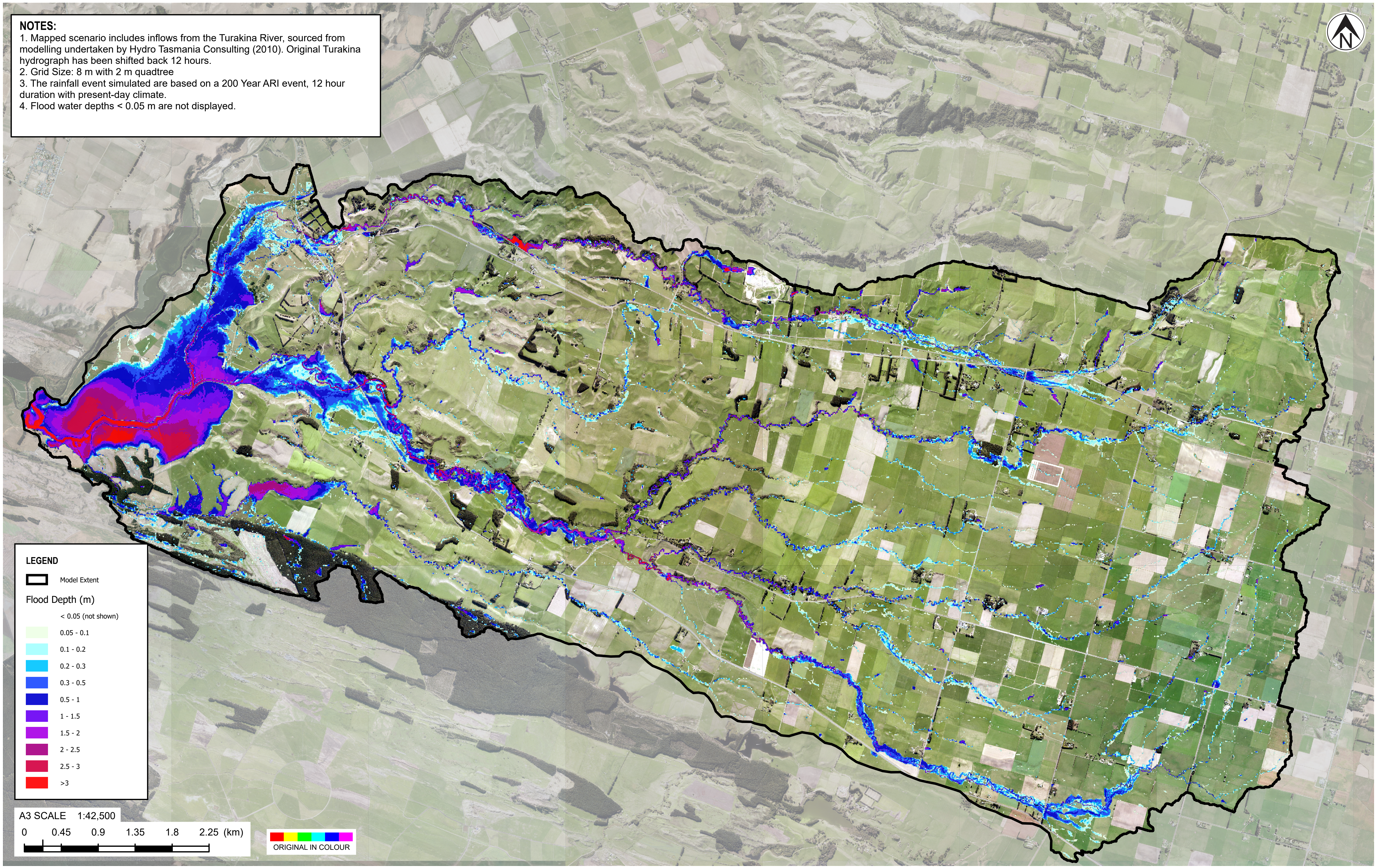
T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx Layout: 200 Year PD 12hr shift Turakina Full Extent 2022-Sep-07 1:08 pm Drawn by ALWH

NOTES:
1. Mapped scenario includes inflows from the Turakina River, sourced from modelling undertaken by Hydro Tasmania Consulting (2010). Original Turakina hydrograph has been shifted back 12 hours.
2. Grid Size: 8 m with 2 m quadtree
3. The rainfall event simulated are based on a 200 Year ARI event, 12 hour duration with present-day climate.
4. Flood water depths < 0.05 m are not displayed.



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NOTES:
Basemap World Imagery: Earthstar Geographics. NZ Navigation Map: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors.

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LOCATION PLAN: Whanganui

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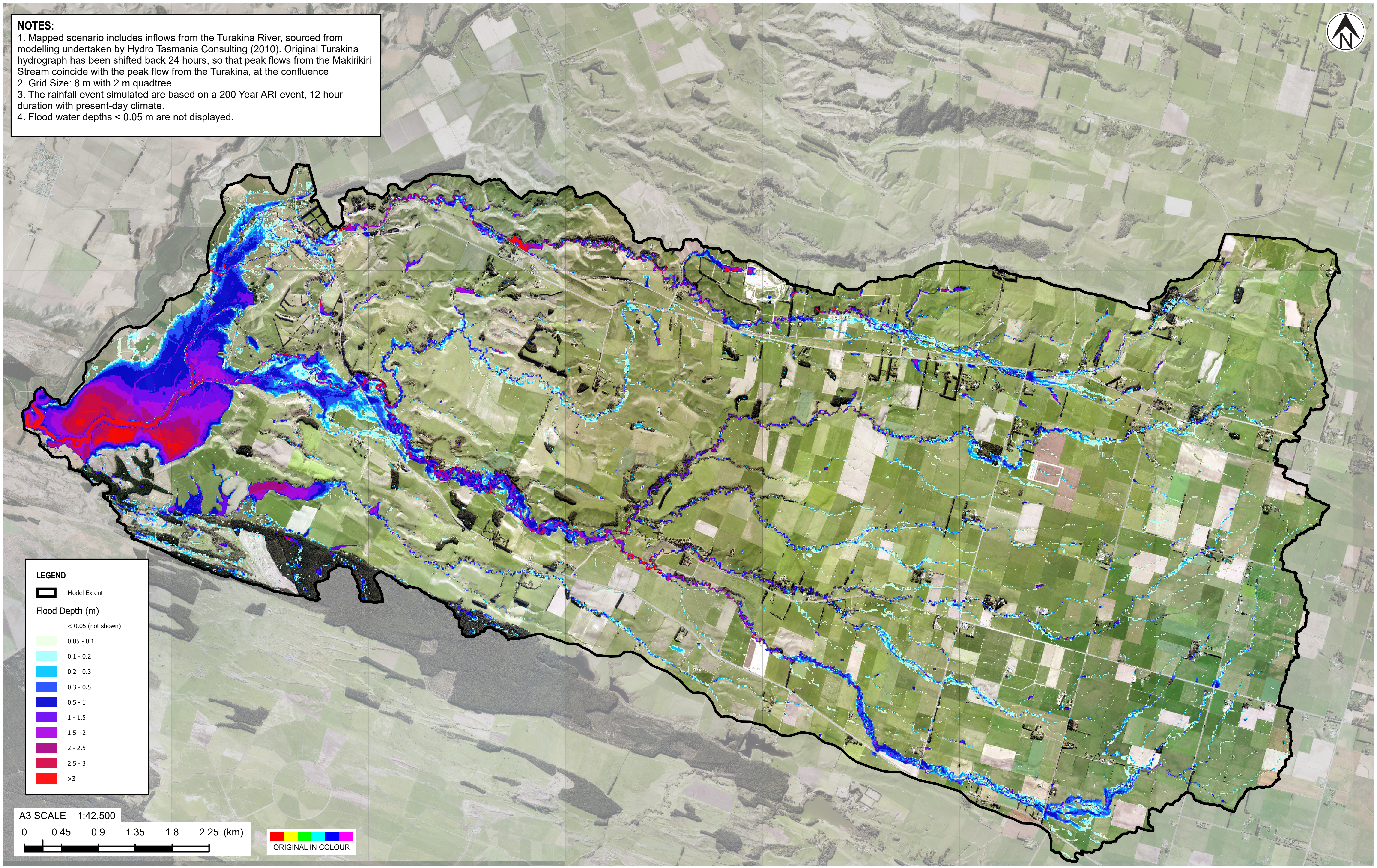
CLIENT HORIZONS REGIONAL COUNCIL
PROJECT MAKIRIKIRI STREAM MODELLING
TITLE 200 YEAR ARI, 12 HOUR DURATION, PRESENT-DAY CLIMATE AND TURAKINA BOUNDARY SHIFTED BACK 12HRS PEAK FLOOD DEPTH
SCALE (A3) 1:42,500 FIG No. FIGURE B11. REV 0

T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx   Layout: 200 Year PD 24hr shift Turakina Full Extent   2022-Sep-07 4:12 pm   Drawn by ALWH

NOTES:
1. Mapped scenario includes inflows from the Turakina River, sourced from modelling undertaken by Hydro Tasmania Consulting (2010). Original Turakina hydrograph has been shifted back 24 hours, so that peak flows from the Makirikiri Stream coincide with the peak flow from the Turakina, at the confluence
2. Grid Size: 8 m with 2 m quadtree
3. The rainfall event simulated are based on a 200 Year ARI event, 12 hour duration with present-day climate.
4. Flood water depths < 0.05 m are not displayed.



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NOTES:
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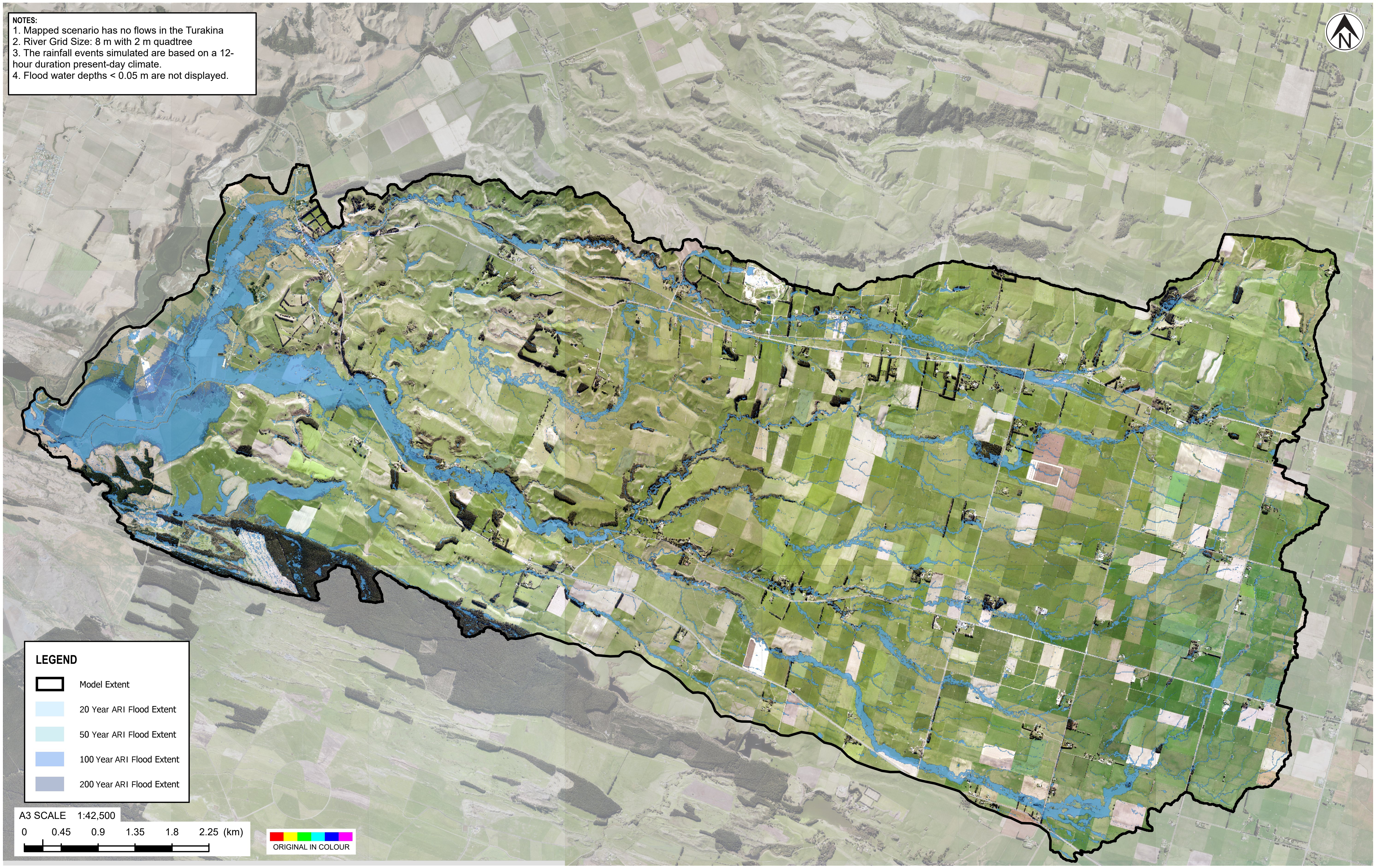
PROJECT **MAKIRIKIRI STREAM MODELLING**
TITLE 200 YEAR ARI, 12 HOUR DURATION, PRESENT-DAY CLIMATE AND TURAKINA BOUNDARY SHIFTED BACK 24HRS PEAK FLOOD DEPTH

SCALE (A3) 1:42,500   FIG No. FIGURE B12.   REV 0

Appendix C Flood extent maps

- **Figure C1: 12-hour duration, present day climate flood extents**
- **Figure C2: 12 hour duration with climate change (RCP6.0, 2120) flood extents**
- **Figure C3: 12 hour duration with climate change (RCP6.0, 2120) flood extents**
- **Figure C4: 100 year ARI 12 hour duration present day flood extent**
- **Figure C4: 200 year ARI 12 hour duration present day flood extent**

T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx Layout: PD Flood Extent 2022-Sep-09 4:59 pm Drawn by ALWH



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NOTES:
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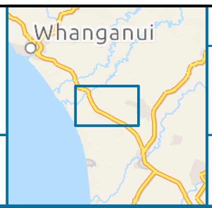

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CLIENT HORIZONS REGIONAL COUNCIL
PROJECT MAKIRIKIRI STREAM MODELLING
TITLE 12-HOUR DURATION, PRESENT DAY CLIMATE - FLOOD EXTENTS

SCALE (A3) 1:42,500 FIG No. FIGURE C1. REV 0

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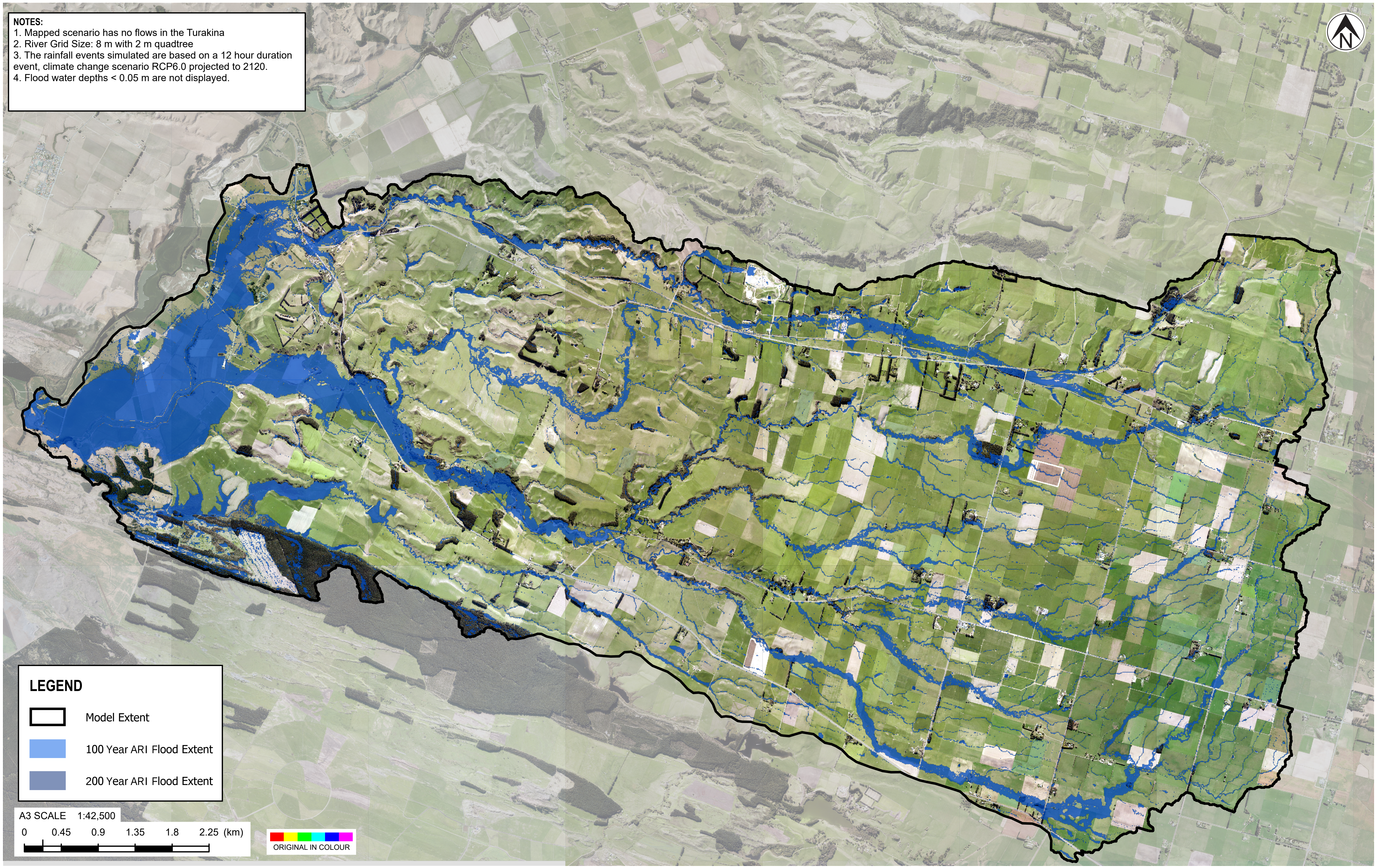

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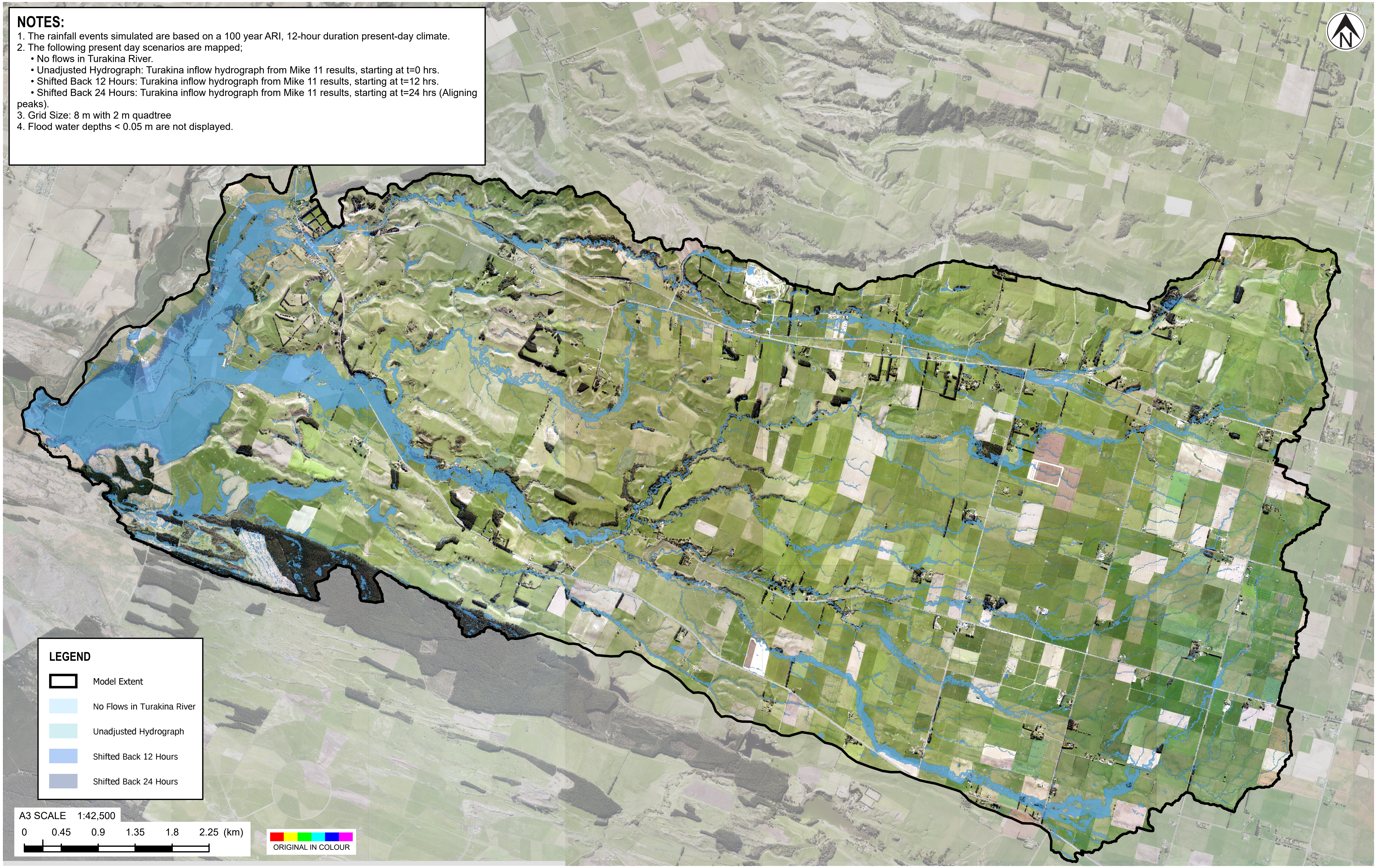
CLIENT HORIZONS REGIONAL COUNCIL
PROJECT MAKIRIKIRI STREAM MODELLING
TITLE 12 HOUR DURATION WITH CLIMATE CHANGE (RCP6.0, 2120) FLOOD EXTENTS

SCALE (A3) 1:42,500 FIG No. FIGURE C2. REV 0

T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx Layout: 100 Year PD Flood Extent 2022-Sep-09 4:59 pm Drawn by ALWH

NOTES:

1. The rainfall events simulated are based on a 100 year ARI, 12-hour duration present-day climate.
2. The following present day scenarios are mapped;
   - No flows in Turakina River.
   - Unadjusted Hydrograph: Turakina inflow hydrograph from Mike 11 results, starting at t=0 hrs.
   - Shifted Back 12 Hours: Turakina inflow hydrograph from Mike 11 results, starting at t=12 hrs.
   - Shifted Back 24 Hours: Turakina inflow hydrograph from Mike 11 results, starting at t=24 hrs (Aligning peaks).
3. Grid Size: 8 m with 2 m quadtree
4. Flood water depths < 0.05 m are not displayed.



LEGEND

- Model Extent
- No Flows in Turakina River
- Unadjusted Hydrograph
- Shifted Back 12 Hours
- Shifted Back 24 Hours

A3 SCALE 1:42,500

0 0.45 0.9 1.35 1.8 2.25 (km)

ORIGINAL IN COLOUR

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NOTES:

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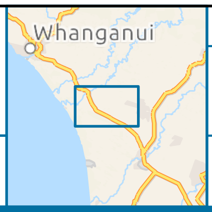

LOCATION PLAN

PROJECT No.	1019994	
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PROJECT MAKIRIKIRI STREAM MODELLING

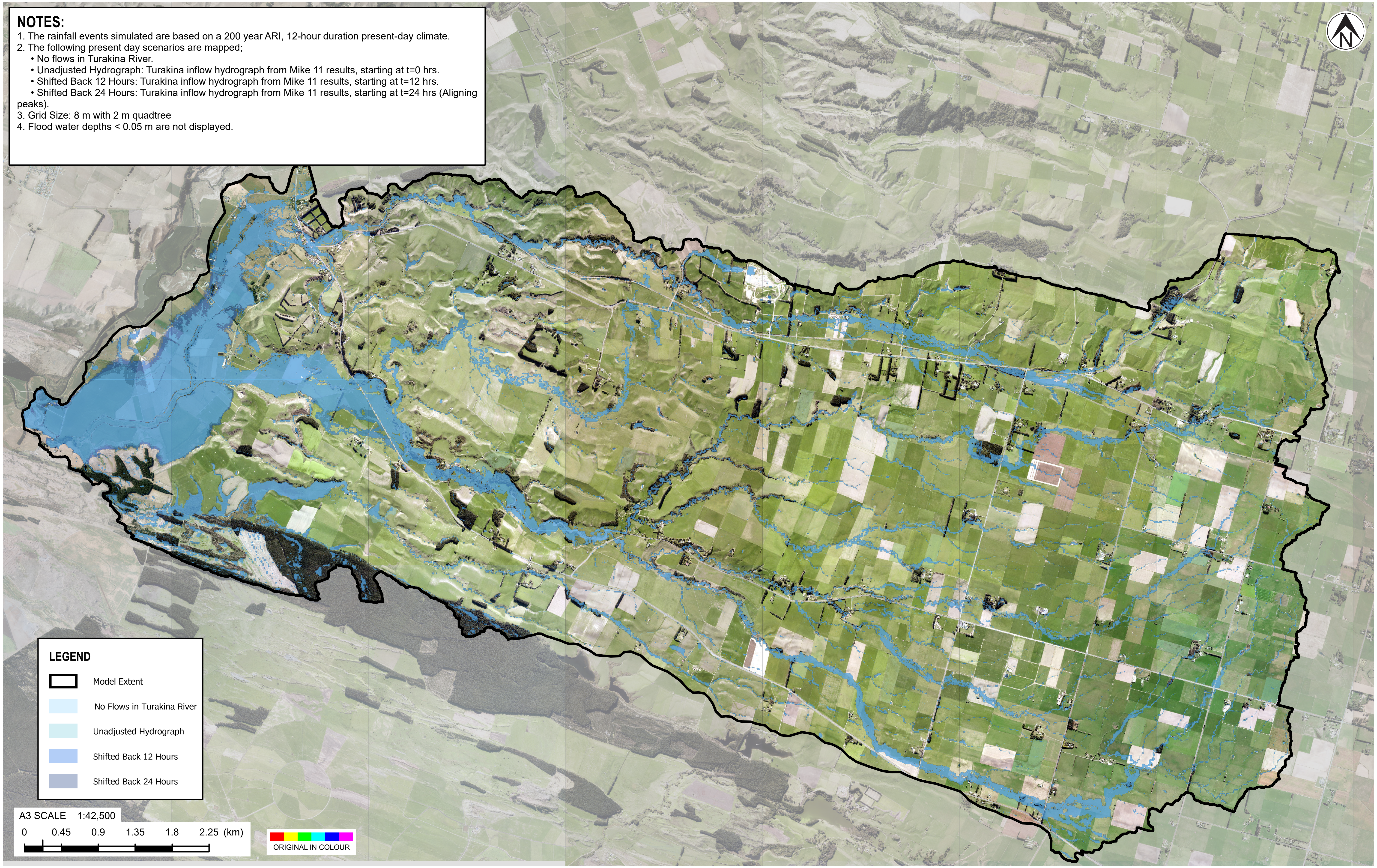
TITLE 100 YEAR ARI 12 HOUR DURATION PRESENT DAY FLOOD EXTENT

SCALE (A3) 1:42,500 FIG No. FIGURE C3. REV 0

T:\Tauranga\Projects\1019994\WorkingMaterial\05_Reporting\Report Figures\Makirikiri Figures\Makirikiri Figures.aprx Layout: 200 Year PD Flood Extent 2022-Sep-09 4:59 pm Drawn by ALWH

NOTES:

1. The rainfall events simulated are based on a 200 year ARI, 12-hour duration present-day climate.
2. The following present day scenarios are mapped;
   - No flows in Turakina River.
   - Unadjusted Hydrograph: Turakina inflow hydrograph from Mike 11 results, starting at t=0 hrs.
   - Shifted Back 12 Hours: Turakina inflow hydrograph from Mike 11 results, starting at t=12 hrs.
   - Shifted Back 24 Hours: Turakina inflow hydrograph from Mike 11 results, starting at t=24 hrs (Aligning peaks).
3. Grid Size: 8 m with 2 m quadtree
4. Flood water depths < 0.05 m are not displayed.



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CLIENT **HORIZONS REGIONAL COUNCIL**

PROJECT **MAKIRIKIRI STREAM MODELLING**

TITLE 200 YEAR ARI 12 HOUR DURATION PRESENT DAY FLOOD EXTENT

SCALE (A3) 1:42,500 FIG No. FIGURE C4. REV 0

Appendix D Sensitivity ‘fuzzy’ map

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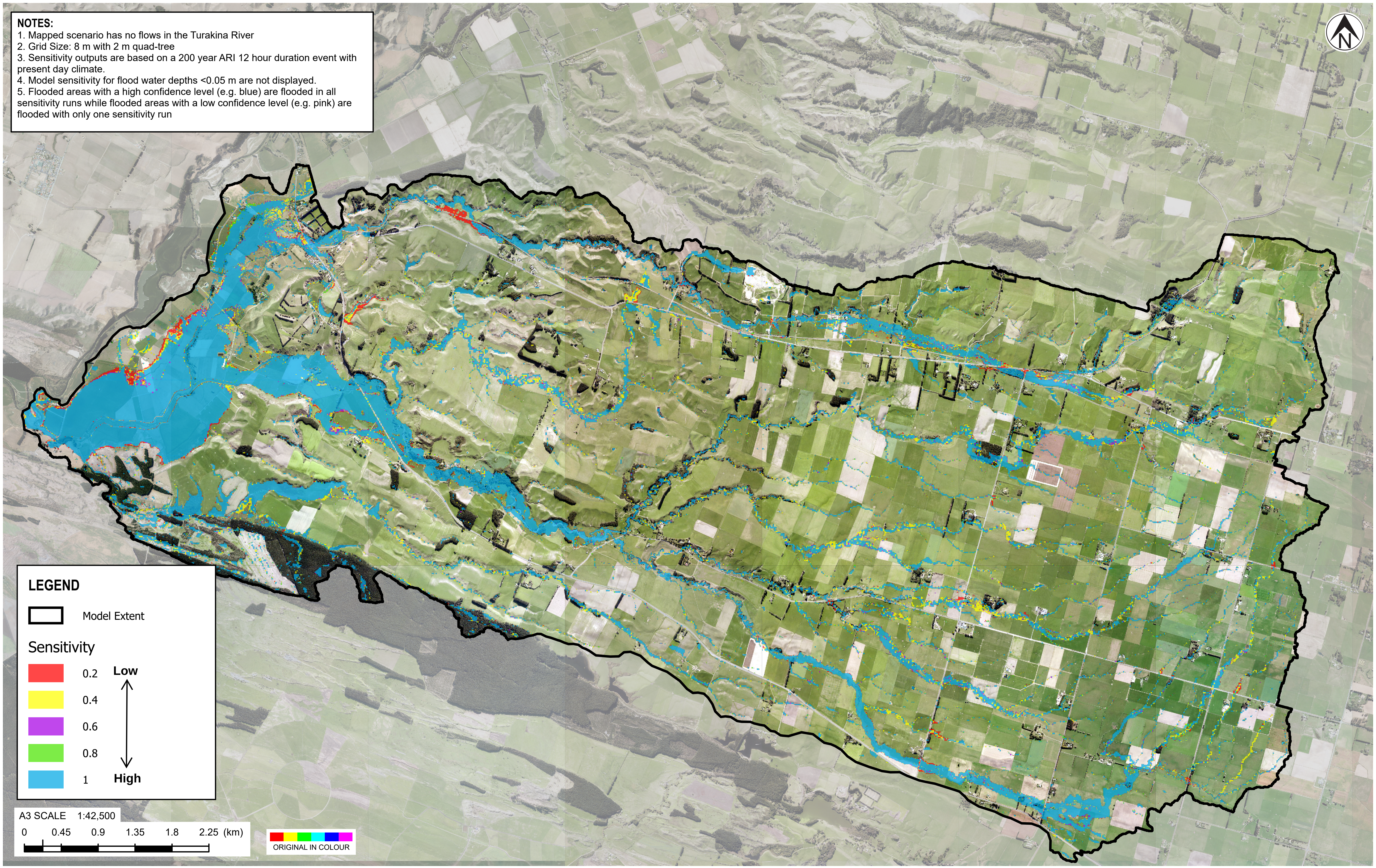
NOTES:
1. Mapped scenario has no flows in the Turakina River
2. Grid Size: 8 m with 2 m quad-tree
3. Sensitivity outputs are based on a 200 year ARI 12 hour duration event with present day climate.
4. Model sensitivity for flood water depths <0.05 m are not displayed.
5. Flooded areas with a high confidence level (e.g. blue) are flooded in all sensitivity runs while flooded areas with a low confidence level (e.g. pink) are flooded with only one sensitivity run



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NOTES:
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Whanganui

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CLIENT HORIZONS REGIONAL COUNCIL

PROJECT MAKIRIKIRI STREAM MODELLING

TITLE 200-YEAR ARI 12-HOUR DURATION PRESENT-DAY PEAK FLOOD DEPTH SENSITIVITY "FUZZY" MAP

SCALE (A3) 1:42,500 FIG No. FIGURE D1. REV 0 www.tonkintaylor.co.nz