Northland Regional Council

Flood modelling for Kaihu valley, Dargaville, and Awakino floodplain

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1. Introduction

Barnett & MacMurray Ltd (B&M) was commissioned by Northland Regional Council (NRC) to undertake flood modelling of the Kaihu valley, Dargaville, and the Awakino floodplain. The project builds on previous Kaihu valley flood modelling work carried out by B&M for NRC. The scope of work as summarised in a letter to NRC dated 20 February 2015, was as follows:

- Apply the June 2014 storm to the existing hydrological model of the catchments upstream of Kaihu Gorge, and adjust the model calibration as necessary
- Extend the existing Kaihu valley HEC HMS hydrological model to include the local Dargaville catchments and the Awakino River, and produce 10 year average recurrence interval (ARI) and 100 year ARI with allowance for climate change design flood hydrographs
- Use the extended hydrological model to produce hydrographs for the ungauged catchment areas in the June 2014 flood event
- Extend the Kaihu valley Mike 11 model upstream to the confluence of the Mangatu Stream and the Waima River using new cross section survey commissioned by NRC
- Incorporate new cross sections in the Mike 11 model between Kaihu Gorge recorder site and the upstream extent of the 2006 Lidar survey, using a new cross section survey commissioned by NRC
- Extend the existing Kaihu valley Mike 11 model up six of the side valleys so as to achieve complete floodmap coverage
- Build a new Tuflow 1d-2d model of the lower Kaihu valley, Dargaville, and the Awakino river and floodplain, linked to Mike 11 model by boundary conditions at the Kaihu valley boundary between the models
- Calibrate the Mike 11 and Tuflow models against flood levels measured in the June 2014 event
- Simulate design storms of 10 year ARI and 100 year ARI with allowance for climate change and sea level rise
- Present the results as maps of maximum flood level, maximum flood depth, and maximum flow velocity, in grids compatible with ArcMap version 10.1
- Provide a WaterRide software project file to allow detailed inspection of Mike 11 and Tuflow model result files within one WaterRide project
- Provide a report on the investigation.

A Short Form Agreement covering the project was signed for NRC by Bruce Howse on 7 April 2015.

In the course of the project, two variations to the original contract were approved by NRC: firstly to provide a draft scope of works document for the Awakino river survey, and secondly to investigate a discrepancy between the NRC levels at the Kaihu Gorge flow recorder, and those found during river cross section survey.

2. Site visit

Hugh MacMurray of B&M and Toby Kay of NRC carried out a site inspection of Dargaville and the Awakino River and floodplain on 12 June 2015. We are familiar with the Kaihu valley from previous work, so it was not necessary to include it in the site visit.

Stormwater asset plans provided by Kaipara District Council were used as a guide to the stormwater outlets from Dargaville to the Northern Wairoa River. It was found that south of the Kaihu River mouth, there were many outfalls not marked on the asset plans. A large proportion of those outfalls were not floodgated. North of the Kaihu River, the asset plans were fairly accurate, except on the undeveloped floodplain south west of the Northern Wairoa bridge. On the basis of the observations it was clear that the outfall survey contract needed to include a requirement to walk the river bank to find all the outfalls.

This contract does not include Dargaville stormwater system modelling, because its focus is on flooding due to Kaihu River and Awakino River floods (with allowance for high tide and sea level rise). In that context, the total outfall capacity and its distribution along the river, and whether or not the outfalls are floodgated, are important parameters. However, under conditions of flooding in Dargaville due to river flows, we assume that the pipes of the stormwater system would play a relatively small role compared with the capacity of the outfalls to the Northern Wairoa River. Thus under this contract it was not necessary to survey the entire Dargaville system (and such survey and modelling is not included in the scope of work).

South of the Kaihu River mouth there is a timber flood wall which would not appear in the processed Lidar data. It was noted that the surveyor should be briefed to measure points on the top of the wall.

The 2015 Lidar data used for the Dargaville and Awakino model was not available at the start of the project, and the 2006 Lidar only covers part of Dargaville. To allow the hydrological modelling tasks to go ahead, it was necessary to make some reasonable estimate of catchment divides from observation on the site inspection. The intersection of Jervois Street (State Highway 14) and Awakino Road is on high ground, and those two streets could roughly be considered a catchment divide, with land to the north and east of the streets draining northwards to the Awakino floodplain drainage system. A contour map made from the 2006 Lidar data shows that most of the land east of the Northern Wairoa bridge and south of State Highway 14 to Whangarei drains directly to the Northern Wairoa River, rather than to the Awakino River.

North of Dargaville township, Awakino Road descends to Awakino floodplain level. The floodplain was traversed on foot from Awakino Road to the Awakino railway bridge, along the disused railway embankment. A floodgated drainage outfall was noted on the true left side of the Awakino River just upstream of the railway bridge. The railway bridge is close to the planned upstream extent of the model. The floodplain is generally in pasture with some fields of various crops.

At the State Highway 14 bridge, the Awakino River has a bed of soft mud which was exposed because the tide level was relatively low. The bridge has three spans, and the waterway area appears to be significantly reduced by siltation. Much of the banks are covered in rice grass. Upstream of the bridge there are de facto stopbanks with a highly variable crest level, produced by placing river dredging spoil in heaps. Upstream of the State Highway 14 bridge there is a 1.2m diameter floodgated drainage outfall on the true left side of the river.

3. Hydrological modelling

3.1 Rainfall data

Rainfall data was assembled for one historic event in June 2014, and for the 10 year and 100 year ARI design events.

3.1.1 June 2014 storm

In June 2014 a rapidly developing low near Whangarei produced heavy rain and severe gales in Northland. Increasingly heavy rain occurred over the Kaihu – Dargaville area culminating in a peak rainfall in the upper Kaihu catchment of 28mm/hr in the late afternoon of June 10 and 12mm/hr at Dargaville 2 hours later. Total rainfall on June 10 in the upper catchment and at Dargaville was 114mm and 68mm respectively. To reproduce the June 2014 storm event, NRC provided recorded data from 4 local rain gauges. The gauge characteristics are summed up in Table 1. Storm details at each gauge are shown in Table 2.

Site name	Site number	Lat (decimal)	Long (decimal)	Elevation	Recording Authority	Recording Interval
Waima at Tutamoe	536613	-35.652	173.654	500	NRC	5 min
Dargaville 2 EWS	A53987	-35.931	173.853	66	NIWA	10 min
Dargaville at Hokianga Rd	539813	-35.9	173.8	66	NRC (NIWA)	daily
Whatoro - Hayward	537614	-35.7	173.6	180	NRC	daily
Mamaranui	A53881	-35.864	173.8	49	NIWA	daily

Table 1: Kaihu and Dargaville area rain stations

Gauge	Tutamoe	Whatoro	Mamaranui	Dargaville
Total rainfall (mm)	190	158	129	120
Maximum daily rainfall (mm)	114.5	87	77.5	68
Occurring *	11/06/2014 8:00	11/06/2014 8:00	11/06/2014 9:00	11/06/2014 9:00
Maximum hourly rainfall (mm/hr)	28	-	-	12
Time	10/06/2014 15:00			10/06/2014 17:00

Table 2: June 2014 storm characteristics
*Note * in the 24 hours prior*

As a check of data integrity, Dargaville 2 EWS rainfall data for June 2014 was compared to the data from Dargaville at Hokianga Rd site. For the 3 day storm period, recorded rainfall depths at the two gauges were within 2%, showing that the Dargaville gauges were consistent during the event. The finer resolution Dargaville 2 EWS site data has been applied to the hydrological models for Dargaville. From Table 1 and Table 2, it can be seen that rainfall depth increases from least for stations on the river flats to most at highest elevation in the hills. The June maximum daily rainfalls at the hill stations Whatoro and Tutamoe are 30% and nearly 70% respectively greater than at Dargaville.

For gauges with daily rainfall data, a temporal distribution has been formed using the daily rainfall totals and the distribution from the nearest sub daily recording gauge. Mamaranui rainfall temporal distribution was based on the Dargaville 10 minute data, and the Whatoro rainfall pattern was based on the Tutamoe data. The actual and derived 10 minute rainfall depths for each gauge were loaded into HEC-HMS for the hydrologic simulation.

3.1.2 Design events

Design flood events for the Kaihu River have already been produced as part of previous Kaihu modelling work. The 10 year ARI and 100 year ARI with climate change event hydrographs generated as part of Job 238 Stage 4 (B&M, 2012) were applied for the present project without alteration. To generate design events for the Dargaville and Awakino catchments, extreme rainfall depth data was obtained from HIRDS v3, the NIWA produced High Intensity Rainfall Design System. Data was generated for the gauge location in Dargaville and at the centre of Awakino sub catchments 2 and 7 to represent the upper and lower Awakino catchment. For the June 2014 storm simulation, rainfall from Mamaranui and Whatoro stations was applied to the Awakino catchment because this was the best available recorded data. However, as both Mamaranui and Whatoro stations lie outside the Awakino catchment, we think that a rainfall based on locations inside Awakino catchment will provide better design rainfall estimates for the catchment. The HIRDS design rainfalls within the Awakino catchment were 2-20% greater than those estimated at Mamaranui and Whatoro.

The climate change scenario used for the 100 year event was the IPCC fourth assessment mid-range emissions scenario of 2.1 degrees C of warming to 2090 (MfE, May 2008). This is the scenario that NRC has generally adopted in extreme rainfall modelling to date. Using HIRDS data, a mean temperature increase of 2.1 degrees corresponds to a 17% increase in the 48 hour storm rainfall depth. The 10 year ARI event rainfall depth is for existing climate conditions so as to be consistent with the NRC approach in other catchments.

The HIRDS rainfall depths for storm durations up to 48 hours at each location are shown in Table 3 and Table 4 for the 10 year and 100 year ARI climate change design events respectively.

	Rainfall depths (mm)								
Station	Duration								
	10m	20m	30m	60m	2h	6h	12h	24h	48h
Dargaville	12.7	18.3	22.6	32.5	42.1	63.7	82.7	107.3	129.9
Awakino-2	13.2	19.2	23.8	34.4	46	72.9	97.5	130.4	159.5
Awakino-7	13	18.6	23	33	42.9	65	84.6	110	133.7
Mamaranui	12.7	18.2	22.4	32.2	42.1	64.6	84.6	110.8	133.8
Whatoro	12.6	17.7	21.7	30.6	40.5	63	83.4	110.2	129.5
Tutamoe	13.4	20	25.3	37.6	51	82.6	112	151.9	185.4

Table 3: HIRDS design rainfall depths for 10 year ARI event

	Rainfall depths (mm)								
Station	Duration								
	10m	20m	30m	60m	2h	6h	12h	24h	48h
Dargaville	22.9	32.9	40.6	58.5	76.9	118.6	155.9	205	248
Awakino-2	23.7	34.3	42.6	61.7	83.5	134.8	182.3	246.7	301.6
Awakino-7	23.5	33.6	41.6	59.5	78.3	120.7	158.5	208.4	253.3
Mamaranui	22.8	32.6	40.3	57.8	76.4	119.1	157.7	208.6	251.8
Whatoro	23	32.5	39.7	55.9	74.8	118.2	157.8	210.7	247.5
Tutamoe	25.3	37.8	47.7	71	96.6	157.4	214.2	291.4	355.8

Table 4: HIRDS design rainfall depths for 100 year ARI event with 2.1degrees C warming

For Awakino and Kaihu design rainfalls NRC provided a rural Priority Rivers 48hr rainfall profile. For the urban catchment of Dargaville, the design rainfall hyetograph is constructed by nesting HIRDS rainfall depths for each duration up to 48 hours, with peak intensity occurring at 70% of event duration. Design rainfalls are plotted in Figure 1 and Figure 2, Appendix A .

The design rainfall totals at Mamaranui, Whatoro and Dargaville were very similar. This was not the case in the June 2014 storm event, where Mamaranui rainfall was 7% higher than at Dargaville and Whatoro rainfall was 30% higher. The relative design rainfalls for these locations differ from those in the historic event because design rainfall estimates are based on long term statistics and may use records from more than one station.

3.2 Catchments

The catchment models have been constructed in HEC-HMS, a hydrologic modelling system for rainfall and runoff processes developed by the US Army Corps of Engineers Hydrologic Engineering Centre (hence HEC-HMS). The models use the SCS curve number loss method to transform rainfall into runoff, and a kinematic wave method to represent surface flow and channel flow routing. The SCS curve number method determines the amount of rainfall lost to infiltration per time interval and is a function of soil type, drainage and land use. This method has been verified by studies in the Auckland region, and is well used in New Zealand, although the Auckland study concentrated on urban catchments. The catchment models make no allowance for evaporation, or antecedent soil conditions. The SCS method is suitable for single event simulation, and lends itself to sharp, more concentrated or major events because it has no mechanism for recovery of soil infiltration capacity during the event. For these reasons, the SCS method is considered a good choice to model design flood events. It might be less suitable for a longer storm, or minor flood events.

3.2.1 Awakino

The Awakino River has a long narrow catchment with area of 116km^2. Rising on the southern side of the divide on the Tutamoe Range, the river flows 29km south to its outlet on the Northern Wairoa River just east of Dargaville. Catchment form, orientation and topography are similar to the adjacent Kaihu catchment although the Kaihu is larger. The topography varies from steep, forested terrain in the upper catchment to rolling hills and flatland pasture with some swamp around the lower river reaches. In the model the catchment has been divided into 9 sub catchments, see Figure 3.

Physical catchment parameters such as area, length and slope were determined from 1:50,000 topomaps showing 20m ground elevation contours. This means that channel and ground slopes are approximate. Land use was divided into forest and pasture areas based on aerial images supplied by NRC and Google Earth images for the upper catchment. Soil drainage classes were estimated using Landcare research Fundamental soil maps (this area of Northland has not yet been included in the latest SMap series). The soils were mainly clays and clay or silt loams with imperfect to poor drainage. The catchment parameters used in the hydrological model are summarised in Table 10 in Appendix B.

In the hydrological model the upper catchments feed into a single channel representing the Awakino River and the flow is routed downstream until the outlet just downstream of sub catchment 6. Sub catchments 1 and 2 flow into sub catchment 3, which is connected to the channel reach downstream. Sub catchments 5 and 7-9 are within the floodplain area and their flow outputs will be applied locally within the hydraulic model.

3.2.2 Dargaville

Dargaville township is situated on the northern bank of the Northern Wairoa and straddling the Kaihu River outlet. The catchment, with an area of 4km^2, falls from an elevation of about 50m around the top of Hokianga Rd to low floodplain areas along the river bank. The land use is urban, mainly residential with some commercial and industrial sites. Soil data was not available for the built up area, but surrounding soils are mostly clay loams with imperfect drainage. The catchment has been divided into 5 sub catchments, based on the stormwater network and topography. Catchment parameters were measured from aerial photographs, stormwater network shape files and manhole lid levels all supplied by NRC. The aerial photographs, together with district planning maps (Kaipara District Council, 2013) were used to determine land use areas, including roads and green space. Green space was further divided into forest and grass. From the land use and related impervious area percentages, curve numbers were calculated for the sub catchment planes. The different land uses also determined the ground roughness for the overland flow routing. Dargaville catchment parameters for the hydrological model are summarised in Table 11 in Appendix B. The sub catchments are shown in Figure 4. Runoff from each sub catchment is applied as a source area flow element inside the hydraulic model domain at the indicated locations.

3.2.3 Kaihu

The Kaihu catchment model was developed for the Kaihu flood control scheme investigations and design rainfall event hyetographs were finalised in 2012. They are based on the NRC rural Priority Rivers 48 hour rainfall profile. The 10 year and 100 year ARI design flood hydrographs produced then for the Kaihu sub catchments will be used as flow boundaries for the Kaihu valley in the current flood simulations.

3.3 Simulation of June 2014 storm

Rainfall in 10 minute increments has been taken directly from the June 2014 records for each station, or for daily rainfall gauges with a temporal distribution formed as described in Section 3.1.1, and loaded into the hydrological model. The upper Kaihu catchments receive weighted combinations of rainfall from the Tutamoe and Whatoro gauges.

3.3.1 Kaihu hydrology verification

The June 2014 event was simulated in HEC-HMS for the upper Kaihu catchments to verify the chosen hydrology parameters. Should there be significant differences between the modelled and observed flows, this would be an opportunity to adjust the model calibration. The HEC-HMS flood hydrograph at the Kaihu Gorge was compared to the observed flow at the Kaihu Gorge in June 2014. The two hydrographs are plotted in Figure 5. Modelled peak discharge is within 2% of the observed peak. The model rising limb starts early and contains greater volume than the observed hydrograph. Modelled peak volume is close to 20% greater than observed, but directly after the falling limb, modelled and observed volume agree to within 5%. Overall, the fit is good, with the model overestimating volume until flood peak, which is conservative. On this basis, the catchment parameters used in the Kaihu hydrology model have been retained for the lower Kaihu June 2014 simulation. Where relevant, the calibrated infiltration and roughness parameters will be applied to the new Awakino and Dargaville catchment models.

3.3.2 Storm simulation in new catchments

All of the rainfall recording stations lie outside the Awakino catchment. Awakino mid catchment is 4-6km away from the closest station and the upper catchment is 9km away from the closest station. For each sub catchment in Awakino, rainfall from the closest gauge has been applied, unless the elevation difference between the station and sub catchment centroid was greater than 50m. In that case, rainfall from the station closest in elevation was applied. This was taken as a reasonable approach because the Awakino has a similar aspect to the areas where the stations are and is likely to have been exposed to the storm in a similar way. It is possible that rainfall in the upper Awakino was heavier than assumed, because the elevation is 70m greater than that at Whatoro station, and the topography more mountainous and forested than at any of the stations. Until a station is placed in Awakino catchment, we cannot be sure about the rainfall there. The rainfall station allocation used for the Awakino sub catchments is in Table 5.

Subcatchment	Station
Awakino-1	Whatoro
Awakino-2	Whatoro
Awakino-3	Mamaranui
Awakino-4	Mamaranui
Awakino-5	Mamaranui
Awakino-6	Mamaranui
Awakino-7	Dargaville 2 EWS
Awakino-8	Dargaville 2 EWS
Awakino-9	Dargaville 2 EWS

Table 5: Rainfall allocation, Awakino sub catchments

All areas of Dargaville lie within 4km of the Dargaville station. Rainfall from the Dargaville 2 EWS station was applied to all of the Dargaville sub catchments.

The June 2014 storm has been simulated for Awakino and Dargaville catchments in HEC-HMS. The Dargaville sub catchments have peak discharges in the range 1-3m^3/s and a combined runoff volume of 270,000m^3. In contrast Awakino has a peak discharge of around 280m^3/s from the upper catchments and a combined catchment yield of 9,890,000 m^3.

3.4 Design storm simulations for 10 and 100 year ARI with climate change

The design 10 year and 100 year ARI with climate change storms have been simulated in HEC-HMS. Construction of the design rainfall hyetographs is described in Section 3.1.2. Runoff peak flow and volume per catchment are summarised in Table 6.

	10 yr ARI		100 yr ARI with climate change	
	Peak flow (m^3/s)	Volume (1000 m^3)	Peak flow (m^3/s)	Volume (1000 m^3)
Dargaville	2 - 6	304	6 - 16	741
Awakino	5 - 212	11,238	10 - 473	25,759
Upper Kaihu	262	14,482	554	24,931
Lower Kaihu	5 - 52	23,899	9 - 104	40,776

Table 6: Design event catchment runoff summary

The Dargaville design runoff is minor compared to that from the river valley catchments; amounting to just 3% of the Awakino design runoff. However, the Dargaville runoff must initially be collected and routed through the Dargaville stormwater system, which has a much lower capacity than the lower Awakino channel and floodplain. While the stormwater layout guided the catchment model construction, including the Dargaville stormwater system was beyond the scope of the current project. Even so, the catchment model outputs will give a reasonable indication of the design flows that might be expected at each of the sub catchment collection points. Design hydrographs for Awakino are shown in Figure 6 and Figure 7 and for Dargaville in Figure 8.

The design runoff volumes for the Upper Kaihu and Awakino catchments are similar, which is logical as they share the same soil types and land uses and each has an area of around $115km^2$.

Comparing the June 2014 storm flow at Kaihu Gorge with the flow produced from the design rainfall events for Upper Kaihu catchment indicates the storm magnitude approached that of a 10 year ARI event, but with a sharper response than the 10 year design storm and rather more rain in the hills and less in the lowlands.

4. Kaihu valley model

4.1 Floodplain branch extensions

The Kaihu valley model was originally built for the purpose of investigating flood management options. It is a quasi two dimensional model, meaning that the floodplains are represented by one dimensional branches linked to the Kaihu River and to each other by weir structures which represent topographical features like stopbanks. In the original Kaihu valley modelling work, inundation mapping was used to indicate the relative virtues of the various options considered, and some minor areas were not included in the mapping. For the present purpose, the model has been upgraded by including those unmapped areas as new or extended branches.

The new floodplain branches are constructed in the same way as those in the original model, from the 2006 Lidar data. That data was interpolated to a 2m square grid using Surfer software. Then Aulos software was used to drag cross section lines into the desired positions and cut the grid to produce the floodplain cross sections.

The Kaihu River cross sections are largely from historical surveys which did not provide coordinates for the surveyed points. To include the Kaihu River in the flood mapping, it would have been necessary to assign coordinates to the ends of all the river cross sections. That was considered for the present project but was not included in the scope because of the time and cost involved.

The floodplain branch extensions are detailed in Table 7.

Branch	Length (m)	Description	Branch extended to approximately	
			Easting (MZTM m)	Northing (NZTM m)
Upper Waihue	1310	Extension of Waihue branch north eastwards, roughly along the line of Waihue Road	1671000	6035900

Branch	Length (m)	Description	Branch extended to approximately	
			Easting (MZTM m)	Northing (NZTM m)
Upper Waiatua	524	Extension of Waiatua branch south eastwards	1671600	6032200
Taita North Valley	2000	Extension westwards of Taita tributary at Mamaranui	1666200	6033800
Upper Taita South	930	Extension south westwards of Taita southern tributary	1667000	6030200
Upper Korari South	1400	Extension south westwards of southern tributary to stream at Korariwhero Flat	1669400	6022900
Upper Scottys	1365	Extension westwards of side valley south of Scottys Camp Road	1672600	6023600

Table 7: Branch extensions in Mike 11 Kaihu valley model

The extensions of the side valley branches provide a longer length of channel over which to distribute the runoff hydrograph inflows. The proportion of each relevant catchment area contributing to the new branch extensions was estimated by inspection of the sub catchment map, and the appropriate proportions of the inflow hydrographs were applied.

4.2 Additional bridge cross sections

Details of the additional bridge cross sections supplied for this project are given in Table 8.

Stream	Crossing	Easting (NZTM m)	Northing (NZTM m)	Notes
Taita	Farm track at Mamaranui	1668105	6033800	Survey includes bridge cross section and road crown. Both included as structures in model branch Taitanorthvalley.
Taita	SH12 at Mamaranui	1668290	6033740	Survey includes 2 culverts, one blocked, and road crown. Ground levels on west side restrict flow access to culvert. Culvert and ground levels included in model in branch Taitanorthsh12br
Taita	Old rail embankment at Mamaranui	1668220	6033730	Survey includes channel through embankment. Included as a weir structure in model branch Taitanorthrlybr1.
Waihue	Waihue Rd	1669160	6034620	Survey gives details of bridge. Included as a culvert structure in

Stream	Crossing	Easting (NZTM m)	Northing (NZTM m)	Notes
				model branch Waihue.
Taita	SH12 at Maitahi	1668660	6032000	Included as a cross section in model branch Taita.
Waitaku huruhuru	Maitahi Rd	1668370	6031850	Included as a culvert in model branch Taitasouth
Waiatua	Opanake Rd	1670220	6033000	Included as a culvert in model branch Waiatua.

Table 8: Additional bridge cross sections used in Mike 11 Kaihu valley model upgrade

4.3 Additional Kaihu valley cross sections

NRC supplied a further 16 cross sections in the upper Kaihu valley to improve the resolution of the model in the reach up to the Kaihu Gorge flow recorder, and further upstream to the bridge over the Kaihu on Opouteke Road. The new cross section points and the digitised river channel alignment used to estimate cross section chainages in the previous versions of the Kaihu model, were plotted over a georeferenced image from the 1:50,000 topomap, using the Surfer software. Also, the points of the 2008 upper Kaihu cross section survey were plotted on the same Surfer map.

The chainages of the new cross sections were estimated by scaling their distances from the digitised river alignment points. Some of the new cross sections more or less overlay the 2008 or older cross sections, in which cases the latter were superseded and were not used in the model. The final mix of 2015, 2008, and older cross sections used in the model reach upstream of Ahikiwi is given in Table 9. Aulos software was used to interpolate cross sections at roughly 300m intervals. In one reach further interpolated cross sections were added to reduce the grid point spacing which was necessary to achieve a stable simulation. The cross sections without names in the Mike 11 cross section database are those produced by interpolation.

Name	Branch	Chainage (m)	Source	Notes
May2015no1	Upper Kaihu	0	NRC 2015	Upstream of Opouteke Rd bridge
May2015no2	Upper Kaihu	166	NRC 2015	Opouteke Rd bridge. Supersedes old CS34
May2015no3	Upper Kaihu	510	NRC 2015	Upper Kaihu branch joins at this point to Kaihu 324m
May2015no3	Kaihu	324	NRC 2015	Same section as Upper Kaihu 510m
May2015no4	Kaihu	906	NRC 2015	
CS33	Kaihu	1130	R&B 2001	
May2015no5	Kaihu	1309	NRC 2015	
May2015no6	Kaihu	1663	NRC 2015	
May2015no7	Kaihu	1781	NRC 2015	Kaihu at Gorge Recorder site. Supersedes old CS32.
May2015no8	Kaihu	1939	NRC 2015	Whole valley section
May2015no9	Kaihu	2091	NRC 2015	Whole valley section

Name	Branch	Chainage (m)	Source	Notes
Upper Kaihu no.8	Kaihu	2550	NRC 2008	Whole valley section
May2015no10	Kaihu	2869	NRC 2015	Whole valley section
Upper Kaihu no.7	Kaihu	3220	NRC 2008	Whole valley section
CS30	Kaihu	3370	R&B 2001	Whole valley section, upstream side of Kaihu settlement
May2015no11	Kaihu	3563	NRC 2015	Whole valley section
Upper Kaihu no.6	Kaihu	3800	NRC 2008	Whole valley section, just downstream of the bridge at Kaihu settlement
May2015no12	Kaihu	4077	NRC 2015	Whole valley section
Upper Kaihu no.5	Kaihu	4360	NRC 2008	Whole valley section
May2015no13	Kaihu	4470	NRC 2015	Whole valley section
Upper Kaihu no.4	Kaihu	4890	NRC 2008	Whole valley section, at Marae on Wood Rd
May2015no14	Kaihu	5157	NRC 2015	Whole valley section
Upper Kaihu no.3	Kaihu	5370	NRC 2008	Whole valley section
May2015no15	Kaihu	5977	NRC 2015	Supersedes Upper Kaihu no.2 of 2008 survey.
CS29	Kaihu	6150	R&B 2001	Whole valley section, just upstream of Waipapataniwha confluence
May2015no16	Kaihu	6498	NRC 2015	Whole valley section

Table 9: Kaihu valley cross sections used in upgraded Mike 11 model

4.4 June 2014 flood simulation

4.4.1 Measured data

The June 2014 flood was used for calibration of the model because of the high maximum flow at Kaihu Gorge (approximately 10 year ARI) and because a useful number of flood peak levels were surveyed from debris marks. The flood level data were supplied in terms of One Tree Point Vertical Datum 1964 (OTP64), except the Kaihu at Gorge recorder data, which was adjusted, see below.

The recorded water level on the Northern Wairoa River at Dargaville (see Figure 9) was used as the downstream boundary condition of the model. Water levels in the lower Kaihu River are mainly determined by the tide level, and a high tide a week or two after the flood peak (which occurred during 12 June in the lower river) could easily be significantly lower than the high tide level at the peak of the flood. The calibration simulation in Mike 11 ends at the end of 12 June, and the highest water level up to that time is reported as the maximum simulation level. Several of the measured peak flood levels in the lower Kaihu River are below the measured high tide level up to the end of 12 June, and therefore are clearly not peak levels during the flood, but rather high tide levels that occurred after the flood.

The cross section survey measured the height of the 2.0m mark on the staff gauge at the Kaihu at Gorge recorder. That measurement in terms of OTP64 put the staff gauge zero 461mm lower than the zero used to date by NRC. A further check survey commissioned by NRC in June 2015 confirmed the difference, and the recorded water levels were adjusted accordingly. The previous staff gauge zero was determined in relation to benchmarks N75A and N75B, which according to NRC records were established in 1957. They were thus established before the OTP64 datum and presumably their levels were given in terms of another mean sea level datum.

4.4.2 Calibration procedure

The positions of the surveyed peak flood levels were plotted on a map in the Surfer software, with a georeferenced topomap image as background. Then by reference to maps showing the locations of the Mike 11 model cross sections representing the floodplains and the Kaihu River, the nearest model cross section to each flood level survey point was selected. Measured and simulated levels were then plotted together on a Kaihu River maximum flood level long section. The surveyed peak flood levels extend from the river mouth to Ahikiwi, with one further point at the Opouteke Road bridge (upstream of the Kaihu at Gorge recorder site). In addition, recorded and simulated water level time series were compared at Parore Bridge and at Kaihu Gorge. Finally the measured peak flood level at Opouteke Road allowed calibration of the reach upstream of the Kaihu at Gorge recorder.

Most of the catchment area contributing to the modelled section of the Kaihu valley lies downstream of the Kaihu at Gorge recorder. Therefore for the most part the model must rely on the accuracy of the hydrological modelling. However for the catchment upstream of the Gorge recorder site, either the recorded flow time series or that produced by the hydrological model simulation could be used. The peak flows agree very well, but the volume of the simulated flood is slightly larger than the actual recorded volume. As an indication of sensitivity to the Kaihu Gorge hydrograph, both options were simulated and plotted.

4.4.3 Calibration results

Figure 10 shows the measured and simulated peak water levels along the Kaihu River from Dargaville to Ahikiwi, with the flow at Kaihu Gorge as calculated by the hydrological model. The tide level is a boundary condition of the model, so it necessarily agrees with the recorded maximum level. The model also agrees well with the recorded maximum level at Parore Bridge. As noted above, the maximum water levels measured between Parore and Dargaville are probably just high tide levels at some time after the flood peak, because it is not realistic that they should be lower than the maximum level at the river mouth. On average the model agrees well with measured peak levels up to approximately river distance 9000m (about 1.5km downstream of Ahikiwi). Upstream of 15000m the scatter of the measured flood levels about a mean profile suggests a significant uncertainty.

At the two most upstream measured flood levels, the simulated levels are significantly higher. This is the region of the model where flow passes from the whole valley cross sections upstream of Ahikiwi and enters the region of quasi two dimensional discretisation (where the Lidar survey covered the floodplains). The Kaihu River branch changes from representing the whole valley to representing just the main river channel. That transition is concentrated into a small distance in the model, as is necessary at such a transition to a quasi two dimensional discretisation, and may cause some artificial backwater effect upstream.

The simulated profile indicates a rising water level with distance downstream at about 24000m. That is in the reach just upstream of the Rotu Bottleneck, where there is a major exchange of water between the river and floodplains. At 24260m there is a large outflow to the true right floodplain, and consequently a recovery of velocity head immediately downstream. The amount of water level difference is approximately 0.2m. The recovery of velocity head is an artefact of the discretisation. Just upstream, the river crosses the floodplain to the true left side, and true left floodplain flows must therefore enter the river. Because of the discrete points of connection between the river and floodplain, the excess flow is contained within the river channel for a short distance, before it can exit to the true right floodplain. The effect on the water surface profile is relatively localised, and reconstruction of the model was not considered justified.

The maximum flood level at the Opouteke Road bridge was 79.924m according to the survey, and 79.906m according to the simulation. Figure 11 compares the simulated and recorded water level time series at Kaihu Gorge. It may be seen that the agreement is quite good, although the simulated water levels rise earlier, and the simulated flood volume is larger than that recorded.

Figure 12 compares the simulated and recorded water levels at Parore Bridge. The agreement of the tidal peaks is quite good during the rising limb of the flood. The peak level is overestimated by the simulation, by approximately 0.2m. In the first tidal cycle, before the arrival of the flood wave, the agreement of both high and low tide levels is quite good. This indicates that the resistance to flow setting in the model is realistic, because the outflow on the ebb tide occurs as in nature. During the flood, the low tide levels are underestimated by the model. The differences are probably largely attributable to the difference between the calculated and actual runoff over the catchment area downstream of Kaihu Gorge.

Using the recorded Kaihu Gorge flow instead of that produced by the hydrological model produced the results shown in Figure 13, Figure 14, and Figure 15. The longitudinal section of maximum water levels is practically the same as that in Figure 10. At Kaihu Gorge, the agreement at the higher flows is good, but the model slightly overestimates the water level at low flows. At Parore Road, the agreement of the simulated low tide levels on the rising limb of the flood with those recorded is slightly improved. The agreement of the model with the peak recorded level is practically the same as in Figure 12. On the falling limb the agreement of the model with the recorded levels is slightly better. These results suggest that the differences between the model and the records are mainly due to differences between the inflows from the hydrological model and those that actually occurred. However the level of agreement is quite satisfactory, and shows that the model generally gives realistic flood levels.

4.5 Design storm simulations for 10 year ARI and 100 year ARI with climate change

The design storm simulations used the Mike 11 model modified as described above, and calibrated against flood levels recorded in June 2014. The 10 year ARI storm assumes present day rainfall statistics (there is no allowance for climate change). The tidal boundary used for the 10 year ARI storm simulation also assumes present day sea levels. The maximum tidal level was 2.236m. The timing of the tide was adjusted so that the highest tidal level at Dargaville coincided with the highest Kaihu River flow at Parore bridges.

The tidal boundary condition used for the simulation of the 100 year ARI with climate change event assumes projected sea level rise of 1.0m up to 2090, and the highest tide level is 3.236m. As in the case of the 10 year ARI flood simulation, the timing of the tide was adjusted so that the highest tidal level at Dargaville coincided with the highest Kaihu River flow at Parore bridges.

Both 10 year and 100 year ARI with climate change simulations ran satisfactorily in the calibrated model, with no further modifications needed. Boundary conditions for the Tuflow model simulations were taken from the Mike 11 model results: discharges in the Kaihu River, the floodplain flow on the true right side downstream of Parore, Baylys branch at State Highway 12, and Mangatara branch at State Highway 12.

The Mike 11 model results were used to generate maps of maximum flood level and maximum flood depth for the Kaihu valley. The flood mapping modules of the Aulos software were used for this purpose.

5. Dargaville and Awakino model

5.1 Data sources

The Dargaville and Awakino model overlaps the Mike 11 Kaihu valley model, and covers Awakino point and the lower Awakino valley. Ground levels in the two dimensional domain of the model were taken from the 2015 Lidar survey. NRC supplied the ground levels as ESRI ASCII grids with 1m grid spacing, The model extent is shown in Figure 19 where the active cells of the two dimensional domain are enclosed within the red border. The extent up the Kaihu and Awakino valleys was limited by the coverage of the 2015 Lidar survey. In other places the boundary of the active cells was determined from consideration of the ground elevation – if there was no chance of flooding, the cells were made inactive to save computational time.

The 1m grids of ground level were used to generate contour maps using the Surfer software. Those contours showed the ground levels with as good a resolution as the Lidar data can reasonably provide. Break lines for the Tuflow two dimensional model domain were generated by digitising along the various features in Surfer, thus producing xyz files. Breaklines were used in the Tuflow model where a topographical feature was likely to act as a hydraulic control, making it desirable to represent the feature as accurately as possible.

Kaihu river cross sections for the reach where the Kaihu valley and the Dargaville – Awakino models overlap were available from previous modelling work. They were extracted from the Mike 11 model and processed into Tuflow format. The distances between the cross sections were likewise taken from the Mike 11 model.

Cross sections on the Awakino River and on three main drains on the Awakino floodplain were surveyed in 2015. Their positions are shown in Figure 16. Those cross sections were processed into Tuflow format, and the river and drain distances were measured using the GIS software QGIS.

Drain outfall pipes and culverts were also surveyed in 2015. The information gathered was pipe invert levels, diameter, and whether floodgated or not. The positions of the surveyed culverts are shown in Figure 17 and Figure 18.

The timber floodwall along the bank of the Northern Wairoa River downstream of Dargaville was surveyed in 2015. It is included in the Tuflow model as a breakline.

5.2 Model details

5.2.1 Two dimensional domain

The Dargaville and Awakino model is built in the Tuflow software, and is linked to the Mike 11 model of the Kaihu valley by transferring flow boundary conditions to the Tuflow model from the Mike 11 result file. The two dimensional (2d) grid of the Tuflow model was aligned so that flow down the Kaihu and Awakino floodplains is approximately aligned with one of the grid directions. The grid cell size used is 5m, which was selected so that the time to complete flood simulations is reasonable, allowing for an iterative process of model development and improvement. The size of the computational domain was limited to the necessary minimum by defining the edge of the active area a short distance above the edge of the floodplains. During the simulation of the 100 year ARI event with allowance for climate change and sea level rise, the maximum number of wet cells was approximately 503,000, representing a flooded area of approximately 12.5km^2. The computational domain of active cells is shown in Figure 19.

At the Northern Wairoa River bank, the edge of the active model cells is set a short distance out into the river. In this case there is no requirement to model the Northern Wairoa, and to do so would require river discharge scenarios which have not been defined. For this model it is assumed that the tidal water level is the same at all points along the Northern Wairoa bank.

5.2.2 River and drain branches

The Kaihu River, Awakino River, and some drains on the Awakino floodplain are represented in the model as one dimensional (1d) branches, using the Estry software which is the 1d component of Tuflow. The 2d domain is inactivated where it lies under the river and drain branches. The rivers and drains are hydraulically linked to the 2d domain along user-defined polylines which more or less follow the river banks or nearby high ground, and form the boundaries between the 1d and 2d domains. The boundary polylines in most cases follow breaklines which were created by digitising from the 1m terrain grid in Surfer.

The river cross sections in the Kaihu branch are the same as are used in the Mike 11 Kaihu valley model. On the Awakino River and the floodplain drains, the surveyed cross sections were used, and in addition some intermediate cross sections were interpolated using the facility provided by Estry. The interpolated cross sections were included to improve the model resolution, and also to avoid the Kaihu and Awakino Courant numbers being significantly different (which could present difficulties in making a stable and accurate model).

The 2015 survey included two drains on the true right side of the Awakino floodplain that run across the floodplain, roughly perpendicular to the main direction of floodplain flow. One of those arises in the small side valley just north of Dargaville Hospital (referred to as the Hospital drain in this report), and the other lies a short distance south of the railway line, and crosses Awakino Road near where it first descends to floodplain level north of Dargaville (called the Northwest drain in this report). Those drains were at first included in the model. However after some simulations it was clear that the main importance of the drains was that their raised banks act as hydraulic restrictions on floodplain flow. In the design flood simulations (particularly the 100 year ARI with climate change) there was flow down the floodplain at significant depth over the drain banks. In the model that means flow must enter the drain over one bank, flow across it (which is not well represented in a 1d branch whose purpose is to carry flow longitudinally) and back to the floodplain over the other bank. It was considered more realistic to allow the drains to be part of the 2d domain, and to represent the drain banks by breaklines in the 2d model. The culverts on the drains are retained in the model, to allow the drains to operate reasonably realistically at low water levels.

The Te Wharau drain which rises near Te Wharau and outfalls on the true left side of the Awakino River about 1km upstream of the State Highway 14 bridge, is included in the model as a 1d branch.

5.2.3 Culverts

The 62 culverts surveyed in 2015 have nearly all been included individually in the model (floodgated 150mm culverts of which there are a couple were considered insignificant and were not included). Most of them have outfalls on the Northern Wairoa, the Awakino, or the Kaihu, but a few are on drains in the floodplain. On the Northern Wairoa bank downstream of the Kaihu confluence, the land ends of the culverts are connected to an artificial depression in the 2d domain (created by lowering a narrow strip of 2d cells), which represents in a schematic way the pipe drainage system, and acts as a manifold to allow any floodwater which accumulates on that floodplain to be distributed amongst the various outfall pipes according to their flow capacities. In other cases where a culvert carries flow between the 1d and 2d domains, the ground level in the 2d domain is locally adjusted around the culvert intake, so that the ground level is below the surveyed culvert invert level. Floodgates are included in Tuflow by specifying that flow in a culvert is possible in one direction only.

The field inspection notes state that there is a 1.2m diameter floodgated culvert discharging to the true left of the Awakino River just upstream of the State Highway 14 bridge. That culvert was not included in the survey. It is understood to be on the roadside drain, and the contour map made from the Lidar data indicates that there is relatively high ground between the culvert intake and a large area of low ground further upstream of the highway. It is not known whether there is any pipe connection between the drain and the larger area of low ground. Because of the uncertainty about the pipe it was included in a check version of the model, with an assumed invert level of -0.5m. In order to maximise its effect it was positioned to drain the larger area of low ground. The modification had no effect on peak levels in the 100 year ARI with climate change design flood, but lowered peak level by 0.04m over a small area immediately upstream of the culvert in the 10 year ARI flood. The simulations using that version of the model were treated as a sensitivity test, and the results are not included in the WaterRide project files or in the grids of maximum flood depth, maximum flood level, and maximum velocity.

5.2.4 Dargaville flood wall

The timber flood wall along the Northern Wairoa River bank was included in the model as a breakline within the 2d domain. The surveyed data was imported into QGIS and saved as a shape file, from which the Tuflow shape file representing the breakline was created.

5.2.5 Manning n values

Manning n for the Kaihu River was set to 0.02, the same value as was used in that reach in the Mike 11 model. The value used for the Awakino River was 0.03. This value was selected because the channel is substantially smaller than the Kaihu River, so the influence of the rougher banks is proportionately greater. It is possibly a conservative estimate, but calibration data would be needed to make an accurate estimate of Manning n for the Awakino River. For all the floodplains, a value of 0.04 was used to represent the mainly pasture ground cover. In Dargaville the resistance to flow is difficult to estimate, with very high values in some properties, but quite low values on streets. The value of 0.04 was assumed to represent the combination of smooth and rough zones in urban areas. The same value of 0.04 was used for the Te Wharau drain.

Concrete and PVC pipe culverts have Manning n of 0.013 in the model. For wooden box culverts Manning n of 0.02 was assumed. For circular corrugated steel culverts Manning n of 0.025 was used. Culvert inlet and outlet loss factors were set to 0.5 and 1.0 respectively.

5.2.6 Boundary conditions

The Tuflow model has boundary conditions representing the tide, inflows generated by the hydrological model, and inflows taken from the Mike 11 Kaihu valley model. The Kaihu River and Awakino River flow boundary conditions are applied directly to the corresponding 1d branches, which extend to the edge of the 2d domain. Inside the model boundary, the 1d branches are free to exchange flow with the 2d domain depending on the relative water levels.

The inflows generated by the hydrological model (other than the Awakino River flow), are applied to the model as source area elements. That means the inflow appears on the ground within a certain user defined area, from which it can spread out over the floodplain. The inflows from the Parore-rb, Mangatara and Baylys floodplain branches of the Mike 11 model on the true right of the lower Kaihu are also treated in this way.

The Awakino Point area has its own drainage system with outfalls to the Northern Wairoa, which was not included in the survey carried out in 2015. In the model Awakino Point acts as an overflow region for Awakino River floodplain flows, but the model does not include the drains and outfalls which must exist in that area (the Lidar data indicates at least one major drain). Awakino Point area is not represented in the hydrological model and therefore all flooding that occurs there in the model is due to overflows from the Awakino River and floodplains, or to tidal overflow from the Northern Wairoa.

The tidal boundary condition is applied along all of that part of the 2d domain boundary that lies in the Northern Wairoa River. Thus the same tidal boundary condition applies over the whole river bank from downstream of Dargaville to the upstream side of Awakino Point. That is a simplification because the water level could vary depending on the Northern Wairoa flow, and in response to the propagation of the tidal wave up the river. It is not practical to model that variation of water level along the Northern Wairoa without modelling a substantial reach of the river, because the tidal prism is understood to extend up to Tangiteroria or thereabouts. It would also be necessary to define Northern Wairoa flow scenarios to include it in the model in a realistic way. Other tidal boundary configurations for the 2d domain were tried, such as including the Northern Wairoa as part of the 2d domain (with an approximate estimated bed level) and applying the tidal boundary condition downstream of Dargaville and at the upstream side of Awakino Point. That proved unsatisfactory because in the absence of flows up and down the river, it is a very low friction environment, and prone to developing standing waves which can make the water levels significantly different at different points along the river bank.

All the culverts which outfall on the Northern Wairoa River have the tidal level applied individually, as a 1d boundary condition. That was a simpler procedure than connecting the culvert ends to the 2d domain.

5.2.7 Model input files

Most of the Tuflow input files are ESRI shape files, which can be read by any GIS software (the exceptions are boundary condition time series and river cross sections, which are .csv text files). The shape files are referenced in three text files, which in turn are referenced by a single controlling text file (with extension .tcf). By working through the hierarchy from the control file it will be possible for Council to use GIS software to review the entire model setup. All the model set up files will be supplied with this report.

5.3 June 2014 simulations

The boundary conditions for the simulation of the June 2014 flood are the recorded tidal level at Dargaville, the hydrological model hydrographs for the Awakino and Dargaville catchments, and the lower Kaihu valley flow hydrographs taken from the Mike 11 model.

For model testing and development, the results were reviewed using Crayfish which is a plug in module for QGIS. Both of those are freeware and would provide a possible way for Council to review the results.

The main purpose of the June 2014 simulation was to calibrate the Kaihu River branch in the Tuflow model, and to check that the flooding shown in the Awakino valley was realistic, and that the maximum water level profile along the Awakino River was reasonable. No water levels on the Awakino River or its floodplain were recorded in the June 2014 flood, and it is recommended that flood levels be collected in future events for verification.

Figure 20 shows the profile of maximum water levels along the lower Kaihu River as calculated by the Tuflow model. The Tuflow profile is slightly steeper than the Mike 11 profile, but still agrees reasonably well with the recorded data. As noted above, the peak levels measured from water level marks are considered unreliable as they lie significantly below the maximum levels according to the water level recorders at Dargaville and Parore. The slight disagreement of the Tuflow model with the Dargaville tide recorder occurs because the time steps that were saved skipped over the time of maximum tide level.

Figure 21 shows the maximum water level along the whole modelled reach of the Awakino River (extending to the northern edge of the 2d domain shown in Figure 19) according to the Tuflow model. The water surface gradient roughly matches that of the river invert, and the average water surface gradient is approximately 0.5 in 1000. In the absence of calibration data this gradient is considered to be reasonably realistic.

Figure 22 shows the simulated maximum extent of flooding on the Awakino floodplain in the June 2014 flood. The figure is an image exported from QGIS and Crayfish, and the mapped parameter is depth. Blue shades represent depths lower than about 1m, while yellow to red shades represent depths greater than 3m. Flood levels on the Awakino floodplain during this event were not available, however it is understood that most of the floodplain north of State Highway 14 was under water at some time during the flood. The flooding is shown as extending up to the boundary of the 2d domain. No flow can cross that boundary in the model, so it is possible that depths in that area are overestimated because of the artificial constraint on flow. The estimated flow hydrographs at the upstream boundary of the 2d domain rely on a very approximate routing in the HEC HMS hydrological model. It is possible that if a more comprehensive routing model extending well up the Awakino valley could be applied, the hydrographs would be more attenuated and the flooding near the northern side of the Tuflow model correspondingly less.

5.4 Design storm simulations for 10 year ARI and 100 year ARI with climate change

5.4.1 Overview of results

Figure 23 is an image from QGIS and Crayfish showing maximum depths in the 100 year ARI with climate change flood. Flooding is predicted to cover most of the Awakino and lower Kaihu floodplains, including the lower parts of Dargaville. The lower parts of Awakino Point (generally a broad strip near the Northern Wairoa) are also predicted to be flooded, by a combination of tidal overflow from the Northern Wairoa, and overflow from the Awakino floodplain. The area beside the Northern Wairoa bank, both upstream and downstream of the State Highway 12 bridge, would also be flooded. The low ground in the Okahu valley (on the true right of the Kaihu near the mouth) is predicted to be flooded. The model predicts that the area beside the Northern Wairoa River south of the Kaihu mouth would also be inundated.

Figure 24 shows the maximum depths in the 10 year ARI flood, according to the Tuflow model. The model predicts that the Kaihu true right floodplain upstream of the Mangatara confluence would be flooded, as would the lower parts of the true left floodplain adjacent to Dargaville (in particular the old river loop). Flooding in Dargaville would be fairly limited. The model predicts widespread flooding of the Awakino floodplain upstream of the State Highway 14. The low ground beside the Northern Wairoa between the Awakino confluence and the Northern Wairoa bridge is also predicted to be flooded. The model predicts that Awakino Point, and the area beside the Northern Wairoa south of the Kaihu confluence, would not be flooded.

Results for the simulations may be conveniently viewed using QGIS with its Crayfish plugin module. Both of those are freeware. Using that approach, all the time steps in the result files will be seen (results were saved every 15 minutes). Flood level, flood depth, and velocity can all be viewed with Crayfish.

The results may also be viewed in WaterRide (project files for the 10 year ARI and 100 year ARI with climate change simulations are provided with this report). That has the advantage that both the Mike 11 Kaihu valley results and the Dargaville and Awakino Tuflow model results may be viewed in a single application. However the time resolution is reduced as the WaterRide project has 1 hour time steps to limit file sizes and make the software reasonably responsive.

There is one area of water level anomaly in the overlap region of the Mike 11 and Tuflow models, on the true right floodplain upstream of Mangatara valley. In this region the Mike 11 model is considered more reliable. The boundary of the Tuflow model in that area follows the edge of the 2015 Lidar data, and lies somewhat obliquely across the floodplain. As a result there is some loss of floodplain volume in the Tuflow model. In the Mike 11 model at that point the floodplain flow is free to spread out over the full width between the river and the high ground, but in the Tuflow model it is constrained. Further south, the Tuflow model boundary follows the State Highway 12, whereas the Mike 11 model is free to exchange flow with the floodplain on the west side of the highway. Both of those factors tend to raise the flood levels in the Tuflow model. Near the Kaihu River, at the upstream end of the Tuflow model, the agreement is reasonably good, with the

Tuflow maximum level being approximately 0.3m higher than the Mike 11 model peak level in the 100 year ARI with climate change flood. Further south the agreement is worse, as the Tuflow model creates a relatively level pool in this region, owing to the restrictions described above.

5.4.2 Details of simulations

The 100 year ARI and 10 year ARI flood events required simulation periods of 36 hours and 48 hours respectively, to cover the peak of the flood at all points in the model. Results were saved every 15 minutes of simulated time. The initial water levels were set equal to the tide level at the start of the simulations.

The model timestep was 2 seconds which is consistent with guidelines given by the Tuflow manual for "healthy" models with 5m grid size. After the first 10 seconds of simulation time, the peak cumulative mass error percentages in the simulations were minus 0.60% and minus 0.17% for the 100 year ARI with climate change and 10 year ARI floods respectively. Tuflow guidelines state that the peak cumulative mass error percentage should be less than 1% in most models. The absolute cumulative mass error is tracked at each time step during the simulation, and is the difference between volume of flow in minus volume of flow out, and volume at this time step minus volume at start. The percentage is calculated by dividing the absolute cumulative mass error by the sum of flow in and flow out. Tuflow can be set to produce a mass balance output file which shows the mass balance errors at all points in the model, thus allowing inaccurate areas to be improved. The other main diagnostic tool was the velocity vector output. Regions of anomalously high velocity were generally also areas of poor mass balance performance.

6. Flood mapping

The Mike 11 model results were processed in the same way as in previous Kaihu valley projects carried out by B&M. Briefly the Mike11 results were used to create a surrogate Aulos result file, and the Aulos flood mapping module was used to generate the grids of maximum water level and maximum depth. We have assumed that as the velocities from the Mike 11 model are cross sectional averages, and the directions are only very coarsely defined by the software, they are not particularly useful and we have not generated grids of maximum velocity from the Kaihu model.

The Tuflow results for the 10 year ARI and 100 year ARI floods were processed into grids of maximum water level, maximum depth, and maximum velocity, using the Tuflow_to_GIS utility.

WaterRide project files were also made for the 10 year ARI and 100 year ARI with climate change simulation results. The Tuflow results were overlaid over the Mike 11 results to produce a single flood surface. The time step in the WaterRide project is one hour, so as to make the response time reasonable when interrogating the project for detailed results.

7. Conclusions

1. The calibration of the Kaihu valley HEC HMS hydrological model was checked using flows and rainfalls recorded in the June 2014 storm. It was found that the model reproduced the recorded flow hydrograph well without any changes. Therefore the Kaihu valley hydrographs for 10 year ARI and 100 year ARI with climate change storms used for the previous flood modelling carried out by B&M, were still valid and were used unchanged for this study.
2. The hydrological model was extended to include Dargaville and the Awakino River, and was used to generate runoff hydrographs for the 10 year ARI and 100 year ARI storms. The extended model was also used to generate hydrographs for the entire Kaihu, Dargaville, and Awakino River catchments in the June 2014 storm.
3. The Mike 11 model of the Kaihu valley was extended upstream in various places: on the main river, up to the confluence of the Mangatu Stream and the Waima River; and up six side valleys to increase the coverage of the floodmaps. New surveyed cross sections were included in the model in various places including the main Kaihu River upstream of Ahikiwi.
4. The extended Mike 11 model was calibrated against flood levels recorded during the June 2014 flood. The recorded levels were reasonably well reproduced with Manning n values in the expected range, varying from 0.02 in the reach downstream of Parore Bridges to 0.056 in the steeper reach downstream of the Kaihu Gorge recorder, to 0.073 in the reach upstream of the flow recorder. Some recorded levels in the tidal reach, surveyed from water or debris marks, were clearly anomalous, as they are lower than the highest tide level during the flood as recorded at the Dargaville tide level recorder.
5. A two-dimensional model of the lower Kaihu valley, Dargaville, and the Awakino valley up to approximately 5km from the river mouth, was built using the Tuflow software. The Awakino River, Kaihu River, and some of the drainage pathways on the floodplain were represented as one dimensional elements within the two dimensional model.
6. The June 2014 flood was simulated in the Tuflow model. The flow boundary conditions were the hydrographs produced by the hydrological model simulation, where they fell within the model, and lower Kaihu valley flows taken from the Mike 11 model simulation. The Tuflow model reproduced the recorded water level profile in the lower Kaihu River reasonably well. No recorded water levels on the Awakino River or its floodplains were available. The Tuflow simulation showed a gradient of maximum water levels along the Awakino River of approximately 0.5 per 1000, which is consistent with the bed slope, and that most of the floodplains upstream of the State Highway 14 would be flooded. This is understood to be realistic.
7. The 10 year ARI and 100 year ARI with climate change floods were simulated in the Mike 11 model of the Kaihu valley, and in the Tuflow model of the lower Kaihu, Dargaville, and the Awakino floodplain. The tidal boundary conditions for the simulations assumed present day sea levels for the 10 year ARI flood, and a sea level rise of 1.0m for the 100 year ARI with climate change event.
8. The 10 year ARI flood simulation predicted widespread flooding of the Awakino floodplain upstream of State Highway 14, but limited flooding of Dargaville. The 100 year ARI with climate change simulation predicted major flooding of the

Awakino floodplain including downstream of State Highway 14 and including the lower ground on Awakino Point (partly caused by tidal flooding). The lower parts of Dargaville would also be flooded in the 100 year ARI event with climate change and sea level rise.

9. Grids of maximum flood level, maximum flood depth, and maximum flood velocity within the two-dimensional domain were produced in ESRI ASCII format.
10. WaterRide project files have been produced in which the Mike 11 and Tuflow model results are combined into a single project in which details of the simulation result may be interrogated.

8. References

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Kaipara District Council, Dargaville land use map series 1, Kaipara District Plan, November 2013

Ministry for the Environment, Climate change effects and impacts assessment, May 2008

Appendix A Figures

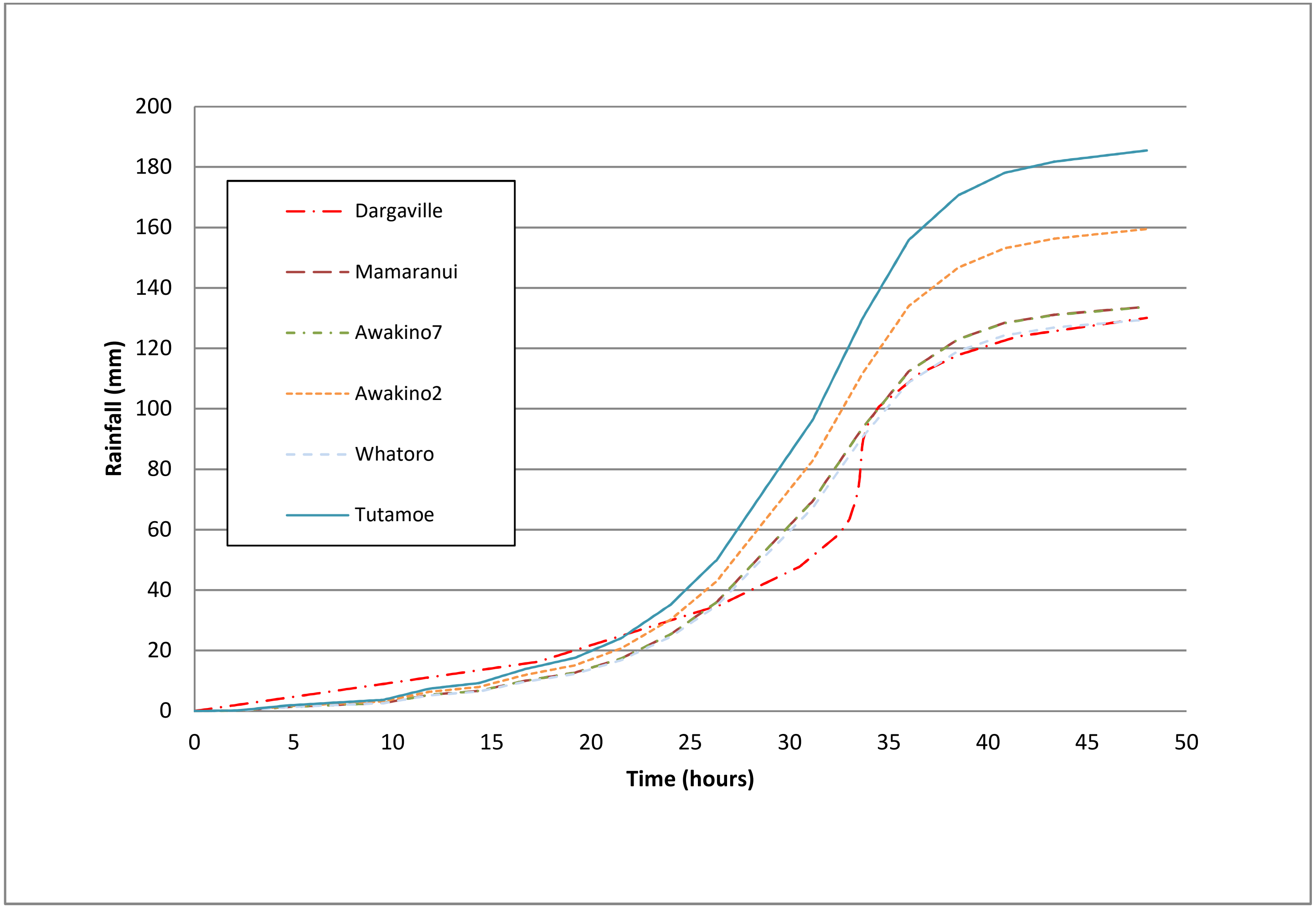

Figure 1: Cumulative rainfall, 10 year ARI design event

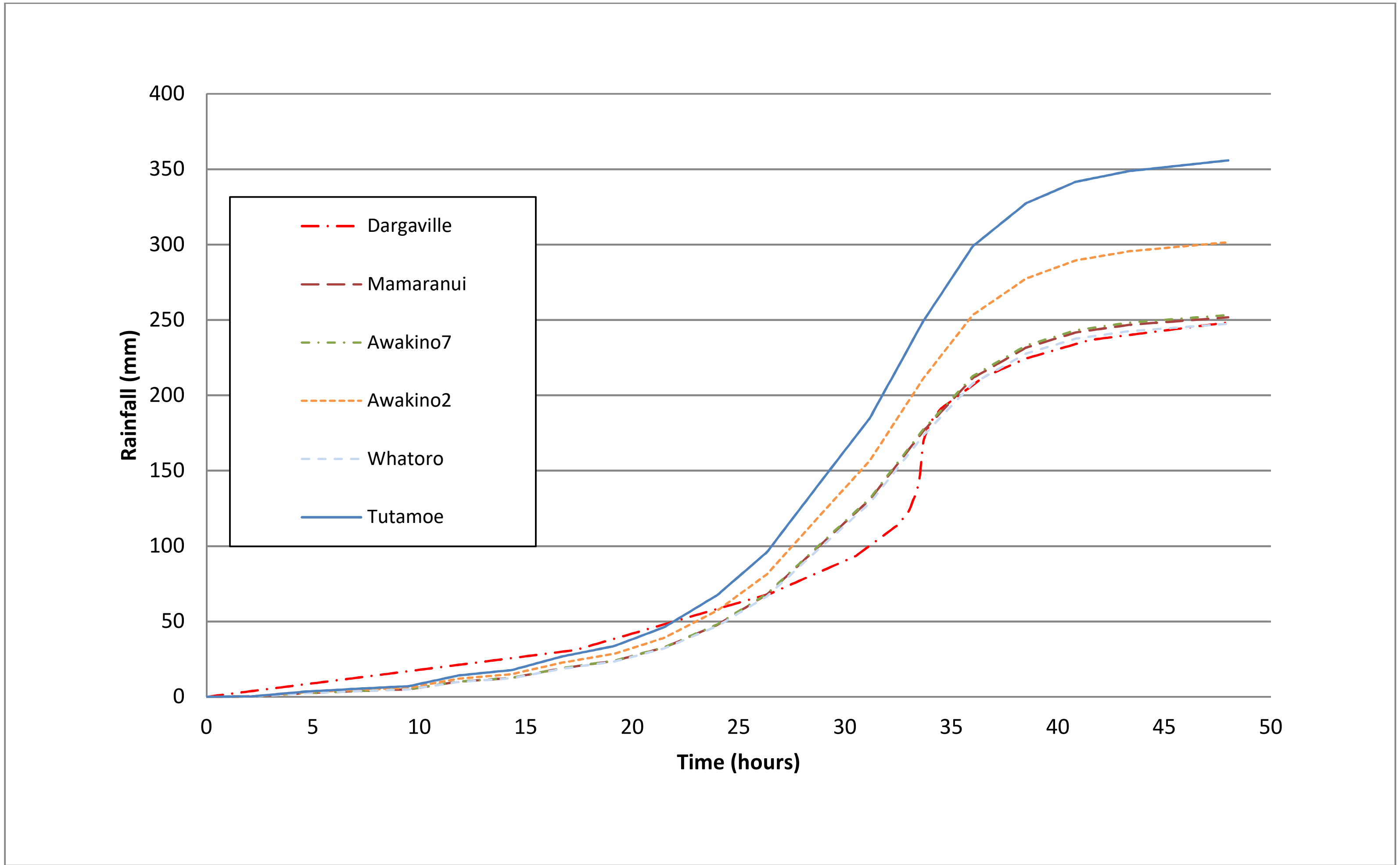

Figure 2: Cumulative rainfall, 100 year ARI design event with climate change allowance

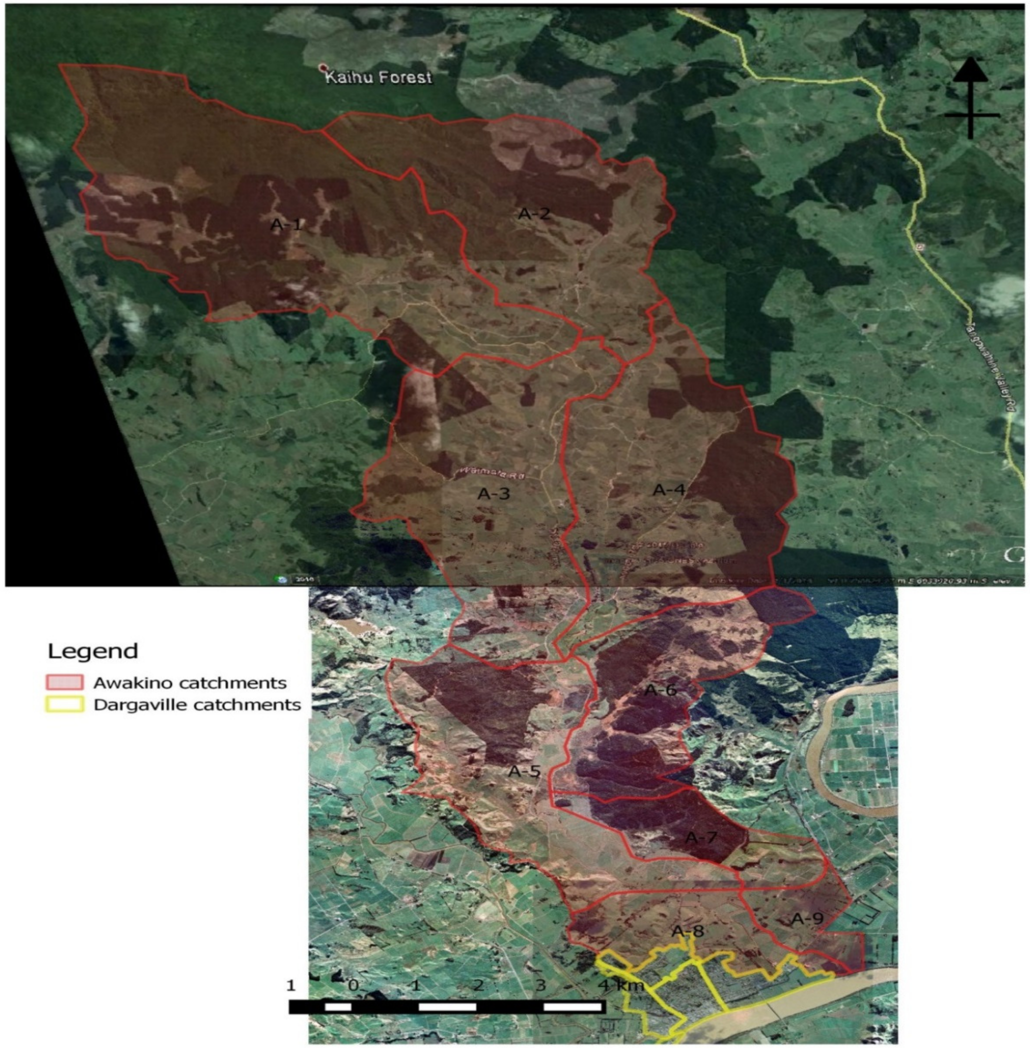

Figure 3: Awakino catchment map

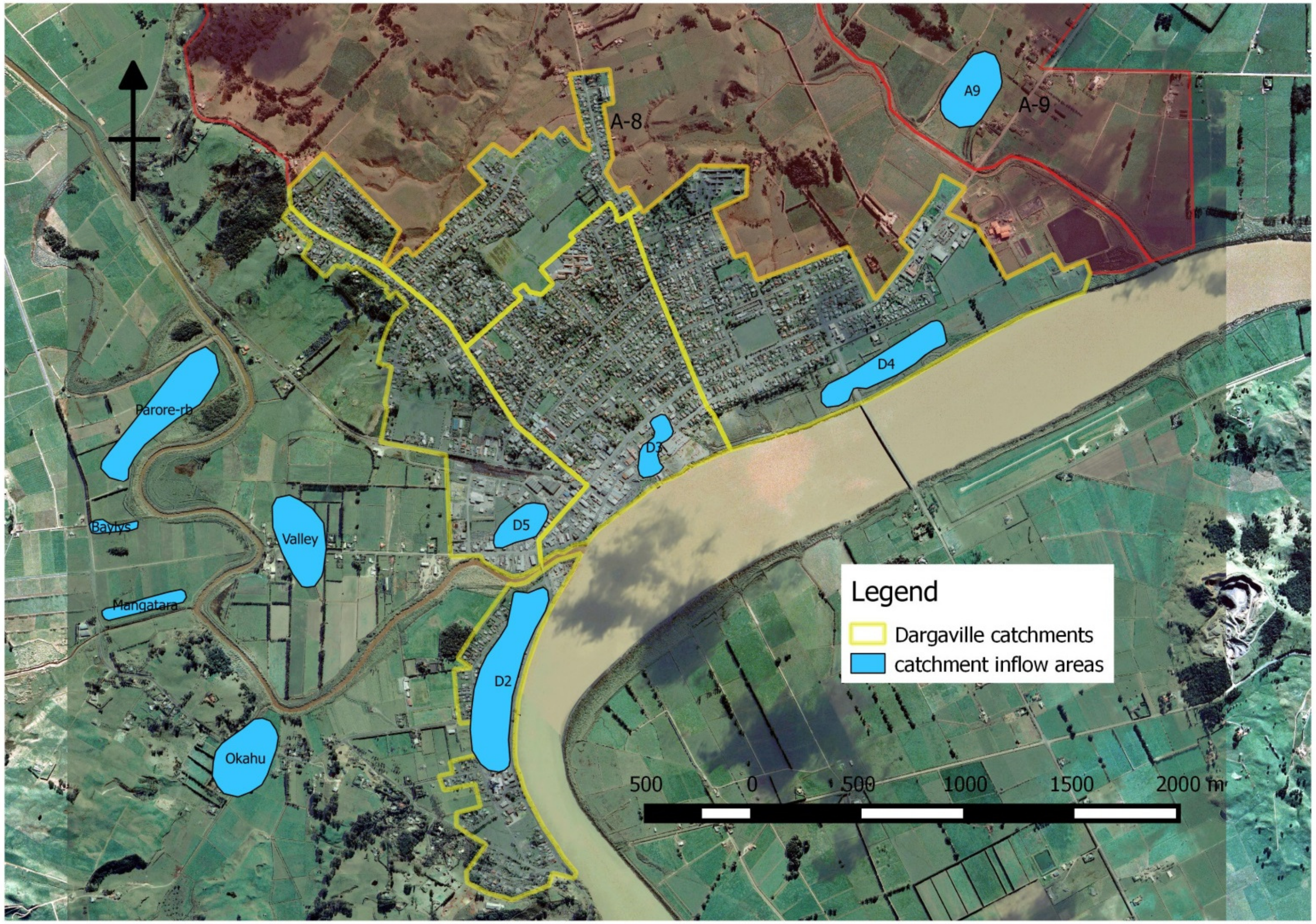

Figure 4: Dargaville catchment map with floodplain model inflow locations

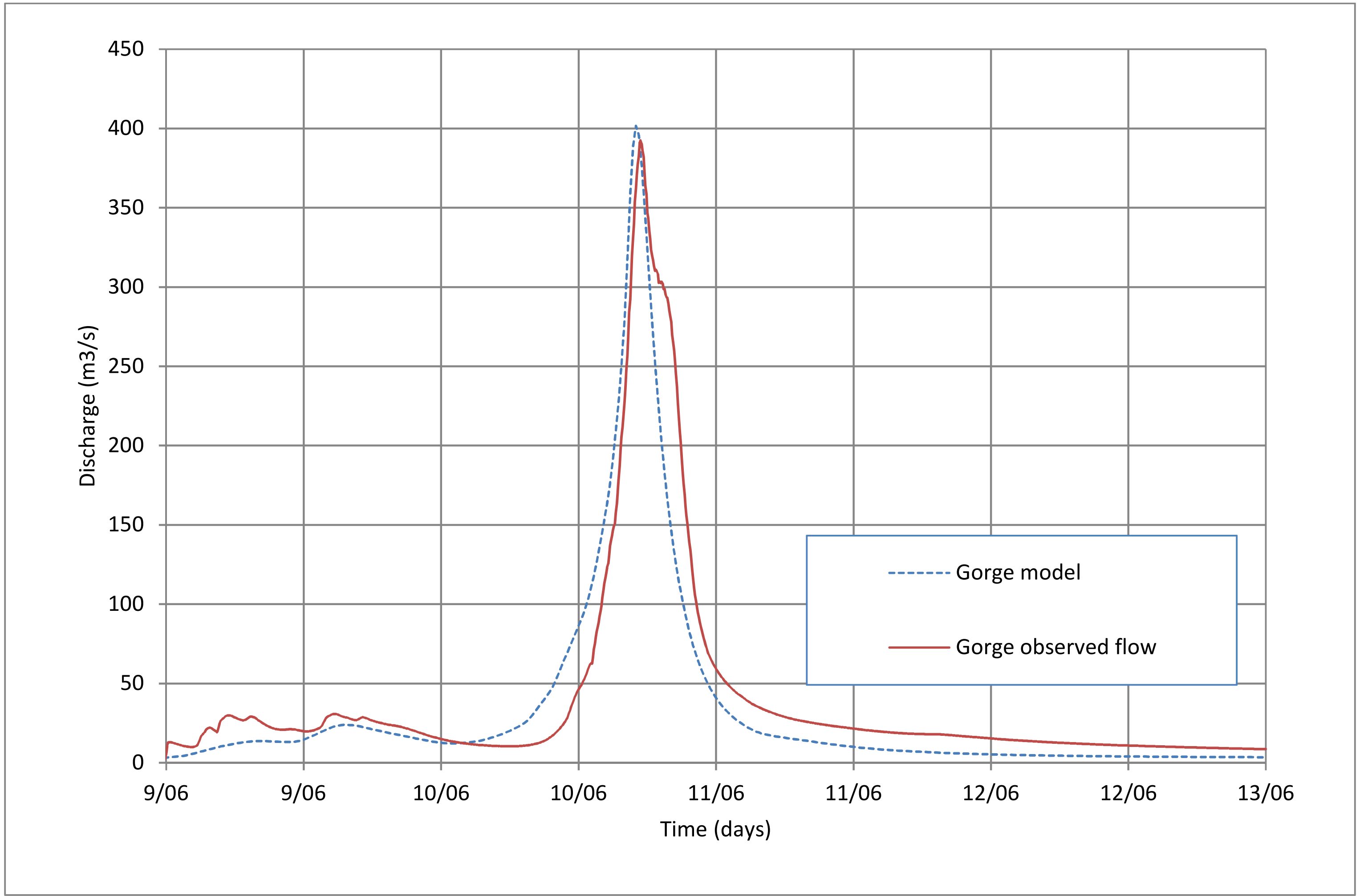

Figure 5: Kaihu gorge, June 2014, modelled and observed flow

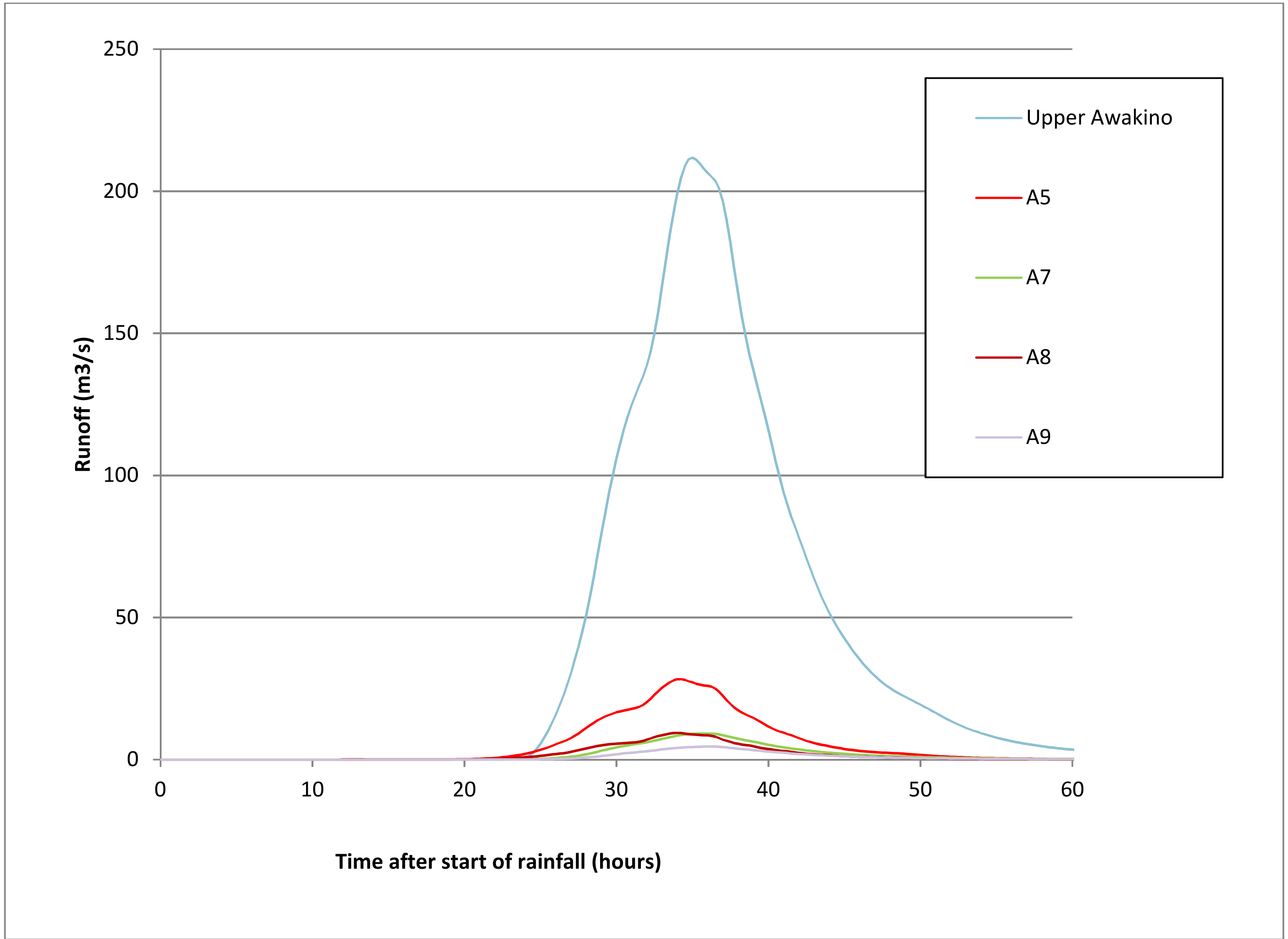

Figure 6: Runoff for design 10 year ARI event, Awakino

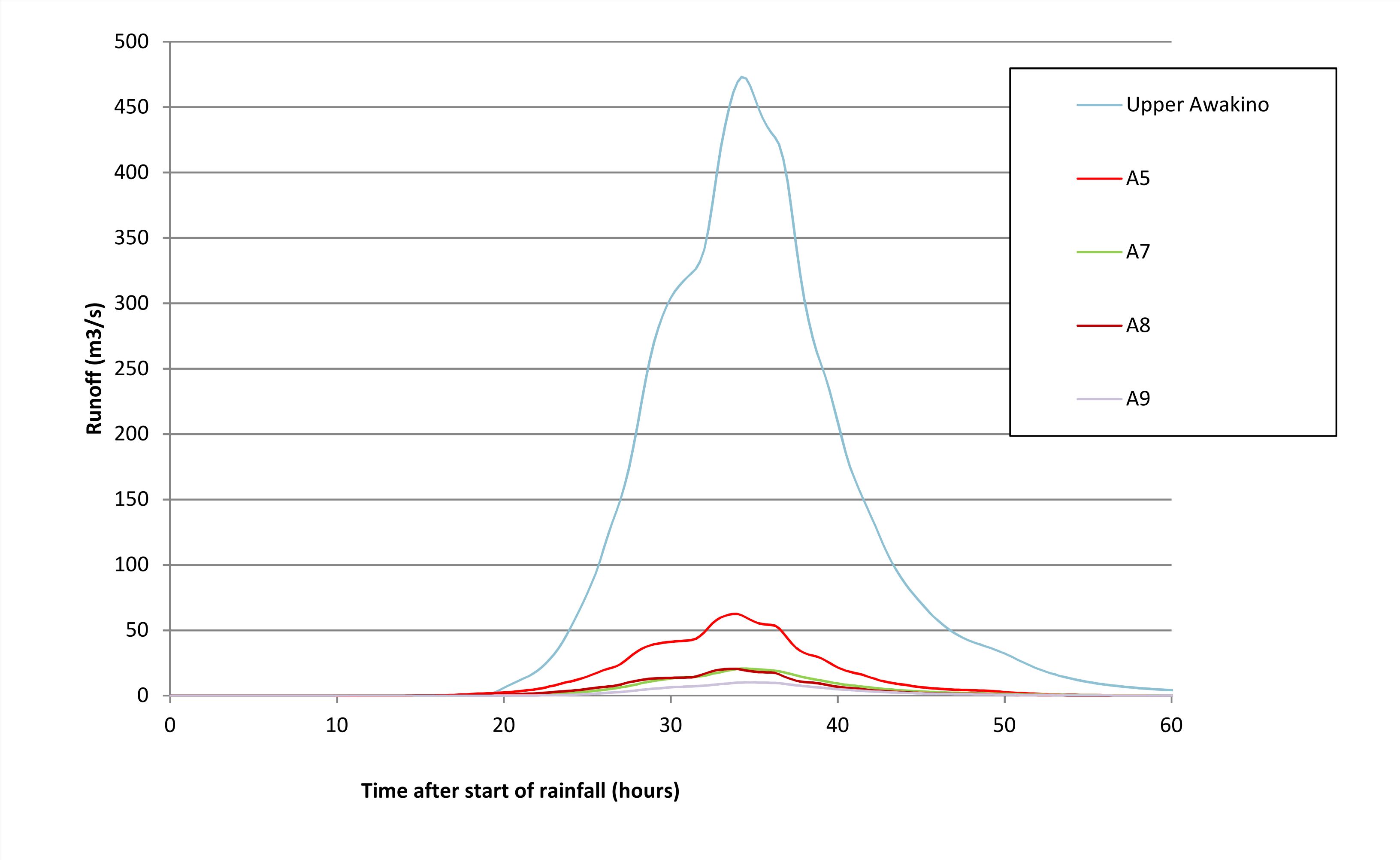

Figure 7: Runoff for design 100 year ARI event with climate change allowance, Awakino

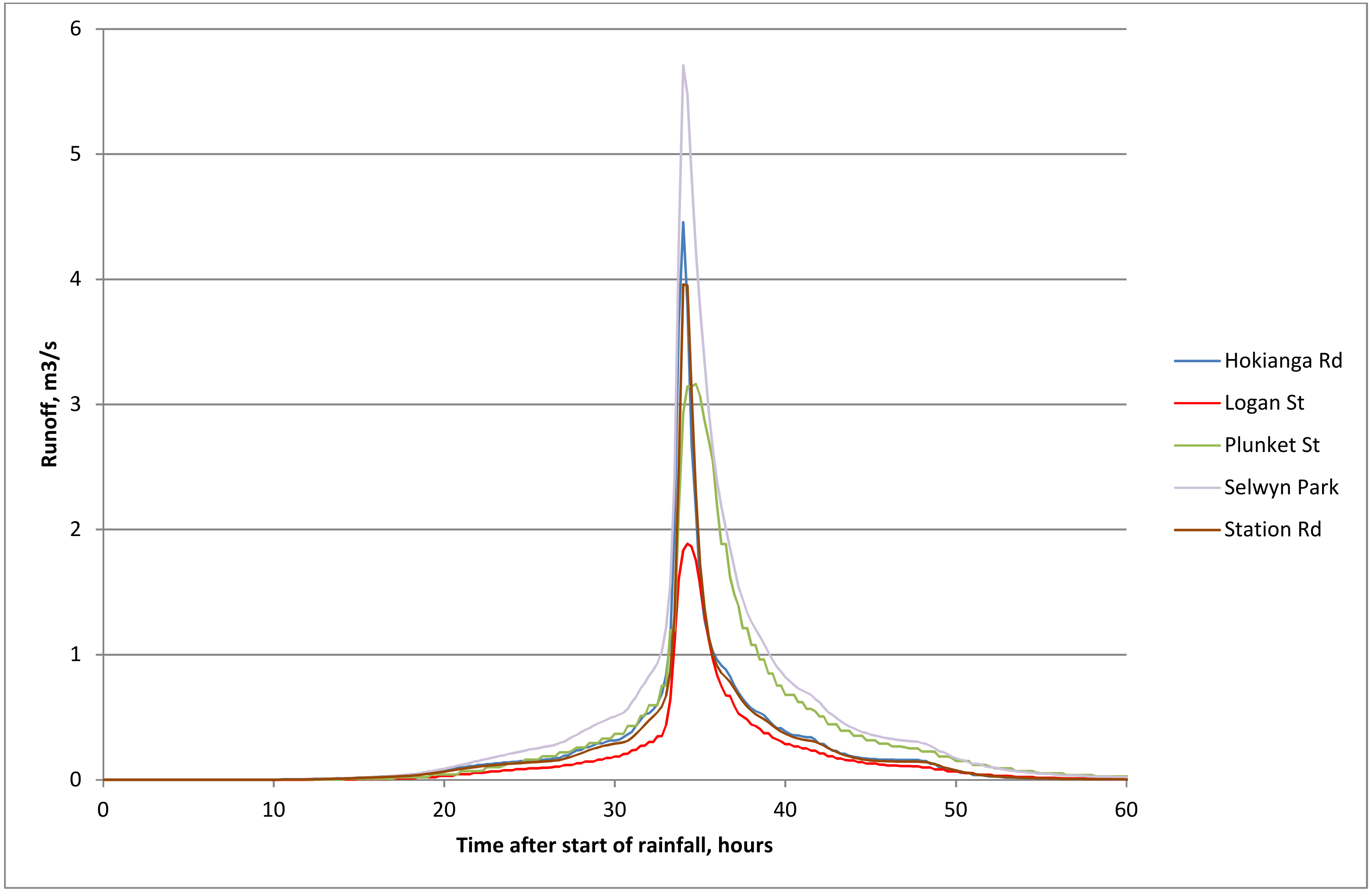

Figure 8: Runoff for design 10 year ARI event, Dargaville

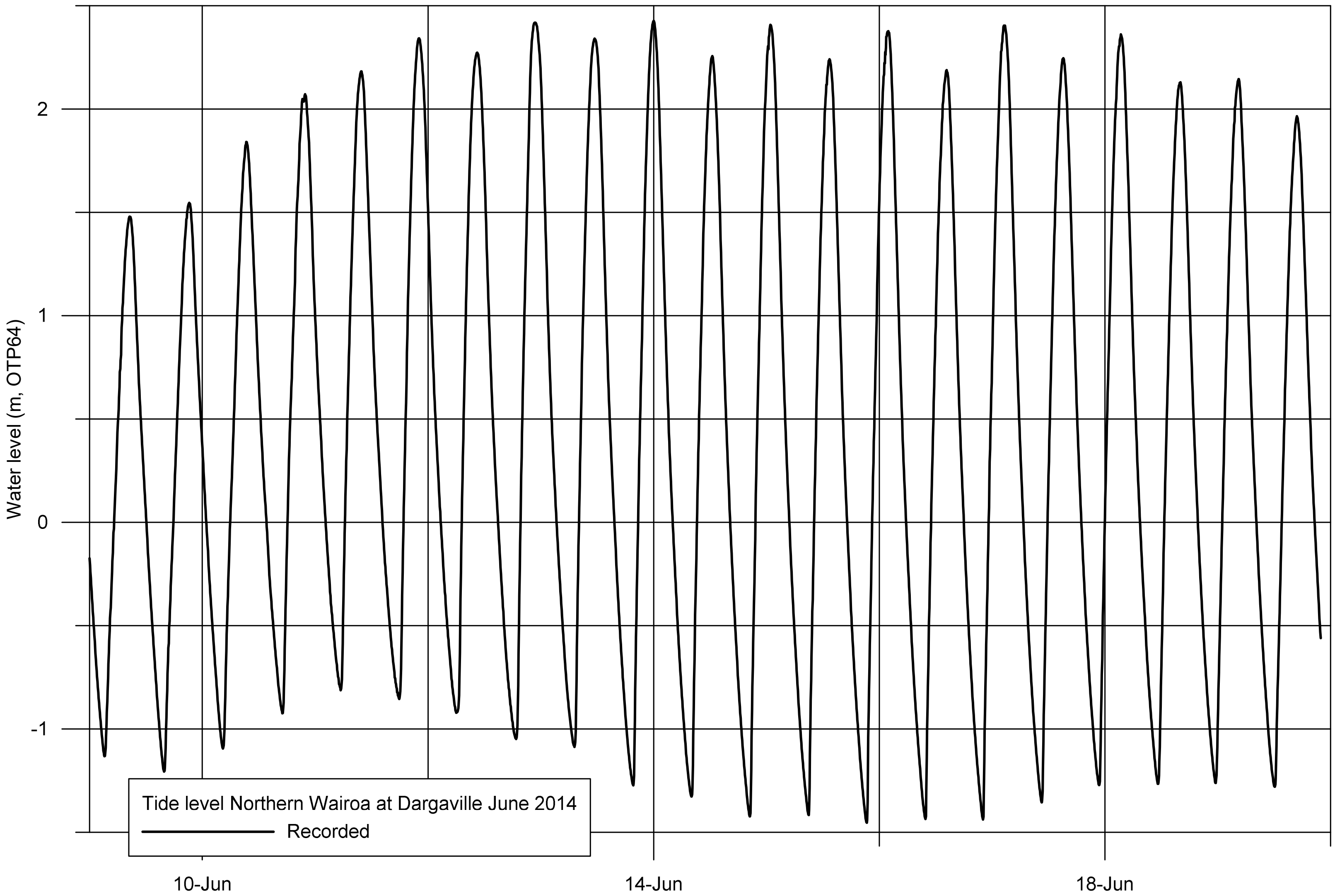

Figure 9: Tide levels at Dargaville during June 2014

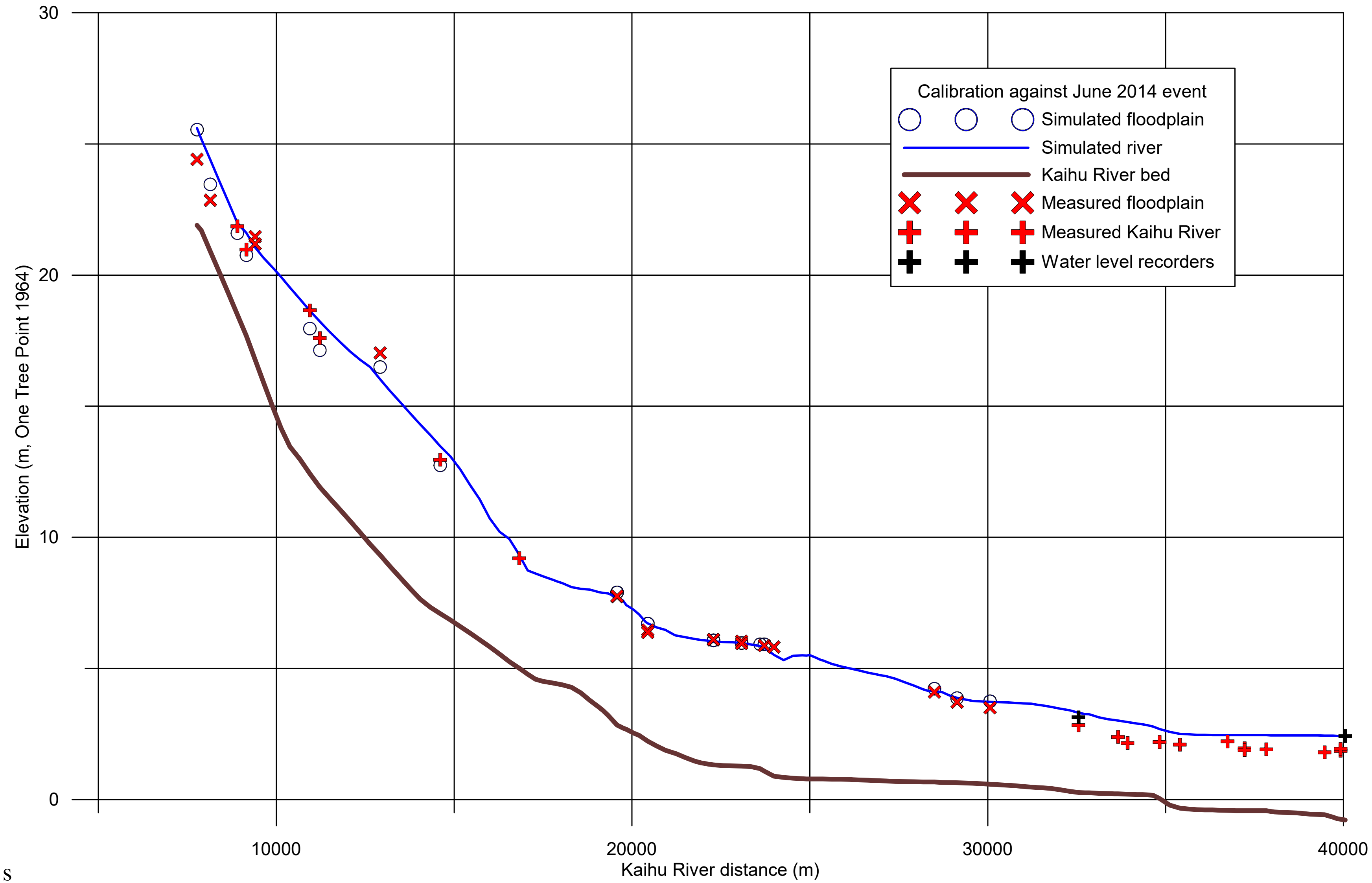

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Figure 10: Longitudinal section of maximum water levels in the June 2014 flood, with the discharge at Kaihu Gorge as estimated by the hydrological model

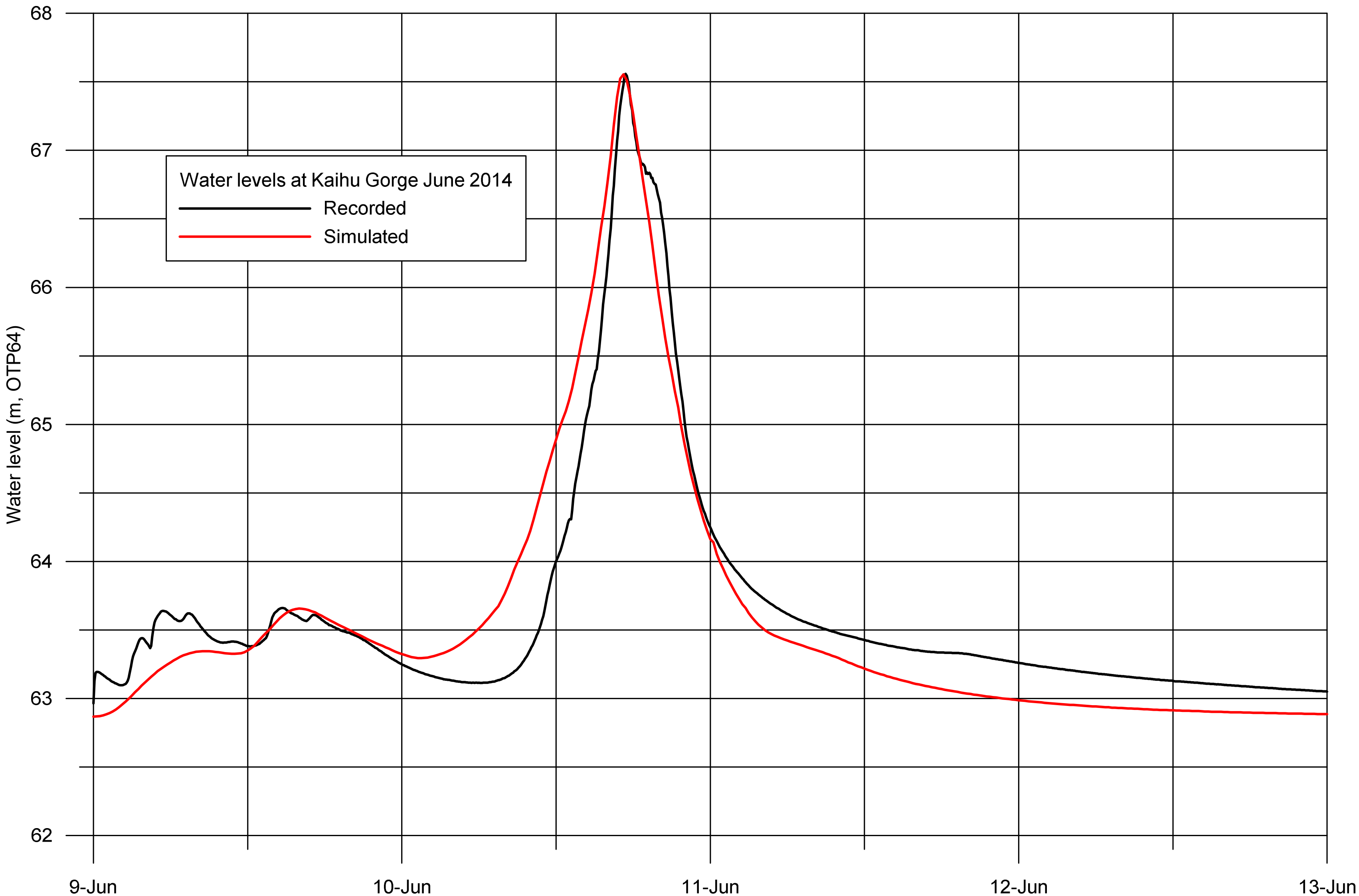

Figure 11: Recorded and simulated water level time series at Kaihu Gorge in the June 2014 flood, using the Kaihu Gorge discharge as estimated by the hydrological model

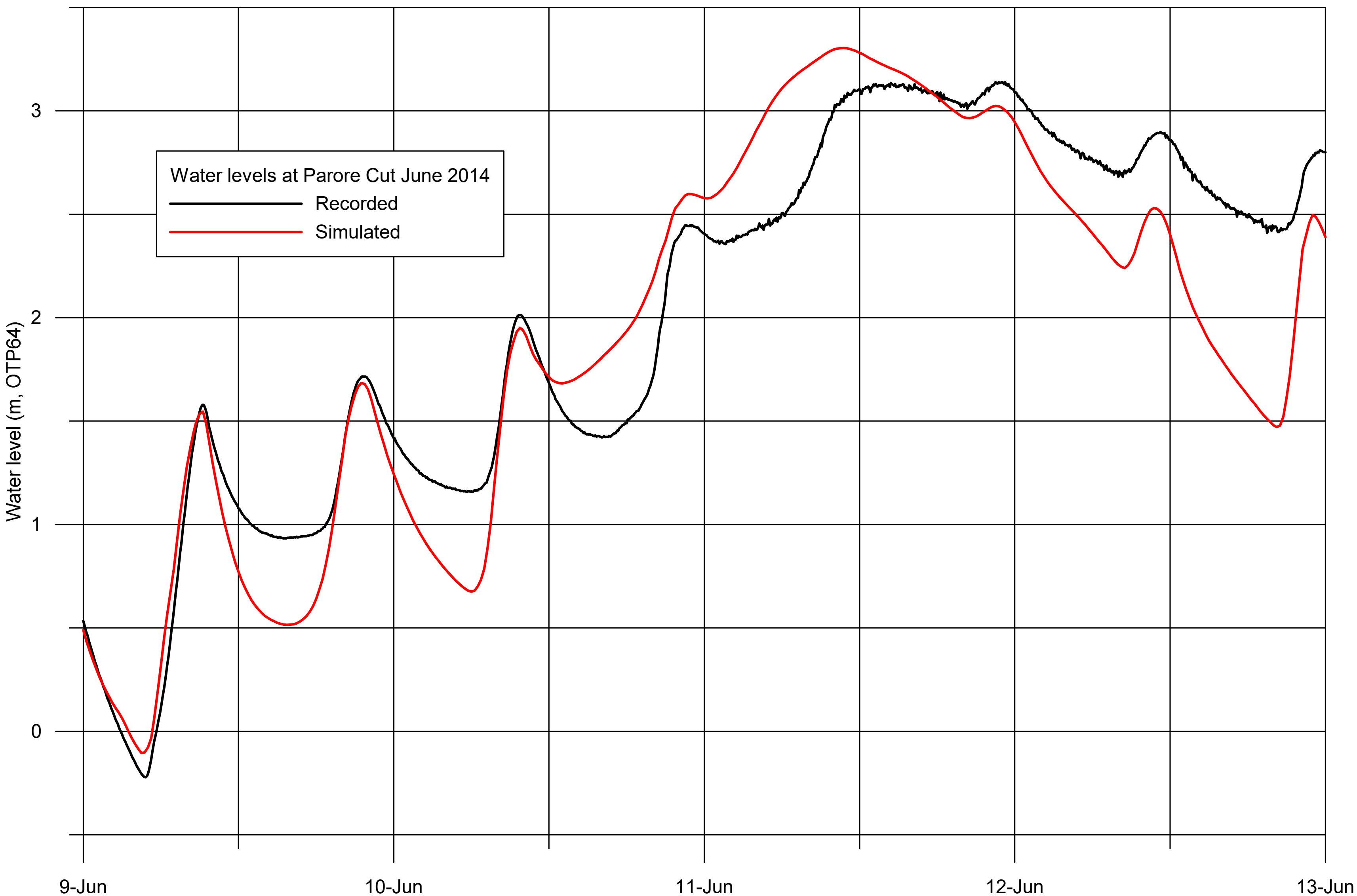

Figure 12: Recorded and simulated water level time series at Parore Road in the June 2014 flood, using the Kaihu Gorge discharge as estimated by the hydrological model

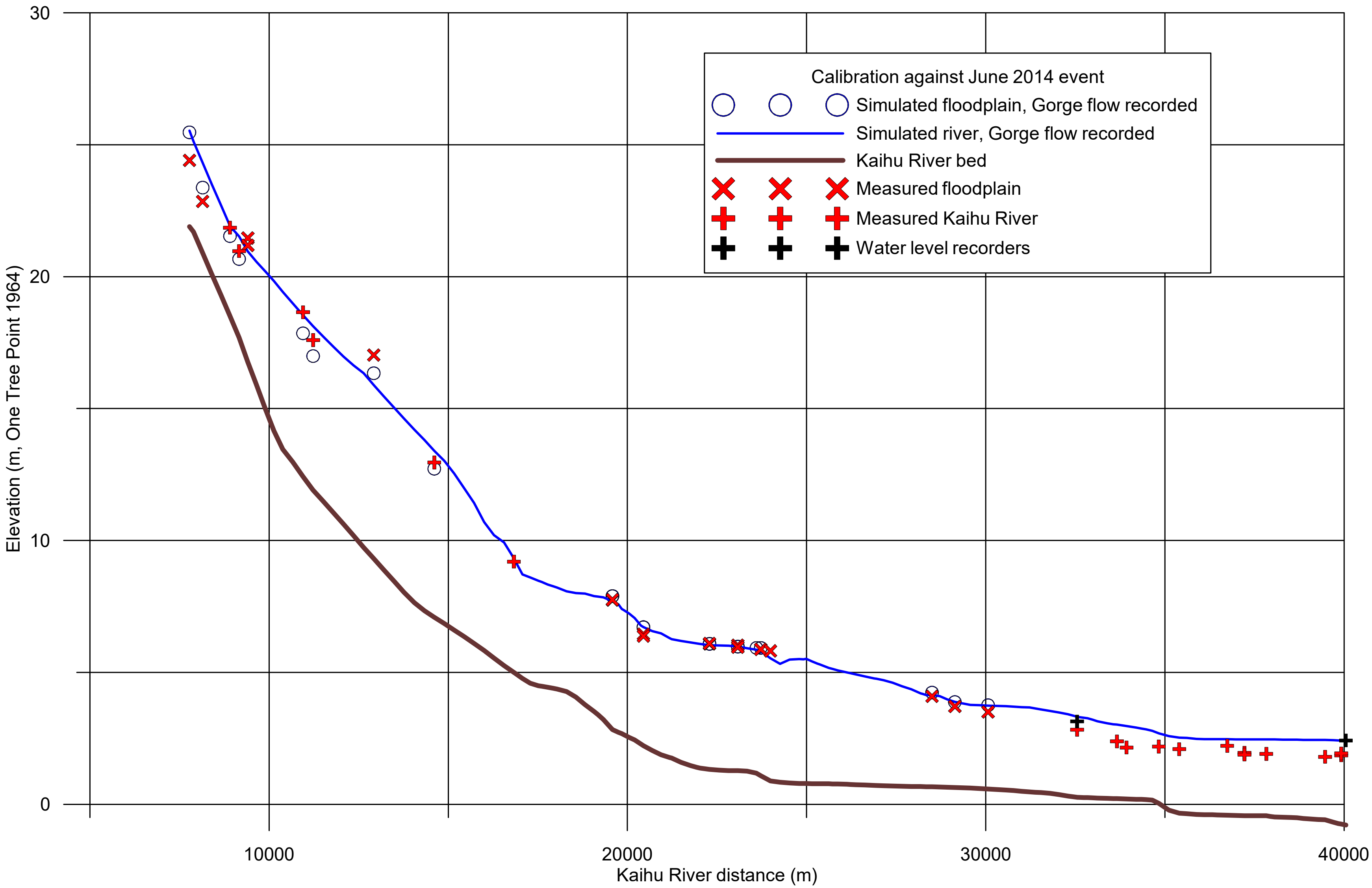

Figure 13: Longitudinal section of recorded and simulated maximum water levels in the June 2014 flood, with the recorded discharge at Kaihu Gorge

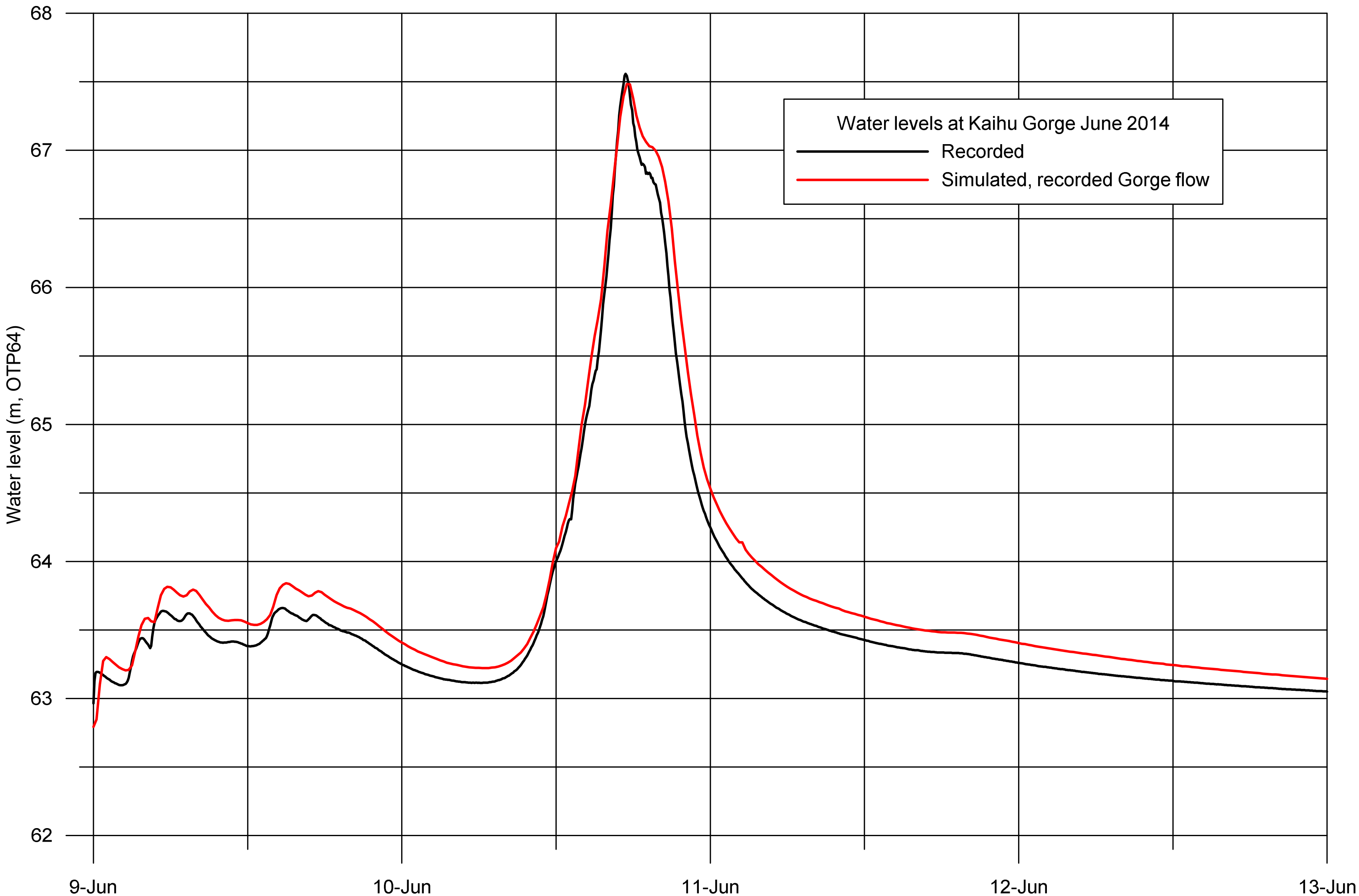

Figure 14: Recorded and simulated water level time series at Kaihu Gorge in the June 2014 flood, using the recorded Kaihu Gorge discharge

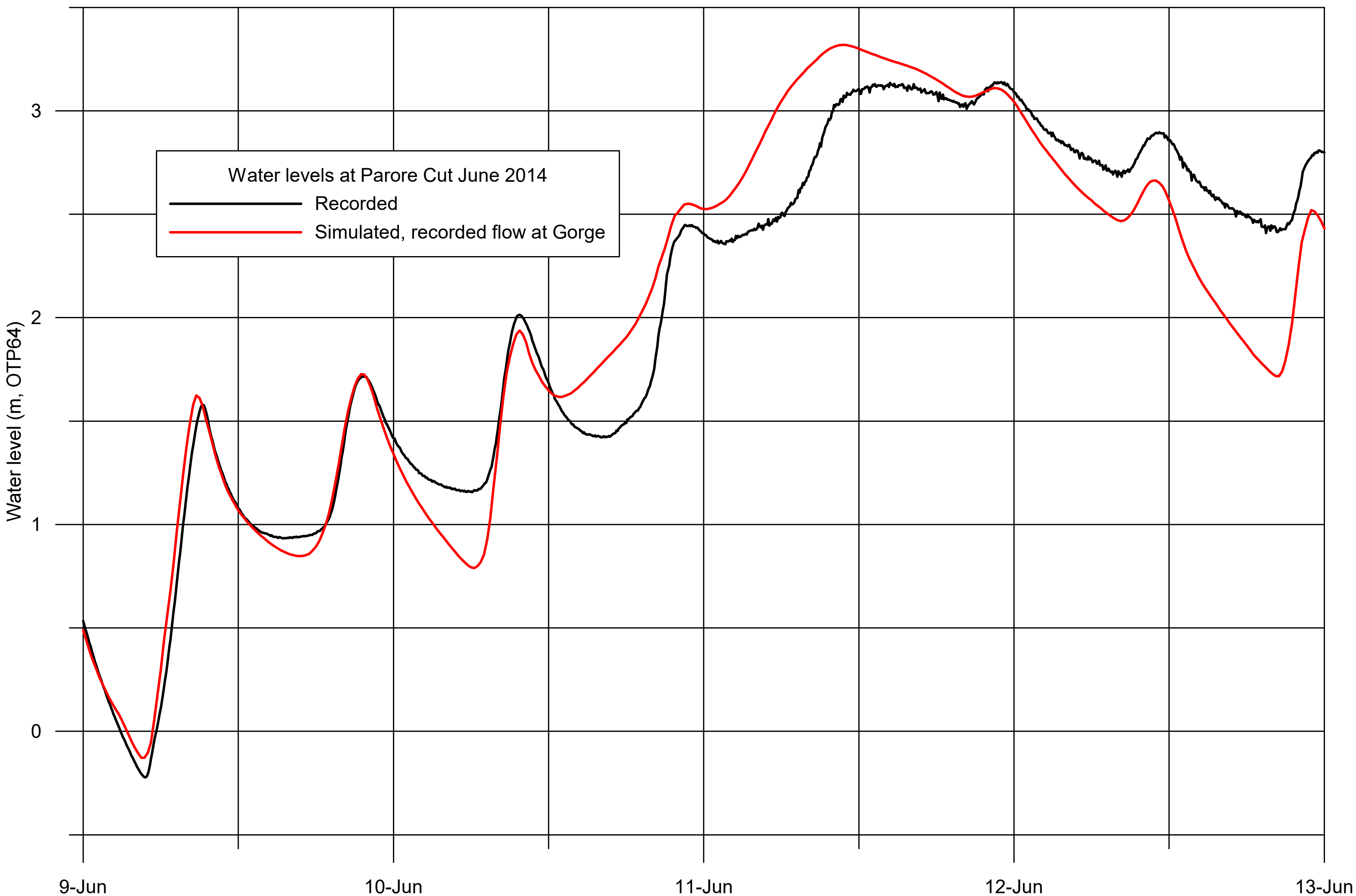

Figure 15: Recorded and simulated water level time series at Parore Road in the June 2014 flood, using the recorded Kaihu Gorge discharge

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Figure 16: Positions of cross sections surveyed in 2015 and included in the Dargaville and Awakino model

Figure 17: Positions of culverts surveyed on the Awakino floodplain in 2015 and included in the model

Figure 18: Positions of culverts surveyed in Dargaville and the Kaihu floodplain in 2015, and included in the model

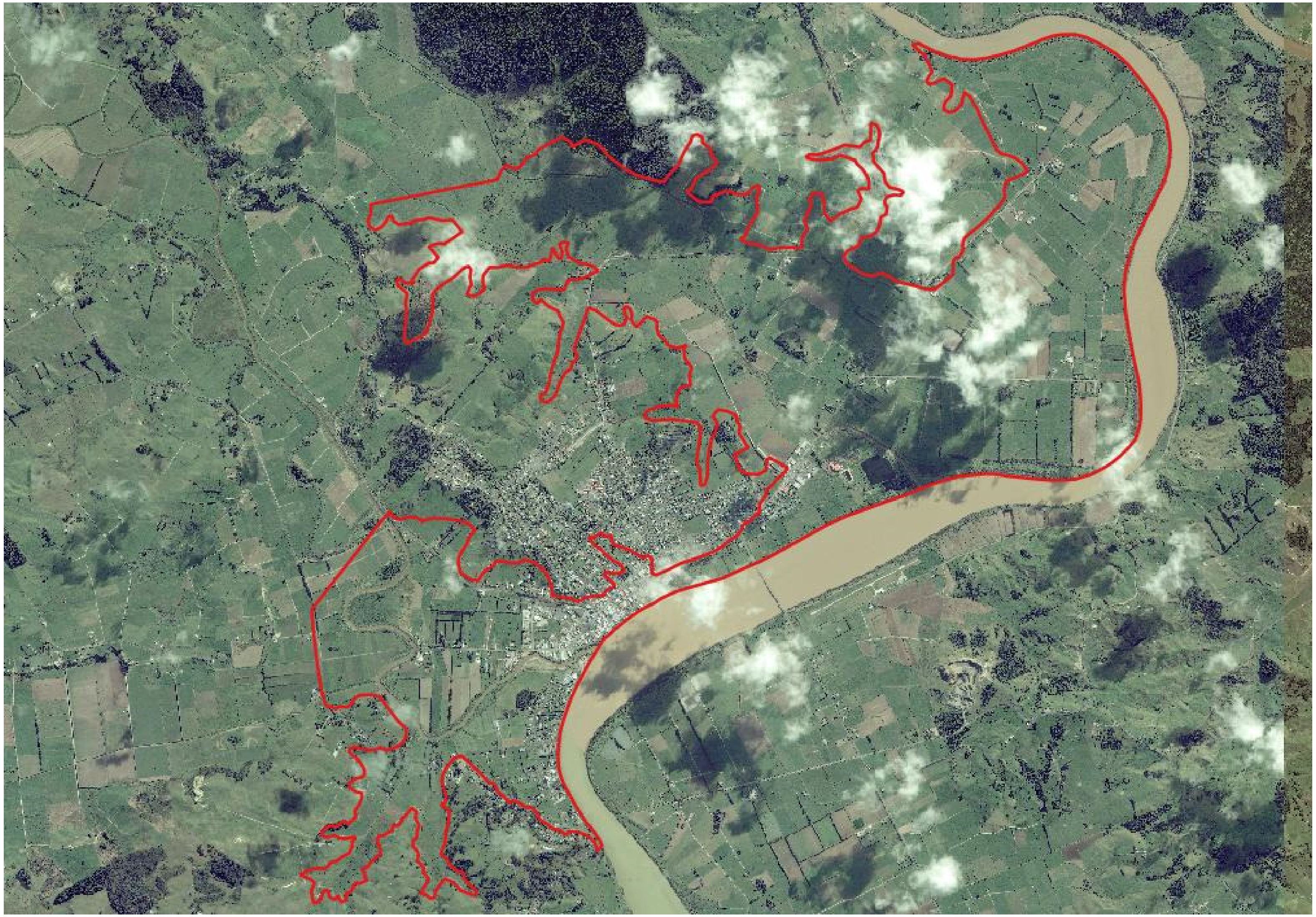

Figure 19: The boundary of the active domain of the Tuflow model of Dargaville and the Awakino floodplains

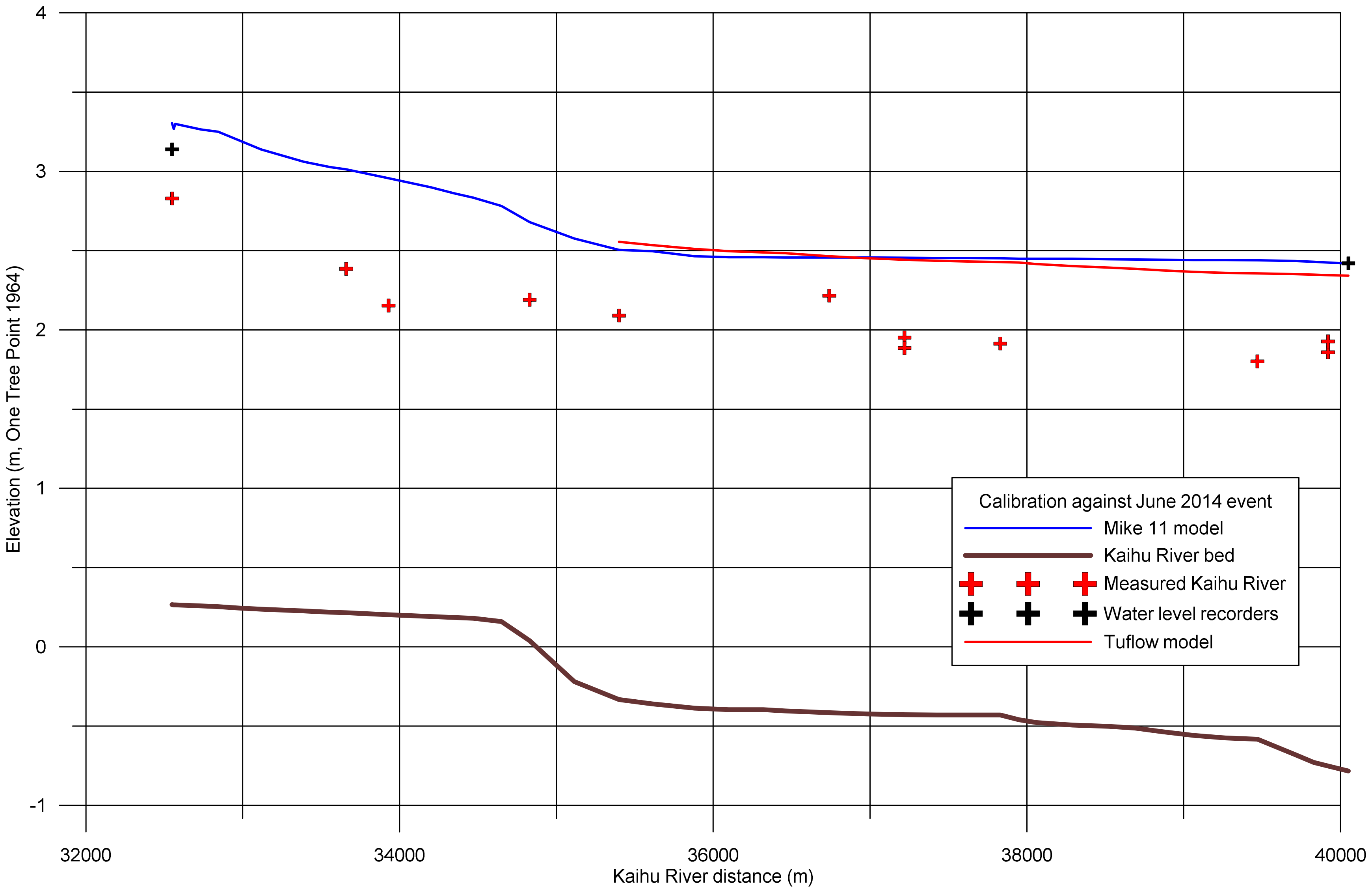

Figure 20: Simulated maximum water level profile along the lower Kaihu River from the Tuflow model simulation of the June 2014 flood

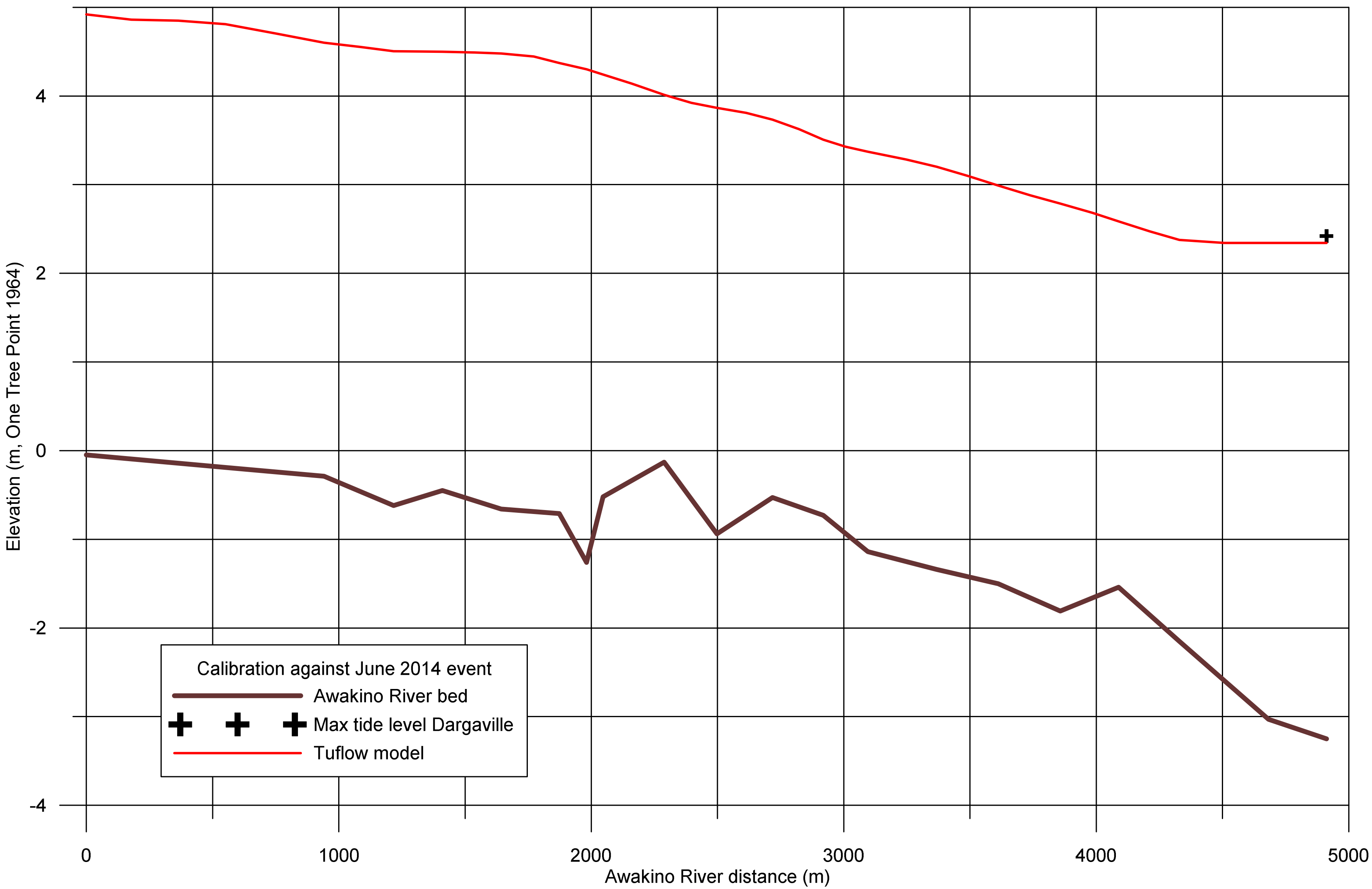

Figure 21: Simulated maximum water level profile along the Awakino River from the Tuflow simulation of the June 2014 flood

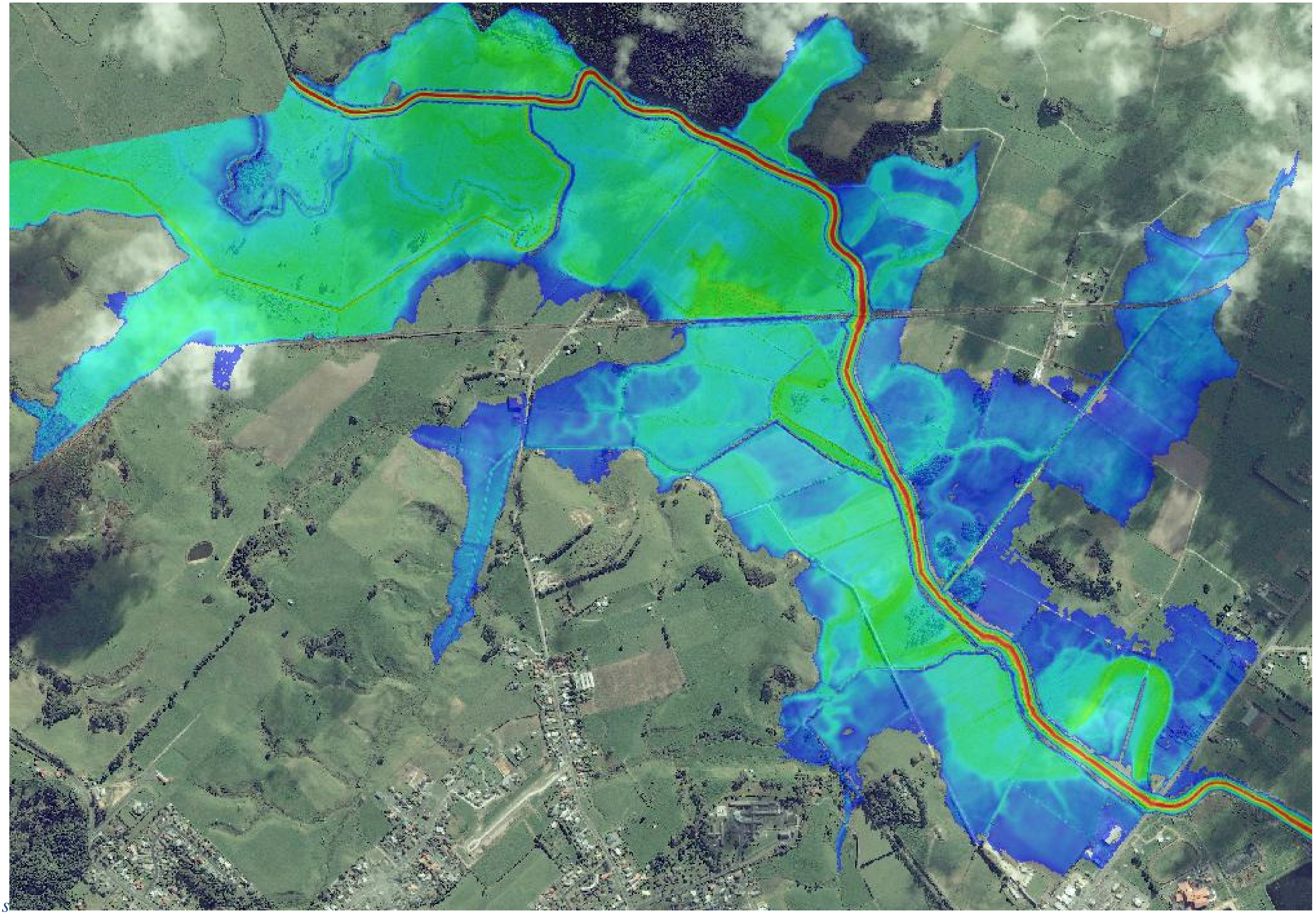

Figure 22: Simulated maximum flood extent on the Awakino floodplain in the June 2014 flood. Blue shades represent depths less than 1m, yellow and red shades represent depths greater than 3m.

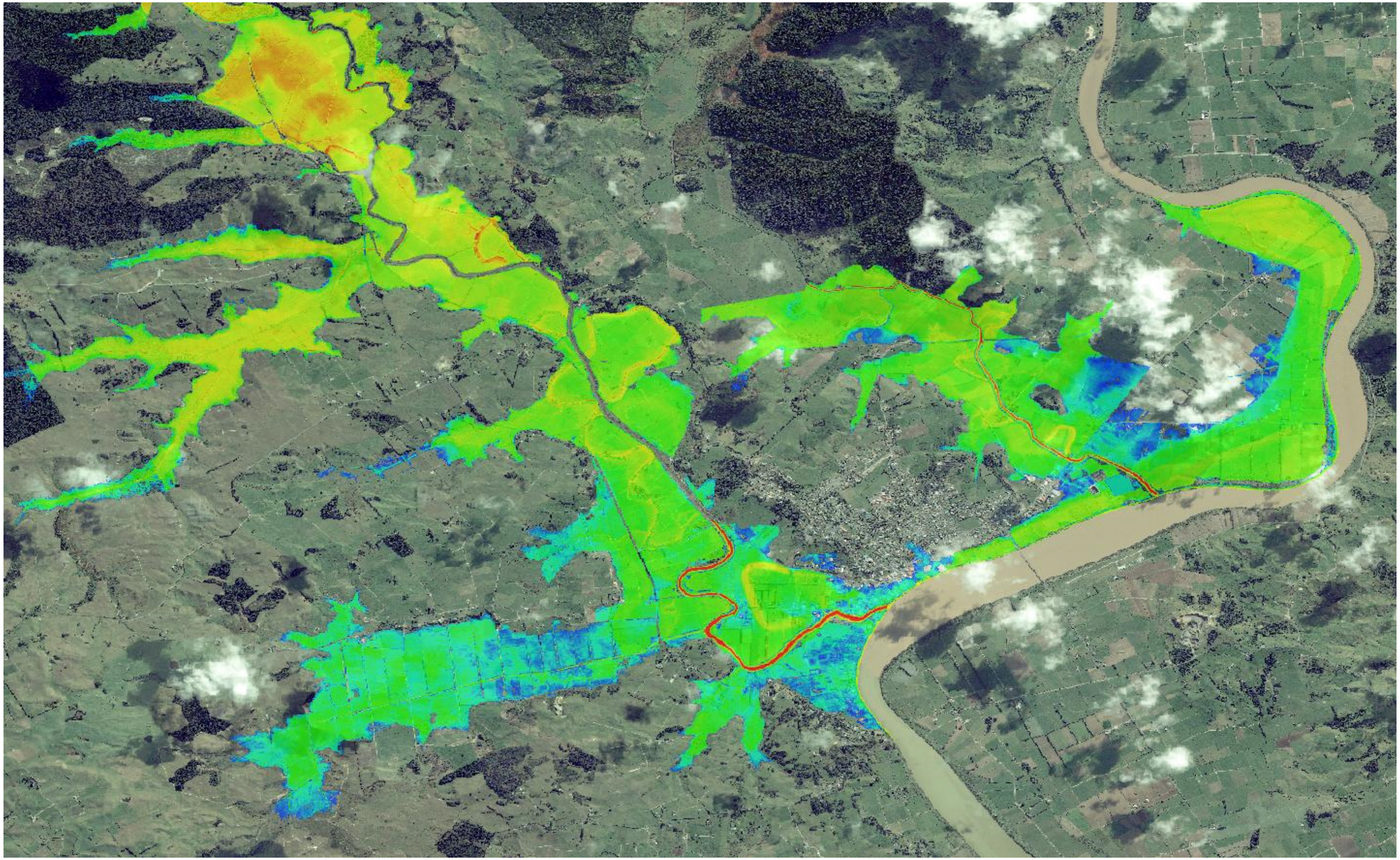

Figure 23: Simulated maximum flood extent in the 100 year ARI with climate change flood. Blue shades represent depths less than 1m, yellow and red shades represent depths greater than 3m.

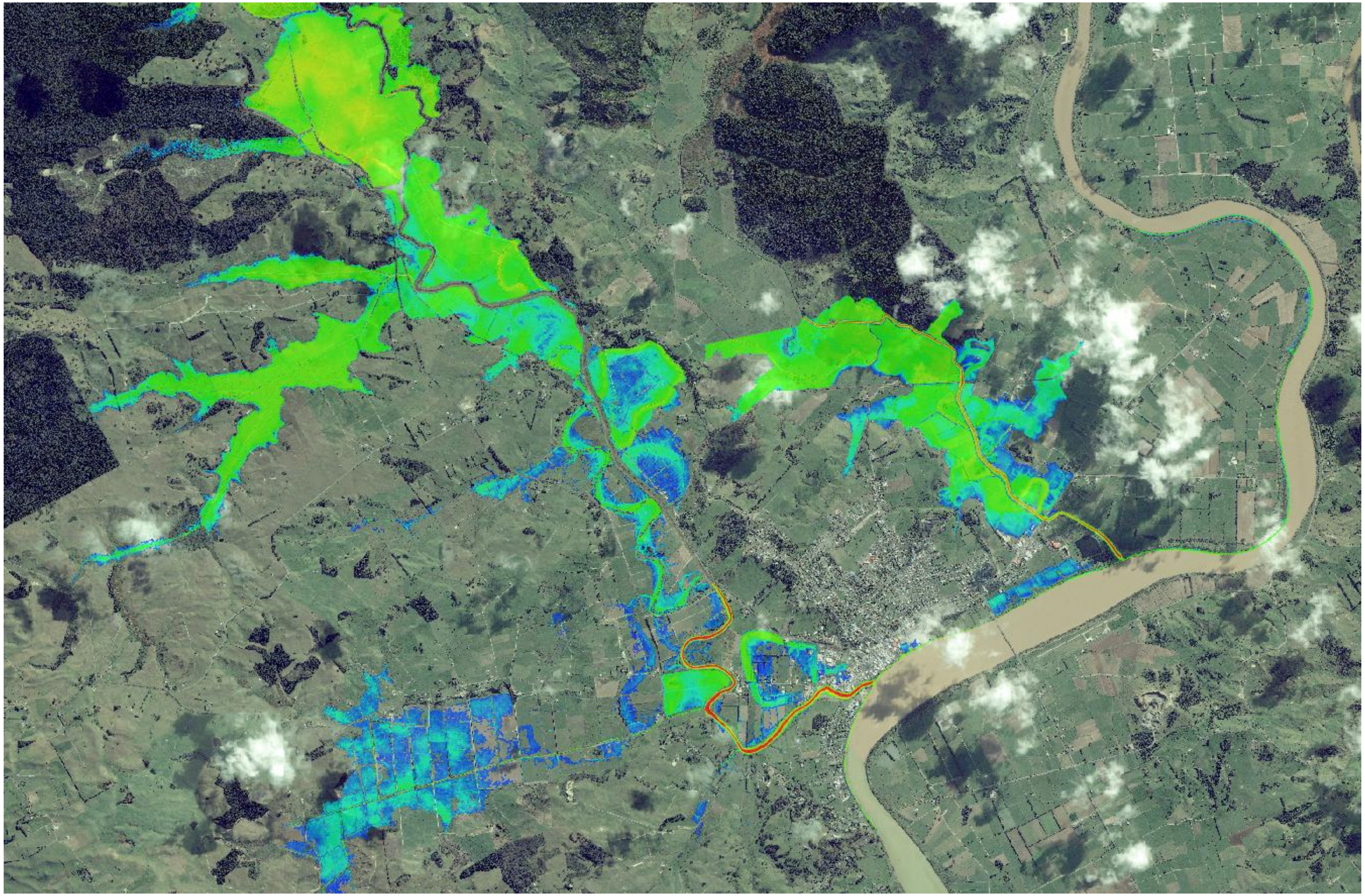

Figure 24: Simulated maximum flood extent in the 10 year ARI flood. Blue shades represent depths less than 1m, yellow and red shades represent depths greater than 3m.

Appendix B Hydrological model parameters

Name	Area (km2)	Plane	Plane areas	% area	Impervious fraction	Downslope length	Slope	Mannings n	C N
1	27.950	1	16.094	58	0	1099	0.22	0.36	75
		2	11.856	42	0	809	0.22	0.27	76
2	16.258	1	12.948	80	0	2637	0.095	0.31	78
		2	3.309	20	0	674	0.09	0.17	80
3	18.058	1	18.058	100	0	2587	0.11	0.19	77
4	18.342	1	7.492	41	0	850	0.13	0.17	78
		2	10.832	59	0	1229	0.05	0.27	77
5	13.648	1	8.699	64	0	960	0.091	0.22	79
		2	4.924	36	0	543	0.089	0.16	80
6	9.605	1	3.437	36	0	504	0.18	0.30	78
		2	6.182	64	0	906	0.06	0.30	78
7	4.717	1	4.717	100	0	1084	0.031	0.26	79
8	4.482	1	2.259	50	0	761	0.06	0.16	80
		2	2.538	50	0.01	881	0.028	0.15	79
9	2.354	1	2.354	100	0	817	0.003	0.15	80
Total	115.41								

Note: initial abstraction set to 5mm for all sub catchments

Collector channel					
Catchment	Channel length (m)	Slope	Mannings n	Base width (m)	Side slope (xH:1V)
1	14650	0.041	0.040	6	2
2	4910	0.020	0.040	3	2
3	6980	0.003	0.040	3	2
4	8810	0.012	0.040	3	2
5	9060	0.009	0.040	3	2
6	6820	0.023	0.040	4	2
7	4350	0.001	0.030	10	2
8	2970	0.019	0.035	10	2
9	2880	0.002	0.030	25	2

Table 10: Catchment parameters used in hydrological model, Awakino River, Northland

Catchment	Area (km2)	% area	% imp	Downslope length (m)	Slope	Mannings n	Green area CN
Logan St	0.467	1	0.39	273	0.003	0.17	74
Hokianga Rd	0.726	1	0.29	354	0.04	0.20	73.6
Selywn Park 1	0.824	0.63	0.38	800	0.016	0.18	73.9
Selywn Park 2	0.477	0.37	0.02	253	0.02	0.17	74
Plunket St	0.995	1	0.47	1118	0.02	0.17	74
Station Rd	0.663	1	0.38	308	0.027	0.17	74
Total	4.152						

Note: initial abstraction set to 5mm for all sub catchments

Collector channel

Catchment	Channel length (m)	Channel slope	Mannings n	Base width (m)	Side slope (xH:1V)
Logan St	150	0.001	0.015	0.5	5
Hokianga Rd	400	0.03	0.03	1	2
Selwyn Park	1380	0.009	0.03	1	2
Plunket St	350	0.02	0.015	0.5	5
Station Rd	1170	0.001	0.03	1	2

Collector channel

Table 11: Catchment parameters used in hydrological model, Dargaville, Northland