Makotuku Stream Model

Model Development & Modelling of Design Events

Horizons Regional Council

Report

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The expert in **WATER ENVIRONMENTS**

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1 Introduction

1.1 Background

The Makotuku River, and its tributary Makara Stream, are steep mountain streams that drain slopes of Mt Ruapehu. Downstream of State Highway 49 (SH49) they cross pastoral land for several kilometres before reaching the town of Raetihi.

Horizons Regional Council has an on-going programme of determining the flooding risk in populated parts of the Region. The Council decided on a numerical modelling study to determine the flood risk for the catchment downstream of SH49 as far as Raetihi's oxidation ponds just downstream of the town. This report covers that numerical modelling.

A small tributary of the Makotuku River enters Raetihi from the west to meet the Makotuku River (see bottom of the map, Figure 1). Although the present study includes the flow from this tributary, it does not address the flooding risk within Raetihi from the tributary itself. This is because assessing that particular flooding risk is not part of the Council's immediate programme.

1.2 Brief and Proposal

Horizons Regional Council provided a "preliminary brief" on 23 May 2016. Following a joint site visit on 26 May, DHI responded with a Proposal for the present work on 3 June 2016.

In short, the work was to comprise:

- A brief review of existing rainfall and runoff information, explained in DHI's Proposal as intended "to double-check that the assumed inputs as a whole are coherent and plausible".
- Building a MIKE FLOOD numerical hydraulic model of stream channels and overland flow from State Highway 49A downstream to about 400m downstream of the Raetihi oxidation ponds.
- Model calibration / validation against the flood event of 15 October 2013, incorporating some sensitivity testing of various model parameters.
- Simulation of design events of 2%, 1%, and 0.5% Annual Exceedance Probability (AEP)
- Simulation of vegetation control in the Makotuku River channel at Raetihi, for one design event (Horizons chose the 0.5% AEP event).

The deliverables from this study, in addition to this report, were specified as:

- Model files: the MIKE Flood model, including the inflow and rainfall files used for both the 2013 validation event and the design extreme events.
- Result files, for both the 2013 validation event and the design extreme events:
    - MIKE 11 channel flow model: .res11 files, , readable using MIKE View.
    - MIKE 21 overland flow model:
        - The .dfs2 files containing the progression of flood depths and levels, and also .dfs2 files containing the maximum flood depth.
        - Each file of maximum overland flood depth converted to either a shape file or an .xyz file.

2 Methodology

2.1 Model Structure

The Makotuku model extends from SH49A downslope to just beyond Raetihi, and is a MIKE FLOOD model, in which 1-dimensional river channel elements (in MIKE 11) are linked with a 2-dimensional overland flow model in MIKE 21 (Figure 1). This part of the Makotuku catchment, largely farmed, is represented in the 2-dimensional model using a 5m rectangular grid derived from LiDAR data.

The Makotuku River itself is represented in the 1-dimensional model by cross-sections surveyed in June 2016 for this study. Makara Stream is also represented in the 1-dimensional model, but most of its cross-sections are simply taken from the LiDAR data rather than surveyed. The diversion of water from the Makara Stream catchment to a power station in the Orautoha valley has been assumed to be minor compared to flood flows and has not been modelled.

The 1-dimensional model also includes the stream that flows through Raetihi from the west to meet the Makotuku, and its catchment is entirely within the MIKE 21 domain. However, the scope of the present work does not include consideration of flooding due to this stream, so it is represented a simple and oversized rectangular channel. Its inclusion in the model is helpful for ensuring flows downstream are well-modelled, but the other reason for including it in this manner is so that the model can be easily adapted later if required to model flooding from this stream.

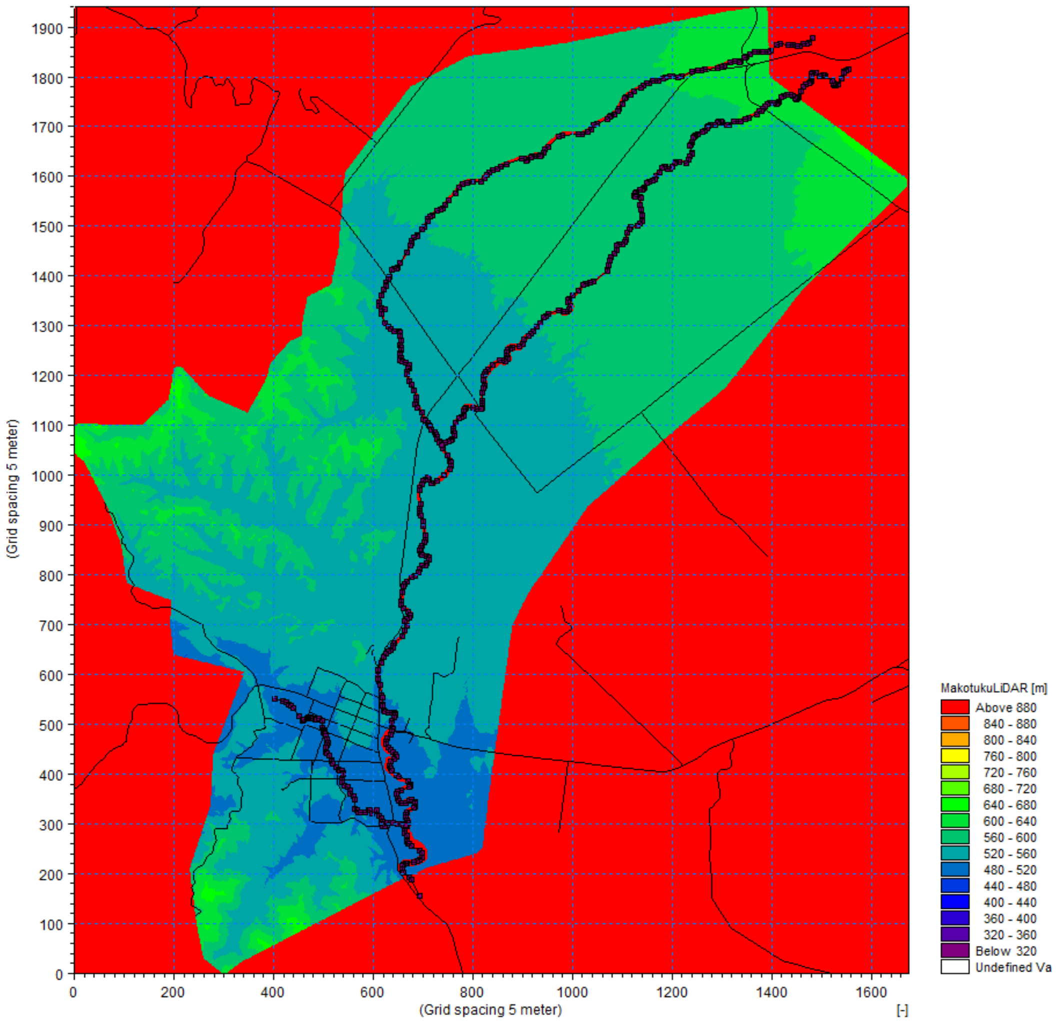

Figure 1: Makotuku model: MIKE 21 bathymetry and MIKE 11 network.

2.1.1 Inflows

Three inflows are applied to the model at SH49A: flow in the Makotuku River and Makara Stream, and flow in a small tributary about 800m south of the Makotuku. A continuous flow record is available from the gauging station on the Makotuku at SH49A, but the other two inflows require some estimation.

Rain is modelled falling directly onto the modelled area, based on rain gauges at Scarrows and SH49A.

2.2 Calibration against the 2013 event

2.2.1 Inflows

One flood event is large enough, and has been measured sufficiently, to provide good calibration data for the Makotuku model. This is the event of 15 October 2013, during which the Makotuku at SH49A peaked at 80 m^3/s (Figure 2). The complete hydrograph is available from the Makotuku gauging station.

A peak flow of 72 m³/s was obtained for Makara Stream from a slope-area gauging. It is understood that observers believe this very high flow rate was due to a debris-dam burst or similar sudden release of water upstream.

As part of preparing the model inputs, a simple analysis was undertaken of the records from the event from the upper Makotuku catchment: the flow hydrograph at SH49A and the two rain gauge records. From these, a time-to-peak of about 5 hours was deduced for the Makotuku at SH49A. Empirical formulas for time of concentration were then considered to estimate time-to-peak for Makara Stream at SH49A (3 hours) and the unnamed tributary at SH49A (2.5 hours). The observed Makotuku flow hydrograph was then scaled, and reduced in volume *pro rata* with area, to provide synthetic flow hydrographs for these two tributaries.

The Makara hydrograph obtained this way had a peak flow of 42 m³/s. However, with the first calibration runs it became clear that this peak flow was too low to achieve calibration. The Makara hydrograph was therefore adjusted to include the observed peak flow of 72 m³/s (Figure 2). In the absence of better information, flow close to this peak was assumed for a period of 30 minutes, comparable to the duration of near-peak flow recorded in the Makotuku River in this event. Given the relatively prolonged and steady nature of the rainfall event, both these flow peaks may be due to the breakout of one or more dams of sediment and/or debris.

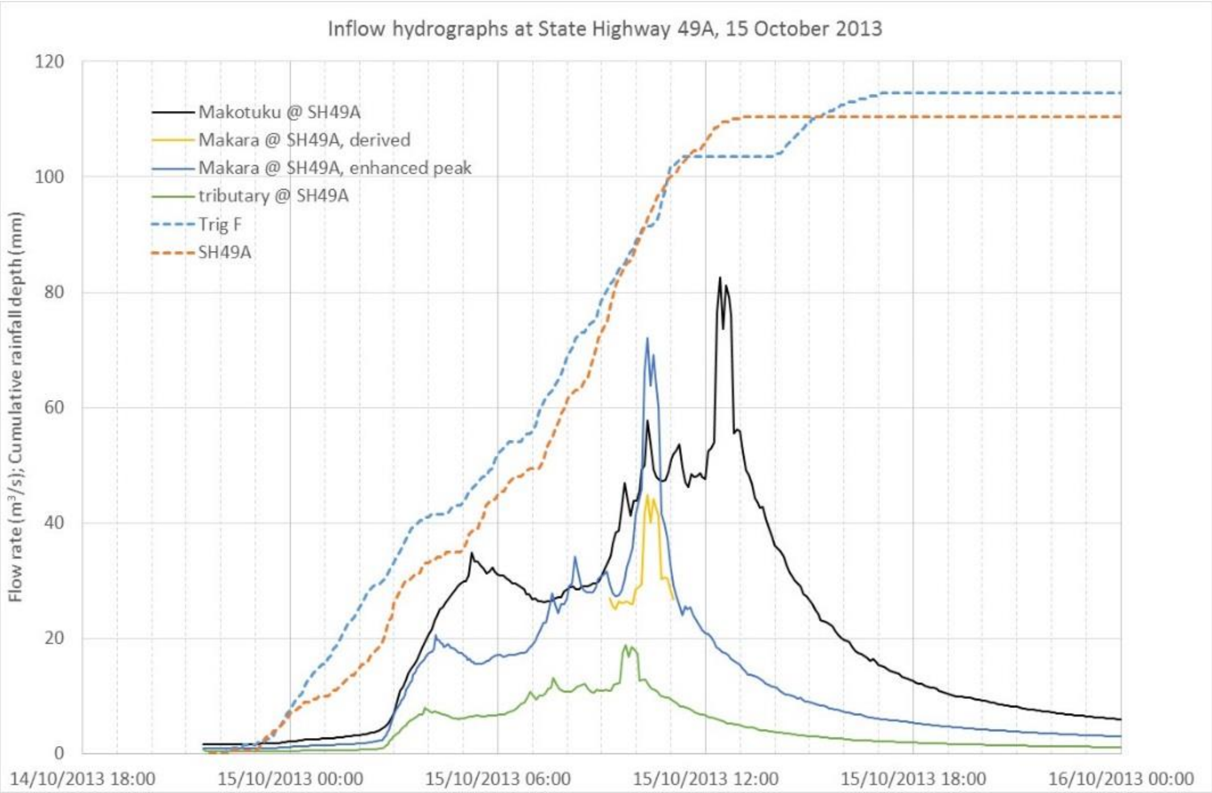

Figure 2 Inflow hydrographs at SH49A, also showing cumulative rainfall depths upstream, 15 October 2013

2.2.2 Rainfall, infiltration and overland flow in the lower catchment

The rainfall hyetograph applied to the 2-dimensional model of the lower catchment was obtained from the two rain gauges closest to the catchment: Mangaetoroa @ Scarrows and Makotuku @ SH49A. The two gauges measured similar rainfall patterns and rainfall totals, so it was decided to simply apply a spatially uniform hyetograph, the average of the two sites (Figure 3).

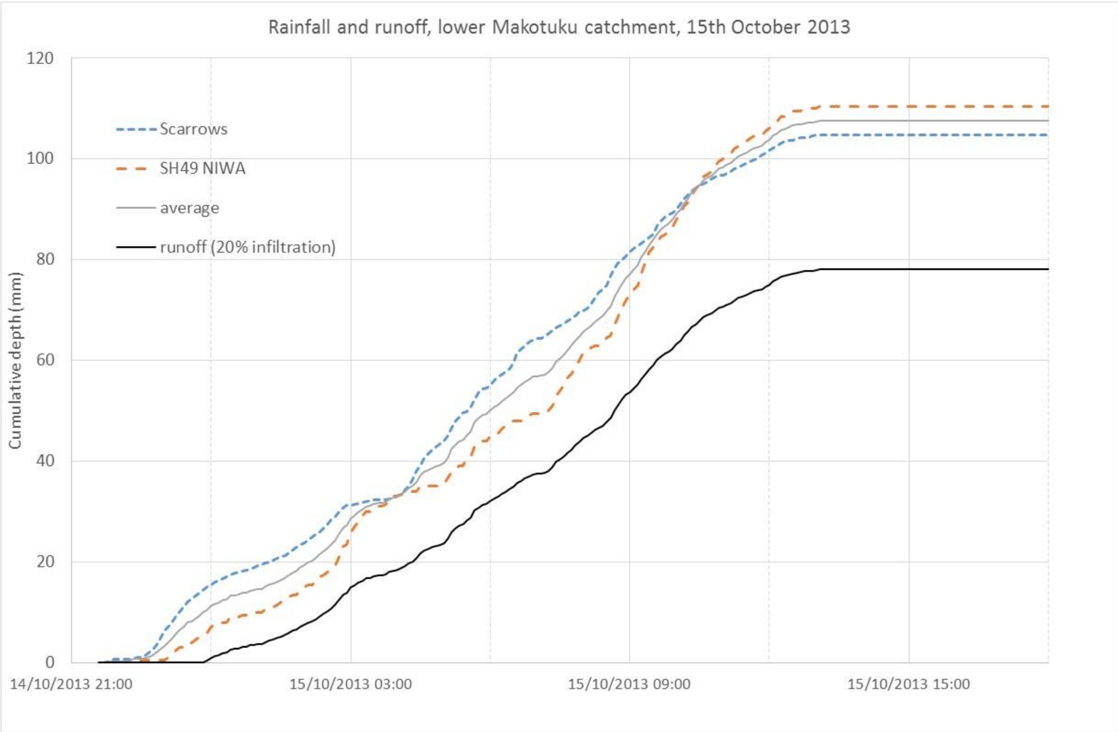

Figure 3 Modelled rainfall and runoff for the lower Makotuku catchment (the MIKE 21 domain), 15 October 2013

For consistency with earlier modelling of Ohakune catchments (Hydro Tasmania Consulting 2010), a constant infiltration fraction of 32.5% of this rainfall was initially assumed, with 10mm initial loss. However, this infiltration percentage has been used as one of the parameters to adjust during calibration, with 20% being adopted in the validated model (Figure 3).

A universal Manning's n value of 0.06 has been applied to overland flow in the 2-dimensional model, and has been retained in the validated model. This parameter was varied as part of the validation and sensitivity testing process, but it was found to have very little effect on flood levels in the Makotuku River near Raetihi.

2.2.3 Calibration data

Peak flood levels in the 2013 event were observed at only a few locations, including both recorded water level and anecdotal accounts:

- The gauging site on the Makotuku River just upstream of Raetihi provides a continuous water level record (although there are doubts about any flows deduced from these levels). Flood debris close to this gauging station approximately confirms the peak recorded gauge level.
- A debris line has been fixed and surveyed on the river's true right bank at the camping ground.
- An approximate flood level is available from a house on the river's true left bank (a downstream address on the Raetihi-Ohakune Road) in that flood waters reached the steps but not floor level.
- The oxidation ponds and the adjacent SH4 were just inundated.

2.2.4 Calibration: adjustment of infiltration and flow resistance

Infiltration within the catchment, and the flow resistance within the river channel, have been adjusted to obtain reasonably close agreement between the observed and modelled flood peak levels:

- Infiltration has been reduced to 20% of rainfall
- Manning's n within the river channel has been increased to 0.06 in most rural reaches and to values varying between 0.06 and 0.08 in and near Raetihi. These values, particularly those in Raetihi, are somewhat high but quite plausible given the bank vegetation and other features of the channel.

Comparison of observed and modelled flood levels (Table 1) shows that the modelled levels are slightly lower. "Floor Level 1" refers to the floor level of a house which was threatened by the 2015 floodwaters, situated on the downstream side of the Raetihi-Ohakune Road. The modelled level of 513.98m is at the house's front door; the modelled levels here for the design floods appear somewhat anomalous (Table 4), so the level in the river a few metres away is also listed.

Table 1: Comparison of observed and modelled peak water levels at key locations, 15 October 2013.

	Observed	Modelled	Difference
Staff gauge	519.44	519.32	0.12
debris line at camping ground	513.31	513.15	0.16
Step below Floor Level 1	514.35	513.98	0.37
River adjacent to Floor Level 1		514.07	

The modelled peak at the staff gauge occurs at 11:55, compared to an observed time of 12:10. This is considered very reasonable agreement, and confirms that the flood peak in Raetihi corresponded to peak runoff from the lower catchment and from Makara Stream, rather than the flow peak in the Makotuku River (which came about an hour later).

The differences are considered very acceptable, and within the accuracy of the modelling process. In a steep river like the Makotuku (Figure 1Figure 4), turbulent fluctuations and some pulsing of flow rates and water levels might be expected, but cannot be replicated in the model. There is likely to be little benefit in further calibration of the model to reduce the 0.1-0.4m differences indicated here, but any allowance for freeboard above design flood event should include them. In other words, the usual freeboard allowances should be increased by about 0.25 m.

Figure 4 Makotuku Rivevr during flood recession, 15 October 2013

2.3 Design Events

Rainfall-runoff events have been modelled with annual exceedance probabilities (AEPs) of 2%, 1% and 0.5%. This investigation has used rainfall and runoff information provided by Horizons Regional Council; the Council has processed the stream flow information to obtain design flows in the Makotuku River and Makara Stream, and has processed the available rainfall data to obtain design hyetographs.

The nature of the recorded large events, notably that of October 2013, indicate that the worst storms for flooding in the Makotuku catchment are typically long-duration and spatially fairly uniform. This implies that the events used to simulate design conditions need to replicate design rainfall totals over longer intervals – 6 hours and 12 hours rather than 2 hours. It also implies that, as a conservative but reasonable approach, the design rainfall events on the lower Makotuku catchment should be combined with design flows of the same AEP in the Makotuku River and Makara Stream at SH49A.

2.3.1 Design event inflows

Horizons Regional Council provided the extreme value analysis of the Makotuku@ SH49A flow gauging site, and the resulting design peak flows for the required AEPs.

To obtain a suitable hydrograph shape, the three largest events (from 1999, 2000 and 2013) were averaged (Figure 5). The resulting hydrograph was then scaled for each AEP to give the required design peak flow (Figure 6).

The timing of the flow peak relative to rainfall on the lower catchment (see 2.3.2 below) was taken from the 2013 event.

Consistent with the approach taken for the 2013 event (2.2.1 above), hydrographs for Makara Stream and the other tributary at SH49A were derived from the design Makotuku hydrographs by decreasing the time-to-peak, whilst preserving the ratio of runoff volume to catchment area (Figure 7).

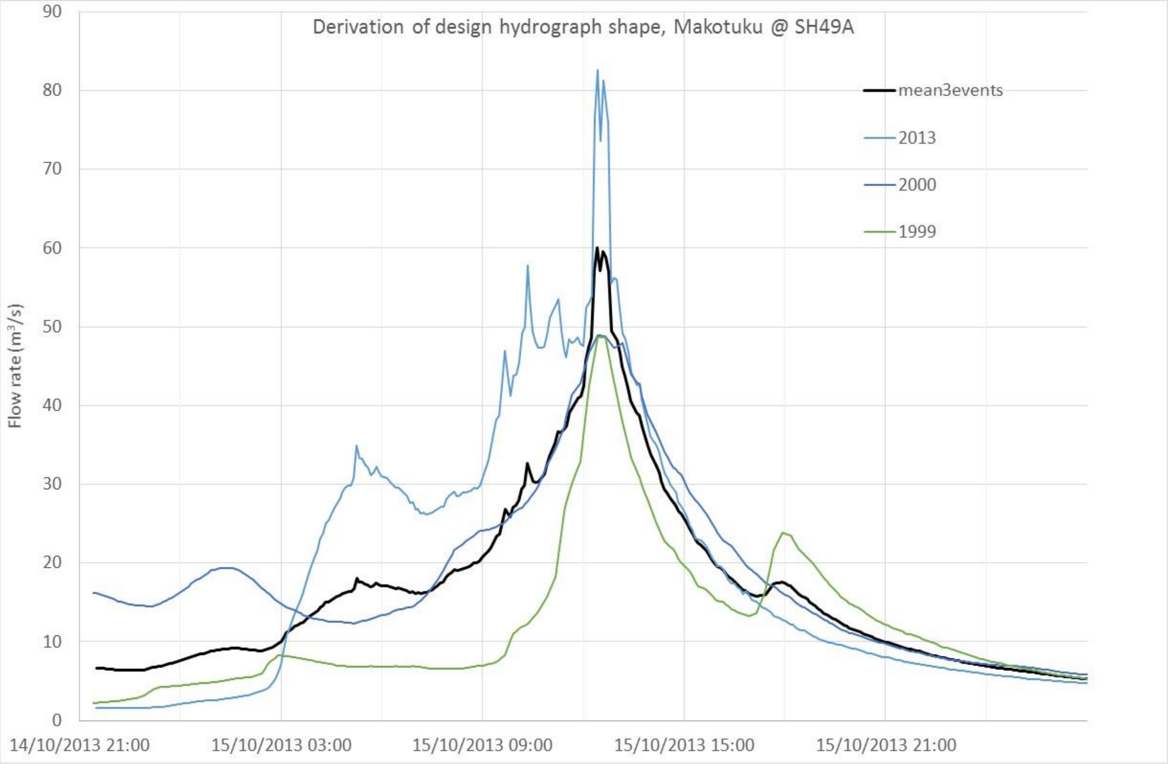

Figure 5 Makotuku River @ SH49A: Three events averaged to obtain a design hydrograph shape.

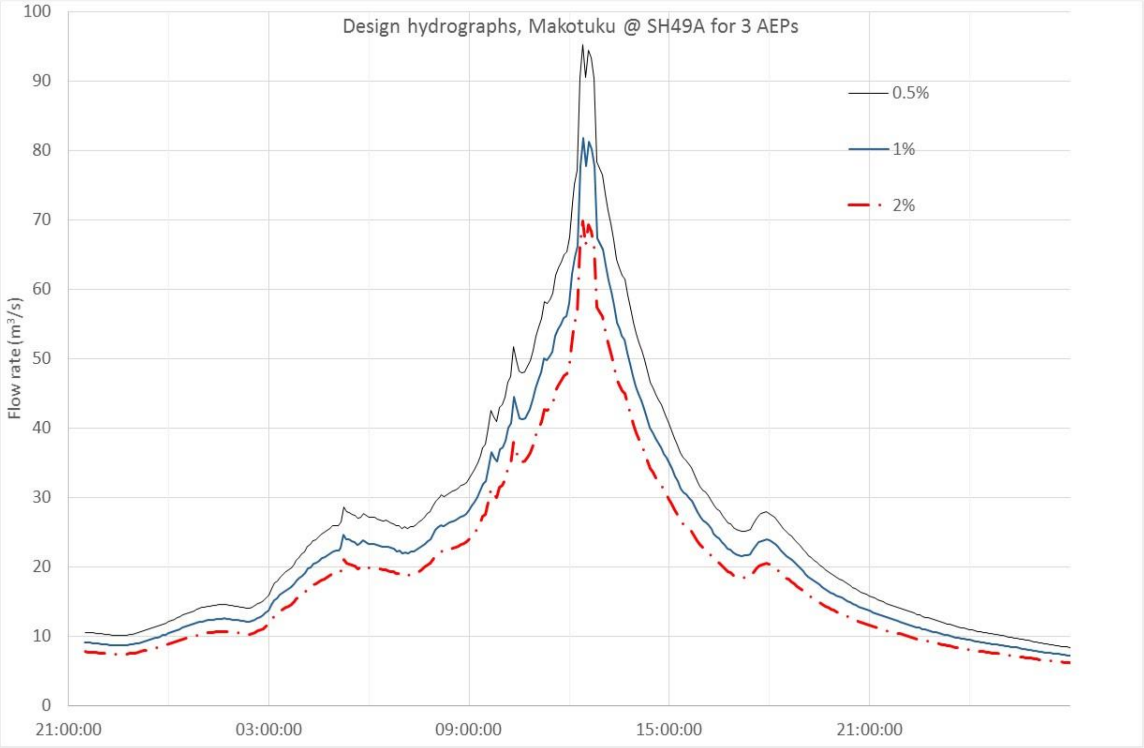

Figure 6 Design hydrographs, Makotuku River at SH49A, 2%, 1% and 0.5% AEPs

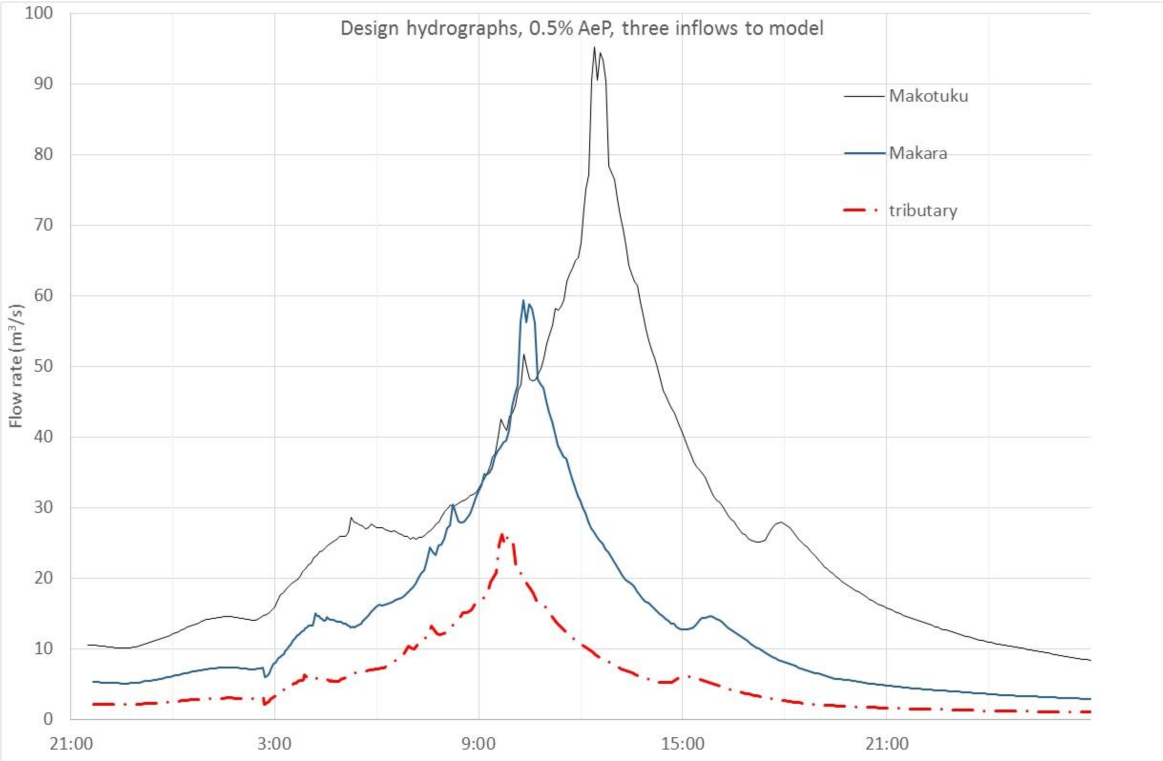

Figure 7 0.5% AEP design hydrographs at SH49A, for Makotuku River, Makara Stream and the unnamed tributary.

2.3.2 Rainfall on the lower Makotuku catchment

Depth-duration-frequency information was available from disparate sources for three rainfall gauges close to the catchment: Makotuku @ SH49A, Makotuku@F Trig and Mangaetoroa@Scarrows (Table 2, in which the Average Recurrence Interval (ARI) is in years and is substantially the reciprocal of AEP). The Scarrows information did not include an AEP of 0.5%, so these depths were extrapolated from the 1% depths by applying a factor of 1.14. This factor is close to the equivalent factors evident in the F Trig and SH49A information.

It is noted in passing that these depths for F Trig are higher than those for the other two sites. This might be expected as this site is further up the slope of Mount Ruapehu, although the 2013 event did not show this difference.

Table 2 Depth-duration-frequency data for three rain gauge sites: rainfall depths in mm

from "Mangaetoroa at Scarrows.docx", with 2013 event data					
Mangaetoroa @ Scarrows	AEP	2hr	6hr	12hr	
	50%	30.2	46.5	61	
	2%	64.4	93.5	118.3	
	1%	74.7	107.3	134.8	
	0.5%	*85.2*	*122.4*	*153.8*	
from Hydro Tasmania (2010) (Appendix):					
Makotuku @ SH49	AEP	2hr	6hr	12hr	
	50%	27.7	43.1	56.9	
	2%	59	86.4	109.9	
	1%	68.6	99.1	125.1	
	0.5%	77	111	141	
F Trig	AEP	2hr	6hr	12hr	
	50%	30.3	53.7	76.9	
	2%	65.2	109.4	151.5	
	1%	75.8	125.9	173.3	
	0.5%	86	140	199	
Mean of Mangaetoroa @ Scarrows and Makotuku @ SH49					
	AEP		6hr	12hr	
	2%		90.0	114.1	
	1%		103.2	130.0	
	0.5%		116.7	147.4	

Consistent with the hyetograph applied for the 2013 event, and again given the very similar depths quoted for Makotuku @ SH49A and Mangaetoroa @ Scarrows, the design rainfall depths to apply to the lower Makotuku catchment were obtained simply by averaging those two sites.

The largest two rainfall events on record at Makotuku@SH49A were averaged to obtain a hyetograph shape, as were the largest three at Mangaetoroa @ Scarrows. These were then averaged, and further modified to reproduce the mean rainfall depths in the last three rows of Table 2. The resulting hyetographs have been applied to the MIKE 21 domain in simulating the three design events (2%, 1% and 0.5% AEP) and are shown in Figure 8

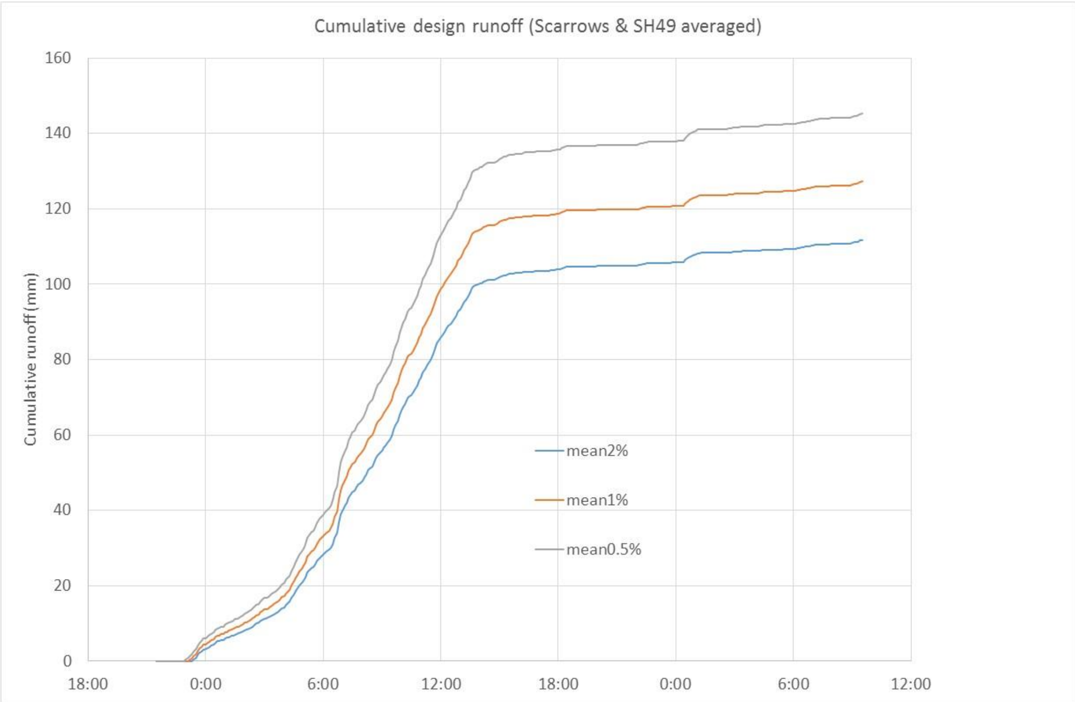

Figure 8 Design hyetographs for the lower Makotuku catchment, as cumulative rainfall depths.

2.4 Lower flow resistance due to managing riverbank vegetation in Raetihi

The 0.5% AEP event was simulated a second time using lower Manning's n values within Raetihi to represent maintenance of riverbank vegetation, which at present could be described as rampant. Determining suitable Manning's n values for the maintained channel is difficult. The particular values used in this simulation have been chosen for an indicative assessment of reasonably rigorous vegetation control.

It has been assumed that were the channel straight and free of other causes of head losses, the present Manning's n value would be about 0.05, and that a value of 0.025 would be obtained with the vegetation control. These can be compared with Manning n values recommended by Chow (1959): 0.05 is typical of unmaintained dredged channels with clean bottom and brush on sides, and 0.025 is typical of straight, and uniform earth channels with short grass and few weeds. Higher n values than 0.05 have been obtained from the calibration process, and the modified n values will therefore be higher than 0.025.

Values from the calculations for this adjustment are set out in Table 3. It is understood that Horizons have applied comparable adjustments in other catchments for the same purpose. The calculations need to assign part of the friction slope (proportional to n^2) to the skin friction and the rest to the other losses. The calculations process of Table 3 is therefore the subtraction and addition of the squares of n values and taking the square root of the result as the newly adopted Manning's n:

$$n_{\text{maintained channel}} = \text{sqrt}\{n_{\text{present channel}}^2 - 0.05^2 + 0.025^2\}$$

Table 3: Calculation of Manning's n to represent vegetation maintenance

Chainage (m)	Value in calibrated model	Assumed to represent skin friction alone, present condition	Assumed to represent skin friction alone, with vegetation maintenance	Calibrated values adjusted for vegetation maintenance
9650	0.066	0.05	0.025	0.0498
9763	0.0678	0.0506	0.025	0.0515
9818	0.0687	0.0509	0.025	0.0524
10536	0.08	0.055	0.025	0.0632
10910	0.073	0.0538	0.025	0.0553
11800	0.065	0.0511	0.025	0.0473
12149	0.08	0.05	0.025	0.0673
12177	0.08	0.05	0.025	0.0673

3 Results

This section identifies peak flood levels at key locations within Raetihi and presents the maps of peak overland flooding depth. The full output data from the simulations described in this report are also being sent to Horizons Regional Council, and include the .res11 files that hold time series of modelled flood level within the Makotuku River and Makara Stream channels

3.1 Calibration event 15 October 2013

Maximum flood levels at three key locations within Raetihi are present in Table 1 above.

A map of maximum flooding depth within the MIKE 21 domain (i.e. overland flow) has been provided as a MIKE .dfs2 file and will also be provided in a form ready for GIS application. The map is also included in this report as Figure 9.

3.2 Design Storms

To reiterate, the three design storm simulated have AEPs of 2%, 1% and 0.5%. Modelled peak flood levels (at the same key locations as in Table 1) are listed in Table 4.

Maps of maximum flooding depth within the MIKE 21 domain (i.e. overland flow) have been provided as MIKE .dfs2 files and will also be provided in a form ready for GIS application. They are also included in this report as Figure 10 to Figure 12, and a map of the Raetihi and its environs is included as

Table 4 Modelled peak water levels at key Raetihi locations, design events.

	2% AEP	1% AEP	0.5% AEP	0.5% AEP with vegetation maintenance
Staff gauge	519.41	519.63	519.84	519.36
Camping ground	513.19	513.33	513.48	513.19
Step below Floor Level 1	513.99	514.00	514.02	514.00
River adjacent to Floor Level 1	513.86	514.00	514.14	513.90

The insensivity to AEP of peak levels at the threatened house (“Floor Level 1”) appear somewhat anomalous, but have at this stage not been investigated. Modelled peak levels in the adjacent river, a few metres away, show a trend more consistent with other peak river levels.

3.3 Reduced flow resistance at Raetihi

To reiterate, the 0.5 AEP event has been simulated with reduced values of Manning’s n in the Makotuku River at Raetihi, as detailed in Table 3, to represent the channel if a programme of vegetation maintenance were in place.

Modelled peak flood levels (at the same key locations as in Table 1) are listed in Table 4.

A map of maximum flooding depth within the MIKE 21 domain (i.e. overland flow) has been provided as a MIKE .dfs2 file and will also be provided in a form ready for GIS application. The map is also included in this report as Figure 14.

4 Conclusions

A numerical model has been developed of flooding in the Makotuku River catchment between State Highway 49A and Raetihi oxidation ponds. The model produced peak flood levels in the Makotuku River and Makara Stream, and peak overland flow flood depths. However, the small stream that runs through the town of Raetihi from the west has not been represented realistically, so that the model cannot be used to assess the flood risk from this stream.

The model has been validated, at least for Raetihi and its immediate environs, by comparing peak flood levels modelled for a storm on 15 October with observed flood levels at a few locations. Recorded flood levels near Raetihi for the 2015 calibration event are all a little higher than modelled for that event. In a steep river like the Makotuku, turbulent fluctuations and some pulsing of flow rates and water levels might be expected, but cannot be replicated in the model. The usual freeboard allowances should therefore be increased by about 0.25 m.

Design storm events with Annual Exceedance Probabilities (AEPs) of 2%, 1% and 0.5% have then been simulated. Significant flood levels on land (as opposed to the Makotuku and Makara channels) are modelled as occurring on the river's true left bank at Raetihi, but only in a few very limited areas elsewhere in the catchment.

The model results with lower river channel Manning's n values applied at Raetihi should be treated with some caution. This is because the assumptions about the likely reduction of Manning's n, while believed to be sound, have not been validated on this river. Nevertheless, the simulation shows a clear reduction in flood levels resulting from a significant effort to maintain an efficient channel. Flood levels in the 0.5% AEP event are modelled reduced to be comparable to those in the 2% AEP event with the channel in its present condition.

5 References

Ven te Chow (1959), Open-channel hydraulics, McGraw-Hill

Hydro Tasmania Consulting (2010), Ohakune Township Flood Modelling – Study Report.

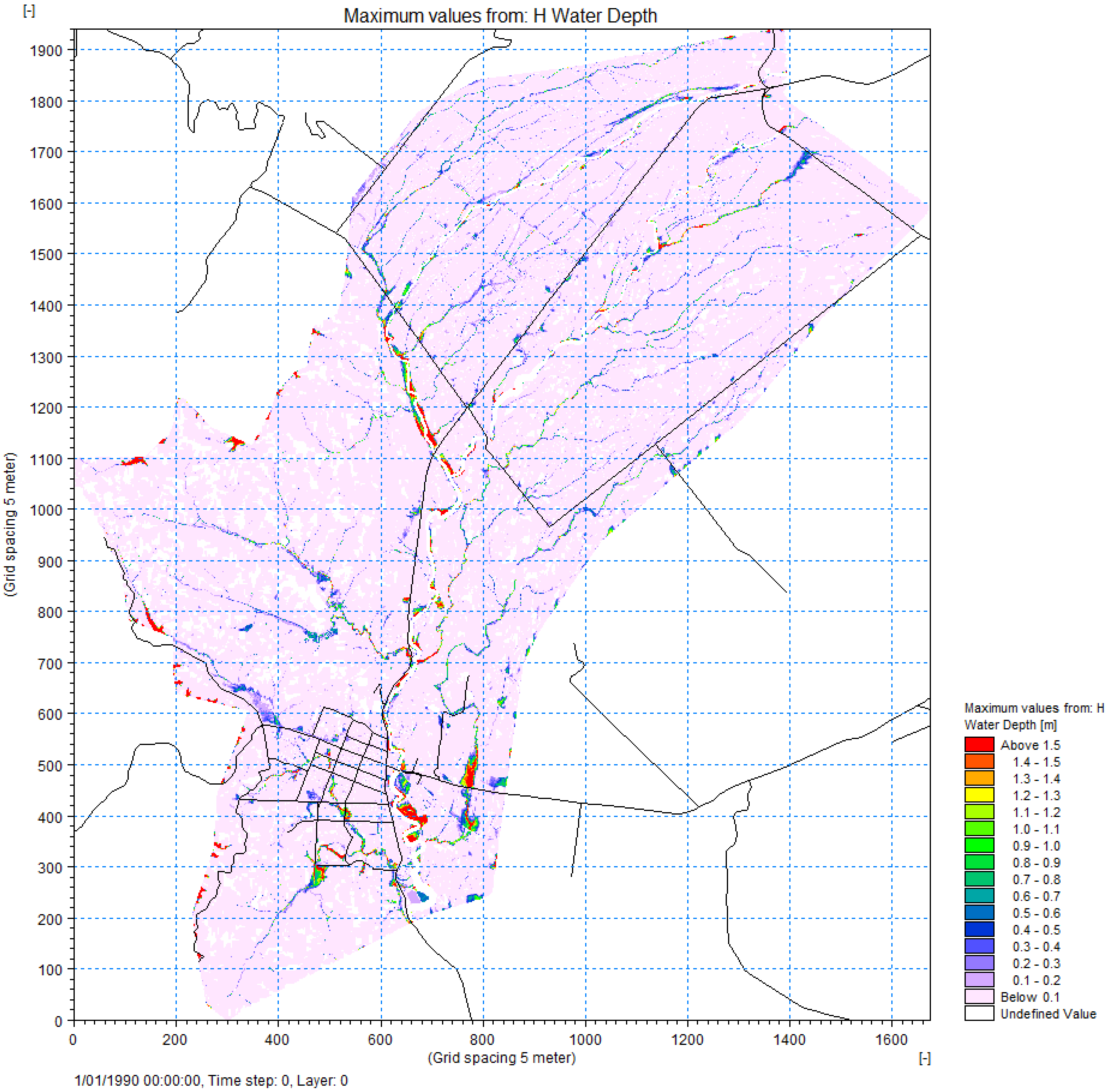

Figure 9 Map of modelled maximum overland flood depth, 15 October 2013 (calibration event)

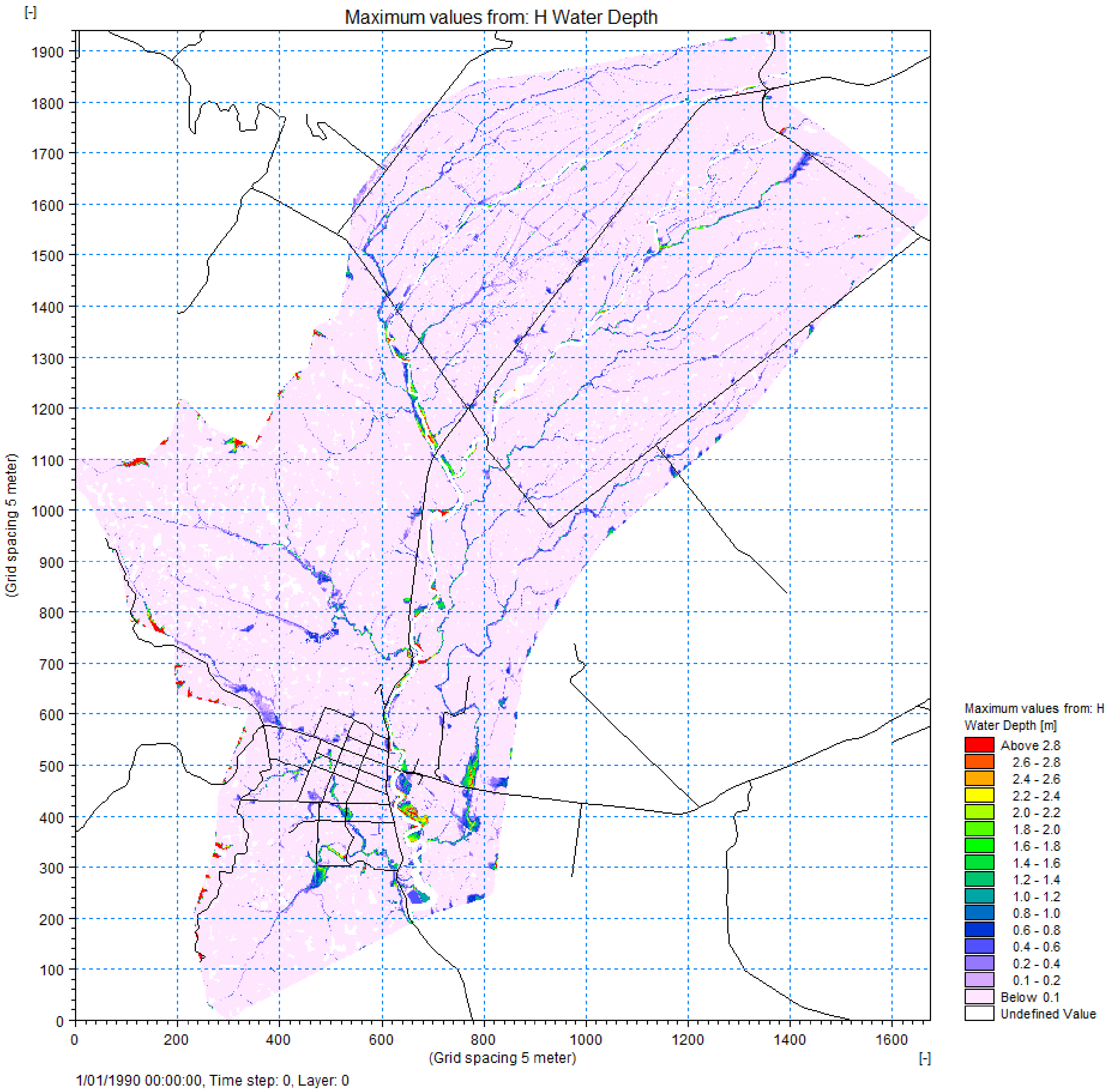

Figure 10 Map of modelled maximum overland flood depth, 2% AEP event

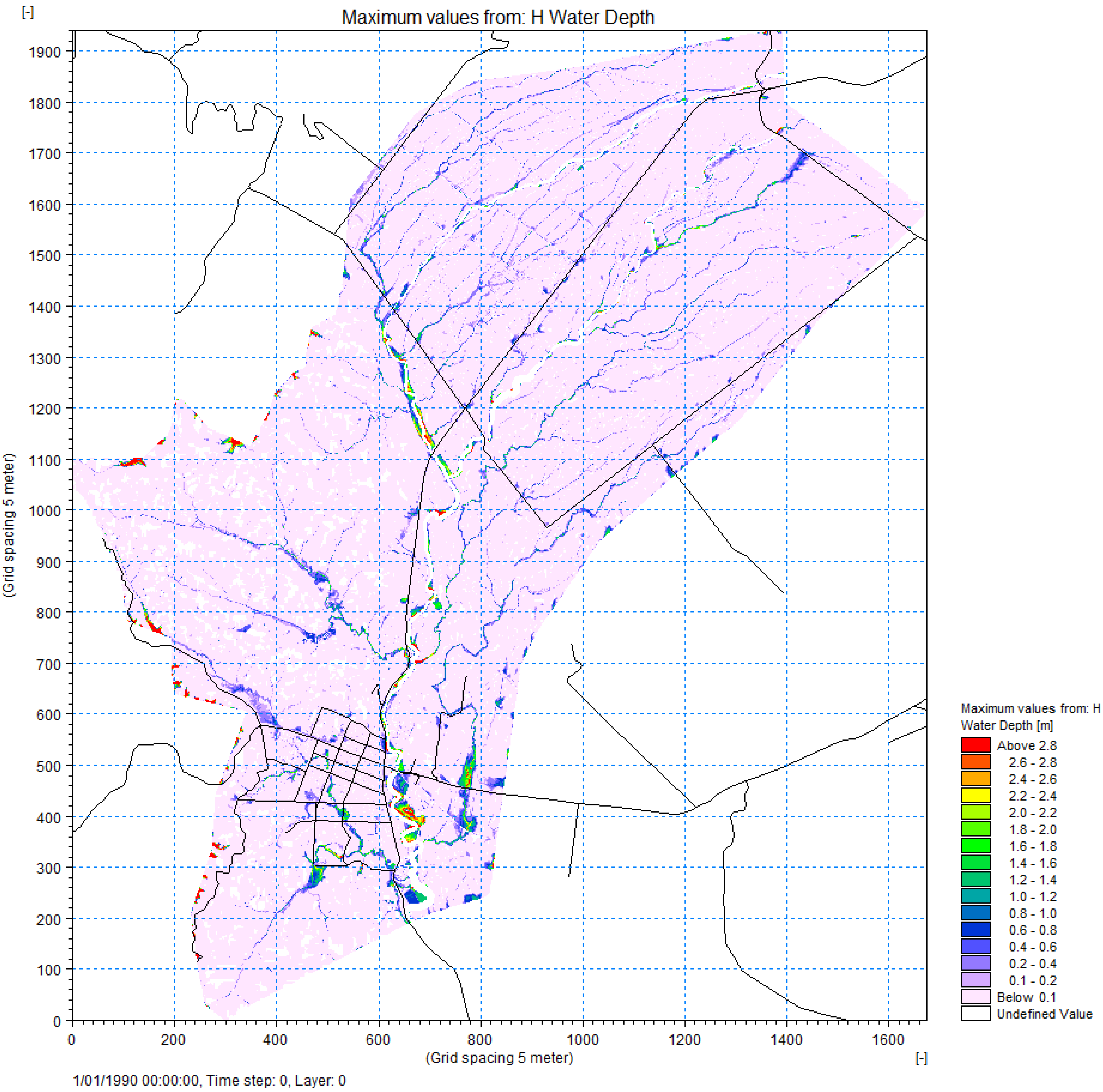

Figure 11 Map of modelled maximum overland flood depth, 1% AEP event

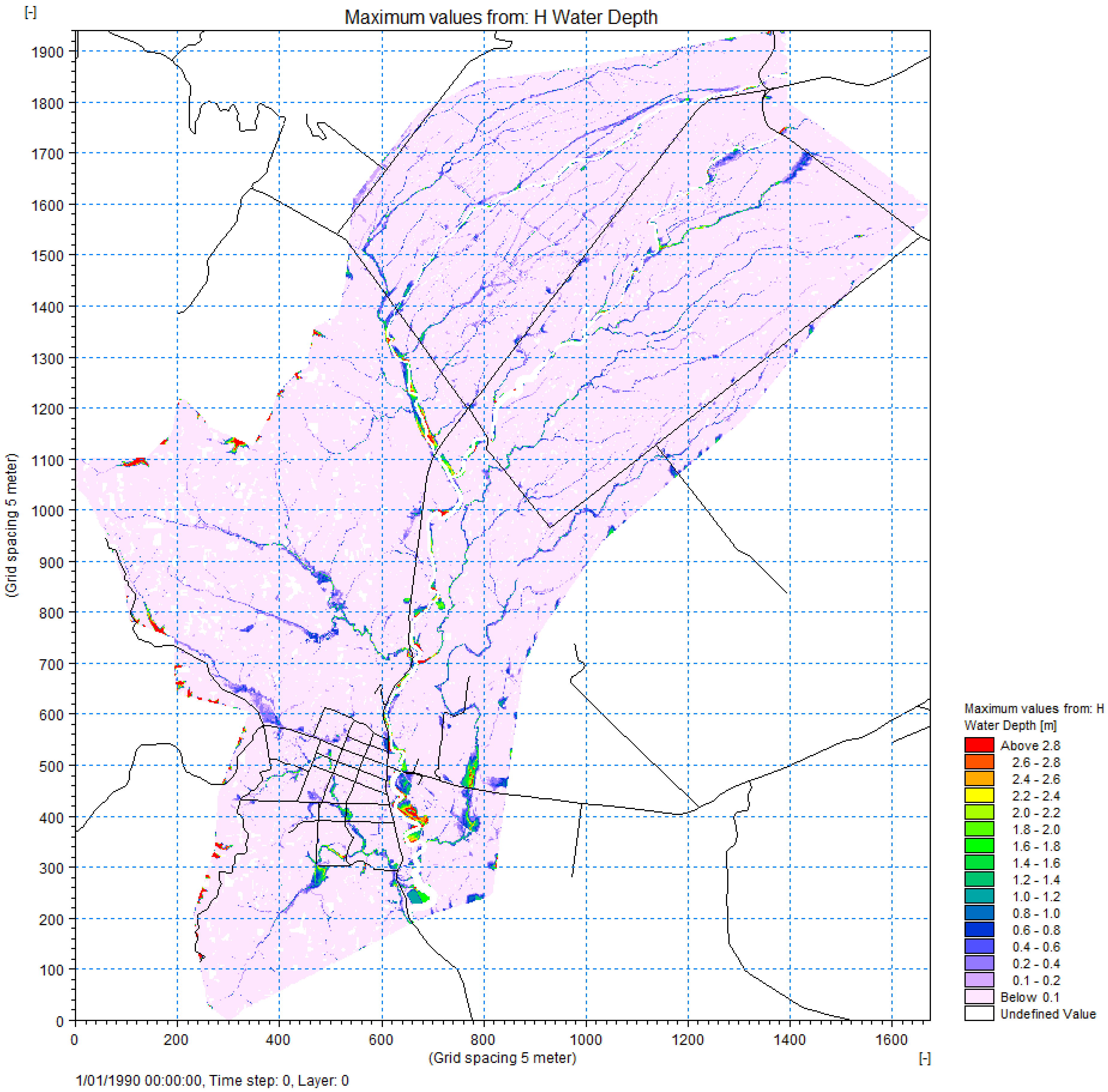

Figure 12 Map of modelled maximum overland flood depth, 0.5% AEP event

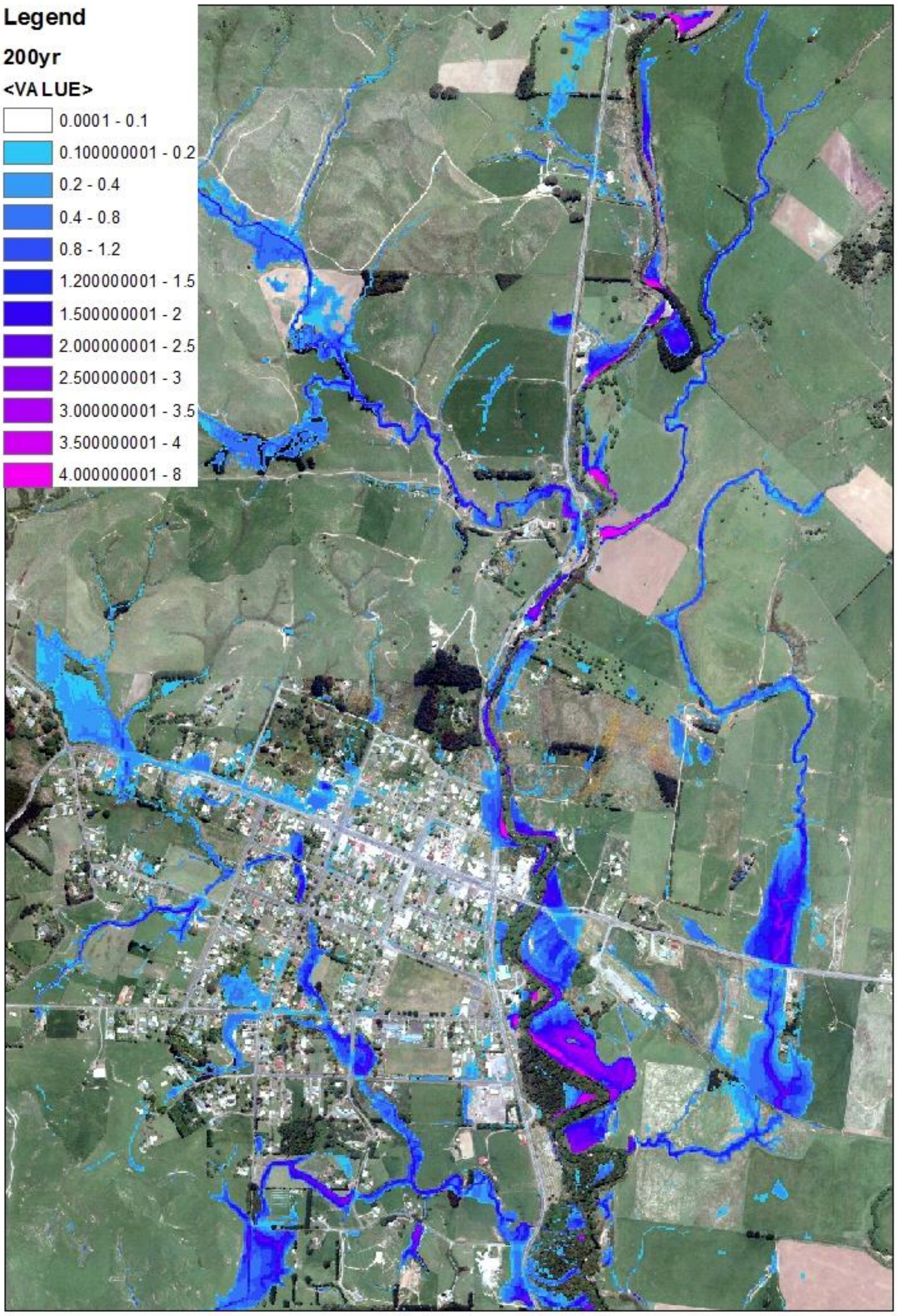

Figure 13 Map of modelled maximum overland flood depth, Raetihi and environs, 0.5% AEP event

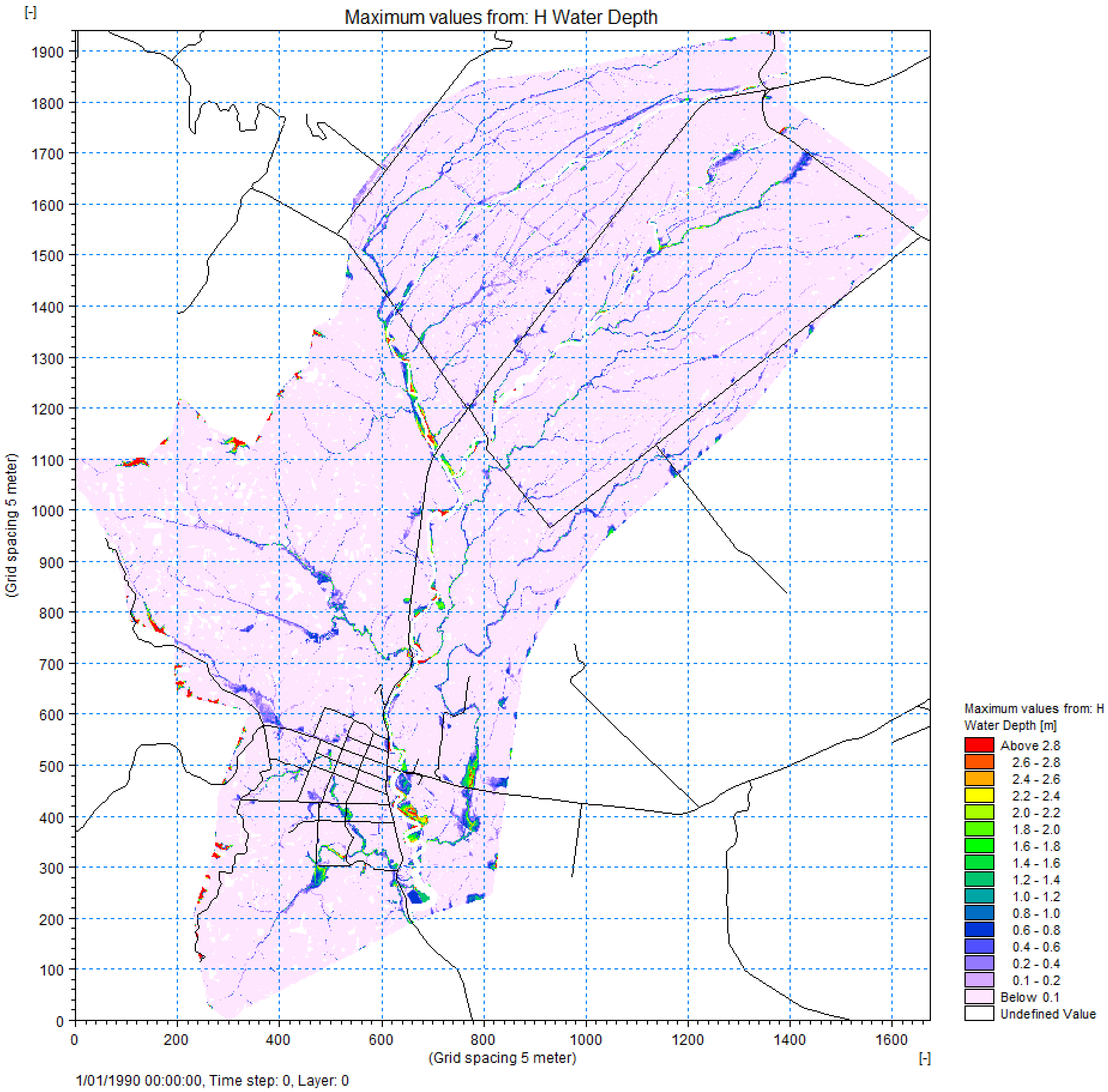

Figure 14 Map of modelled maximum overland flood depth, reduced channel flow resistance at Raetihi, 0.5% AEP event