Flood modelling of the Makowhai / Piakatutu catchment

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1 Introduction

The Makowhai / Piakatutu catchment lies immediately south of the Rangitikei River, and flows into the Rangitikei River about 12 km from the sea. The catchment is almost entirely in pasture, although it includes the town of Sanson and the Air Force base at Ohakea. The catchment is generally rolling farmland, a sloping plain intersected by gullies, varying in elevation from 8m to 131m (both Mt Biggs and Mt Stewart).

The soils of most of the catchment have been described[1] as "loess overlying sandstone and gravel", with the loess soil described as having a "clay to clay loam texture".

This flooding study was proposed is in response to an e-mail from Horizons Regional Council (Jon Bell, 8 May 2017) requiring numerical modelling to produce flood maps for this catchment for the 2%, 1% and 0.5% Annual Exceedance Probability (AEP) flood events, aka 50-year, 100-year and 200-year Average Recurrence Interval (ARI). Horizons also requested modelling of a rainfall event from June 2015, in order to use debris levels to calibrate the numerical model.

The Makowhai / Piakatutu catchment extends 15km east-west by 12 km north-south (Figure 17), and roughly bounded by Rongotea Road to the south and Ngaio Road to the north. Within the domain specified by Horizons, a small area near Ohakea drains directly to the Rangitikei River rather than to Makowhai Stream.

1.1 Some observations from a site visit

A site visit covering most roads in the catchment provided some insights into the nature of the flood risk. The measured debris levels were generally close to road culverts (Figure 1 and Figure 2), and the performance of these culverts can be expected to govern the extent of flooding. Over most of the catchment, flow paths are generally constrained within gullies and swales, and significant flood plains can be found only in the lowest parts of the catchment.

[1] "Soils of Manawatu County, North Island, NZ", J.D. Cowie & Vl.C. Rijkse, NZ Soil Survey Report 30, DSIR (1977).

Figure 1 Typical table-drain culvert, Rowe Road

Figure 2 Twin culvert, Rowe Road

There are about 15 stream crossings (Figure 3 and Figure 4); some of these might be regarded structurally as bridges rather than culverts, but all appeared suitable for description in the model as culverts.

Figure 3 Typical stream crossing, Taylor Road

Figure 4 Typical stream crossing, Cemetery Road, Sanson

2 Methodology: model build

2.1 Modelling framework and overland flow grid

The model was built in MIKE 21 "Classic", i.e. the rectangular-grid form of overland flow model, with "Inland flooding" specified. The model domain (an irregular shape 15km by 12 km) has an area of 150 square kilometres. A 5m square grid was chosen to provide the best compromise between model run time and representing the topography in sufficient detail. In particular, this grid size provided continuous representation of roads and of stream channels.

The catchment was modelled as a "closed" area, i.e. with its entire perimeter represented as land. Outflowing streams including Makowhai Stream were represented as sinks, with the outflow rate set high enough to accommodate peak flood flow.

In some locations, the modelled area extended beyond the limits (Figure 17) set by Horizons. This was done partly for convenience and partly to avoid difficulties with boundary conditions affecting the area required to be modelled. Parts of the additional fringing areas affected in this way have been manually removed from those results, but other parts where results appear reliable have been retained.

The model was run with a time step of 0.75 s. Instabilities leading to "blow-ups" typically occurred 2-3 times during a run, necessitating a restart using the "hot-start" file.

2.2 Culverts and Bridges

A culvert function within MIKE 21 was used to model all the bridges and culverts for which survey data were available. This function accommodates circular and rectangular pipes as well as irregular cross-sections, and is therefore very suitable for the stream crossings within the catchment.

The model includes all culverts and bridges for which sufficient data were available. In addition, seven culverts were included that had been surveyed at one end only or not at all (Table 1). The four that were not surveyed were identified from areas that ponded in preliminary model runs, and confirmed from aerial photographs (Google). The assigned invert levels and diameters for these four culverts are estimates.

Table 1 Culverts that have been modelled despite missing data

Surveyed point no.	Easting	Northing	Invert level	Diameter (mm)
193	1807138	5545981	65.65	450
456	1805844	5548075	69.08	450
606	1801155	5543738	29.57	450
assumed	1804162	5546773	46.50	450
assumed	1803172	5541012	23.52	450
assumed	1804737	5542990	38.75	450
assumed	1805447	5543907	43.65	375

Culverts are represented in MIKE 21 by specifying an impervious barrier perpendicular to the culvert. The wall is placed on the nearest computational cell boundaries, and the culvert then provides the only flow through which then provides the only flow through that barrier. A consequence is that overland flow is prevented for the length of the impermeable barrier, which in this model was always set to 10m. This approximation could be remedied by adding a weir structure at each culvert. However, in this model overflow, if it occurred, would occur at most culverts over a length well over 10m. It was therefore decided that the approximation was close enough for a weir structure at each culvert to be unnecessary.

2.3 Rainfall hyetographs

Horizons supplied hyetographs for three adjacent rainfall gauge locations: Forest Rd @ Drop Structure, Mangaone @ Milson Lane, and Makino @ Halcombe Rd. The data comprised the rainfall measured during the significant event in June 2015 (Figure 5), as well as design hyetographs for 2% and 1% AEP rainfall events (Figure 6).

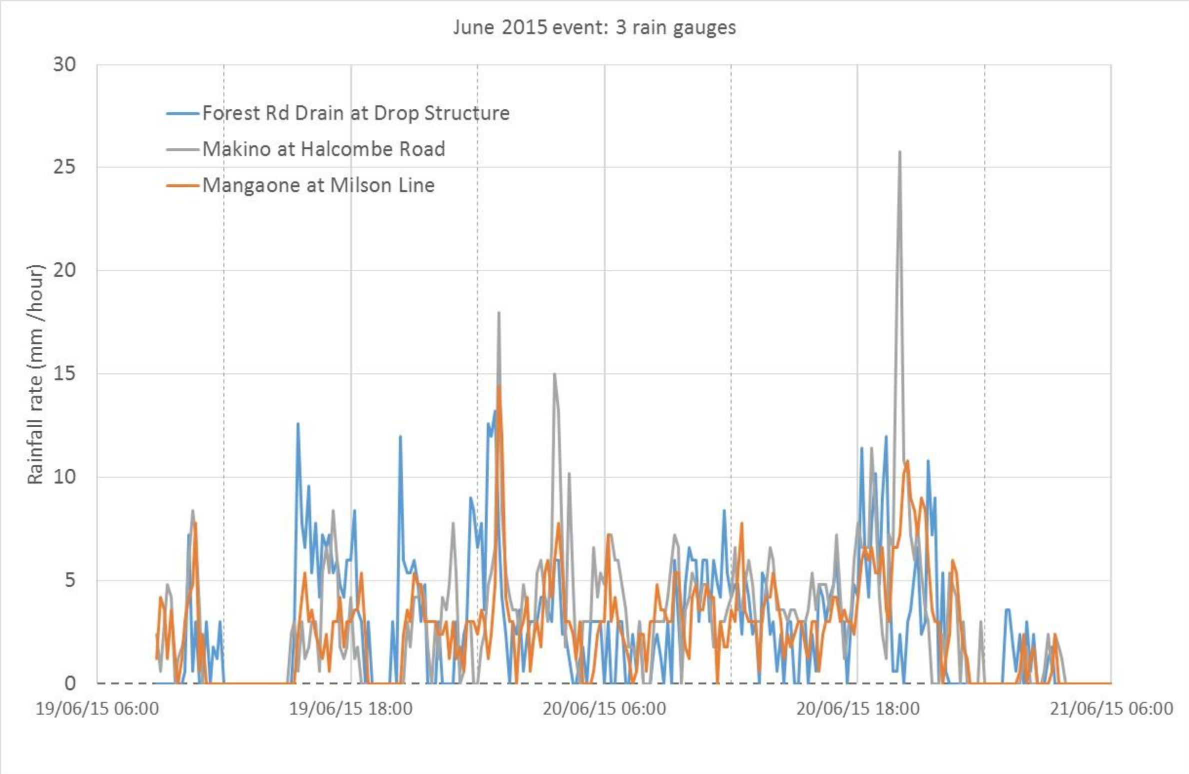

Figure 5 Gauged 2015 hyetographs

The design events are understood to have been obtained from HIRDS version 3, and are in the "Chicago" form, in which rainfall events of different duration but the same AEP are nested within one another. This form of design hyetograph may well be unrepresentative of any single observed event, but have the strong advantage that every sub-catchment, regardless of its response time, experiences the rainfall likely to produce a peak flow with the specified AEP.

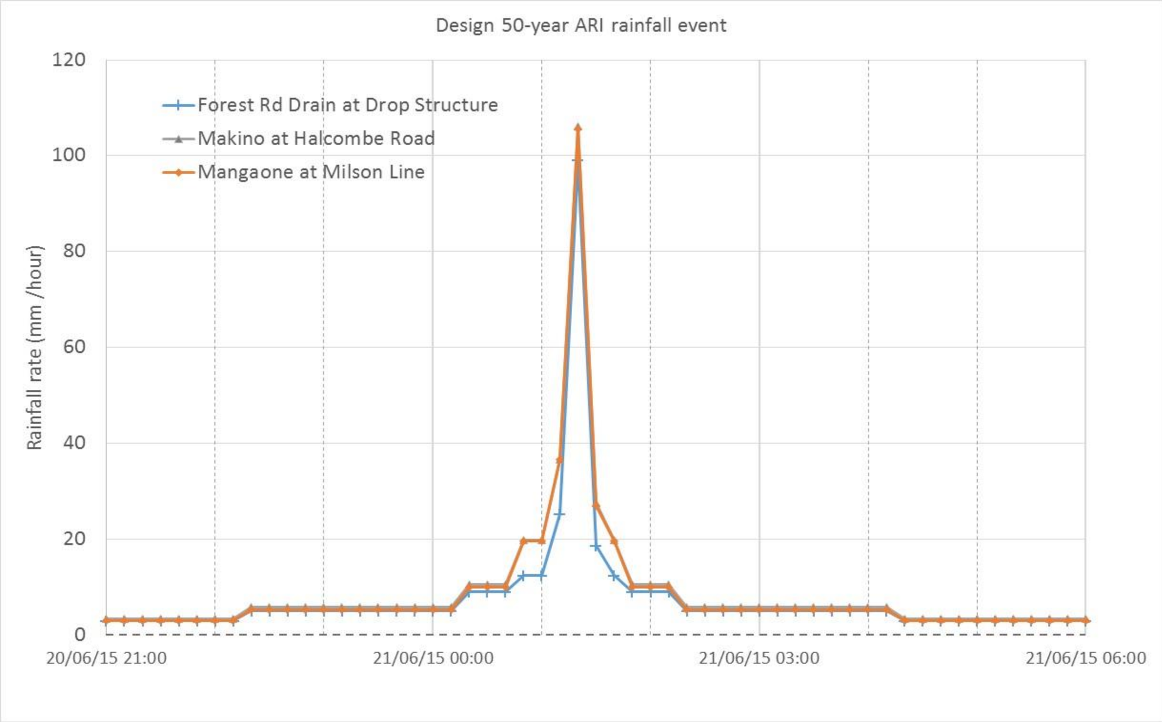

Figure 6 Design 50-year AEP hyetographs for rainfall gauge locations

HIRDS does not provide rainfall depths for the 200-year ARI event, nor for yet more extreme events. It was agreed with Horizons that a 200-year ARI event would be represented by the 100-year ARI design event scaled by 1.14. This multiplier was adopted in flood studies for Ohakune and later for the Makotuku catchment, and appears reasonably consistent with the difference between the 2% and 1% events.

The differences between the design hyetographs at the three rainfall gauge sites are relatively minor. Because of this, it was agreed with Horizons to apply a single hyetogaph to the entire Makowhai-Piakatutu modelled area. Thiessen polygons were applied to determine a weighting of 45% to the Forest Road site and 55% to the Makino @ Halcombe Rd site. These weightings were applied both to the June 2015 event and to the design hyetographs (Figure 7).

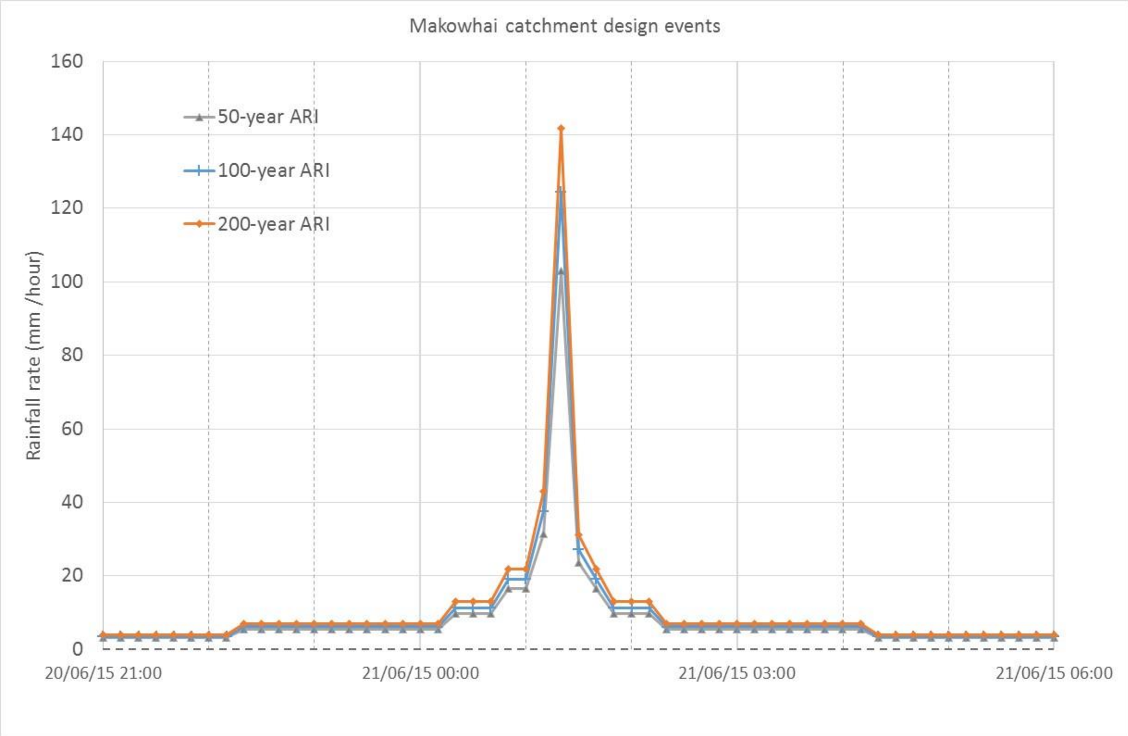

Figure 7 Design hyetographs, weighted for the Makowhai-Piakatutu modelled area

2.4 Rainfall to runoff

Infiltration losses were treated simply, as an initial loss depth and a continuing loss rate. The initial loss was manually subtracted from the hyetographs, and for simplicity the continuing loss was specified as evaporation (rather than specified with the infiltration function).

These losses were initially set by considering the soil properties of the catchment. Some minor adjustment was made as part of the calibration against the 2015 event (see below). The values adopted for the "production runs" were an initial loss of 20 mm and a continuing loss rate of 3.2 mm/hour.

The flooding and drying depths were set to 0.02 m and 0.01 m respectively. With "inland flooding" specified, these two depths define a gradual introduction of hydraulic flow with increasing depth, depths below the drying depth being treated as standing water.

2.4.1 Flow resistance for overland flows

A single Manning M value of 23 (reciprocal of Manning's n=0.0435) was applied to almost all the catchment. This includes the operational areas of Ohakea Base, including the runways.

Within the urban areas of Sanson and Ohakea, different values were applied (Figure 8), including a low flow resistance of M=45 (n=0.022) in the streets and a very high flow resistance M=8 (n=0.125) within residential, commercial and "industrial" lots. The high modelled resistance for the built-up areas represents the effect of obstructed flow paths as well as actual roughness. It has been implemented as a pragmatic alternative to time-consuming detailed specification of individual buildings and other features that divert runoff.

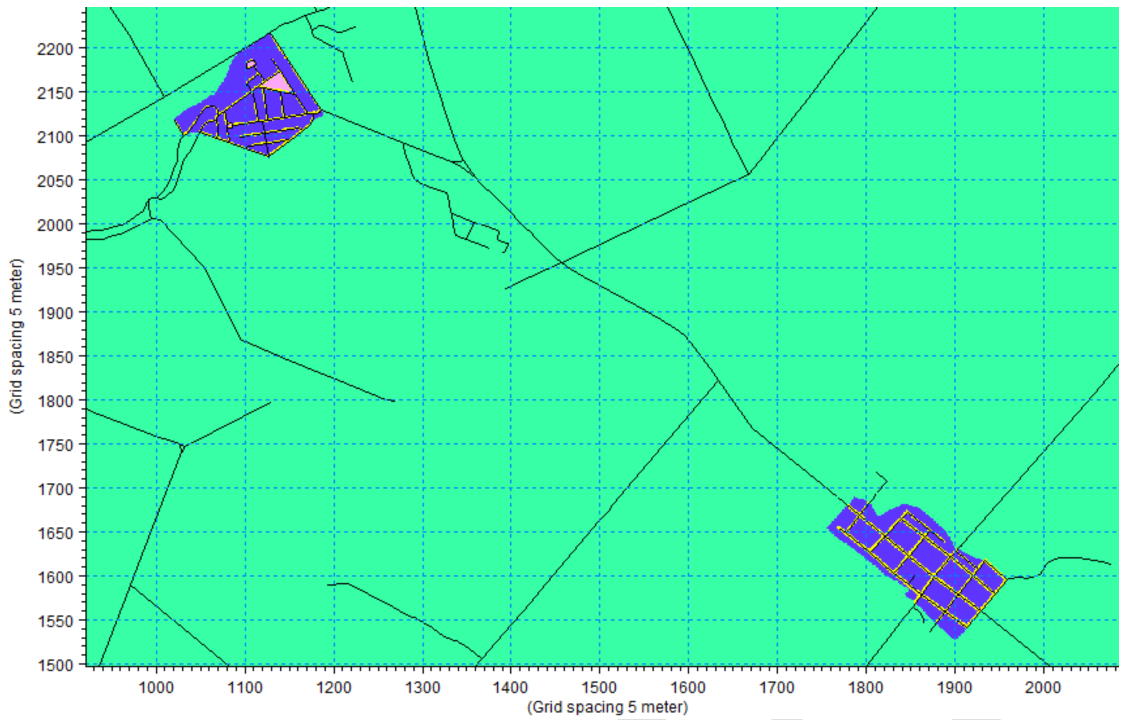

Figure 8 Map of overland flow resistance (Manning's M = 1/n) as modelled, Ohakea to Sanson. M values denoted by: Green: 23; blue: 8 (urban sections); yellow: 45 (urban streets); pink: 33 (lawn)

2.4.2 Cattle underpasses

It was originally intended to model cattle under-passes as culverts. However, two underpasses were inspected and appeared well bunded from adjacent low-lying land, and would therefore be unlikely to pass flood flows. The underpasses were therefore not modelled.

3 Calibration /validation against the 2015 event

The significant rainfall evet of June 2015 was modelled primarily for model calibration. A large number of levels were taken of flood debris, most of them being on roadsides close to culverts. This dataset is a valuable resource for developing an accurate numerical hydraulic model. However, debris levels are somewhat approximate indicators of peak flood level, and can be misleading. Stream flow directed at a stream bank can cause a localised and unrepresentative area of high water levels, whereas debris left during the flood recession will result in an under-estimate of peak flood level.

Model calibration typically involves adjusting various model parameters but principally the flow resistance of channels, to obtain the best agreement between measured and modelled water levels. As it happened in this calibration, the infiltration rate and the parameters of some culverts were adjusted. Debris levels higher than modelled peak water levels were accommodated by assuming a less efficient culvert, either by increasing the head loss coefficients or by reducing the cross-sectional area consistent with an assumption of partial blockage by debris or sediment. There is less scope for reducing modelled peak water levels that are higher than measured debris levels, but increasing the infiltration rate had the effect of lowering flood levels everywhere.

The model was run three times with parameters adjusted after each run. At the end of this process, 53% of modelled peak water levels at debris locations were within ±0.2 m of the debris levels, and 87% were within ±0.5 m.

This was considered a reasonable model calibration, given the uncertainty noted above with debris levels, and also given the nature of the 2015 event: 36 hours of steady moderate rain (Figure 5). With this type of hyetograph, flood levels and flood flows are particularly sensitive to the choice of infiltration rate.

The infiltration propeorties of the calibrated model are an initial loss of 20mm and a continuing loss rate of 3.2 mm/hour. These appear to be reasonably consistent with the soil types and the generally good-quality pasture of the catchment.

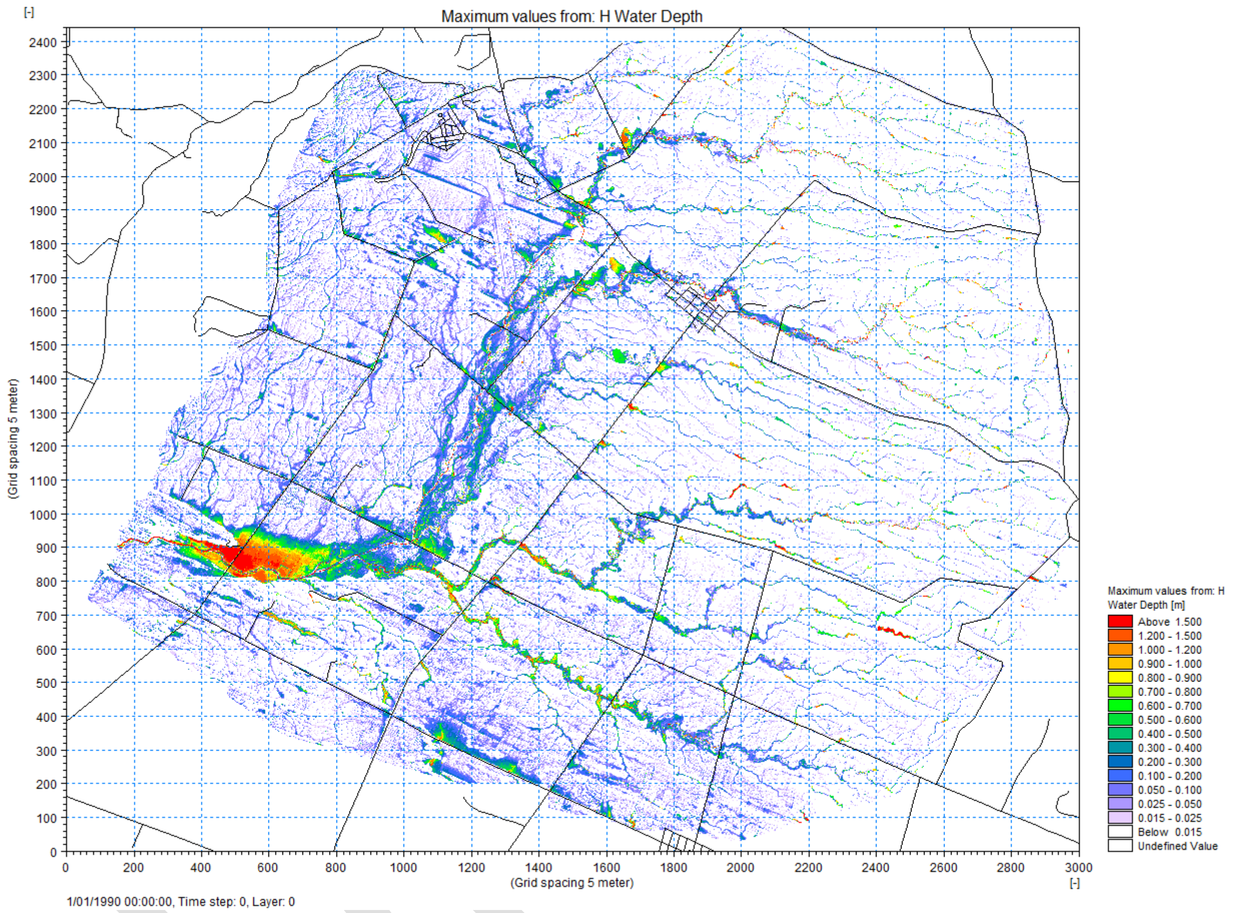

Figure 9   Computed maximum depths, June 2015 event, following model calibration

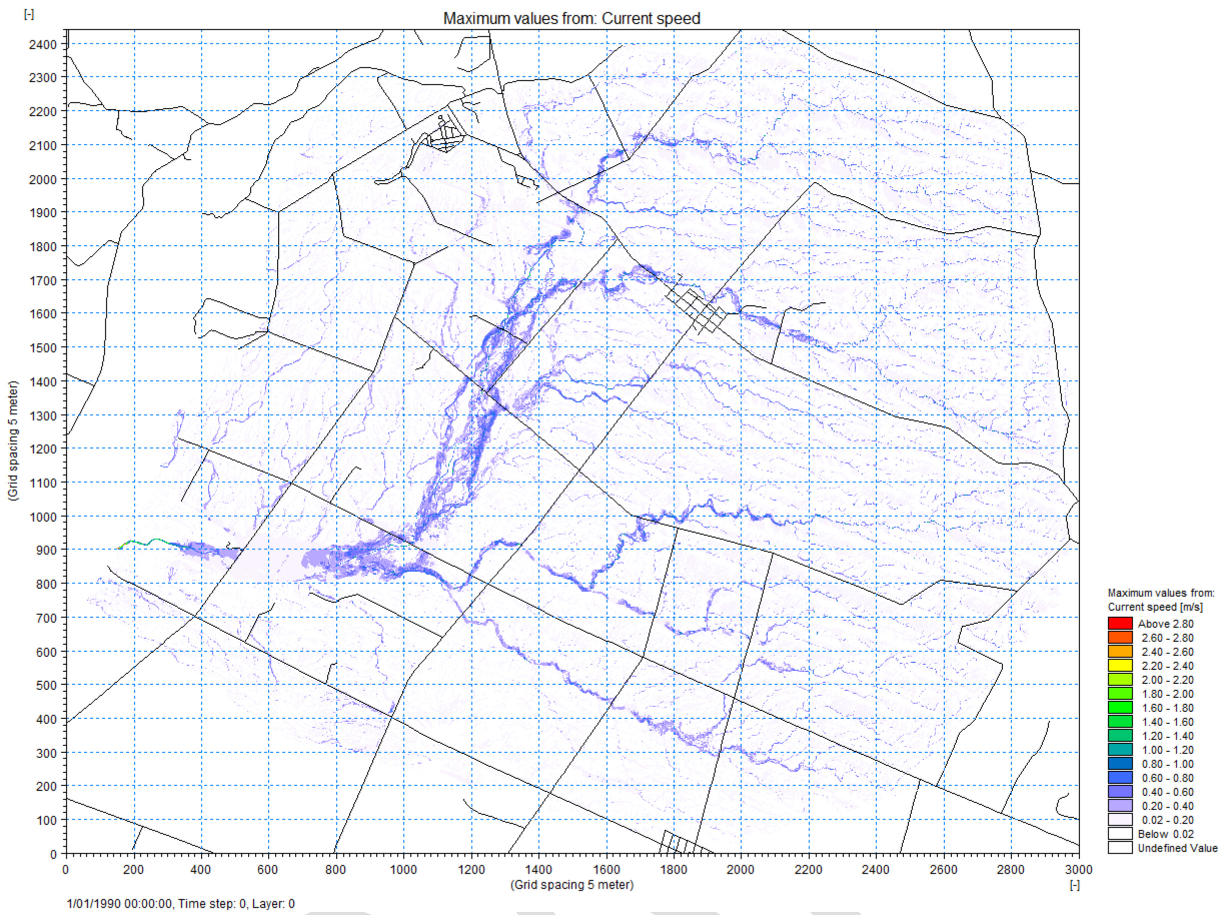

Figure 10 Computed maximum velocities, June 2015 event, following model calibration

4 "Production runs": the design events

The "production runs" with the model comprised the three design hyetographs of Figure 7, with assigned ARIs of 50 years, 100 years and 200 years. Model parameters included a computational time step of 0.75s and flooding and drying depths of 20mm and 10mm. With the overland flow version of MIKE 21, water does not flow at depths less than the drying depth, and fully observes the fluid mechanics equations of motion at depths exceeding the flooding depth, with a gradual transition between those two depths.

The model was therefore started at the time that the cumulative rainfall of the hyetograph equalled the initial loss plus the drying depth, with rainfall equal to the drying depth delivered within a single time step.

Output data was saved every 15 minutes. From inspection, this interval was short enough to capture flood levels very close to peak values.

The model runs were continued until about 5 hours after the hyetograph peak. Checks were made to ensure that peak water levels had been reached earlier throughout the model domain.

5 Post-processing and file delivery

The MIKE 21 Toolbox (a suite of software tools primarily for post-processing) includes a tool for extracting maximum values for every cell within the domain. This tool has been used to obtain maps of peak water level and of peak velocity.

5.1 Maps of maximum flood depth

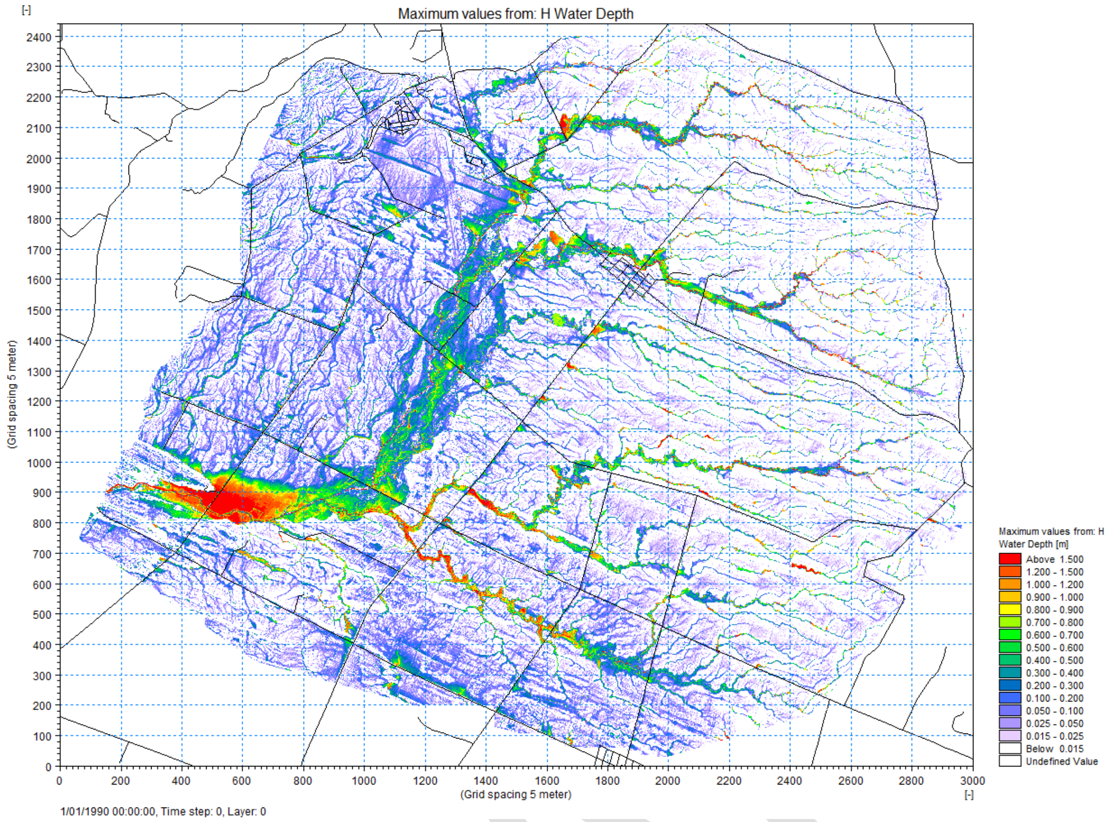

Figure 11 Computed maximum depth, 50-year ARI design event

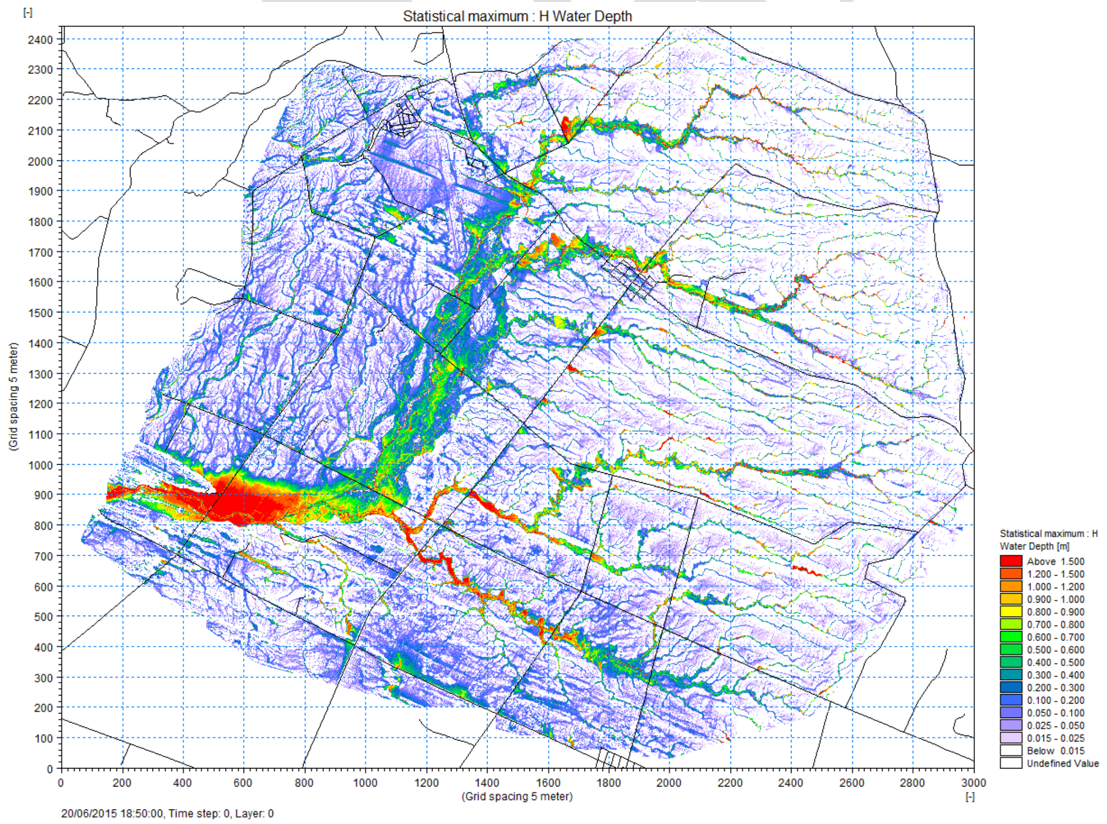

Figure 12 Computed maximum depth, 100-year ARI design event

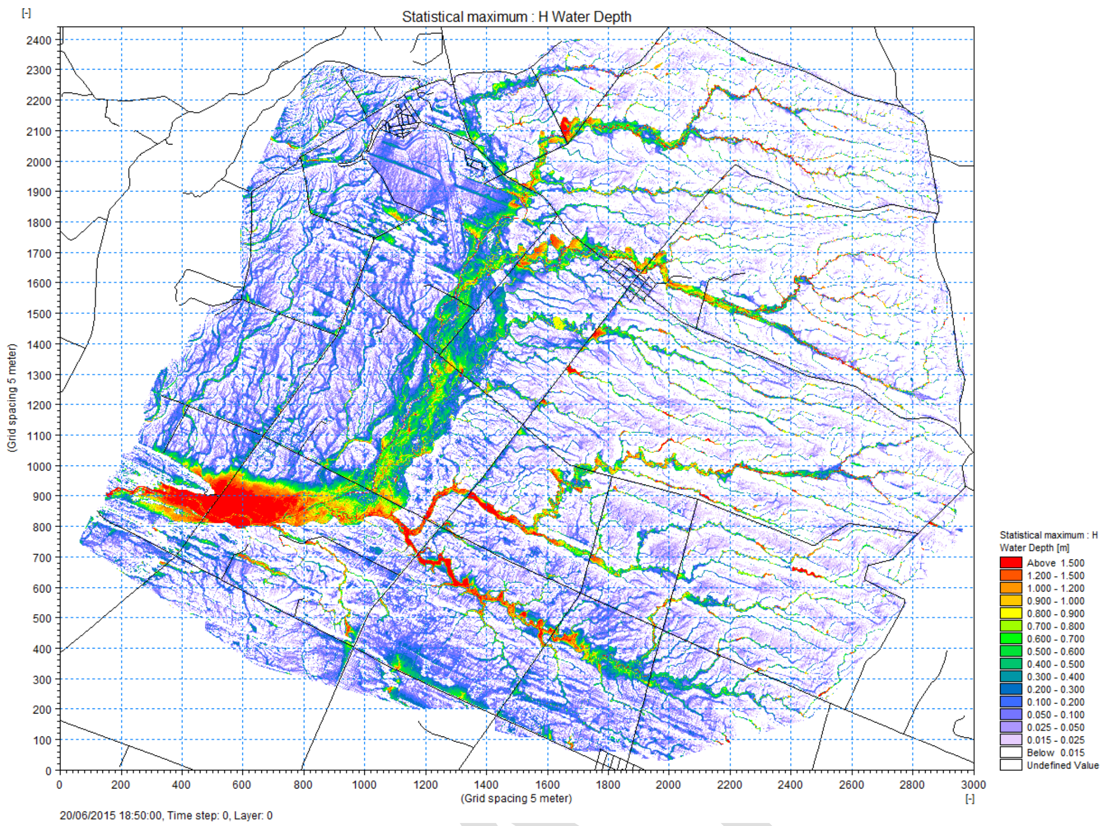

Figure 13 Computed maximum depth, 200-year ARI design event

5.2 Maps of maximum velocity

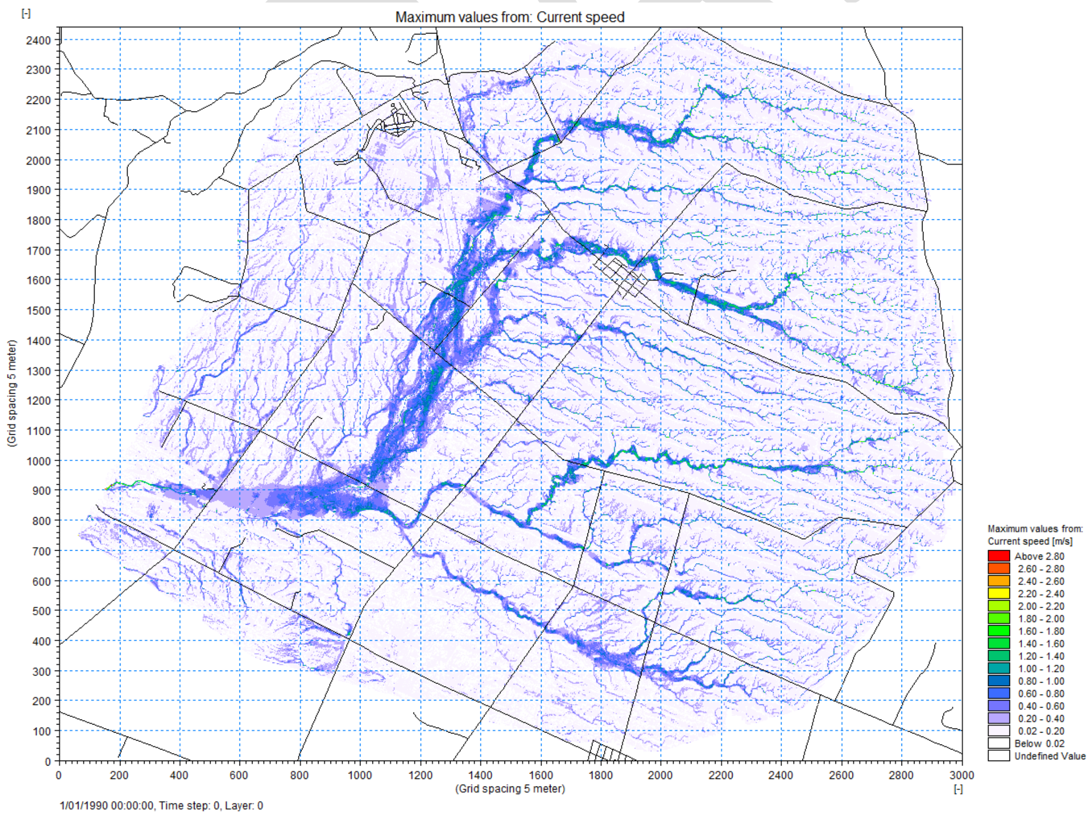

Figure 14 Computed maximum velocity, 50-year ARI design event

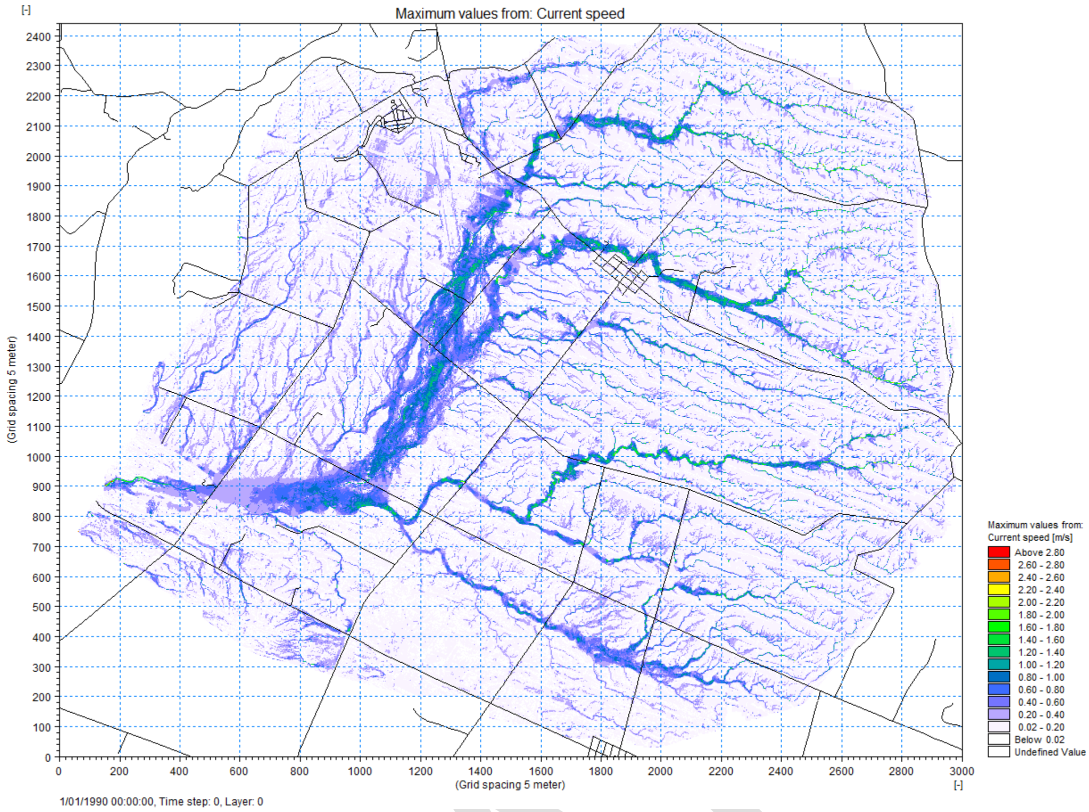

Figure 15 Computed maximum velocity, 100-year ARI design event

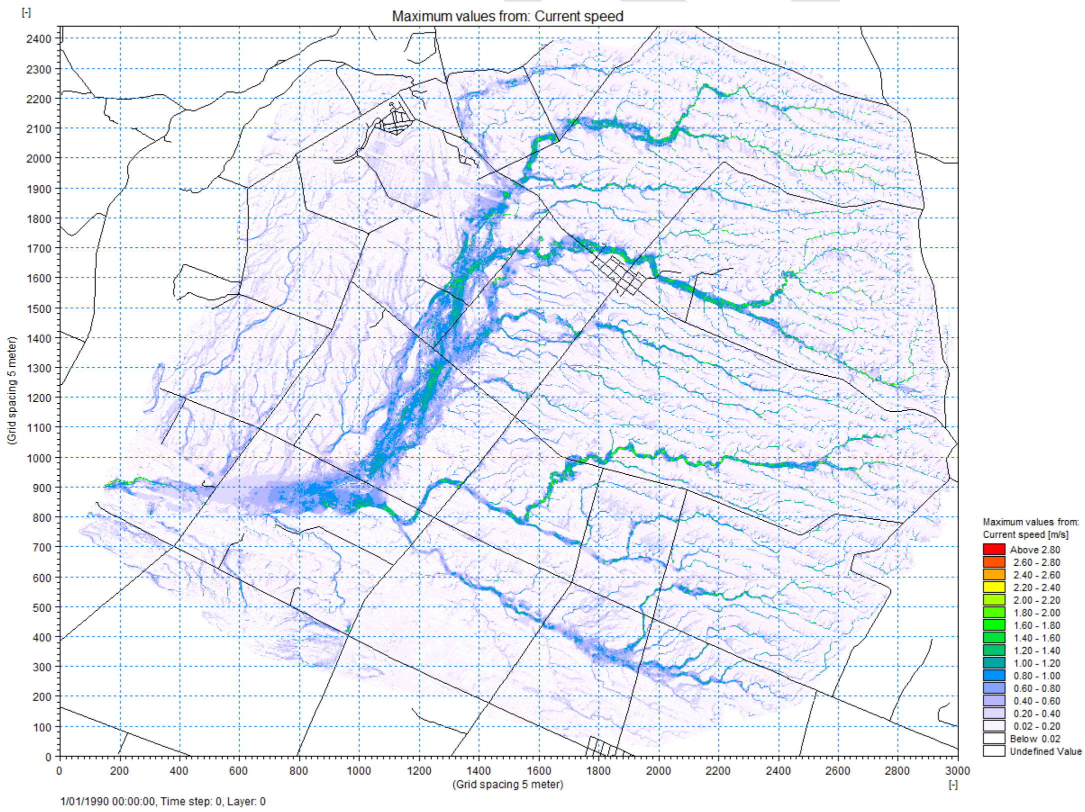

Figure 16 Computed maximum velocity, 200-year ARI design event

5.3 Files to be supplied with this report

5.3.1 Output files

MIKE 21 raw output files (time series of maps of depth and velocity components)

These files include fringe parts of the modelled area that were not required for this study and have been excluded from the peak level data below.

Makowhai5m2015E170719cont.dfs2
makowhai200yr.dfs2
makowhai100yr.dfs2
makowhai50yr.dfs2

MIKE 21 maps of maximum depth and velocity

Makowhai5m2015E170719TimeCroppedMAXH.dfs2
Makowhai5m2015E170719TimeCroppedMAXVel.dfs2
makowhai50yrMAXDepth.dfs2
makowhai50yrMAXVel.dfs2
makowhai100yrMaxDepth.dfs2
makowhai100yrMAXVel.dfs2
makowhai200yrMaxDepth.dfs2
makowhai200yrMaxDepthMark2.dfs2
makowhai200yrMAXVel.dfs2

Image files of maximum depth and velocity

Makowhai_200yrDepth.png
Makowhai50yrMaxDepth.png
Makowhai50yrMaxVel.png
Makowhai100yrMaxDepth.png
Makowhai100yrMaxVel.png
Makowhai200yrMaxDepth.png
Makowhai200yrMaxVel.png
MakowhaiJune2015MaxDepth.png
MakowhaiJune2015MaxVel.png

5.3.2 Model files

makowhai5m170628Resist.dfs2	Flow resistance map, M=1/Manning's n
makowhai5mBathy170719.dfs2	"Bathymetry" map, as edited to accommodate MIKE 21 culverts
Model170717calEstart1600.m21	Control file, final calibration run
Model170721ARI50ev3_2.m21	Control file, 50-year ARI design event
Model170721ARI100ev3_2.m21	Control file, 50-year ARI design event
Model170823ARI200ev3_2.m21	Control file, 50-year ARI design event
Makowhai2015_170712.dfs0	Rainfall file, June 2015 calibration event
Makowhai50yrRainRate3_2mmhr.dfs0	Rainfall file, 50-year ARI design event
Makowhai100yrRainRate3_2mmhr.dfs0	Rainfall file, 100-year ARI design event
Makowhai200yrRainRate3_2mmhr.dfs0	Rainfall file, 200-year ARI design event

All model runs ended abnormally due to "blow-up", and had to be restarted with a modified .m21 file using the Hotstart file generated by the original run. These files are not included with this report but can be supplied on request.

6 Conclusions

An overland flow model of the Makowhai catchment has been assembled, using a Digital Elevation Model with a 5m grid derived from LiDAR. The model has been calibrated against the significant rainfall event from June 2015. This model includes 187 culverts and bridges, most being culverts draining roadside table drains. The calibration involved adjustment of the assumed infiltration rate and the hydraulic properties of some of the culverts, to replicate debris lines from the 2015 event. Agreement was reasonable overall, although with some outliers for which no hydraulic explanation was obvious.

The entire rural catchment is presented by a single flow resistance value, Manning's n of 0.0435, but the urban areas of Sanson and Ohakea have a high resistance for developed land and a low resistance for the roads.

With these features, the model should provide a good broad-brush representation of flooding in response to design events. With the road culverts included, model output should provide a good indication of where culvert drainage is adequate and where it might be improved by additional culverts or larger ones.

However, the model's 5m grid, and the approach taken to flow resistance, do not make it particularly suitable for detailed analysis of local drainage. Furthermore, the model does not include the drainage network in the two towns, nor any culverts on farm land.

Three design events have been modelled, with ARIs of 50, 100 and 200 years. The design hyetographs for these events at the three nearest rain gauges are quite similar, lending some confidence to the weighted hyetographs applied to the model. The peak flooding depths from these simulations show a generally flooded width of about 800m either side of Makowhai Stream, from Fagan Road to the bottom of the catchment. Elsewhere in the catchment, flooding is generally less than 0.3m (even in the 200-year ARI event) and discontinuous.

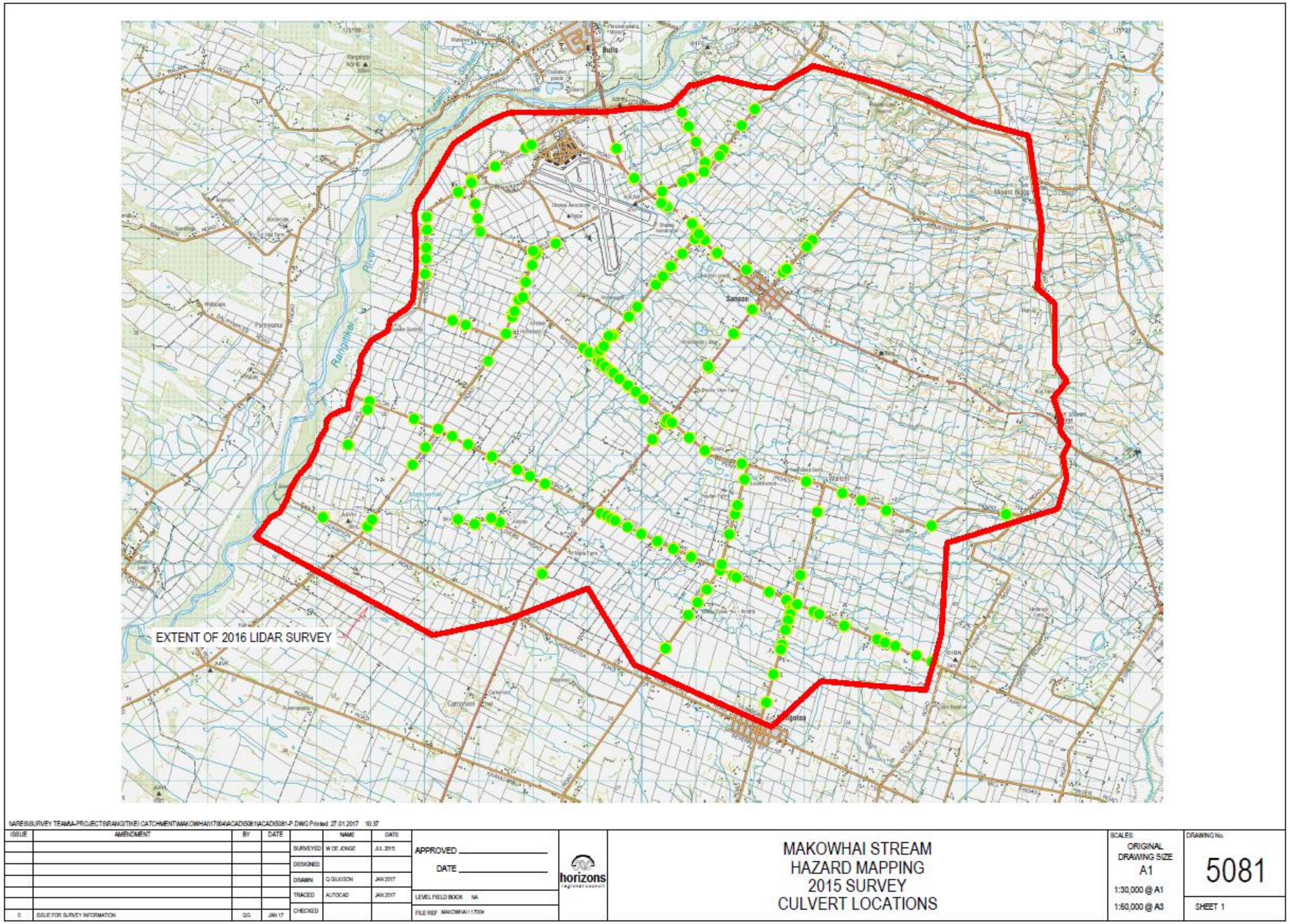

Figure 17: Model domain was required to include the area labelled "Extent of 2016 LiDAR Survey"; The green dots indicate culverts