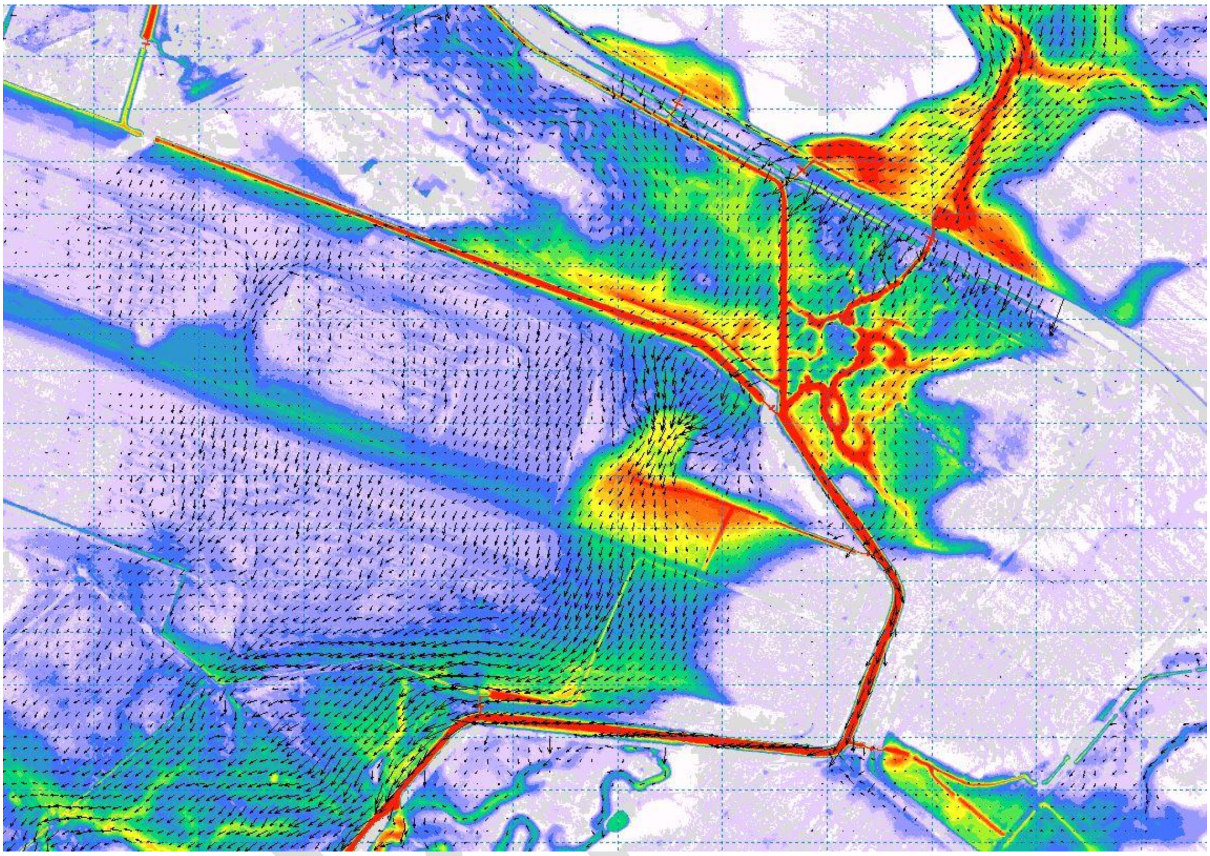
Flood modelling of the Ohakea Air Base and environs



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1 Introduction

This report describes a numerical flooding study that was proposed in response to a NZ Defence Force Request for Tender dated October 2017, and is covered by a contract ("short-form agreement") dated 23rd October 2017.

The numerical model is of flooding at Ohakea Air Force Base and the surrounding land. The base is situated on the northern boundary of the Makowhai / Piakatutu catchment, and immediately south of the Rangitikei River. The contract requires numerical modelling to produce flood maps for Ohakea for the flood events with 5-year and 100-year Average Recurrence Intervals (ARIs).

The opportunity to carry out this modelling study was made easier by an earlier flood model study of the Makowhai / Piakatutu catchment carried out for Horizons Regional Council. Information on rainfall, infiltration and topography that was assembled for that study has been applied to this study, and boundary inflows into the present model have been taken from output from the Makowhai / Piakatutu model.

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

The modelled domain is more or less a square 4km east-west by 4 km north-south and in particular includes land to the east of the runways so as to include the adjacent Makowhai Stream. Within this domain, a small area drains directly to the Rangitikei River rather than to Makowhai Stream.

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 has an area of about 16 square kilometres. A 1m square grid was chosen to provide a good compromise between model run time and representing the topography in sufficient detail. In any event, due to the limitations of the LiDAR data, there is no benefit in reducing the grid size much below 1m. Horizons Regional Council kindly resampled their LiDAR data on a 1m grid to provide a raster of ground elevations, at no charge.

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.

The "higher level" flooding model run for Horizons was used to obtain inflows to the present model domain. This was in part a manual process, as the input flows, from a model with a 5m grid, were converted to several point inflows placed in obvious flow paths including Makowhai Stream.

The model domain was extended downstream (south and west) further than the area of interest around Ohakea. This was done to avoid difficulties with boundary conditions affecting the area that had to be modelled. These additional areas have been cropped from the files of maximum flood depth and velocity.

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

The model was run with a time step between 0.1 s and 1 s. Instabilities leading to "blow-ups" typically occurred frequently, necessitating a restart using the output water level file and sometimes requiring a change of time step.

2.2 Culverts

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 significant culverts and bridges for which sufficient data were available. Road culverts had already been incorporated in the Makowhai model, and their details were transferred to this model (requiring some modification of the bathymetry file due to the way culverts are specified in MIKE 21.

In addition, several culverts within the base were included, east of the runways; the specifications for these were provided by Harrison Grierson within a shapefile of assets.

Although the stormwater reticulation within the base was not modelled, a "culvert" was added to represent part of the network that drains an area in the north-east of the base that would otherwise pond significantly. This modelled culvert does not convey that runoff to its true point of discharge to open drain, as that proved impracticable, but conveys the runoff a shorter distance to be discharged further upstream. This discrepancy is unlikely to have more than a minor effect on calculated water levels.

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 route 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 5m. This approximation could have been remedied by adding a weir structure at each culvert. However, at most culverts in this model, any overflow would occur over a length well over 5m. It was therefore decided that the approximation was close enough for a weir structure at each culvert to be unnecessary.

2.3 Rainfall hyetographs

The choice of hyetographs owes much to the earlier choice for the Makowhai catchment flooding model developed for Horizons. The detail described in the report for that study is therefore produced here:

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 1), as well as design hyetographs for 50-year ARI (Figure 2) and 100-year ARI rainfall events.

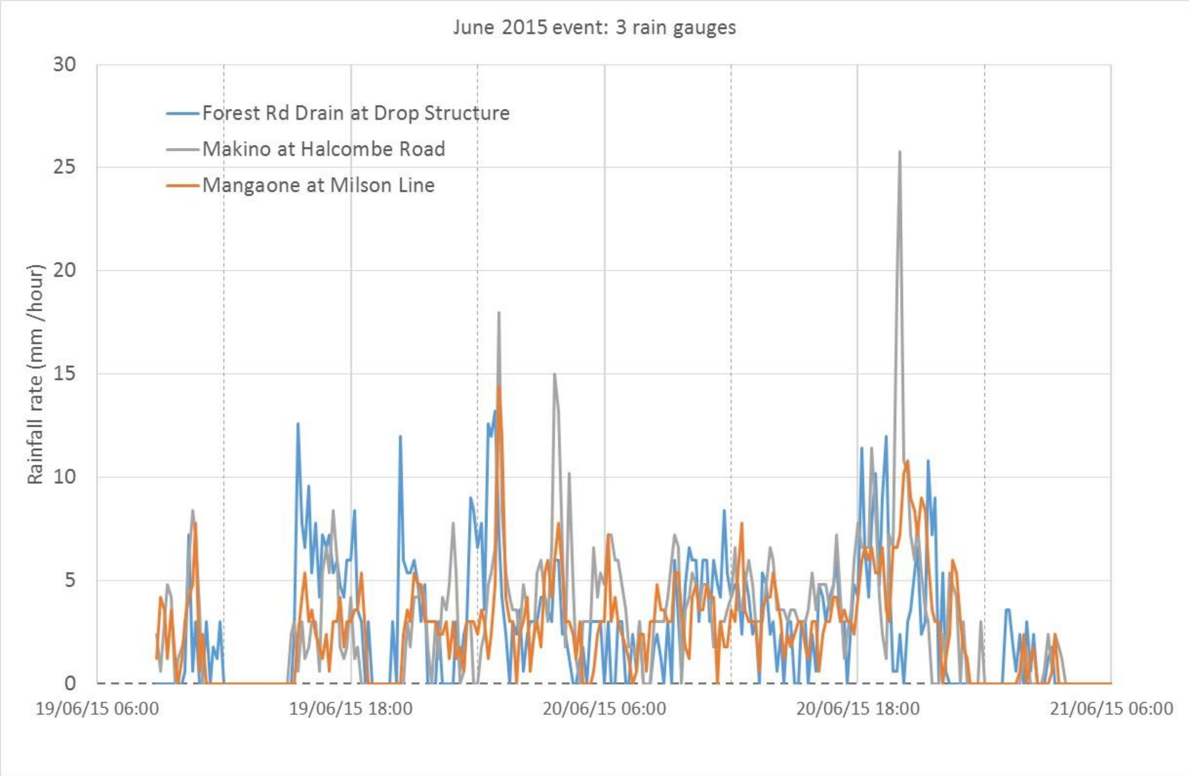

Figure 1 Gauged 2015 hyetographs

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 ARI are nested within one another. This form of design hyetograph may well be unrepresentative of any single observed event, but has the strong advantage that every sub-catchment, regardless of its response time, experiences the rainfall likely to produce a peak flow with the specified ARI.

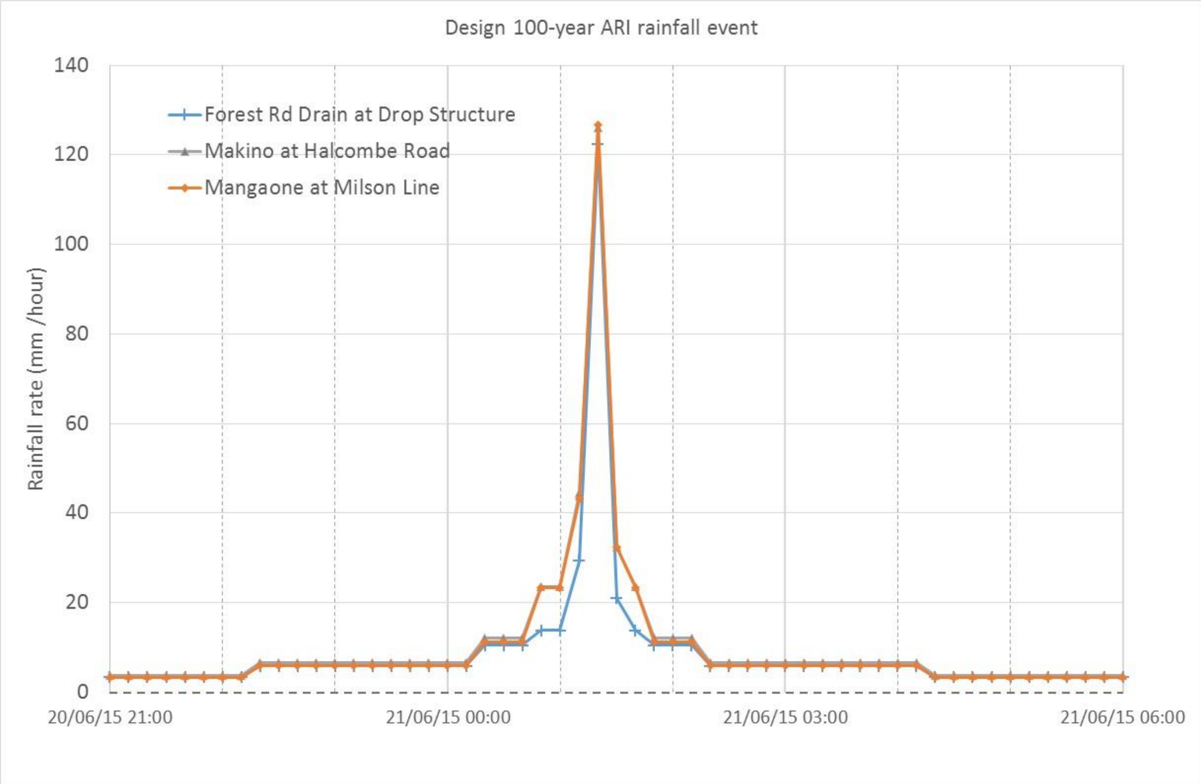

Figure 2 Design 100-year ARI hyetographs for rainfall gauge locations

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 hyetograph 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 then applied to the design hyetographs (Figure 3).

The same application of Thiessen polygons to the Ohakea model domain leads to a weighting of 47% to the Forest Road site and 53% to the Makino @ Halcombe Rd site. This weighting is so similar to that adopted for the Makowhai catchment model that the same hyetographs were adopted for the present study.

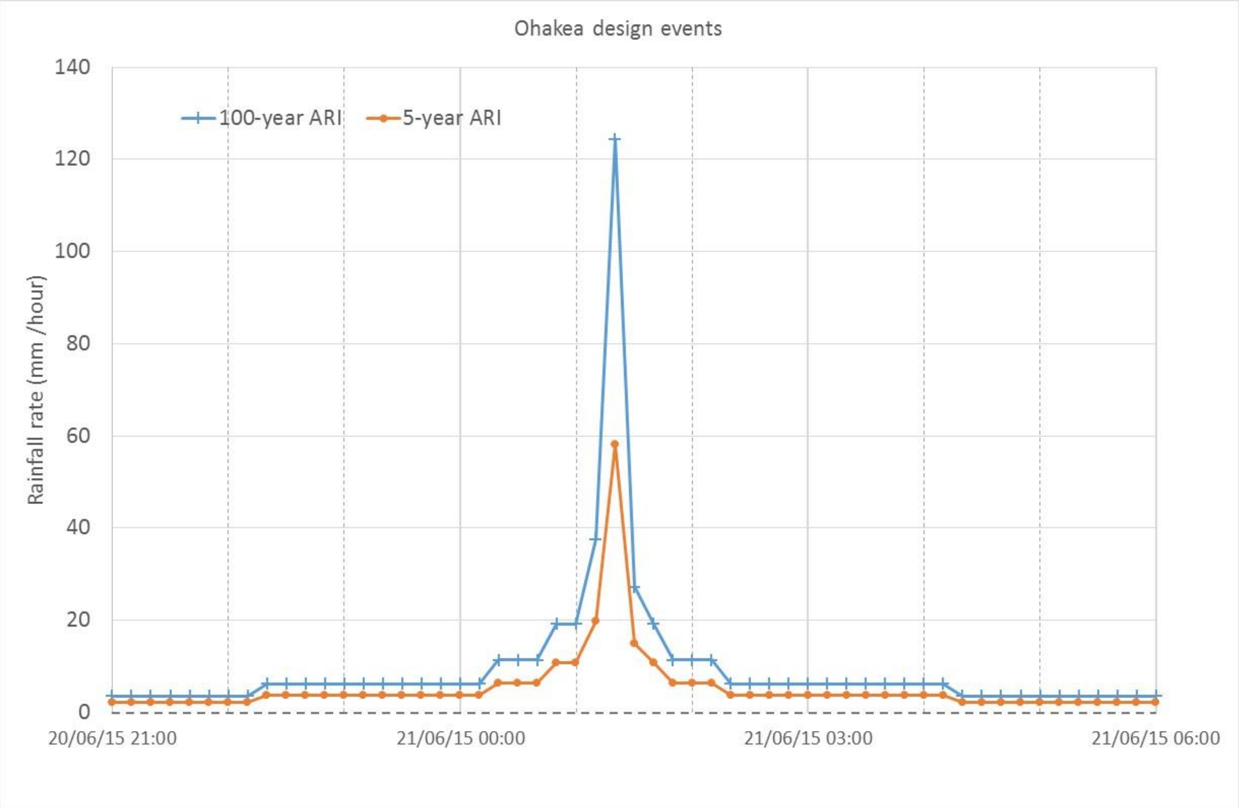

Figure 3 Design hyetographs, weighted for the Makowhai-Piakatutu catchment and for Ohakea

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 using the infiltration function within MIKE 21).

The same losses were assumed for this model as for the Makowhai model. These losses were initially set by considering the soil properties of the catchment, but were adjusted slightly as part of calibration against 2015 event. The values finally adopted were an initial loss of 20 mm and a continuing loss rate of 3.2 mm/hour.

These losses were applied throughout the model domain. This is clearly an approximation in areas of roading or hard stand. However, any errors due to this assumption are offset by other approximations; this is discussed below.

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

Harrison Grierson provided a GIS map of land use for Ohakea Air Base. For this model, flow resistance values were assigned according to land use (Figure 4), including a low flow resistance of M=45 (n=0.022) for hard-strands and roads, and a very high flow resistance M=8 (n=0.125) for buildings. The high modelled resistance for buildings 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.

A single Manning M value of 23 (reciprocal of Manning's n=0.0435) was applied to almost all the rural catchment.

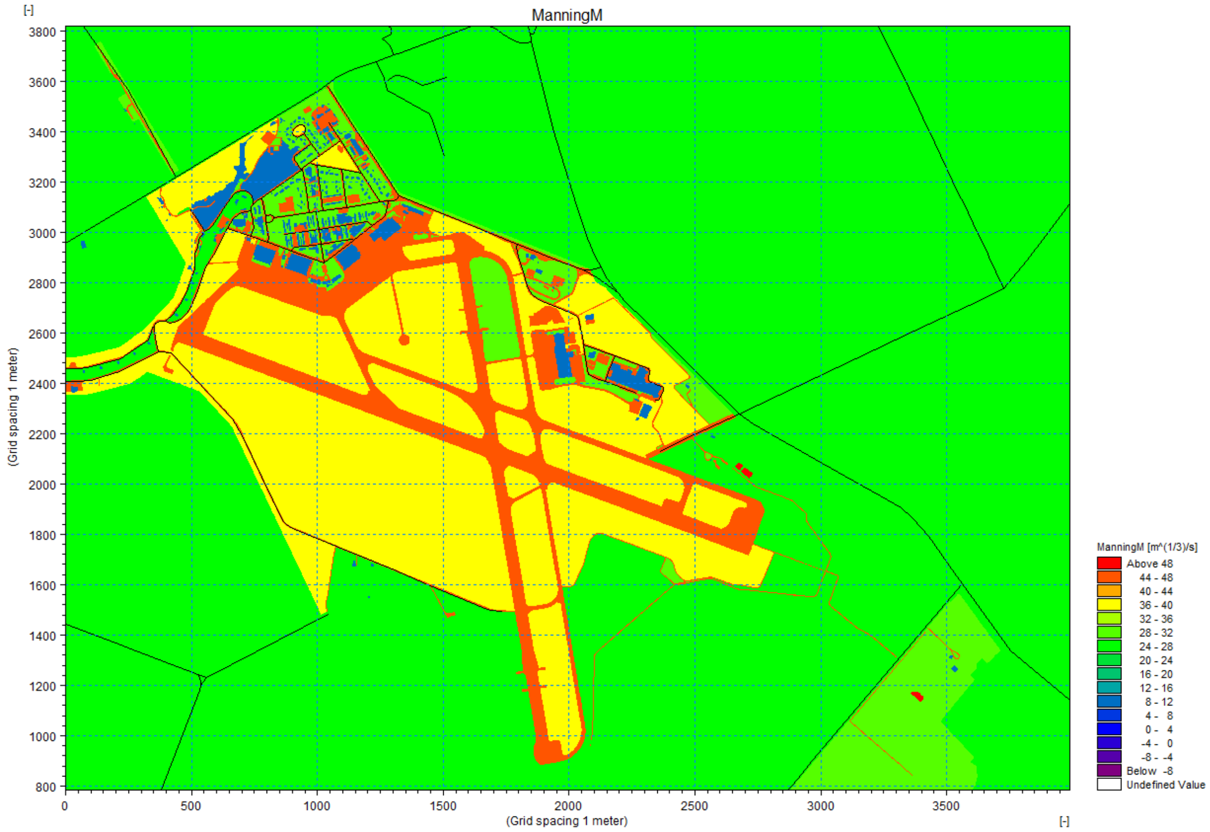

Figure 4 Map of overland flow resistance (Manning's M = 1/n) as modelled, Ohakea to Sanson. M values denoted by: Green: 23; blue: 8 (buildings); yellow: 37 (grassed); red: 45 (roads, hard-stand)

3 Modelling the design events

The two "production runs" of the model comprised the two design hyetographs of Figure 3, with assigned ARIs of 5 years and 100 years.

The computational time step was variously set at 0.1s to 0.5s (depending on model stability), and the flooding and drying depths were 20mm and 10mm respectively.

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. Some modelling time was therefore saved by starting the model 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 2.5 hours after the hyetograph peak. Checks were made to ensure that peak water levels at critical locations had been reached by then.

4 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 (Figure 5 and Figure 6) and of peak velocity (Figure 7 and Figure 8.

4.1 Maps of maximum flood depth

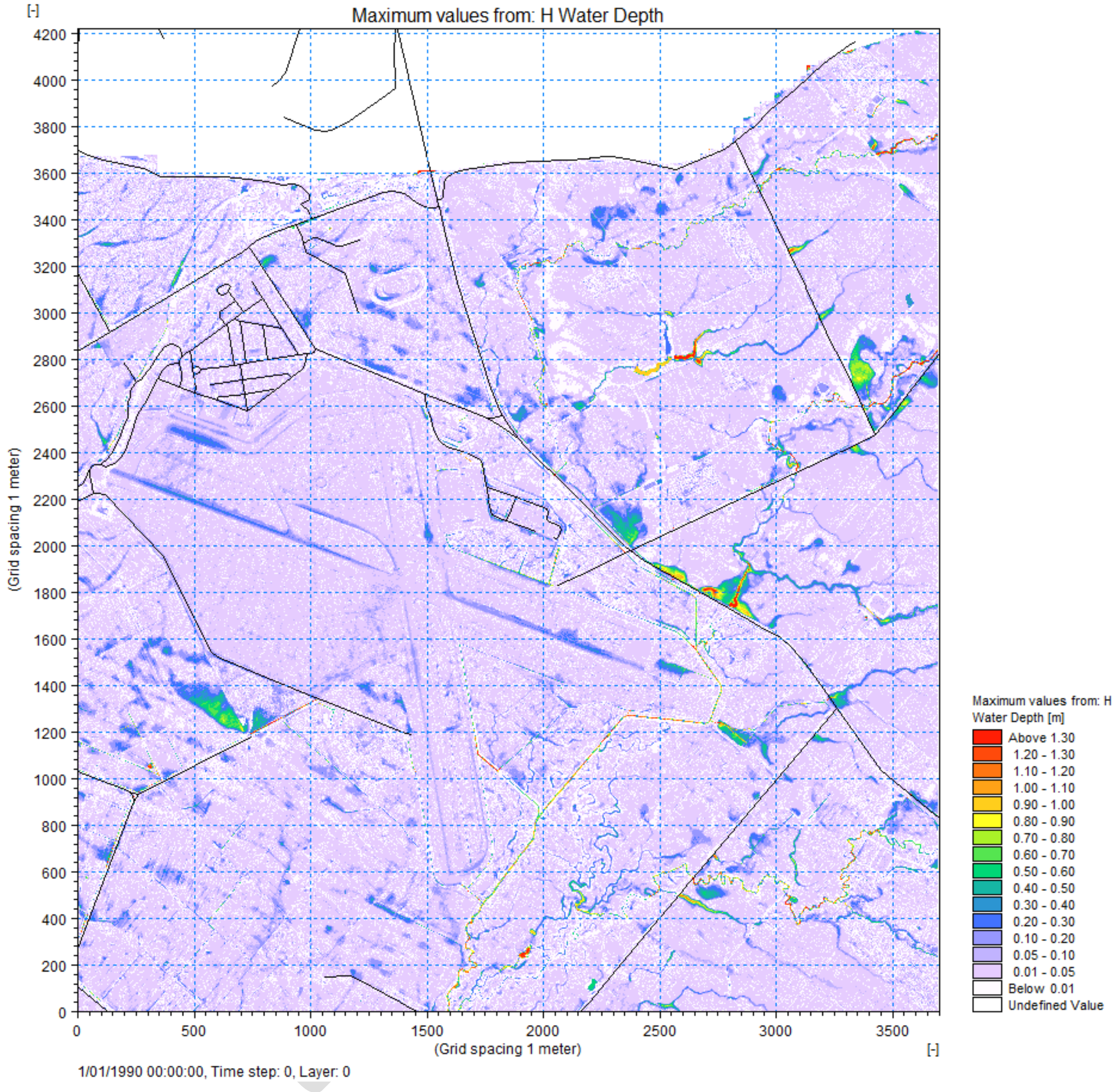

Figure 5 Computed maximum depth, 5-year ARI design event

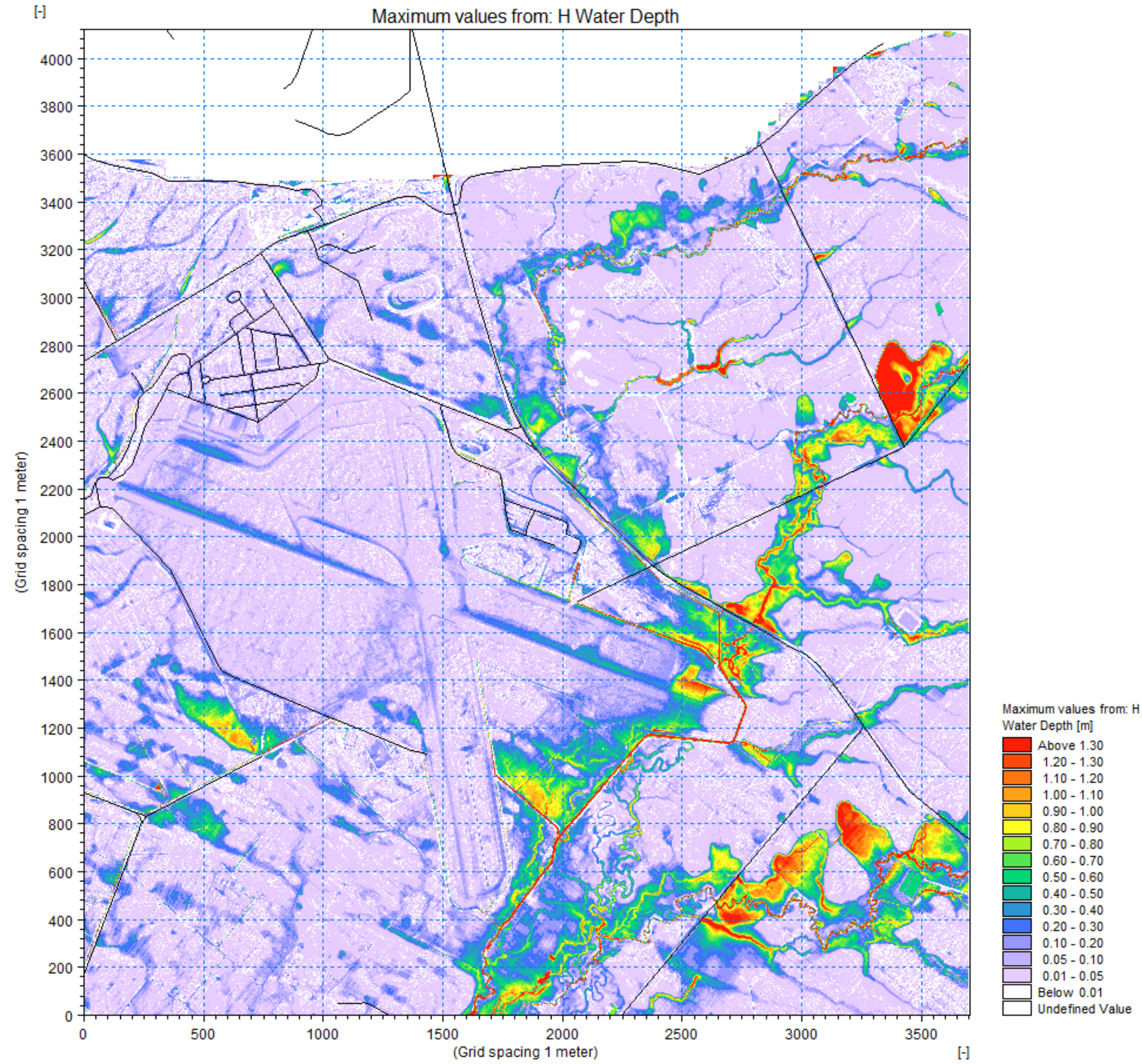

Figure 6 Computed maximum depth, 100-year ARI design event

4.2 Maps of maximum velocity

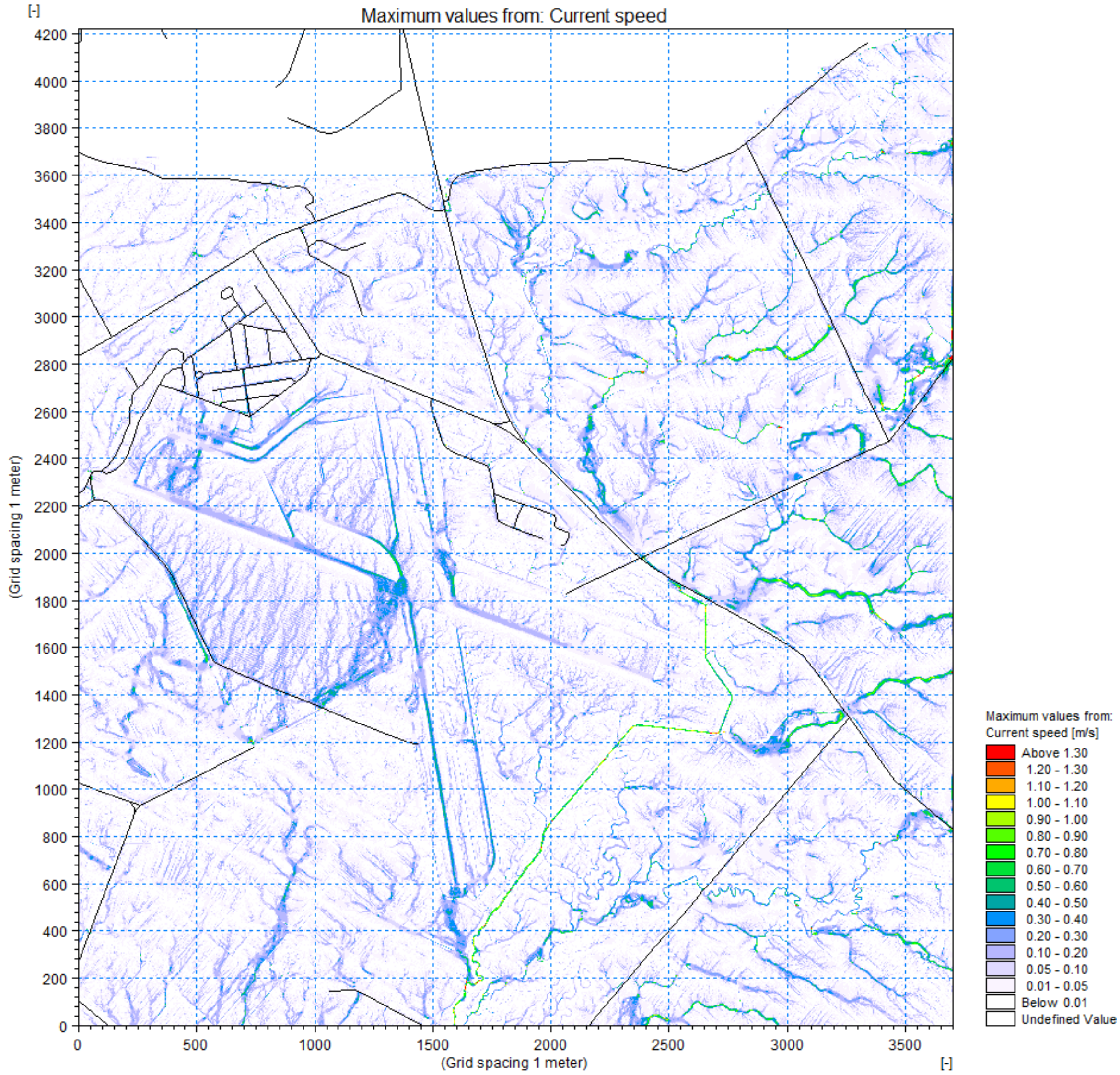

Figure 7 Computed maximum velocity, 5-year ARI design event

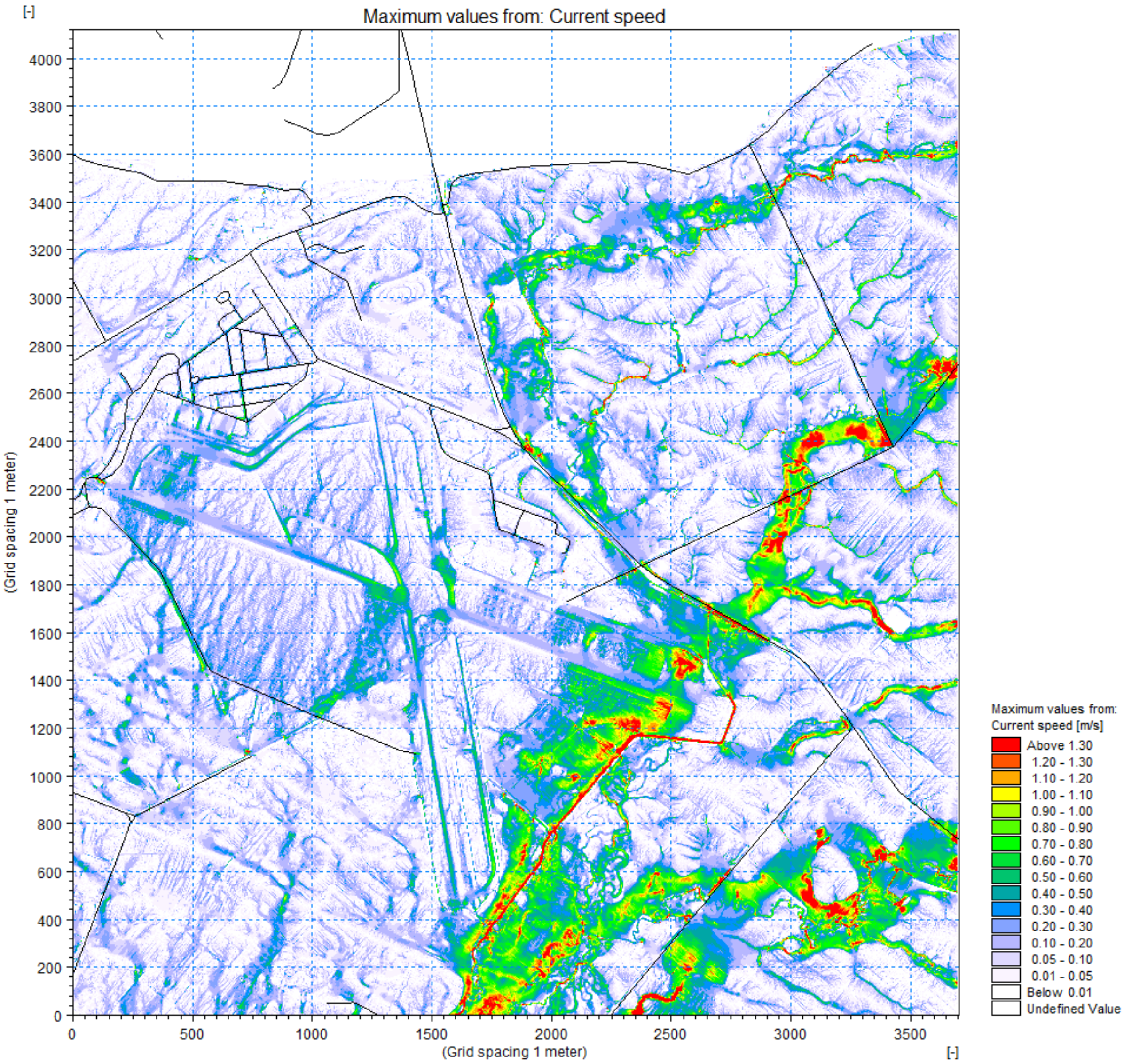

Figure 8 Computed maximum velocity, 100-year ARI design event

4.3 Files to be supplied with this report

4.3.1 Output files

MIKE 21 maps of maximum depth and velocity

Ohakea5yr171109MAXdepth.dfs2
Ohakea5yr171109MAXvel.dfs2
ohakea100yr171206MAXDep.dfs2
ohakea100yr171206MAXVel.dfs2

Image files of maximum depth and velocity

Ohakea5yrDepthMax1.png
Ohakea5yrMAXVel.png
Ohakea100yrMAXDepth.png
Ohakea100yrMAXVel.png

Animations of flooding depth and extent

These files have been produced from the full MIKE 21 output files (time series of maps of depth and velocity components)

Ohakea5yrFlood.avi
Ohakea5yrFloodEastEnd.avi
Ohakea100yrFlood.avi
Ohakea100yrFloodEastEnd.avi

4.3.2 Model files

OhakeaManningM171106b.dfs2	Flow resistance map, M=1/Manning's n
Ohakea1mDEM171028Culv1121a.dfs2	"Bathymetry" map, as edited to accommodate MIKE 21 culverts
Ohakea5yr171109.m21	Control file, 5-year ARI design event
Ohakea100yr171115contC.m21	Control file, 100-year ARI design event
Makowhai5yrRainRate3_2mmhr.dfs0	Rainfall file, 5-year ARI design event
Makowhai100yrRainRate3_2mmhr.dfs0	Rainfall file, 100-year ARI design event
Ohakea5yrInflowsEast.dfs0	Inflows, 5-year ARI design event, from Makowhai model
Ohakea5yrInflowsWest.dfs0	Inflows, 5-year ARI design event, from Makowhai model
Ohakea100yrInflowsEast171117.dfs0	Inflows, 100-year ARI design event, from Makowhai model
Ohakea100yrInflowsWest.dfs0	Inflows, 100-year ARI design event, from Makowhai model

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

5 Limitations of this model

The approximations made in this numerical model are all considered appropriate for the purpose of the study, and are not expected to lead to significant inaccuracies. Nevertheless, it is useful to list the principle approximations, to avoid the model results being applied in unintended ways.

- The stormwater reticulation network at Ohakea base was not included, nor were field drains on the runways; to do so would have required additional software and would have required a considerably more complex analysis. This will have resulted in over-estimated overland flow. However, the effect on the 100-year event will have been minor, as stormwater networks are typically designed for no more than the 5-year event.
- Infiltration rates suitable for the wider catchment were applied universally, event on hard-stsand areas. This will have resulted in under-estimated overland flow, and therefore compensates to some degree for the over-estimate due to ignoring the stormwater network.
- The design hyetographs are a convenient way of incorporating design events of widely differing durations, so that one model run is likely to find the worst flooding conditions. However, these hyetographs, with a marked peak in the middle of the event, are unlike any real events.
- Calibration of the Makowhai model was limited, and this model has relied on the model parameters (especially infiltration rate) determined from that calibration. This is a source of some uncertainty in both flood levels and stream flow rates.

6 Conclusions

An overland flow model has been assembled of Ohakea Air base and surrounding land, using a Digital Elevation Model with a 1m grid derived from LiDAR. This model includes all significant culverts and bridges, but does not include the stormwater pipe network that drains the base.

The model adopted some parameters determined in developing a similar model of the entire Makowhai catchment (of which Ohakea is a part). The assumed infiltration rate and the hydraulic properties of some of the culverts had been adjusted within the Makowhai model as calibration against a 2015 event.

The entire rural catchment is presented by a single flow resistance value, Manning's n of 0.0435, but different resistance values were assigned to different land uses within the base: low resistance for roads and hard-stands, but high resistance for buildings (largely to reflect the obstructions to flow and resulting circuitous flow paths).

With these features, the model is expected to provide a good broad-brush representation of flooding and stream flow in response to design events.

Two design events have been modelled, with ARIs of 5 and 100 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 are quite different, as might be expected from two disparate events. Much of the 5-year rainfall is assumed to be lost as infiltration, so that there is little overflow from stream channels and drains. The 100-year event, however, is modelled as producing significant ponding on farmland and some overland flow across the runways.