Flood Modelling of the Mangaone Stream and East of Levin

Model Build Report

IZ130600-CH-RPT-0002 | B

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Horizons Regional Council

2019/12 & 2019/13

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Jacobs New Zealand Limited

Level 8, 1 Grey Street
Wellington, 6143
PO Box 10-283
Wellington 6011
New Zealand
T +64 4 473 4265
F +64 4 473 3369
www.jacobs.com

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Executive Summary

Horizons Regional Council (HRC) have identified the need to increase their understanding of flood hazard in the Upper Mangaone Stream Catchment and the area East of Levin (Figure 1.1), including the Koputaroa Stream, as part of their Hazard Mapping Project. Jacobs have been commissioned by Horizons Regional Council (HRC) to build hydraulic models of these catchments to enable mapping of the areas that are likely to be inundated in a range of flood events.

A hydrological model was developed in HEC HMS for each catchment. The loss method adopted used an initial abstraction loss and a constant loss per hour. The kinematic wave method was used as the transform method for runoff and for reach routing. The approach adopted for the rainfall runoff modelling was to first confirm the parameters used for the Mangaone Stream Catchment, where a flow gauge at the downstream end of the catchment is present. The results were tested against flood frequency analysis and selected storm flows as a sensibility check. Once the parameters for Mangaone Stream catchment were finalised the same methods were used to estimate parameters for the East of Levin catchment.

The overall approach adopted for the hydraulic models was a fully 2D HEC RAS model. We initially investigated using a 1D model with selected areas in 2D however the LiDAR data wasn't suitable for this approach as the channels were not sufficiently well defined and vegetation included in the channel surface created unrealistic barriers to flow and affected model stability. A 5 metre 2D grid was adopted as this was found to have a good balance between sufficient resolution of the terrain and model run time. Key structures such as bridges and culverts were identified and modelled as HEC RAS 2D connections. Structures that were not surveyed but we identified as causing backwater and potentially unrealistic flow paths to be activated were modelled using the HEC RAS terrain modification channel.

The hydraulic flood models we have developed for the Upper Mangaone and East of Levin catchments are suitable for regional flood mapping. We have used the models to simulate flooding for mapping purposes for three design events: the 10-year, 100-year, and 200-year ARI. The simulations include an allowance for the effects of climate change on rainfall to the period 2081-2100 under the RCP 6.0 scenario.

For the Mangaone Stream catchment gauged flows were available, and these were used to sense check the model flows against a flood frequency analysis of the gauge. The model results show that there are significant out of bank flows on the northern side of the Mangaone, so the gauged flows may underestimate the flows in larger floods. Some roads form barriers to overland flooding, for example Waughs and Campbell Roads north east of Bunnythorpe and Kairanga Bunnythorpe Road south west of Bunnythorpe.

For the Levin East catchment, excluding Koputaroa Stream we applied rainfall directly to the entire model 2D surface since this area does not have a well-defined river network. The 2D rain on grid approach means there is shallow flooding over much of the 2D model extent; in the results presented only flood depths greater than 50mm are shown.

For the Koputaroa Stream catchment, the water level in the lower part of the model is determined by the channel capacity at the railway line crossing at the downstream end of the model. The widespread flooding upstream of the railway line significantly attenuates the flow in the channel downstream of the railway in all flood events. Although the flood extents are very similar for all three events, the water level varies by around 1m between the 10 year and 200 year events. Although there was no calibration data available for the Koputaroa Stream, photographs of flooding in this area confirm that the extents are comparable to what has been observed.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to report results of flood hazard modelling for the Upper Mangaone Catchment and the area East of Levin. The scope of services was developed in consultation with Horizons Regional Council ("the Client"), and it is defined in the contract agreement. A summary of the objectives is included in Section 1 of this report. In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate, or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

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1. Introduction

Horizons Regional Council (HRC) have identified the need to increase their understanding of flood hazard in the Upper Mangaone Catchment and the area East of Levin (Figure 1.1) as part of their Hazard Mapping Project. Jacobs have been commissioned by Horizons Regional Council (HRC) to build hydraulic models of these catchments to enable mapping of the areas that are likely to be inundated in a range of flood events.

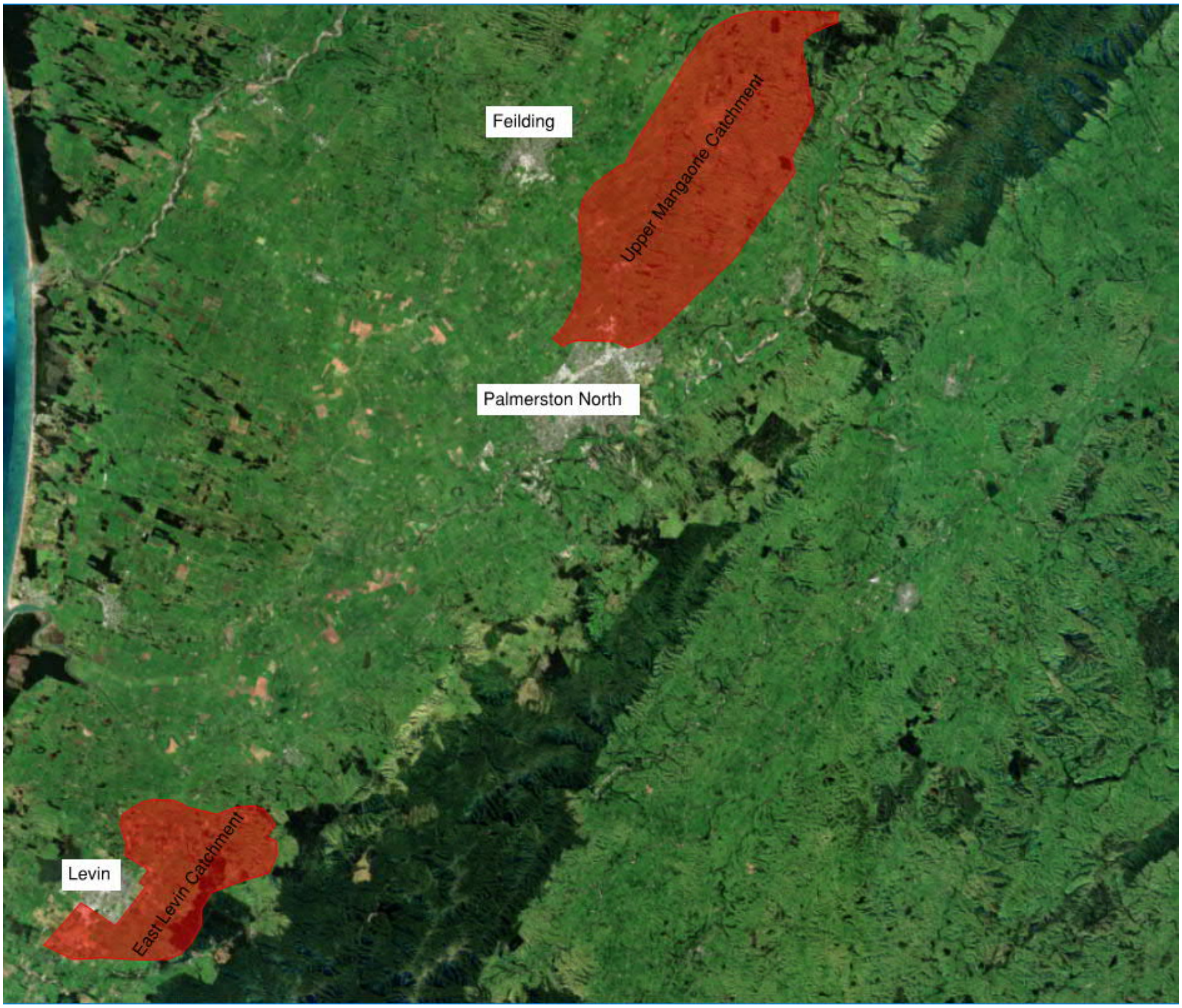


Figure 1.1: Approximate locations of Upper Mangaone and East of Levin Catchments:

1.1 Background

The Upper Mangaone Stream Catchment is situated immediately north of Palmerston North and is defined as the Mangaone stream above Milson Line and all its tributaries. No flood modelling has been carried out previously for this area.

Developments in the south of the catchment have already started and are expected to continue in the future. To enable HRC to review future applications for changes in land-use by the Palmerston North City Council (PNCC) or

Manawatu District Council (MDC), it is important that HRC can independently determine the changes in the flood risks as a result of changes in land-use. HRC therefore needs a hydraulic flood model of the catchment to assist the Council with identifying the flood risks.

The East of Levin catchments include the catchments between the Koputaroa Stream in the north and the Ohau River in the south, but do not include the Ohau River catchment itself. Along the west, the boundaries of the catchments are formed by the railway line, Arapaepae Road and the town of Levin. The downstream boundary of the Koputaroa Stream catchment is also formed by the North Island Main Trunk railway line. These catchments have not been modelled previously.

A significant number of developments are proposed on the southern and eastern sides of Levin by the Horowhenua District Council (HDC). HRC require a hydraulic flood model of the catchments to assist with identifying flood risks, particularly during the review of future land-use changes.

1.2 Project Scope

In August 2019, Jacobs was commissioned by Horizons Regional Council to develop two flood models:

- The Mangaone (and its tributaries above Milson Line) Flood Model
- The East of Levin (Levin East and Koputaroa Stream catchments) Flood Model

A scoping stage was carried out for each catchment. Data was gathered from site visits, HRC and other sources to carry out a desktop study to confirm the watercourses, catchment delineation, locations of culverts and bridges, including a recommendation for structures to be included in a topographical survey, and other GIS inputs into the model. The suitability of the available rainfall data was evaluated and a recommendation for the model rainfall events was put forward to HRC together with a modelling strategy.

The scope of the modelling was reviewed by HRC before the model build was carried out, utilizing HEC software.

Two reports have been produced as part of this project. The first describes the outcomes of the scoping stage including the recommendations for the model build stage and the available data that can be used in the model build stage. This report was forwarded to HRC for comments in November 2019 and finalised in December 2019 (Flood Modelling of the Mangaone Stream and East of Levin: Scoping Stage, IZ130600-CH-RPT-0001 | 1, 11 December 2019).

This report describes the model build process, the main features of the model, information on accuracy and reliability of the model, a summary of the assumptions and limitation associated with the model and maps of the predicted flood depth.

1.3 Project Objectives

As agreed with Horizons Regional Council in the accepted offer dated 5/08/2019, the objectives of the study are as follows:

- Develop a coupled 1D/2D hydraulic flood models in HEC-RAS software for the Upper Mangaone and East of Levin catchments suitable for regional flood mapping
- Model rainfall events as agreed upon during the scoping stage.
- Produce high-level report describing the modelling undertaken and the assumptions underlying it.
- Upon completion of the model build, transfer of the original model files to HRC.

1.4 Scope Clarification

Jacobs have only made allowance for the models to be compared to an existing flood data set, but it will not be calibrated, validated, or verified.

1.5 Limitations and Assumptions

We have developed hydraulic flood models in HEC-RAS software for the Upper Mangaone and East of Levin catchments suitable for regional flood mapping and produced results for design runs for three design events: the 10-year,100-year, and 200-year, including allowance for the effects of climate change under the RCP 6.0 scenario for the period 2081-2100.

We have taken an approach that is suitable for developing regional flood maps. The models and flood depths and extents provided are not suitable for use in more detailed or site specific studies.

We have made the following assumptions in our methodology:

- The Mangaone Stream and Koputaroa Stream catchments have similar initial and constant loss profiles, we recommend that this assumption be confirmed through flow monitoring on the Koputaroa Stream.

The modelling and results provided have the following limitations:

- The model resolution is limited by the resolution and accuracy of the LiDAR data.
- The model is not suitable for use in more frequent events, the main channel is entirely represented in 2D which is reasonable for larger floods where much of the flow is out of the main channel but may under-represent the channel capacity in the smaller events due to the model 2D cell size and reliability of the LiDAR data in the channel.
- Unsurveyed structures have been represented in a simplified manner by a 0.5m wide open channel. Actual details of these unsurveyed structures should be added to the model if more detailed results are required at these locations.
- The model has not been calibrated to recorded events although it has been sense checked against the observed discharge for the Mangaone catchment and observed flooding for the Koputaroa Stream. The flood extent maps have also been reviewed by Horizons Regional Council staff based on their experience of flood mechanisms in the catchments.

2. Rainfall Runoff Model

A hydrological model was developed in HEC HMS for each catchment, based on the recommendations from the scoping study. The loss method adopted uses an initial abstraction and constant continuing loss per hour. The kinematic wave method was used as the transform method for runoff and for reach routing. The model parameters used in the model are discussed in the following sections.

The approach that was adopted for the rainfall runoff modelling was to first confirm the parameters used for the Mangaone Stream catchment, test the results against flood frequency analysis and selected storm flows as a sensibility check (our scope did not include model calibration, validation or verification) and once the parameters for the Mangaone Stream were finalised the same methods were used to estimate parameters for the Levin East catchment.

The data used for the model build process is described in detail in the scoping report, and we have provided a list of the main data used for the rainfall runoff model build in this report:

- Digital Elevation Models (DEM) based on 2016 LiDAR data provided by HRC
- Flow data for the Mangaone at Milson Line, flow gauge from HRC ,1980- present
- Land cover database, v 5.0, Jan 2020

2.1 Methodology

The inputs to the hydrological model in HEC-HMS are subcatchment areas, rainfall depths, rainfall temporal profiles, rainfall losses, hydrograph transformation parameters, and reach routing parameters. Further discussion of the methodology used for each parameter follows in the sections below.

2.1.1 Subcatchment delineation

Subcatchments were delineated using the DEM's provided by HRC and GIS processing as part of the Scoping Stage (Jacobs, 2019). The number of subcatchments was based on the areas of interest and the recommendation from the scoping report to model streams of order 3 and above and some level 1 and 2 streams in the upper reaches where rainfall is likely to be much higher.

2.1.2 Rainfall Depths

Rainfall depths from HIRDs v4 were used for the design rainfall depths for the catchment hydrological models. The rainfall at the centroid of each subcatchment was used, and a 9-hour duration was used for Mangaone and a 3 hour duration for Levin East. The selection of the time of concentration and modelled event duration is discussed in more detail in sections 2.2.1 and 2.3.1.

2.1.3 Design Rainfall Profile

For the design storm we tested several design rainfall profiles. These included a rectangular (constant rainfall) rainfall profile and triangular profiles. The triangular profiles have the same volume as each other (and the same volume as the rectangular rainfall profile), with peak rainfall intensities that are double the average rainfall intensity. The volume will be based on the rainfall depth for the critical duration storm for the catchment based on HIRDS v4 outputs. We also tested the HIRDs v4 storm profile for the west of the North Island for a 24h duration. We compared rainfall records from the Mangaone at Milson Line rainfall gauge for a number of large storms to the design rainfall profiles to assess which profile to use. Figure 2.1 shows the rainfall profiles that we tested. Figure 2.2 a) – d) show a cumulative hyetograph comparing the normalized rainfall for selected recorded storm against each design profile. Based on this analysis the rectangular design profile was selected as there was variation between storms that had peak intensity early in the storm and those that had a peak between ½ and 2/3 of the way through the storm. A rectangular profile represents a reasonable average of the observed storm profiles.

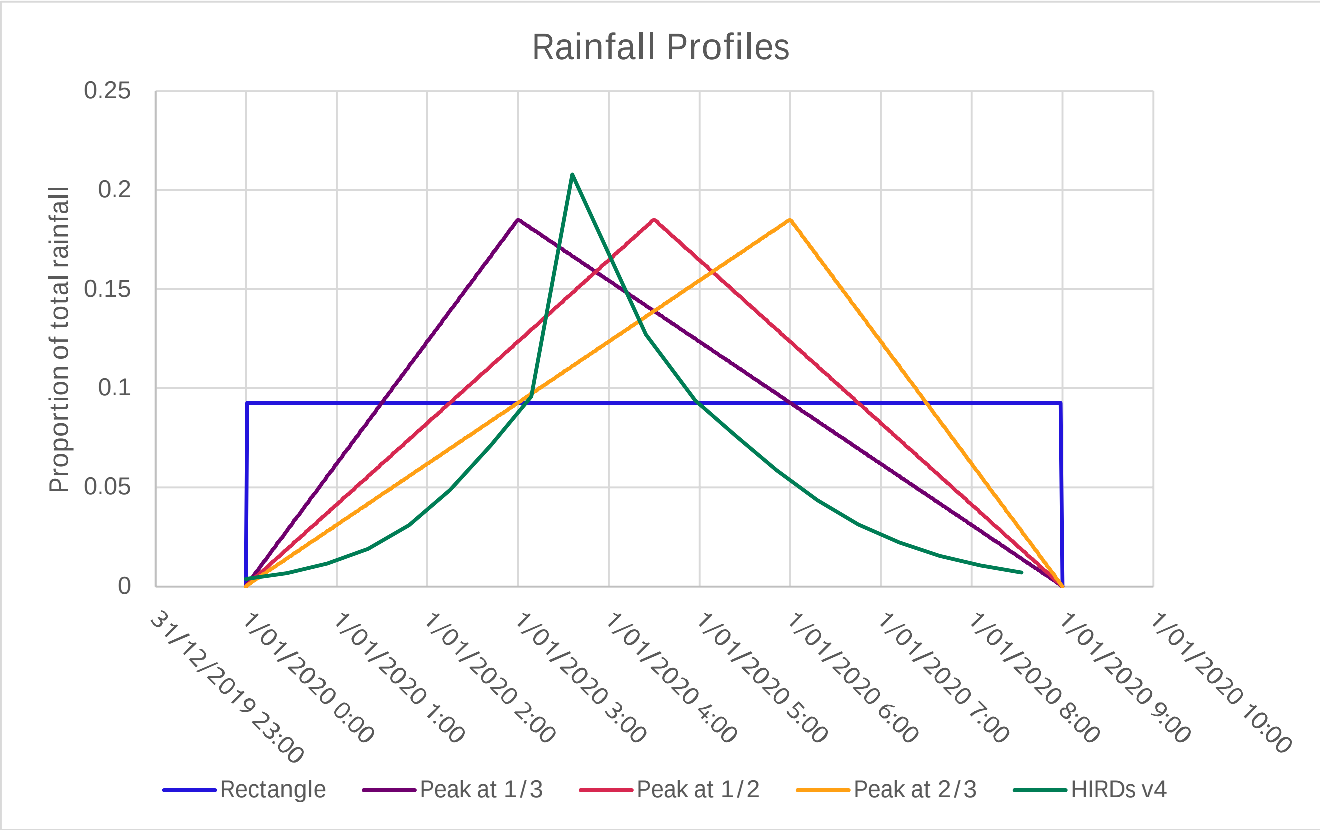


Figure 2.1: Design rainfall profiles tested

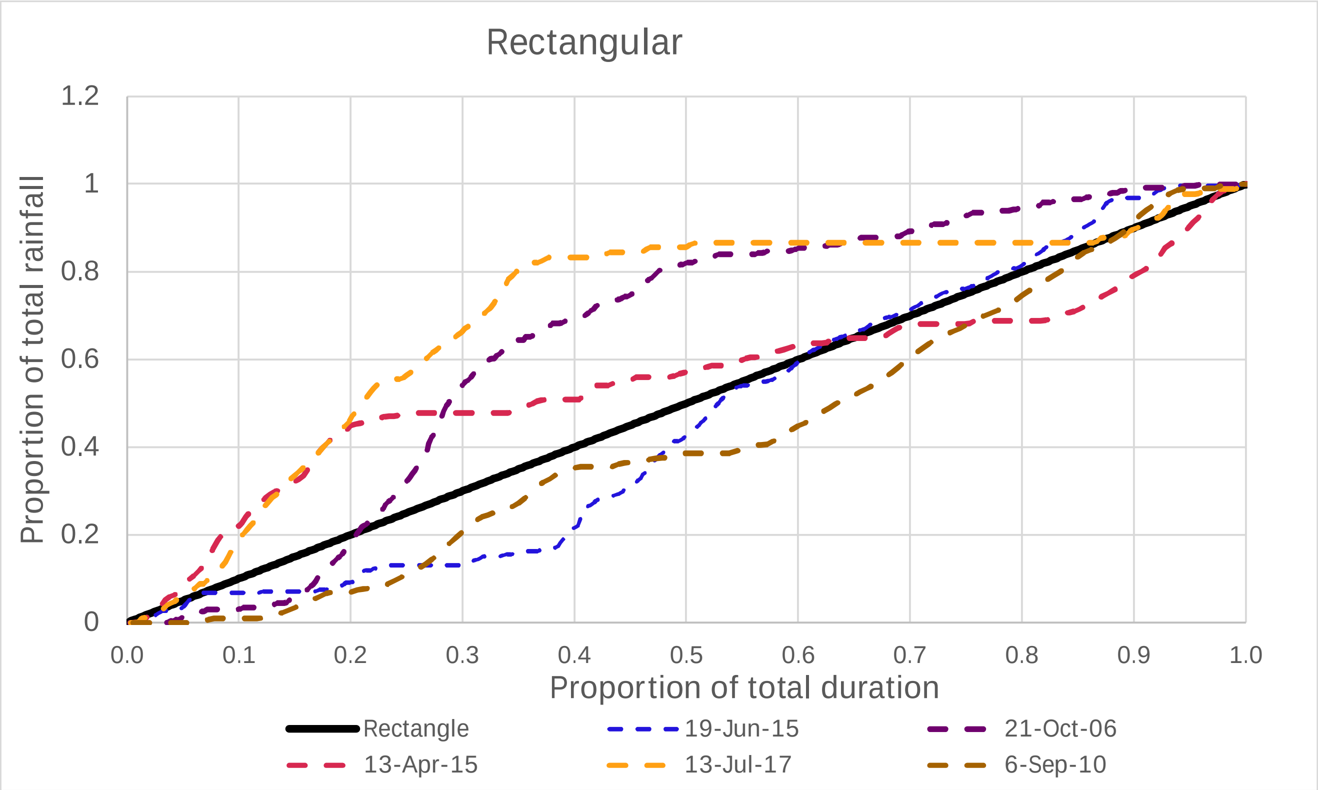
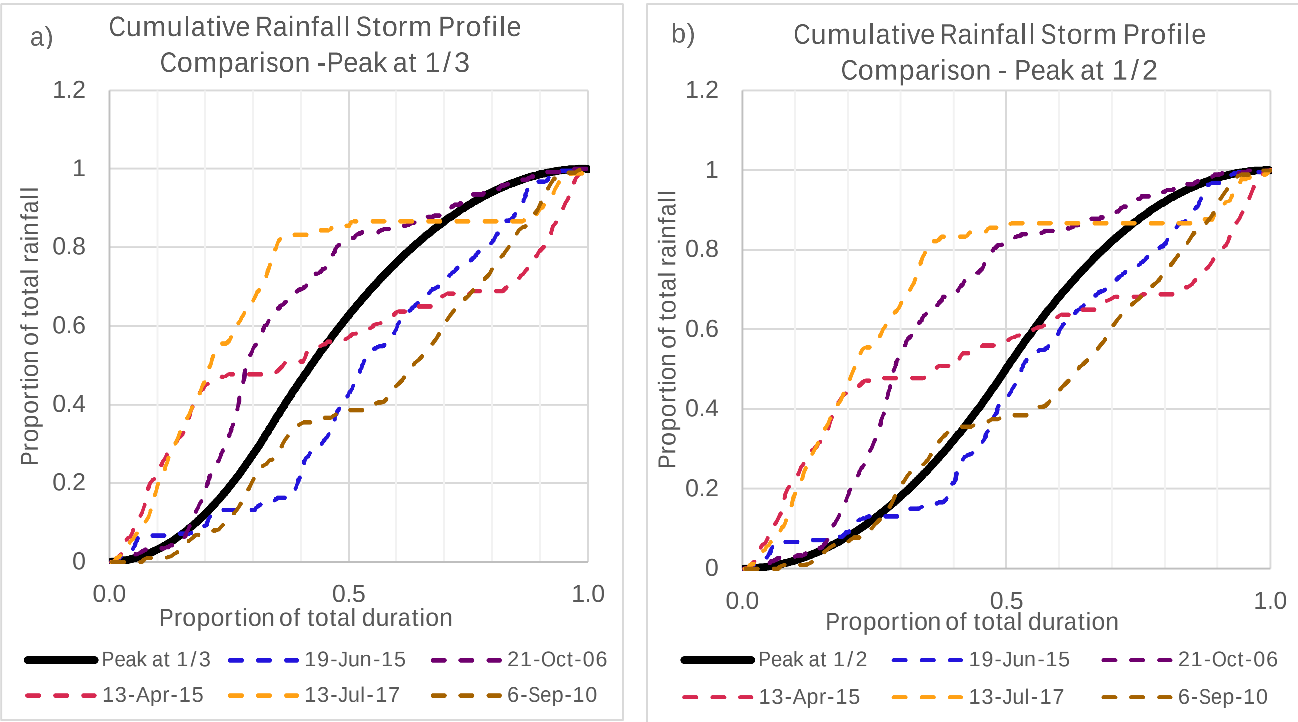


Figure 2.1: Comparison of the rectangular design storm profile to selected storms at the Mangaone at Milson Line rainfall gauge.



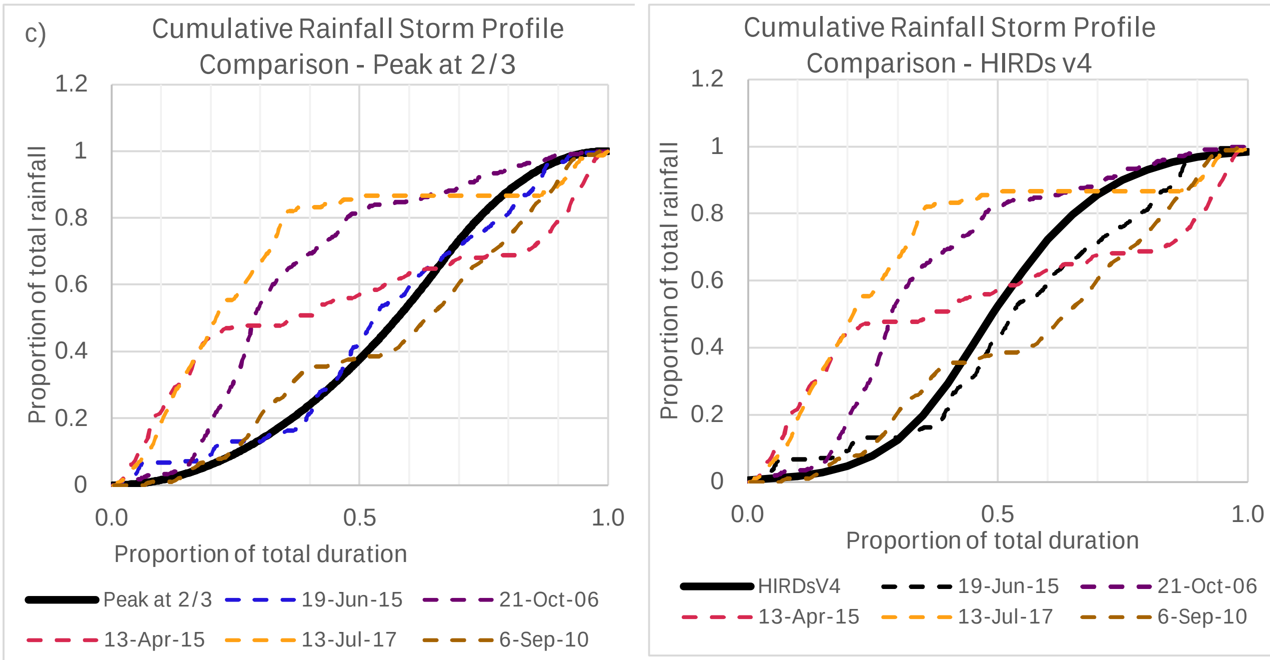


Figure 2.2: Comparison of four design storm profiles to selected storms at the Mangaone at Milson Line rainfall gauge.

2.1.4 Rainfall Losses

Rainfall losses within the sub-catchments were applied as a simple initial abstraction (I_a) and constant loss per hour (CL). Initial abstraction values were calculated using the SCS method; this method uses a Curve Number (CN) to calculate a storage factor, S, and the initial abstraction is a ratio of the storage factor. The initial abstraction is calculated using a ratio, *r* x the storage factor, *S*, where *S* is defined as:

$$S = \left(\frac{1000}{CN} - 10\right)25.4$$

$$I_a = rS$$

The parameters used to estimate the CN and storage factor for each subcatchment are shown in Table C.1 for the Mangaone Stream and Table C.2 for the East of Levin catchment (Appendix C). We tested our hydrological and hydraulic models with a range of initial abstraction ratios and constant loss values for the 200-year and 10-year events. The results for both the HEC-HMS hydrological model and HEC-RAS hydraulic model at the Milson Line flow gauge for a range of initial abstraction ratios and continuing loss values are presented in Table 2.2. Flows in the hydraulic model are generally lower than in the hydrological model due to more comprehensive modelling of storage and routing through the catchment.

The hydrological modelling showed that a ratio value of 0.2 or 0.1, while varying the constant loss value, resulted either in underestimating the 10-year event by up to 50% or overestimating the 200 year event. We therefore selected an initial abstraction ratio of 0.05, this is a typical value adopted in New Zealand (Reference Guide for Design Storm Hydrology Standardised Parameters for Hydrological Modelling, Cardno, 2019). Using a ratio of 0.05 for initial abstraction we modelled constant losses of 2, 3 and 4mm. A constant loss of 3mm was adopted, as while flows were still overestimated for the 200 year and underestimated for the 10 year events, this combination had the least overestimate for the 200 year event without underestimating the 10-year event. While this estimate may be conservative, we were reluctant to adopt higher losses that may significantly underestimate the more frequent flood risks. For the intended use of the flood model, it was considered better to overestimate the peak flow rather than underestimate it. The peak flows using these methods were sense checked against the flood frequency analysis for the Mangaone at Milson Line flow gauge, results are presented in Table 2.3.

Table 2.2: Mangaone: Estimated peak flows at Milsons Line gauge location for a range of IA ratios and CL values

		Peak flow (m^3/s)								
		IA ratio = 0.2				I_a ratio = 0.1	I_a ratio = 0.05			Flood frequency
Constant Loss (mm)		4	2	1.5	1	4	4	3	2	
200-year	HEC-HMS	263	357	379	401	272	273	319	362	209
	HEC RAS	190	*	*	N/A	*	*	288	300	
10-year	HEC-HMS	49	125	145	165	69	76	126	171	113
	HEC RAS	*	74	*	102	*	*	74	121	

**where the HEC-HMS modelled peak flow was determined to be too high or too low to be likely to match the flood frequency flow estimate for the same event when modelled in HEC-RAS hydraulic modelling was not carried out.*

Table 2.3: Mangaone Stream : Estimated peak flows at Milsons Line gauge location for the adopted Ia ratio (0.05) and CL (3mm) values

Climate	Source of flow estimate		200-year (m^3/s)	100-year (m^3/s)	10-year (m^3/s)
Existing Climate	Flood Frequency		209	187	113
	HEC-HMS		319	276	126
	HEC RAS		288	240	88
Climate Change (RCP 6.0)	HEC-HMS		357	125	125
	HEC RAS		373	319	126

2.1.5 Hydrograph Transform Parameters

The Kinematic Wave Method was used to transform the excess rainfall after losses had been applied from each subcatchment into runoff from the subcatchment. This method conceptualizes the subcatchment as a rectangular plane with a length and slope that flows into a main channel, from where it is routed to the subcatchment outlet. HEC-HMS also allows sub-collector and collector channels parameters to be defined, however these were not used in this case. One plane and one main channel was defined for each subcatchment.

The parameter values for each subcatchment were derived using GIS measurements. Subcatchment areas were obtained directly from GIS. Average subcatchment plane and main channel flow lengths and slopes were derived from GIS calculations. A Manning's *n* value of 0.05 was used for both the planes and the main channel. A trapezoidal channel cross section with a width of 10m and a side slope of 1:1 was used.

2.1.6 Reach Routing Parameters

River reaches were used to route flows from subcatchments to the outlet using the Kinematic Wave Method. A channel with a trapezoidal cross section was defined. Manning's *n* roughness of 0.05 and reach length and slope from GIS were used.

2.2 Mangaone Stream catchment

The model schematization is shown in Figure 2.3. The subcatchments used for the model are shown in Figure 2.4. The model parameters are provided in Appendix A. As described in section 2.1.4 an I_a ratio of 0.05 was adopted, and a constant loss of 3mm/hour was applied.

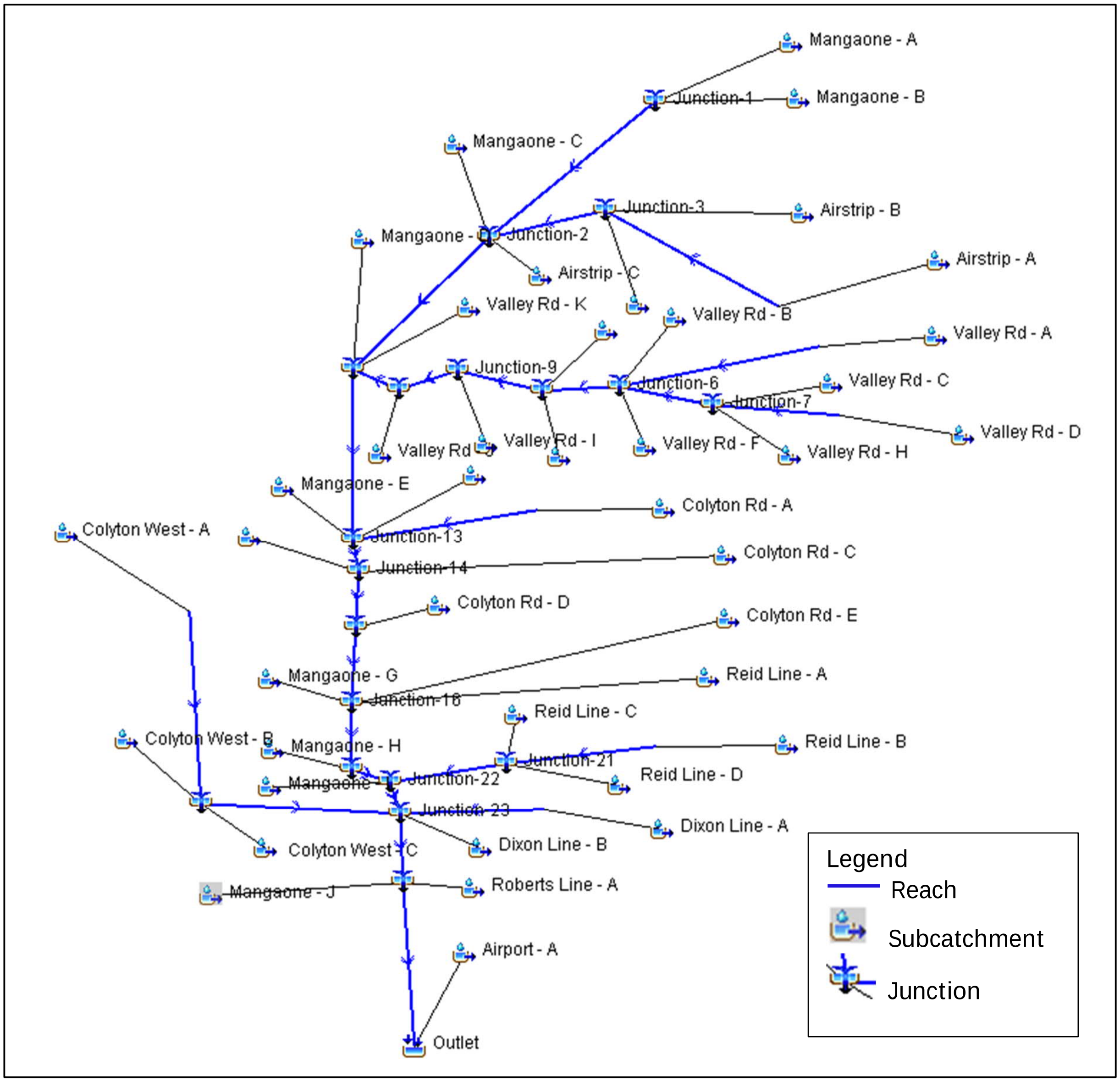


Figure 2.3: Mangaone Stream Hydrological Model Schematisation

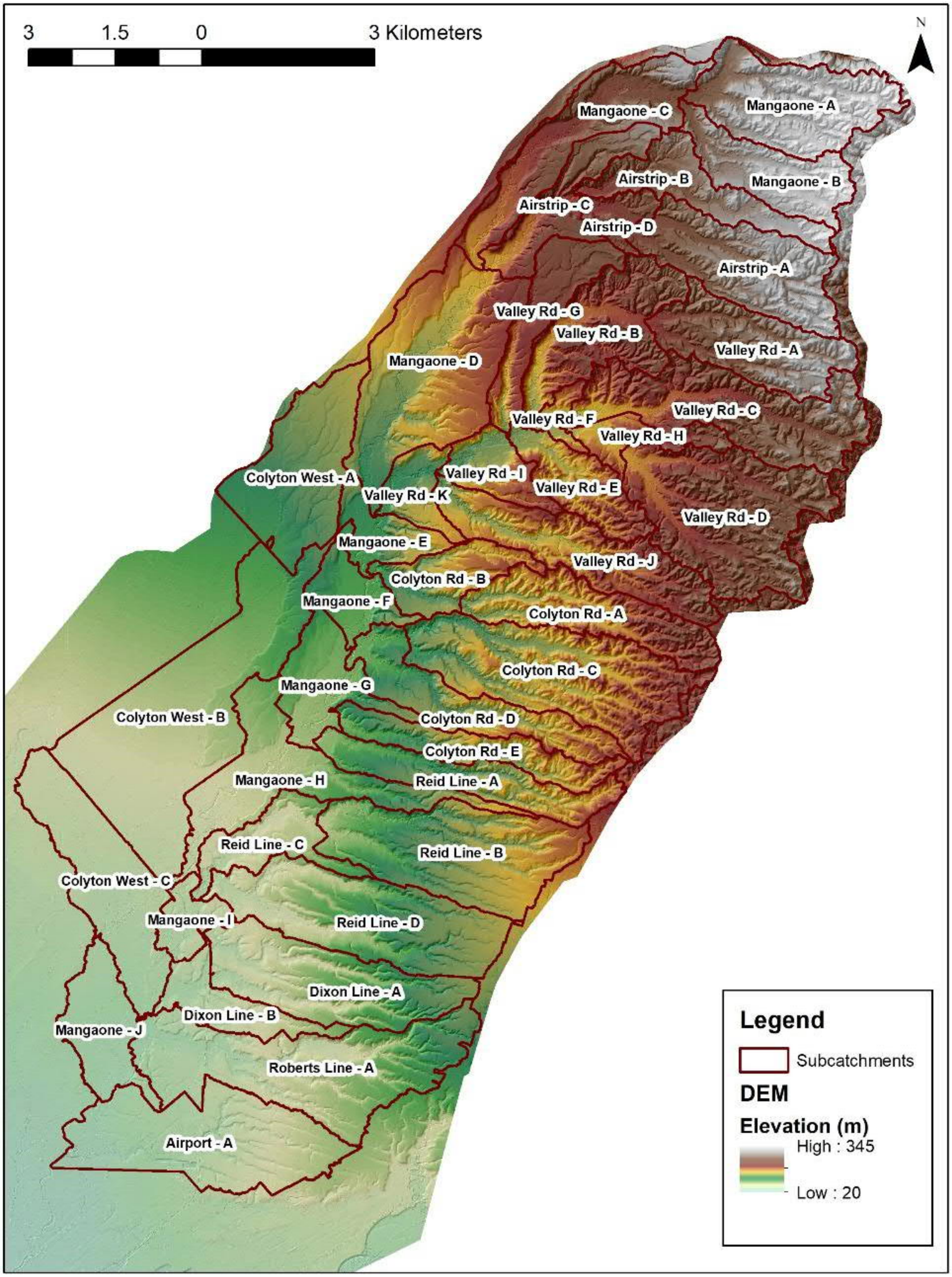


Figure 2.4: Mangaone Stream Subcatchments

2.2.1 Time of Concentration

To obtain estimates for the time of concentration, T_c, for the Mangaone Stream catchment, three methods have been used:

- Kirpich
- Bransby Williams
- SCS

To calculate T_c the parameters as shown in Table 2.4 for the catchment were obtained from the GIS database based on catchment delineation carried out as part of the Scoping Stage (Jacobs, 2019). These parameters yield estimates for T_c, varying between 8.2 hours and 18 hours (Table 2.5).

Table 2.4: Mangaone Stream catchment parameters used to calculate estimates for T_c

Parameter	Variable (Unit)	Value
Length of the stream flow path	L_s (km)	44.5
Length of overland flow path	L_o (km)	0.8
Stream Catchment Area	A_s (km^2)	155
Overland Catchment Area	A_o (km^2)	0.26
Average stream slope	S_s (-)	0.0057
Average overland slope	S_o (-)	0.074
Stream roughness	n (s/m$^{1/3}$)	0.035
Average stream cross-sectional area	A_{xs} (m^2)	1.25
Average stream velocity	U_s (m/s)	1.55
Average overland flow velocity	U_o (m/s)	1.34
Stream Catchment Curve Number	CN_s (-)	60
Overland Catchment Curve Number	CN_o (-)	50

Table 2.5: Mangaone Stream catchment estimates for T_c

Method	T_c (hrs)
Kirpich	9.7
Bransby Williams	18
SCS	8.2

To increase confidence in the estimate for T_c, estimates for T_c have also been obtained by investigating the available rainfall data and stream flow data in the catchment. For five storms, the time delay between the peak in the rainfall and the peak in the flow rate at Milson Line was determined. To ensure this time delay yields a reasonable representation of the time of concentration of the catchment, only rainfall events that impact the whole catchment evenly should be used. Therefore, for each of the storms investigated, the rainfall patterns at the Valley Rd gauge and the Milson Line gauge were similar.

An example is given in Figure 2.5 for a storm that started in the early hours of October 22nd, 2006. The peak in the rainfall intensity at both the Valley Rd and Milson Line gauges occurred at approximately 7:00am, while the peak in the flow rate at Milson Line occurred at approximately 3:00am. The difference, and therefore the estimate for T_c, is 8 hours.

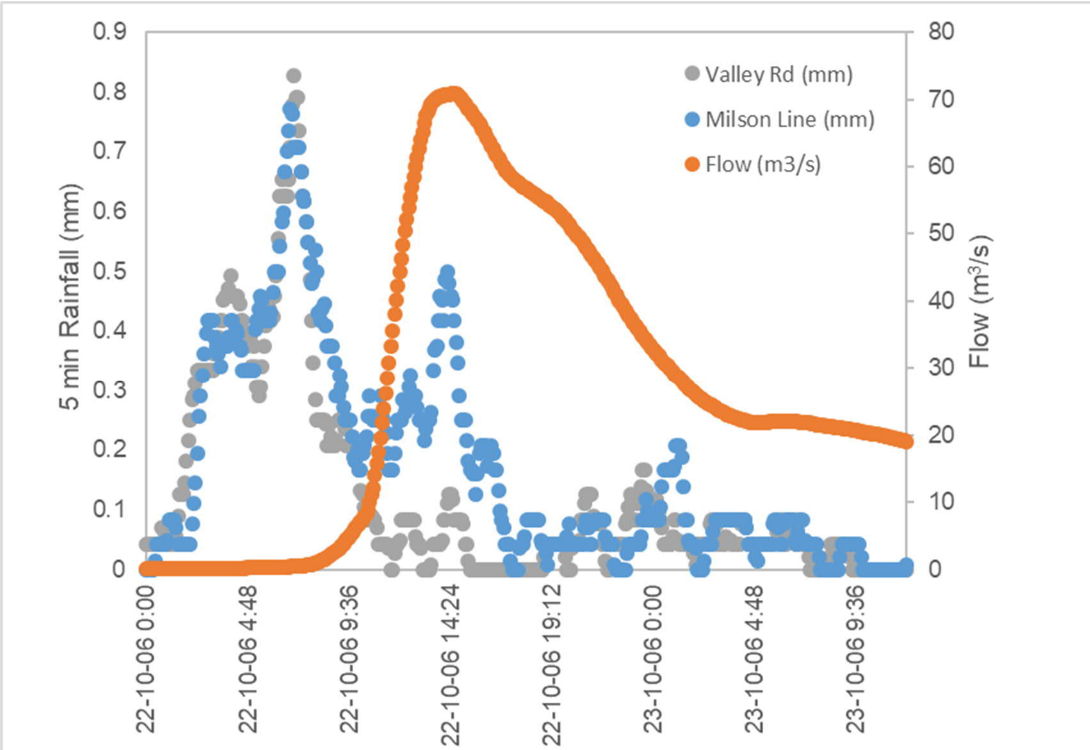


Figure 2.5: Mangaone Stream catchment rainfall and flow rate data

For the storms investigated, the estimated T_c varied between 7 and 10 hrs. This is in reasonable agreement with the estimates for T_c as obtained from the Kirpich and SCS method and indicates that the estimate from the Bransby Williams method may be too high. Excluding the Bransby Williams method, the averages from the calculations and the data are both approximately 9 hrs; this was used as the event duration for the Mangaone Stream catchment design runs.

2.2.2 Flood Frequency Analysis

We carried out a flood frequency analysis using Hilltop hydrometric software to estimate the return periods of observed floods and to estimate the 10-year, 100-year, and 200-year flows at the Mangaone at Milson Line gauge. The results are presented in Table 2.6 and Figure 2.6 together with the modelled flows for the same return periods in Table 2.7.

Table 2.6: Mangaone at Milson Line, maximum flows and return periods

Date recorded	Maximum measured flow (m3/s)	Return period (y)
21-Jun-15	163	47
24-Jul-88	144	25.8
19-Oct-80	122	13
6-Sep-10	111	9.4
15-Aug-01	109	8.8

Date recorded	Maximum measured flow (m3/s)	Return period (y)
13-Jul-17	98	6.2
21-Oct-98	97	6.2
16-Nov-94	95	5.8
15-Oct-13	95	5.8
25-Aug-86	94	5.7
22-Jul-92	91	5.1
7-Jul-06	85.8	4.5
25-Jul-02	85.6	4.4

Table 2.7: Mangaone at Milson Line Modelled flow comparison:

Event	Peak Flow (m^3/s)		
	Flood Frequency	Modelled (HEC-HMS)	Modelled (HEC-RAS)
10% AEP	113	126	89
1% AEP	187	277	240
0.5% AEP	209	319	288

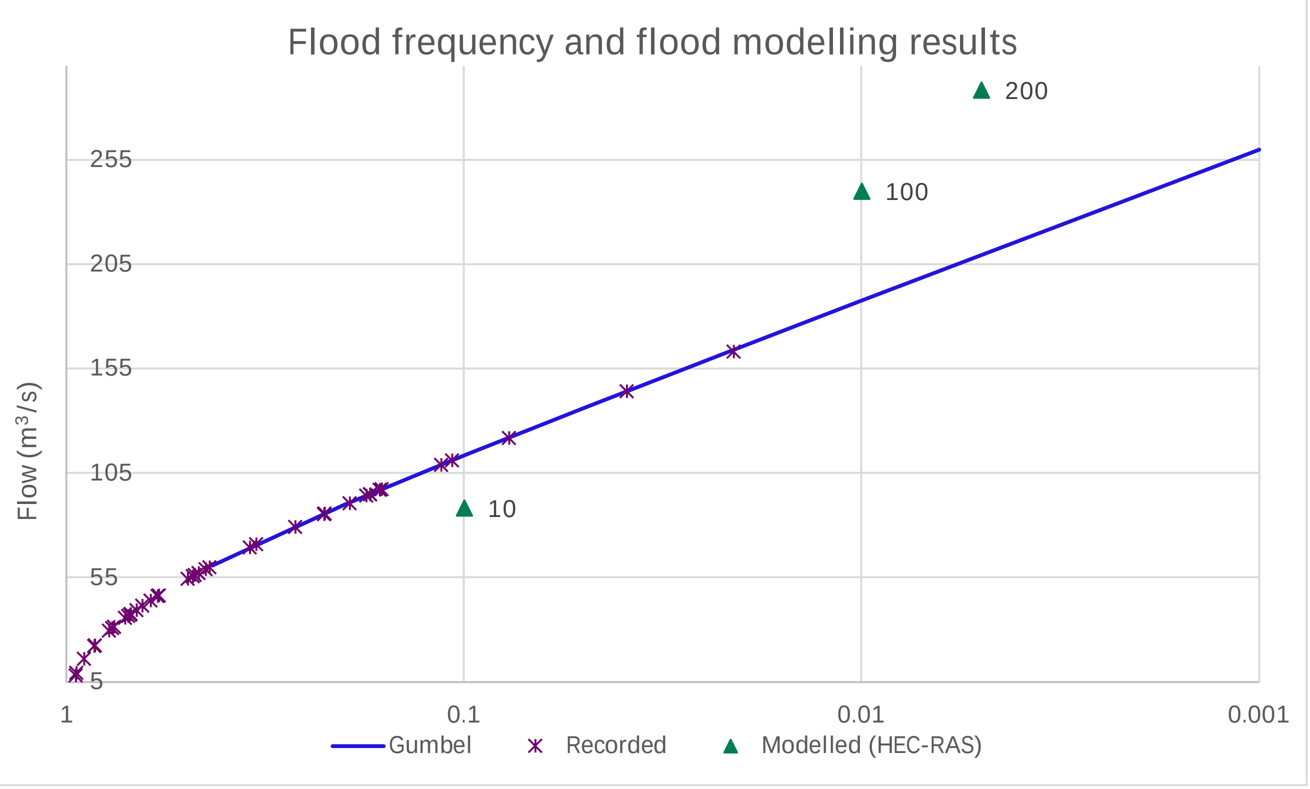


Figure 2.6: Flood frequency compared to modelled results: Mangaone at Milson Line

2.2.3 Design Runs

Once the hydrological parameters were confirmed, the hydrological model was run for the 10-year, 100 year and 200-year events and for the same three events with climate change for the period to 2081-2100, using RCP 6.0. The event duration was 9 hours for the Mangaone Stream catchment.

The design rainfall depths were obtained for the centroid of each subcatchment and applied to each subcatchment. As discussed in Section 2.1.3 the rainfall temporal profile adopted was a rectangular profile and the rainfall losses used an initial abstraction and a constant loss of 3mm. The rainfall depths used are provided in Appendix B.

2.3 East of Levin catchment

The Koputaroa Stream catchment which drains to the north was modelled using a hydrological model in HEC-HMS, using the approach developed for the Mangaone Stream catchment. The model schematization is shown in Figure 2.7 and the subcatchment delineation is shown in Figure 2.8. The hydrological model parameters for each subcatchment are provided in Appendix A.

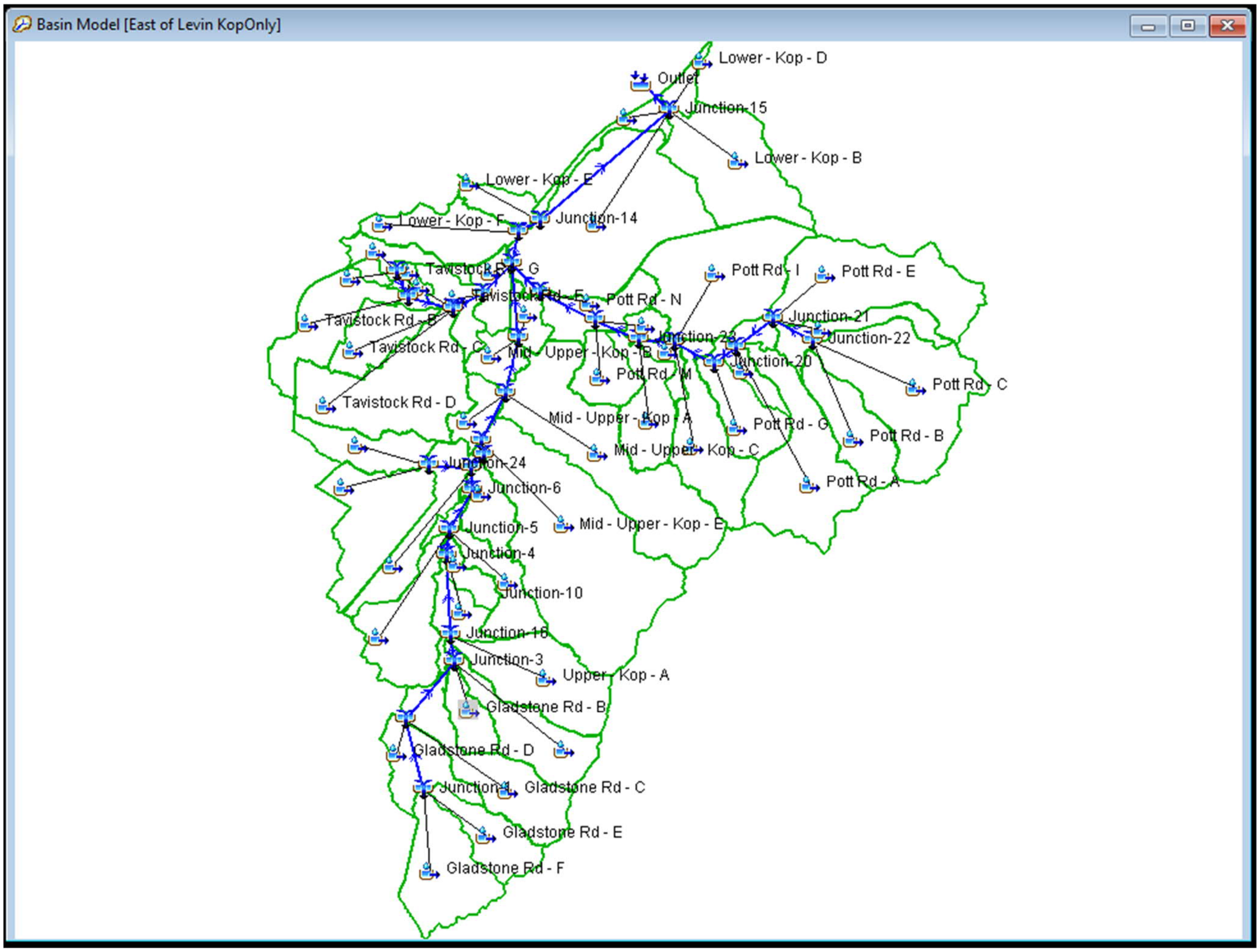


Figure 2.7: Koputaroa Stream Hydrological Model Schematisation

The upper Arawhata Stream which drains to the west (referred to as Levin East) was modelled as rain on grid in the hydraulic model, with rainfall initial abstraction and constant loss calculated in a spreadsheet and the rainfall excess applied within the hydraulic model. The 2D approach was taken as the network is not well defined and there are a number of small agricultural drainage channels. The initial abstraction used a ratio of 0.05 × the storage factor, *S*, where *S* is defined as:

Equation 1 $$S = \left(\frac{1000}{CN} - 10\right)25.4$$

A constant loss of 3mm/hour was applied.

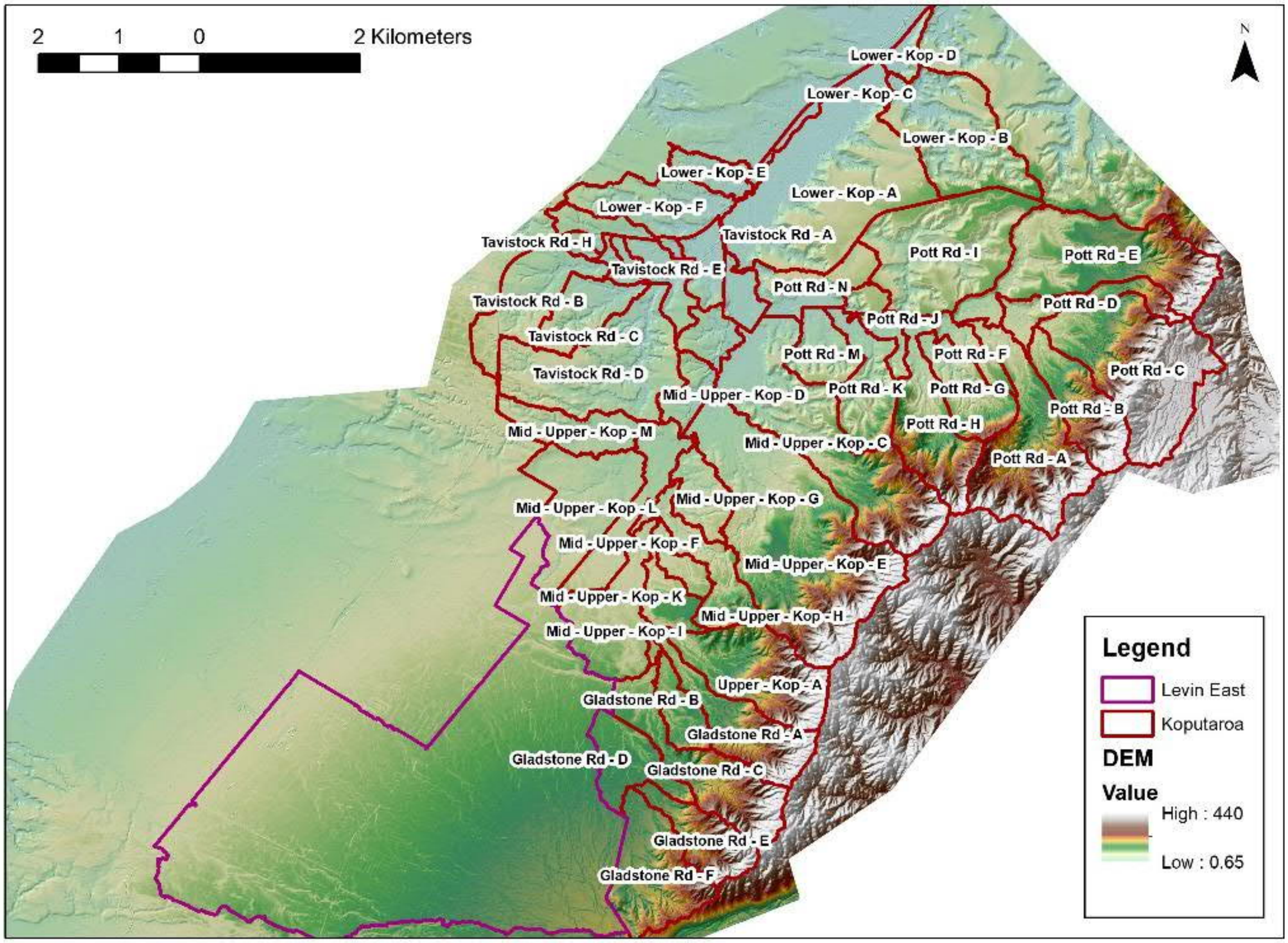


Figure 2.8: East of Levin Subcatchments

2.3.1 Time of Concentration

For the Levin East catchment, the time of concentration calculated varied between 1 and 3 hours. The parameters used to estimate the T_c are shown in Table 2.8. For the Koputaroa Stream catchment the T_c was estimated using Ramser Kirpich, Bransby Williams and SCS formulas, the estimated T_c ranged from 1.9 hours for SCS to 6 hours for the Bransby Williams method (Table 2.9). A time of concentration of 3 hours was adopted.

Table 2.8: Koputaroa Stream catchment parameters used to calculate estimates for T_c

Parameter	Variable (Unit)	Value
Length of the stream flow path	L_s (km)	15.2
Length of overland flow path	L_o (km)	0.51
Stream Catchment Area	A_s (km^2)	52.2
Overland Catchment Area	A_o (km^2)	0.24
Average stream slope	S_s (-)	0.013462
Average overland slope	S_o (-)	0.299
Stream roughness	n (s/m$^{1/3}$)	0.035
Average stream cross-sectional area	A_{xs} (m^2)	1.25
Average stream velocity	U_s (m/s)	2.25
Average overland flow velocity	U_o (m/s)	3.84
Stream Catchment Curve Number	CN_s (-)	49
Overland Catchment Curve Number	CN_o (-)	69

Table 2.9: Koputaroa Stream catchment estimates for T_c

Method	T_c (hrs)
Kirpich	3.1
Bransby Williams	6
SCS	1.9

2.3.2 Design Runs

The hydrological parameters used were based on the parameters used for the Mangaone Stream catchment. The hydrological model of the Koputaroa Stream was run for the 10-year, 100-year and 200-year events with climate change for the period to 2081-2100, using RCP 6.0. The event duration was 3 hours for the Levin East and Koputaroa catchments. This is not one of the standard event durations so the formula for calculating non-standard durations provided within HIRDs v4 was used, with a temperature rise of 1.63 ^{o}C (Table 8. *High Intensity Rainfall Design System, Version 4, NIWA, August 2018*).

The design rainfall depths were obtained for the centroid of each subcatchment for the Koputaroa Stream catchment and applied to the same subcatchment in HEC-HMS. For the Levin East catchment rainfall for the centroid of the entire 2D area was obtained and losses were manually subtracted, and the resulting rainfall excess applied as rain on grid within the HEC-RAS 2D area. As discussed in Section 2.1.3 the rainfall temporal profile adopted was a rectangular profile and the rainfall losses applied were an initial abstraction, defined as a ratio of 0.05 × the storage factor, S (as defined in Equation 1) and a constant loss of 3mm.

The rainfall depths used (before losses) are provided in Appendix B.

3. Hydraulic Model

The overall approach adopted for both models is a 2D model. We initially investigated using a 1D model with selected areas in 2D however the LiDAR data wasn't suitable for this approach as the channels were not sufficiently defined and vegetation included in the channel surface created unrealistic barriers to flow and affected model stability.

A 5 metre 2D grid was adopted as this was found to have a good balance between sufficient resolution of the terrain and model run time. Some break lines were used to provide definition in the channels.

The 2D models were schematised with the subcatchment flows from the HEC-HMS model for each subcatchment applied to the 2D grid within the channel at approximately the midpoint of the subcatchment reach. The inflow was applied to a boundary condition line with a flow hydrograph distributed across several cells using a slope based on the measured slope perpendicular to the inflow line, typically between 0.001 and 0.02. An example is shown in Figure 3.1. Outflow boundaries were defined as normal depth boundaries with a representative slope based on the terrain data.

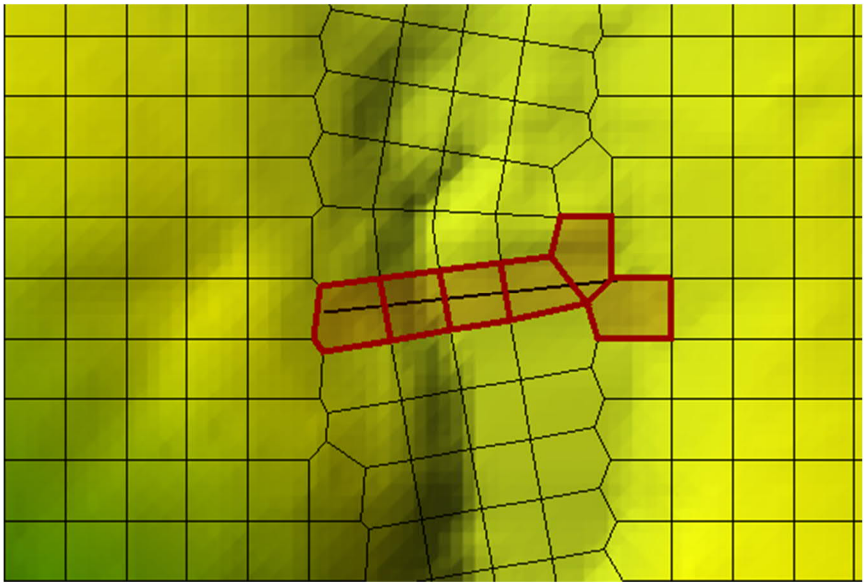


Figure 3.1: Example of inflow boundary applied across a channel

Key structures such as bridges and culverts were identified and modelled as 2D connections. 2D Connections connect 2D cells and control the flow between them by defining a flow structure such as a bridge, culvert or gate and a weir that represents the road or other embankment above the flow structure.

Structures that were not surveyed but we identified as causing backflows and potentially unrealistic flow paths to be activated were modelled using a terrain modification channel with a width of 0.5m and vertical sides as shown in Figure 3.2.

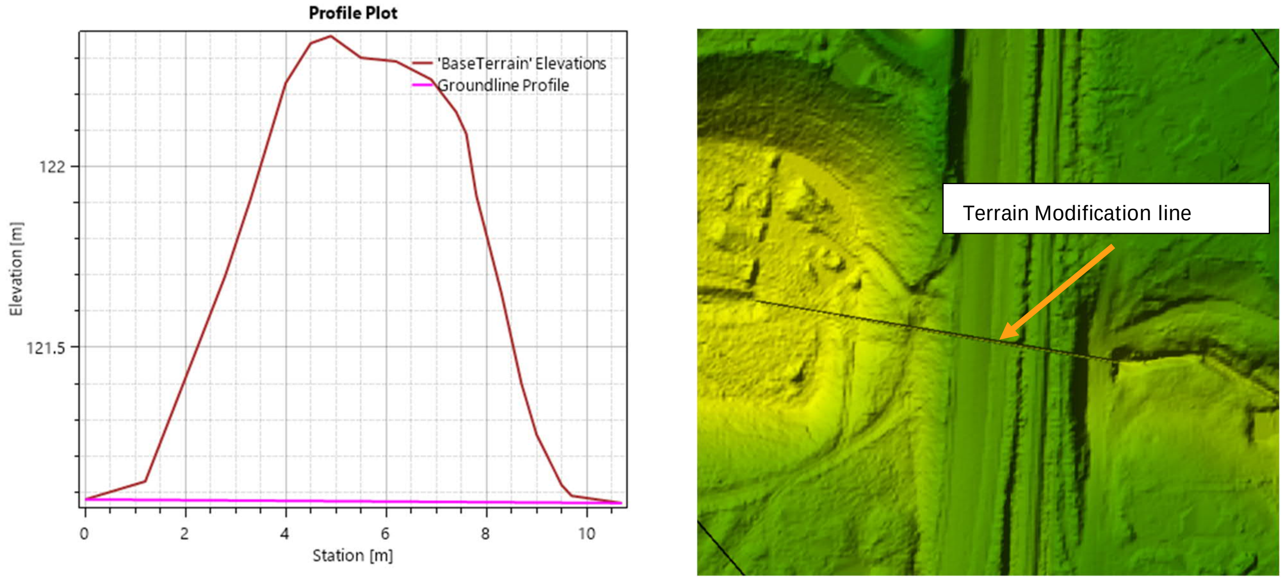


Figure 3.2: Example of Terrain Modification Channel

Critical stopbanks were also modelled as 2D connections, this was to prevent overtopping caused by the 5m grid resolution not sufficiently resolving the stopbank crest levels in the 2D grid.

The 2D model extent was based on the 200-year event with climate change and was adjusted where necessary to ensure no ponding ("glass walling") at the model boundary.

Roughness was specified using the NZ Vegetation layers and NZ Road Centrelines GIS layers downloaded from LINZ buffered to 5m each side of the road centreline to give a total width of 10m. The roughness values adopted for each vegetation or land use type are shown in Table 3.1. Areas that were not covered by any of these layers had a pasture roughness of 0.06 applied.

Table 3.1: Manning's n Roughness values adopted

GIS Layer	Manning's *n*
NZ Exotic Forest	0.1
NZ Native	0.1
NZ Scattered scrub	0.08
NZ Scrub	0.08
NZ Shelterbelt	0.08
NZ Tree points	0.08
NZ Road centrelines	0.015
Default roughness (pasture)	0.06

3.1 Mangaone Stream catchment

For the Mangaone Stream catchment we identified the key structures to be surveyed for inclusion in the model, and these were modelled as 2D connections represented as bridges, or culverts. A table of the modelled structures, based on survey data, is provided in Table 3.2 and structure locations are shown in Figure 3.3.

Table 3.2: Mangaone Stream- Structures Modelled as 2D Connections

Culvert ID (Survey)	Location	Culvert Type	Culvert Diameter	
			W (m)	H (m)
101	Creamery Road	Box	2.93	1.53
106	Valley Road	Box (twin)	3.05	2.8
111	Milson Line	Bridge		
112	Reid Line E	Box	2.98	1.24
113	Taonui Road	Circular (twin)	1.05	
118	Campbell Road	Box	2.75	1.45
120	Te Ngaio Road	Box	3.6	1.95
121	Railway Line 2	Box	2.55	1.65
122	Waughs Road	Box	2.9	1.43
142	Kairanga Bunnythorpe Road	Bridge	6.23	2.79
144	Roberts Line	Bridge	4.56	
145	Roberts Line	Box	2.4	2
146	Railway Road	Box (natural bed)	3.18	1.428
147	Railway Line	Bridge (with pier)	1.42	2.05
501	Richardsons Line	Bridge (soffit arched)	3.62	2.2
502	Tutaki Rd	Circular	1.85	
503	Te Ngaio Rd	Bridge (with pier)		
504	Railway Line	Box	1.8	1.25
505	Railway Line (Rd)	Circular (twin)	1.35 & 0.9	
506	Parrs Rd	Circular (twin)	1.05	
507	Stoney Creek Rd	Box	1.55	1.94
509	Reid Line East	Circular	1.35	
511	Colyton Rd	Box	1.37	1.85
512	Valley Rd	Box	3.15	1.6
601	Mangaone SB	Box	2.28	1.24
602	Setters Line culvert	Circular	0.45	

Stopbanks in the lower reaches were modelled as 2D connections to correctly represent the overtopping of banks given the stopbanks crests could not be sufficiently resolved within the grid size. Stopbank locations are shown in Figure 3.4.

Structures that were not surveyed but we identified as causing backflows and potentially unrealistic flow paths to be activated were modelled using a terrain modification channel with a width of 0.5m and vertical sides. The locations of the terrain modification channels are shown in Figure 3.5.

The locations of inflow and outflow boundaries are shown in Figure 3.6. In some cases, flow from a subcatchment was distributed to two flow locations where there was more than one defined channel within the catchment.

Roughness values were assigned based on the values in Table 3.1 as a landcover layer within HEC-RAS. The roughness was applied to the 2D model so only covered the 2D model extent rather than the full hydrological catchment. The distribution of roughness is shown in Figure 3.7.

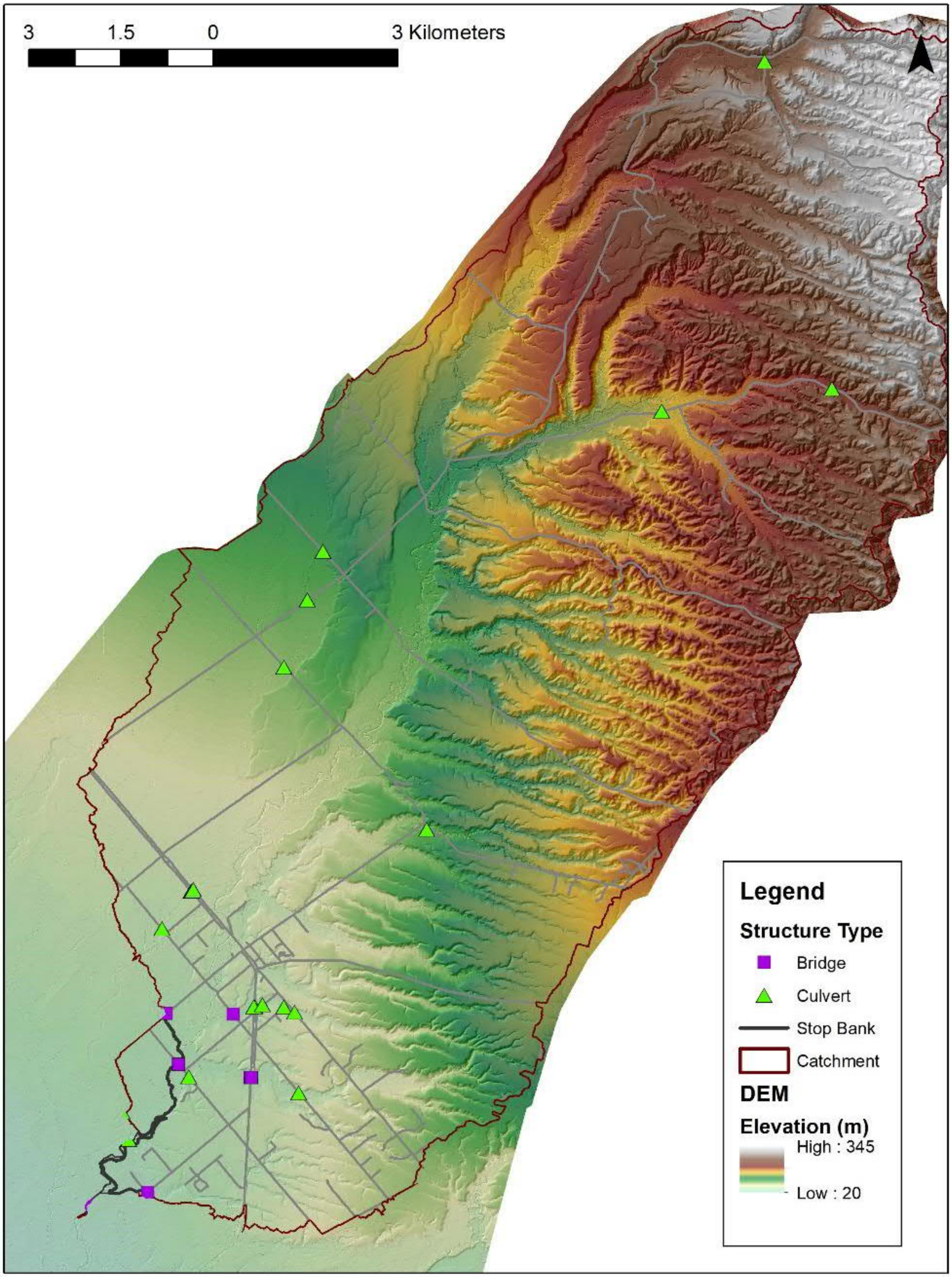


Figure 3.3: Mangaone Stream - Structures Modelled as 2D Connections

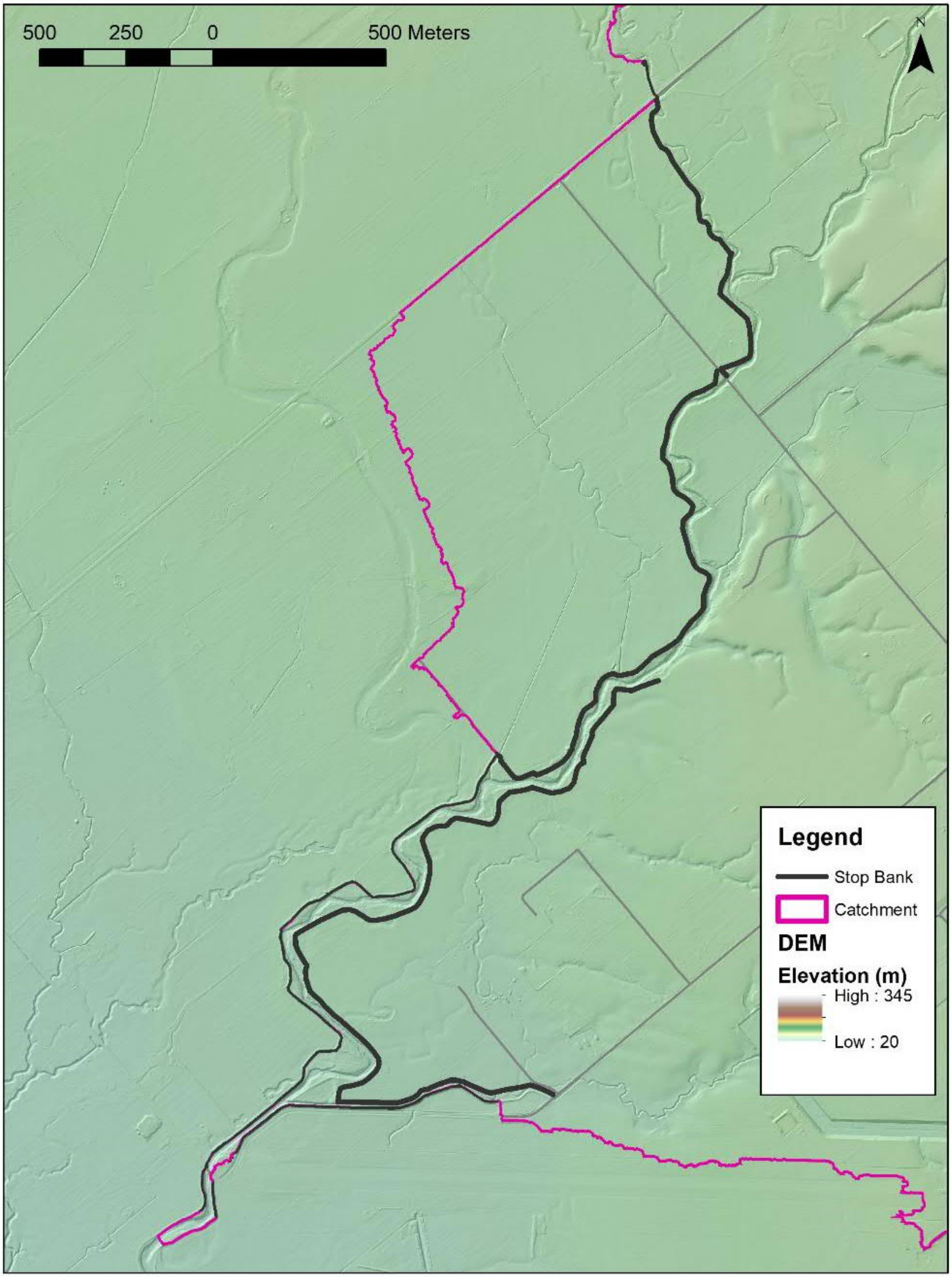


Figure 3.4: Mangaone Stream - Critical Stopbanks Modelled as 2D Connections

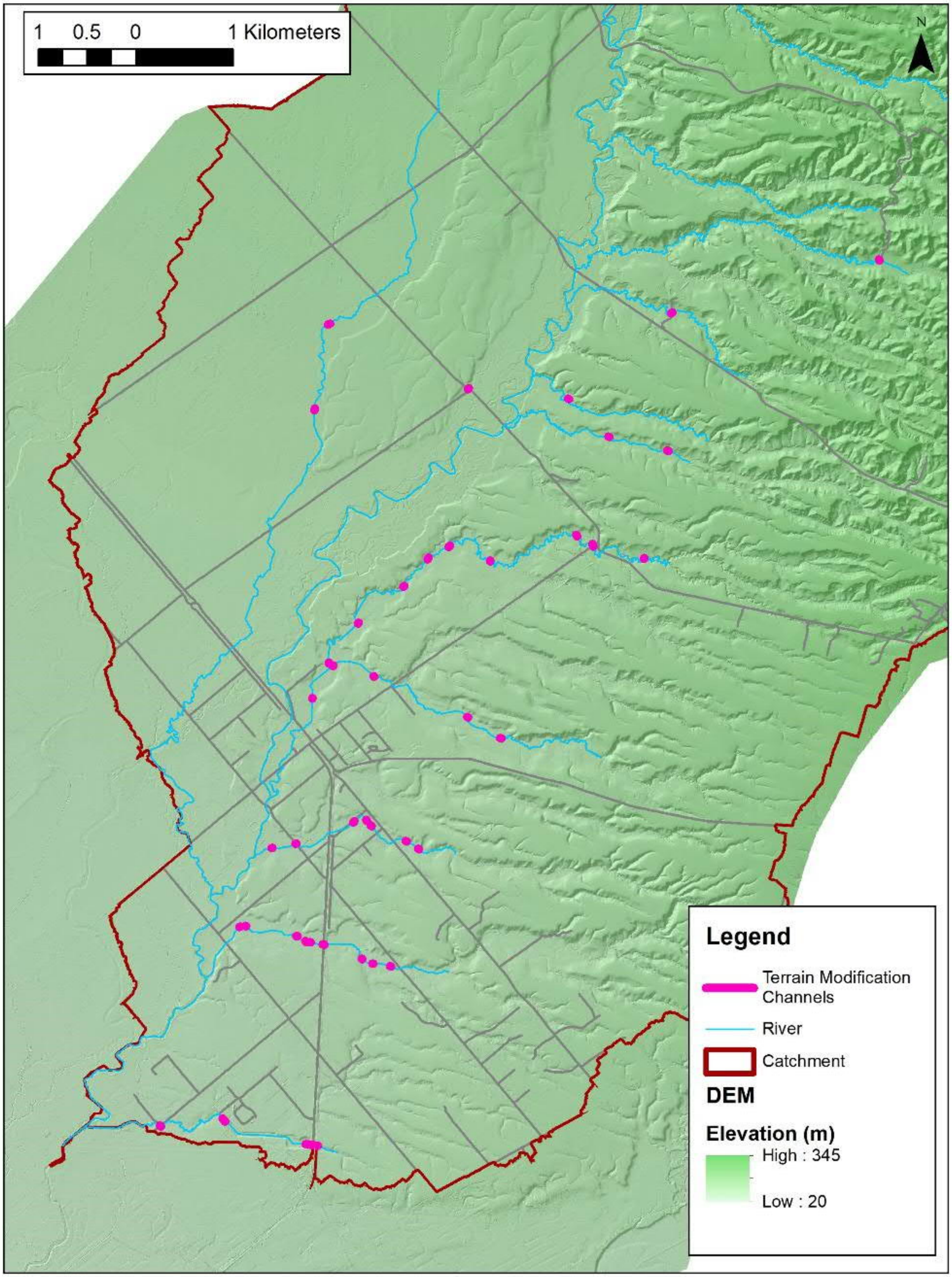


Figure 3.5: Mangaone Stream - Unsurveyed Structures Modelled as Channels

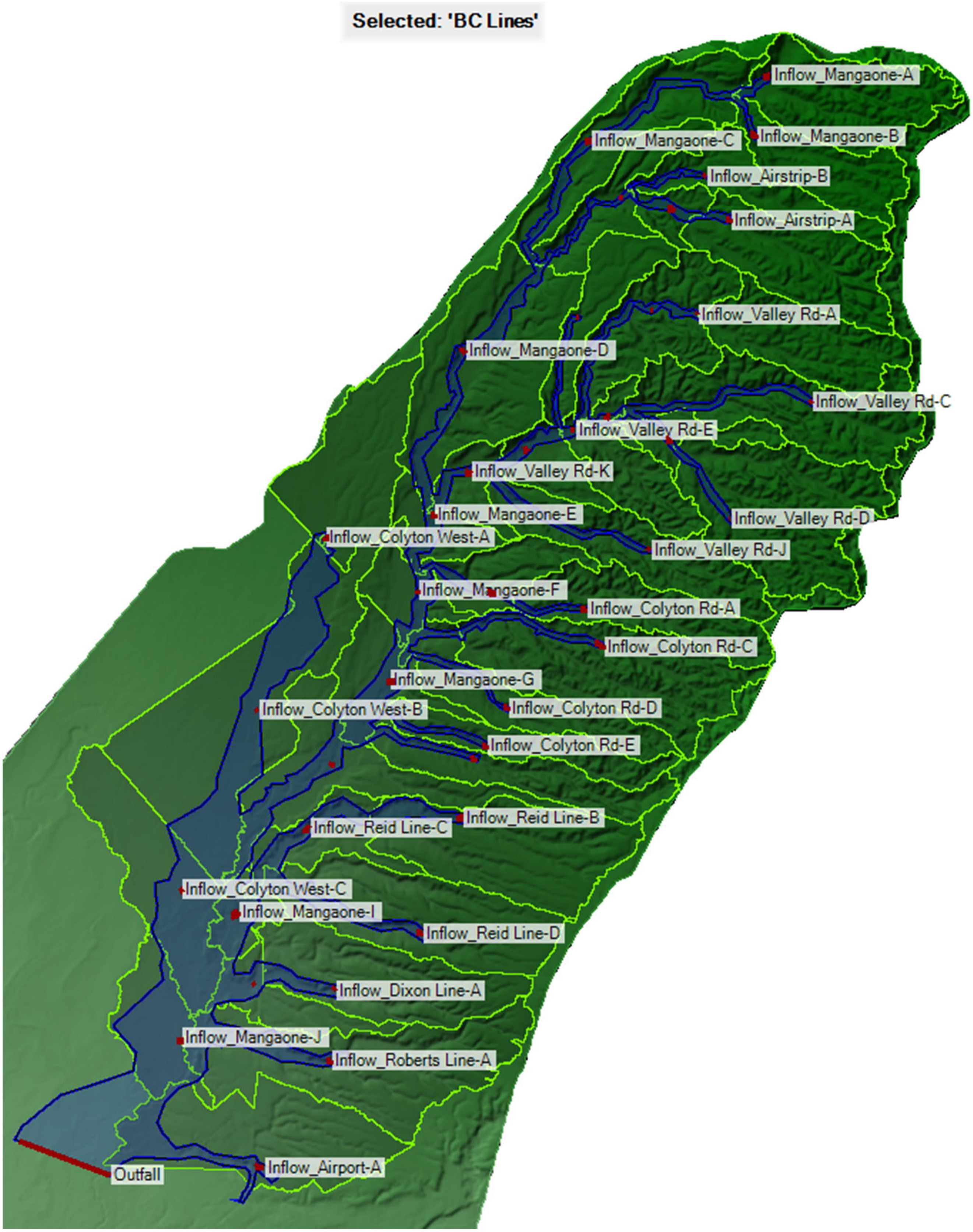


Figure 3.6: Mangaone Stream - Inflow and Outflow boundaries

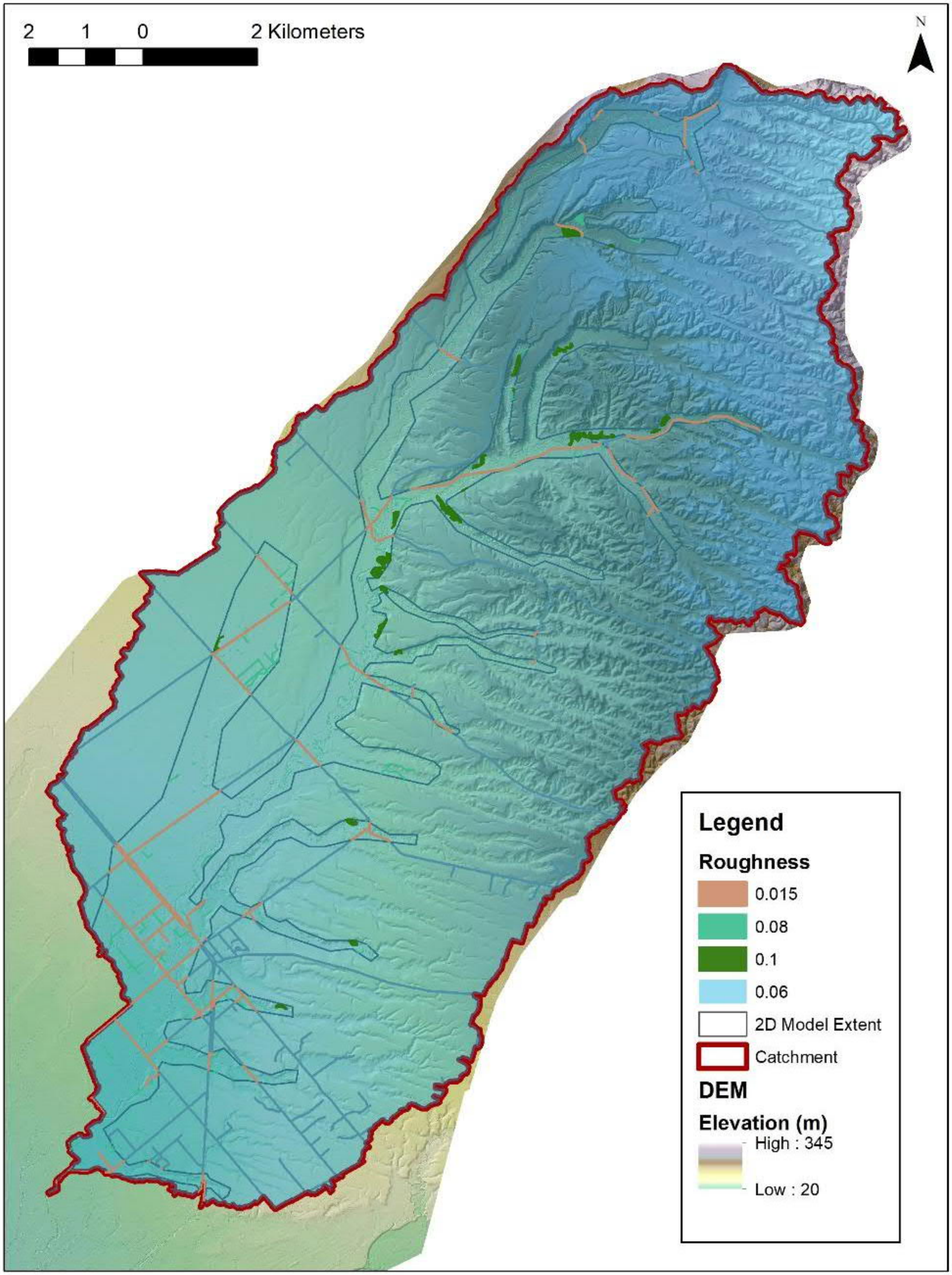


Figure 3.7: Mangaone Stream - roughness values applied

3.2 East of Levin

The East of Levin hydraulic model comprises two catchments. The Koputaroa Stream catchment was modelled using inflow hydrographs, while the Levin East catchment was modelled using rainfall excess applied to the entire model 2D surface as this area did not have a defined river network and had a number of agricultural drains.

For the Koputaroa Stream catchment we identified the key structures to be surveyed for inclusion in the model, and these were modelled as 2D connections represented as bridges, or culverts. A table of the modelled structures and their dimensions is provided in Table 3.3 and structure locations are shown Figure 3.8.

Stopbanks in the lower reaches of the Koputaroa were modelled as 2D connections to correctly represent the overtopping as the stopbank crest heights could not be sufficiently resolved within the grid size. Stopbanks modelled as 2D connections are shown in Figure 3.9.

Structures that were not surveyed but we identified as causing backflows and potentially unrealistic flow paths to be activated were modelled using a terrain modification channel with a width of 0.5m and vertical sides. The locations of the terrain modification channels are shown in Figure 3.10.

The locations of inflow and outflow boundaries are shown in Figure 3.11. In some cases, inflow from a subcatchment was distributed to two flow locations where there was more than one defined channel within the catchment using the percentage area for each defined channel to allocate the flow. The Koputaroa Stream model had one outflow boundary at the rail crossing. The opening is defined by the rail embankments on either side and so the water level in the lower part of the model is determined by the channel capacity at the railway line crossing at the downstream end of the model.

For the East Levin catchment (rain on grid area) the downstream boundaries are defined downstream of the railway embankment. Flood levels are controlled primarily by overtopping of the low points on the raised railway embankment along the western boundary. Drainage culverts under the railway are not included in the model as there was no survey available. However, these culverts are relatively small and are constrained by downstream conditions (State Highway One culverts and field drains) so will not carry a significant proportion of the runoff in larger flood events.

Roughness values were assigned based on the values in Table 3.1 as a landcover layer within HEC-RAS. The roughness was applied to the 2D model extent. The distribution of roughness is shown in Figure 3.12

Table 3.3: Koputaroa Stream - Structures Modelled as 2D Connections

Culvert ID (Survey)	Location	Culvert Type	Culvert Diameter	
			W (m)	H (m)
201	SH57	Box	8.81	3.5
202	Tavistock Rd	Circular (Twin)	1.2	
203	Potts Rd	Pipe Arch	1.68	
204	SH57	Circular	4.45	
207	SH57	Box	3.81	1.52
218	Gladstone Rd	Circular (Twin)	1.2	
219	Pohutukawa Dr	Circular (Twin)	1.2	
220	334 SH57	Box	2.92	1.2

Culvert ID (Survey)	Location	Culvert Type	Culvert Diameter	
			W (m)	H (m)
221	Pohutukawa Dr	Circular (Twin)	1.2	
222	1161 Queen St	Box	4.5	1.6
300	Twin Peaks	Circular	0.525	
301	Twin Peaks	Circular	0.525	
302	Heatherlea East	Circular	0.375	
303	Arapaepae Rd	Circular	0.975	
Koputaroa Mid	Rail Culvert	Circular	0.3	
Koputaroa North	Rail Culvert	Circular	0.45	
Koputaroa North	Road Culvert	Circular	0.3	
Koputaroa South	Rail Culvert	Circular	0.3	
Koputaroa South	Road Culvert	Circular	0.75	

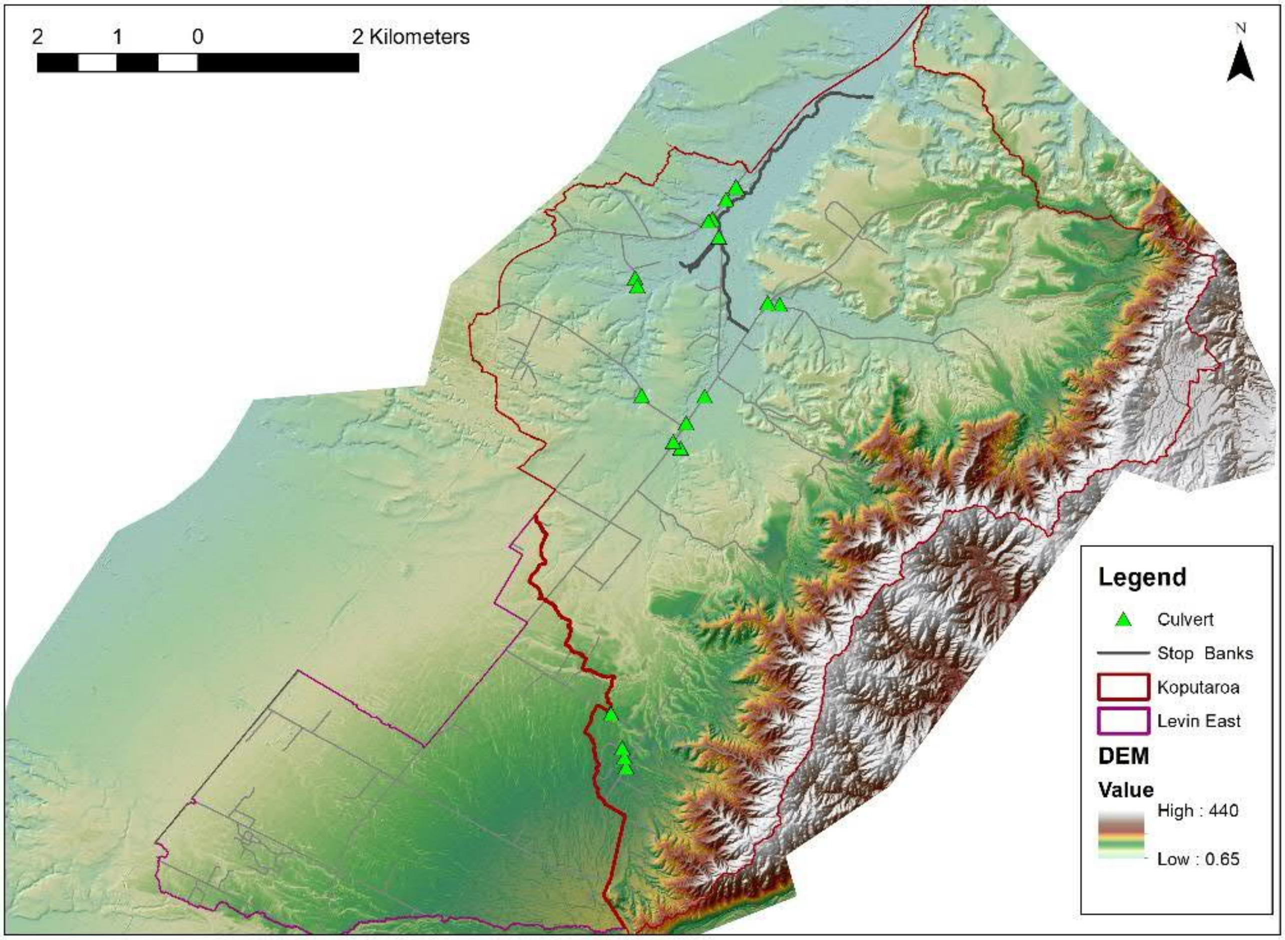


Figure 3.8: East of Levin - Structures Modelled as 2D Connections

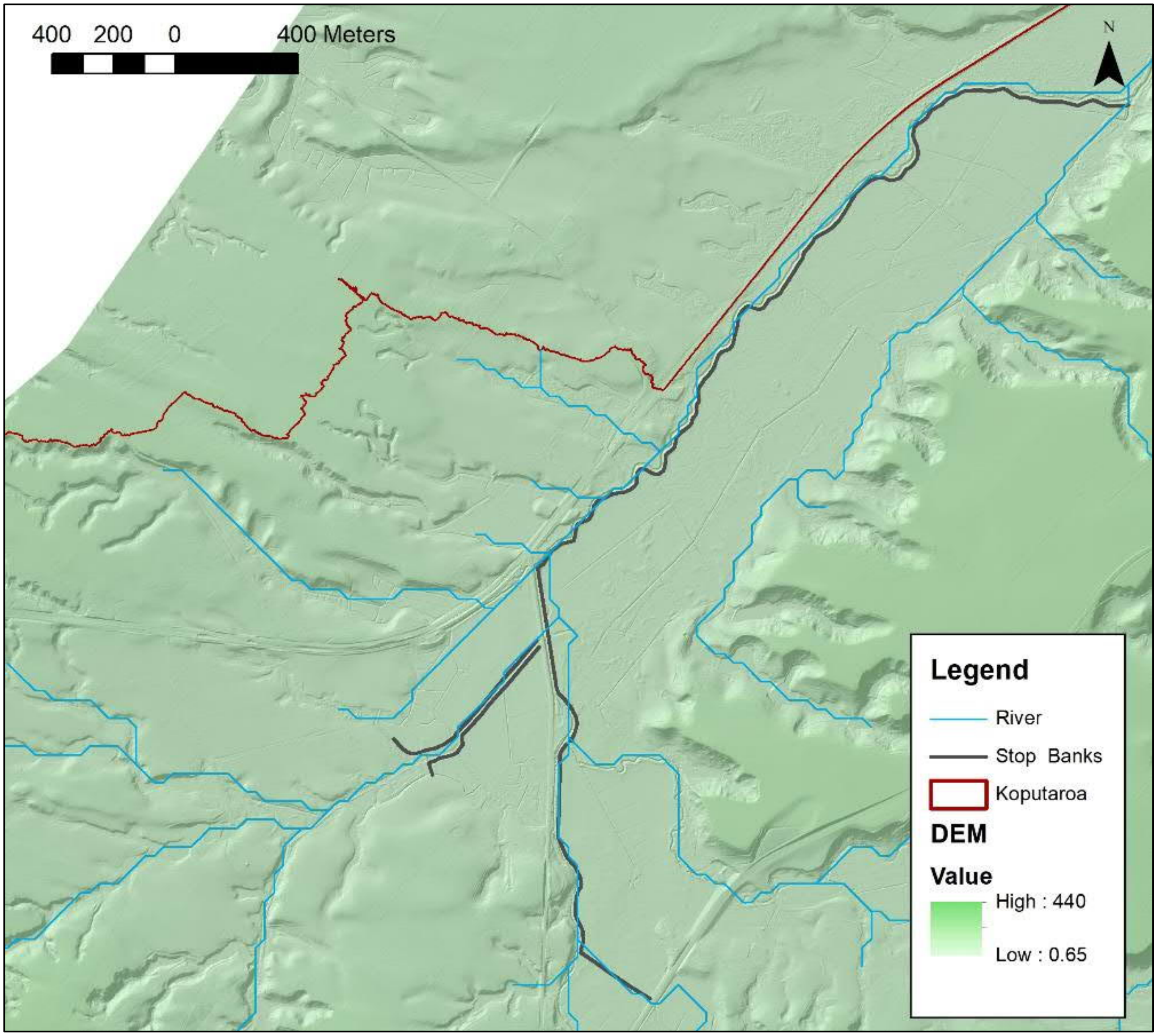


Figure 3.9: Koputaroa Stream - Stopbanks modelled as 2D connections

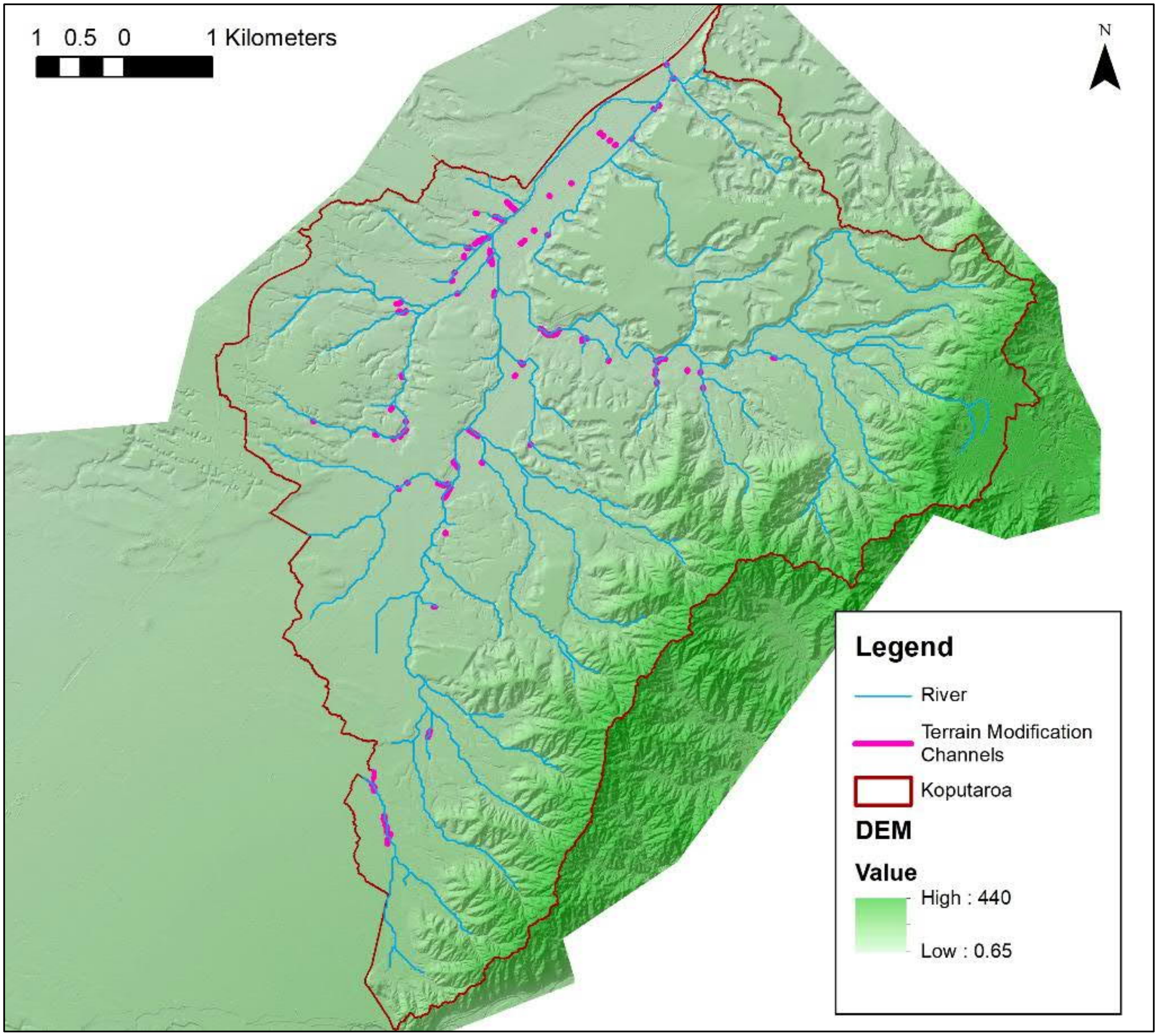


Figure 3.10: East of Levin - Unsurveyed Structures Modelled using Terrain Modification

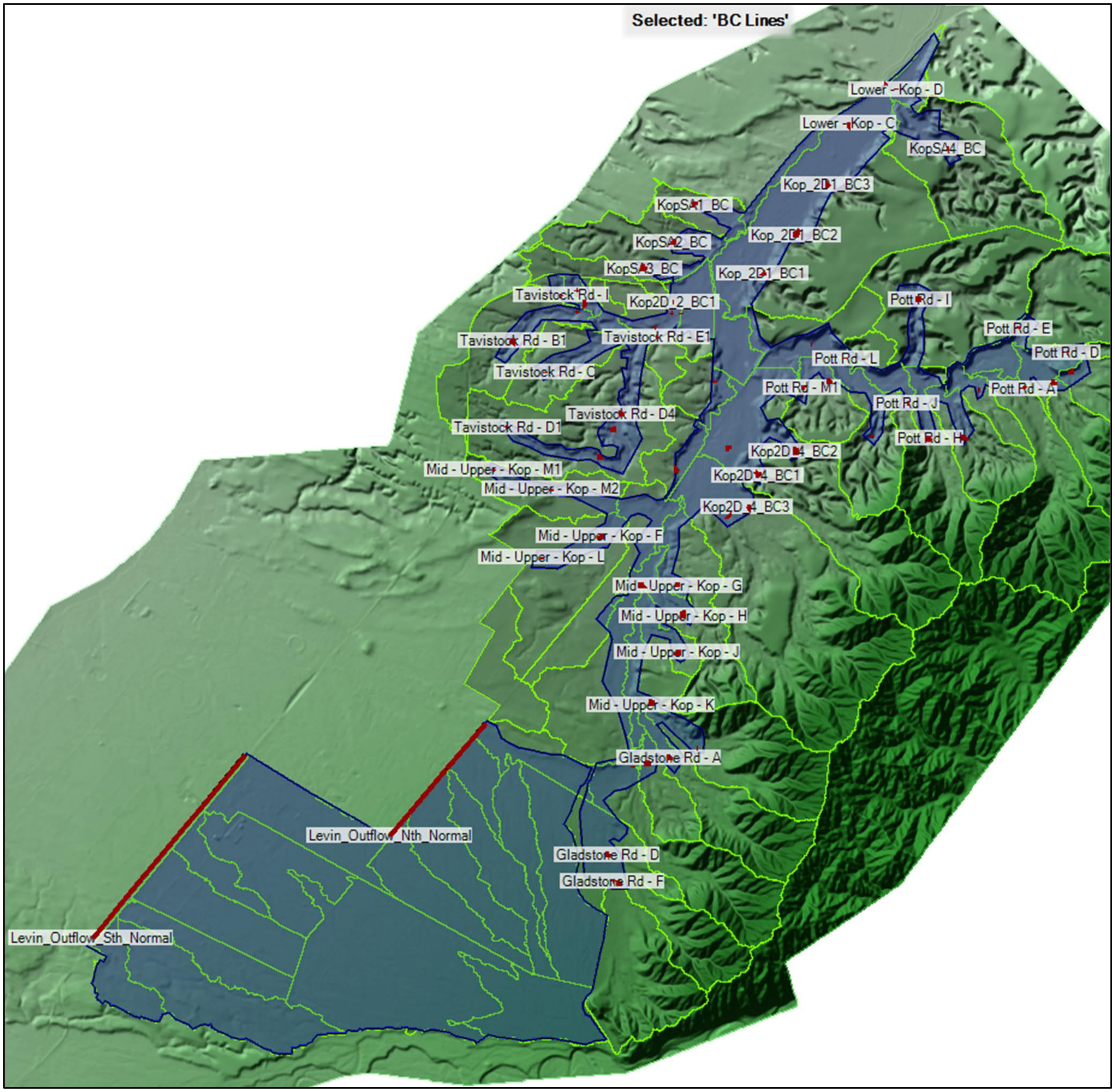


Figure 3.11: East of Levin - Inflow and Outflow boundaries

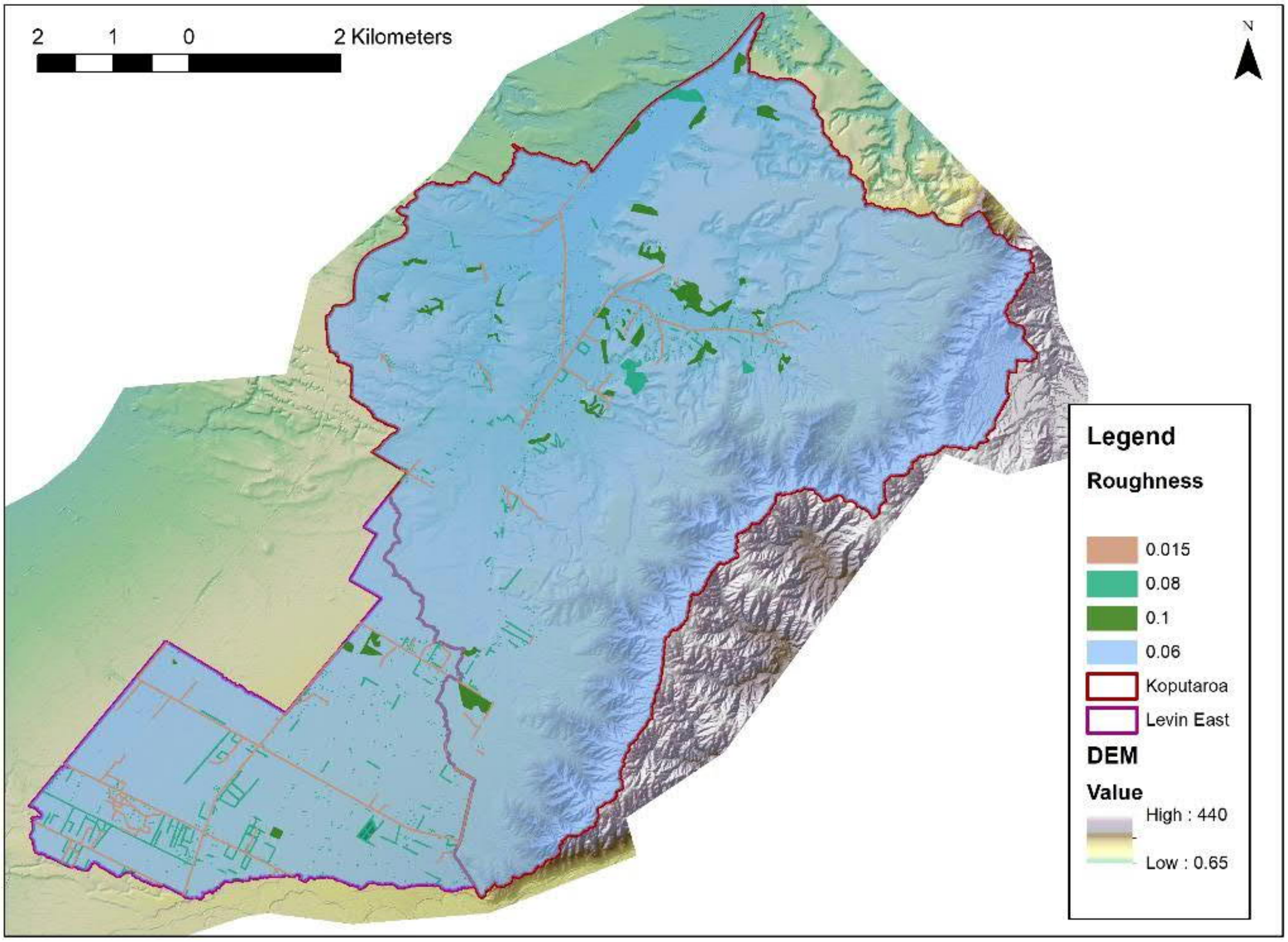


Figure 3.12: East of Levin Roughness values applied

4. Results

The hydraulic models for each catchment were run for three design events:

- 10-year, RCP 6.0
- 100-year, RCP 6.0
- 200-year RCP 6.0

An allowance for the effect of climate change on rainfall under the RCP 6.0 scenario for the period 2081-2100 was included.

4.1 Mangaone Stream

For the Mangaone Stream catchment gauged flows were available, and these were used to sense check the flows against flood frequency analysis of the gauge. The model results show that there are significant out of bank flows on the northern side of the Mangaone Stream, so the gauged flows may underestimate the flows in larger floods. Some roads form a barrier to overland flooding, for example Waughs and Campbell Roads north east of Bunnythorpe and Kairanga Bunnythorpe Road and Roberts Line N south west of Bunnythorpe, as shown in the Long Section 1 and in plan view in Figures 4.1 and 4.2. Figures 4.3 to 4.5 show the flood extents from the model simulations for the three events.

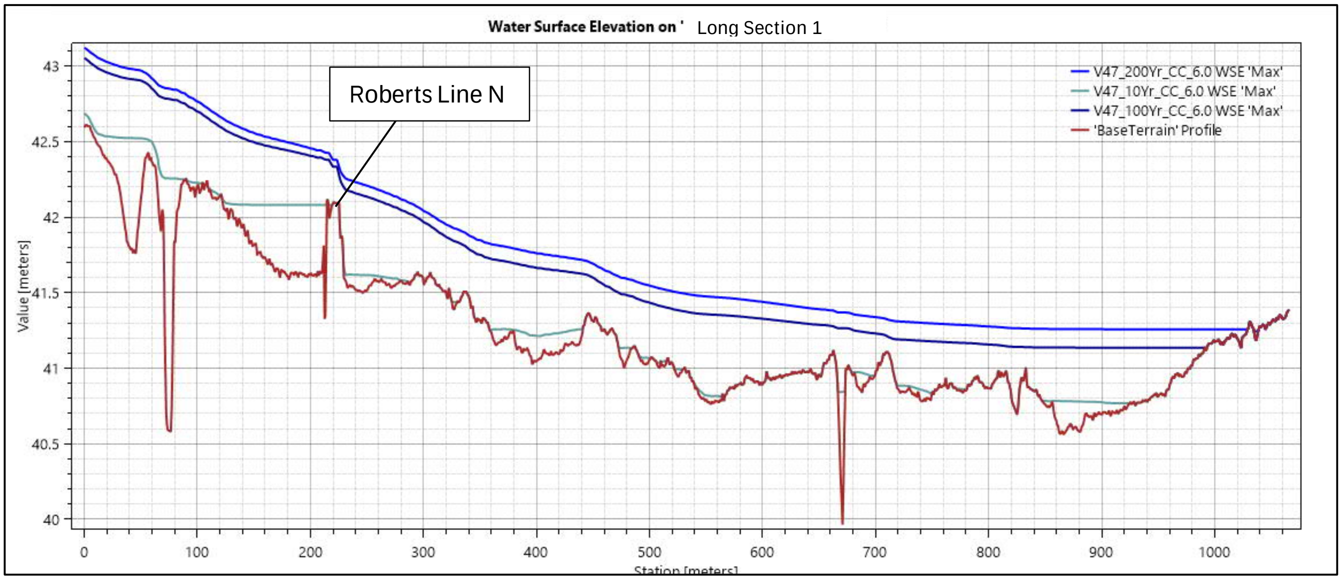


Figure 4.1: Mangone catchment - Long Section 1 showing flood levels for the 10-year, 100-year and 200-year events (with climate change RCP6.0)

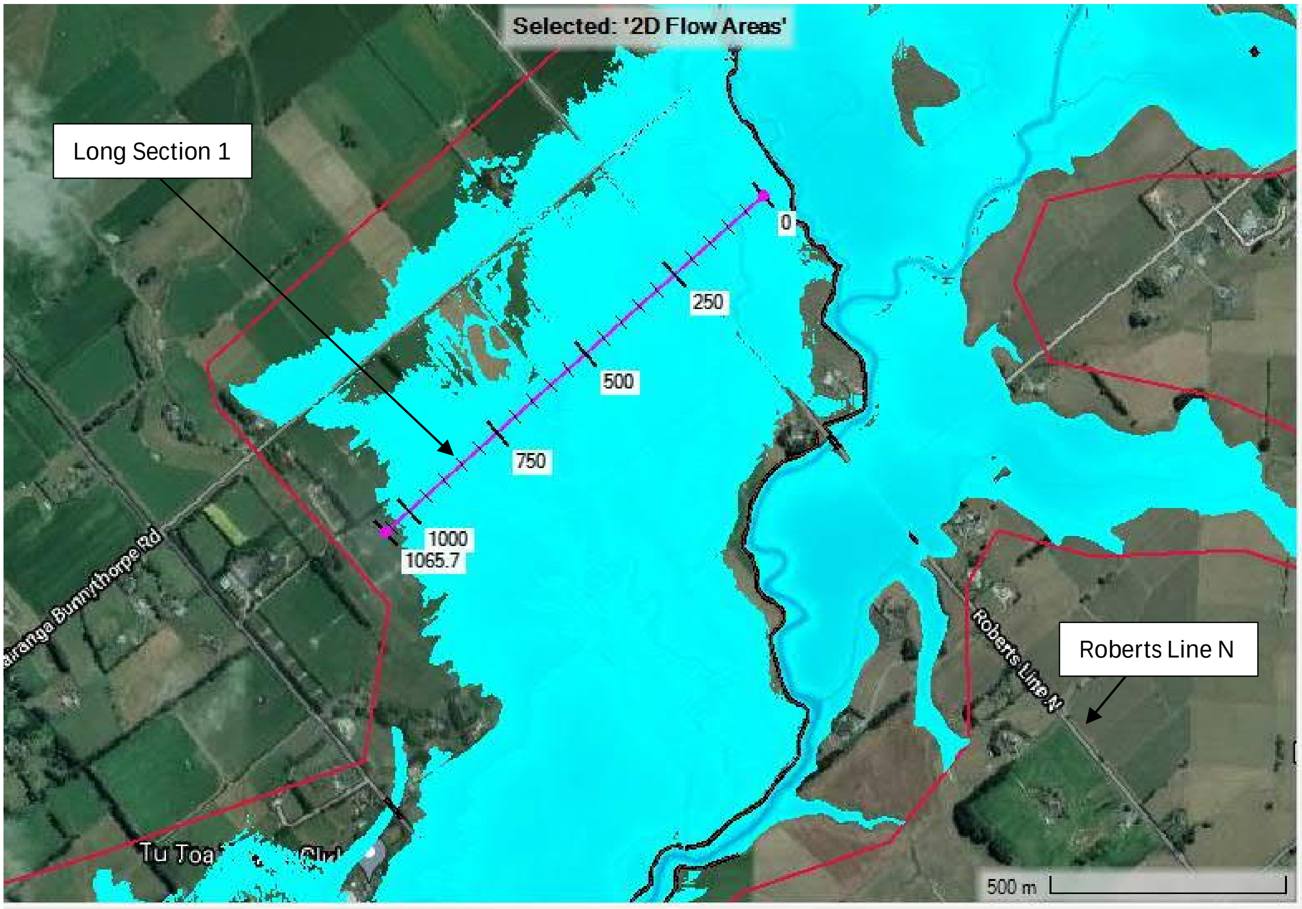


Figure 4.2: Mangone catchment - Long section location

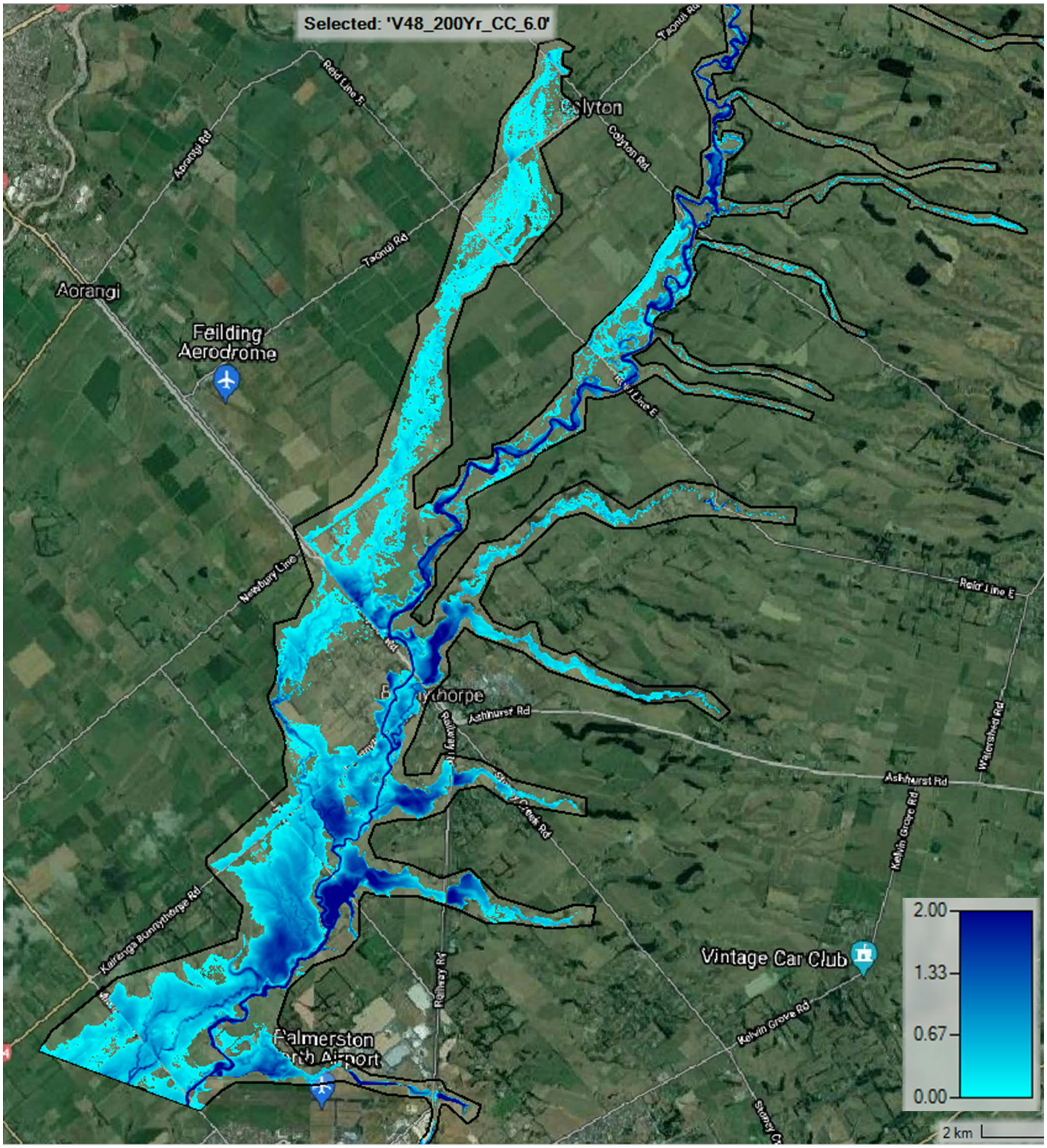


Figure 4.3: Mangaone Stream catchment - 200-year Maximum Flood Depths (with climate change RCP6.0)

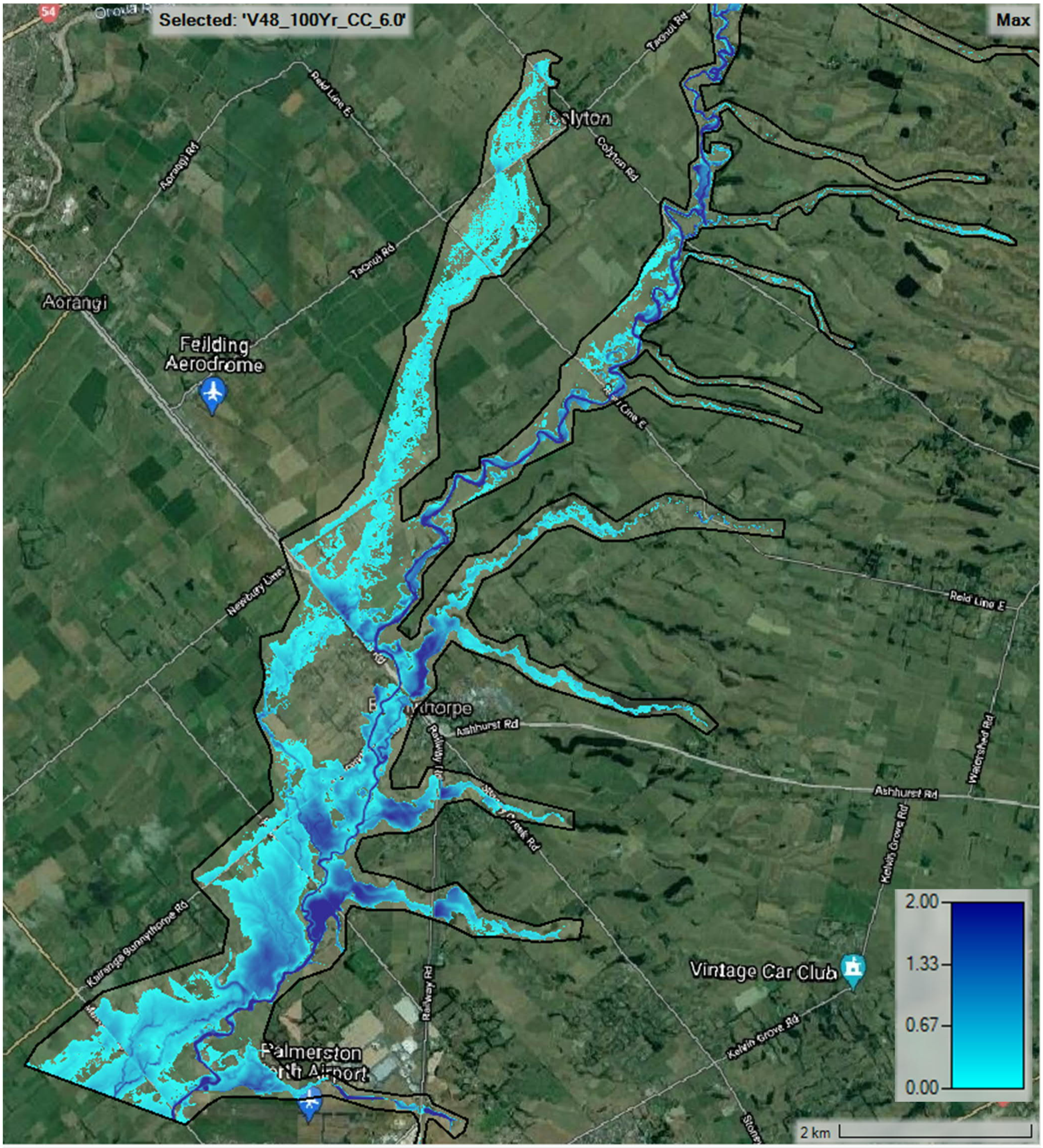


Figure 4.4: Mangaone Stream catchment - 100-year Maximum Flood Depths (with climate change RCP6.0)

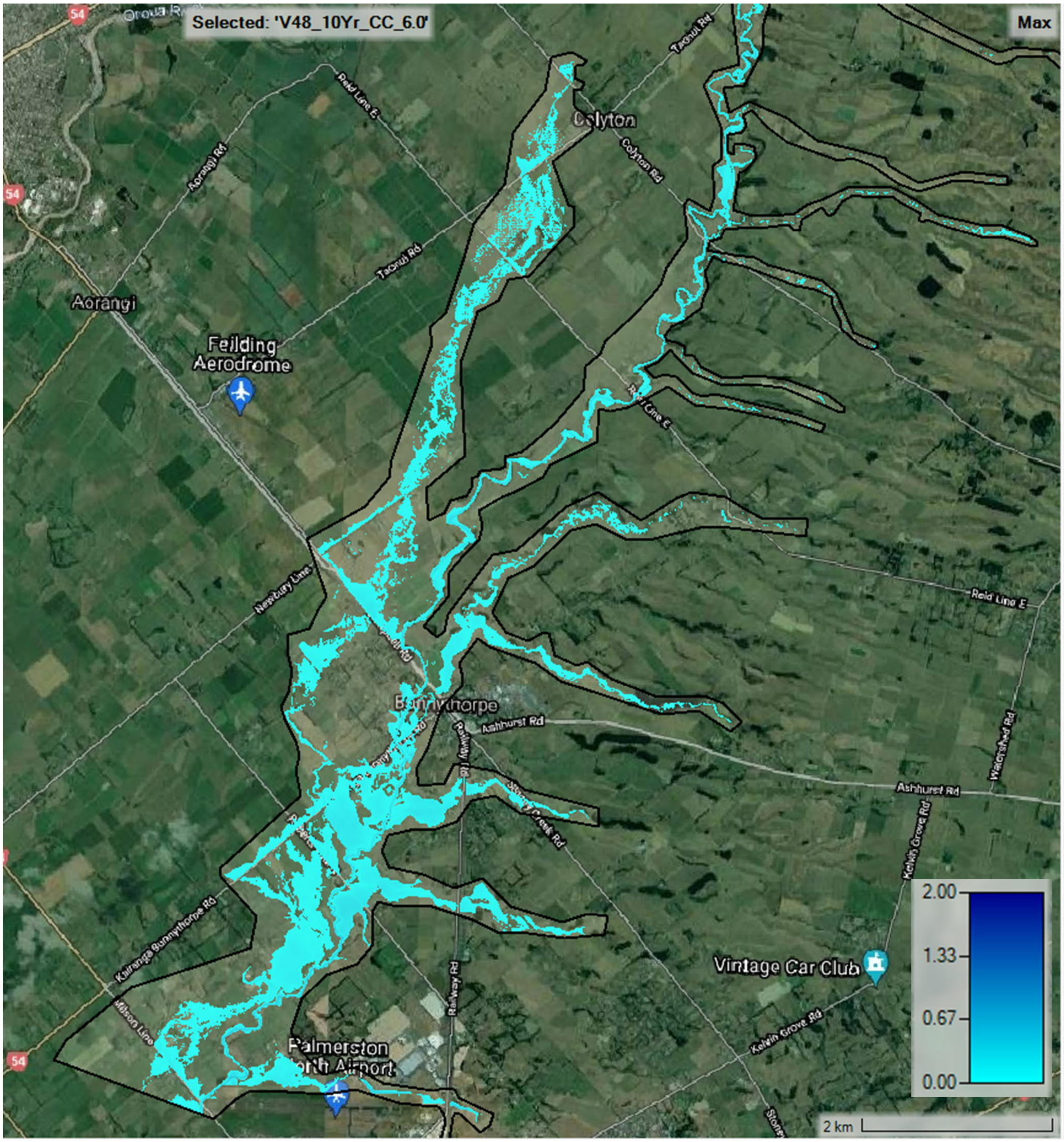


Figure 4.5: Mangaone Stream catchment - 10-year Maximum Flood Depths (with climate change RCP6.0)

4.2 East of Levin

For the Levin East catchment, the 2D rain on grid approach means there is shallow flooding over much of the 2D model extent; in the results presented in the figures below, only flood depths greater than 50mm are shown. Flood levels are controlled primarily by overtopping of the low points on the raised railway embankment along the western boundary. Drainage culverts under the railway are not included in the model as there was no survey available. However, these culverts are relatively small and are constrained by downstream conditions (State Highway One culverts and field drains) so will not carry a significant proportion of the runoff in larger flood events.

For the Koputaroa Stream catchment the water level in the lower part of the catchment is determined by the channel capacity at the railway line crossing at the downstream end of the model. The stopbank on the true left bank of the stream downstream of the railway is around 1m higher than the stopbanks upstream of the railway line and over 2m higher than the floodplain ground levels (see Figure 4.6 and 4.7). This means the stream will start to flood upstream before it comes out of the channel downstream (apart from the narrow strip on the true right bank between the channel and the railway embankment which does not provide significant conveyance capacity due to the bank across it a short distance downstream). The widespread flooding upstream of the railway line significantly attenuates the flow in the channel downstream of the railway in all flood events (see Figure 4.8 and 4.9). Although the flood extents are very similar for all three events (Figure 4.12, Figure 4.13, Figure 4.14) the water level does vary by around 1m. Figure 4.6 shows a long section of the model results for the three events along the valley upstream of the railway. The shape of the valley (steep sided away from the floodplain) means that the differences in flood level do not change the extent of flooding very much.

Note that for the downstream model boundary we have applied a normal depth condition and haven't allowed for any backwater effect from the Manawatu River. A high water level in the Manawatu River would raise the water levels in the downstream end of the modelled area but it is unlikely to change the extent of flooding very much as this is defined mainly by the topography (water depths would increase though).

Although there was no gauged flow data available, photos of the flooding confirm that the extents are comparable to what has been observed in the lower Koputaroa Stream (Figure 4.10 and Figure 4.11).

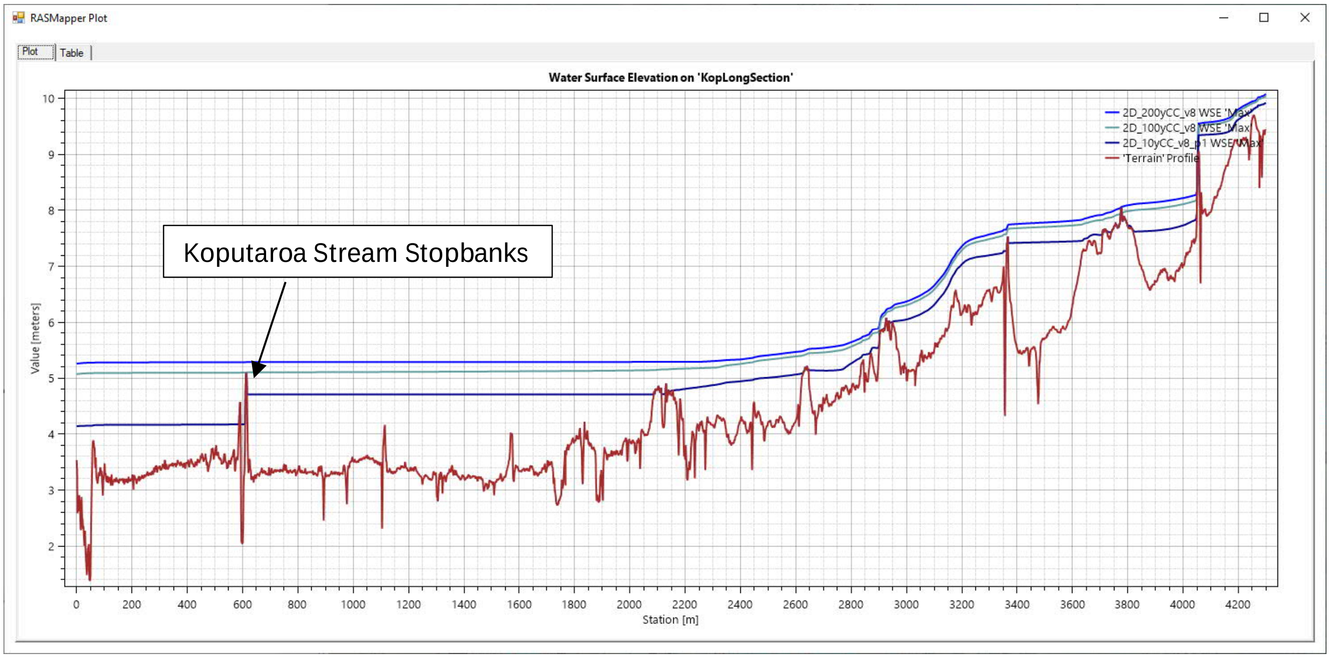


Figure 4.6: Koputaroa Stream catchment- Long section of flood levels in the lower catchment for the 10-year, 100-year and 200-year events (with climate change RCP6.0)

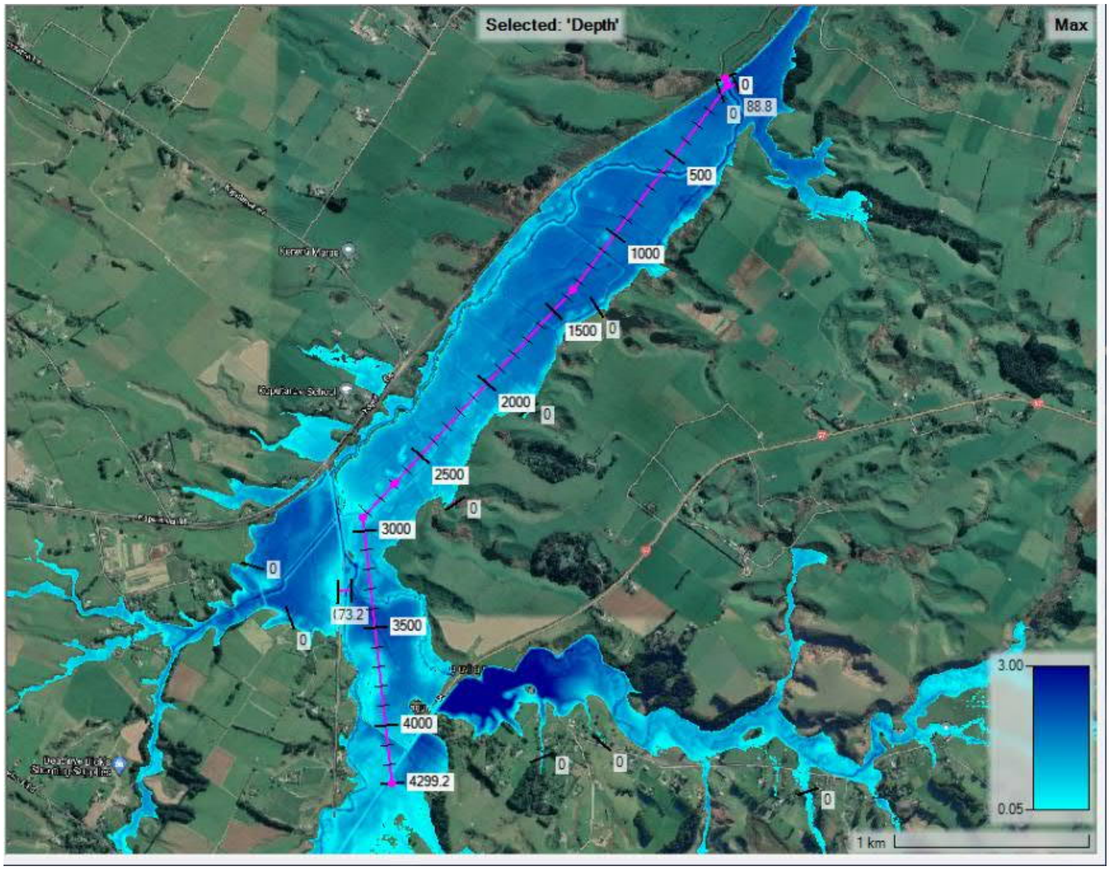


Figure 4.7: Koputaroa Stream catchment - Long section location

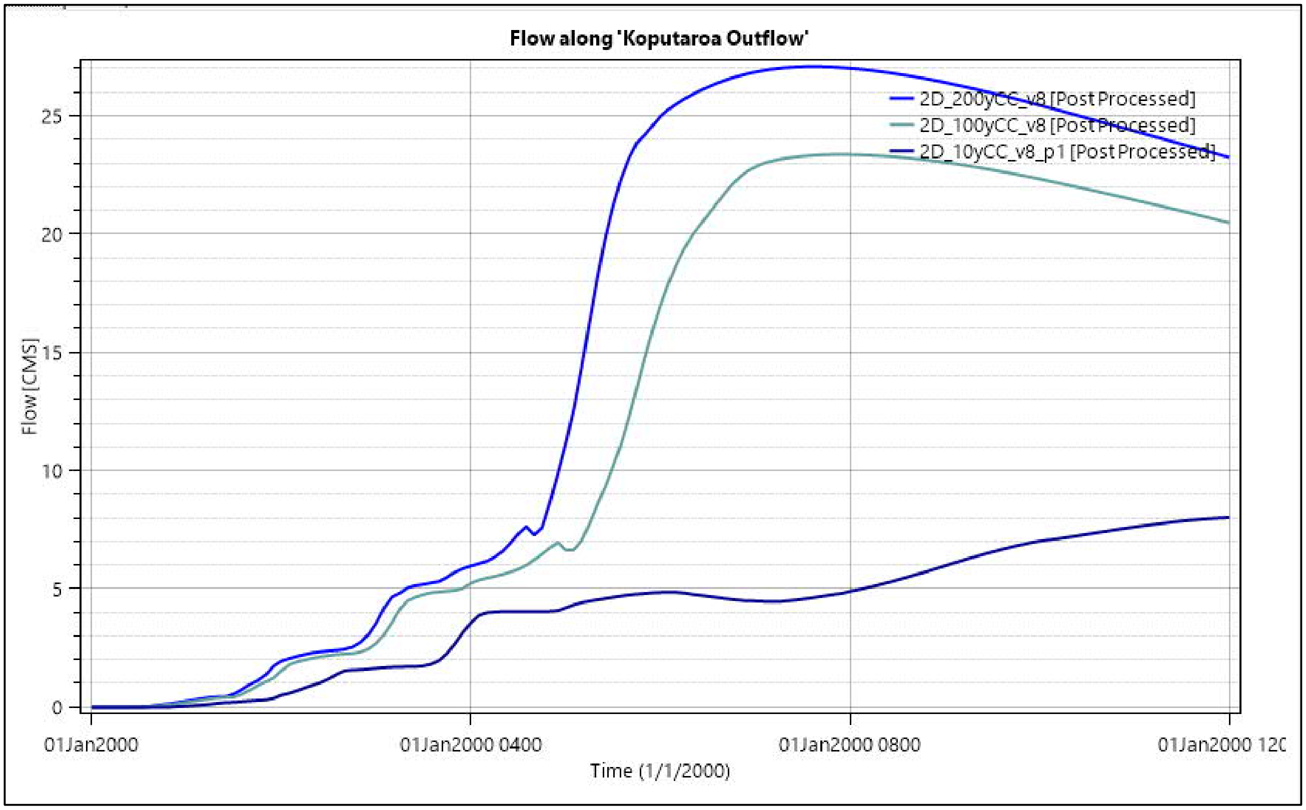


Figure 4.8: Koputaroa Stream - Discharge at the model outflow boundary for the 10-year, 100-year and 200-year events (with climate change RCP6.0)

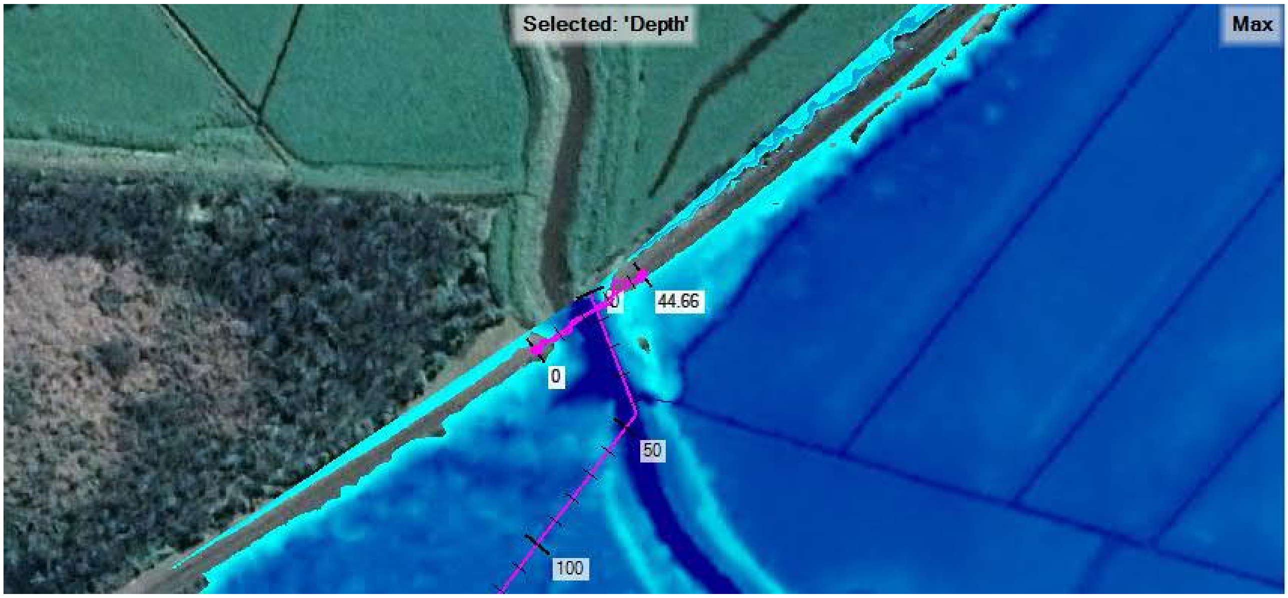


Figure 4.9: Koputaroa Stream - Discharge line location

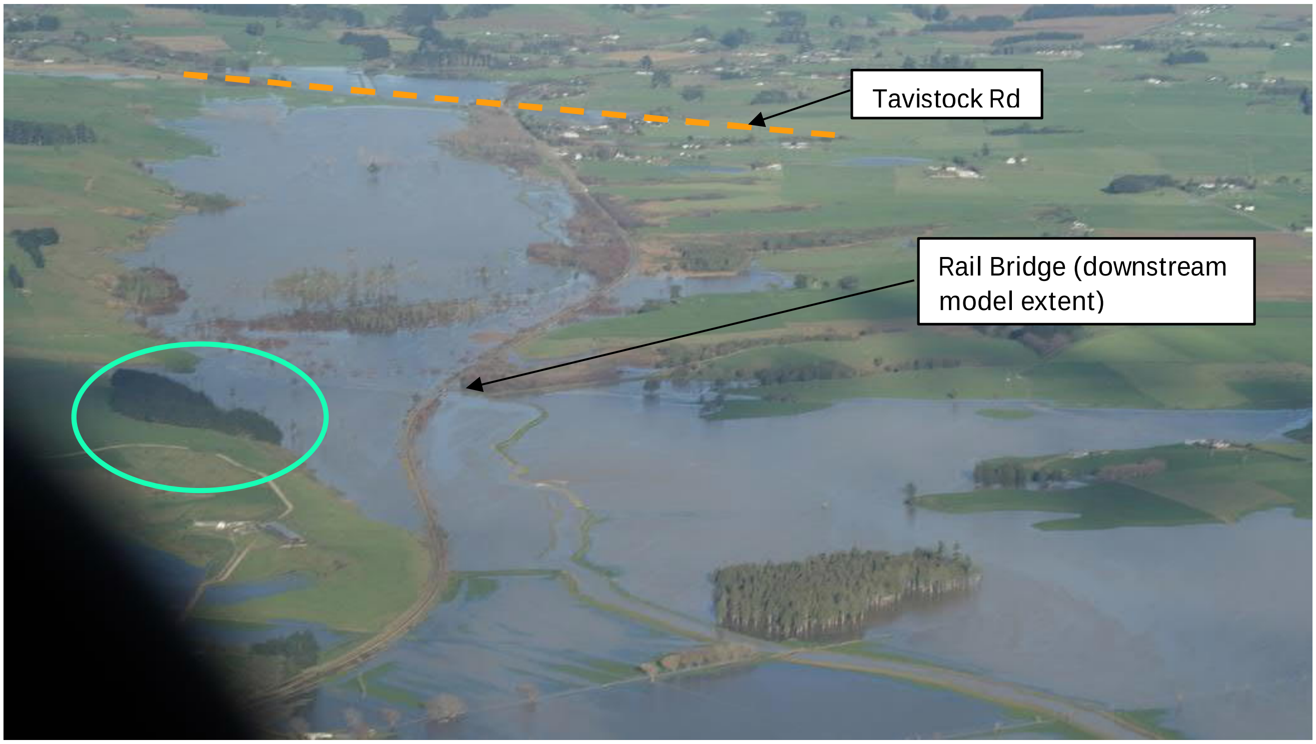


Figure 4.10: Photo of Flooding at Koputaroa, 22 June 2015 (source : Massey University Aviation)

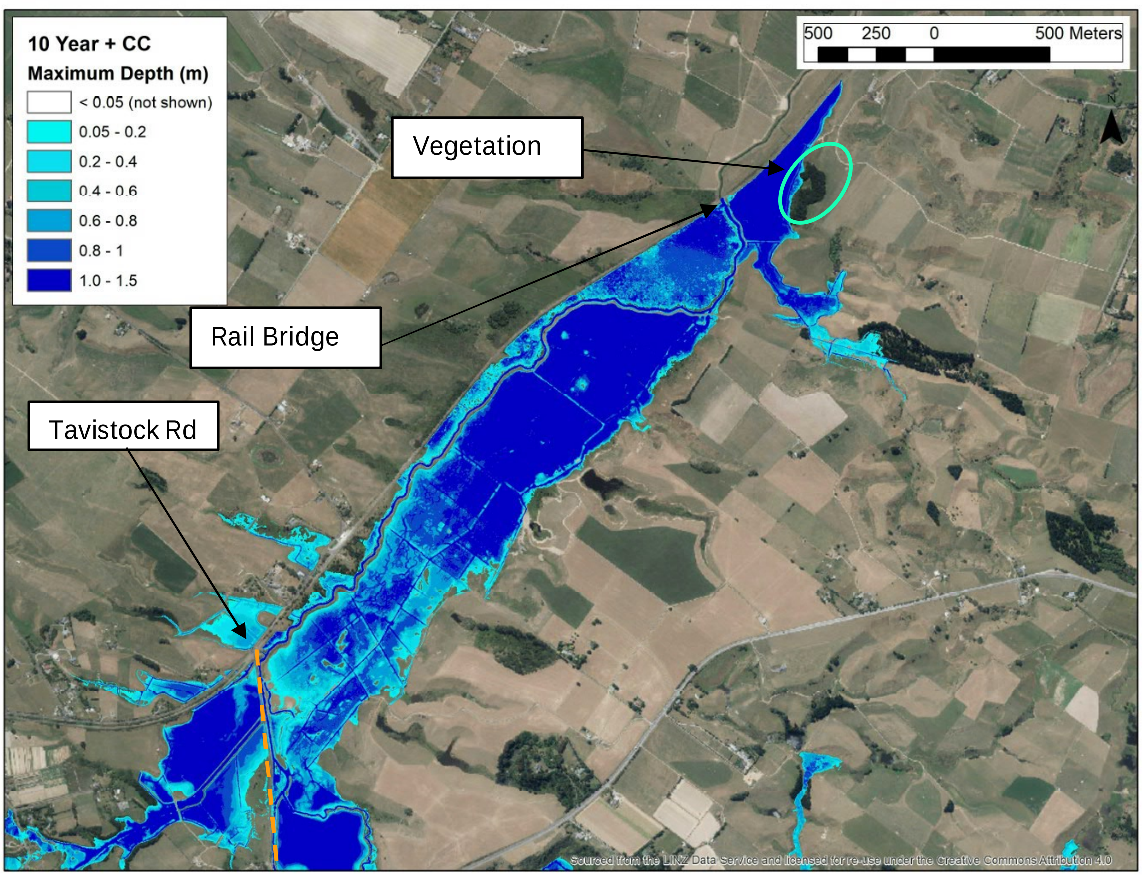


Figure 4.11: Lower Koputaroa Stream - Modelled Flooding in 10-year Event (with climate change RCP 6.0)

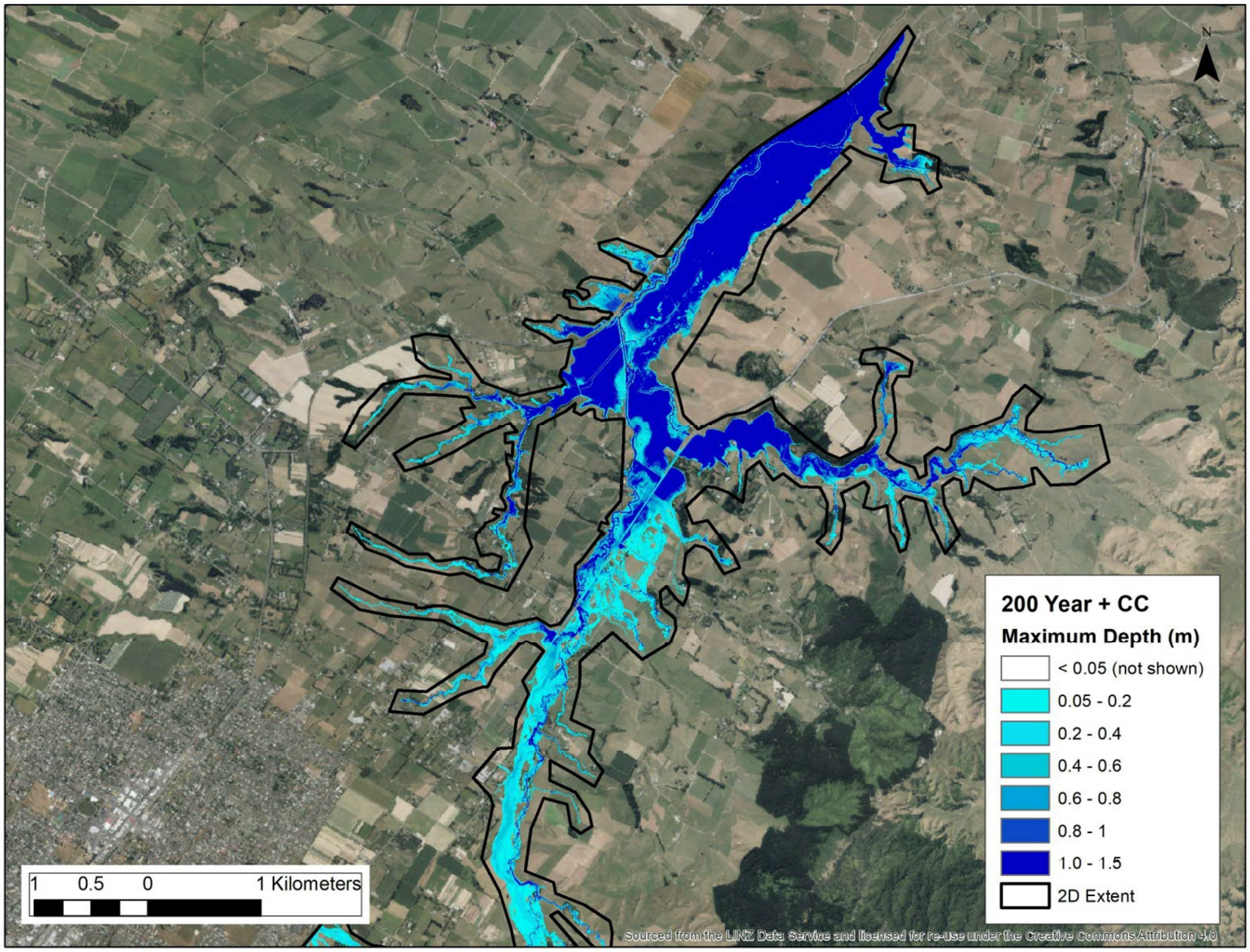


Figure 4.12: Lower Koputaroa Stream - 200-year Maximum Flood Depths (with climate change RCP 6.0)

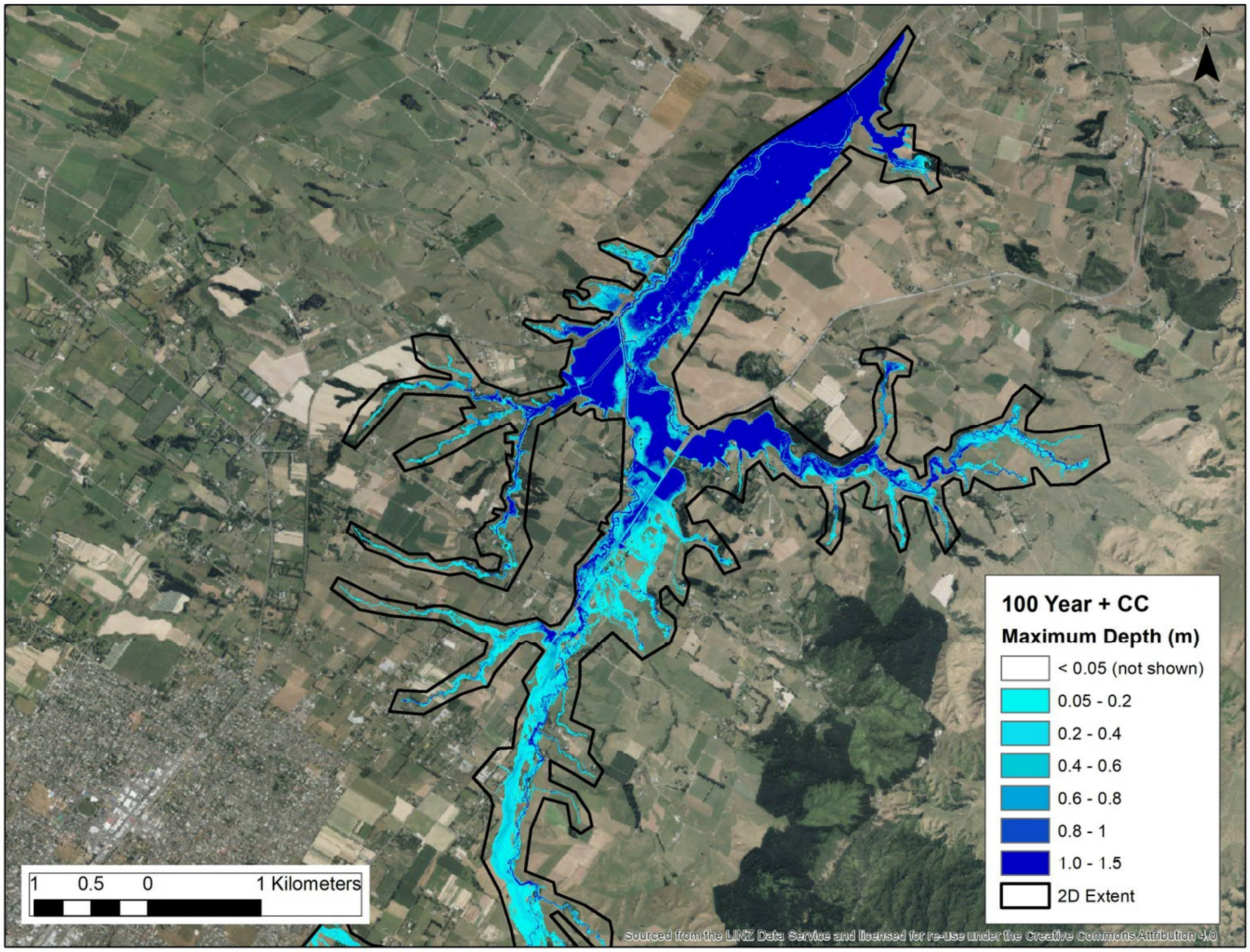


Figure 4.13: Lower Koputaroa Stream - 100-year Maximum Flood Depths (with climate change RCP 6.0)

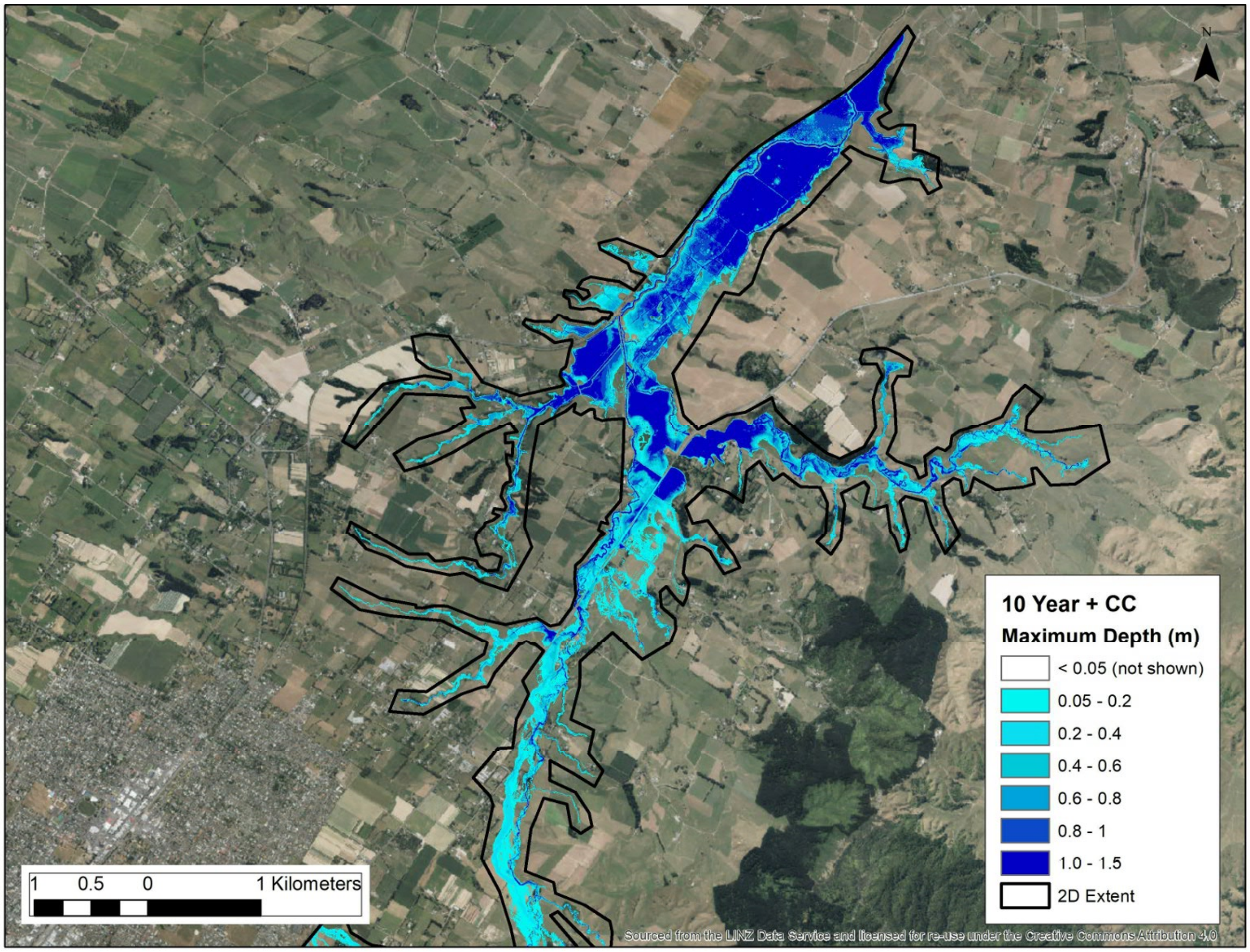


Figure 4.14: Lower Koputaroa Stream - 10-year Maximum Flood Depths (with climate change RCP 6.0)

Figure 4.15 and Figure 4.16 show how the railway line alongside State Highway One controls the flood levels in the East of Levin catchment south of Levin. Figures 4.17 to 4.19 show the overall extents of flooding in this area. Note that for the rain on grid area of the model depths below 50mm are not shown.

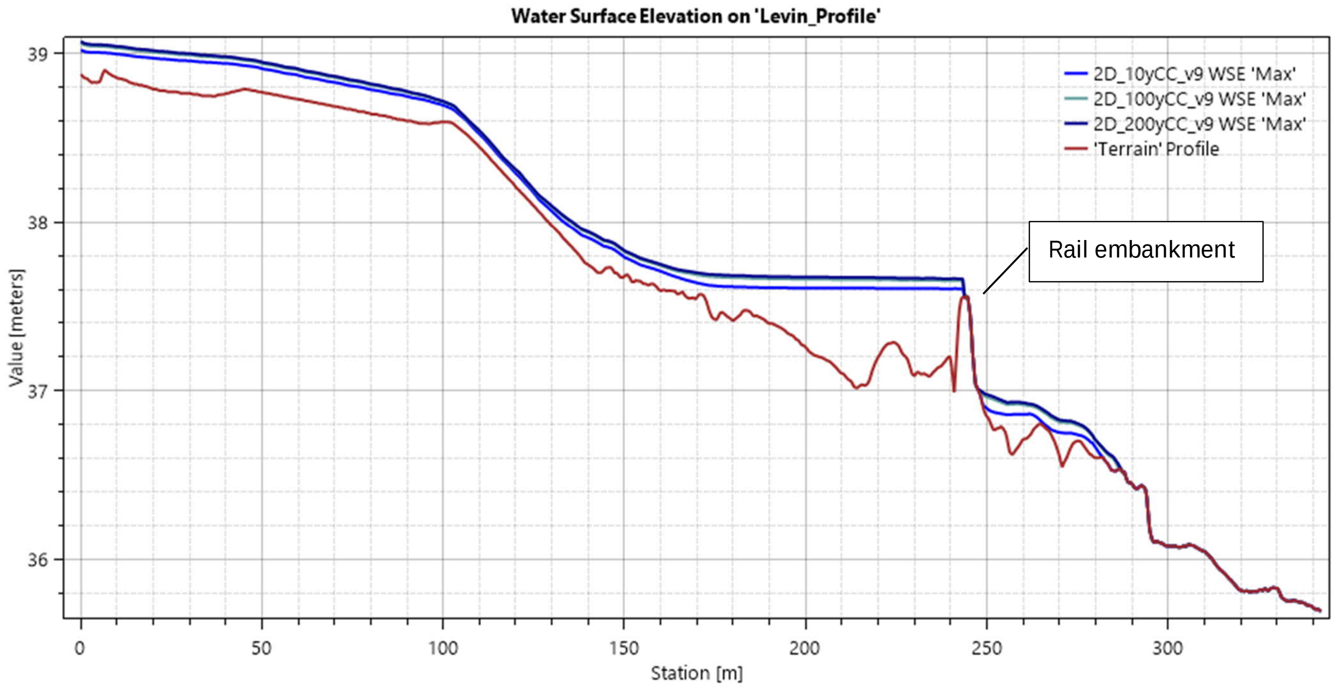


Figure 4.15: Levin East - Long Section showing Rail embankment which controls flood levels in the lower catchment for the 10-year, 100-year and 200-year events (with climate change RCP6.0)

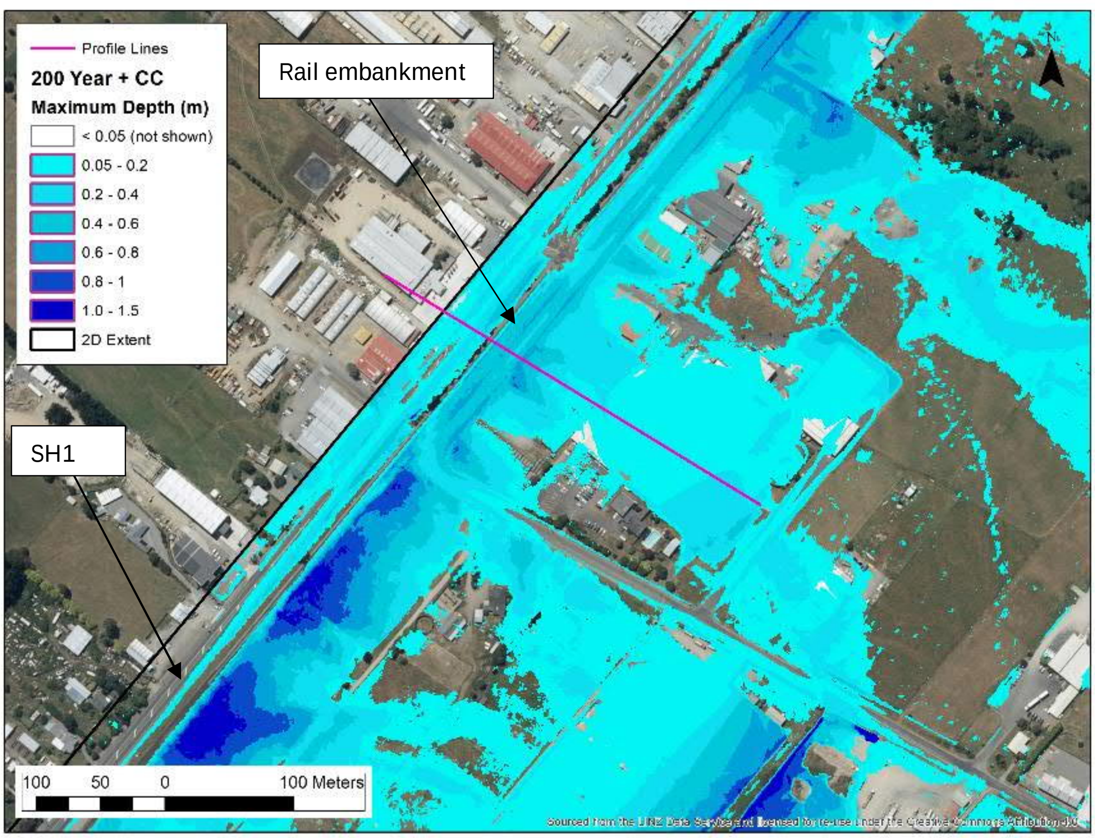


Figure 4.16: Levin East - Long Section Location

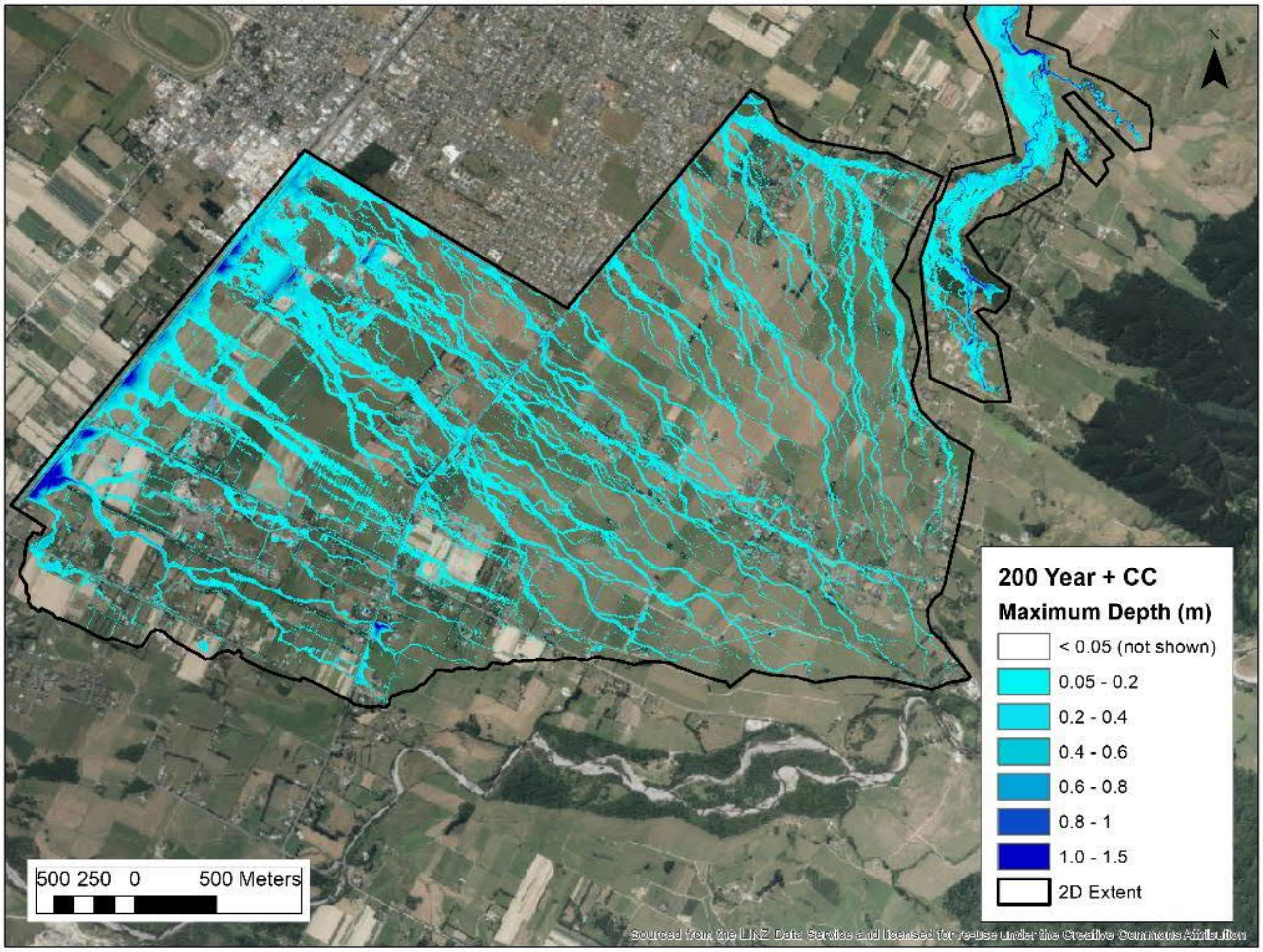


Figure 4.17: Upper Koputaroa Stream and East Levin - 200-year Maximum Flood Depths (with climate change RCP6.0). Note: depths below 50mm are not shown.

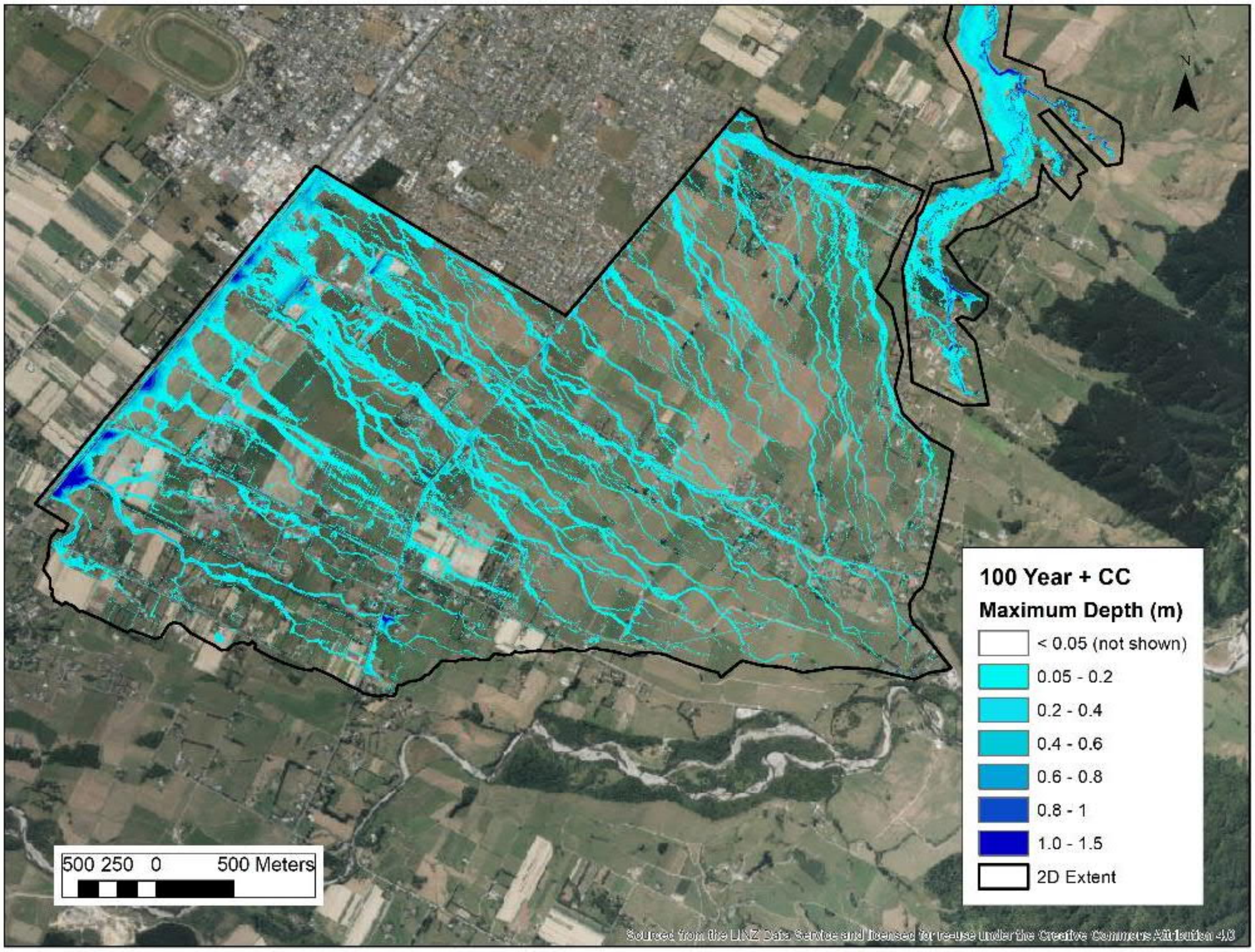


Figure 4.18: Upper Koputaroa Stream and East Levin - 100-year Maximum Flood Depth (with climate change RCP6.0). Note: depths below 50mm are not shown.

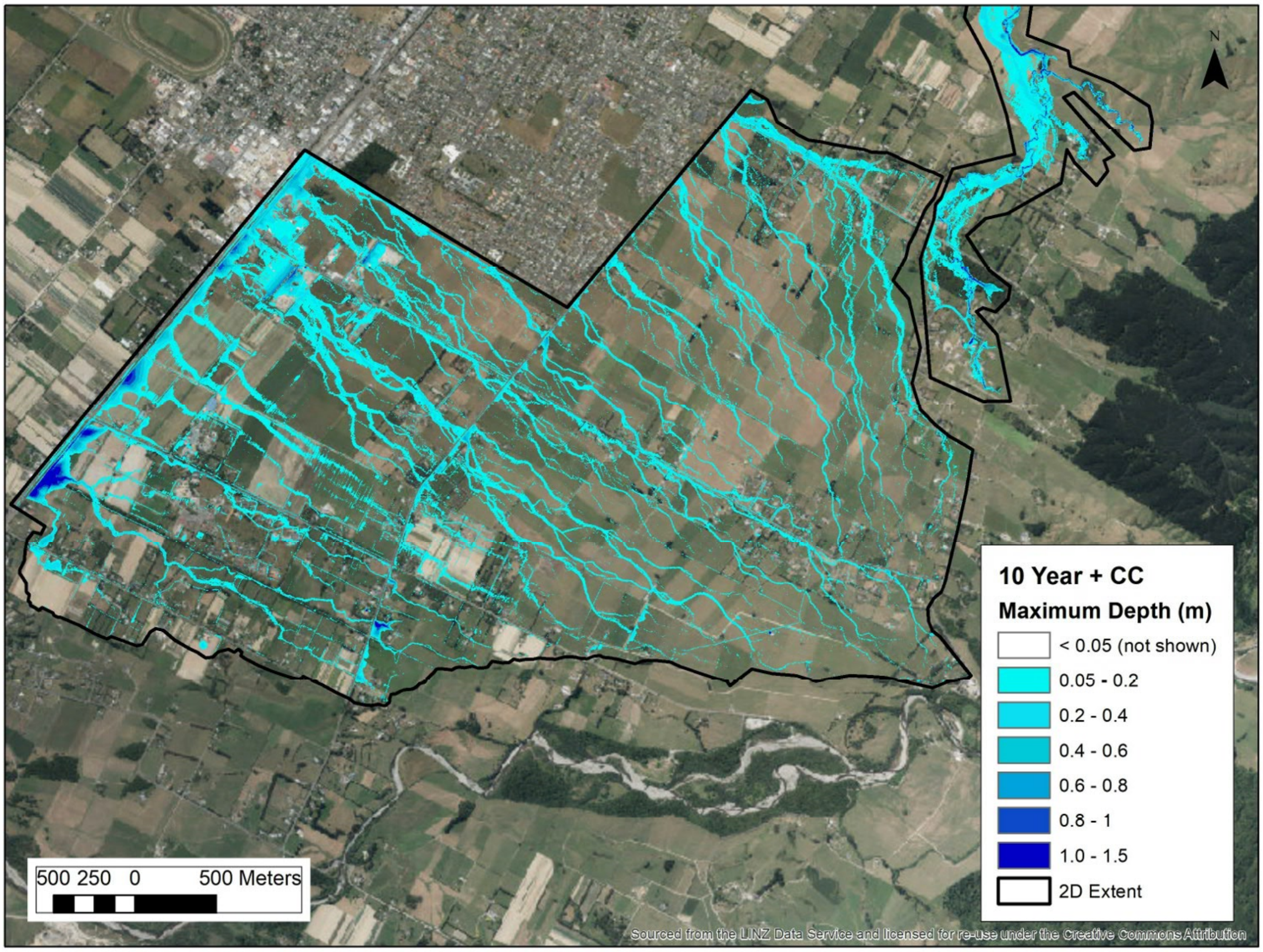


Figure 4.19: Upper Koputaroa Stream and East Levin - 10-year Maximum Flood Depth (with climate change RCP6.0). Note: depths below 50mm are not shown.

Appendix A. Model Hydrological Parameters

Table A.1: Mangaone Stream Hydrological Parameters - Area and Losses

Subcatchment	Area (km^2)	Initial Abstraction (mm)	Constant rate (mm/hr)
Airport - A	6.391	8.125	3
Airstrip - A	4.494	8.125	3
Airstrip - B	2.756	8.125	3
Airstrip - C	2.505	8.125	3
Airstrip - D	0.899	3.175	3
Colyton Rd - A	3.678	8.125	3
Colyton Rd - B	2.072	8.125	3
Colyton Rd - C	6.802	8.125	3
Colyton Rd - D	3.483	3.175	3
Colyton Rd - E	2.523	3.175	3
Colyton West - A	4.705	3.175	3
Colyton West - B	9.962	3.175	3
Colyton West - C	4.715	8.125	3
Dixon Line - A	5.100	8.125	3
Dixon Line - B	1.915	3.175	3
Mangaone - A	4.568	8.125	3
Mangaone - B	2.903	8.125	3
Mangaone - C	4.380	8.125	3
Mangaone - D	7.423	8.125	3
Mangaone - E	1.536	8.125	3
Mangaone - F	1.670	8.125	3
Mangaone - G	2.530	8.125	3
Mangaone - H	4.885	8.125	3
Mangaone - I	1.105	3.175	3
Mangaone - J	2.575	3.175	3
Reid Line - A	3.062	8.125	3
Reid Line - B	6.236	8.125	3
Reid Line - C	2.186	3.175	3
Reid Line - D	6.260	3.175	3
Roberts Line - A	7.539	8.125	3
Valley Rd - A	3.780	8.125	3
Valley Rd - B	4.082	8.125	3
Valley Rd - C	5.745	3.175	3
Valley Rd - D	6.687	8.125	3

Subcatchment	Area (km^2)	Initial Abstraction (mm)	Constant rate (mm/hr)
Valley Rd - E	2.273	3.175	3
Valley Rd - F	0.523	3.175	3
Valley Rd - G	2.472	8.125	3
Valley Rd - H	1.297	3.175	3
Valley Rd - I	1.575	8.125	3
Valley Rd - J	4.391	3.175	3
Valley Rd - K	1.324	8.125	3

Table A.2: Mangaone Stream Hydrological Parameters - Kinematic Wave Plane and Main Channel parameters

	Subcatchment Plane			Subcatchment Main Channel		
Subcatchment	Length (m)	Slope (m/m)	Roughness	Routing steps	Length (m)	Slope (m/m)
Airport - A	3475	0.0105	0.05	5	3475	0.0105
Airstrip - A	3408	0.0220	0.05	5	3408	0.022
Airstrip - B	3349	0.0240	0.05	5	3349	0.024
Airstrip - C	2234	0.0410	0.05	5	2234	0.041
Airstrip - D	1165	0.0407	0.05	5	1165	0.0407
Colyton Rd - A	4481	0.0252	0.05	5	4481	0.0252
Colyton Rd - B	2781	0.0278	0.05	5	2781	0.0278
Colyton Rd - C	4626	0.0220	0.05	5	4626	0.022
Colyton Rd - D	3049	0.0215	0.05	5	3049	0.0215
Colyton Rd - E	3663	0.0267	0.05	5	3663	0.0267
Colyton West - A	3645	0.0125	0.05	5	3645	0.0125
Colyton West - B	2707	0.0037	0.05	5	2707	0.0037
Colyton West - C	2886	0.0043	0.05	5	2886	0.0043
Dixon Line - A	5219	0.0149	0.05	5	5219	0.0149
Dixon Line - B	2812	0.0155	0.05	5	2812	0.0155
Mangaone - A	3393	0.0318	0.05	5	3393	0.0318
Mangaone - B	2881	0.0270	0.05	5	2881	0.027
Mangaone - C	1037	0.0720	0.05	5	1037	0.072
Mangaone - D	1610	0.0360	0.05	5	1610	0.036
Mangaone - E	1383	0.0437	0.05	5	1383	0.0437
Mangaone - F	1877	0.0074	0.05	5	1877	0.0074
Mangaone - G	1671	0.0142	0.05	5	1671	0.0142
Mangaone - H	4648	0.0201	0.05	5	4648	0.0201
Mangaone - I	643	0.0183	0.05	5	643	0.0183
Mangaone - J	2825	0.0028	0.05	5	2825	0.0028

	Subcatchment Plane			Subcatchment Main Channel		
Subcatchment	Length (m)	Slope (m/m)	Roughness	Routing steps	Length (m)	Slope (m/m)
Reid Line - A	3844	0.0212	0.05	5	3844	0.0212
Reid Line - B	3942	0.0177	0.05	5	3942	0.0177
Reid Line - C	2822	0.0173	0.05	5	2822	0.0173
Reid Line - D	4778	0.0169	0.05	5	4778	0.0169
Roberts Line - A	3836	0.0182	0.05	5	3836	0.0182
Valley Rd - A	3828	0.0220	0.05	5	3828	0.022
Valley Rd - B	1793	0.0260	0.05	5	1793	0.026
Valley Rd - C	3339	0.0216	0.05	5	3339	0.0216
Valley Rd - D	3654	0.0249	0.05	5	3654	0.0249
Valley Rd - E	2774	0.0293	0.05	5	2774	0.0293
Valley Rd - F	926	0.0720	0.05	5	926	0.072
Valley Rd - G	2152	0.0305	0.05	5	2152	0.0305
Valley Rd - H	2276	0.0424	0.05	5	2276	0.0424
Valley Rd - I	1966	0.0379	0.05	5	1966	0.0379
Valley Rd - J	2536	0.0287	0.05	5	2536	0.0287
Valley Rd - K	1439	0.0390	0.05	5	1439	0.039

Table A.3: Mangaone Stream Hydrological Parameters - River Reach Routing Parameters

Reach Name	Length (m)	Slope (m/m)	Roughness	Index Celerity (m/s)
R - Airport - A	3475	0.011	0.05	2
R - Airstrip - C	2234	0.041	0.05	2
R - Airstrip - D	1165	0.041	0.05	2
R - Colyton Rd - B	2781	0.028	0.05	2
R - Colyton Rd - D	3049	0.022	0.05	2
R - Colyton West - B	2707	0.004	0.05	2
R - Colyton West - C	2886	0.004	0.05	2
R - Dixon Line - B 1	2812	0.016	0.05	2
R - Dixon Line - B 2	2812	0.016	0.05	2
R - Mangaone - C	1037	0.072	0.05	2
R - Mangaone - D	1610	0.036	0.05	2
R - Mangaone - E	1383	0.044	0.05	2
R - Mangaone - F	1877	0.007	0.05	2
R - Mangaone - G	1671	0.014	0.05	2
R - Mangaone - H	4648	0.020	0.05	2
R - Mangaone - I 1	643	0.018	0.05	2

Reach Name	Length (m)	Slope (m/m)	Roughness	Index Celerity (m/s)
R - Mangaone - I 2	643	0.018	0.05	2
R - Mangaone - J	2825	0.003	0.05	2
R - Reid Line - C	2822	0.017	0.05	2
R - Valley Rd - B	1793	0.026	0.05	2
R - Valley Rd - E	2774	0.029	0.05	2
R - Valley Rd - F	926	0.072	0.05	2
R - Valley Rd - H	2276	0.042	0.05	2
R - Valley Rd - I	1966	0.038	0.05	2
R - Valley Rd - J	2536	0.029	0.05	2
R - Valley Rd - K	1439	0.039	0.05	2

Table A.4: East of Levin Hydrological Parameters - Area and losses

Subcatchment	Area (km^2)	Initial Abstraction (mm)	Constant rate (mm/hr)
Gladstone Rd - A	1.1424	3.3759	3
Gladstone Rd - B	0.4787	8.1197	3
Gladstone Rd - C	1.4893	3.7935	3
Gladstone Rd - D	0.7935	9.1966	3
Gladstone Rd - E	0.7755	3.3759	3
Gladstone Rd - F	1.1427	3.3759	3
Lower - Kop - A	3.5202	8.1197	3
Lower - Kop - B	1.8810	4.4622	3
Lower - Kop - C	0.3698	8.1197	3
Lower - Kop - D	0.2389	4.4622	3
Lower - Kop - E	0.3801	8.1197	3
Lower - Kop - F	1.0701	8.1197	3
Mid - Upper - Kop - A	0.3379	4.4622	3
Mid - Upper - Kop - B	0.3987	8.1197	3
Mid - Upper - Kop - C	3.0116	4.4622	3
Mid - Upper - Kop - D	0.3908	4.4622	3
Mid - Upper - Kop - E	4.3618	4.4622	3
Mid - Upper - Kop - F	0.9321	4.4622	3
Mid - Upper - Kop - G	0.5880	8.1197	3
Mid - Upper - Kop - H	0.8604	8.1197	3
Mid - Upper - Kop - I	1.2590	2.7878	3
Mid - Upper - Kop - J	0.3065	8.1197	3
Mid - Upper - Kop - K	0.5199	8.1197	3

Subcatchment	Area (km^2)	Initial Abstraction (mm)	Constant rate (mm/hr)
Mid - Upper - Kop - L	1.5555	8.1197	3
Mid - Upper - Kop - M	0.7552	8.1197	3
Pott Rd - A	2.0880	3.175	3
Pott Rd - B	1.0164	3.175	3
Pott Rd - C	2.4970	3.175	3
Pott Rd - D	0.6291	4.4622	3
Pott Rd - E	2.4994	8.1197	3
Pott Rd - F	0.3226	8.1197	3
Pott Rd - G	0.8295	8.1197	3
Pott Rd - H	1.3396	3.3759	3
Pott Rd - I	2.3014	8.1197	3
Pott Rd - J	0.2372	4.4622	3
Pott Rd - K	0.9263	9.1966	3
Pott Rd - L	0.1865	4.2333	3
Pott Rd - M	0.5914	8.1197	3
Pott Rd - N	0.7661	2.7878	3
Tavistock Rd - A	0.4265	4.4622	3
Tavistock Rd - B	1.1296	4.2333	3
Tavistock Rd - C	0.7433	8.1197	3
Tavistock Rd - D	2.2808	8.1197	3
Tavistock Rd - E	0.5005	8.1197	3
Tavistock Rd - F	0.1548	8.1197	3
Tavistock Rd - G	0.0676	8.1197	3
Tavistock Rd - H	0.4011	8.1197	3
Tavistock Rd - I	0.1031	8.1197	3
Upper - Kop - A	1.5898	3.3759	3

Table A.5: East of Levin Hydrological Parameters - Kinematic Wave Plane and Main Channel parameters

	Subcatchment Plane			Subcatchment Main Channel		
Subcatchment	Length (m)	Slope (m/m)	Roughness	Routing steps	Length (m)	Slope (m/m)
Gladstone Rd - A	356	0.125	0.05	5	2350	0.125
Gladstone Rd - B	241	0.073	0.05	5	1432	0.073
Gladstone Rd - C	392	0.120	0.05	5	2699	0.120
Gladstone Rd - D	353	0.082	0.05	5	1055	0.082
Gladstone Rd - E	345	0.137	0.05	5	1760	0.137
Gladstone Rd - F	483	0.107	0.05	5	1609	0.107

	Subcatchment Plane			Subcatchment Main Channel		
Subcatchment	Length (m)	Slope (m/m)	Roughness	Routing steps	Length (m)	Slope (m/m)
Lower - Kop - A	738	0.012	0.05	5	3425	0.012
Lower - Kop - B	528	0.025	0.05	5	2458	0.025
Lower - Kop - C	78	0.005	0.05	5	2253	0.005
Lower - Kop - D	238	0.010	0.05	5	904	0.010
Lower - Kop - E	200	0.016	0.05	5	905	0.016
Lower - Kop - F	424	0.012	0.05	5	1859	0.012
Mid - Upper - Kop - A	255	0.003	0.05	5	790	0.003
Mid - Upper - Kop - B	316	0.039	0.05	5	615	0.039
Mid - Upper - Kop - C	440	0.097	0.05	5	3545	0.097
Mid - Upper - Kop - D	207	0.053	0.05	5	508	0.053
Mid - Upper - Kop - E	828	0.100	0.05	5	3748	0.100
Mid - Upper - Kop - F	219	0.010	0.05	5	2545	0.010
Mid - Upper - Kop - G	333	0.022	0.05	5	1299	0.022
Mid - Upper - Kop - H	190	0.080	0.05	5	1857	0.080
Mid - Upper - Kop - I	467	0.016	0.05	5	2167	0.016
Mid - Upper - Kop - J	156	0.045	0.05	5	863	0.045
Mid - Upper - Kop - K	310	0.075	0.05	5	1075	0.075
Mid - Upper - Kop - L	515	0.010	0.05	5	2195	0.010
Mid - Upper - Kop - M	214	0.028	0.05	5	720	0.028
Pott Rd - A	517	0.126	0.05	5	3114	0.126
Pott Rd - B	258	0.184	0.05	5	2031	0.184
Pott Rd - C	604	0.125	0.05	5	2959	0.125
Pott Rd - D	86	0.137	0.05	5	2236	0.137
Pott Rd - E	473	0.102	0.05	5	3026	0.102
Pott Rd - F	141	0.039	0.05	5	1122	0.039
Pott Rd - G	276	0.124	0.05	5	1405	0.124
Pott Rd - H	366	0.150	0.05	5	2311	0.150
Pott Rd - I	635	0.027	0.05	5	1769	0.027
Pott Rd - J	152	0.065	0.05	5	744	0.065
Pott Rd - K	299	0.079	0.05	5	1618	0.079
Pott Rd - L	183	0.064	0.05	5	646	0.064
Pott Rd - M	310	0.040	0.05	5	1008	0.040
Pott Rd - N	217	0.047	0.05	5	749	0.047
Tavistock Rd - A	304	0.020	0.05	5	784	0.020
Tavistock Rd - B	369	0.031	0.05	5	590	0.031
Tavistock Rd - C	336	0.014	0.05	5	645	0.014

	Subcatchment Plane			Subcatchment Main Channel		
Subcatchment	Length (m)	Slope (m/m)	Roughness	Routing steps	Length (m)	Slope (m/m)
Tavistock Rd - D	603	0.020	0.05	5	1375	0.020
Tavistock Rd - E	509	0.034	0.05	5	872	0.034
Tavistock Rd - F	173	0.024	0.05	5	567	0.024
Tavistock Rd - G	53	0.039	0.05	5	350	0.039
Tavistock Rd - H	137	0.030	0.05	5	568	0.030
Tavistock Rd - I	151	0.044	0.05	5	304	0.044
Upper - Kop - A	463	0.169	0.05	5	1778	0.169

Table A.6: East of Levin Hydrological Parameters - River Reach Parameters

Reach Name	Length (m)	Slope (m/m)	Roughness	Index Celerity (m/s)
R - Gladstone Rd - A	646	0.0825	0.06	2
R - Gladstone Rd - C	1654	0.0786	0.06	2
R - Gladstone Rd - D	1166	0.1024	0.06	2
R - Lower Kop - C	213	0.0319	0.06	2
R - Lower - Kop - D	340	0.0249	0.06	2
R - Lower - Kop - E	514	0.0693	0.06	2
R - Lower - Kop - F	2664	0.0199	0.06	2
R - Mid - Upper - Kop - A	383	0.1237	0.06	2
R - Mid - Upper - Kop - A 1	1102	0.1397	0.06	2
R - Mid - Upper - Kop - B	884	0.1015	0.06	2
R - Mid - Upper - Kop - D	1049	0.0772	0.06	2
R - Mid - Upper - Kop - E	128	0.0277	0.06	2
R - Mid - Upper - Kop - G	524	0.0894	0.06	2
R - Mid - Upper - Kop - H	700	0.0700	0.06	2
R - Mid - Upper - Kop - J	431	0.0588	0.06	2
R - Mid - Upper - Kop - K	1446	0.0630	0.06	2
R - Mid - Upper - Kop - L	762	0.0670	0.06	2
R - Pott Rd - D	698	0.0519	0.06	2
R - Pott Rd - E	1048	0.0784	0.06	2
R - Pott Rd - F	743	0.0511	0.06	2
R - Pott Rd - G	762	0.0668	0.06	2
R - Pott Rd - J	851	0.0968	0.06	2
R - Pott Rd - K	1145	0.0965	0.06	2
R - Pott Rd - N	1310	0.1397	0.06	2
R- Mid - Upper - Kop - F	146	0.0581	0.06	2

Reach Name	Length (m)	Slope (m/m)	Roughness	Index Celerity (m/s)
R- Tavistock Rd - A	572	0.0515	0.06	2
R- Tavistock Rd - E	402	0.0785	0.06	2
R- Tavistock Rd - F	722	0.0345	0.06	2
R- Tavistock Rd - G	321	0.0380	0.06	2

Appendix B. Design Rainfall Depths

Table B.1: Mangaone Stream : Design Total Rainfall Depths

Subcatchment	Total Rainfall Depth (mm) (9 hour duration)		
Design Event	10-year RCP 6.0	100-year RCP 6.0	200-year RCP 6.0
Airport - A	62.9	83.5	108.1
Airstrip - A	65.3	87.7	114
Airstrip - B	65.1	87.4	113.3
Airstrip - C	63.9	85.8	111.5
Airstrip - D	64.3	86.4	112.1
Colyton Rd - A	64.3	86.2	111.8
Colyton Rd - B	62.9	84.3	109.3
Colyton Rd - C	64.4	86.3	111.8
Colyton Rd - D	63.7	85.3	110.8
Colyton Rd - E	64.2	85.8	111.2
Colyton West - A	62	83.2	108.3
Colyton West - B	61.9	82.6	107.3
Colyton West - C	62.3	83.1	107.8
Dixon Line - A	62.8	83.7	108.5
Dixon Line - B	62.5	83.4	108
Mangaone - A	66.3	88.8	115.5
Mangaone - B	65.8	88.2	114.2
Mangaone - C	64	86	111.7
Mangaone - D	62.4	83.7	108.9
Mangaone - E	62.1	83.3	108.3
Mangaone - F	62.3	83.4	108.3
Mangaone - G	62.4	83.4	108.3
Mangaone - H	61.9	82.7	107.3
Mangaone - I	66	87.6	113.3
Mangaone - J	62.1	82.6	106.9
Reid Line - A	64.2	85.9	111.3
Reid Line - B	64.2	85.8	111.3
Reid Line - C	62	82.8	107.5
Reid Line - D	63.2	84.3	109.1
Roberts Line - A	62.8	83.7	108.4
Valley Rd - A	65.5	87.8	114
Valley Rd - B	62.9	84.6	109.7
Valley Rd - C	65.5	87.9	114
Valley Rd - D	65.4	87.7	113.7

Subcatchment	Total Rainfall Depth (mm) (9 hour duration)		
Design Event	10-year RCP 6.0	100-year RCP 6.0	200-year RCP 6.0
Valley Rd - E	62.4	83.6	108.5
Valley Rd - F	62.1	83.4	108.3
Valley Rd - G	63.2	84.9	110.2
Valley Rd - H	62.6	84	109.2
Valley Rd - I	62.7	84.1	109.3
Valley Rd - J	63.3	85	110.3
Valley Rd - K	62.3	83.6	108.3

Table B.2: East of Levin : Design Total Rainfall Depths

Subcatchment	Total Rainfall Depth (mm) (3 hour duration)		
Design Event	10-year RCP 6.0	100-year RCP 6.0	200-year RCP 6.0
Gladstone Rd - A	52	79.9	87.8
Gladstone Rd - B	48.9	75.2	82.6
Gladstone Rd - C	50.6	77.8	85.6
Gladstone Rd - D	48.5	74.5	81.9
Gladstone Rd - E	52.2	80	88
Gladstone Rd - F	51	78.5	86.2
Lower - Kop - A	43.8	68	74.8
Lower - Kop - B	44.9	69.7	76.8
Lower - Kop - C	43.7	67.7	74.6
Lower - Kop - D	44	68.2	75.2
Lower - Kop - E	43.8	67.7	74.6
Lower - Kop - F	43.9	67.9	74.7
Mid - Upper - Kop - A	44.2	68.4	75.4
Mid - Upper - Kop - B	44.7	69	76
Mid - Upper - Kop - C	47.4	73.3	80.7
Mid - Upper - Kop - D	44.9	69.5	76.5
Levin East 2D Area	48.5	74.2	82.4
Mid - Upper - Kop - E	49.7	76.7	84.4
Mid - Upper - Kop - F	45.6	70.4	77.4
Mid - Upper - Kop - G	41.9	64.5	70.9
Mid - Upper - Kop - H	47.9	73.8	81.2
Mid - Upper - Kop - I	46.7	71.9	79.1
Mid - Upper - Kop - J	46.9	72.4	79.5
Mid - Upper - Kop - K	47	72.4	79.5

Subcatchment	Total Rainfall Depth (mm) (3 hour duration)		
Design Event	10-year RCP 6.0	100-year RCP 6.0	200-year RCP 6.0
Mid - Upper - Kop - L	45.5	70.1	77
Mid - Upper - Kop - M	44.8	69.1	76.1
Pott Rd - A	64.4	98.8	108.4
Pott Rd - B	61.7	94.7	104
Pott Rd - C	60.1	92.3	101.4
Pott Rd - D	53.1	82	90.2
Pott Rd - E	51	78.8	86.7
Pott Rd - F	53.5	82.4	90.6
Pott Rd - G	57.2	88.1	96.7
Pott Rd - H	57.1	87.7	96.3
Pott Rd - I	45.8	71	78.1
Pott Rd - J	48.1	74.4	81.9
Pott Rd - K	49.2	75.9	83.6
Pott Rd - L	45.4	70.3	77.4
Pott Rd - M	45.2	70	76.9
Pott Rd - N	45.2	70	76.9
Tavistock Rd - A	44.1	68.3	75.2
Tavistock Rd - B	44.4	68.7	75.5
Tavistock Rd - C	44.5	68.7	75.5
Tavistock Rd - D	44.7	68.9	75.9
Tavistock Rd - E	44.3	68.4	75.4
Tavistock Rd - F	44.2	68.4	75.3
Tavistock Rd - G	44.2	68.3	75.2
Tavistock Rd - H	44.1	68.1	74.9
Tavistock Rd - I	44.2	68.2	75
Upper - Kop - A	51.7	79.4	87.2
Levin East 2D Area	48.5	74.2	82.4

Appendix C. Subcatchment Initial Abstraction Parameters

Table C.1: Mangaone Stream : Inital Abstraction parameters

Subcatchment	Landuse	Hydrological Condition	CN	S	Initial Abstraction (mm)	Constant rate (mm/hr)
Airport - A	Pasture	Good	61	162.4	8.125	3
Airstrip - A	Pasture	Good	80	63.5	8.125	3
Airstrip - B	Pasture	Good	80	63.5	8.125	3
Airstrip - C	Pasture	Good	61	162.4	8.125	3
Airstrip - D	Pasture	Good	61	162.4	3.175	3
Colyton Rd - A	Pasture	Good	80	63.5	8.125	3
Colyton Rd - B	Pasture	Good	61	162.4	8.125	3
Colyton Rd - C	Pasture	Good	80	63.5	8.125	3
Colyton Rd - D	Pasture	Good	61	162.4	3.175	3
Colyton Rd - E	Pasture	Good	80	63.5	3.175	3
Colyton West - A	Pasture	Good	61	162.4	3.175	3
Colyton West - B	Pasture	Good	61	162.4	3.175	3
Colyton West - C	Pasture	Good	80	63.5	8.125	3
Dixon Line - A	Pasture	Good	61	162.4	8.125	3
Dixon Line - B	Pasture	Good	61	162.4	3.175	3
Mangaone - A	Pasture	Good	61	162.4	8.125	3
Mangaone - B	Pasture	Good	61	162.4	8.125	3
Mangaone - C	Pasture	Good	61	162.4	8.125	3
Mangaone - D	Pasture	Good	61	162.4	8.125	3
Mangaone - E	Pasture	Good	61	162.4	8.125	3
Mangaone - F	Pasture	Good	61	162.4	8.125	3
Mangaone - G	Pasture	Good	61	162.4	8.125	3
Mangaone - H	Pasture	Good	61	162.4	8.125	3
Mangaone - I	Pasture	Good	61	162.4	3.175	3
Mangaone - J	Pasture	Good	80	63.5	3.175	3
Reid Line - A	Pasture	Good	61	162.4	8.125	3
Reid Line - B	Pasture	Good	61	162.4	8.125	3
Reid Line - C	Pasture	Good	80	63.5	3.175	3
Reid Line - D	Pasture	Good	61	162.4	3.175	3
Roberts Line - A	Pasture	Good	61	162.4	8.125	3
Valley Rd - A	Pasture	Good	80	63.5	8.125	3
Valley Rd - B	Pasture	Good	80	63.5	8.125	3
Valley Rd - C	Pasture	Good	80	63.5	3.175	3
Valley Rd - D	Pasture	Good	80	63.5	8.125	3

Subcatchment	Landuse	Hydrological Condition	CN	S	Initial Abstraction (mm)	Constant rate (mm/hr)
Valley Rd - E	Pasture	Good	80	63.5	3.175	3
Valley Rd - F	Pasture	Good	61	162.4	3.175	3
Valley Rd - G	Pasture	Good	61	162.4	8.125	3
Valley Rd - H	Pasture	Good	80	63.5	3.175	3
Valley Rd - I	Pasture	Good	61	162.4	8.125	3
Valley Rd - J	Pasture	Good	80	63.5	3.175	3
Valley Rd - K	Pasture	Good	61	162.4	8.125	3

Table C.2: East of Levin : Inital Abstraction parameters

Subcatchment	Landuse	Hydrological Condition	CN	S	Initial Abstraction (mm)	Constant rate (mm/hr)
Gladstone Rd - A	Woods-Grass	Good	79	67.5	3.4	3
Gladstone Rd - B	Pasture	Good	61	162.4	8.1	3
Gladstone Rd - C	Woods	Good	77	75.9	3.8	3
Gladstone Rd - D	Woods-Grass	Good	58	183.9	9.2	3
Gladstone Rd - E	Woods-Grass	Good	79	67.5	3.4	3
Gladstone Rd - F	Woods-Grass	Good	79	67.5	3.4	3
Levin - A	Row Crops (SR+CR)	Good	75	84.7	4.2	3
Levin - B	Pasture	Good	61	162.4	8.1	3
Levin - C	Pasture	Good	61	162.4	8.1	3
Levin - D	Pasture	Good	61	162.4	8.1	3
Levin - E	Pasture	Good	61	162.4	8.1	3
Levin - F	Pasture	Good	61	162.4	8.1	3
Levin - G	Pasture	Good	61	162.4	8.1	3
Levin - H	Pasture	Good	61	162.4	8.1	3
Levin - I	Pasture	Good	61	162.4	8.1	3
Levin - J	Pasture	Good	74	89.2	4.5	3
Levin - K	Row Crops (SR+CR)	Good	82	55.8	2.8	3
Levin - L	Row Crops (SR+CR)	Good	82	55.8	2.8	3
Levin - M	Pasture	Good	74	89.2	4.5	3
Levin - N	Row Crops (SR+CR)	Good	82	55.8	2.8	3
Levin - O	Row Crops (SR+CR)	Good	75	84.7	4.2	3
Levin - P	Pasture	Good	74	89.2	4.5	3
Levin - Q	Pasture	Good	61	162.4	8.1	3
Lower - Kop - A	Pasture	Good	61	162.4	8.1	3

Subcatchment	Landuse	Hydrological Condition	CN	S	Initial Abstraction (mm)	Constant rate (mm/hr)
Lower - Kop - B	Pasture	Good	74	89.2	4.5	3
Lower - Kop - C	Pasture	Good	74	89.2	4.5	3
Lower - Kop - D	Pasture	Good	74	89.2	4.5	3
Lower - Kop - E	Pasture	Good	61	162.4	8.1	3
Lower - Kop - F	Pasture	Good	61	162.4	8.1	3
Mid - Upper - Kop - A	Pasture	Good	74	89.2	4.5	3
Mid - Upper - Kop - B	Pasture	Good	61	162.4	8.1	3
Mid - Upper - Kop - C	Pasture	Good	74	89.2	4.5	3
Mid - Upper - Kop - D	Pasture	Good	74	89.2	4.5	3
Mid - Upper - Kop - E	Pasture	Good	74	89.2	4.5	3
Mid - Upper - Kop - F	Pasture	Good	74	89.2	4.5	3
Mid - Upper - Kop - G	Pasture	Good	61	162.4	8.1	3
Mid - Upper - Kop - H	Pasture	Good	61	162.4	8.1	3
Mid - Upper - Kop - I	Row Crops (SR+CR)	Good	82	55.8	2.8	3
Mid - Upper - Kop - J	Pasture	Good	61	162.4	8.1	3
Mid - Upper - Kop - K	Pasture	Good	61	162.4	8.1	3
Mid - Upper - Kop - L	Pasture	Good	61	162.4	8.1	3
Mid - Upper - Kop - M	Pasture	Good	61	162.4	8.1	3
Pott Rd - A	Pasture	Good	80	63.5	3.2	3
Pott Rd - B	Pasture	Good	80	63.5	3.2	3
Pott Rd - C	Pasture	Good	80	63.5	3.2	3
Pott Rd - D	Pasture	Good	74	89.2	4.5	3
Pott Rd - E	Pasture	Good	61	162.4	8.1	3
Pott Rd - F	Pasture	Good	61	162.4	8.1	3
Pott Rd - G	Pasture	Good	61	162.4	8.1	3
Pott Rd - H	Woods-Grass	Good	79	67.5	3.4	3
Pott Rd - I	Pasture	Good	61	162.4	8.1	3
Pott Rd - J	Pasture	Good	74	89.2	4.5	3
Pott Rd - K	Woods-Grass	Good	58	183.9	9.2	3
Pott Rd - L	Row Crops (SR+CR)	Good	75	84.7	4.2	3
Pott Rd - M	Pasture	Good	61	162.4	8.1	3
Pott Rd - N	Row Crops (SR+CR)	Good	82	55.8	2.8	3
Tavistock Rd - A	Pasture	Good	74	89.2	4.5	3
Tavistock Rd - B	Row Crops (SR+CR)	Good	75	84.7	4.2	3
Tavistock Rd - C	Pasture	Good	61	162.4	8.1	3
Tavistock Rd - D	Pasture	Good	61	162.4	8.1	3

Subcatchment	Landuse	Hydrological Condition	CN	S	Initial Abstraction (mm)	Constant rate (mm/hr)
Tavistock Rd - E	Pasture	Good	61	162.4	8.1	3
Tavistock Rd - F	Pasture	Good	61	162.4	8.1	3
Tavistock Rd - G	Pasture	Good	61	162.4	8.1	3
Tavistock Rd - H	Pasture	Good	61	162.4	8.1	3
Tavistock Rd - I	Pasture	Good	61	162.4	8.1	3
Upper - Kop - A	Woods-Grass	Good	79	67.5	3.4	3
Mid - Upper - Kop - M	Pasture	Good	61	162.4	8.1	3