Oroua and Manawatu Rivers

Flood Hazard Assessment

Hydraulic Modelling and Mapping

Horizons Regional Council

Final Report
April 2008

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Final Report

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1 INTRODUCTION

1.1 Background

The Manawatu region suffered severe flooding in February 2004, which resulted in large financial losses and social disruption. The area around Palmerston North was severely affected with major rivers flowing near bank full capacity and smaller rivers experiencing extreme flows, which overtopped and broke through stopbank protection systems.

Figure 1-1 Flooding south of Glen Oroua in February 2004, direction south east (Source: Horizons Regional Council)

Horizons Regional Council (HRC) engaged DHI Water & Environment to assess the risk of flooding due to high water levels in the Oroua River, in the reaches between Fielding and the confluence with the Manawatu River with concurrent flod events in the Managaone Stream and Manawatu River. The model study area incorporates the following: the area immediately west of the Oroua River from Fielding to the confluence with the Manawatu River; the area immediate west of the city of Palmerston North (studied in a previous project, see Ref./1/); and the Manawatu River from Teachers' College to Moutoa floodgates. The model area extends from Fielding and Bunnythorpe in the north to Moutoa floodgates in the south, covering an area of approximately 250 km^2.

1.2 Approach

HRC have supplied DHI with a high-accuracy land level data set acquired by an airborne laser survey (ALS, or LiDAR) of the entire study area. The availability of such data lends itself to a two-dimensional modelling approach, in which the land level data is used as the topographic input for the overland and floodplain flow model. Because the study area also includes a number of large drains and small streams, a traditional one-dimensional model has also been used in order to capture important flow characteristics of these channels. The two models – 2D floodplain model and 1D channel model, are dynamically linked to form a combined model describing in detail the complete physical flow characteristics in the study area.

1.3 Projections and Datum

All models have been built to NZMG map projection and levels refer to the Wellington datum. Where required conversions from Moturiki datum have been applied with a +76 mm correction as advised by HRC.

2 PHYSICAL DESCRIPTION

2.1 Setting

The study area covers the middle to lower reaches of the Manawatu-Oroua river system, including the Mangaone-Taonui system, the Makino River, (a triburary of the Oroua) and the drainage system of the lower Oroua.

The Manawatu River is the second largest river in the North Island in terms of flow. It forms the south-eastern border of the Mangaone-Taonui Basin and bounds suburban Palmerston North to the east. The river is braided and is extensively stopbanked, with internal stopbanks to stabilise the shape of the river and control flow direction during high-flow events. Flood relief is provided by the Hamiltons Line spillway, which spills excess flood flows into the Taonui Basin.

The Oroua River forms the western border of the Mangaone-Taonui catchment. It originates in Ruahine Range in the north and flows in a south-westerly direction, joining the Manawatu River near Opiki. Important tributaries in the lower reaches of the river include the Kiwitea Stream, which enters the Oroua upstream of Fielding, and the Makino Stream, which enters the Oroua upstream of the SH3 bridge at its crossing in Awahuri. Left and right bank stopbanks begin just downstream of the SH3 bridge and run to the confluence with the Manawatu River. Lowered left bank stopbanks at Kopane and Rangiotu form spillways to mitigate downstream flooding.

The Mangaone-Taonui catchment is located to the north, west and south of Palmerston North and covers a combined area of 330 km^2. The upper catchments are located at higher elevations up to just over 300 m, in contrast to the lower half of the catchment where the land levels range between 8-20 m.

The Mangaone Stream is the largest watercourse in the Mangaone-Taonui catchment, draining an area of approximately 157 km^2, eventually discharging to the Manawatu River just south of the city. The Mangaone is stopbanked from approximately 5 km upstream of Palmerston North to the Manawatu confluence. High flows in the Mangaone are diverted away from the main population centre via a spillway located upstream of the city at Flygers Line.

The Taonui stream is located to the west of the Mangaone and drains the remaining catchment to a low lying area known as the Taonui Basin. The basin is bordered by the Oroua stopbanks to the west and the Manawatu stopbanks to the south and east. The basin has been developed for agriculture through the construction of large drainage channels, of which Main Drain and Burkes Drain form the backbone. These join and eventually discharge to the Manawatu River via a set of large floodgates near Rangiotu.

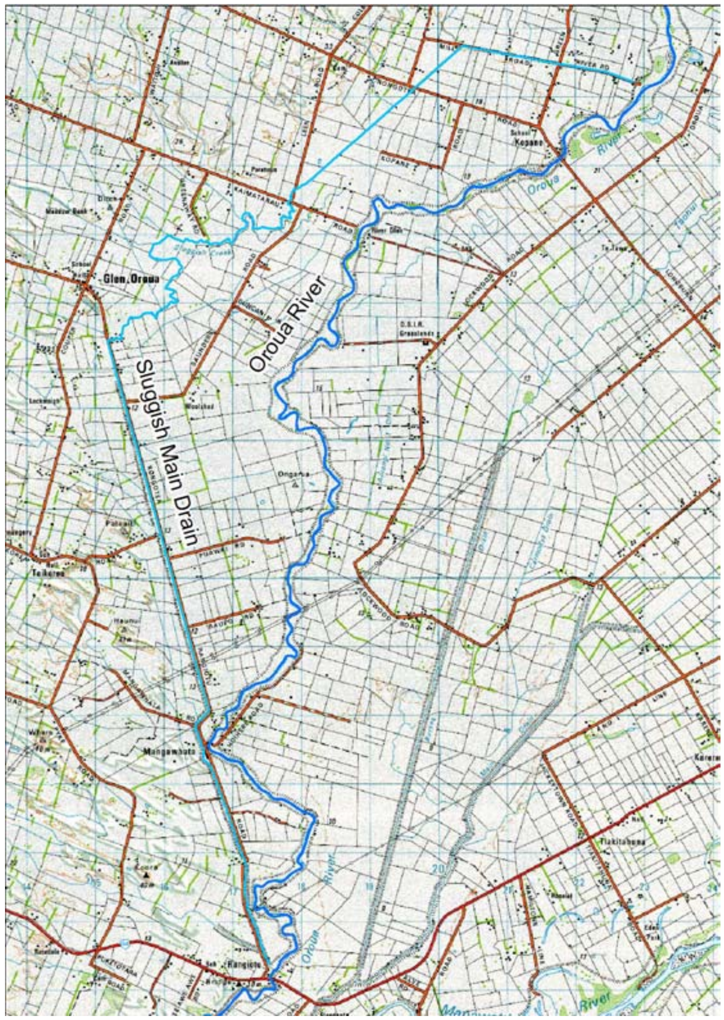


Figure 2-1 Sluggish Main Drain Location in relation to the Oroua River.

The Sluggish Main Drain is located on the right bank of the lower Oroua River, refer to
Figure 2-1. It comprises an engineered channel in its upper reach with its head at River Road, a natural channel in the middle reach from Kimatarau Rd and an engineered channel beside Rongotea Road to the Rangiotu floodgates, where it discharges into the Oroua. This channel drains the surrounding farmland and is important in returning breakout flows from the Oroua right bank back to the river.

2.2 Rainfall

Hydrological modelling for the contributing catchments has been carried out in a previous study (see Ref./1/ for a detailed description). Results from this modelling have been used directly in the present study.

2.3 Flood Behaviour

Both the Manawatu and Oroua Rivers have been highly modified, through the construction of stopbanks on both left and right banks in the middle and lower reaches. The existing Manawatu stopbanks are designed to a 100-year ARI standard and the Oroua River stopbanks are currently being upgraded from a 1:50 year AEP to a 1:100yr AEP design.

The Taonui Basin is used as flood detention storage for excess floodwaters originating in the Mangaone, Oroua and Manawatu Rivers. Floodwaters enter the basin via a number of constructed spillways comprising the Flygers Line spillway on the Mangaone, Hamilton's Line on the Manawatu and Kopane and Rangiotu spillways, both on the Oroua. In past flood events the basin has also received floodwaters from overtopping and breaching of the Oroua and Mangaone stopbanks. Local runoff contributes to, but is not the major cause of, flooding in the Taonui Basin.

Figure 2-2 Oroua River spilling over the Rangiotu Spillway, 2004 (Photo courtesy of www.ourregion.co.nz)

Controlled spills from the Mangaone Stream into the upper Taonui basin occur when water levels in the river exceed a threshold large enough to activate a series of gates built into the Flygers Line spillway, see Figure 2-3. Floodwaters travel overland, joining the local runoff in Whiskey Creek, and eventually enter the Taonui Basin. Similarly, spills from the Kopane spillway travel overland and through local drainage channels before reaching the basin. The Hamilton's Line and Rangiotu spillways discharge directly into the lower basin.

Figure 2-3   Mangaone Spillway, looking downstream

Drainage from the Taonui basin occurs via Burkes Drain through the Rangiotu floodgates. The gates close when the water levels in the Manawatu rise higher than the levels in the drain.

Flooding on the upper Oroua (downstream of Fielding) and Makino Stream occurs when water levels exceed natural bank levels. Downstream of Awahuri, the Oroua is stopbanked, in places with both low summer banks and higher winter banks. Flood releases take place on the left bank via the Kopane and Rangioutu spillways.

Downstream of Kopane floodwaters have previously broken out from the Oroua caused by overtopping and subsequent failure of constructed stopbanks. Floodwaters are ultimately drained through Sluggish Creek, also known as Sluggish Main Drain in its downstream reaches where it has been formed into a stopbanked, engineered channel. Flap-gated side drains deliver water from the surrounding farmland. The Sluggish Main Drain floodgates (Figure 3-4) prevent backflows from the Oroua at the downstream end of the engineered channel.

3 HYDRODYNAMIC MODEL BUILD & CALIBRATION

3.1 Model Description

The hydrodynamic model comprises separate 1D and 2D models, dynamically linked to enable full exchange of flows between the two model domains. The modelling software used is MIKE 11 for the 1D component and MIKE 21 for the 2D component. The coupling between the two is provided via MIKE FLOOD (MF), see Ref./3/. The Mangaone-Taonui model, (see Ref./1/), was used as the base model. This base model was augmented with additional MIKE 11 models of the Manawatu and Oroua Rivers. The Manawatu MIKE 11 model was developed and provided by HRC, while the Oroua model was developed by Opus for a previous study (Ref./2/). The 2D domain was extended to include the right bank of the Oroua.

3.2 Channel Selection – 1D or 2D?

The 1D model component is necessary to enable important drainage and channel networks to be accurately represented in the combined model. As a general rule, channels less than 3-5 grid squares in width cannot be adequately resolved in a 2D grid. In addition, where channels are embanked, or include important hydraulic structures; these need to be represented in the 1D model.

The study area in the upper reaches and particularly around Sluggish Main Drain includes many fine drainage channels which are observable in the LIDAR data. The decision to include these smaller channels in the 1D model was made based on the importance to the overall drainage of the area. Channels were included in the 1D model where they were seen to play an important role in the overall conveyance capacity of the floodplain, but were too small to be resolved accurately in the 2D model grid, which has a cell size of 25 m x 25 m.

The following description relates to the augmentation, extension and development of the pre-existing 25 m model. For a description of the development of the base model see Ref./1/.

3.3 Physical Description

The model study area covers approximately 260 km^2, and is bounded to the north and north east by the North Island Main Trunk Railway, to the south east by the Manawatu -lright-bank stopbanks and to the west by hills lying directly to west of the Oroua right bank stopbanks.

Topographic relief with the 2D model area varies from approximately 70 m in the north west to less than 10 m in the Taonui Basin and less than 3 m near the Moutoa floodgates, which form the downstream boundary of the model.

3.4 Methodology and Data Availability

The LiDAR dataset provided by HRC formed the basis for the development of both the 1D and 2D models. A 1 m-resolution DEM was generated by Phil Wallace from 1 km x 1 km flow-enforced TINs. The resulting data set differs slightly from the data provided for the earlier study (Ref./1/) due to small 1 m x 2 m horizontal displacement error in the earlier data, which has been corrected in the new data set.

In addition to the land level data, HRC has previously provided a wide range of GIS datasets including roads and railways, stopbanks, watercourses, soil types, land use, topo maps, and aerial photography.

HRC also provided previously developed MIKE 11 models, including result files, of the Manawatu and Oroua Rivers. Both models have previously been calibrated to the 2004 flood event, to varying degrees of accuracy.

HRC also provided surveyed cross sections of Sluggish Main Drain. However as the data are more than 20 years old, it was decided to extract sections from the DEM instead.

3.5 MIKE 11 Model Build

3.5.1 MIKE 11 Model Domain

The MIKE 11 model build process has been significantly complicated by the fact that the components of the final model have come from four different sources and comprise six interconnected major branches. Appendix A contains a summary of all the branches in the model and their respective sources. Figure 3-1 shows an overview of the layout of the 1D MIKE 11 branches incorporated into the final MIKE FLOOD model.

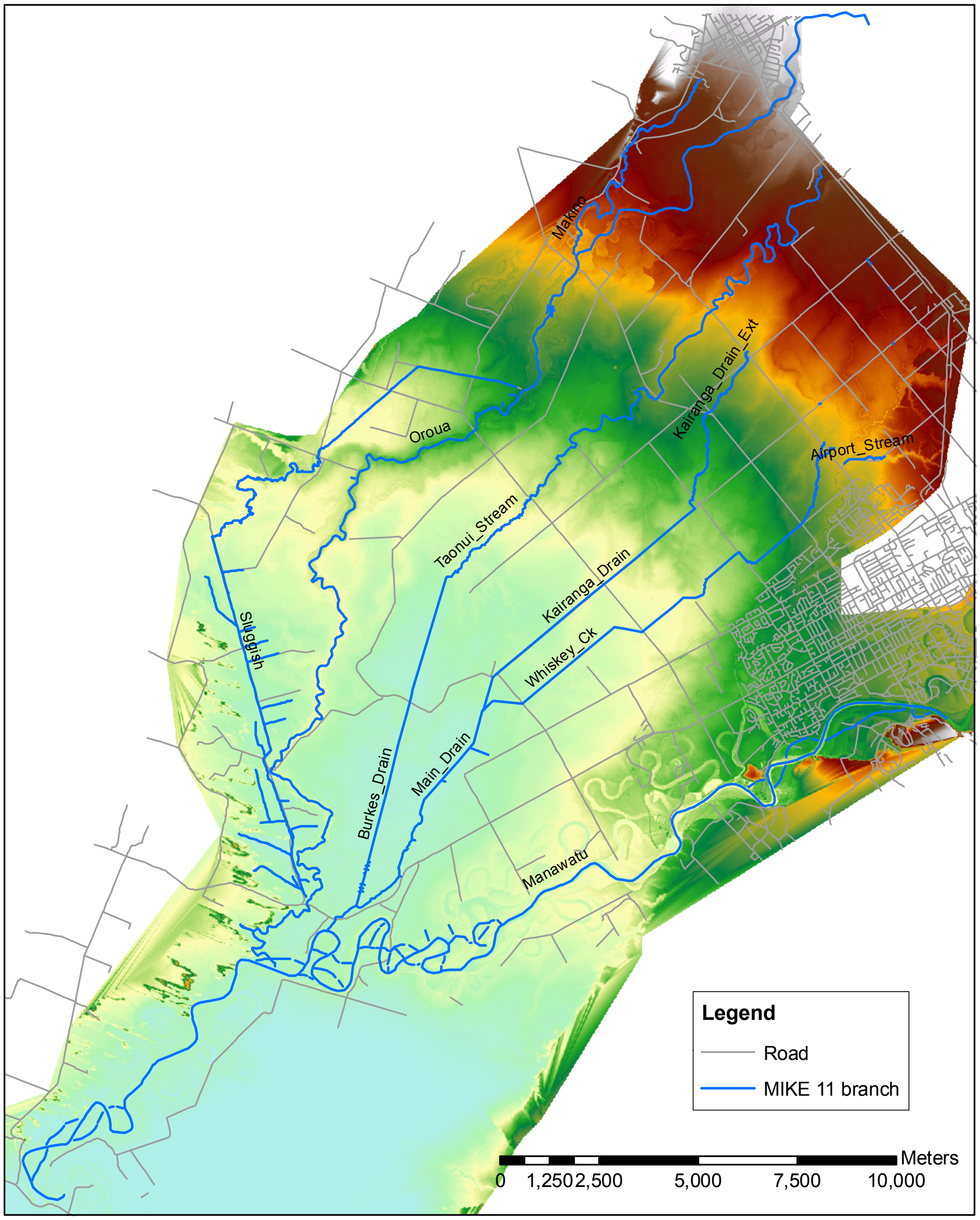


Figure 3-1 Overview of MIKE 11 model with major branches labelled.

The major rivers included in the MIKE 11 model include the Manawatu River, from Teachers College to Moutoa floodgates and the Oroua River from Fielding to the Manawatu conflucence.

Within the Taonui Basin, the important drainage channels, included as MIKE 11 branches, are the Taonui Stream, Burkes Drain, Main Drain, Whiskey Creek, and Kairanga Drain. The Mangaone Stream is not included in the model, as this is embanked for most of its length within the model area, and therefore interacts to only a limited degree with other parts of the drainage network. For a more detail description of the setup of the Mangaone Stream and other drainage entities in the Taonui Basin catchment refer to /1/.

On the Oroua right bank, the Makino Stream, Sluggish Main Drain and important side drains have been included. Side drains are connected to Sluggish Main Drain via flap-gated culverts.

3.5.2 Cross Sections

MIKE 11 cross sections throughout the model are derived from field surveys or by extraction from the 1 m DEM.

Oroua River

The Oroua River is the main focus of this study and is the most complicated in terms of model build. All cross sections have been taken from the post-February 2004 cross section database, which was created by Opus for the Oroua River Investigation project, see Ref /2/. The post-February-2004-event cross sections have been used to calibrate the model to the February 2004 event, as discussed with HRC . This is based on the assumption that significant transport of river sediment occurs on the rising limb of the river flood wave. Note however that the Opus calibration of this event is based on cross sections which were surveyed prior to 2004, see section 7.3 of Ref./2/.

Complications arose during the model build as the original MIKE 11 Oroua model contains a network of three channels comprising a main channel connected to left and right flood berms. This description was used to represent most of the length of the Oroua. Modification of berm channel width and roughness was used to compensate for 2D flow effects further complicating the model schematization. In order to simplify the model for this study and make it possible to dynamically link the 1D and 2D models, the berm channels were removed and the main channel bank markers widened to include the berm channels.

The river surveys, carried out after the February-2004 event, did not include every previously-surveyed location. Therefore older surveyed cross sections have been included to provide a more detailed representation of the river. In order to account for the significant changes in river bed levels that occurred during the 2004 flood the pre 2004 survey sections have been modified by linearly interpolating the thalweg level from cross sections surveyed after the flood event. This modification was performed by Opus, however it was carried out separately for the two berm channels and the main channel by altering the vertical datums for the three separate channels.

In the model constructed for the present study, the berm channels have been removed so the level modifications are instead directly applied to the portions of the composite channel representing the berm while separately allowing for vertical datum shifts of the main channel if neccessary. Figure 3-2 provides an example of this operation. The grey lines represent the original cross section, while the black lines are the modified result. The main channel has degraded while the berms have aggraded by different amounts. Note that the bank marker levels, representing the top of the stopbanks, have been altered so that they match the original cross section levels. The top of the outer stopbanks and the internal summer stopbanks are assumed to not have changed in height since the previous field survey.

Modification of berm levels has only been carried out for cross sections between chainages -28750 and -1175. Outside of these reaches only the main channel is modelled in 1D and the berms are modelled in 2D. Many of the cross section surveys carried out after February 2004 only covered the main channel area and therefore berms from older surveys have been spliced in to complete the cross section. Therefore a cross section that appears to have been surveyed in 2004 may include older data for the berms.

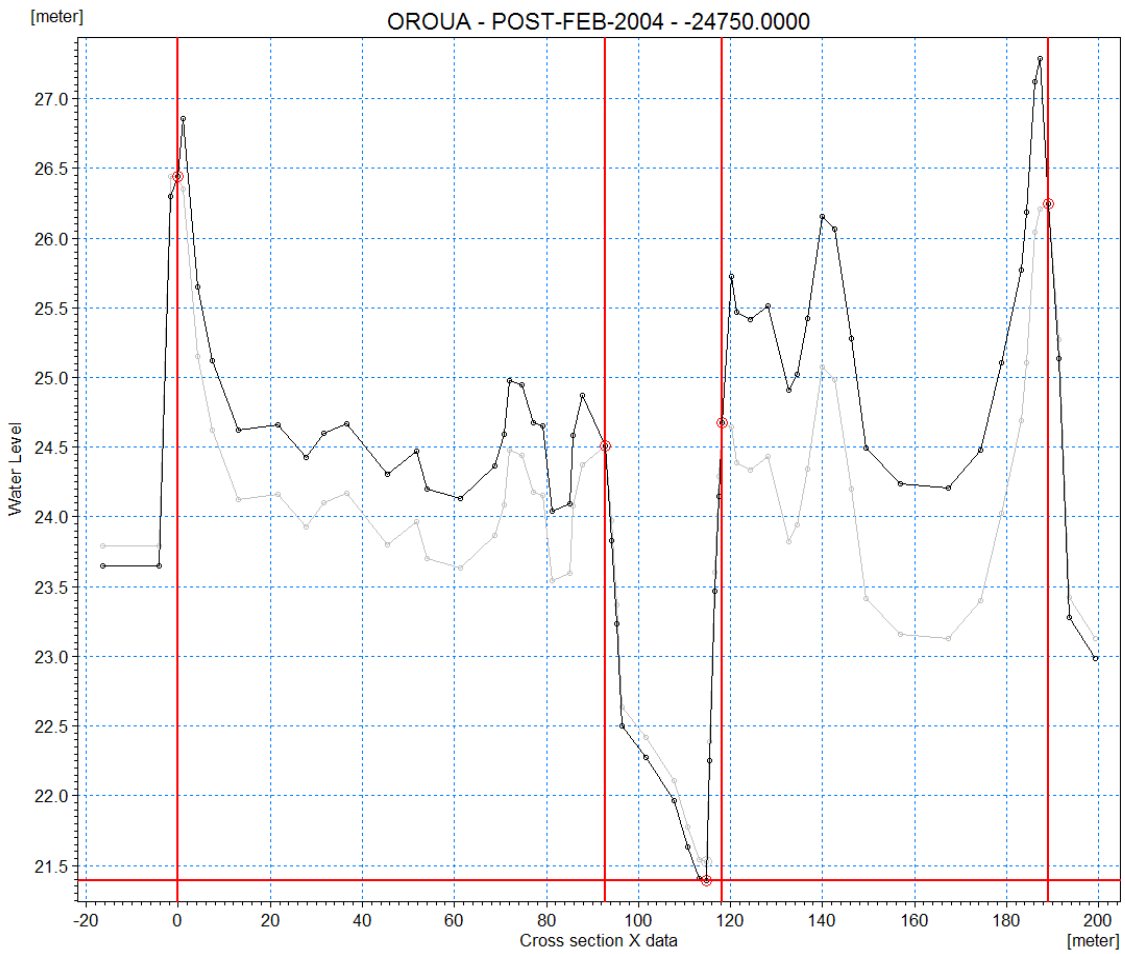


Figure 3-2 Oroua River cross section. Pre-2004 survey shown in light grey and post-2004 modified cross section in black. Red circles identify bank markers used in the hydraulic model to define the channel extent and top of stopbank.

The last level modification made to the Oroua cross sections was the addition of 76 mm to the vertical datum to convert from Moturiki to Wellington datum.

The Manning roughnesses for the main channel from the Opus MIKE 11 model has been adopted for the entire channel, including the berms. The original model used different roughnesses for the main and berm channels. The roughnesses for the latter vary rapidly between 0.014 and 0.05. The roughness used in the main channel in the final model ranges from 0.05 at Fielding to 0.036 at the confluence with the Manawatu.

Manawatu River

Cross sections for the Manawatu branch have been taken from the model provided by HRC, which has been calibrated to the 2004 event. Due to limitations in modelling berm channels in 1D models, the cross sections have been modified by HRC and additional storage areas introduced to account for the additional flooded area. The only connections to other model components are located at the Hamiltons Line spillway, Burkes Drain confluence, and the Oroua confluence.

Sluggish Main Drain

Cross section databases for the Sluggish Main Drain containing surveyed data have been supplied by HRC. After inspection of the databases, it was decided to extract the cross sections from the 1 m DEM for the following reasons:

- field surveys were carried out in the mid eighties and there were uncertainties about the level of correspondence between the cross section levels and the LIDAR survey levels, which would become important at the flood model coupling stage;
- the spacings of the cross sections was not consistent;, and
- there are uncertainties about the locations of the field surveys beyond the upstream extent of the engineered channel as they did not seem to follow the natural channel.

Upon extraction of the cross sections from the DEM a rough comparison could be made with the survey data. In most places the cross section match is reasonable as can be seen in Figure 3-3. A raised bed level in the channel in the extracted cross section could be explained by siltation or the channel being full of water at the time of the LiDAR survey. No adjustment has been made to the bed levels of the extracted cross sections.

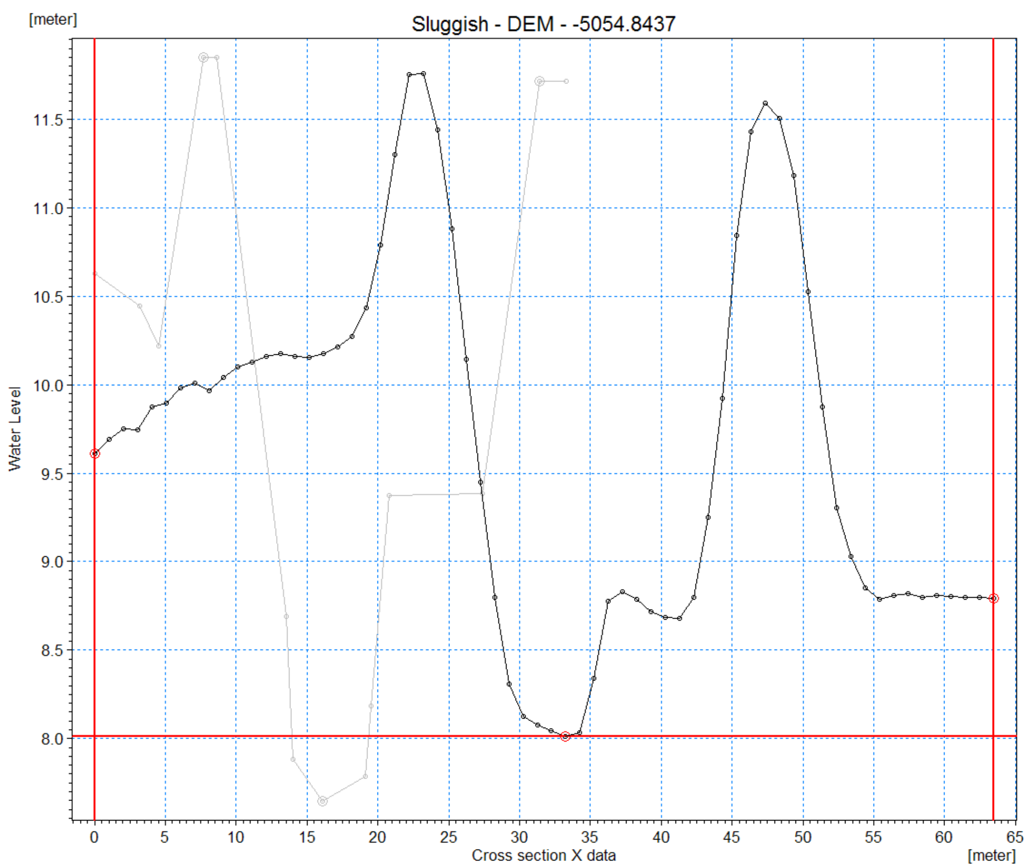


Figure 3-3 Comparison of a cross sections for Sluggish Main Drain; the greyed one from the mid-eighties, HRC field survey and the black one extracted from the 1 m DEM.

Makino Sream
The Makino cross sections have been extracted from the 1 m DEM as no pre-existing surveys were available. In order to ensure an increasing channel conveyance in the downstream direction, the vertical datums of neighbouring cross sections have been adjusted. This modification was necessary due to the narrowness and close spacing of the cross sections and eliminates large energy spikes and improves the quality of the numerical solution.

For all river branches, cross sections have been interpolated or copied, where required, for the purposes of connecting to the 2D model. Lateral linkages require cross sections to be defined at the beginning and end of each branch and extra cross sections are required at locations where the 1D model transitions from a non-laterally-linked reach to a laterally-linked reach.

3.5.3 Structures

All structures that existed in the original Mangaone-Taonui model have been retained in the expanded model, as well as structures in the original Manawatu MIKE 11. New structures, which have been added to the model include:17 circular culverts connecting Sluggish Main Drain and its side drains, and two rectangular culverts to represent the upper and lower doors of the Sluggish Main Drain flood gates, see Figure 3-4. All culverts act as flap gates and only allow flow in the downstream direction. The geometry of the flood gate was taken from a drawing supplied by HRC. The Sluggish Main Drain side drain culverts have been given an estimated diameter of 1 m.

Figure 3-4 Downstream aspect of Sluggish Main Drain flood gates.

Five dam-break structures were included in the original Oroua MIKE 11 model. Investigation of the water levels along the Oroua in the 200-year ARI flood event identified three areas of stopbank that are vulnerable to overtopping and subsequent failure. These have been added to the ARI models and the flooding simulated. In the calibration model the dam-breaks are triggered to initiate at observed times, whereas in other simulations the failure is triggered by a river water level 300 mm greater than the crest level. Table 3-1 summarises the important attributes. The Kimatarau Road breach is excluded from the ARI-event simulation as the failure, during the February 2004 event, was due to geotechnical failure, which is not expected to reoccur.

Table 3-1 Dam-break structures locations and attributes.

Name	Oroua Chainage (m)	Side of River	Crest Level (m)	Final Breach Width (m)	Included in Simulation and Triggering Method		
					Calibration	ARI	ARI + additional breaches
Kimatarau Breach	-20490	Left	21.266	80	Yes - Time	No	No
Kopane Breach	-24815	Right	26.324	30	Yes - Time	Yes - Level	Yes - Level
River Rd Breach1	-25540	Right	28.066	10	Yes - Time	Yes - Level	Yes - Level
River Rd Breach2	-26300	Right	29.066	75	Yes - Time	Yes - Level	Yes - Level
Awahuri Breach	-28880	Left	35.016	90	Yes - Time	Yes - Level	Yes - Level
OrouaBreachCh-24760R	-24760	Right	26.328	40	No	No	Yes - Level
OrouaBreachCh-24660R	-24660	Right	25.7	50	No	No	Yes - Level
OrouaBreachCh-3530R	-3530	Right	13.049	50	No	No	Yes - Level
OrouaBreachCh-1250L	-1250	Left	13.3	100	No	No	Yes - Level

See Figure 3-5 and Figure 3-6 for dam-break locations

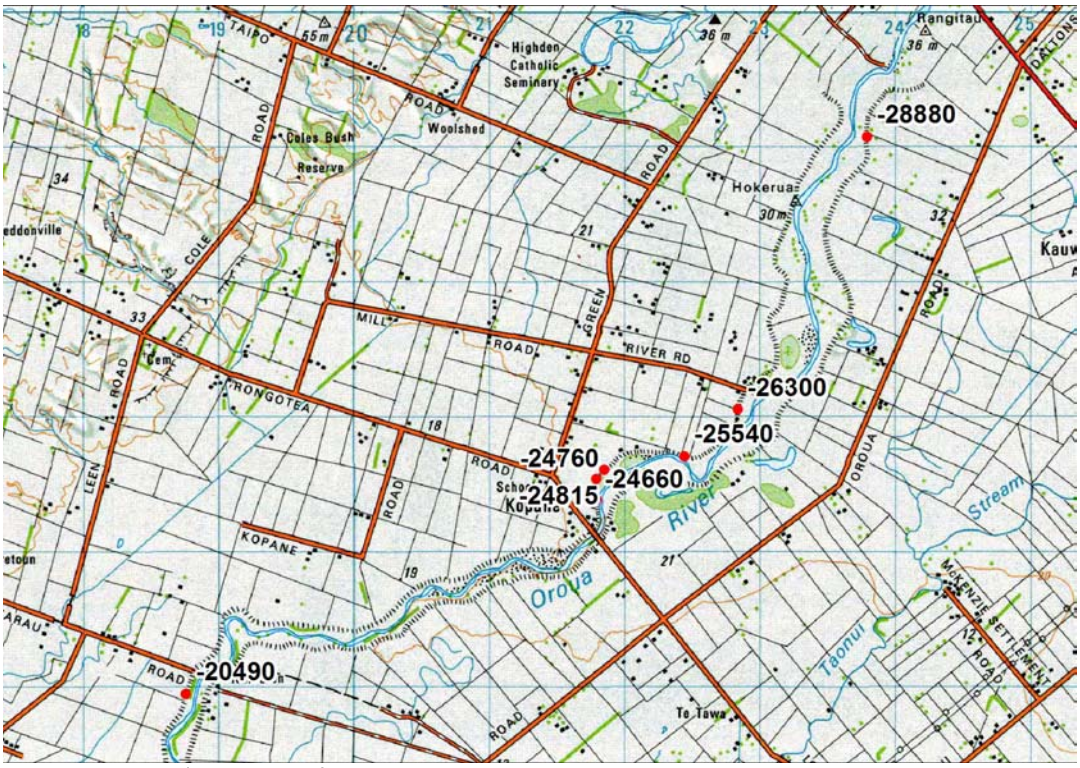


Figure 3-5 Map of the middle Oroua River with stopbank breach locations modelled using MIKE 11 dam-break structures.

Figure 3-6 Map of the lower Oroua River with stopbank breach locations modelled using MIKE 11 dam-break structures.

Crest levels for the additional dam-break structures have been taken from the MIKE 11 stopbank crest levels except for the dam-breaks at chainages -1250 and -24660 where the LiDAR level is seen as more accurate.

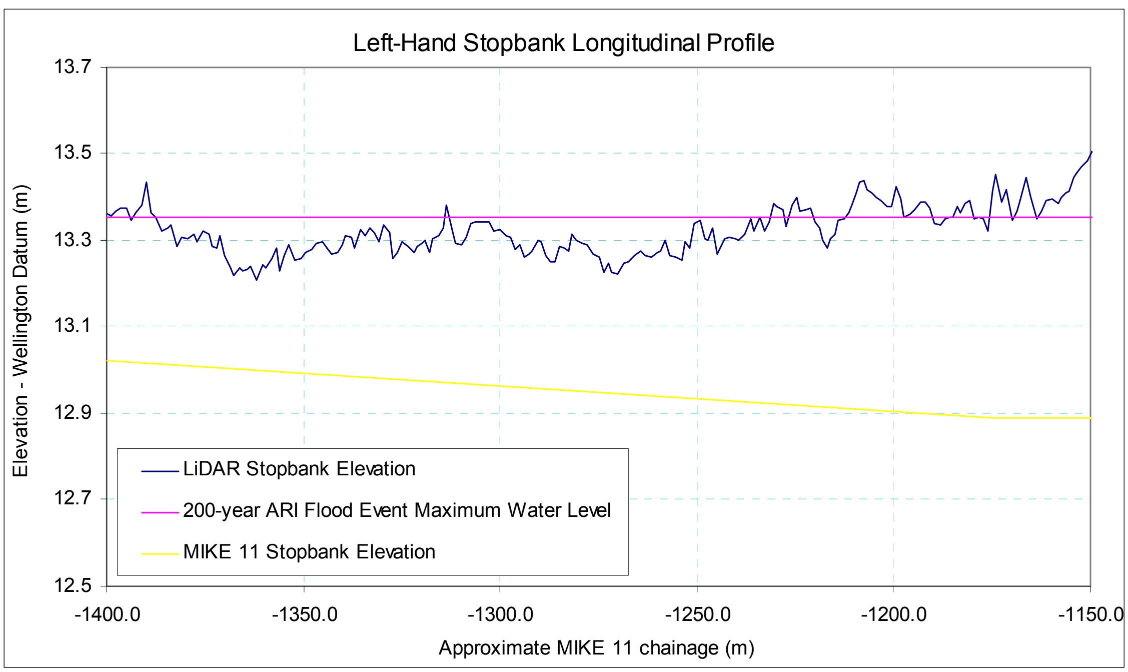


Figure 3-7 Left-hand Oroua River stopbank near location of dam-break structure at chainage -1250.

The LiDAR has been used at chainage -1250 as the MIKE 11 left bank crest level appears to be too low. This decision is backed up by the fact that the water level in the calibration model exceeds the left bank level at this location, however no spilling was observed along this reach.

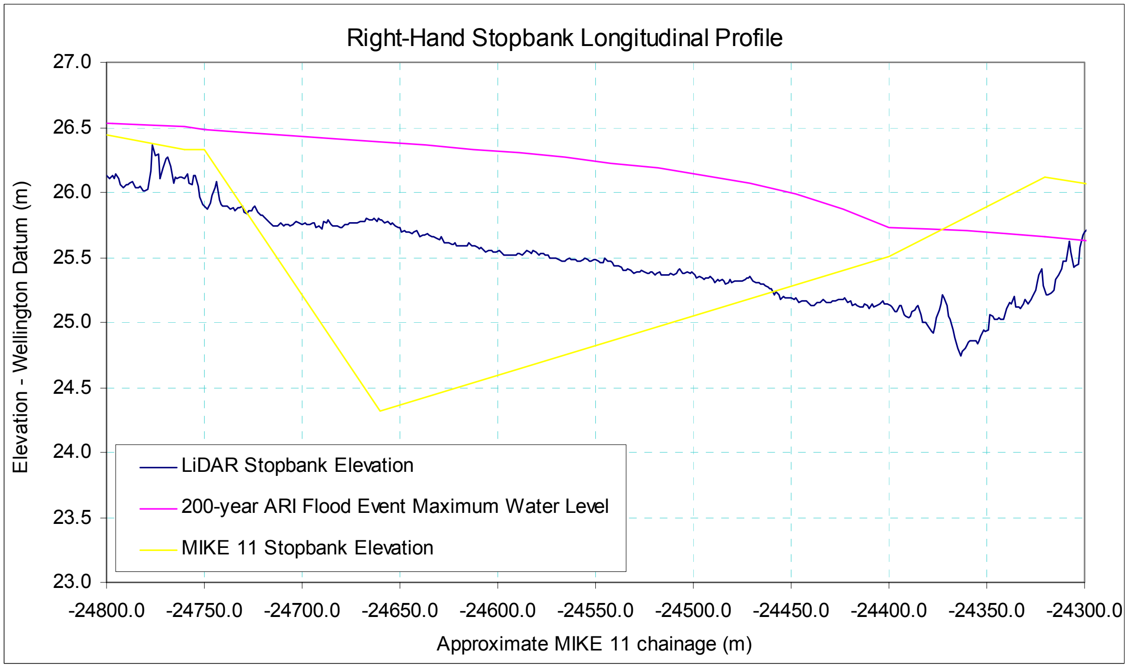


Figure 3-8 Right-hand Oroua River stopbank near location of dam-break structure at chainage -24660.

The LiDAR has been used at chainage -24660 as the MIKE 11 left bank crest level appears to be too low. Inspection of the cross section shows that the right stopbank has not been included in the survey.

3.5.4 Boundaries and Catchment Connections

Inflows to the MIKE 11 model come from a number of sources: the calibrated rainfall-runoff model, which was produced in the Mangaone-Taonui study, gauged flow data and derived flows. All boundary conditions for the calibration event (February 2004) and design events (100- and 200-year return period), excluding the rainfall-runoff results, have been provided by HRC.

Aside from pre-existing boundaries from the Mangaone-Taonui model, there are four new, external boundaries:

- upstream inflow into the Oroua (gauged flow);
- upstream inflow into the Makino at the Rata St. gauge (gauged flow);
- inflow into the Manawatu upstream of Teachers' College gauge (gauged flow); and
- rating curve applied at downstream boundary of the Manawatu River , which takes into account the flood mitigation effect of the Moutoa flood gates.

The Kiwitea-stream discharge has been included as a point source on the Oroua, located at chainage -42350. This discharge has been derived by HRC from the Oroua inflow. It has been scaled up and retarded by 3 hours, as can be seen in Figure 3-9.

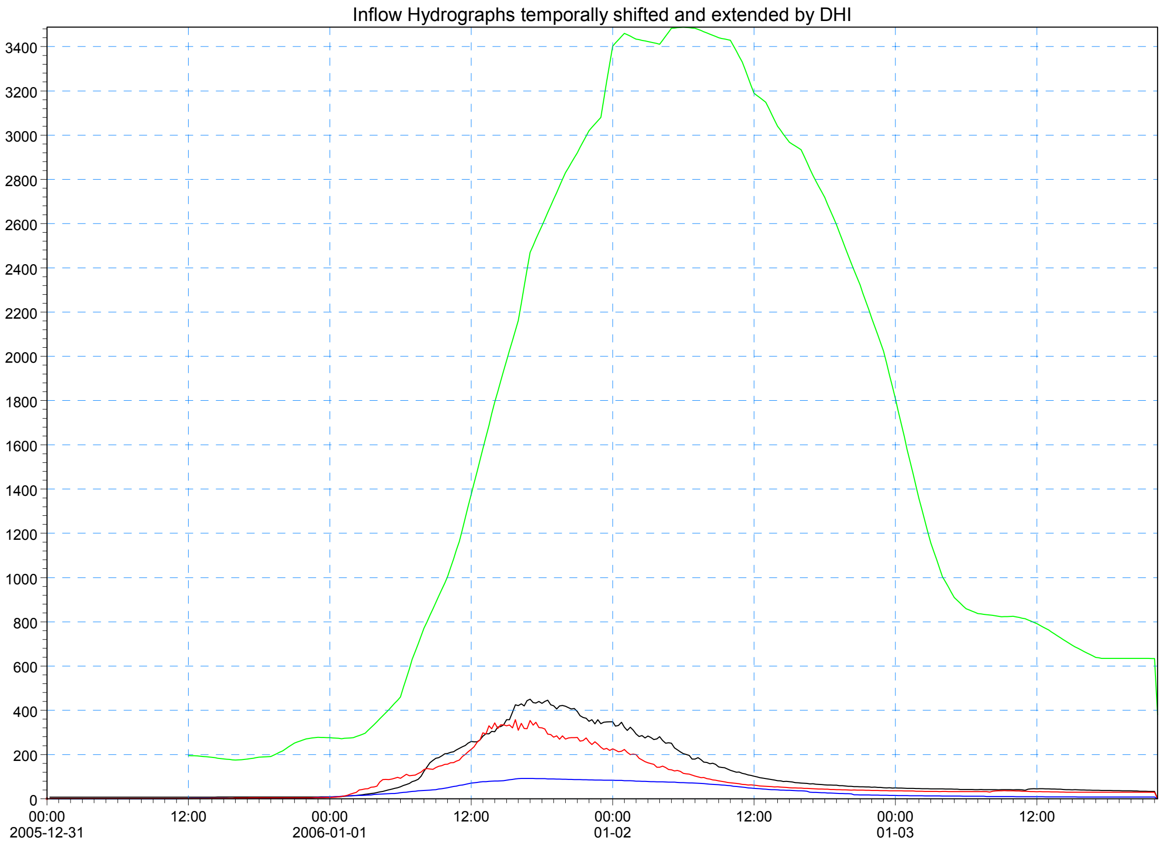


Figure 3-9 Inflow boundary conditions: Manawatu River (in green), Oroua River (in red), Kiwitea Stream (in black), and Makino Stream (in blue).

The downstream water level boundary of Burkes Drain has been replaced with a direct connection to the Manawatu River branch.

3.6 MIKE 21 Model Build

3.6.1 MIKE 21 Model Domain

The MIKE 21 model domain has been extended to include the Oroua right bank floodplain. Refinement to the model area has been made, after initial simulations, to reduce the size of the domain to only flood affected areas in order to reduce the model simulation time. In the previous study (see Ref /1/.), a model grid size of 25m had been selected as a reasonable compromise between model resolution and practical model run times. The extended model grid incorporates 810 x 961 cells on a 25 m grid, ie 535,000 cells in total, of which 419,086 are active (non-land) points.

3.6.2 Topography and Features

The process of developing the 2D topography model was undertaken in two steps. Firstly, a single 25 m grid was produced from the 1 m grid (supplied by Philip Wallace in four tiles), which encompassed the whole model area. Secondly, the newly created grid was overwritten in the Mangaone-Taonui area by the 25 m grid generated for the previous study, thus maintaining the road and stopbank features which had been manually added in previously. The composite grid thus produced reflected the development of the previous model and the enlarged extent of the new data.

Within the extended model area, many fine grid features, such as embankments and roads to the west of the Oroua, were lost in the interpolation to the 25 m grid size. Within the study area, particularly in the lower part, the presence of embankments and roads will have an important effect on the floodplain flows. It is therefore essential that these features are represented accurately in the model.

The process in which these features are introduced back into the model grid is known as "burning in" and briefly involves the following:

- accurate digitization of embankment and road crest alignments;
- extraction of the underlying DEM values and conversion to 3D GIS layers;
- conversion of the 3D layers to raster coverages matching the model grid;
- replacing the interpolated model grid with the digitized grid; and
- infilling of "holes" in the model grid, for example between river stopbanks.

This is a time-consuming process, but the result is a 2D model grid that is hydraulically correct, as it includes all of the land features that will affect the hydraulic behaviour of the overland flow.

In addition to the features already included in the previous Taonui-Basin model, roads and stopbanks adjacent to the Oroua and Manawatu rivers have been burned into the 2D grid. The final grid levels have been spot checked against the original 1 m grid data to verify the burning in process has captured the important floodplain features.

3.6.3 Catchment Inflows

Catchment inflows have been maintained the same as the previously developed Mangaone-Taonui model. For details see Ref./2/. No additional local catchments have been included in the model, as the local drainage runoff in the extended model areas is not considered significant for the flood events being considered.

3.6.4 Boundaries

The 25 m MIKE 21 model does not contain any open boundaries. Inflows to the model take place either through direct sources as described above, or from the MIKE 11 model via the MIKE FLOOD link. Outflows take place only through the MIKE 11 model linkages.

3.6.5 Hydraulic Resistance

A 2D hydraulic resistance map has been derived from the land use GIS layer supplied by HRC. Land uses types were mapped to various hydraulic resistances (Manning numbers) based on experience and accepted use in the industry. The adopted mapping is shown in Table 3-2. The vast majority of the floodplain in the study area is grassland and therefore is assigned a Manning n of 0.05. Pockets of urban development, forest or shelterbelts are assigned a value of 0.125. The final resistance map is shown in Figure 3-10.

Table 3-2 Adopted hydraulic resistance based on land use types

Description (LCDB2)	Code	n	M
High Producing Exotic Grassland	40	0.050	20
Pine Forest - Closed Canopy	66	0.125	8
Manuka and or Kanuka	52	0.125	8
Pine Forest - Open Canopy	65	0.125	8
Indigenous Forest	69	0.125	8
Orchard and Other Perennial Crops	32	0.125	8
Built-up Area	1	0.010	10
Short-rotation Cropland	30	0.050	20
Vineyard	31	0.125	8
Broadleaved Indigenous Hardwoods	54	0.125	8
Other Exotic Forest	67	0.125	8
Urban Parkland / Open Space	2	0.033	30
River	21	0.020	50
River and Lakeshore Gravel and Rock	11	0.020	50
Gorse and or Broom	51	0.125	8
Afforestation (imaged, post LCDB 1)	63	0.125	8
Deciduous Hardwoods	68	0.125	8
Lake and Pond	20	0.020	50
Major Shelterbelts	61	0.125	8
Surface Mine	3	0.050	20
Transport Infrastructure	5	0.100	10
Afforestation (not imaged)	62	0.125	8
Low Producing Grassland	41	0.050	20
Mixed Exotic Shrubland	56	0.050	20
Forest Harvested	64	0.125	8

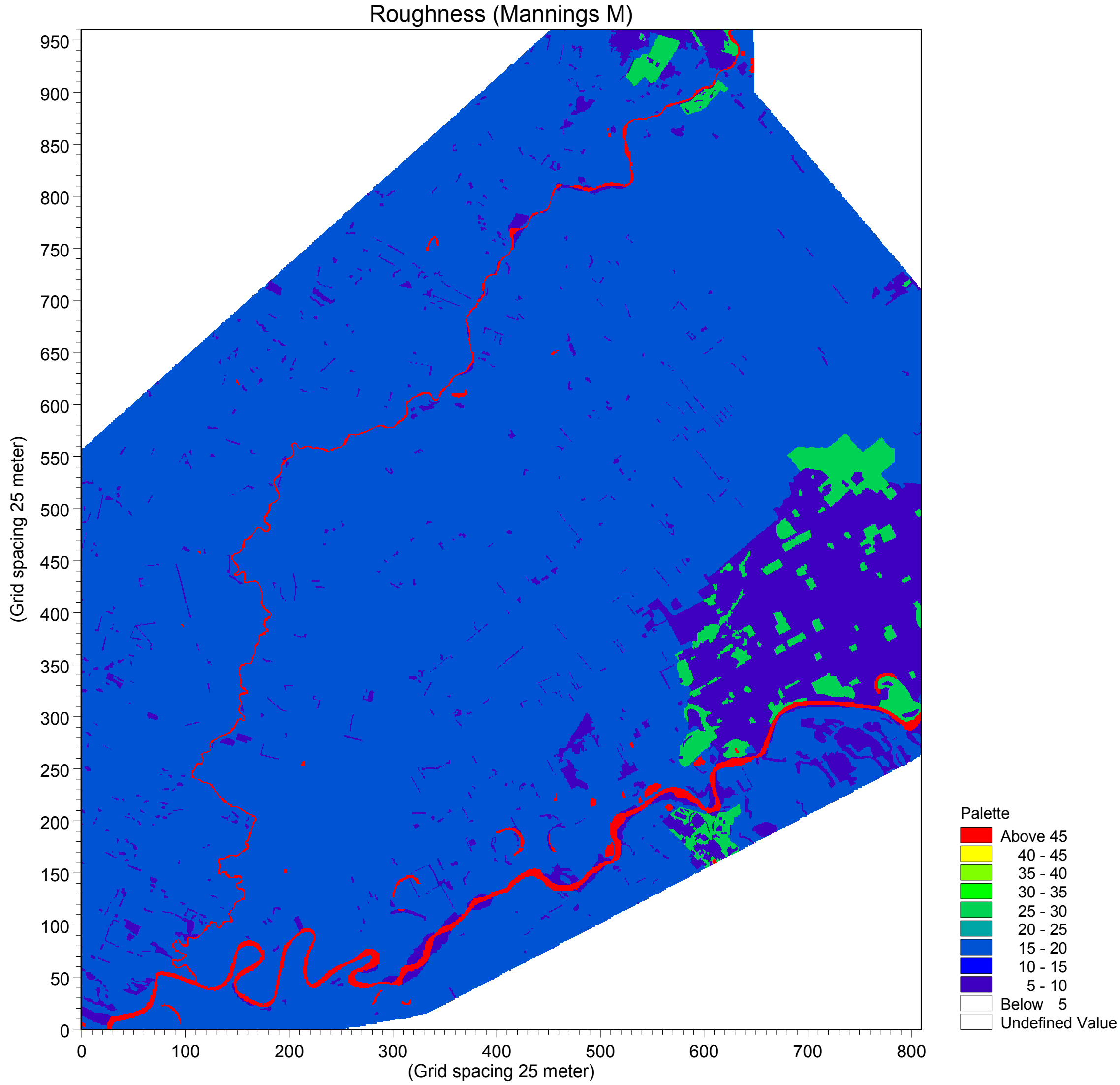


Figure 3-10 Generated hydraulic roughness map (M = 1/n)

3.7 MIKE FLOOD Model Build

3.7.1 Linkages

Dynamic linkages between the MIKE 11 and MIKE 21 models are achieved through the specification of each link in the MIKE FLOOD interface. MIKE FLOOD allows three types of linkages:

Standard – a MIKE 11 branch end is linked to one or more MIKE 21 cells
Lateral – a range of MIKE 11 chainages is linked to a range of MIKE 21 cells
Structure – a MIKE 11 structure is specified to add to or replace the flows across two adjacent MIKE 21 cells

In total, 176 separate linkages have been implemented in the final 2004 calibration model. This includes those developed in the previous model plus new lateral links along the Makino, upper Oroua and Sluggish Main Drain (including side drains) as well as standard links (representing flap gates) on the Sluggish Main Drain side drain branches.

3.7.2 Kopane and Rangiotu Spillways

The Kopane and Rangiotu Spillways have been included in the final MIKE FLOOD model because of their importance to flooding in the Taonui Basin and the behaviour of the Oroua River.

Kopane Spillway. This spillway is located on the left bank of the Oroua River between MIKE 11 chainages -26750 and -26420. The Opus Oroua MIKE 11 model schematised this spillway as two separate link channels connected to Oroua River chainages -26745 and -26525. Both channels were 220 m wide and the upstream and downstream link channels had bed levels of 29.21 m and 28.66 m respectively. The MIKE FLOOD model uses a lateral link to connect the MIKE 11 model to the MIKE 21 grid. The MIKE 21 grid elevations define the spilling structure crest levels. Grid levels have been taken from field surveys supplied by HRC. The datum of the original survey data is Moturiki. Initially a correction of +0.076 m has been applied to convert the levels to Wellington datum. It has since been decided to lower the spillway levels in the model by 100 mm to increase the spilling discharge to match that provided by HRC for the previous study (see Ref./1/). The peak and total volume of spillway discharge has proved insensitive to this adjustment and the levels have been left in this modified state. A visual comparison of the placement of spilling structures in the MIKE 11 and MIKE FLOOD models is depicted in Figure 3-11.

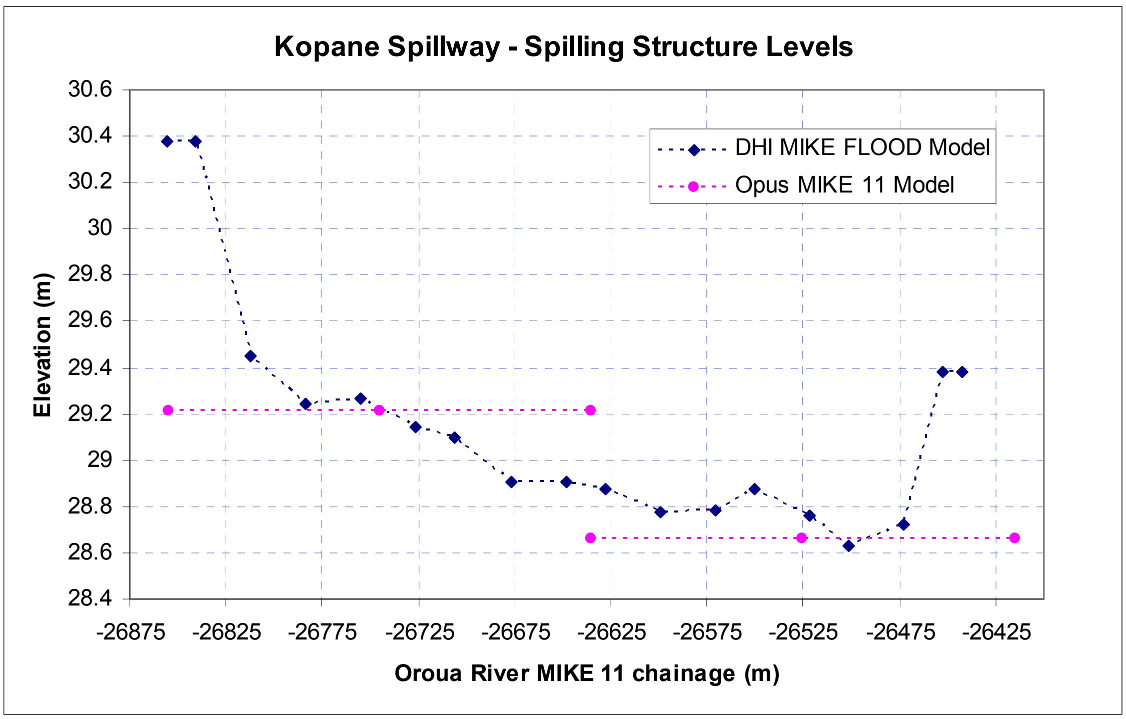


Figure 3-11 Comparison of Kopane spillway structure bed levels from Opus's MIKE 11 model and DHI's MIKE FLOOD model.

Rangiotu Spillway. This spillway is located on the left bank of the Oroua River between MIKE 11 chainages -6530 and -4630. The Opus Oroua MIKE 11 model schematised this spillway as six separate link channels connected to Oroua River chainages -5680, -5480, -5280, -5080, -4880 and -4680. All channels are 200 m wide and have bed levels, from upstream to downstream, of 12.918 m, 13.06 m, 12.721 m, 12.576 m, 12.595 m, and 12.505 m respectively. The MIKE FLOOD model uses a lateral link to model the spillway similar to the one used at the Kopane spillway as described above. The crest levels are taken directly from the MIKE 21 grid with no adjustment. Figure 3-12 shows the comparison of structure crest level placement between the MIKE 11 and MIKE FLOOD models.

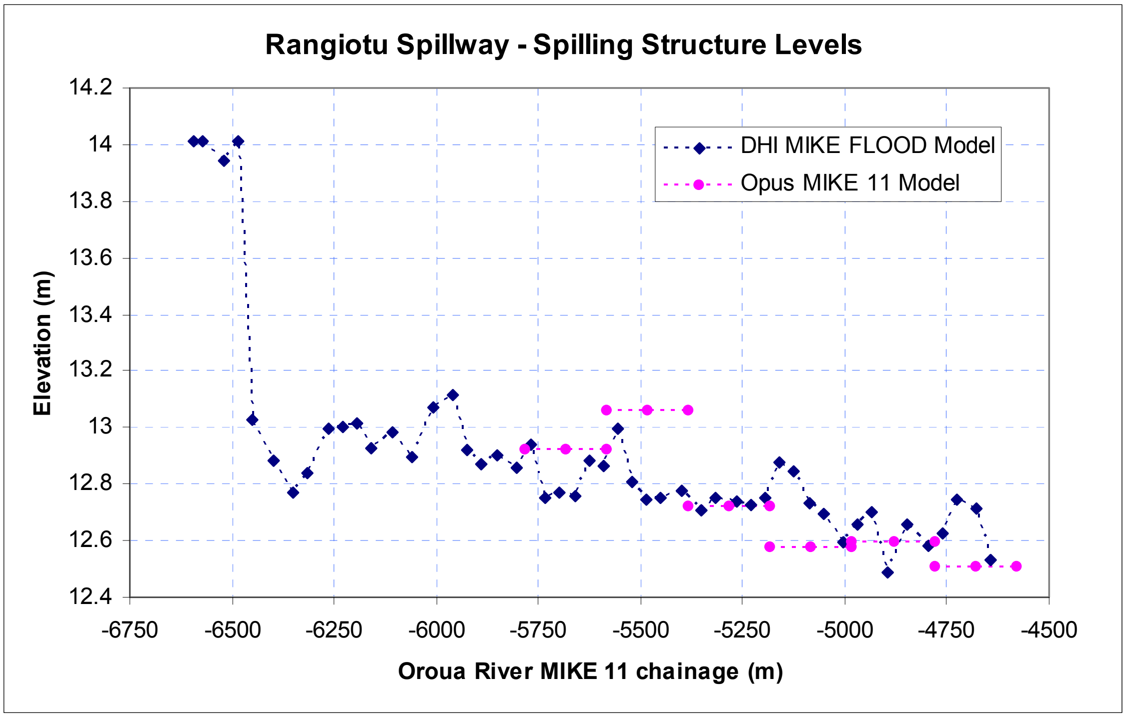


Figure 3-12 Comparison of Rangiotu spillway structure bed levels from Opus's MIKE 11 model and DHI's MIKE FLOOD model.

Hamilton's Line Spillway. The spillway is modelled by two channels, which connect the Manawatu River and adjacent floodplain in the Taonui Basin. The downstream connection links directly to chainage 49600 and the upstream channel connects to a berm channel. The spillway is represented in these channels by weirs, which have crest levels of 15.12 and 15.3. The floodplain end of the channels are dynamically coupled to M21 grid cells.

3.7.3 Model Simulations

The coupled models are run with a 1.5 second timestep and results are saved every 30 minutes. The model simulations take approximately 9 days on a HPxw4300 3.8GHz computer. Model runs times are affected by the number of flooded cells and the number and density of MIKE FLOOD links. Lateral links in particular have a significant affect on model run times. MIKE 21 result files are approximately 1.7GB in size. A reduction in timestep to 1 s was required for the design simulations due to numerical instability.

3.8 Model Validation

The validation of the combined MIKE FLOOD model was undertaken after the initial 100-year-design-event simulations proved to be inconsistent with expectations of the HRC staff. No modification of Mannings numbers have been made to the original river models, which have been calibrated separately. The 100-year model was modified by swapping the Oroua cross sections for those that were surveyed after the February 2004 flood event, including the Kimatarau Road dam-break structure, setting all breaches to initialise at set times and changing boundary conditions. Results were discussed at a meeting with HRC in Palmerston North and via email. As a result a number of minor changes were made to the model based on verification data and anecdotal evidence.

The verification data provided by HRC, which pertain to the February 2004 flood event, include:

- observed flood extents as GIS layers (digitized from aerial photographs);
- spot levels obtained by HRC for the 2004 flood in both the Taonui Basin and along the Oroua River. These have been produced from aerial photos and interviews with local residents; and
- MIKE 11 result file from the Manawatu model, which was built and calibrated by HRC.

An attempt has been made to calibrate the model, although uncertainty concerning inflow boundaries, modelled cross sections, and the accuracy of the observations together with the complexity of the system and the long simulation times has made a more detailed calibration infeasible. Therefore the comparison to observed data can be considered a validation only. As a consequence, care must be taken when interpreting model results for design runs. Results of the validation for the floodplain and Oroua River are presented and discussed below.

3.8.1 Floodplain Inundated Extent

A map showing the maximum simulated water level and extent compared to the observed extent is shown in Drawing 1 in Appendix B. In general, the flood extent is reproduced to a reasonable degree by the model. Areas of concern include:

- both sides of the Oroua downstream of the SH54 crossing (the right bank shows too much overtopping and the left bank shows too little);
- Taonui Stream where the model predicts no flooding; and
- a second flow crossing of Milson's Line predicted by the model, located northwest of the observed road inundation.

Simulated water levels at locations of observations in the Taonui Basin ponding area vary in agreement with observations between approximately 0.5 m too low to 0.4 m too high. The ponding in the basin reached a peak of 9.66 m, which is 0.05 m higher than the simulated peak water level in the previous Mangaone-Taonui study (ref. /1/). There are doubts regarding the accuracy of some of the spot level observations which have been addressed in the previous study.

Despite the agreement of water levels in the Taonui Basin with previous modelling, the distribution of flows into the basin is quite different. Figure 3-13 and Figure 3-14 contain discharge timeseries for the Rangiotu and Kopane spillways and include timeseries provided by HRC for the Mangaone-Taonui study, the discharge extracted from the MIKE 11 results that were provided with the Opus Oroua model, and the extracted discharge from the final MIKE FLOOD calibration simulation. At both spillways the MIKE FLOOD model produces a significantly lower peak discharge than those provided by HRC, however the Rangiotu spillway flow is higher than the Opus prediction.

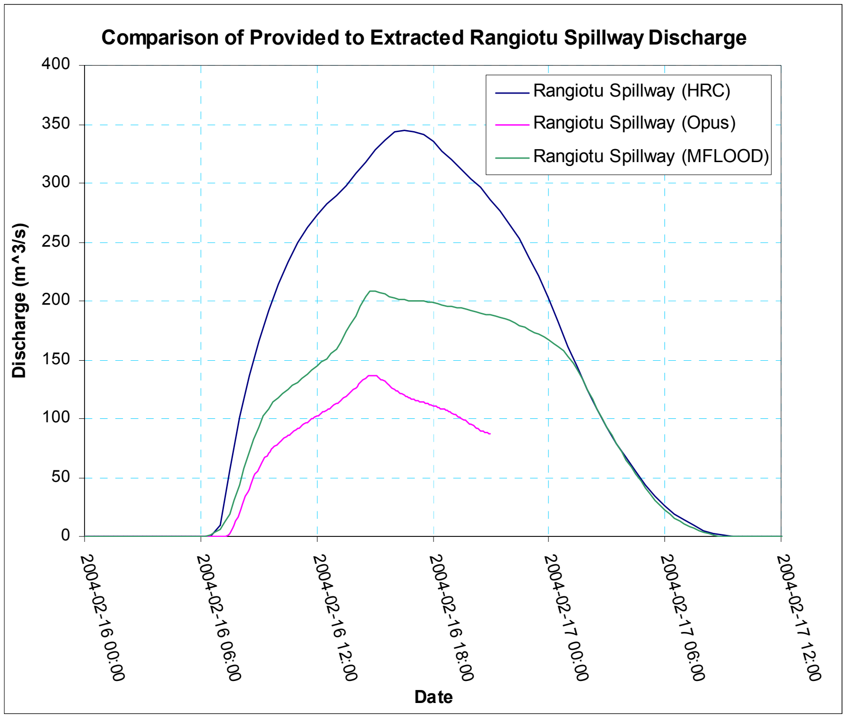


Figure 3-13 February 2004 Rangiotu Spillway Discharges from HRC (blue), Opus MIKE 11 model (magenta), and MIKE FLOOD model (green). Note that the Opus MIKE 11 discharge is truncated due to a shortened simulation period.

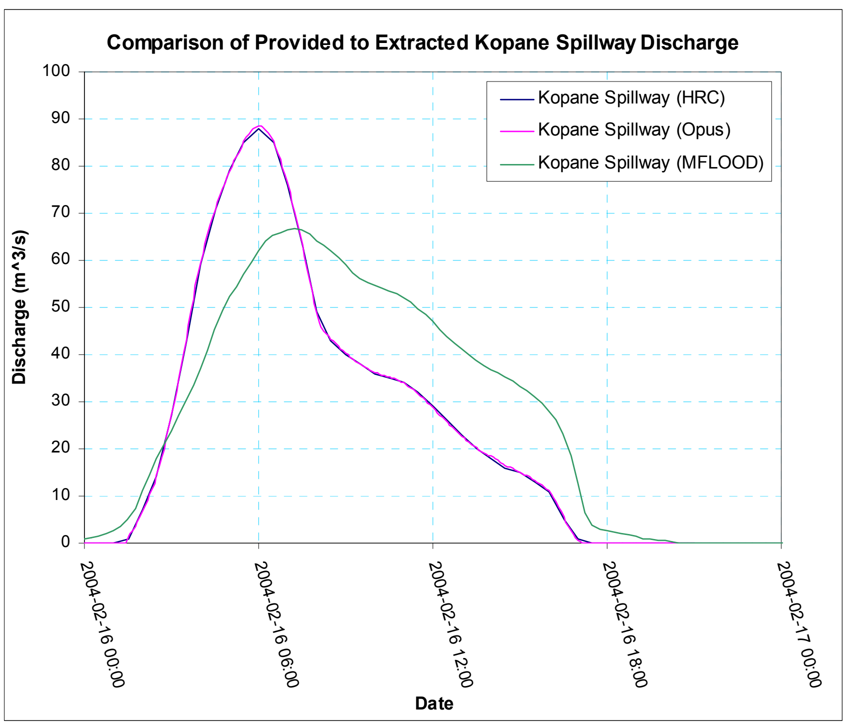


Figure 3-14 February 2004 Kopane Spillway Discharges from HRC (blue), Opus MIKE 11 model (magenta), and MIKE FLOOD model (green).

Table 3-3 shows the total spill volumes of the Kopane and Rangiotu Spillways for the timeseries presented in Figure 3-13 and Figure 3-14. The Rangiotu spillway discharge extracted from the Opus model is not included, as the timeseries is truncated.

Table 3-3 Accumulated Discharge from Kopane and Rangiotu Spillways.

Spillway	Accumulated Discharge (m^3)		
	HRC	Opus (MIKE 11)	MIKE FLOOD
Kopane	2,127,600	2,134,169	2,481,581
Rangiotu	18,406,800	-	11,902,955
Total	20,534,400	-	14,384,536

When comparing the results of this study to those of the previous study (see Ref./1/) the peak water level in the Taonui Basin is only 0.05 m higher. However, as can be seen in Table 3-3 there is a difference of 6.1 million cubic metres of water discharged into the Taonui Basin from the constructed spillways. The difference is made up by increased spilling from the Oroua River upstream of Awahuri. Flooding along the left bank of the Oroua downstream of Te Arakura Road matches the observed flood extent reasonably well although water levels are up to 0.85 m lower than observed, which suggests that even more water than predicted by the MIKE FLOOD model may have flowed down this flood path during the 2004 calibration event. If further investigation supports this finding then infrastructure in this flood path will be subject to greater flood damage than previous studies suggest.

Observed spot levels are not available to the west (right bank) of the Oroua. The model results have been compared to the observed flood extent, with the model showing a good agreement to the observations. See Drawing 1, Appendix B.

3.8.2 Oroua River Levels

As the focus of this study is flooding on the right bank of the Oroua, this part of the model has received considerable attention. Calibration data for the Oroua River consists of 48 peak water levels that have been either recorded by HRC staff soon after the event or estimated based on anecdotal evidence of local residents. The latter type is regarded as less reliable. The following discussion of the comparison of observed levels to simulated water levels, presented in Figure 3-15, will proceed from upstream (left in the figure) to downstream (right).

The MIKE FLOOD model begins downstream of the SH54 bridge at chainage -38600. Upstream of this point the MIKE 11 branch serves only to route flow from the boundary condition locations. Effort has not been focused on this reach.

The worst match occurs at chainage -32266 where the simulated water level is 1.3 m lower than observed. Figure 3-16 depicts a longitudinal profile of the maximum water level around this location. The main channel is laterally linked to the 2D model in this area and so the bank levels in the figure are not stopbank levels but are internal or summer stopbanks. In order to produce a matching water level a large constriction would need to be added to the model, which is not apparent from the LiDAR. A raised water level here would also dramatically increase upstream discharge onto the floodplain and subsequently reduce downstream discharges.

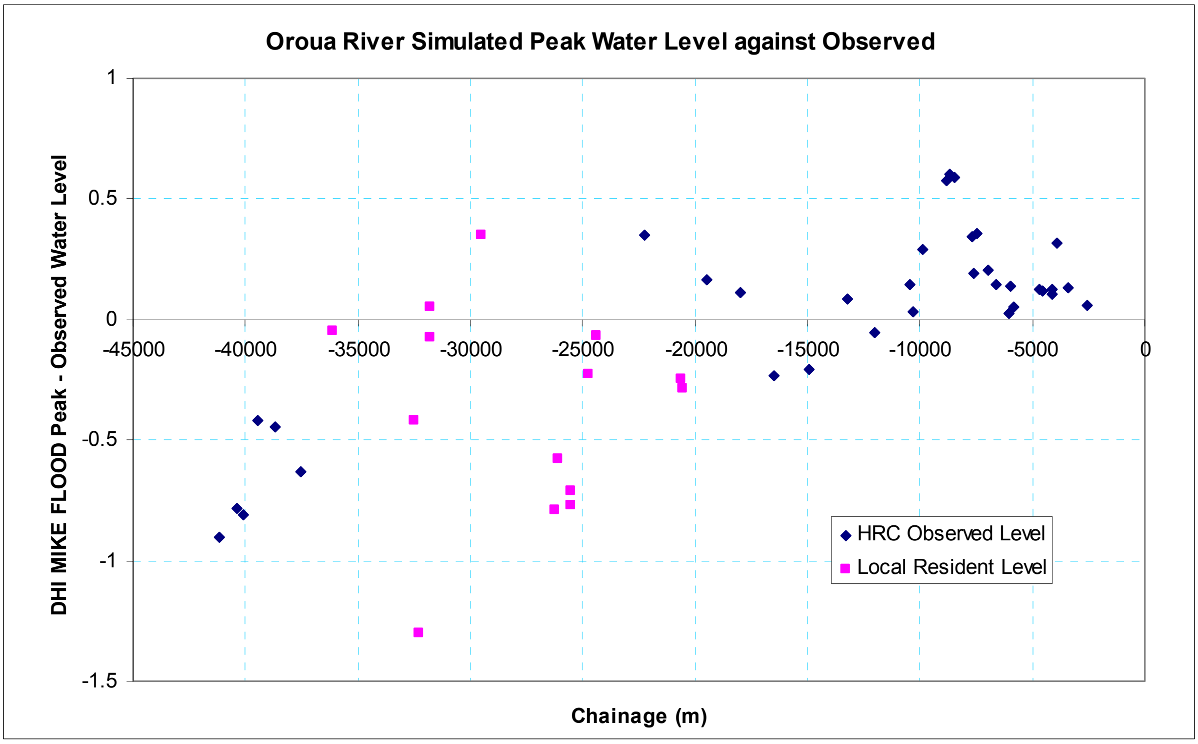


Figure 3-15 Peak simulated water level compared to observed water levels.

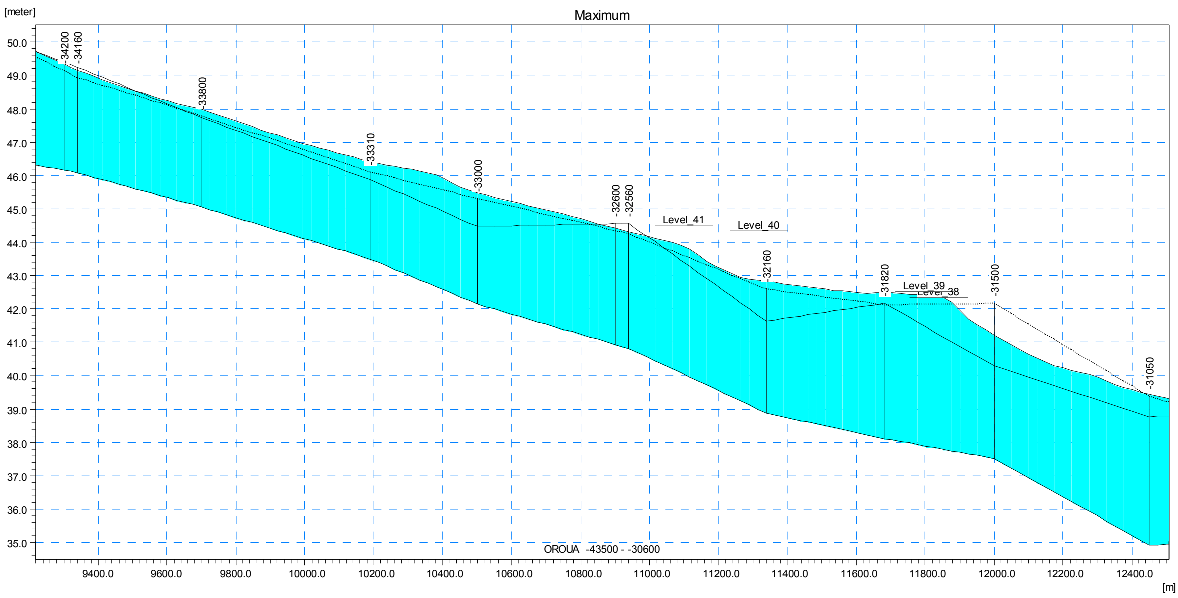


Figure 3-16 Longitudinal profile of maximum water level in the Oroua River between chainages -34200 and -31050. Solid black vertical lines are cross section locations, other solid black lines are bed and right bank, stippled black line is left bank.

In the downstream 15 km reach the of the model, predicted water levels are higher than observed. In this stretch of river the locations, at which HRC has surveyed levels, the three worst matches are at chainages -8481, -8656, and -8823 with differences of 0.59 m, 0.61 m, and 0.58 m respectively. There is a high level of uncertainty regarding the cross sections at these chainages as their source is not provided in the Opus report and the main channel has been raised by more than 1.2 m (from its pre-2004 surveyed level) by Opus to account for aggradation. For the 2004 calibration event, the model predicts overtopping further downstream at chainage -3530 on the right bank and overtopping between chainages -2600 and -1200 on the left bank. This was not observed during the event and may be due to incorrect stopbank levels or too large a modification of the cross section datum levels leading to erroneously high water levels.

In general, a full-scale calibration of the Mannings roughnesses was not deemed appropriate due to the uncertainty of the age of many cross sections and the accuracy of the modifications made to the cross sections to account for aggradation/degradation.

3.8.3 Manawatu River

The Manawatu River model was built and calibrated to the February 2004 event by HRC. Verification checks were made on the final MIKE FLOOD model to ensure that Hamilton's Line spillway, the connection to the bottom of Burkes Drain, and the connection at the Oroua confluence are functioning correctly.

During the 2004 flood simulation, a small section of the upstream end of Hamilton's Line spillway does spill, which was not observed. However, as the volume is relatively small (4,450 cubic metres), it has been neglected. To prevent this flooding the spillway would need to be raised by less than 20 mm in the model.

Figure 3-17 presents a comparison between the simulated water level in the Manawatu at the Burkes Drain confluence and that provided by HRC for the Mangaone-Taonui study. The difference in maximum water level is approximately 100 mm.

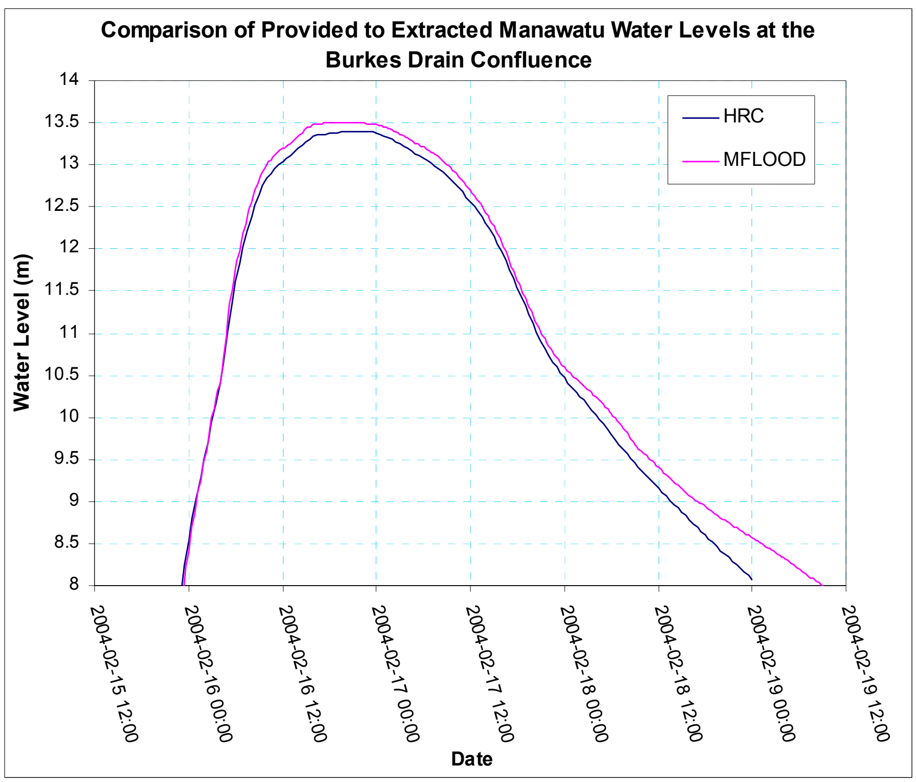


Figure 3-17 Comparison plot of water levels on the Manawatu at the Burkes Drain Confluence. The blue was provided by HRC for the Mangaone-Taonui study and the magenta was extracted from the final calibration MIKE FLOOD model.

The water level at the Oroua-Manawatu confluence is important in controlling spilling at the Rangiotu spillway on the left bank of the Oroua River. The simulated peak is 13.07 m, which is 120 mm higher than the downstream boundary used in the Opus MIKE 11 model and 110 mm higher than that predicted by the HRC Manawatu MIKE 11 model. This could be lowered by reducing the river roughness in the Manawatu River. The rating curve at the downstream boundary, which was provided by HRC, may also influence this level. No attention has been focussed, in this study, on the Q/h relationship used as the downstream boundary.

4 FLOOD RISK ASSESSMENTS

The validated MIKE FLOOD model has been used as the basis to generate flood depths and extents for two design flood events, 100-year and 200-year ARI. The results have been post-processed to produce current speed and flood hazard (depth x velocity product). The flood maps (Drawings 2 – 17) can be viewed in Appendix B.

Two sets of simulations have been run:

Set 1: 100 and 200 year ARI simulations with the model representing a situation similar to that at the 2004 flood, but with minor modifications (see section 4.1.1). Flood maps for these simulations are shown in Drawings 2 – 9 in Appendix B. These runs only include dam-break structures at locations of breaches during the February 2004 event

Set 2: The Set 1 simulations were analysed and where stopbank overtopping was seen to occur, dam-breaks structures were inserted in the model (see Table 3-1). This model was then run for the two design conditions and resulting flood maps are Drawings 10 – 17 in Appendix B.

4.1 Design Events

Catchment inflows were generated in the Mangaone-Taonui study (see Ref./1/) and are used directly. All other inflows, which include upstream boundary flows for the Kiwitea Stream, Makino Stream, Oroua River and Manawatu River, have been provided by HRC.

4.1.1 Model Modifications

The MIKE FLOOD model, which was validated against the 2004 event, has been modified for use in simulating the Set 1 ARI design events (100- and 200-year flood).

Modifications to the MIKE FLOOD model include:

- removal of the Kimatarau Road stopbank breach; and
- alteration of all dam-break structures so that they trigger when the water level in the river exceeds the crest level by 300 mm instead of being triggered to initiate collapse at a specified time.

For the Set 2 simulations, the results of the Set 1 runs were analysed and dam-break structures were installed at locations along the stopbank where water levels exceeded the crest by approximately 300 mm on either the left or right stopbank. The exception is the reach between ch-24700 and ch-15000 on the left bank and between ch-24000 and ch-15000 on the right bank as recent reconstruction works are considered adequate by HRC to contain a 200-year river discharge.

4.1.2 Results

A similar pattern of flooding exists in the Taonui Basin for the 2004 validation event and the design events. Significantly less flooding occurs on the right bank of the Oroua River in the design events because the Kimatarau Road breach is not included in the design event models. Maps of simulated flooding are presented in Appendix B.

Set 1: 100-year Event

Reference is made to flood maps in Drawings 2-5 in Appendix B. The flood extent in the Taonui Basin is similar to that of the verification event, although more water is spilt by the Rangiotu spillway, thus raising the water level and increasing the ponding extent. The water level in the Taonui Basin peaks at 10.1 m.

A small amount of flooding occurs on the right bank of the Oroua from overtopping downstream of the SH54 bridge and upstream of the Kopane Bridge. This flood water does not travel beyond River and Mill Roads. A small volume overtops the right bank at River Road but does not cross Mill Road. Downstream of this area there is no spilling from the Sluggish Main Drain network.

The Hamiltons Line spillway discharges approximately 313,000 m^3 and peaks at 14.5 m^3/s.

Set 1: 200-year Event

Reference is made to flood maps in Drawings 6-9 in Appendix B. The pattern of flooding is similar to that of the verification event, although here the water level in the Taonui Basin peaks at 10.8 m.

Flooding emanating from Awahuri overtopping on the right bank extends down to Rongotea road and overtops in several places. The water depth does not exceed 0.5 m across River Road or Mill Road. Overtopping flows on the right bank of the Oroua at River Road cross the road and is collected, in the most part, by the drain that runs along the road. Downstream of this area there is no spilling from the Sluggish Main Drain network.

The Hamiltons Line spillway discharges approximately 3.16 million m^3 and peaks at 89.7 m^3/s.

Set 2: 100-year Event (with Additional Breaches)

References made to flood maps in Drawings 10-13 in Appendix B. The water level in the Taonui Basin peaks at 11.4 m. Two large breaches occur on the Oroua at chainage -24460 (right bank) and chainage -1250 (left bank). The former discharges 8.42 million m^3 of water, with a peak of 157 m^3/s onto the floodplain to the west of the Oroua and is the sole cause of flooding in this area, which can be seen in Drawings 10-13 in Appendix B. The latter breach reaches a full width of 100 m and discharges 62.3 million m^3 into the Taonui Basin before draining out 33.9 million m^3 as the levels in the river drop. This contributes all the additional water in the Taonui Basin and is responsible for raising the maximum water level from 10.1 m (without the breach) to 11.4 m.

The MIKE 11 results show some instability in the discharge at the large breach on the Oroua left bank at chainage -1250. The instabilities appear to have an insignificant effect on water levels in both the MIKE 11 and MIKE 21 model results.

The Hamiltons Line spillway discharges approximately 313,000 m^3 and peaks at 14.5 m^3/s. This shows that even with higher water levels in the Taonui Basin the Hamiltons Line spillway operates the same, with and without breaches on the Oroua for the 100-year event.

Set 2: 200-year Event (with Additional Breaches)
References made to flood maps in Drawings 13-17 in Appendix B. The water level in the Taonui Basin peaks at 12.0 m. The two large breaches on the Oroua, at chainages -24460 and -1250, spill 10.7 million m^3 (with a peak discharge of 173.9 m^3/s) and 81.0 million m^3 respectively out of the Oroua River. The latter breach is solely responsible for raising the maximum water level in the Taonui Basin from 10.8 m (without breach) to 12.0 m. A flood volume corresponding to 50.4 million m^3 is then drained back out of the Taonui Basin once the river water level recedes. The simulation ends before the Taonui Basin drains completely, which means that the volume that drains back into the river, reported above, is an underestimation.

Similar instabilities as described for the 100-year event (with additional breaches) above occur near the breach at chainage -1250 on the left bank of the Oroua.

The Hamiltons Line spillway discharges approximately 1.92 million m^3 and peaks at 64.5 m^3/s. This discharge is significantly lower than that of the Set 1 simulation in both volume and peak. This is due to the large breach on the Oroua at chainage -1250 drawing water out of the Manawatu River and subsequently lowering the peak water level at the Oroua-Manawatu confluence by almost 120 mm. The water level at the confluence affects water levels upstream and lowers the water level in the Manawatu River at Hamiltons Line (10.5 km upstream) by a maximum of 90 mm. This results in the reduced spillway discharge mentioned above.

When considering the results from the Set 2 simulations, it should be noted that although a dam-break structure has been placed at chainage -1250 it is not certain that a stopbank breach will occur at this location in reality. The model predicts overtopping at this site during the verification event, although there was no actual observed spilling. This indicates that the relationship between the river and the stopbank levels may not be correct, that is the stopbank levels may be too low. The LiDAR levels suggest that the left stopbank levels are higher than presently represented in the model. This dam-break is 100 m wide and discharges a very large amount of water into the Taonui Basin, raising flood levels significantly.

Flood Hazard Mapping
Flood hazard has been classified according to the NSW Floodplain Development Manual (Ref. /5/) as shown in Figure 4-1. The MIKE 21 model results have been post-processed to compute the velocity-depth product at each grid cell and each timestep, and a maximum taken of the final result. High hazard areas are evident in the areas of high depth and velocity described above, most commonly at road crossings. The upper Mangaone tributary areas are also defined as high hazard as a result of high speeds in this area. The Taonui basin is determined as an area of high hazard due to depths over 1.0 metre. The majority of the hazard areas are classified as either "low" or "high" with little in between, which results from the narrow definition of this category according to Figure 4-1. High hazards do not occur on the western side of the Oroua River for the 100-year ARI flood event, but there is a small area on the northern side of Mill Road that has a high hazard rating (due to depth) in the 200-year run (see Drawings 5 and 9 in Appendix B). In the Set 2 simulations there are many locations of high hazard all the way down the Sluggish Main Drain (see Drawings 13 and 17 in Appendix B). The high hazard rating, in these areas, is mainly due to water depths exceeding 1.0 m. Flow speeds around the Sluggish Main Drain generally do not exceed 1 m/s, as can be seen in Drawings 12 and 16 in Appendix B.

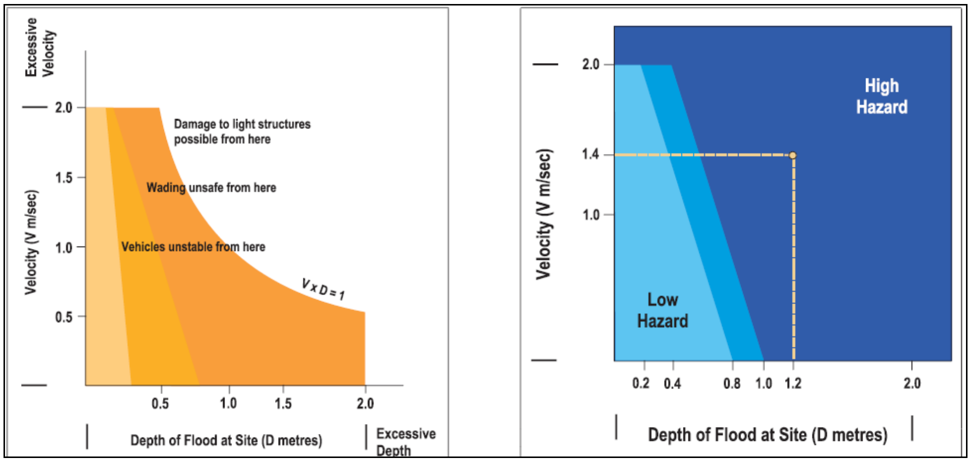


Figure 4-1 Floodplain Hazard Categories (Source: NSW Floodplain Development Manual, App. L)

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A comprehensive flood model of the Mangaone Stream and Taonui Basin, including portions of the Oroua and Manawatu Rivers, has been developed for use in assessing flood hazards to the west (right bank) of the Oroua River. The model comprises a dynamically coupled 1D channel model and a 2D overland flow model. It is the amalgamation of the Mangaone-Taonui Basin MIKE FLOOD model, Oroua River MIKE 11 model, and Manawatu MIKE 11 model. The modelled floodplain has been augmented with the addition of terrain data to the west of the Oroua and new MIKE 11 models of the Makino Stream and Sluggish Main Drain area have been developed and incorporated into the final MIKE FLOOD model.

The 1D channel model includes portions of the Oroua and Manawatu Rivers and the main drainage channels in the study area, including the Taonui Stream, Main Drain, Burkes Drain, Whiskey Creek, Makino Stream, and Sluggish Main Drain. The model does not include the Mangaone Stream itself or its tributaries.

The model has been validated, with moderate success, against the February 2004 event. It reproduces water levels along the Oroua River, generally within 0.5 m of observed values. The model satisfactorily reproduces most of the observed flooding extent.

The verified model has been used to develop flood extent maps indicating flood depth, level, speed and hazard for the 100 and 200 year ARI flood events considered.

The design event simulations predict a breach on the Oroua, just south of the Kopane spillway on the right bank. This breach causes a significant flood hazard to property and residents on the west side of the Oroua River north of Kaimatarau Road. The 200-year simulation has additional flooding along Saunders Road, which is not present in the 100-year simulation.

Along the western side of the Oroua River flood water is slowed by the shape of the land and drainage infrastructure and takes longer to reach peak flood depths compared to flood flows in the Taonui Basin. The peak of the flood wave from breaches in the Set 2 simulations takes more than 3 days to reach the bottom of the Sluggish Main Drain.

5.2 Recommendations

5.2.1 Uncertainties

The model has been developed to provide the basis for flood risk assessments for the floodplain on the right bank of the Oroua. Based on the model validation results against observed flood extents and levels, the model predictions need to be treated with some caution. The main uncertainties in the model relate to the flow conveyance capacity of the Oroua River, which is subject to rapid and often undetectable aggradation and erosion. The model has been shown to be sensitive to channel conveyance, which is dictated by cross sectional area and the assumed Manning roughness. Relatively small changes in the Oroua water level affect the volumes of flow spilling at Kopane and Rangiotu, and dictate whether embankment failure is likely to occur as a result of overtopping.

5.2.2 Model Improvement

Due to the size and complexity of this model there are a significant number of areas that would benefit from further attention.

i. Refinement of the Sluggish Main Drain by addition of more side drains and a more accurate description of the culverts. Currently the culvert inverts and diameters are estimated.

ii. Further investigation of area surrounding chainage -32266 on the Oroua to identify reasons for the very high observed water levels.

iii. Thorough review of the Oroua cross sections and possible refinement of the Mannings roughnesses.

iv. Improved field survey data to confirm LiDAR accuracy for use in defining stopbank levels.

6 REFERENCES

/1/. DHI Water & Environment: *Mangaone Stream and Taonui Floodplain Hazard Assessment, Hydraulic Modelling and Mapping*, March 2007

/2/. Opus: *Oroua River Investigations: Reids Line to Manawatu River Confluence, Engineering Study*, August 2005

/3/. DHI Water & Environment: *MIKE FLOOD Reference Manual*

APPENDIX A

MIKE 11 Model-Component Source Summary

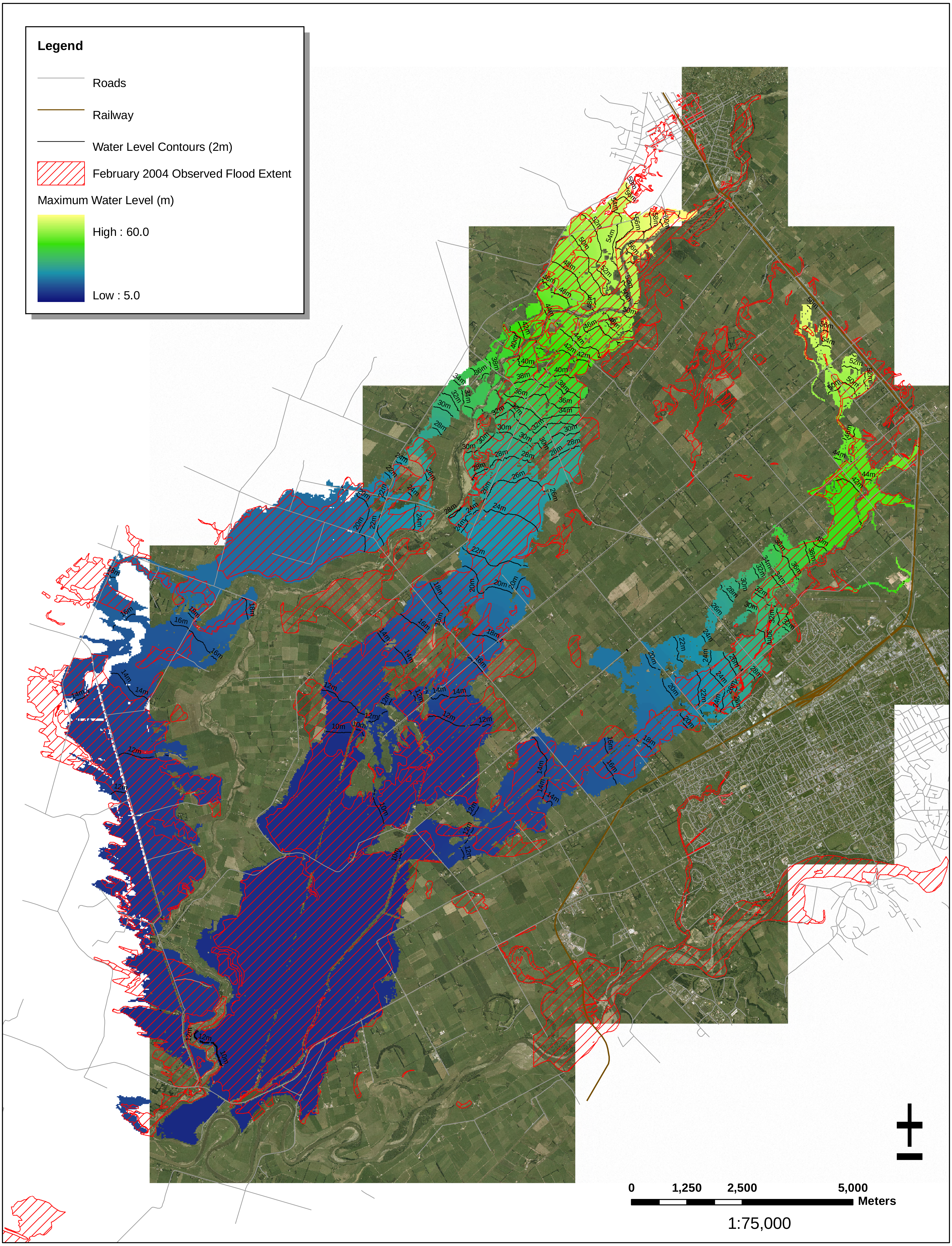
Branch	MIKE 11 Component	Source	Comments
AIRPORT_STREAM	All	Mangaone-Taonui Model	
AWAHURI BREACH	Cross sections	Oroua MIKE 11 Model	Cross sections shifted vertically to lessen grade
	Other		Branch shortened
BOOTH	All	Manawatu MIKE 11 Model	
BUICK	All	Manawatu MIKE 11 Model	
BURKES	All	Manawatu MIKE 11 Model	
BURKES_DRAIN	All	Mangaone-Taonui Model	
BURKES_SPILL_1A_LB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_1A_RB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_1B_LB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_1B_RB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_1C_LB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_1C_RB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_2A_LB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_2A_RB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_2B_LB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_2B_RB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_2C_LB	All	Mangaone-Taonui Model	Dummy branch for spilling
BURKES_SPILL_2C_RB	All	Mangaone-Taonui Model	Dummy branch for spilling
CON3L1	All	Manawatu MIKE 11 Model	
CON3L9	All	Manawatu MIKE 11 Model	
CONC-WEIR	All	Manawatu MIKE 11 Model	
DUMP	All	Manawatu MIKE 11 Model	
HAM-38	All	Manawatu MIKE 11 Model	
HAM-CROSS	All	Manawatu MIKE 11 Model	
HAMILTON	All	Manawatu MIKE 11 Model	
HAM-SPILL-DS	All	Manawatu MIKE 11 Model	Downstream channel for Hamilton's Line spillway
HAM-SPILL-US	All	Manawatu MIKE 11 Model	Upstream channel for Hamilton's Line spillway
HIMATANGI	All	Manawatu MIKE 11 Model	
KAIRANGA_DRAIN	All	Mangaone-Taonui Model	
KAIRANGA_DRAIN_EXT	All	Mangaone-Taonui Model	
KEEBLE			
KIMATARAU BREACH	Cross sections	Oroua MIKE 11 Model	Cross sections shifted vertically to lessen grade

	Other		Branch shortened
KOPANE BREACH	Cross sections	Oroua MIKE 11 Model	Cross sections shifted vertically to lessen grade
	Other		Branch shortened
LBERM3	All	Manawatu MIKE 11 Model	
MAIN_DRAIN	All	Mangaone-Taonui Model	Dummy branch for spilling
MAIND_L1000	All	Mangaone-Taonui Model	Dummy branch for spilling
MAIND_L2100	All	Mangaone-Taonui Model	Dummy branch for spilling
MAIND_L3900	All	Mangaone-Taonui Model	Dummy branch for spilling
MAIND_L4900	All	Mangaone-Taonui Model	Dummy branch for spilling
MAKINO	All	Manually Digitised from 1m DEM	Modifications made to cross sections after initial simulations
MANAWATU	Alignment	Manually Digitised from 1m DEM	Chainages approximated from bank markers supplied by HRC
	Other	Manawatu MIKE 11 Model	
MEECH	All	Manawatu MIKE 11 Model	
OPIKI-RD	All	Manawatu MIKE 11 Model	
OPIKI-RD-BRJ	All	Manawatu MIKE 11 Model	
OPIKI-RD-U	All	Manawatu MIKE 11 Model	
OROUA	Alignment	Manually Digitised from 1m DEM	
	Cross sections	Manawatu MIKE 11 Model	Modifications made to bank marker positions and berm levels
	Other		
OROUA_3.0	All	Manually Digitised from 1m DEM	Oroua side branch near confluence with the Manawatu
OROUA_DUMMY1_L	Cross sections	Oroua MIKE 11 Model and Extracted from 1m DEM	Upstream berms extracted and downstream cross section taken from pre-existing model
	Other	Manually Digitised from 1m DEM	Berm channel for MIKE 21 to MIKE 11 transition
OROUA_DUMMY1_R	Cross sections	Oroua MIKE 11 Model and Extracted from 1m DEM	Upstream berms extracted and downstream cross section taken from pre-existing model
	Other	Manually Digitised from 1m DEM	Berm channel for MIKE 21 to MIKE 11 transition
OROUA-CONFLU	All	Manawatu MIKE 11 Model	
POPLAR1	All	Manawatu MIKE 11 Model	
POPLAR2	All	Manawatu MIKE 11 Model	
RANGITANE	All	Manawatu MIKE 11 Model	
RIVER RD BREACH1	Cross sections	Oroua MIKE 11 Model	Cross sections shifted vertically to lessen grade
	Other		Branch shortened
RIVER RD BREACH2	Cross sections	Oroua MIKE 11 Model	Cross sections shifted vertically to lessen grade
	Other		Branch shortened
SLUGGISH	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_1.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter

SLUGGISH_1.1	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_10.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_11.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_13.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_15.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_18.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_19.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_2.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_20.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_22.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_24.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_4.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_5.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_7.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_7.2	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
SLUGGISH_8.0	All	Manually Digitised from 1m DEM	Culvert size approximated to be circular with 1m diameter
STRUC-DHI-13	All	Mangaone-Taonui Model	Dummy branch for structure in MIKE 21
STRUC-DHI-15	All	Mangaone-Taonui Model	Dummy branch for structure in MIKE 21
STRUC-DHI-16	All	Mangaone-Taonui Model	Dummy branch for structure in MIKE 21
STRUC-DHI-22	All	Mangaone-Taonui Model	Dummy branch for structure in MIKE 21
STRUC-DHI-36	All	Mangaone-Taonui Model	Dummy branch for structure in MIKE 21
STRUC-DHI-37	All	Mangaone-Taonui Model	Dummy branch for structure in MIKE 21
STRUC-DHI-38	All	Mangaone-Taonui Model	Dummy branch for structure in MIKE 21
TANE	All	Manawatu MIKE 11 Model	
TAONUI_STREAM	All	Mangaone-Taonui Model	
TOLL	All	Manawatu MIKE 11 Model	
TOLL-36	All	Manawatu MIKE 11 Model	
U-28	All	Manawatu MIKE 11 Model	
USFITZ	All	Manawatu MIKE 11 Model	
WELLFIELD_STREAM	All	Mangaone-Taonui Model	
WHISKEY_CK	All	Mangaone-Taonui Model	

APPENDIX B

Flood Maps

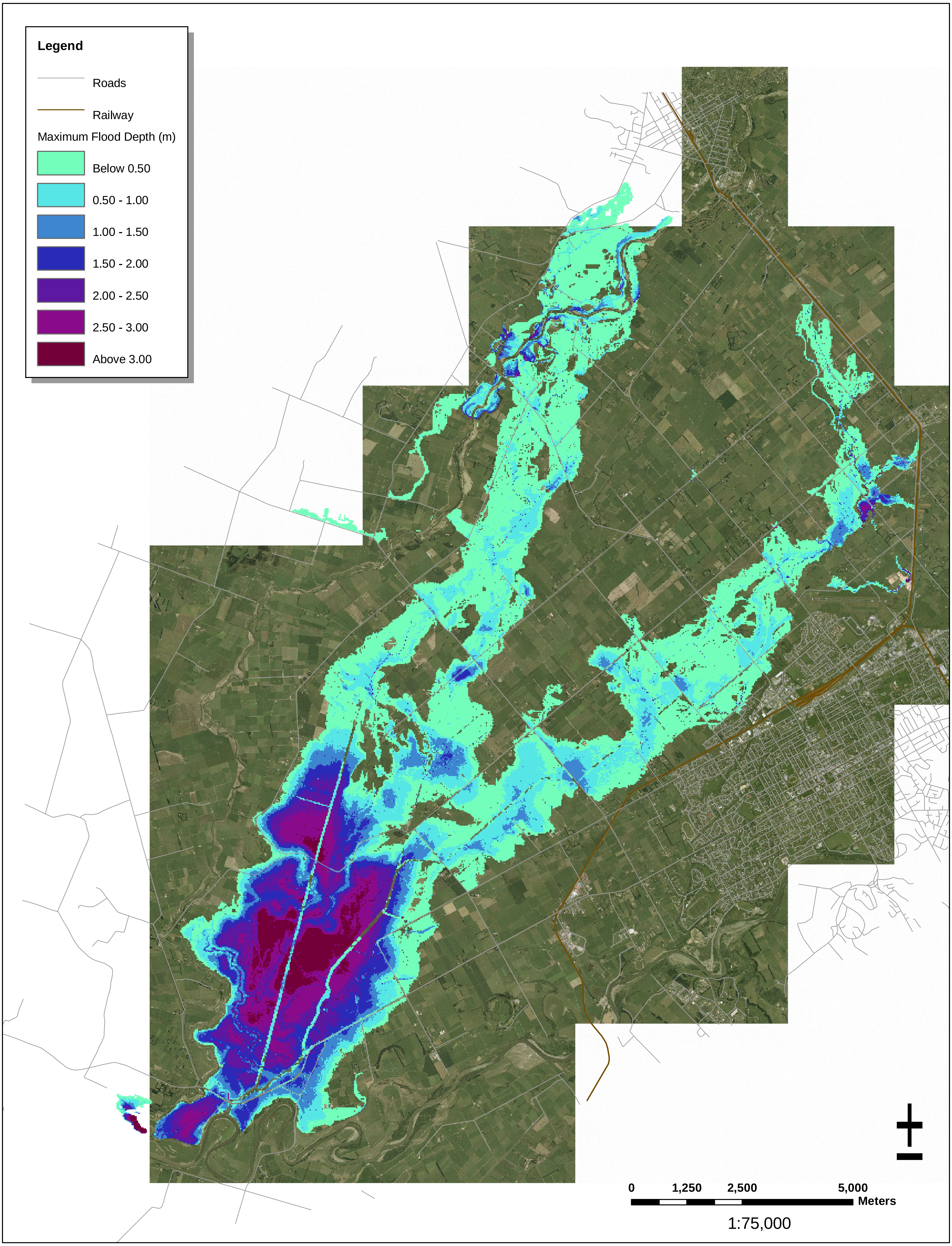


horizons regional council

Oroua River Flood Hazard Assessment

Maximum Flood Level: February 2004 Flood - Verification

Location	Mangaone-Taonui Area
Drawing No.	1
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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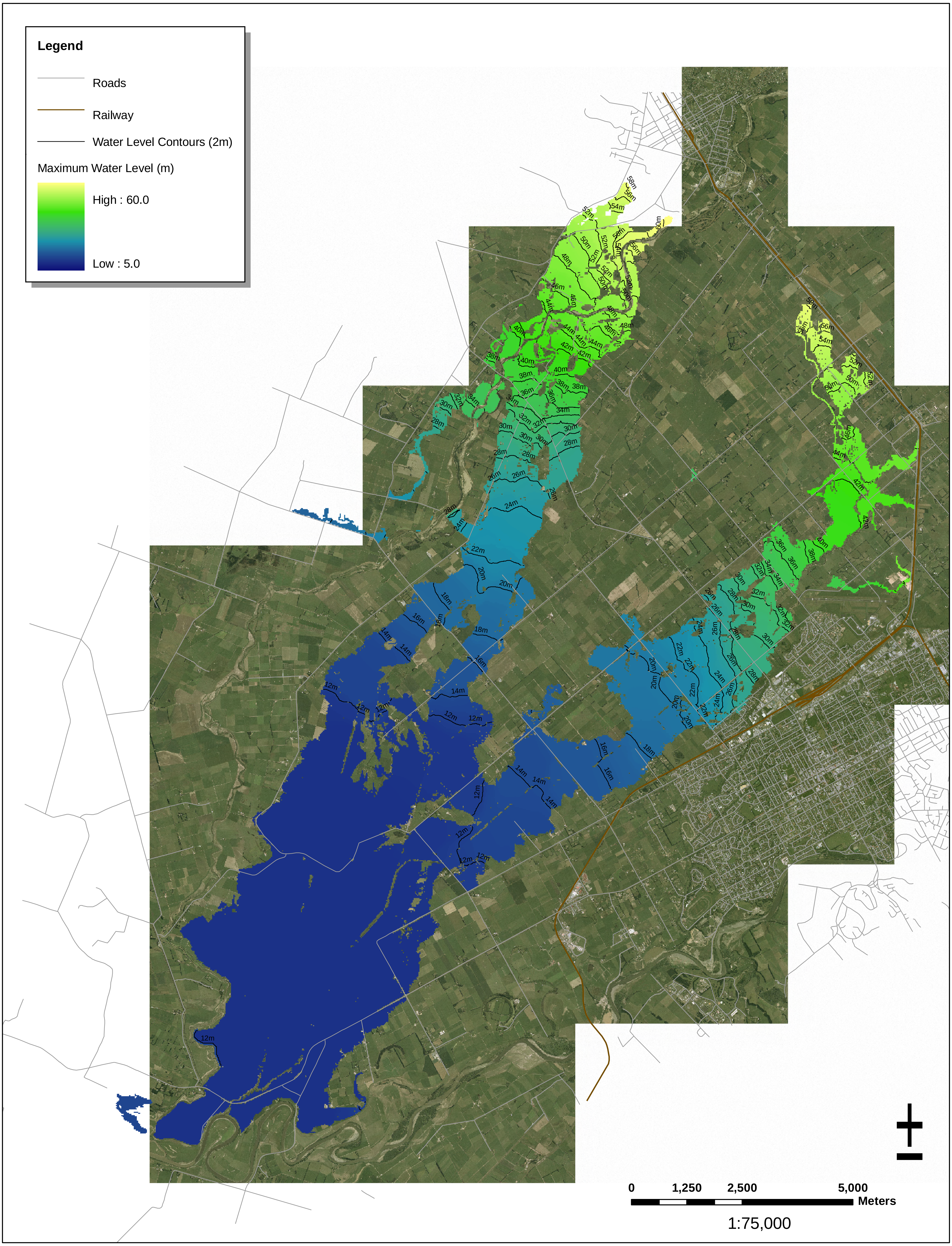
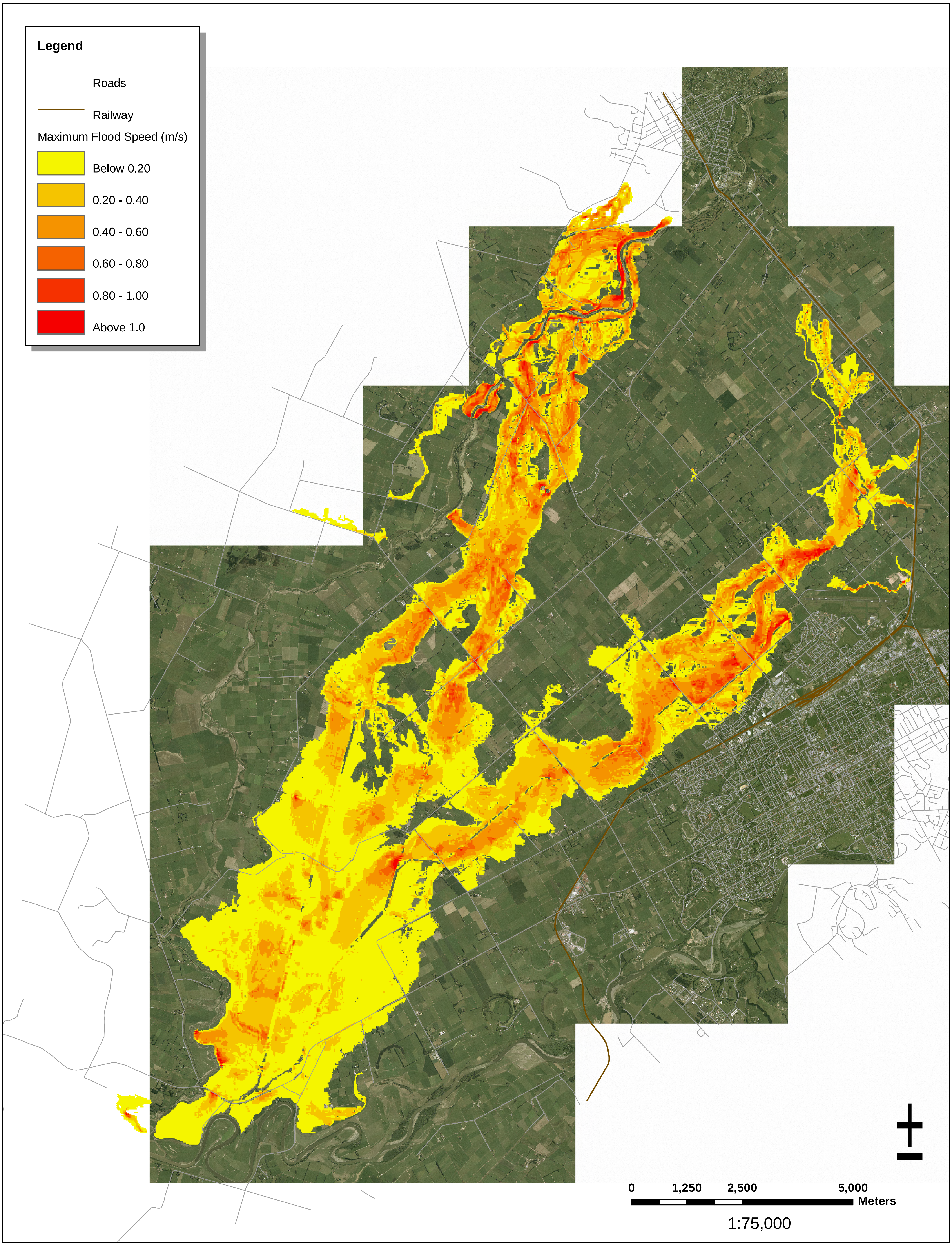
Oroua River Flood Hazard Assessment

Maximum Flood Depth: 100-year ARI Flood

Location	Mangaone-Taonui Area
Drawing No.	2
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



horizons regional council	**Oroua River Flood Hazard Assessment**	Location	Mangaone-Taonui Area
		Drawing No.	3
	Maximum Water Level: 100-year ARI Flood	Creation Date	3/4/2008
		Prepared by	DHI Water and Environment Ltd.
		Approved by	

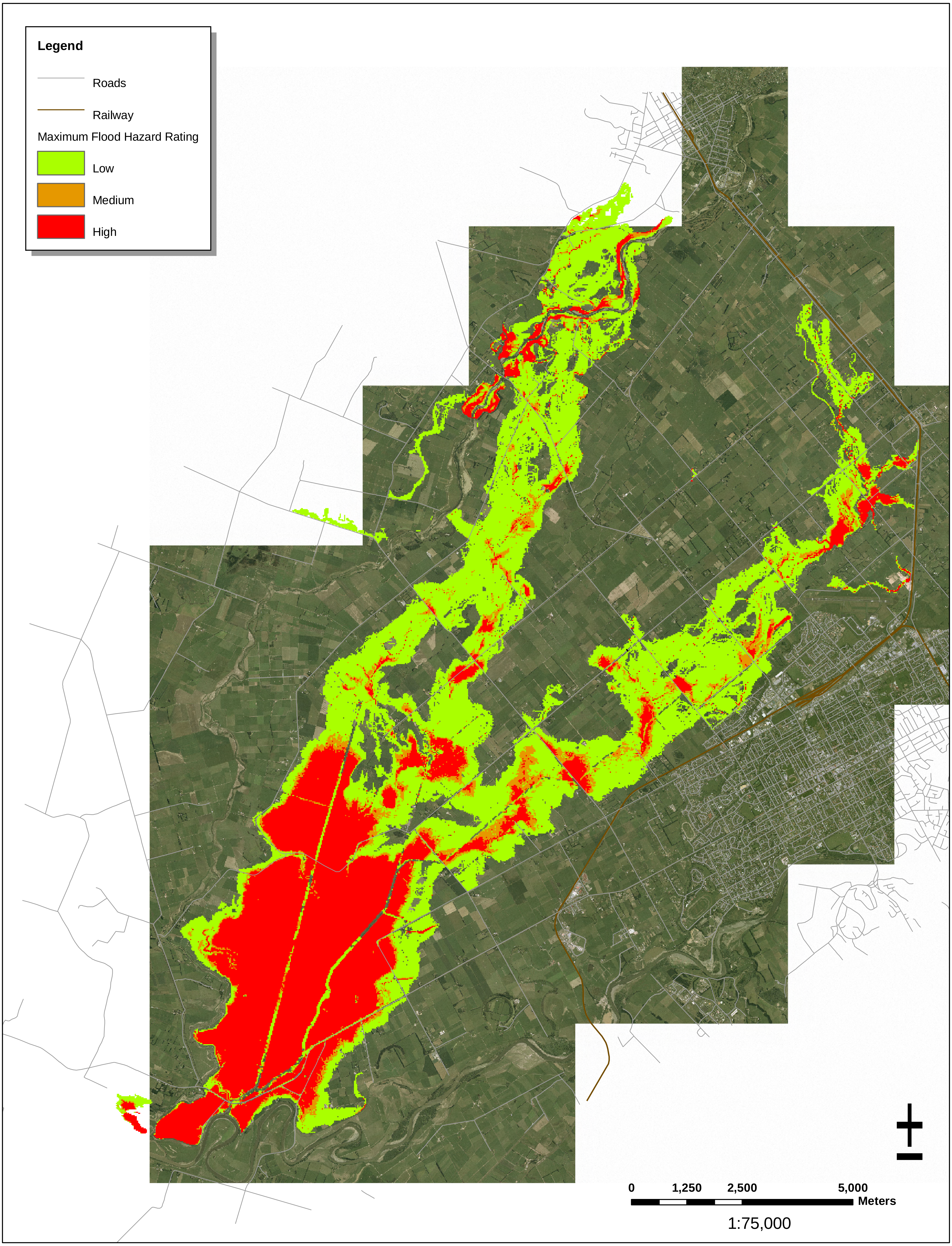


horizons regional council

Oroua River Flood Hazard Assessment

Maximum Flood Speed: 100-year ARI Flood

Location	Mangaone-Taonui Area
Drawing No.	4
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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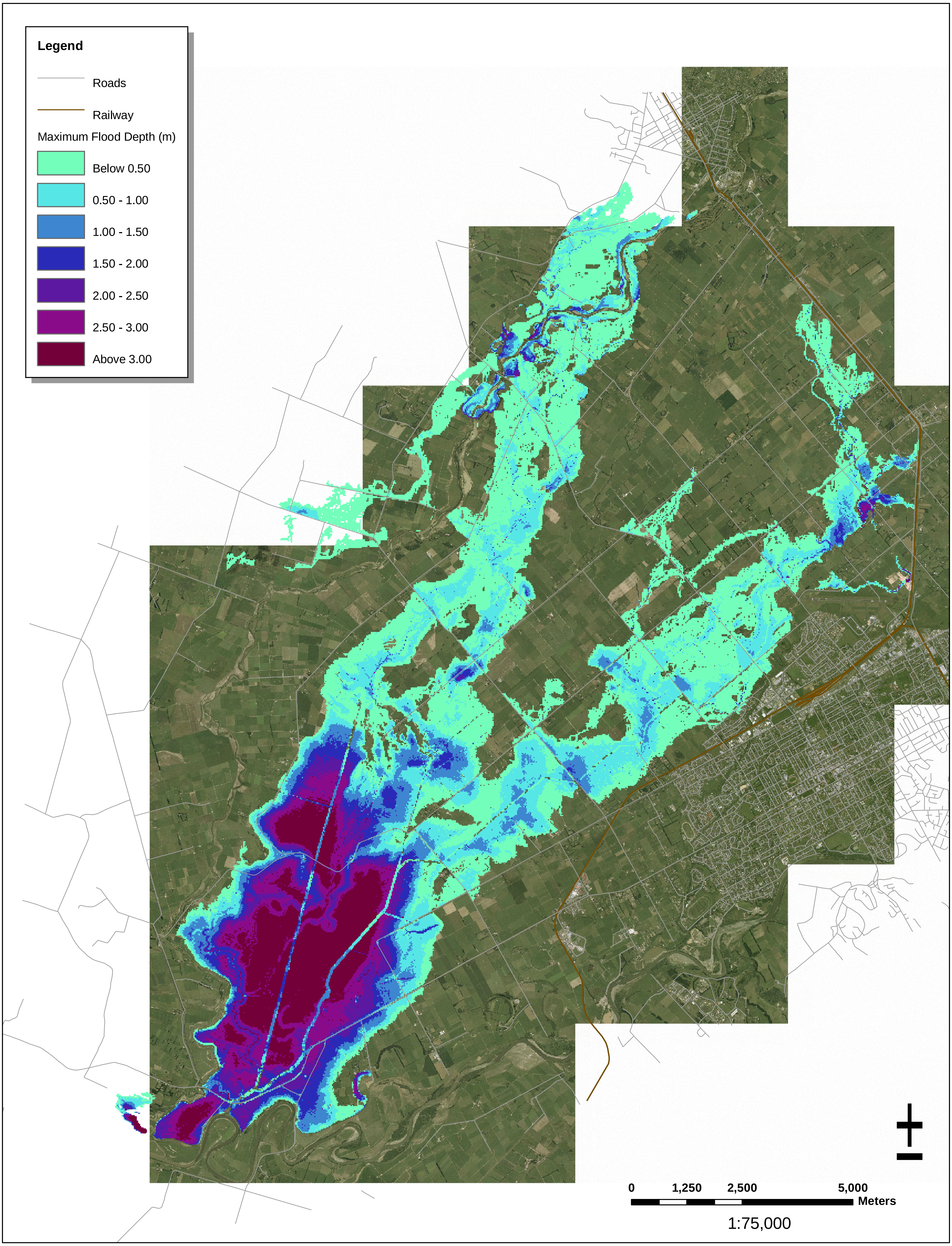
Oroua River Flood Hazard Assessment

Maximum Flood Hazard Rating: 100-year ARI Flood

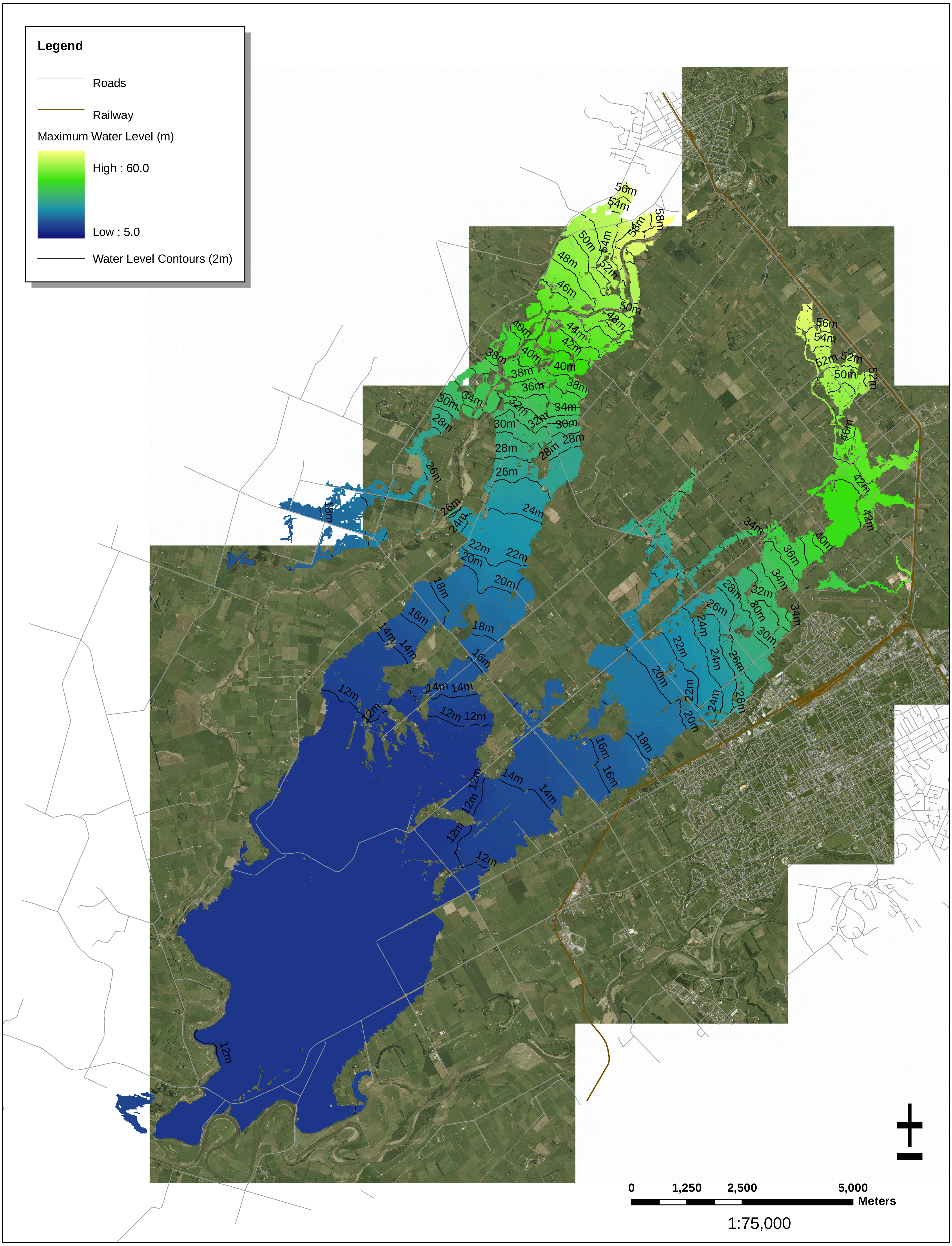
Location	Mangaone-Taonui Area
Drawing No.	5
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



Oroua River Flood Hazard Assessment

Maximum Flood Depth: 200-year ARI Flood

Location	Mangaone-Taonui Area
Drawing No.	6
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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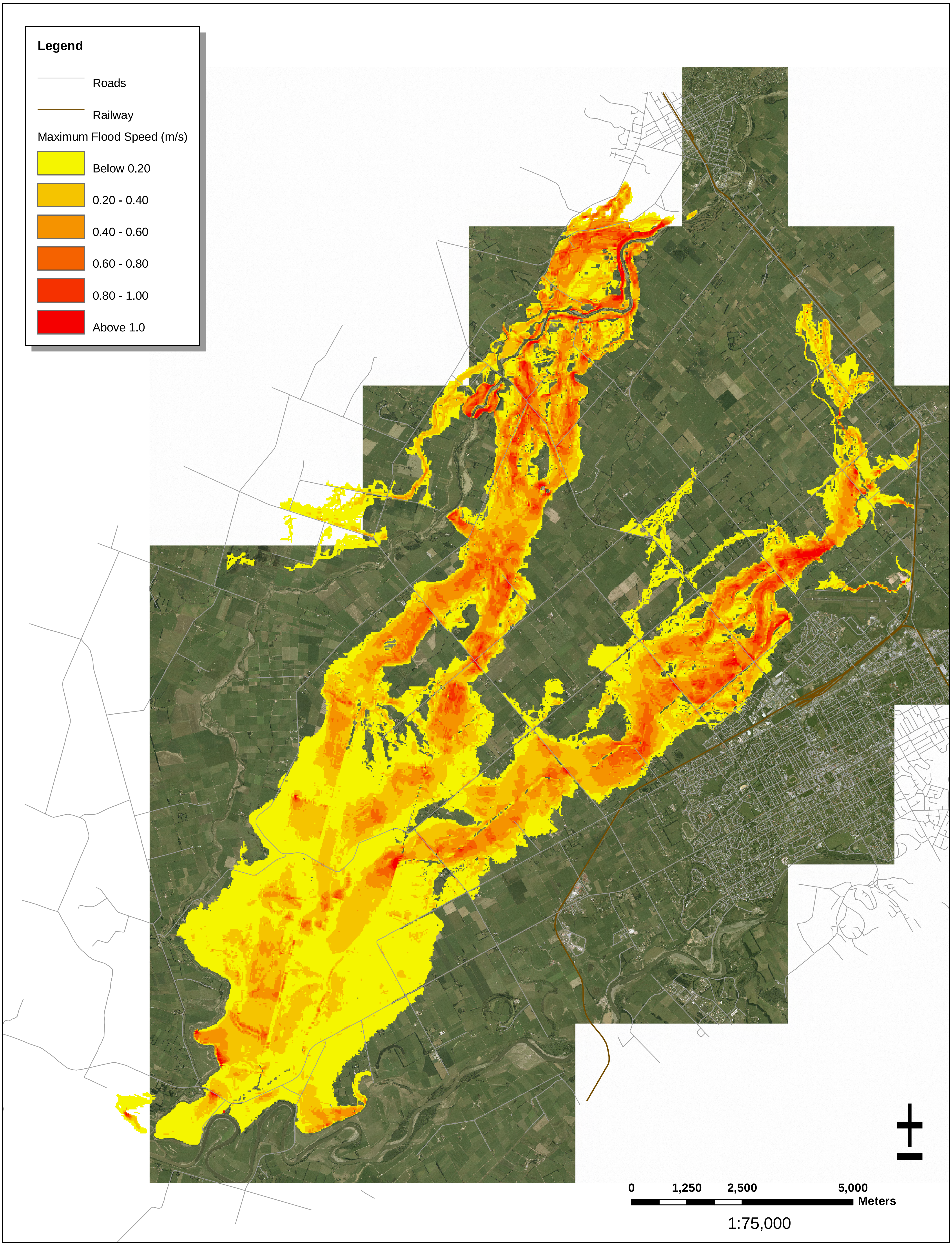
Oroua River Flood Hazard Assessment

Maximum Water Level: 200-year ARI Flood

Location	Mangaone-Taonui Area
Drawing No.	7
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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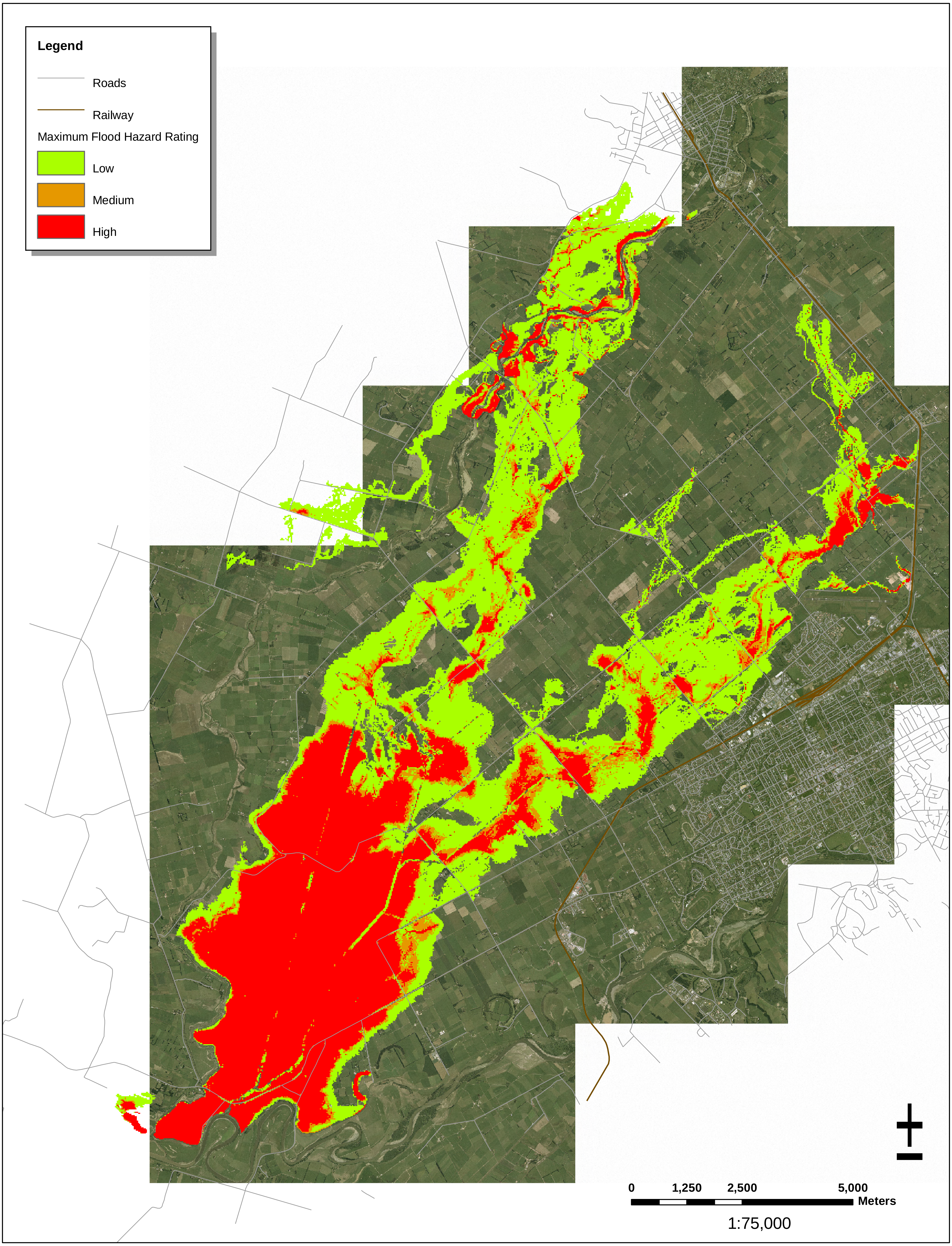
Oroua River Flood Hazard Assessment

Maximum Flood Speed: 200-year ARI Flood

Location	Mangaone-Taonui Area
Drawing No.	8
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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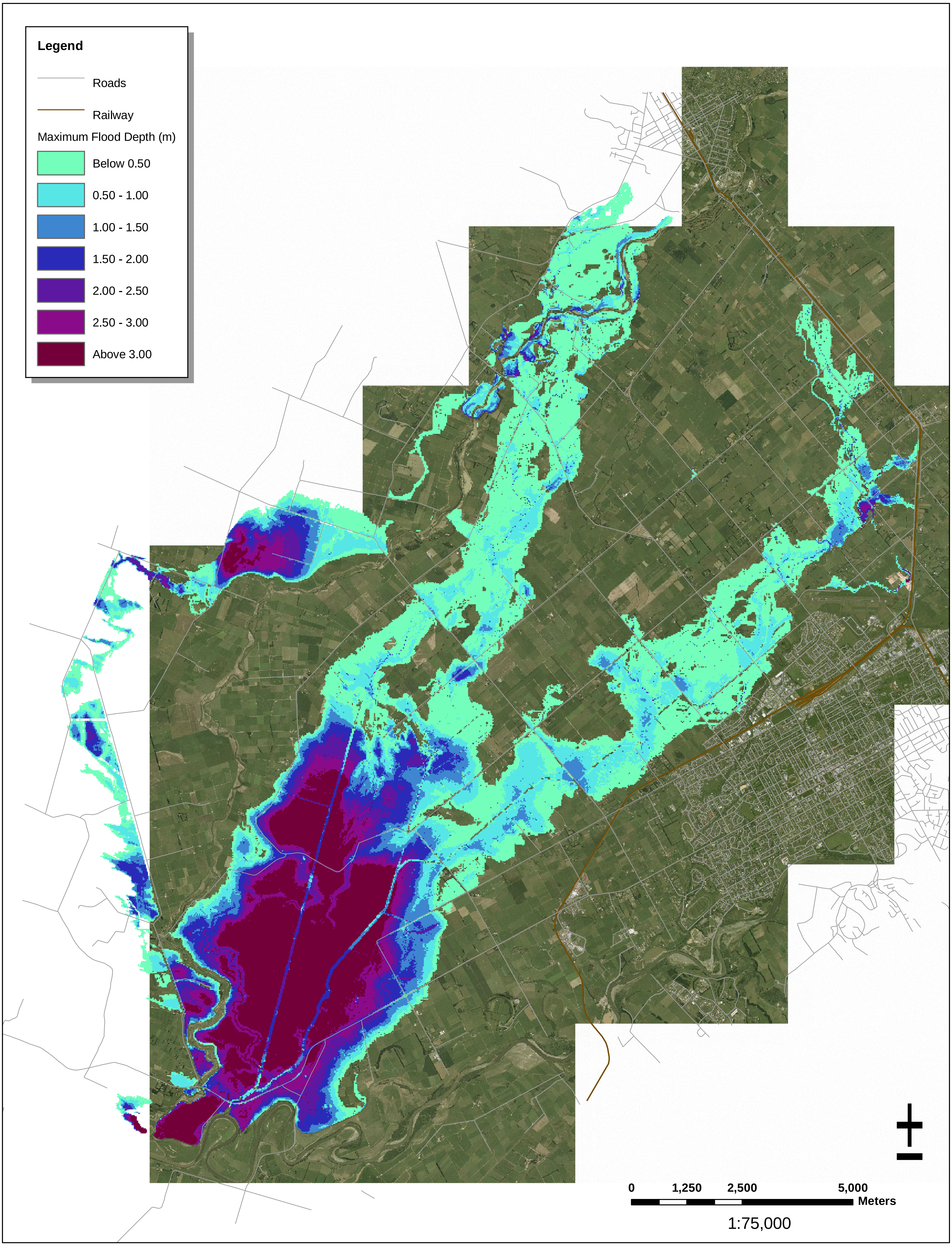
Oroua River Flood Hazard Assessment

Maximum Flood Hazard Rating: 200-year ARI Flood

Location	Mangaone-Taonui Area
Drawing No.	9
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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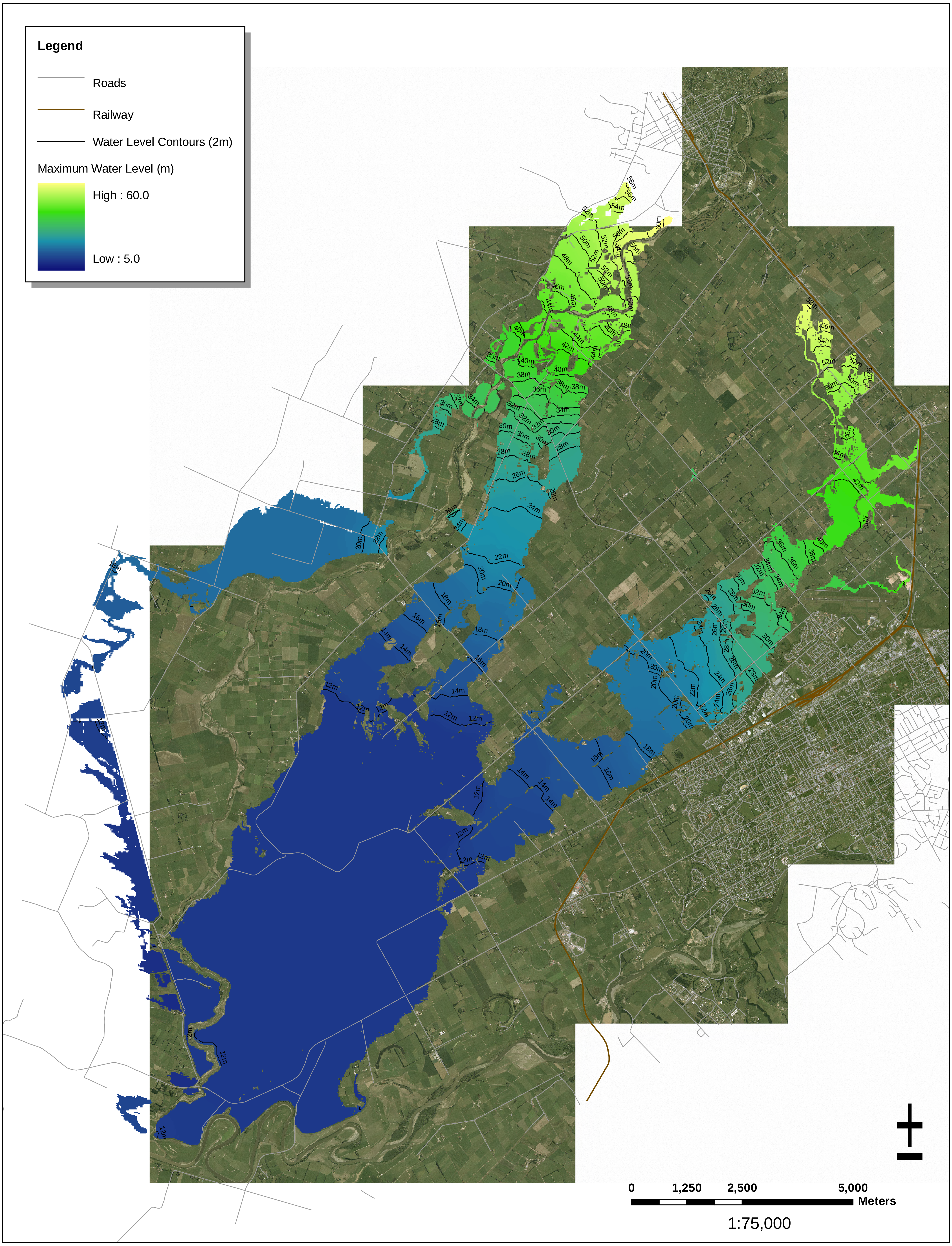
Oroua River Flood Hazard Assessment

Maximum Flood Depth: 100-year ARI Flood with Additional Oroua Stopbank Breaches

Location	Mangaone-Taonui Area
Drawing No.	10
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	

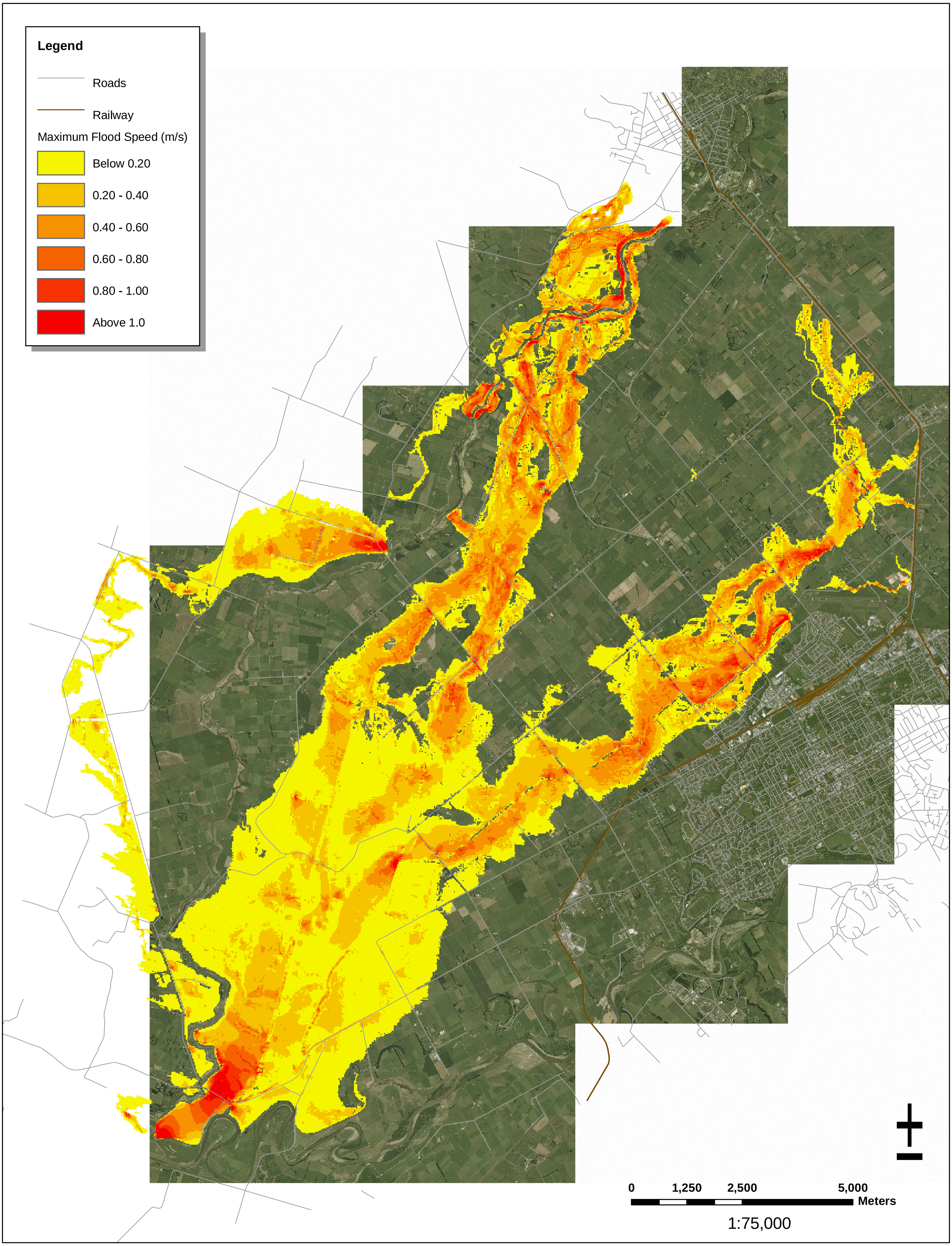


horizons regional council

Oroua River Flood Hazard Assessment

Maximum Water Level: 100-year ARI Flood with Additional Oroua Stopbank Breaches

Location	Mangaone-Taonui Area
Drawing No.	11
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	

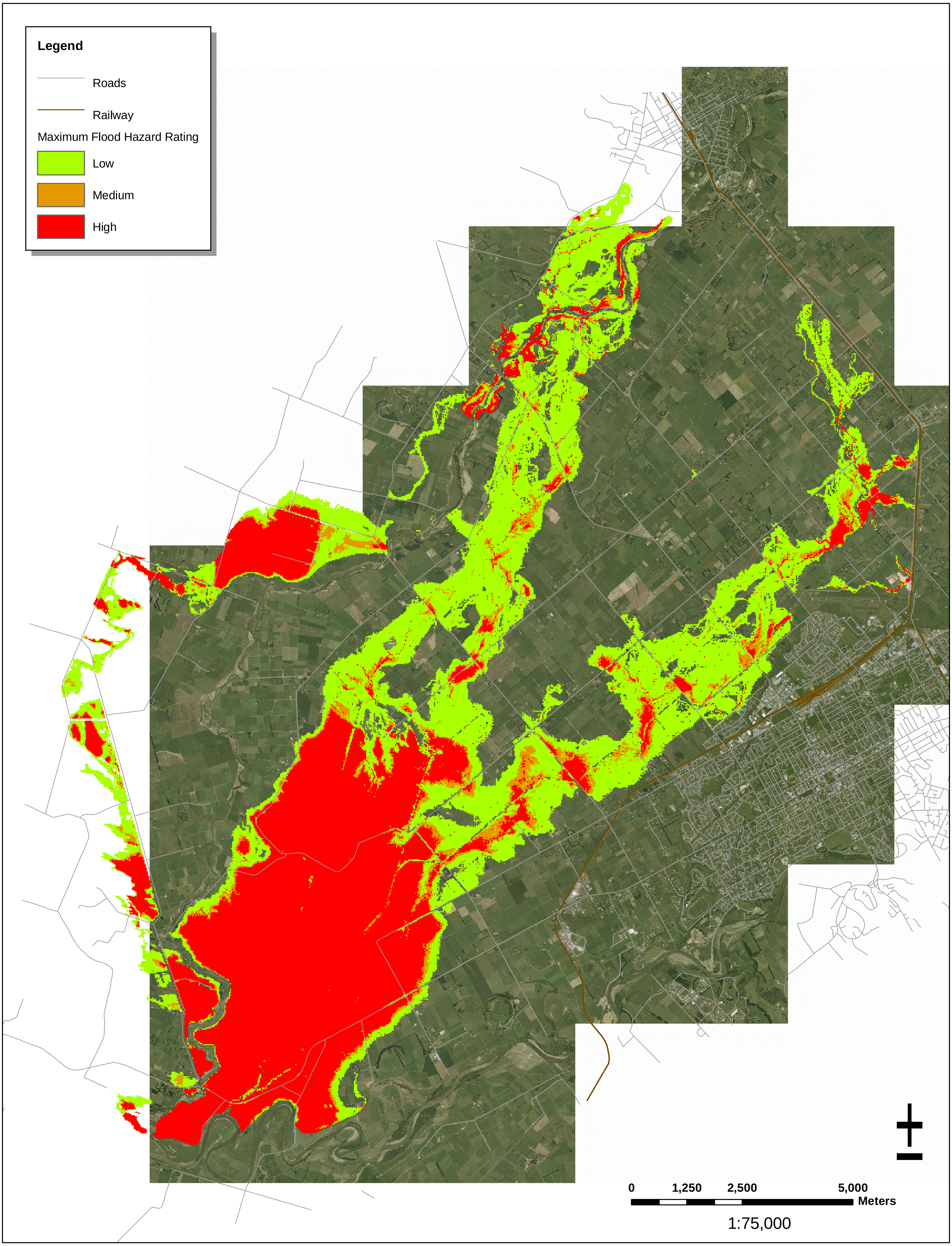


horizons regional council

Oroua River Flood Hazard Assessment

Maximum Flood Speed: 100-year ARI Flood with Additional Oroua Stopbank Breaches

Location	Mangaone-Taonui Area
Drawing No.	12
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	

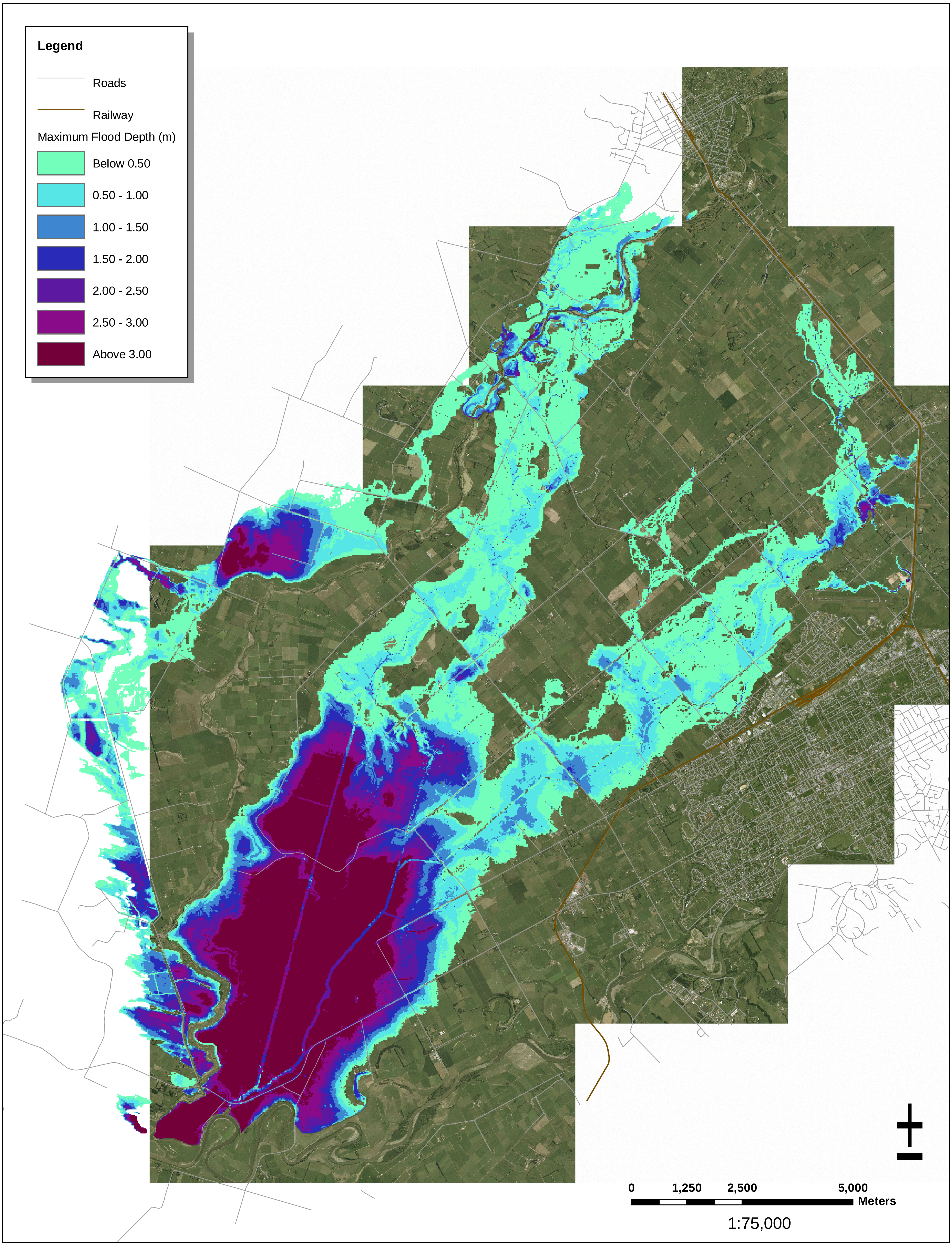


horizons regional council

Oroua River Flood Hazard Assessment

Maximum Flood Hazard Rating: 100-year ARI Flood with Additional Oroua Stopbank Breaches

Location	Mangaone-Taonui Area
Drawing No.	13
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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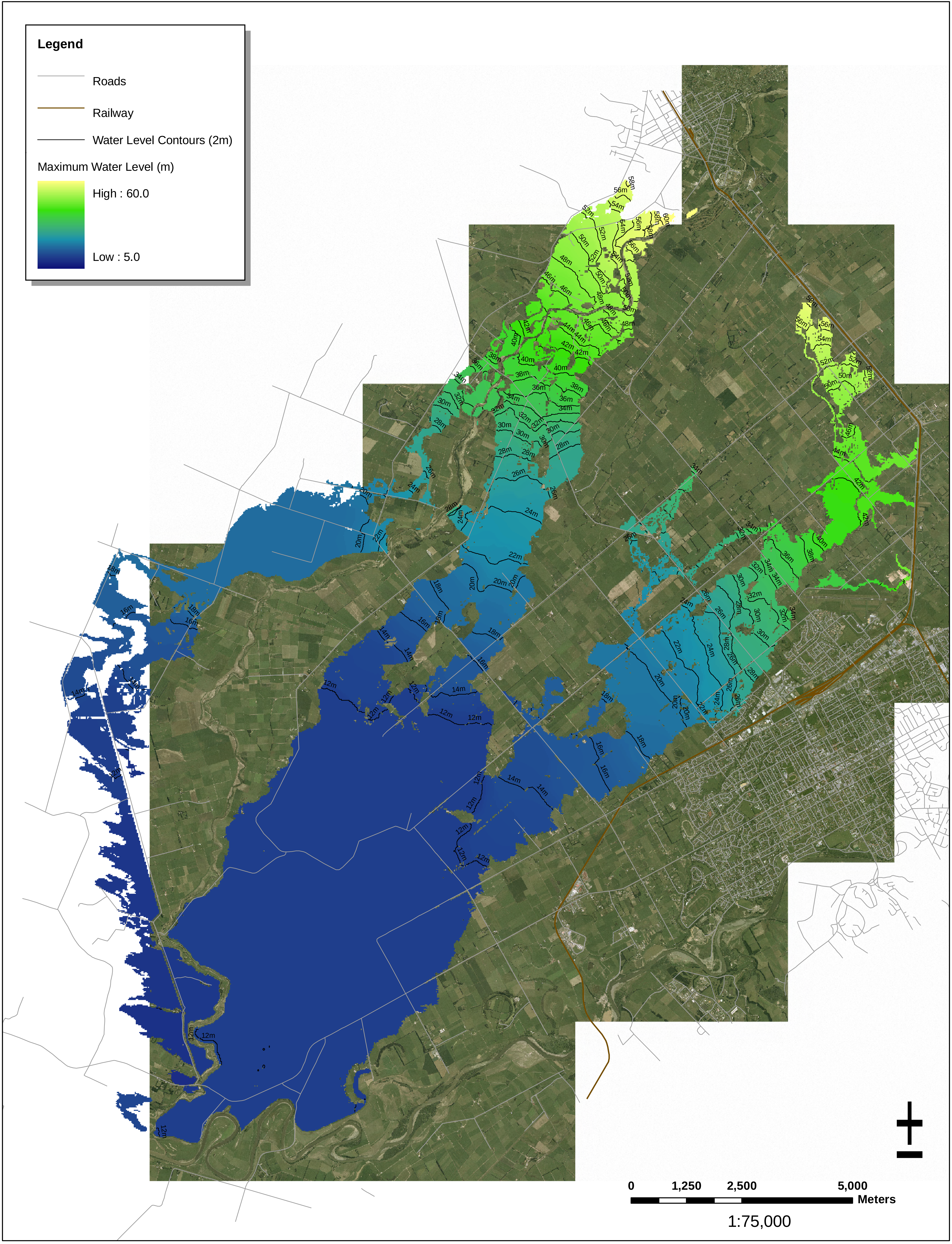
Oroua River Flood Hazard Assessment

Maximum Flood Depth: 200-year ARI Flood with Additional Oroua Stopbank Breaches

Location	Mangaone-Taonui Area
Drawing No.	14
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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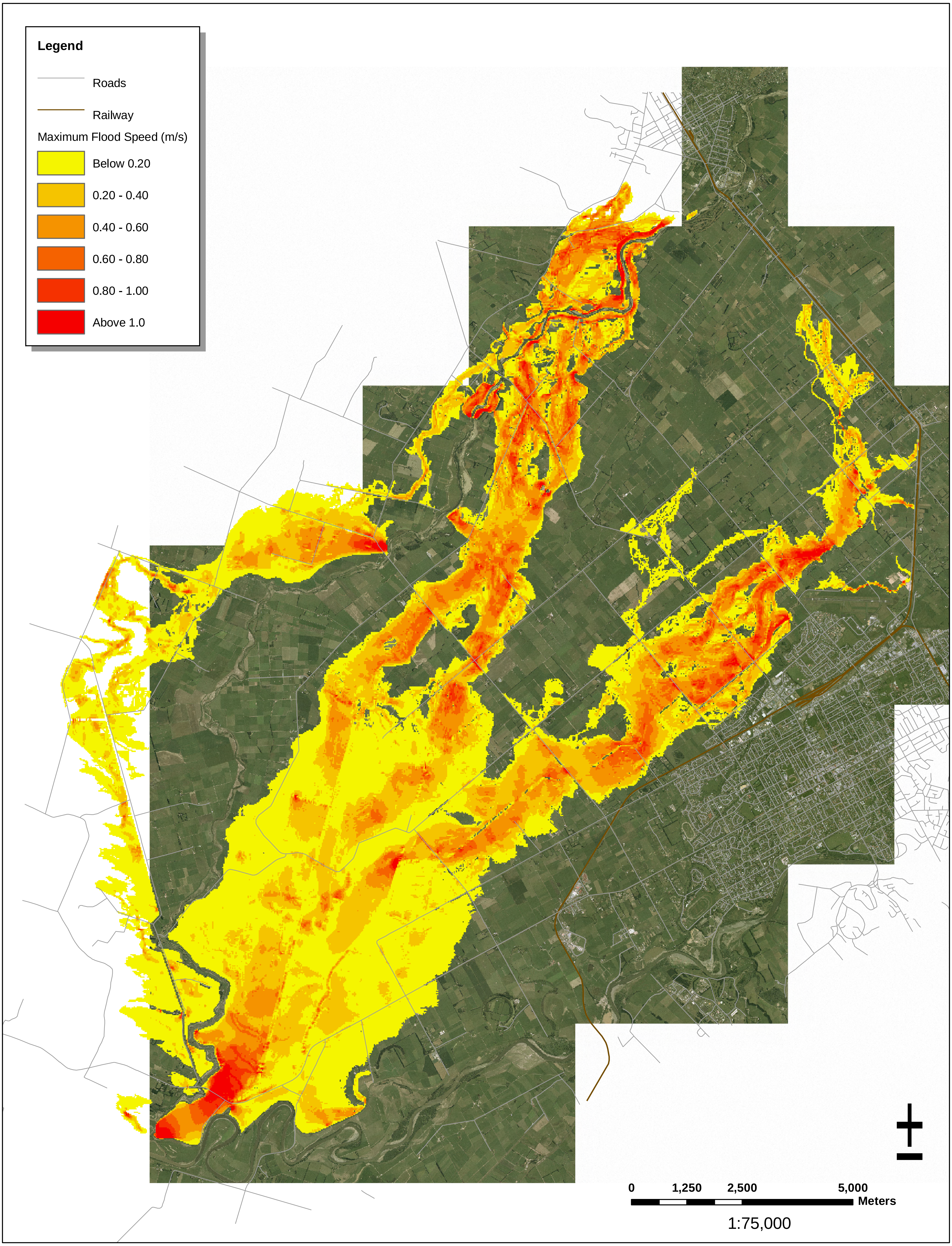
Oroua River Flood Hazard Assessment

Maximum Water Level: 200-year ARI Flood with Additional Oroua Stopbank Breaches

Location	Mangaone-Taonui Area
Drawing No.	15
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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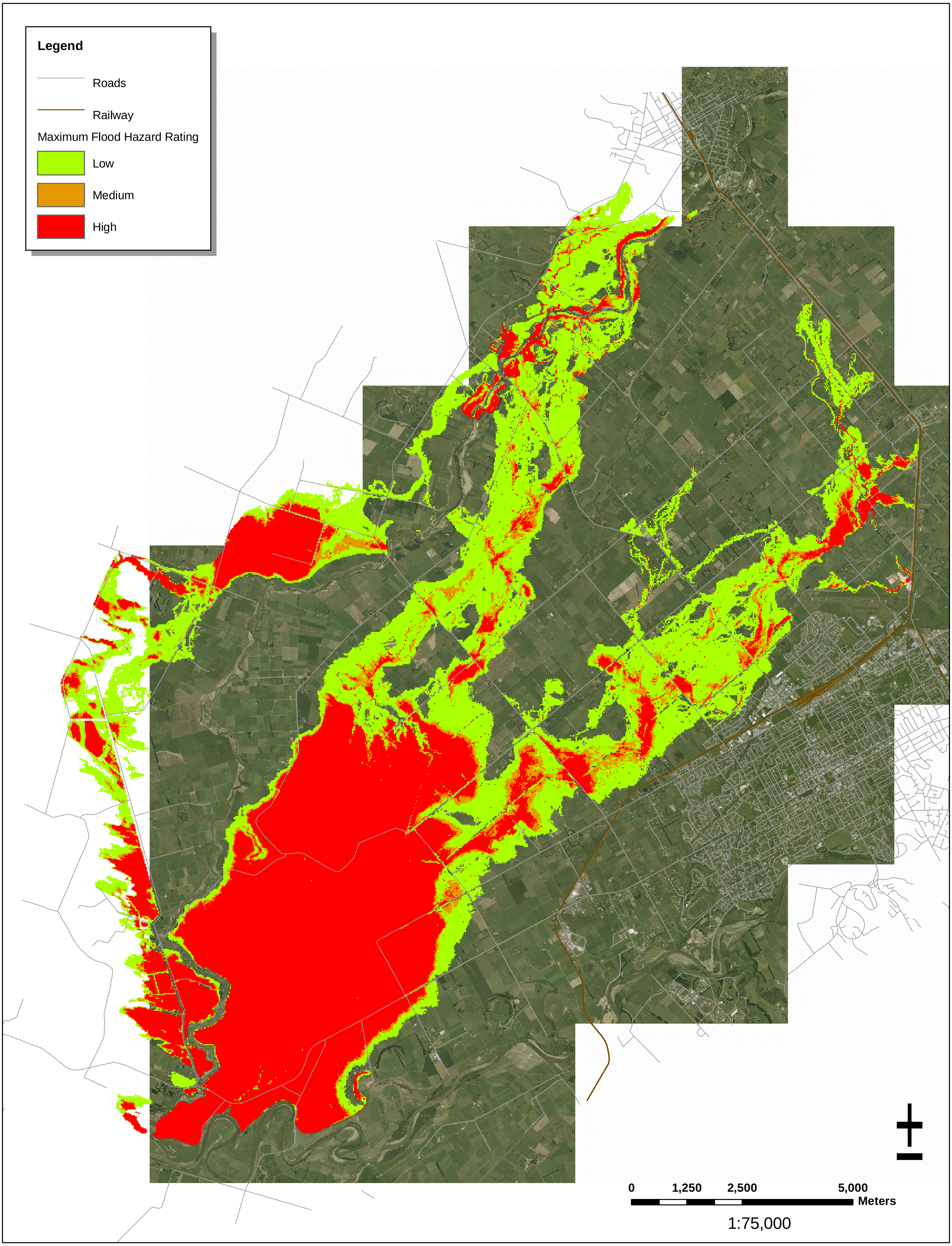
Oroua River Flood Hazard Assessment

Maximum Flood Speed: 200-year ARI Flood with Additional Oroua Stopbank Breaches

Location	Mangaone-Taonui Area
Drawing No.	16
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	



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Oroua River Flood Hazard Assessment

Maximum Flood Hazard Rating: 200-year ARI Flood with Additional Oroua Stopbank Breaches

Location	Mangaone-Taonui Area
Drawing No.	17
Creation Date	3/4/2008
Prepared by	DHI Water and Environment Ltd.
Approved by	