Wairoa Catchment

Numerical Modelling – MIKE FLOOD Model Build, Validation and Flood Hazard Mapping

Tauranga City Councilland

Report

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The expert in WATER ENVIRONMENTS

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Numerical Modelling – MIKE FLOOD Model Build, Validation and Flood Hazard Mapping

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1 Executive Summary

Tauranga City Council (TCC) has been engaged in a long-term campaign of building flood models of stormwater catchments across its district for use in flood-hazard-mapping as well as for remedial options analysis. Public reaction to flooding during the April 2013 storm event has precipitated an increased urgency for the construction of mitigation measures in a number of TCC's stormwater catchments.

DHI Water and Environment Ltd (DHI) was engaged by TCC to build the MIKE FLOOD model for the lower Wairoa River, floodplain and stormwater reticulation. Following the model build, the model was validated against peak water level data that was available in the form of a good number of debris marks which were picked up by BOPRC along the length of the Wairoa River between the Ruahihi flow gauge and the railway bridge for the 28th – 29th January 2011 storm. A number of photographs of the flooding at various locations along the river were made available as well from the report prepared by Tonkin & Taylor (Tonkin & Taylor Ltd, 2013). The calibration indicated that the model reproduces the observations reasonably well.

The sensitivity of the model has been further assessed by simulating variations to tributary inflows and to channel and floodplain resistance.

Following the calibration, 1% AEP river flow and 1% AEP storm surge design events were simulated to produce flood maps.

2 Introduction

2.1 Background and Purpose

TCC engaged DHI to build a MIKE FLOOD model for the Wairoa River catchment. The model represents the Wairoa River and floodplain (downstream of Ruahihi) as well as stormwater pipe network. These elements are dynamically interconnected in the model.

The model's capability to reproduce realistic flooding was validated using the January 2011 event. After the model was validated, the final flood hazard maps were prepared using the 2-D model built under this project. These maps will be incorporated into the TCC GIS for public use.

2.2 Description of Study Area

The Wairoa catchment is dominated by a large river but also has limited areas serviced by a stormwater pipe reticulation. It is important to address the flood risk in this catchment, recognising that there are some potential growth areas in the catchment.

The Wairoa catchment covers approximately 450 km^2 and discharges into the Tauranga Harbour (see Figure 2-1). A little under 9 km^2 of the catchment is within the TCC district, consisting of two discrete areas in the lower part of the catchment. It is predominantly rural and semi-rural.

The remainder of the catchment is in the WBOP district, mostly rural in nature, predominantly pastoral and horticultural in the lower catchment and exotic and native forest in the upper catchment.

The entire catchment is in the Bay of Plenty region. Bay of Plenty Regional Council (BOPRC) also has a mandate to plan for and manage flood hazards. Although there is no regionally-managed river scheme associated with the Wairoa River, BOPRC does provide advice on, and assistance with, river works in the catchment and has frequently been asked to provide comment on flood risk for developments within the catchment.

Trustpower is the final organisation with a significant interest in the Wairoa River catchment. Trustpower manages the Kaimai Hydro-electric Power Scheme (HEPS), consisting of four hydro-electric power stations fed by the catchment. The largest and most-downstream of these is the Ruahihi power station, discharging into the Wairoa River approximately 12 km from the river mouth. The river flows downstream of the power station are significantly influenced by the operation of the power scheme.

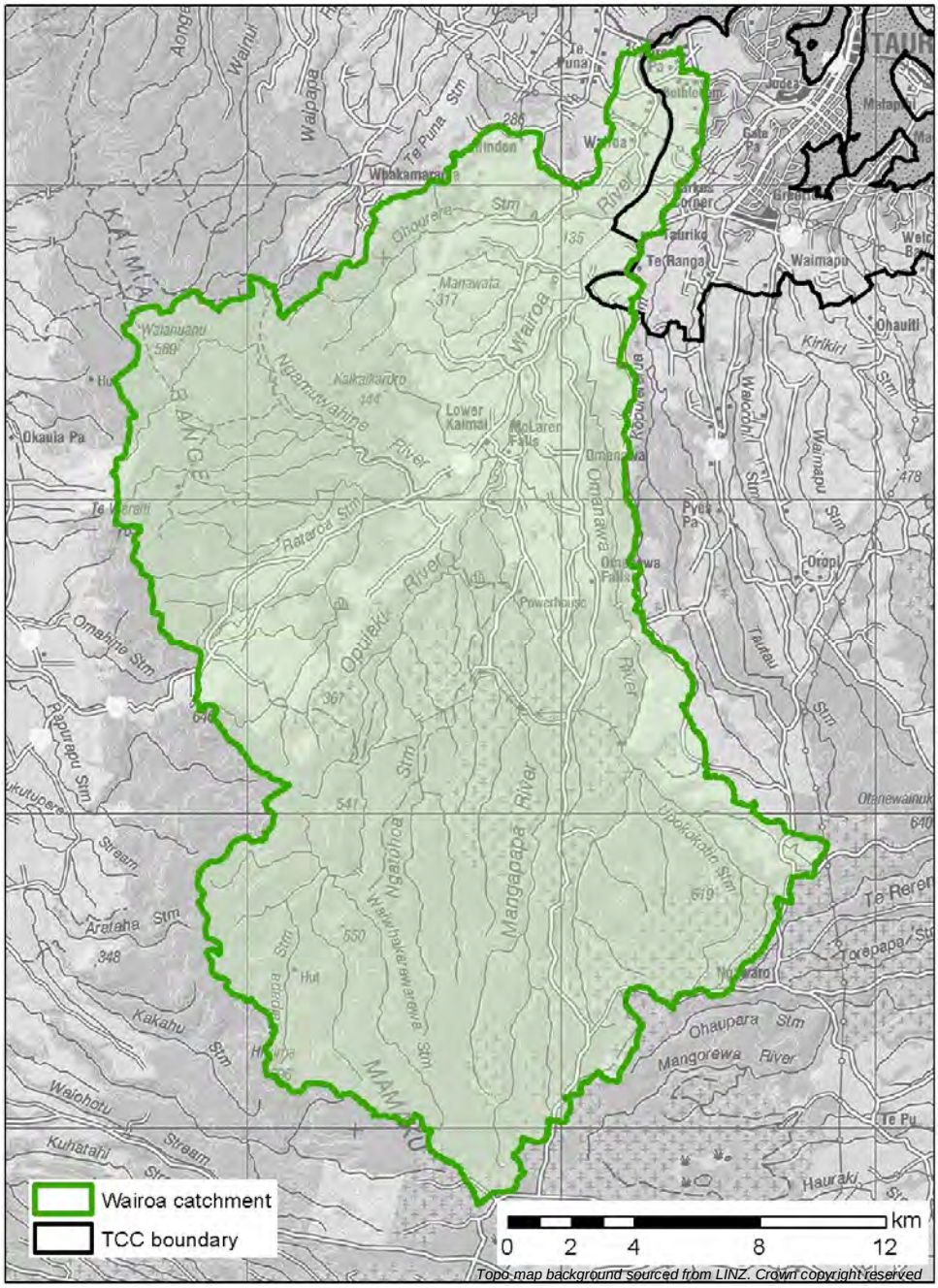

Figure 2-1 Wairoa Catchment

2.3 Previous Modelling and Reports

Number of studies were carried out in the Wairoa catchment over the years. Some of the most relevant studies and reports describing previous modelling of the Wairoa River and catchment investigations include the following:

1. Riley Consultants carried out *Kaimai HEPS Flood Study* (Riley Consultants Ltd, 2005) for Trustpower. A HEC-HMS model of the HEPS was developed and flows were routed through

the HEPS. Model outputs include design flows (10 year ARI[1], 100 year ARI, 1000 year ARI, PMF[2]) for the catchment at Ruahihi (including the contribution from the HEPS). The model was calibrated to flows at the Wairoa River recorder just downstream of Ruahihi Power Station.

2. Tonkin & Taylor carried out *Kaimai Hydro Electric Power Scheme: PIC Assessment* (Tonkin & Taylor Ltd, 2013) for Trustpower. Dam break hydrographs (derived from HEC-HMS) were routed from the Mangaonui Dam to the Tauranga harbour, via the Opuaiki and Wairoa Rivers, using Mike 11. LiDAR and photogrammetry were used to derive river cross-sections, supplemented in lower reaches by manual adjustment to invert levels with the aid of three actual cross-sections near the power station.

3. Ryder Consulting undertook a river modelling exercise for a proposed development near Tauriko, *Wairoa River at Tauriko – Floodplain Assessment* (Ryder Consulting Ltd, 2010). River cross-sections were surveyed over a 2.6km reach adjacent to Tauriko, while cross sections downstream to the railway (near the mouth) were based on 1m contours over the remaining reach to the railway near the mouth. The exercise was carried out using HEC-RAS.

2.4 Scope of Work

The focus of this study is to build a MIKE FLOOD model of the Wairoa River and floodplain, downstream of Ruahihi Power station. The model area covers that shown in Figure 2-2. It should be noted that the upstream extent of the model is upstream of tidal effects.

The scope included the following tasks:

- Validate an existing HEC-HMS model of the upper catchment and use it to prepare design Wairoa River flow hydrographs.
- Build the 2-D surface model using MIKE 21 FM (quadrilateral elements);
- Build a MIKE URBAN model of the Wairoa stormwater catchment reticulation;
- Build a MIKE 11 model of the Wairoa river;
- Dynamically link the 1-D pipe network model, 1-D river model and the 2-D surface model;
- Validate the model by comparing the outputs to the existing observed and anecdotal information for the January 28th-29th 2011 event; and
- Carry out sensitivity simulations to understand the model predictions sensitivity to changes in hydrologic input and surface roughness; and
- Carry out production runs to produce flood hazard maps.

[1] Average Recurrence Interval. A 10 year ARI event is also referred to as a 10% AEP (Annual Exceedance Probability) event. Likewise, a 100 year ARI event is also referred to as a 1% AEP event.

[2] Probable Maximum Flood

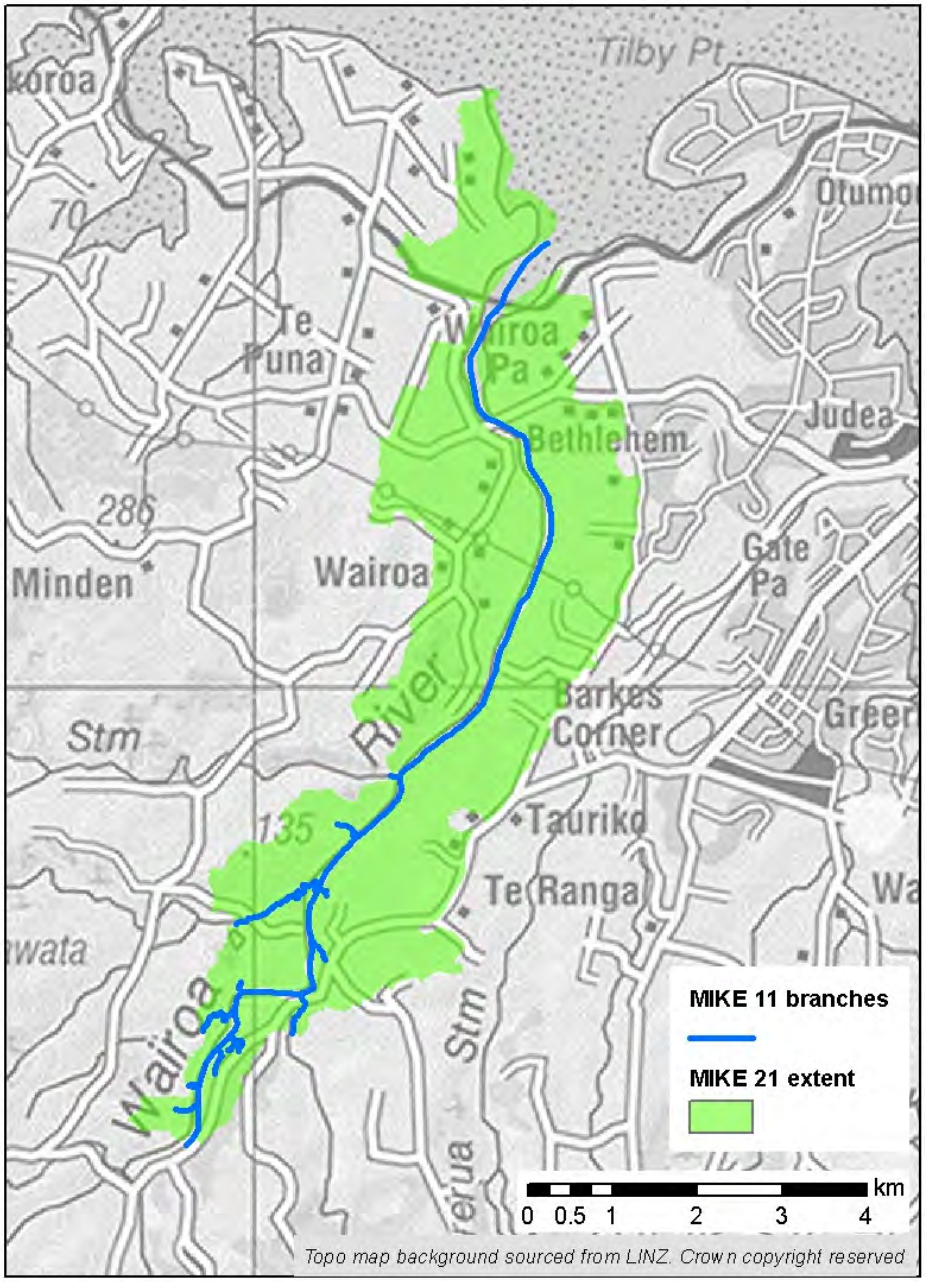

Figure 2-2 Model Extent

2.5 Approach to the Study

A fully 3-way coupled MIKE FLOOD model was built and it consists of

- a 2-D model that uses LiDAR data converted into a 4 m grid to represent the overland 2-D terrain (MIKE 21 model),
- a 1-D river model that uses surveyed stream cross sections (MIKE 11 model), and
- a pipe network model that is based on the stormwater asset data provided by the TCC (MIKE URBAN model).

The completed model with its various hydrological scenarios was compared against flood debris levels (i.e. peak water levels) down the river collected by BOPRC during a flood event from 28th-29th January 2011 as well as some flood photographs from the same event presented in *Kaimai Hydro Electric Power Scheme: PIC Assessment* report (Tonkin & Taylor Ltd, 2013).

The modelling work was carried out in accordance with TCC's Guidelines for Stormwater Modelling using MIKE FLOOD (DHI, 2013). That document presents guidelines and general advice on best practice concerning schematisation and model build using MIKE FLOOD. It also specifies the format for the deliverables, including the table of contents for the model build report.

2.6 Task Outline

The following steps were taken to ensure the delivery targets are met both in terms of time and DHI's high standards:

1. Undertake a site visit;
2. Review available data for the model build, identify data gaps and present the extent of missing data to TCC;
3. Identify what, if any, flood observations are available for model calibration and verification;
4. Prepare a river cross-section survey specification, structures survey specification and required format; survey of verifiable flood marks from actual events (e.g. identified in photographs or described by residents);
5. Confirm hydrological inputs;
6. Prepare a MIKE 11 model of the Wairoa River from Ruahihi to the Tauranga Harbour;
7. Build a MIKE URBAN model of the stormwater reticulation in the catchment;
8. Construct a MIKE 21 Flexible Mesh (FM) model of the catchment's surface;
9. Couple the MIKE 11, MIKE URBAN and MIKE 21 models using MIKE FLOOD;
10. Verify model parameters by assessing the model's capability to reproduce flooding observed during the storm events of January 2011;
11. Produce flood maps for the existing-climate, 100 year-ARI design event using catchment and boundary condition parameters relevant for the existing case;
12. Produce a model build and flood-hazard mapping report to accompany the hand-over of the final model and associated results to TCC.

4 Model Components

4.1 MIKE URBAN

The model has been built using stormwater asset data extracted on 18th of February 2016. The following layers with numbers of elements were used to build the model:

- SWManhole: 101
- SWNode: 4
- SWSoakHole: 19
- SWStructure: 46
- SWSump: 86
- SWServiceLine 97
- SWMain 125

The majority of imported pipes has diameter and material information. However, many of imported nodes have either ground level or invert levels missing, as seen in **Error! Reference source not found.** and Table 4-2. Missing invert levels were replaced by interpolated (source 'Inserted') values or in terms of sumps and soak holes by standard configurations described later in this report. Missing ground levels were extracted from LiDAR information.

Table 4-1 Source of information for invert levels

Invert Level Source	
GIS	79
Inserted	72
Sump Configuration	86
Soak Hole Configuration	19

Table 4-2 Source of information for ground levels

Ground Level Source	
GIS	78
LIDAR	178

4.1.1 Sumps

There are 96 sumps in the model. Eight-six of these were imported asset data and 10 are dummy sumps. These dummy sumps were added for pipes that do not have an upstream node in the defined in the asset data.

The sumps are set up using TCC's Guidelines for Stormwater Modelling using MIKE FLOOD (DHI, 2013):

- Sump depth 1.2 m;
- Lead diameter 0.35 m if unknown;
- Lead upstream level sump invert + 0.45 m;
- Maximum lead slope 10% if possible; and
- Minimum lead slope 1% if possible.

Sumps are coupled to MIKE 21 2-D overland model and the coupling parameters were adopted as per the guidelines (DHI, 2013), i.e. the inlet area, discharge coefficient and QdH factor were based on the physical properties of the sump.

4.1.2 Cesspit Manholes

Cesspit manholes, from Asset layer SWManhole type Cesspit Manhole, are modelled as sumps. There are two cesspit manholes in the model.

4.1.3 Inlets

Inlets, from Asset layer SWStructure type Inlet, are modelled as manholes which are coupled to MIKE 21. The inlet areas in the couple file are set to match the cross section area of the connecting pipe. There are 18 inlets in total in the model.

4.1.4 Outlets

Outlets, from Asset layer SWStructure type Outlet (28 elements in total) and SWNode type End (3 elements in total), are modelled as manholes which are coupled to MIKE 21. The inlet areas in the couple file are set to match the cross section area of the connecting pipe. One exception is manhole id 57997 which discharges into the river. This outlet was modelled as an outlet structure and it was coupled to MIKE 11. The model has 35 outlets of which four are dummy outlets placed at pipes with no downstream nodes defined in the asset data.

4.1.5 Soak holes

A total of 19 soak holes in the model were set up as per TCC guidelines for soak holes in mainland catchments. There are no as-builds or asset information on soak holes apart from their location, hence standard assumptions were used as per Modelling Approach for Soak Holes (DHI, 2014):

- 3 m deep;
- 1 m in diameter; and
- Soakage rate 157.1 l/h when ground level is above 3 m (which was the case for all 19 soak holes).

Each soak hole is modelled as a manhole with a dummy pipe with a dummy outlet on the downstream end. Dummy pipes are assigned a passive flow regulation of 157.1 l/h; the dummy outlets were not linked to MIKE 21, thereby the water is removed from the model. This approach represents the water soaking into the ground at the bottom of the soak hole. The soak hole itself is linked to MIKE 21 to enable spilling onto the ground if the water level in the soak hole itself reaches the ground level.

4.2 MIKE 11

The MIKE 11 model consists of the main Wairoa stream downstream of the Ruahihi flow gauge and 12 smaller tributary streams. In the model the Wairoa stream branch has been split into sections to allow for the full length of the two bridges, SH2 and the Railway Bridge, to be modelled while maintaining the smaller max dx of 20m in the remainder of the Wairoa Stream. Survey cross sections from February 2016 were used for the length of the Wairoa. These survey sections are spaced at approximately 400m intervals (Appendix C). A second survey was undertaken to check the very deep cross section measured at the bed upstream of the SH2 bridge (model chainage Wairoa_US 10252) (Figure 5-7); it was confirmed that there is a deep

hole that drops below -17m RL (Appendix C). Where the lateral links were moved beyond the extent of the cross section survey, these cross sections have been extended using a 2x2m raster of the LiDAR data. Additional tributary streams were included in the model to ensure that the floodplain could correctly drain into the Wairoa and to facilitate the connection of some of the external catchments into the MIKE FLOOD model. The cross sections for all of the tributary streams were extracted from the 2x2m LiDAR raster except for the Omanawa Stream where survey cross sections were available.

Catchment inflows into the MIKE 11 model were applied at the upstream end of the model (Wairoa @ Ruahihi) and at the upstream end of six of the 12 tributary streams (Table 4-3 and

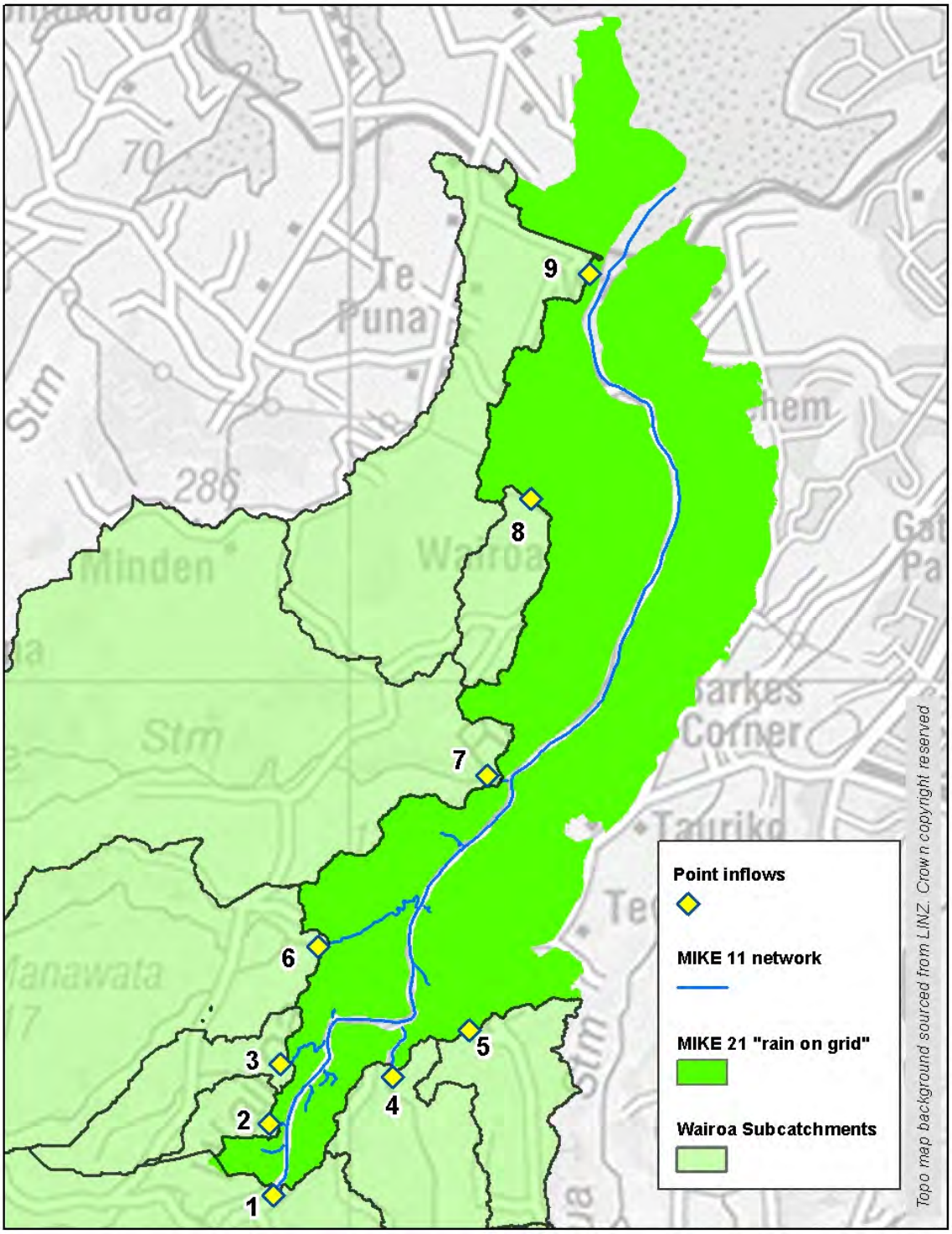

Figure 4-1). With the exception of the Wairoa @ Ruahihi site for the calibration event (where the recorded flow was used), these inflows were first generated in the HEC-HMS rainfall-runoff model (refer section, 5.1). A tidal boundary condition is applied at the downstream end of the Wairoa River.

Table 4-3 Hydrological inputs to hydraulic model

Site (Figure 4-1)	Sub-catchment	Applied as	Hydrograph source (Model validation)	Hydrograph source (Design)
1	Wairoa @ Ruahihi	MIKE 11 point inflow	Recorder	HEC-HMS
2	Wairoa6	MIKE 11 point inflow	HEC-HMS	HEC-HMS
3	Wairoa5	MIKE 11 point inflow	HEC-HMS	HEC-HMS
4	Omanawa	MIKE 11 point inflow	HEC-HMS	HEC-HMS
5	East Omanawa	MIKE 21 source	HEC-HMS	HEC-HMS
6	Waireia (Wairoa3)	MIKE 11 point inflow	HEC-HMS	HEC-HMS
7	Ohourere (Wairoa4)	MIKE 11 point inflow	HEC-HMS	HEC-HMS
8	Vernon Rd (Wairoa1)	MIKE 21 source	HEC-HMS	HEC-HMS
9	Wairoa2	MIKE 11 point inflow	HEC-HMS	HEC-HMS

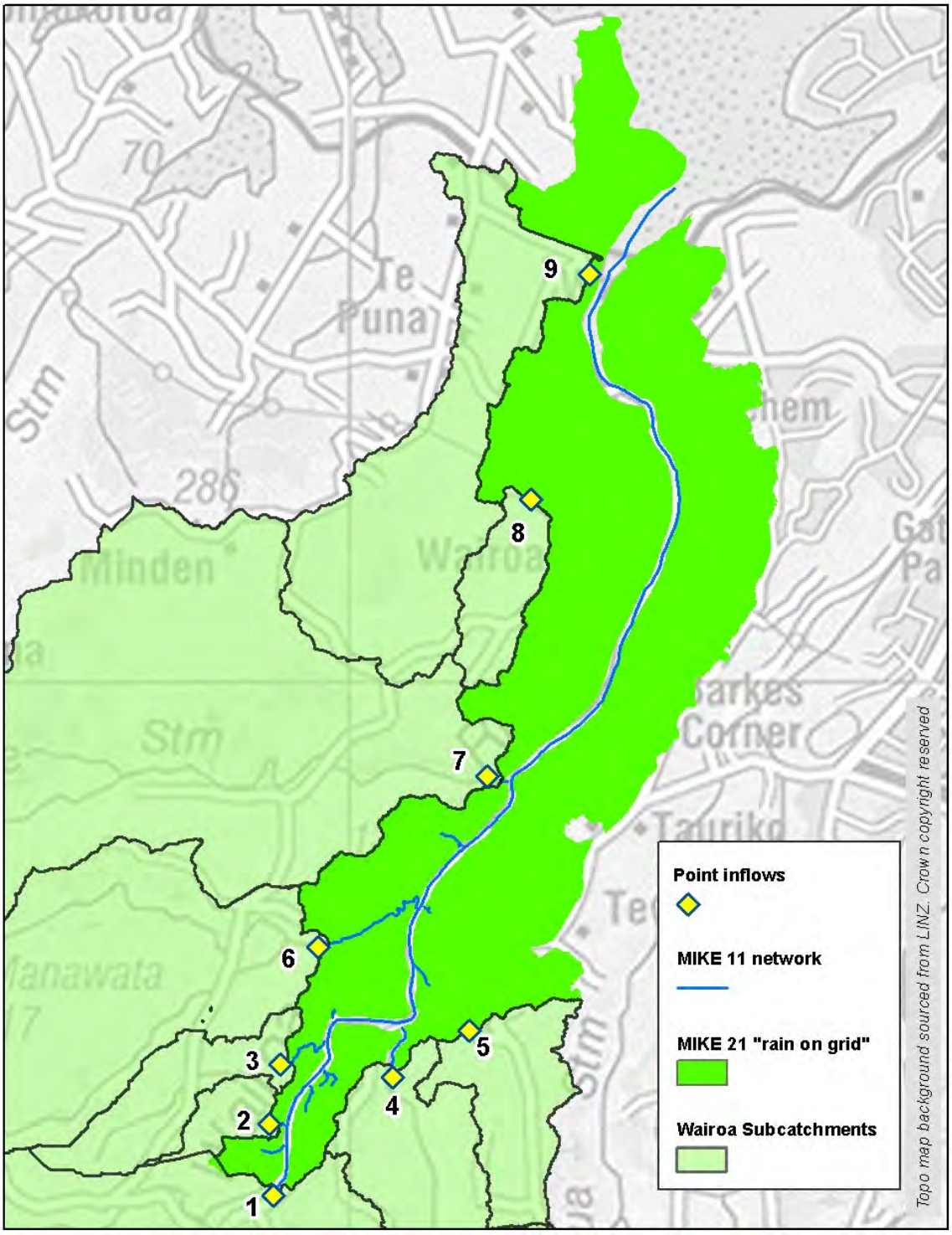

Figure 4-1 Hydrological inputs to hydraulic model

The 1D bed roughness was applied as uniform in the transverse distribution and varied along the length of the Wairoa River (as part of the model validation process, see Figure 5-6). The roughness in the tributary streams was set to a constant of 0.037.

Five structures were included into the MIKE 11 model. The properties of these structures are provided in Table 4-4 MIKE 11 structure parameters.

Table 4-4 MIKE 11 structure parameters

Name	Branch	Chainage	Geometry	Size	Length
Flapgate	Wairoa_US	10007	Circular, Side Structure	0.6m	6m
SH 29 Culvert	Branch 20	682	Circular	1.2m	15m
Rail Bridge	Wairoa_Rail	12414	Bridge with Piers (7% blocked)	Soffit @ 3.87m	24m
SH2 Bridge	Wairoa_SH2	10883	Bridge with Piers (5% blocked)	Soffit @ 4.975m	30m
SH29 Bridge	Omanawa_Bridge	462	Bridge with Piers (9% blocked)	Soffit @ 6.2m	15m

The initial water level was set to that of the starting level of the tidal boundary condition. The initial flow was set to zero.

Both the ‘delta’ and ‘delhs’ values were adjusted in the MIKE 11 HD setup. The ‘delta’ value was set to 0.85 which is standard for a MIKE FLOOD simulation with a small time step. The ‘delhs’ value was increased from 0.01 to 0.02 to stabilise the flow calculation through the downstream bridges where the tidal effects are significant.

1D mapping was setup for the simulation to allow for the 1D and 2D results to be more easily merged into a single flood map.

4.3 MIKE 21

The MIKE 21 flexible mesh (FM) was derived from the 2011 and 2014 LiDAR surveys. These LiDAR surveys were combined by prioritising the newer 2014 dataset. Open drains were burned into the resulting dataset by lowering the cells by 500mm. The outline of the MIKE 21 mesh was derived by performing a catchment delineation on the 4x4m grid, the delineation was assisted by digitising additional sink points and trench lines to encourage the flow accumulation to coincide with the existing open channels in the floodplain. The downstream harbour edge was manually edited to match the curve of the coast. Areas beyond the extent of the delineated catchment and within the extent of the MIKE 11 cross sections, were set to land in the 2D grid. Once the 2D grid was complete it was converted into a mesh with rectilinear elements and the harbour boundary was set to code 2. The complete MIKE 21 FM grid consists of areas of steep terrain combined with relatively flat floodplain as seen in Figure 4-2.

A depth correction file was used to replace the MIKE 21 FM mesh values; this allows for easier editing of mesh values and better accuracy in bed levels. The following modifications to the model grid were made using the depth correction file:

- Areas where high velocities were occurring due to steep slopes were smoothed using the filter tool;
- Elements at the Harbour boundary were lowered so that the boundary would never dry out throughout the tide cycle;
- Element levels were adjusted at the location of standard and side structure links so that the MIKE 21 level matched the connecting MIKE 11 cross section; and
- Element levels were lowered to allow flow to pass through the MIKE 21 FM culverts.

Three culverts and one weir were included directly into the MIKE 21 FM model to allow flow to pass through road obstructions away from the MIKE 11 model. The location of these culverts is shown in Figure 4-2 and the properties of these are presented in Table 4-5.

Table 4-5 MIKE 21 Structure Parameters

Name	Geometry	Size (m)	Length (m)
SH2 Culvert	Irregular Arch	1.75 x 1.4	8
Wairoa Rd 1	Circular	0.45	10
Wairoa Rd 1	Circular	0.45	10
Weir Wairoa Rd 1	Weir	18m RL, 16m wide	

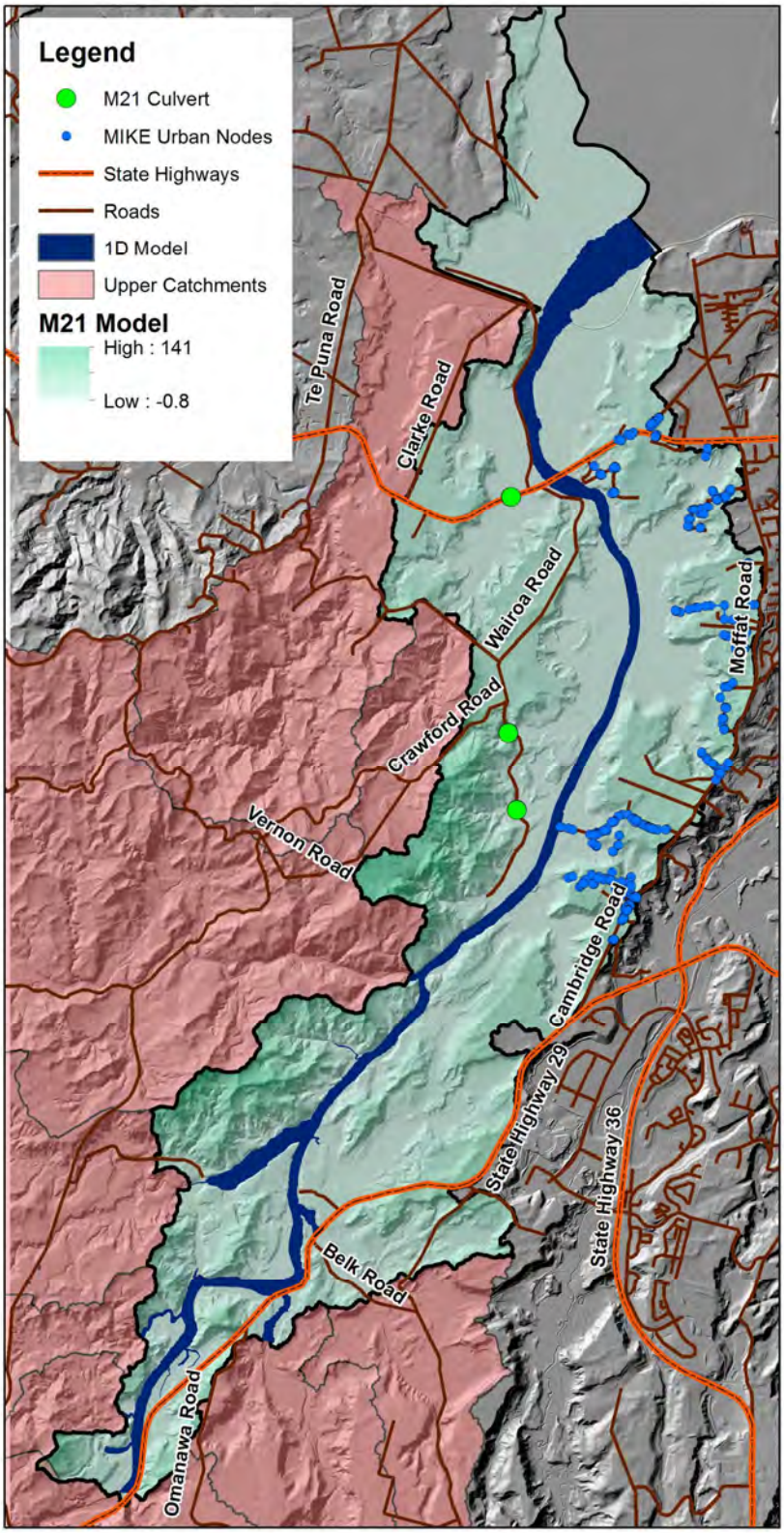

Figure 4-2 Model Layout

Rainfall is applied directly to the mesh within the 2D model area (Figure 4-1). In addition two of the external sub-catchments were connected to the MIKE 21 grid as MIKE 21 source points. These catchments are Vernon Road and East Omanawa. The location of the sources is also shown in Figure 4-2.

The 2D roughness was derived from the LCDB version 4.1 and the TCC inland land use layer (based on aerial photography analysis), since the TCC layer only covered the TCC section of the catchment. Where data was not available on the road extent a new extent was created by applying a 5m buffer to the road centre lines. The road centreline was first checked and adjusted so that the roads aligned with the aerial photography. Where data was not available on the buildings these were drawn manually based on the Aerial photography. The roughness was applied as a dfs2 file at 4x4m resolution. The Manning's values used for each land use type are outlined in Table 4-6.

Table 4-6 MIKE 21 roughness

Landuse type	Manning's M
Forest	12
Crops and bushes	8
Grass	20
Water	80
Roads + other impervious	70
Buildings	5
Built up area	12

Infiltration was applied to the model using the constant infiltration with capacity method. To define the infiltration rates and initial losses the land use was split into four categories;

- Impervious areas, i.e. road, pavement and water;
- Buildings above an elevation of 3m;
- Buildings below an elevation of 3m; and
- Pervious areas, i.e. grass, vegetation, gravel.

The following parameters were used for these different land use types, Table 4-7.

Table 4-7 MIKE 21 infiltration values

Landuse Type	Infiltration mm/hr	Initial loss depth (mm)
Impervious	.0083333	0.05
Buildings > 3m	13.1	16.1
Buildings < 3m	8.5	20.8
Pervious areas	2.54	5

The MIKE 21 FM simulation uses a maximum time step of 0.25s and a minimum time step of 0.1s. The drying, flooding and wetting values are 0.002, 0.005 and 0.01m respectively.

The initial water level is set to that of the starting level of the tidal boundary condition.

4.3.1 MIKE FLOOD

The model is dynamically linked using the MIKE FLOOD software. The model contains a total of two standard links, 72 lateral links, 168 MU inlet links, one MU outlet to river link and one side structure link.

5 Model validation

Model validation has been a two-stage process: firstly, validation of the hydrological model (HEC-HMS) of the upper catchment, and secondly validation of the hydraulic model (MIKE FLOOD).

The storm event of 28th – 29th January 2011 was used as the validation event, because of the size of the event and the availability of calibration data. The estimated peak Wairoa River flow at Ruahihi was 1193 m^3/s, the largest since records began in 1990. Debris marks indicating peak water levels were subsequently surveyed along the river between Ruahihi and the harbour.

This storm was short and intense, as can be seen in the flow record at Ruahihi (Figure 5-1). It also followed a lesser, but still significant, storm on 23rd – 24th January 2011. As a result, the catchment would have been primed and runoff was more rapid in the second storm. (Note also that the recorder failed at or just before the peak, and hence there is no recorded recession. Peak flow estimates have provided by a slope-area calculation carried out by BOPRC.)

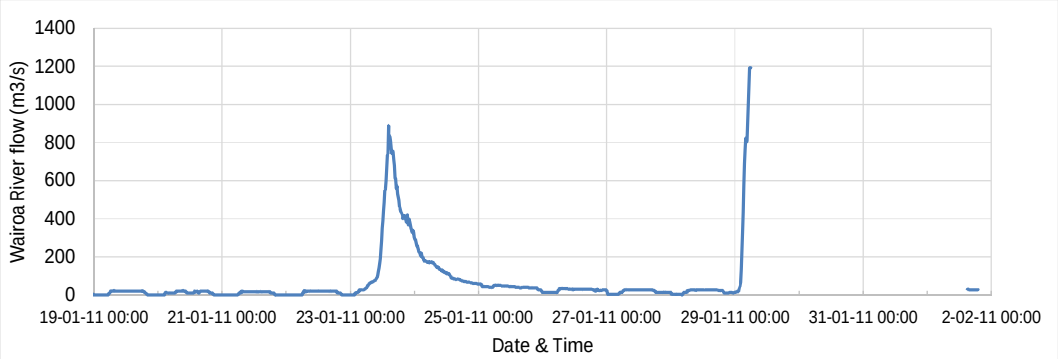

Figure 5-1 Wairoa River flow, immediately downstream of Ruahihi Power Station

5.1 Hydrological model validation

The existing HEC-HMS model of the Kaimai HEPS (Riley Consultants, 2005) has been updated as part of an exercise being carried out by Opus for Trustpower. The update has included a recalibration, taking into consideration a number of storm events: July 1998, May 1999, February 2004 and both January 2011 events. The rainfalls Opus used for the recalibration were based on a single rain gauge: the Lloyd Mandeno recorder, but scaled up in upper parts of the catchment (as explained in the original Riley Consultants report).

The recalibrated HEC-HMS model parameters (losses, times of concentration, etc.) are given in Appendix B. Comparison of the recorded and model predictions for the 29th January 2011 event are given in Figure 5-2.

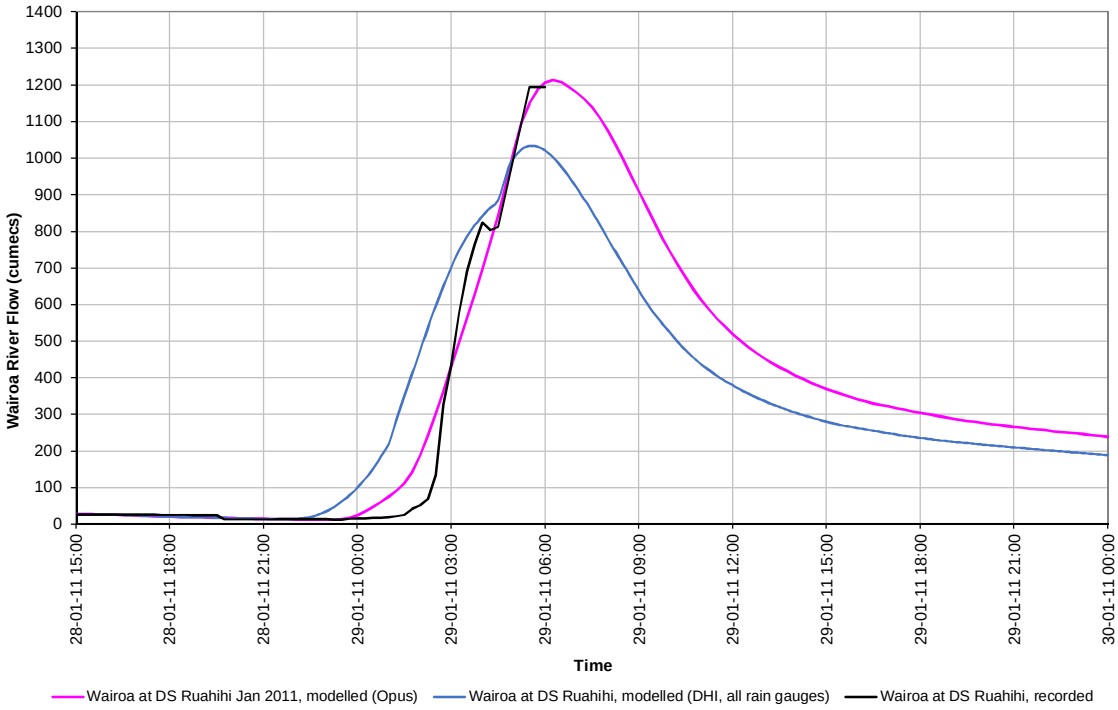

Figure 5-2 Recorded and modelled flows, Wairoa River downstream of Ruahihi, 29 January 2011

DHI has also used the same HEC-HMS model but with records from a number of rain gauges in and around the Wairoa catchment, as a further check on the calibration (Appendix B). Results for that check are also shown in Figure 5-2.

The simpler approach of Opus produces a good fit to the available data. Using all the available rain gauge information does not produce as good a fit. A possible reason is that the Mangakarengorengo Diversion rain gauge, which is applied over a significant part of the mid-catchment in the more detailed method, may have underestimated rainfall. The total recorded at that gauge is somewhat less than for all other gauges (Figure B-3). The nearby Lower Wairoa rain gauge has not been used in the analysis, as only daily rain totals were recorded at that time.

In addition to the rain gauge information, rain radar records were available. Peter West of Blue Duck Design has compared the rain totals suggested by the rain radar with the weighted sub-catchment rainfall depths calculated for the DHI approach. Figure B-4 presents his comparison. An interpretation of that figure is:

- the rain radar seems to confirm that the Mangakarengorengo recorder underestimated the rain totals;
- the rain radar has underestimated the rain in the south of the catchment (a blind spot in that area is more clearly evident in the hourly rain radar records); and
- elsewhere there is no major discrepancy between the rain gauge and rain radar totals.

Given that the Opus work also considered a number of other storms for recalibration, the recalibrated HEC-RAS model is considered acceptable for design flow estimations.

5.2 Hydraulic model validation

5.2.1 Boundary conditions

The actual recorded river flow at Ruahihi has been used for the upstream boundary condition, at least on the rising limb of the hydrograph. For the falling limb, a rate of recession similar to that of the 23rd January 2011 event has been used (falling at a rate of 4% every 15 minutes), rather than using the more gradual model predictions of river flow. Regardless the rate of recession is not expected to have any significance on downstream peak water levels for this short storm.

For sub-catchments downstream of Ruahihi, the Opus HEC-RAS model has been extended to include these sub-catchments and so provide inflow hydrographs for them. Similar loss parameters used in the Opus recalibration work for this particular storm have been used for those sub-catchments, and times of concentration estimated with the aid of empirical formulae. Appendix B summarises the parameters used.

Over the MIKE 21 domain, a rain on grid approach has been used. The rain hyetograph assumed is that of the Landing Road rain gauge, being the gauge closest to that area of the model.

The downstream boundary condition is the harbour water level record from the “Tauranga Harbour @ Omokoroa” recorder, about 5 km to the northwest. This recorder is the closest to the river mouth of the three harbour level recorders maintained by BOPRC.

5.2.2 Calibration information

Peak water level data on the event was available in the form of a good number of debris marks which were picked up by BOPRC along the length of the Wairoa River between the Ruahihi flow gauge and the railway bridge. The relative accuracy of the survey marks was also recorded with the levels. (Figure 5-3 to Figure 5-5).

A number of photographs of the flooding at various locations along the river are presented in Tonkin & Taylor (2013).

5.2.3 Simulations and results

A number of simulations were run to attempt to match the model to the measured flood levels. In the process a number of different variables were adjusted; these were: the 1D channel roughness, the 2D floodplain roughness, the infiltration from the 2D mesh and the runoff from the tributary catchments. It was found that the model was not particularly sensitive to these parameters, except for the 1D roughness which had a larger effect on water levels. The lack of sensitivity can be explained by comparing the relative catchment area upstream and downstream of the Ruahihi gauge. The catchment area upstream is approx. 380km^2 while downstream the area is approx. 80km^2, which is only 17% of the total catchment area. This means that any error in the flow measurement at the gauge will have a significant effect on the flood flows and levels downstream.

The findings from the validation iterations are detailed here:

1D bed resistance: Lowering channel resistance along the length of the river by 10% from the initial assumption had the effect of lowering the water levels by between 380mm and 90mm. The final values adopted are shown in Figure 5-6. These values are considered to be at the lower end of the expected range of Manning’s n values for such a river.

2D bed resistance: The 2D bed resistance for the vegetated open space area was adjusted from a Manning's M of 20, to 30. This lowered the Wairoa water levels up to 40mm.

2D infiltration: The pervious infiltration rates for the area of the MIKE 21 mesh were adjusted from 2.54mm/hr to 5mm/hr. This had the effect of lowering the water levels in the Wairoa by 10mm.

Runoff from the tributary catchments: The runoff from the tributary catchments, except Omanawa, was removed completely to test the sensitivity of the runoff on the Wairoa water levels. This had the effect of lowering the water levels in the Wairoa by approx. 40-120mm, indicating the relative insensitivity of the model results to the lower tributary inflows.

The final validation event combined a number of the model adjustments together. These adjustments were to decrease the tributary catchment runoff by approx. 10% by adjusting the infiltration parameters and adjusting the 1D roughness to the values in Figure 5-6. In the process of the validation some additional adjustments were also made to the model such as improving the definition of vegetation areas in the 2D roughness file, increasing the roughness of the roads, adjusting the flooding and drying values, and small adjustments to the flood links and MIKE 11 cross sections. However for the most part, these changes were made to improve model stability and the detail of the model rather than as an explicit calibration exercise.

The final results are illustrated in Figure 5-3 to Figure 5-6.

In the upper reaches of the model, above the Omanawa River confluence, the model predictions are close to the measured data. However, in the middle reaches the predicted water levels are still showing as significantly higher than the measured levels, with differences up to 700 mm for measurements with medium confidence.

Possible reasons postulated for the discrepancies included:

- River bed changes between the flood event and the time of the cross-section survey (an interval of five years);
- Overestimation of peak debris levels (deciding upon appropriate debris levels is a subjective exercise, notwithstanding the level of confidence in that was recorded in this case);
- Inaccuracies in the river flow rating; and
- Inaccuracies in the peak flow estimate (based on a slope area calculation).

Limited cross-section information from around the time of the flood event was subsequently obtained and assessed. That information does not explain the differences between model predictions and debris levels, as the 2016 cross-sections seem to have a lower invert than the earlier ones (Figure 5-7).

BOPRC also was comfortable with the rating curve at the Ruahihi site (Mark James, BOPRC, pers. comm.). Thus, it remains unclear why the model under-predicts the calibration event as much as it does.

Without further lowering the channel resistance, to unrealistic values, a closer fit to the observed data is unlikely.

Figure 5-8 and Figure 5-9 provide a comparison between flood photographs from the event provided in Tonkin & Taylor (2013) and model predictions. The photographs were presumably taken after the flood peak (that occurring before daybreak), but still will give an approximate indication of peak levels (as no debris lines above the water level are evident in the photographs). The modelled results may slightly over-predict the flood depths, particularly at the Hospice site, but nonetheless are considered in to show reasonable agreement with the photographs. (Other photographs are also available, but these do not add any information additional to the surveyed debris levels.)

Overall, even though the model has over-predicted levels in the middle reaches of the modelled river, realistic resistance values have been used, and the model validation is considered acceptable.

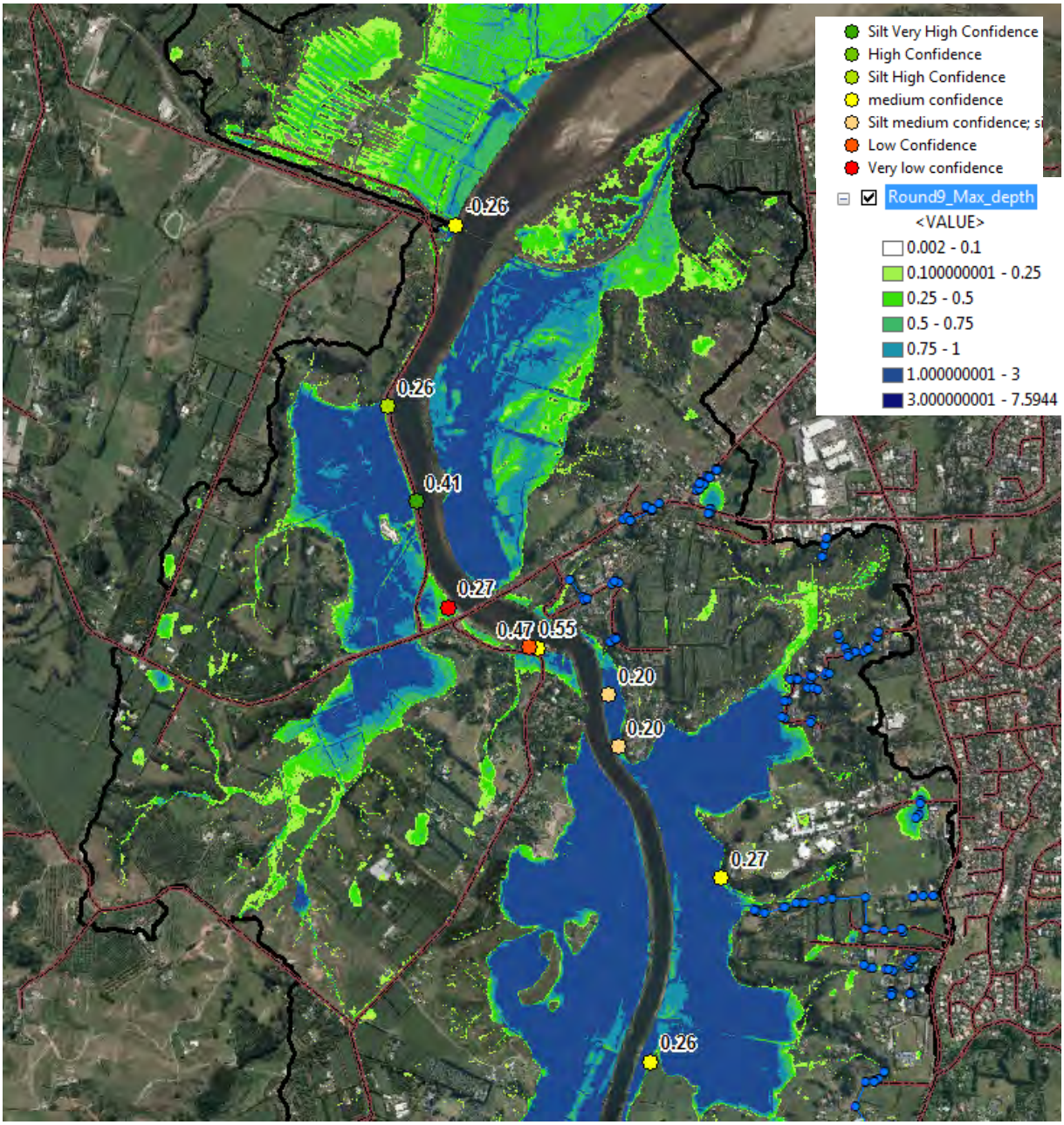

Figure 5-3 Difference between predicted and recorded peak flood levels, 29 January 2011 event, lower reaches.

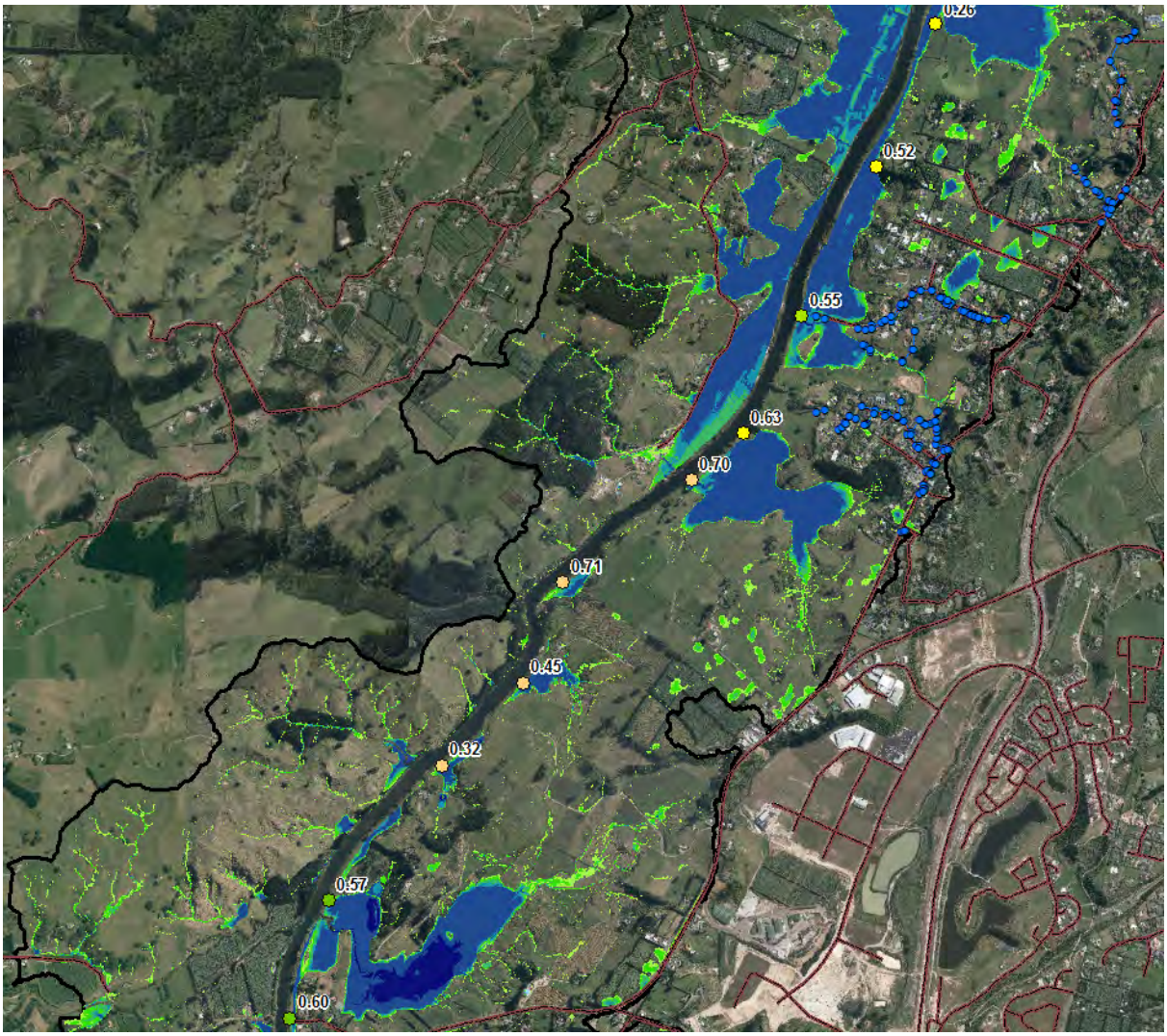

Figure 5-4 Difference between predicted and recorded peak flood levels, 29 January 2011 event, mid reaches

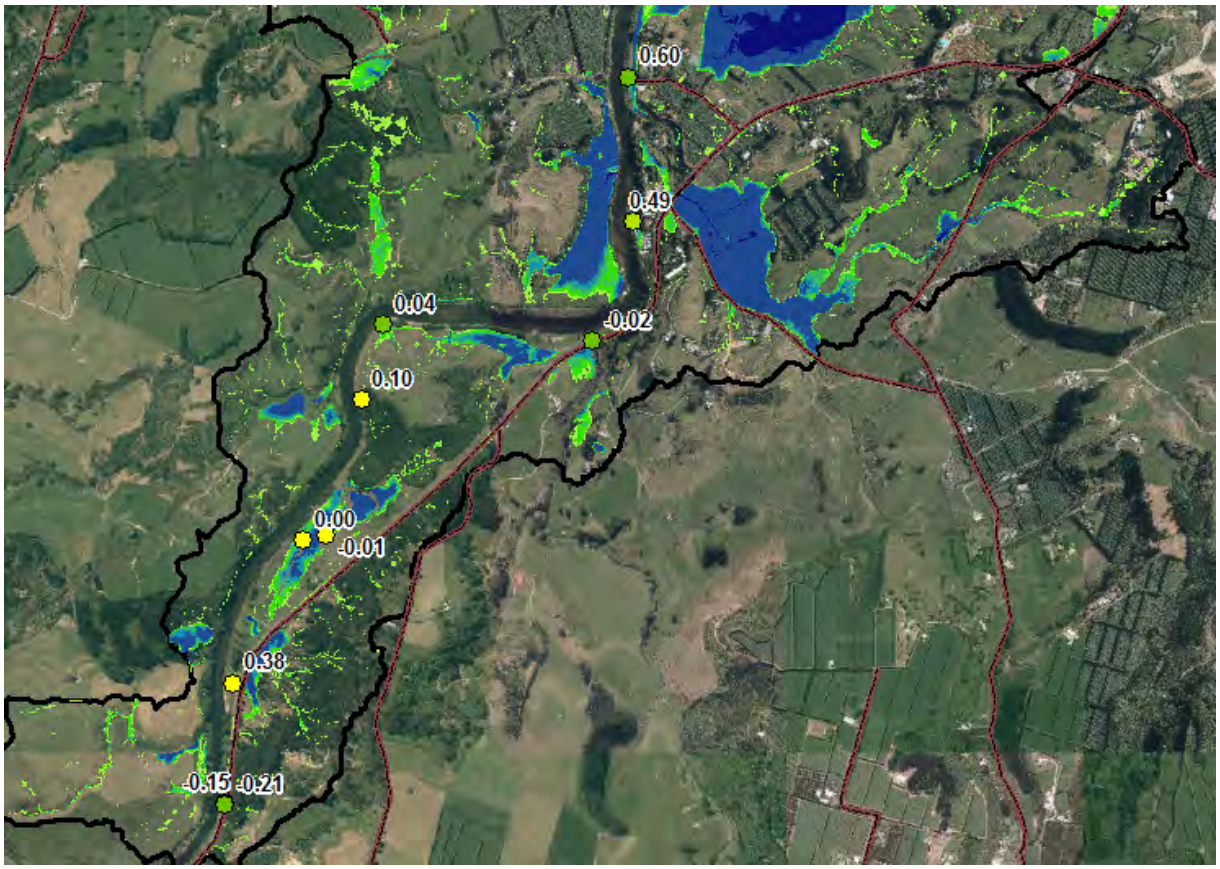

Figure 5-5 Difference between predicted and recorded peak flood levels, 29 January 2011 event, upper reaches

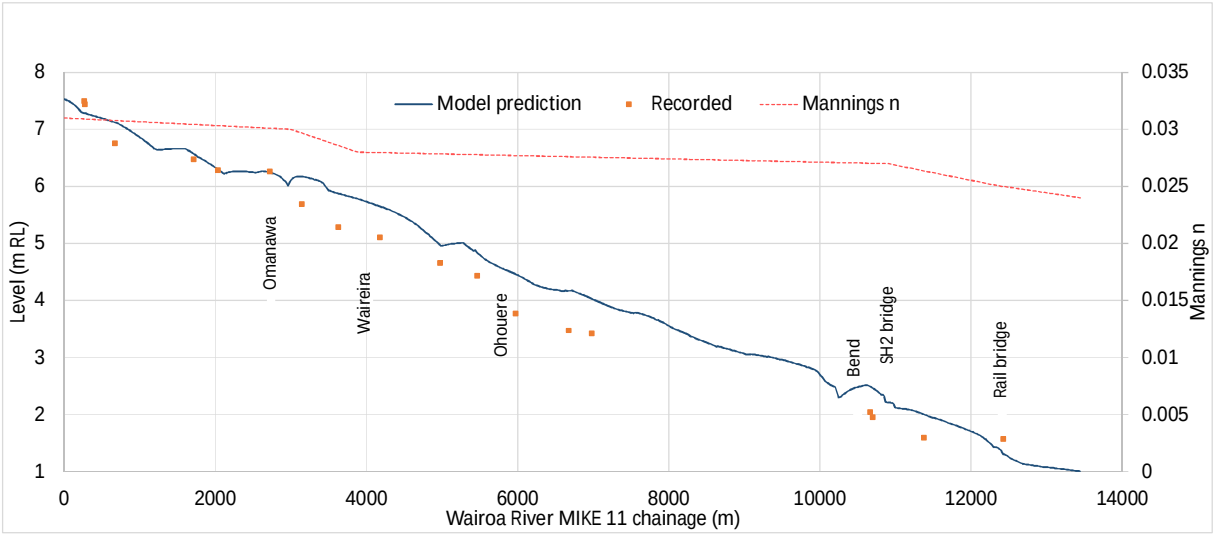

Figure 5-6 Final model validation runs, river channel peak levels

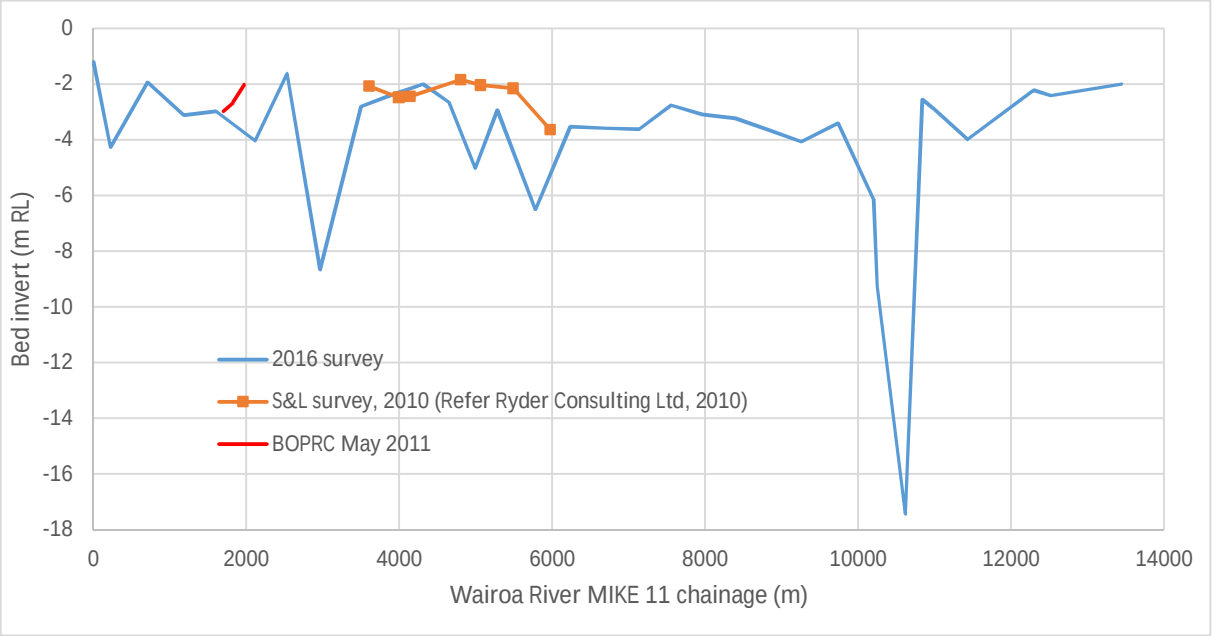

Figure 5-7 Wairoa River bed invert profile

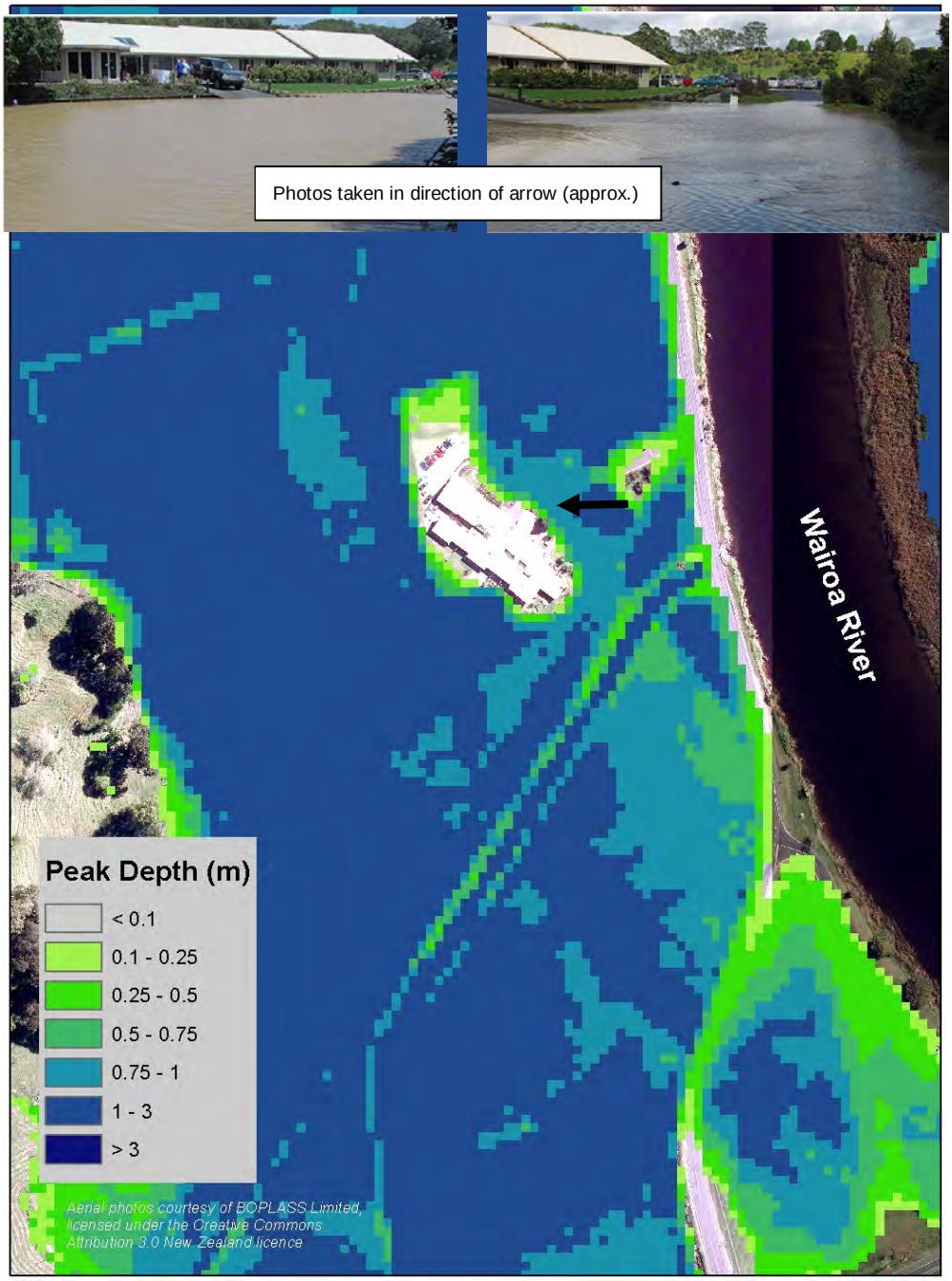

Figure 5-8 Flood depths at Hospice, 29 January 2011: modelled and photographs

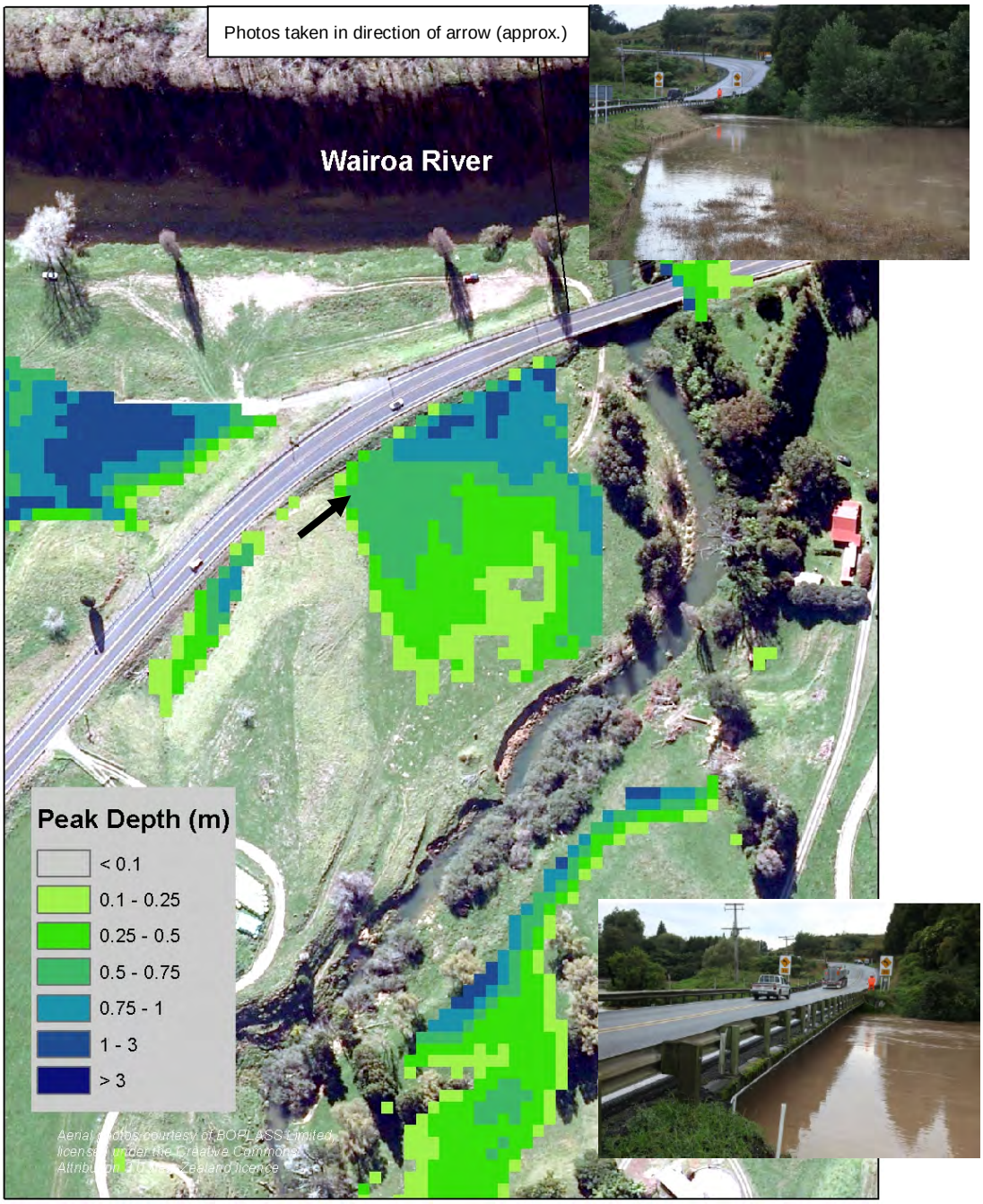

Figure 5-9 Flood depths at Omanawa confluence, 29 January 2011: modelled and photographs

6 Design event

The design events modelled used the existing development with current climate, i.e. no adjustments for climate change. Two rainfall and tide combinations were modelled, where combined these represent the 100 year ARI tide and rainfall event. These events were the 100 year ARI rain fall and river flows + 10 year ARI storm surge/harbour levels and the 100 year ARI storm surge/harbour levels +10 year ARI rain fall and river flows. The maximum results of these two simulations was combined to create the final result presented in the flood maps. Figure 6-1 is a summary of the flood depth map. More detailed maps have been provided to TCC separately.

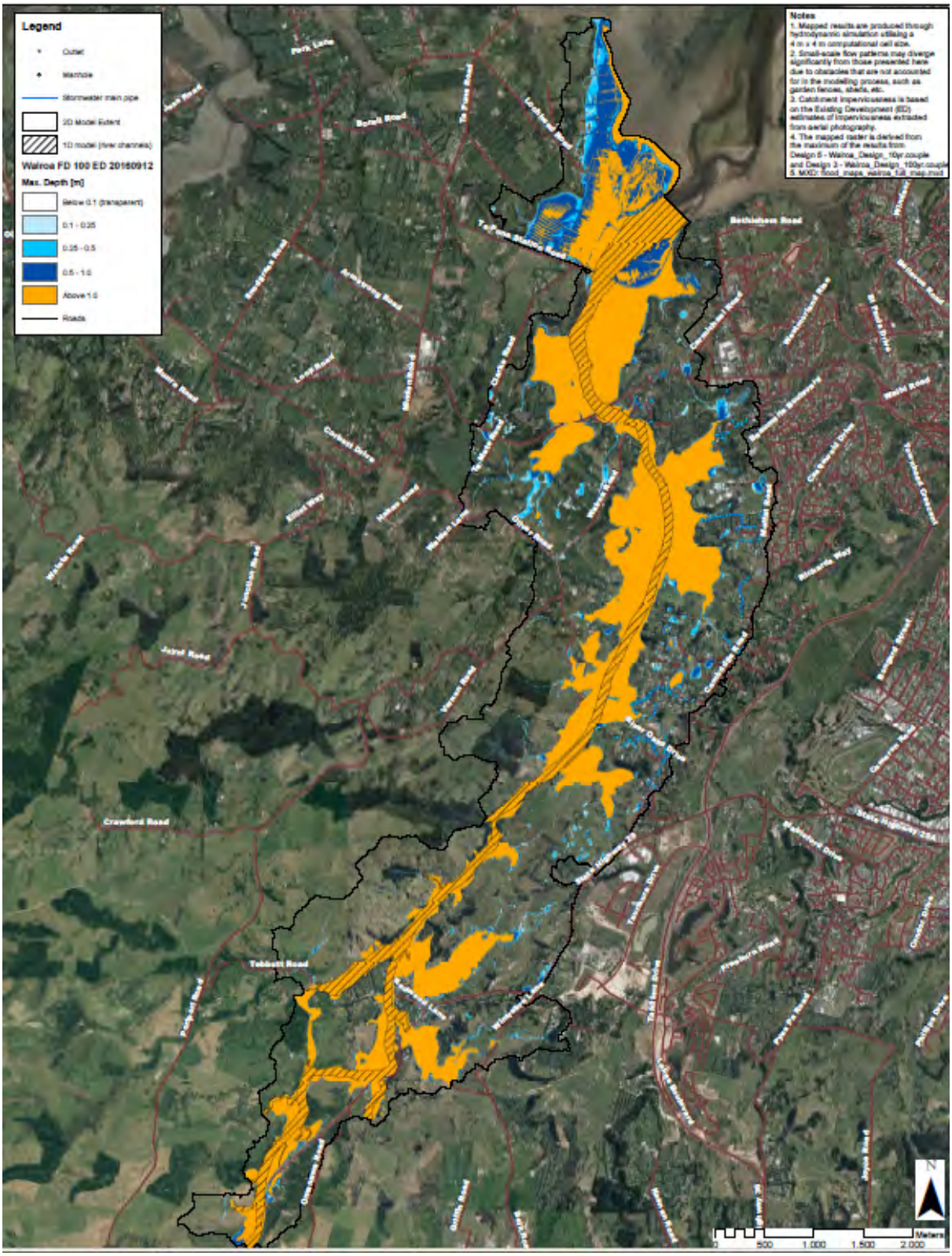

Figure 6-1 100 year ARI flood map, peak depths

7 Results Presentation and Reporting

The following deliverables were provided to Tauranga City Council in digital format:

- All cross section information that has been surveyed for the purposes of this study;
- All model files required to run the verification events, the design events and the sensitivity scenarios;
- All result and summary files for all components of the MIKE FLOOD model for the verification events, the design events and the sensitivity scenarios;
- GIS polygon of the outline of the modelled catchment extent;
- ArcGIS geodatabase containing the post-processed rasters of:
    - maximum flood depth,
    - maximum flood surface elevation,
    - maximum velocity, and
    - maps of maximum flood depth, surface elevation and velocity, for the verification events and the design events.
- This technical report in electronic format.

Maximum flood extents and surface elevation files were named according to the TCC requirements and provided in the format specified in *Guidelines for Stormwater Modelling using MIKE FLOOD* (DHI, 2013).

8 Quality Assurance

As a part of the internal QA at DHI, integrity checks have been made throughout the modelling process to ensure quality in both the computational model and the outputs.

Detailed checks were performed during the model build, validation and production run phases to ensure the models were setup in the correct way and the outputs produced are sensible and without evidence of any significant numerical instabilities.

9 Conclusions and recommendations

The production of the flood maps for the lower Wairoa catchment has involved development and refinement of both a hydrological model and a hydraulic model. The hydrological model in particular was reasonably complex, given that much of the upper catchment is part of the Kaimai HEPS, with its multiple diversions, lake storages and power stations.

The HEC-HMS model of the Kaimai HEPS, developed by Opus, was a work-in-progress at the time of this report. Further refinement and development of that model is possible in the course of the investigations that Opus is carrying out for Trustpower. It is recommended that TCC keep abreast of any revisions of the HEC-HMS model made on behalf of Trustpower.

Future refinement of the hydrological model could consider making use of rain radar data, to complement data from the rain gauge network.

The three-way coupled MIKE FLOOD hydraulic model of the river, floodplain and stormwater network, all downstream of Ruahihi, has been built using recent data. Although a comprehensive set of peak flood levels along the river measured following the 29 January 2011 storm event was available for model validation, the model predictions in the mid to lower reaches were higher than the observations. Nonetheless, realistic model parameters (primarily channel resistance values) have been used, and the model validation is considered acceptable.

In the event of future flood events, it is recommended that efforts be made to carry out high flow gauging of the Wairoa River recorder immediately upstream of the Ruahihi power station outfall. Peak flood levels along the river and on the floodplain should again be recorded and the maximum flood extent should be captured (e.g. by aerial photography and ground truth surveys). Observations of flows and blockages at all major structures should also be made.

10 References

/1/ DHI; *Guidelines for Stormwater Modelling using MIKE FLOOD*; Report produced for Tauranga City Council; November 2013.

/2/ DHI; *MIKE FLOOD model conversion guidelines - Classic grid to Flexible mesh;* Technical note produced for Tauranga City Council, November 2014.

/3/ BECA; *TCC Rainfall Profile Review*; Report produced for Tauranga City Council, November 2014.

/4/ AECOM; *Joint Probability Analysis of Sea Level and Rainfall*; Report produced for Tauranga City Council, June 2014.

/5/ USGS; *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains;* Paper; 2009.

/6/ DHI; *Soakage and Infiltration - spreadsheet describing soakage and infiltration parameters for different catchment types, land covers and elevations*; *September 2013.*

/7/ Tonkin & Taylor Ltd; *Kaimai Hydro Electric Power Scheme: PIC Assessment;* Report produced for Trustpower, 2013.

/8/ Riley Consultants Ltd; *Kaimai HEPS Flood Study;* Report produced for Trustpower, 2005.

/9/ Ryder Consulting Ltd; *Wairoa River at Tauriko – Floodplain Assessment*; Report produced for Boma No. 2 Trust, May 2010.

/10/ DHI; *Modelling Approach for Soak Holes*; *Email describing recommended approach for soak holes for different catchment types and elevation;* Sent out 3rd of April 2014.

APPENDICES

APPENDIX A – Roles

Project Team

A Project Team

Table A-1 Wairoa Stormwater Catchment Model Project Team

Organisation	Name	Role
Tauranga City Council	Dayananda Kapugama	Project Manager (Client)
DHI	Dragan Tutulic	Project Manager and Internal QC
DHI	Philip Wallace	Technical Lead
DHI	Henrik Locke	Project Engineer
DHI	Antoinette Taylor	Project Engineer

APPENDIX B–Hydrological Model

Sub-catchments and HEC-HMS model

B Sub-catchments and HEC-HMS model

B.1 Sub-catchments and parameters

The HEC-HMS model of the Kaimai HEPS recently updated by Opus, as part of an exercise being carried out by for Trustpower, includes sub-catchments upstream of Ruahihi as well as the Omanawa sub-catchment. These sub-catchments are shown in Figure B-1 and listed in Table B-1. More detail on the sub-catchment parameters adopted during the calibration Opus undertook is given in Table B-1 (email from Paul Mitchell to Philip Wallace, 27 May 2016).

As described in sections 5.1 and 4.2 of this report, that model has been validated against the 29 January 2011 storm event and then used to generate design hydrographs for the hydraulic modelling.

DHI has also prepared HEC-HMS models for the sub-catchments downstream of Ruahihi (those shown in Figure 4-1). Table B-1 gives the key model parameters adopted after consideration of those in Table B-1. These lower sub-catchment HEC-HMS models have then been used to generate sub-catchment runoff hydrographs for the validation and design events.

Table B-1 Sub-catchments in upper HEC-HMS model

Sub-catchment		Area (km^2)	Initial loss (mm) Jan11/Design	Continuing loss(mm/hr) Jan11/Design	Time of concentration (hours)
A	Upper Opuiaki	54.7	10/8	4/2	2.3
B	Tauwharawhara	1.3	10/8	4/2	0.5
C	Ngatuhoa	21.1	10/8	4/2	2
D	Awakotuku	1.23	10/8	4/2	0.5
E	Lake Mangaonui	4.85	10/8	8/2	1
F	Upper Mangapapa	42.8	10/8	8/2	2.8
G	Ruakaka Stream	3.06	10/8	8/2	1.8
H	Omanawa (upper)	52.1			
I	Opuiaki	25.1	10/8	4/2	2.5
J	Lower Mangapapa	11.4	10/8	8/2	1.5
K	Mangakarengorengo	108.3	10/8	8/2	2 (Jan11) 1.8 (Design)
L	Lake McLaren	4.7	10/8	8/2	1
M	Ruahihi tributaries	7.7	10/8	8/2	1.5
N		0.29			
O		2.51			
P		0.56			
Q	Wairoa local	14	10/8	8/2	1

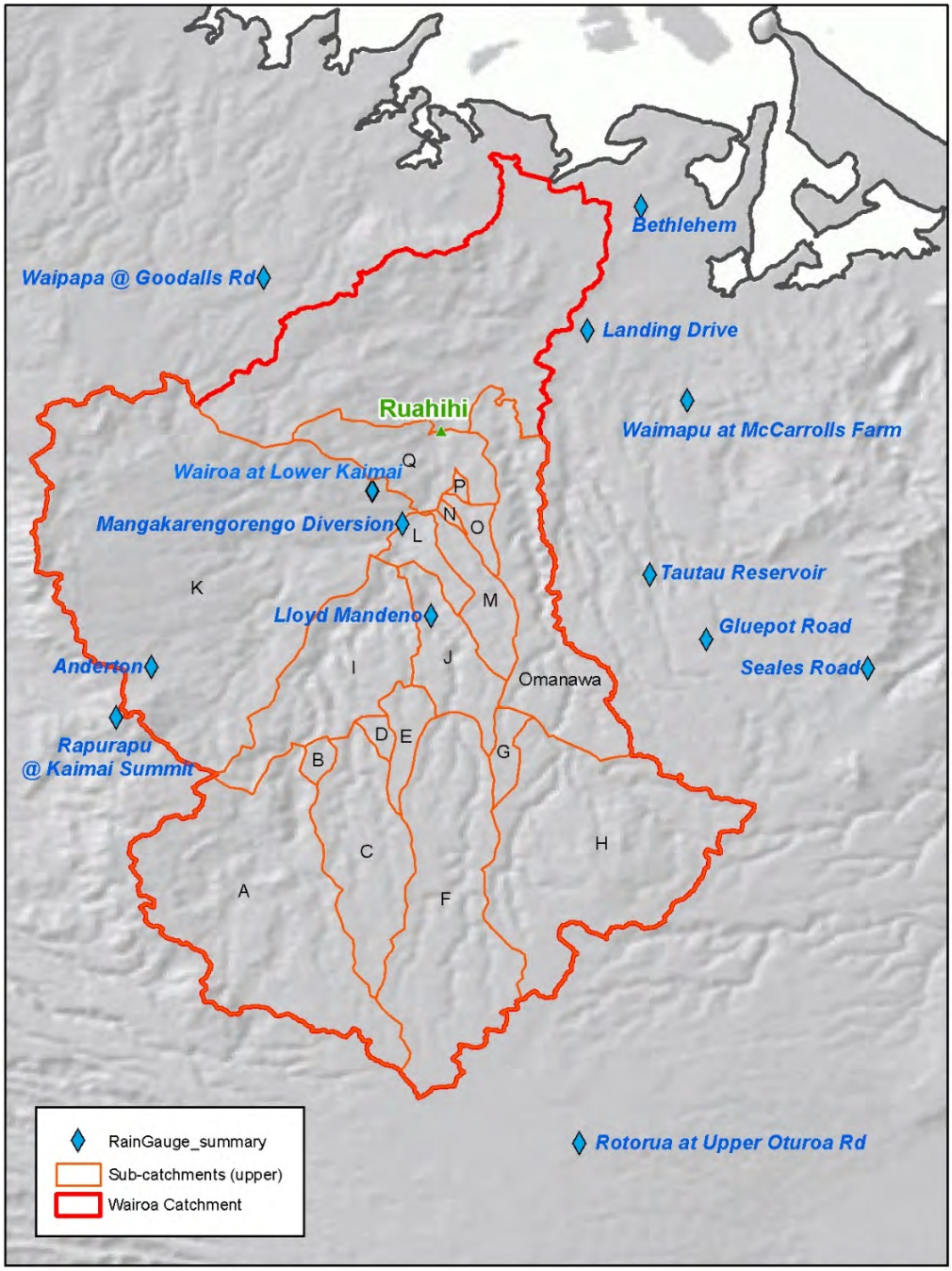

Figure B-1 Sub-catchments (upper) used in HEC-HMS model and rain gauge locations

Table B-1 Model parameters for upper catchment HEC-HMS model, Opus calibration

Components	Area km^2	Initial Loss (mm)	Constant Loss (mm/hr)	Tc (hrs)	Storage (hrs)	Baseflow	Initial Baseflow (cumecs)	Baseflow Recession Constant	Baseflow Ratio
Omanawa and Ruakaka c/ments									
July 1998	55.2	8.0	2.0	1.8	2.5	None	NA	NA	NA
May 1999		20.0	15.0	1.8	2.5	None	NA	NA	NA
Feb 2004		30.0	22.0	1.8	3.5	None	NA	NA	NA
Jan 2011a		30.0	8.0	1.8	2.0	None	NA	NA	NA
Jan 2011b		10.0	8.0	1.8	2.0	None	NA	NA	NA
Average		*19.6*	*11.0*	*1.8*	*2.5*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**1.8**	**2.0**	**None**	**NA**	**NA**	**NA**
Upper Mangapapa c/ment									
July 1998	42.8	8.0	2.0	2.8	3.5	None	NA	NA	NA
May 1999		20.0	15.0	2.8	3.5	None	NA	NA	NA
Feb 2004		30.0	22.0	2.8	4.5	None	NA	NA	NA
Jan 2011a		30.0	3.0	2.8	3.0	None	NA	NA	NA
Jan 2011b		10.0	8.0	2.8	3.0	None	NA	NA	NA
Average		*19.6*	*10.0*	*2.8*	*3.5*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**2.8**	**3.0**	**None**	**NA**	**NA**	**NA**
Lake Mangaonui									
July 1998	4.86	8.0	2.0	1.0	1.5	None	NA	NA	NA
May 1999		20.0	15.0	1.0	1.5	None	NA	NA	NA
Feb 2004		30.0	22.0	1.0	2.5	None	NA	NA	NA
Jan 2011a		30.0	7.0	1.0	1.5	None	NA	NA	NA
Jan 2011b		10.0	8.0	1.0	1.5	None	NA	NA	NA
Average		*19.6*	*10.8*	*1.0*	*1.7*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**1.0**	**1.5**	**None**	**NA**	**NA**	**NA**
Upper Opuiaki c/ment									
July 1998	54.7	8.0	2.0	2.3	3.0	None	NA	NA	NA
May 1999		20.0	12.0	2.3	3.0	None	NA	NA	NA
Feb 2004		20.0	15.0	2.3	4.0	None	NA	NA	NA
Jan 2011a		30.0	2.0	2.3	2.5	None	NA	NA	NA
Jan 2011b		10.0	4.0	2.3	2.5	None	NA	NA	NA
Average		*17.6*	*7.0*	*2.3*	*3.0*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**2.3**	**2.5**	**None**	**NA**	**NA**	**NA**
Tauwharawhara c/ment									
July 1998	1.3	8.0	2.0	0.5	0.5	None	NA	NA	NA
May 1999		20.0	15.0	0.5	0.5	None	NA	NA	NA
Feb 2004		20.0	15.0	0.5	1.0	None	NA	NA	NA
Jan 2011a		30.0	2.0	0.5	0.5	None	NA	NA	NA
Jan 2011b		10.0	4.0	0.5	0.5	None	NA	NA	NA
Average		*17.6*	*7.6*	*0.5*	*0.6*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**0.5**	**0.5**	**None**	**NA**	**NA**	**NA**
Ngatuhoa c/ment									
July 1998	21.1	8.0	2.0	2.0	3.0	None	NA	NA	NA
May 1999		20.0	15.0	2.0	3.0	None	NA	NA	NA
Feb 2004		20.0	15.0	2.0	3.5	None	NA	NA	NA
Jan 2011a		30.0	2.0	2.0	2.0	None	NA	NA	NA
Jan 2011b		10.0	4.0	2.0	2.0	None	NA	NA	NA
Average		*17.6*	*7.6*	*2.0*	*2.7*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**2.0**	**2.0**	**None**	**NA**	**NA**	**NA**
Awakotuku c/ment									
July 1998	1.23	8.0	2.0	0.5	1.0	None	NA	NA	NA
May 1999		20.0	15.0	0.5	1.0	None	NA	NA	NA
Feb 2004		20.0	15.0	0.5	1.5	None	NA	NA	NA
Jan 2011a		30.0	2.0	0.5	0.5	None	NA	NA	NA
Jan 2011b		10.0	4.0	0.5	0.5	None	NA	NA	NA
Average		*17.6*	*7.6*	*0.5*	*0.9*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**0.5**	**0.5**	**None**	**NA**	**NA**	**NA**

Components	Area km^2	Initial Loss (mm)	Constant Loss (mm/hr)	Tc (hrs)	Storage (hrs)	Baseflow	Initial Baseflow (cumecs)	Baseflow Recession Constant	Baseflow Ratio
Lower Mangapapa c/ment									
July 1998		8.0	2.0	1.5	2.0	None	NA	NA	NA
May 1999		20.0	15.0	1.5	2.0	None	NA	NA	NA
Feb 2004		20.0	22.0	1.5	3.0	None	NA	NA	NA
Jan 2011a	11.4	30.0	3.0	1.5	2.0	None	NA	NA	NA
Jan 2011b		10.0	8.0	1.5	2.0	None	NA	NA	NA
Average		*17.6*	*10.0*	*1.5*	*2.2*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**1.5**	**2.0**	**None**	**NA**	**NA**	**NA**
Lake McLaren c/ment									
July 1998		8.0	2.0	0.7	1.0	None	NA	NA	NA
May 1999		20.0	15.0	0.7	1.0	None	NA	NA	NA
Feb 2004		20.0	15.0	0.7	2.0	None	NA	NA	NA
Jan 2011a	4.7	30.0	8.0	0.7	1.0	None	NA	NA	NA
Jan 2011b		10.0	8.0	0.7	1.0	None	NA	NA	NA
Average		*17.6*	*9.6*	*0.7*	*1.2*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**0.7**	**1.0**	**None**	**NA**	**NA**	**NA**
Opuiaki R c/ment									
July 1998		8.0	2.0	1.8	2.5	None	NA	NA	NA
May 1999		20.0	15.0	1.8	2.5	None	NA	NA	NA
Feb 2004		20.0	15.0	1.8	3.5	None	NA	NA	NA
Jan 2011a	25.1	30.0	2.0	1.8	2.5	None	NA	NA	NA
Jan 2011b		10.0	4.0	1.8	2.5	None	NA	NA	NA
Average		*17.6*	*7.6*	*1.8*	*2.7*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**1.8**	**2.5**	**None**	**NA**	**NA**	**NA**
Ruahihi Tribs									
July 1998		8.0	2.0	1.5	2.0	None	NA	NA	NA
May 1999		20.0	15.0	1.5	2.0	None	NA	NA	NA
Feb 2004		20.0	15.0	2.0	2.5	None	NA	NA	NA
Jan 2011a	11.1	30.0	8.0	1.5	1.5	None	NA	NA	NA
Jan 2011b		10.0	8.0	1.5	1.5	None	NA	NA	NA
Average		*17.6*	*9.6*	*1.6*	*1.9*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**1.5**	**1.5**	**None**	**NA**	**NA**	**NA**
Mangakarengorengo catchment									
July 1998		8.0	2.0	2.5	2.7	Recession	30	0.37	0.70
May 1999		20.0	15.0	1.8	2.5	Recession	12	0.40	0.85
Feb 2004		20.0	12.0	2.5	4.0	Recession	25	0.46	0.99
Jan 2011a	108.3	30.0	8.0	2.0	2.2	Recession	15	0.40	0.85
Jan 2011b		10.0	4.0	2.0	2.2	Recession	15	0.40	0.88
Average		*17.6*	*8.2*	*2.2*	*2.7*	Recession	*19*	*0.41*	*0.85*
For Design		**8.0**	**2.0**	**1.8**	**2.2**	**Recession**	**30**	**0.50**	**0.90**
Local c/ment ds McLaren									
July 1998		8.0	2.0	1.0	1.5	None	NA	NA	NA
May 1999		20.0	15.0	1.0	1.5	None	NA	NA	NA
Feb 2004		20.0	15.0	1.5	2.0	None	NA	NA	NA
Jan 2011a	14.0	30.0	8.0	1.0	1.0	None	NA	NA	NA
Jan 2011b		10.0	8.0	1.0	1.0	None	NA	NA	NA
Average		*17.6*	*9.6*	*1.1*	*1.4*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**1.0**	**1.0**	**None**	**NA**	**NA**	**NA**
Omanawa local c/ment to Wairoa									
July 1998		8.0	2.0	2.0	2.0	None	NA	NA	NA
May 1999		20.0	15.0	2.0	2.0	None	NA	NA	NA
Feb 2004		10.0	15.0	2.0	2.0	None	NA	NA	NA
Jan 2011a	31.8	30.0	8.0	2.0	2.0	None	NA	NA	NA
Jan 2011b		10.0	8.0	2.0	2.0	None	NA	NA	NA
Average		*15.6*	*9.6*	*2.0*	*2.0*	None	NA	NA	NA
For Design		**8.0**	**2.0**	**2.0**	**2.0**	**None**	**NA**	**NA**	**NA**

Table B-2 Sub-catchments in lower HEC-HMS models

Sub-catchment	Area (km^2)	Initial loss (mm) Jan11/Design	Continuing loss(mm/hr) Jan11/Design	Time of concentration (hours)
Wairoa6	0.63	10/8	8/2	0.5
Wairoa5	1.85	10/8	8/2	0.83
East Omanawa	2.21	10/8	8/2	0.75
Waireia (Wairoa3)	8.78	10/8	8/2	1.2
Ohourere (Wairoa4)	29.78	10/8	8/2	2.5
Vernon Rd (Wairoa1)	1.32	10/8	8/2	0.7

B.2 Analysis of 29 January 2011 storm

As an alternative check of the Opus HEC-HMS model calibration, Thiessen polygons were derived around the rain gauges for the 29 January 2011 storm and used to derive weighted rainfall hyetographs for the Sub-catchments in the HEC-HMS model. The location of the gauges and the Thiessen polygons are shown in Figure B-2. The total rainfall recorded at each gauge is shown in Figure B-3. As noted in section 5.1, the Wairoa at Lower Kaimai recorder has not been used, despite having a recorded total more in line with other rain gauges than the Mangakerengorengo recorder, as only daily rainfall totals were recorded.

As concluded in 5.1, the simpler Opus approach using only the rain gauge data from the Lloyd Mandeno recorder gives a better fit to the recorded flow at Ruahihi than the approach of using all the rain gauges and Thiessen polygons.

Figure B-4 gives a comparison of the rain gauge data with rain radar data for the storm (ratio of rain gauge total to rain radar total).

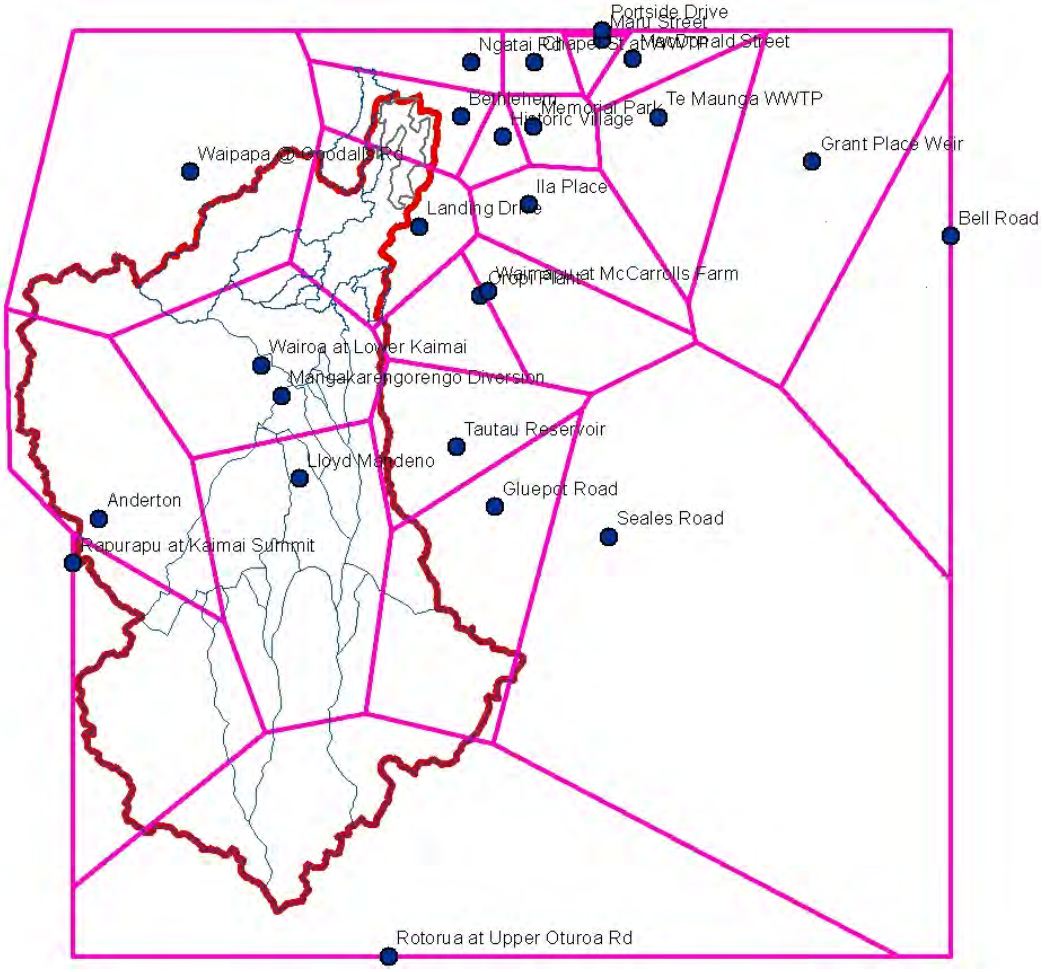

Figure B-2 Wairoa sub-catchments, rain gauges and Thiessen polygons

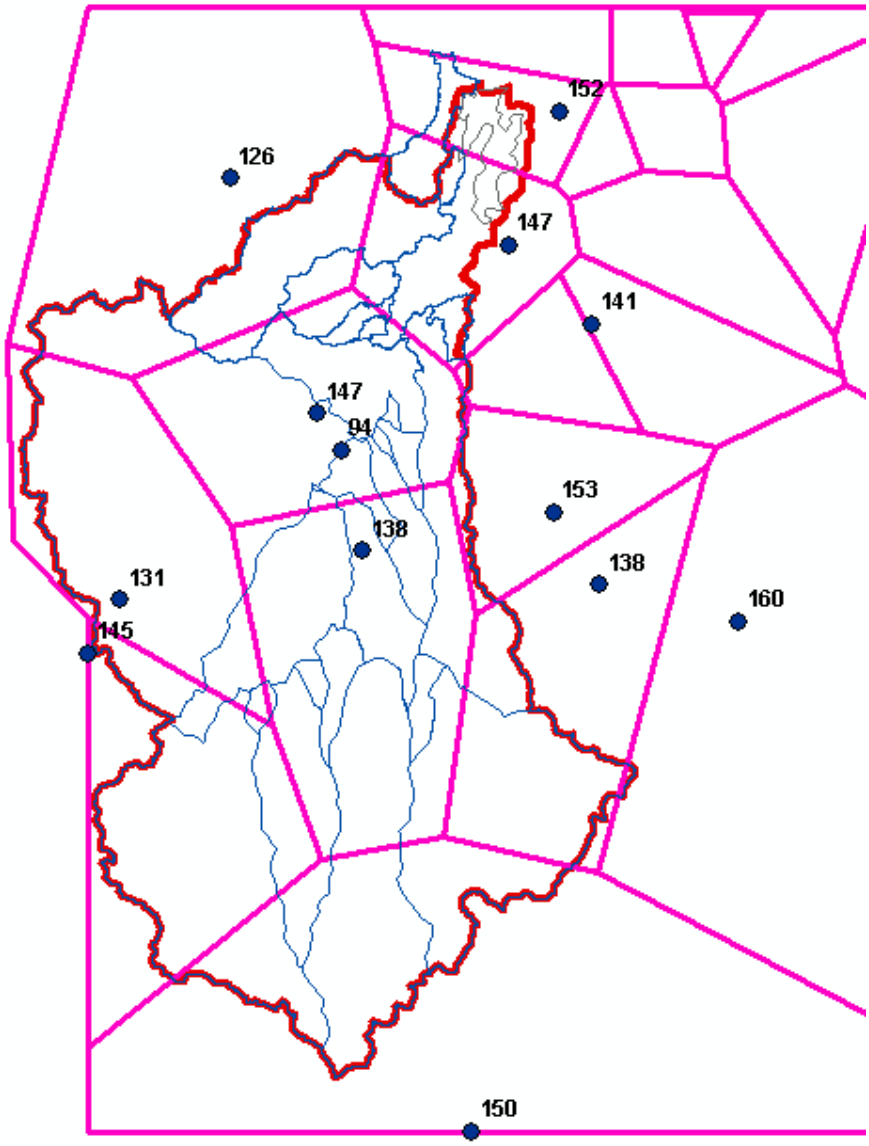

Figure B-3 Rainfall totals (mm), 28th – 29th January 2011 event

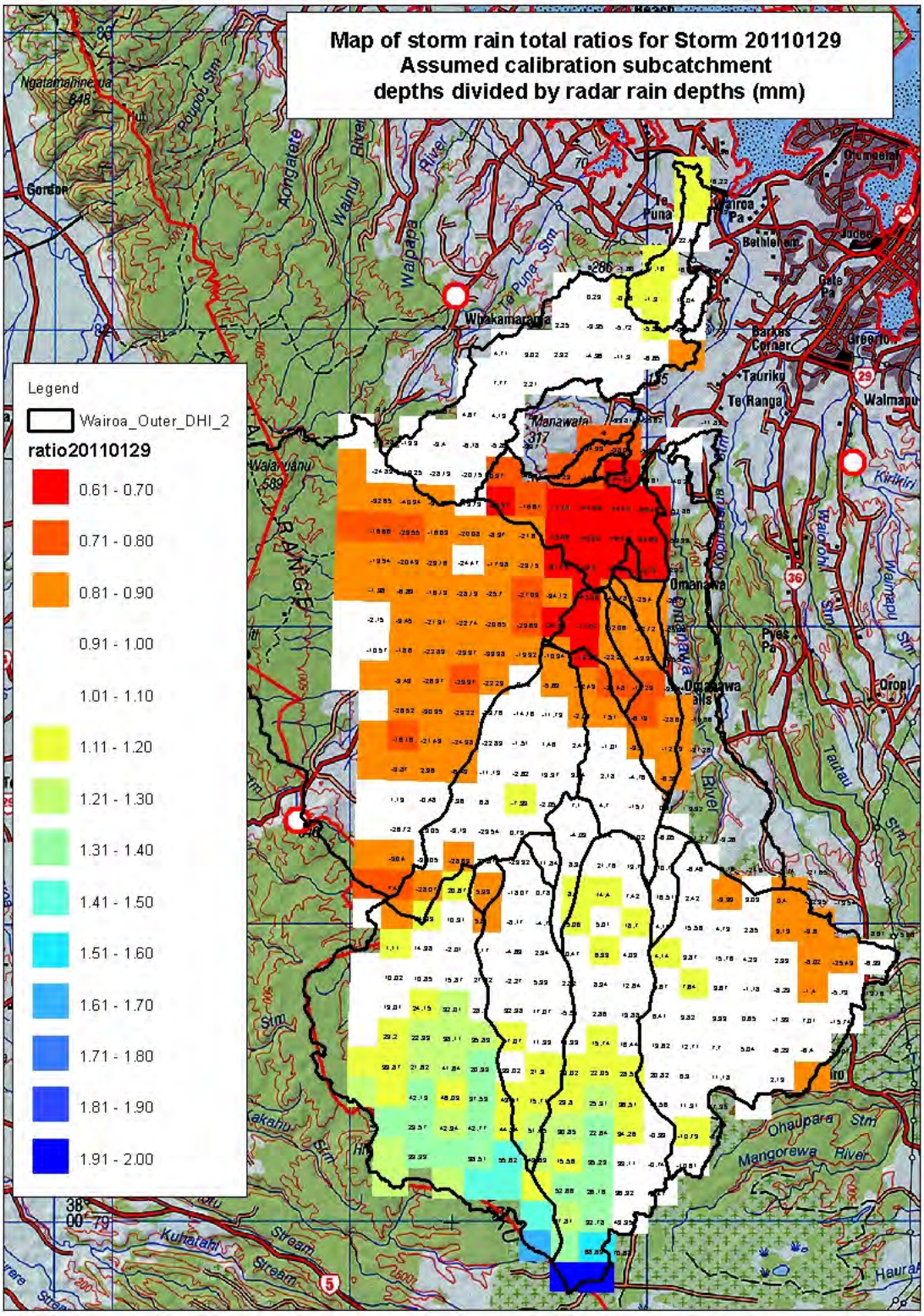

Figure B-4 Storm rain total ratios for the 29th January 2011 event

APPENDIX C–River Survey

Cross-section and bridge crossing survey

C Cross-section and bridge crossing survey

C.1 River cross-section survey

Aurecon carried out a river cross-section survey out between January and March 2016. Figure C-1 shows the cross-section locations.

Figure C-1 River cross-section locations

The initial survey showed a deep hole near the bend upstream of the State Highway 2 bridge (Figure 5-7). To investigate this further, additional bed survey was subsequently undertaken around the bend (Figure C-2). At the same time, an extra cross-section was surveyed at a constriction upstream of that bend.

Figure C-3 shows the bed surface, confirming the existence of a hole.

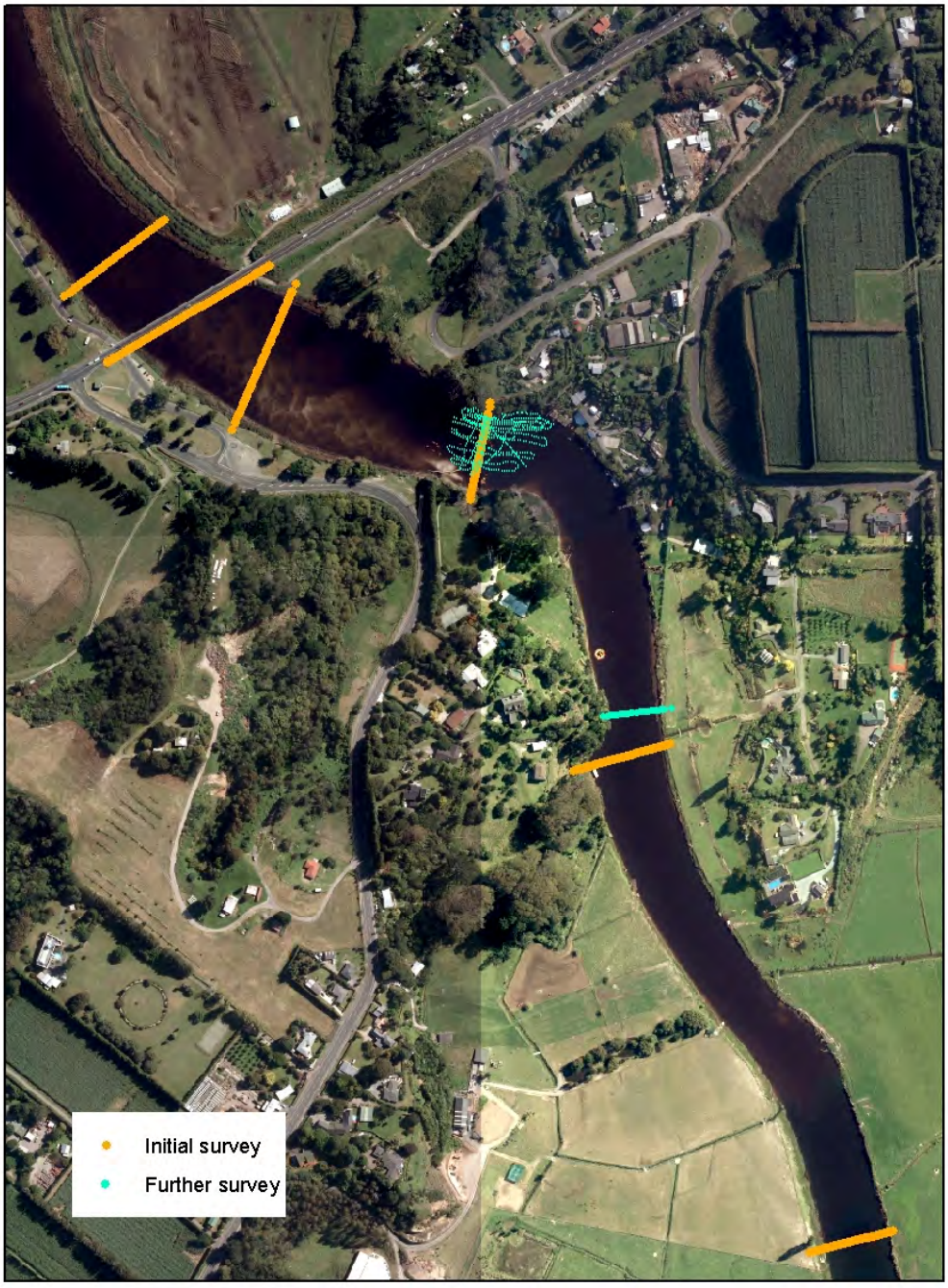

Figure C-2 Follow-up survey

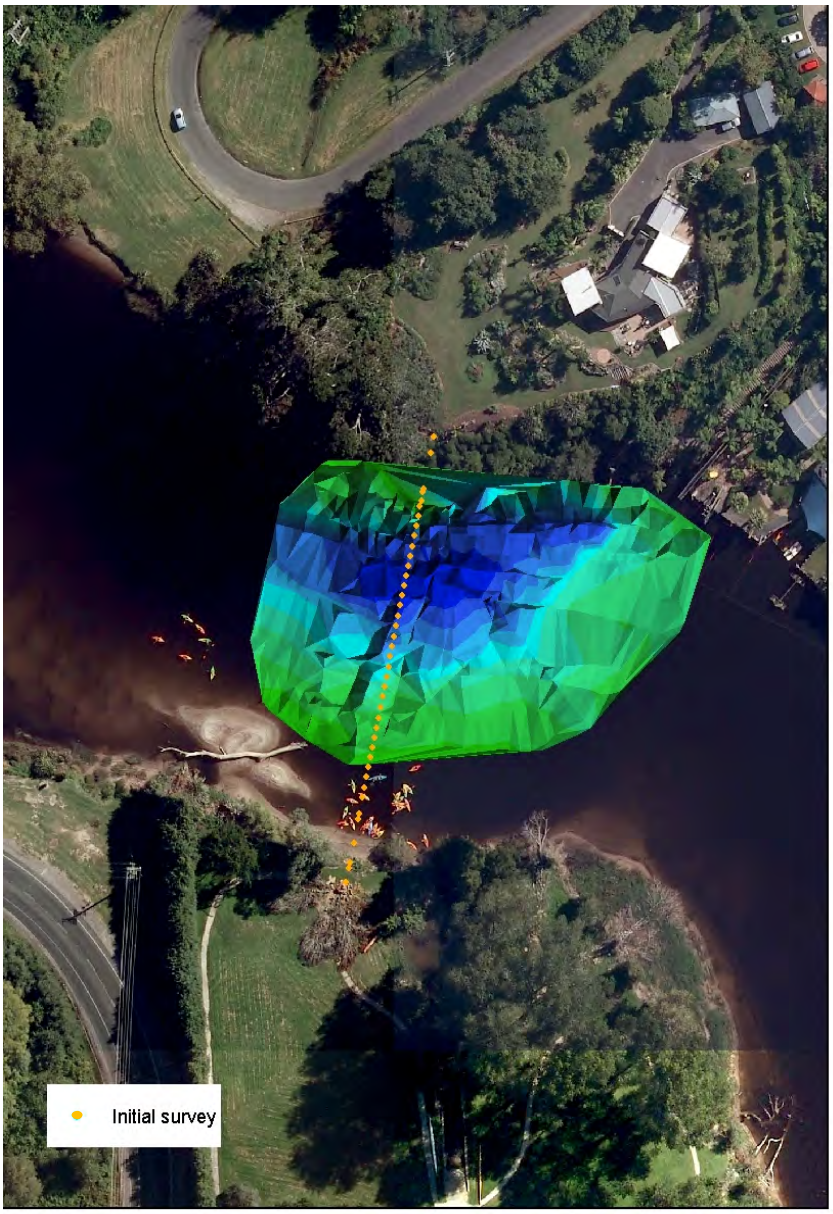

Figure C-3 Hole in river bed at bend upstream of SH2 bridge

C.2 Bridge survey

Aurecon also surveyed key dimensions of the three bridges over the Wairoa and Omanawa Rivers. Figures C-4 to C-6 show the surveyed features.

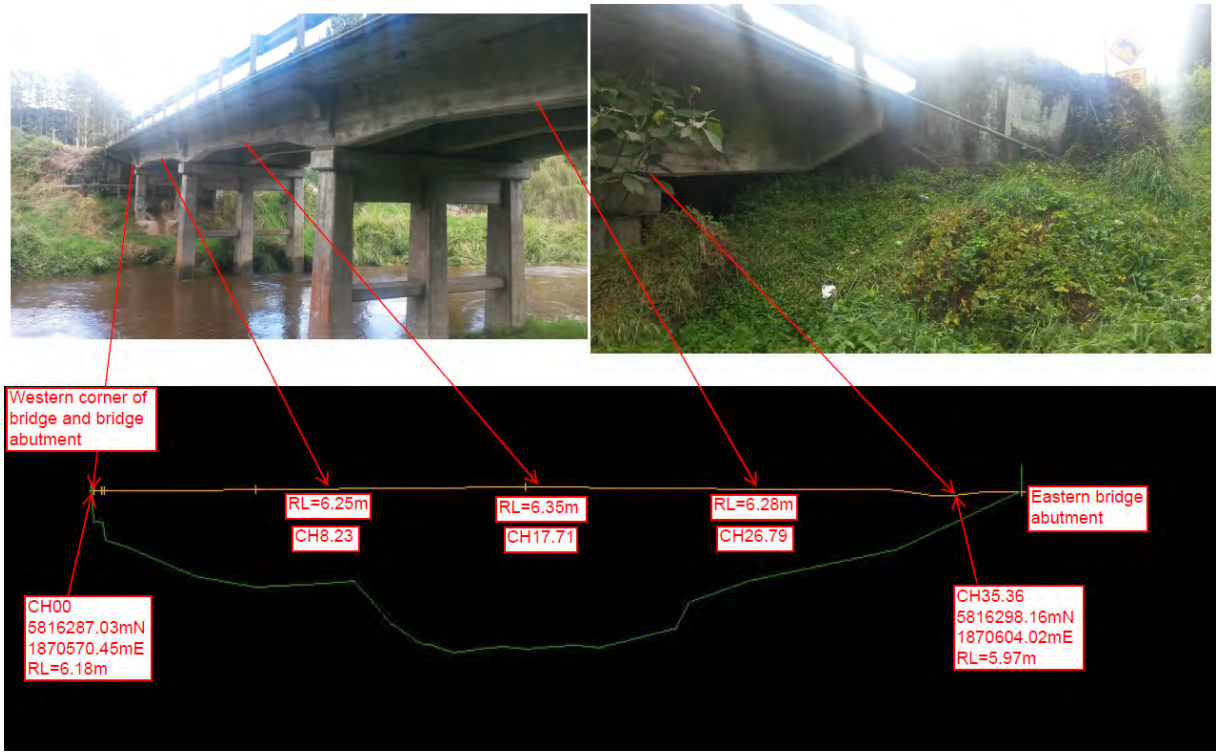

Figure C-4 SH29 bridge over Omanawa River

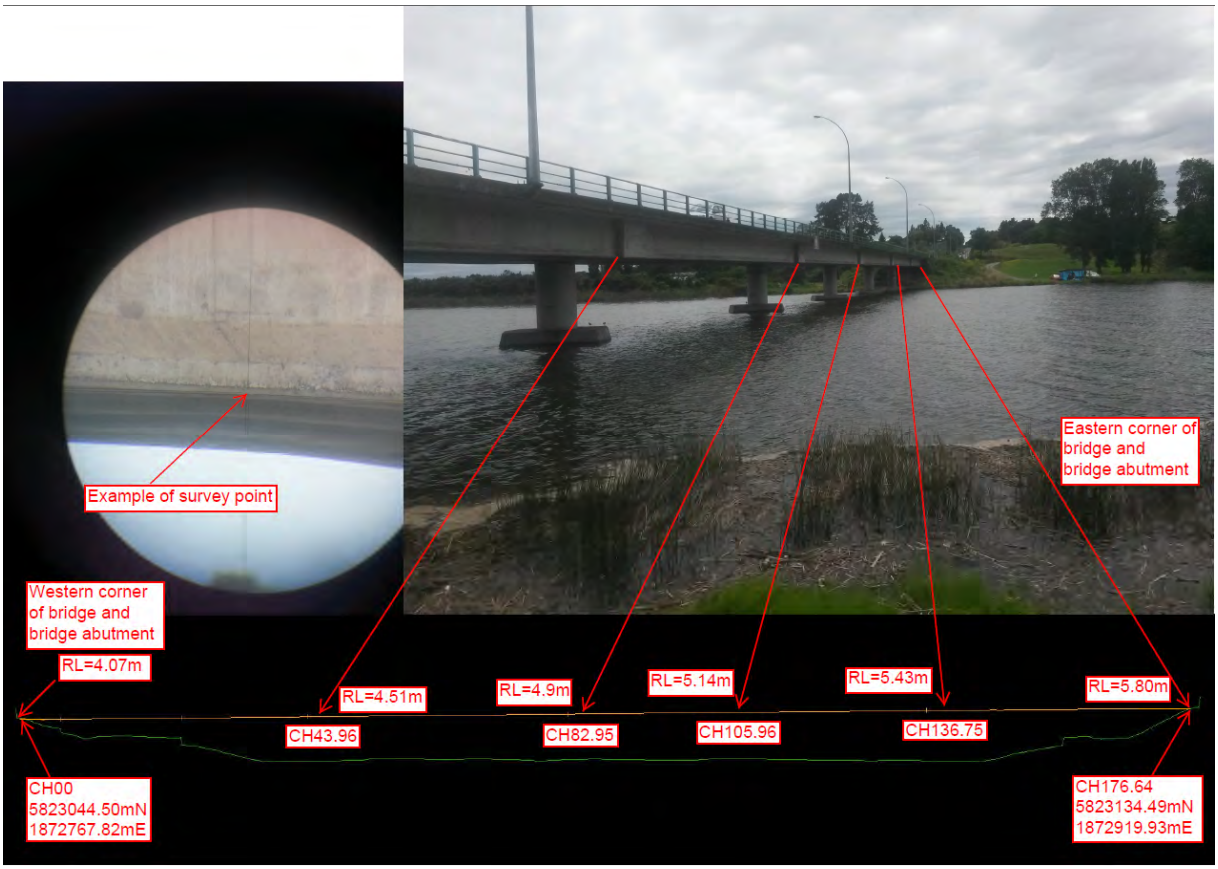

Figure C-5 SH2 bridge over Wairoa River

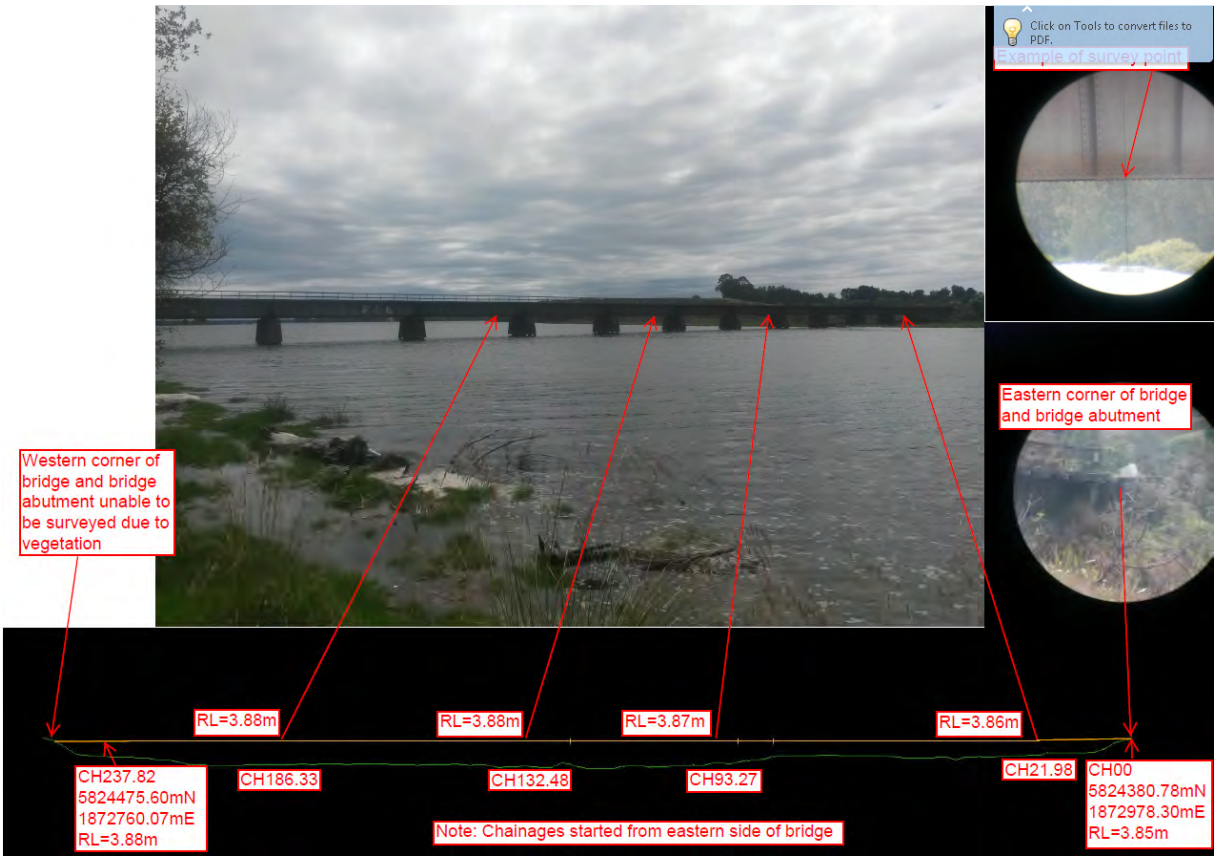

Figure C-6 Railway bridge over Wairoa River

APPENDIX D–Mass Balance

Validation and Design Simulations

D Mass Balance

The mass errors generated by the MIKE FLOOD simulations are insignificant, as shown in Tables D-1 to D-6 below.

D.1 January 2011 Validation Event

Table D-1 Mass Balance, MIKE 11 model – January 2011 Validation event

C:\DHI\44800847_TCC_Wairoa_River_Model\1\Round 9 - Wairoa Calibration 29Jan2011\M11 \Wairoa_Calibration_29Jan2011.sim11

Volume Balance Summary

A: Initial volume in model area					**2956674.31**	**m^3**
B: Final volume in model area					**3731815.88**	**m^3**
MIKE 21 lateral inflow	43220527.76	m^3				
MIKE 21 boundary inflow	540394.28	m^3				
MIKE URBAN CS lateral inflow	4955.76	m^3				
MIKE URBAN CS boundary inflow	0.00	m^3				
Lateral sources inflow	518574.00	m^3				
Lateral correction	0.00	m^3				
Open boundaries inflow	36305954.62	m^3				
C: Total inflow					**80590406.43**	**m^3**
MIKE 21 lateral outflow			42382044.86	m^3		
MIKE 21 boundary outflow			266306.08	m^3		
MIKE URBAN CS lateral outflow			2274.15	m^3		
MIKE URBAN CS boundary outflow			0.00	m^3		
Lateral sinks outflow			0.00	m^3		
Open boundaries outflow			37194397.40	m^3		
D: Total outflow					**79845022.49**	**m^3**
E: Continuity balance = B-A-C+D =					**29757.63**	**m^3**
Relative deficit E/max(A,B,C,D) =					**0.00**	**()**

Table D-2 Mass Balance, MIKE 21 model – January 2011 Validation event

C:\DHI\44800847_TCC_Wairoa_River_Model\1\Round 9 - Wairoa Calibration 29Jan2011\M21 \Wairoa_Calibration_29Jan2011.m21fm

Volume Balance Summary

A: Initial volume in model area					**347325.04**	**m^3**
Final volume in wet area					**1433563.15**	**m^3**
Final volume in dry area					**27556.23**	**m^3**
B: Final volume in model area					**1461119.38**	**m^3**
Source inflow	178907.90	m^3				
MIKE 11 inflow target	42648350.31	m^3				
MIKE 11 inflow correction	-0.00	m^3				
MIKE Urban inflow target	51144.66	m^3				
MIKE Urban inflow correction	0.00	m^3				
Source outflow			0.00	m^3		
MIKE 11 outflow target			43760921.39	m^3		
MIKE 11 outflow correction			-3.98	m^3		
MIKE Urban outflow target			54779.66	m^3		
MIKE Urban outflow correction			-0.78	m^3		
C: Total volume from source					**-937293.44**	**m^3**
D: Total volume from precipitation/evaporation					**2367548.95**	**m^3**
E: Total volume from boundaries					**-316482.73**	**m^3**
F: Continuity balance (B-A-C-D-E)					**21.57**	**m^3**

Table D-3 Mass Balance, MIKE URBAN model – January 2011 Validation event

Continuity Balance

1 :	**Start volume in Pipes, Manholes and Structures**			**17.1 m3**
2 :	**End volume in Pipes, Manholes and Structures**			**964.8 m3**
3 :	**Total inflow volume**			
	Non-specified inflows			
	Outlets (inflow) :	2281.7 m3		
	Inflow from 2D overland :	54779.7 m3		
		57061.3 m3	-->	**57061.3 m3**
4 :	**Total diverted volume**			
	Operational, non-specified outflows			
	Outlets :	5019.1 m3		
	Flow to 2D overland :	51144.7 m3		
		56163.8 m3	-->	**56163.8 m3**
5 :	**Water generated in empty parts of the system :**			**113.2 m3**
6 :	**Continuity Balance = (2-1) - (3-4+5) :**			**-63.0 m3**
	Continuity Balance max value :		1.1 m3	
	Continuity Balance min value :		-99.9 m3	

D.2 100 year ARI Existing Development Scenario

Table D-4 Mass Balance, MIKE 11 model – 100 year ARI rainfall

C:\DHI\44800847_TCC_Wairoa_River_Model\2\Design3\M11\Wairoa_Design_100yr.sim11

Volume Balance Summary

A: Initial volume in model area					**2260763.18**	**m^3**
B: Final volume in model area					**5999997.10**	**m^3**
MIKE 21 lateral inflow	228189794.53	m^3				
MIKE 21 boundary inflow	1674142.56	m^3				
MIKE URBAN CS lateral inflow	4680.03	m^3				
MIKE URBAN CS boundary inflow	0.00	m^3				
Lateral sources inflow	1290990.05	m^3				
Lateral correction	0.00	m^3				
Open boundaries inflow	104643361.31	m^3				
C: Total inflow					**335802968.48**	**m^3**
MIKE 21 lateral outflow			233335031.31	m^3		
MIKE 21 boundary outflow			591447.88	m^3		
MIKE URBAN CS lateral outflow			7294.18	m^3		
MIKE URBAN CS boundary outflow			0.00	m^3		
Lateral sinks outflow			0.00	m^3		
Open boundaries outflow			98292842.36	m^3		
D: Total outflow					**332226615.73**	**m^3**
E: Continuity balance = B-A-C+D =					**162881.17**	**m^3**
Relative deficit E/max(A,B,C,D) =					**0.00**	**()**

Table D-5 Mass Balance, MIKE 21 model – 100 year ARI rainfall

C:\DHI\44800847_TCC_Wairoa_River_Model\2\Design3\M21\Wairoa_Design_100yr.m21fm

Volume Balance Summary

A: Initial volume in model area					**69512.25**	**m^3**
Final volume in wet area					**4934471.39**	**m^3**
Final volume in dry area					**322.28**	**m^3**
B: Final volume in model area					**4934793.67**	**m^3**
Source inflow	745598.84	m^3				
MIKE 11 inflow target	233926467.01	m^3				
MIKE 11 inflow correction	-0.05	m^3				
MIKE Urban inflow target	81700.29	m^3				
MIKE Urban inflow correction	0.00	m^3				
Source outflow			0.00	m^3		
MIKE 11 outflow target			229863925.13	m^3		
MIKE 11 outflow correction			-1.67	m^3		
MIKE Urban outflow target			81500.37	m^3		
MIKE Urban outflow correction			-0.01	m^3		
C: Total volume from source					**4808342.26**	**m^3**
D: Total volume from precipitation/evaporation					**4092792.65**	**m^3**
E: Total volume from boundaries					**-4035865.88**	**m^3**
F: Continuity balance (B-A-C-D-E)					**12.39**	**m^3**

Table D-6 Mass Balance, MIKE URBAN model – 100 year ARI rainfall

Continuity Balance

1 :	**Start volume in Pipes, Manholes and Structures**			**17.1 m3**
2 :	**End volume in Pipes, Manholes and Structures**			**2481.7 m3**
3 :	**Total inflow volume**			
	Non-specified inflows			
	Outlets (inflow) :	7300.8 m3		
	Inflow from 2D overland :	81500.4 m3		
		88801.2 m3	-->	**88801.2 m3**
4 :	**Total diverted volume**			
	Operational, non-specified outflows			
	Outlets :	4772.7 m3		
	Flow to 2D overland :	81700.3 m3		
		86472.9 m3	-->	**86472.9 m3**
5 :	**Water generated in empty parts of the system :**			**147.0 m3**
6 :	**Continuity Balance = (2-1) - (3-4+5) :**			**-10.6 m3**
	Continuity Balance max value :		0.0 m3	
	Continuity Balance min value :		-138.8 m3	