Attachment 1 to Report 17.257

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Report

Waiohine FMP - Flood Modelling and Mapping Audit

Prepared for Greater Wellington Regional Council

Prepared by Beca Ltd (Beca)

9 May 2017

Revision History

Revision Nº	Prepared By	Description	Date
1	**Michael Law**	Draft	9 March 2017
2	**Michael Law**	Final	9 May 2017
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4			
5			

Document Acceptance

Action	Name	Signed	Date
Prepared by	**Michael Law**		9 May 2017
Reviewed by	**Graham Levy**		9 May 2017
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on behalf of	Beca Limited		

Executive Summary

Flood hazard maps have been developed by GWRC and their consultants for the Waiohine River in the Wairarapa. The maps are based on the outputs of hydrological and hydraulic modelling carried out from 2009 to 2014, and are being used to inform options for managing flood risk to Greytown and the surrounding area as part of the development of the Waiohine Flood Management Plan (FMP).

Greater Wellington Regional Council (GWRC) sought an independent audit of the Waiohine FMP[1] flood hazard maps, and the underlying modelling, to ensure that the work carried out is fit for purpose.

The main purposes of the modelling were:

- Catchment-scale flood hazard assessment, including classification of hazard into different categories, for the Waiohine River and the lower Mangatarere Stream;
- Development and conceptual design of different flood management options (including being used for analysis of potential flood damages);
- Providing information for use by District Councils in LIMs, land use controls and for building controls (Local Government Act, Resource Management Act and Building Act requirements); and
- To update existing flood hazard information in the District Plan.

This audit report contains a review of the hydrological and hydraulic modelling, the application of freeboard, and the presentation and interpretation of the flood hazard maps. The Terms of Reference of the audit required that particular attention be paid to:

- Approach, inputs and the suitability of hydrological and hydraulic methods used;
- Calibration and/or validation or sensitivity analysis, including any recent events that might be relevant;
- Whether the model is representative of current and proposed development status; and
- Whether the outputs and their interpretation are appropriate to the purpose of the work, and to facilitate clear communication of findings to lay persons?

The audit has indicated that the hydrological modelling is fit for use. Though the hydraulic modelling software, approach and inputs were generally appropriate and fit for purpose, the review of the modelling indicated that further work is required to ensure that the model results used to derive the flood hazard maps are fit for purpose. The issues to be resolved relate to model calibration/validation, channel roughness, channel bed levels, and the application of freeboard within the model. It is noted that some of these refinements could increase flood levels, while others may reduce flood levels, but that the overall effect has not been assessed.

Though the flood maps accurately represent the information extracted from the flood modelling, there are difficulties accessing the maps and detailed site-specific flood information. Map legends, definitions and terminology are limited, and in some cases misleading. These issues can lead to confusion and misunderstanding within the community regarding the interpretation and use of the maps.

[1] FMP: Flood Management Plan

Use of the 10 m grid for flood modelling and mapping (which was appropriate when the model was first constructed) leads to anomalies in flood depths and velocities at the site-specific scale, particularly in urban areas where there is variable topography and features, which further compromises user acceptance of the maps. If further modelling is undertaken, there is the opportunity to use a smaller grid size or flexible mesh in the model, and to post-process model results to smooth flood outlines to reflect more detailed underlying topography. These would improve the presentation of flood information in map form, as would ensuring standard terminology on maps.

Stakeholder meetings held as part of the 'modelling and mapping' audit process have highlighted the state of the relationship between GWRC and the Wairarapa community, as represented by the District Councils and residents. The community has outstanding issues with the Waiohine FMP process, options and implementation.

Confirming the main conclusion of the audit:

- **The hydrological modelling is fit for use.**
- **The hydraulic flood model was built using industry standard software and approaches, used appropriate inputs, and is generally fit for purpose. However, some aspects of the modelling have been identified for review, resolution of which would improve confidence in the model outputs.**
- **The flood maps could be improved to better communicate flood information to the community, and smooth the relationships in Waiohine FMP consultation process**

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Appendices

1 Introduction and scope

1.1 Purpose

Flood hazard maps have been developed by Greater Wellington Regional Council (GWRC) and their consultants for the Waiohine River in the Wairarapa. The maps are based on the outputs of hydrological and hydraulic modelling carried out from 2009 to 2014, and are being used to inform option for managing flood risk to Greytown and the surrounding area as part of the development of the Waiohine Flood Management Plan (FMP).

GWRC sought an independent audit of the Waiohine FMP[2] flood hazard maps, and the underlying modelling. The terms of reference (ToR) for the audit are presented in Section 1.3. This report is the output of the audit.

This audit report contains a review of the hydrological and hydraulic modelling, the application of freeboard, and the presentation and interpretation of the flood hazard maps. Meetings have been held with GWRC, South Wairarapa District Council (SWDC), Carterton District Council (CDC), and two local residents with long experience of working and living with the river. Where they fall within the ToR of the audit, the concerns raised by stakeholders are addressed in this report.

1.2 Background

The Waiohine Floodplain Management Plan (FMP) covers the river and floodplain from the river's emergence from the Gorge in the Tararua Ranges downstream to the confluence with the Ruamahanga River, and includes the lower reaches of the Mangatarere Stream. Along this reach, the river forms the boundary between Carterton District Council and South Wairarapa District Council, and loops around the urban area of Greytown.

The river is crossed by the Wairarapa-Wellington rail line at Woodside soon after the river emerges from the Tararua Ranges, and by SH2 northeast of Greytown. Upstream of SH2, the river's gravel fairway is generally 100-200 m wide with one or two braided channels. Downstream of SH2, the river narrows to 50-100 m wide, with one active channel. There are some existing stopbanks and natural berms along the river.

The current Floodplain Management Plan process commenced in 2009. During the investigations phase, hydrological and hydraulic models were developed, with the outputs used to develop flood mapping and hazard information, and to inform flood mitigation options. In May 2016, GWRC's preferred flood mitigation option was presented in the draft FMP[3], and the community was consulted. The draft FMP generated 107 submissions from the community and stakeholders, with the majority opposed to the proposals. The submitters raised concerns about the:

a. Accuracy of the hydrological and hydraulic modelling
b. Inclusion and representation of freeboard on flood maps
c. Appropriate standard of protection (Average Recurrence Interval [ARI]) for the area.
d. Inclusion of and allowance for the effects of climate change.
e. Choice, location and extent of mitigation measures.

[2] FMP: Flood Management Plan

[3] ***Waiohine Floodplain Management Plan – Draft for Consultation***, GWRC. May 2016. http://www.gw.govt.nz/assets/floodprotection/AW15079FMPDRAFT20160531screenspreads.pdf

f. Relative weight given to modelling results over local knowledge
g. Consultation processes
h. Cost of proposed scheme
i. Lack of peer review or independent audit
j. Balance between decreased flood risk for some and increased risk for others.

It is not with the remit of the audit to address all of the issues raised in the submissions. Those excluded from the audit include the items c, e, g, h, and j, yet auditing the modelling and mapping (item 'i') to determine whether it is fit for purpose allows for a more informed debate on the excluded items.

1.3 Terms of Reference

GWRC's decision to carry out an independent audit of the modelling and flood hazard maps was to ensure that the work carried out is fit for purpose. The main purposes of the modelling were:

- Catchment-scale flood hazard assessment, including classification of hazard into different categories, for the Waiohine River and the lower Mangatarere stream;
- Development and conceptual design of different flood management options (including the model being used for analysis of potential flood damage);
- Providing information for use by District Councils in LIMs, land use controls and for building controls (Local Government Act, Resource Management Act and Building Act requirements); and
- To update existing flood hazard information in the District Plan.

The terms of reference were laid out on pages 2 and 3 of the Request for Proposal (RFP), and included the requirement to check on the appropriateness and fitness for purpose of the following:

General

- *The type of software and the modelling package used for the hydrology and hydraulic model*
- *The modelling method used and its appropriateness for both hydrology and the hydraulic model*
- *The use of freeboard and method by which it was applied including a definition of freeboard in the flood maps*
- *Representation of the flood hazard through the way in which maps are displayed and information provided.*

Input Data

- *Rainfall data*
- *Measured flow records*
- *Cross section surveys*
- *LiDAR surveys*
- *Representation of the Rail and SH2 Bridges*
- *Calibration data against historical events.*

Assumptions

- *Run-off coefficients or similar hydrological parameters*
- *Predicted flood flows used for design events*
- *Climate change allowances*
- *Roughness coefficients of the channel and floodplain*
- *How the buildings and structures on the floodplain are treated through use of roughness coefficients*
- *Treatment of bridges, culverts and pipe crossings*
- *Use of freeboard to define flood hazard.*

GWRC also noted in the RFP that they would welcome suggestions for additional criteria to be included in the Terms of Reference. A key issue within the submissions to the draft FMP was concern as to how local knowledge and anecdotal information has been incorporated into the modelling and FMP process. This has been addressed.

The audit pays attention to:

- Approach, inputs and the suitability of hydrological and hydraulic methods used;
- Calibration and/or validation or sensitivity analysis, including any recent events that might be relevant;
- Whether the model is representative of current and proposed development status; and
- Whether the outputs and their interpretation are appropriate to the purpose of the work, and to facilitate clear communication of findings to lay persons.

2 Background information

There is a lot of information relating to the development of the Waiohine FMP and the modelling and mapping that underlies it. GWRC provided the auditor with an extensive list of reports and background information. The reports listed below are available through the Waiohine River Background Reports[4] page on the GWRC website.

- Waiohine River Floodplain Management Plan Phase 1 Summary Report - August 2011
- Waiohine River Floodplain Management Plan Hydraulic Modelling of Options (Phase 2) – April 2013
- Waiohine Draft Floodplain Management Plan – Phase 3 Summary Report - 2014
- Waiohine Floodplain Management Plan Phase 2 Summary Report - 2010
- Waiohine River Investigations and Hydraulic Modelling Further Investigations: Waiohine FMP Phase 3 Modelling - River Edge Consulting Limited, April 2013
- Waiohine River Draft FMP Hydraulic Modelling - Land River Sea Consulting Ltd, April 2014 - available on request
- Waiohine FMP Phase 3 Options Assessment Stopbank Construction, Costs, Materials, and Timeline Report - Opus, April 2013
- Waiohine FMP Phase 3 Detailed Option 7 Assessment - PDP, 2014
- Waiohine FMP Phase 2 Options Selection - Combinations of Options, June 2012
- Waiohine River FMP Phase 2 Looking at Ranges of options For MCA Including emphasis on River Management - available on request
- Waiohine Floodplain Management Plan: Phase 3 Consultation Report, September 2014
- Waiohine River Floodplain Management Plan Advisory Committee (WRFMPAC) Phase 3 Option Selection, April 2013
- Guidelines for Floodplain Management Planning Flood Protection Department, July 2013
- Floodplain management planning - Principles, March 2015
- Flood hydrology of the Waiohine River and Mangatarere Stream, April 2009
- Waiohine FMP Cultural Impact Assessment - Kahungunu Ki Wairarapa, November 2010
- Waiohine FMP – Phases 2 & 3 Assessment of Land Use, Location/Property and Designation Issues for Stopbanks - Boffa Miskell, April 2013
- Waiohine FMP – Phases 2 & 3 Assessment of Land Use Planning Controls - Boffa Miskell, March 2013
- Combined Drawing for Report 5_2941_5204_1 to 16 - Opus, Feb 2013

[4] http://www.gw.govt.nz/waiohine-river-background-reports/ accessed 8 March 2017

- Using the Cultural Health Index: How to assess the health of streams and waterways - Ministry for the Environment, June 2006
- Geotechnical Investigation Waiohine River Stopbanks, - Neil A Climo, Chartered Engineer, August 2010
- Waiohine River Scheme Review Report on Investigations - River Characteristics and Sedimentation, G & E Williams Consultants Ltd, 2010 - available on request
- REPORT: WDC FMS Whangarei CBD Flood Management Study Flood Damage Assessment. Prepared for Whangarei District Council, URS, September 2006
- Wairarapa Division Planning and Resources Department Operations - Waiohine River Floodplain Management Scheme - Sediment Transport, Bed Level and design Meander Width Analysis, May 1992
- Design Flood Hydrology Waiohine River Catchment, Hydro Tasmania Consulting, May 2009
- Climate change and water. Intergovernmental Panel on Climate Change, June 2008
- High Intensity Rainfall and Potential Impacts of Climate Change in the Waiohine Catchment - NIWA, Feb 2009

Not all of these reports are directly relevant to the audit of the Waiohine FMP modelling and mapping audit.

The key outputs from the modelling underlying the FMP are maps that can be used for planning purposes and for informing the choice of options for reducing flood risk. These include the Overall Planning Maps presented in Appendix A for the current situation (Figure A1) and for the situation after the implementation and construction of the flood mitigation measures proposed in the FMP (Figure A2). The two maps are taken from the ***Waiohine Draft Floodplain Management Plan – Phase 3 Summary Report – 2014***. The key difference to note between the flood extents on the two maps is the reduction in flooding through the main part of Greytown's urban area.

GWRC provided survey, model files, and GIS files for the three phases of the FMP process. Two versions of the files were provided; each amounting to over 20 GB of data. While referring to the earlier phases of modelling so as to understand the current situation, the audit concentrates on the later modelling undertaken and maps produced as part of Phase 3 of the FMP.

The model was reviewed in 2012 by Susan Borrer (GWRC). The GWRC model review was very thorough and detailed, and undertaken by an experienced modeller. The review raised several generally minor issues and details with the model, though two issues remain of significant relevance to this audit, namely model calibration and the incorporation of freeboard. River Edge Consulting Limited (the modellers) responded to the model review in July 2013, commenting on how changes as a result of the review were to be accommodated in Phase 3 of the modelling.

3 Meetings

As part of this audit, the auditor (Mike Law of Beca Ltd) carried out the following meetings and visits:

- 8 & 9 January 2017 Briefing by James Flanagan (GWRC's Project Manager), and site visit to the Waiohine River and Greytown.
- 24 January 2017 Meetings with:
  - South Wairarapa District Council (SWDC) Mayor Vivian Napier and Councillor Colin Wright
  - Carterton District Council (CDC) Mayor John Booth, CEO Jane Davis and Councillor Mike Ashby
- 25 January 2017 Meeting and site visits to Waiohine River and development sites within Greytown with local residents Michael Hewison and Bruce Slater

- 12 April 2017 Meeting with Philip Wallace (formerly with River Edge Consulting, and now with DHI) to discuss the flood modelling.

The auditor appreciates the time given by the District Council's representatives and officers, Michael Hewison, and Bruce Slater to attend the meetings and provide valuable insights into a range of issues relating to the Waiohine River, local flood risk and the FMP. Issues relating specifically to the flood modelling and mapping included:

- The choice of flood modelling software;
- Whether the appropriate level of climate change been used;
- Accounting for degradation of the channel bed level and changes in the channel width;
- Availability of technical information underlying the flood maps; and
- Design flows and flood frequency analysis.

Issues raised that were not directly related to the flood modelling and mapping are not included in this audit report.

4 Model Review and Checklist

A review of the hydrological and hydraulic modelling has been carried out as part of this audit as required by the terms of reference, and is described below.

The general scope for the model review is described in the terms of reference as an audit of:

- The type of software and modelling package used for the hydrology and hydraulic model;
- The modelling method used and its appropriateness for both hydrology and the hydraulic model;
- The use of freeboard and the method by which it was applied; and
- Representation of the flood hazard through the way in which maps are displayed and information provided.

Elements of the modelling have been reviewed (Sections 4.1 and 4.2) and rated using a 0-3 scoring system (described in Table 4.1), which flags up issues that will affect model use. This provides more definition than the simpler Yes/No categorisation specified in the terms of reference.

Table 4.1 – Model review rating scheme

Description	Audit rating	Fit for use
No issue: The element or parameter being reviewed is modelled acceptably	0	Yes
Minor issue: There is an issue, but it is unlikely to significantly affect model results	1	
Major issue: Failure to resolve the issue compromises the model and should be rectified, but may be resolved by explanation or acceptance of model limitations.	2	Yes, No, Review
Fatal flaw: Failure to resolve this issue severely compromises the model, and should be rectified before the model is accepted.	3	No

4.1 Hydrological modelling

The hydrological modelling was carried out by Hydro Tasmania Consulting (HTC) in 2009[5]. The modelling used recorded flow data to calibrate design flow hydrographs developed using rainfall-runoff modelling.

Table 4.2 – Hydrological modelling

Item	Comment	Audit rating	Fit for Use
Software	The hydrological modelling was undertaken using Hydstra software. Hydstra is a standard software package that incorporates a catchment runoff model, and is appropriate for this level of analysis.	0	Yes
Rainfall data	Data from five rain gauges in (or close to) the Waiohine-Mangatarere catchment were used for the rainfall-runoff modelling. The modelling of extreme rainfall depths and profiles is well described in the HTC report and is considered appropriate. As rainfall records lengthen over time and more severe storm events are included in the record, it is worth undertaking occasional reviews of the design rainfall depths and profiles as this will increase the reliability of the modelling in predicting more extreme storms.	0	Yes
Temporal patterns	Temporal patterns for design rainfall depths were derived from analysis of measured storms. This is not described in detail in the HTC report, but is not considered to have a significant effect on the calculated hydrographs, which have been compared to recorded flow hydrographs at the Waiohine and Mangatarere flow recorders. The critical duration storm was calculated to be 12 hours, which is reasonable.	1	Yes
Catchment definition	Catchment and sub-catchment definition is acceptable, with the Waiohine-Mangatarere catchment divided into 29 sub-catchments upstream of the four locations (Waiohine River, Upper Mangatarere Stream, Kaipaitangata Stream and lower Mangatarere Stream catchment) where inflows were required for the hydraulic flood model.	0	Yes
Hydrological method	Initial and (constant) Continuing losses were used to calculate the effective rainfall, and Hydstra coefficients *Alpha* and *n* used to route flows through the sub-catchments to the catchment outfall. The method is appropriate	0	Yes
Measured flood flows and calibration	The Hydstra rainfall-runoff model was calibrated against 10 flood events on the Waiohine River and 9 flood events on the Mangatarere Stream. The largest calibration event on the Waiohine River was the January 1990 flood that had a peak flow of 1400 m^3/s and an ARI of over 20 years. The calibration events were used to calibrate not only the peak flows, but also the shape of the design flow hydrographs. The result was that two temporal rainfall patterns were developed to generate the design flow hydrographs. The justification for two temporal patterns, and hence hydrographs, for each ARI is not explained in detail in the HTC report. The choice of hyetograph will affect the shape of the hydrograph and timing of the peak flow. This may affect flood levels and extents, but is considered acceptable as based on calibration against recorded events.	1	Yes

[5] ***Design Flood Hydrology Waiohine River Catchment***, Document **consult-22112**. Hydro Tasmania Consulting for GWRC, 21 May 2009

Item	Comment	Audit rating	Fit for Use
Calculated flows	The peak flows calculated in 2009 and used in the flood modelling have been checked against GWRC's current flood frequency analysis[6] for the Waiohine River at the Gorge flow recorder. The current estimate of the 100-year ARI peak flow is 1729 m^3/s, compared to 1738 m^3/s estimated in 2009. The updated estimate has been calculated with the benefit of seven years of additional flow record, and the difference between the two estimates is less than 1%, well within the expected confidence intervals for the design flow estimates. Therefore, the calculated peak flows are still current, and have been used in the hydraulic model.	**0**	**Yes**
Climate change	Climate change was not included in the HTC hydrological modelling of the Waiohine-Mangatarere catchment, but was required to be included in the hydraulic flood modelling, as noted in Section 5.2 of the 2011 hydraulic modelling report[7]. In line with GWRC practice and the 2008 guidelines from MfE, rainfall depths and intensities were increased by 16.8% to represent mid-range projections of climate change through to 2090 (100 years after the baseline year of 1990). The increase in rainfall resulted in peak flow increases of 16.9% to 27.5% for the hydraulic model inflow locations. The smallest increase was for the Waiohine River, and the larger increases for the Mangatarere Stream and its lowland tributaries. In 2016, MfE published updated guidance from NIWA on the range of temperature and rainfall increases to be considered because of potential climate change. Rather than applying a single % increase in rainfall, the guidance recommends applying a range of increases, and assessing the sensitivity of the results. While academically robust, this adds an additional layer of uncertainty to the flood modelling and requires an additional decision-making process to determine which results to apply. The 16.8% increase in rainfall used in the Waiohine modelling is in the mid-range of the 2016 MfE recommendations, and so is considered appropriate.	**1**	**Yes**

Though the basis of the hydrological modelling is nearly eight years old, there have not been any significant flood events in that period that would materially change the flood frequency estimates for the contributing catchments. The hydrological modelling was calibrated against recorded flow data, and the estimated peak flows have been checked against updated flow records. The allowance made for increased rainfall, and hence flows, as a result of potential climate change were appropriate at the time that the hydrological modelling was undertaken, and still appropriate given the latest guidance from MfE.

The conclusion of the review of the hydrological modelling is that the derived peak flows and hydrographs are fit for use in the hydraulic modelling of the Waiohine catchment.

4.2 Hydraulic modelling

Three phases of hydraulic modelling of the Waiohine River have been carried out as part of the Waiohine FMP process, and utilise the outputs of HTC's hydrological modelling. The first phase was reported in 2011, the second undertaken in 2012, and the 2013-2014 modelling for the third phase reported in January 2015. The scope of work for each phase is summarised as follows:

[6] http://graphs.gw.govt.nz/?siteName=Waiohine%20River%20at%20Gorge&dataSource=Flow

[7] ***Hydraulic Modelling of the Waiohine River and Floodplain***, River Edge Consulting Limited, 2011.

- Phase 1: Modelling the existing situation, including model calibration and an assessment of the effect of the Saywell Stopbank on the right bank of the Waiohine downstream of the railway bridge.
- Phase 2: Multiple options for mitigating flood risk were modelled, as described in the Phase 2 modelling report.
- Phase 3: Detailed modelling of flood mitigation options following update of the model to account for new channel cross-section data and the recommendations of GWRC's 2012 review of the earlier modelling.

With three distinct phases of modelling and multiple scenarios modelled, it has not been possible to review all model files. Currently, it is difficult to navigate to the appropriate model files. Indeed, given the amount of modelling undertaken and large number of model files, GWRC agree[8] the benefit of cataloguing the model files, and providing a clear link between model files, mapped outputs and FMP options.

The hydraulic modelling review has concentrated on the modelling undertaken as part of Phase 3, and takes a broader approach than GWRC's 2012 model review that correctly concentrated on the model detail rather than its place within the Waiohine FMP process. Taking account of the recommendation of the 2012 review and River Edge's response and model update, this audit review concentrates on the modelling approach, inputs, parameters, and outputs that determine whether the modelling is fit for purpose.

Table 4.3 – Hydraulic modelling

Item	Comment	Audit rating	Fit for Use
Software	The hydraulic modelling was carried out using DHI's MIKE FLOOD software package to build a coupled 1D/2D model. Their MIKE software is one of the two or three most widely used software packages for flood modelling worldwide, and probably the most widely used in New Zealand. It is suitable for modelling the Waiohine River and floodplain. The Waiohine River channel and berms were modelled in 1D using MIKE 11, as were culverts around the Apple Barrel Floodway. The floodplain was modelled in 2D using MIKE 21. The software and modelling approach (coupled 1D/2D model) were appropriate when the modelling was undertaken, and are still valid.	**0**	**Yes**
Boundary conditions	The upstream boundary conditions for the model are the flow hydrographs for the Waiohine River and Mangatarere Stream derived from recorded flow data, as noted in section 4.1. The downstream model boundary is provided by flow and water level hydrographs in the Ruamahanga River, a reach of which is included in the model. The hydrographs have been extracted from GWRC Wairarapa model, ensuring appropriate timing of flood peaks in the two rivers. The boundary conditions are considered acceptable.	**0**	**Yes**
Design events and climate change	The MIKE FLOOD model has been run for the: ■ 10, 20, 50, and 100-year ARI flood events without climate change; ■ 50 and 100-year ARI flood events with an allowance for climate change (16.8% increase in rainfall); and ■ Over-design event (1.5x100-year ARI without climate change). In addition, scenarios including an allowance for 'modelling freeboard' have been modelled. See below.	**0**	**Yes**

[8] Discussion (20 April 2017) with Graeme Campbell prior to finalisation of this report.

Item	Comment	Audit rating	Fit for Use
Model Extent	The 1D flood model includes the: ▪ Waiohine River from the flow recorder at the Gorge down to the confluence with the Ruamahanga River ▪ Mangatarere Stream from the flow recorder at the Gorge down to the confluence with the Waiohine River at SH2 ▪ Tributaries of the Mangatarere Stream, including Beef Creek ▪ Ruamahanga River from Kokotau Road to Moiki Road The modelled 2D floodplain extended over an area of about 100 km^2, from where the Waiohine emerges from the Tararua Ranges to the higher ground on the true left bank of the Ruamahanga River, and including Greytown and lower lying ground on either side of the Waiohine River and between the Mangatarere Stream and the Waiohine River. The model extents are appropriate, including sufficient floodplain to prevent 'glass-walling'. The inclusion of a reach of the Ruamahanga River ensures that flood levels in the lower reaches of the modelled area are not unduly influenced by the downstream boundary.	**0**	**Yes**
Cross-sections	Cross-sections of the main river channel were surveyed for the modelling in 2009 (the year of the model calibration event – see below), at 350-400 m intervals. This is an appropriate spacing for the Waiohine River. Similar suitable spacing was used for the Mangatarere Stream and Ruamahanga River sections of the hydraulic model. The river was resurveyed in 2013 and the model cross-sections (and links to the 2D model floodplain) updated for the Phase 3 modelling. The best available cross-section data has been used for the modelling.	**0**	**Yes**
Channel bed levels	Bed levels in the river have continued to degrade to a recorded low over the last ten years due to the lack of new material entering the lower reaches of the river. Generally, bed load material enters the river system in the Tararua Ranges due to landslips generated by extreme storm runoff or earthquake. There have been no such events in recent years to generate or transport material. With a low river bed, modelled flood levels, and the amount of spill over stopbanks, will be lower than if bed levels were higher. It might not be appropriate to use the lower bed levels for modelling the performance of flood mitigation measures that will have a lifespan of up to 100 years and so is likely to include periods with greater bedload availability and transport potential, and so higher bed levels. <u>It is recommended that GWRC seek further technical advice to determine appropriate bed levels for testing the performance of the mitigation options</u>.	**2**	**Review**
Stream channel roughness coefficients	Within the stream channels a default Manning's 'n' value of 0.030 was applied to represent channel roughness. This is relatively low, as noted in GWRC's 2012 model review, but within a range that could be considered appropriate for the river. Applying a low roughness will generally reduce flood levels and increase velocities. Roughness is varied along the river. A higher model roughness is applied when modelling higher ARI events, as justified in Section 5.3 of the 2011 modelling report, and based on the modeller's experience modelling the Manawatu River. This is counter to some other studies that correlate roughness *"with discharge; as discharge increases, so do cross-sectional area and depth, and the frictional effect on the channel boundary declines."*[9] However, the limited model calibration (see below) indicated a better fit of modelled and observed water levels if roughness values were even lower. Therefore, the roughness values used are at the low end of what might be expected, but potentially higher than required for good model calibration, and could be refined during future model development.	**2**	**Review**

[9] Chapter 8 of ***Freshwaters of New Zealand***, edited by Jon Harding et al. 2004

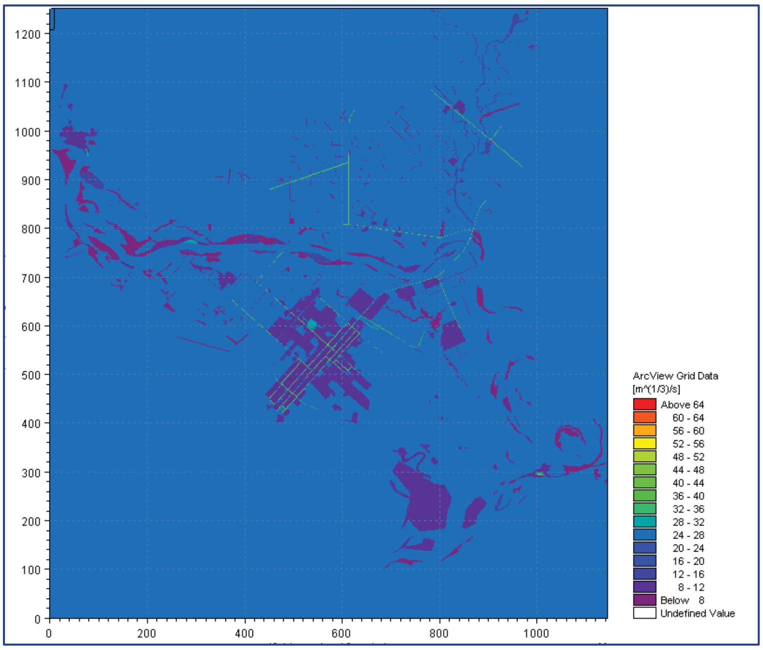
<table>
<tr><th>Item</th><th>Comment</th><th>Audit rating</th><th>Fit for Use</th></tr>
<tr><td>Floodplain cross-sections and/or 2D extent</td><td>Gridded LiDAR data was used to construct the 2D model bathymetry. The LIDAR data was collected in 2008, and so was acceptably current at the time of the initial model build. The use of LiDAR data is generally appropriate. LiDAR is widely used when constructing flood models, but can be less reliable in dense vegetation and for small channels within the flood plain, where topographical and channel survey is required.

The 2D model bathymetry had a grid spacing of 10 m. This gives reasonable definition for defining overland flow paths and ponding areas in generally flat areas, but is relatively coarse for defining flood depths, extents and detailed overland flow paths where smaller obstructions (such as road curbs), buildings and localised changes in ground level across a property may have a significant effect.

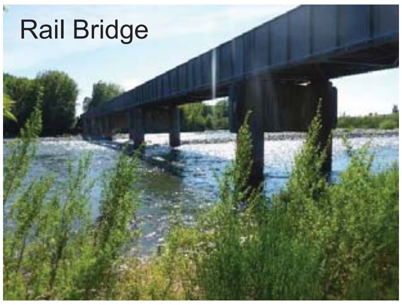
Ideally a smaller grid size would be used, but a smaller grid would have significantly increased the time taken to run the model, especially when it was built in 2009. As such, a 10 m grid spacing would have been appropriate at that time. Advances in computing power have reduced model run times, and so a smaller grid (especially for the urban areas may be more appropriate).

The current version of DHI's MIKE software has the ability to use a flexible mesh approach to model bathymetry, which coupled with advances in computing power could be used in future to refine the 2D component of the model to improve the definition of flood depths and extents at the site-specific level.</td><td>1</td><td>Yes</td></tr>
<tr><td>Flood plain obstructions</td><td>Roughness factors (Manning's 'M') are applied to the 2D model bathymetry surface to represent how easily water can flow across the surface (image below). Smoother surfaces such as roads have a higher M value (lower roughness) than dense vegetation. The M values used in the MIKE 21 model are appropriate. Individual buildings and structures on the floodplain have not been blocked out, rather high roughness has been applied to urban areas and dense vegetation.

This approach is generally acceptable, especially with a 10 m grid.



Were a tighter grid or flexible mesh to be applied to the 2D floodplain, it would be possible to block out individual buildings and provide better definition of overland flow paths in the urban areas, and this should be considered if the model is updated.</td><td>1</td><td>Yes</td></tr>
</table>

Item	Comment	Audit rating	Fit for Use
Structures - Weirs, bridges and culverts	<u>Minor structures</u> There are 10 culverts, 5 bridges, and 5 weirs modelled in the Waiohine model. All of these structures are on the minor watercourses (not the Waiohine River) and floodplain.	**0**	**Yes**
	<u>Rail and SH2 bridges across the Waiohine River</u> The rail and SH2 bridges (below) across the Waiohine River have not been included in the model, as noted in paragraph 3.1.3 of the 2011 modelling report[10]. The decks of the two bridges are above 100-year flood level, though there is less than one metre of clearance to the rail bridge soffit. The bridge piers are a potential obstruction to flow, especially were debris to accumulate. However, the decision to not model the two bridges was based on an assessment that the effects of river bed level changes was more significant than the effects of the piers and debris.  While the effects of the piers and debris would be localised due to the gradient of the river channel, it would be expected that the two largest river crossings would be included in the model for completeness. The inclusion of bridges in flood models is standard. However, their omission from the model is not likely to significantly affect the flood risk to Greytown.	**2**	**Yes**
Blockage	The probability and consequence of culverts, bridges and channels being fully or partial blocked during floods by water borne debris is a reality, especially in heavily vegetated (including forestry) catchments with many culverts and bridges. Blockage has not been applied to the bridges or culverts in the model. The blockage of the smaller bridges and culverts on the floodplain is unlikely to be a significant issue globally within the model, it might be locally significant at locations such as the Apple Barrel Floodway. The absence in the model of the rail and SH2 bridges precludes the opportunity to assess the effects of debris build up on those structures. The steepness (0.4%) of the Waiohine River channel upstream of SH2 means that any increase in water levels as a result of debris on the bridge will be restricted to a relatively short reach of the river upstream, and is so unlikely to have a significant effect on flood levels and extents. Therefore, the effect of not including blockage is unlikely to materially affect the global representation of flood hazard, but will have local effects and so should be included in any future developments of the model.	**2**	**Review**

[10] ***Hydraulic Modelling of the Waiohine River and Floodplain***, River edge Consulting limited, January 2011.

Item	Comment	Audit rating	Fit for Use
Calibration and validation	The only event used for calibration of the model was the July 2009 event (the cross-sections were surveyed in 2010), which had an ARI of about 2 years, as reported in Section 4 of the 2011 modelling report (The Phase 3 modelling has not been calibrated). Flows were contained within the river channel, which means that only the in-river performance of the model could be assessed and not the water depths, extents and overland flow paths on the floodplain. The calibration indicated that the modelled flood levels were on average about 200 mm above observed flood levels in the Waiohine River upstream of SH2, though in places the modelled flood levels on the true right bank were up to 500 mm higher than observed flood levels. Downstream of SH2, the situation is less clear-cut, with modelled flood levels being higher than observed levels in some areas, and lower in others. The 2011 modelling report suggests that the general over-estimate in modelled flood levels may be due to an over-estimate in the recorded flow, though the peak flow for the 2009 is still reported on the GWRC website as 869 m^3/s, as modelled in 2010/2011, and has not been amended as a result of a rating review. As such, the calibration of the model using the July 2009 did not provide the level of confidence in the model results that would have been hoped for, but was the only available event to use. The 2011 model report notes that there were also significant flood events in 1990, 1998, 2004, and 2008, and that the hydrological inputs for these events were input to the 2009 model and flood extent maps produced. In each case, the modelled flood extents indicated overland flow on the floodplain, with parts of Greytown flooded in the 1990 and 1998 events. There are no reports of flood water in the urban centre of Greytown during those events, though SH2 was closed at the Apple Barrel Floodway. However, the model was not calibrated or validated against these events. As the 1990 peak flow of 1408 m^3/s equated to an ARI of over 20 years, it would have been prudent to seek anecdotal information on the depth and extent of flooding at key locations (such as the SH2 crossing of the Apple Barrel Floodway[11]), even in the absence of surveyed flood marks, to validate the flood modelling. Modelling of the historic events can be difficult (if not impossible), as it requires the model geometry to be setup to reflect historic conditions; including appropriate channel bed elevations, stopbanks, and floodplain features present at the time, and that information is often not available. However, providing better calibration or validation would increase confidence in the modelling, both for reviewers and the local community.	**2**	**Yes**
Reporting	As noted above, hydraulic modelling reports were produced for Phases 1, 2 and 3. The reports for Phase 1 contain reasonable descriptions of the model inputs and parameters, while the Phase 2 report explained the FMP options. The Phase 3 report is very brief in terms of model description. None of the report links model file names to outputs. Though this does not directly affect whether the model is fit for purpose, it does make it difficult to navigate to the appropriate model files and to confirm that the modelling approach, inputs and parameters are appropriate.	**1**	**Yes**[12]

[11] A flood level for the 1990 event is marked on the fence at the SH2 crossing of the Apple Barrel Floodway, as shown in the photograph on the front cover of this audit report.

[12] The reporting does not affect the validity of the modelling, but improving the reporting would be beneficial.

Item	Comment	Audit rating	Fit for Use
Model freeboard	In addition to modelling a range of flood events, with and without an allowance for climate change, the 50 and 100-year ARI have also been modelled with an allowance for freeboard. The approach is described in Section 5.5 of the 2011 model report, which states that modelling freeboard *“allows for uncertainties in model data and for phenomena such as waves that cannot be modelled”.* In simplified terms, the approach to modelling freeboard is to take the design event (50 or 100-year ARI) flood levels in the Waiohine River and on the floodplain, and then increase the river channel flood levels only by 600 mm. With zero additional flow coming into the Waiohine River, the additional 600 mm of water in the channel is then allowed to spill onto the floodplain. As the floodplain already has water on it, the additional spill increases floodplain water depths and extents. It is these ‘with freeboard’ flood extents that appear to have been adopted in the planning maps (Figures A1 and A2), yet the 50 and 100-year ARI flood extents without model freeboard are not included in the model report (or obvious in the received model files) to allow the relative effect of incorporating model freeboard to be assessed. While it is appropriate to consider model uncertainty, and including model freeboard is one method of doing that, the approach has some shortcomings. ▪ It is not possible to determine whether increasing channel water levels by 600 mm is appropriate for modelling uncertainty in the Waiohine. One means of increasing confidence in applied freeboard is to report how the freeboard allowance has been built up. *For example, 200 mm of the 600 mm total may be to account for wave action, and 100 mm for channel roughness, etc.* It has been recommended above that channel roughness, model calibration and bed levels should be reviewed by undertaking sensitivity runs in the model. <u>Doing this may reduce the need for applying as much as 600 mm of model freeboard.</u> ▪ it is not possible to easily assess the increase in flood depths and extents due to adding model freeboard, due to the absence of clear reporting of the differences. For determining floodplain sensitivity to flooding, one advantage of applying freeboard in the manner used for the Waiohine is that the resulting changes in flood depths and extents are sensitive to the floodplain topography. As such, the effect in this case is similar to modelling an ‘oversize’ flood event, as was included in the Phase 3 modelling with the results for 1.5x100-year ARI flood presented. Both approaches to identifying areas beyond the ‘without freeboard’ modelled flood extent (where flood risk should still be considered) are more refined than applying a uniform increase in flood level. The oversize event option represents a change in only one variable (flow), whereas applying model freeboard can account for multiple variables. The model freeboard approach is crude in the channel where it is first applied, whereas the oversize event will also account for sensitivity in the channel to changes in flow. The freeboard approach used for the Waiohine modelling has some technical merit, but requires justification as to how the 600 mm increase for the river channel water levels was derived and what it covers implicitly, and careful consideration as to how the method and results are to be communicated to stakeholders.	2	**Review**

The conclusion of the review of the Waiohine FMP hydraulic modelling is that the model software, approach and inputs are generally fit for purpose, and reflect industry standard practice at the time that the modelling was undertaken. However, there are areas of the flood modelling that need to reviewed (or would benefit from being updated to reflect advances in modelling software, or additional information) to improve the inputs for defining flood extent and hazard maps, and for assessing the performance of the FMP flood mitigation options. Specifically:

- Include the Rail and SH2 bridges in the model, and consider the potential effects of debris and blockage on these and other structures (bridges and culverts) as part of the model sensitivity testing.
- The model should be validated (if insufficient information is available for calibration) against the 1990 flood event at least. That will require reference to anecdotal information held within the local community, and acknowledgement of that could assist in improving public acceptance of the model. It is probably not feasible to validate the model against the larger 1955 flood, but understanding what occurred during both the 1955 and 1990 floods will assist GWRC in validating the model (with appropriate river bed levels), identifying anomalies in the model, and ultimately providing a model that is accepted by stakeholders.
- Connected to the calibration or validation of the model, reviews should be undertaken of the channel roughness and what bed levels are appropriate for assessing flood risk and the performance of mitigation measures that could have a lifespan of 100 years, and so are likely to experience higher bed levels than the current historic low bed levels used in the later modelling.
- The approach to applying model freeboard should be reviewed, including the possibility of sensitivity runs and specific build-up of freeboard from uncertainty elements, and that will include careful consideration of how the adopted approach is to be communicated to stakeholders.

4.3 Flood hazard mapping

As noted in Section 2, the key output from the flood modelling are the area-wide planning maps (Figures A1 and A2 in Appendix A). Figure A1 is the ***WAIOHINE RIVER – Overall Planning Map (Before Option 7)***, and so represents the current flood risk and is the map currently used for informing planning decisions. Figure A2 is the ***WAIOHINE RIVER – Overall Planning Map (After Option 7)***, which represents the flood risk were the proposed Waiohine FMP options to be implemented. The flood depths and extents associated with the *After* map are significantly less than those associated with the *Before* map.

According to the legends on the two maps, both maps represent the 100-year ARI flood hazard with an allowance for climate change. There is no mention on the maps as to whether the flood extents include the effects of modelled freeboard. Away from the river corridor (shown red) areas affected by flooding are shown as **Overflow Paths** (shaded yellow) or **Ponding** (shaded blue) areas. No definitions are provided for Overflow Paths or Ponding. Complementing the area-wide maps are larger scale maps, and GIS layers of flood depth and velocity. Visual representation of these parameters is provided as Figures in the January 2015 Phase 3 modelling report.

Elements of the Flood maps have been reviewed and rated using a 0-3 scoring system (described in Table 4.1), which flags up issues that will affect the understanding and interpretation of the maps. As with the review of the hydrology and hydraulic modelling this provides more definition than the simpler Yes/No categorisation specified in the terms of reference.

Table 4.4 – Mapping review rating scheme

Description	Audit rating	Fit for use
No issue: The element or parameter being reviewed is represented acceptably	0	Yes
Minor issue: There is an issue, but it is unlikely to significantly affect use of the maps	1	
Major issue: Failure to resolve the issue compromises the maps and should be rectified, but may be resolved by explanation or acceptance of map limitations.	2	Yes, No, or Review
Fatal flaw: Failure to resolve this issue severely compromises the understanding and interpretation of the maps, and should be rectified before the maps are accepted.	3	No

Table 4.5 – Flood hazard mapping

Item	Comment	Audit rating	Fit for Use
Access to the flood maps	As part of the audit, GWRC provided copies of model files, results, outputs and images. These included the Overall Planning Maps shown in Figures A1 and A2, as well as some larger scale images. An internet search for "Greytown Flood Hazard Map" leads to the http://mapping.gw.govt.nz/Wairarapa/ website (below), where it is possible to is see flood outlines for the 50 and 100-year ARI flood hazard zones. This website is a joint initiative of the three Wairarapa district councils, and it is important that flood information shown is not different from GWRC's latest flood maps. 	2	Review

Item	Comment	Audit rating	Fit for Use
	It is not possible determine flood depths or velocities from the maps, and the legend does not indicate whether the flood outlines include an allowance for climate change or modelled freeboard. The maps legend includes an item labelled “for flood info see WRC”. It is assumed that “WRC” is GWRC. For detailed site-specific information, users are required to contact GWRC and can be provided with site maps of flood depths and velocities. These are pixilated to the 10 m grid, which can cause anomalies in interpretation, as discussed in Section 5.2. Use of smaller grid sizes (or flexible mesh) for flood modelling, and post-processing flood levels to generate smooth flood outlines based on detailed underlying topography can remove issues of pixilation.		
Application of freeboard	As discussed in the last item in Table 4.4, freeboard is added during the hydraulic modelling and not during the preparation of the maps. This is an approach that has been used elsewhere by GWRC, but can be confusing for differentiating those areas within the ‘non-freeboard’ flood extent, and for explaining what flood velocity information in those areas relates to. A review of how it is best implemented has been recommended. The published flood maps should state whether or not freeboard has been applied.	**2**	**See Table 4.4**
Scenarios	The Overall Planning Maps show the Q100cc (100-year ARI plus an allowance for climate change) Overflow paths and Ponding areas, while the http://mapping.gw.govt.nz/Wairarapa/ website shows the 50 and 100-year ARI flood hazard areas.	**1**	**Yes**
Presentation of flood hazard maps	The legend of the Overall Planning Maps refers to them being Flood Hazard Maps, while the website legend indicates that the shaded areas are Flood Hazard Areas. However, both sets of maps show the flood extents for the 50 or 100-year ARI flood using a single shading for the whole flood hazard extent. This does not give a full understanding of the hazard in each location. ‘Flood hazard’ is the term used by GWRC for flood extent maps. Elsewhere, the term ‘flood hazard’ often refers to a value related to both flood depth and the water velocity. This is useful from a hazard assessment perspective to understand potential danger to people and buildings, and can be readily calculated from the outputs of 2D hydraulic models. This suggests that using the term ‘hazard’ in the title of the GWRC maps may be confusing (especially for those areas that are only shown to be at risk once freeboard has been added) and that an alternative name should be used for the information shown on these maps. The terminology currently used may be one of the reasons why some sections of the local community are struggling to accept the current maps. This may be especially the case in areas where the local community do not perceive that certain areas are at risk of flooding, and that inclusion within the mapped flood hazard extent could adversely affect the value or development potential of those areas or property. Subject to the underlying flood modelling being fit for use, the information on the flood maps is useful, but the terminology could be improved to avoid confusion, as has occurred in other catchments in the region.	**1**	**Yes**

Item	Comment	Audit rating	Fit for Use
FMP option maps	Though not published apart from in modelling reports, flood depth, extent and velocity maps have been produced as GIS layers for comparing the performance of the Waiohine FMP flood mitigation options. The information on these maps/layers are outputs from the hydraulic modelling and are useful. As with the flood models themselves, it is hard to navigate to the appropriate map/layer given the many model runs and outputs produced since 2009. Therefore, these maps/layers should be catalogued and a document produced to ease navigation to the appropriate map/layer and to clearly describe the parameter being shown.	**1**	**Yes**

The review of the flood hazard maps used for planning purposes indicates that the maps are a true reflection of the outputs of the hydraulic flood modelling. However, the map legends could be improved to better describe the information being displayed and the provenance of that information. It should be clearly stated whether the maps include model freeboard and an allowance for climate change.

Access to detailed flood hazard information could be improved, and automated. However, implementation of such an arrangement will depend on GWRC balancing open and easy access to information with a desire to provide information in context by ensuring that a GWRC officer has input to responding to requests for information.

5 Other issues

5.1 Council and stakeholder relationships

During the auditor's meetings with District Councils, and local residents Michael Hewison and Bruce Slater, the conversations moved beyond the strict 'modelling and mapping' terms of reference of the audit, and covered many aspects of the Waiohine FMP process, options and implementation. Below is a list of issues raised during the stakeholder meetings. It is not the purpose of this audit to pass comment on those issues that are not part of the terms of reference. The issues raised reflect the investment of the communities in the Waiohine FMP process and include the following, as expressed by those spoken to.

- Relationship between GWRC and the stakeholders regarding the Waiohine FMP is poor, and has affected relationships at a personal level between GWRC officers and stakeholders.
- Consultation (especially on the Carterton side of the river) regarding Waiohine FMP was limited, and local knowledge has not been fully utilised to validate the modelling or develop the flood mitigation options:
  - Seasonality of flooding
  - Capacity of the Apple Barrel Floodway; historic, current and with respect to erosion control
  - Channel bed levels
  - Historical flood extents, levels and durations, and changes that may have altered flood risk since the 1955 flood.
- Existing stopbanks along the lower reaches of the Mangatarere Stream prevent floodwaters draining back to the river and the road alignment on the Carterton side of the SH2 Bridge has exacerbated local flood risk.
- Cost and the appropriate level of protection, especially for a small rural ratepayer base:
  - Inclusion of climate change for design of stopbanks means that today's ratepayers are paying for future generations' flood protection. Phased raising of defences was suggested; adaptive management.

- Cost of future maintenance.

- Adding freeboard to the model and hence the maps is difficult to understand. However, it is understood that freeboard should be applied to structures, such as stopbank height or building floor levels.
- Anomalies in flood levels, depths and velocities at the site-specific scale (see Section 5.2).
- Staged approach to developing options. For example, isolating the effect of widening the river at Fullers Bend.
- Tying stopbanks into natural contours, where appropriate, and reducing the incursion of stopbanks onto productive farmland.
- Delay in agreeing a solution and the ongoing use of the 'Before' Overall Planning Map, which is more onerous on developers and LIMs.

The stakeholder meetings confirmed that the relationship between GWRC and the Wairarapa community (as represented by the District Councils, Michael Hewison and Bruce Slater) has been damaged by the Waiohine FMP process. Strong opinions are held on both sides, and <u>yet it is apparent that all have a shared desire to reduce flood hazard in Greytown without unduly increasing flood risk to rural land on either side of the river</u>.

5.2 Anomalies in flood information at the site-specific scale

Of the issues raised above, one that is directly related to the 'modelling and mapping' terms of reference of the audit and has not been addressed in Section 4, is the issue of anomalies in flood information at the site-specific scale. Flood maps are limited by the quality of the information used to derive them. As has been noted above, the definition of flood depths and extents in Greytown is restricted by the grid spacing of the model bathymetry, which is 10 m. Michael Hewison provided Beca with examples of sites (Figure 5.1) where the flood information provided by GWRC apparently did not agree with his knowledge of the sites in question, or where the information was anomalous.

Figure 5.1 Development locations provided by Michael Hewison

Figure 5.2 shows the detailed flood depth map for 11a Reading Street with annotation by Michael Hewison. Due to the pixilation caused by the 10 m model grid and the flood depth layers used in the map legend, it is possible to imply a 400 mm difference in water level across a relatively flat section and a distance of 10-20 m, but that does not necessarily reflect a true interpretation of the information.

At the Kuratiwhiti Street and West Street properties, Michael Hewison noted similar sudden differences in flood depth and level that he could not reconcile with site contours, and at Kuratiwhiti Street also noted that while flood depth apparently altered significantly, there was no apparent change in water velocity.

As part of the audit, these apparent anomalies have not been investigated in detail, but they represent the difficulties of translating flood modelling undertaken with a relatively large grid size to mapped outputs at the site-specific scale. A 10 m grid means that the area of each grid cell is 100 m^2, approximately half the size of the medium-large house footprint, and only six to ten grid cells would cover most suburban residential sections. Ground levels can vary significantly within one grid cell, especially if it contains drainage channels, road edges or crowns, or property boundaries, and flood levels across a property may reflect flooding from more than one source or flow path.

Within the MIKE software, one ground level is applied to the whole grid cell, which loses the underlying definition of the ground surface, and results in the pixilated flood maps, such as shown in Figure 5.2. A way round this problem is to user a smaller model grid size (or flexible mesh) to improve definition, though this will have an impact on model run times.

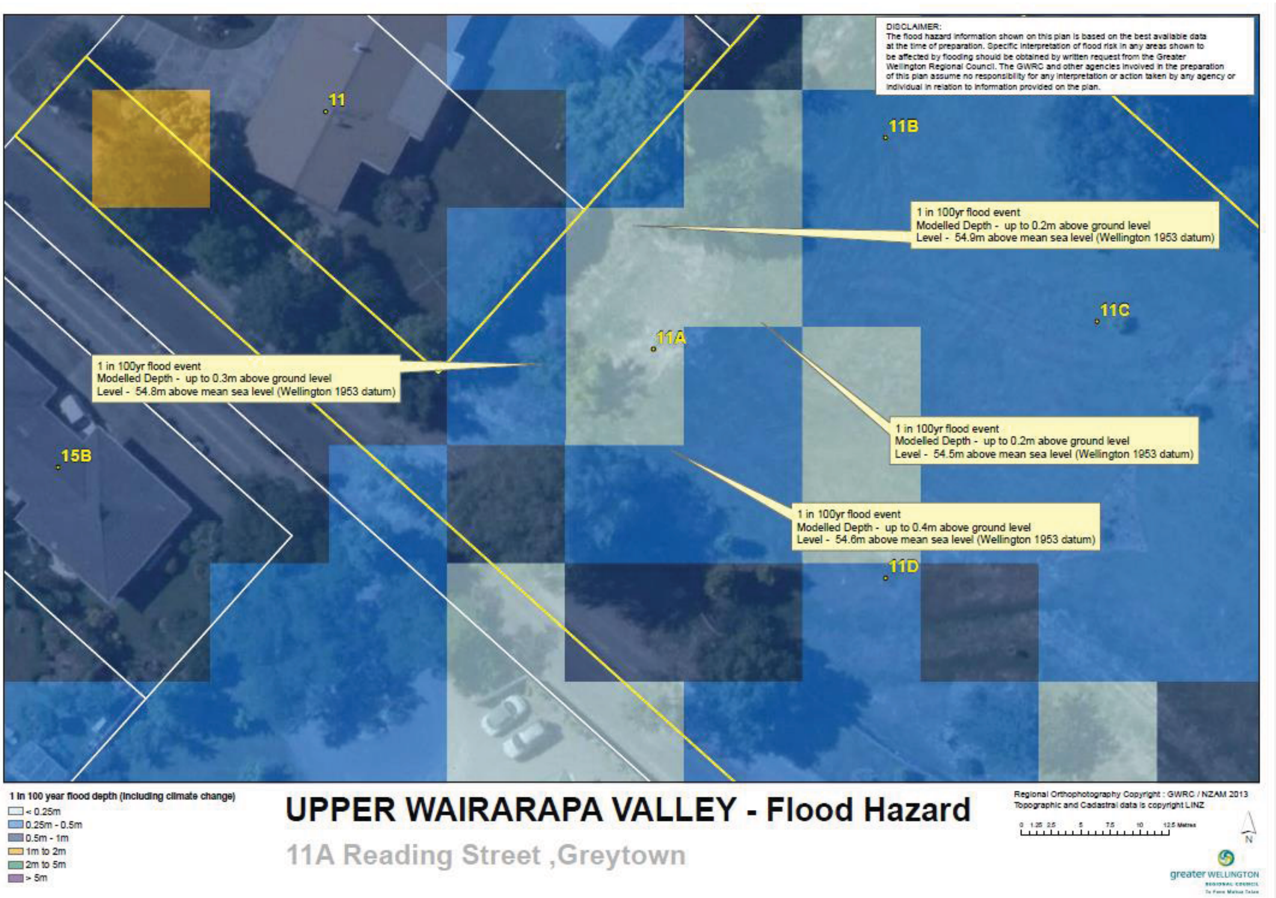


Figure 5.2 Detailed flood map for 11a Reading Street, Greytown

Alternatively, post-modelling process of map outlines can be carried out to smooth flood outlines, remove isolated anomalous cells, and ground truth the results. This is an approach being used in Hamilton and incorporated into Hamilton City Council's update stormwater modelling guidelines. However, post-modelling intervention does bring a subjective element into the mapping process, which could be open to dispute.

Some 2D flood modelling packages (such as HEC-RAS) retain the ground surface detail even if the grid spacing is relatively large, and use that detail when preparing the flood outlines. This smooths the outlines, thereby removing pixilation and the risk of anomalous interpretation of the flood information.

6 Conclusions and Recommendations

6.1 Conclusions

The methods and level of detail reflected the catchment information and hydrological/hydraulic modelling methods available when modelling commenced in 2009.

The audit has indicated that the hydrological modelling is fit for use, but there are aspects of the hydraulic flood modelling that must be reviewed and resolved before the flood modelling used to derive the flood hazard maps can be considered fit for purpose. The issues to be resolved relate to model calibration/validation, channel roughness, channel bed levels, and the application of freeboard within the model.

Though the flood maps accurately represent the information extracted from the flood modelling, there are difficulties accessing the maps and detailed site-specific flood information. Map legends, definitions and terminology are limited, and in some cases misleading. These issues lead to confusion and misunderstanding within the community regarding the interpretation and use of the maps.

Use of the 10 m grid for flood modelling and mapping leads to anomalies in flood depths and velocities at the site-specific scale, which further compromises user acceptance of the maps. As such, the presentation of flood information in map form should be modified.

Stakeholder meetings held as part of the 'modelling and mapping' audit process have brought to the fore the state of the relationship between GWRC and the Wairarapa community, as represented by the District Councils and residents. The community has outstanding issues with the Waiohine FMP process, options and implementation, which will need to be resolved.

6.2 Recommendations

6.2.1 Hydrological modelling

The hydrological modelling is 7-8 years old. The absence of any major flood in the last ten years and a review of Waiohine flood frequency indicates that the hydrological modelling is still valid. However, the modelling should be reviewed following any major flood event (especially if the stopbanks are over-topped) or to account for development related to climate change projections.

6.2.2 Hydraulic flood modelling

Though the hydraulic modelling software, approach and inputs were generally appropriate, the review of the modelling indicated that the following issues should be actioned before the model can be considered fit for use for producing the flood extent and hazard maps, and for assessing the performance of the FMP flood mitigation options.

- The model should be validated (if insufficient information is available for calibration) against the 1990 flood event at least. That will require reference to anecdotal information held within the local community,

and acknowledgement of that could help repair relationships between GWRC and the community. It is probably not feasible to validate the model against the larger 1955 flood, but understanding what occurred during both the 1955 and 1990 floods will assist GWRC in validating the model, identifying anomalies in the model, and ultimately providing a model that is accepted by stakeholders.
- Reviews should be undertaken of the channel roughness and what bed levels are appropriate for assessing flood risk and the performance of mitigation measures that could have a lifespan of 100 years, and so experience future higher bed levels.
- The approach to applying model freeboard (or representing flood model sensibility/uncertainty in an alternative manner) should be reviewed, and that will include careful consideration of how the adopted approach is to be communicated to stakeholders.

Better definition of flood depths, extents and overland flow paths could be provided if the modelling were updated to account for current computer processing power and advances in modelling software. Specifically:

- The use of a finer grid or flexible mesh to construct the 2D model bathymetry would provide better definition of flood extents and overland flow paths, particularly in areas where detail is important.
- Blocking out buildings within the 2D model bathymetry would improve definition of overland flow paths and should be considered if the models are to be re-run.
- Including the Rail and SH2 bridges across the Waiohine River in the model, and testing flood level sensitivity to debris / blockage of bridges and culverts.

While advances in modelling methods and available information since 2009 could be used to improve aspects of the modelling, it is unlikely that updating and upgrading the models would significantly alter the relative performance of the Waiohine FMP flood mitigation options, but it would improve site-specific detail and provide more confidence in the application of freeboard to account for model sensitivity.

6.2.3 Flood hazard mapping

Map legends, descriptions and terminology should be improved. Improvements to online access to the flood maps and detailed flood information should be reviewed. Post-processing of flood model outputs should be considered to improve the rendering of flood maps and reduce anomalies as a result of pixilation caused by the 10 m model grid.

Confirming the main conclusion of the audit:

- **The hydrological modelling is fit for use**
- **The hydraulic flood model was built using industry standard software and approaches, and used appropriate inputs, and is generally fit for purpose. However, the aspects of the modelling have been identified for review, resolution of which would significantly improve confidence in the model outputs.**
- **The flood maps could be improved to better communicate flood information to the community, and smooth the relationships in Waiohine FMP consultation process**

Appendix A – Overall Planning Maps

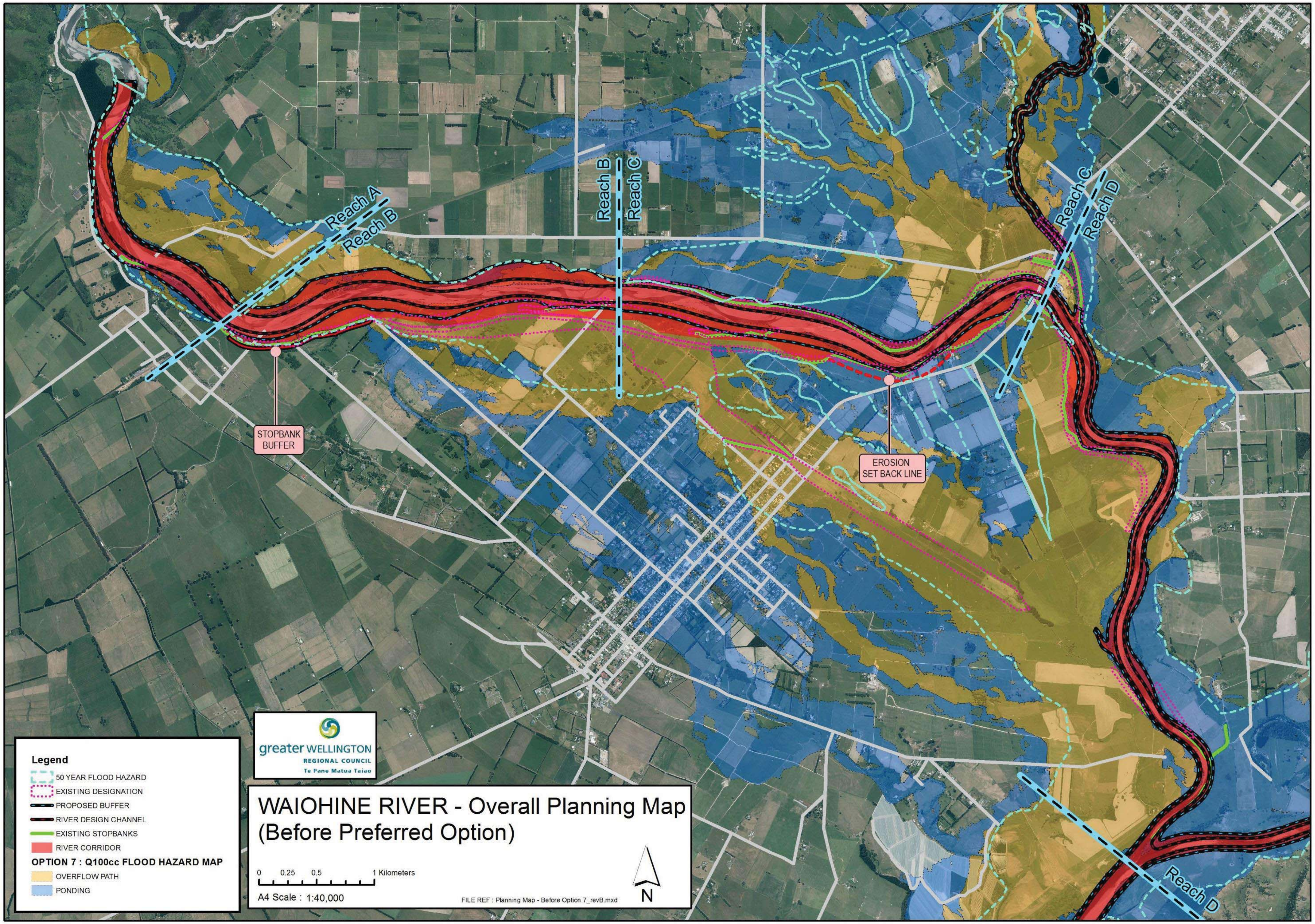


Figure A1 Overall Planning Map – pre-FMP options

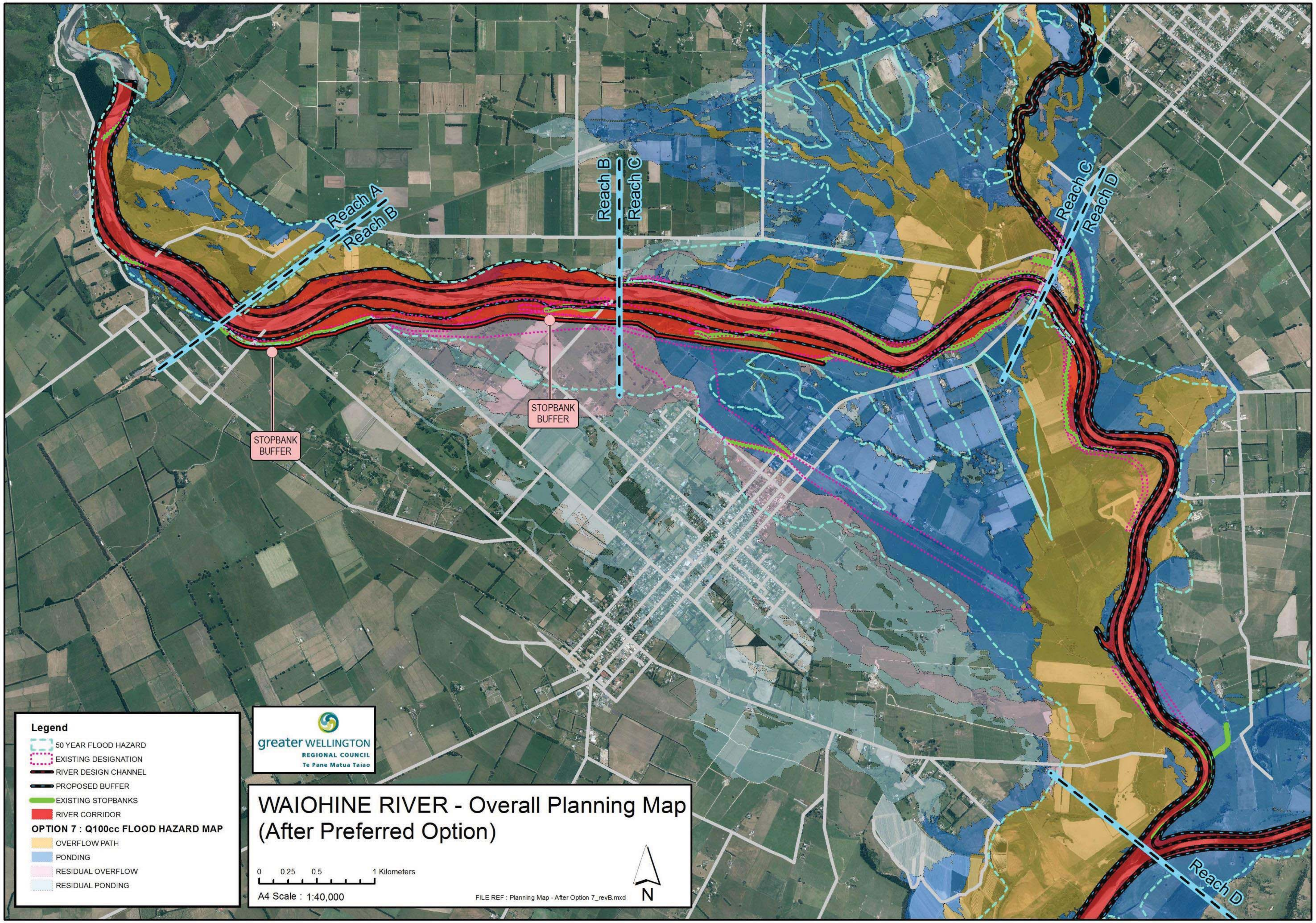


Figure A2 Overall Planning Map – post-FMP options