IN THE MATTER OF

The Resource Management Act 1991

AND

IN THE MATTER OF

Proposed Plan Change 42 to the Upper Hutt City Council District Plan (2004) –Mangaroa and Pinehaven Flood Hazard Extents

Statement of evidence of MICHAEL CHARLES LAW

30 August 2017

Introduction

1. My full name is Michael Charles Law. I am the Senior Associate - Water Resources at Beca. I have worked for Beca since 1 August 2009.

2. I hold a BSc(Hons) degree in Geography from Huddersfield Polytechnic in the United Kingdom. I also have a Post-Graduate Diploma in Agricultural Water Management (Soil & Water Engineering) from Silsoe College, part of Cranfield University in the United Kingdom (UK).

3. I am a:

   (a) Chartered member of the Chartered Institute of Water and Environmental Management (CIWEM);

   (b) Chartered member of the Society for the Environment (CEnv);

   (c) Member of the New Zealand Hydrological Society, and;

   (d) Member of the British Hydrological Society.

4. I have twenty-seven years' experience as a water resource and hydrological specialist, particularly in the areas of water resource management, hydrology, hydrological modelling, flood risk assessment and control, river restoration, and hydraulic modelling.

5. Prior to joining Beca as a Water Resource Manager, I was a Director of Weetwood Service Ltd an independent consultancy in water management and sustainability in the UK. Previous to that I was a Hydrology Team Leader at the Environment Agency in England.

6. I have been engaged by Upper Hutt City Council (UHCC) to provide independent expert advice on matters relating to hydrological and hydraulic modelling, and flood hazard mapping for the Pinehaven Catchment.

7. In preparing my evidence, I have:

   (a) Visited the Pinehaven Catchment

   (b) Referred to the independent audit of the flood modelling and mapping of the Pinehaven Catchment that I undertook on behalf of Greater Wellington Regional Council (GWRC) in 2015, and subsequent. The scope, tasks undertaken, and conclusions of the audit are described in paragraphs 10-28 of this evidence.

(c) Read the Pinehaven Stream Floodplain Management Plan – Volume 1, produced by GWRC and dated 6 September 2016, and the accompanying Flood Hazard Maps.

(d) Reviewed the S32 Evaluation report prepared by Mr Brett Osborne and Mr James Beban.

(e) Reviewed the Submissions relevant to the Pinehaven catchment (2, 4, 8, 9, 11, 12, 13, 14, 16, 19, 20, 23, and 25).

8. I have read and agree to comply with the Code of conduct for expert witnesses outlined in the Environment Court Practice Note 2014. I understand that, according to the current Code of conduct:

(a) an expert witness has an overriding duty to assist the Commissioner impartially on relevant matters within the expert's area of expertise;

(b) an expert witness is not an advocate for the party who engages the witness.

9. I confirm that the statements made in this evidence are within my area of expertise (unless I state otherwise) and I also confirm that I have not omitted to consider material facts which might alter the opinions stated in this evidence.

Scope of Evidence

10. I have been engaged by UHCC to prepare independent expert evidence in relation to issues raised by submitters relating to the Pinehaven catchment flood maps, with particular reference to:

(a) The accuracy of the flood maps, and the data used to inform the maps

(b) Whether 'hydraulic neutrality' provisions applied to future development in the catchment will work.

(c) Whether the maps should show 'freeboard', and to comment on the effect of adding freeboard on mapped flood extents and depths.

(d) Removing shallow water (<100 mm) flooding from the mapped Flood Hazard Areas.

11. I have structured the contents of this evidence in four parts.

(a) Firstly, I will briefly outline the scope and findings of my 2015 audit of GWRC's flood modelling and flood hazard maps of the Pinehaven catchment;

(b) Secondly, I comment on the flood maps proposed in Plan Change 42;

(c) Thirdly, I will summarise the submissions received on Plan Change 42; that relate to the Pinehaven flood maps, and;

(d) And finally, I will address the issues raised in the submissions.

2015 Flood Modelling and Mapping Audit

Background

12. In 2014, GWRC published flood hazard maps in Appendix D of the Pinehaven Stream Floodplain Management Plan (FMP)[1]. The maps were based on the outputs of hydrological and hydraulic modelling carried out from 2008 to 2010, and the maps were/are to be used to inform control of development and flood alleviation options for the catchment.

13. In 2015, GWRC appointed me to undertake an independent audit of the flood modelling and mapping of the Pinehaven Catchment.

14. The terms of reference (ToR) for the audit and appointment of the auditor (me) were subject to community scrutiny, and were in response to a request from the Hutt Valley Floodplain Management subcommittee for a "more comprehensive audit" to allay community concerns that had not been addressed by previously completed investigations and peer reviews of the modelling and mapping.

15. The audit report contained a review of the:

(a) Hydrological and hydraulic modelling, including the software used, model inputs and parameters, and results

(b) Application of freeboard

(c) Presentation and interpretation of the flood hazard maps.

16. Meetings were held with the modellers and with two community groups; Save Our Hills and Pinehaven Progressive Association. The concerns raised, and case studies provided, by the Save Our Hills group were addressed in the audit.

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[1] ***Pinehaven Stream Floodplain Management Plan***, Revision 2, GWRC. 13 October 2014.

17. As requested in the ToR, guidance was also provided in the report on how to:

(a) Set storm water neutrality provisions within district plan.

(b) Define the impact of intensification of development on the runoff characteristics of the Pinehaven hills.

Audit Findings and Recommendations

Flood Modelling

18. My audit review found that the hydrological and hydraulic modelling is fit for purpose, reflecting the available catchment information and representing standard modelling practice.

Flood Mapping

19. I concluded that that the inclusion of allowances for climate change to a suitable horizon and freeboard in the maps was appropriate. However, I also noted that simply describing the consolidated maps as ‘flood extent plus freeboard’ would not adequately reflect the complexity of information included and could therefore lead to confusion and misunderstanding within the community when interpreting the Flood Hazard Maps.

20. Therefore, in order to provide greater transparency and understanding I recommended that the presentation of flood information by GWRC could distinguish between modelled extents with, and without, the application of freeboard. Focus group meetings were held with the community in 2016 to explain the different hazard layers illustrated through separate maps in order to aid community understanding of how the flood hazard maps were compiled and discuss what information could be presented on the maps.

Hydraulic Neutrality and Intensity of Development

21. In the audit report, I noted the issue of including stormwater (or hydraulic) neutrality into local planning guidelines is complicated. While general principles regarding matching or lowering peak flows at the outlets from developments are widely adopted, the hydrological effect of potential developments should be considered on a case by case basis, as in some cases downstream flood risk may be reduced if runoff from the development is discharged early to the receiving water course before floodwater from upstream arrives. However, this is unlikely to be the case for the Pinehaven catchment, where runoff attenuation is likely to provide the most benefit to reducing downstream flood risk. Later in my evidence, I comment on the PC42 proposals for achieving hydraulic neutrality in the Pinehaven catchment.

22. With regard to assessing the hydrological effect of potential future development on the Pinehaven Hills, peak flows in the affected sub-catchments could increase

by about 18% (if not attenuated) and flood volumes may increase by about 6%. Further down the catchment the relative percentage increases in peak flow and flood volume will be smaller, as the cumulative catchment area is increased by the inclusion of catchments that have not been subject to future development.

Community concerns

23. Section 5 of my audit report responded directly to concerns raised by the community. The issues addressed included case studies provided by the Save Our Hills group, the representation of culvert and channel blockage by debris in the modelling, and the effects of future development

Audit Conclusion

24. To confirm the main conclusion of the audit; the hydrological and hydraulic modelling underlying GWRC's flood extent and hazard maps is fit for purpose.

25. I recommended that the way that flood information was presented in map form could be modified to increase the understanding of the maps by the community for GWRC's Floodplain Management Plan process.

26. The community concerns with the flood model were addressed within the flood model.

27. I presented the findings of the audit to the Hutt Valley Floodplain Management subcommittee in July 2015.

28. Subsequently, GWRC's modelling consultants reviewed the model with reference to the audit comments and recommendations, and GWRC held meetings with the community to discuss proposed changes to the way that flooding is represented on the maps. I attended one of these meetings in May 2016.

PC42 Flood Maps

29. I have reviewed the latest version of the PC42 Flood Hazard Maps dated 27 July 2017, which were sent to me by Brett Osborne (UHCC) on 14 August 2017. These differ from the PC42 Flood Hazard Maps available on the UHCC PC42 website[2]. Figure 1 shows one of the nine flood maps that cover the Pinehaven catchment. The map shown represents the area in the centre of the catchment, which includes the flatter valley bottom around the playing fields and some of the steeper, narrower valleys towards the top of the catchment.

[2] https://upperhuttcity.com/wp-content/uploads/2017/03/PC-42-Maps.pdf accessed on 17 August 2017

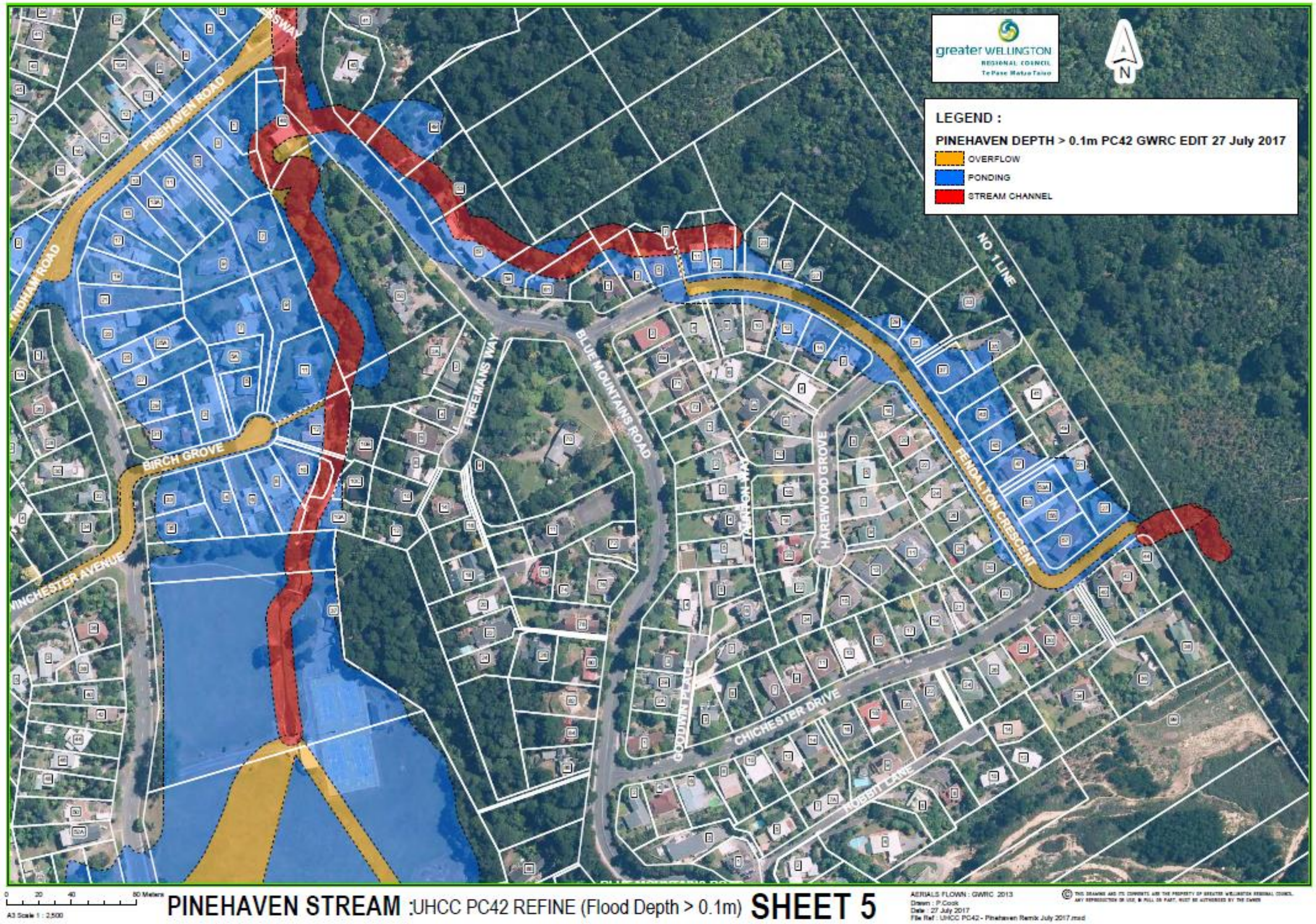

Figure 1 – PC42 Flood Map 46

30. The ‘Ponding Area’ flood extent on the latest Plan Change 42 flood hazards map is slightly less than the 100-year flood extent shown on GWRC’s ***Flood Hazard Information Sheet 3 - Pinehaven Stream***[3]. This is due to the removal from the flood extents of areas with modelled flood depths of less than 100 mm.

31. As my later response to submissions acknowledge, the flood hazard maps do not show all of the flood related information that the community may wish to see, but the flood hazard extents shown on the maps accurately reflect the results of GWRC’s flood modelling of the 100-year ARI flood including allowances for freeboard and blockage. As such, they are fit for the purpose of defining flood hazard areas for Plan Change 42.

Submissions

Summary

32. Twenty-five submissions were received on Plan Change 42, of which fifteen related to the Pinehaven catchment. Four further submissions were received from the Save our Hills (SOH) group in response to the initial submissions.

33. In Table 1, I have cross-referenced the issues raised with the submission number. This is a simplification of the many issues raised, but highlights areas of key concern that I will address later in the evidence.

34. The comments opposing Plan Change 42 and/or raising issues about the flood maps generally fall into one or more of the following categories listed in the first column of Table 1, and are summarised as follows:

    (a) Concern about the **accuracy of the flood maps**, and the issues raised by my 2015 audit. These include comments about flood extents and depths, particularly in reference to the 1976 flood and to observations at specific locations. They include comments about whether flood depth should be shown, and whether ‘freeboard’ should be included in reported flood extents.

    (b) Three submitters commented either that it was not stated which GWRC maps were used to define the flood extents shown on the Plan Change 42 maps, or that it was unclear where **responsibility** lies for the accuracy of the information on the maps.

    (c) Two submitters questioned the **definitions** used for the information represented on the flood maps.

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[3] http://www.gw.govt.nz/assets/Our-Services/Flood-Protection/Pinehaven/Ph-Hazard-Maps/Pinehaven-Stream-Flood-Hazard-Information-Sheet-3.pdf downloaded on 16 August 2017.

(d) The definition of **flood hazard** is raised by submitters, and specifically how that relates to areas of **shallow flooding**. This issue relates to the definitions used for **ponding areas** and **overflow paths** shown on the maps.

(e) **Relationships** between the community and council(s) are strained over the issue of the flood maps, with community demands for independent auditing and amendment of the flood maps.

(f) In opposing Plan Change 42, the majority of submitters requested that the **plan change be withdrawn or postponed**.

(g) **Future urban and residential development** in the Pinehaven catchment is a concern to many, and particularly the potential for increases in flood risk as a result of additional runoff. Submitters question whether Plan Change 42 and the flood maps provided sufficient safeguards to ensure **hydraulic neutrality** as a result of future development.

35. In the following sections, I address specific issues relating to the accuracy of the flood maps, the information presented, flood hazard and shallow flooding, and hydraulic neutrality.

Table 1 - Submission topics

Issues	Submission number														
	2	4	5	8	9	11	12	13	14	15	16	19	20	23	25
Flood map accuracy & 2015 audit	✓			✓		✓	✓			✓	✓	✓		✓	✓
• Flood extents		✓					✓				✓	✓			✓
• Flood depths		✓					✓				✓	✓			
• Freeboard									✓						
Flood map providence and accountability		✓					✓			✓		✓			
Flooding definitions		✓												✓	
Flood Hazard and shallow flooding							✓					✓			
Community concerns and relationship with councils		✓					✓								
Withdraw or postpone PC42	✓	✓	✓	✓			✓	✓			✓		✓	✓	✓
Future development and hydraulic neutrality	✓				✓		✓					✓	✓		

Flood Map Accuracy

36. The flood maps attached to Plan Change 42 are based on the results of flood modelling undertaken by GWRC for the Pinehaven Stream Floodplain Management Plan, and the GWRC flood hazard maps produced as a result.

Flood modelling

37. Some submissions raise a general concern with the accuracy of the flood maps. This can be due to the mapped flood extents not aligning with community observations of previous flood events, as well as understanding of how they are compiled, or an assumption that the underlying flood modelling is incorrect.

38. I concluded in my 2015 audit that the hydraulic modelling behind the GWRC flood maps was fit for purpose for producing the flood extent and hazard maps for the current development situation for the Floodplain Management Plan.

39. The modelling represented industry standard practice and a further audit would not change this or alter the flood extent and depths for the design flood events and scenarios modelled, and so the flood modelling is fit for defining the flood hazard extents proposed in Plan Change 42.

40. During the audit, I noted an error in the way that future development had been modelled. This was subsequently corrected. I will expand on the potential effects and mitigation of future development later in my evidence.

Flood Mapping General Comments

41. Some submitters on Plan Change 42 hold very strong views on the flood hazard extents and other information shown on the flood maps. These views include:

    (a) The floodplain is floodplain “grossly overstated” (Submitter #8)

    (b) The “flood maps are grossly inaccurate & even grossly misleading” (Submitter #11)

    (c) “We have evidence of data in GWRC’s flood maps being tampered with to produce the inflated picture that the flood maps paint” (Submitter #12)

    (d) The flood maps are “impossible to read”, “absurd”, and “unnecessary”. (Submitter #23)

42. While I disagree with such statements, they highlight that the flood maps have not been accepted by some members of the community. However, the flood maps have been audited and confirmed as fit for purpose and therefore it is important to note that there are different purposes between maps produced to inform GWRC's FMP process (where the community needs to understand the different components forming the flood hazard maps) and UHCC's District Plan (where the maps need to clearly identify the area the provisions of the District Plan address), even when those maps have been derived from the same flood model.

43. Submitters also raise specific issues relating to the information presented, the terminology surrounding the flood maps, the validity of the mapped flood extents, and comparisons with historic flooding. I address these issues in the following paragraphs.

44. **Information Presented and Terminology**

45. The flood hazard maps differentiate between *ponding areas* and *overland flow paths*. Submitters #4 and #19 note that the maps do not show water depth or velocities, and queried the definition of *ponding area*, while Submitter #2 requested that the flood risk areas should be "separated".

46. Providing more detail (such as flood depths or velocities) to the maps would give users more information. But it is not the purpose of these planning maps to provide that level of detail; rather it is to identify flood hazard areas, not to quantify the flood hazard within that area. As such, in my view it is appropriate that maps only show an outline and uniformly shaded areas that relate to the provisions of the District Plan.

47. Submitters #4, #12, and #19 questioned the provenance of the information contained within the flood maps. The mapped flood extents are based on GWRC's flood modelling, and it is my understanding the details on the water depth and velocity can be provided for individual properties on request from GWRC.

48. Submitter #23 questions the terminology (*ponding areas* and *overland flow paths*), suggesting that using terms such as "100 year flood extent" or "floodplain"' would be appropriate. The terminology used on the latest Flood Hazard Maps (such as *ponding areas* and *overland flow paths*) is in line with that used elsewhere in the Greater Wellington region, and so appropriate for the District Plan.

1976 Flood Extent

49. Though over forty years ago, the flood of 1976 is the clear reference point for flooding for those in the community that remember, or have been told about, the event. The 1976 flood was reported to be a 100-year event. Some members of the community expect the current flood maps to reflect the 1976 flood outline.

50. During my 2015 audit, it was apparent that the modelled flood hazard area outline extended well beyond the 1976 flood extent (also noted by Submitter #19, and others). This was due to adding ‘freeboard’ to the mapped flood extents, but also included the allowance for climate change and assumptions about culvert blockage (albeit bearing in mind that debris blockage is considered a factor during the 1976 event). The modelled flood extent is appropriate as it reflects anticipated future climate conditions and the variables represented by the inclusion of freeboard.

Representation of Freeboard

51. GWRC’s 100-year flood depth and extent map includes an allowance for ‘freeboard’ in defining the Flood Hazard Area, and this extent has been carried through to the Plan Change 42 flood maps, as noted above and as raised in some submissions (such as Submission #14). Freeboard is an additional depth added to modelled water levels, and is an allowance for:

(a) Uncertainty in the modelling process or parameters, such as limited survey, lack of recorded flow data, and assumptions regarding stream and floodplain roughness, and antecedent conditions.

(b) The residual risk of flooding from extreme events (i.e. those greater than the design event), although this is not an element included in freeboard applied to GWRC Flood Hazard Maps.

(c) Local wave action and obstructions.

52. Application of freeboard extends the potential floodplain beyond the modelled flood extent, and is used to assist in the setting of levels for floors and vulnerable services.

53. For the Pinehaven catchment, freeboard has been applied by increasing flood levels by 300mm in the flatter parts of the catchment and by 500mm in the steeper and narrower upper valleys. These increases in flood level are reflected in an increase in flood extent. The difference in freeboard depths between the flatter and steeper parts of the catchment reflects the relative sensitivity of areas to the variables incorporated in freeboard. While methods of applying freeboard vary around the country, the approach adopted for the Pinehaven catchment is used elsewhere and is appropriate for the provisions of the District Plan.

Model and map definition

54. Submitters (#12, #16, and #25) have questioned the mapped flood extents on their properties on Elmslie Road in the in one of the steeper and narrower upper parts of the catchment, where ground levels change over short distances, and there are multiple obstructions to flow in and around the stream channel.

55. The Pinehaven catchment flood model used a 5m grid to model overland flooding beyond the stream channel. The choice of grid size is based on the quality of ground surface information available, the size of the area to be modelled, computing capacity, and model run times. The 5m grid generated mapped flood hazard extents are appropriate for guiding development control in these areas.

Flood Hazard and Shallow Flooding

56. Submitter #12 raises the point that the initial PC42 flood hazard maps included areas where they consider that the flooding is 'insignificant'. I believe that this is based on the approach taken by some other councils or regions, where flood depths of 100 mm are considered insignificant and not included in flood hazard maps. For example, Figure 2 shows how flood hazard is defined in Hamilton where flooding of less than 100 mm depth is described as 'insignificant'.

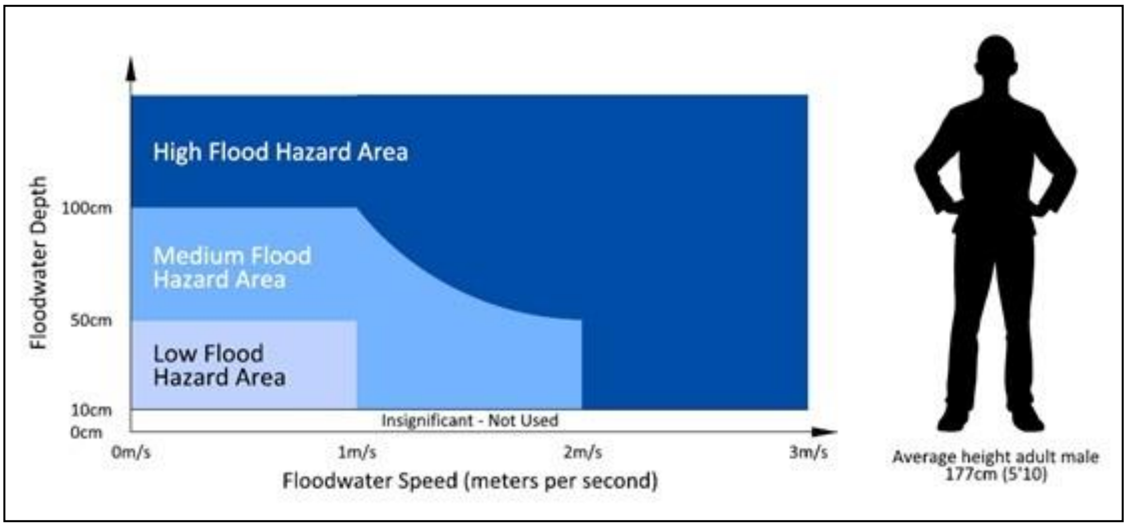

Figure 2 – Definition of flood hazard

57. The PC42 flood hazard maps have been updated to remove areas with flood depths of less than 100 mm from the mapped flood extents. This is in line with the "insignificant" flood depth used elsewhere, and will not affect the purpose of the Plan Change 42 to promote development safe from flood hazard.

58. Removal of shallow flooding from the flood hazard maps will reduce the mapped flood extents, particularly in areas with shallow overland flow paths along the valleys.

Future Development and Hydraulic Neutrality

59. Submission #12 notes that "Plan Change 42 fails to address the risk to people and property from flooding that could arise from future development on the hills around Blue Mountains, Pinehaven and Silverstream, and specifically from proposed development on the Guildford land (referred to in the Section 32 report as "the southern growth area")." I will address the issues around Future Development and Hydraulic Neutrality in the following paragraphs.

Future Development

60. As raised by Submitter #12, my 2015 audit noted that there was a discrepancy in the way that sub-catchment flow hydrographs had been derived for a 'future development' scenario in the Pinehaven catchment. While there was an increase in peak flow, there was no anticipated increase in flood volume. This suggested that the future hydrology had included an allowance for quicker post-development runoff, but had not allowed for the additional runoff generated by increased impervious areas post-development. This had a knock-on effect of showing a less than expected difference between existing and 'future development' flood extents provided by GWRC.

61. This was acknowledged by GWRC and in March 2017, GWRC's consultants (Jacobs) updated the 'future development' hydrology, and sent me the results for comment. This included an updated flood extent difference map to indicate the effects of <u>unmitigated</u> future development. Following discussion and an exchange of correspondence I am satisfied that Jacobs' reworking of the future development hydrology is appropriate.

Hydraulic Neutrality

62. Concern over the potential increase in flood risk resulting from future development is raised by submitters, with five of them expressing concerns; in some cases linking their view that the flood maps too large a large flood extent, with a fear that the increased flows (and hence flood risk) as a result of future development be hidden within the current flood extents, and so it will not be possible to control post-development runoff.

63. I note that Plan Change 42 sets out objectives (9.3.2 and 9.3.4) to control future development in the Pinehaven catchment, with Objective 9.3.4 outlining provisions to prevent increased development in the upper catchment from increasing flood hazard downstream. This is to be achieved through limiting post-development peak runoff rates to no more than pre-development flows. This is referred to as hydraulic neutrality.

64. Peak flow is one measure of the changes in hydraulic response due to development. Increases in peak flow are caused by a combination of a reduction in permeable area and quicker runoff from smoother post-development channels and overland flow paths. The decrease in permeable area is also likely to result in an increase in flood volume.

65. For a relatively steep catchment such as Pinehaven, limiting peak flows is the critical factor for controlling downstream flood extents and depths, and so is an appropriate form of control. Peak flows can be reduced by providing storage within the development to attenuate the flow hydrograph.

66. The effect of attenuation is to release storm runoff later than would have occurred without storage in the expectation that flood levels throughout the receiving catchment will be receding when the water is released and so peak flood levels are not increased. This approach works where flood volume is not the critical factor in determining flood levels and where attenuated flows do not coincide with peak flows arriving from other parts of the receiving catchment that have longer times of concentration.

67. It is my opinion that the hydraulic neutrality provisions in Section 1.8.11 of proposed Plan Change 42 will manage the hydrological effects of proposed development in the Pinehaven catchment to achieve hydraulic neutrality.

68. I note that the provision allows for either matching pre-development flows catchment-wide, or limiting peak outflows from development sites to no more than 80% of pre-development rates, and that both the 10-year and 100-year flood events should be considered.

69. These are pragmatic approaches to managing the range of developments and flood events that may occur in the catchment, and achieve effective hydraulic neutrality to address any future development in the upper catchment.

Conclusions

70. Based on my review of the available information and previous experience auditing GWRC's flood modelling and mapping of the Pinehaven catchment, I conclude that:

    (a) The flood modelling used to derive the flood hazards maps is fit for purpose.

    (b) The Plan Change 42 Flood Hazard Maps (including allowances for climate change and freeboard) are appropriate for defining the areas subject to the flood hazard and development provisions of the revised District Plan.

    (c) The provisions in the revised District Plan for limiting the hydrological effects of future development through 'hydraulic neutrality' are appropriate.

BEFORE THE UPPER HUTT CITY COUNCIL

IN THE MATTER OF	**the Resource Management Act 1991**
AND IN THE MATTER OF	**Proposed Plan Change 42 to the Upper Hutt City Council District Plan (2004) – Mangaroa and Pinehaven Flood Hazard Extents**

STATEMENT OF EVIDENCE OF KYLE JOHN CHRISTENSEN

25 August 2017

Introduction

1. My name is Kyle Christensen and I am an Independent Consultant specialising in river and stormwater engineering. My qualifications are a Bachelor of Natural Resources Engineering (Hons) from the University of Canterbury, a Masters of Natural Resources Engineering specialising in water resources from Lincoln University and a Masters of Business Administration from Victoria University. I am a member of the Institute of Professional Engineers of New Zealand (MIPENZ) as well as an IPENZ practice area assessor for water resources and stormwater, a Chartered Professional Engineer (CPEng) and an International Professional Engineer (IntPE(NZ)). I am also a member of the New Zealand Hydrological Society, Water New Zealand and the New Zealand Society of Large Dams and am the Chairman of the IPENZ/Water NZ Rivers Group. I have over 17 years' experience in water resources engineering including hydrological and hydraulic modelling, design of river control works, floodplain management and erosion risk assessments.

2. I have been engaged by Upper Hutt City Council (UHCC) to provide independent expert advice on matters relating to hydrological and hydraulic modelling, flood hazard mapping and erosion hazards for the Mangaroa catchment.

3. In preparing my statement of evidence I have –

   - Visited the Mangaroa Valley;
   - Reviewed the following technical documents –
     - Watts, L. (2005). Flood Hydrology of the Mangaroa River. Greater Wellington Regional Council Technical Report;
     - Westlake, S. (2009). Mangaroa Photographs and Hydrological Records. Letter to Mrs Noeline Berkett on behalf of the Greater Wellington Regional Council;
     - Sinclair Knight Merz (2006). Mangaroa River Flood Hazard Erosion Hazard Report: Technical Report to the Greater Wellington Regional Council;

- Sinclair Knight Merz (2007a). Mangaroa River Flood Hazard Assessment Hydraulic Modelling Report: Volume 1. Technical Report to the Greater Wellington Regional Council;

- Sinclair Knight Merz (2007b). Mangaroa River Flood Hazard Assessment Hydraulic Modelling Report: Volume 1. Technical Report to the Greater Wellington Regional Council;

- Jacobs (2015). Mangaroa River Flood Hazard Assessment – Mangaroa Hydraulic Modelling Report. Revision F. Technical Report to the Greater Wellington Regional Council.

- Reviewed the historic daily rainfall records of Noeline Berkett and met with Mrs Berkett to discuss the rainfall information in relation to the rainfall information collected by the Greater Wellington Regional Council and NIWA;

- Undertaken a peer review of the 2006 – 2007 hydrological and hydraulic modelling that was being used as the basis for the previous proposed plan change (plan change 15) and produced a peer review report - Christensen, K.J. (2014). Mangaroa River Flood & Erosion Peer Review. Pattle Delamore Partners Ltd Technical Report to Upper Hutt City Council (See Annex 1).

- Participated in a Mangaroa Hazard Mapping Workshop to agree a method for determining freeboard on 20 May 2015.

- Provided written verification that the outstanding items from the 2014 peer review have been resolved – Christensen, K.J. (2016). Mangaroa River Flood & Erosion Peer Review. Cardno NZ Ltd Letter to Upper Hutt City Council (See Annex 2).

- Reviewed the S32 Evaluation report prepared by Mr Brett Osborne and Mr James Beban, and

- Reviewed the Submissions relevant to the Mangaroa catchment (2, 6, 10, 12, 14 17, 18, 19, 22, 23).

4. I have read and agree to comply with the Code of conduct for expert witnesses outlined in the Environment Court Practice Note 2014. I understand that, according to the current Code of conduct:

(a) an expert witness has an overriding duty to assist the Consenting Authority impartially on relevant matters within the expert's area of expertise;

(b) an expert witness is not an advocate for the party who engages the witness.

5. I confirm that the statements made in this evidence are within my area of expertise (unless I state otherwise) and I also confirm that I have not omitted to consider material facts which might alter the opinions stated in this evidence.

Scope of Evidence

6. My evidence includes a summary of relevant background information followed by discussion of issues identified by the submitters in relation to the Mangaroa Valley. The issues have been summarised to include the following with reference to submissions provided in brackets -

i. Accuracy of Flood Modelling (2, 6, 12, 17, 18, 19, 22, 23);
ii. Freeboard in Mapping (14);
iii. Definition of Terms – Hazard, Ponding, River Corridor, Overflow Path (19,23);
iv. Hydraulic Neutrality for Mangaroa (2);
v. Accuracy of Erosion Hazard Information (18, 23);
vi. Site Specific Erosion Hazard 43 Mt Marua Drive (10)

Background

7. The avoidance or mitigation of natural hazards is a fundamental function that Upper Hutt City Council must provide under section 31(1)(b)(i) of the Resource Management Act 1991 (RMA). This includes controlling the effects of the use of land for the avoidance or mitigation of natural hazards and specifically controlling development and activities in hazard-prone areas through the District Plan.

8. The RMA also requires that District Plans give effect to Regional Policy Statements. Objective 19 of the Wellington Regional Policy Statement (WRPS) states "The risks and consequences to people, communities, their businesses, property and infrastructure from natural hazards and climate change effects are reduced". The WRPS goes on to

have a specific policy (Policy 29) of "Avoiding inappropriate subdivision and development in areas at high risk from natural hazards in district and regional plans".

9. Under the Local Government Act 2002 (LGA) the avoidance and mitigation of natural hazards is set out as a core service that councils must pay particular regard to. The Local Government Information and Meetings Act 1987 requires District Councils to disclose known information on matters including potential inundation (flooding) that affect any property to the extent that this information is not apparent from the relevant district plan. District Councils are required to maintain records on known natural hazards, and to make that information known through any Land Information Memorandum (LIM) that is sought in respect of any property.

10. The legislation cited above repeatedly refers to avoidance as a method for managing flood risk. It is worth noting at this point that there isn't currently a National Environmental Standard or National Policy Statement relating to the management of flood hazard in New Zealand. There is however a Ministry for the Environment (MFE) publication "Meeting the Challenges of Future Flooding in New Zealand" (MFE, 2008) which provides a useful basis for understanding the overall national direction for flood risk management.

11. In particular this document includes a "Local Government Position Statement" from the Local Government New Zealand Regional Affairs Sub-Committee on Flooding. Within this position statement there is a list of solutions highlighted for central government to consider addressing through a National Policy Statement. Included within this list of solutions is, "require preference to be given to flood hazard avoidance in RMA documents" and the position statement goes on to suggest that solutions for local government to implement are to "consistently implement hazard avoidance provisions in RMA documents, undertake a better review of and develop a better response to land-use intensification".

12. A further point to note on the overall philosophy of flood hazard management is to recognise the guiding principles described in the 2010 Ministry for the Environment guideline – Preparing for Future Flooding: A Guide for Local Government in New Zealand. A summary of these guiding principles is provided below –

- Take a precautionary approach;

- Use flexible or adaptive management options;
- Use no or low regrets options;
- Avoid making decisions that potentially compromise future options;
- Progressive risk reduction;
- Integrated sustainable approach.

13. Of particular note is the recommended precautionary approach which is relevant to the discussion on accounting for uncertainty in the hydrological and hydraulic modelling used for generating flood hazard maps.

14. The above legislative drivers as well as the overall direction of managing flood hazards through precautionary avoidance, provide the overarching need for providing flood hazard information in the UHCC District Plan.

15. At this point it is important to highlight that the provision of flood hazard information in the district plan only forms part of the overall flood hazard management solution. Comprehensive management of flood risk involves implementing four key categories of tools;

River Management & Maintenance (e.g. gravel extraction, sand/silt dredging, weed spraying/removal (aquatic and terrestrial), river bed and beach recontouring, hard river bank protection (groynes, rock revetments), planted willow buffer zones and other riparian planting);

Structural Works (e.g. stopbanks, flood diversion channels, detention dams, floodplain storage compartments, pump stations, raising or flood proofing buildings);

Planning & Land Use Controls (e.g. designations, flood hazard maps or zones in District Plan, restrictions on subdivision or building, minimum floor levels, voluntary or compulsory property purchase);

Emergency Management (e.g. flood risk awareness and education, community readiness, flood forecasting and warning, evacuation triggers and procedures, inspection of key structures, planned emergency works (deployment of sand bags, installation of temporary flood barriers), asset monitoring and reactive emergency works, insurance).

16. It must be highlighted that effective flood hazard management requires consideration of all four categories of tools for the full range of flood events up to very extreme events beyond the capacity of the primary structural works.

17. With specific regard to the Mangaroa catchment there are currently no structural flood management works (i.e. stopbanks) and as such there are only minimal river management and maintenance activities undertaken. This means that effective planning controls are therefore the primary tool for managing flood risk in the Mangaroa Catchment. Residual risks can also be managed through emergency management provisions but are not discussed further as they are beyond the scope of this evidence.

Accuracy of Flood Modelling (Submissions 2, 6, 12, 17, 18, 19, 22, 23)

18. The majority of the submissions relating to the Mangaroa catchment raise concerns regarding the accuracy of the flood modelling and mapping. This is often on the basis that there has been no flooding observed historically in the areas identified in the flood maps.

19. With specific regard to this point it is worth highlighting that the you would generally not expect to have experienced flooding to the extent shown in the flood hazard maps as the maps are based on a very large flood (100 year return period) with an allowance for 100 years of climate change. If these maps were in fact showing areas that had frequently flooded in the past then this would suggest that the maps were not accurate in they were underestimating the larger floods that we are expecting to experience in the future.

20. In more general terms regarding the accuracy of the modelling; I have undertaken a detailed peer review of the hydrological (turning rainfall into river flow) and hydraulic (depth, extent and speed of river/floodplain flow) modelling that has been used as the basis for generating the flood maps. A copy of my report summarising the outcomes of my initial peer review is provided in Annex 1.

21. My initial peer review highlighted three areas (rainfall-runoff model, calibration and freeboard) where there were discrepancies, that were sufficient departures from best practice, to justify re-evaluation of some key parameters. It was agreed by the Greater

Wellington Regional Council (GWRC) and their consultants (Jacobs) who had undertaken the original modelling that these three areas would be addressed along with;

- incorporating more accurate ground level survey that was now available;
- extension of the Black Creek channel within the model with new survey information;
- refining the channel alignment;
- increasing the model resolution with the use of a 5 m (rather than 10 m) grid cell size.

22. The model was subsequently updated by Jacobs and the final report (Revision F) submitted in November 2015.

23. With the three fundamental areas of concern addressed and the additional improvements to the model the peer review I was able to sign off my peer review as complete. My final summary and final sign-off is provided in Annex 2.

24. In my view the hydrological and hydraulic model meets the expected industry standards and is fit for purpose for the production of flood hazard maps.

Freeboard in Mapping (Submission 14)

25. One of the particular matters that was highlighted in the initial peer review was the inconsistent and over conservative (in some areas) application of freeboard to the model results. The previous model added between 0.5 m and 0.8 m to the model outputs, largely based on the width of the river channel and floodplain at a particular location.

26. Freeboard is an allowance for uncertainty in the hydraulic model and accounts for such things as –

- Blockage of bridges and culverts (sediment of other debris);
- Higher than expected channel or floodplain roughness (larger, denser vegetation or other obstructions e.g. fences);

- Uncertainty in the design hydrology;
- Coincidence with high flows in the receiving channel (Hutt River) creating a backwater affect;
- Build-up of sediment in the channel (aggradation);
- Inaccuracies in the topographical survey;
- Waves from vehicles or due to localised hydraulic effects (e.g. upstream of buildings);
- Higher water levels around the outside of bends (superelevation);

27. The range of uncertainty arising from many of the above items can be quantified by running sensitivity scenarios in the hydraulic model. For example – how does a 20 – 90% blockage of culverts and bridges or a 25% increase in channel and floodplain roughness affect peak flood levels. The full details of all the sensitivity scenarios is described in the Jacobs Report – Mangaroa River Flood Hazard Assessment (Rev F).

28. There are some variables that can't be represented by the hydraulic model (e.g. waves, superelevation & survey inaccuracies) as well as unknown, unknowns. I discussed this with GWRC and Jacobs and it was agreed that is was prudent, as well as consistent with taking a precautionary approach, to add 300 mm to the maximum flood levels determined by the sensitivity scenarios. In my view, the addition of 300 mm of freeboard to the maximum flood levels determined by the sensitivity scenarios is appropriate.

29. There is not currently a formal New Zealand standard or guideline for the application of freeboard but the sensitivity scenario approach used for the Mangaroa Catchment is forming the basis of a best practice guideline which is being developed by the IPENZ/Water NZ Rivers Group.

30. In my opinion, that together with the other changes and with the appropriate allowance for freeboard determined that the model can be used for generating flood hazard maps.

Definition of Terms – Hazard, Ponding, River Corridor, Overflow Path (Submissions 19,23)

31. When generating flood hazard maps it is useful to define different hazard zones based on the different degrees of hazard that exist so that planning controls are proportionate to the degree of risk at a particular site.

32. The industry practice (e.g Hamilton City Council District Plan - http://www.hamilton.govt.nz/our-council/council-publications/districtplans/flood/Pages/Flood-FAQ.aspx#15, NSW Government, 2005, FEMA, 2014) is to use the depth and velocity of flood water to determine the degree of flood hazard at a particular location. This is on the basis that deep and fast flood water is more hazardous than shallow and slow moving floodwater.

33. The three categories of hazard used for flood mapping in the Mangaroa Catchment are

- High Hazard – River Corridor (Depth > 0.8 m, Velocity > 2m/s or Depth x Velocity > 0.5 m/s, also considers past location of main river channel);
- Medium Hazard – Overflow Path (Depth > 0.25 m & Velocity > 0.5 m/s or Depth x Velocity > 0.25 m^2/s);
- Low Hazard – Ponding (Depth 0.1 to 0.25 m, Velocity < 0.5 m/s or Depth x Velocity < 0.25 m^2/s).

34. It was agreed during the finalisation of the flood maps that ponding areas less than 0.1 m deep would be excluded from the district plan maps but still retained for advisory purposes. In my view this is considered acceptable and I note that the provisions of the Building Act 2004 and Building Code will provide foundations that are at least 100 mm above ground level.

35. In my view the degree of hazard attributed to each zone is considered appropriate and consistent with the definitions provided in the best practice guidelines (NSW, 2005 & FEMA 2014). An excerpt from FEMA (2014) which defines various classes of hazard zone is provided in Annex 3.

Hydraulic Neutrality for Mangaroa (Submission 2)

36. Hydraulic neutrality is a common stormwater management philosophy that is often applied to land development projects in urban environments. Land development will normally involve an increase in the impervious surfaces (roads, roofs, other paved areas) within a catchment which results in faster and higher rates of run-off and an increase in downstream flood peaks. The basis of hydraulic neutrality is that peak stormwater flows following the development of land are managed to a level that is the same or less than the pre-development situation. This generally requires the construction of storage elements within the development such as wetlands, swales, detention/retention dams, tanks, soakage trenches.

37. The provision of hydraulic neutrality is vitally important in small urban catchments which have constrained downstream pipe networks or discharge to small urban streams such as the Pinehaven Catchment.

38. Within the large rural catchment of the Mangaroa Valley there is relatively limited scope for large, intensive residential or industrial developments and the main river channel is of a scale that there would be less than minor effects in terms of peak flood flows from an adjacent development.

39. In my view hydraulic neutrality is not required in the Mangaroa Catchment.

Accuracy of Erosion Hazard Information (Submissions 18, 23)

40. The erosion hazard lines have been developed using a risk based approach with the likelihood and consequences of failure assessed based on the height of the river bank (terrace), whether erosion has been observed at the site, the type of material (silty gravel, weathered greywacke) and whether any existing structures were at risk.

41. This process was used to identify three categories of risk – extreme, high & medium. Based on the level of risk an erosion hazard offset was determined based on a a multiplier of the height of the bank + 15 m. This is an approximate empirical method but I consider it as being acceptable for approximating the possible extent of erosion at an eroding river bank.

42. It is acknowledged that further site specific details may modify the likely extent of erosion and this would require a more detailed assessment from an appropriately

qualified person. The opportunity to undertake a site specific assessment is provided for in the proposed plan change and in my view it is considered that the level of detail used to determine the current erosion hazard set-back is appropriate for planning purposes and is in keeping with the recommended precautionary approach.

43. In my view the erosion hazard set-back lines have been developed using an appropriate methodology and are fit for purpose.

Site Specific Erosion Hazard (Submission 10 - 43 Mt Marua Drive)

44. As highlighted above the current erosion hazard set-back is based on a level of detail appropriate for planning purposes and that it does not preclude individual property owners seeking their own site specific assessment.

Conclusions

45. The hydrological and hydraulic model used to generate the flood hazard maps for the Mangaroa Catchment has been updated following an initial peer review which identified elements that needed to be improved to bring it in line with industry best practice. The model is now considered fit for the purpose of generating flood hazard maps.

46. An appropriate amount of freeboard has been applied to the outputs from the model which is based on accurately testing the sensitivity of key variables as well as allowing for variables that can't be modelled and unknown, unknowns. This approach is being used as the basis for a best practice guideline currently under development by the IPENZ/Water NZ Rivers Group.

47. Flood hazard zones have been identified based on the outputs of the hydraulic model which are consistent with the recognised degrees of hazard from industry guidelines (NSW, 2005 & FEMA, 2014).

48. Hydraulic neutrality is not required in the Mangaroa Catchment as the scale of effects on peak flood flows from the likely degree of development will be less than minor.

49. Erosion set-back lines have been established using a risk based assessment which is considered fit for the purpose of land-use planning.

Signed:

Kyle Christensen

Date: 25 August 2017

References

Ministry for the Environment and The Flood Risk Management and River Control Review Steering Group (2008). Meeting the Challenges of Future Flooding in New Zealand. Published in August 2008 by the Ministry for the Environment Manatū Mō Te Taiao PO Box 10362, Wellington, New Zealand ISBN: 978-0-478-33126-4, Publication number: 900.

New South Wales Government, Department of Infrastructure, Planning and Natural Resources (2005). Floodplain Development Manual – The Management of flood liable land. ISBN:0734754760. **http://www.environment.nsw.gov.au/floodplains/manual.htm**

Federal Emergency Management Agency (FEMA), (2014). Guidance for Flood Risk Analysis and Mapping – Flood Depth and Analysis Grids. Guidance Document 14.

Ministry for the Environment, (2010). Preparing for Future Flooding – A Guide for Local Government in New Zealand.

Annex 1 – Initial Peer Review Summary Letter

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solutions *for your environment*

14 April 2014

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Dear Steve

RE: Mangaroa River Flood and Erosion Hazard Peer Review

Introduction

Pattle Delamore Partners (PDP) has been commissioned by Upper Hutt City Council (UHCC) to peer review the accuracy of the models and data used for the flood and erosion hazards assessments that have formed the basis of proposed hazard zones in Plan Change 15 for the Mangaroa River. The following reports have been reviewed as part of the peer review process:

- Watts, L. (2005). Flood Hydrology of the Mangaroa River. Greater Wellington Regional Council Technical Report;
- Westlake, S. (2009). Mangaroa Photographs and Hydrological Records. Letter to Noeline Berkett on behalf of Greater Wellington Regional Council;
- Sinclair Knight Merz (2007a). Mangaroa River Flood Hazard Assessment Hydraulic Modelling Report: Volume 1. Sinclair Knight Merz Technical Report;
- Sinclair Knight Merz (2007). Mangaroa River Flood Hazard Assessment Hydraulic Modelling Report: Volume 2. Sinclair Knight Merz Technical Report;
- Sinclair Knight Merz (2006). Mangaroa River Flood Hazard Erosion Hazard Report. Sinclair Knight Merz Technical Report.

In addition to reviewing these documents a site visit of the Mangaroa Valley was undertaken by Kyle Christensen of PDP on 10 January 2014 accompanied by Steve Taylor and James McKibbin of UHCC. For the review of the hydraulic model a workshop was held with Ben Fountain of Sinclair Knight Merz/Jacobs (SKM/Jacobs) on 23 January 2014. During this workshop key files and components of the hydraulic model were inspected and discussed.

The following peer review comments provide a critique of the data and models that were used to undertake the flooding and erosion hazard assessments based on the standards considered appropriate at the time the work was done (2005 – 2007). The comments have been divided into three sections covering the hydrology, hydraulic modelling and erosion assessment.

The key outstanding issues highlighted in this report were discussed with Greater Wellington Regional Council (GWRC) and SKM/Jacobs at a meeting held on 10 February 2014. A response to these comments was provided by SKM/Jacobs on 24 March 2014 and a subsequent meeting held on 4 April 2014 to discuss the best way to close out the outstanding issues. A summary of the expectations around the closure of these outstanding issues is also provided in this report.

Flood Hydrology of the Mangaroa River

The first key aspect of the hydrology report is the rainfall run-off model. We consider that the rainfall run-off modelling has been undertaken very thoroughly and has provided acceptable results with an average error of less than 10% in the modelled peak flow and a 1.5 hour range in the error associated with the timing of the peak. A significant point to note in relation to the hydrological model is the channel lag and non-linearity parameters that have been used as part of the model calibration. These two factors provide for the storage and routing that occurs in the channel and floodplain as the hydrograph is translated downstream. These two factors along with the initial and continuing loss parameters relating to rainfall are what are adjusted to allow the model to be calibrated. However, in the hydrological model it is not possible to determine how accurately each parameter is in fact representing the actual physical process that it is trying to estimate. For example a reduction in flows due to floodplain storage and routing could be partially represented by increasing initial or continuing rainfall loss parameters. This is an important factor to note when considering the use of the hydrological model outputs in the hydraulic model where the channel/floodplain storage and routing are physically calculated through the model geometry. This point is further discussed in the comments on the hydraulic modelling below.

The next key aspect of the flood hydrology is the at-site flood frequency analysis. This was undertaken by GWRC to estimate the peak flows for a range of return periods using the available flow record for the Mangaroa River at Te Marua (site 29830). The analysis was undertaken in 2005 and hence the available flow record at the time was limited to May 1977 to February 2005.

PDP obtained the flow record for this site from GWRC to check the flood frequency analysis including the latest eight years of record. The additional eight years of available record length did not appreciably change the flood frequency analysis as no large flood events have occurred over the last eight years. The largest 11 flood events all occurred prior to February 2005. Therefore, when using an EV1 and log Pearson Type 3 distribution on the annual maxima the flood flow estimates for the design flow return periods were very similar to the estimates reported by Watts (2005).

It has been recognised in the Watts (2005) report that the EV1 or log Pearson Type 3 distributions do not provide "a particularly good fit to the largest flood peaks on record due to several high annual maxima of about the same magnitude"(Watts, 2005 pg 25). We considered other frequency distributions (such as Wakeby) however, we concur with the comments in the Watts (2005) report that this would likely lead to flood frequency being underestimated (especially for the large flood events). In other words the resulting flood flow estimates for the 50 year return period event (Q50), Q100 and Q200 would all be of a similar magnitude which was considered unrealistic.

In summary we believe that the rainfall run-off model has been thoroughly and successfully calibrated noting the limitations outlined above in relation to matching the calibration parameters to the real world processes they are representing. We also concur with the flood frequency analysis and estimated peak flows for the design return periods as detailed in the Watts (2005) report.

Mangaroa River Flood Hazard Assessment

Calibration

The calibration plots of measured and modelled flows provided on pages 19 to 22 of the SKM (2007a) report show the model over predicting the measured flows by 8%, 38%, 38% and 28% respectively for the four floods the model was calibrated against. It is specifically noted that the hydraulic model over predicts the 21 October 1998 flood by 38% in terms of peak flow whereas the hydrological model only over predicts the peak by 3.8% (Watts, 2005 pg 22) for this event. This strongly suggests that the channel routing parameters being physically calculated within the hydraulic model discussed above don't provide an equivalent affect to those used in the hydrological model.

The range in the acceptable difference in the measured to modelled peak flow depends on the specific situation and the accuracy of the information available but is typically in the 10 - 15% range. Three of the four calibration events in the Mangaroa River model are significantly higher than this range and on this basis we do not consider that the hydraulic model has not been calibrated to an acceptable level of accuracy.

Following from this it is unclear how the design hydrology has been used for generating design flood events. It is stated in the hydraulic modelling report that the six hour design storm has been used. Given that the calibration events over predict peak flows by almost 40% it is possible that the six hour 100 year return period rainfall is also over predicting the design Q100 flow at Te Marua as determined by the at-site flood frequency analysis. Further clarification is required on the design rainfall and resulting flows used in the model.

Freeboard

The freeboard has been assessed by considering a sensitivity analysis to debris blockage, sedimentation and extreme (1.5 x Q100) flows. This has formed the basis for applying a freeboard allowance to the Q50 and Q100 design flood levels. It is noted that at the time of this study this was considered the standard approach but it is now more common to use the actual levels from the modelled extreme events. It is considered that appropriate freeboard has been applied to the more confined sections of the river upstream of Katherine Mansfield Drive and downstream of the Black Creek confluence but the intervening reach needs further consideration. The wide flat floodplain area extending from Katherine Mansfield Drive to the Black Creek confluence has had 0.5 m of freeboard added to modelled flood levels upstream of Wallaceville Road and 0.8 m of freeboard added downstream of Wallaceville Road. For a large flat area with significant storage these freeboard allowances appear excessive and are higher than the mostly 0 – 0.2 m difference identified in the sensitivity test between the 100 year flood and the extreme 1.5 x Q100 flood (pg 50, SKM, 2007a).

It is acknowledged that Wallaceville Road is a very important feature in this part of the model and that it acts as a detention embankment during flood events less than the Q100 event with it only overtopping in an extreme event. Further consideration of the threshold at which this overtops and any residual risk should be provided in the assessment of freeboard required for the downstream floodplain area.

It is also noted that climate change isn't mentioned in the report. This is not surprising given that awareness and specific allowances for increased rainfall were only really starting to be developed during this time. It is certainly something that would be considered now and should be taken into account if any further modelling is to be undertaken.

Model Schematisation/Representation of Structures

Bridges have been represented as irregular shaped culverts with Mannings n set to 0.045 and inlet headloss factors ranging from 0.1 to 0.4 to account for abutment and pier losses. The bridge decks have been incorporated as broad crested weirs set at the road crest or at the top of impermeable barriers if present. This is considered an appropriate method for representing these structures.

Culverts have been included using the standard culvert tool with Mannings n set to 0.013 on the basis that during high flows any gravel will be flushed out and the concrete surface will be exposed. The inlet headloss factors range from 0.4 to 0.5 to account for the different headwall geometry evident at each culvert. It is considered that the culverts have been included in an appropriate way.

Delineation and Linking of 1-D/2-D Domains

The main Mangaroa River channel, Huia Stream, Narrow Neck Stream as well as Black Creek are included in the MIKE 11 1-D domain of the model and a total of 170 surveyed cross sections were included. This is considered to provide a good representation of the river channel network. The 2-D domain is represented by a 10 m grid in MIKE 21 and was derived from LiDAR flown in 2004. This grid spacing is considered appropriate for this model.

The 1-D and 2-D models were coupled using lateral links with weir formula 1 flow calculation (including a friction term) and HGH as the geometry source. This is the standard approach and is considered appropriate for this model.

Model Stability and Computational Parameters

The model was stable and was run with a two second time step and a delta of 0.75. The time step and delta coefficient are both considered acceptable for a model of this kind.

Mangaroa River Erosion Hazard Assessment

The erosion hazard in the Mangaroa Valley was assessed using both desktop analysis and high level site walkovers. Included in the desktop assessment was a review of aerial photography, geological maps and topography derived from the 2004 LiDAR. Sites were identified based on geomorphic evidence of past erosion. For each site a risk assessment was undertaken using five consequence factors ranging from insignificant to catastrophic and five likelihood factors from rare to almost certain. The combined risk rating from these two factors was used to determine whether each site was extreme, high or medium risk and on this basis a setback was proposed. The setback was based on the bank height multiplied by a risk factor of 1, 2, or 3 depending on the risk from medium to extreme respectively. In addition to this 15 m was added to account for uncertainty in the analysis.

The methodology and subsequent assessment is considered appropriate as a high level screening tool to identify potential areas at risk of erosion. It is noted that it is proposed to have the erection of buildings and structures as well as subdivision as non-complying activities within the erosion hazard zone. This is the same activity status that is proposed for the flood hazard zones. It is suggested that the level of accuracy of the flood hazard zone is far greater than that of the erosion hazard zone and consideration could be given to a different activity status to reflect the lower level of accuracy in the erosion hazard analysis.

Summary of Outstanding Issues Discussed at 10 February 2014 Meeting

The below points were discussed at a meeting held at the GWRC offices on 10 February 2014.

- The hydraulic model over predicts the measured peak flow by up to 38% for two of the four calibration events. Further justification and consideration of the effects of this conservatism is needed with regard to the design events as well as the sensitivity testing that has been undertaken to quantify freeboard;
- With the over prediction during calibration it is not clear how the flow generated by the hydraulic model in the six hour 100 year rainfall event compares to the Q100 flow determined by the at-site flood frequency analysis;
- Along with consideration of the above two points further justification is needed for the freeboard allowance between Katherine Mansfield Drive and the Black Creek confluence which appears to be over conservative given the wide floodplain within this area. Particular attention is needed on the effects of Wallaceville Road including how it has been incorporated in the hydraulic model;
- It is suggested that consideration is given to changing the non-complying status proposed for the erosion hazard area to a less onerous status given that the analysis to determine this zone is considered more of a high level, relative screening tool rather than a definitive assessment.

It was agreed that the first three items would be considered by SKM/Jacobs and GWRC and that a written response would be provided. The fourth item was considered to be a planning issue and not a technical peer review matter, so it was decided that this would be left to UHCC and GWRC planning staff to agree and this item was closed out in terms of this peer review.

Response to Outstanding Issues

SKM/Jacobs provided a written response to the three outstanding issues outlined above in a memorandum dated 24 March 2014. Relating to the first two issues, the memorandum stated that the hydraulic model did in fact have flows 30% greater than the Q100 estimated by the flood frequency analysis. Discussion was provided around this discrepancy focusing on the fact that the model hadn't taken climate change into account and that the 30% higher flow would be a reasonable addition to allow for climate change which is now considered best practice[1].

The second part of the SKM/Jacobs response provided a sensitivity analysis of different freeboards below Wallaceville Road. The main conclusion being that a change from 800 mm to 500 mm made very little difference in terms of inundation extents.

A further meeting was held at the GWRC offices on 4 April 2014 to discuss these issues and to agree on a process for closing them out. It was noted that the 30% higher flow in the model represented a significant departure from the intended Q100 design flow and further calibration would be needed to get this within an acceptable range for the calibration flood events (21 & 28 Oct 1998, Jan 2005 and Feb 2004) and the Q100 determined by the flood frequency analysis. With the hydrological model appropriately calibrated climate change could be specifically assessed based on an appropriate predicted temperature increase. The current guidance[2] provides a 2.1^{o} C temperature

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[1] Ministry for the Environment (2010). Tools for estimating the effects of climate change on flood flow:

A guidance manual for local government in New Zealand.

[2] Ministry for the Environment (2008). Climate Change Effects and Impacts Assessment: A

Guidance Manual for Local Government in New Zealand. 2nd Edition.

increase to 2090 and recent work completed on the McKays to Peka Peka Expressway suggests that a $2.4^{\circ}C$ increase is appropriate for the 2115 time horizon based on extrapolation of the A1B mid scenario curve. Table 5.2 in the MfE 2008 guidance provides the % increase in rainfall per degree increase in temperature than can then be applied to the design rainfall for the model.

It was agreed that the model would be recalibrated and that climate change would then be assessed using the predicted temperature and rainfall increases through to 2115. There was some general discussion around the freeboard allowance and it was agreed that this would be discussed further once the model had been recalibrated.

SKM/Jacobs are currently in discussion with GWRC to confirm the scope and programme for updating the model and it has been indicated that the work could take up to three and half months to complete. It is envisaged that the updated model would be reviewed specifically on the calibration plus any other changes that are made.

Yours faithfully

PATTLE DELAMORE PARTNERS LIMITED

Kyle Christensen

Technical Director – Water Resources

Annex 2 – Final Peer Review Sign-Off

Our Ref NZ0151064
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22 January 2016

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Dear Nicola

RE: Mangaroa River Flood and Erosion Hazard Peer Review

This letter provides the final close out of the peer review that has been undertaken on the flooding and erosion hazard assessments which form the basis for Plan Change 43 for the Mangaroa Valley. The initial peer review was completed in January 2014 and a draft peer review report produced on 14 April 2014. The draft peer reviewed concluded that the following items were acceptable and in line with best practice –

- Model schematisation/representation of structures;
- Delineation and linking of 1-D/2-D domains;
- Model stability and computational parameters; and
- The methodology and outputs from the erosion hazard assessment.

Two critical issues which were considered unacceptable in the draft peer review were –

- Unacceptable variance between measured and modelled flows in model calibration (up to 38% compared to the generally accepted +/- 15%); and
- Conservative and inconsistent application of freeboard in some areas of the model.

A meeting was held at the Greater Wellington Regional Council offices on 4 April 2014 to discuss these issues and agree a way forward. In terms of the model calibration it was agreed that the hydraulic model would be recalibrated using an integrated hydrological model to achieve acceptable model performance. The freeboard needed further consideration and it was agreed that a workshop was required to determine the appropriate scenarios to consider when assessing the freeboard requirements.

A workshop on freeboard was held on 20 May 2015 and parameters were agreed to define freeboard for the Mangaroa Valley which built on current NZ best practice as well as international guidelines. The agreed freeboard parameters are provided in the attached memorandum.

An updated modelling report (Revision F dated 6 November 2015) was produced incorporating the agreed changes.

Most importantly the following changes were evident –

- The model calibration/verification was greatly improved and was within the acceptable range (+/- 15%). Specifically the February 2004 event (250 m^3/s) was

modelled to within 12%, and May 1981 (250 m^3/s) was modelled to within 14%; and
- Freeboard was appropriately and consistently applied across the catchment in line with NZ and international best practice.

With these changes completed it is now considered that the integrated hydrological and hydraulic model of the Mangaroa Valley is fit for purpose and the flood hazard outputs from the model are appropriate for use in defining flood hazard zones as part of Plan Change 43.

Yours faithfully

Kyle Christensen
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Encl. Copy of Minutes of Freeboard Workshop

JACOBS Meeting Minutes

Purpose	**FINAL Minutes of Mangaroa Hazard Mapping Workshop held Wed 20th May 2015**		
Project	Mangaroa Flood Hazard Mapping	**Project No.**	AE04609 / IZ016700
Prepared by	Ruth Abbott	**Phone No.**	+64 4 914 8469
Location	Jacobs Wellington office	**Date/Time**	10/06/2015
Participants	Craig Martel (Awa Consultng), Ben Fountain (Jacobs) Sharyn Westlake (GWRC) Mark Hooker (GWRC) Susan Borrer (GWRC) Kyle Christensen (Cardno)		
Distribution	All participants		

Notes	
1	The context of the Mangaroa hazard mapping in relation to Pinehaven was noted i.e. advised that if there are any differences between freeboard approach and mapping between Pinehaven and Mangaroa, these will need to be justified. Noted that there are legitimate differences between the two catchments e.g. rural vs urban.
2	Noted that there is a need to provide clear explanation and transparency when communicating the approach adopted in hazard mapping and determining freeboard. The use of a numerical approach linked back to known values or best engineering judgement should help to ensure that the process adopted is seen to be robust and defensible. *Post-meeting, Ben sent round an email regarding recent experience in Auckland which supports the above position.*
3	A methodology for determining freeboard for the Mangaroa Hazard Mapping was proposed. This is presented below.
Actions	
i	**Craig** provide examples from literature supporting appropriate magnitude of freeboard for the factors of uncertainty that are not represented in the model and cannot be captured through sensitivity modelling (see Section C in ‘Proposed methodology for determining freeboard for the Mangaroa Hazard Mapping’ below). *Post-Workshop note: Craig has done this. In general there is not a great deal of applicable material in the literature. The WRc Fluvial Freeboard Guidance Note[1] (i.e. UK freeboard best practice guidance) provides some useful suggestions and where possible/appropriate these have been used as explained in relevant sections of the ‘Proposed methodology for*

[1] WRc (Environment Agency), 2000, “Fluvial Freeboard Guidance Note. R&D Technical Report W187”

	determining freeboard for the Mangaroa Hazard Mapping' presented below.
ii	**GWRC** advise whether they are able to provide a 100 year flood hydrograph on the Hutt River at the Mangaroa confluence for use in the 'downstream boundary' sensitivity run.
iii	**GWRC** advise on future proposed urban development (as per Craig's emails at the end of last week). Seeing as Mangaroa was incorporated into the District Plan as a growth area, should/how this be incorporated into the Hazard Mapping/Modelling being undertaken? *GWRC have now confirmed that future proposed urban development scenarios do not need to be incorporated into the modelling as there are no firm plans for development.*
iv	**All workshop participants** read through and confirm agreement with the 'Proposed methodology for determining freeboard for the Mangaroa Hazard Mapping' presented below. Any suggestions for alternative approach/values should be emailed to all participants to aid further discussion and final agreement.
v	**Ruth** to provide Sharyn with revised proposal. The existing proposal will need revising in light of the number of proposed sensitivity runs and confirmation of the use of the 'modelling technique' (as opposed to more traditional 'mapping technique') for adding on freeboard.

Proposed methodology for determining freeboard for the Mangaroa Hazard Mapping

A. Identify and quantify hazards that can be represented in the model and can be captured through undertaking Sensitivity Runs.

In the Workshop (and in some instances during post-Workshop supplementary investigation) the following factors and their associated appropriate representation in a Sensitivity Run were agreed. In accordance with the Actions listed above, it is hoped that all participants in the Workshop will review and confirm (or suggest alternative) values proposed herein.

Factor	Magnitude of allowance for incorporation in Sensitivity Run	Reasoning behind choice of magnitude value in previous column
Blockage	As per *Appendix A*. Culverts and bridges blocked between 20% and 90% Plus blockage in Black Creek downstream of Wallaceville Road.	The proportion of blockage allocated for each of the structures represents an engineering judgement on the likely behaviour of the system in a large flood event. This judgement has been informed by the type and size (shape/height/length) of structure. A greater proportion of blockage expected at culverts compared to large bridges. The Mangaroa catchment is rural and the channel is heavily vegetated along many of the reaches, The potential for mobilisation of this vegetation (and subsequent structure blockage) in a large flood event is therefore a significant hazard in this catchment. A comparison of the downstream hydrograph for blockage vs no blockage situation will be undertaken.
Manning's	Increase	Due to lack of good calibration of the model against

'n'	floodplain and in-channel Manning's n value by 25%	flows/levels throughout the catchment, +25% is appropriate for capturing the level of uncertainty associated with the choice of Manning's 'n' value in this particular model. 25% is slightly more conservative than the often-used 20%.
Hydrology	21%	As stated in the Mangaroa Hydraulic Modelling Report, the Flood Frequency Analysis undertaken in on the Te Marua gauge data (using full gauge record and EV1 Gumbels distribution) suggests 1% AEP flood event discharge (and associated uncertainty) of 355 ± 73 m^3/s. The proposed increase of 21% is of a similar magnitude to the IPPC High scenario allowance (an additional 24%)
Downstream boundary	100 year flow on the Hutt River coinciding with 100 year flow in Mangaroa.	This is a conservative approach which reflects the current uncertainty in understanding the probability/timing of a large flood on both rivers and associated tailwater effect on the lower reaches of the Mangaroa.
Combination run	Blockage as above PLUS +10% hydrology PLUS +10% Manning's	In reality, these factors may coincide and have inter-related effects.
Landslide/ Aggradation	No Sensitivity Run required,	Whilst landslide/aggradation are known potential hazards that could be subject to inclusion in a Sensitivity Run, it has been determined that such runs will not be undertaken as part of the Mangaroa Hazard Mapping as their effect will be accounted for in the blockage Sensitivity Run.

B. Produce an output which captures the effect of these hazard factors on the flood risk.

As detailed above, there will be a total of 5 sensitivity runs. The results will be *combined* to produce a Peak Hazard Sensitivity Output representing the worst case from each of the Sensitivity Runs over the catchment. Note this output is not produced by adding all the individual maximum depth result grids; rather, the worst result at each cell in the model will be taken. This reflects the fact that the most influential hazard factor from the list above will vary spatially throughout the catchment.

C. Identify a freeboard which captures factors that are not represented in the model and cannot be accounted for through hazard sensitivity modelling.

This freeboard should be included in the map-producing process. Based on discussion in the Workshop and subsequent research, the following factors have been considered and an appropriate magnitude of freeboard presented.

Factor	Reasoning
LiDAR	LiDAR is generally accepted to have an accuracy of approximately ±100 mm in open, un-vegetated areas. However, the potential for inaccuracy is higher in areas of dense vegetation and at thin linear features e.g. narrow channels. The apparent inaccuracy of the LiDAR data in a key vegetated floodplain flow path location within the Mangaroa catchment has been highlighted in the Mangaroa Hydraulic Modelling Report; the current version of the model has an area in which raw LiDAR data has been smoothed to remove inaccuracies in the LiDAR.
Cross section survey	The survey used to construct the Mangaroa model includes all structures and the open channel sections are typically approximately 300 m apart. This is a typical resolution of survey for a model of this nature and should be sufficient to capture the key geometric variables influencing hydraulic behaviour under flooding conditions. There may, however, be some reaches of the channel between cross section locations whose geometry has a local influence that will not be captured in the model.
Wave effects arising from uneven floodplain surface or from cars driving through floodwater	This is a known phenomenon which has been reported in the Wellington region during recent flood events. Magnitude is hard to measure and effects are localised. Over a wide area +100 mm is considered appropriate.
Hydrodynamic Action	The localised increase in flooding depth on the upstream side of building on a floodplain, as has been observed in numerous steep catchments across the Wellington region (e.g. Waikanae). Magnitude is velocity dependant, however, values of 100-300 mm are typical.
Superelevation	A method of estimating the rise in water surface elevation relative to normal water level due to superelevation at bends is presented in the WRc Fluvial Freeboard Guidance Note (i.e. UK freeboard best practice guidance). This has been applied on bends on the Mangaroa and super elevations of between 100-200 mm were calculated.

Consideration of each of these factors as presented above indicates that **a freeboard of 300 mm** is appropriate. This value represents a best engineering judgement in the absence of a formal prescriptive methodology for calculating a single freeboard magnitude from a range of factors of this nature. The engineering judgement was informed with consideration to the purpose of the maps for which freeboard is being derived; that is, as maps to inform the planning process and allow the hazard associated with fluvial flooding to be accounted for in planning decision making.

A potential approach would be to add all of the uncertainty magnitudes for each of the factors identified (e.g. 200mm for superelevation + 200 mm for hydrodynamic action + 100 mm for LiDAR etc) however this is considered to be an overly conservative approach which effectively represents a situation whereby the uncertainty associated with all of the factors uniformly affects the catchment across its whole area. This is not reflective of reality, as it is known for example that Superelevation effects are generally restricted to river bends, and Hydrodynamic Action primarily affects the area immediately surrounding building walls.

A more realistic scenario is that at any one point in the catchment, the uncertainty associated with 3 or 4 of the above 5 factors is having a potential impact on the modelling results. As such, 300 mm is an appropriate freeboard magnitude to use.

D. Incorporate the freeboard magnitude above into the mapping process.

The 300 mm freeboard from Section C will be added to the Peak Hazard Sensitivity Output from Section B to produce a hazard map.

It was agreed in the Workshop that a modelling approach will be used to achieve this through using initial conditions representing the freeboard in the model. Note that there is a need to take care to ensure an appropriate run time is used when 'modelling' the freeboard. Run time should be sufficient to let the water spread out and capture the impact of hazard in one cell on those elsewhere, however, too long a run time can result in 'over' routing and artificial build up behind structures. A sensibility check on the results will be undertaken.

It was discussed in the Workshop that whilst there are some disadvantages to this approach (e.g. associated with applying a total volume of water into the model and routing this through the system), this approach does have advantages over the more traditional mapping approach in which freeboard is added through contouring. These advantages include the usefulness of an output raster grid with values at all locations throughout the modelled catchment; and the ability to capture the decreasing hazard at the floodplain fringes compared to the floodplain immediately adjacent to the channel.

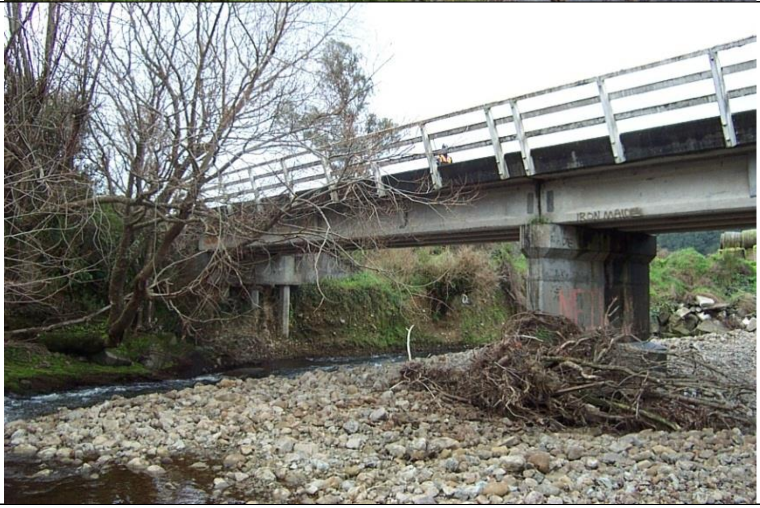
Appendix A

ID	Structure name	Proportion blocked in Blockage Sensitivity Run	Photo
1	Bridge 913 Whitemans Valley Road	20%	

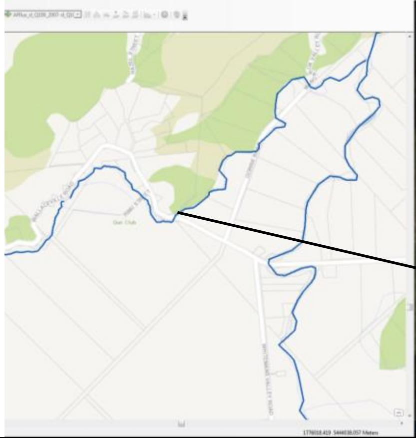
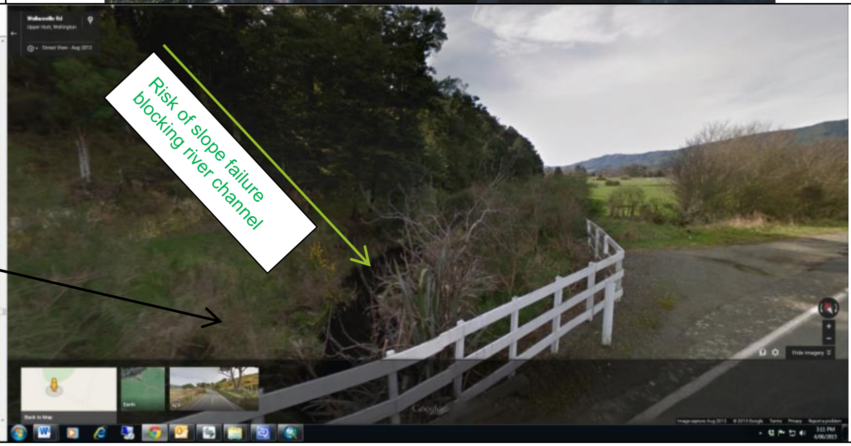
2	Whitemans Valley Road Bridge	50%	
3	#13 Russel Road	90%	

4	Whitemans Valley Trib Stream Bridge	90%	

5	Bridge 750 Whitemans Valley Road	20%	
6	Bridge 408 Whitemans Valley Road	20%	

7	Bridge Whitemans Valley Road	20%	
8	Bridge Mangaroa Valey Road	20%	

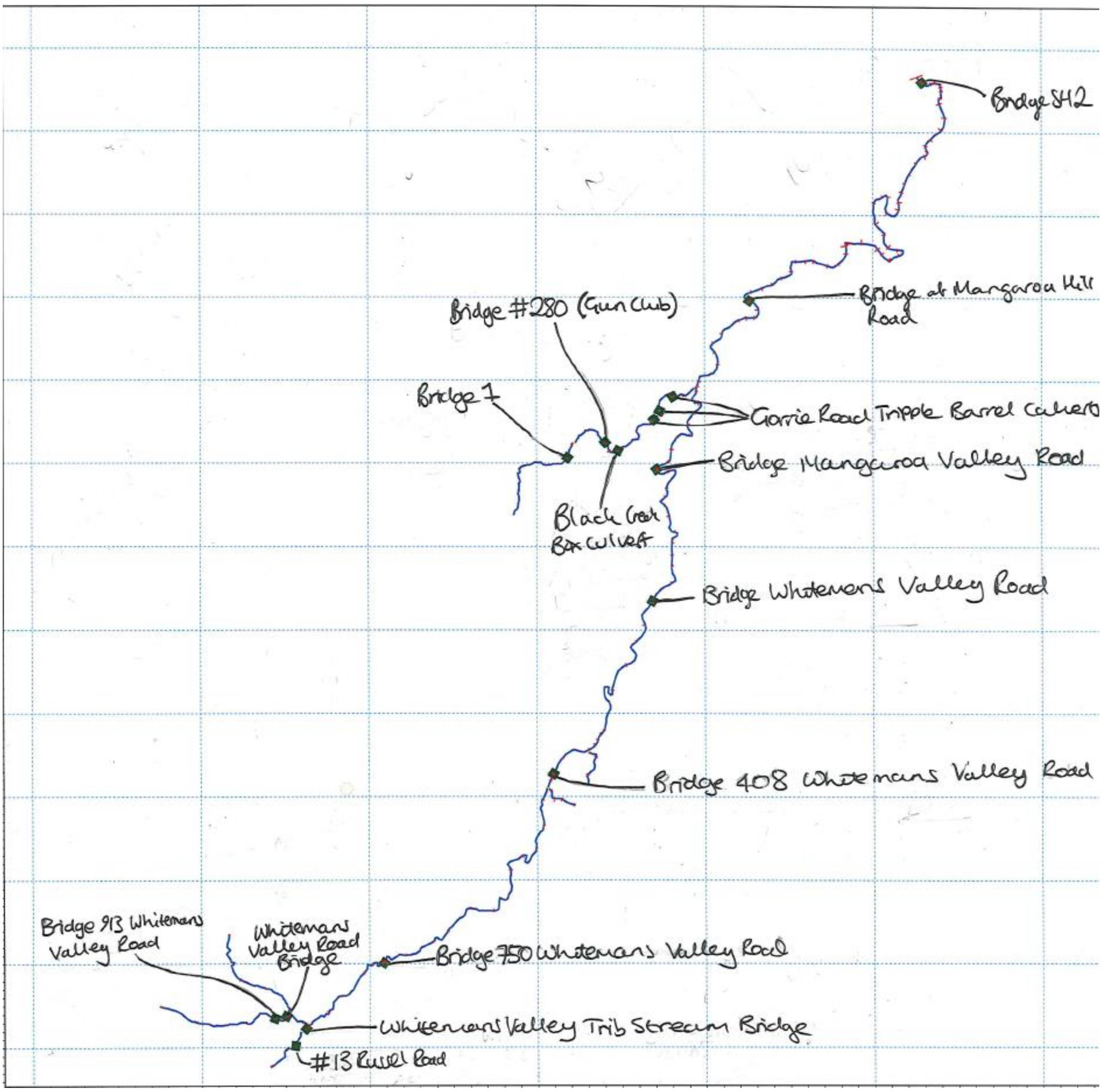
9	Bridge 1	50%	
10	Bridge #280 (Gun Club)	50%	

11	Black Creek Box culvert	50%	
	Blockage in Black Creek downstream of Wallaceville Road.		

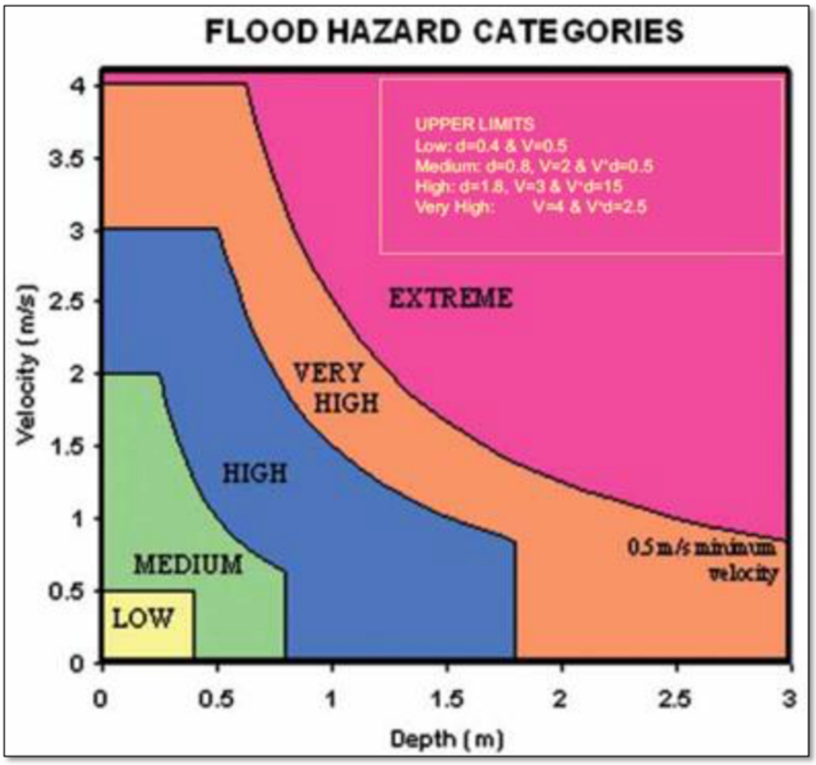
12	Gorrie Road triple barrel culvert 1	90%		
13	Gorrie Road triple barrel culvert 2	90%		

14	Gorrie Road triple barrel culvert 2 (# 85)	90%	
15	Bridge at Mangaroa Hill Road	20%	

16	Bridge SH2	20%	


Bridge SH2
Bridge at Mangaroa Hill Road
Bridge #280 (Gun Club)
Bridge 7
Gorrie Road Tripple Barrel Culverts
Bridge Mangaroa Valley Road
Black Creek Box Culvert
Bridge Whitemans Valley Road
Bridge 408 Whitemans Valley Road
Bridge 913 Whitemans Valley Road
Whitemans Valley Road Bridge
Bridge 750 Whitemans Valley Road
Whitemans Valley Trib Stream Bridge
#13 Russel Road

Annex 3 – Definition of Flood Hazard Relating to Depth and Velocity (FEMA – Guidance for Flood Risk Analysis and Mapping – Flood Depth and Analysis Grids)



Flood Severity	Depth x Velocity Range (m^2/s)
Low	< 0.2
Medium	0.2 – 0.5
High	0.5 – 1.5
Very High	1.5 – 2.5
Extreme	> 2.5