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

Supplementary Evidence of MICHAEL CHARLES LAW

19 October 2017

Introduction and scope

1. My full name is Michael Charles Law. I am the Senior Associate - Water Resources at Beca. My qualifications and experience are provided in my Evidence-in-Chief (evidence) dated 30 August 2017.

2. 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.

3. I confirm that the statements made in this Supplementary 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.

4. The scope of this Supplementary Evidence is to respond to:

   (a) Questions and issues raised by the Commissioner. These include:

      (i) Questions listed in Annexure 1 of the *Minute 2 of Commissioner*.[1]

      (ii) Issues raised by the Commissioner verbally during verbal representations by Submitters at the Hearing

   (b) Written and verbal submissions presented at the hearing

5. I also provide a response to the Evidence-in-Chief submitted by Mr Robert Hall on Tuesday 26 September 2017, noting that it is unfortunate that a meeting of experts was not achieved prior, or during, the hearing.

6. The structure of this interim Supplementary Evidence is that I have considered each issue raised in turn; providing answers or additional information. Where appropriate, I have referenced the relevant paragraphs of my, or others, evidence.

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[1] ***Upper Hutt City Council, Proposed Plan Change 42, Mangaroa And Pinehaven Flood Hazard Extents, Minute 2 Of Commissioner***. Received by UHCC, 3 October 2017

Questions from the Commissioner

Annexure 1 of Minute 2 of Commissioner

7. The Commissioner provided a list of questions as Annexure 1 of his *Minute 2 of Commissioner*. Below I have provided responses to the relevant Questions 13, 14, 15, 17, 18, 19, and 21. The questions posed by the Commissioner are bold italicised, while my responses are non-italicised

8. ***Question 13. Mr Law to provide written update of minor corrections to his evidence in chief (at paragraphs 53 and 62).***

9. In paragraph 53 of my evidence in chief, I incorrectly stated the areas of the catchment where freeboard depths of 300 mm and 500 mm had been applied as part of GWRC's flood hazard mapping of the Pinehaven catchment. Paragraph 53 should have read as follows (underlined text indicates the revised part of the paragraph)

> *For the Pinehaven catchment, freeboard has been applied by increasing flood levels by 300mm <u>for the majority of the Pinehaven catchment, with the exception of the reach between Pinehaven Reserve and the bypass channel at Whitemans Road where the freeboard of 500mm was applied</u>. These increases in flood level are reflected in an increase in flood extent. The difference in freeboard depths 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.*

10. The word "show" is missing from the third line of Paragraph 62 of my Evidence-in-Chief. The paragraph should read (with the added word underlined).

> *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 <u>show</u> 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.*

11. Neither of these corrections change the conclusions of my evidence.

12. ***Question 14. Mr Law to obtain peak flow volumes from GWRC for 1:25 and 1:100-year events.***

13. As part of the 2015 audit, GWRC and Jacobs provided me with the MIKE FLOOD model files. These included the MIKE 11 boundary (.bnd) files that contained the flow hydrographs used in the flood model.

14. The flood model was run with for the 5, 10, 20, 50, and 100-year ARI[2] storm events without allowing for climate change, and the 100-year ARI storm events with climate change. As such, flows for the '1:25-year event' are not available. In lieu of that, I have provided the 20-year ARI peak flows in Table 1, as well as the 100-year peak flows with and without climate change. In all cases, the peak flows provided are for the current development situation, as that is the baseline.

15. Figure 1 (Figure 7 in SKM's report[3]) shows the location of each sub-catchment.

Table 1 – Peak flows (m^3/s)

Sub-catchment	No allowance for climate change		100-year ARI with climate change
	20-year ARI	100-year ARI	
A	1.883	2.258	2.534
B	2.312	2.751	3.071
C	1.191	1.430	1.606
D	1.590	1.905	2.136
E	1.667	2.000	2.250
F	2.043	2.434	2.718
G	1.320	1.582	1.776
H	1.403	1.684	1.893
I	0.685	0.843	0.964
J	1.112	1.342	1.514
K	1.215	1.455	1.636
L	0.890	1.079	1.221
M	0.543	0.666	0.762
N	0.621	0.765	0.876
O[4]	*0.380*	*0.465*	1.196

16. I can confirm that the 100-year peak flows in Table 1 are the same as used in GWRC's MIKE FLOOD model and as provided by Alistair Allan (GWRC) to Mr Christensen during the PC42 Hearing. Only the 100-year ARI plus climate change (100CC) scenario is relevant to the preparation of the PC42 flood hazard maps.

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[2] ARI = Average Recurrence Interval

[3] ***Pinehaven Stream Flood Hazard Assessment – Flood Hazard Investigation Report: Volume 1***, Revision E, SKM (now Jacobs) for GWRC. 25 May 2010

[4] The 20 and 100-year peak flows for sub-catchment O without climate change maybe not be accurate when compared to the neighbouring sub-catchments M and N.. However, this is not an issue for PC42 as the 100-year with climate change peak flow is correct (showing a similar catchment response to sub-catchments M and N), and it is this flow that has been used in the modelling scenario that underlies the PC42 flood hazard maps.

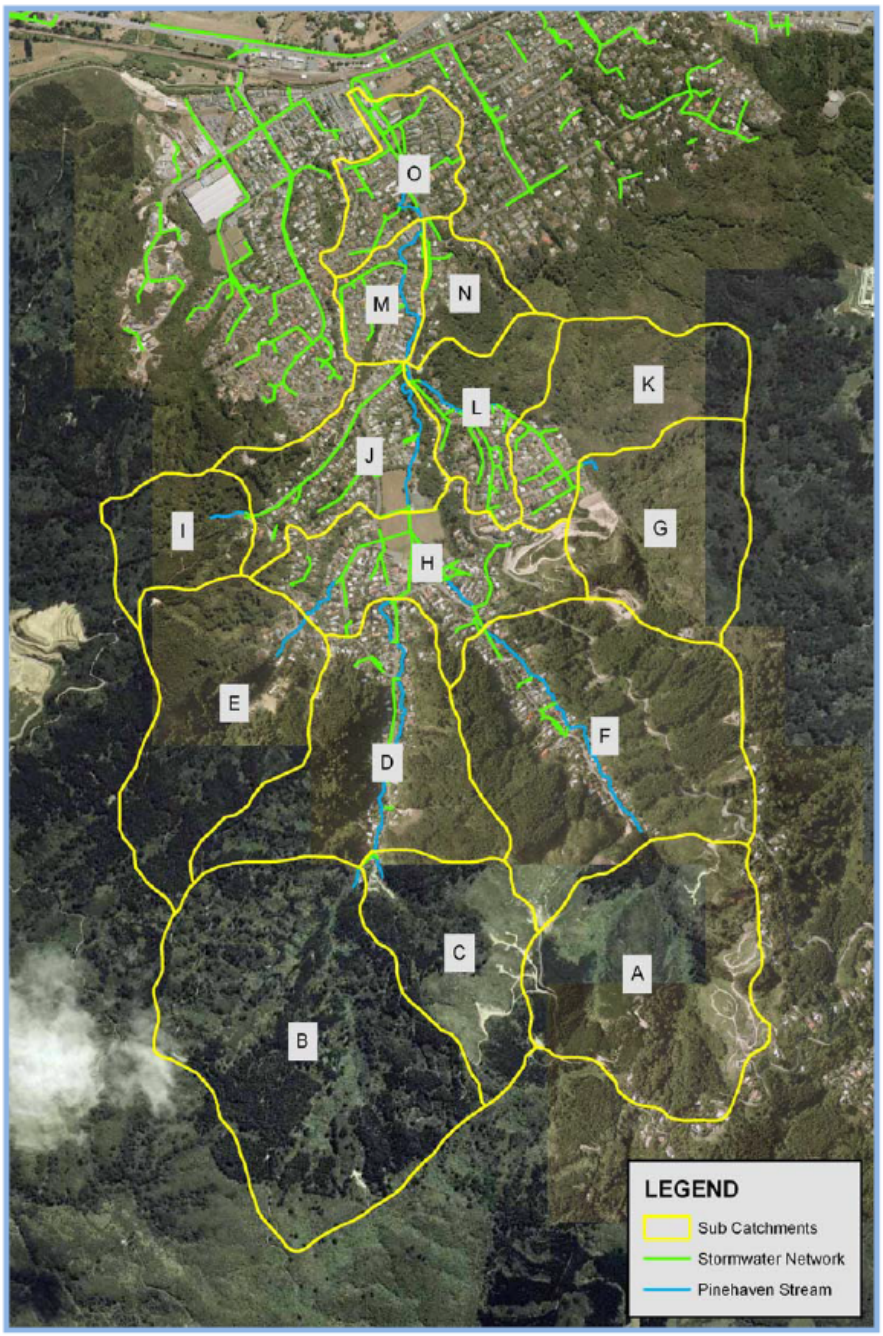

Figure 1. Pinehaven sub-catchments

17. ***Question 15. Mr Law / Mr Christensen to discuss the running of the 1976 flood event as a test scenario in the flood model.***

18. Pages 23 to 25 of SKM's report describe a section titled *Comparison to Observed 1976 Flood Extents*. This describes a model run undertaken to compare modelled flood extents to eye witness accounts and photographs from the 1976 event. The model files are available. SKM confirmed on page 23 of the report that they removed the post-1976 bypass structures from the model. Figure 2 replicates Figure 14 of the SKM report, which shows the 1976 modelled and approximate flood extents.

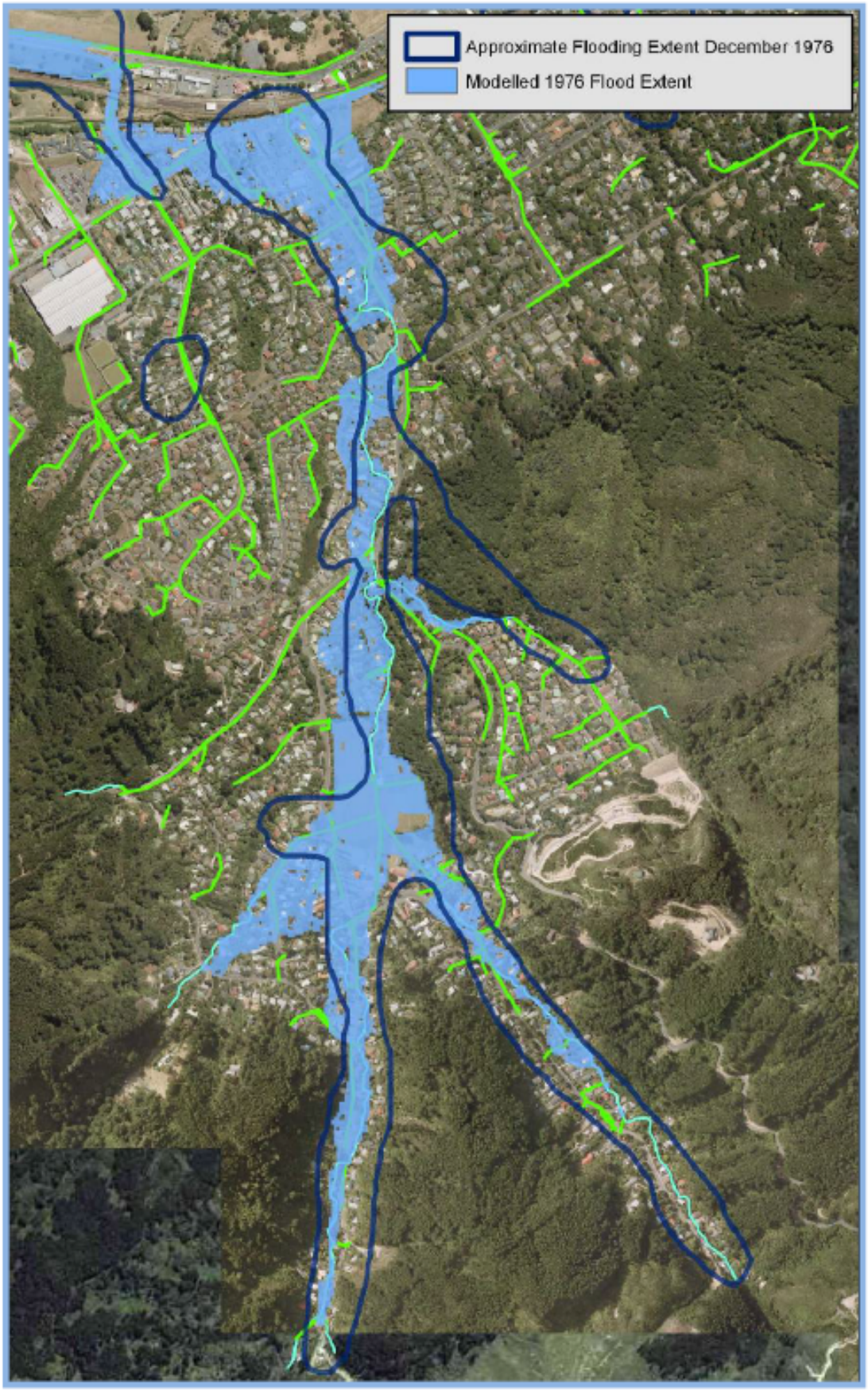

Figure 2. Comparison of 1976 modelled and approximate flood extents

19. The conclusion of SKM's modelling of the 1976 event was that:

> *"Overall the predicted flooding extents match well with the observed 1976 flooding. Where there are anomalies they can be explained by either the conversion of the paper records of the flooding into an electronic GIS layer or by the influence of blockages. The model results as shown in Figure 14 do not take into account the blockages of structures or sediment/debris movement along the channel which are known to occur in the 1976 event. Due to a lack of information on the location of the blockages they were not included in the analysis of this event."*[5]

20. So in answer to the Commissioner's question, the 1976 event was used to assist in the calibration of the model. However, as SKM acknowledge, there are differences between the modelled and observed/approximate flood extents. SKM put this difference down to the quality of records from 1976, and their decision not to include debris blockages in the model.

21. While modelling historic flood events to calibrate a model is good practice, it also presents difficulties:

    (a) The model geometry (channels, crossings, obstructions, structures, development, etc.) must reflect the situation at the time of the historic event; in this case 1976.

    (b) Ideally good quality rainfall and flow data will be available to provide the correct hydrological inputs to the model. There was (and is) no flow recorder in the Pinehaven catchment and (as I explain in Paragraph 64), there was limited rainfall information for the catchment during the 1976 event.

    (c) Eye-witness accounts are useful, but can be selective or not representative of the peak of the flood.

    (d) Every flood event is different:

        (i) Rainfall patterns don't follow 'design event' profiles or vary across the catchment

        (ii) Debris and blockages occur at some (but not all) structures, though all may be at similar risk of blockage.

        (iii) Downstream conditions vary; affecting the backwater or ponding effects in the lower catchment.

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[5] Page 25, ***Pinehaven Stream Flood Hazard Assessment – Flood Hazard Investigation Report: Volume 1***, Revision E, SKM (now Jacobs) for GWRC. 25 May 2010

22. It is therefore necessary to weigh the benefits of calibrating using historic flood events against the difficulties in representing the conditions at the time. This is especially true where there is a long time between the event and the calibration modelling; 33 years in the case of the 1976 Pinehaven flood event.

23. ***Question 17. To what extent has potential urban development in the 'Southern Hills Growth Area' (and associated increased runoff) been considered in the flood modelling underpinning PC42? If the level of growth turns out to be more intense than predicted, what will the result be?***

24. It is important to clarify that the effect of runoff from development in the Southern Hills Growth Area (SHGA) is addressed and managed through the site specific hydraulic neutrality provisions proposed in the plan change. The PC42 flood hazard maps are based on modelling of current levels of development plus an allowance for the potential effects of climate change on stream flows. Therefore, if the level of growth is more intense than predicted, there will be no change to the flood extent identified on the PC42 flood hazard maps.

25. As such, the potential urban development in the 'Southern Hills Growth Area' is not part of the flood modelling scenario that underpins PC42 flood hazard maps, rather the current development modelling results are the baseline against which the effects of future development will be assessed and managed.

26. From my experience of flood and stormwater modelling for developers and regulators, the effect on downstream properties is a standard test for the acceptability of the effects of development, and the proposal to limit runoff to 80% of peak pre-development flows is the primary means in PC42 to protect downstream properties.

27. ***Question 18. What provisions currently apply to the Southern Growth Area in the District Plan and what level of subdivision and development is anticipated (based on activity standards)? If the area was subject to a plan change or resource consent to intensify/urbanise, would drainage and flooding be a material consideration for determining such a proposal? If those effects are assessed as being significant on properties downstream, could the proposal be rejected? Is there a potential scenario where such a future proposal would entail amendment to the flood extent maps?***

28. Primarily, this is a planning question, and so I will defer to Mr Osborne and Mr Beban to respond to the specific planning provisions in PC42 and how they will be implemented.

29. ***Question 19. Related to the previous questions, is there any preliminary indication as to what extent would any structural works in the Pinehaven Stream be likely to mitigate increased runoff from future development in the Pinehaven Catchment and/or improve existing drainage?***

30. The proposed structural works within the Pinehaven catchment are described in Greater Wellington Regional Council's Floodplain Management Plan. The purpose of these works is to 'improve existing drainage' within the catchment, accounting for current levels of development and potential increases in flows as a result of climate change.

31. It is not the intention that the proposed works mitigate increased runoff from future development, which will be mitigated within the development boundary through the hydraulic neutrality requirements as proposed by the plan change.

32. ***Question 21. Mr Law to provide some explanation as to why the flood extent maps discussed in Mr Hall's evidence for 27 Elmslie Road are materially different to the PC42 flood extent area.***

33. In considering the differences between the PC42 flood hazard map extents and the flood extents and depths provided in Mr Hall's evidence, I concur with Mr Christensen's supplementary evidence paragraphs 14 to 18 regarding catchment scale modelling of the Mangaroa catchment. The same applies for the Pinehaven model. Flood extent differences are quite possible when detailed site-specific survey and alternative hydraulic analysis are used, in comparison to catchment-wide flood modelling and mapping. This is the case for 27 Elmslie Road.

34. For Mr Hall's modelling, a detailed ground model of one property has been combined with a simple approach to the hydrological inputs. When undertaking flood modelling for a site, it is required practice to account for hydraulic conditions upstream and downstream of the site that can affect flow routes, water depths and flood extents at the site.

35. Mr Hall's modelling does not appear to account for upstream and downstream conditions, which in this case could include water leaving the stream upstream of the site due to channel constraints or blockage, or downstream effects such as backing up of water from constrictions or blockages. GWRC's catchment-wide model does consider upstream and downstream influences on flooding.

36. Mr Hall's modelling does not account for fences or building obstructions that have the potential to divert or obstruct flow. These uncertainties are accommodated in the application of freeboard to modelled flood levels.

37. Mr Pattinson noted differences in the GWRC modelled channel alignment and his surveyed stream location at 27 Elmslie Road. This is due to interpolation between GWRC's surveyed cross-sections that don't pick up the sinuosity of the stream as it meanders through properties. As I noted in my 2015 audit, the distances between channel cross-sections in the upper reaches of the streams (such as along Elmslie Road) are longer than ideal, but that this understandable as the streams flow through or behind private properties where access can be an issue. However, I am comfortable that this is undertaken to an appropriate standard to inform the flood hazard extents for PC42.

38. For GWRC's Pinehaven flood modelling, the use of a 5m grid for the 2D flood model elements aligns with acceptable practice in New Zealand, which provides more accurate definition of floodplain inundation and flow paths than the simple 1D undertaken by Mr Hall.

39. So at the site-specific scale, I am not surprised that there are differences between GWRC's modelled flood extents and a simple assessment at a site specific level. However, I reiterate that the Pinehaven flood modelling was undertaken to industry standard practice, using appropriate software, and that the PC42 flood hazard maps generated from the results of the modelling are fit for purpose.

40. I provide additional comments on Mr Hall's evidence-in-chief later in this supplementary evidence.

Issues raised by the Commissioner verbally during the Hearing

41. During the Hearing, the Commissioner raised other questions and issues that he indicated at the time required a response. In paragraphs 42 to 74, I expand on my verbal response delivered on the final day of the Hearing; covering:

    (a) Flood modelling;

    (b) Purpose of the flood maps; and

    (c) Future Development and Hydraulic Neutrality

    (d) Freeboard

    (e) Climate change

Flood modelling

42. The Commissioner asked whether there is any reason to re-address the flood modelling. In responding to this query, I will also comment on the 2005 ***Pinehaven 100 year Flood Map*** (Figure 3) presented by Mrs Nicholson at the Hearing

43. I do not believe that there is a need to re-model the Pinehaven catchment. The hydrological and hydraulic flood modelling was undertaken using industry standard modelling software and methods. The inputs, parameters, and assumptions were appropriate to the catchment wide scale of the model.

44. I refer the Commissioner to my 2015 audit report of the Pinehaven flood modelling and mapping, as this provides a tabulated review of the components of the flood model. The report is provided as an appendix to Volume 1 of the Pinehaven Flood Management Plan, and includes a copy of the Terms of Reference for the audit. I trust that the audit report will answer the Commissioner's questions about model variables, including roughness.

45. I can confirm that the structural improvements to the Pinehaven stream channels of the 1980's have been incorporated in GWRC's flood model.

46. I wish to point out that the audit was independent, and that I had not undertaken any work for Greater Wellington Regional Council before they appointed me to do the audit.

47. At the Hearing, Mrs Nicholson presented the ***Pinehaven 100 Year Flood Map*** (Figure 3), and asked why that flood map could differ from the PC42 flood hazard maps if the same software had been used. The map is provided as an attachment to a preliminary ***Pinehaven Stormwater Management Study*** report[6] (2005 report) dated 4 August 2005 for Upper Hutt City Council. The report provides a concise summary of the catchment's flood history and issues following the 1976 flood and the programme and costing for implementing a Floodplain Management Plan for Pinehaven.

48. There are only two references in the 2005 report that indicate the provenance of the flood map for the modelling that underlies the Pinehaven 100 year Flood Map. These are:

(a) 4th paragraph of Section 3 (page 4)

"UHCC has implemented ongoing investigations and stormwater catchment studies in Pinehaven area and obtained a thorough understanding of the nature of local stream and existing stormwater system performance. In addition, stormwater system model and flood maps have been developed for the entire city. UHCC will continue further investigations and upgrading the model and floodplain study together with GWRC"

(b) 4th Bullet point of Phase 1 Technical Investigations and Tasks in Section 4.1 (page 8)

"Hydraulic Modelling: review and update the existing MIKE 11 Model. Upgrade the model to 2D (MIKE Flood) for Pinehaven catchments, calibrate and verify the Model. Determine boundary conditions for design floods and simulate the Model."

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[6] http://www.gw.govt.nz/assets/council-reports/Report_PDFs/2005_626_3_Attachment.pdf

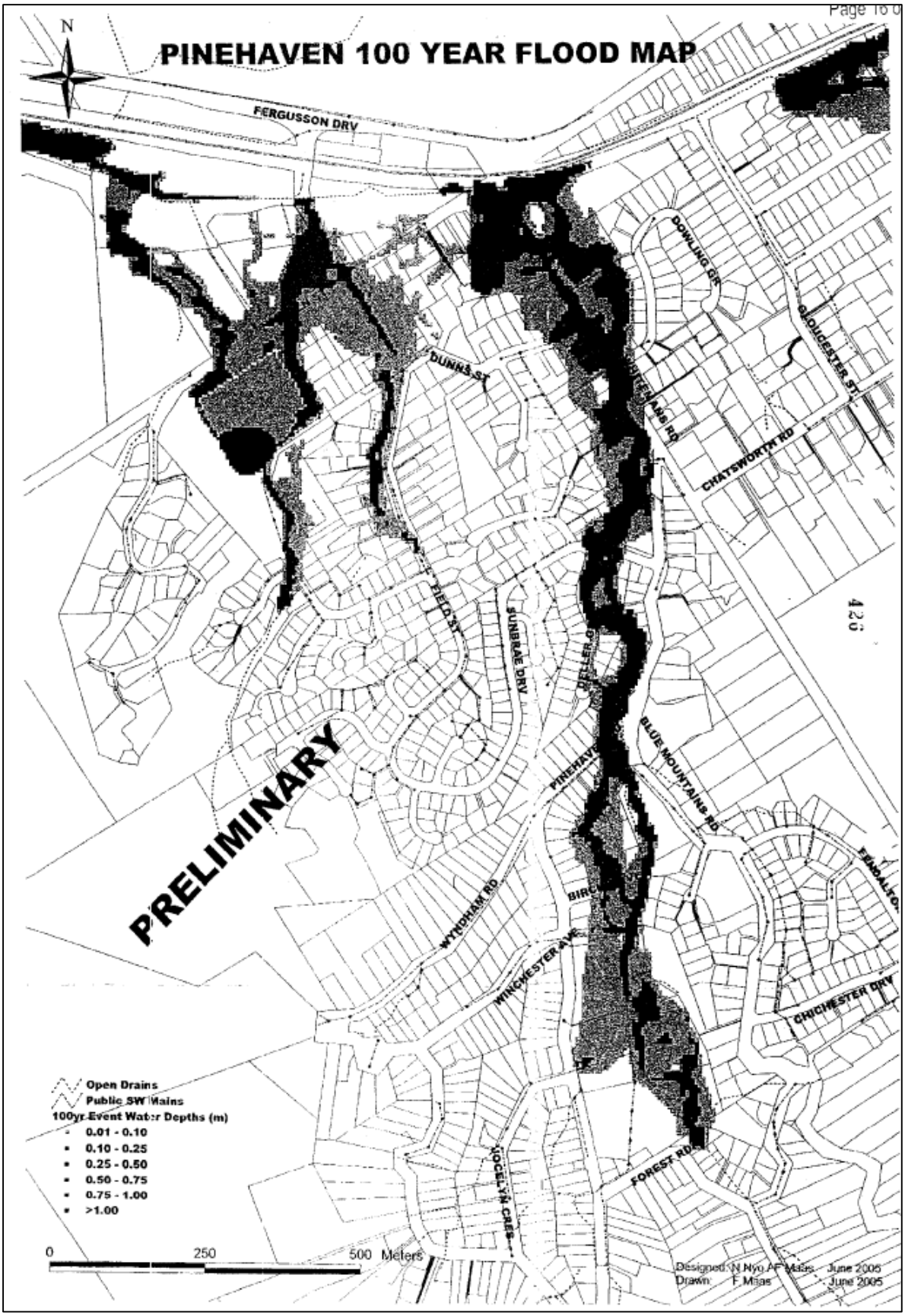

Figure 3. 2005 Pinehaven 100 Year Flood Map

49. These two extracts from the 2005 report indicate to me that the Pinehaven 100 year Flood Map (Figure 3) was derived from the outputs of an existing 1D MIKE 11 model. A 1D model only uses cross-sections to represent flow along the stream cannel and flood plains. It is not possible with a 1D model to readily represent overland flow routes on the floodplain, and hence the proposal to upgrade the model to include 2D elements. 2D modelling became more common and accessible through the mid-2000s with its inclusion in commercially available flood modelling software (such as MIKE by DHI) and developments in computer processing power and speed.

50. The 2005 report does not provide any information on the hydrological inputs (rainfall and/or flow) to the 1D model, cross-sections (spacing and extent), structures, channel/floodplain roughness, or other parameters that will affect the derivation of the flood depths and extents. It is not known whether any allowance is made for climate change or debris blockage.

51. The extent of the catchment shown in Figure 3 suggests that the 1D model did not extend upstream of Pinehaven Reserve; omitting the streams along Upper Pinehaven Road, Elmslie Road, Wyndham Road, and Fendalton Crescent.

52. GWRC's current Pinehaven flood model is a coupled 1D/2D MIKE Flood model, and represents standard industry practice.

53. Therefore, the likely reasons for the difference between the 2005 Pinehaven 100 Year Flood Map and the amended PC42 flood hazard maps include:

    (a) Better definition of floodplains in the PC42 maps due to the upgrade to include 2D elements in the model.

    (b) Extension of the model to include the upper catchments

    (c) Potential differences between the models in the number and spacing of cross-sections, number and dimensions of culverts and bridges included in the model, how informal private structures have been accounted for, other model inputs such as channel/floodplain roughness.

    (d) Inclusion (or otherwise) of climate change, full or partial blockage of structures, and freeboard.

54. As such it is not unexpected that there are differences between the 2005 Pinehaven 100 Year Flood Map and the amended PC42 flood hazard maps.

Purpose of the Flood Maps

55. The Commissioner has asked about the purpose of the flood hazard maps, and drew attention to Paragraph 42 of my evidence, where I stated

"…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."

56. To confirm; all the Pinehaven flood maps produced for GWRC and UHCC are derived from the same flood model, but different information can be displayed on maps generated from that model. The flood extents can be displayed:

    (a) With freeboard (PC42 flood hazard maps) or without (1976 modelled outline shown in Figure 2); and with

    (b) Outlines to delineate zones for implementation of policy (such as the PC42 maps), or provide detailed information on flood depths, or high-medium-low flood hazard.

57. I expanded on this in my 2015 audit report with respect to GWRC's flood mapping) and the information presented in paragraphs 45-48 of my evidence-in-chief. However, I reiterate that the level of detail provided on the PC42 flood hazard maps is appropriate for delivering the provisions of PC42.

Future Development and Hydraulic Neutrality

58. How the flood maps are used, and what they should show, leads into the discussion on the modelling of proposed future development upstream and the effectiveness of the hydraulic neutrality provisions in PC42. These were raised as major concerns by some submitters.

59. The Commissioner requested that I expand on paragraphs 60-61 of my evidence-in-chief, where I consider future development. However, as future development and hydraulic neutrality are linked, I will also refer to paragraphs 62-69 of my evidence-in-chief.

60. Most submitters are concerned that the flood maps incorporating freeboard will not protect them from the effects of upstream development. It's important to clarify that the impact from future development will be managed through the hydraulic neutrality provisions in PC42, not through the flood extent maps.

61. That is, any proposal in the upper catchment will have to demonstrate that *peak flows* from the outlet of the development is no more than 80% of current (pre-development) peak flows, and no greater than current peak flows further down the catchment. It will be a quantitative assessment of flows, not a comparison of flood extent with freeboard. As such it will not be possible to 'hide' the effects of development on peak flows, but rather used to protect downstream communities from increased flood risk.

1976 Pinehaven flood event

62. The Commissioner asked about the relationship between eye-witness accounts of the 1976 flood, the 1976 flood outline, and the flood extents presented in the PC42 flood maps. As discussed in response to the Commissioner's Question 15, I have commented on GWRC's modelling of the 1976 flood event to help validate their catchment-wide flood model.

63. The '1976 flood' occurred as a result of a storm on 20 December 1976 that affected a swathe of the region between Upper Hutt and Wellington City. The Wellington Regional Water Board (WRWB) produced ***Report on Storm of 20 December, 1976*** (1976 Report), published in 1977, which collated and documented information relating to the storm and its effects.

64. Drawing on the limited rainfall information provided in the WRWB 1976 Report, I have concluded that the Average Recurrence Interval (ARI) for the 3-hour[7] rainfall over the Pinehaven catchment was slightly in excess of 100 years. The peak 3-hour rainfall is estimated[8] as 97 mm between 4am and 7am on the 20 December. In total about 300 mm of rain fell over the Pinehaven catchment in 24 hours, the majority being between 3am and 12 noon.

65. I can confirm that it is reasonable to consider the ARI of the 1976 storm to be 100 years, based on rainfall that has not been adjusted to account for climate change.

66. Furthermore, it is clear from reviewing section 3 of the 1976 report which documents the effect of the event on streams and adjacent areas that it is important the flood model includes provision for blockages in Pinehaven given previous issues where blockages exacerbated the flood hazard effect in the catchment. Section 3.1.2 relates specifically to the Pinehaven-Silverstream Area, and highlights;

    (a) *"Minor slips resulting in partial blockage of streams and culverts began occurring by 7 o'clock and before 9 o'clock several large slips had occurred in the Pinehaven and Elmslie Road areas, completely blocking culverts, filling stream channels, threatening houses in Pinehaven Road and half burying three houses in Elmslie Road.*

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[7] It is rainfall over 2-3 hours that generates the biggest flows in the Pinehaven catchment.

[8] 3-hour rainfall recorded at the Tasman Vaccine raingauge in the upper Makaroa was 65 mm (Figure 2.2.3, 1976 Report). Figure 2.2.4 of the 1976 Report indicates that 24-hour rainfall depths over the Pinehaven catchment were 300 mm, compared to 200 mm at the Tasman Vaccine gauge. Hence the 3-hour rainfall over the Pinehaven catchment was *65 x 1.5 = 97 mm*.

(b) *"At the same time, it is apparent (following an aerial inspection of the catchment) that further large slips occurred particularly in the catchment southeast of the end of Pinehaven Road, sending tons of debris down the channels. These earth movements resulted in any flood carrying structures downstream whose capacity was already exceeded, being rendered completely inoperative and the flood waters being forced to find the lowest point by flowing through private property, houses, across streets and finally back into the stream channel. The extent of the flooding is shown in Map I."*

(c) *"The principal areas of damage due to flooding and debris were Upper Pinehaven Road, Elmslie road, and the low area near the junction of Pinehaven and Blue Mountains Road.*

(d) *"It is apparent … that these slips caused debris dams in the catchment, some of which allowed water to build up behind them until such time as they were overtopped or gave way. This resulted in a surge of water and debris flowing down Pinehaven and Elmslie Roads causing, in the case of Elmslie Road, severe property damage."*[9]

67. Map I as referenced from the above report is reproduced above (Figure 4). The scale of the map and the hand-drawn nature of the flood outline suggest that the extent is indicative of areas affected. The map is not of an accuracy that could be used for model calibration nor is its methodology clear on how the extent was recorded, and therefore it is understandable that it does not align with eye-witness accounts of the 1976 flood.

68. Key points to draw out from Section 3.1.2 of the 1976 Report are:

(a) The time (6am) that flooding commences. This ties in with the critical storm duration for the catchment being 2-3 hours, as the intense rainfall started about 3am.

(b) The importance of slips, debris dams, and channel/structure blockage in exacerbating flood inundation and damage, especially along Pinehaven Road and Elmslie Road.

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[9] Pages 24 and 25, ***Report on Storm of 20 December, 1976***, Wellington Regional Water Board. Undated

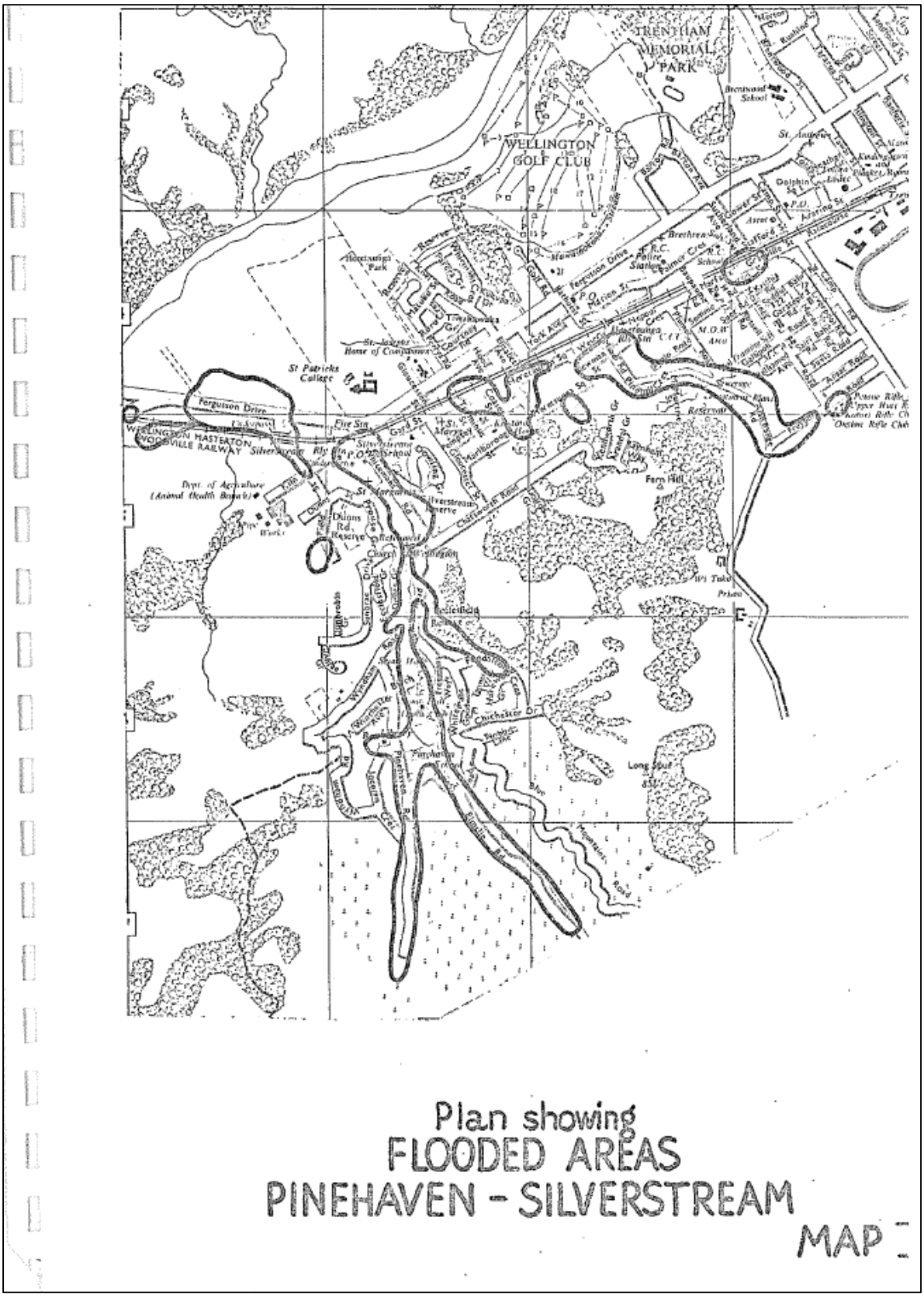

Figure 4. 1976 Report Map I showing flood Pinehaven-Silverstream flood extent

69. Figure 5 shows a well-publicised photograph of flooding at 47 Elmslie Road following the breach of a debris dam that had formed further up the catchment. It is the ongoing risk of this kind of unpredictable event that is partially accounted for by the inclusion of freeboard and culvert/bridge blockage in flood hazard maps.

70. Mr Pattinson and other submitters either commented about debris in the stream or concern regarding ongoing land use activities (such as logging) in the upper catchment that increases the availability of debris material and hence the risk of downstream damage and blockage. Having reviewed the blockage factors (against the ARR *Blockage of Hydraulic Structures*[10] guidelines) applied to the flood modelling, I am satisfied that blockage has been accounted for in an appropriate manner in the modelling.

Figure 5. Flooding at 47 Elmslie Road during the 1976 flood[11]

71. By modelling blockage, allowing for climate change, and accounting for uncertainty through the application of freeboard, it is not unexpected that the PC42 flood maps identify areas at risk that eyewitnesses did not record as inundated during the 1976 flood.

Freeboard

72. In paragraphs 19 to 33 of his supplementary evidence, Mr Christensen has addressed the application of freeboard in the Pinehaven and Mangaroa flood hazard maps, and with reference to practice around the country. I concur with the information that he has provided, including how the 100 mm depth was removed in the amended version of the flood hazard maps.

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[10] http://arr.ga.gov.au/revision-projects/project-list/projects/project-11

[11] http://www.radionz.co.nz/news/national/335943/councils-urged-to-avoid-building-on-flood-plains

Climate Change

73. In his submission at the Hearing, Mr Pattinson accused the council of scaremongering over climate change, and claimed that this included reference to sea level rise affecting Upper Hutt.

74. I can only comment on how climate change has been applied to the modelling for the Pinehaven catchment, and confirm that it included an allowance for increased rainfall and no consideration of sea level rise, given that the outlet from the catchment is not affected by sea level. The allowances made were in line with 2008 MfE guidance.

Response to Robert Hall's Evidence-In-Chief

75. Many of the issues raised by Mr Hall's Evidence-in-Chief (received on 26 September 2017) are addressed above in relation to questions raised directly, or indirectly, by the Commissioner. However, below I address some issues with reference to specific points in Mr Hall's evidence.

76. In the middle of Paragraph 11, Mr Hall requests that stream flows are provided with PC42, so as to provide a baseline against which the effects of future development can be assessed. These peak flows are provided in Table 1 above, in response to Question 14 from the Commissioner.

77. Pre- and post-development modelling at the outlets from the given proposed application site must be undertaken in accordance with the provisions of PC42 with regard to matching or reducing peak flows. Hydrological methods, inputs, and standards may be refined before development consents are sought, which could supersede the peak flows in Table 1. Therefore, I would not recommend the inclusion of the tabulated peak flows in PC42.

78. In Mr Hall's paragraphs 11, 12 and 21, Mr Hall comments on:

    (a) The inclusion of freeboard in the flood hazard maps

    (b) Showing flood hazard using a high-medium-low categorisation

    (c) Terminology (Ponding, overflow areas)

79. The evidences-in-chief and supplementary evidences of Mr Christensen and I have explained importance of freeboard in the PC42 flood hazard maps, confirmed that the terminology used on the maps is in line with terminology used elsewhere in the Greater Wellington region, described why it can be appropriate for flood maps to include different levels of information depending on the end use of the map.

80. I have not had the opportunity to discuss with Mr Hall his modelling (as summarised in paragraphs 19 and 27 of his evidence) of 27 Elmslie Road. It appears that while the ground model was based on a detailed survey undertaken by Mr Pattinson, the hydrological and hydraulic modelling was simple:

(a) Reference is made in Paragraph 27 to use of the simplistic Rational Method for calculating overland flows. This only provides a single peak flow. While it is appropriate for assessing the differences between pre- and post-development peak flows for small development areas, it does not provide the changes of flow over time that GWRC's model requires to assess the catchment-wide interaction of flows from the different sub-catchments.

(b) No information is provided as to what software or approach was used for the hydraulic modelling to derive flood depths and extents from the calculated flows.

(c) Very limited information is provided regarding the modelling parameters and inputs used.

(d) My understanding is that no account was taken of upstream and downstream factors (such as constrictions and blockage) that could affect flows and water levels at 27 Elmslie Road.

81. I am not aware that Mr Hall has had his modelling reviewed.

82. In Paragraph 22 of his evidence, Mr Hall refers to "M.Laws (SKM)". I assume that Mr Hall is referring to me; Michael Law of Beca Ltd. I have never worked for SKM or Jacobs. If I had done, I would not have undertaken the independent audit of the Pinehaven flood modelling and mapping for GWRC in 2015.

83. Later in the Paragraph 22, Mr Hall refers to "Becca". I assume that he means Beca, as this is part of a reference to my 2015 audit report.

84. In his Paragraph 24, Mr Hall's view is that fences, house platforms and other restrictions would make it "near impossible" for floodwaters to affect the berm at 27 Elmslie Road. Such obstructions can prevent inundation, but just as easily can exacerbate and divert flooding, as demonstrated by Figure 4; the 1976 photograph of 47 Elmslie Road.

Signed:

Michael Charles Law

Date: 19 October 2017