Alexander Ross - Expert Evidence

AK Ross Evidence 27_07_2020
2019-12-08_Pinehaven Stream flood event_CDA Drawings_Rev A
Alasdair Keane_Memo Pinehaven rainfall assessment for 08 December 2019 storm Graeme Horrell_review of RJ Hall & Assoc report 27_7_20
Graeme Horrell_Revised_Letter 2009 flood
Graeme Horrell_CV

Before Independent Hearings Commissioners

At Wellington

Under	The Resource Management Act 1991
In the matter of	Applications for resource consents, and a Notice of Requirement for a Designation by Wellington Water Limited on behalf of Upper Hutt City Council, for the construction, operation and maintenance of the structural flood mitigation works identified as the Pinehaven Stream Improvements Project

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Statement of Evidence of Alexander Keith Ross

Dated 27 July 2020

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Statement of Evidence of Alex Ross

1.0 Qualifications and Experience

1.1 My full name is Alexander Keith Ross.

1.2 At the time the applications for this project were prepared I was a resident on Pinehaven Road. I have lived there for 8 years.

1.3 I am a retired Civil Engineer with in excess of 40 years experience in Civil Engineering Works associated with Local Government.

I trained at Silsoe College in the United Kingdom (now part of Cranfield University) in Agricultural Engineering. I have a New Zealand Certificate in Civil Engineering issued in 1972, and was a Registered Engineering Associate from 1977. I was a member of the Institute of County Engineers, later Association of Local Government Engineers.

My relevant employment experience is detailed below.

I worked for the Hawke's Bay Catchment Board on flood protection and drainage Schemes for the Te Aute Swamp for the Waipa Rivers Board, and the flood protection and drainage scheme for Omaranui Swamp. I was also involved in taking hydrological measurements for the Board.

1.4 I was employed by Hauraki Plains County Council as Assistant County Engineer, where I was in charge of the design and construction of drainage schemes for three Land Drainage Boards.

1.5 I was employed by Egmont County Council as County Engineer for 13 years in charge of design and construction of all works including roads; stormwater; water supply both urban and rural; bridges and culverts.

1.6 After the 1989 Council restructuring I was employed by South Taranaki District Council as Technical Services Manager in charge of all design and contract works including stormwater and roading.

1.7 I joined Apex Consultants in 1999 as Quality Manager for the company and obtained AS/NZS ISO 9001:1994 certification for the company, which was later upgraded to ISO 9001:2000. During this time I wrote several activity management plans including the Stormwater Activity Management Plan for South Taranaki District Council.

1.8 I worked for six months on secondment to Rangitikei District Council as Asset Manager and reviewed their roading, water and wastewater asset management plans.

1.9 I also reviewed the Waitomo District Council asset management plans for water, wastewater, stormwater, and roading.

1.10 I retired in 2010.

1.11 My evidence relates to a Notice of Requirement ('**NOR**') for Designation and associated resource consent applications for the construction, operation and maintenance of the structural flood mitigation works identified as the Pinehaven Stream Improvements Project ('**the Project**'). Wellington Water Limited ('**WWL**') has lodged the resource consent applications and NOR on behalf of Upper Hutt City Council ('**UHCC**').

1.12 I am familiar with the area that the Project covers, and have been involved with the Project since it was notified to the public, and prior to that notification with Plan Change 42 by UHCC.

1.13 The data, information, facts and assumptions I have considered in forming my opinions are set out in my evidence to follow. The reasons for the opinions expressed are also set out in my evidence to follow.

2.0 Scope of evidence

2.1 My evidence addresses the following matters:

a History

b Infiltration

c Model Calibration

d Upper Reaches of Pinehaven Stream

e Hydrology Model

f Quality Assurance

g Economic Considerations

j Evidence from other witnesses.

3.0 History

3.1 On review of GWRC flood maps which showed my property underwater in a 0.1% AEP. My experience suggested the maps did not appear to be correct. I investigated further and found that not only was 300mm of freeboard shown as floodwater added to the flood maps as indistinguishable from flooding, also a 100mm depth of water and lower was shown as flooding.

3.2 In my experience freeboard is usually differentiated from flood waters and minimal water levels are not usually shown on flood maps as flooding. More investigation showed that the anticipated flood peak flow would have been handled by the existing stream channel and secondary flow in the road gutter. This showed, in my opinion that there was obviously something wrong in the GWRC calculations of peak flood flow.

3.3 For UHCC PC42 I submitted that UHCC should remove the 300mm freeboard shown as floodwater from the flood maps. I was relying on reason and common sense to prevail, unfortunately that did not happen and the flood maps were adopted despite numerous objections from residents. In hindsight mixing the Mangaroa and Pinehaven plan changes into one plan change "muddied the waters" so much that many of the arguments from my perspective appeared unclear to the Commissioner. This may have been deliberate strategy by UHCC in order to get the plan change adopted expediently.

3.4 The Pinehaven Stream works application is where WWL are acting as project managers for UHCC and GWRC seeking permission from UHCC and GWRC to carry out works designed by the consultants who also produced the flawed flood maps in the first place. The reports in relation to the Pinehaven Stream work were reviewed by the same reviewer [M. Law BECCA] who glossed over the fact that changing the infiltration from a green-field site to a proposed construction of 1600 houses made no difference to flood volumes.

3.5 The problem with the flood maps is the excess run off that the consultants have allocated to the forested and bush clad hills surrounding Pinehaven. These forested and bush clad hills make up about 80% of the catchment area. If the infiltration factor used in the GWRC calculations for their prediction of runoff is too low considerably more runoff will be predicted. *The model used 5 mm initial followed by 2 mm per hour for infiltration.*

3.6 I carried out infiltration tests in the forest and bush areas at the top of Pinehaven road in July 2019. Most (87%) tests gave results greater than 500mm per hour, which is detailed in the report I compiled ""Report on Infiltration Tests carried out on the Pinehaven Stream Catchment During July 2019" [attached at Appendix A]

4.0 Model Calibration

4.1 GWRC stated in their evidence (MWH Report) that they had calibrated their model to a surveyed debris line flood of between one to two year recurrence interval on 31 July 2008. *A very small flood* which has been scaled up to a 1 in 100 year flood *(a very Large Flood)* in order to produce the flood maps. This was updated later after a flood on 23 July 2009.

The MWH Report states
6.2.1 23 July 2009 Event
Recorded flow data for this flood event have been supplied by GWRC. The peak flow is extimated to be 8.8 m^3/s. It must be noted that due to the short period of record and lack of certainty about the conversion of high measured water levels to flow (rating curve), the 8.8 m^3/s estimate may be revised in the future when new information is available.

4.2 This model is 12 years out of date. To compound this error there have been several larger floods in the catchment and GWRC have not collected any flood data from them. GWRC have even removed a depth gauge from the catchment in 2013 thus loosing years of useful record.

4.3 Applicants response to a Section 92 request which shows reluctance to use the 8 December event to assist with calibrating / validating the model. The response is produced below:

from Page 35 Notified Officers Section 42A Report GWRC.

- The applicant responded that the 8 December 2019 event was a 1-in-30-year event for the two hour duration. Mr Law agreed with this.
- The applicant advised that there were no model outputs for a directly comparable flood, so they compared the flooding observations to the modelled 1-in-10-year and 1-in-100-year events as presented in the PSFMP.

Mr Law commented the focus of the assessment was on flood extents with no mention of flood levels along the stream. He considered that if post flood surveys of trash marks, flood photographs and anecdotal reports were conducted by the council's or WWL then they should have been compared to the modelled water levels. The applicant has advised that no post-flood surveys or trash markings were undertaken by WWL. Mr Law noted he was disappointed that there was no post-flood survey undertaken against which to calibrate the model.

Mr Law commented that the annotated maps appear to be overlain on the PSFMP maps, which hampers direct comparison (due to climate change allowances). He requested Jacobs run the Pinehaven model to provide a comparison with the December 2019 event. He noted this could be done with the December 2019 event hydrology, or (as that would be highly resource intensive) he later suggested it would be possible to use the 1-in-10-year with climate change design rainfall scenario which would be comparable to the December 2019 event. The applicant provided this to GWRC in the updated Flood Hazard Assessment on 15 June 2020, and it is discussed further in subsections (h) and (i) below.

· The applicant noted that the Pinehaven Stream flood model's hydrological method used the Initial Loss – Continuous Loss model to represent the infiltration capacity of the catchment, and the catchment had not been treated as 'bare'. This hydrological method used does not use a CN value, and there were some concerns raised by the way the back-calculation in Mr Hall's report (which formed part of submission 11) had been undertaken. Mr Law generally agreed with the applicant's comments. In relation to the validation of the model he considers the 8 December 2019 event provides an opportunity for additional detailed validation.

- The applicant did not consider that the hydrological input into the model needed to be re-done and model re-run and commented that '*the hydrological input to the model is from a calibrated and validated model of the rainfall-runoff processes in the catchment. While no model is perfect… MWH have demonstrated that the inputs to the hydraulic model are robust and suitable for the purposes of the Pinehaven Stream.*

4.4 The errors can be seen using the GWRC 10 year flood map and comparing it with a 25 year actual flood occurrence that happened on 8 December 2019. The flood extents should be a lot less in a 10 year storm than a 25 year storm even with an allowance for climate change. This is obviously not the case on the flood maps and the applicants are "mudding the waters" using climate change and water depths as low as 2mm as a strategy to obfuscate the issue.

4.5 The flood maps show that the runoff is greatly exaggerated and this is why GWRC stated that the Pinehaven Stream channel has less than a 1 in 5 year flood capacity instead of the 1 in 25 year storm capacity that much of the stream channel coped with on 8 December 2019.

4.6 As a result the WWL proposes to widen the stream channel, not just widen but triple the size. This is because the runoff modelled bears no resemblance to what actually occurs as evidenced by the flood of 8 December 2019.

4.7 If the stream works as proposed are constructed they will in reality be able to cope with much larger floods, certainly greater than a 1 in 50 year flood and probably as much as a 1 in 100 year flood.

4.8 However these benefits from the works will be masked by the flawed flood maps which will still show properties in the flood zone when the $40,000,000 to be spent by the Councils could show much larger benefits. Conversely, the cost of the work could be reduced if the stream works were sized for an actual 25 year flood plus climate change.

5.0 Upper Reaches of Pinehaven Stream

5.1 In the application it was stated that the Pinehaven Stream Flood Management Plan includes proposed structural works within the lower reaches of the Stream as well as in the upper catchment.

5.2 However, the residents now find out that no works are proposed in the upper catchment where there are several problems that need addressing. This despite the cost ballooning out from $10M to now over $40M when interest on loans is factored in. (See photograph attached).

5.3 I understand that GWRC is only responsible for the stream up to the Pinehaven Reserve. I assume this is why there is no work occurring to fix the problems in the upper catchment, as this part is controlled by UHCC. Yet

UHCC ratepayers bear the majority of the cost of the work in the lower reaches .

5.4 After submissions closed on 18 December 2019 the Applicants changed the design, designated areas and the modelled depth of flooding. It appears reasonable that this design work should have been carried out prior to any notification, so that residents and submitters know exactly what is proposed. Since 20 July 2020 submitters have had only a short time to re-evaluate all the changes. This short timeframe is unreasonable given the limited resources of the submitters compared to the Applicants.

6.0 Infiltration and Runoff

6.1 When rainfall falls on the land the resulting stormwater runoff depends on catchment characteristics, on land usage, on the degree of urbanisation etc. These factors also influence the amount of infiltration. Soils have varying capacities to infiltrate water. Influencing factors are soil type, degree of saturation and nature of ground cover. Activities that change the soil surface or alter its properties [e.g. compaction of soil during subdivision development] also have an effect.

6.2 The infiltration tests I undertook in July 2019 were to establish a reasonable estimate for the infiltration rate on the various land and soil types in the Pinehaven Catchment [refer Appendix A].

6.2.1 The infiltration test results show that existing pine forest and regenerating bush (which make up about 80% of the Pinehaven catchment) have exceptionally high infiltration rates. Double-Ring Infiltrometer (DRI) tests on pine forest and regenerating bush areas at Elmslie Road, Pinehaven gave infiltration rates between 512 – 900 mm/hr, and single ring infiltrometer tests in the pine forest and regenerating bush areas of Sub-catchment B on Guildford land gave an average infiltration rate of 603mm/hr consistent with the results of the DRI tests at Elmslie Road.

6.2.2 On grassed Pinehaven Reserve areas and residential lawns in the developed urban portion of Pinehaven catchment, DRI test results all gave infiltration rates of just 1 – 2 mm/hr. Along with impermeable areas of roofs, roads, footpaths and driveways, the urban areas will provide the majority of the stormwater runoff in the Pinehaven catchment due to their negligible infiltration capacity.

6.3 The infiltration test results show that the forest and bush areas in the Pinehaven catchment have much higher infiltration rates than assumed in the flood model calculations by GWRC of just 5mm initial abstraction and 2 mm/hr ongoing infiltration losses. Consequently, GWRC’s peak flood calculations, volumes, and extent of flooding shown on the GWRC flood maps for the

Pinehaven catchment are grossly exaggerated because their calculations grossly under-estimate infiltration losses and grossly over-estimate runoff.

6.4 Extract from M Laws Technical Review

50 SOH (with Mr Ross) have undertaken their own studies[4] of infiltration and hydrological inputs for the upper valley, Elmslie Road and Pinehaven Reserve. These concluded that the average infiltration rate was in the order of 600 mm/h. This exceeds the historical 1% AEP (100-year ARI) 10-minute rainfall intensity of 114 mm/h for Pinehaven extracted from NIWA's HIRDS5 (High Intensity Rainfall Design System) Version 4, and would result in no surface runoff if applied directly to the calculation of flood flows.

6.5 This statement is not correct. As the rainfall would also fall on the urban portions of the catchment, lawns and grassed areas driveways and roads and .would certainly produce run off which would produce flow.

[4] Pinehaven - submission (11_3) Save Our Hills - Report on Infiltration Tests_Alex Ross (18-12-2019)

7.0 The Hydrological model

7.1 The inputs to this model are critical to the design of the Pinehaven Stream works. Unfortunately, the modelling for the flood maps is reliant on poor calibration.

The Opus Report Greater Wellington Region Climate Change Impacts Scoping Study to GWRC states:

2 Review of Existing Modelling

2.1 Hydrology

2.1.1 Assessment of hydrology quality used

The quality of the hydrological inputs to any computational hydraulic model are critical to the reliability and accuracy of the results. It is therefore essential to assess the accuracy and reliability of the hydrological inputs to the model.

Although it is estimates of design flows or design hydrographs which are used in hydraulic models, these are invariably derived from measurements of the water level in the river. These water level measurements are then converted to flow information using a rating curve.

Consequently, the reliability of any hydrological inputs to a flood model is a function of:

- *The length of the flow record and therefore the robustness of any analysis of the frequency and magnitude of flood events. This then affects the reliability of any design flood estimates;*
- *The accuracy with which water levels are recorded; and*
- *The accuracy of the rating which is used to convert the water level information to flows.*

2.1.3 Accuracy of rating curves

With most flow records therefore it is actually the water level in the river which is measured quasi-continuously not the actual flow. The current 'standard' is to measure water level every 15-minutes, although this temporal resolution is often considerably longer during early records because of limitations in the technology available. These water level readings are then converted to estimates of flow using a rating curve i.e. essentially a calibration which relates the water level to the volume of flow. The rating curve is developed by undertaking a series of measurements of the actual flow in the river and recording the particular water level at the time. A relationship is then derived (i.e. the rating curve) which allows all thewater level measurements to be converted to estimates of flow.

The accuracy of flow estimates in any river is therefore a function of both the accuracy of the water level measurements (currently accepted to be ±1mm under normal conditions) and the accuracy of the rating curve.

The accuracy of a rating curve depends on a range of variables including the stability of the channel, the number of actual flow gaugings used to define the curve, and the range of the flows gauged. While flows measured using industry best practice are usually regarded as being ±8%, the uncertainty increases during higher flows (i.e. floods). This is because of the rapidly changing water level, and difficulties in measuring accurately both depth and velocity. Consequently, during flood events the uncertainty of flow estimation can increase to ±30%.

The robustness of estimates of the magnitude of various design storm events is directly related to the length and reliability of the hydrometric record. Consequently, as the critical hydrometric records get longer the estimates of the design storms is likely to alter and they should become more robust.

Therefore, at least once every 10 years the magnitude of the design events used in the various hydraulic models should be reviewed against the latest hydrological data.

7.2 "Even where there is good calibration data, it is still good practice to undertake a 'common sense' check of flood extent areas against observations from known events" was also stated in the Opus report.

8.0 Hard Data on the Pinehaven Stream

8.1 The initial MWH Hydrology report stated that there was less than one year of recorded flood flow data for the Pinehaven Catchment, and that GWRC installed a flow recorder on the Pinehaven Stream at Chatsworth road in August 2008 (it was removed in 2013). In this short period of time there has been only one flood event worthy of use for calibration purposes. This event was 23 July 2009. During this event the rain gauge within the Pinehaven catchment malfunctioned providing no records for the storm. The absence of data is noted in the following extract from *M Laws Report for PC42:*

Unfortunately, stream flows and water levels were not recorded in the catchment prior to MWH's hydrological modelling in 2008, which meant that the derived flow hydrographs in their report were derived from general hydrological methods rather by calibration against observed events. Temporary flow and water level measurement was installed for a period during 2008 and 2009, during which a small flood event was recorded on 23 July 2009. This event was used to calibrate the hydrological modelling in the 2009 update to the report, but it is noted that the July 2009 event had an ARI of about 10 years; significantly lower than the 1976 event.

GWRC reviewed MWH's hydrology and did not find any major issues, although they acknowledged the absence of data against which to calibrate the modelling.

MWH's derived flow hydrographs were used in the coupled 1D/2D hydraulic modelling of the Pinehaven catchment by SKM (now Jacobs) in 2009.

The modelled flows were calibrated against the relatively small flood events of 31 July 2008 (Mean Annual Flood) and 23 July 2009 (10-year ARI).Ideally, the model should be calibrated against a larger flood event. In the absence of recorded water level and flow data for the catchment, calibration against the hydrological response of a monitored catchment with similar hydrological characteristics would increase confidence in the modelled flow hydrographs.

The calculated peak flows have been cross-referenced against regional methods for estimating peak flows, and similar results found. It is six years since the hydrological modelling was carried out, and consideration should be given to reviewing the hydrology as a longer period of rainfall data becomes available, as predictions for the effects of climate change evolve, and as the understanding of the hydrological response of the Pinehaven Stream (and similar catchments) improve.

It is six years since the hydrological modelling was undertaken. Flood maps are periodically updated in line with council long term plans, or in response to significant new data becoming available. At such time, the hydrology should be updated to account for longer rainfall records and more storm events. More robust hydrology could be provided by calibration against recorded flow data, especially for a large flood event. In the absence of recorded data, calibration *against the hydrological response of a similar catchment should be considered when the hydrology is reviewed.*

8.2 The following extract shows that the modeller is not confident of the results due to the poor calibration of the model. The hydrological inputs to the model have not changed since the original model was built.

Extract from MWH Report by M. Harkness

6.4 Rainfall-Runoff Model Limitations

The major limitation of the rainfall-runoff modelling process for the Pinehaven Stream is the lack of calibration data. Although a single calibration point was available, it was a relatively minor flood event. The use of the model to simulate extreme flood events will therefore carry relatively high uncertainties. This uncertainty is reduced by comparing modelled output with peak estimates from other methods as summarised in Section 7.

A number of recorded flood hydrographs is preferred for calibration purposes to ensure estimates of peak flows and hydrograph shape are as accurate as possible.

It is recommended that GWRC make use of data from its recently installed flow recorder on the Pinehaven Stream and check/re-calibrate the rainfall-runoff model after a number of years or flood events have been recorded.

8.3 The flow data was provided by GWRC to MWH (M. Harkness) and the estimated peak flow was 8.8 m^3/s. (*MWH 2009 Revised hydrology appendix B section 6.2.1 23 July 2009 event*). However this estimate is unreliable due to the fact that there is only a short period of record; the lack of certainty in converting high measured water levels to flow (the rating curve). SKM in their report *Pinehaven Flood Hazard Investigation 2010* state in order to provide a reliable rating curve a minimum of three or four high flood events are required.

8.4 Fortunately the storm of 8 December 2019 provided an opportunity to use the flood data for calibration. However, GWRC has ignored this opportunity and it has been left for submitters at their cost to do the Councils work for it.

8.5 The major limitation of the rainfall runoff modelling process for the Pinehaven Stream is the lack of calibration data (neither GWRC or WWL have instigated stream flow data collection in the years since the original model was constructed). Although one calibration event has been used by the modellers there are uncertainties around the accuracy of the recorded data as the high flow rating is unconfirmed (the modellers used 1.2m and the actual recorded water depth in the stream was 1.6m - *see SKM Pinehaven Flood Hazard Investigation Report 2010)*

8.6 P.Kinley in his evidence (at paragraph 6.1 (c)) states:

The model had been calibrated to an observed flood event. This means the model parameters had been adjusted to achieve a good fit of the model outputs to an observed flood event, and shows that the model accurately represents the physical processes within the catchment.

However, as can be seen from the extracts quoted above the calibration relied on is at best questionable and at worst misleading.

8.7 P.Kinley in his evidence (at paragraph 6.1 (d)) also states:

The model had been validated against independent methods for estimating peak flood flows. Validating is the process of comparing model outputs to independent data sets and checking how similar the results are. The validation showed the calibrated model produces peak flowrates that are similar to outputs from the independent methods.

8.8 It has been stated that the model was validated against McKercher & Pearson Regional method. This method has accuracy of + or - 28% i.e. it is a very coarse tool. (See McKercher & Pearson 1991) Similarly, it was validated against the Rational method which is very subjective to the 'C' value (infiltration) used. The model also has dubious Mannings 'n' value of 0.2 incorporated for flows in the upper catchment.

I consider that the validations were a self-fulfilling prophesy as their inputs were chosen to give the expected results.

8.9 The attached graph ex R Hall shows how the peak flows have been exaggerated in the model as even the GWRC 8.8 m3/sec peak flow does not fit their own rating curve but does fit the rating curve calculated by the submitters.

9.0 Economic Considerations

9.1 Initially the cost of the project was around $10M split equally between UHCC and GWRC, however that has now ballooned out to over $40M when interest payments on loans raised are taken into account. The majority of the repayments ($35M) are to be paid by Upper Hutt residents. However, the present UHCC does not appear to be worried about the increased cost.

9.2 In my view it would be prudent to get the base hydrology corrected before spending this amount of money when the country is heading towards a recession and justification for the design (4%AEP) will be required, when the works are well over designed due to the flawed hydrology.

10.0 Conclusions

10.1 Every consultant hired by GWRC to work on the Pinehaven Stream has requested in their reports that flood flow data be collected and that the models be updated with the collected data, but this has never happened in the 12 years since the model was produced.

10.2 The result is that the Hydraulic model will have incorporated large uncertainties which is why the model outputs look nothing like the real world when actual floods are compared to the model. This is also why the over designed stream channel is being massively widened with new bridges.

10.3 My conclusion from these reports is that the hydrological input to the Hydraulic model is so unreliable that it should not have proceeded without further data collection in order to produce a reliable rating curve. Also, the model results should have been compared to real world events as a check on the models veracity once the updated rating had been produced.

10.4 Far from being fit for purpose the model is so unreliable that it should be discarded until further data is collected and the flood maps corrected.

10.5 Both WWL and GWRC state that the model is fit for purpose when clearly the errors and uncertainties incorporated within the hydrology and calibration / validation are of such low quality that it is not fit for use to predict flood levels from a storm event.

Appendix A

Report on Infiltration Tests carried out on the Pinehaven Stream Catchment During July 2019

When rainfall falls on the land the resulting runoff depends on catchment characteristics, on land usage, on the degree of urbanisation etc. These factors also influence the amount of infiltration and ground water yield.

Rain storms vary in duration, and the shorter the storm the greater the intensity of the rainfall. This simple observation is very important.

Infiltration is a significant component of hydrologic processes. Soils have varying capacities to infiltrate water. Influencing factors are soil type , degree of saturation and nature of ground cover. Activities that change the soil surface or alter its properties also have an effect.

When the rainfall intensity is less than the infiltration capacity, all of the water reaching the ground can infiltrate into the ground, such that there is no surface run off. But if the rainfall intensity exceeds the infiltration capacity, infiltration will only occur at the infiltration capacity rate, and water in excess of that capacity will be stored in depressions, become surface run off or evaporate. In general, the initial infiltration capacity of a dry soil is high. As rainfall continues, and as the soil becomes saturated , it diminishes to a relatively constant rate.

The tests undertaken were to establish a reasonable estimate for the infiltration rate on the various land and soil types in the Pinehaven Catchment.

TESTS

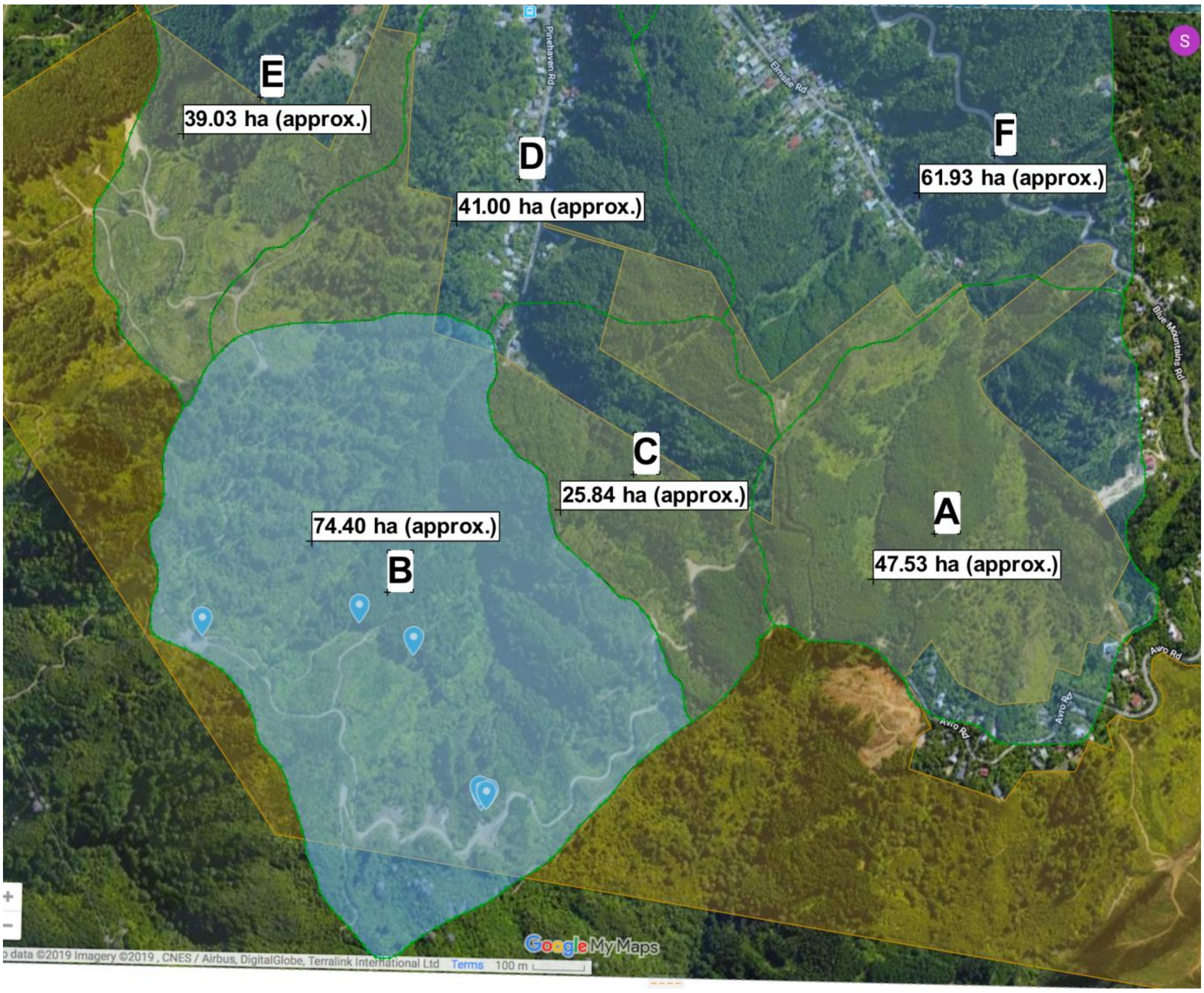
The first tests were carried out using a 100mm diameter uPVC pipe driven into the ground about 70mm and filled with water to a head of 20mm timing how long it took for the water to soak away.

A nominal 100mm Ø PVC pipe x 140mm long was set 70mm into the soil (after clearing the pine needles and leaf litter away). A line had been marked at 70mm from the top inside the pipe (soil level), and another line 20mm above it. 3 or 4 soakings were applied to the soil before timing how long it took for 20mm of water to soak away.

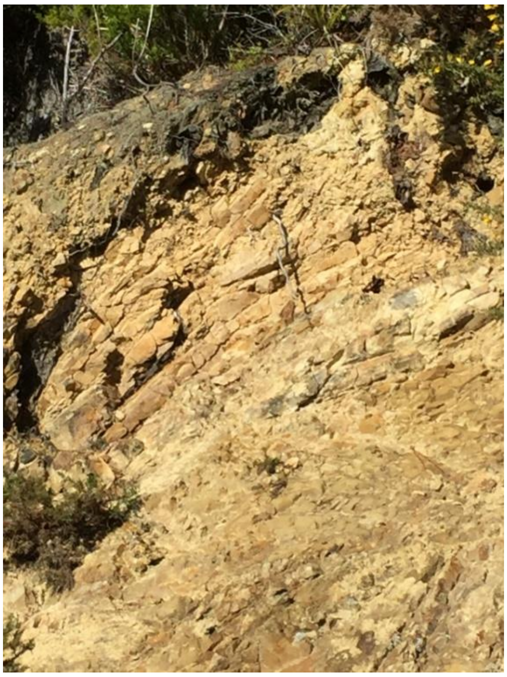
These tests were carried out in several locations in forest, and in regenerating bush. These tests were limited due to the availability of water which had to be carried to the various sites on foot for several kilometres.

The locations of the tests were plotted by GPS app on a cell phone. Then the sites were located on Google maps. This map was then overlaid on a map of the catchment showing other features.

This map is reproduced below.



Soil and rock were observed in road cuttings as transport of the water for the tests proceeded.



Photographs showing tests using single ring infiltrometer.

DOUBLE RING INFILTROMETER

Following the first series of tests a double ring infiltrometer (DRI) was used for the remaining tests . The double ring infiltrometer had a 100mm diameter inner ring, and a 300mm diameter outer ring. The purpose of the outer ring is to keep the water in the inner ring infiltrating vertically into the soil. The rings were inserted into the ground to a depth of 130mm. (which is within the suggested range of 50 - 150 mm described by most methods). The outer ring was filled with water to 100mm above the soil and the inner ring was also filled to the same depth. The timer was started and the depth of water in the inner ring noted at regular intervals whilst keeping the water in the outer ring at the same level as the inner ring by the addition of water. When the water in the inner ring infiltrated the soil it was replenished to the 10 cm mark and the water in the outer ring was also replenished, the depth of water was then measured at the next time interval. The test repeated until the infiltration depths remained constant for the same time interval. The locations of the tests were plotted by GPS app on a cell phone.

In all eight tests were performed on different areas of the catchment and on different ground conditions from forest areas to grassed lawns and reserves.

The photographs below show the various test sites at 27 Elmslie Road, Pinehaven and in the Pinehaven Reserve.

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DRI Test 1 Edge of Pines

DRI Test2 Middle of Pines

DRI Test #3 Regenerating Bush

DRI Test # 4 Back Lawn

DRI Test #5 Mid Lawn

27 Elmslie Road

DRI Test #6 Front Lawn

DRI Test #7 Pinehaven Reserve

DRI Test #8 Pinehaven Reserve

RESULTS OF TESTS

The test results were graphed for tests 1 - 3 of the double Ring Infiltrometer (as shown below), and gave base infiltration rates between 512 - 900 mm/hr for the Bush and forest areas at 27 Elmslie Road.

The initial single ring tests in Sub Catchment B gave results of :-

Test 1	36 sec
Test 2	56 sec
Test 3	106 sec
Test 4	435 sec

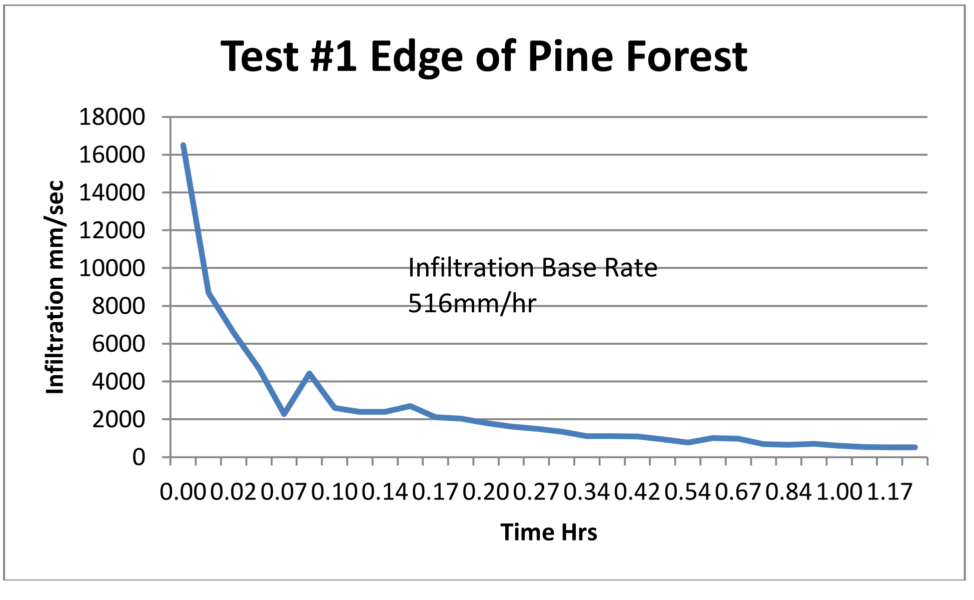
In Regenerating Bush for 20 mm of water to soak into the soil. And

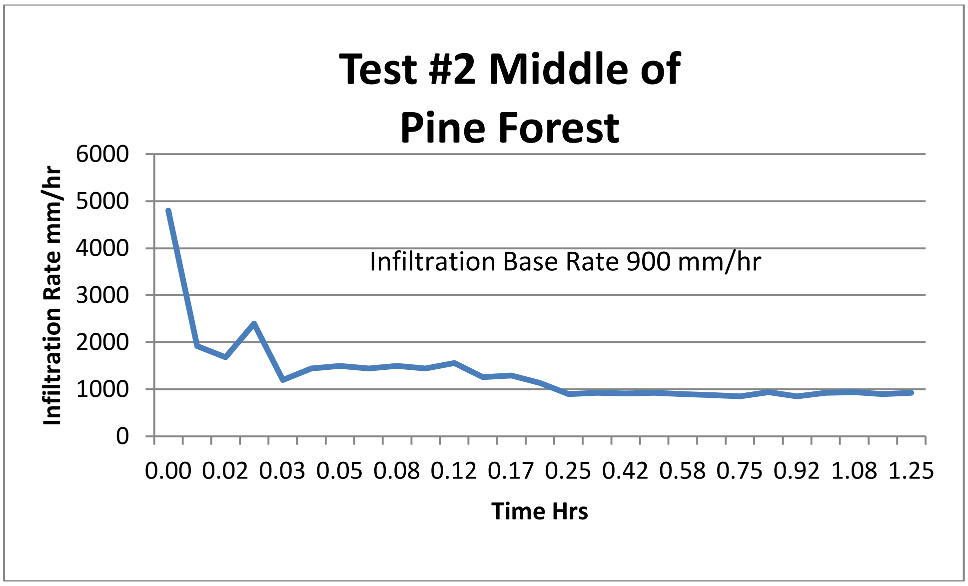
Test 5	60 sec
Test 6	7 sec
Test 7	40 sec
Test 8	85 sec

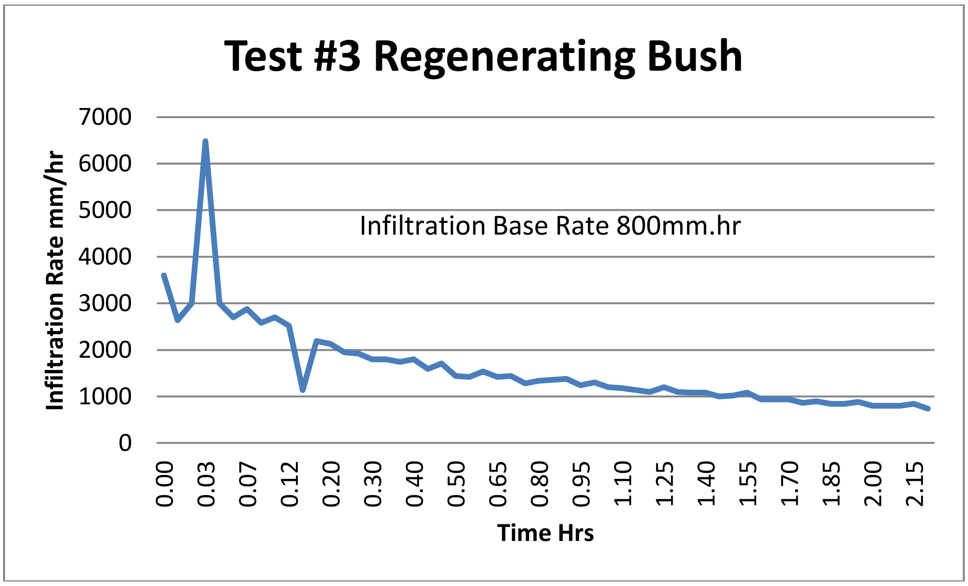
In the forest area for 20 mm water to soak into the soil.

Setting aside the outlier of Test #6 at 7 sec the average time is 119 sec giving an infiltration rate of 603 mm / hr Which is reasonably consistent with the double ring tests.

The tests on the lawn areas and the Pinehaven Reserve gave consistent results of 1 - 2 mm/hr for the infiltration rate on this type of land cover.







Conclusion

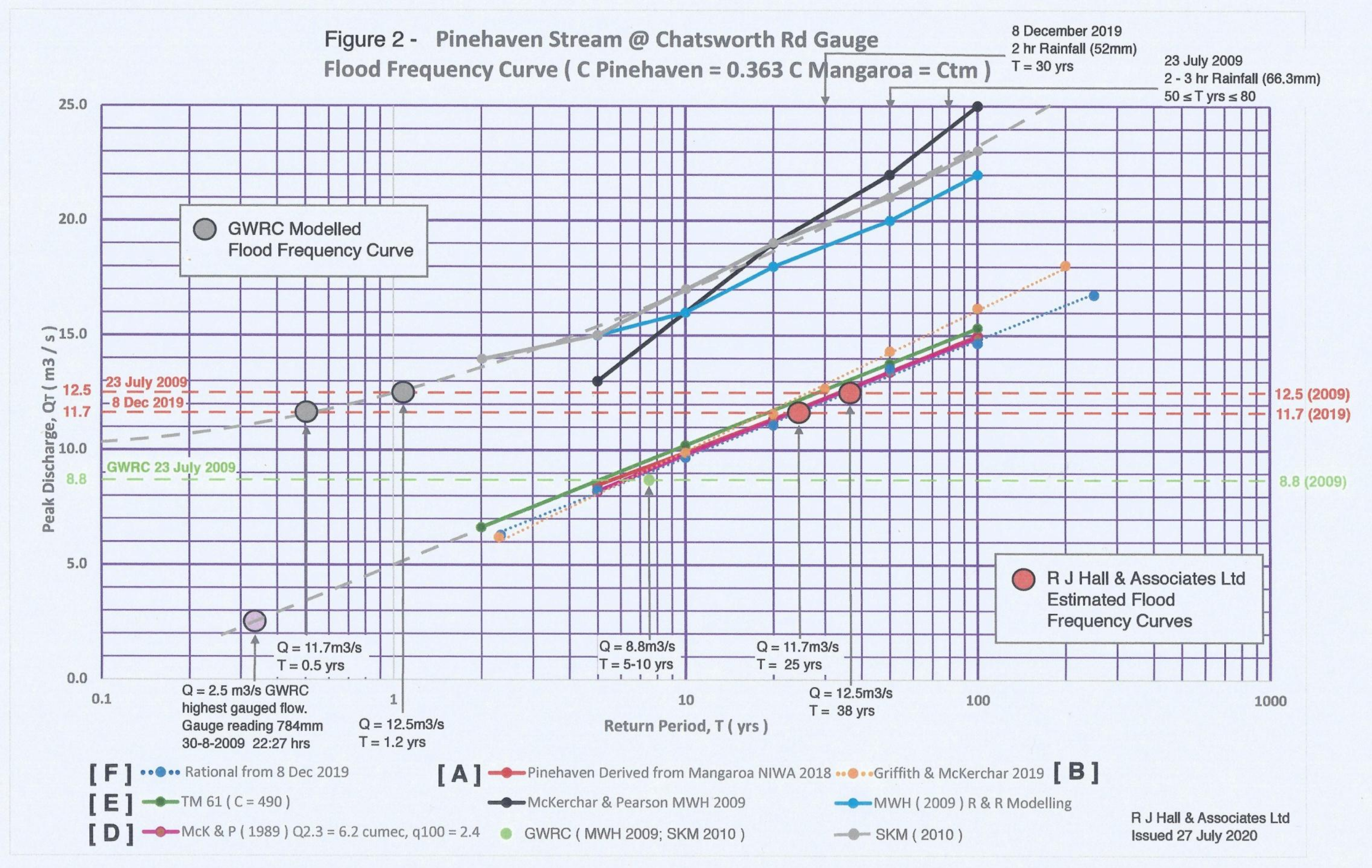
The results show that the forest and bush areas in the Pinehaven catchment have much higher infiltration rates than what was proposed in the flood model calculations by WRC and as such the peak flood calculations, volumes, and extent of flooding shown on the maps based on the catchment as presented in 2019 are grossly exagerated.

The other conclusion from the tests is that the lawns and grassed reserve areas in the developed urban portion of the catchment along with the impermiable areas of roads, footpaths, driveways, and roofs will provide the majority of the run off due to their negligable infiltration capacity.

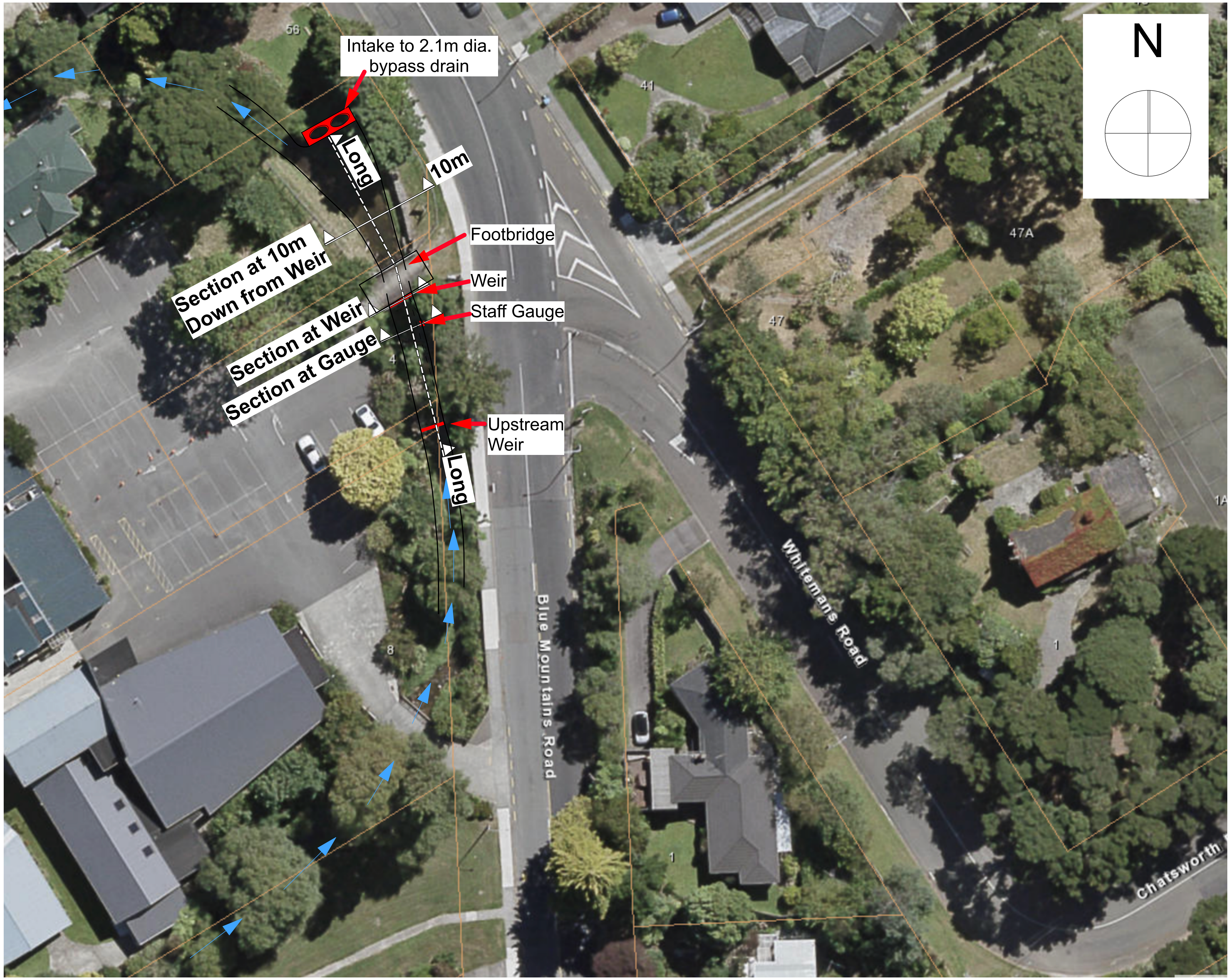
A.K. Ross
N.Z.C.E.
Retired Civil Engineer

Photograph of secondary flow path caused by undersized culvert and vegetation blocking the channel below the culvert at 122 Pinehaven Road.

Rating Curve from RJ Hall showing Peak Discharge vs Return Period and Highlighting the error in GWRC flood estimates.



2019-12-08_Pinehaven Stream flood event_CDA Drawings_Rev A



Staff Gauge Site - Location

1:500

1-in-30 Year Rainfall Event 8 Dec 2019

Rev	Date	Issue	By
A	27-7.20	08 December 2019 event	SP

co-designarchitects
27 Kings Crescent, Lower Hutt, ph(04) 938 4555
Box 48-070, Silverstream, Upper Hutt 5142

Storm in Pinehaven and Silverstream on 8 December 2019
For "Save Our Hills (Upper Hutt) Incorporated"

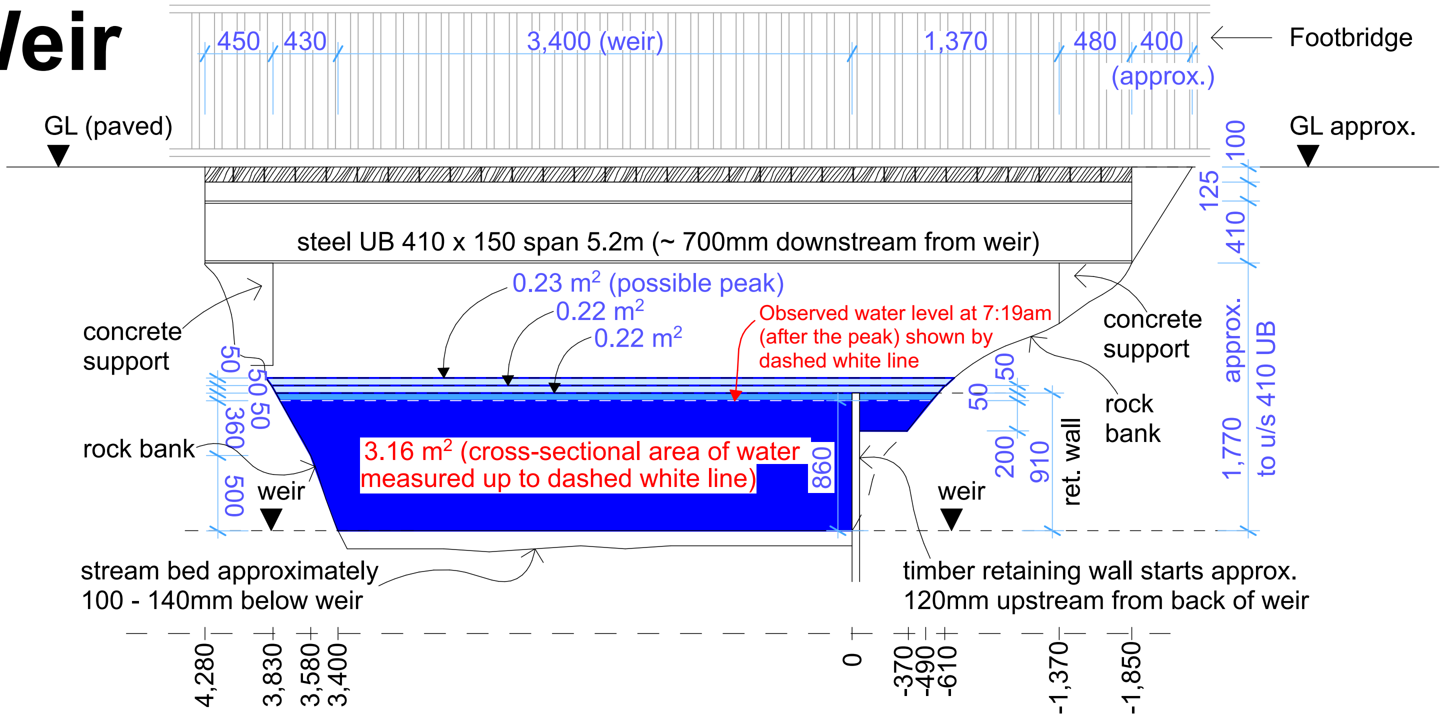
 Date Issued: 27/07/20

Site Locality Plan & Contents

Scale:	Job No:	Sheet No:	Rev:
As shown @A3 size	2002 /	101	A

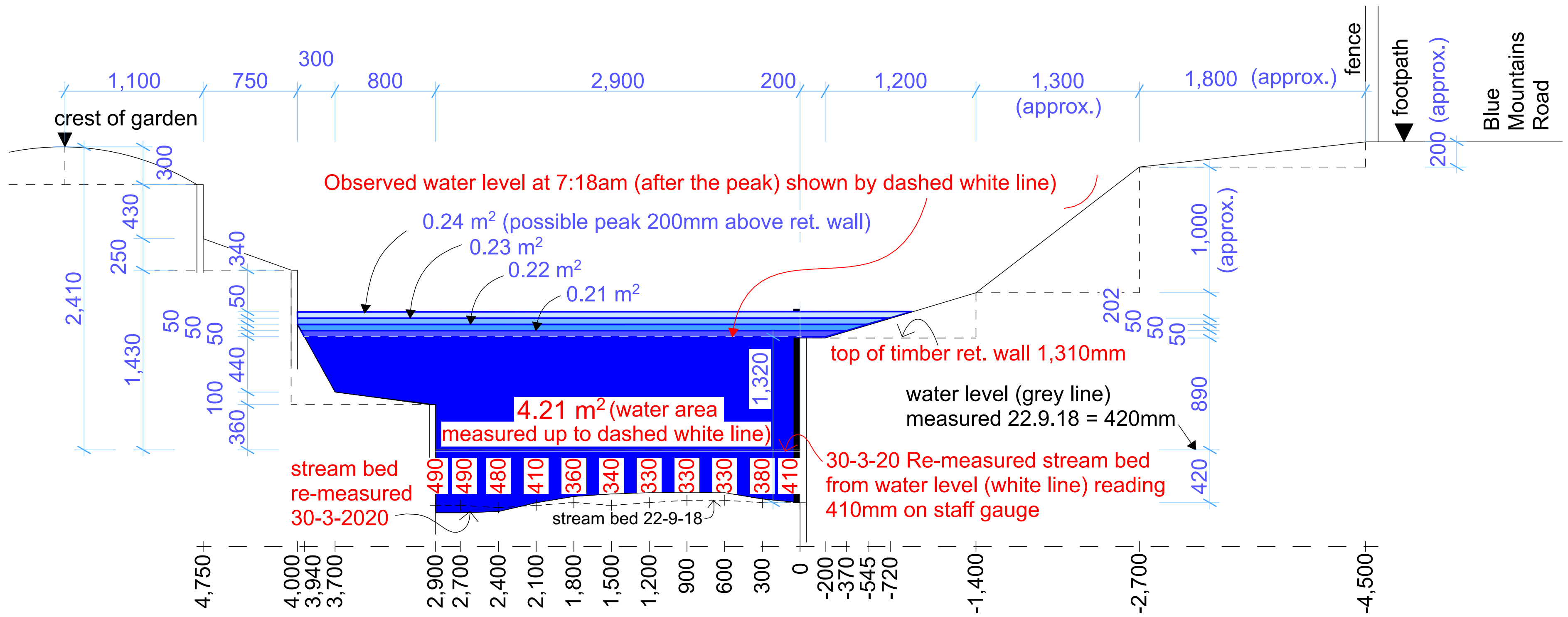
Check all dimensions on site before starting construction

At Weir



Cross-Section of Pinehaven Stream channel at Weir Under Footbridge (looking downstream)
22.9.18 - Measurements taken on site by Steve Pattinson (SOH)
0.81m approx. depth of flow over weir observed 8th Dec 2019 at 7:19am

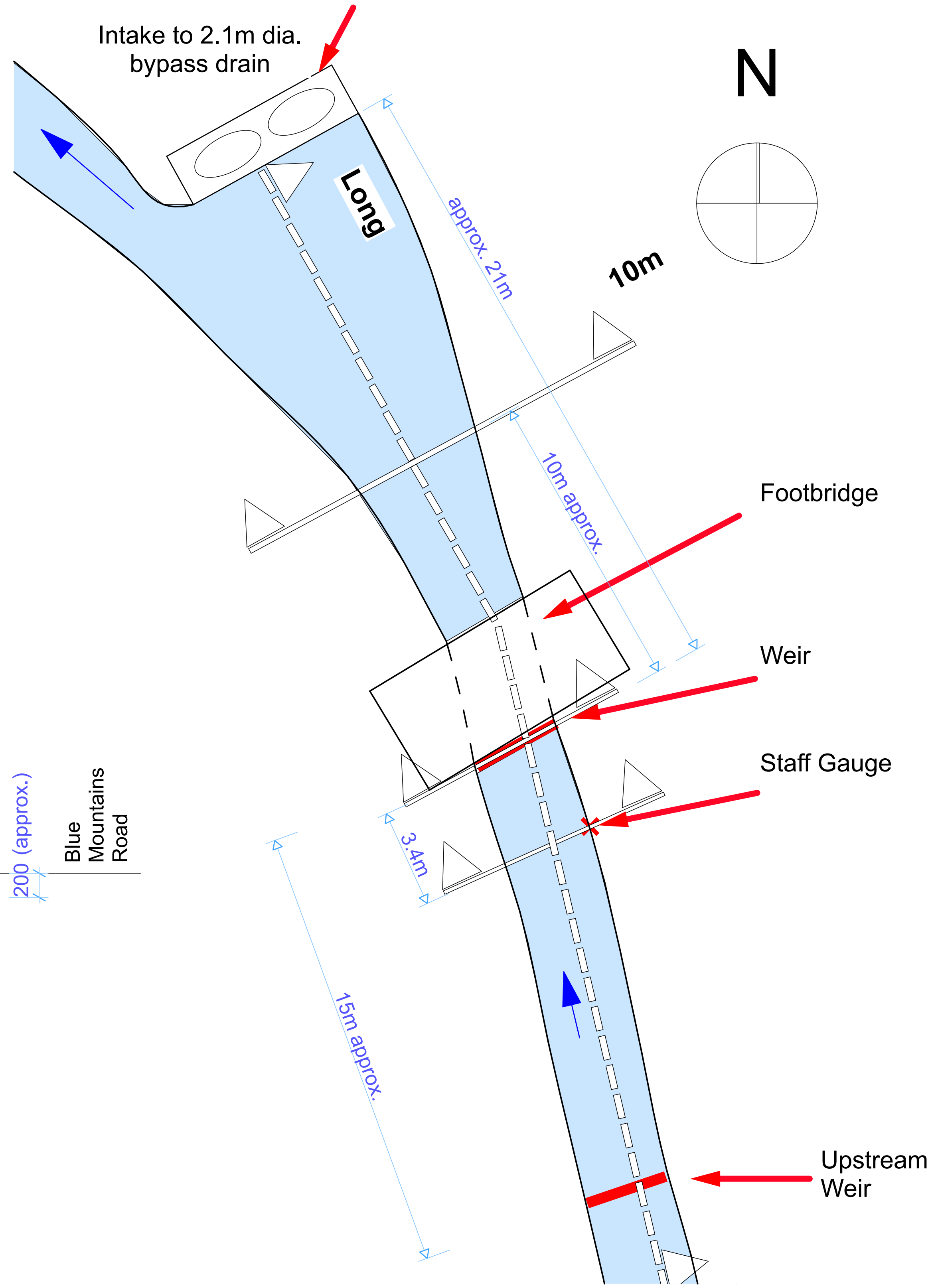
Weir under Footbridge - Channel Section 1:50



At Gauge

Cross-Section of Pinehaven Stream channel at staff gauge (looking downstream)
(Staff gauge location approximately 3.4m upstream of footbridge weir)
22.9.18 - Measurements taken on site by Steve Pattinson (SOH)
1.32m approx. depth of flow observed 8th Dec 2019 at 7:18am

Staff Gauge Location - Channel Section 1:50



Stream Plan 1:200

(Approximate Scale only)

1-in-30 Year Rainfall Event 8 Dec 2019

Rev	Date	Issue	By
A	27-7.20	08 December 2019 event	SP

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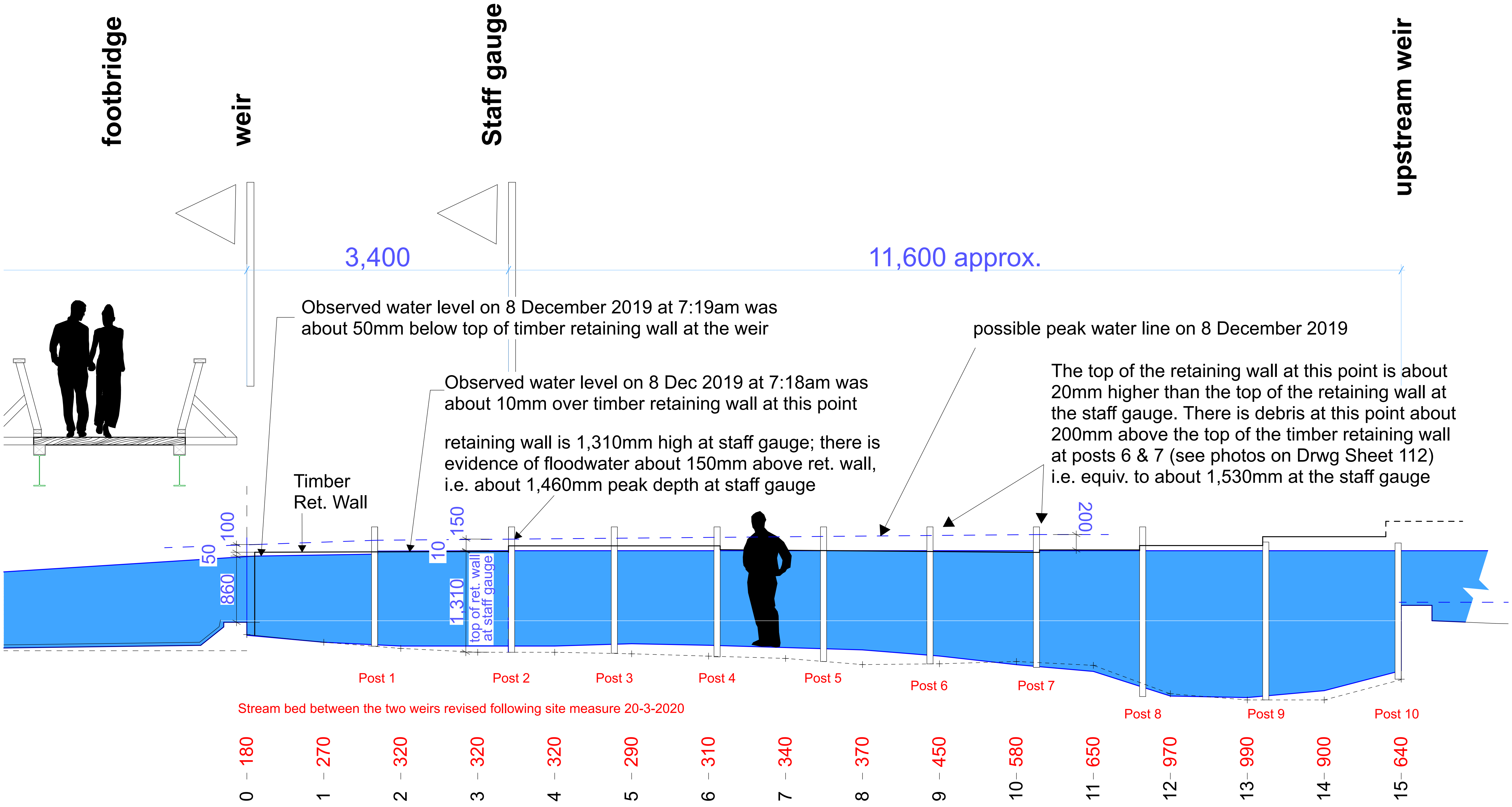
For "Save Our Hills (Upper Hutt) Incorporated"

 Date Issued: 27/07/20

Channel Sections at Weir and Staff Gauge

Scale: As shown @ A3 size | Job No: 2002 / | Sheet No: 102 | Rev: A

Check all dimensions on site before starting construction



Longitudinal Section of Stream Invert 1:50

1-in-30 Year Rainfall Event 8 Dec 2019

Rev	Date	Issue	By
A	27-7.20	08 December 2019 event	SP

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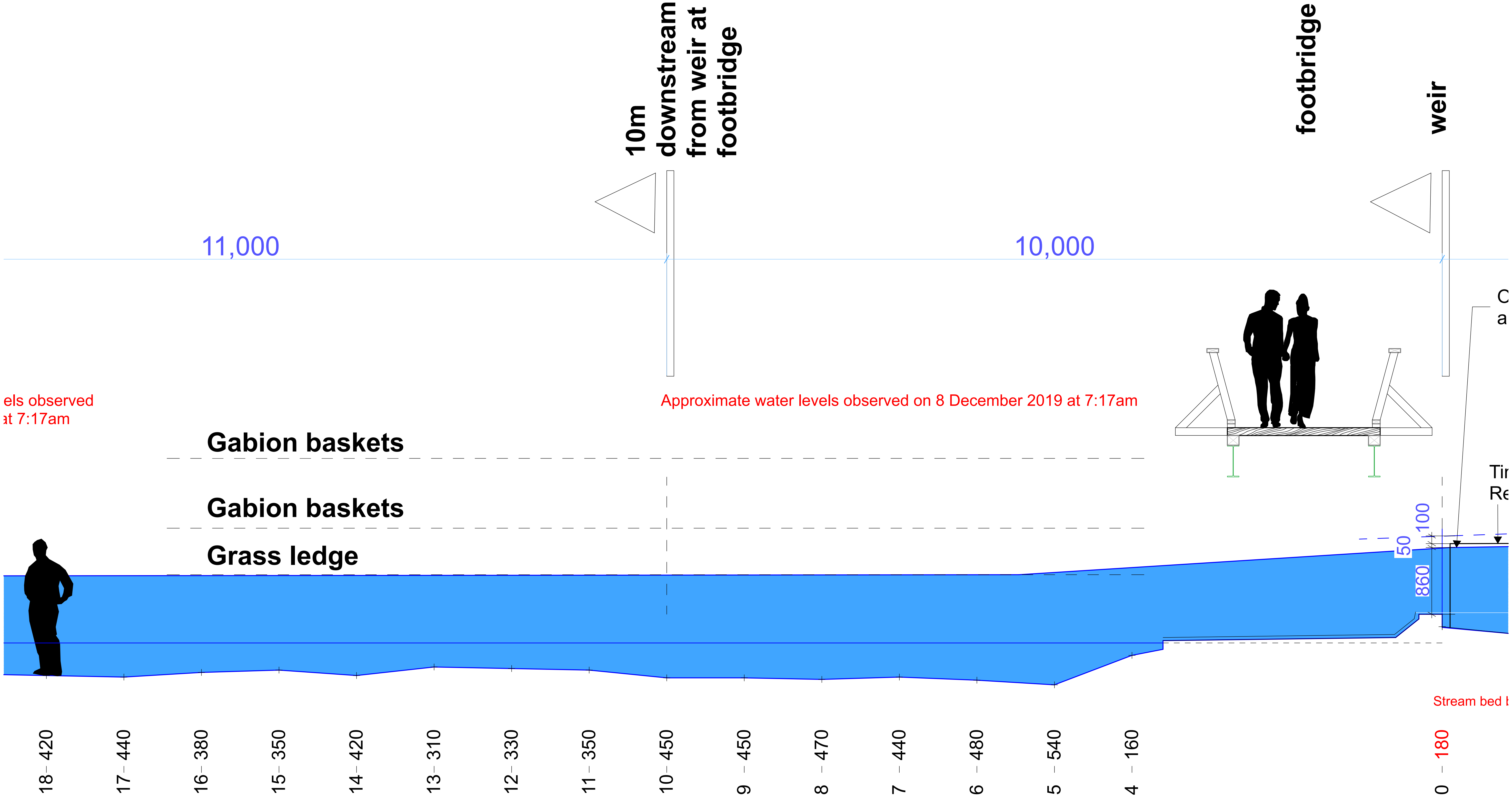
Storm in Pinehaven and Silverstream on 8 December 2019
For "Save Our Hills (Upper Hutt) Incorporated"

 Date Issued: 27/07/20

Longitudinal Section - Stream Centreline (Contd.)

Scale: As shown @ A3 size | Job No: 2002 / | Sheet No: 104 | Rev: A

Check all dimensions on site before starting construction



Longitudinal Section of Stream Invert **1:50**

1-in-30 Year Rainfall Event 8 Dec 2019

Rev	Date	Issue	By
A	27-7.20	08 December 2019 event	SP

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Box 48-070, Silverstream, Upper Hutt 5142

Storm in Pinehaven and Silverstream on 8 December 2019
For "Save Our Hills (Upper Hutt) Incorporated"
 Date Issued: 27/07/20

Longitudinal Section - Stream Centreline (Contd.)

Scale:	Job No:	Sheet No:	Rev:
As shown @A3 size	2002 /	105	A

Check all dimensions on site before starting construction

1 - Left Bank at Footbridge

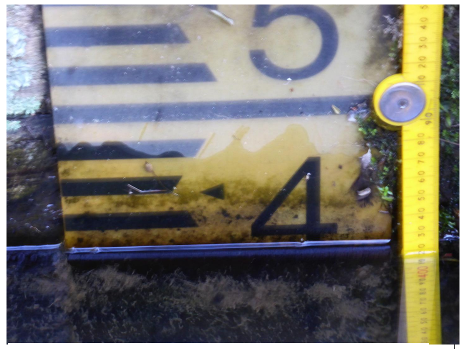
2 - Weir under Footbridge

3 - Staff Gauge on True Right Bank approx 3.4m upstream from Footbridge Weir

6 - Staff Gauge

4 - Right Bank at Footbridge

5 - Under footbridge (looking upstream at weir)



7 - Water Depth 420mm (Date 22/9/18)

Rev	Date	Issue	By
A	27-7.20	08 December 2019 event	SP

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Storm in Pinehaven and Silverstream on 8 December 2019
For "Save Our Hills (Upper Hutt) Incorporated"

 Date Issued: 27/07/20

Photos at Staff Gauge 22/9/18

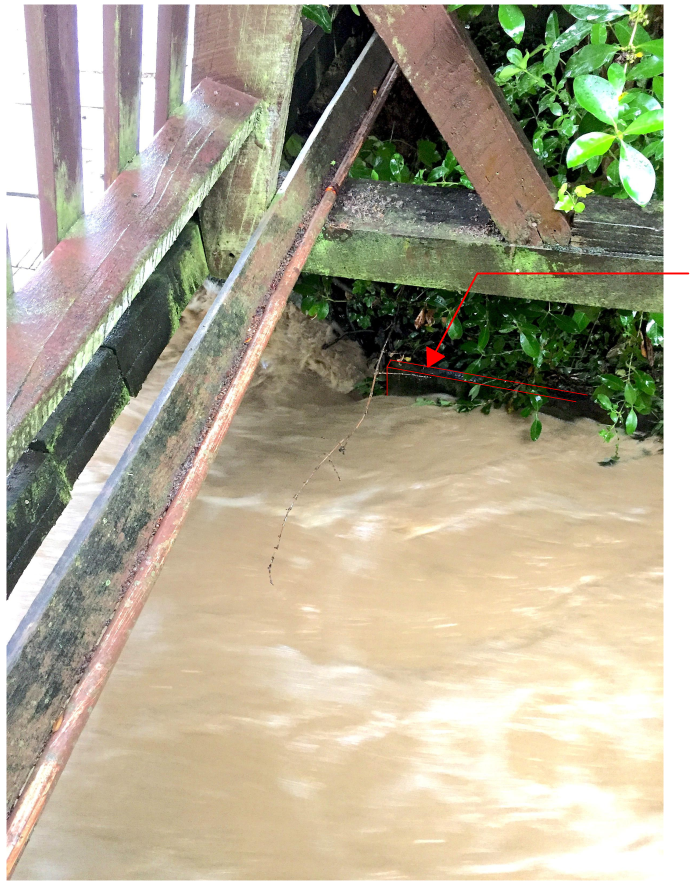
Scale:	Job No:	Sheet No:	Rev:
As shown @A3 size	2002 /	107	A

Check all dimensions on site before starting construction

1 - View downstream from footbridge 8 Dec 2019 at 6:14am

2 - View downstream from footbridge 8 Dec 2019 at 7:17am

On 8 Dec 2019 at 7:17am, water level appears to be about level with grass ledge (a little lower than at 6:14am - see Photo 1 opposite).



3 - Right Bank at Weir on 8 Dec 2019 at 7:19am

On 8 Dec 2019 at 7:19am, water level appears to be about 50-150mm below top of timber retaining wall (top of timber retaining wall is 910mm above the weir).

4 - Right Bank at Retaining Wall post (about 1.8m upstream of weir) 7:18am

On 8 Dec 2019 at 7:18am, the water level appears to be just overtopping the 1,310mm high timber retaining wall (on the upstream side of the steel post, which is about 1.8m upstream of the weir) and just below the top of the timber retaining wall on the downstream side of the steel post. Note: the staff gauge is about 1.6m further upstream from the steel post in this photo).

1-in-30 Year Rainfall Event 8 Dec 2019

Rev	Date	Issue	By
A	27-7.20	08 December 2019 event	SP

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Box 48-070, Silverstream, Upper Hutt 5142

Storm in Pinehaven and Silverstream on 8 December 2019
For "Save Our Hills (Upper Hutt) Incorporated"

 Date Issued: 27/07/20

Photos at Staff Gauage on 8 Dec 2019

Scale: As shown @A3 size | Job No: 2002 / | Sheet No: 108 | Rev: A

Check all dimensions on site before starting construction

1 - Debris 100mm to 150mm above top of retaining wall.

On 16/3/20 there is still debris evidently washed up against the base of the tree above the retaining wall, possibly 100mm to 150mm above the retaining wall.
- see Photo 1 opposite and see Photo 4 below.

2 - Debris still evident 16/3/20 above retaining wall and at base of tree.

3 - Top of steel post is 317mm above top of retaining wall

On 8 Dec 2019 at 7:18am, there is evidence of dirty floodwater above the level of the timber retaining wall. This suggests the peak flow, which occurred before 7:18am, went above the retaining wall, which is 1,310mm at the staff gauge.
(Note: the top of the steel post is 315mm above the top of the retaining wall - see Photo 3 opposite).

4 - Right Bank at Retaining Wall post (about 1.8m upstream of weir) 7:18am

1-in-30 Year Rainfall Event 8 Dec 2019

Rev	Date	Issue	By
A	27-7.20	08 December 2019 event	SP

co-designarchitects
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Box 48-070, Silverstream, Upper Hutt 5142

Storm in Pinehaven and Silverstream on 8 December 2019
For "Save Our Hills (Upper Hutt) Incorporated"

 Date Issued: 27/07/20

Photos of overtopping of retaining wall

Scale:	Job No:	Sheet No:	Rev:
As shown @A3 size	2002 /	109	A

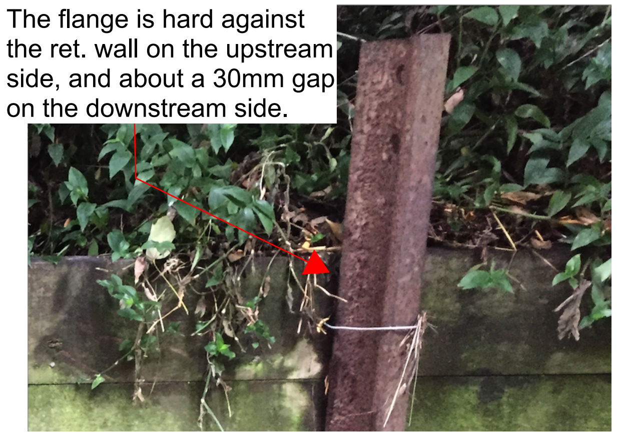
Check all dimensions on site before starting construction

1 **2019-12-08 07.18.01_**

2 **2019-12-08 07.18.08_**

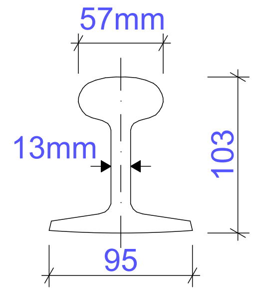
3 **2019-12-08 07.19.19_**

6 - Railway iron at retaining wall



7 - Railway iron - close up

8 - Railway iron - Top view



Railway Iron 1:5

Post 1 in the timber retaining wall on the True Right Bank at the staff gauge site

The distance from the top of the timber retaining wall down to the water in this photograph (on the downstream side of the railway iron) is 135mm (approx.) - See Drawing Sheet 110.1

top of timber retaining wall

4 **2019-12-08 07.19.19_zoom in_**

5 - 108mm to No.8 wire from top of ret. wall

1-in-30 Year Rainfall Event 8 Dec 2019

Rev	Date	Issue	By
A	27-7.20	08 December 2019 event	SP

co-designarchitects

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Box 48-070, Silverstream, Upper Hutt 5142

Storm in Pinehaven and Silverstream on 8 December 2019
For "Save Our Hills (Upper Hutt) Incorporated"

 Date Issued: 27/07/20

Retaining wall railway iron post at true right bank near footbridge

Scale:	Job No:	Sheet No:	Rev:
As shown @ A3 size	2002 /	110	A

Check all dimensions on site before starting construction

Alasdair Keane_Memo Pinehaven rainfall assessment for 08 December 2019 storm

MEMORANDUM

KEANE ASSOCIATES Ltd.

10a Heretaunga Square
Upper Hutt 5019
New Zealand
Phone: 64 4 528 4024
Email: alasdair@keaneassociates.co.nz
Web: www.keaneassociates.co.nz

To	**Steve Pattinson**	*from*	**Alasdair Keane**
	Save Our Hills (Upper Hutt) Inc.	*date*	***3 July 2020***
	stephenjpattinson@gmail.com	*Reference no.*	

Pinehaven Reservoir - 8 Dec 2019 rainfall analysis

Dear Steve,

As requested I have undertaken an examination of the Pinehaven Reservoir rainfall record to;

- Estimate ARI return period of rainfall event for the Time of Concentration at the staff gauge in the stream at the Dutch Reformed Church, Silverstream (4-8 Blue Mountains Rd) for the 8 December 2019 storm. Are the Cardno/Wellington Water Ltd estimates of 10-20yrs ARI (20 minute duration) and 30-40yr ARI (1 hour duration) relevant? If not, please explain why they are not relevant,
- What was the antecedent condition for the 8 December 2019 storm? How would that have influences flows in Pinehaven catchment on 8 December 2019,
- What might the flood return period have been on 8 December 2019,

Hydrological Data

Hourly rainfall data at the Haywards Hill, Pinehaven Reservoir and Tasman Vaccine Ltd rain gauges is available on the Wellington Regional Council web site. The concurrent rainfall datasets were downloaded.

A very basic quality check carried out on the Pinehaven Reservoir rainfall record (Jul 2010 to present) to confirm the rainfall record was complete (no gaps or accumulated totals) and that the cumulative rainfall trend was consistent with an adjacent rain gauge over the period. The data was complete for the full period and cumulative rainfall trend is consistent with rainfall recorded Tasman Vaccine Ltd (Figure 1).

Critical Duration Rainfall

The term “critical duration” is used to describe the duration of rainfall in a storm that produces the highest peak flow (or largest hydrograph volume) under similar antecedent conditions. The critical duration is roughly equivalent to the time of concentration for flow, a measure of the travel time for rain falling at the head of the catchment to flow to its outlet or a location where flow is measured. The annual recurrence interval for the critical duration storm event tends to produce a flood of a similar probability of exceedance or annual return period, provided rainfall across the catchment is uniform and that the antecedent conditions do not influence runoff rates significantly.

RJ Hall and Associates has estimated the time of concentration for the Pinehaven Stream catchment at the Dutch Reform Church to be 2 hours and this seems to be the generally accepted figure for the critical rainfall duration for peak flows in the catchment (Pattinson pers. Comm., 30 May 2020).

Pinehaven Reservoir - 8 Dec 2019 rainfall analysis

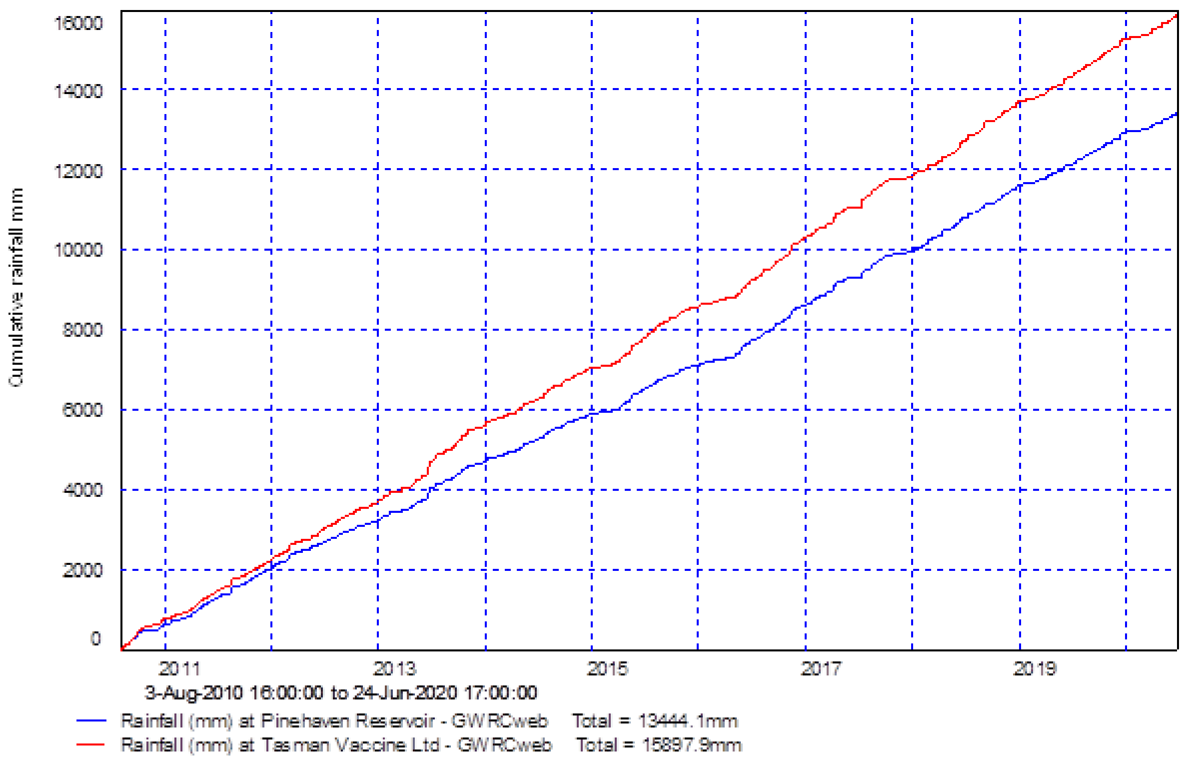


Figure 1 Comparison between cumulative rainfall at Pinehaven Reservoir and Tasman Vaccine Ltd rain gauges.

Rainfall Frequency Analysis

A rainfall frequency analysis has been carried out on the Pinehaven Reservoir rain gauge record for the calendar years 2011 to 2019. The Rainfall Duration option in the Hilltop Hydro Event fits a General Extreme Value (GEV) distribution to annual rainfall extremes for durations between 6 minutes and 3 days and generates a table and plot of rainfall depth for a range of durations and average recurrence intervals (Appendix A).

It is noted that the Pinehaven Reservoir rain gauge record is relatively short for frequency analysis with 9 calendar years available to analyse. The results for the critical duration of the Pinehaven catchment at the Dutch Reform church are shown in Table 1 below and compared with the equivalent analysis from HIRDS4.

The peak 2 hour rainfall during the 8 December storm event was 52mm between 3am and 5am. Based on the Pinehaven reservoir record, the 8 Dec 2019 event has an ARI of about 28 years.

	Rainfall (mm)	
ARI (yrs)	Pinehaven Reservoir	HIRDS 4
2	24.4	27.7
5	30.4	35.8
10	37.5	41.9
20	47	48.2
30		52
40		54.7
50	65	56.9
100	84.6	63.7

Table 1 Rainfall depth and frequency for 2 hour rainfall at Pinehaven Reservoir (2011-2019) and selected values from HIRDS4 (after Save our Hills 2018[1]).

[1] Save our Hills (2018) Report on Storm in Pinehaven on Sunday 08 December 2019, Preliminary Report, 18 December 2019, Save our Hills (Upper Hutt) Inc. 28p

Distribution of Rainfall

Rainfall during the 8th December storm event appears to have been relatively uniform across the Pinehaven catchment and the surrounding area. This is apparent in the six hourly rainfall totals to 6am;

- Haywards Hill Reservoir to the northwest (90.3mm)
- Pinehaven Reservoir at the north end of the catchment (78.2mm)
- Longstaffe rain gauge at 25 Elmslie Rd in the centre of the catchment (80mm)
- Tasman Vaccine Ltd in the Mangaroa Valley to the southeast of the catchment (77.3mm)

The uniform spatial distribution of rainfall in a band over the area of the Pinehaven catchment is also apparent in the total rainfall accumulation for the storm based on radar imagery (Hopkirk 2019)[2].

Antecedent conditions

The months prior to December 2018 can be characterised as a typical spring. Rainfall occurred at intervals throughout the preceding months.

The antecedent conditions leading up to the 8 December storm can be assessed by comparing spring rainfall Sept – Nov) in 2019 compared with other years in the record (Table 2). This shows that in the antecedent conditions in Pinehaven catchment prior to the 8th December storm were likely average because the rainfall in the preceding months was about average, ranking 4 or 5 out of 9.

	Total Rainfall (mm)			Rank		
	Sep-Nov	Oct-Nov	Nov	Nov	Oct-Nov	Sep-Nov
2010	358.8	99	15.8			
2011	333.4	276.8	123			
2012	208.6	141.6	36.2			
2013	403.8	240.4	47.8			
2014	272.8	156.2	60			
2015	280.1	186.7	61.1			
2016	567.4	381.6	247.8			
2017	235.6	95	33			
2018	392.4	286.8	145.8			
2019	350.6	251	102.8	5	4	4

Table 2 Assessment of antecedent conditions for 8 December 2019 storm based on prior spring rainfall at Pinehaven Reservoir.

Average antecedent catchment conditions mean that the run-off response to rainfall in the catchment in December 2019 would not have been unusually severe or subdued for the pattern of rainfall that occurred in that particular storm.

Conclusion

Combining all these elements,

- average antecedent conditions,
- rainfall distributed evenly over the catchment area
- rainfall at the critical duration being about a 1 in 28 year ARI

I conclude that the rainstorm on the 8 December 2019 was likely to have generated a peak flow with a magnitude equivalent to the critical duration rainfall of 1 in 28 years ARI. The annual exceedance probability (AEP) of the peak flood flow at the staff gauge near the Dutch Reform Church on 8th December 2018 is likely to have been in the order of 0.04 to 0.033 AEP (a 1 in 25 year to 1 in 30 year average annual return period).

---

[2] Hopkirk C, 2019 "Frequency Analysis - Rainfall Event on 8th December 2019, Wellington Water Technical Memorandum, 13 December 2019, 6p

<u>Note on reported storm rainfall durations</u>

Hopkirk (2019) reports 20min and 1 hour duration rainfall for the 8 December 2019 storm. The shorter durations are relevant for estimating localised flooding effects in branches of the Pinehaven catchment. For example 20 minutes rainfall totals might be relevant for sub-areas of the catchment where the time of concentration is about 20 minutes such as for storm water drains. Similarly 1 hour rainfall totals could be relevant for assessing flooding at the downstream ends of larger sub-areas or halfway down the catchment where the time of concentration of flow is about 1 hour. So the shorter duration rainfalls may be relevant for assigning peak flows in different parts of the catchment and related localised inundation effects. In combination, these separate peak flows when routed to the outlet, say in a rainfall-runoff model with its nominated outlet at the Dutch Reform Church staff gauge, should equate to the observed peak flows at the staff gauge near the Dutch Reform Church.

It is quite possible in a single rain storm assigned a 1in 25 year ARI for some parts of the catchment to have experienced 1in 15 year rainfall and other parts 1in 40year rainfall for the relevant critical duration at that location in the catchment, and for those parts to experience associated inundation effects. The unders and overs should be recognised and adjustments made in mapping inundation for a particular nominal ARI storm rainfall or AEP flood flow.

Yours sincerely

Alasdair Keane

Appendix A: Depth-Duration-Frequency Table for Pinehaven Reservoir.

~~~ Hilltop Hydro ~~~ Version 6.53 2-Jul-2020

~~~ Rainfall Duration Distribution ~~~

Source is E:\!Projects\Pattinson Pinehaven St\Data1.hts

Rainfall (mm) at Pinehaven Reservoir - GWRCweb

From 1-Jan-2011 00:00:00 to 1-Jan-2020 00:00:00

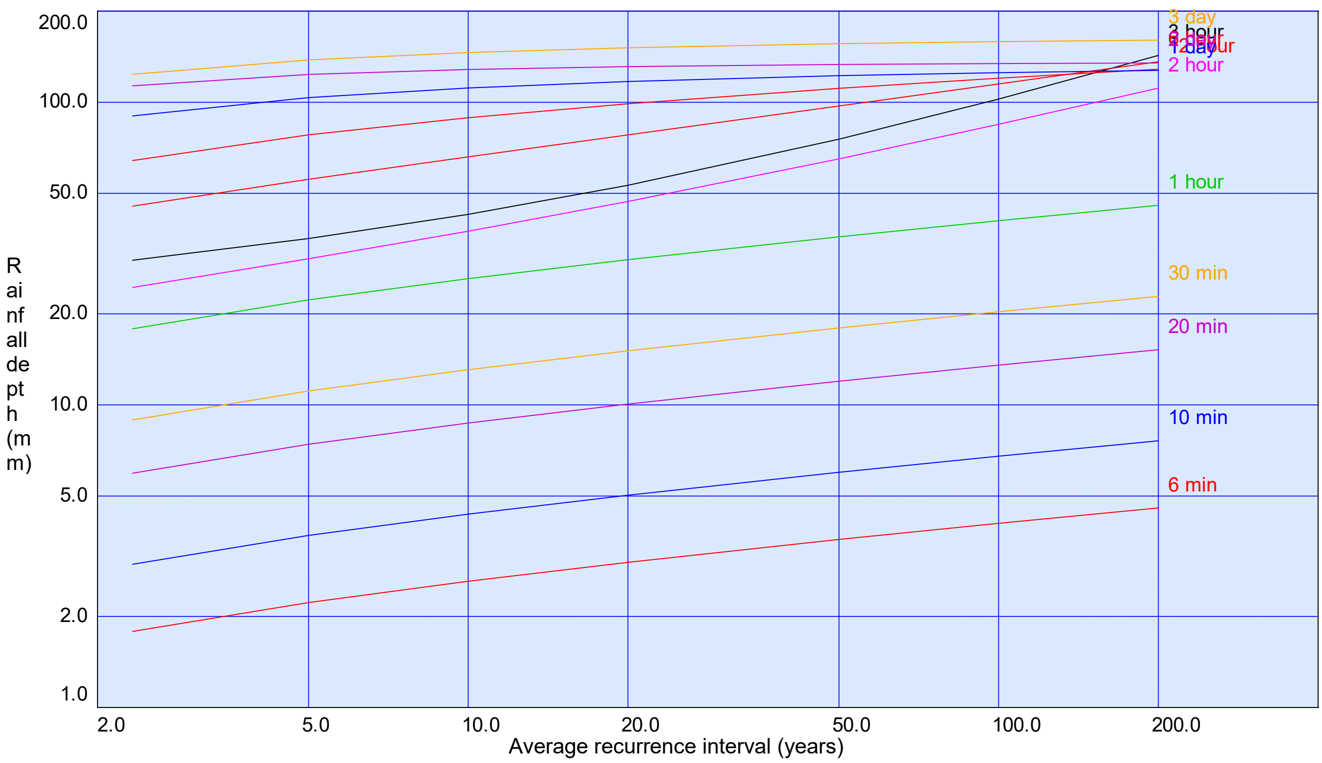
Distribution with 12 month partition

Values smaller than 0.000 not used when fitting

Values larger than 0.0000 not used when fitting

	ARI						
Duration	2.33	5	10	20	50	100	200
6 minute	1.8	2.2	2.6	3.0	3.6	4.1	4.6
10 minute	3.0	3.7	4.4	5.0	6.0	6.8	7.6
20 minute	5.9	7.4	8.7	10.1	12.0	13.5	15.2
30 minute	8.9	11.1	13.1	15.1	18.0	20.3	22.8
1 hour	17.8	22.2	26.1	30.2	35.9	40.6	45.7
2 hour	24.4	30.4	37.5	47.0	65.0	84.6	111.3
3 hour	30.1	35.5	42.6	53.2	75.5	102.4	142.9
6 hour	45.4	55.7	66.0	78.0	97.2	115.0	136.1
12 hour	64.2	78.1	88.9	98.9	111.2	120.1	128.6
1 day	90.1	103.6	111.5	117.1	122.4	125.3	127.4
2 day	113.3	123.6	128.4	131.2	133.3	134.2	134.8
3 day	123.7	138.0	145.9	151.4	156.2	158.7	160.5

,



Rainfall [Rainfall] versus ARI at Pinehaven Reservoir - GWRCweb from 1-Jan-2011 00:00:00 to 1-Jan-2020 00:00:00 GEV distribution

Graeme Horrell_review of RJ Hall & Assoc report 27_7_20

Graeme Horrell - Review of:

"Pinehaven Stream flood 8 December 2019 at Chatsworth road gauge site and its implications for flood frequency estimates in the catchment" by R J Hall & Associates Ltd, 27 July 2020.

The report provides an estimate of the peak flow for this event at Chatsworth Road staff gauge. Extensions are made to the incomplete GWRC rating curve, which then enables a revision of the previous (MWH, SKM) flood frequency analysis for Pinehaven Stream.

Flood profile survey data was provided by 'Save Our Hills Upper Hutt Incorporated' [SOH] for this analysis which is in lieu of flood flow measurements not undertaken by GWRC.

Section 1:

Whilst not a hydraulics engineer, I can confirm the mean velocity derived are close to the previous independent work completed for the 23 July 2009 flood which was some 67 mm higher on the staff gauge. This independent work was based on mean velocity estimates passing through a measured area for the same location.

Section 2:

The extended rating curve will provide more reliable estimates.

Section 3:

This is a thorough reality check using 6 methods to derive flood frequency curves and is something that was missing from previous flood frequency studies for Pinehaven Stream which were limited, and over-estimated flows considerably. When compared MWH mean annual flood will have an average return interval of approximately 10 years. Furthermore MWH's 10 year flood is revised to be beyond the 100 year return interval.

Conclusions

The conclusions drawn from the analysis are sound, indicating clearly that previous flood frequency analysis prepared for GWRC be abandoned along with the proposed stream upgrade. I would add, future upgrades be delayed until at least 10 years of continuous flow measurements have been completed on Pinehaven Stream to enable a revision of the Pinehaven Stream flood frequency analysis. It is unfortunate the flow recorder site installed in 2008 was removed, as 12 years of flow data would have been available today.

Graeme Horrell 27 July 2020

Graeme Horrell_Revised_Letter 2009 flood

Graeme Horrell Consultancy Limited

8 November 2018, revised 24 July 2020

Steve Pattinson
President
Save Our Hills (Upper Hutt) Inc
Hutt Valley
Wellington

Assessment of the Pinehaven Stream 23 July 2009 flood peak.

1 Back ground

You have requested me to become familiar with the information you have sent, and provide a check on the GWRC flow record of the 23 July 2009 event measured at Pinehaven Stream opposite Chatsworth Road: stage, gaugings, rating curve and rating curve extension to peak stage measured. Provide my opinion on the peak discharge and ARI findings in a letter.

My understanding of your requirements is that GWRC has used the 23 July 2009 flood event to calibrate a model which has been used to show the flood extent of a 100 year design flood on the community in Pinehaven. You are requesting an independent assessment of the 23 July 2009 event in terms of flood peak and return period.

2 Rating curve extension issues

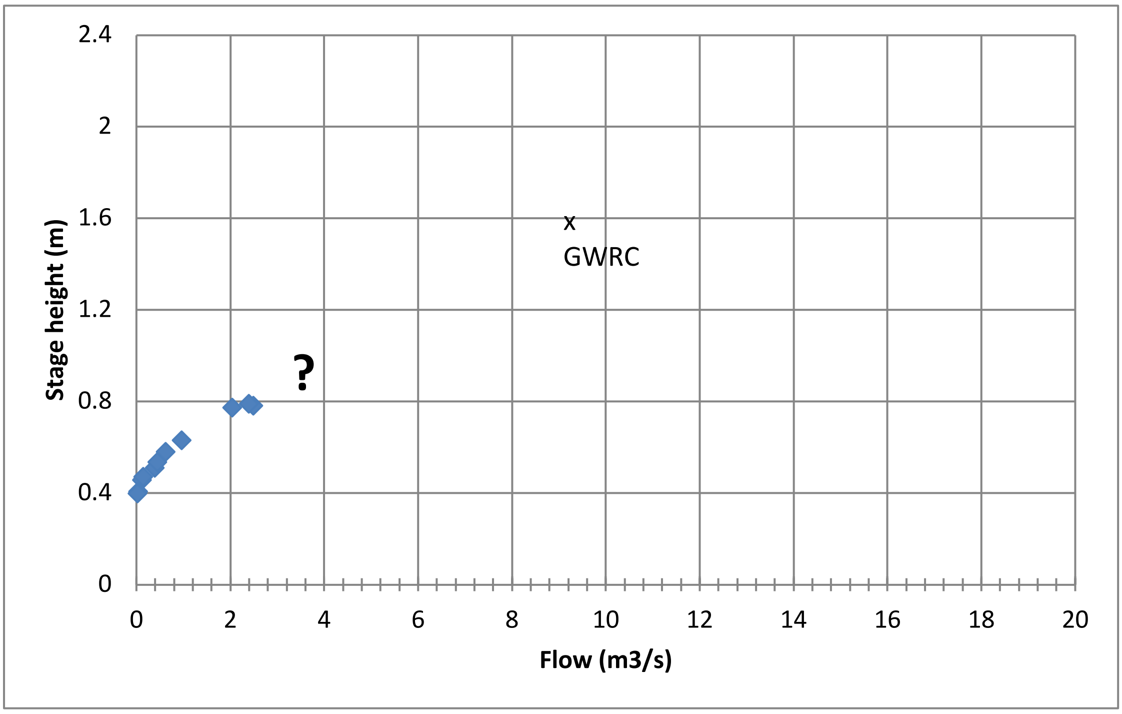


Figure 1: Flow gaugings available and the problem with extending the rating curve without high flow gaugings.

The problem for the GWRC hydrology team was how to extend the rating curve from 0.8 m to 1.6 m Figure 1, due to the lack of high flow measurements. The lack of any flood measurements or mapped flood marks during the peak of the 23 July 2009 is disappointing as the capture of flood measurements for flood design purposes is the main reason for the flow recorder site on Pinehaven Stream opposite Chatsworth Road.

High flow gaugings will give key information for extending the rating curve to provide accurate values of the peak flood. Unfortunately one gauging was completed the day after on 24th July but the flows had receded considerably to only 0.44 m3/s. An attempt was made on 30 August 2009 to measure high flows to define the top end of the rating however stage height levels measured were less than 0.8 m, some 0.77 m less than the 1.577m peak measured on 23 July 2009 peak.

Plots of the 23 July flood hydrograph with the gauging plotted are displayed on Figure 2 and the 30 August peak with three gaugings plotted are shown on Figure 3.

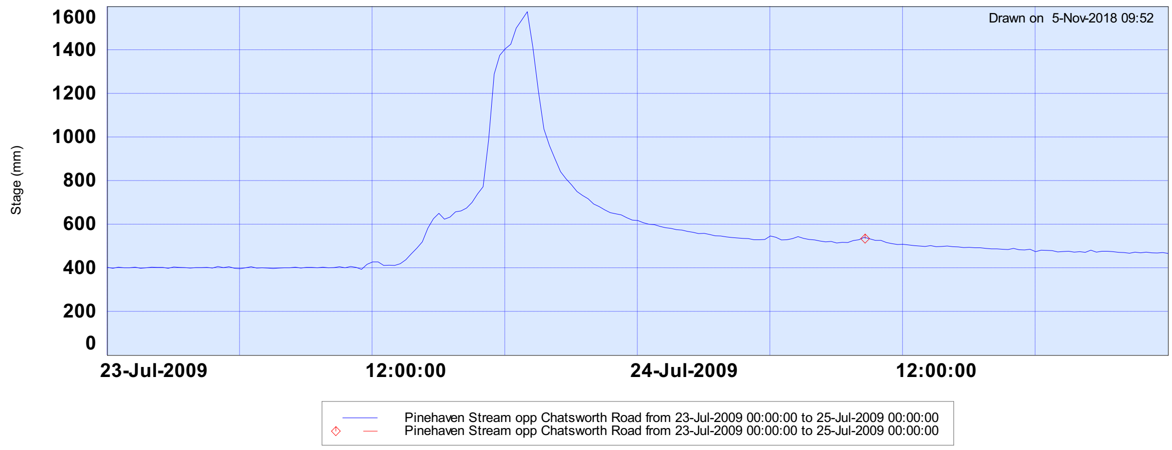


Figure 2: Pinehaven Stream flood hydrograph for 23 July 2009 and single gauging of 24 July 2009 (red diamond).

Figure 3: Fresh of 30th and 31st August 2009, 3 gaugings measured are displayed as red diamonds.

It is not common to gauge a river on the peak; however gaugings below the peak are often achieved and used to extend the rating curve to derive the peak flow.

It is standard practise to extend the top end rating curve using an area curve to develop a stage versus mean velocity curve Figure 4. A recorder cross-section is surveyed and a stage versus area curve developed. A recorder cross-section is available (perhaps at downstream weir which is acceptable). For this site the area curve will be accurate as I believe degradation or aggregation of the bed during the flood event on Pinehaven Stream will be minimal, at other natural river sites this can be large e.g. braided rivers. The area curve is used and divided by the measured flow for each completed gauging to develop a stage versus mean velocity curve (Figure 4).

Some knowledge of what will happen to velocities at higher stage values is required. For example if the river were to break out over a flood plain the velocities may become slower as the stage height increases, this will not happen here (until perhaps 2.5 m stage height). From experience (there are many exceptions) the maximum mean velocity for most rivers is between 3 - 4 metres per second. The channel is very smooth and downstream of a steep slope and could be higher than this, only measurements will answer this, but none are available which seriously detracts from this rating curve extension method.

With the lack of higher flow gaugings, extending the velocity curve is difficult, see Figure 4 below.

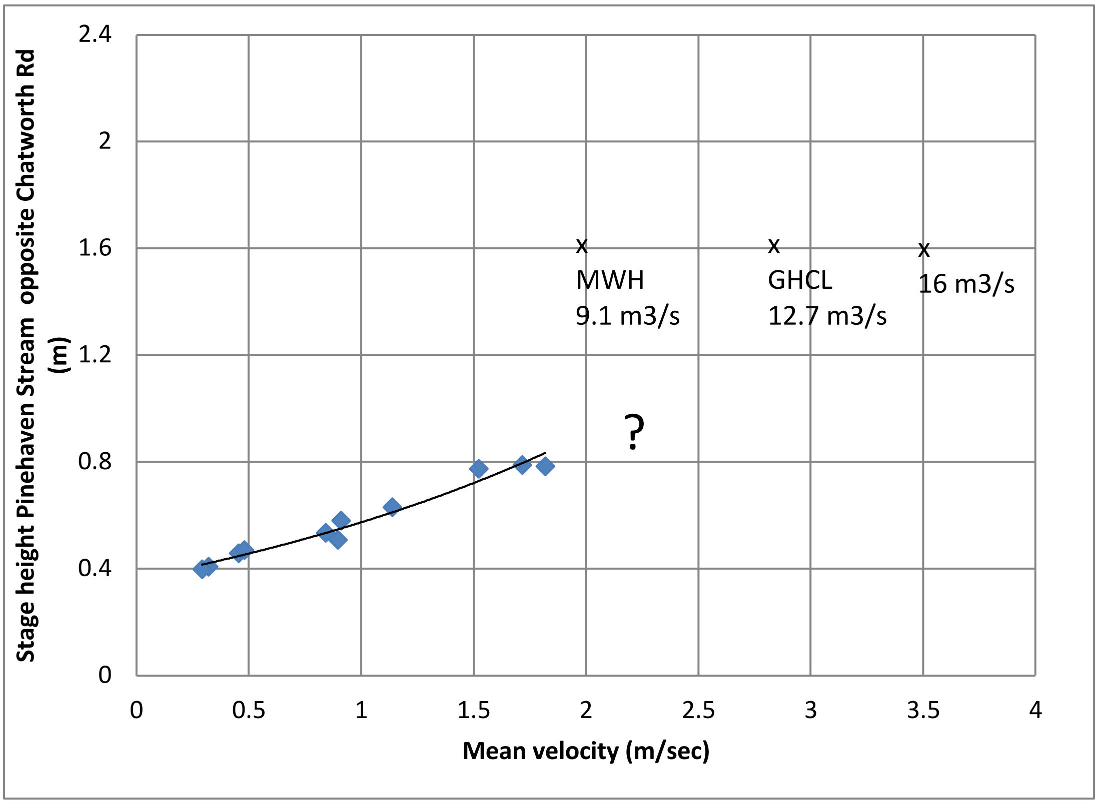


Figure 4: Pinehaven Stream at Chatsworth road stage height versus mean velocity curve

Figure 4 displays the problem with extending the stage/velocity curve between 0.8 m and 1.6 m. The MWH approach was to adopt 2 m/sec at stage 1.6 m. However this is only a 10 % increase in mean velocity from the stage of 0.8 m. This is not plausible in such a smooth bedded and smooth walled channel. My estimate is 2.8 m/sec which would result in a 12.7 m3/sec flow at 1.6 m, however for a flow of 16 m3/s a mean velocity of 3.51 m/sec would be required.

My estimate of the flow peak at 1.577 m on 23 July 2009 is 12 m3/s, however future high stage gaugings to define the stage/mean velocity curve would provide higher confidence to estimates.
I consider the 8.8 m3/s an underestimate. Interestingly the SKM (2010) reported modelling of 23 July 2009 event shows a peak discharge of approximately 11.8 m3/s, but unfortunately their depth at the staff gauge is 400 mm less than measured, this detracts from the use of this single calibration.

3 Pinehaven Stream design flood estimates

ARI (Years)	Harkness 2009 (Rainfall runoff model) 3 methods (m3/s)	Horrell 2020 Pearson (1990), Henderson & Collins 2016 (m3/s)	Horrell 2020 5 years data Henderson & Collins 2016 (m3/s)	Henderson 2018 Henderson & Collins (2016) Regional flood study (m3/s)	Bob Hall 2020 Mangaroa, Runoff coefficient ratio and NIWA 2018 (m3/s)
Mean annual flood	9.8	6.5	5.04	7.39	6.2
5	15	8.6	6.6	9.8	8.5
10	16	10.3	8.0	11.8	9.9
20	18	12.0	9.3	13.7	11.4
50	20	14.3	11.1	16.3	13.4
100	22	15.9	12.3	18.1	15.0
PMF	86	-		-	

Table 1: Pinehaven Stream design flood estimates.

i) It should be noted that to give reliable estimates of the return period of the 23 July 2009 flood event, a continuous flow record of Pinehaven Stream is required. If for example 100 years of flow record existed then the estimate of the return period for this event would be very reliable.

ii) The next best estimate would be if there were some years of continuous flow records, say 10 or 20 years; and the annual maximum floods can then be used to calculate the mean annual flood. This is then applied to the ratio for specific annual return intervals e.g. 5 year, 10 year. The ratio is provided from regional flood studies, McKerchar and Pearson (1989), or the recent Henderson and Collins (2016). This method is commonly used by hydrologists and engineers for design purposes as hydrological records are usually collected. However this method was not available to GWRC as the Pinehaven site was only operating from 2008 to 2013 and the high flow part of the stage/discharge rating curve was not defined by measurements as described above. It is unthinkable that a key site for design purposes is closed. Perhaps GWRC installed another site?

iii) The next best method is to obtain a calculated runoff coefficient from a neighbouring catchment which has a long flow record. Fortunately the Mangaroa catchment boarders Pinehaven Catchment, and has records from 1977 (42 years), this is a valuable record.

This study was undertaken by Bob Hall. This is the best method available to establish what the mean annual flood is (6.2 m3/s) for Pinehaven stream. The ratios as described above can then be applied.

iv) Regional flood studies are very useful for providing estimates of the mean annual flood and flood estimates for various annual return intervals where very little or no data exists. The key proviso is that they are estimates only.

Engineers designing structures for the communities protection prefer to use hydrological data from their catchment of interest rather than solely from regional studies, however they will often cross check their at site analysis with (i, ii, iii above) with a regional study.

This study Horrell (2020) used the Pearson (1990) maps to estimate the mean annual flood and the Henderson and Collins (2016), to estimate the ratio from mean annual flood to selected ARI's.

The additional Horrell (2020) study used the 5 years of stage data collected at the site before closure and applied the corrected rating curve described above to estimate the mean annual flood and the Henderson and Collins (2016) to estimate the ratio from mean annual flood to selected ARI's. This method whilst with the advantage of using actually measured flow data from Pinehaven , which no other method includes, however it falls short of the 10 years recommended to establish the mean annual flood flow.

The Henderson and Collins 2016 regional study is added to Table 1 and 2 for completeness.

	Harkness 2009	Horrell 2020	Horrell 2020 (5 years data)	Henderson 2018	Bob Hall 2020
ARI of 12 m3/s	3.5	20	80	12	28

Table 2: Estimates of the annual return interval (ARI) for the 23 July 2009 12 m3/s peak flow

The recommended frequency analysis is that completed by Bob Hall, it is noted the Harkness analysis disagrees considerably with the four other analysis in Table 1 for the ARI for 5 , 10, and 20 years and subsequently in Table 2.

4 Review of the 'Pinehaven Flood Hydrology' report prepared by Mike Harkness

As requested I have reviewed the Pinehaven Flood Hydrology report prepared by Mike Harkness (4 November 2008 and revised additions 25 November 2009). Listed below in blue are key quotes from the report.

"Limited calibration data is available – only one flood event was available to be used to calibrate the model."

This rainfall runoff modelling if proceeded with will result in large uncertainties.

Typically at least 8 sizable floods (derived from fully developed rating curves, described in 2/ above) are used to determine meaningful design estimates. At least 4 of these floods will be used in the calibration phase of the model and once calibrated the model is tested using the remaining 4 floods.

The Pinehaven design estimates are the result of just one flood with no testing.

Recorded flow data for this flood event have been supplied by GWRC. The peak flow is estimated to be 8.8m3/s. It must be noted that due to the short period of record and lack of certainty about the conversion of high measured water levels to flow (rating curve), the 8.8 m3/s estimate may be revised in the future when new information is available.

Agree with this comment and believe the rainfall runoff modelling should not have proceeded.

There are uncertainties in calibrating a rainfall-runoff model to just a single recorded flood event. Particularly when there is uncertainty associated with the actual flow data due to the short length of record at the site and a lack of other high flow events to confirm the flow rating.

Agree

Ideally a number of recorded flood hydrographs would be available for calibration to provide confidence in the modelled peak flow estimates and hydrographs shapes.
However, it is better to have the one peak flow estimate to calibrate the model to than nothing at all.

Agree a number of hydrographs are required, however Mike does not know the uncertainties that come with his method, from my experience at least ± 100 %.

6.4 Rainfall-Runoff Model Limitations (2008 version)
The major limitation of the rainfall-runoff modelling process for the Pinehaven Stream is the lack of calibration data. Although a single calibration point was available, it was a relatively minor flood event. The use of the model to simulate extreme flood events will therefore carry relatively high uncertainties.
Agree

A number of recorded flood hydrographs is preferred for calibration purposes to ensure estimates of peak flows and hydrograph shape are as accurate as possible.
Agree

This uncertainty is reduced by comparing modelled output with peak estimates from other methods as summarised in Section 7.
This is somewhat self-fulfilling, as you are effectively using these studies to get an answer, then the model is manipulated/calibrated to get those same results.
MWH 's testing appears to be a comparison with regional flood studies which gave them confidence to recommend to GWRC that hydraulic modelling could proceed. These hydraulic modelling flood inundation outputs will have large uncertainties and are the major cause for disagreement with the locally observed historic flood levels.

"Despite the lack of calibration data available for the model the result obtained are similar to those derived by the regional methods. This provides confidence in the use of the modelled results and the design flood hydrographs for further hydraulic modelling"

This model has not been tested against measured flood events.

Hydstra Modelling has been used in many hydrological applications in New Zealand and around the world for rainfall-runoff and design modelling.

I have no doubt this is an appropriate model to use for this analysis, however it is dependent upon reliable rating curves and multiple floods for calibration and testing, only then will it give reliable estimates.

It is recommended that GWRC make use of data from its recently installed flow recorder on the Pinehaven Stream and check/re-calibrate the rainfall-runoff model after a number of years or flood events have been recorded.
Agree but disappointing to find the site was closed in 2013.

The rainfall analysis looks plausible however it is disappointing the raingauge within the Pinehaven Catchment malfunctioned providing no records of the 23 July 2009 storm event.

5 Summary

1/ The top end rating curve for Pinehaven stream opposite Chatsworth Road has not been defined due to the poor data collection, even though this site ran for 5 years. It is considered the estimated flood peak of 8.8 m3/s on 23 July 2009 is an under estimation.

2/ My estimate of the 23 July 2009 flood peak is 12 m3/s (based upon an estimate of the peak mean velocity) which is approximately a 28 year ARI (Mangaroa study using runoff coefficient ratio)

3/ The use of only one flood (with an incorrect flow peak estimate) and lack of any catchment rainfall for calibration followed by the lack of any testing against actual data makes the analysis invalid. Any further use such as a hydraulic modelling will introduce large errors, as shown in the differences in modelled flood extent and those observed by many in the community.

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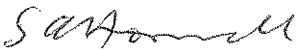
Yours sincerely



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ACADEMIC QUALIFICATIONS:

- New Zealand Certificate of Science – 1985
- University of New South Wales – Post Graduate Course in Hydrology – 1990
- University of New South Wales – MSc Engineering Science (Hydrology) – 1992

SPECIALIST EXPERTISE:

- Integrated catchment water management
- Hydrological modelling
- Water resource mapping
- Flood forecasting
- High intensity rainfall frequency analysis
- Flood warning in flood prone catchments
- Data processing and quality

PROFESSIONAL EXPERIENCE:

2016 -	Graeme Horrell Consultancy Limited
2008 – 2016	Engineering Hydrologist and project Leader, NIWA Christchurch
1990 – 2008	Surface Water Quantity Scientist Team Leader, Environment Canterbury, Christchurch
1986 – 1989	Senior Analyst, North Canterbury Catchment Board, Christchurch
1983 – 1985	Hydrological Engineering Officer Power Investigations (Consultants to ECNZ), MWD, Wellington
1970 – 1981	Hydrological Technical Officer – MWD and MWD Hydrology Centre, Christchurch, Greymouth, Timaru, Lake Tekapo, Antarctica

PROFESSIONAL AFFILIATIONS/MEMBERSHIPS:

- New Zealand Hydrological Society (period as executive member) - since 1983
- New Zealand Meteorological Society – since 1984
- New Zealand Deer Farmers Association – since 1997
- Irrigation New Zealand – since 2006
- Waihora/Ellesmere Trust - since 2007
- Ministry of the Environment Hearings Commissioner - since 2013
- Adjunct Fellow, Waterways Centre, University of Canterbury - since 2016

PROFESSIONAL DEVELOPMENT:

High Intensity Rainfall Design System (HIRDS)

- Testing and promoting New Zealand's high intensity rainfall design system to be fit for purpose and readily adopted by design engineers throughout New Zealand.
- Planned and obtained funding for the 2016 HIRDS upgrade, to include NZ's first areal reduction curves and temporal design storm patterns.

Integrated catchment management

- Set up Environment Canterbury's first completely integrated catchment water resource survey on the Orari catchment, this included surface and groundwater interaction as well as the full measurement of all surface and groundwater abstractions.

Mapping water resources

- Overseen the complete mapping of the Canterbury region's water resources at low flow, including concurrent gaugings to detect losing and gaining reaches.

Water loss and gain surveys

- Completed on the, Rakaia, Waimakariri, Rangitata, Orari, Ohapi, Ashburton, Selwyn, Avon, Waipara, and Ashley rivers.

Naturalising river flow

- Advanced the knowledge of the naturalised Ashburton River flow regime to enable integrated catchment water resource management.
- Water Plan scenario modelling of tributaries and main stem minimum flows and allocation, to achieve the same high reliability of supply for all catchment irrigators.

Water balance modelling

- Developed a practical (42 year) daily water balance model of Te Waihora (Lake Ellesmere) for lake level scenario testing for optional management rules, used in two WCO Hearings.
- The key witness at the Hearing for the amendments to the WCO on Te Waihora (Lake Ellesmere) to improve the environmental health of this fourth largest lake in New Zealand.
- Model used in the Selwyn/Waihora Zone limit setting.

Environment Court negotiations

- Advanced the Opihi River Plan environment Court negotiations by modelling the influence of the Opuha Dam.
- Negotiating consent conditions for the abstraction of water from the Hakataramea River

Flood Forecasting

- Successfully developed one of the first flood forecasting systems in Australasia. Forecasts provide 16 hours warning to Christchurch of Waimakariri River floods.
- Forecast floods for the Ashley River to the Rangiora traffic Bridge, from storm rainfalls. Providing up to six hours warning of flood peaks within ±13% of the actual magnitude and within ± one hour of arrival time. The model was used to confirm the 100 year design flood for the Ashley Floodplain Management Regional Plan.

Team Leader

- Led a surface water monitoring team operating a large hydrometric network and successfully increased the annual data processed, from 40% to 99%. Youngest research team leader in the Antarctic.

Rainfall research

- Set up and serviced climatological and hydrological stations across a transect of the Southern Alps of New Zealand from Mt Hutt to the Waitaha Valley on the West coast.

- Included organised teams of up to 28 scientists and technicians to complete monthly measurements using helicopters in a rugged mountainous area, where the weather can change very quickly. Measurements of 13000 mm annual rain and winds of 210 mph were common.

MANAGEMENT SKILLS:

- Ability to motivate people to undertake and complete projects
- Highly organised, experienced coordinator and delegator of tasks
- Patient listener with empathy for people's opinions and feelings

PUBLICATIONS:

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