APPENDIX F – Hydrology

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1) Technical Note with Agreed Design Flows

Comrie and Dalginross Flood Study

Baseline Design flows and Water Levels

Produced for

Perth and Kinross Council

The Atrium 137 Glover Street

Perth PH2 0HY

Prepared by

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Date: 24th March 2015

Version	Status	Author	Date	Check	Date	Authorised	Date
1.0	Draft	T Jolley P Ghimirie	06/02/15	T Jolley	10/02/15	P Swift	10/02/15
2.0	Final	T Jolley P Ghimirie	24/03/15	T Jolley	24/03/15	P Swift	24/03/15

The checking process includes text, calculations and figures prepared for this report.

Introduction

The purpose of this note is to set out the design flows that will be used to derive the baseline water levels and the method that will be used to derive the water levels for options.

Following a meeting on 17th February SEPA confirmed that they are satisfied with the recommendations and that the flows and method can be used for the appraisal of (Appendix A).

Design Flows

The design flows were presented in the Mouchel report *Results of the Simplified Hydrological Joint Probability Analysis*[1] and are reproduced in Appendix B.

Alternative combinations of flows (referred to as scenarios) have been run through the baseline hydraulic model to determine which ones give the highest water level for a specified location (Table 1). This approach ensures that the return period for a given design standard is constant throughout the model domain.

Scenario	Description
1	The return period of flows in the Ruchill, Upper Earn and Lednock are all equal and the peaks are assumed to coincide at Dalginross.
2 3 4	Scenarios 2, 3 and 4 represent the cases where the design flow occurs in each water course with almost zero flow in the other two water courses. These scenarios have been superseded by scenarios 6, 7 and 8.
5	Scenario 5 gives the flows in each of the rivers that combine to give the design flow at Dalginross. The flows are calculated using a simplified joint probability analysis which gives flows equivalent to the 80 year in the Ruchill, 25 year and 8 Year in Upper Earn and Lednock.
6 7 8	Scenarios 6, 7 and 8 were requested by SEPA. The design flow in each river assumed to be coincident with the 10 year flow in the other two rivers.

Table 1: Alternative Design Flow Scenarios

[1] *Results of the Simplified Hydrological Joint Probability Analysis* (Version A Draft) Issued to PKC for comment 28th November 2014 and to SEPA on 9th December 2014

The return periods and flows for each scenario are given in Table 2 and Table *3* for the 200 year and 200 year with climate change events respectively.

Scenario	Return Period (Years)			Flow (m^3/s)		
No.	Ruchill	Upper Earn	Lednock	Ruchill	Upper Earn	Lednock
1	200	200	200	303.4	196.0	145
2	200	~ 0	~ 0	303.4	~ 0	~ 0
3	~ 0	200	~ 0	~ 0	196.0	~ 0
4	~ 0	~ 0	200	~ 0	~ 0	145
5	80	25	8	275.5	128.5	74.5
6	200	10	10	303.4	104.9	77.5
7	10	200	10	213.7	196.0	77.5
8	10	10	200	213.7	104.9	145

Table 2: Alternative Design Flow Scenarios for the 200 year Flow at Dalginross

Scenario	Return Period (Years)			Flow (m^3/s)		
	Ruchill	Upper Earn	Lednock	Ruchill	Upper Earn	Lednock
1	200	200	200	364.1	235.2	111.8
2	200	~ 0	~ 0	303.4	~ 0	~ 0
3	~ 0	200	~ 0	~ 0	235.2	~ 0
4	~ 0	~ 0	200	~ 0	~ 0	111.8
5	80	25	8	330.6	154.3	66.0
6	200	10	10	364.1	125.9	68.6
7	10	200	10	256.4	235.2	68.6
8	10	10	200	256.4	125.9	111.8

Table 3: Design Flow Scenarios for the 200 year + Climate Change Flow at Dalginross

The Flood Estimation Handbook (FEH) statistical method was used to estimate the peak flows for the Ruchill and Upper Earn. The FEH rainfall-runoff approach was used for the Lednock based on the calibration results of the model calibration and the SEPA post flood survey for the event of 23rd February 2014.

Design Levels and Flows at Dalginross

Estimates of the water level and flow at Dalginross have been compared for three methods:

- Hydraulic modelling using the design inflows at Cultybraggan, Aberuchill and Lednock as inflows
- FEH single site analysis using the water level record and the SEPA rating curve
- FEH single site analysis using the water level record and the model rating curve

Water Level

Hydraulic Modelling

The water level frequency curve in the Dalginross based on the model results with various return periods under scenario 1 (equal return periods in all three water courses) is given in Figure 1 and Table 4.

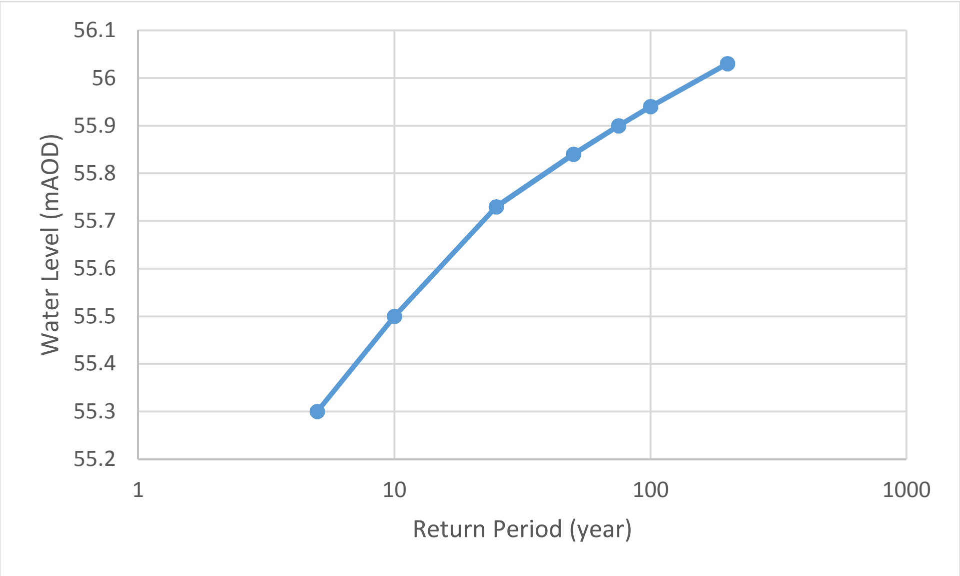

Figure 1: Growth Curve at Dalginross

Scenario	Flow (m^3/s)	Level (mAOD)	Return Period (Years)
1	472	56.04	200
5	397	55.75	25
6	405.5	55.79	25 to 50
7	394	55.73	25
8	398	55.75	25
1997 event[2]	NA	55.67	20
1993 event[3]	NA	55.78	25 to 50

Table 4: Growth Curve at Dalginross

[2] The event water level is the recorded water level by SEPA

[3] The event water level is the recorded water level by SEPA

Single site analysis of Water Level Data

Single site analysis of the annual maxima water level record has been used to estimate the growth curve for Dalginross. Estimates for return periods greater than 20 years must be treated with caution given the short relatively record length and the large confidence interval at high return periods. In addition, as the water level increases the out-of bank flow increases significantly resulting in attenuation of the hydrograph and reduced sensitivity of water level to flow.

Return Period (Years)	Water Level (mAOD)	Upper Limit (mAOD)	Lower Limit (mAOD)
1	53.21	52.32	58.24
2	54.92	54.70	55.10
5	55.26	55.02	55.47
10	55.47	55.26	55.73
25	55.75	55.54	56.16
50	55.97	55.67	56.50
100	56.2	55.70	56.88
200	56.44	55.66	57.31
500	56.77	55.47	57.88

Table 5: Water Level Growth Curve using Single Site Analysis

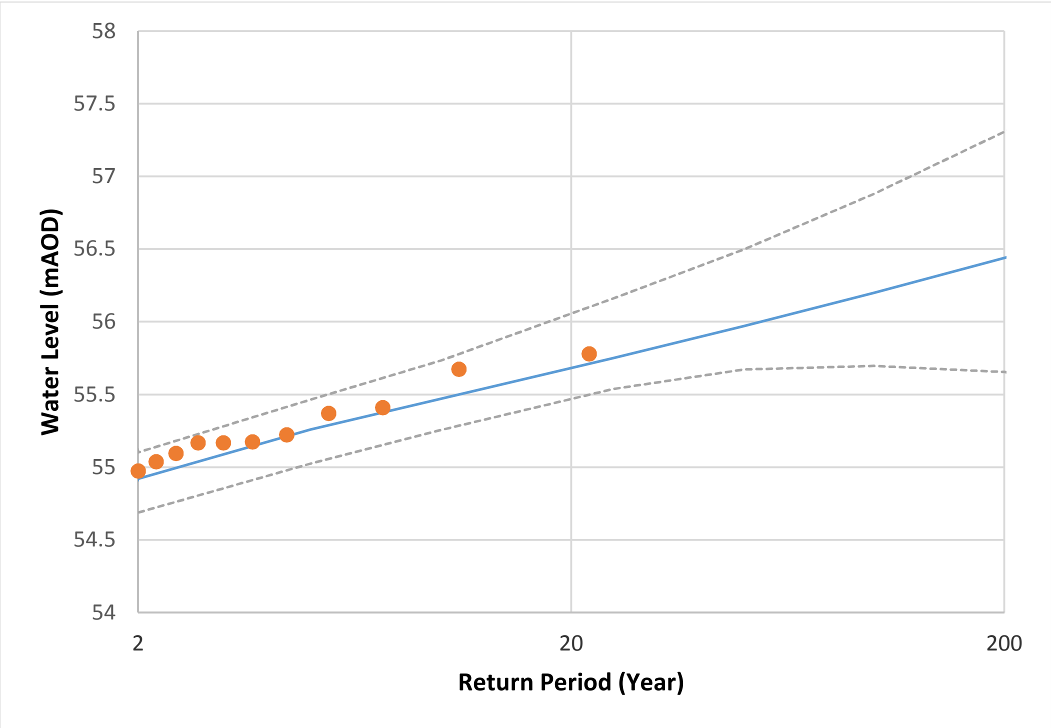

Figure 2: The Water Level Growth Curve using Single Site Analysis

Based on the model, 200 years flow at Cultybraggan, Aberuchill and Lednock (scenario 1) gives the level of 56.04mAOD at Dalginross; which lies between the 50 year and 100 year levels based on single site analysis. However, 56.04 mAOD lies well within the confidence interval for the 200 year level (56.66mAOD to 57.31mAOD).

The 200 years joint probability flow (Scenario 5) gives a level of 55.75 mAOD at Dalginross; which is approximately the 25 year event.

A summary of the return periods for specific flood events and scenarios estimated using the single site analysis are given in Table 6.

Event	Water Level (mAOD)	Return Period (year)
1997	55.67	20
1993	55.78	25
Scenario 1 (200 year in all rivers)	56.04	75
Scenario 5 (Joint probability flows (80 year in the Ruchill, 25 year and 8 Year in Upper Earn and Lednock[4]))	55.75	25

Table 6: Estimated return periods using single site analysis

The Dalginross Rating Curve

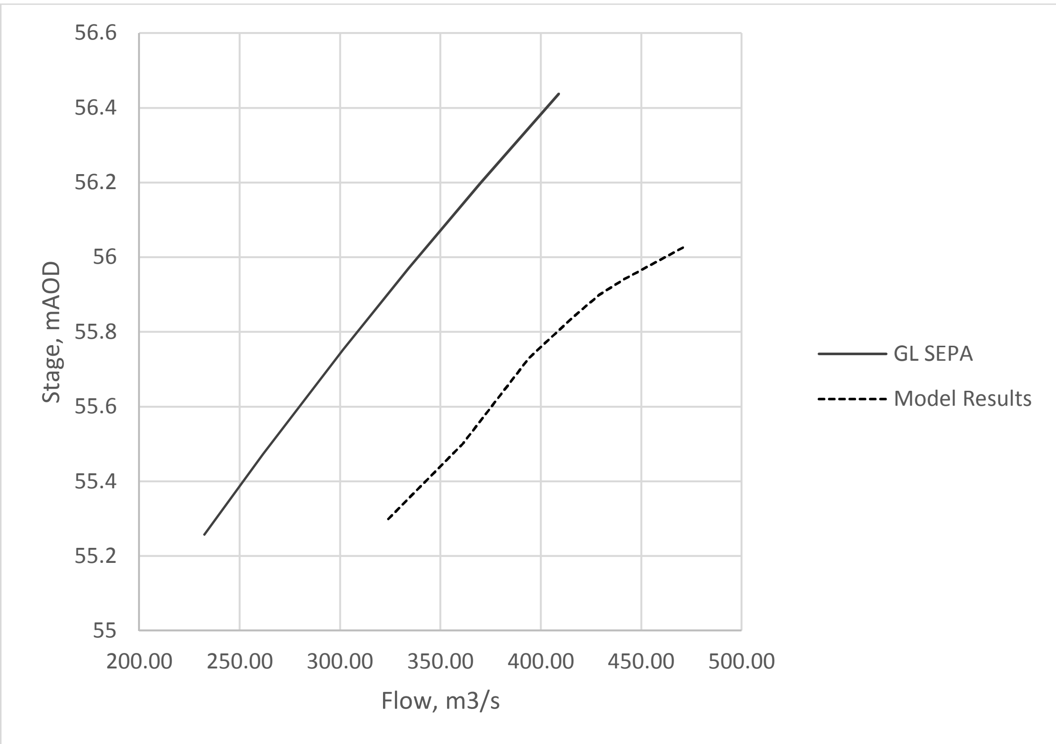

Figure 3: Rating curves at Dalginross

[4] FEH rainfall runoff flows used in Lednock

The model rating[5] (Figure 3) gives higher value of flow for the same water level compared to SEPA rating (blue line). The model rating is derived from the model results and it takes account of flood plain flow upstream of Dalginross, whereas SEPA rating is not valid when there is out of bank flow. The extent of the out-of bank flow is shown in the figure below.

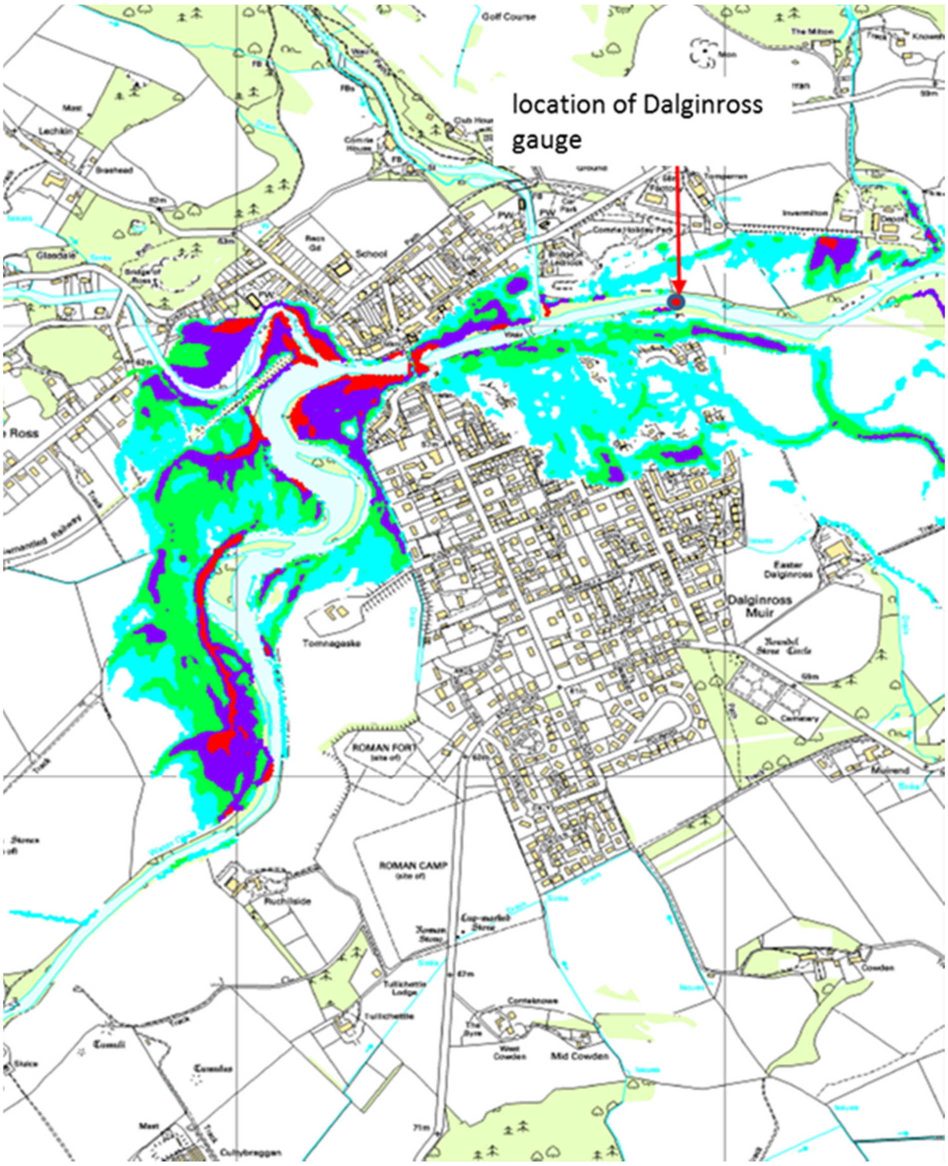

Figure 4: Flood Extent for Single site analysis and the model rating

The flow at Dalginross

The flow at Dalginross has been estimated using three approaches:

i) FEH pooling group analysis at Dalginross with QMED calculated from median water levek and SEPA rating curve.

[5] The model rating currently on the chart is directly derived from the model results and no equation has been applied to extrapolate data

This approach requires that all inflows are increased to ensure the sum of the inflows equals the design flow at Dalginross. This can be achieved by either using lateral inflows between the inflows and Dalginross or by increasing the inflows to the model. Neither option is ideal. Using lateral inflows ensures that the flows at Cultybraggan, Aberuchill, Lednock and Dalginross equate to the design RP but will present difficulties when options are appraised.

To obtain 459m^3/s at the Dalginross gauge, the respective flow ratio at the Cultybraggan: Aberuchill: Lednock would have to be 369:171:73. This ratio corresponds to >500 year RP at the Cultybraggan, approximately the 100 year at the Aberuchill and slightly less than 50 years for the Lednock.

These flows and associated RP's indicate that the estimated 200 year flow at Dalginross is not consistent with the 200 year flows in the Ruchill, Upper Earn and Lednock.

We would note that the FEH analysis should be treated with caution due to the influence of the upstream confluence and out-of bank flow. The location is not typical of the gauging stations used within FEH and the method does not ensure that flows upstream and downstream of the confluence balance for a given RP.

ii) Hydraulic modelling using the design inflows at Cultybraggan, Aberuchill and Lednock as inflows

This approach allows the hydraulic model to determine the level at Dalginross. It ensures that the inflows, the hydraulics and the rating at Dalginross are all consistent. No correction factors are required and the appraisal of options is straightforward.

Three scenarios have been run:
Scenario 1: the 200 year flow in each river
Scenario 5: the joint probability flows
Scenario 6: the 200 year flow in the Ruchill and 10 year flows in the Upper Earn and Lednock

iii) Single site analysis using the water level record at Dalginross and the SEPA rating

This approach estimates the growth curve at Dalginross using WINFAP with QMED estimated from the median stage and the SEPA rating. Estimates cannot be relied upon for RP greater than 20 years.

iv) Single site analysis using the water level record at Dalginross and the model rating

This approach is the same as for iii) but the model rating is used to estimate flow. This overcomes the limitation of the SEPA rating and ensures consistency with flows and levels predicted by the model.

The estimated flows using the four approaches are given in Table 7 below.

	(i)	(ii)			(iii)	(iv)
RP	Joint Probability[1]	Scenario 1	Scenario 5[2]	Scenario 6	Single Site (SEPA)	Single Site (Model)
2	188				190	173
5	239	324			232	219
10	274	361			262	250
25	323	394			301	294
50	364	416			334	332
100	40.	441			370	373
200	459	472	390	405	409	419
500	534				466	487

[1] The flows derived using joint probability at Dalginross

[2] The flow produced by the model at Dalginross when the joint probability flows are used as input to the model.

Table 7: Estimate peak flows at Dalginross

Comparison with post-flood surveys

The modelled water levels (Scenario 1 with equal return periods in all three water courses) were compared with the post-flood survey levels for the 1997 event (Table 8).

The figure below shows the locations where the water levels are compared and the results are given in Figure 5**Error! Reference source not found.**.

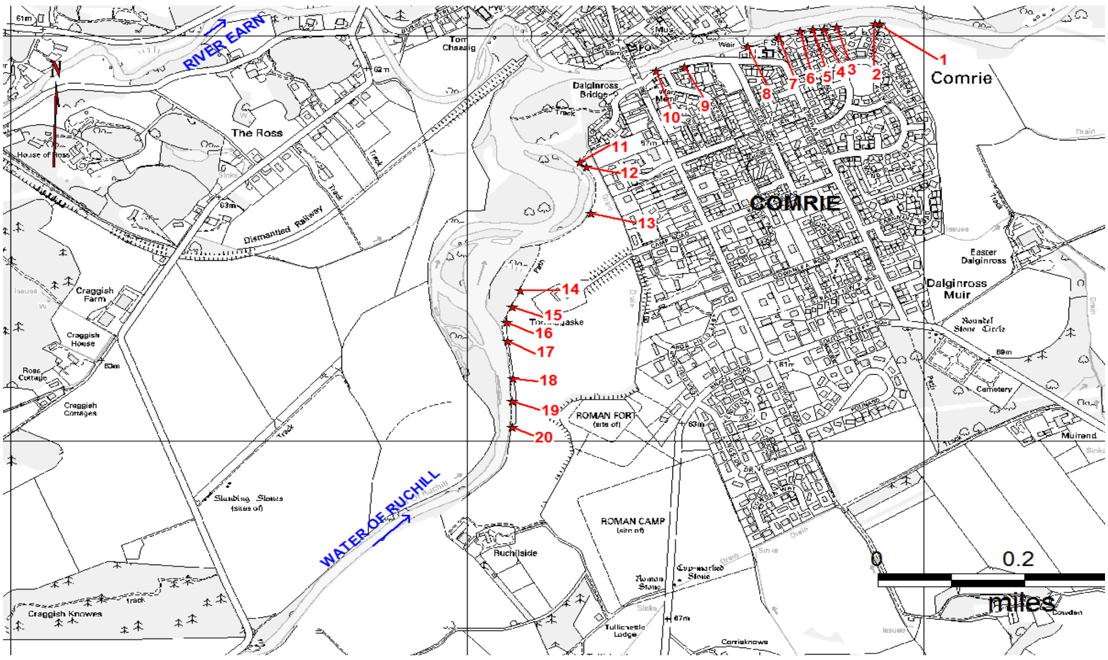

Figure 5: Locations where the model and recorded water levels are compared

Location	Arup recorded water level, mAOD	Mouchel 200 years all model level	Mouchel 100 years all model level	Mouchel 75 years all model level	Mouchel 50 year all model level	Mouchel 25 year all model level	Mouchel 10 year all model level	Mouchel model nodes
1	55.67	56.04	55.94	55.90	55.84	55.73	55.50	R000 (Dalginross gauge)
2	55.784	56.10	56.00	55.95	55.90	55.79	55.58	close to R025c
3	55.94	56.32	56.24	56.21	56.17	56.09	55.92	R100
4	56.13	56.37	56.29	56.26	56.22	56.15	56.00	R125
5	56.17	56.33	56.25	56.22	56.18	56.11	55.98	R150
6	56.21	56.53	56.43	56.39	56.34	56.25	56.10	R175
7	56.548	56.67	56.59	56.55	56.51	56.42	56.27	R225
8	56.897	57.20	57.07	57.02	56.96	56.86	56.68	R300
9	56.923	57.36	57.31	57.29	57.27	57.21	57.10	R450
10	57.1	57.65	57.58	57.54	57.50	57.42	57.27	R500
11	58.678	58.95	58.82	58.77	58.72	58.63	58.54	Between R1100 and R1200
12	58.425	58.95	58.82	58.77	58.72	58.63	58.54	Between R1100 and R1200
13	59.108	58.95	58.82	58.76	58.71	58.66	58.59	R1225
14	59.949	60.07	60.05	60.04	60.03	60.00	59.96	R1500
15	60.284	60.31	60.29	60.28	60.26	60.24	60.19	R1550
16	60.7	60.76	60.73	60.71	60.68	60.64	60.57	R1600
17	61.2	61.10	61.06	61.04	61.01	60.96	60.87	R1650
18	61.646	61.41	61.36	61.34	61.30	61.24	61.14	BETWEEN R1725 and R1750
19	61.656	61.77	61.73	61.71	61.67	61.62	61.53	R1800
20	61.955	61.90	61.87	61.85	61.83	61.78	61.71	BETWEEN 1850 AND 1875

Table 8: Model validation results for the 1997 flood event (The shaded cells indicate the RP of the 1997 recorded level)

In general, the post-flood level varies between the 20 to 30 year level downstream of the confluence between the Ruchill and Upper Earn (location 10). The estimated return period of the surveyed water level in the Ruchill is variable ranging from less than 10 year to greater than the 200 year which may well reflect the greater uncertainty in post-flood surveys in areas where flood plain flow is prevalent.

A chart showing comparison of Arup's and Model results (scenario 5 without flow constraint at the Dalginross gauge is presented below:

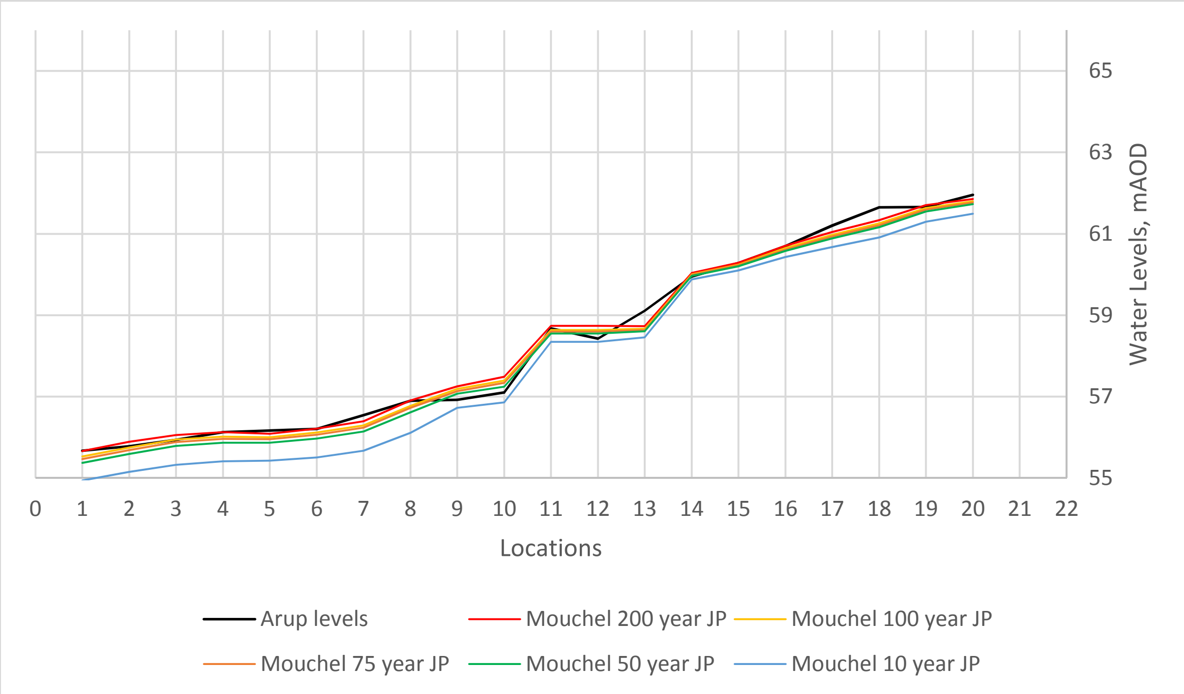

Figure 6: Model validation for the 1997 flood event

Comparison with SEPA flood map

A comparison between the SEPA map and scenario 1 (with 200 years in all three watercourse) flood extent is shown in Figure 7.

Figure 7: Comparison between 200 year flood map and the SEPA flood map

The scenario 1 flood extent is close to the SEPA map which is expected as it is understood that the SEPA flood map is based on a 200 year flow in each river.

Possible Flooding of Ross

SEPA raised concerns that the risk of flooding to the properties at The Ross may increase and asked Mouchel to confirm if the flood study will be investigating the risk of flooding from water overtopping both the right and left banks of the Ruchill.

The flood maps show that the gardens of 2 houses are at the risk of flooding. During the flood peak the houses at the Ross get flooded from the Ruchill Water rather than from the Earn with most of the over the bank spill from the left bank of the Ruchill returning to the Ruchill further downstream.

Prior to the flood peak the properties are at risk from both the Ruchill and Upper Earn (Figure 8).

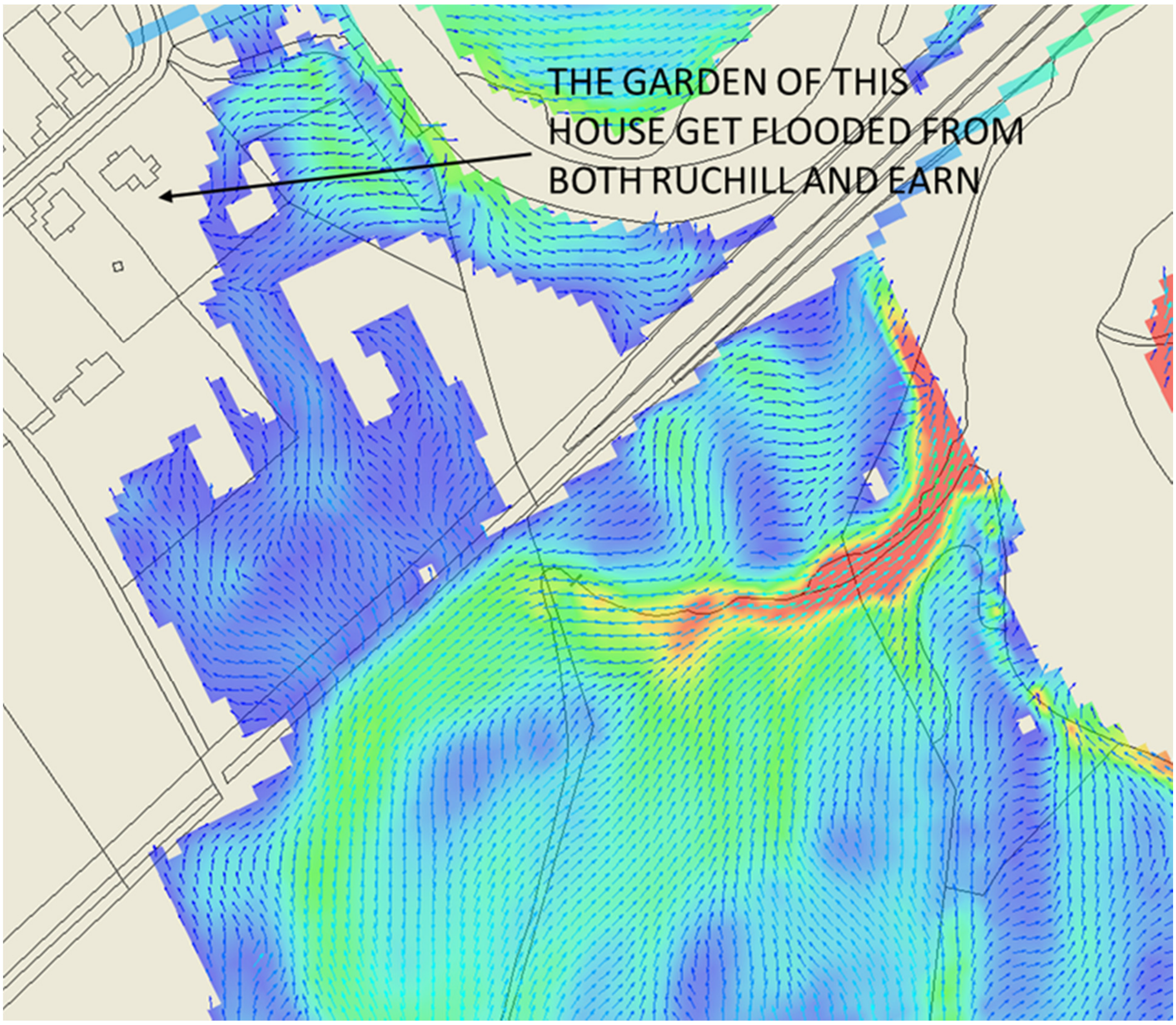

Figure 8: The 200 year flood map at The Ross

Discussion

When the model is run for scenario 1 the level at Dalginross for the 1997 event has a return period of 20 years. This is consistent with the results of the single site analysis which also estimates a return period of 20 years.

The 200 year water level at Dalginross simulated using the joint probability scenario (scenario 5) only has a return period of 20 years when compared with the single site analysis. Given that we have confidence in the single site analysis for return periods up to 20 years it is reasonable to conclude that scenario 5 under-estimates the flow at Dalginross. This is confirmed by the FEH statistical method that gives a 200 year flow at Dalginross of $459m^3/s$ (some $69m^3/s$ greater than the $390m^3/s$ derived using scenario 5).

The post flood survey of peak water levels for the 1997 event compare well with the modelled 20 year water levels using scenario 1. The comparison deteriorates upstream of the confluence which could be explained by increased uncertainty in the survey.

It would therefore seem reasonable to be precautious and to proceed using scenario 1 as the baseline scenario. Scenarios 5 and 6 will be used to test for the sensitivity of water level to the uncertainty in flow during the appraisal of options. The sensitivity of water level to alternative scenarios is not easy to predict given the different hydrographs for each river and the effect of attenuation.

Recommendations

The following recommendations have been accepted by SEPA as the basis for the appraisal of options:

- Accept the design flow estimates for the Ruchill at Cultybraggan, Aberuchill and the Lednock.
- Allow the model to determine the flow and level at Dalginross (i.e. do not impose a design flow or water level at Dalginross)
- Use scenario 1 (200 year in all rivers) as the design scenario
- Use scenarios 5, 6, 7 and 8 to quantify the sensitivity of the water levels to uncertainty in the flow
- Include flooding of The Ross in the appraisal of options

Appendix A

SEPA email

From: MacConnachie, Malcolm [mailto:Malcolm.MacConnachie@SEPA.org.uk]
Sent: 26 February 2015 14:08
To: Tim Jolley; Alistair Scotland
Cc: Paul Swift; Pravin Ghimire; Hamilton, Richard
Subject: RE: Comrie FPS - design flows

Tim,

The results of the modelling work look much improved using the revised design flows for the Lednock.

I can confirm that we are now satisfied with the recommendations at the end of the revised report and pleased that you now have a basis on which to start investigating options for flood mitigation.

One thing that we note from the inundation map that forms part of your report is that flood flows no longer spill into the field upstream of Tomnagaske. Following the recent flood defence works undertaken at Dalginross most of the out of bank flow from the Ruchill heads off towards The Ross. I am concerned that the risk of flooding to the properties at The Ross may have been increased. I am also fully aware that the channel will continue to migrate to and fro across its floodplain and that the extent shown on the inundation map is merely a snap shot of where the channel and flood extent might be at the moment. Things will constantly change on the Ruchill. Are you able to confirm if the flood study will be investigating the risk of flooding
from water overtopping both the right and left banks of the Ruchill and investigating options to protect not only Dalginross but also properties in the vicinity of The Ross?

Kind regards,

Malcolm

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Appendix B

Design Flows

Calculation of QMED

The QMED values used to calculate peak flood flows are given in Table B1.

- The QMED for the Ruchill at Cultybraggan is derived from single site analysis.
- The value for the Upper Earn at Aberuchill is based on the stage record and the SEPA rating and was adjusted using the Ruchill at Cultybraggan as a donor.
- The value for the Lednock at the confluence is based on the FEH ungauged approach adjusted using the Ruchill at Cultybraggan as a donor.
- The QMED for the Earn at Dalginross was calculated using the stage record at Dalginross and the SEPA rating curve.

River	Location	QMED (m^3/s)
Water of Ruchill	Cultybraggan	161.4
River Earn	Dalginross	188.4
Upper Earn	Aberuchill	67.1
River Lednock	Ungauged	40.6

Table B1: QMED Values

Growth Curves

Growth curve factors were derived using the following method:

- Single site analysis is used for Cultybraggan.
- A pooling group comprising 14 sites and 503 years of data was used for Aberuchill.
- A pooling group with 15 sites and 538 years of data was used for River Lednock at its confluence with the River Earn
- A pooling group with 13 sites and 502 years of data was used for Dalginross.

Return period (years)	Growth curve factor	Flow (from FEH statistical method) (m3/s)	Flow (from FEH RR method) (m3/s)
2	0.985	***159.0***	75.0
5	1.194	***192.7***	102.0
10	1.324	***213.7***	121.8
25	1.489	***240.3***	150.7
50	1.616	***260.8***	175.1
100	1.746	***281.8***	199.0
200	1.88	***303.4***	227.4
500	2.066	***333.5***	271.6

Table B.2: Water of Ruchill peak flows at Cultybraggan gauge

Return period (years)	Growth curve factor	Flow (from FEH statistical method) (m3/s)	Flow (from FEH RR method) (m3/s)
2	1	***188.4***	223.9
5	1.269	***239.1***	309.0
10	1.456	***274.3***	368.9
25	1.716	***323.3***	455.9
50	1.933	***364.2***	529.2
75	2.070	***390.0***	568.8
100	2.172	***409.2***	601.1
200	2.437	***459.1***	686.4
500	2.834	***533.9***	818.7

Table B.3: River Earn peak flows at Dalginross gauge

Return period (years)	Growth curve factor	Flow (from FEH statistical method) (m3/s)	Flow (from FEH RR method) (m3/s)
2	1	***67.1***	115.9
5	1.326	***89.0***	160.2
10	1.563	***104.9***	191.0
25	1.906	***128.0***	236.3
50	2.201	***147.8***	274.4
100	2.537	***170.3***	311.6
200	2.92	***196.0***	355.5
500	3.513	***235.9***	424.5

Table B.4: River Earn (Upper) peak flows at Aberuchill gauge

Return period (years)	Growth curve factor	Flow (from FEH statistical method) (m3/s)	Flow (from FEH RR method) (m3/s)
2	1	***39.3***	46.9
5	1.272	***50.0***	64.8
10	1.456	***57.2***	77.5
25	1.706	***67.1***	96.0
50	1.91	***75.1***	111.6
100	2.13	***83.7***	126.8
200	2.37	***93.2***	145.0
500	2.721	***107.0***	173.2

Table B.5: River Lednock peak flows at confluence with River Earn

2) Natural Flood Management (NFM) Technical Note

Project: Comrie and Dalginross Flood Study

Technical Note on Natural Flood Management

Produced for
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A	Draft	T. Jolley	22/05/15	AW/PG	22/05/15	T. Jolley	
B	Final	T. Jolley	10/06/15	AW/PG	10/06/15	T. Jolley	10/06/15

1.0 Background

Natural Flood Management includes “alteration (including enhancement) or restoration of natural features and characteristics of any river basin or coastal area in a flood risk management district”. The features should be such that they “assist in the retention of flood water, whether on a permanent or temporary basis, (such as floodplains, woodlands and wetlands) or in slowing the flow of such water (such as woodlands and other vegetation), those which, contribute to the transporting and depositing of sediment, and the shape of rivers and coastal areas”.

A description of natural flood management approaches is provided in Figure 1.

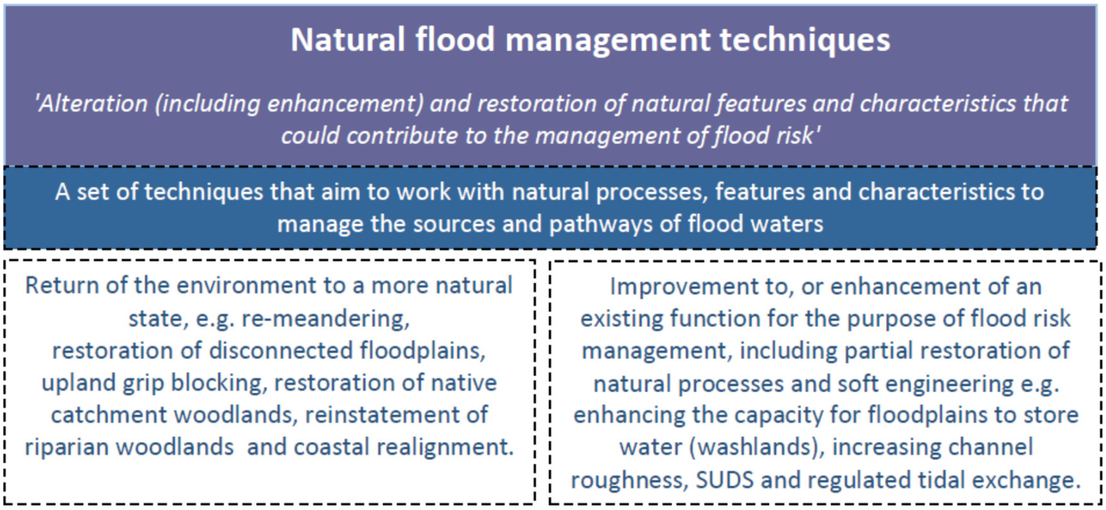

Figure 1 - Natural flood management approaches (from SNIFFER, 2011)

Natural flood management techniques include, but are not limited to the following (Environment Agency, 2012):

- Managed realignment, the creation of inter-tidal habitat through breaching or removing existing sea wall or embankments. This can reduce both wave height and energy and deliver additional benefits to wildlife.
- Sustainable Drainage Systems (SuDS), which encompass a range of runoff management techniques to mimic natural processes. This can help to minimise the impact of development on runoff generation and at the same time result in habitat creation and social benefits.
- Flood storage, in the form of on-line or off-line storage can attenuate the peak of river flows and reduce flood levels downstream.
- Floodplain reconnection can return storage volumes to the river system by breaching artificial barriers to connectivity such as agricultural embankments. This can help to reduce the magnitude of flood peaks, reduce bed scour and increase the time to peak.
- Increase in channel roughness by planting trees and other vegetation can reduce flow velocities, resulting in increased water levels which will mobilise floodplain storage and potentially reduce flood risk downstream. This also has environmental benefits through habitat creation.
- Soil management can improve groundwater recharge and reduce the amount of runoff from soils. This can also help to reduce sediment, pollution and nutrient loading on receiving water bodies.

• The management of sediment transport through source control can reduce the loss of floodplain storage and channel conveyance through deposition.

• Woodland creation could be used to increase interception storage and evapo-transpiration, increasing infiltration and reducing surface runoff, hence slowing down runoff.

The Environment Agency (2012) has demonstrated the benefits of all of the above techniques, but also notes that the benefits vary considerably between catchments (Environment Agency, 2008): the findings of one case study cannot be reliably transferred to another site. This highlights the need for a detailed site / catchment specific study.

2.0 Previous Natural Flood Management Studies and Key Findings

Although the effects of natural flood management on a small scale are well known (i.e. SuDS), there is only a limited evidence of the effect at catchment scale.

Demonstration projects to address the knowledge gap include the Allan Water, Upper Clyde, Eddleston Water, Tarland Burn and Balmaleedy Burn. The Allan Water, Eddleston Water and Firth of Forth Futurescapes are currently supported by SEPA. Other projects include WWF's work on the River Devon catchment and the Pickering catchment in England. There are other ongoing studies, however, the findings and conclusions from the studies show that the impact of NFM is site specific varying between catchments.

The following is an extract taken from the Environment Agency's 2008 study which examined the role of land use management in delivering flood risk management benefits (Environment Agency, 2008):

"The lack of robust catchment scale evidence does not necessarily mean that there is no catchment scale effect, but rather may just indicate that effects are difficult to detect and differ between catchments. Some observational examples, such as at Crowlas in Cornwall, do appear to show that flood risk in small catchments responded dramatically to land use changes. However, because flood risk management policy should be based on sound scientific evidence, the lack of robust catchment scale evidence currently provides a major constraint in considering land management as an effective tool to manage flood risk."

The report also highlights that the effect of local measures get diluted at catchment scale. The report also states that it is difficult to transfer findings from one site to another; the various findings are very site specific. Where uncertainty exists over hydrograph peak timings on multiple river systems at a catchment scale, the benefits of catchment scale solutions will also become more difficult to prove or rely upon.

3.0 The Approach

Methods can generally be classified as:

- High level approaches which use catchment characteristics to estimate changes in the design hydrograph
- Detailed studies which use integrated catchment models to simulate the effect of specific measures

It is proposed to use a high level approach to investigate the sensitivity of the catchment upstream of Dalginross to NFM measures. If the results show that NFM measures would potentially impact on the design flows at Dalginross then a more detailed assessment will be proposed.

The approach considers measures that effect the:

- runoff potential
- time to peak of a flood hydrograph
- flood plain storage and conveyance

Upstream storage is not included as it is included in the appraisal of options.

It must be emphasised that published research indicates that there is a high degree of uncertainty in the impact of NFM measures on a flood hydrograph. However, there is a general acceptance that the restoration of a catchment and the enhancement of natural storage do reduce the percentage runoff and attenuate flow. A high level sensitivity analysis is the most pragmatic way to explore the potential benefit of NFM measures and therefore to focus more detailed studies.

3.1 Runoff Potential

The SEPA screening map of runoff potential[1] shows that the catchments have areas of high and low runoff potential in their upper reaches. The areas of high potential are associated with the blanket peat bog in the upper parts of the catchments.

The runoff potential is based on rainfall (SAAR), soils and hydrogeology (BFIHOST), slope and land use. Hence, NFM measures focus on land management practises which impact on the response of a catchment to rainfall (SPR, BFIHOST and land use).

HOST[2] reflects the hydrogeology, soil type and structure. It can therefore be used to represent changes in land management[3].

The HOST dataset is not publically available due to license issues. However, it can be estimated using the 1:250,000 soil map of Scotland[4].

[1] http://map.sepa.org.uk/floodmap/map.htm

[2] Hydrology of soil types: a hydrologically based classification of the soils of the United Kingdom. IoH repot 106. D.B. Boorman, J.M. Hollist & A. Lilly (November 1995)

[3] Review of impacts of rural land use and management on flood generation. Short-term improvement to the FEH rainfall-runoff model: Technical background. R&D Project Record FD2114/PR3. J.C. Packman, P.F. Quinn, J. Hollis and P.E. O'Connell (November 2004)

[4] http://www.soils-scotland.gov.uk/data/soil-survey

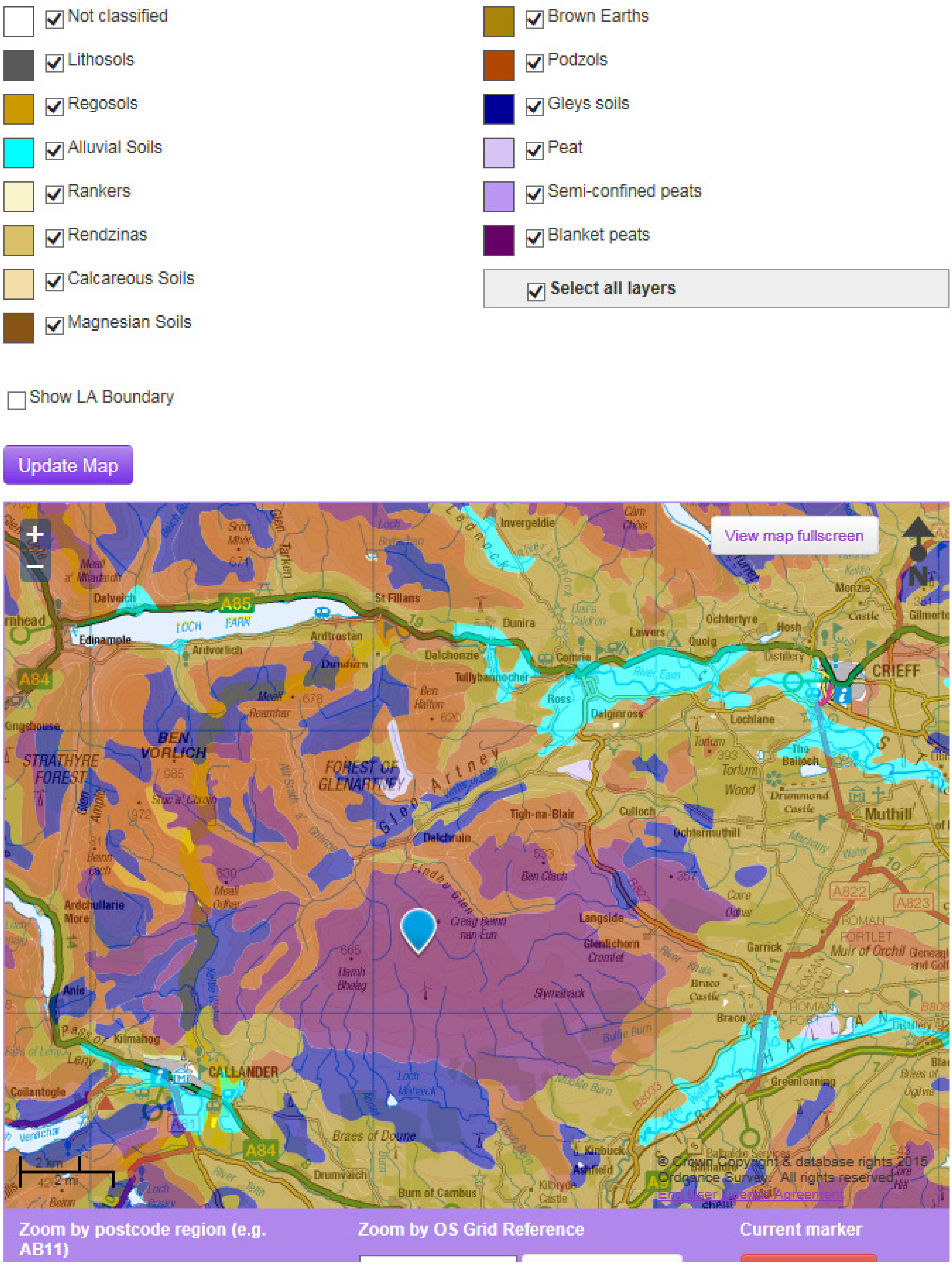

Figure 1: **The 1:25,000 Soil Map for the catchment of the Ruchill Water**

Figure 1 shows that soils in the catchments are peaty gleys, podzols, brown soils, blanket peat and alluvial soils. The areas of medium and high runoff potential are associated with podzols, gleys and blanket peat due to higher SAAR and steeper slopes. These soils equate to HOST classes given in the table below. The values of SPR and BFI associated with these classes are also given (Table 1).

Soil Association	Description	Map Unit	HOST class	SPR	BFI
Foudland	Brown Earths. Drifts derived from slates, phyllites and other weakly metamorphosed argillaceous rock	251-253	15	48.4/29.2	0.380/0.609
Strichen	Peaty Gleys. Drifts derived from arenaceous schists and strongly metamorphosed argillaceous schists of the Dalradian Series	501	15/29	48.4/60.0	0.380/0.226
Organic Soils	Blanket peat	4	29	60.0	0.791
Alluvial Soils	Mineral alluvial soils with peaty alluvial soils	1	7/8/9/10/12	25.3 – 60.0	1.000

Table 1: HOST classes present in the catchment upstream of Dalginross

Packman et al.[3] recommend that changes in land use should be represented by a horizontal change in HOST:

Thus the general principle is that soil structural degradation affects the soil storage / wetness component of the HOST classification but does not alter the hydrogeological component. Analogue HOST classes are therefore derived by moving from left to right across the columns in table 2.1, but not by moving vertically across the broad row groupings in table 2.1, which represent three distinct hydrogeological groupings based on permeability (HOST classes 1 to 6 are all on permeable substrates) and depth to groundwater

While Packman et al. looked at the impact of degradation the principle equally applies to improvements in soil structure. Measures that reduce the intensity of farming practises, increase the surface retention of runoff through changes in vegetation type and the use of strategically located shelter belts and features that retain runoff all lead to improved soil structure and a reduction in SPR.

The change in HOST class is linked to changes in BFI and SPR using the expressions developed by Boorman et al[5]. (See Appendix A). Table 2.2 of Packman et al. (reproduced in Appendix A) gives a value of SPR for the revised HOST (i.e. after improved land management). These should be regarded as maximum changes given than the land management measures typically used for NFM are more localised and less intensive than rural land use. In addition, no account is taken of changes in vegetation.

If we consider the catchment of the Ruchill, for example, the soil types are classified as brown earths in the valley bottom transitioning to peaty gleyed podzols on the hillsides and to blanket peat on the upper slopes. SPR varies between 30% and 48% (although SPR values as high as 60% will occur in

[5] Report No. 126. *Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom*. D.B. Boorman, J.M. Hollist & A. Lilly.November 1995

areas of blanket peat during periods of high saturation). Table 2 gives the catchment values of SPR and Tp.

Catchment	SPR (%)	Tp (h)
Upper Earn @ Aberuchill	42.3	4.5
Ruchill @ Cultybraggan	43.97	4.5
Lednock @ Dalginross	44.16	3.7
Total	43.2	10

Table 2: SPR and Tp for each catchment

Application of Table 2.2 from Packman et al (Table 3) indicates that SPR is most sensitive to a change in land use on areas of HOST class 7 which is associated with mineral soils with an impermeable layer within 100cm of the surface or a gleyed layer at 40-100cm. Humus podzols are most likely to have these characteristics.

HOST class	Original	Revised	Alternative	Change (%)
15	48	48	48	0
29	60.0	60	60	0
7	44	44	48	0-11
8	44	44	44	0
9	25	25	25	0
10	25	25	25	0
12	60	60	60	0

Table 3: Change in SPR resulting from improved soil structure

A map of the podzols in the catchment is shown in Figure 2.

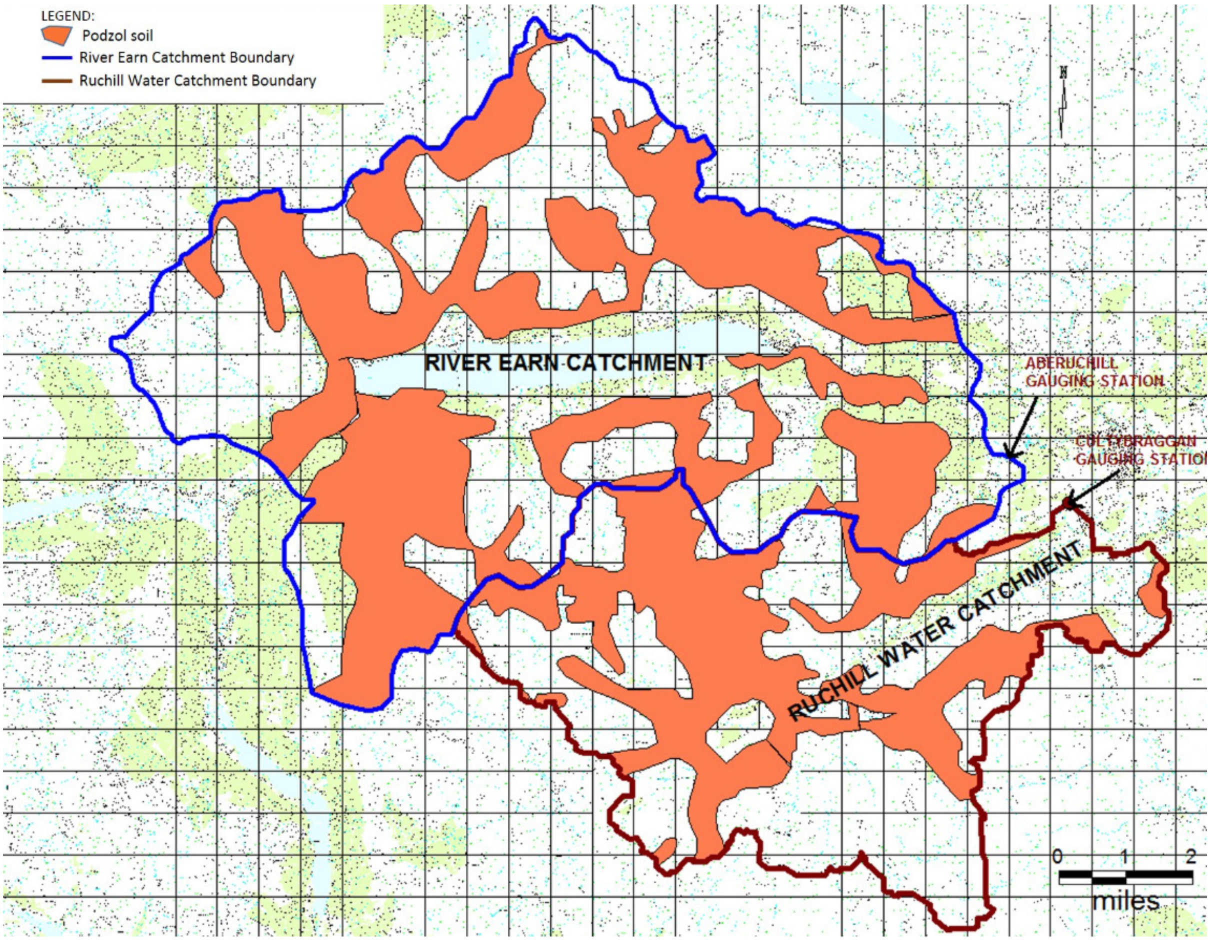

Figure 2: Podzol soil in the Earn and Ruchill catchments

Given that podzols cover approximately 45% of the sub-catchments a reduction in runoff of 6% is not unreasonable if it is assumed that the change in land management is applied across the catchment.

Land drainage measures such as grip blocking may be possible in the Ruchill catchment. The potential impact of these measures is site-specific being dependent on factors that include water table, location and soil type[6]. It's not possible to predict a % reduction in runoff at the catchment scale with any confidence.

Forestry, planted in gulleys or shelter belts, can control runoff before it reaches a channel. Although it is generally accepted to have beneficial effects on flood risk there are no published results on the scale of the impact.

In conclusion, a reduction in SPR of 6% will be used to estimate the potential effect of a combination of measures to reduce runoff.

3.2 Time to Peak

The SEPA screening map indicates that there is potential to reduce flood risk through NFM measures that change the timing of flood peaks and so reduce the risk of peak flows combining. Land

[6] Natural flood management (NFM) knowledge system: Part 3 - The effect of land drainage on flood risk and farming practice. Final Report. Blanc, J., Arthur, S., Wright, G. & Beevers, L. (July 2012)

management measures such as changes in agricultural practise and changes in vegetation cover will impact on the timing of runoff as well as the peak runoff.

For example, Packman et al. suggest that forest drainage could reduce local Tp by 2-3 hours; agricultural drainage in soils with low SPR could reduce local Tp by 1-2 hours, but in high SPR soils increase Tp by 1-2 hours. They suggest that the impact of changes in Tp should be assessed using sensitivity analysis.

Time to peak and runoff are inter-dependent and it is therefore is appropriate to combine a change in runoff and Tp. It is assumed that an increases in SPR will be associated with a reduction in Tp. There are exceptions, for example drainage can reduce Tp in low SPR soils. However, given that the soils in the catchment have high SPR values it is assumed that Tp will decrease with an increase in SPR.

The increase in Tp noted by Packman et al. is based on a small number of catchments, it is therefore reasonable to assume the increase is dependent on the size of the catchment and the magnitude of Tp before any adjustments are made. Increasing the value of Tp 10% seems a reasonable approach for both the Ruchill and Upper Earn..

There is some potential to increase the Tp in the Lednock through the use of woody debris dams or similar measures to attenuate channel flows. However, the response of the catchment is determined by the discharge from Loch Lednock and therefore no increase in Tp is assumed.

3.3 Flood Plain Storage

The SEPA NFM screening map indicates that there is potential to increase flood plain storage in the Ruchill Water downstream of Cultybraggan. However, this is the area being focussed on in this study which includes flood plain storage options so no further measures will be considered in the study.

The SEPA map does show some potential to enhance storage within reaches of Ruchill where the flood plain width increases. The most significant reaches being the east bank tributary south of Drumchok and the upper reaches of Allt na Gaisge (Findhu Glen) and Allt Srath a Ghlinne.

The Upper Earn flood plain upstream of Aberuchill is already acting as natural storage with no significant opportunities to enhance storage or change land use.

The proposed reduction in Tp will quantify the sensitivity of increased flood plain storage which, if significant, would point to more detailed investigation of these reaches.

4.0 Summary of the Approach

Table 4 below summarises how the potential impact NFM measures will be quantified.

Measure	Comment	Method
Managed realignment	There are no reaches which have been naturally re-aligned. The channel is naturally mobile.	The restoration of re-aligned sections is not applicable to this study.
Flood Storage	To be considered as an option	Flood plain storage downstream of Cultybraggan is Included in the hydraulic model study and appraisal of options.

Measure	Comment	Method
		The effect of increased flood plain storage in the upper reaches of the Ruchill assessed using a reduction in Tp of 1h. Increased storage in the Upper Earn upstream of Aberuchill will not be considered as it already functions as storage and there is no potential to change land use. Reservoir storage options in the Ruchill and Upper Earn upstream of Dalginross are included in the appraisal of options.
Floodplain reconnection	Not applicable	
Increase in channel roughness	This includes the installation of woody debris dams as well as changing the flood plain vegetation.	Sensitivity to flood plain roughness (manning's n) is included in the model study downstream of Cultybraggan. A reduction of Tp will capture potential measures upstream of Cultybraggan. Measures in the upper Earn and Lednock will not be included as their responses are dominated by discharges from Loch earn and the Lednock reservoir.
Land management	This includes measures such as reducing the intensity of livestock, agricultural practises and crop selection. All measures aim to restore and improve soil structure.	The high level investigation reported on in this note indicates that an increase in SPR of 6% and an increase in Tp of 1h are reasonable catchment scale estimates for the purpose of sensitivity analysis. These changes will be applied to the Upper Earn and Ruchill.
Sediment Management	The Ruchill is a highly mobile channel and the character of the flood plains reflects the high sediment yield of the catchment.	Sediment management will be a key factor in assessing the effectiveness of any proposed option. The impact of measures to control sediment mobilisation within the catchment are very difficult to quantify and depend on a good understanding of the sediment processes. It is not proposed to assess options as a part of the NFM assessment.
Woodland creation	Woodland creation can impact on the rate and quantity of runoff.	The impact of woodland is included in the increase in SPR and reduction in Tp.

Measure	Comment	Method
		Measures such as shelter belts and forested channels will be assessed further if the sensitivity to SPR and Tp justify it.

Table 4: Summary of the approach to be taken to NFM measures

5.0 Sensitivity Analysis

The approach was applied to the Ruchill and Upper Earn catchments to quantify the effect of NFM measures and therefore to establish the benefit of including a detailed assessment NFM measures in the appraisal of options.

Inflows to the model were reduced by approximately 6 % and Tp increased by 10%.

These changes give a reduction in flow of approximately 6.7% and 6.9% at Cultybraggan and Aberuchill and approximately 4% at Dalginross. No reductions were made in runoff from the Lednock or the Earn downstream of the confluence with the Ruchill.

The hydraulic model was re-run for reduced flows and the resulting water level was compared with the baseline model. The results are given in Appendix B and are summarised in Table 5.

Watercourse	200year	200year+cc	Location	Note
Ruchill Water	-130mm	-120mm	Confluence with the Upper Earn	Sensitivity decreases with distance upstream of the confluence
Upper Earn	-190mm	-220mm	Upstream of the Bridge of Ross	The greater sensitivity compared to the Ruchill reflects the narrower flood plain.
Earn	-140mm	-130mm	Confluence	Sensitivity rapidly decreases downstream falling to 10mm and 50mm at Dalginross for the 200yr and 200yr+cc respectively
Lednock	-70mm	-80mm	Confluence	Levels are only effected at the confluence

Table 5: The impact of NFM measures on the 200 year water level

The magnitude of the effect at the confluence may be of value when the economics of the primary options are estimated. However, further work would be required to establish the specific measures required to reduce runoff, the cost and the acceptance by stakeholders.

6.0 Conclusion and Recommendations

There is no standard for the design and implementation of NFM measures and viable options take substantial time to implement. Design, cost, stakeholder acceptance and maintenance all have to be addressed on a case-by-case basis.

The results of this high level approach indicate the benefit of runoff reduction will be limited to the confluence of the rivers and upstream of the Bridge of Ross.

Upstream storage and enhanced flood plain storage are included in the list of primary options.

Woody debris dams may be of benefit in the Lednock Water and upper Ruchill water but will not affect the 200 year peak flow or water levels.

Recommendations:

i) Runoff reduction measures will not be progressed further as a secondary option.
ii) Runoff reduction should be considered as a longer term approach to increasing the resilience of the scheme. This is best progressed through discussion with SEPA to identify measures where there are multiple benefits (eco-services and morphology in particular) and where it is known that stakeholders are open to discussion.
iii) Upstream storage will be progressed as a primary option
iv) Flood plain enhancement will be progressed as a primary option

<u>**Appendix A: The HOST Classification and link with SPR**</u>

<table>
<tr><td rowspan="2">SUBSTRATE HYDROGEOLOGY</td><td colspan="6">MINERAL SOILS</td><td colspan="2" rowspan="2">PEAT SOILS</td></tr>
<tr><td>Groundwater or aquifer</td><td>No impermeable or gleyed layer within 100cm</td><td colspan="2">Impermeable layer within 100cm or gleyed layer at 40-100cm</td><td colspan="2">Gleyed layer within 40cm</td></tr>
<tr><td>Weakly consolidated, microporous, by-pass flow uncommon (Chalk)</td><td rowspan="6">Normally present and at >2m</td><td>1 4.31</td><td colspan="2" rowspan="6">13 0.87</td><td colspan="2" rowspan="6">14 0.66</td><td colspan="2" rowspan="6">15 9.93</td></tr>
<tr><td>Weakly consolidated, microporous, by-pass flow uncommon (Limestone)</td><td>2 2.12</td></tr>
<tr><td>Weakly consolidated, macroporous,by-pass flow uncommon</td><td>3 1.58</td></tr>
<tr><td>Strongly consolidated, non or slightly porous. By-pass flow common</td><td>4 3.33</td></tr>
<tr><td>Unconsolidated, macroporous, by-pass flow very uncommon</td><td>5 5.07</td></tr>
<tr><td>Unconsolidated, microporous, by-pass flow common</td><td>6 2.61</td></tr>
<tr><td>Unconsolidated, macroporous, by-pass flow very uncommon</td><td rowspan="2">Normally present and at ≤2m</td><td colspan="3">7 1.01</td><td>$IAC^{*} < 12.5$ ($< 1m\ day^{-1}$)</td><td>$IAC^{*} \geq 12.5$ ($\geq 1m\ day^{-1}$)</td><td>Drained</td><td>Undrained</td></tr>
<tr><td>Unconsolidated, microporous,by-pass flow common</td><td colspan="3">8 1.62</td><td>9 3.68</td><td>10 2.21</td><td>11 0.55</td><td>12 2.94</td></tr>
<tr><td>Slowly permeable</td><td rowspan="5">No significant groundwater or aquifer</td><td>16 0.43</td><td>$IAC^{\#} > 7.5$
18 5.40</td><td>$IAC^{\#} \leq 7.5$
21 4.02</td><td colspan="2">24 13.85</td><td colspan="2">26 2.49</td></tr>
<tr><td>Impermeable (hard)</td><td>17 9.28</td><td>19 2.16</td><td>22 1.10</td><td colspan="2"></td><td colspan="2">27 0.83</td></tr>
<tr><td>Impermeable (soft)</td><td></td><td>20 0.69</td><td>23 1.31</td><td colspan="2">25 3.64</td><td colspan="2"></td></tr>
<tr><td>Eroded Peat</td><td colspan="5"></td><td colspan="2">28 0.58</td></tr>
<tr><td>Raw Peat</td><td colspan="5"></td><td colspan="2">29 5.73</td></tr>
</table>

Small numbers are HOST class number. Large numbers are percentage land cover in England, Wales and Scotland. Also unclassified (urban) areas (5.15%) and lakes (0.74%).
No extensive UK soil types exist outside the table or within the shaded portions of the diagram.
*** IAC used to index lateral saturated hydraulic conductivity** **# IAC used to index soil water storage capacity**

Figure 3.3 *The HOST classification*

Table A.1: The HOST Classification

(Reproduced from: Report No. 126. *Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom*. D.B. Boorman, J.M. Hollist & A. Lilly.November 1995)

HOST Class	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Analogue	3	3	7*	6*	7*	8	7*	8	9	10
Original SPR	2	2	15	2	15	34	44	44	25	25
Revised SPR	14	14	27	15	27	44	44	44	25	25
Alternate SPR	9	9	22	11	22	39	48	44	25	25
HOST Class	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Analogue	11	12	3*	24	15	18*	18	20	22	20
Original SPR	2	60	3	25	48	29	29	47	60	60
Revised SPR	2	60	15	40	48	47	47	59	60	60
Alternate SPR	2	60	9	30	48	41	35	55	60	60
HOST Class	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	
Analogue	23	27	25	25	25*	26	27	28	29	
Original SPR	47	60	60	40	50	59	60	60	60	
Revised SPR	60	60	60	49	60	59	60	60	60	
Alternate SPR	55	60	60	47	60	59	60	60	60	

Table A.1: Host class, analogue, SPRHOST and revised alternate degraded SPR

(Reproduced from: Review of impacts of rural land use and management on flood generation. Short-term improvement to the FEH rainfall-runoff model: Technical background. R&D Project Record FD2114/PR3. J.C. Packman, P.F. Quinn, J. Hollis and P.E. O'Connell (November 2004)

Analogue: HOST class that represents the degraded soil; Original SPR: Value of SPR based on HOST database; Revised SPR: Based on SPRHOST; Alternative: Based on BFI

Appendix B Results of the Model Sensitivity Analysis

Section reference (see sketch below for locations of the sections)	Model Node Reference	1 IN 200 YEAR WATER LEVELS, mAOD			1 IN 200 + cc YEAR WATER LEVELS, mAOD		
		Baseline model water level mAOD	Secondary option with natural flood management		Baseline model water level mAOD	Secondary option with natural flood management	
			Water level mAOD	Difference with baseline model, m		Water level mAOD	Difference with baseline model, m
A. RUCHILL WATER							
1	R2415	64.44	64.38	-0.06	64.58	64.53	-0.05
2	R2073	62.48	62.45	-0.03	62.58	62.55	-0.03
3	R1850	61.77	61.72	-0.04	61.87	61.83	-0.04
4	R1675	61.28	61.24	-0.05	61.38	61.35	-0.04
5	R1450	59.88	59.85	-0.03	59.94	59.92	-0.01
6	R1200	58.97	58.87	-0.10	59.28	59.17	-0.11
7	R1000	58.91	58.78	-0.12	59.24	59.12	-0.12
8	R800	58.87	58.74	-0.13	59.21	59.09	-0.12
B. UPPER EARN							
9	E1700_ND	61.19	61.06	-0.13	61.57	61.41	-0.16
10	E1407_N	61.11	60.95	-0.16	61.57	61.37	-0.19
11	E1185_N	60.72	60.56	-0.15	61.17	60.97	-0.20
12	E916_N	60.61	60.43	-0.18	61.10	60.89	-0.21
12A	E916b	60.48	60.29	-0.19	60.99	60.77	-0.22
13	E712_N	59.53	59.42	-0.11	59.78	59.63	-0.15
14	E538	59.01	58.89	-0.12	59.32	59.21	-0.11
15	E360	58.99	58.86	-0.13	59.31	59.19	-0.12
16	E157	58.85	58.71	-0.14	59.20	59.08	-0.13
17	E000	58.76	58.62	-0.14	59.11	58.98	-0.13
C. EARN							
18	R700	58.60	58.46	-0.14	58.95	58.82	-0.13
19	R575U	57.88	57.81	-0.07	58.07	58.00	-0.07
20	R350	57.43	57.37	-0.05	57.55	57.51	-0.04
21	R150	56.31	56.27	-0.04	56.45	56.40	-0.05
22	R000	56.02	55.97	-0.05	56.16	56.11	-0.05
D. LEDNOCK							
23	L108	56.70	56.63	-0.07	56.97	56.89	-0.08
24	L176	57.19	57.13	-0.06	57.44	57.41	-0.03
25	L289	57.58	57.58	0.00	57.74	57.74	0.00
26	L372	58.19	58.19	0.00	58.42	58.42	0.00
27	L519	59.18	59.18	0.00	59.35	59.35	0.00
28	L703	61.24	61.24	0.00	61.50	61.50	0.00

Table B.1: Sensitivity of water level to runoff reduction (6% and 6% for the Ruchill Water and Upper Earn catchments respectively)

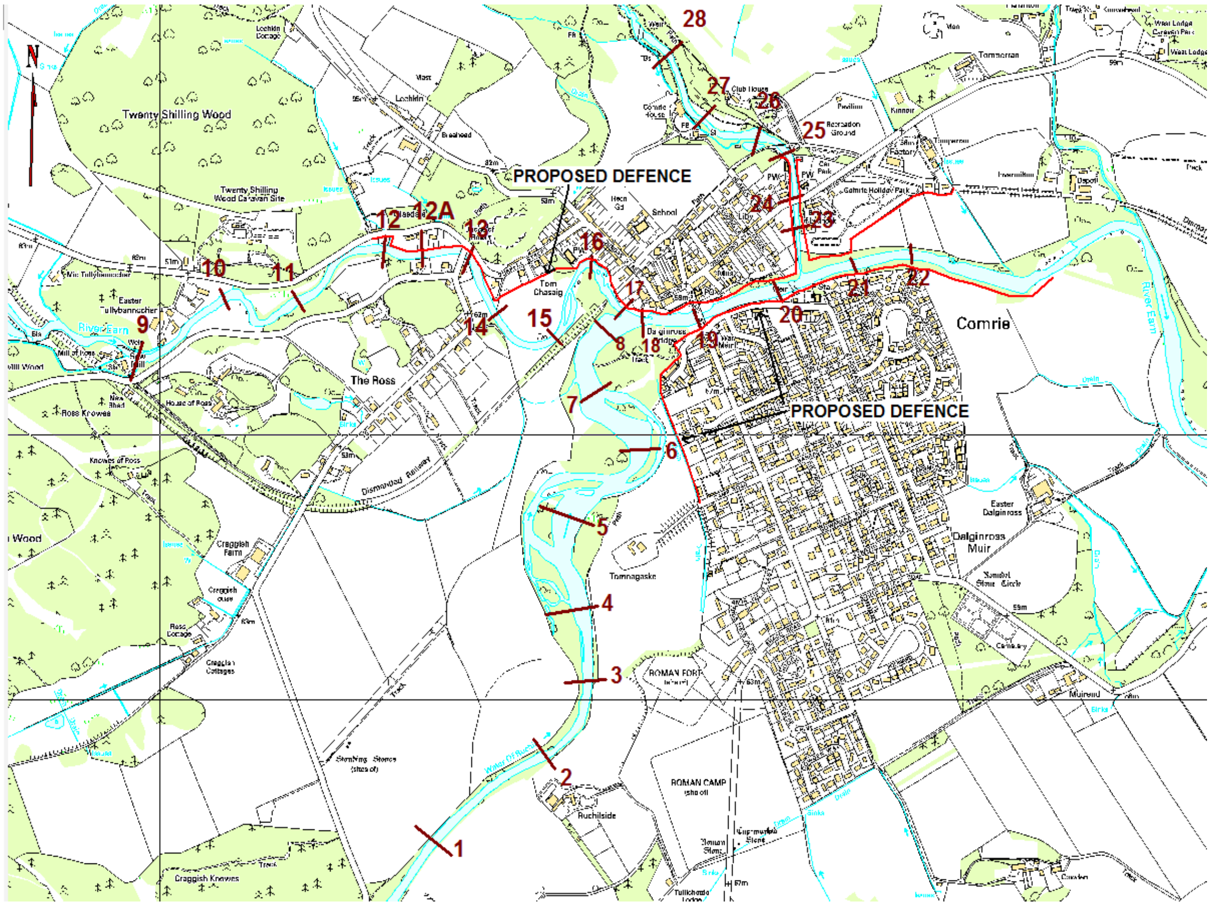

Table B.1: Model cross section locations

3) Joint Probability Technical Note

Comrie and Dalginross Flood Study

Results of the Simplified Hydrological Joint Probability Analysis

Produced for
Perth and Kinross Council
The Atrium 137 Glover Street
Perth PH2 0HY

Prepared by
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Document Control Sheet

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Distribution

Date	Organisation	Contact	Copies
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1 Background

Further to the preliminary results of the Hydrological Joint Probability Analysis provided to Perth and Kinross Council and SEPA by Mouchel, and to the comments received from SEPA on these results on the 10th February 2014, this document presents the simplified hydrological joint probability analysis as discussed and agreed with SEPA and Perth and Kinross Council on 10th February 2014, and refines the results presented to SEPA and Perth and Kinross Council on 3rd June 2014.

The comments received from SEPA in response to the preliminary results reflected that due to the inaccuracies at the Aberuchill gauging station, and the lack of a river gauging station on the River Lednock, an extreme value joint probability analysis would not be appropriate for these catchments[1]. Therefore, it was agreed with SEPA and Perth and Kinross Council that Mouchel will carry out a 'simplified' joint probability analysis making best use of the available data (i.e. using recorded data at the Dalginross gauging station on the River Earn, Aberuchill gauging station on the Upper Earn and Cultybraggan flow gauging station on the Water of Ruchill).

2 Approach

2.1 General

Comrie lies at the confluence of the Water Ruchill, Rivers Lednock and Earn with each catchment having quite distinct hydrological characteristics (Figure 1).

As a result the flow and water level around the confluence is dependent on the flows in each watercourse. A full assessment of the flood frequency would require joint probability analysis to account for all possible combinations of tributary flows. However, sufficient data is rarely available and therefore the approach is simplified by limiting the analysis to a number of extreme (but credible) scenarios.

[1] *Preliminary Results of the Hydrological Joint Probability Analysis, issued to Perth and Kinross Council on 8th January 2014*

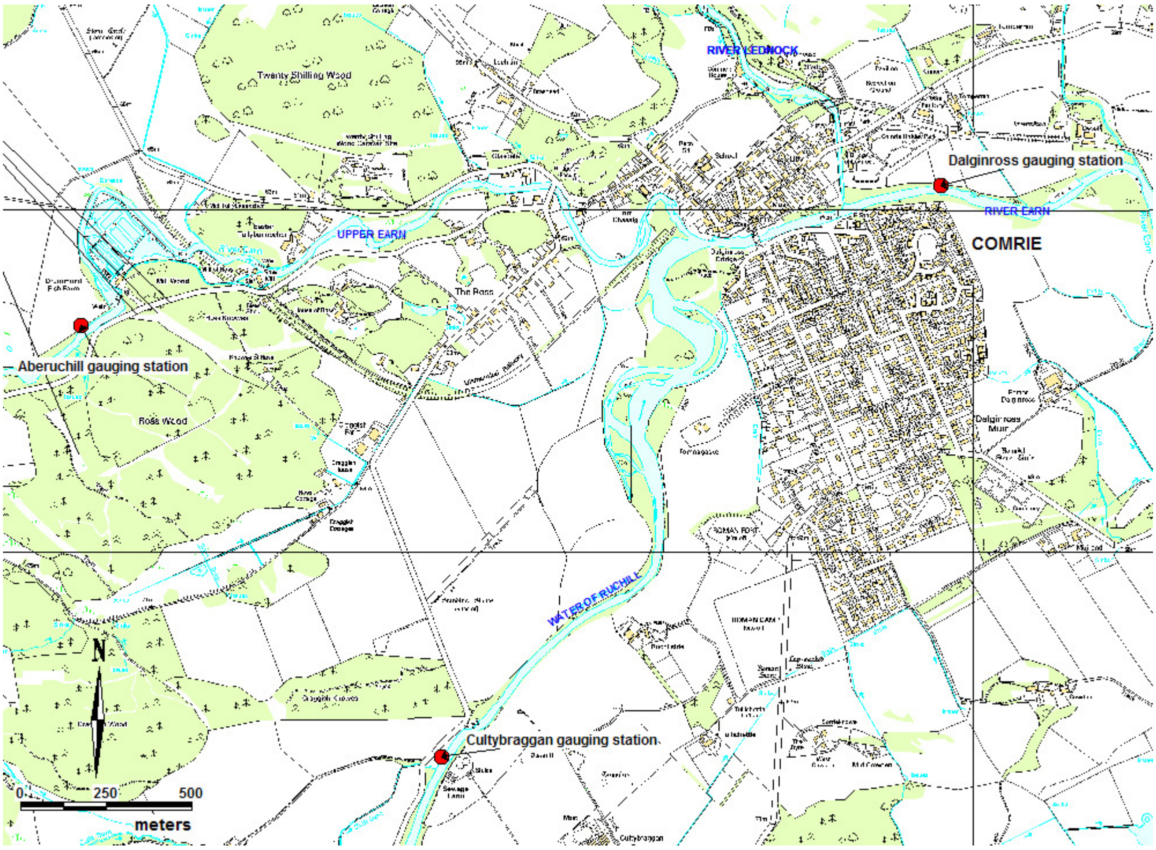


Figure 1: Location Map showing SEPA Monitoring Sites

When flooding arises from a combination of flows the design water level can potentially be drawn from a number of scenarios depending on the location[2]. For example, the design level for Camp Road may be drawn from a different scenario to the design level for Manse Lane.

2.2 Method

The following steps of the simplified hydrological joint probability analysis have been carried out based on the discussion and agreement with SEPA and PKC:

1) **Review of the hydrometric data:** A review has been carried out of the available hydrometric data to identify any anomalies and to confirm that it can be used with confidence.

2) **Comparison of rating curves**: The SEPA and modelled rating curves at the Dalginross gauging station has been compared to check for consistency within the gauged range and to explain any differences at higher flows.

3) **Flood frequency analysis** (using FEH – WINFAP software) has been undertaken for the Dalginross, Aberuchill and Cultybraggan gauging stations. Analysis has also been carried out for the River Lednock upstream of the confluence with the River Earn using estimated flows.

4) **Selection of design flow scenarios.** Alternative combinations of flow in each of the rivers is required to account for the influence of the confluence on the design water

[2] After a consideration of the benefit/cost ratio there may be an economic case to vary the standard level of protection.

levels. The simplified approach limits the number of combinations (referred to as scenarios in this note) to those which will result in the maximum water level for at all locations to be protected by the flood protection scheme. Judgment is needed to ensure that the combinations are credible based on recorded data and local knowledge.

5) **Analysis of correlation between peak flows**: For each scenario the design flows have been derived using the growth curves calculated in step 3 and an analysis of the correlation between peak flows in three rivers. These design flows have been then checked with SEPA's local knowledge before being taken forward for hydraulic modelling.

The following sections describe the steps in detail and discuss the results and their implications

3 Review of the available hydrometric data

Before carrying out any analysis it is important to review the quality of the recorded flows. While the published AMAX data can be assumed to be of acceptable quality, the quality of the sub-daily data should be assessed prior to carrying out the correlation analysis. Care must be taken to ensure that the recorded flows are consistent (e.g. the flows balance across the confluence) given the high dependency on the records at Cultybraggan and Dalginross.

The available data is summarised in Table 1 and the gauging station locations are shown in Figure 1.

	Aberuchill		Cultybraggan		Dalginross	
Dataset.	*Start*	*End*	*Start*	*End*	*Start*	*End*
Daily Maximum Levels	16/09/92	05/05/14	16/09/92	05/05/14	16/09/92	05/05/14
Annual Maxima (AMAX)	1991/92	2013/14	2005/06	2013/14	1992/93	2013/14

Table 1: List of reviewed hydrometric datasets

The data was reviewed and accepted based on the quality control checks provided by SEPA for each recorded value. The datasets between 1992 and 2013 for both gauges had a few missing data and few values with quality flag 'unverified' (CU). These flows were discarded from any further analysis, and only values with quality flag 'good' (CG) were used from that point. In both datasets, there were some dates with two flows and no values for the previous or following day. The missing values were filled in by selecting the highest flow values between the previous or following day.

The records are too short to test for significant trends but a visual inspection indicates that the cumulative flows of the Upper Earn, Water of Ruchill and River Lednock add up to the flows at Dalginross (assuming addition of negligible outflow onto the floodplain during higher flow events).

4 Comparison of rating curves

SEPA provided Mouchel with the following rating curve for the Dalginross gauging station:

$$Q = 35.2259(h-0.0927523)^{1.70995}$$

The variable h is the stage in metres and the flow Q is in m^3/s. The equation, derived by SEPA using a bed slope value of 0.003 was based on normal depth calculations and is applicable to water levels higher than 54.23 mAOD.

To compare to the SEPA curve, Mouchel derived rating curves with the hydraulic model using ISIS-3 for a range of average bed slopes. Then, the rating curves were derived using the methodology described in Ghimire and Reddy (2010) and the baseline model and are presented in Table 2 and Figure 2. The hydraulic model presents a more accurate assessment of the hydraulic conditions at the Dalginross gauge and has fewer assumptions than the theoretical rating curve provided by SEPA.

Slope	Rating curve equation
0.002	$Q = 19.164\ (h-0.00093)^{1.9959}$
0.003	$Q = 23.469\ (h-0.0002)^{1.9959}$
0.005	$Q = 23.469\ (h-0.0005)^{1.9959}$

Table 2: The Rating Equation for Dalginross derived from the Model with varying bed slopes

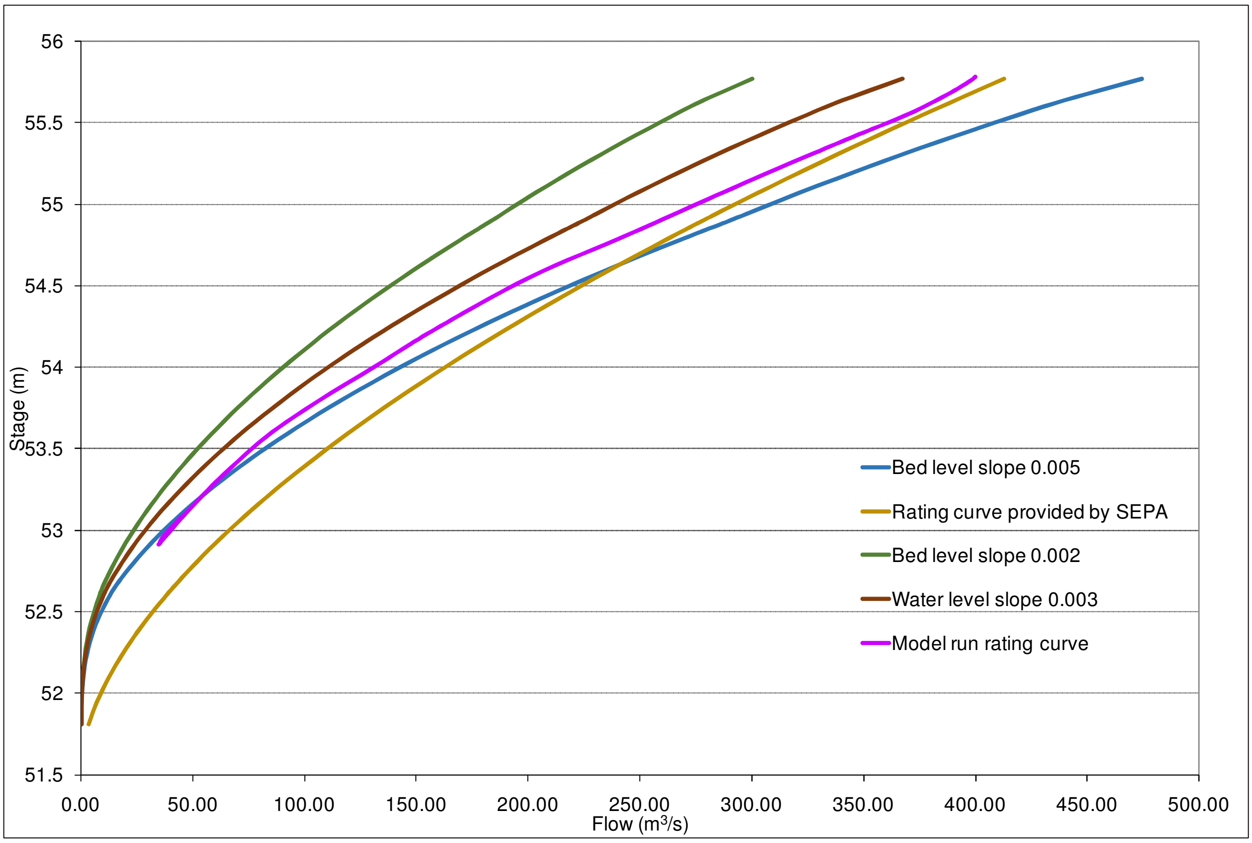


Figure 2: The Rating curves for Dalginross derived from the model with varying bed slope compared with the SEPA rating curve

From Figure 2, it can be seen that the model run rating curve is in close agreement with the SEPA rating curve for higher flow values and in close agreement with the 0.005 bed level gradient rating curve for lower values of flow. The modelled and SEPA rating curves at high flows are sufficiently close to accept the SEPA rating and so avoid any inconsistencies between calculated flow values. The SEPA rating curve has therefore been taken forward to derive the flows from the recorded levels at Dalginross gauging station.

5 Flood Frequency Analysis

The flood frequency analysis for Aberuchill, Cultybraggan and Dalginross gauging stations and the River Lednock at its confluence with the River Earn was carried out using the FEH WINFAP software (version 3).

5.1 Derivation of QMED values

Cultybraggan gauging station on the Water of Ruchill is a flow gauge of the Hi-Flows-UK database. Its AMAX series of 54 years of data (up to 2013) was used to derive the QMED value (148.1 m^3/s). SEPA informed Mouchel on 23rd May 2014 that "the flow and stage data on the HI-Flows-UK database is different from that held by SEPA", resulting in a difference (8.9%) in QMED value for that gauge. Mouchel had used an AMAX series ending in the water year 2007/2008 whereas the dataset used by SEPA has data up to and including water year 2013/2014. Mouchel confirmed that the additional years of AMAX data are consistent with Hi-Flows dataset[3] before accepting the value derived by SEPA (161.4 m^3/s).

The Dalginross level gauge is not in the Hi-Flows-UK database nor listed in the WINFAP software. The QMED value for Dalginross gauging station was derived by creating an AMAX series from the daily maximum stage data (1993 – 2013). The SEPA rating curve (Figure 2) has been used to convert the median stage into median flow (QMED) giving a value of 188.4 m^3/s. For the purpose of comparison the value of QMED for Dalginross gauging station was also calculated using the Earn @ Kinkell Bridge (16001) as a donor site. The QMED calculated from this method was 145.7 m^3/s. Kinkell Bridge is not an ideal donor site because of the significant increase in catchment area and therefore it was agreed with SEPA that QMED derived from the AMAX series would be taken forward for further analysis. The use of the FEH ungauged method was discounted on the basis that the analysis for Cultybraggan and subsequently for Aberuchill confirmed the value of using quality controlled SEPA data.

Similarly, for Aberuchill gauging station, the QMED value was derived by creating an AMAX series from the daily maximum stage data (1993 – 2013) received from SEPA. The SEPA rating curve[4] has been used to convert the median stage into median flow (QMED). Using this method, the value of QMED for Aberuchill gauging station is 75.4 m^3/s. A second method of deriving the value of QMED using the Ruchill Water @ Cultybraggan (16003) as the donor site[5] gives a slightly high value of 76.1 m^3/s. The QMED value of 67.1 m^3/s. has been accepted.

For the River Lednock (ungauged catchment) at its confluence with the River Earn, Ruchill Water @ Cultybraggan (16003) was used as the donor site, and the adjusted QMED value 40.6 m^3/s has been accepted.

The QMED values were checked for the four points above using the FEH bankfull method[6] and the FEH catchment descriptors. The bankfull method is used as a reality check on QMED when the statistical approach is deemed to be unreliable. The method, which relies on a stable channel and uniform flow has wider confidence intervals than the statistical method and is used here as a check. Table 3 presents the QMED values using all three methods. The QMED values in bold italics were taken forward for flood frequency analysis.

3 Results of Simplified Joint Probability Analysis - Draft_v1_20.05.2014.doc – Issued 20th May 2014

[4] *Q = 52.778*(SG-0.464)^1.564 (SG : Stage Gauge (in m))*

5 Centroid to centroid distance of 9.48 km.

[6] *FEH volume 3, chapter 5*

Name of watercourse	Name of gauging station	Type of gauging station	Catchment area at the point of interest (km^2)	QMED (m^3/s)		
				bankfull method	AMAX series	catchment descriptors
Water of Ruchill	Cultybraggan	Flow gauge	98.5	86.0	148.1 (Mouchel) ***161.4*** (SEPA)	87.6
River Earn	Dalginross	Level gauge for flood warning	349.6	215.6	***188.4*** 171.6 (with donor)	137.1
Upper Earn	Aberuchill	Level gauge	177.1	89.0	75.4 ***67.1*** (with donor)	53.8
River Lednock	Ungauged	n/a	61.8	57.2	***40.6*** (with donor)	32.5

Table 3 QMED values derived with three methods for the four catchments

5.2 Growth Curves

Growth curve factors were derived for Cultybraggan gauging station based on a single site analysis. Results are presented in Table 4 together with peak flows derived using the FEH rainfall runoff method for comparison. It is common for the rainfall runoff method to give different results to the statistical method and in this case the statistical peak flows are accepted as they make the best use of the observed flow data at the gauging station.

Return period (years)	Growth curve factor	Flow (from FEH statistical method) (m3/s)	Flow (from FEH RR method) (m3/s)
2	0.985	***159.0***	75.0
5	1.194	***192.7***	102.0
10	1.324	***213.7***	121.8
25	1.489	***240.3***	150.7
50	1.616	***260.8***	175.1
100	1.746	***281.8***	199.0
200	1.88	***303.4***	227.4
500	2.066	***333.5***	271.6

Table 4: Water of Ruchill peak flows at Cultybraggan gauge

The record at Dalginross is relative short and the rating curve uncertain. While it is acceptable to make maximum use of local data to improve QMED it is not acceptable for the growth curve. Therefore the growth curve factors were derived for Dalginross gauging station based on a pooling group which has 13 sites and 502 years of data, with no adjustments. Results are presented in Table 5 together with peak flows derived using the FEH rainfall runoff method for comparison.

Return period (years)	Growth curve factor	Flow (from FEH statistical method) (m3/s)	Flow (from FEH RR method) (m3/s)
2	1	***188.4***	223.9
5	1.269	***239.1***	309.0
10	1.456	***274.3***	368.9
25	1.716	***323.3***	455.9
50	1.933	***364.2***	529.2
75	2.070	***390.0***	568.8
100	2.172	***409.2***	601.1
200	2.437	***459.1***	686.4
500	2.834	***533.9***	818.7

Table 5: River Earn peak flows at Dalginross gauge

Growth curve factors were derived for Aberuchill gauging station based on a pooling group which has 14 sites and 503 years of data. The stage values from the Aberuchill gauging station were not taken into the analysis as it is understood from SEPA that the gauge is bypassed at higher flows. Adjustments were made to the initial pooling group to remove sites with a FARL value below 0.8 due to the influence of Loch Earn. Results are presented in Table 6 together with peak flows derived using the FEH rainfall runoff method for comparison.

Return period (years)	Growth curve factor	Flow (from FEH statistical method) (m3/s)	Flow (from FEH RR method) (m3/s)
2	1	***67.1***	115.9
5	1.326	***89.0***	160.2
10	1.563	***104.9***	191.0
25	1.906	***128.0***	236.3
50	2.201	***147.8***	274.4
100	2.537	***170.3***	311.6
200	2.92	***196.0***	355.5
500	3.513	***235.9***	424.5

Table 6: River Earn (Upper) peak flows at Aberuchill gauge

Loch Lednock Reservoir is relatively high in the catchment and is assumed, based on the local knowledge of SEPA, to spill during flooding. Therefore a precautionary approach has been taken to assume that the catchment can be treated as a natural catchment when calculating the growth curve.

Growth curve factors were derived for the River Lednock at its confluence with the River Earn, based on a pooling group with 15 sites and 538 years of data. No adjustments were made to the initial pooling group. Results are presented in Table 7 together with peak flows derived using the FEH rainfall runoff method for comparison.

Return period (years)	Growth curve factor	Flow (from FEH statistical method) (m3/s)	Flow (from FEH RR method) (m3/s)
2	1	***39.3***	46.9
5	1.272	***50.0***	64.8
10	1.456	***57.2***	77.5
25	1.706	***67.1***	96.0
50	1.91	***75.1***	111.6
100	2.13	***83.7***	126.8
200	2.37	***93.2***	145.0
500	2.721	***107.0***	173.2

Table 7 : River Lednock peak flows at confluence with River Earn

The values given in Tables 6 to 8 have been accepted by SEPA and are taken forward to the next step, the selection of design scenarios.

6 The Selection of the Design Flow Scenarios

6.1 Approach

The catchments of the Ruchill Water, Earn and Lednock have different characteristics which is reflected in the recorded hydrographs. The different time to peaks, base flow and runoff rates means that it is extremely unlikely for all rivers to peak at the same time at the confluence. If they were to coincide then the event would have an AEP significantly less than the AEP of the flows in each river.

The approach used has been to calculate the distribution of flow between the three rivers for the significant events in the available record and to select scenarios that will give a range of credible flows in each river. Model sensitivity runs have been carried out to assess the significance of the different modelled water levels. The results have been discussed with SEPA and a single design scenario selected.

6.2 Flow scenarios

6.2.1 Scenario 1: Baseline

The first scenario comprises the flows and return periods in the three upstream catchments that generate a 0.5% AEP flood at the Dalginross gauging station.

The 0.5% AEP flow at Dalginross is given in Table 6. While there are a large number of potential combinations of flows and associated AEP for the three upstream rivers the available data and the local knowledge of SEPA hydrologists has been used to determine the most credible scenario.

The flows in the Upper Earn and Lednock are based on the flow in the Ruchill being the dominant influence on the flow at Dalginross. Correlation analysis has therefore been used to calculate the flows at Aberuchill and in the Lednock.

Fifteen of the highest daily maximum flows which had been quality controlled by SEPA were selected for the Water of Ruchill at Cultybraggan station, River Earn at Aberuchill station and the River Earn at Dalginross station. Correlation analysis was undertaken and the percentage contribution to the total flow at Dalginross gauge from each of the two stations was derived. Results are provided in Table 8.

Date	Daily maximum flows (m³/s) at:				
	Dalginross	Cultybraggan	% contribution	Aberuchill	% contribution
19/02/1997	283.0	229.0	81%	95.7	34%
23/02/2014*[7,8]	270.2	140.0	52%	105.0	39%
15/01/1993	248.3	174.0	70%	87.7	35%
20/12/2013[9]	245.7	166.0	68%	97.4	40%
27/08/2012	241.0	198.0	82%	55.5	23%
19/11/2012	240.5	163.0	68%	68.9	29%
15/01/1993	232.4	174.0	75%	87.7	38%
01/02/2002	221.7	165.0	74%	61.8	28%
28/11/1999	215.3	169.0	79%	80.4	37%
05/03/1994[10]	214.6	64.9	30%	44.4	21%
19/11/2009	214.4	165.0	77%	38.3	18%
17/02/1997	212.1	181.0	85%	79.4	37%
29/11/2011	205.4	143.0	70%	67.4	33%
13/01/2008	198.3	137.0	69%	45.0	23%
15/01/2011	197.5	146.0	74%	65.5	33%
Average (%)			**70**	**-**	**31**
Standard deviation (%)			**13**	**-**	**7**

Table 8: Percentage contribution of flows in the River Earn at Dalginross from the (Upper) River Earn at Aberuchill and Water of Ruchill at Cultybraggan

From Table 8, the Water of Ruchill typically contributes 70% of the flow at Dalginross station, and the combined contribution of the Upper Earn and River Lednock makes up 31%. The small discrepancies between the sum of the flows and the flow at Dalginross are caused by errors in the calculated flows, the growth curves and differences in the timing of the peak flows.

For flows higher than the maximum on record (283.0 m³/s), it is assumed that the percentage split remains the same. Results of the standard deviation calculations of each percentage contribution are also shown in Table 8. As this analysis is carried out for the highest flows, it is assumed that the relationship holds true for all values of flow lower than the selected threshold. The uncertainty relating to the rating curves used at Dalginross and Aberuchill gauging station is has been considered for this methodology. Additionally,

SEPA, who have a local knowledge of the catchments, advised that the flows on the combined Upper Earn and the River Lednock contribute to a higher proportion of flows than 31%[11].

7 SEPA informed Mouchel of "issues during late 2013/early 2014 with trees in the channel just downstream of the level site which may have created a backing up affect…which could result in the peak stage value being estimated at circa 0.1m higher". Mouchel can confirm that this would have only negligible effects to the calculations carried out in Section 5.

8 SEPA informed Mouchel of overflowing levels on Loch Lednock, upstream of River Lednock. Therefore, the flow contributions for this date are anomalous to the rest of the data.

9 See footnote 8.

10 SEPA raised doubts about the accuracy of this record in conference with Mouchel on 2nd June 2014. Upon verification, Mouchel can confirm that this low flow record is from the measured gauge reading.

11 Meeting of 2nd June 2014

Therefore, using this information as well as the standard deviation values of 13% for the Water of Ruchill and 7% for the combined flows of the Upper Earn and River Lednock, the percentage contributions to the flows were adjusted to fit the advice of SEPA but still within one standard deviation of the mean. The agreed split in flow is given by the equation below:

Flow (Dalginross) = 0.6 Flow (Ruchill) + 0.4 Flow (Upper Earn & Lednock)

Three methods were used to calculate the relative contributions from the Upper Earn and Lednock that make up the 40% in the equation above:

- A ratio of areas of the two catchments at the confluence with the River Earn
- A ratio of QMED values derived using FEH bankfull method
- A ratio of peak flows from the FEH rainfall runoff method

The results are outlined in Table 9.

		River Earn	River Lednock	Ratio
Catchment area at confluence (km^2)		177.1	61.8	2.9
QMED value (bankfull method) (m^3/s)		153.4	89.0	2.7
Peak flows from FEH RR (m^3/s)	**Return period (years)**	**River Earn**	**River Lednock**	**Ratio**
	10	191.0	77.5	**2.4**
	50	274.4	111.6	**2.4**
	75	295.9	123.3	**2.4**
	100	311.6	126.8	**2.4**
	200	355.5	145.0	**2.4**
Average of three methods:				**2.5**

Table 9: Three methods to derive a relationship between flows in Upper Earn and River

From this, a ratio of 2.5 has been taken forward for the calculations to derive the contribution of flows from each of the three catchments to the flows at Dalginross gauge. The resulting equation is:

Flow (Dalginross) = 0.6 Flow (Ruchill) + 0.28 Flow (Upper Earn) + 0.12 Flow (Lednock)

This scenario is referred to as **scenario 1** in this note and represents the baseline scenario for the purpose of comparison.

6.2.2 Scenario 2

The correlation results given in Table 8 indicate that the flow in the Ruchill Water could be as high as 80% of the flow in the River Earn at Dalginross with an equivalent flow in the Upper Earn of up to 30%. The sum of the proportions is greater than 100% due differences in the timing of the peak flows and errors in the estimated flows. The sum of the proportions has therefore been adjusted to equal 100%.

The correlation factor between the flows in Upper Earn and the Lednock has been maintained at a value of 2.5 thus giving the relationship between all flows as:

Flow (Dalginross) = 0.8 Flow (Ruchill) + 0.057 Flow (Upper Earn) + 0.143 Flow (Lednock)

It should be noted that for the 0.5% AEP at Dalginross this relationship gives a flow of 367.3 m^3/s at Cultybraggan which exceeds the 0.2% AEP. While this is an extreme case it has been included in the analysis to give an upper bound to the predicted water levels.

This scenario is referred to as **scenario 2** in this note.

6.2.3 Scenario 3

It is more credible to assume that the flow in the Ruchill Water is equivalent to the 0.5% AEP and the flows in the Upper Earn and Lednock are equivalent to the QMED value. This is referred to as **scenario 3** in this report.

6.3 Model Results

The flows used for each scenario are given in Table 10 and the results of model runs are given in Table 11. The water levels are given at 13 locations which are shown in Figure 3.

Scenario	Flow distribution factor			Water of Ruchill at Cultybraggan (m^3/s)	River Earn at Aberuchill (m^3/s)	Lednock at confluence with River Earn (m^3/s)	Dalginross (m^3/s)
Scenario 1	0.6	0.28	0.12	275.5	128.5	55.1	459.1
Scenario 2	0.8	0.143	0.057	367.3	65.7	26.2	459.1
Scenario 3	0.5% AEP	QMED	QMED	303.4	67.1	39.3	

Table 10 Flow Distribution for each Scenario

No.	Scenario 1		Scenario 2				Scenario 3			
	Water level (mAOD)	Water depth (m)	Water level (mAOD)	Water depth (m)	Change in water depth (m)	Change in water depth (%)	Water level (mAOD)	Water depth (m)	Change in water depth (m)	Change in water depth (%)
1	61.25	2.87	61.40	3.02	0.15	5.23	61.28	2.90	0.03	1.05
2	60.05	2.33	60.13	2.41	0.08	3.43	60.07	2.35	0.02	0.86
3	59.24	2.18	59.37	2.31	0.13	5.96	59.24	2.18	0.00	0.00
4	58.85	2.41	59.05	2.61	0.20	8.30	58.81	2.37	-0.04	-1.66
5	58.76	3.24	58.94	3.42	0.18	5.56	58.63	3.24	0.00	0.00
6	58.70	3.91	58.88	4.09	0.18	4.60	58.54	3.75	-0.16	-4.09
7	58.62	3.62	58.74	3.74	0.12	3.31	58.34	3.34	-0.28	-7.73
8	58.39	5.06	58.56	5.23	0.17	3.36	58.17	4.84	-0.22	-4.35
9	57.75	3.89	57.83	3.95	0.06	1.54	57.61	3.75	-0.14	-3.60
10	57.22	3.74	57.28	3.80	0.06	1.60	57.09	3.61	-0.13	-3.48
11	56.15	4.09	56.15	4.09	0.00	0.00	56.03	3.97	-0.12	-2.93
12	55.78	3.97	55.78	3.97	0.00	0.00	55.58	3.77	-0.20	-5.04
13	56.49	2.73	56.48	2.72	-0.01	-0.37	56.31	2.55	-0.18	-6.59

Table 11 Modelled water levels for each flow scenario

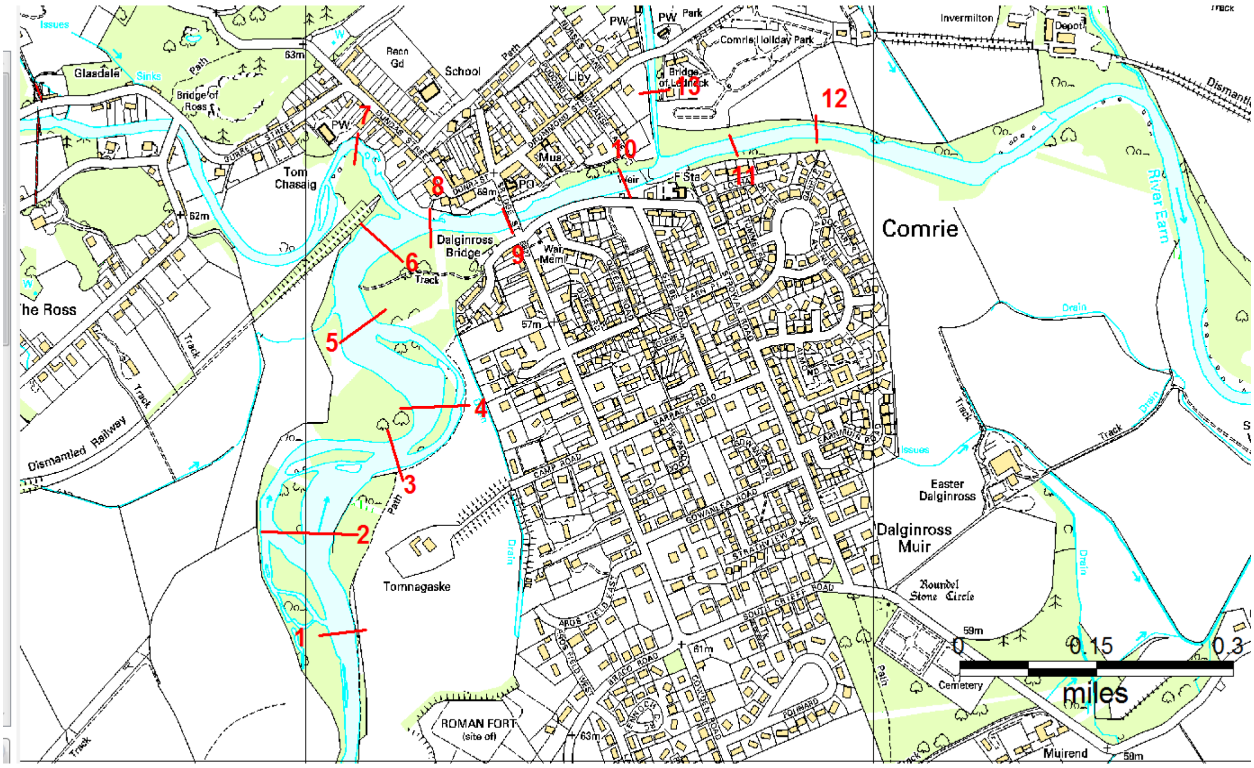


Figure 3: Location of cross sections listed in Table 11

The results given in Table 11 indicate that the higher flow in the Ruchill for scenario 2 inevitably lead to higher water levels upstream of the confluence but that there are almost no changes in level downstream of the confluence.

Scenario 3 shows that if the flow in the Ruchill is limited to the 0.5%AEP the differences in water level are small in the Ruchill Water but negative at Dalginross as flows in the upper Earn and Lednock are limited to QMED.

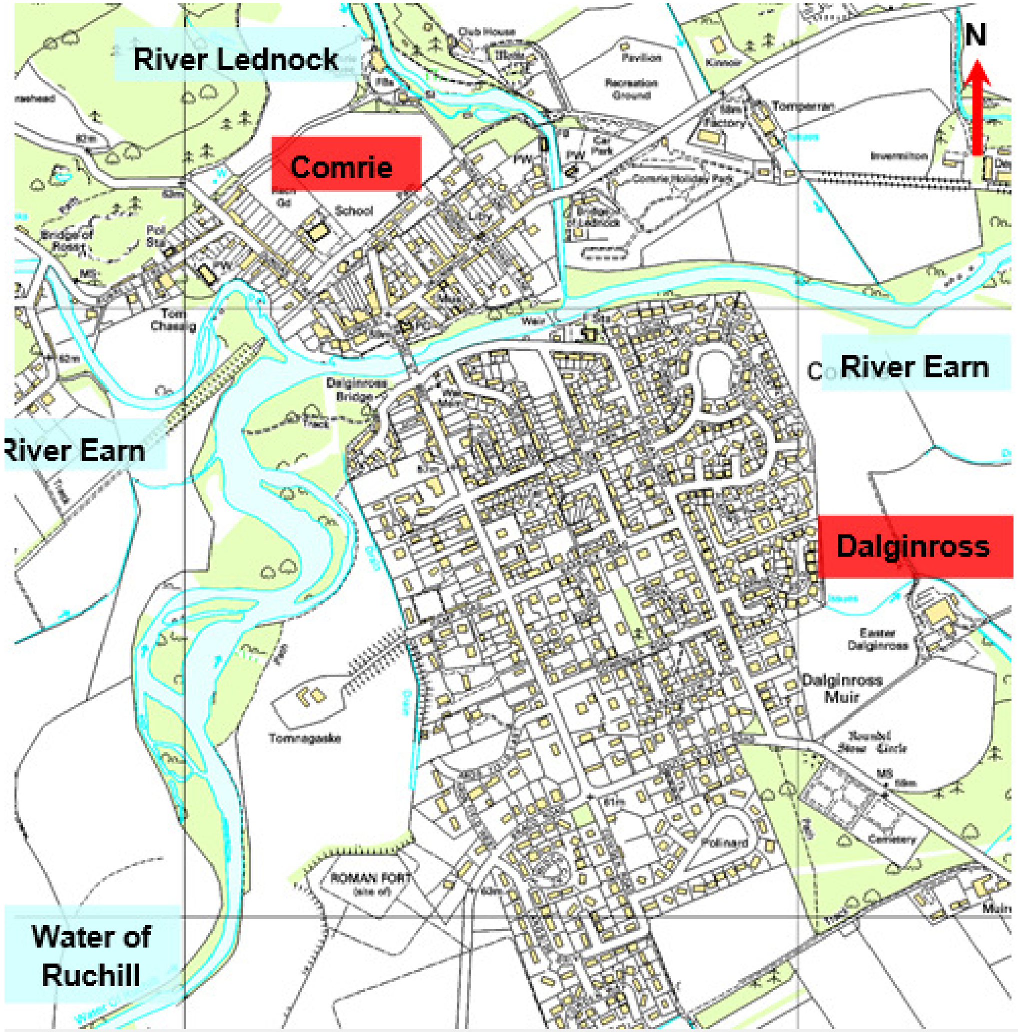
The results of the sensitivity analysis show that scenario 1 gives water levels that are equivalent to the 0.5% AEP at Cultybraggan and Dalginross. Although the flow at Cultybraggan is less than the 0.5% AEP the water levels differ by less than 3 cm at location 1 upstream of Tomnagaske.

7 Conclusion

The simplified joint probability analysis has been used to derive design flows that give a specified AEP at the Dalginross gauging station. The comparison between the three credible scenarios shows that scenario 1, which has been agreed with SEPA, can be used for the purpose of feasibility study.

4) Technical Review

Comrie Flood Prevention Scheme – River Modelling and Hydrology



mouchel
building great relationships

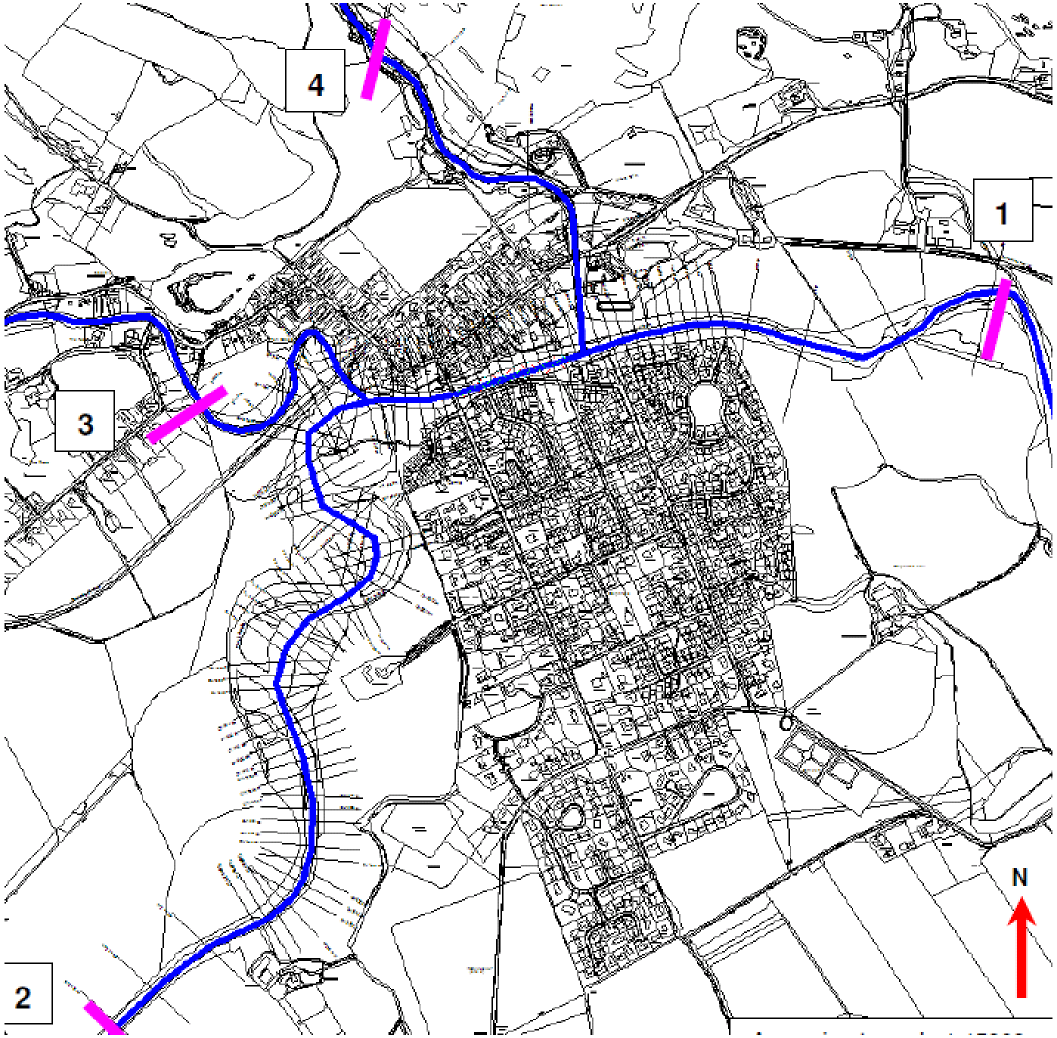
River	Comment
Lednock	64 km2 of which 28km2 controlled by SSE dam. Dam operated so as not to spill as far as possible (spilled on 4 occasions in the last 10 years: December & January 2006/07 and February & March 2014)
Earn	183 km2 of which 140 km2 drains to Loch Earn. Weir at St Fillans controls outflows. Spills c13 weeks per year. Receives flow from Dalchonzie HEP upstream of Comrie
Ruchill	103 km2. Steep and mobile. Floodplain upstream of confluence has changed over recent years. Historically flow path originally passed through Dalginross.

The Approach

1) Data review
2) Flood Estimation Handbook
3) Hydraulic Model
4) Calibration and validation
5) Design flows
6) Check model sensitivity
7) Design flows and levels
8) Freeboard calculation

Data:

- SEPA level, flow and rauinfall records at Culltybraggan, Aberuchill, Lednock and Dalginross
- Post-flood surveys for 1995, 1997, 2012, 2014
- SEPA flood map and SEPA knowledge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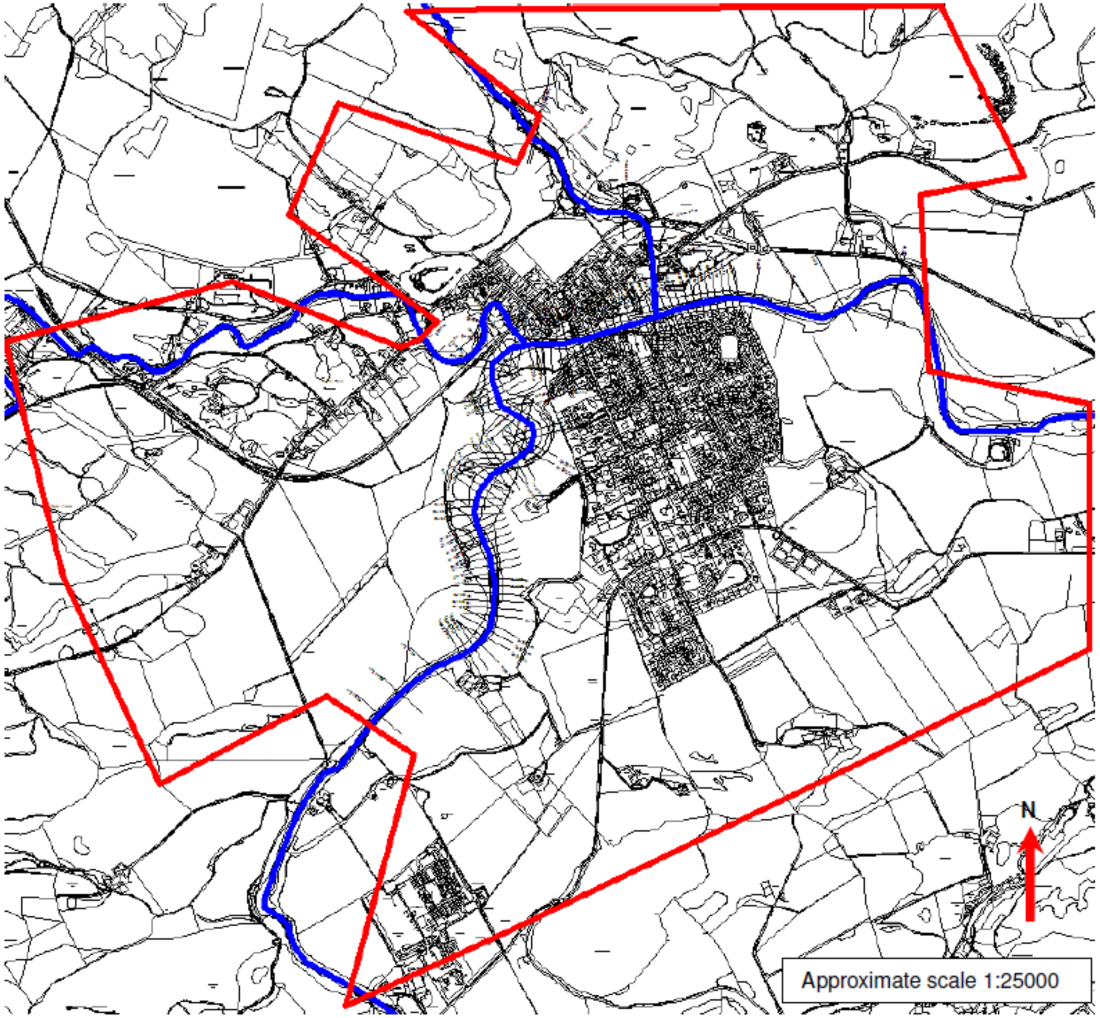

N
Approximate scale 1:25000

Gauge	Type	Abbreviation	Location (Easting, Northing)	Frequency of Record	Length of Record
Auchinner	Rainfall	AU	269449, 715825	15 minutes	34 years
Lochearnhead	Rainfall	LO	258755, 723105	Daily	18 years
Cultybraggan	River flow & stage	CU	276441, 720399	15 minutes	50 years
Aberuchill	River flow & stage	AB	275383, 721661	15 minutes	32 years
Dalginross	River stage	DA	277901, 722071	15 minutes	18 years

Date of Rainfall Peak [20]	Gauge data available	Other Information Available
<u>16th Jan 1993</u>	AU,LO, CU, AB, DA	• CU – 1 in 20yr return period flow from rating curve • AB – 1 in 2yr return period flow from rating curve • Anecdotal evidence of flooding from discussions with PKC and local residents. • Flood mechanism plotted in Mouchel 2006 report[21]
<u>19th Feb 1997</u>	AU,LO, CU, AB, DA	• CU – 1 in 20yr return period flow from rating curve • AB – 1 in 2yr return period flow from rating curve • Anecdotal evidence of flooding from discussions with PKC and local residents.
9th Aug 2004	AU,LO, CU, AB, DA	• CU – 1 in 6yr return period flow from rating curve • AB –1 in 2yr return period flow from rating curve
6th Feb 2001	AU,LO, CU, AB, DA	• CU – 1 in 7yr return period flow from rating curve • AB – 1 in 2yr return period flow from rating curve

Table 4.9 – Comparison of information available for verification events

Plus:
August and November 2012
February 2014

Scenario	Description
1	The return period of flows in the Ruchill, Upper Earn and Lednock are all equal and the peaks are assumed to coincide at Dalginross.
2	Scenarios 2, 3 and 4 represent the cases where the design flow occurs in each water course with almost zero flow in the other two water courses. These scenarios have been superseded by scenarios 6, 7 and 8.
3	
4	
5	Scenario 5 gives the flows in each of the rivers that combine to give the design flow at Dalginross. The flows are calculated using a simplified joint probability analysis which gives flows equivalent to the 80 year in the Ruchill, 25 year and 8 Year in Upper Earn and Lednock.
6	Scenarios 6, 7 and 8 were requested by SEPA. The design flow in each river assumed to be coincident with the 10 year flow in the other two rivers.
7	
8	

Table 1: Alternative Design Flow Scenarios

- Hydraulic modelling using the design inflows at Cultybraggan, Aberuchill and Lednock as inflows
- FEH single site analysis using the water level record and the SEPA rating curve
- FEH single site analysis using the water level record and the model rating curve

- Topo surveys carried out in 2006 and 2009 (including structures)
- Cross sections at 25m spacing
- Composite ground model developed using topographic surveys and Intermap DTM

Included:

Description	Model label	Easting (m)	Northing (m)
Dalginross Bridge over the River Earn	R575	277364	721914
Weir downstream of Dalginross Bridge	R300	277599	721985
Weir at upstream model boundary on River Lednock	L787	277217	722586

Table 4.17 – Hydraulic structures along the River Earn and River Lednock

Excluded:

Description	Closest Model Node	Easting (m)	Northing (m)
Bridge of Lednock carrying A85 road bridge	L289	277607	722188
Footbridge close to St Margaret's Church	L176	277584	722302

Table 4.18 – Hydraulic structures excluded from model

	(i)	(ii)			(iii)	(iv)
RP	Joint Probability[1]	Scenario 1	Scenario 5[2]	Scenario 6	Single Site (SEPA)	Single Site (Model)
2	188				190	173
5	239	324			232	219
10	274	361			262	250
25	323	394			301	294
50	364	416			334	332
100	40.	441			370	373
200	459	472	390	405	409	419
500	534				466	487

[1] The flows derived using joint probability at Dalginross
[2] The flow produced by the model at Dalginross when the joint probability flows are used as input to the model.

Table 7: Estimate peak flows at Dalginross

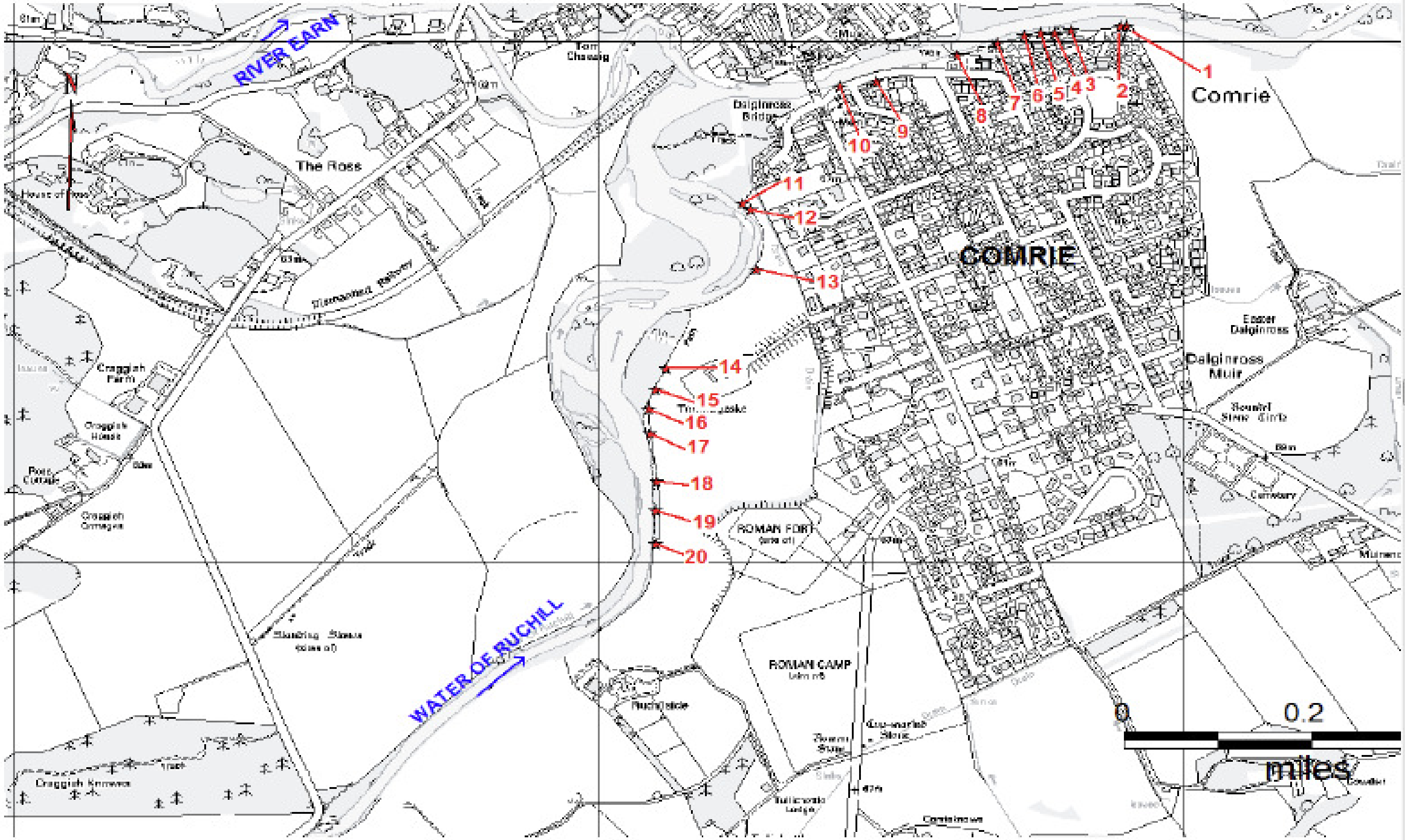


Figure 5: Locations where the model and recorded water levels are compared

Location	Arup recorded water level, mAOD	Mouchel 200 years all model level	Mouchel 100 years all model level	Mouchel 75 years all model level	Mouchel 50 year all model level	Mouchel 25 year all model level	Mouchel 10 year all model level	Mouchel model nodes
1	55.67	56.04	55.94	55.90	55.84	55.73	55.50	R000 (Dalginross gauge)
2	55.784	56.10	56.00	55.95	55.90	55.79	55.58	close to R025c
3	55.94	56.32	56.24	56.21	56.17	56.09	55.92	R100
4	56.13	56.37	56.29	56.26	56.22	56.15	56.00	R125
5	56.17	56.33	56.25	56.22	56.18	56.11	55.98	R150
6	56.21	56.53	56.43	56.39	56.34	56.25	56.10	R175
7	56.548	56.67	56.59	56.55	56.51	56.42	56.27	R225
8	56.897	57.20	57.07	57.02	56.96	56.86	56.68	R300
9	56.923	57.36	57.31	57.29	57.27	57.21	57.10	R450
10	57.1	57.65	57.58	57.54	57.50	57.42	57.27	R500
11	58.678	58.95	58.82	58.77	58.72	58.63	58.54	Between R1100 and R1200
12	58.425	58.95	58.82	58.77	58.72	58.63	58.54	Between R1100 and R1200
13	59.108	58.95	58.82	58.76	58.71	58.66	58.59	R1225
14	59.949	60.07	60.05	60.04	60.03	60.00	59.96	R1500
15	60.284	60.31	60.29	60.28	60.26	60.24	60.19	R1550
16	60.7	60.76	60.73	60.71	60.68	60.64	60.57	R1600
17	61.2	61.10	61.06	61.04	61.01	60.96	60.87	R1650
18	61.646	61.41	61.36	61.34	61.30	61.24	61.14	BETWEEN R1725 and R1750
19	61.656	61.77	61.73	61.71	61.67	61.62	61.53	R1800
20	61.955	61.90	61.87	61.85	61.83	61.78	61.71	BETWEEN 1850 AND 1875

Table 8: Model validation results for the 1997 flood event (The shaded cells indicate the RP of the 1997 recorded level)

19 November 2012

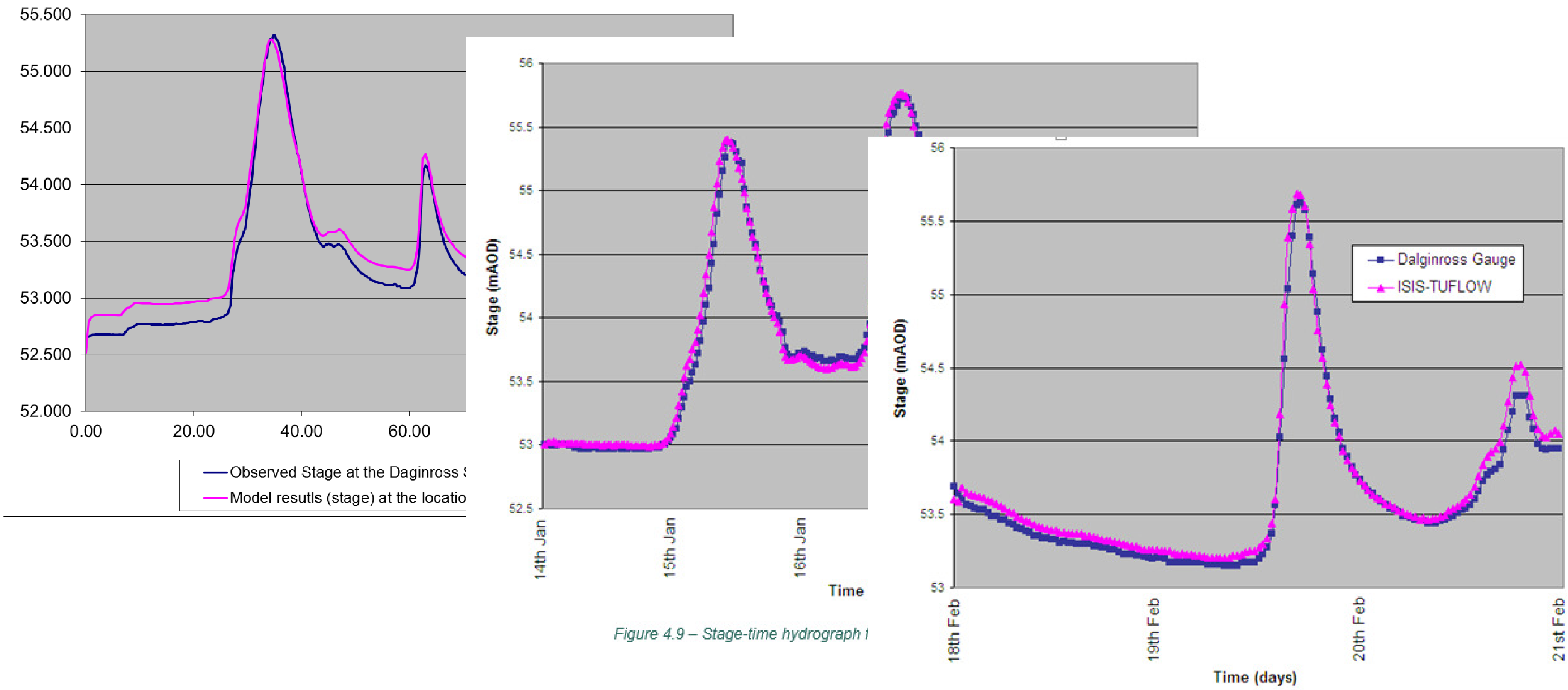
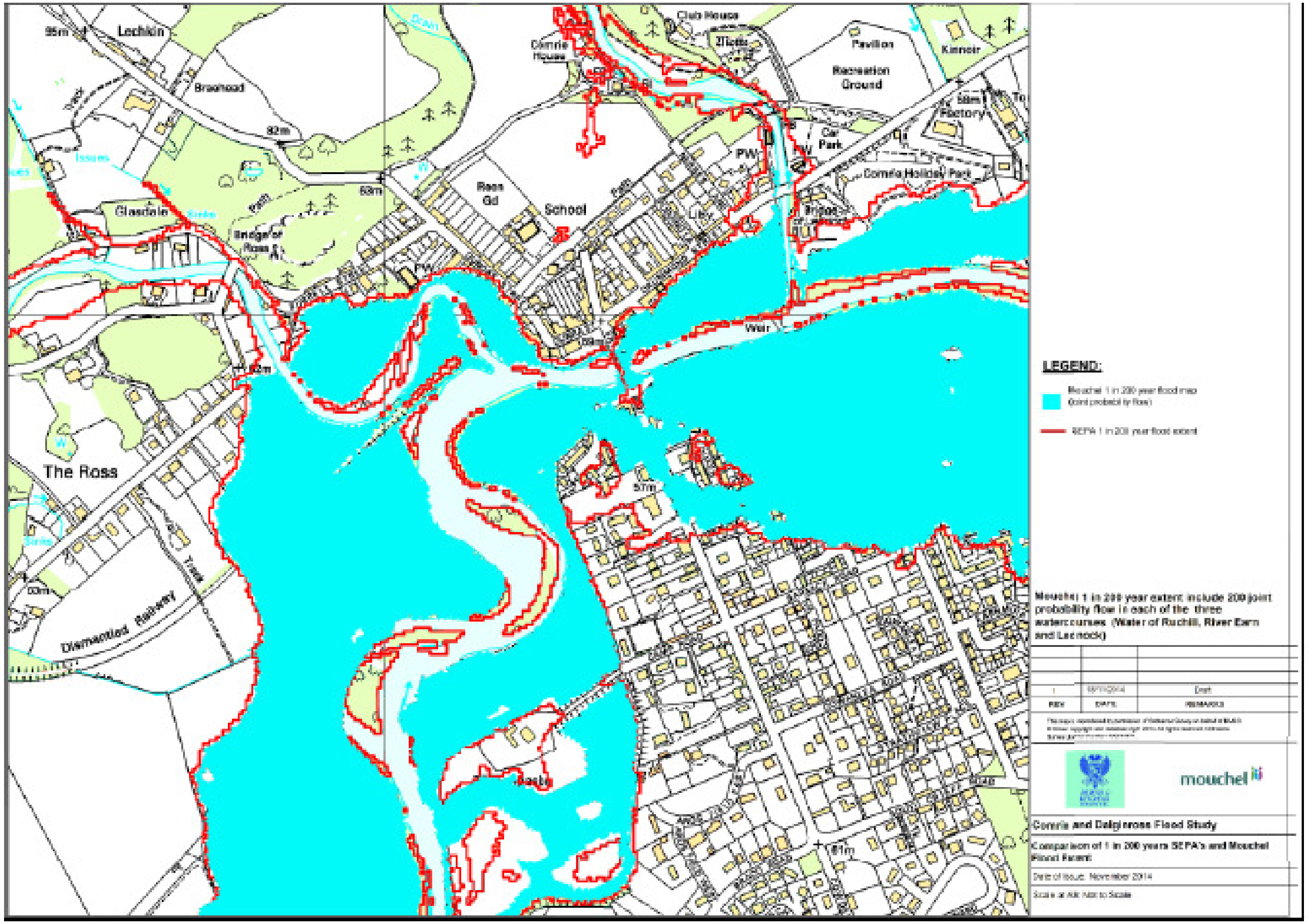


Figure 4.9 – Stage-time hydrograph f

Figure 4.10 – Stage-time hydrograph for February 1997 flood event

building great relationships



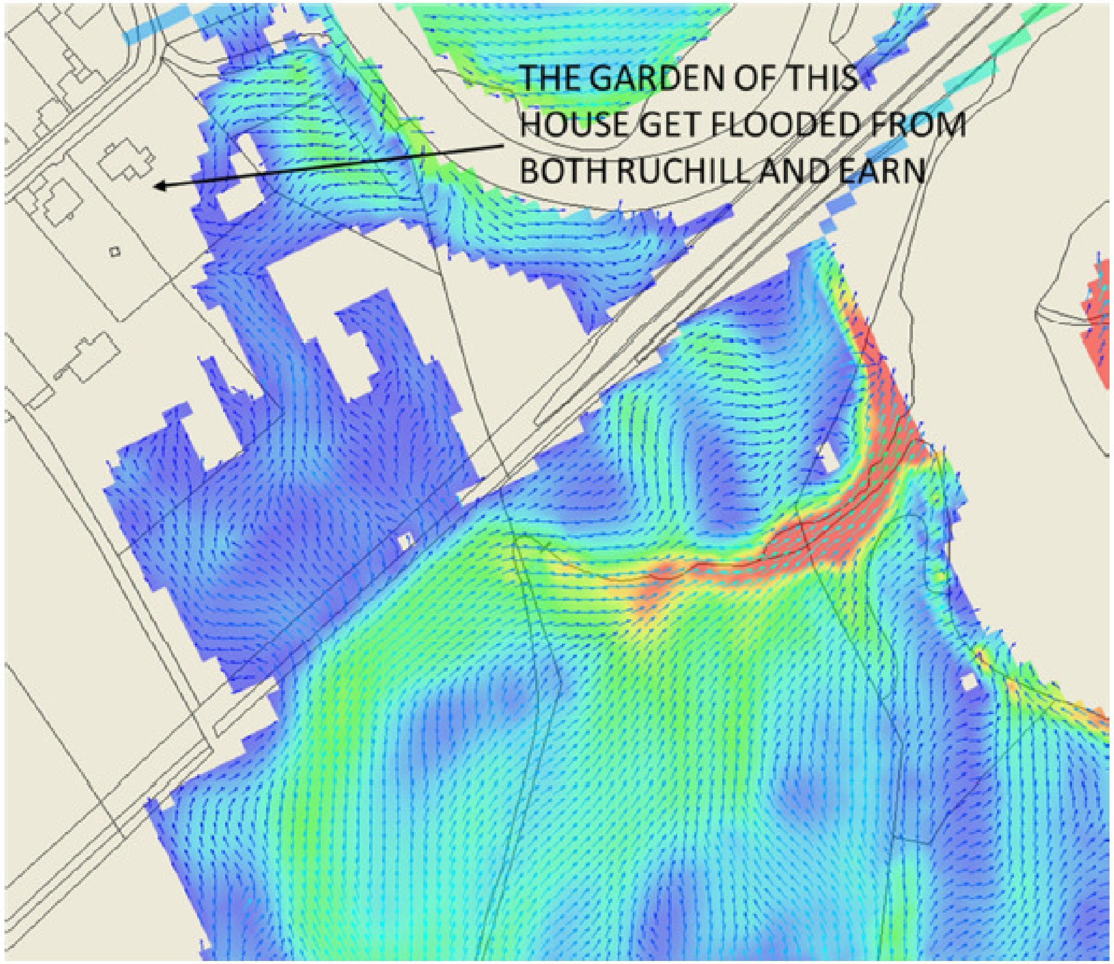


Figure 8: The 200 year flood map at The Ross

mouchel
building great relationships

Recommendations

The following recommendations have been accepted by SEPA as the basis for the appraisal of options:

- Accept the design flow estimates for the Ruchill at Cultybraggan, Aberuchill and the Lednock.
- Allow the model to determine the flow and level at Dalginross (i.e. do not impose a design flow or water level at Dalginross)
- Use scenario 1 (200 year in all rivers) as the design scenario
- Use scenarios 5, 6, 7 and 8 to quantify the sensitivity of the water levels to uncertainty in the flow
- Include flooding of The Ross in the appraisal of options

From: MacConnachie, Malcolm [mailto:Malcolm.MacConnachie@SEPA.org.uk]
Sent: 26 February 2015 14:08
To: Tim Jolley; Alistair Scotland
Cc: Paul Swift; Pravin Ghimire; Hamilton, Richard
Subject: RE: Comrie FPS - design flows

Tim,

The results of the modelling work look much improved using the revised design flows for the Lednock.

I can confirm that we are now satisfied with the recommendations at the end of the revised report and pleased that you now have a basis on which to start investigating options for flood mitigation.

One thing that we note from the inundation map that forms part of your report is that flood flows no longer spill into the field upstream of Tomnagaske. Following the recent flood defence works undertaken at Dalginross most of the out of bank flow from the Ruchill heads off towards The Ross. I am concerned that the risk of flooding to the properties at The Ross may have been increased. I am also fully aware that the channel will continue to migrate to and fro across its floodplain and that the extent shown on the inundation map is merely a snap shot of where the channel and flood extent might be at the moment. Things will constantly change on the Ruchill. Are you able to confirm if the flood study will be investigating the risk of flooding
from water overtopping both the right and left banks of the Ruchill and investigating options to protect not only Dalginross but also properties in the vicinity of The Ross?

Kind regards,

Malcolm

A.Malcolm MacConnachie
Senior Hydrologist
Scottish Environment Protection Agency
7 Whitefriars Crescent
Perth

tel: 01738 627989
fax: 01738 630997
email: malcolm.macconnachie@sepa.org.uk

Issues and Risks

Risk	Impact	Mitigation/Comment
Future flood events	Revised design flows/levels (delay, cost, etc.)	Build uncertainty into freeboard; Advise PKC of risk
In appropriate assumptions and/or technical errors.	Programme delay and cost Additional modelling Potentially revised design flows/levels	Internal model checks carried out in September 2015. Minor issues only which have all been addressed.
Challenge by SEPA	Programme delay and cost Additional modelling Potentially revised design flows/levels	The modelling was checked by SEPA in 2012 and reviewed in February 2016. SEPA raised an issue with the d/s BC which has been responded to. However, SEPA expect a final model report.
FEH revision (FEH15)	Revised design flows	SEPA have agreed hydrology. Could carry out sensitivity if necessary.
Revised topography	Local changes to levels	Sensitivity to see if it is accommodated within freeboard. SEPA have agreed GS datum

5) SEPA Comments and Mouchel Response

Comrie Flood Prevention Scheme A record of how the Issues raised by SEPA have been addressed		
Source	**Issue**	**Response**
SEPA E-mail from Malcolm MacConnachie dated 05 June 2014	Time to peak (tp) and travel times to SEPA gauging stations.	Mouchel issued the note "Notes on Peak Flow Travel Time" in July 2014. The note reported the modelled travel times to give SEPA confidence in the model and inputs.
	SEPA's calculation of Qmed for the Water of Ruchill gauging station at Cultybraggan is higher than that calculated by Mouchel. SEPA has a Qmed of 161.4 m3s-1 whereas Mouchel's Qmed is 148.1 m3s-1. The difference is probably down to the difference in datasets. The flow and stage data on HiFlows is different from that held by SEPA. The HiFlows stage and flow data was extracted independently.	Mouchel adopted the value suggested by SEPA (161.1 m^3/s) as reported in section 5.1 and Table 2 of this note.
	I would suggest a further method to determine the Qmed at Dalginross and that would be to use the available water level record for the station. I would suggest that this be done in any case to support the estimates from other methods. While there is always a degree of uncertainty about flow figures much more confidence can be placed on the water level data.	The SEPA rating curve has been reviewed in sections 4 and the growth curve explained in 5.1. The QMED value is given in Table 2. The SEPA method to derive the growth curve has been accepted.
	Our estimate of the 0.5% AEP (1:200) flood flow for Cultybraggan is approximately 301 m^3/s. In table 2 you have this as approximately the 0.2% AEP (1:500) flow. These different results are again likely to be due to the different datasets used.	Mouchel revised the value of QMED (see earlier response) and updated the AEP estimates. As a result we revised the 0.5% AEP to 302.4 m^3/s.
	The design floods for the River Lednock look too low. We undertook a post flood survey on the River Lednock after flooding on 23 February 2014. We surveyed flood trash	The design flows on the Lednock have not been revised as the approach subsequently accepted by SEPA has been to base the flow in the Lednock on a correlation

Comrie Flood Prevention Scheme

A record of how the Issues raised by SEPA have been addressed

Source	Issue	Response
	lines and a number of cross-sections to estimate the peak flow. We estimated the peak flow to be in the range of 75 to 90 m3s-1 at a location draining a catchment area of 60.5 km2, NGR NN 76800 23741. The closest rain gauge, at Auchnafree in the River Almond catchment, recorded 53.8 mm in a 24 hour period. 300 mm had been recorded between 1 February and 23 February 2014 and the capacity of the reservoir was significantly reduced. The dam was on spill. It is understood, that the dam has been on spill about eight times since 1985. We put an estimate of 5-10% AEP (1:10-1:20) on the February flood event.	with flow in the Ruchill. This approach overcomes the significant uncertainty in QMED, the growth curve and the impact of the reservoir on flood flows. The approach is presented in section 5.2 and the results are given in Table 7.
	I would also suggest that the design flows for Aberuchill are perhaps on the high side given that the Earn catchment drains through a large loch a few kilometres upstream of Comrie.	Adjustments were made to the initial pooling group to remove sites with a FARL value below 0.8 due to the influence of Loch Earn. Results are presented in Table 6 together with peak flows derived using the FEH rainfall runoff method for comparison (see section 5.2). Extending the model to include Loch Earn would introduce substantial uncertainty and has not been considered. Ultimately the approach adopted uses flow in the Ruchill to derive the flow in the upper Earn.
	Further to the above comments regarding the design flow assessments I also wish to comment on the final table of the report that shows the return period events that it is proposed to model. If a 0.29% AEP (1:350) flood is modelled in the Water of Ruchill as proposed in order to achieve a 0.5% AEP (1:200) flood on the River Earn then most of Dalginross will be flooded from the Water	The note of 6 June 2014 further investigated the split in flow within the Ruchill Water, Upper Earn and Lednock and concluded that a split of 0.6 : 0.28 : 0.12 was appropriate to give the 0.5% AEP at Dalginross. The flows are equivalent to the 1.25% (80 year) in the Ruchill, the 4% (25 year) in the Upper Earn and the

Comrie Flood Prevention Scheme A record of how the Issues raised by SEPA have been addressed		
Source	**Issue**	**Response**
	of Ruchill. Any proposals to erect defences along the River Earn would only prevent floodwater from entering into the River Earn. Resulting flooding in Dalginross would be deeper and over a longer duration than what would currently occur if defences were raised along the River Earn. I would suggest that the design flows to input into the model requires further investigation.	12.5% (8 year) in the Lednock (see Table 9 of the June report). This note reviews the split in the flows and considers 2 additional scenarios. Scenario 2 considers a split in flows that is more consistent with the recorded data than the 0.6 : 0.28 : 0.12 split (see section 6.2.2). The split derived is 0.8 : 0.143 : 0.057. This scenario gives an extreme case for the Ruchill (> 0.2% AEP) with approximately the 50% AEP (2 year) flows in the upper Earn and Lednock. A third extreme scenario was run which combined the 0.5% AEP (200 year) in the Ruchill with flows equivalent to QMED in the Upper Earn and Lednock. The scenarios are summarised in Table 10 and the results are given in Table 11. It is concluded that "The results given in Table 11 indicate that the higher flow in the Ruchill for scenario 2 inevitably lead to higher water levels upstream of the confluence but that there are almost no changes in level downstream of the confluence. Scenario 3 shows that if the flow in the Ruchill is limited to the 0.5%AEP the differences in water level are small

Comrie Flood Prevention Scheme A record of how the Issues raised by SEPA have been addressed		
Source	**Issue**	**Response**
		in the Ruchill Water but negative at Dalginross as flows in the upper Earn and Lednock are limited to QMED. The results of the sensitivity analysis show that eh differences between the three scenarios is insignificant at Cultybraggan and Dalginross. The flows presented in the June note (0.6 : 0.28 : 0.12) have therefore been accepted as the design flows for options assessment.
SEPA E-mail from Malcolm MacConnachie dated 25/02/2014	Can I please correct a comment in the first bullet point of your notes from the tele-conference on 10 February? The floodwater does not by-pass the gauging station at a stage of 1.5m. Floodwaters bypass the weir downstream of the station ie. flows spill onto the left bank at the weir.	Noted.
	I have produced flows from the cross-section you sent which are similar to those for the estimated calibration that we hold. The flows derived from your cross-section were determined using a surface water slope of 0.003. I am hoping that you might be able to tell me if this is similar to your model output. We do not appear to have a cross-section of the river at the station. Our stage-flow relationship for Dalginross has been estimated using only the limited stage and flow estimates for the gauging stations at Cultybraggan and Aberuchill. Eqn for WL > 54.23 mAOD, Q= 35.2259 x (h - 0.0927523) ^ 1.70995, where h = stage	Section 4 of this note reports on the findings of the comparison between the modelled and SEPA rating curves. Figure 2 shows the comparison. It is concluded that “The modelled and SEPA rating curves at high flows are sufficiently close to accept the SEPA rating and so avoid any inconsistencies between calculated flow values. The SEPA rating curve has therefore been taken forward to derive the flows from the recorded levels at Dalginross gauging station.

Comrie Flood Prevention Scheme A record of how the Issues raised by SEPA have been addressed		
Source	**Issue**	**Response**
	I am generally satisfied with the rest of your notes and the approach proposed to take things forward. However given that a reported 100 cumecs was recorded in the Lednoch on Sunday there is possibly a need to review the estimated flow inputs to your model to represent the Lednoch.	Data for the event of 14 November has been requested and the need to check the model calibration will be discussed with PKC.
PKC List of actions from PKC and Mouchel progress meeting on 12. 11.2014	Joint probability flows – PKC wants to know what frequency analysis has been carried out (and used) at the Dalginross gauge. Mouchel to clarify with SEPA and answer PKC.	This was given in the note of June 2014 and has been confirmed in this note. The flows presented in June 2014 have been accepted by SEPA.
	Mouchel to provide comments/notes after comparing SEPA and Mouchel flood map.	A note was issued on 1st December for PKC comment. The note compares the modelled outline with the SEPA map and confirms the method used for the SEPA map.
	Mouchel to provide a notes on comparison of worse scenario and joint probability flows in Comrie area. PKC wants to know if the flood defence level designed based on the joint probability flow would spill under the worst case scenarios	What is regarded as the worst credible scenario has been presented in the Joint Probability note of November 2014 (it is referred to as Scenario 3). The sensitivity analysis shows very little sensitivity to the change in flows at Dalginross. A scenario with the 0.5% AEP in all water courses has not been modelled to date.
	Dredging to be considered both upstream and downstream of the Dalginross Bridge, for 1m deep.	This note does not address this issue.
	Natural Flood Management measures and sediment control to be carried out by Mouchel	This note does not address this issue.

6) SEPA Meeting Agenda

<u>Agenda</u>

- Introductions
- Purpose
  Follow up actions since last meeting (21/01/15) and report the findings
  Agree baseline (reference) state
  Agree method to be used for options appraisal

- Resume of work to date

- Definition of the baseline state

- Method for options appraisal

- Close

Actions from meeting of 21st January 2015

Action List			
No.	**Description**	**Owner**	**Date**
1	SEPA to provide PKC and Mouchel with information on the flood levels/flows in the Lednock for the event of February 2014.	MM/RH	Closed
2	SEPA to provide a copy of the flood levels recorded by Ove Arup for the flood event of February 1997 (drawing number: 50148 FL-01 (RevA)	MM/RH	Closed
3	SEPA to provide copies of the survey of the January 1993 flood event.	MM/RH	Closed
4	PKC to check for copies of the Ove Arup report and circulate.	AS	Closed
5	SEPA to provide information on the bench marks and zero stage levels at Culltybragan, Aberuchil and Dalginross.	MM/RH	Open
6	Mouchel to review the design flows and levels in light of the new information and to produce a short/succinct summary of the results for SEPA and PKC	TJ	Open
7	Mouchel to discuss the results with SEPA and to arrange a further meeting if one is required.	TJ	Open

Design Flows

Scenario	Return Period (Years)			Flow (m^3/s)		
	Ruchill	Upper Earn	Lednock	Ruchill	Upper Earn	Lednock
1	200	200	200	303.4	196.0	93.2
2	200	~0	~0	303.4	~0	~0
3	~0	200	~0	~0	196.0	~0
4	~0	~0	200	~0	~0	93.2
5	80	25	8	275.5	128.5	55.1
6	200	10	10	303.4	104.9	57.2
7	10	200	10	213.7	196.0	57.2
8	10	10	200	213.7	104.9	93.2

Table 1: Alternative Design Flow Scenarios for the 200 year Flow at Dalginross

Scenario	Return Period (Years)			Flow (m^3/s)		
	Ruchill	Upper Earn	Lednock	Ruchill	Upper Earn	Lednock
1	200	200	200	364.1	235.2	111.8
2	200	~0	~0	303.4	~0	~0
3	~0	200	~0	~0	235.2	~0
4	~0	~0	200	~0	~0	111.8
5	80	25	8	330.6	154.3	66.0
6	200	10	10	364.1	125.9	68.6
7	10	200	10	256.4	235.2	68.6
8	10	10	200	256.4	125.9	111.8

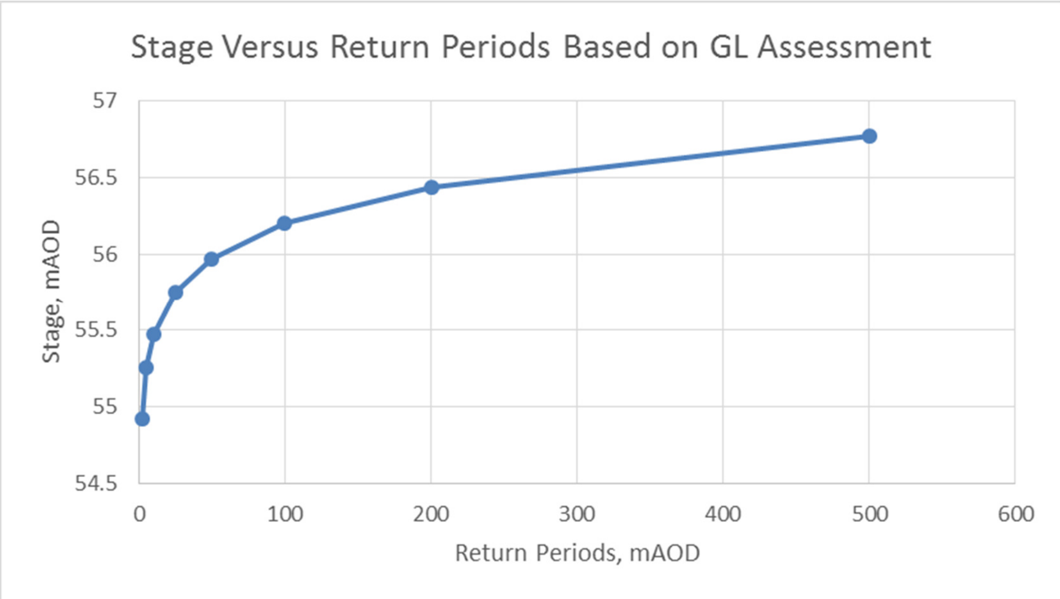
Table 1: Alternative Design Flow Scenarios for the 200 year + Climate Change Flow at Dalginross

Flows and Levels at Dalginross

- *The water level at Dalginross*

Single site analysis of the annual maxima stage record has been used to estimate the growth curve for Dalginross (Estimates for return periods greater than 20 years must be treated with caution).

Based on the model, 200 years flow at Cultybraggan, Aberuchill and Lednock (scenario 5) gives the level of **55.97 mAOD** at Dalginross; which is approximately equal to 50 year RP based on single site analysis.

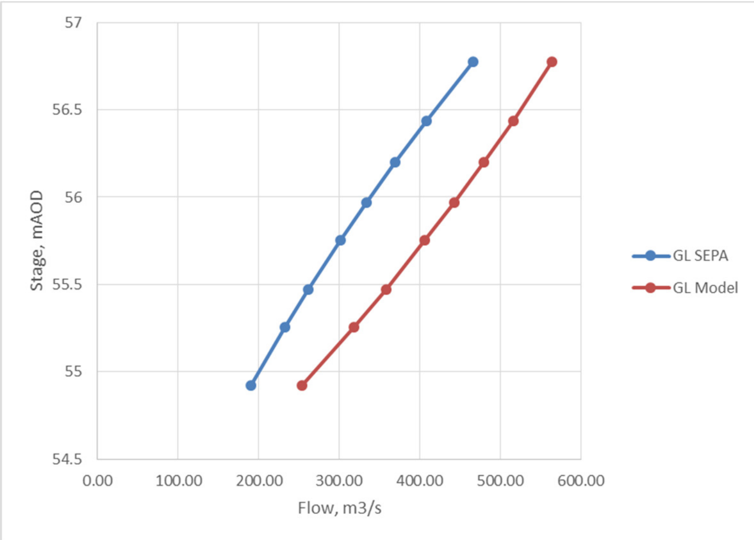


Based on the model, 200 years JP flow at Cultybraggan, Aberuchill and Lednock (Scenario 5) gives the level of **55.65 mAOD** at Dalginross; which is approximately equal to 20 year RP.

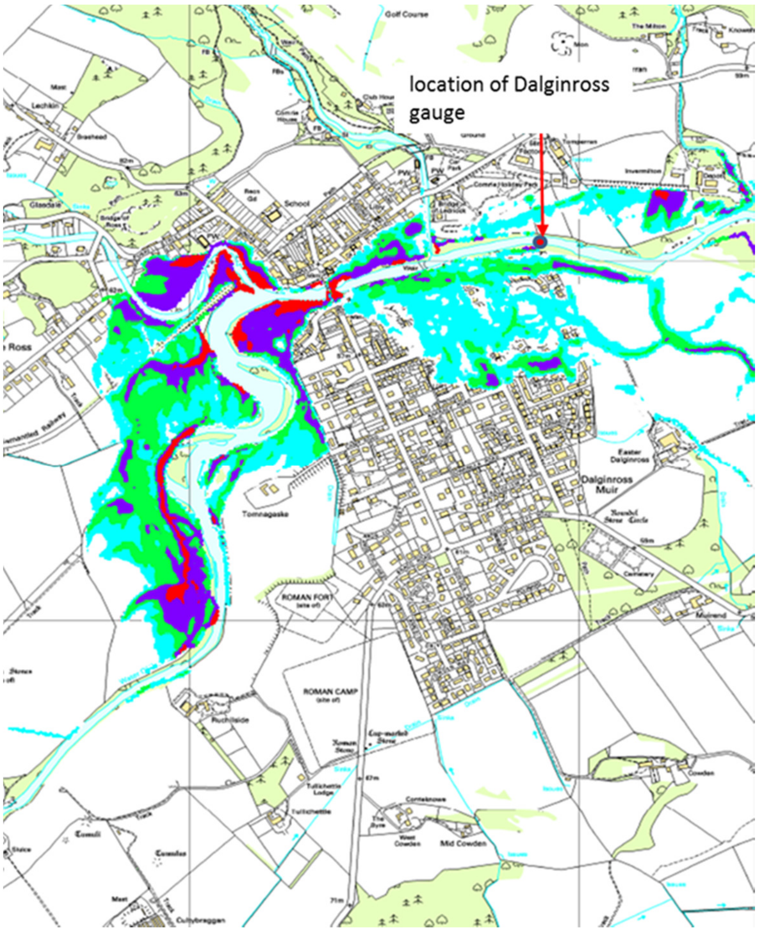
The table below summarises the levels and estimated RP based on single site analysis.

Event	**Level (mAOD)**	**RP (year)**
1997	55.67	20
1993	55.78	25
200 year in all rivers	55.96	50
Joint probability flows (80 year in the Ruchill, 25 year and 8 Year in Upper Earn and Lednock)	55.66	20

- *The rating at Dalginross*



Model rating gives higher value of flow for the same stage compared to SEPA rating (blue line). The model rating is derived from the model results and it takes account of flood plain flow form the location of the Dalginross gauge and upstream, whereas SEPA rating is not valid when there is Out of bank flow.



- *The flow at Dalginross*

  The flow at Dalginross has been estimated using three approaches:

  i) FEH pooling group analysis at Dalginross with QMED calculated from median stage and SEPA rating curve.

     This approach requires that all inflows are increased to ensure the sum of the inflows equals the design flow at Dalginross. This can be achieved by either using lateral inflows between the inflows and Dalginross or by increasing the inflows to the model. Neither option is ideal. Using lateral inflows ensures that the flows at Cultybraggan, Aberuchill, Lednock and Dalginross equate to the design RP but will present difficulties when options are appraised.

     To obtain 459 m^3/s at the Dalginross gauge, the respective flow ratio at the Cultybraggan: Aberuchill: Lednock would have to be 369:171:73. This ratio corresponds to >500 year RP at the Cultybraggan, approximately the 100 year at the Aberuchill and slightly less than 50 years for the Lednock.

     These flows and associated RP's indicate that the estimated 200 year flow at Dalginross is not consistent with the 200 year flows in the Ruchill, Upper Earn and Lednock. The 459m^3/s cannot be accepted without further analysis.

     We would note that the FEH analysis should be treated with caution due to the influence of the upstream confluence and attenuation. The location is not typical of the gauging stations used within FEH and the method does not ensure that flows upstream and downstream of the confluence balance for a given RP.

  ii) The hydraulic model with design inflows at Cultybraggan, Aberuchill and Lednock

     This approach allows the hydraulic model to determine the level at Dalginross. It ensures that the inflows, the hydraulics and the rating at Dalginross are all consistent. No correction factors are required and the appraisal of options is straightforward.

     Three scenarios have been run for the 200 year flow (at Dalginross):
     Scenario 1: the 200 year flow in each river
     Scenario 5: the joint probability flows
     Scenario 6: the 200 year flow in the Ruchill and 10 year flows in the Upper Earn and Lednock

  iii) Single site analysis using the stage record at Dalginross and the SEPA rating

     This approach estimates the growth curve at Dalginross using WINFAP with QMED estimated from the median stage and the SEPA rating. Estimates cannot be relied upon for RP greater than 20 years and for out-of bank flows (for which the SEPA rating is not applicable).

  iv) Single site analysis using the stage record at Dalginross and the model rating

This approach is the same as for iii) but the model rating is used to estimate flow. This overcomes the limitation of the SEPA rating and ensures consistency with flows and levels predicted by the model.

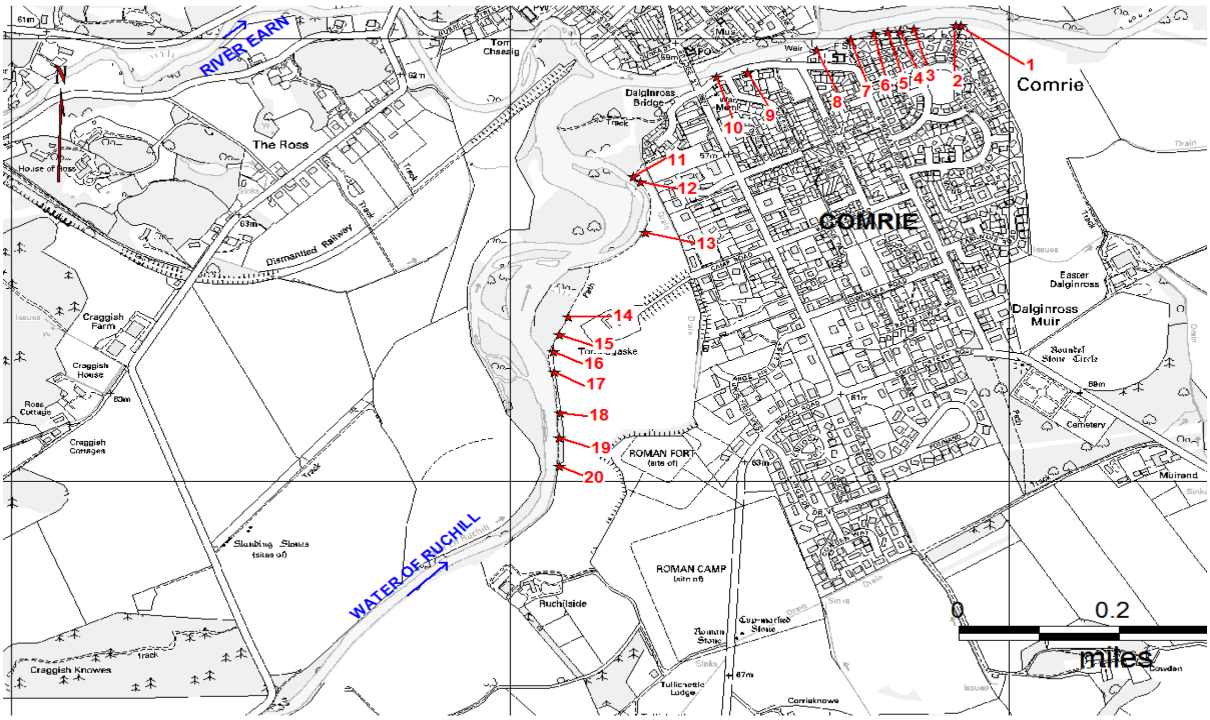
The estimated flows using the four approaches are given in the table below. When the flow at Dalginross is determined by the model (approach (ii)) the resulting flows for scenarios 5 and 6 have a RP of about 25 years based on the single site analysis. The more extreme case of the 200 year flow in all rivers (scenario 1) gives a flow of 444m^3/s which has an estimated RP of 50 years.

RP	FEH	Scenario 1	Scenario 5	Scenario 6	SS (Model)	SS (SEPA)
	(i)		(ii)		(iv)	(iii)
2	188.4				254.14	190.00
5	239.1				318.61	232.53
10	274.3				357.96	261.60
25	323.3				406.82	301.41
50	364.2				443.26	334.12
100	409.2				479.73	369.83
200	459.1	444	390	394	516.18	408.86
500	533.9				564.32	466.44

- *Comparison with post-flood surveys*

The modelled water levels (scenario 5 with and without flow constraint at Dalginross) were compared with the post-flood survey levels for the 1997 event.

The figure below shows the locations where the water levels are compared.



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Comaprison of Scenario 5 (with 459 m3/s in Dalginross) water levels with Arup's recorded water levels

Locations (please see figure below for the location of points)	Arup recorded water level, Maod	Mouchel 200+CC JP model level	Mouchel 200 years JP model level	Mouchel 100 years JP model level	Mouchel 75 years JP model level	Mouchel 50 year JP model level	Mouchel 10 year JP model level	Mouchel model nodes
1	55.855		56.01	55.81	55.67	55.53	55.04	R000 (Dalginross gauge)
2	55.784		56.07	55.87	55.75	55.60	55.11	close to R025c
3	55.94		56.30	56.15	56.06	55.94	55.43	R100
4	56.13		56.34	56.21	56.14	56.02	55.52	R125
5	56.17		56.32	56.18	56.09	56.00	55.53	R150
6	56.21		56.50	56.32	56.24	56.12	55.62	R175
7	56.548		56.65	56.49	56.40	56.29	55.78	R225
8	56.897		57.30	57.05	56.92	56.78	56.24	R300
9	56.923		57.40	57.34	57.27	57.20	56.81	R450
10	57.1		57.76	57.62	57.51	57.41	56.96	R500
11	58.678		59.21	58.89	58.74	58.62	58.39	Between R1100 and R1200
12	58.425		59.21	58.89	58.74	58.62	58.39	Between R1100 and R1200
13	59.108		59.22	58.89	58.72	58.65	58.48	R1225
14	59.949		60.09	60.05	60.02	59.99	59.89	R1500
15	60.284		60.34	60.29	60.26	60.22	60.11	R1550
16	60.7		60.80	60.72	60.67	60.62	60.45	R1600
17	61.2		61.14	61.06	61.00	60.93	60.70	R1650
18	61.646		61.45	61.35	61.28	61.21	60.94	BETWEEN R1725 and R1750
19	61.656		61.81	61.72	61.66	61.59	61.33	R1800
20	61.955		61.92	61.85	61.81	61.76	61.51	BETWEEN 1850 AND 1875

It is observed that the SEPA record for Dalginross gives a maximum water level of 55.67mAOD, 0.18m less than the level given by the post-flood survey.

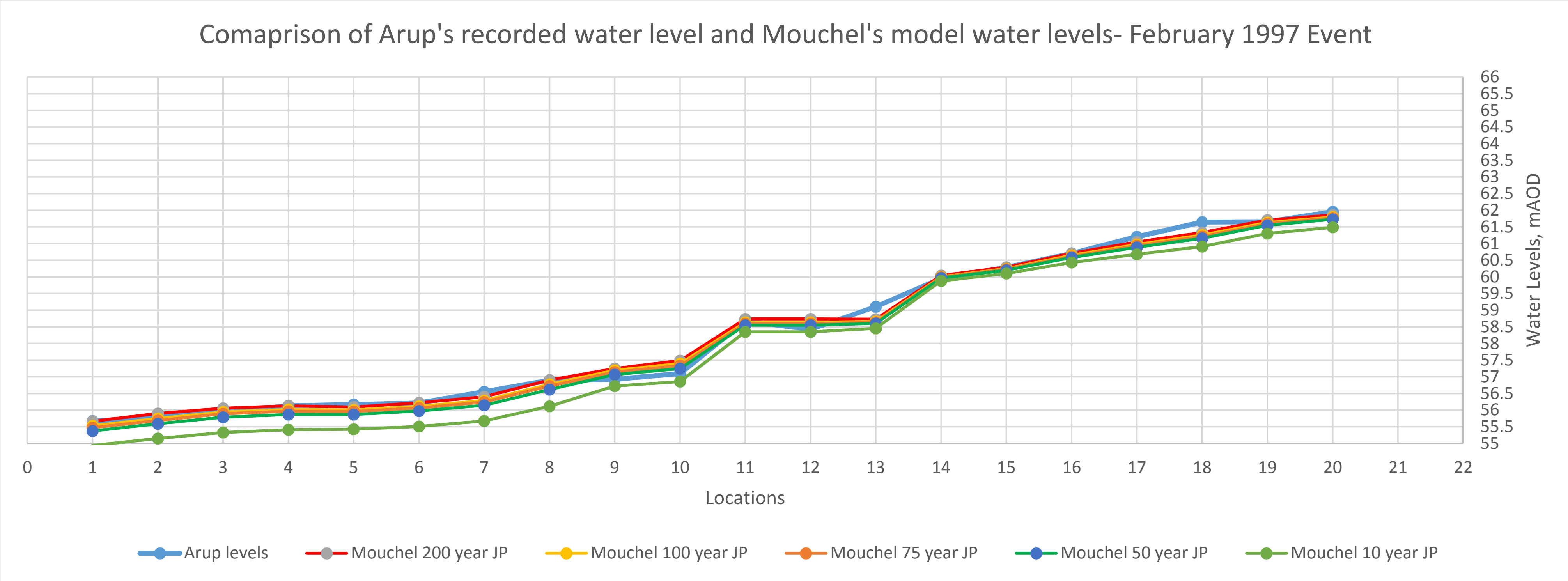
The post-flood levels vary between the 50 and 100 year levels, with the majority being close to the 50 year level, as given by the scenario 5 (with 459 m3/s at the Dalginross) model. However, it is evident that the RP is very sensitive to water level.

Comaprison of Scenario 5 (without flow constraint in Dalginross) water levels with Arup's recorded water levels

Locations (please see figure below for the location of points)	Arup recorded water level, mAOD	Mouchel 200+CC JP model level	Mouchel 200 years JP model level	Mouchel 100 years JP model level	Mouchel 75 years JP model level	Mouchel 50 year JP model level	Mouchel 10 year JP model level	Mouchel model nodes
1	55.855		55.66	55.53	55.47	55.37	54.94	R000 (Dalginross gauge)
2	55.784		55.89	55.75	55.69	55.59	55.15	close to R025c
3	55.94		56.06	55.95	55.89	55.79	55.33	R100
4	56.13		56.13	56.02	55.97	55.87	55.41	R125
5	56.17		56.09	56.00	55.96	55.87	55.43	R150
6	56.21		56.22	56.12	56.07	55.97	55.51	R175
7	56.548		56.40	56.29	56.24	56.14	55.68	R225
8	56.897		56.91	56.78	56.72	56.62	56.12	R300
9	56.923		57.25	57.19	57.14	57.07	56.72	R450
10	57.1		57.49	57.40	57.34	57.25	56.86	R500
11	58.678		58.74	58.64	58.59	58.55	58.34	Between R1100 and R1200
12	58.425		58.74	58.64	58.59	58.55	58.34	Between R1100 and R1200
13	59.108		58.73	58.67	58.64	58.60	58.45	R1225
14	59.949		60.04	60.01	59.99	59.97	59.88	R1500
15	60.284		60.29	60.24	60.23	60.20	60.10	R1550
16	60.7		60.71	60.65	60.61	60.58	60.43	R1600
17	61.2		61.04	60.97	60.93	60.89	60.68	R1650
18	61.646		61.33	61.25	61.21	61.16	60.91	BETWEEN R1725 and R1750
19	61.656		61.70	61.63	61.59	61.55	61.30	R1800
20	61.955		61.85	61.80	61.77	61.73	61.49	BETWEEN 1850 AND 1875

The post-flood levels vary between the 50 to 200 year levels as given by the scenario 5 (without flow constraint m^3/s at the Dalginross) model. However, it is evident that the RP is very sensitive to water level.

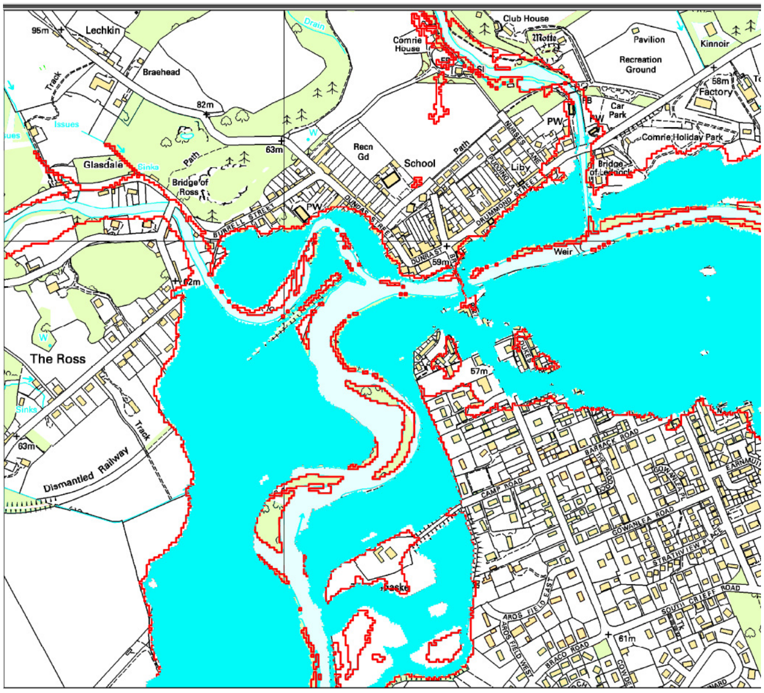
A chart showing comparison of Arup's and Model results (scenario 5 without flow constraint at the Dalginross gauge is presented below:



Comaprison of Arup's recorded water level and Mouchel's model water levels- February 1997 Event
Water Levels, mAOD
Locations
66
65.5
65
64.5
64
63.5
63
62.5
62
61.5
61
60.5
60
59.5
59
58.5
58
57.5
57
56.5
56
55.5
55
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Arup levels
Mouchel 200 year JP
Mouchel 100 year JP
Mouchel 75 year JP
Mouchel 50 year JP
Mouchel 10 year JP

- *Comparison with SEPA flood map*

  Figure below shows comparison of SEPA 200 years (red outline) and model results of scenario 5 without flow constraint at the Dalginross Gauge(light blue)



  The SEPA's and Mouchel flood extent compares very well. The comparison shows that the SEPA's flood extent is slightly bigger than Mouchel's extent in number of places. It has to be noted that SEPA has used 200 years flow in all three watercourses, however Mouchel has used JP flows (less than 200 year) in each of three water courses.

- *Uncertainty in the level and flow at Dalginross*

  The following factors are uncertain:
- The SEPA rating curve at Dalginross
- The growth curve based on single site analysis for RP > 20 years
- The 1993 and 1997 post flood surveys are based on trash lines

  The following factors are considered to be more certain:
- The SEPA water level records at Dalginross, Cultybraggan and Aberuchill
- The SEPA rating at Cultybraggan
- The cross section and floodplain elevations
- The estimated flow at Cultybraggan, Aberuchill and Lednock

  The water level at Dalginross is insensitive to flow for out-of bank flows (see the rating given previously).

  The single site growth curve, which was derived using WINFAP, is based on annual maxima water level and an assumed distribution type. In this case the generalised logistic distribution was used however, there are a number of alternatives each one giving different curves. Moreover, given the record is 22 years long estimates for return periods greater than 20 years must be treated as being indicative.

While we have confidence in the SEPA stage record at Dalginross the post flood surveys for 1993 and 1997 must be treated with caution as they are based on trash marks, survey posts and questionnaires. The value of these surveys is in validating the overall long profile rather than individual points.

- *Recommendations*

- Accept the design flow estimates for the Ruchill at Cultybraggan, Aberuchill and the Lednock.
- Allow the model to determine the flow and level at Dalginross.
- Adopt the scenario approach whereby scenarios 5 to 8 are run for the baseline and all options.

The inconstancy between the design flows input to the model and the recorded water level at Dalginross can be explained by uncertainty in the RP estimates from the single site analysis.

7) SEPA Presentation

Simplified Hydrological Joint Probability Analysis

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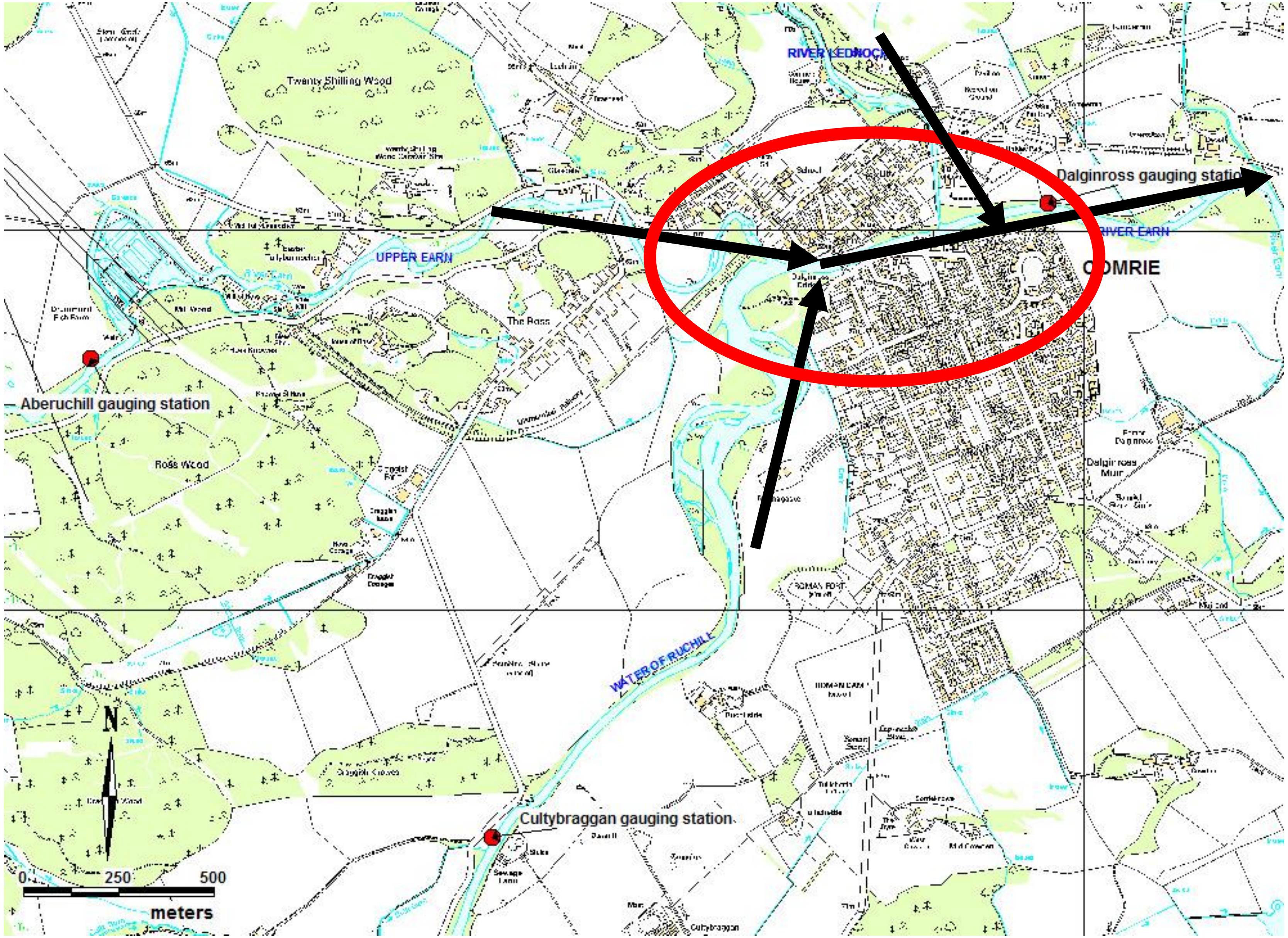

The Approach

1) Data review
2) Select rating curve at Dalginross
3) Flood frequency analysis
4) Simplified Joint Probability for Dalginross
5) Select alternative design flows
6) Check sensitivity of modelled water levels to flow
7) Develop a methodology for design flows and levels

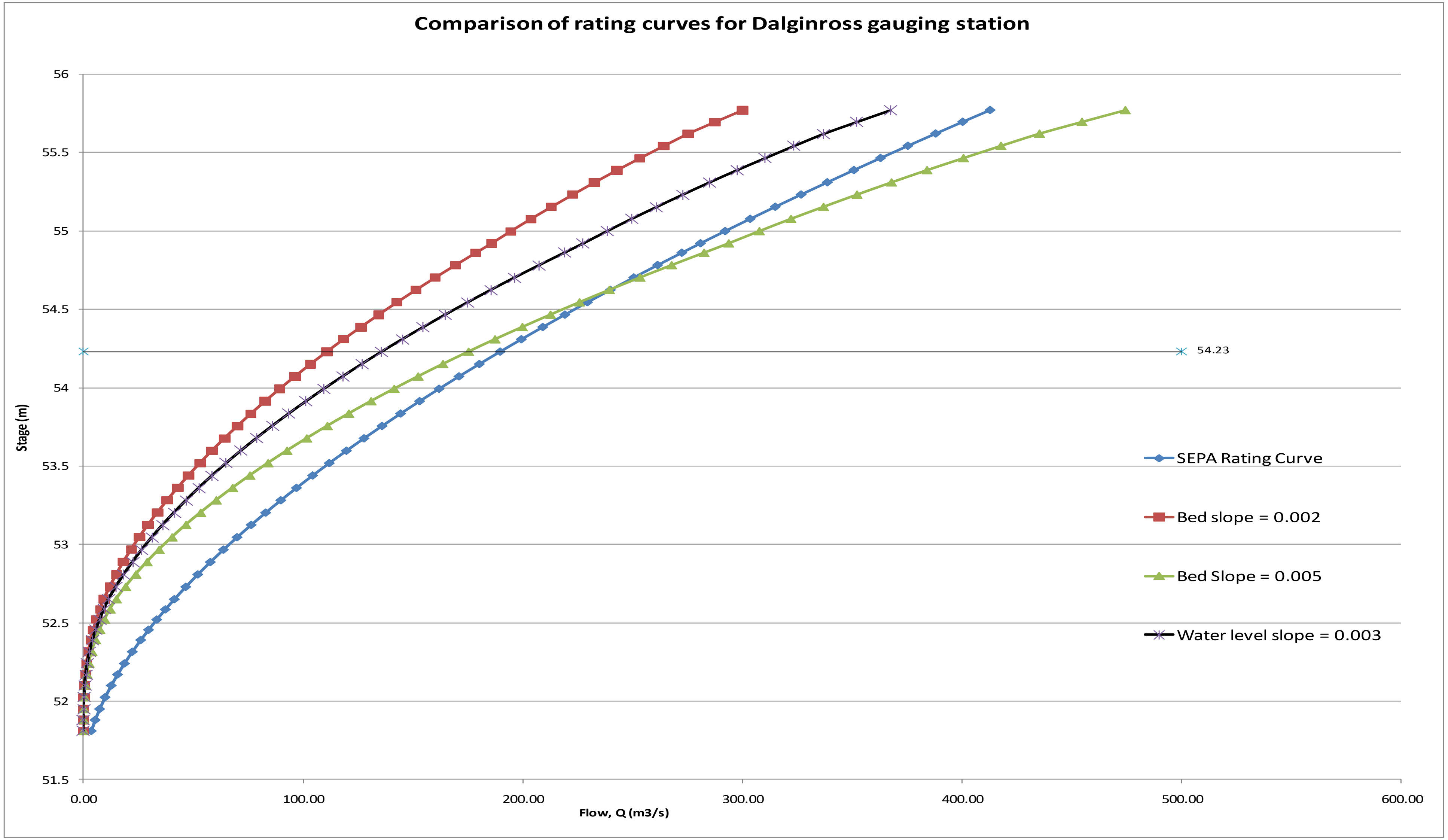

Figure 1: Rating curves at Dalginross gauging station

Name of watercourse	Name of gauging station	Type of gauging station	Catchment area at the point of interest (km^2)	QMED (m^3/s)		
				bankfull method	AMAX series	catchment descriptors
Water of Ruchill	Cultybraggan	Flow gauge	98.5	86.0	148.1 (Mouchel) ***161.4*** (SEPA)	87.6
River Earn	Dalginross	Level gauge for flood warning	349.6	215.6	***188.4*** 171.6 (with donor)	137.1
Upper Earn	Aberuchill	Level gauge	177.1	89.0	75.4 ***67.1*** (with donor)	53.8
River Lednock	Ungauged	n/a	61.8	57.2	***40.6*** (with donor)	32.5

River	200 year	200 year +CC
Ruchill	303.4	364.1
UpperEarn	196.0	235.2
Lednock	93.2	111.8
Earn	459.1	550.9

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$$\text{Flow}_{\text{(Dalginross)}} = 0.6\ \text{Flow}_{\text{(Water of Ruchill)}} + 0.4\ \text{Flow}_{\text{(Combined Upper Earn \& River Lednock)}}$$

Flows and flood return period events in the upstream catchments generating a
1 in 200 year return period flood event **(459.1 m³/s)** at Dalginross gauge

Name of watercourse	Name of gauging station / site	Flows (m3/s)	Return period (years)
Water of Ruchill	Cultybraggan	275.5	**80**
Upper Earn	Aberuchill	128.5	**25**
River Lednock	Ungauged	55.1	**8**

Flows and flood return period events in the upstream catchments generating a
1 in 200 year + climate change return period flood event **(550.9 m³/s)** at Dalginross gauge

Name of watercourse	Name of gauging station / site	Flows (m3/s)	Return period (years)
Water of Ruchill	Cultybraggan	330.6	**460**
Upper Earn	Aberuchill	154.3	**50**
River Lednock	Ungauged	66.0	**23**

Technical Note on Model Sensitivity

Scenario	Return Period (Years)			Flow (m^3/s)		
	Ruchill	Upper Earn	Lednock	Ruchill	Upper Earn	Lednock
1	200	200	200	303.4	196.0	93.2
2	200	~0	~0	303.4	~0	~0
3	~0	200	~0	~0	196.0	~0
4	~0	~0	200	~0	~0	93.2
5	**80**	**25**	**8**	**275.5**	**128.5**	**55.1**
6	200	10	10	303.4	104.9	57.2
7	10	200	10	213.7	196.0	57.2
8	10	10	200	213.7	104.9	93.2

Flow Scenarios included in the analysis

Cross Section	Scenario 1	Scenario 2	Scenario 5	Scenario 6
	200 year in all rivers	200 year in Ruchill combined with 0 in other two	Joint probability flows (80 year in the Ruchill, 25 year and 8 Year in Upper Earn and Lednock)	200 year in Ruchill combined with 10 year in other two
	(±mm)	(±mm)	(mAOD)	(±mm)
1	+88	+86	64.36	**+86**
2	+39	+26	62.46	**+26**
3	+43	+33	61.74	**+33**
4	+47	+35	61.25	**+35**
5	+36	+21	59.85	**+21**
6	+170	-86	**58.85**	-13
7	+203	-259	**58.76**	-50
8	+229	-348	**58.70**	-62

Ruchill Water

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Cross Section	Scenario 1	Scenario 3	Scenario 5	Scenario 7
	200 year in all rivers	200 year in Upper Earn combined with 10 in other two	Joint probability flows (80 year in the Ruchill, 25 year and 8 Year in Upper Earn and Lednock)	200 year in Upper Earn combined with 10 year in other two
	(±mm)	(±mm)	(mAOD)	(±mm)
9	+590	+427	60.67	**+513**
10	+640	+419	60.55	**+541**
11	+620	+345	60.22	**+527**
12	+675	+289	59.98	**+558**
13	+469	+322	59.45	**+356**
14	+792	-171	58.74	**+60**
15	+300	-195	**58.74**	-38
16	+315	-1030	**58.62**	-144
17	+273	-1301	**58.56**	-205

Upper Earn Water

Cross Section	Scenario 1	Scenario 4	Scenario 5	Scenario 8
	200 year in all rivers	200 year in Lednock combined with 10 in other two	Joint probability flows (80 year in the Ruchill, 25 year and 8 Year in Upper Earn and Lednock	200 year in Lednock combined with 10 year in other two
	(±mm)	(±mm)	(mAOD)	(±mm)
28	+428	+424	60.32	**+425**
27	+519	+514	58.21	**+515**
26	+523	+494	57.13	**+499**
25	+489	+360	56.72	**+396**
24	+306	-249	56.55	**+24**
23	+204	-815	**56.49**	-179

Lednock Water

Cross Section	Scenario 1 (±mm)	Scenario 2 (±mm)	Scenario 5 (mAOD)	Scenario 6 (±mm)
	200 year in all rivers	200 year in Ruchill combined with 0 in other two	Joint probability flows (80 year in the Ruchill, 25 year and 8 Year in Upper Earn and Lednock	200 year in Ruchill combined with 10 year in other two
	(±mm)	(±mm)	(mAOD)	(±mm)
17	+273	-523	**58.56**	-91
18	+268	-504	**58.39**	-92
19	+146	-362	**57.75**	-59
20	+78	-589	**57.22**	-52
21	+138	-470	**56.15**	-28
22	+200	-600	**55.78**	-50

River Earn

River	Cross Section	Scenario	Return Period (Year)		
			Ruchill	Upper Earn	Lednock
Ruchill	1	6	200	10	10
	2				
	3				
	4				
	5				
	6	5	80	25	8
	7				
	8				
Upper Earn	9	7	10	200	10
	10				
	11				
	12				
	13				
	14				
	15	5	80	25	8
	16				
	17				
Lednock	28	8	10	10	200
	27				
	26				
	25				
	24				
	23	5	80	25	8
Earn	17	5	80	25	8
	18				
	19				
	20				
	21				
	22				

Any Questions?

8) SEPA Meeting Minutes

Perth & Kinross Council Environment Service
Hydrology and Hydraulic Modelling - Comrie and Dalginross Flood Study

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Date: 10:00 – 12:00, Wednesday 21 January 2015
Location: SEPA, Whitefriars Crescent, Perth.

Attendees:

Alistair Scotland (AS)	PKC
Tim Jolley (TJ)	Mouchel (Chair)
Malcolm MacConnachie (MM)	SEPA
Richard Hamilton	SEPA

Ciurculation:

PKC:	Alistair Scotland, Peter Dickson and Craig McQueen
SEPA:	Malcolm MacConnachie and Richard Hamilton
Mouchel:	Tim Jolley, Paul Swift, Pravin Ghimirie

Minute

1 The agenda and purpose of the meeting was agreed:
- To brief SEPA on the hydrology and hydraulic modelling
- To present the results of the model sensitivity analysis
- To record SEPA comments
- To agree the method to derive design flows and levels
- To record any further actions required by SEPA

2 TJ gave a presentation on the hydrology and hydraulic modelling (the presentation was circulated with the agenda and will be circulated with the Minute). The issues covered were:
- The need to establish a robust method to determine design flows and levels for each water course (Ruchill, Upper Earn, Lednock and Earn).
- The uncertainty in the rating curve for the SEPA level only station at Dalginross.
- The calculations of QMED values for each location (Ruchill at Cultybraggan, Upper Earn at Aberuchill, Lednock at the confluence and the Earn at Dalginross).
- The final 200 year and 200year +cc flows for each water course
- The development of the simplified probability approach to determine the typical contributions from the Ruchill, Upper Earn and Lednock to the design flow at Dalginross
- The design flow scenarios used in the sensitivity analysis.
- The results of the sensitivity analysis giving the set of scenarios that would have to be run to derive the design water level for each model cross section.
- The proposed approach of running multiple scenarios for each design flow and option to be appraised.

3 The results of the hydrology and hydraulic analysis were discussed and the following points made:

3.1 The rating curve at Dalginross is uncertain the SEPA rating is based on an indirect method.
3.2 The estimated flow in the Lednock needs to be compared with the flow estimated for the event in February 2014
3.3 SEPA concur with the view of Mouchel in that the design flows at Dalginross are precautionary (on the high side).
3.4 The flows at Culltybragan and Aberuchil appear reasonable to SEPA given that they are based on the standard FEH approach.
3.5 SEPA surveyed flood levels at Dalginross following the 1993 flood event and would want Mouchel to compare these levels with the modelled levels. An initial comparison indicates that the model may be under-estimating the design level.
3.6 The bench marks and zero stage datums of the SEPA stations have not been checked recently.
3.7 A survey of maximum flood levels in the Ruchill was carried out By Ove Arup in 1997 as a part of a rural flood survey. These water levels should be used for model validation.
3.8 Any future floods should be surveyed to aid model validation. Continuous monitoring additional to the existing stations, will not increase confidence in the modelling of flood levels.
3.9 SEPA and most likely PKC hold additional information such as photographs and observations which could further increase confidence in the modelled levels.

4 TJ summarised the points of agreement:

6.1 The design flows for the Ruchill and Upper Earn are acceptable
6.2 The design flow for the Lednock needs to be reviewed in light of the February 2014 data
6.3 The design flow at Dalginross is accepted
6.4 The modelled levels at Dalginross should be reviewed in light of the data from the 1993 and 1997 events
6.5 All bench marks and zero datums need to be checked
6.6 The proposal to use multiple flow scenarios to establish the design water level is acceptable
6.7 The results of the analysis should be submitted to SEPA as a succinct report using tables as far as possible.
6.8 A further meeting will only be arranged if the results raise issues that need detailed discussion.

5 SEPA advised TJ and AS that they needed a summary of the design flows and design levels along with a succinct explanation of the methodology.

6 The actions listed in the action table were agreed. Actions should be completed by the 6th February. Mouchel would confirm that this is achievable.

7 No other business was raised.

8 The meeting closed at 12:00.

Action List			
No.	**Description**	**Owner**	**Date**
1	SEPA to provide PKC and Mouchel with information on the flood levels/flows in the Lednock for the event of February 2014.	MM/RH	23/01/15
2	SEPA to provide a copy of the flood levels recorded by Ove Arup for the flood event of February 1997 (drawing number: 50148 FL-01 (RevA)	MM/RH	23/01/15
3	SEPA to provide copies of the survey of the January 1993 flood event.	MM/RH	23/01/15
4	PKC to check for copies of the Ove Arup report and circulate.	AS	30/01/15
5	SEPA to provide information on the bench marks and zero stage levels at Culltybragan, Aberuchil and Dalginross.	MM/RH	23/01/15
6	Mouchel to review the design flows and levels in light of the new information and to produce a short/succinct summary of the results for SEPA and PKC	TJ	06/02/15
7	Mouchel to discuss the results with SEPA and to arrange a further meeting if one is required.	TJ	06/02/15

9) SEPA Correspondence

Andrew Williamson

From: Paul Swift
Sent: 27 February 2015 16:44
To: Tim Jolley; Pravin Ghimire
Subject: RE: Comrie FPS - design flows

Good news Tim. Well done.

I think the next step is to develop our long list of options – I have a list Majlinda produced which I can circulate and we can review – setting out what we can discount now and what we check in the model. Then agree these with PKC. Then crack on with the modelling.

I will set up a conference call next week to discuss this if you all in agreement with this approach.

From: Tim Jolley
Sent: 26 February 2015 14:30
To: Alistair Scotland; Peter Dickson; Craig McQueen
Cc: Paul Swift
Subject: FW: Comrie FPS - design flows

For information.

Tim

From: MacConnachie, Malcolm [mailto:Malcolm.MacConnachie@SEPA.org.uk]
Sent: 26 February 2015 14:08
To: Tim Jolley; Alistair Scotland
Cc: Paul Swift; Pravin Ghimire; Hamilton, Richard
Subject: RE: Comrie FPS - design flows

Tim,

The results of the modelling work look much improved using the revised design flows for the Lednock.

I can confirm that we are now satisfied with the recommendations at the end of the revised report and pleased that you now have a basis on which to start investigating options for flood mitigation.

One thing that we note from the inundation map that forms part of your report is that flood flows no longer spill into the field upstream of Tomnagaske. Following the recent flood defence works undertaken at Dalginross most of the out of bank flow from the Ruchill heads off towards The Ross. I am concerned that the risk of flooding to the properties at The Ross may have been increased. I am also fully aware that the channel will continue to migrate to and fro across its floodplain and that the extent shown on the inundation map is merely a snap shot of where the channel and flood extent might be at the moment. Things will constantly change on the Ruchill. Are you able to confirm if the flood study will be investigating the risk of flooding
from water overtopping both the right and left banks of the Ruchill and investigating options to protect not only Dalginross but also properties in the vicinity of The Ross?

Kind regards,

Malcolm

A.Malcolm MacConnachie
Senior Hydrologist
Scottish Environment Protection Agency
7 Whitefriars Crescent
Perth

tel: 01738 627989
fax: 01738 630997
email: malcolm.macconnachie@sepa.org.uk

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From: Tim Jolley [mailto:Tim.Jolley@mouchel.com]
Sent: 25 February 2015 14:28
To: Alistair Scotland; MacConnachie, Malcolm
Cc: Paul Swift; Pravin Ghimire; Hamilton, Richard
Subject: Comrie FPS - design flows

Alistair, Malcolm,

We have updated the model runs using the rainfall/runoff flows for the Lednock which give a peak flow that is consistent with the event you recorded last year.

The results show that what we call scenario 1 (same return period in all rivers) compares well with the 1997 event. We propose to proceed to use Scenario 1 but holding on to scenarios 5 to 8 for sensitivity tests as we look at options. The impact of flow uncertainty on level is not straightforward to predict without modelling so we'd need to do the assessment for each option.

I attach the updated the note. We'd be grateful for a confirmation that you are happy to accept our recommendations for the baseline scenario and the proposed approach to options appraisal.

Once I have received your comments I'll combine with Alistair's and re-issue as a final note.

Kind regards
Tim

Tim Jolley CEng MCIWEM

Mouchel
Technical Director (Hydrology)
Environmental Science and Engineering

Mouchel, Lanark Court, Ellismuir Way, Tannochside Park, Uddingston, Glasgow, G71 5PW

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Please consider the environment before printing this e-mail

Andrew Williamson

From: Tim Jolley
Sent: 08 December 2014 17:28
To: Malcolm.MacConnachie@SEPA.org.uk
Cc: Peter Dickson; Craig McQueen; Alistair Scotland; Paul Swift
Subject: RE: Comrie Joint Probability Analysis following activities
Attachments: Comrie Hydrology - SEPA Comments.docx

Malcolm,

Alistair has asked me to confirm what flows and scenarios we are using for the Comrie FPS model. We appreciate the time you have taken to advise us given your knowledge of the catchments. The flows given below are as presented in the simplified joint probability report in June which incorporated your advice on QMED values and the relative flows in the Ruchill, Upper Earn and Lednock.

Much of the information given below has been given in previous technical notes. I have summarised the logical steps in the progress. I am aware that several notes have been issued in the past so I want to avoid issuing further notes. If you are happy with the information presented below then I will discuss how best to bring the various notes together.

You may recall that we also reported on the time of travels given by the model. I understand that SEPA was happy with these results.

For completeness I've attached a summary of the issues raised by SEPA and how they have been addressed.

If you have any further queries let Alistair know and I would be more than happy to discuss.

Tim

Tim Jolley
Technical Manager
Mouchel

The Table below summarises the flows we are using.

Flows and flood return period events in the upstream catchments generating a **1 in 200 year** return period flood event (**459.1 m^3/s**) at Dalginross gauge

Name of watercourse	Name of gauging station / site	Flows (m3/s)	Return period (years)
Water of Ruchill	Cultybraggan	275.5	**80**
Upper Earn	Aberuchill	128.5	**25**
River Lednock	Ungauged	55.1	**8**

Table 9 : Flows & return period events generating a 1 in 200 year flood event at Dalginross gauge

Flows and flood return period events in the upstream catchments generating a **1 in 200 year + climate change** return period flood event (**550.9 m^3/s**) at Dalginross gauge

Name of watercourse	Name of gauging station / site	Flows (m3/s)	Return period (years)
Water of Ruchill	Cultybraggan	330.6	**460**
Upper Earn	Aberuchill	154.3	**50**

River Lednock	Ungauged	66.0	**23**

Table 9a : Flows & return period events generating a 1 in 200 year flood event + climate change allowance at Dalginross gauge

- These flows are based on the design flow at Dalginross which is made up of 60% from the Ruchill, 28% from the Upper Earn and 12% from the Lednock. The 60:28:12 ratio is based on an analysis of the flows in the Ruchill and Upper Earn and your recommendation.

- The flow at Dalginross was derived using the QMED and growth curves derived for the Dalginross gauging station. We had checked the SEPA rating and although there are some differences with rating derived from the model accepted the SEPA rating as the two curves are very close at the 200 year flow. So there is total consistency between the design flows and the recorded levels at Dalginross.

- You'll recall that the QMED values were derived using a range of methods. It was agreed that we would use the value suggested by SEPA at Culltybraggan. We used values derived using donor catchments for Aberuchill and the Lednock.

Over the last month I have asked for two further flow scenarios to be checked to confirm that a single scenario can be used for design purposes:

Scenario 2: flows divided in the ratio 80 : 14.3 : 5.7 and the 200 year flow at Dalginross.
Scenario 3: The 200 year event in the Ruchill with QMED in the Upper Earn and Lednock

The ratio of flows used for Scenario 2 better fitted the correlation between peak flows in the Ruchill and Upper Earn. However, it gives a flow in the Ruchill of >500 year event which is felt to be too extreme. The uncertainty in the rating at Dalginross and the growth curves at high return periods means that the return period is very sensitive to relatively small changes in flow.

Scenario 3 represents a case with a high flow in the Ruchill combined with typical flood flow (QMED) in the Upper Earn and Lednock. This was used to test the sensitivity of levels to the assumed flow in the Ruchill for those areas effected by flooding from the Ruchill directly.

The flows for each scenario are:

Scenario	Flow distribution factor			Water of Ruchill at Cultybraggan (m^3/s)	River Earn at Aberuchill (m^3/s)	Lednock at confluence with River Earn (m^3/s)	Dalginross (m^3/s)
Scenario 1	0.6	0.28	0.12	275.5	128.5	55.1	459.1
Scenario 2	0.8	0.143	0.057	367.3	65.7	26.2	459.1
Scenario 3	0.5% AEP	QMED	QMED	303.4	67.1	39.3	

Table 10 Flow Distribution for each Scenario

A comparison of the modelled water levels indicates that the scenario 1 (the 60:28:12 ratio) gives slightly precautionary levels compared to Scenario 3 (200 year in Ruchill). The largest increase in water level was found to be 3cm.

Scenario 2 is felt to be too extreme (>500 year flow in Ruchill) and was not taken forward.

We have not done runs with a 200 year flow in the Upper Earn or Lednock.
I would suggest that we do two further runs. One with the 200 year flood in the Upper Earn (plus QMED in the Ruchill and Lednock) and one with the 200 year in the Lednock (and QMED in Upper Earn and Ruchill).

Could you confirm that you are happy with these combination of flows.

Thanks
Tim

Tim Jolley CEng MCIWEM
Technical Manager (Hydrology), Mouchel Environment

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From: Alistair Scotland [mailto:AScotland@pkc.gov.uk]
Sent: 08 December 2014 15:21
To: Paul Swift; Tim Jolley
Cc: Peter Dickson; Craig McQueen
Subject: FW: Comrie Joint Probability Analysis following activities

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From: MacConnachie, Malcolm [mailto:Malcolm.MacConnachie@SEPA.org.uk]
Sent: 04 December 2014 15:14
To: Alistair Scotland
Subject: RE: Comrie Joint Probability Analysis following activities

Hi Alistair,

For the sake of clarity to ensure that there is no misunderstanding can I suggest that before Mouchel run any more flows in its models that it advises what flows it intends to use to represent the key design flows. I assume these will be the 200 year flood with and without climate change for the Ruchill at Cultybraggan gauging station, the River Earn at Dalginross and the Lednock at Comrie. We will advise whether or not these are satisfactory estimates to allow the modelling to progress. We have previously advised that the model results for Dalginross be checked against a frequency analysis using the river level data available for the Dalginross gauging station on the River Earn.

How do you feel about this as a way forward? I just want to keep it as simple as possible.

Kind regards,

Malcolm

A.Malcolm MacConnachie
Senior Hydrologist
Scottish Environment Protection Agency

7 Whitefriars Crescent
Perth

tel: 01738 627989
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email: malcolm.macconnachie@sepa.org.uk

From: Alistair Scotland [mailto:AScotland@pkc.gov.uk]
Sent: 03 December 2014 15:47
To: MacConnachie, Malcolm
Cc: Tim Jolley; Peter Dickson; 'Paul Swift'; 'Majlinda Thresh'; Craig McQueen
Subject: RE: Comrie Joint Probability Analysis following activities

Hi Malcolm,

Further to our telephone conversation earlier today.

I have spoken to Peter Dickson and rather than have a meeting next week we could try an finalise what analysis would be acceptable to SEPA and finalise the hydrological analysis and modelling approach for Comrie.

This could include SEPA's written acceptance of the Frequency analysis at Dalginross gauge and running the worst case scenarios (1 in 200 +CC) approach for each of the three watercourses in turn, in the Baseline Design model to get predicted model (water level) outputs to inform the detailed design.

Your comments could also cover the acceptability (or not) of the Joint Probability modelling approach (3rd June 2014) which was previously recommended by Mouchel.

I believe that it may be worthwhile Tim Jolley giving you a call to address the above matters and agreeing an acceptable approach for completing the modelling.

I will be speaking to Tim this evening to discuss the best way forward and review your previous comments and queries on the JP.

Hope we can get some acceptance and closure on this soon.

Regards

Alistair Scotland

Engineer (Flooding)
Structures and Flooding Section
The Environment Service
Pullar House
35 Kinnoull Street
Perth PH1 5GD

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ascotland@pkc.gov.uk

From: MacConnachie, Malcolm [mailto:Malcolm.MacConnachie@SEPA.org.uk]
Sent: 28 July 2014 16:38
To: Majlinda Thresh
Cc: Craig McQueen; Peter Dickson; Paul Swift; Pravin Ghimire; Brindavana Nagendran; Hamilton, Richard; Thom, Una; Alexander, Sara
Subject: RE: Comrie Joint Probability Analysis following activities

Dear Majlinda,

Please accept my apologies for the delay in responding to your email below. I have considered the contents of your "Notes on Peak Flow Travel Time" document and believe that the proposed approach to modelling the design flood at Dalginross is satisfactory and will now provide a platform for you to investigate options for flood mitigation for Comrie.

Please do not hesitate to contact me again if you wish to discuss any issues during the further studies.

Kind regards,

Malcolm

A.Malcolm MacConnachie
Senior Hydrologist
Scottish Environment Protection Agency
7 Whitefriars Crescent
Perth

tel: 01738 627989
fax: 01738 630997
email: malcolm.macconnachie@sepa.org.uk

From: Majlinda Thresh [mailto:Majlinda.Thresh@mouchel.com]
Sent: 08 July 2014 17:07
To: MacConnachie, Malcolm
Cc: Craig McQueen; Peter Dickson; Paul Swift; Pravin Ghimire; Brindavana Nagendran
Subject: FW: Comrie Joint Probability Analysis following activities

Dear Malcolm

Please find in the attached document the assessment of travel times and inflow adjustment as per my previous email dated 10th June, enclosed,.

Looking forward to your answer,

Kind regards

Majlinda Thresh (M.CIWEM; C.WEM)
Senior Engineer, Mouchel

Flooding and Drainage

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From: Majlinda Thresh
Sent: 10 June 2014 15:04
To: 'MacConnachie, Malcolm'; 'Craig McQueen'; 'Peter Dickson'
Cc: Olivier Drieu; Brindavana Nagendran
Subject: Comrie Joint Probability Analysis following activities

Hello All,

Taking into consideration SEPA advice received recently, please find below an outline of the hydraulic modelling activities we are proposing to carry out before any modelling of the optioneering. Also, answers to SEPA email dated 5th June are also included below.

Mouchel is proposing to undertake the following activities :

1. The results of the Simplified Hydrological Joint Probability Analysis (issued to SEPA on 4th June) provide flows and return period of the flood events (at the gauging stations and Lednock confluence) to generate specific return periods and flows at Dalginross gauge. The upstream extents of the hydraulic model (points of inflow into the model) along the 3 watercourses are upstream of these gauging stations and the confluence of the Lednock. Therefore, the first step encompasses generating (higher) hydrographs at each of the 3 points of inflow into the model which will respectively match the hydrograph at each gauge (or Lednock confluence). Every hydrographs at the 2 gauges and confluence of Lednock will be based on the FEH RR method scaled to the peak flow (from Tables 9 to 12, depending of the targetted design return period flood event PKC wishes Mouchel to model). Similarly, the hydrographs at the points of inflows will be based on the FEH RR method and scaled to peak flows determined after trials and errors to match the peak flows at the 2 gauges and Lednock confluence. This will be carried out for each watercourse separately to start with for 3-5 return periods events. When the 3 inflow hydrographs will have been generated, then the 2D hydraulic model will be run to compare the modelled and anticipated flows (and shape of hydrographs) at Dalginross gauge, and then adjustments at the 3 points of inflow may be made if appropriate. Mouchel will provide SEPA and PKC with preliminary modelling results for their comments before continuing further modelling activities.

2. Time to peak (Tp) : the hydrological calculations have been made based on bereaved records, simultaneous occurrence of the peak flows in each respective upstream catchment and their combination at Dalginross gauge. In the calculations, it was not necessary to use rainfall data to derive the design flows of Tables 9 to 12, therefore Tp (i.e. : time between the beginning of the rainfall event and the resultant peak flow in a watercourse) is not a key parameter in the design flows for this study.
   Travel time is a very key parameter and will be assessed as the second step of the hydraulic modelling activities. To estimate the shortest (worst case) respective travel times with the model, it is proposed to run for a few (4 - 5) observed and design events separately for each watercourse first, and then for the whole system. Sensitivity analysis on the travel times will be undertaken and a comparison with observed travel times (recorded by SEPA loggers) will be carried out. Mouchel will provide SEPA and PKC with modelling results for their comments before continuing further modelling activities. Adjustments at the 3 points of inflow may be made if appropriate to ensure the worst case scenario is modelled.

3. After completion of steps 1 and 2, Mouchel will undertake optioneering modelling activities, including natural flood management measure especially in the Water of Ruchill catchment.

PKC's decision of the required design return period event at Dalginross gauge to be investigated (Tables 9 to 12) by Mouchel with the model is necessary prior to the start of the proposed hydraulic modelling activities (as also stated in the results of the Simplified Hydrological Joint Probability Analysis (issued to SEPA on 4th June)). .

Answers to SEPA comments :

- *First paragraph:* - Mouchel is proposing to run the 200 year flood event at Dalginross (with flows and return periods upstream as per Table 9 of the Simplified Hydrological Joint Probability Analysis (issued to SEPA on 4th June)) and will undertake a comparison with the values mentioned by SEPA in their email. Mouchel will issue to SEPA and PKC the results of the stage at Dalginros gauging station. Kinkell Bridge is out of our model extents and area of study, however the SEPA flood maps show that the area between Dalginross gauge and Kinkell Bridge floods.

- *Second paragraph* and the last question of third paragraph (*Will this be how you will model a 0.5% AEP (1:200) flood on the Water of Ruchill and River Earn at the same time?) :* it is unclear whether SEPA is suggesting to run the model with a 200 years return period event in both the Water of Ruchill and the (Upper) River Earn ? (and in fact in the 3 upstream catchments ?) Could you please clarify. Would this run be needed to inform / compare with SEPA flood maps ? If this is the case, similarly to Step 1 of the modelling activities, Mouchel is proposing to run the model with the 200 years statistical flows simultaneously in each of the 3 upstream catchments (Tables 3, 5 and 6) with possible adjustments made to the model after completion of Step 2. However, the risk of having a 200 year flood event simultaneously in the 3 upstream catchments is very low (as shown by the joint probability analysis undertaken) .

- *Third paragraph* – please refer to Steps 1 and 2 of the above outline modelling activities.

Kind regards

Majlinda Thresh (M.CIWEM; C.WEM)
Senior Engineer, Mouchel

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From: MacConnachie, Malcolm [mailto:Malcolm.MacConnachie@SEPA.org.uk]
Sent: 05 June 2014 09:36
To: Majlinda Thresh
Cc: Olivier Drieu; Peter Dickson; Craig McQueen; Thom, Una
Subject: RE: Joint Probability Analysis Issues/Teleconference

Dear Majlinda,

First paragraph - I have reviewed the revised report and would make the following comments. The figures reflect the discussions that we had earlier this week during our tele-conference. One observation in regard to the 0.5% AEP (1:200) design flow for Dalginross is that it is significantly higher than that for the River Earn at Kinkell Bridge downstream. This difference in flows can possibly be explained in part by the attenuation of the flood peak as it spills onto the floodplain between the two locations. However given the difference in flows I did some further investigation by undertaking a frequency analysis on the stage data for Dalginross. Extrapolation up to a 0.5% AEP (1:200) flood level resulted in a stage level of 3.96 metres. Using the calibration that we put together for Dalginross and the calibration that Mouchel derived from modelling results in a 0.5% AEP (1:200) flood level of around 4.44 metres. This is a difference of approximately 500 mm. There is considerable uncertainty to these two estimated flood levels and we will await the results of the further modelling that Mouchel will be carrying out.

Second paragraph - I am assuming that Mouchel will be investigating a 0.5% AEP (1:200) flood on the Water of Ruchill in addition to the 0.5% AEP (1:200) flood on the River Earn. Would I be correct then in assuming that there may be a need for two separate hydraulic modelling runs to determine the extent of flooding to Comrie and inform design levels for mitigation?

Third paragraph - I agree that the component flows in Tables 9 to 12 are a summary of the coinciding flow at Dalginross. The report states that Mouchel will continue to investigate the travel times. Can you please clarify if this means that it is proposed to input hydrographs with higher peak flows and organise travel times so that the resultant peak flow at Dalginross matches those stated in Tables 9 to 12? Will this be how you will model a 0.5% AEP (1:200) flood on the Water of Ruchill and River Earn at the same time?

Kind regards,

Malcolm

A.Malcolm MacConnachie
Senior Hydrologist
Scottish Environment Protection Agency
7 Whitefriars Crescent
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tel: 01738 627989
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email: malcolm.macconnachie@sepa.org.uk

From: Majlinda Thresh [mailto:Majlinda.Thresh@mouchel.com]
Sent: 04 June 2014 13:56
To: MacConnachie, Malcolm
Cc: Olivier Drieu; Peter Dickson; Craig McQueen; Thom, Una
Subject: Joint Probability Analysis Issues/Teleconference

Hello Malcolm

Thank you for your comments in the summary of our conference call on Monday, 2nd June.

Please see enclosed the PDF and word format of our Joint Probability calculations updated based on our discussions and agreements on the conference call.

It would be highly appreciated if you could have a look at the attached document and let us know if you have any comment or require more explanations from this end.

Kind regards

Majlinda Thresh (M.CIWEM; C.WEM)
Senior Engineer, Mouchel

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From: MacConnachie, Malcolm [mailto:Malcolm.MacConnachie@SEPA.org.uk]
Sent: 04 June 2014 10:40
To: Majlinda Thresh
Cc: Olivier Drieu; Craig McQueen; Peter Dickson; Thom, Una; Alexander, Sara; Hamilton, Richard
Subject: RE: Joint Probability Analysis Issues/Teleconference

Dear Majlinda,

Thank you for preparing this note of our teleconference. I have only made a couple of chages to the note. On reflection and drawing on my experience of operating flood warning in this area I believe that 45 - 60 minutes is too long for the time of travel between the Cultybraggan and Dalginross monitoring stations so I have amended the figures down to 15 to 30 minutes.

I have also added a comment to reflect our concerns regarding the provision of upstream flood storage in the Water of Ruchill catchment although I fully understand that there is a need to consider all options for flood mitigation.

Please don't hesitate to get back to me with any queries or if there are any issues you wish to discuss.

Kind regards,

Malcolm

A.Malcolm MacConnachie
Senior Hydrologist
Scottish Environment Protection Agency
7 Whitefriars Crescent
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fax: 01738 630997
email: malcolm.macconnachie@sepa.org.uk

From: Majlinda Thresh [mailto:Majlinda.Thresh@mouchel.com]
Sent: 03 June 2014 10:54
To: MacConnachie, Malcolm
Cc: Olivier Drieu; Craig McQueen; Peter Dickson
Subject: Joint Probability Analysis Issues/Teleconference

Dear Malcolm

Please see below the email summarising our discussion yesterday, which it is cc to PKC.

Dear Craig,

I called your office on Monday but was informed that we are off all week, therefore please see below the summary of the discussion we had Monday morning with SEPA (Malcolm MacConnachie) regarding the simplified hydrological joint probability.

The main points that we discussed with SEPA were:

1 – Referring to first paragraph of SEPA email, time to peak (tp) and travelling time of the flows from each gauging station: It was mentioned that in our current hydrological calculations (based on observed / recorded datasets) tp is not specifically taken into account.
Based, so far, on the 2 first observed events listed in Table 7, we estimated with the hydraulic model ISIS that the travel time ranges between 15-30 minutes from Cultybraggan to Dalginross gauging stations, which matches well with the estimations by SEPA (mentioned in their email dated 23 May 2014).
It was mentioned and agreed that both tp and travel time will be assessed with the hydraulic model (through sensitivity analysis). This analysis with the hydraulic model will be important to possibly adjust the design flood return period in the River Earn near to the Dalginross gauge (i.e. : downstream of the confluences of the other watercourses).

2 - Second paragraph of SEPA email – Qmed at Cultybraggan of SEPA = 161.1 m3/s whereas Mouchel's Qmed is 148.1 m3/s. The difference in values is =13.3 m3/s (8.9%). As mentioned by SEPA this is likely due to different datasets used. It was explained to SEPA using the 161.1m3/s in our calculations had an impact (decrease) on the return periods (derived with the FEH statistical analysis).

3 - Third paragraph of SEPA email refers to further method to determine Qmed at Dalginross by using the water level records at the station to enhance the comparison of the 3 methods that Mouchel have already used. SEPA advised to derive this Qmed value by calculating the (observed) median water stage and use the rating curve for that gauge. These calculations are carried out and will be included in our technical note.

4 & 5 - Fourth and fifth paragraphs of SEPA email refer to different values of flows between our calculations and with SEPA flows. SEPA suggested we undertook calculations with the Qmed value they stated (161.4m3/s). Regarding the results in Tables 9 & 10, SEPA mentioned that the flows in the River (Upper) Earn were too high and that those in River Lednock were too low. Mouchel suggested not to attempt at refining the combined flows between the Lednock and the Upper Earn due to many uncertainties in both catchments which have some influence on the flows (i.e. : dam, dam spill, loch, flashiness, snow melt. etc). Therefore Table 8 will be disregarded and the assumption agreed previously with SEPA will be used ('return period of the same order should be applied to the Upper Earn and Lednock catchments' - see 3rd paragraph of the Introduction section of Mouchel technical note). This was agreed with SEPA.

6 - Sixth paragraph of SEPA email: Mouchel undertook calculations using value of Qmed = 161.4m3/s, the results discussed with SEPA were :
* to obtain a 100yr return period flood event in Dalginross gauge : Water of Ruchill flow is 270.6m3/s which corresponds to a 70 years return period event to which SEPA agreed to. However, River (Upper) Earn flow is 58m3/s (which corresponds to 2 years return period event) and River Lednock flow is 58m3/s (8 years return period) were considered too low. River Lednock is an ungauged river which brings uncertainties in the flows estimation for that catchment.
Mouchel suggested to carry out the FEH RR for River Lednock and River Earn (Upper) to compare with results of the FEH statistical method. But based on SEPA existing knowledge of the catchment, it was discussed that the event on the River Upper Earn should be approx. 10 years RP, and the one on River Lednock approx. 15 years RP.

* similarly to obtain a 200yr return period flood event in Dalginross gauge : Water of Ruchill flow is 303.6m3/s which corresponds to a 200 years return period event to which SEPA agreed to. River (Upper) Earn flow is 65.1 m3/s (which corresponds to 3 years return period event) was considered too low. River Lednock flow is 65.1 m3/s (23 years return period) was considered in the correct order.
Mouchel suggested to carry out the FEH RR for River Lednock and River Earn (Upper) to compare with results of the FEH statistical method. But based on SEPA existing knowledge of the catchment, it was discussed that the event on the River Upper Earn should be approx. 10 -15 years RP, and the one on River Lednock approx. 23- 25 years RP.

Mouchel is currently updating the calculations based on the discussion with SEPA.

Calculations for the 50 and 75 years return period flood events will also be undertaken.

In additionSEPA and Mouchel discussed some possible flood alleviations measures : SEPA advised to run three dredging scenarios (dredging depth of 0,5m, 1m and 1,5m).

Upstream storage on the Water of Ruchill was briefly discussed as a potential option for flood mitigation. SEPA still believe that the operation of upstream storage would be difficult and unsustainable due to the significant movement of woody debris, sediments and gravels down the river system. We believe that storage capacity would be rapidly lost to materials being collected behind any dam structure. A barrier to the existing sedment transport down the Ruchill would also likely increase the rates of erosion already experienced in the Water of Ruchill and River Earn in the Comrie area.

Finally, Mouchel informed SEPA of the necessity of having design flows and return periods agreed with SEPA before any optioneering of the hydraulic model can be carried out. Mouchel also informed SEPA that the deadline for completion of this flood alleviation feasibility study is end of August.

Way forward:

Mouchel will update the calculations and document and issue the results to SEPA (and PKC) by Wednesday 4th June for their approval.

Kind regards

Majlinda Thresh (M.CIWEM; C.WEM)
Senior Engineer, Mouchel

Flooding and Drainage

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enquiries@liveactive.co.uk or 01738 454600.

General enquiries to TACTRAN should be made to info@tactran.gov.uk or 01738 475775.

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10) SSE Correspondence

Andrew Williamson

From: Graham, Alister <alister.graham@sse.com>
Sent: 30 June 2015 12:06
To: Tim Jolley
Subject: FW: Lednock releases

Tim,

As discussed, the dam at Lednock has spilled on 4 occasions in the last 10 years.

December & January 2006/07 and February & March 2014.

Regards

Alister.

Alister Graham
Renewable Operations Centre

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From: Tim Jolley [mailto:Tim.Jolley@mouchel.com]
Sent: 18 June 2015 11:59
To: Noble, Mark
Subject: RE: Lednock releases

Mark,

Stuart gave me your name as the person to contact re Lednock Reservoir.

Mouchel are currently working for Perth and Kinross Council on options for the Comrie flood prevention scheme. You'll no doubt be aware of the various issues around flooding in the lower reaches of the Lednock. The council has been discussing options with the community and one of the issues raised is the possibility of using the Lednock reservoir to hold back flows.

I'm familiar with the typical issues that this raises in terms of viability and potential impacts – but we need to assess the potential for this option as a part of a wider scheme.

Would you be available to discuss the issues/opportunities? I could come up to your offices (Perth or Pitlochry?) if convenient or we could arrange a call whatever suits you.

Kind regards
Tim

Tim Jolley CEng MCIWEM

Technical Manager
Mouchel Environment

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From: King, Stuart [mailto:stuart.j.king@sse.com]
Sent: 10 June 2015 12:26
To: Tim Jolley
Cc: Noble, Mark
Subject: RE: Lednock releases

Tim

Good to hear from you.

I would suggest initially that you contact Mark Noble, Head of Civil O & M. I have copied him in on this e-mail so you have his e-mail address.

Regards

Stuart

From: Tim Jolley [mailto:Tim.Jolley@mouchel.com]
Sent: 10 June 2015 11:19
To: King, Stuart
Cc: Alistair Scotland
Subject: Lednock releases

Stuart,

Trust all is well with you.
You may know that Mouchel are working for Perth and Kinross Council to assess the options for a flood prevention scheme at Comrie.

One of the options we want to consider is the possibility of managing releases from Loch Lednock during periods of high flow in the Earn. I'm aware of the issues this raises from my days with SEPA but nevertheless the community expect the Council to explore all possibilities.

Could you give me the name of the appropriate contact in SSE who would be able to assist in our assessment? I was thinking that it might be Dave Crookall but don't have his contact details.

Thanks
Tim

Tim Jolley CEng MCIWEM

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