APPENDIX G – Hydraulic Modelling Calibration and Verification Technical Note

Comrie and Dalginross Flood Study

Checks on Calibration of the extended cross sections of the Water of Ruchill and River Earn

Draft by PG

Reviewed by OD/MT

Date 27th Sep 2014

Background of the Existing Hydraulic Model

- The existing 2D hydraulic model was calibrated for two flood events (16th January 1993 and 19th February 1997). This calibration was presented to and approved by SEPA and PKC during the Dalginross (Water of Ruchill) Flood Protection Works – Option Assessment Report, Mouchel, 2010. The event of 19th November 2012 occurred while the Comrie and Dalginross Flood Study was in the report writing stage, therefore, due to limited time and event data, the existing model was not verified or calibrated for the 19th November 2012 event.
- The Comrie and Dalginross Flood Study started in September 2013. The first task of this study was to check whether the existing hydrology required updating and to verify the existing model with data from the latest event of 19th November 2012. These tasks were completed on 24th October 2013 and a technical note was issued to SEPA and PKC. The findings of this technical note were agreed with SEPA. A copy of the technical note is included in Appendix A.
- The existing hydraulic model was extended by using additional cross section data from the topographic survey carried out in 2014. The additional cross sections were incorporated into the existing hydraulic model (this is named hereafter as the Original model).
- This note presents the changes made to the Manning's n values and weir coefficients at the additionalcross sections in order to re-check the calibration for the three above mentioned flood events. Data from the 1993, 1997 flood events and the latest event of 19th November 2012 were used to check the calibration of the model, at the Cultybraggan and Aberuchill gauging stations[1]. The model with changes to the Manning's n values at the additional cross sections and change of the weir coefficients is named hereafter as the Adjusted model. Please note that the River Lednock is an ungauged river, therefore no calibration checks were possible for the additional cross sections for this watercourse.

Tasks undertaken

- Firstly, in order to identify the corresponding return period for each flood event, design flows were derived based on the results of the FEH statistical analysis at the Cultybraggan and Aberuchill gauging stations. The results are presented in Table 1.

	16.01.1993	19.02.1997	19.11.2012

[1] *Cultybraggan is a flow gauge and Aberuchill is a stage gauge. Flow data from both the gauges were obtained from SEPA. The flow data provided by SEPA for the Aberuchill gauge were based on rating curve.*

	Peak flow, (m3/s)	Return period, (year)	Peak flow, m3/s	Return period, (year)	Peak flow, (m3/s)	Return period, (year)
Cultybraggan	228	17	229.4	17.8	191.7	5.3
Aberuchill	66	2.5	64.2	2.4	67.3	2.6

Table 1 – Peak flows and return periods of the calibration events

- Secondly, the FEH rainfall runoff (FEH RR) method hydrographs have been generated at the Water of Ruchill and River Earn for the respective return periods as per Table 1. A low flow rate was maintained in the River Lednock for the purpose of model stability. The inflow (FEH RR) hydrographs were applied in the model at the extended reaches of the Water of Ruchill and the River Earn.
- Thirdly, a comparison of the design and observed stage hydrographs at the two gauging stations was undertaken before any adjustments were made to model parameters.
- Fourthly, the Manning's n roughness values and weir coefficients have been adjusted to match the design peak stage with the observed peak stage as following:
    - Water of Ruchill: the original Manning's n values in the extended reach have been increased by 20 to 30% depending on the particular location, and
    - River Earn: the original Manning's n values in the extended reach have been increased by 0 to 20 % and the weir coefficient of the weir downstream of the Aberuchill gauging station near Dummond Fish Farm has been decreased from 1 to 0.5[2].

The original and adjusted value of the Manning's n roughness values at the additional cross sections for the Water of Ruchill and the River Earn are shown in Table 2. Maps showing the locations of these reaches are presented in Appendix B.

Models	Water of Ruchill				River Earn									
	Reach 1		Reach 2		Reach 1		Reach 2		Reach 3		Reach 4		Reach 5	
	Channel	Flood plain	Channel	Flood plain	Channel	Flood plain	Channel	Flood plain	Channel	Flood plain	Channel	Flood plain	Channel	Flood plain
Original	0.045	0.047	0.055	0.065	0.035	0.04	0.04	0.05	0.045	0.05	0.05	0.055	0.06	0.065
Adjusted	0.058	0.06	0.065	0.08	0.037	0.04	0.04	0.055	0.05	0.055	0.055	0.06	0.06	0.065

Table 2: Original and adjusted Manning's n values

Stage – Time Hydrographs Results

The comparisons between observed S-T hydrographs (S-T) with those of the original and adjusted models are shown in Figures 1 to 6.

[2] *In ISIS model, the default value of the weir discharge coefficient is 1. However, the discharge coefficient can be less or more than 1. Water level upstream of the weir increases with decrease in the coefficient of discharge. Therefore, discharge coefficient of the weir has been decreased to increase the water level upstream such that the model peak matches with the observed peak.*

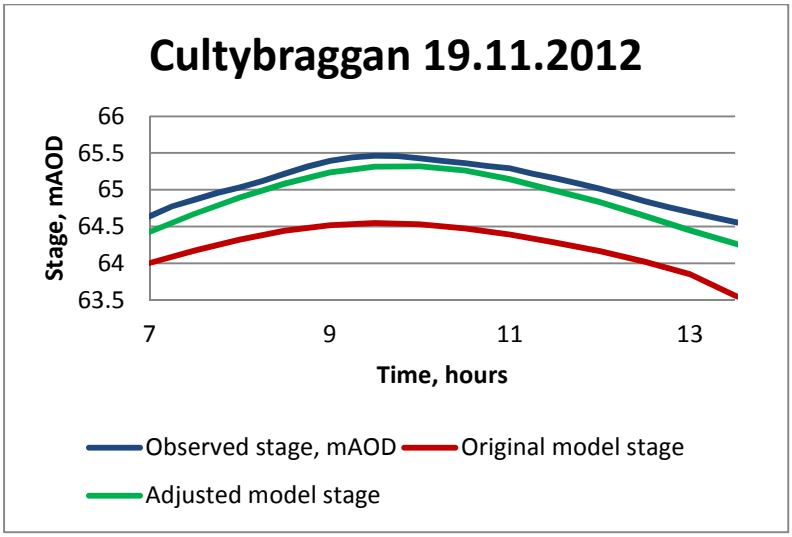

Figure 1: Comparison of peak stage at the Cultybraggan gauging station – 19.11.2012 event

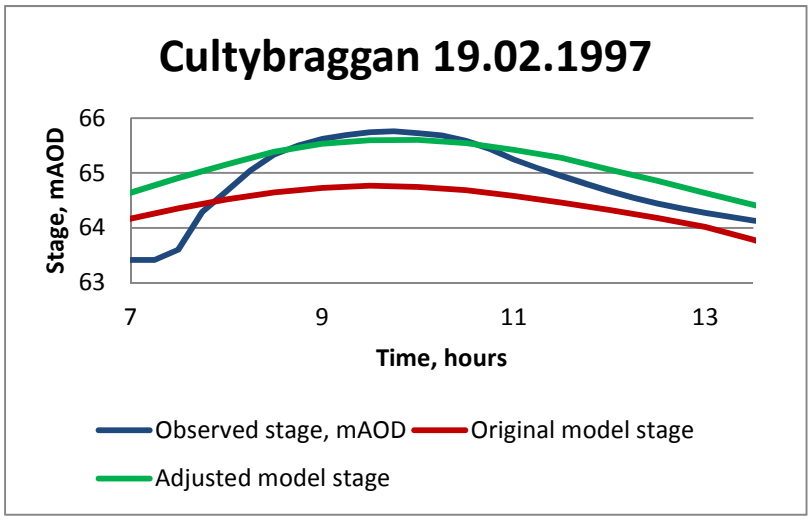

Figure 2: Comparison of peak stage at the Cultybraggan gauging station – 19.02.1997 event

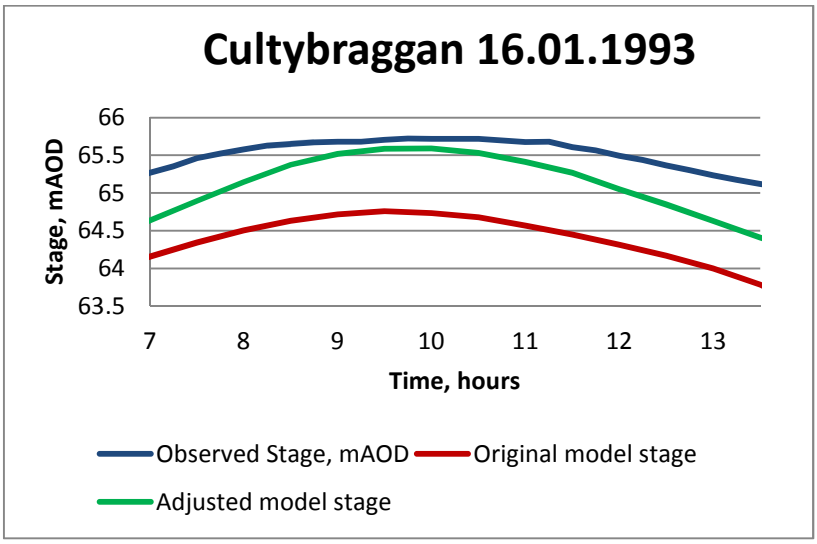

Figure 3: Comparison of peak stage at the Cultybraggan gauging station – 16.01.1993 event

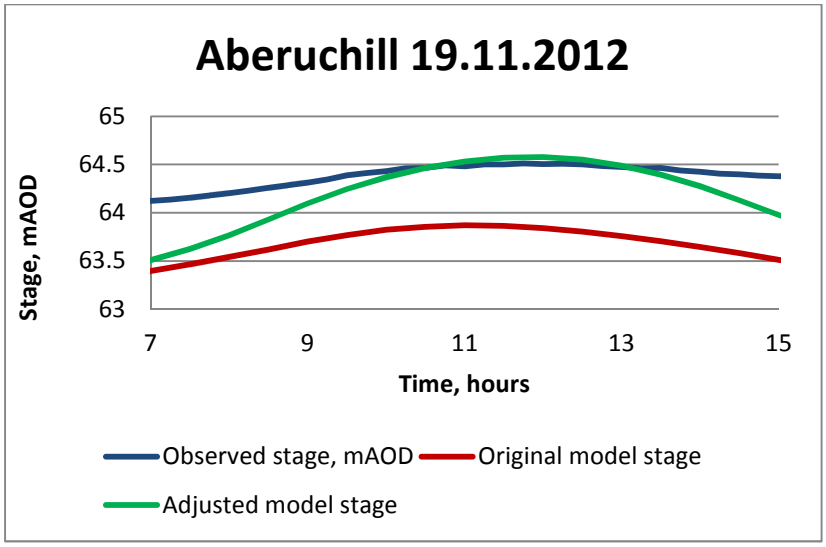

Figure 4: Comparison of peak stage at the Aberuchill gauging station – 19.11.2012 event

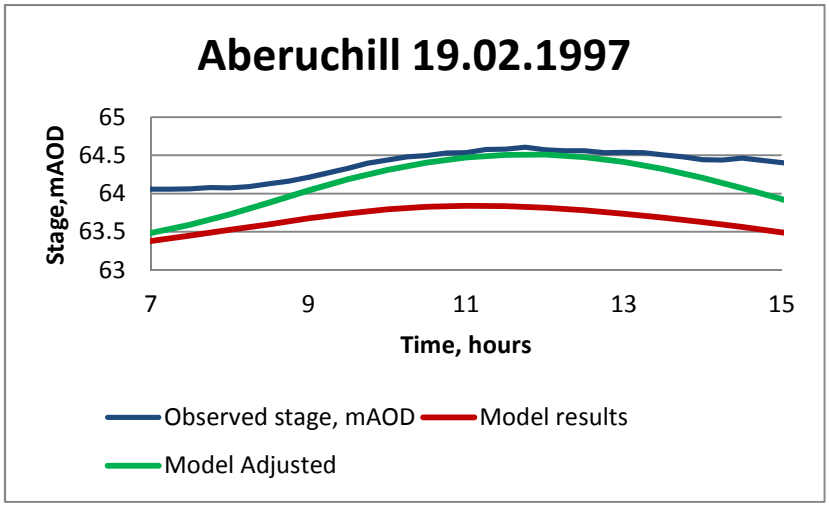

Figure 5: Comparison of peak stage at the Aberuchill gauging station – 19.02.1997 event

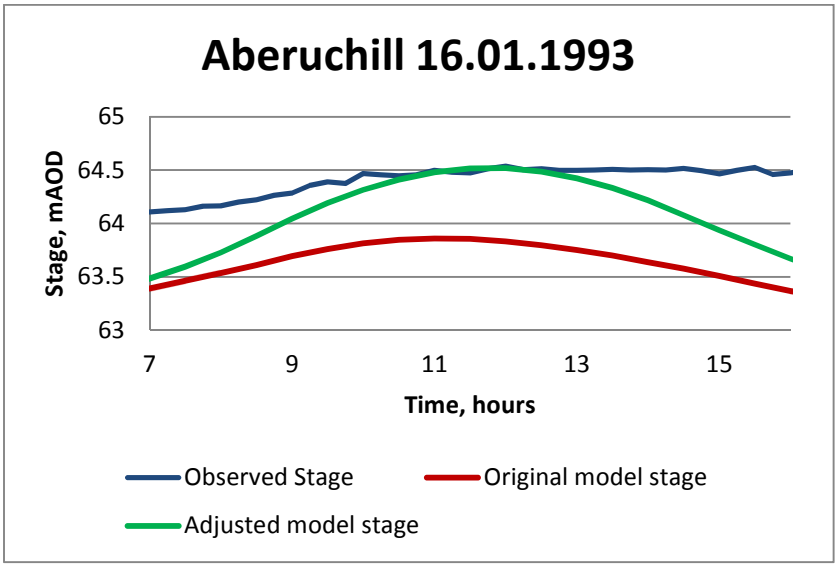

Figure 6: Comparison of peak stage at the Aberuchill gauging station – 16.01.1993 event

Figures 1 to 6 show that the observed peak stage and time to peak (tp) reasonably match with peak stage and (tp) of the adjusted model.

The results have shown that an approximate increase of 15 to 20% to the original Manning's n values were required at the additional cross sections in order to match the design peaks with the observed peaks at the Cultybraggan and Aberuchill gauging stations. Therefore, for consistency the original Manning's n roughness value[3] at the additional cross sections of the River Lednock were also increased by using a coefficient of 1.175 (17.5%)[3]. A map showing the reaches of the River Lednock is presented in Appendix B.

In order to check for any changes in peak stage between the original model and adjusted model nine cross sections were selected to compare the original baseline peak stage levels with the adjusted peak stage levels. These checks were carried out for the 1 in 50 year, 1 in 100 year and 1 in 200 year with climate change allowance flood events.

Figure 7 overleaf shows the locations of the nine cross sections where the baseline peak stage levels results (original and adjusted models) have been compared. The results of these peak stage levels are shown in Table 3:

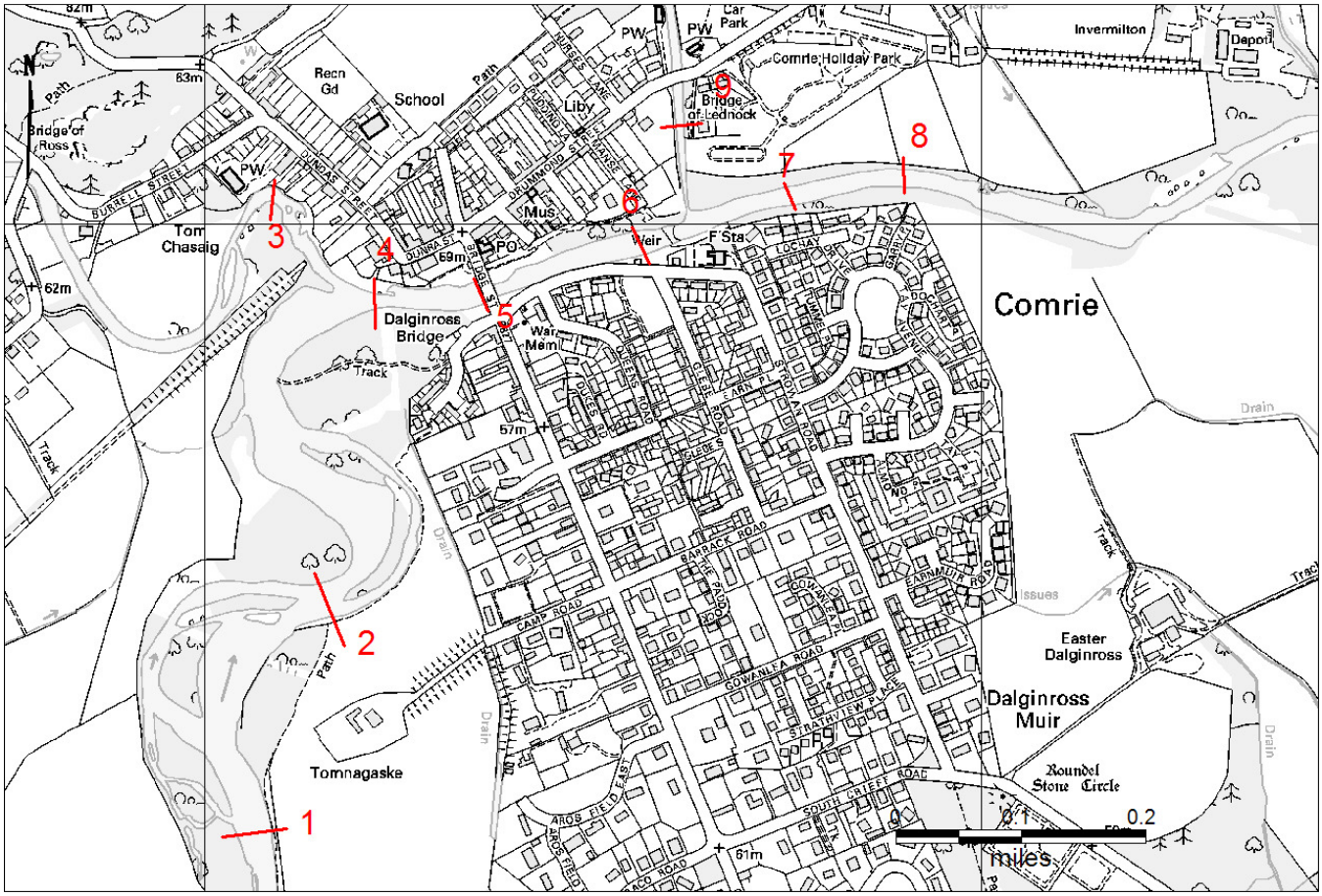

Figure 7: Location of cross sections

[3]The 17.5% increase of the Manning's n roughness value for the adjusted model is is based on the best engineering judgement, photographic evident and available information from the survey data

Cross-sections reference	1:50 year			1:100 year			1:200 year + CC		
	Original model water level, mAOD	Adjusted model water level, mAOD	Difference (m)	Original model water level, mAOD	Adjusted model water level, mAOD	Difference (m)	Original model water level, mAOD	Adjusted model water level, mAOD	Difference (m)
1	61.062	61.078	0.016	61.16	61.169	0.009	61.361	61.355	-0.006
2	59.117	59.129	0.012	59.183	59.191	0.008	59.372	59.373	0.001
3	58.175	58.172	-0.003	58.406	58.394	-0.012	59.105	59.064	-0.041
4	57.969	57.975	0.006	58.185	58.185	0	58.74	58.787	0.047
5	57.514	57.513	-0.001	57.644	57.64	-0.004	57.937	57.953	0.016
6	56.969	56.968	-0.001	57.119	57.115	-0.004	57.318	57.286	-0.032
7	55.96	55.957	-0.003	56.075	56.071	-0.004	56.285	56.272	-0.013
8[4].	55.476	55.472	-0.004	55.652	55.644	-0.008	55.974	55.968	-0.006
9	56.218	56.215	-0.003	56.369	56.364	-0.005	56.68	56.67	-0.01

Table 3: Comparison of peak stage levels between the original and adjusted models

Conclusion:

The modelling results show that the peak stage levels change by 0 to 47cm, depending upon the particular location and return period.

The modelling results also show that cross section 8 (which presents the location of the Dalginross gauging station) the changes in peak stage levels are between 0.004m to 0.008m. This indicates that the adjustment made at the cross section of the adjusted model does not affect the calibration of the model carried out previously.

However, Mouchel will runs other return periods (1 in 75 years, 1 in 200 year and 1 in 100 years with climate change allowance flood events) in the adjacent model.

Flood outline maps will be provided to PKC for all return periods (using the adjusted model) which will replace the original model flood outlines (baseline maps issued to PKC on 21st August 2014).

The conclusion of this note is that the adjusted model will be used as the baseline model for further optioneering modelling tasks.

[4] *Section 8 cross section is the Dalginross gauging station.*

APPENDIX A

Project: Comrie and Dalginross Flood Study

Date – 24th October 2012

Hydrology Update

Project Background

Perth and Kinross Council (PKC) has appointed Mouchel' Flooding and Drainage team, to undertake a Flood Study in Comrie & Dalginross. Comrie and Dalginross are located at the confluence of three watercourses (River Earn, the Water of Ruchill and the River Lednock and historically have suffered flooding from these watercourses. As part of this study a review of the existing hydrology of previous (Mouchel report 2010, and Camp Road flood alleviation optioning report, April 2013).

This document provides a short summery of the existing model hydrological review and outcomes.

Introduction and Background

Study Area

Comrie and Dalginross are located approximately 40 kilometres west of Perth at the confluence of thee watercourses (River Earn, River Lednock and the Water of Ruchill), as shown in Figure 1 below.

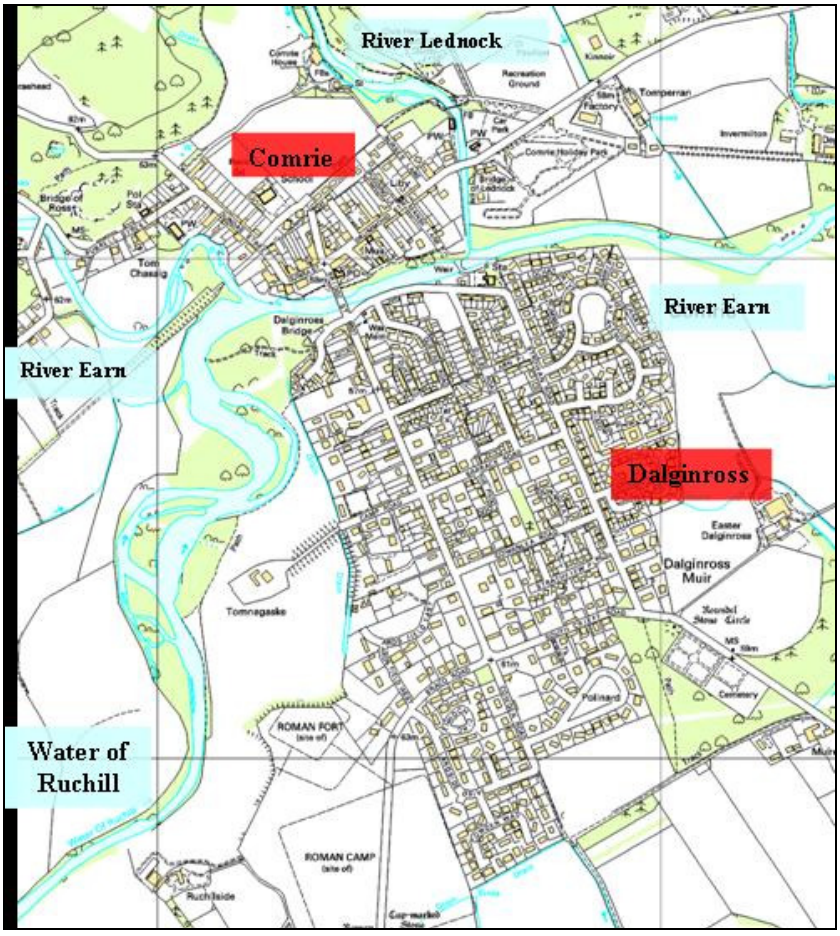

Fig 1: Site location map showing principal water courses and places

Hydrological Model Review

An ISIS-TUFLOW hydrological and hydraulic model was built, as part of Mouchel 2010 flood study, to investigate the extents of the flooding in Comrie and Dalginross. A hydrodynamic model was required due to the possible over bank flow routes and the potential for key structures to attenuate flood flows. During larger events the ability to accurately assess over bank flow routes becomes critical, and this cannot be achieved within the confines of a simple steady–state (peak flow) regime. Therefore, flow hydrographs are required as input to the hydrodynamic model.

The model was calibrated using river and rainfall gauge data obtained from SEPA. Formal consultation was also carried out with SEPA to agree the flows used in the hydrological model. Flood outlines for a range of return periods were produced (10, 25, 75, 100 and 200) to confirm the flood mechanisms in Comrie and Dalginross and assess the severity of flooding in extreme events.

The standard approach taken on the existing hydrological analysis was to use the hybrid method i.e. a combination of FEH statistical and rainfall runoff techniques.

The FEH CDROM 2 (2007) has been used on the existing hydrological analysis and the base year for the calculations was 2009.

Sub-Catchment Delineation

In order to produce a detailed hydrological model of the catchment, clear delineation of the catchment into sub-catchments was undertaken. The catchment was sub-divided using information from the FEH CD-ROM 2 with sub-catchments based on direct tributary inflows.

The catchment was divided into three sub-catchments shown on the map in Appendix D. Details are outlined in Table 1.

Catchments descriptors were derived in the existing model using the FEH CD-ROM 2.

Watercourse	Site	Catchment area (km2)	% of catchment total area
River Earn	River Earn downstream of Comrie and Dalginross and immediately upstream of the Milton Burn confluence (whole catchment)	350.5	100%
Water of Ruchill	Water of Ruchill at the Cultybraggan gauge	101.3	28.9%
River Earn	River Earn upstream of Comrie and immediately downstream of the Bridge of Ross	182.8	52.2%
River Lednock	River Lednock at the weir upstream of Comrie	61.4	17.5%
River Earn	Additional catchment from towns of Comrie and Dalginross	5.0	1.4%

Table 1 – Existing Hydrology sub-catchment delineation

As part of the hydrological review, the catchments descriptors were derived using the FEH CD-ROM3 (2009). As shown in the Table 2 below, areas of the sub-catchments are the same with those derived from FEH CD-ROM 2.

Watercourse	Site	Catchment area (km2)	% of catchment total area
River Earn	River Earn downstream of Comrie and Dalginross and immediately upstream of the Milton Burn confluence (whole catchment)	349.44	100%
Water of Ruchill	Water of Ruchill at the Cultybraggan gauge	103.47	33%
River Earn	River Earn upstream of Comrie and immediately downstream of the Bridge of Ross	183	51%
River Lednock	River Lednock at the weir upstream of Comrie	61.8	21%

Table 2 – Hydrology Review sub-catchment delineation

In the existing model, catchment descriptors were obtained, for each direct inflow, using FEH CD-ROM2. The URBEXT2000 values were estimated with an updated UEF equation[1].

The key catchment descriptors for each direct inflow are shown in Table 3.

FEH Catchment Descriptor	River Earn upstream of Milton Burn confluence POI ref 1	Water of Ruchill at Cultybraggan gauge POI ref 2	River Earn downstream of Bridge of Ross POI ref 3	River Lednock at the weir POI ref 4	Units
AREA	350.5	101.3	182.8	61.4	km^2
ALTBAR	394	394	376	474	m
BFIHOST	0.443	0.434	0.452	0.424	
DPLBAR	17.65	12.9	18.58	10.85	km
DPSBAR	222	214.8	234.5	209.5	m / km
FARL	0.865	1	0.786	0.894	
LDP	33.21	22.96	31.26	17.99	km
PROPWET	0.63	0.59	0.66	0.65	
RMED – 1H	10.5	10.8	10.2	10.7	mm
RMED – 1D	49.9	52.3	48.5	50.1	mm
RMED – 2D	69.6	73.1	68.1	68.5	mm
SAAR	1738	1887	1730	1555	mm
SPRHOST	43.18	44.12	42.44	44.23	
URBEXT2000	0.001	0	0.0005	0	
URBEXT2000 (2009)	0.001	0	0.0005	0	

Table 3 – Existing FEH catchment descriptors for each direct inflows

As part of the hydrological review, the key catchments descriptors were derived using the FEH CD-ROM 3 (2009). As shown in the Table 2 below, these sub-catchments descriptors are very similar with those derived from FEH CD-ROM 2.

[1] *UEF = 0.7851 + 0.2124 tan-1[(Year – 1967.5) / 20.32)] The equation used is taken from CEH document named 'The use of LCM2000 to provide improved definition of the FEH catchments descriptor URBEXT in Northern Ireland; Stage 2- Calculation and dissemination of URBEXT2000 values' CEH, March 2006*

FEH Catchment Descriptor	River Earn upstream of Milton Burn confluence	Water of Ruchill at Cultybraggan gauge	River Earn downstream of Bridge of Ross	River Lednock at the weir	Units
AREA	349.44	103.47	183.13	61.78	km^2
ALTBAR	395	387	375	471	m
BFIHOST	0.443	0.437	0.452	0.425	
DPLBAR	16.86	14.65	19.11	11.53	km
DPSBAR	222.5	211.4	234.3	209	m / km
FARL	0.865	1	0.786	0.895	
LDP	32.38	24.98	31.82	18.77	km
PROPWET	0.63	0.59	0.66	0.65	
RMED – 1H	10.5	10.7	10.2	10.7	mm
RMED – 1D	49.9	52.2	48.5	50.1	mm
RMED – 2D	69.6	73	68.1	68.5	mm
SAAR	1740	1875	1729	1553	mm
SPRHOST	43.2	43.97	42.43	44.16	
URBEXT2000	0.0006	0.0004	0.0005	0	
URBEXT2000 (2013)				0	

Table 4 – Review FEH catchment descriptors for each direct inflows

Calibration of the existing model (Mouchel 2010): - Two events (16th January 1993 and 19th February 1997) were selected for model verification and calibration. These events have been selected as they were the largest floods, of recent years, recorded in Comrie and Dalginross and there were sufficient gauge data and anecdotal information available in order to carry out the model verification. In addition, the FEH statistical assessment has incorporated the AMAX data from the Cultybraggan and Aberuchill river gauges. The length of records at the Cultybraggan and Aberuchill gauges were 46 years and 32 years respectively and the Cultybraggan gauge (a HiFlows-UK station) indicating that it is suitable for estimating QMED. Therefore there were suitable available data for estimating the inflows for the Water of Ruchill and River Earn sub-catchments.

On 27th August 2012, the Water of Ruchill caused flooding in Dalginross. Following this flooding, PKC commissioned Mouchel in September 2012 to investigate the flooding of 27th August 2012 and in particular the flood mechanism that allowed flood water from the Water of Ruchill to enter Camp Road. The design and model calibration have been undertaken as part of the Camp Road Flood Alleviation Scheme (Mouchel April 2013) using data from the August 2012 flood event. This hydrological verification confirmed that gauged river flows and stages provided by SEPA indicated that the approximate return period of the 27th August 2012 flood event was 1 in 7 years and that the standard of flood protection at the time provided to Comrie and Dalginross by the existing flood defences and bank tops was approximately 1 in 5 years[2]; as such there is a 20% chance of a similar flood occurring in any one year.

[2] Please note that the standard of protection of 1:5 years is revised down from previous assessment (by Arup) of 1:50years and 1:19 years.

During the development of the Camp Road Flood Alleviation Scheme a second flood occurred on 19th November 2012 of a similar scale. However, the impact of flooding of 19th November 2012 was much greater as approximately double of properties were flooded.

As part of this review the existing model is verified with data from 19th November 2012 flood event. The observed flow data from 18th -21st November 2012, from Aberuchill, and Cultybraggan gauging stations were routed in the existing and the observed models and water levels results were then compared at the location of the Dalginross gauging station. The observed hydrographs at Dalginross gauging station provided a very close comparison with the existing model hydrograph at the location of the Dalginross gauging station.

Figure 2 below shows that both hydrographs match very well and therefore no further adjustments to the existing model are recommended.

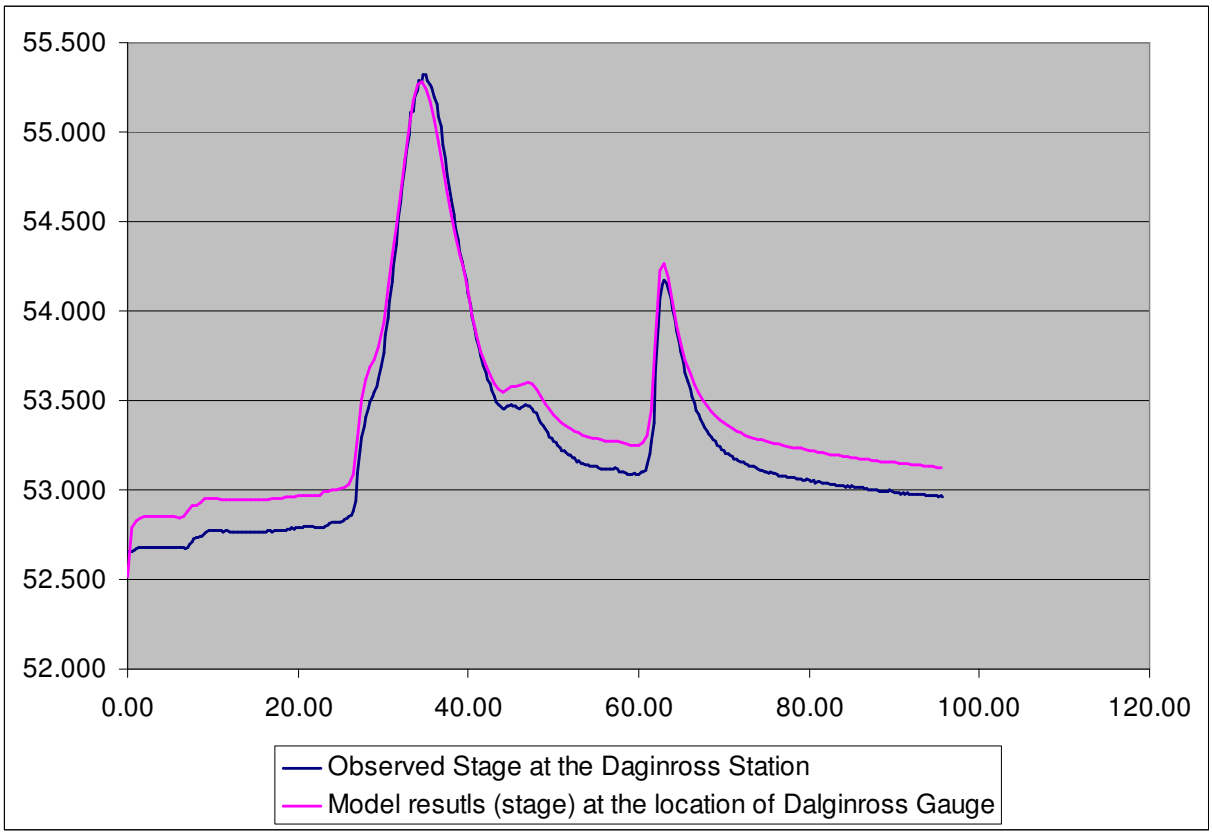

Fig 2.: 19th November flood event verification hydrographs

This hydrological review and the verification with 19th November 2012 event concluded that final design flows selected as inputs into the hydraulic model are kept the same as those of the existing model (Table 5).

Site	Hydrological method used	Q75	Q100	Q200	Q200+CC
Water of Ruchill at the Cultybraggan gauge	FEH Statistical	280.4	292.6	323.8	388.5
River Earn immediately downstream of the Bridge of Ross	FEH Statistical	144.5	153.0	175.3	210.4
River Lednock at the weir upstream of Comrie	FEH Rainfall Runoff	126.0	133.2	152.0	182.4

Table 5 – Verified flows selected as inputs into the hydraulic model (m^3/s)

APPENDIX B

REACH 2
Manning's value for channel = 0.05
Manning's value for Flood Plain vary from 0.03 to 0.07 depending upon the locations

REACH 1
Manning's value for channel = 0.04
Manning's value for Flood Plain = 0.06

N

NOTES

REV	DATE	REMARKS
1	25/09/2014	Draft

PERTH & KINROSS COUNCIL

No Window

Comrie and Dalginross Flood Study

Reaches of River Lednock for Manning's Roughness

Date of Issue: September 2014

Scale at A3: Not to Scale

REACH 5

REACH 4

REACH 3

REACH 1

REACH 2

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NOTES

REV	DATE	REMARKS
1	25/09/2014	Draft

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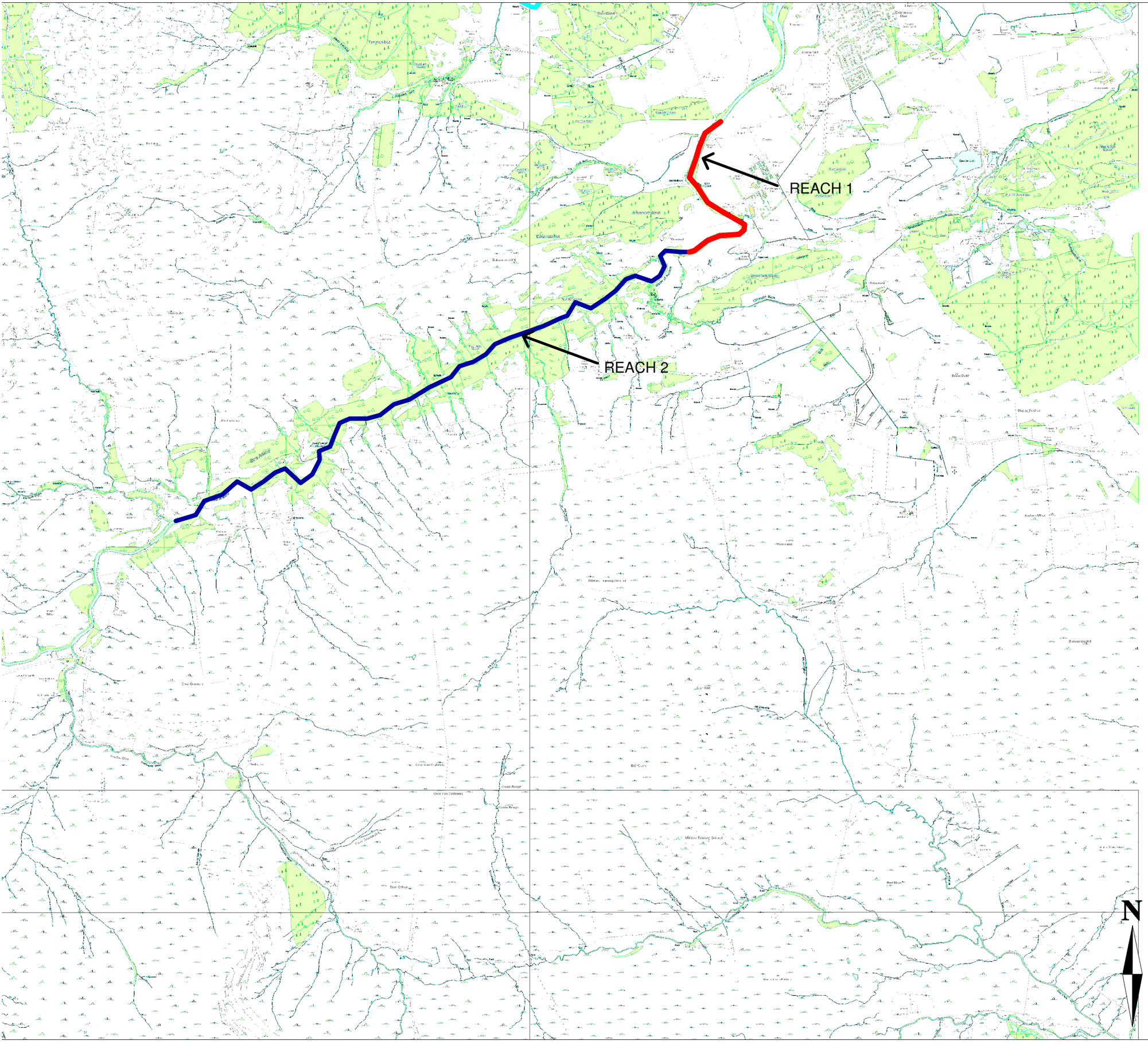
No Window

Comrie and Dalginross Flood Study

Reaches of River Earn for Manning's Roughness

Date of Issue: September 2014

Scale at A3: Not to Scale



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Date of Issue: September 2014

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