Appendix D. SLR (November, 2017) FRA extract

FORT AUGUSTUS SUBSTATION AUCHTERAW

Proposed Substation Extension
Platforms LT92 and LT94

APPENDIX FRA-A: Hydrological Modelling Report

FLOOD RISK ASSESSMENT

Prepared for: Scottish and Southern Energy

SLR Ref: 405.00660.00047
Version No: 1
November 2017

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Drawing No. APP-A-1: Baseline Model Hydrological Overview
Drawing No. APP-A-2: Development Model Hydrological Overview

APPENDICES

Appendix 01: Baseline Model Inflow Hydrographs
Appendix 02: Development Model Inflow Hydrographs

1.0 Introduction

1.1 Context

SLR Consulting Ltd (SLR) has been appointed by Scottish and Southern Energy (SSE) to undertake a Flood Risk Assessment (FRA) to support a planning application for the proposed extension of the existing electrical substation facility at Auchteraw, Fort Augustus (the Site) in the Scottish Highlands.

The proposed substation expansion comprises the construction of 2no. new platforms referred to as LT92 and LT94 which will adjoin to the existing platform boundary.

SEPAs Flood Maps for the Study Site, are produced at an indicative and strategic level scale and only modelled for watercourses with catchment areas >3km^2 and thus fails to capture the potential flood risk posed by the 'minor' watercourses flowing through and adjacent to the development site area.

This report therefore presents the detailed Hydrological Analysis for the flood flows to inform the 1-Dimensional (1D)/2-Dimensional (2D) linked TUFLOW model developed for the FRA. Appendix FRA-B should be referred to for detail of the hydraulic model developed and associated mapped outputs.

1.2 Model Scenarios

Two separate model scenarios have been considered for the Hydraulic Model:

- **Baseline** – assesses the flood risk to the existing platform during a 0.5% and 0.1% Annual Exceedance Probability (AEP) events. The flood risk to the existing platform when allowing for the impact of climate change (+20%) on the 0.5% AEP event has also been assessed.
- **Proposed Development** – assesses the impact of the proposed LT92 and LT94 substation platforms on the flood risk at the development site and elsewhere. Under this scenario, flood mitigation measures, including new / diverted watercourses and culverts have been assessed (without flood compensatory analysis to determine the likely initial compensation requirements to be detailed at the post-planning stage). As for the baseline scenario, the impact of the proposed platforms on flood risk has been assessed during a 0.5% (with and without a +20% allowance for climate change) and 0.1% AEP events.

1.3 Model Inflow locations

There are 4no. watercourses relevant to the assessment and these are depicted on Drawing No. APP-A-1 and APP-A-2 - these have been explicitly represented within the Hydraulic Flood Models for the Baseline and Development scenarios.

Modelled inflow location are also presented on the aforementioned drawings and summary hydrological details are provided in Table 1-1 and Table 1-2 below for the Baseline and Development models.

Table 1-1
Baseline Model – Hydrological Overview

Inflow ID	Inflow Type	Watercourse	Catchment Delineation NGR	Catchment Area (km^2)	SAAR[1] (mm)	SPRHOST[2]	BFIHOST[3]	Upstream Boundary Condition
B_I1(a)	Point Hydrograph	Auchteraw Burn (Watercourse 1)	NH 35205 08257	3.13	1481	0.52	0.32	Site access road bridge at NGR: NH 35724 08641

Inflow ID	Inflow Type	Watercourse	Catchment Delineation NGR	Catchment Area (km^2)	SAAR[1] (mm)	SPRHOST[2]	BFIHOST[3]	Upstream Boundary Condition
B_I1(b)	Point Hydrograph	Auchteraw Burn (Watercourse 1)	NH 35459 07898	0.54	1455	0.49	0.38	Governed by water level in the Auchteraw Burn
B_I2	Point Hydrograph	Allt na Fearna (Watercourse 2)	NH 35721 08644	2.79	1492	0.54	0.311	Minor road bridge at NGR: NH 35207 08254
B_I3(a)	Hyetograph (overland flow)	Tributary to the Auchteraw Burn (Watercourse 3)	NH35370 08491	0.06	1455	0.49	0.38	Governed by capacity of the NW Boundary ditch
B_I3(b)	Point Hydrograph	Tributary to the Auchteraw Burn (Watercourse 3	NH 35195 08518	0.59	1455	0.49	0.38	Forestry Track Drainage Ditch at NH 35195 08518
B_I4	Point Hydrograph	Tributary to the Auchteraw Burn (Watercourse 4)	NH 35481 08373	0.0025	1455	0.49	0.38	Governed by the capacity of Culvert H

Table 1-2
Development Model – Hydrological Overview

Inflow ID	Inflow Type	Watercourse	Catchment Delineation NGR	Catchment Area (km^2)	SAAR (mm)	SPR HOST	BFI HOST	Upstream Boundary Condition
D_I1(a)	Point Hydrograph	Auchteraw Burn (Watercourse 1)	NH 35205 08257	3.13	1481	0.52	0.32	Site access road bridge at NGR: NH 35724 08641
D_I1(b)	Point Hydrograph	Auchteraw Burn (Watercourse 1)	NH 35459 07898	0.54	1455	0.49	0.38	Governed by water level in the Auchteraw Burn
D_I2	Point Hydrograph	Allt na Fearna (Watercourse 2)	NH 35721 08644	2.79	1492	0.54	0.311	Minor road bridge at NGR: NH 35207 08254
D_I3	Point Hydrograph	Tributary to the Auchteraw Burn (Watercourse 3	NH 35195 08518	0.59	1455	0.49	0.38	Forestry Track Drainage Ditch at NH 35195 08518
D_I4	Point Hydrograph	Tributary to Watercourse 3 (Watercourse 4)	NH35386 08422	0.0554	1455	0.49	0.38	Beginning of Watercourse 4

2.0 Hydrological Analysis

2.1 Overview

All watecourses relevant to the assessment are ungauaged and thus flow estimation using the methods outlined in the Flood Estimation Handbook (FEH)[1] for ungauged catchments in the UK has been adopted.

The FEH offers two principal methods of flood flow estimation; the Rainfall-Runoff Method and the Statistical Method. The Statistical Method estimates peak flow for a catchment for a given AEP event using a combination of historic gauging station data and catchment descriptors. The Rainfall Runoff Method estimates the response of a catchment to a rainfall event of a given AEP and generates a peak flow based entirely on catchment descriptors.

The FEH is supported by WINFAP-FEH and the Revitalised Flood Hydrograph V.2 (ReFH2) software applications which are used in combination with the FEH Web Service[2].

The FEH Web Service provides digital catchment descriptors for any catchment in the UK with an area greater than 0.5km^2. Physical catchment descriptors are estimated from the Institute of Hydrology Digital Terrain Model (IHDTM). Other catchment descriptors are estimated from various publically available sources including soils and climatic datasets.

The WINFAP-FEH software supports the statistical procedures for flood frequency estimation, using historic annual maxima data alongside catchment descriptors. The latest version of WINFAP, version 4.0, has been used in this study.

2.2 Rainfall-Runoff Method

The ReFH2 design package utilises the Rainfall Runoff Method to generate a hydrograph for any catchment generated by a rainfall event of a given AEP. The ReFH2 software is the first version to incorporate SEPA data and thus be calibrated to Scottish catchments/environmental conditions. This method is therefore considered appropriate for this study. It should be noted that during the calibration of ReFH2 the estimated time to peak is considerably reduced and the peak flow increased to reflect the more responsive nature of a Scottish upland catchment[3].

The Institute of Hydrology carried out a number of studies on revising the runoff equations produced in the original Flood Studies Report (1975). IH124 was specifically produced to address the runoff from small catchments (Institute of Hydrology, 1994) and is thus regarded as a valid method for the Site, with the largest inlfow catchment having an area of only 3.13ha.

However, the IH124 method relies on an equation / relationship which does not take into account key catchment descriptors such as the SPRHOST and BFIHOST. It therefore considered to be less accurate than the more recent FEH based methods[4].

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[1]Centre for Ecology and Hydrology (CEH), 1999. Flood Estimation Handbook
[2]Centre for Ecology and Hydrology (CEH), 2017. Flood Estimation Handbook Web Service accessed on 05.09.2017 at: https://fehweb.ceh.ac.uk/GB/map
[3]WHS, 2016. Revitalised Flood Hydrograph Model ReFH2: Technical Guidance, pp 67
[4] CIRIA C753, 2015. The SuDS Manual, 24.3.2

2.3 Statistical Method

2.3.1 Overview

The Statistical Method is broadly a two part process; the estimation of the mean annual flood (QMED) and the derivation of a growth curve. The growth curve relates the increase in peak flow as a multiple of QMED against the rarity of the AEP event.

QMED can be generated from either annual maxima flow data or catchment descriptors, whereas the growth curve is generated solely from annual maxima data.

The annual maxima data required to generate the growth curve can either be from a single gauged site, or from a pooled group of hydrologically similar gauged sites.

The use of the single site analysis technique is only recommended when the flow record length, R, for a gauging station is longer than the required return period, T.

If the record length is between T and 2T, then it is suggested that both a pooling group and single site analysis are competed. Only if the flood data record is longer than 2T is it suggested to use only single site analysis. The record lengths for the selected gauging stations are 34 and 35 years. As the flood risk at the Site is being assessed for a 0.1% AEP both the single site and pooled analyses have been completed for this study.

The statistical method is only applied on the downstream end of the Site at the 1D model outflow location (i.e. on Watercourse 1 – the Auchteraw Burn) as the individual upstream catchment sizes are considered too small for the statistical method to be appropriately applied. Instead the downstream peak flow values are scaled using the relevant catchment areas to upstream inflow locations – this is considered to be a pragmatic approach as all other individual watercourses form tributaries to Watercourse 1 and thus are hydrologically of the same catchment system.

2.3.2 Gauging Stations

Two hydrologically similar gauging stations were selected as donor sites. These were the National River Flow Archive (NRFA) gauging station 28033 – River Dove at Hollinsclough; and 91802 on the Allt Leachdach. Both these sites have small catchment areas with similar key FEH catchment characteristics such as Flood Attenuation by Reservoirs and Lakes (FARL) index, BFIHOST, SAAR and SPRHOST.

2.3.3 QMED

The QMED for the Site is applied to the growth curve to estimate the flood flow of a given AEP event.

There are three methods for deriving a value of QMED for an ungauged site, these are:

1. Directly from the FEH catchment descriptors downloaded for the Site. The QMED estimation from catchment descriptors performed by WINFAP-FEH is in line with the updated 2008 statistical guidelines published by Kjeldsen (2008)[5].
2. FEH donor transfer scheme which provides an estimate of QMED at the target location. This adjusts the value of QMED at the selected donor sites based of the differences in the catchment areas and geographical centroids of the target and donor sites. The donor transfer scheme is applied to both donor locations.

[5]Kjeldsen et al, 2008. Improving the FEH statistical procedures for flood frequency estimation

3. WINFAP multiple donor QMED adjustment function. This method is new for WINFAP V.4 and based upon Kjeldsen et al. (2014)[6]. It uses six donor catchments selected by WINFAP to adjust the catchment descriptor derived value of QMED for the target location.

Estimates of QMED using each method are summarised in Table 2-1 below.

Table 2-1
QMED Estimates – Statistical Method (results in m^3s^{-1})

Inflow ID	Physical Catchment Descriptors	Donor Transfer (91802)	Donor Transfer 28033	WINFAP Multiple Donor Adjustment
Downstream Boundary	8.08	6.95	8.08	8.71

The analysis indicates how the estimate of QMED from the WINFAP Multiple Donor Adjustment method is slightly higher than QMED derived from catchment descriptors or donor transfer. Taking a precautionary (conservative) approach which is entirely appropriate for flood risk assessments, the value of QMED derived from the WINFAP Multiple Donor Adjustment has been selected to develop the Hydraulic Model flood flows.

2.3.4 Growth Curve

Single Site Analysis

Single site analysis requires annual maxima flow data to estimate the peak flow for a given AEP event. As the target location is ungauged, the single site analysis will be performed on the two selected donor sites.

The gauging station annual maxima flow data is used to generate growth curves. L-moments are the preferred Statistical Method[7] for estimating parameters of a probability distribution from a data sample as they are robust in the presence of outliers in the data set, which are often present in flood data sets.

A flood growth curve for NFRA Gauges 91802 and 28033 has been generated in WINFAP-FEH by fitting a set of extreme value distributions to the observed annual maxima data. The General Logistic (GL), 3 Parameter Lognormal (LN3) and Generalised Extreme Value (GEV) distributions provided the best fit to the annual maxima data. However, the GL distribution was selected to estimate peak flows for a range of AEPs for the Site in line with the FEH guidance (Section 17.3.2). The guidance concludes that the GL distribution is the most appropriate selection for UK catchments.

No adjustment for urbanisation is required as the catchment is essentially rural as discussed at Section 2.2.

Pooling Group Analysis

As discussed previously, due to a record length of 25 years at NFRA 4006, a pooling group analysis alongside a single site analysis is advised for flood frequency estimation of peak flow for lower AEP events. A pooling group comprises gauging stations with similar catchment characteristics to the target site. Gauging stations within a pooling group need not to be close to one another in geographical space, but rather have similar area

[6]Kjeldsen, T. R., D. A. Jones, and D. G. Morris (2014), Using multiple donor sites for enhanced flood estimation in ungauged catchments, Water Resour. Res., 50, 6646–6657, doi:10.1002/ 2013WR015203.
[7] Centre for Ecology and Hydrology (CEH), 1999. Flood Estimation Handbook

(AREA), SAAR and BFIHOST. By utilising a pooling group, more flood data becomes available to obtain more reliable estimates for lower probability AEP events.

A pooling group for both the target site and the both donor sites were automatically generated using WINFAP-FEH. Discordancy of a pooling station is a measure of how different annual maxima data is from the pooled values L-moment ratios, with a higher value indicating a higher degree of variation. The discordancy values indicate the annual maxima data for one gauging station in the 28033 pooling group was deemed unsuitable (NFRA Gauge 49006) and so was removed from the pooling group. NFRA Gauge 26802 was added as a replacement. The remaining gauging stations were suitably similar to the pooled values L-moment ratios. Values of discordancy and heterogeneity statistic (H_2) are measures to evaluate pooling station suitability to predict a flood curve for the target or donor site. H_2 compares the variability of L-CV and L-skewness across the pooling group, with a high H_2 value indicating that group members have different growth curves. The low H_2 values for the donor site pooling groups indicate that both pooling groups are acceptably homogenous and that there is no hydrological reason for adjusting the pooling group further.

A set of flood growth curves has been generated for each of the pooling groups in WINFAP-FEH. The 'goodness of fit' test, which evaluates the fit of extreme value distributions to the pooled data, indicates that GL, GEV and LN3 are statistically acceptable fits. Of the three, the GL distribution has been selected for both pooling groups as it is widely used in UK flood frequency analyses with a strong theoretical justification[10]. It also provides the highest peak flow estimates for all AEP events and is therefore deemed a precautionary approach.

2.4 Revitalised Flood Hydrograph

Unlike the Statistical Method discussed previously, which provide only an estimate of peak flow, the Rainfall Runoff Method provides a full flood hydrograph for a given AEP flood event.

The catchment descriptors extracted from the FEH Web Service for each catchment detailed in Table 2-1 and 2-2 were used in the ReFH2 Scottish catchments analysis to generate a 0.1% and 05% AEP event hydrographs for each model input locations. The R&D Technical Report FD1913/TR report, published jointly by the Department for Environment, Food and Rural Affairs (Defra) and the Environment Agency in 2005, recommends a winter design profile be used for rural catchments (URBEXT < 0.125).

The rainfall depth is distributed across the design storm duration using the appropriate design storm profile as described by Houghton-Carr (1999)[8].

2.5 Institute of Hydrology Report No. 124 (IH124)

Due to the small input catchment areas, the IH124 is a suitable method to estimate the model input peak flows. The FEH catchment descriptors as summarsied in Table 1-1 and Table 1-2 have been used to provide the values of SAAR and SPRHOST for each catchment. The IH124 calculation has been completed within the 'Rural-Runoff' calculator built-into the MicroDrainage software package. The minimum area for a IH124 catchemnt in microdrainage is 50ha, so 50ha has been used for each area and then the value has been scaled linearly for each catchment, as stated in CIRIA SuDS Manual EQ 24.3[9].

[8] Centre for Ecology and Hydrology (CEH), 1999. Flood Estimation Handbook (Vol 4)
[9] CIRIA C753 2015. The SuDS Manual, page 513

2.6 Summary of Hydrograph Method Selection

A summary of the peak flows derived for the downstream boundary catchment for the baseline are included in Table 2-2 below.

Table 2-2
QMED Estimates (results in m^3s^{-1})

Annual Exceedance Probability (%)	ReFH2	IH 124	Statistical Methods				
			Donor (28033)		Donor (91802)		Target
			Single	Pooled	Single	Pooled	Pooled
0.5	22.1	266.54	43.44	35.90	23.56	23.35	30.54
0.5+20% CC	26.52	319.85	52.13	43.08	28.28	28.01	***36.65***
0.1	28.08	344.31	80.82	56.46	33.73	32.27	45.13

It is clear that the peak flow values generated from the IH124 method are an order of magnitude higher than the alternative methods and are therefore discounted. However, as discussed at Section 2.0, IH124 method is relatively simple approach derived in 1994[10]. As such, the more advanced and up to date techniques of the Statistical analysis and ReFH2 are seen as providing more reliable peak flow results for the input catchments.

The Statistical Method is preferred to the Rainfall Runoff Method due to the inclusion of observed flood data from a pooling group. The Statistical Method also provides higher estimates of peak flow and has therefore been adopted as a precautionary approach.

As discussed at Section 2.1.1, the Statistical Method has been applied to the two donor sites, pooling groups for each of these donor sites and the target site. The single site analysis for the two donor sites have been discounted as the record length is insufficient for the long return period required for the hydraulic analysis (0.1% AEP). When comparing the relative merits of the donor and target pooling groups, it must be noted that the target pooling group generated is directly applicable to the Site, as the pooling group was generated using the Site catchment descriptors rather than those for the donor station.

The Statistical Method applied to the pooled group target site has therefore been adopted as the preferred method for the estimation of flood flows for input to the hydraulic model. The downstream value of flow for the 0.1% and 0.5% AEP events have been scaled directly to each catchment via their relative areas.

The preferred method of estimating input catchment flows provides only a peak flow and a flood hydrograph is required as an input to the model. The ReFH2 hydrographs for each catchment have then been scaled so that the peak matches the target pooling group peak flow for each catchment. This provides a hydrograph which has the form/shape relative to each catchment (smaller catchments having shorter hydrographs) but with the peak flow from the chosen hydrological method.

The **Development** model hydrographs have been scaled using their relative areas from the **Baseline** hydrographs.

[10] HR Wallingford, 2017, UKSUDS. Accessed on 13.09.2017 at http://www.uksuds.com/FAQRetrieve.aspx?ID=55033

The design hydrographs developed and used for the **Baseline** and **Development** Hydraulic Models are enclosed as Appendix 01 and Appendix 02.

2.7 Hyetograph

The above discussed methodology has been applied to all catchments except Catchment I3(a) – in the Baseline Model only - as demonstrated in Drawing No.APP-A-1.

The receiving watercourse (part of Watercourse 3) is essentially flat with no positive (unilateral) flow direction and is aligned perpendicular to the runoff flow direction from the upstream catchment. The watercourse will therefore intercept runoff along its reach rather than at a discrete location. A hyetograph has been selected for use for this catchment rather than a point inflow. The hyetograph has been applied across the upstream catchment area.

The Rainfall Runoff Method is the only hydrological method discussed above which can generate a hyetograph, which uses the FEH catchment descriptors to generate a hyetograph. The hyetograph has been generated for a 0.5% and 0.1% AEP events and a copy of the graphical input also included in Appendix 01.

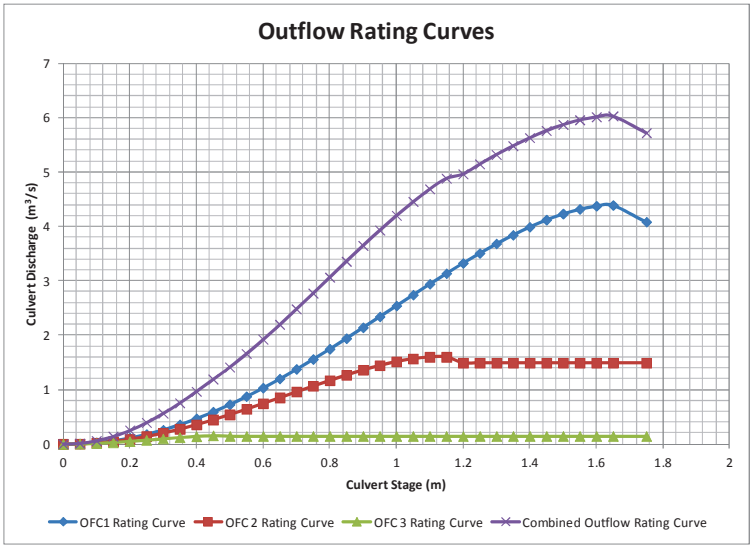
The hyetograph was removed in favour of a point inflow for Watercourse 4 in the Development model which replaced the flat section of Watercourse 3 from the Baseline model – refer to Inflow I4 on Drawing No.APP-B-2

3.0 1D Downstream Model (Outflow) Boundary

The 1D model outflow boundary condition is governed by the outflow capacity of 3 x circular corrugated steel culverts on the Auchteraw Burn (Watercourse 1), which are located approximately 550m southeast of the proposed development area as shown on Drawing No's. APP-B-1 and APP-B-2. Thus a total combined rating curve has been derived by applying Manning's principles of pipe flow.

The combined outflow rating curve combines the individual rating curves for each of the three culverts (OFC 1, OFC 2 and OFC 3) as presented in Figure 1 below.

Figure 1
Downstream Boundary Developed Rating Curves



The same combined rating curve is used in both the baseline and proposed development and models.

4.0 Climate change

Scottish Planning Policy (SPP)[11] recommends that:

> *'a precautionary approach to flood risk from all sources, including coastal, water course (fluvial), surface water (pluvial), groundwater, reservoirs and drainage systems (sewers and culverts)' be adopted by the planning system, 'taking account of the predicted effects of climate change.'*

Although the 2009 climate change predictions (UKCP09) provides information on spatial variations in the potential effects climate change, a 20% increase in peak flow has been adopted in line with SEPA recommendations.

A 20% increase has therefore been applied to the 0.5% AEP flood hydrographs to represent the impact of climate change on fluvial flood flows.

5.0 Conclusions

This summary Hydrological Modelling report forms Appendix FRA-A to the Flood Risk Assessment report and informs the development of Flood flows for the 1D/2D linked Hydraulic TUFLOW Models for the Baseline and Development scenarios - Appendix FRA-B should be consulted for full details of the hydraulic modelling.

The hydrological analysis undertaken is considered to be suitable for the purposes of this assessment and takes due cognisance of SEPAs requirements and adopts current industry best practice for the development of flood flows using the most current industry standard hydrological modelling methods / packages.

[11] The Scottish Government, 2014. Scottish Planning Policy

DRAWINGS

235000 235500 236000 236500

809000 808500 808000

INFLOW I3a DETAILS:
CATCHMENT AREA = 0.06km^2
(MODELLED AS HYETOGRAPH INPUT)
PEAK 1:200yr FLOW = 0.24m^3/s
PEAK 1:200yr + 20% CC FLOW = 0.29m^3/s
PEAK 1:1000yr FLOW = 0.35m^3/s

INFLOW I2 DETAILS:
CATCHMENT AREA = 2.79km^2
PEAK 1:200yr FLOW = 11.17m^3/s
PEAK 1:200yr + 20% CC FLOW = 13.4m^3/s
PEAK 1:1000yr FLOW = 16.5m^3/s

INFLOW I4 DETAILS:
CATCHMENT AREA = 0.0025km^2
PEAK 1:200yr FLOW = 0.01m^3/s
PEAK 1:200yr + 20% CC FLOW = 0.012m^3/s
PEAK 1:1000yr FLOW = 0.015m^3/s

INFLOW I3b DETAILS:
CATCHMENT AREA = 0.59km^2
PEAK 1:200yr FLOW = 2.36m^3/s
PEAK 1:200yr + 20% CC FLOW = 2.83m^3/s
PEAK 1:1000yr FLOW = 3.49m^3/s

INFLOW I1a DETAILS:
CATCHMENT AREA = 3.13km^2
PEAK 1:200yr FLOW = 12.53m^3/s
PEAK 1:200yr + 20% CC FLOW = 15.03m^3/s
PEAK 1:1000yr FLOW = 18.51m^3/s

INFLOW I1b DETAILS:
CATCHMENT AREA = 0.54km^2
PEAK 1:200yr FLOW = 2.16m^3/s
PEAK 1:200yr + 20% CC FLOW = 2.59m^3/s
PEAK 1:1000yr FLOW = 3.19m^3/s

I1a I1b I2 I3a I3b I4

A B C D E F G H J K L M

EXISTING SUBSTATION
PROPOSED LT94
PROPOSED LT92
EXISTING SGT4
El Sub Sta
FILTER DRAIN AND SOAKAWAY TO DISCHARGE FLOW FROM I4
AUCHTERAW BURN DISCHARGES TO RIVER OICH
DOWNSTREAM MODEL BOUNDARY AT CULVERTS BENEATH FORESTRY TRACK

Waterfall Weir Waterfalls Drain Sheepfold Forestry Nurs Path FB Lundie Cottage Talamh Carraig Auchteraw Hostel Torr Sionnaich Whinhill Auchteraw House Auchteraw Burn River Track

48m 43m 39m 54m 51m 44m 41m

N

0 50 100 150 200
Metres

NOTES

1. CONTOURS GENERATED FROM GETMAPPING 5m AP DERIVED DTM INTEGRATED WITH SLR TOPO SURVEY.

LEGEND

- SSE LAND OWNERSHIP BOUNDARY
- EXISTING PLATFORM BOUNDARY
- SGT4 PLATFORM EXTENT
- PROPOSED LT92 PLATFORM EXTENT
- PROPOSED LT94 PLATFORM EXTENT
- CULVERT + ID
- WATERCOURSE 1 - AUCHTERAW BURN
- WATERCOURSE 2 - ALLT NA FEARNA
- WATERCOURSE 3 - MINOR WATERCOURSE (ENGINEERED)
- WATERCOURSE 4 - MINOR WATERCOURSE (ENGINEERED)
- MODEL INFLOW LOCATION + ID
- UPSTREAM MODEL BOUNDARY LOCATION
- DOWNSTREAM MODEL BOUNDARY LOCATION
- WATERCOURSES RELEVANT TO STUDY (NOT MODELLED)
- SITE BUILDING
- 1m CONTOUR

SSE

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EH12 9DH
T: +44 (0)131 335 6830
www.slrconsulting.com

FORT AUGUSTUS FRA
HYDROLOGICAL MODELLING REPORT
BASELINE MODEL
APP-A-1

Scale 1:5,000 @ A3
Date NOVEMBER 2017

00660.00047.18.AppA-1.0 Hydrological Overview

Contains Ordnance Survey data © Crown copyright and database rights (2017) 0100031673 Expires 14/11/2018

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235000 235500 236000 236500

809000 808500 808000

INFLOW I2 DETAILS:
CATCHMENT AREA = 2.79km^2
PEAK 1:200yr FLOW = 11.17m^3/s
PEAK 1:200yr + 20% CC FLOW = 13.4m^3/s
PEAK 1:1000yr FLOW = 16.5m^3/s

INFLOW I4 DETAILS:
CATCHMENT AREA = 0.06km^2
PEAK 1:200yr FLOW = 0.22m^3/s
PEAK 1:200yr + 20% CC FLOW = 0.27m^3/s
PEAK 1:1000yr FLOW = 0.33m^3/s

INFLOW I3 DETAILS:
CATCHMENT AREA = 0.59km^2
PEAK 1:200yr FLOW = 2.36m^3/s
PEAK 1:200yr + 20% CC FLOW = 2.83m^3/s
PEAK 1:1000yr FLOW = 3.49m^3/s

INFLOW I1a DETAILS:
CATCHMENT AREA = 3.13km^2
PEAK 1:200yr FLOW = 12.53m^3/s
PEAK 1:200yr + 20% CC FLOW = 15.03m^3/s
PEAK 1:1000yr FLOW = 18.51m^3/s

INFLOW I1b DETAILS:
CATCHMENT AREA = 0.54km^2
PEAK 1:200yr FLOW = 2.16m^3/s
PEAK 1:200yr + 20% CC FLOW = 2.59m^3/s
PEAK 1:1000yr FLOW = 3.19m^3/s

10m STANDOFF FROM L94 PLATFORM TO DIVERTED WATERCOURSE 3. STANDOFF DISTANCE LIKELY TO BE INCREASED TO 15-20m

STEPPED PLATFORM ELEVATIONS

STEPPED PLATFORM ELEVATIONS

EXISTING SUBSTATION

PROPOSED LT94

PROPOSED LT92

EXISTING SGT4

AUCHTERAW BURN DISCHARGES TO RIVER OICH

DOWNSTREAM WATERCOURSE NETWORK BOUNDARY AT TRACK CULVERTS

I1a I1b I2 I3 I4 L M (NEW) D (NEW) J

Waterfall Weir Waterfalls Waterfalls Drain Drain Drain Drain Sheepfold Forestry Nurs Path FB Lundie Cottage Talamh Carraig Auchteraw Hoste Torr Sionnaich Whinhill Auchteraw House Auchteraw Burn River Track Track

0 50 100 150 200 Metres

NOTES

1. CONTOURS GENERATED FROM GETMAPPING 5m AP DERIVED DTM INTEGRATED WITH SLR TOPO SURVEY.

2. LAYOUT AND DETAILS OF PROPOSED WATERCOURSE DIVERSIONS AND NEW WATERCOURSE ARE CONSIDERED INITIAL DESIGN AND SUBJECT TO REFINEMENT AT THE POST PLANNING STAGE.

LEGEND

- SSE LAND OWNERSHIP BOUNDARY
- EXISTING PLATFORM BOUNDARY
- SGT4 PLATFORM EXTENT
- PROPOSED LT92 PLATFORM EXTENT
- PROPOSED LT94 PLATFORM EXTENT
- CULVERT + ID
- WATERWAYS RELEVANT TO STUDY (NOT MODELLED)
- WATERCOURSE 1 - AUCHTERAW BURN (UNCHANGED)
- WATERCOURSE 2 - ALLT NA FEARNA (UNCHANGED)
- WATERCOURSE 3 - REVISED DESIGN
- WATERCOURSE 4 - NEW INTERCEPTION DRAIN
- SITE BUILDING
- MODEL INFLOW LOCATION + ID
- UPSTREAM MODEL BOUNDARY LOCATION
- DOWNSTREAM MODEL BOUNDARY LOCATION
- 1m CONTOUR

SSE

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FORT AUGUSTUS FRA

HYDROLOGICAL MODELLING REPORT

DEVELOPMENT MODEL HYDROLOGICAL OVERVIEW

APP-A-2

Scale 1:5,000 @ A3

Date NOVEMBER 2017

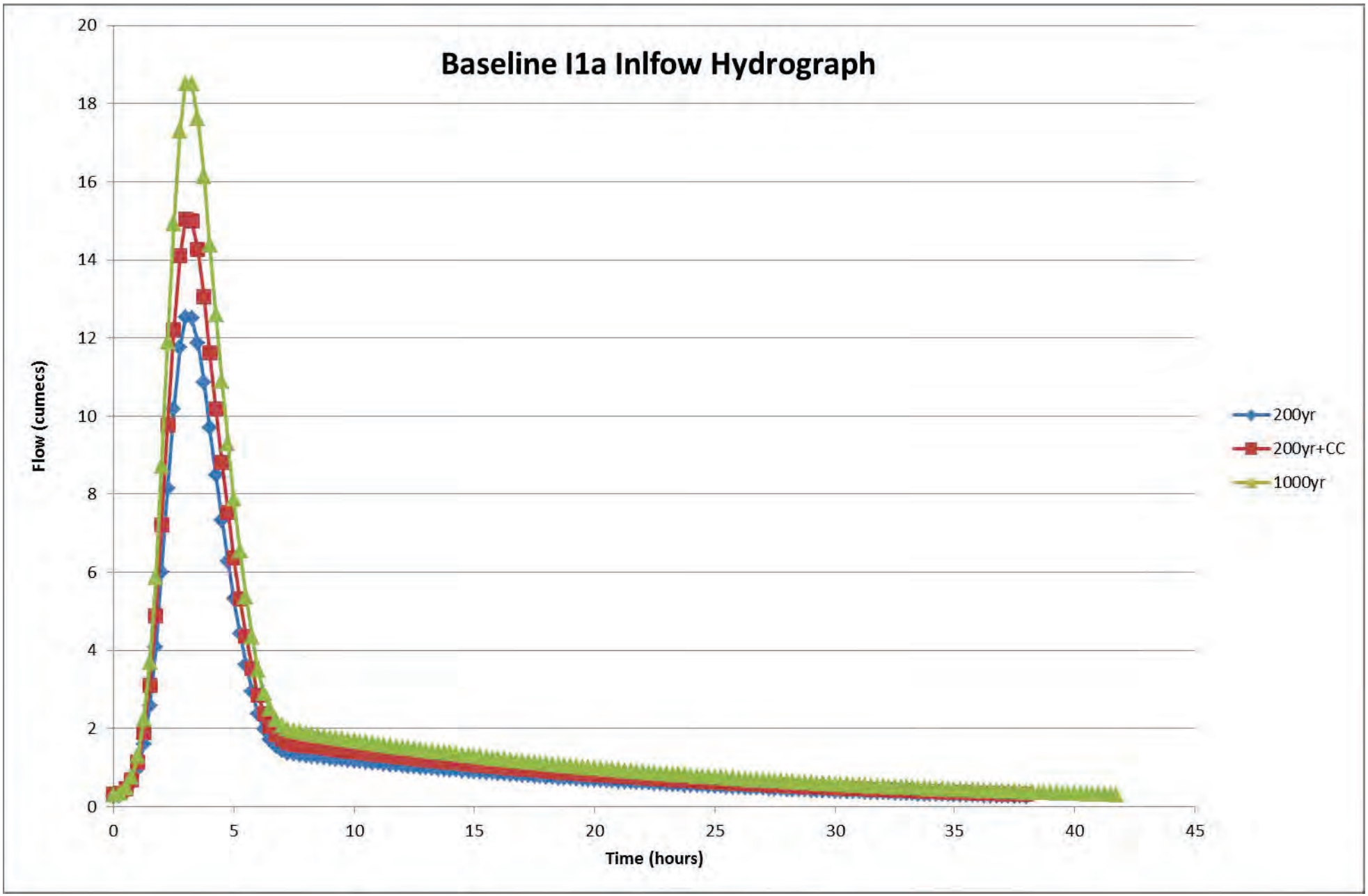
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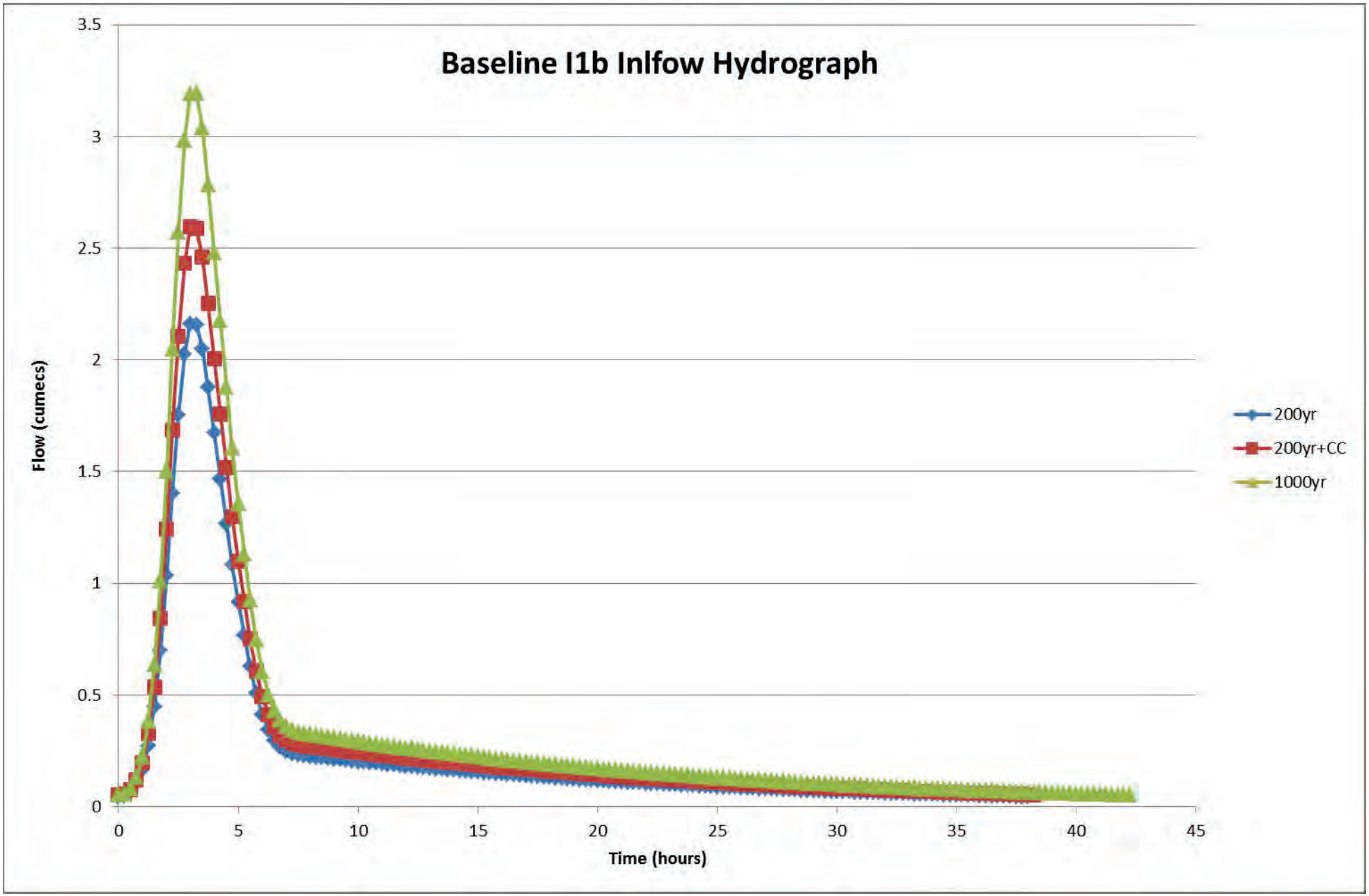
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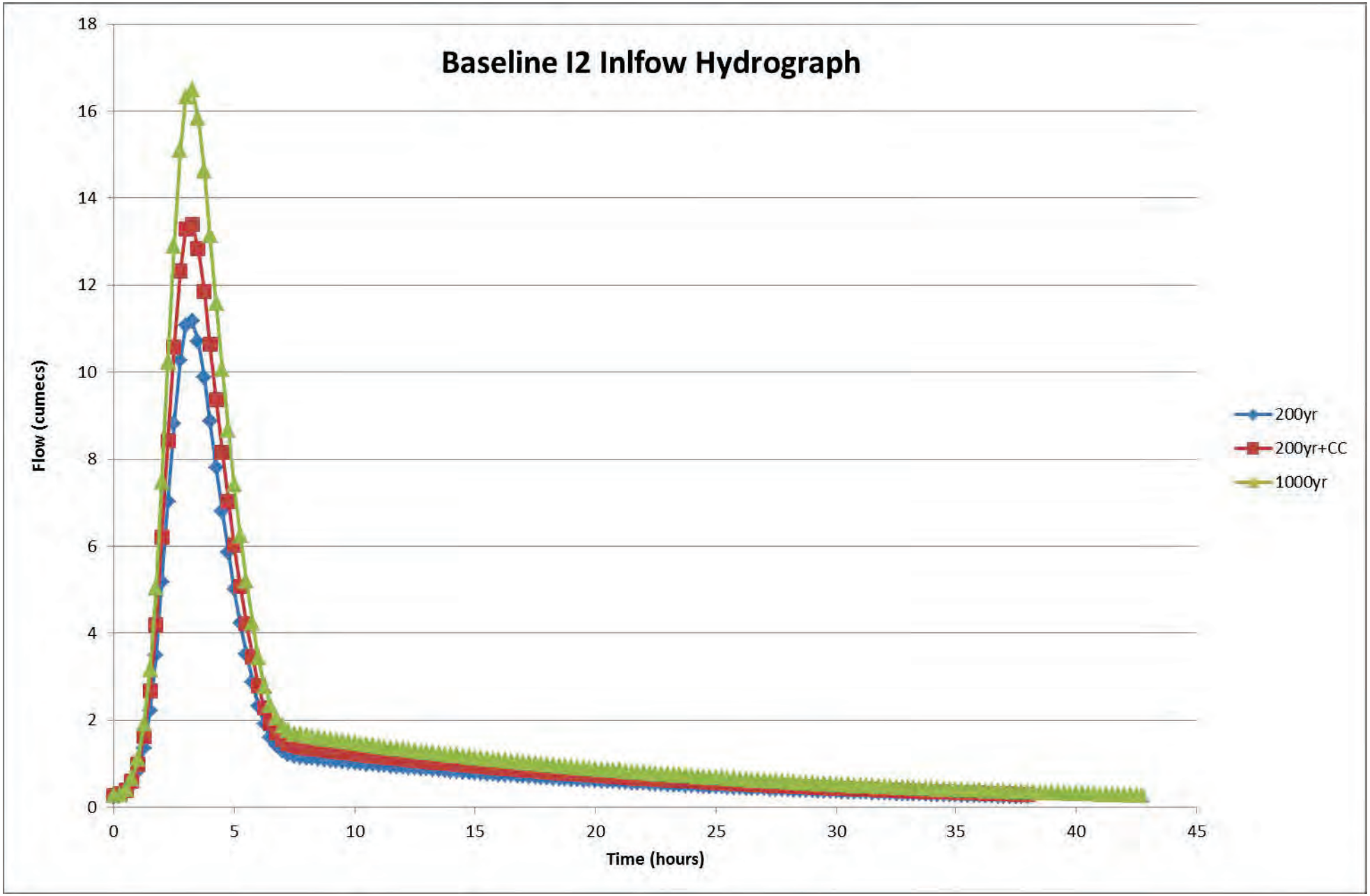
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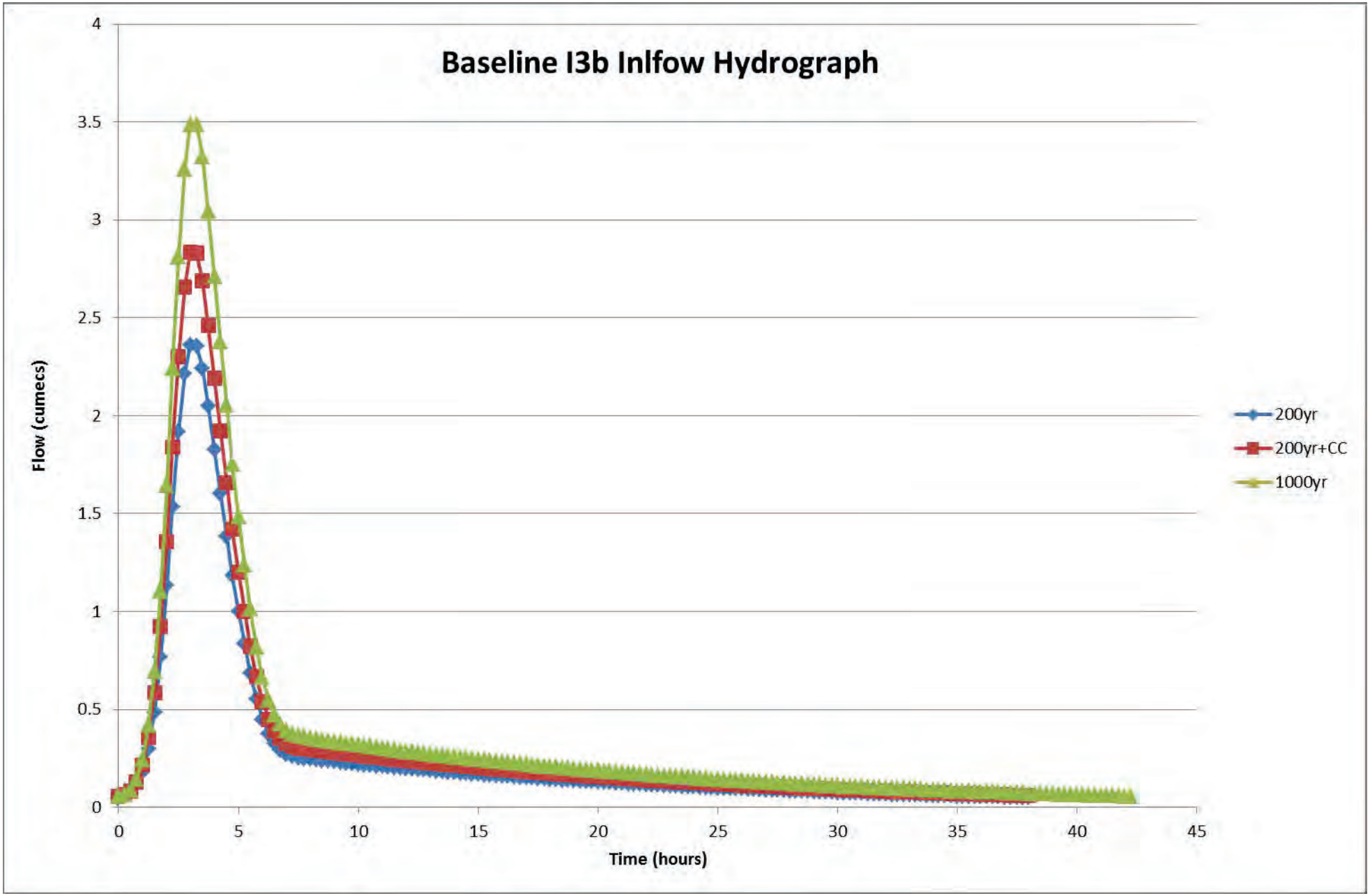
APPENDIX 01

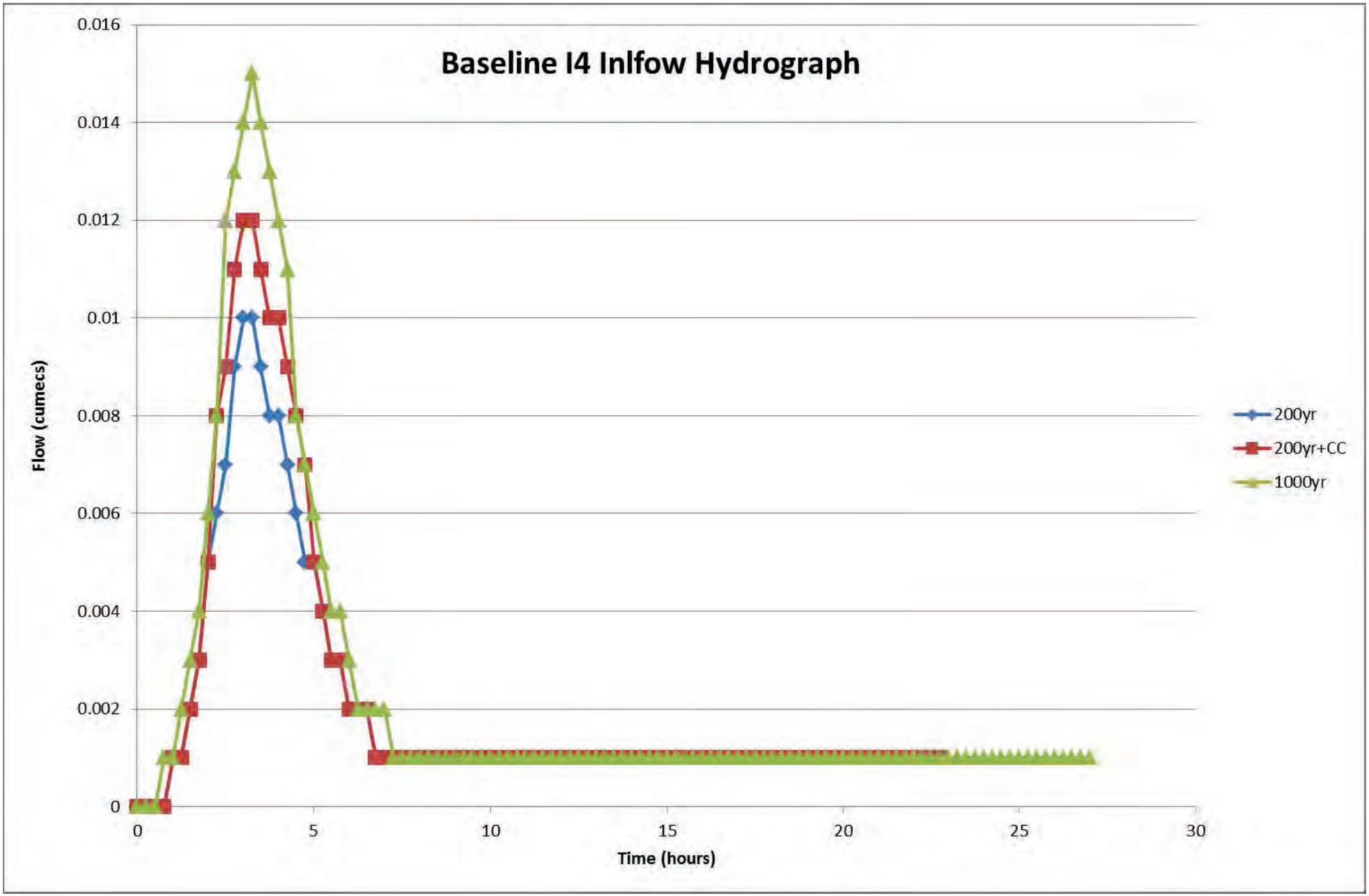
Baseline Model Inflow Hydrographs

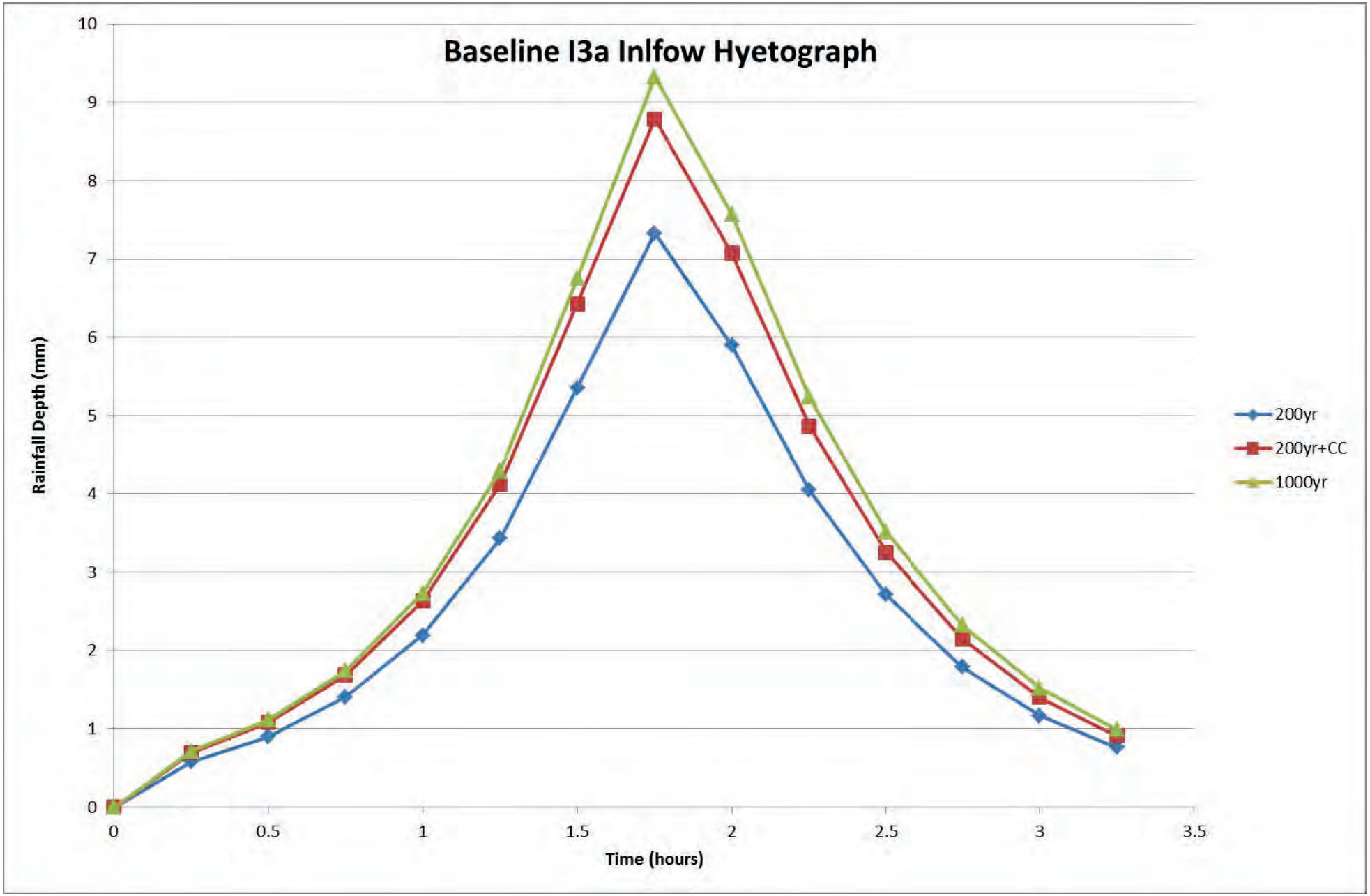

Baseline I1a Inlfow Hydrograph
Flow (cumecs)
Time (hours)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35
40
45
200yr
200yr+CC
1000yr


Baseline I1b Inlfow Hydrograph
Flow (cumecs)
Time (hours)
0
0.5
1
1.5
2
2.5
3
3.5
0
5
10
15
20
25
30
35
40
45
200yr
200yr+CC
1000yr


Baseline I2 Inlfow Hydrograph
Flow (cumecs)
Time (hours)
0
2
4
6
8
10
12
14
16
18
0
5
10
15
20
25
30
35
40
45
200yr
200yr+CC
1000yr

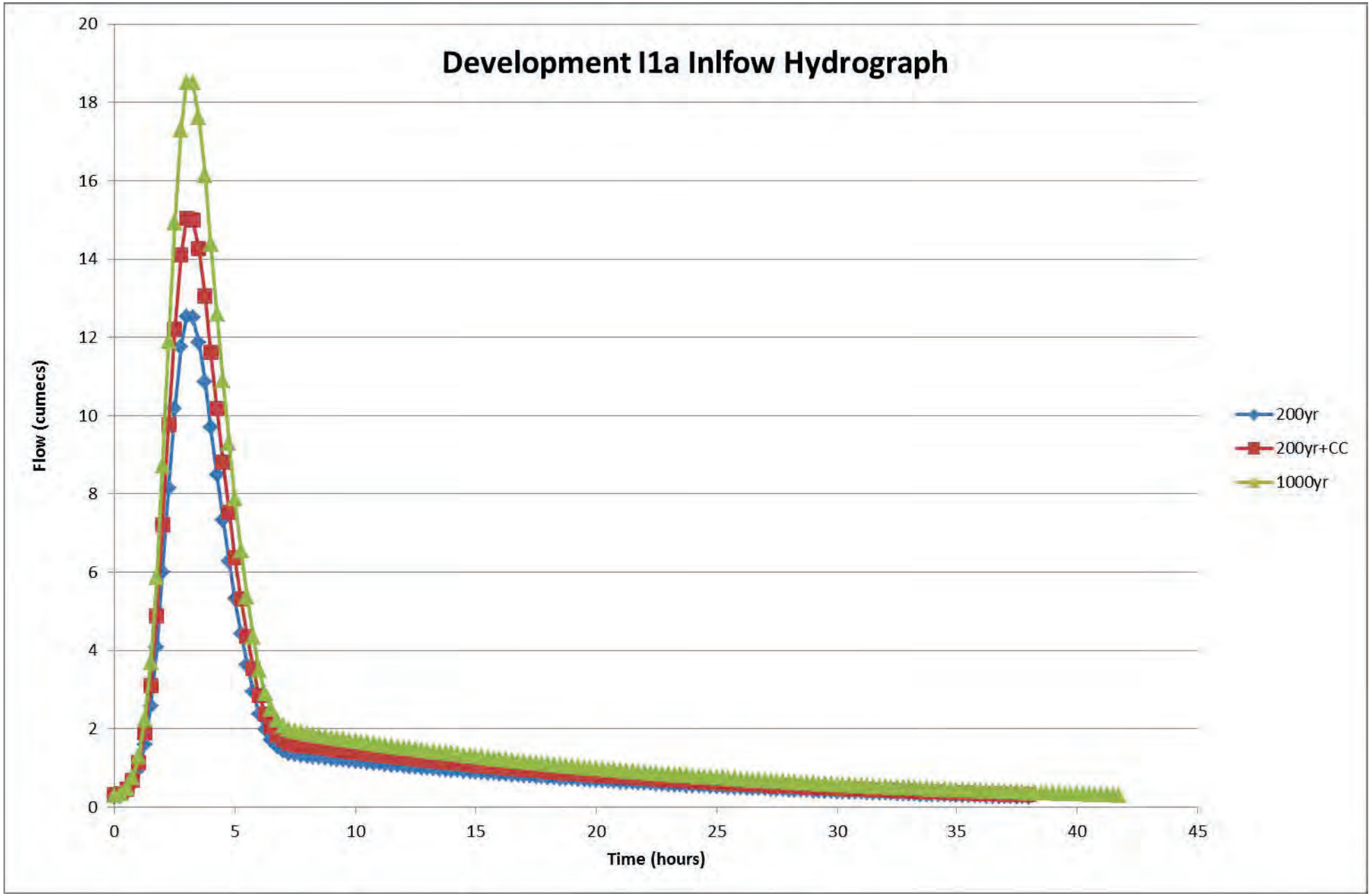

Baseline I3b Inlfow Hydrograph
Flow (cumecs)
Time (hours)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30
35
40
45
200yr
200yr+CC
1000yr

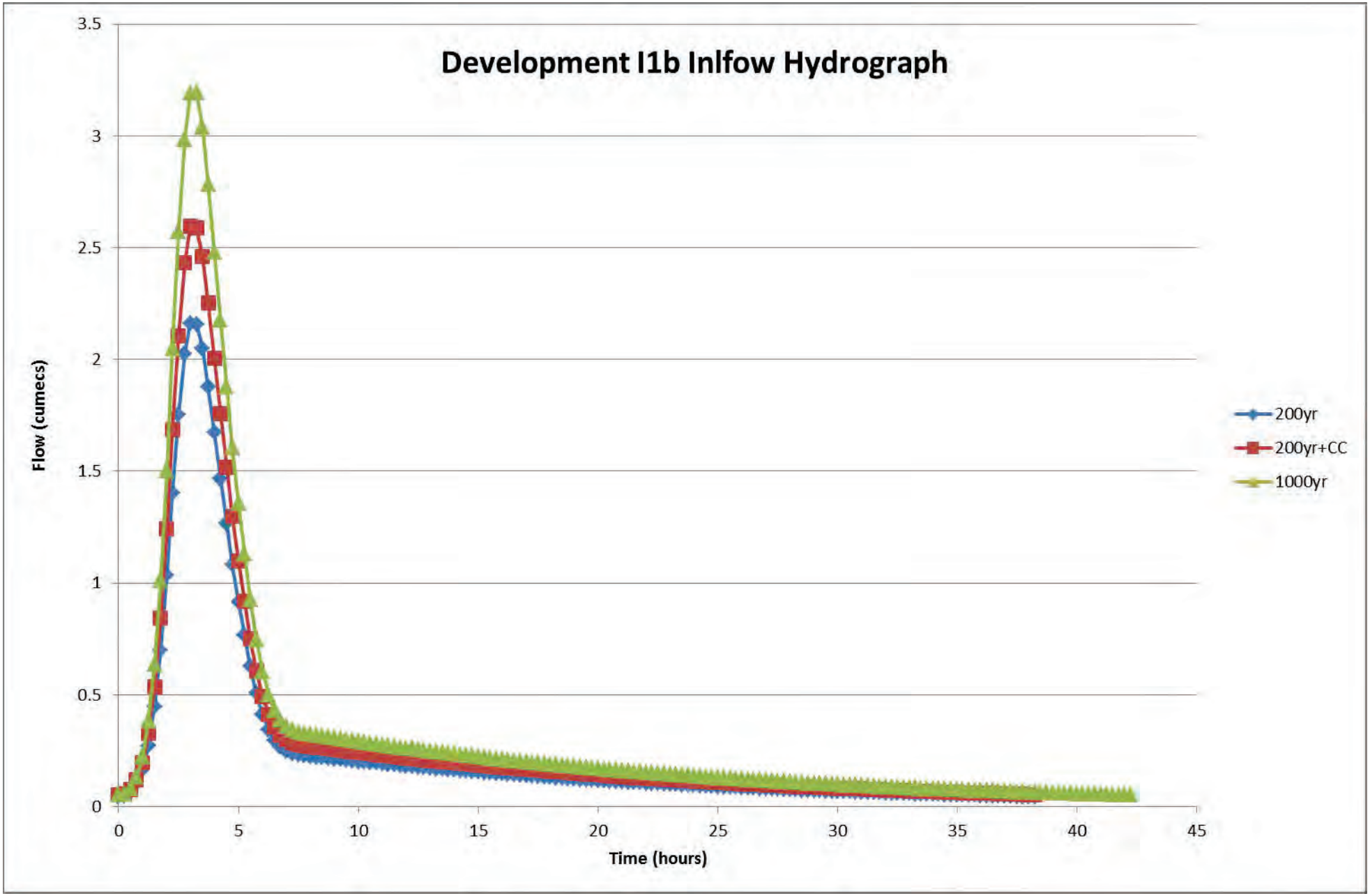

Baseline I4 Inlfow Hydrograph
Flow (cumecs)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
5
10
15
20
25
30
Time (hours)
200yr
200yr+CC
1000yr

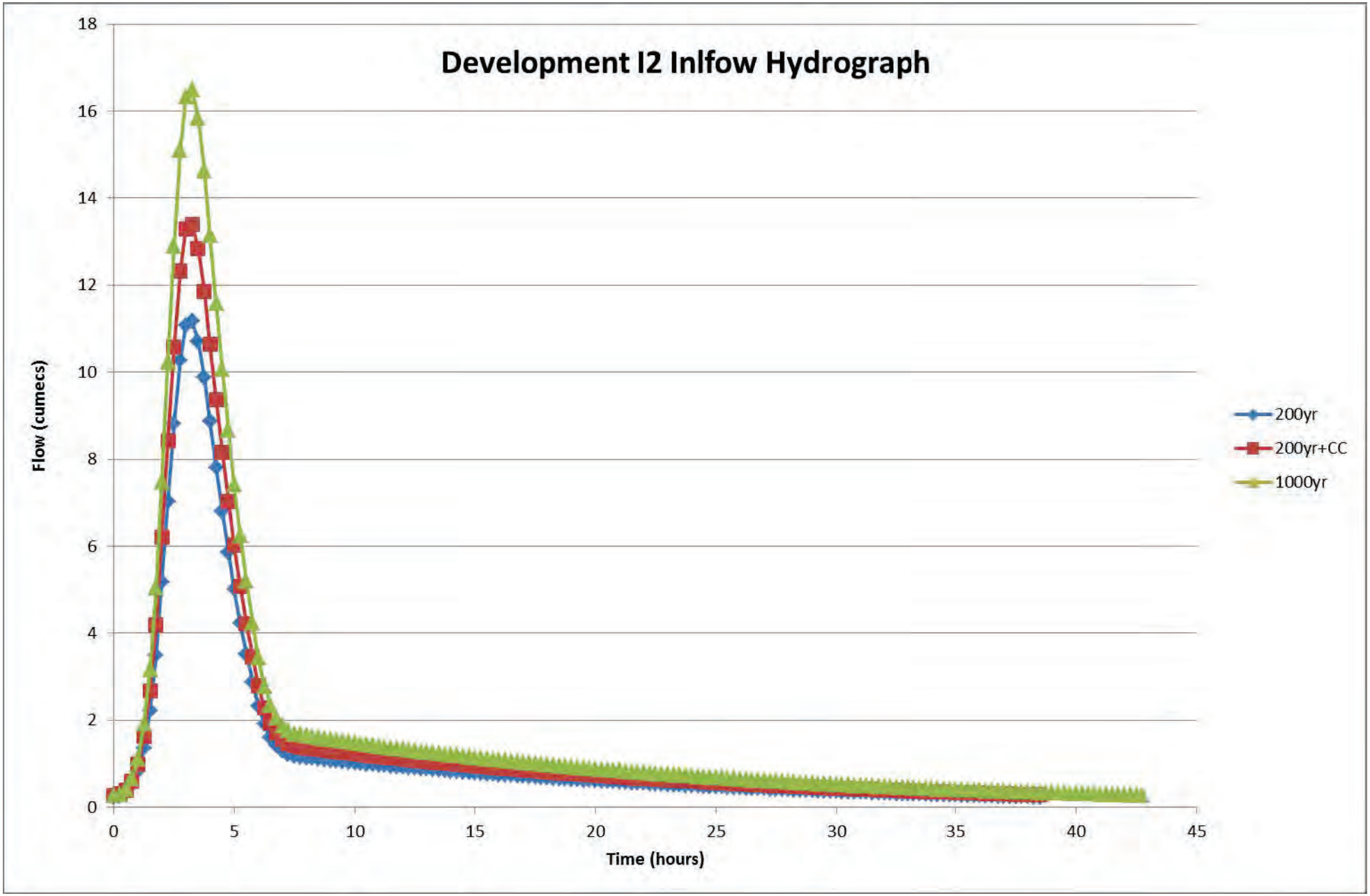

Baseline I3a Inlfow Hyetograph
Rainfall Depth (mm)
Time (hours)
0
1
2
3
4
5
6
7
8
9
10
0
0.5
1
1.5
2
2.5
3
3.5
200yr
200yr+CC
1000yr

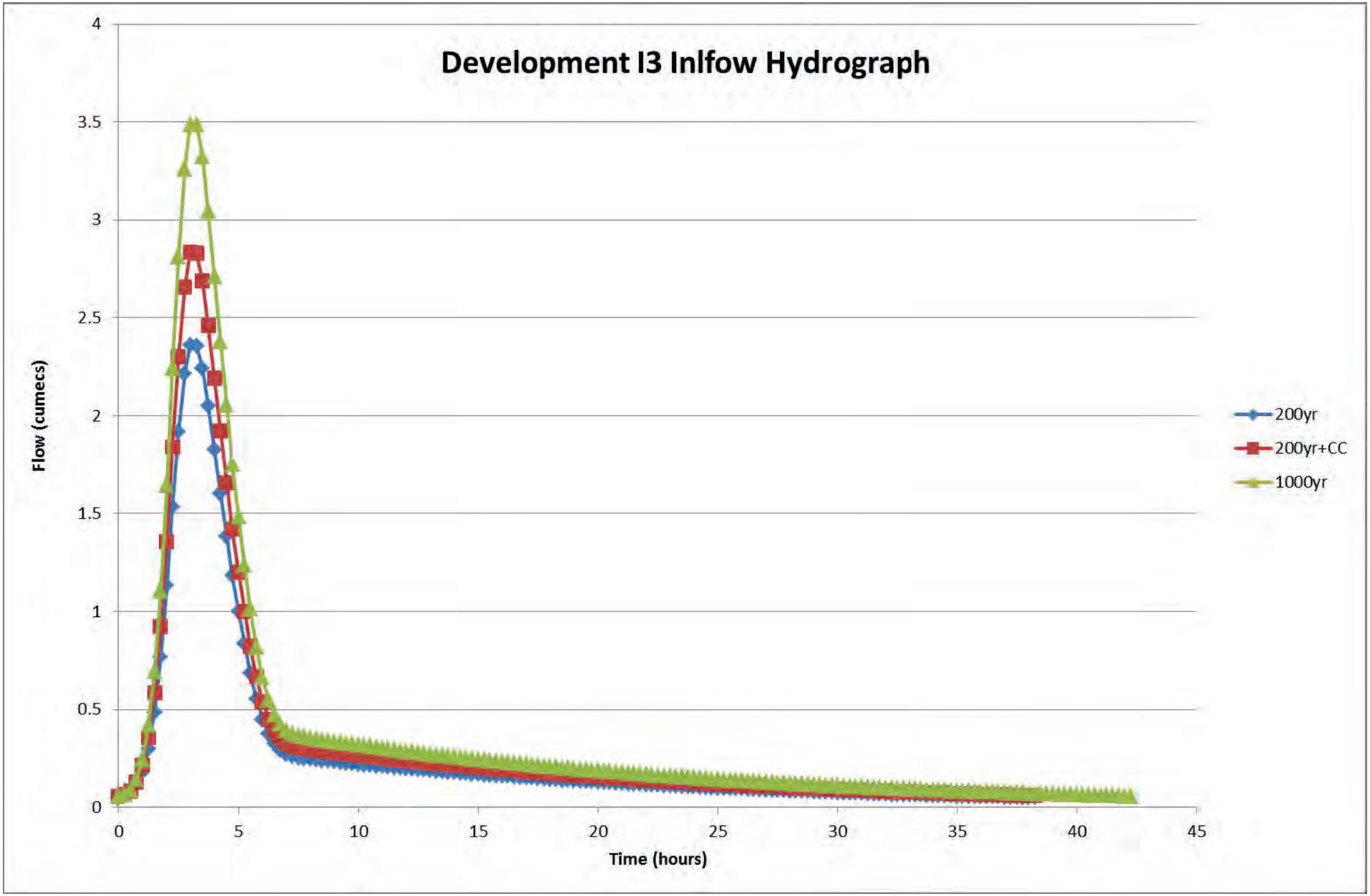
APPENDIX 02

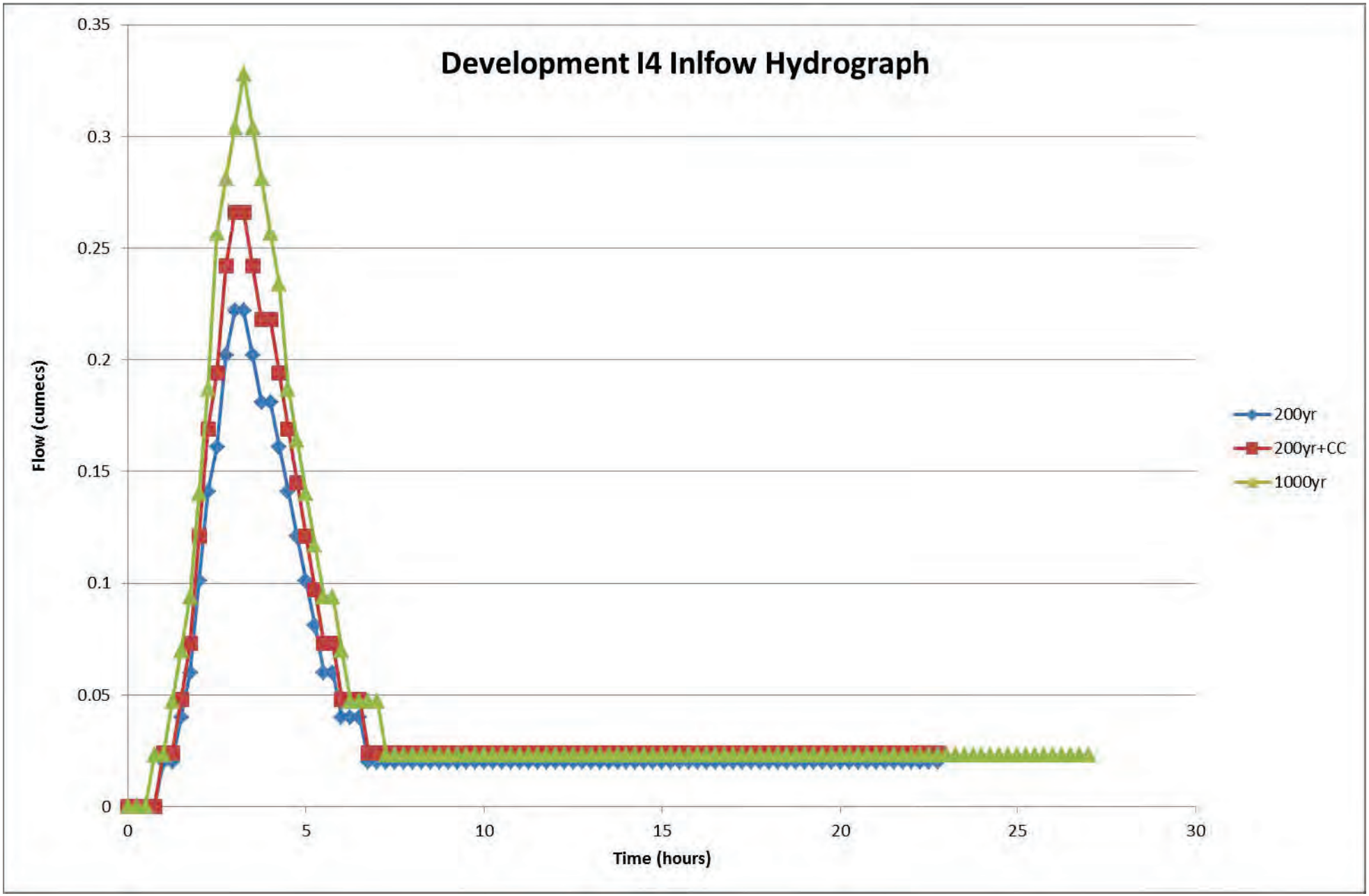
Development Model Inflow Hydrographs


Development I1a Inlfow Hydrograph
Flow (cumecs)
Time (hours)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35
40
45
200yr
200yr+CC
1000yr


Development I1b Inlfow Hydrograph
Flow (cumecs)
Time (hours)
0
0.5
1
1.5
2
2.5
3
3.5
0
5
10
15
20
25
30
35
40
45
200yr
200yr+CC
1000yr


Development I2 Inlfow Hydrograph
Flow (cumecs)
Time (hours)
0
2
4
6
8
10
12
14
16
18
0
5
10
15
20
25
30
35
40
45
200yr
200yr+CC
1000yr


Development I3 Inlfow Hydrograph
Flow (cumecs)
Time (hours)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30
35
40
45
200yr
200yr+CC
1000yr


Development I4 Inlfow Hydrograph
Flow (cumecs)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
Time (hours)
200yr
200yr+CC
1000yr

APPENDIX FRA-B

Hydraulic Modelling Report

FORT AUGUSTUS SUBSTATION AUCHTERAW

Proposed Substation Extension
Platforms LT92 and LT94

APPENDIX FRA-B: Hydraulic Modelling Report

FLOOD RISK ASSESSMENT

Prepared for: Scottish and Southern Energy

SLR Ref: 405.00660.00047
Version No: 2
November 2017

BASIS OF REPORT

This document has been prepared by SLR Consulting Limited with reasonable skill, care and diligence, and taking account of the manpower, timescales and resources devoted to it by agreement with Scottish and Southern Energy (the Client) as part or all of the services it has been appointed by the Client to carry out. It is subject to the terms and conditions of that appointment.

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Drawing No. APP-B-5c: 1,000yr Development Model Output
Drawing No. APP-B-6: Conceptual Flood Compensation Scheme

1.0 Introduction

1.1 Terms of Reference and Objectives

SLR Consulting Ltd (SLR) has been appointed by Scottish and Southern Energy (SSE) to undertake a Flood Risk Assessment (FRA) to support a planning application for the proposed extension of the existing electrical substation facility at Auchteraw, Fort Augustus in the Scottish Highlands.

The proposed substation expansion comprises the construction of 2no. new platforms referred to as LT92 and LT94 which will adjoin to the existing platform boundary.

SEPAs Flood Maps for the Study Site, are produced at an indicative and strategic level scale and only modelled for watercourses with catchment areas >3km^2 and thus fails to capture the potential flood risk posed by the 'minor' watercourses flowing through and adjacent to the development site area.

This document presents the summary Hydraulic Modelling Report (HMR) which forms Appendix FRA-B to the FRA and summarises the construction of a linked 1-Dimensional (1D) 2-Dimensional (2D) hydraulic model of the watercourses in the vicinity of the proposed development area, developed to inform the FRA and detailed site development proposals in the context of fluvial flood risk.

Two separate model scenarios have been considered for the hydraulic model:

- **Baseline** – This assesses the flood risk to the existing platform during a 0.5% and 0.1% Annual Exceedance Probability (AEP) events. The flood risk to the existing platform when allowing for the impact of climate change (+20%) on the 0.5% AEP event has also been assessed.
- **Proposed Development** – assesses the impact of the proposed LT92 and LT94 substation platforms on the flood risk at the development site and elsewhere. Under this scenario, flood mitigation measures, including new / diverted watercourses and culverts have been assessed (without flood compensatory analysis to determine the likely initial compensation requirements to be detailed at the post-planning stage). As for the baseline scenario, the impact of the proposed platforms on flood risk has been assessed during a 0.5% (with and without a +20% allowance for climate change) and 0.1% AEP events.

A diagrammatic overview of the baseline and proposed development scenarios are presented as Drawing No.APP-B-1 and APP-B-2 enclosed.

1.2 Model Selection

A linked 1-Dimensional/2-Dimensional (1D/2D) hydraulic model has been selected to quantify the extent and depth of flooding at the development as it provides a more accurately representation of 'out-of-bank' flows and flood water propagation than a 1D hydraulic model.

The hydraulic model has been constructed using the ESTRY TUFLOW linked hydraulic modelling package. This packaged is distributed by CH2M Hill and is widely used throughout the UK.

The watercourses across the Site along with the structures such a bridges and culverts have been modelled using the 1D hydraulic model package, ESTRY, which is linked to the 2D hydraulic modelling package, TUFLOW. The out-of-bank flood propagation (2D flow) has been simulated using TUFLOW. The 2D TUFLOW computational engine computes flow paths by dividing the floodplain into a grid of individual cells.

The flow of water between cells is then computed repeatedly at regular time-steps by solving the 2D Shallow Wave Equation (Syme, 1991[1]; Huxley, 2004[2] and WBM, 2006[3]) to estimate the spread of flooding. As each cell contains information on the ground level, flood flows can be routed in any direction and will naturally tend to follow the local topography. These models are therefore ideally suited to cope with morphological changes in the floodplain particularly in area with complex flow paths.

2.0 Data Collection

2.1 Overview

The construction of 1D/2D linked hydraulic models requires a number of data sets and parameters which are summarised below:

- Channel topographic cross sections;
- Floodplain topography in the form of a digital terrain model (DTM);
- Hydraulic structures; and
- Roughness (Manning's n).

2.1.1 Channel Topographic Cross Sections

Cross sections of the flood model river channels were surveyed by SLR in separate surveys in 2014 and 2017 - copies of the topographic surveys are enclosed at Appendix FRA-D of the FRA.

Georeferenced levels were taken along cross sections along the watercourses within the extent of the study area shown on Drawing No.APP-B-1. The location of each section was converted to a chainage relative to the left bank of each watercourse. To enable the channel to be accurately represented in the 1D domains, cross sections were specified where a significant change in the river morphology occurred, such as at a change in direction, channel width or channel depth.

It is noted that, due to the dense riperian forestry along a few of the river corridors, some of the cross sections have been interpolated using a combination of upstream and downstream surveyed sections and site observations / measurements.

2.1.2 Floodplain Topography

As no aerial photogrammetry data (LiDAR) is available for the Study Site, a Digital Terrain Model (DTM) of the study area has been generated from an amalgamation of 5m DTM grid resolution, the highest grid resolution available for the area at the time of writing, and the 2014 and 2017 topographic surveys.

2.1.3 Structures

There are a number of structures (i.e. culverts) along watercourses relevant to the assessment and these have been explicitly represented within the 1D model. The structural details of the culverts and bridges which are required for 1D modelling were collected during the 2014 and 2017 surveys. These include invert levels, soffit

[1] Syme, W. J., 1991. *Dynamically linked two dimensional / one dimensional hydrodynamic modelling program for rivers, estuaries and coastal waters*, Masters Thesis, Department of Civil Engineering, The University of Queensland
[2] Huxley, C.D. 2004. *TUFLOW Testing and Validation*, Undergraduate Thesis for Bachelor of Engineering in Environmental Engineering, School of Environmental Engineering, Griffith University, June 2004
[3] WBM Oceanics, 2006. *TUFLOW user manual: GIS Based 2D/1D Hydrodynamic Modelling*, WBM Oceanics Australia

levels, culvert diameters, type of structure, condition and blockage percentage, along with the length and width of each structure.

2.1.4 Roughness (Manning' n)

Channel and floodplain roughness was represented within the model by Manning's n coefficients. Values are based upon those published within texts such as Chow (1959) by comparison with site observations and photographs of the river and floodplain taken during the topographic surveys.

3.0 Baseline Model

3.1 Software Version

The TUFLOW model was constructed using the TUFLOW.2016-03-AE-w64 version of the software which was the latest model version at the start of the project.

3.2 Grid Size and Timestep

The 2D domain was constructed with a 1m grid which was considered an appropriate grid size, being less that the width of the narrowest cross section (some 1.7m). The top of bank on either side of the watercourses are therefore explicitly captured by separate cells resulting in an effective estimate of the exchange of water between the 1D and 2D interface.

In accordance with best practice, the timestep used for the 2D element of the model should be between $^1/_5$ and $^1/_2$ of the grid size while the timestep for the 1D element of the model should be set at $^1/_2$ the timestep of the 2D element. As such, a 0.2 second timestep has been used for the 2D element and 0.1 second for the 1D element.

3.3 Model Extents

The extent of watercourses pertinent to the Baseline modelling scenario is outlined on Drawing No.APP-B-1.

The 2D model extent extends to the edge of River Oich in the south and across the flat forested land to the east of the Site. This allows for the natural propagation of the 2D flows across this area which will then follow the local topography gradually towards the River Oich.

The 2D boundary is set along the 26.0m Above Ordnance Datum (AOD) contour parallel to the River Oich which is identified as the 1,000yr floodplain extent on SEPAs Indicative Flood Map[4].

3.4 Hydraulic Boundaries

Hydraulic boundaries were selected to be located a minimum of approximately 100m from the existing and proposed platforms such that hydraulic features likely to impact flood mechanism at the platforms are explicitly represented and accounted for.

[4] Scottish Environment Protection Agency (2017) Online Interactive Flood Map Tool, available at: http://map.sepa.org.uk/floodmap/map.htm (accessed 5th November 2017).

3.4.1 Upstream Boundary

The hydrological inputs mark the upstream boundaries for each modelled watercourse extent. These are all represented as hydrographs with the exception of Inflow I3a for the baseline scenario which is represented as an inflow Hyetograph as discussed at Section 2.5 of the Hydrology Report, enclosed as Appendix FRA-A of the FRA.

The upstream boundaries are located where possible at constraints in the 1D domain, i.e. culverts and are shown on Drawing No.APP-B-1 for the baseline modelling scenario.

3.4.2 Downstream Boundary

The 1D model outflow boundary condition is governed by the outflow capacity of 3no. circular corrugated steel culverts on the Auchteraw Burn (Watercourse 1), which are located approximately 550m southeast of the proposed development area. Thus a total combined rating curve has been derived by applying Manning's principles of pipe flow. Refer to Section 3.0 of the Hydrological Modelling Report contained as Appendix FRA-A to the FRA for further details.

A 2D outflow boundary has also been applied along the River Oich at 26.0mAOD, the downstream extent of the 2D domain, and allows flood water to dissipate beyond the model extent and prevents 'glass walling' effects and an overestimate of flood depth.

A rating curve has also been for the 2D downstream boundary albeit generated automatically by TUFLOW based on gradient perpendicular to the boundary of 0.0833.

3.5 Cross Sections

The georeferenced cross sections of the watercourses across the study site surveyed by SLR were used to build the 1D channel cross sections. Cross sections were trimmed to the left and right top of bank so that the edge of the 1D domain could be limited to the watercourses and out-of-bank flow solely represented within the 2D model element.

3.6 Structures

The location of the 1D structures in the baseline scenario are shown on Drawing No. APP-B-1 and Table 3-1 below contains the surveyed details included within the 1D model.

Blockages of culverts have been estimated from site observations and photographs taken during the 2014 and 2017 SLR site surveys.

Table 3-1
Baseline Scenario: Culvert / Structure Details

Structure ID	Type	Dimensions	Material	% Blocked	Condition	Manning's *n* Value	Length (m)
A	Circular Culvert	300mm ø	PVC	80%	OK	0.015	48.944
B	Rectangular Culvert	W= 0.55m H = 0.275m	PVC	10%	OK	0.015	3.541
C	Circular Culvert	275mm ø	PVC	0%	OK	0.015	0.405
D	Circular Culvert	600mm ø	Corrugated	0%	Moderately	0.024	15.181

Structure ID	Type	Dimensions	Material	% Blocked	Condition	Manning's *n* Value	Length (m)
			Steel		deteriorated		
E	Circular Culvert	600mm ø	PVC	50%	Moderately deteriorated	0.013	6.916
F	Circular Culvert	275mm ø	Corrugated Steel	80%	Unknown (due to blockage)	0.024	56.004
G	Circular Culvert	350mm ø	PVC	0%	OK	0.015	25.200
H	Circular Culvert	500mm ø	PVC	0%	OK	0.015	177.063
I	Open Span Rectangular Bridge	W= 2.248m H= 1.24m	Concrete	0%	OK	0.02	2.687
J	Open Span Rectangular Bridge	W= 4.078m H = 1.78m	Concrete	0%	OK	0.02	5.838
K	Circular Culvert	450mm ø	PVC	0%	OK	0.015	15.883
L	Circular Culvert	500mm ø	Steel	0%	OK	0.015	9.307
M	Twin Circular Culvert	2 x 375mm ø	Concrete	0%	OK	0.015	4.193

3.7 Manning's n Values

The Manning's n values in 1D and 2D domains are based on published values set out in Chow (1959). 1D Manning's n values have been based on site observation and photographs of the river and floodplain taken during the site surveys. Along reaches containing dense overgrown vegetation / timber debris within the watercourses, the 1D Manning's n values were increased to 0.1 which represents significant hydraulic constraint.

The 2D Manning's n values have been allocated using satellite images / site observations of the site to ascertain the land use. Table 3-2 below summarises the different Manning's n values to different land uses across the study site.

Table 3-2
2D Manning's n Values

Manning's 'n' Value	Land use
0.1	Default global (Floodplain - Trees - Heavy stand of timber)
0.038	Roads
0.2	Buildings
0.035	Inland Water
0.08	Wood
0.03	Pasture

3.8 Existing Substation Platforms and Buildings

The current substation platform have been explicitly represented in the DTM for both the baseline and proposed development scenarios. Ground levels along the north western boundary of the existing platform are around 42-42.5mAOD and gently fall to approximately 41-41.5m AOD at the south eastern boundary. The SGT4 platform (Constructed in 2015) is located at 39.8mAOD as recommended within the FRA completed by SLR in 2014, undertaken to advise the finished platform level.

The buildings in the northern end of the existing platforms have been assigned increased elevations to exclude 2D flows across the footprint of these buildings and represent site conditions during a flood event i.e. flows are diverted around the buildings as would be expected based on site observations.

3.9 ESTRY/TUFLOW Interface

The 1D and 2D elements of the model have been linked along the top of banks using HX lines. The left and right hand top of bank lines have been allocated elevations to allow for the correct interaction between the 1D and 2D domains. These elevations are extracted from the right and left hand top of bank points of the 1D cross sections.

4.0 Proposed Development Model

4.1 Hydraulic Boundaries

As discussed at Section 2.5 of the Hydrology Report, the hyetograph for catchment 3I(a) has removed and a point inflow, applied as a hydrograph at I4, has been adopted for Watercourse 4. This is a conservative approach as it is inputting the entire downstream catchment at the beginning of the watercourse.

All other upstream model boundaries remain the same as the Baseline Model scenario.

Similarly the downstream model boundary remains the same as the Baseline Model scenario.

Model boundaries are for the Development Model are depicted on Drawing No.APP-B-2.

4.2 Cross Sections and Structures

Drawing No.APP-B-3 outlines the new watercourse section details (initial designs) for the proposed development scenario however, a summary of the key alterations to the baseline model is provided below and an overview depicted in plan on Drawing No.APP-B-3:

- The existing (under capacity) circular **Culvert D** is replaced with a new box culvert with dimensions 4.5m (wide) x 1.5m (high) to have sufficient capacity to convey the design 0.1% AEP flow.
- Existing (undersized) **Culvert M** will be replaced with new box culvert dimensions 3.3m (wide) x 1.2m (high) to have sufficient capacity to convey the 0.1% AEP flow.
- Existing **Culvert H**, outflow Filter Trench / Soakaway and perimeter section of Watercourse 3 (along northwest boundary of existing substation platform) to be made redundant (can be maintained on site however will have limited functionality).
- **Watercourse 3** between point Inflow I3 and Culvert L to be upsized to contain the design 0.1% AEP flow and has a 1m high embankment along the right hand bank.
- **Watercourse 3** from new Culvert D is diverted around eastern edge of the proposed LT94 platform. However, the location of the confluence of Watercourse 3 and Watercourse 1 (Auchteraw Burn) for the

baseline scenario has been retained. The diverted watercourse has an increased capacity compared to existing and has a 1m high embankment along the right hand bank to protect LT94.

- **Watercourse 3** between Culvert D and Culvert M to be re-profiled and upsized to contain the design 0.1% AEP flow.
- Introduction of new 'interception' drain (**Watercourse 4**) upslope of the current perimeter section of Watercourse 3 (along northwest boundary of existing substation platform) to contain the design 0.1% AEP flow. This acts as effective interception and storage of runoff / fluvial flows from small catchment between Watercourse 3 further up-gradient and the existing substation. The new Watercourse 4 discharges at a new confluence with Watercourse 3 immediately upstream of the new box Culvert D. Watercourse 4 also has a 1m bund on downstream side

Table 4-1 below provides an overview of New and Revised structures / culverts proposed for the Development Model.

Table 4-1
Proposed Development Model: Culvert / Structure Details

Structure ID	Type	Dimensions	Material	Manning's *n* Value	Length (m)
D (New)	Rectangular Culvert	W= 4.5m H= 1.5m	Concrete	0.024	32.032
I	Open Span Rectangular Bridge	W= 2.248m H= 1.24m	Concrete	0.02	2.687
J	Open Span Rectangular Bridge	W= 4.078m H = 1.78m	Concrete	0.02	5.838
L	Circular Culvert	500mm ø	Concrete	0.015	9.307
M (New)	Rectangular Culvert	W= 3.3m H= 1.2m	Concrete	0.015	4.193

5.0 Model Results

Discussion in flood risk planning terms for the flood modelling results is presented within the FRA and thus the following sections outline and briefly discuss the salient model results.

5.1 Baseline Model

Drawing No's.APP-B-5a, 5b and 5c enclosed present the mapped flood model outputs for the 0.5% AEP, 0.5% AEP + 20% Climate Change (CC) and 0.1% AEP events for the Baseline Model.

Tables 5-1 and 5-2 below present the Baseline 1D and 2D model outflows (Peak Flow and Cumulative Volume) for the 3no. AEP events.

Table 5-1
Baseline 1D Model: Outflow Summary

AEP Event (%)	1D Peak Model Outflow (m^3/s)	1D Cumulative Outflow Volume (m^3)
0.5	6.031	148233.2

AEP Event (%)	1D Peak Model Outflow (m^3/s)	1D Cumulative Outflow Volume (m^3)
0.5 + 20% CC	6.031	150158.0
0.1	6.031	150980.7

Table 5-2
Baseline 2D Model: Outflow Summary

AEP Event (%)	2D Peak Model Outflow (m^3/s)	2D Cumulative Outflow Volume (m^3)
0.5	46.1	493514.3
0.5 + 20% CC	58.0	607047.8
0.1	73.0	774042.3

The above tabulated Baseline Model outflow results demonstrate that the 1D model outflow is significantly less than the 2D model outflow which given the extended floodplain propagation towards the 2D downstream boundary at the River Oich is expected.

The 1D model outflow is limited to the capacity of the 1D downstream boundary culverts as discussed in Section 3.4.2 and thus levels out at 6.031m^3/s (refer to Section 3.0 of Appendix FRA-A for further details).

5.2 Development Model

Drawing No's.APP-B-6a, 6b and 6c enclosed present the mapped flood model outputs for the 0.5% AEP, 0.5% AEP + 20% Climate Change (CC) and 0.1% AEP events for the proposed Development Model (without flood compensation).

Tables 5-3 and 5-4 below present the Development 1D and 2D model outflows (Peak Flow and Cumulative Volume) for the 3no. AEP events.

Table 5-3
Development 1D Model: Outflow Summary

AEP Event (%)	1D Peak Model Outflow (m^3/s)	1D Cumulative Outflow Volume (m^3)
0.5	6.031	152329.7
0.5 + 20% CC	6.031	154154.9
0.1	6.031	154887.8

Table 5-4
Development 2D Model: Outflow Summary

AEP Event (%)	2D Peak Model Outflow (m^3/s)	2D Cumulative Outflow Volume (m^3)
0.5	50.7	534348.4
0.5 + 20% CC	62.3	668238.4
0.1	80.6	847735.4

As per the Baseline Model results the 1D model outflow is significantly less than the 2D model outflow for the same reasons described above.

5.3 Baseline $_v$ Development Model Results and Flood Compensation

Table 5-5 below compares the combined 1D/2D Baseline $_v$ Development Model outflow results for Peak Flow and Cumulative Volume.

Table 5-5
Combined 1D/2D Outflow: Baseline $_v$ Development Model Comparison

AEP Event (%)	Baseline Model Results		Development Model Results	
	1D / 2D Combined Peak Model Outflow (m^3/s)	1D / 2D Combined Cumulative Outflow Volume (m^3)	1D / 2D Combined Peak Model Outflow (m^3/s)	1D / 2D Combined Cumulative Outflow Volume (m^3)
0.5	52.1	641747.5	56.7	686678.1
0.5 + 20% CC	70.0	757205.8	68.9	822393.2
0.1	79.1	925023.0	86.6	1002623.0

The results above (and as evident on Drawing No's.APP-B-6a, 6b and 6c) indicates that implementation of the Development Model increases the flood risk downstream if unmitigated.

Scottish Planning Policy (SPP) and SEPA's Technical Flood Risk Guidance dictates that a 'neutral or better' impact in terms of flood risk should be achieved to enable the proposed development to satisfy policy requirements and is pertinent to the 0.5% AEP event.

Therefore a formal Flood Compensation Scheme is required to be incorporated into Development Model to offset the increased flood risk offsite by the proposed development for the 0.5% AEP event. The results comparison above for this AEP event suggests that **c.45,000m^3** of additional floodplain storage is required to be provided within SSEs Land Ownership Boundary and the peak outflow at the combined 1D / 2D downstream boundary needs to be reduced by **4.6m^3/s** to have a 'neutral' impact on flood risk downstream.

As such Drawing No.APP-B-7 enclosed presents an overview of the initially proposed Flood Compensation Scheme which demonstrates there are sufficient means, volume and land to implement a working solution to mitigate the increased flood risk downstream as a result of the proposed development.

The initial proposal is for a flood storage bund (engineered earth and landscaped) to be elevated at a maximum of 39.2mAOD along the southern and part of the eastern SSE Land boundary to contain the additional floodplain displacement (and offset the peak outflow too) from the Baseline $_v$ Development model scenarios.

The conceptual compensation scheme confirms that c.110,000m^3 of residual storage is available at 39.2mAOD storage elevation and only c.45,000m^3 is required. The minimum bund elevation required to provide the 45,000m^3 of flood attenuation is calculated to be approximately 38.6mAOD.

In addition to this the increased peak model outflow needs to be offset by 4.6m^3/s via the inclusion of hydraulic throttles on the downstream end of Watercourse 3 (just before the confluence with the Auchteraw Burn – Watercourse 1) and Watercourse 2 immediately east of the LT94 platform at the kink in the land boundary.

A lateral weir on Watercourse 1 in the southwest corner of SSEs land boundary will also encourage floodwater within the storage area for attenuation (if required).

Clearly the final detailing / analysis and modelling of the flood compensation scheme would be undertaken at the post planning stage when there is an agreed scheme between SSE and all interested parties / stakeholders, however at this planning stage the initial analysis presented demonstrates that there is sufficient land within SSEs ownership and the means to offset the increased 0.5% AEP cumulative flood volume / peak flow as a result of the proposed LT92 and LT94 platform developments, the need to protect the existing substation platforms and the resulting proposed flood management strategy.

6.0 Conclusions

This document presents the summary Hydraulic Modelling Report (HMR) which forms Appendix FRA-B to the Flood Risk Assessment (FRA) report and summarises the construction of a linked 1-Dimensional (1D) 2-Dimensional (2D) hydraulic model of the watercourses in the vicinity of the proposed development area, developed to inform the FRA and detailed site development proposals in the context of flood risk.

This report provides relevant information concerned with the flood model construction / basis and associated design details.

The FRA report should be referred to for planning related flood risk requirements and Appendix FRA-A for the derivation of the hydraulic model Hydrological inputs.