Appendix 11

Supporting Chapter 11 – Road Drainage and the Water Environment

Appendix 11.1 – Water Quality Assessment

Appendix 11.2 – Dean Burn Diversion Hydromorphology Design Technical Note

Appendix 11.3 – Flood Risk Assessment

Appendix 11.4 – WFD Water Classification

Appendix 11.5 – Hydrogeological Assessment Technical Note

Appendix 11.1 – Water Quality Assessment

Serious Spillage Risk calculations

Catchment 1

The runoff from this section will be discharged to ***********

P_{INC} = The probability of a spillage with an associated risk of a serious pollution incident occurring
P_{SPL} = Annual probability of a spillage with the potential to cause a serious spillage incident
P_{POL} = The probability, given a spillage, that a serious pollution incident will result (based on sensitivity of watercourse and emergency services response time).
RL = Road length in kilometres
SS = Serious Spillage Rates
AADT = Annual Average Daily Traffic (using Design Year 2031)
%HGV = Percentage of Heavy Goods Vehicles

Road Lengths (RL) Comprise

Normal Road (Rural All Purpose)
NOTE : Road more than 100m from Roundabout, Slip Road and Side Road

Road within 100m of Roundabout
Road within 100m of Side Road
Road within 100m of Slip Road

Link	AADT	Road Description	Total Length (m)	Roundabout (m)	Side road (m)	Slip Road (m)	Normal (m)	HGV %
449z/480	11548	side	576.24	100	476.24			7.8
460z/461z	7737	slip	356.1	100		256.1		5.9
436z/437z	21169	main	890			200	690	11.2
438z/439z	19655	main	812			200	612	11
466z/474	6560	slip	276.5	100		176.5		4.6
333/451z	13705	side	279.6	100	179.6			4.8
442z/443z	16730	side	148.92	100	48.92			7.2
453z/454z	8216	slip	510.2	100		410.2		6.9
458z/459z	8118	slip	492.1	100		392.1		6.3
445z/446z	16382	side	333.71	100	233.71			6.4
467ze/477	22765	roundabout	400.2	400.2				6.8
5/435z	21171	main	226			100	126	11.2
440z/29	27870	main	239			100	139	9.8

Percentage HGVs	variable	%
Emergency Response time	<20	minutes
Probability of serious pollution incident occurring (P_{POL}) SW	0.45	
Probability of serious pollution incident occurring (P_{POL}) GW	0.3	

(DMRB Volume 11, Section 3, Part 10, Table D.1.2)

Serious Spillage Rates (SS): -
(DMRB Volume 11, Section 3, Part 10, Table D.1.1)

Normal Road (Urban All Purpose)	-	0.31	per Billion HGV km/year
Road within 100m of Roundabout	-	5.35	per Billion HGV km/year
Road within 100m of Side Road	-	1.81	per Billion HGV km/year
Road within 100m of Slip Road	-	0.36	per Billion HGV km/year

Calculation of Spillage Risk

a) Probability of serious accidental spillage (Pspl) is given by: -

$$P_{spl} = RL \times SS \times (ADDT \times 365 \times 10^{-9}) \times (HGV\%/100)$$

Link 449z/480

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 11548 x (365x10^{-9}) x (7.8 / 100) = 0
Roundabout
P_{spl} = 0.1 x 5.35 x 11548 x (365x10^{-9}) x (7.8 / 100) = 0.0001759
Side Road
P_{spl} = 0.47624 x 1.81 x 11548 x (365x10^{-9}) x (7.8 / 100) = 0.0002834
Slip Road
P_{spl} = 0 x 0.36 x 11548 x (365x10^{-9}) x (7.8 / 100) = 0

P_{spl} = 0.0004593

Link 460z/461z

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 7737 x (365x10^{-9}) x (5.9 / 100) = 0
Roundabout
P_{spl} = 0.1 x 5.35 x 7737 x (365x10^{-9}) x (5.9 / 100) = 8.914E-05
Side Road
P_{spl} = 0 x 1.81 x 7737 x (365x10^{-9}) x (5.9 / 100) = 0
Slip Road
P_{spl} = 0.2561 x 0.36 x 7737 x (365x10^{-9}) x (5.9 / 100) = 1.536E-05

P_{spl} = 0.0001045

Link 436z/437z

Normal road RL SS AADT
P_{spl} = 0.69 x 0.31 x 21169 x (365x10^{-9}) x (11.2 / 100) = 0.0001851
Roundabout
P_{spl} = 0 x 5.35 x 21169 x (365x10^{-9}) x (11.2 / 100) = 0
Side Road
P_{spl} = 0 x 1.81 x 21169 x (365x10^{-9}) x (11.2 / 100) = 0
Slip Road
P_{spl} = 0.2 x 0.36 x 21169 x (365x10^{-9}) x (11.2 / 100) = 6.231E-05

P_{spl} = 0.0002474

Link 445z/446z

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 16382 x (365x10^{-9}) x (6.4 / 100) = 0
Roundabout
P_{spl} = 100 x 5.35 x 16382 x (365x10^{-9}) x (6.4 / 100) = 0.2047357
Side Road
P_{spl} = 233.71 x 1.81 x 16382 x (365x10^{-9}) x (6.4 / 100) = 0.1618809
Slip Road
P_{spl} = 0 x 0.36 x 16382 x (365x10^{-9}) x (6.4 / 100) = 0

P_{spl} = 0.3666166

Link 467ze/477

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 22765 x (365x10^{-9}) x (6.8 / 100) = 0
Roundabout
P_{spl} = 400.2 x 5.35 x 22765 x (365x10^{-9}) x (6.8 / 100) = 1.209763
Side Road
P_{spl} = 0 x 1.81 x 22765 x (365x10^{-9}) x (6.8 / 100) = 0
Slip Road
P_{spl} = 0 x 0.36 x 22765 x (365x10^{-9}) x (6.8 / 100) = 0

P_{spl} = 1.209763

Link 5/435z

Normal road RL SS AADT
P_{spl} = 126 x 0.31 x 21171 x (365x10^{-9}) x (11.2 / 100) = 0.0338053
Roundabout
P_{spl} = 0 x 5.35 x 21171 x (365x10^{-9}) x (11.2 / 100) = 0
Side Road
P_{spl} = 0 x 1.81 x 21171 x (365x10^{-9}) x (11.2 / 100) = 0
Slip Road
P_{spl} = 100 x 0.36 x 21171 x (365x10^{-9}) x (11.2 / 100) = 0.0311569

P_{spl} = 0.0649622

Link 438z/439z

Normal road RL SS AADT
P_{spl} = 0.612 x 0.31 x 19655 x (365x10^{-9}) x (11 / 100) = 0.00015
Roundabout
P_{spl} = 0 x 5.35 x 19655 x (365x10^{-9}) x (11 / 100) = 0
Side Road
P_{spl} = 0 x 1.81 x 19655 x (365x10^{-9}) x (11 / 100) = 0
Slip Road
P_{spl} = 0.2 x 0.36 x 19655 x (365x10^{-9}) x (11 / 100) = 5.68E-05

P_{spl} = 0.000207

Link 466z/474

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 6560 x (365x10^{-9}) x (4.6 / 100) = 0
Roundabout
P_{spl} = 0.1 x 5.35 x 6560 x (365x10^{-9}) x (4.6 / 100) = 5.89E-05
Side Road
P_{spl} = 0 x 1.81 x 6560 x (365x10^{-9}) x (4.6 / 100) = 0
Slip Road
P_{spl} = 0.1765 x 0.36 x 6560 x (365x10^{-9}) x (4.6 / 100) = 7E-06

P_{spl} = 6.59E-05

Link 333/451z

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 13705 x (365x10^{-9}) x (4.8 / 100) = 0
Roundabout
P_{spl} = 0.1 x 5.35 x 13705 x (365x10^{-9}) x (4.8 / 100) = 0.000128
Side Road
P_{spl} = 0.1796 x 1.81 x 13705 x (365x10^{-9}) x (4.8 / 100) = 7.81E-05
Slip Road
P_{spl} = 0 x 0.36 x 13705 x (365x10^{-9}) x (4.8 / 100) = 0

P_{spl} = 0.000207

Link 442z/443z

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 16730 x (365x10^{-9}) x (7.2 / 100) = 0
Roundabout
P_{spl} = 0.1 x 5.35 x 16730 x (365x10^{-9}) x (7.2 / 100) = 0.000235
Side Road
P_{spl} = 0.04892 x 1.81 x 16730 x (365x10^{-9}) x (7.2 / 100) = 3.89E-05
Slip Road
P_{spl} = 0 x 0.36 x 16730 x (365x10^{-9}) x (7.2 / 100) = 0

P_{spl} = 0.000274

Link 440z/29

Normal road RL SS AADT
P_{spl} = 139 x 0.31 x 27870 x (365x10^{-9}) x (9.8 / 100) = 0.042957
Roundabout
P_{spl} = 0 x 5.35 x 27870 x (365x10^{-9}) x (9.8 / 100) = 0
Side Road
P_{spl} = 0 x 1.81 x 27870 x (365x10^{-9}) x (9.8 / 100) = 0
Slip Road
P_{spl} = 100 x 0.36 x 27870 x (365x10^{-9}) x (9.8 / 100) = 0.035889

P_{spl} = 0.078846

Link 453z/454z

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 8216 x (365x10^{-9}) x (6.9 / 100) = 0
Roundabout
P_{spl} = 0.1 x 5.35 x 8216 x (365x10^{-9}) x (6.9 / 100) = 0.00011
Side Road
P_{spl} = 0 x 1.81 x 8216 x (365x10^{-9}) x (6.9 / 100) = 0
Slip Road
P_{spl} = 0.4102 x 0.36 x 8216 x (365x10^{-9}) x (6.9 / 100) = 3.1E-05

P_{spl} = 0.00014

Link 458z/459z

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 8118 x (365x10^{-9}) x (6.3 / 100) = 0
Roundabout
P_{spl} = 0.1 x 5.35 x 8118 x (365x10^{-9}) x (6.3 / 100) = 1E-04
Side Road
P_{spl} = 0 x 1.81 x 8118 x (365x10^{-9}) x (6.3 / 100) = 0
Slip Road
P_{spl} = 0.3921 x 0.36 x 8118 x (365x10^{-9}) x (6.3 / 100) = 2.6E-05

P_{spl} = 0.00013

Combined total annual probability of a spillage incident for all sections of road

$P_{spl\ (Total)}$ = 1.7220192

Annual probability of a serious pollution incident:

P_{INC}	=	$P_{SPL\ (Total)}$	x	P_{POL}
Surface	=	1.72202	x	0.45
Water	=	**0.77491**		
	=	77.491 %		

P_{INC}	=	$P_{SPL\ (Total)}$	x	P_{POL}
Groundwater	=	1.722019	x	0.3
	=	**0.516606**		
	=	51.661 %		

Return Period (years)

SW = **1.29**
GW = **2**

Proposed mitigation measure: Detention Pond

Pollution reduction factor = 0.5

P_{INC} = **0.38745**
SW = 38.745 %

P_{INC} = **0.258303**
GW = 25.830 %

Return Period (years) - with mitigation

SW = **2.6**
GW = **4**

Serious Spillage Risk calculations

Catchment 4

The runoff from ged to******

P_{INL} = The probability of a spillage with an associated risk of a serious pollution incident occurring

P_{SPL} = Annual probability of a spillage with the potential to cause a serious spillage incident

The probability, given a spillage, that a serious pollution incident will result (based on sensitivity of watercourse and emergency services response time).

RL = Road length in kilometres

SS = Serious Spillage Rates

AADT = Annual Average Daily Traffic (using Design Year 2031)

%HGV = Percentage of Heavy Goods Vehicles

Road Lengths (RL) Comprise

Normal Road (Rural All Purpose)

NOTE : Road more than 100m from Roundabout, Slip Road and Side Road

Road within 100m of Roundabout

Road within 100m of Side Road

Road within 100m of Slip Road

Link	AADT	Road Description	Total Length (m	Roundabout (m	Side road (m	Slip Road (m	Normal (m	HGV
110/226	16730	Side	390	100	290			7.2
146/145	8177	Side	58.5	58.5				2.3
108/107	26498	Side	60.3	60.3				8.3
227/113	21194	Side	71.1	71.1				6.6
234/109a	18265	Roundabout	91.5	91.5				6.9

Percentage HGVs	variable	%
Emergency Response time	<20	minutes
Probability of serious pollution incident occurring (P_{POL}) SW	0.45	
Probability of serious pollution incident occurring (P_{POL}) GW	0.3	

(DMRB Volume 11, Section 3, Part 10, Table D1.2)

Serious Spillage Rates (SS): -

(DMRB Volume 11, Section 3, Part 10, Table D1.1)

Normal Road (Urban All Purpose)	-	0.31	per Billion HGV km/year
Road within 100m of Roundabout	-	5.35	"
Road within 100m of Side Road	-	1.81	per Billion HGV km/year
Road within 100m of Slip Road	-	0.36	per Billion HGV km/year

Calculation of Spillage Risk

a) Probability of serious accidental spillage (Pspl) is given by: -

P_{spl} = RL x SS x (ADDT x 365 x 10^{-9}) x (HGV%/100)

Link 110/226

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 16730 x (365x10^{-9}) 7.2 / 100) = 0

Roundabout
= 0.1 x 5.35 x 16730 x (365x10^{-9}) 7.2 / 100) = 0.000235

Side Road
P_{spl} = 0.29 x 1.81 x 16730 x (365x10^{-9}) 7.2 / 100) = 0.000231

Slip Road
P_{spl} = 0 x 0.36 x 16730 x (365x10^{-9}) 7.2 / 100) = 0

P_{spl} = 0.000466

Link 146/145

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 8177 x (365x10^{-9}) 2.3 / 100) = 0

Roundabout
P_{spl} = 0.059 x 5.35 x 8177 x (365x10^{-9}) 2.3 / 100) = 2.15E-05

Side Road
= 0 x 1.81 x 8177 x (365x10^{-9}) 2.3 / 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 8177 x (365x10^{-9}) 2.3 / 100) = 0

P_{spl} = 2.15E-05

Link 108/107

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 26498 x (365x10^{-9}) 8.3 / 100) = 0

Roundabout
P_{spl} = 0.06 x 5.35 x 26498 x (365x10^{-9}) 8.3 / 100) = 0.000259

Side Road
P_{spl} = 0 x 1.81 x 26498 x (365x10^{-9}) 8.3 / 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 26498 x (365x10^{-9}) 8.3 / 100) = 0

P_{spl} = 0.000259

Link 0

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 0 x (365x10^{-9}) 0 / 100) = 0

Roundabout
P_{spl} = 0 x 5.35 x 0 x (365x10^{-9}) 0 / 100) = 0

Side Road
= 0 x 1.81 x 0 x (365x10^{-9}) 0 / 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 0 x (365x10^{-9}) 0 / 100) = 0

P_{spl} = 0

Link 0

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 0 x (365x10^{-9}) x (/ 100) = 0

Roundabout
P_{spl} = 0 x 5.35 x 0 x (365x10^{-9}) x (/ 100) = 0

Side Road
P_{spl} = 0 x 1.81 x 0 x (365x10^{-9}) x (/ 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 0 x (365x10^{-9}) x (/ 100) = 0

P_{spl} = 0

Link 227/113

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 21194 x (365x10^{-9}) 7 / 100) = 0

Roundabout
P_{spl} = 0.0711 x 5.35 x 21194 x (365x10^{-9}) 7 / 100) = 0.000194

Side Road
P_{spl} = 0 x 1.81 x 21194 x (365x10^{-9}) 7 / 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 21194 x (365x10^{-9}) 7 / 100) = 0

0.000194

Link 234/109a

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 18265 x (365x10^{-9}) 7 / 100) = 0

Roundabout
P_{spl} = 0.0915 x 5.35 x 18265 x (365x10^{-9}) 7 / 100) = 0.000225

Side Road
P_{spl} = 0 x 1.81 x 18265 x (365x10^{-9}) 7 / 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 18265 x (365x10^{-9}) 7 / 100) = 0

P_{spl} = 0.000225

Link 0

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 0 x (365x10^{-9}) 0 / 100) = 0

Roundabout
P_{spl} = 0 x 5.35 x 0 x (365x10^{-9}) x (/ 100) = 0

Side Road
P_{spl} = 0 x 1.81 x 0 x (365x10^{-9}) x (/ 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 0 x (365x10^{-9}) x (/ 100) = 0

P_{spl} = 0

Link 0

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 0 x (365x10^{-9}) x (/ 100) = 0

Roundabout
P_{spl} = 0 x 5.35 x 0 x (365x10^{-9}) x (/ 100) = 0

Side Road
P_{spl} = 0 x 1.81 x 0 x (365x10^{-9}) x (/ 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 0 x (365x10^{-9}) x (/ 100) = 0

P_{spl} = 0

Link 0

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 0 x (365x10^{-9}) x (/ 100) = 0

Roundabout
P_{spl} = 0 x 5.35 x 0 x (365x10^{-9}) x (/ 100) = 0

Side Road
P_{spl} = 0 x 1.81 x 0 x (365x10^{-9}) x (/ 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 0 x (365x10^{-9}) x (/ 100) = 0

0

Link 0

Normal road RL SS AADT
P_{spl} = 0 x 0.31 x 0 x (365x10^{-9}) x (/ 100) = 0

Roundabout
P_{spl} = 0 x 5.35 x 0 x (365x10^{-9}) x (/ 100) = 0

Side Road
P_{spl} = 0 x 1.81 x 0 x (365x10^{-9}) x (/ 100) = 0

Slip Road
P_{spl} = 0 x 0.36 x 0 x (365x10^{-9}) x (/ 100) = 0

P_{spl} = 0

Combined total annual probability of a spillage incident for all sections of road

$P_{spl\,Total}$ = 0.00117

Annual probability of a serious pollution incident:

P_{INC} = $P_{SPL\,Total}$ x P_{POL}
Surface = 0.00117 x 0.45
Water = **0.00052**
= 0.052 %

P_{INC} = $P_{SPL\,Total}$ x P_{POL}
Groundwater = 0.00117 x 0.3
= **0.00035**
= 0.035 %

Return Period (years)

SW = **1906** GW = **2859**

Proposed mitigation measure: Detention Pond

Pollution reduction factor = 0.5

P_{INC} = **0.00026** P_{INC} = **0.00017**
SW = 0.026 % GW = 0.017 %

Return Period (years) - with mitigation

SW = **3812** GW = **5718**

Watercourse	Catchment 1a (West)		
Outfall Number	2		
Site Location (Easting)	332000	Bed Width (m)	1.8
Site Location (Northing)	667756	Manning's n	0.045
Base Flow Index	0.52	Side Slope	0.778
Estimated River Width (m)	6	Long Slope	0.0021
Impermeable Area (Ha)	2.337		
Permeable Area (Ha)	0		

To calculate the Q95 value as set out in the IOH Report No. 108, the mean flow in the river must be determined. This is done using equations from the FEH & IOH Report

From the IOH Report No. 108, the mean flow is given by:

$MF = 2.7 \times 10^{-7} \times (AREA^{1.02}) \times (SAAR^{1.82}) \times (PE^{-0.284})$

The river characteristics SAAR and AREA are gained from the FEH

Where…

Catchment Area (km^2) = 6.19

SAAR (mm) = 685

PE is taken as approximately 1/3 of total rainfall

PE = 228

Therefore…

MF = 0.05370

Is a gauging station available to allow a low flow curved to be derived specific to this river? NO

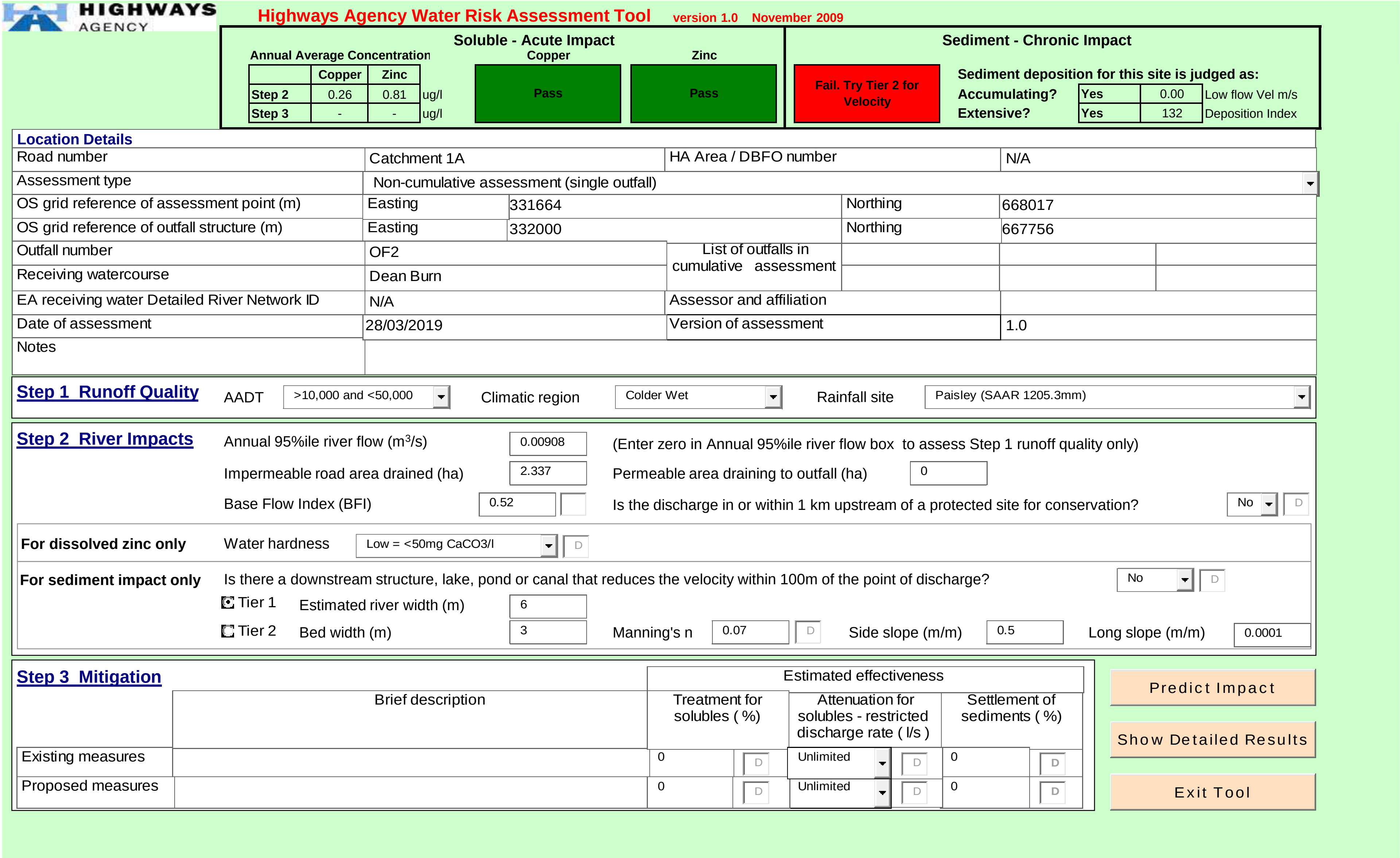
From IOH Report, the mean value of Q95 as a percentage of the MF is 16.9%

Q95 m^3/s = 0.00908

		Treatment Efficiency			
	Treatment Train	Dissolved Cu	Dissolved Zn	TSS	*Risk reduction factor applied for treatment performance of secondary and tertiary levels
1	Filter Drain	0	45	60	
2	Retention Pond	40	30	76	
3	Retention Pond	40	30	76	

Estimated effectiveness of Mitigation

Treatment of Cu%	52
Treatment of Zn%	60
Settlement of Sediments %	85
Discharge Rate (l/s)	32.36



Highways Agency Water Risk Assessment Tool

version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.26	0.81	ug/l
Step 3	-	-	ug/l

Copper	Zinc
🟩 Pass	🟩 Pass

Sediment - Chronic Impact

🟥 **Fail. Try Tier 2 for Velocity**

Sediment deposition for this site is judged as:

Accumulating?	**Yes**	0.00	Low flow Vel m/s
Extensive?	**Yes**	132	Deposition Index

Location Details

Road number	Catchment 1A	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331664	Northing	668017
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 2.337

Permeable area draining to outfall (ha): 0

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No

For dissolved zinc only

Water hardness: Low = <50mg CaCO3/l

For sediment impact only

Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No

● Tier 1 Estimated river width (m): 6

○ Tier 2 Bed width (m): 3

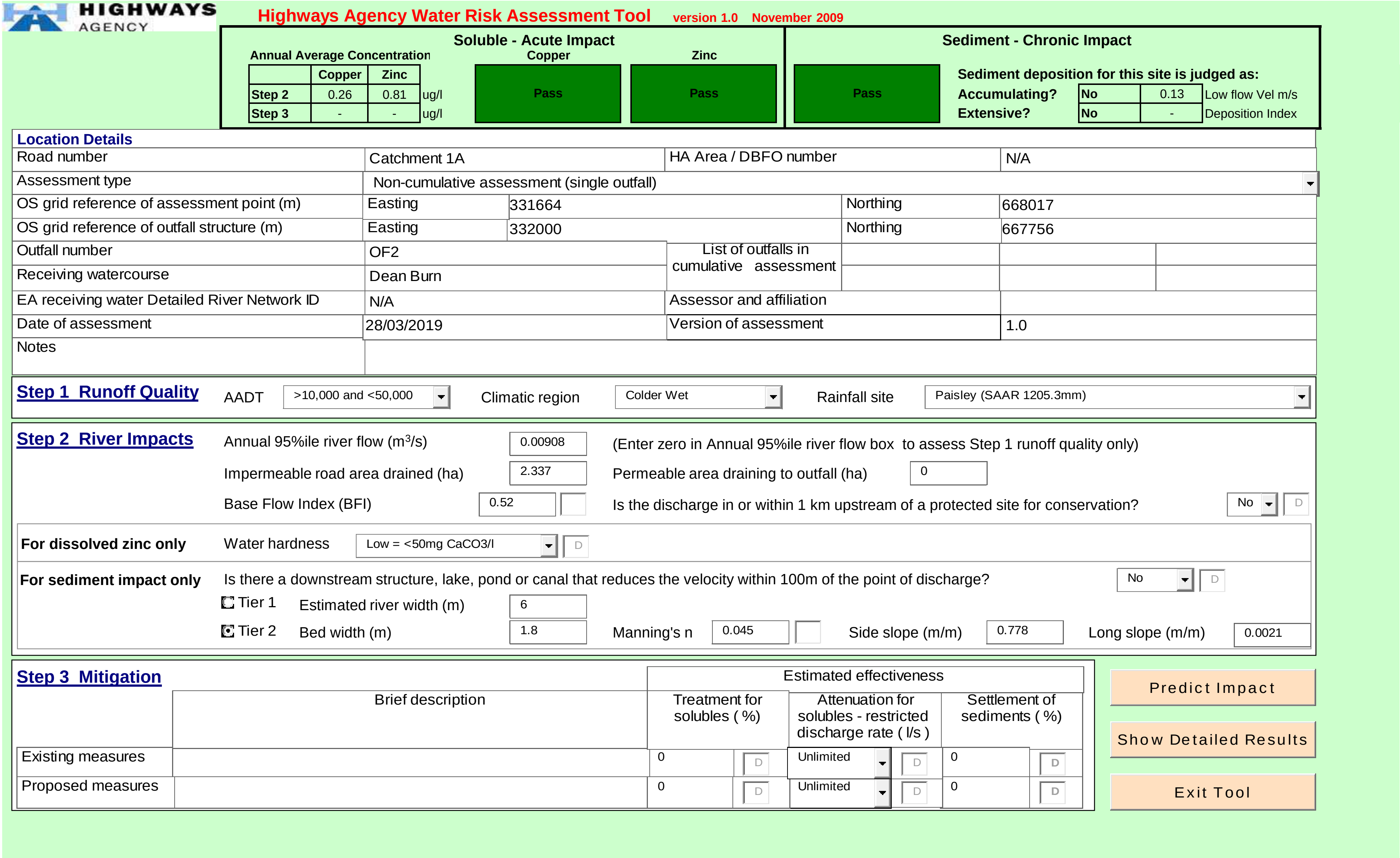
Manning's n: 0.07

Side slope (m/m): 0.5

Long slope (m/m): 0.0001

Step 3 Mitigation

	Brief description	Estimated effectiveness		
		Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures		0	Unlimited	0



Highways Agency Water Risk Assessment Tool

version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.26	0.81	ug/l
Step 3	-	-	ug/l

Copper	Zinc
Pass	Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	No	0.13	Low flow Vel m/s
Extensive?	No	-	Deposition Index

Location Details

Road number	Catchment 1A	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331664	Northing	668017
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 2.337

Permeable area draining to outfall (ha): 0

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No D

For dissolved zinc only

Water hardness: Low = <50mg CaCO3/l D

For sediment impact only

Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No D

○ Tier 1 Estimated river width (m): 6

● Tier 2 Bed width (m): 1.8 Manning's n: 0.045 Side slope (m/m): 0.778 Long slope (m/m): 0.0021

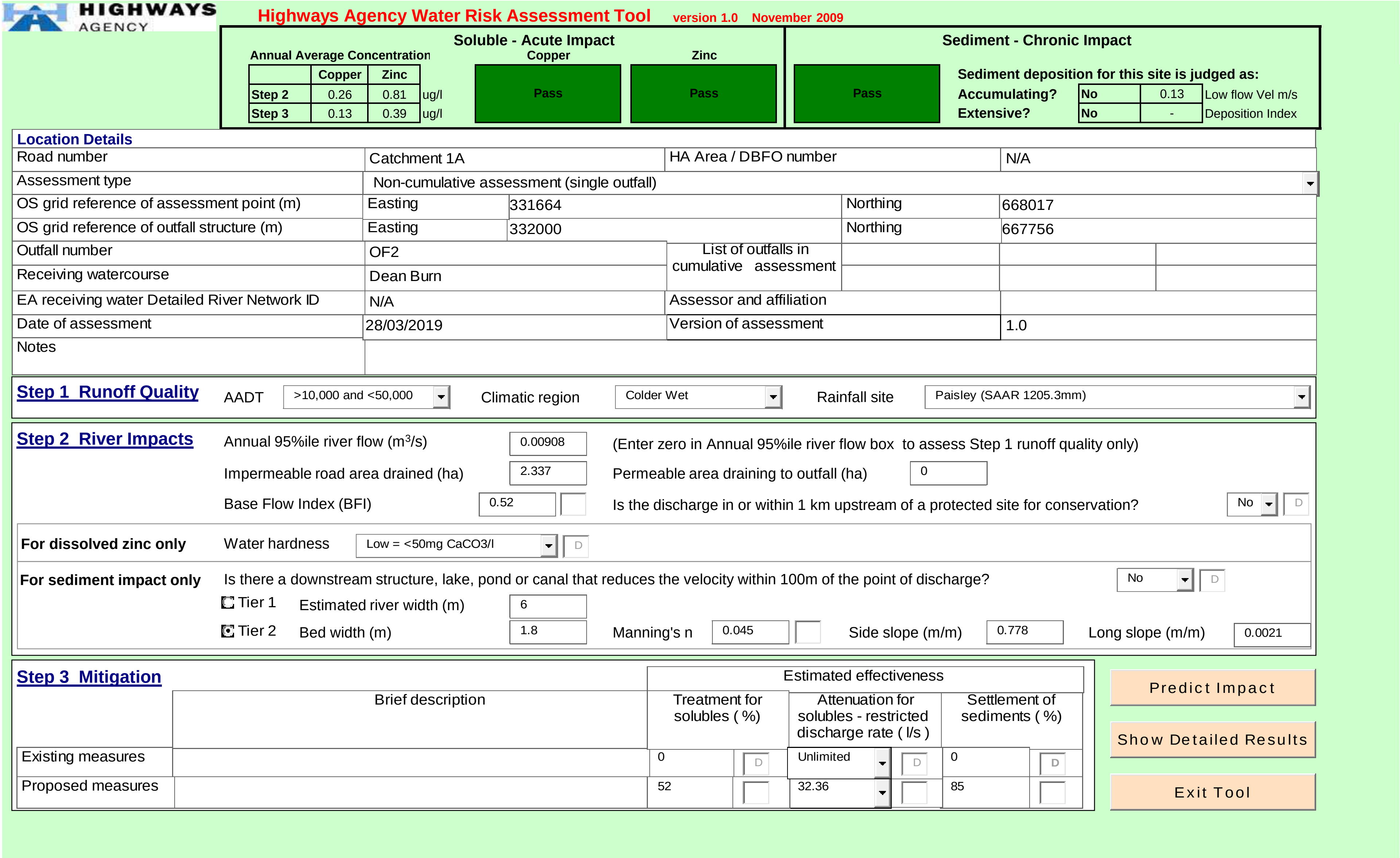
Step 3 Mitigation

	Brief description	Estimated effectiveness Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0 D	Unlimited D	0 D
Proposed measures		0 D	Unlimited D	0 D

Predict Impact

Show Detailed Results

Exit Tool



Highways Agency Water Risk Assessment Tool

version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.26	0.81	ug/l
Step 3	0.13	0.39	ug/l

Copper: Pass

Zinc: Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	No	0.13	Low flow Vel m/s
Extensive?	No	-	Deposition Index

Location Details

Road number	Catchment 1A	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331664	Northing	668017
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 2.337

Permeable area draining to outfall (ha): 0

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No D

For dissolved zinc only Water hardness: Low = <50mg CaCO3/l D

For sediment impact only Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No D

○ Tier 1 Estimated river width (m): 6

● Tier 2 Bed width (m): 1.8 Manning's n: 0.045 Side slope (m/m): 0.778 Long slope (m/m): 0.0021

Step 3 Mitigation

	Brief description	Estimated effectiveness Treatment for solubles (%)		Attenuation for solubles - restricted discharge rate (l/s)		Settlement of sediments (%)	
Existing measures		0	D	Unlimited	D	0	D
Proposed measures		52		32.36		85	

Watercourse	Catchment 1B (Centre)
Outfall Number	2

Site Location (Easting)	332000	Bed Width (m)	1.8
Site Location (Northing)	667756	Mannings n	0.045
Base Flow Index	0.52	Side Slope	0.778
Estimated River Width (m)	6	Long Slope	0.0021
Impermeable Area (Ha)	1.09		
Permeable Area (Ha)	2.3		

To calculate the Q95 value as set out in the IOH Report No. 108, the mean flow in the river must be determined. This is done using equations from the FEH & IOH Report

From the IOH Report No. 108, the mean flow is given by:

$MF = 2.7 \times 10^{-7} \times (AREA^{1.02}) \times (SAAR^{1.82}) \times (PE^{-0.284})$

The river characteristics SAAR and AREA are gained from the FEH

Where…

Catchment Area (km^2) =	6.19
SAAR (mm) =	685

PE is taken as approximately 1/3 of total rainfall

PE =	228

Therefore…

MF =	0.05370

Is a gauging station available to allow a low flow curved to be derived specific to this river?	NO

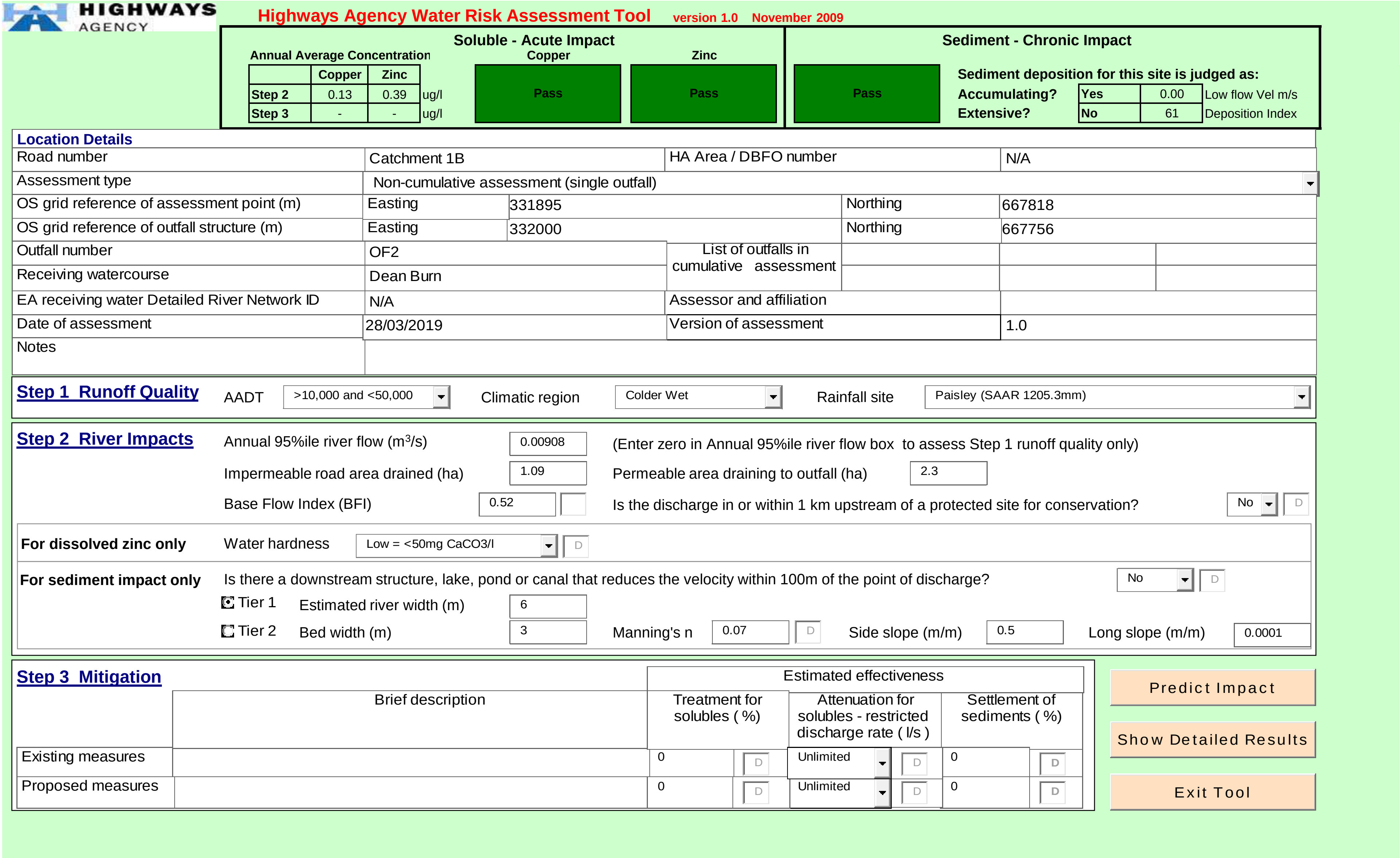
From IOH Report, the mean value of Q95 as a percentage of the MF is 16.9%

Q95 m^3/s =	0.00908

	Treatment Efficiency			
Treatment Train	Dissolved Cu	Dissolved Zn	TSS	*Risk reduction factor applied for treatment performance of secondary and tertiary levels
1 Filter Drain	0	45	60	
2 Retention Pond	40	30	76	

Estimated effectiveness of Mitigation

Treatment of Cu%	40
Treatment of Zn%	53
Settlement of Sediments %	75
Discharge Rate (l/s)	32.36



Highways Agency Water Risk Assessment Tool version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.13	0.39	ug/l
Step 3	-	-	ug/l

Copper	Zinc
Pass	Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	Yes	0.00	Low flow Vel m/s
Extensive?	No	61	Deposition Index

Location Details

Road number	Catchment 1B	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331895	Northing	667818
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 1.09

Permeable area draining to outfall (ha): 2.3

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No

For dissolved zinc only

Water hardness: Low = <50mg CaCO3/l

For sediment impact only

Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No

● Tier 1 Estimated river width (m): 6

○ Tier 2 Bed width (m): 3

Manning's n: 0.07

Side slope (m/m): 0.5

Long slope (m/m): 0.0001

Step 3 Mitigation

	Brief description	Estimated effectiveness: Treatment for solubles (%)	Estimated effectiveness: Attenuation for solubles - restricted discharge rate (l/s)	Estimated effectiveness: Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures		0	Unlimited	0

Highways Agency Water Risk Assessment Tool

version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.13	0.39	ug/l
Step 3	-	-	ug/l

Copper	Zinc
Pass	Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	**No**	0.13	Low flow Vel m/s
Extensive?	**No**	-	Deposition Index

Location Details

Road number	Catchment 1B	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331895	Northing	667818
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 1.09

Permeable area draining to outfall (ha): 2.3

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No D

For dissolved zinc only

Water hardness: Low = <50mg CaCO3/l D

For sediment impact only

Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No D

○ Tier 1 Estimated river width (m): 6

● Tier 2 Bed width (m): 1.8

Manning's n: 0.045

Side slope (m/m): 0.778

Long slope (m/m): 0.0021

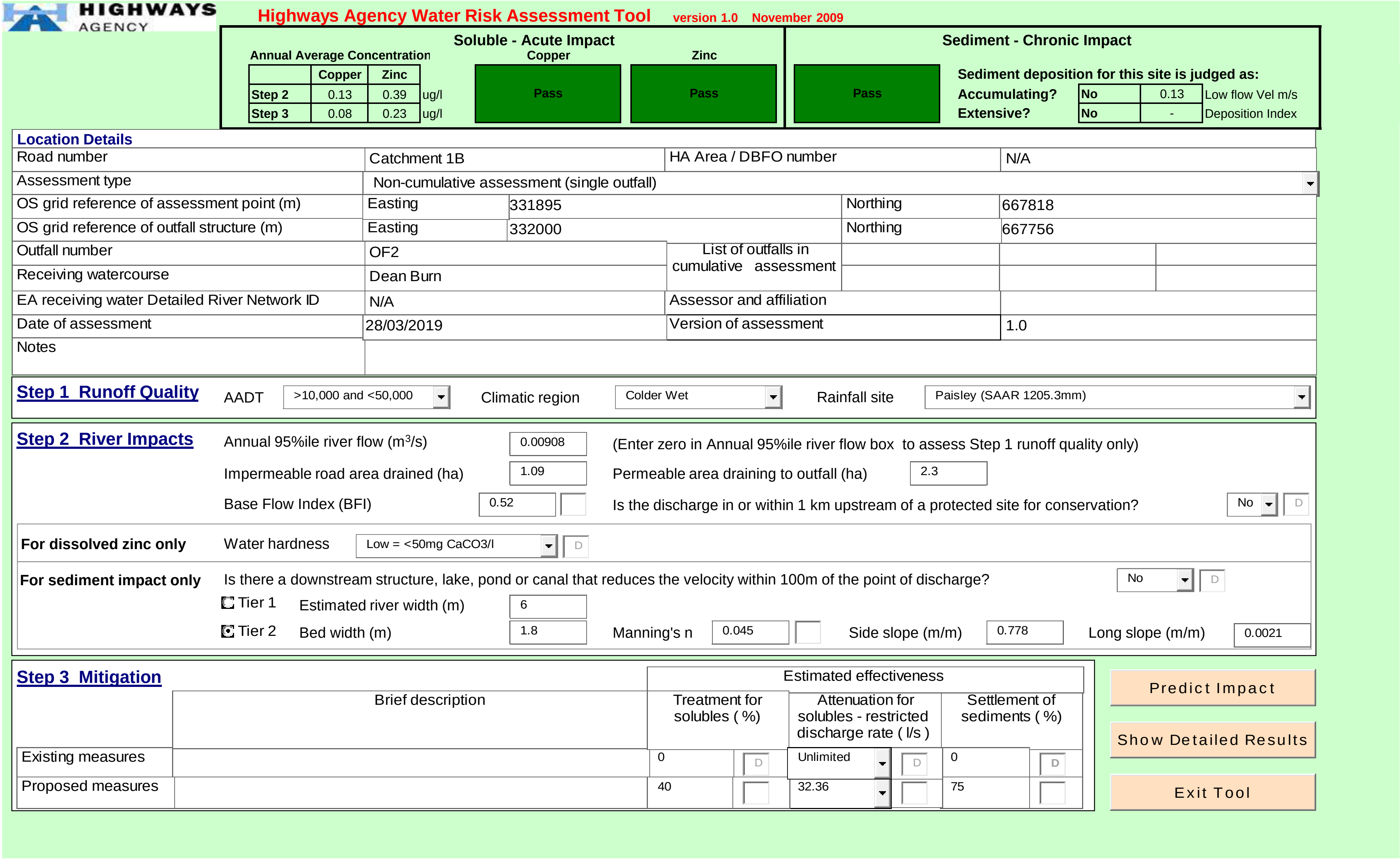
Step 3 Mitigation

	Brief description	Estimated effectiveness		
		Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0 D	Unlimited D	0 D
Proposed measures		0 D	Unlimited D	0 D

Predict Impact

Show Detailed Results

Exit Tool



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Highways Agency Water Risk Assessment Tool version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.13	0.39	ug/l
Step 3	0.08	0.23	ug/l

Copper	Zinc
Pass	Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	**No**	0.13	Low flow Vel m/s
Extensive?	**No**	-	Deposition Index

Location Details

Road number	Catchment 1B	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331895	Northing	667818
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 1.09

Permeable area draining to outfall (ha): 2.3

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No

For dissolved zinc only

Water hardness: Low = <50mg CaCO3/l

For sediment impact only

Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No

○ Tier 1 Estimated river width (m): 6

● Tier 2 Bed width (m): 1.8

Manning's n: 0.045

Side slope (m/m): 0.778

Long slope (m/m): 0.0021

Step 3 Mitigation

	Brief description	Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures		40	32.36	75

Watercourse	Catchment 1C (east)		
Outfall Number	2		
Site Location (Easting)	332000	Bed Width (m)	1.8
Site Location (Northing)	667756	Mannings n	0.045
Base Flow Index	0.52	Side Slope	0.778
Estimated River Width (m)	6	Long Slope	0.0021
Impermeable Area (Ha)	2.3		
Permeable Area (Ha)	0.2		

To calculate the Q95 value as set out in the IOH Report No. 108, the mean flow in the river must be determined. This is done using equations from the FEH & IOH Report

From the IOH Report No. 108, the mean flow is given by:

$MF = 2.7 \times 10^{-7} \times (AREA^{1.02}) \times (SAAR^{1.82}) \times (PE^{-0.284})$

The river characteristics SAAR and AREA are gained from the FEH

Where…

Catchment Area (km^2) = 6.19

SAAR (mm) = 685

PE is taken as approximately 1/3 of total rainfall

PE = 228

Therefore…

MF = 0.05370

Is a gauging station available to allow a low flow curved to be derived specific to this river? NO

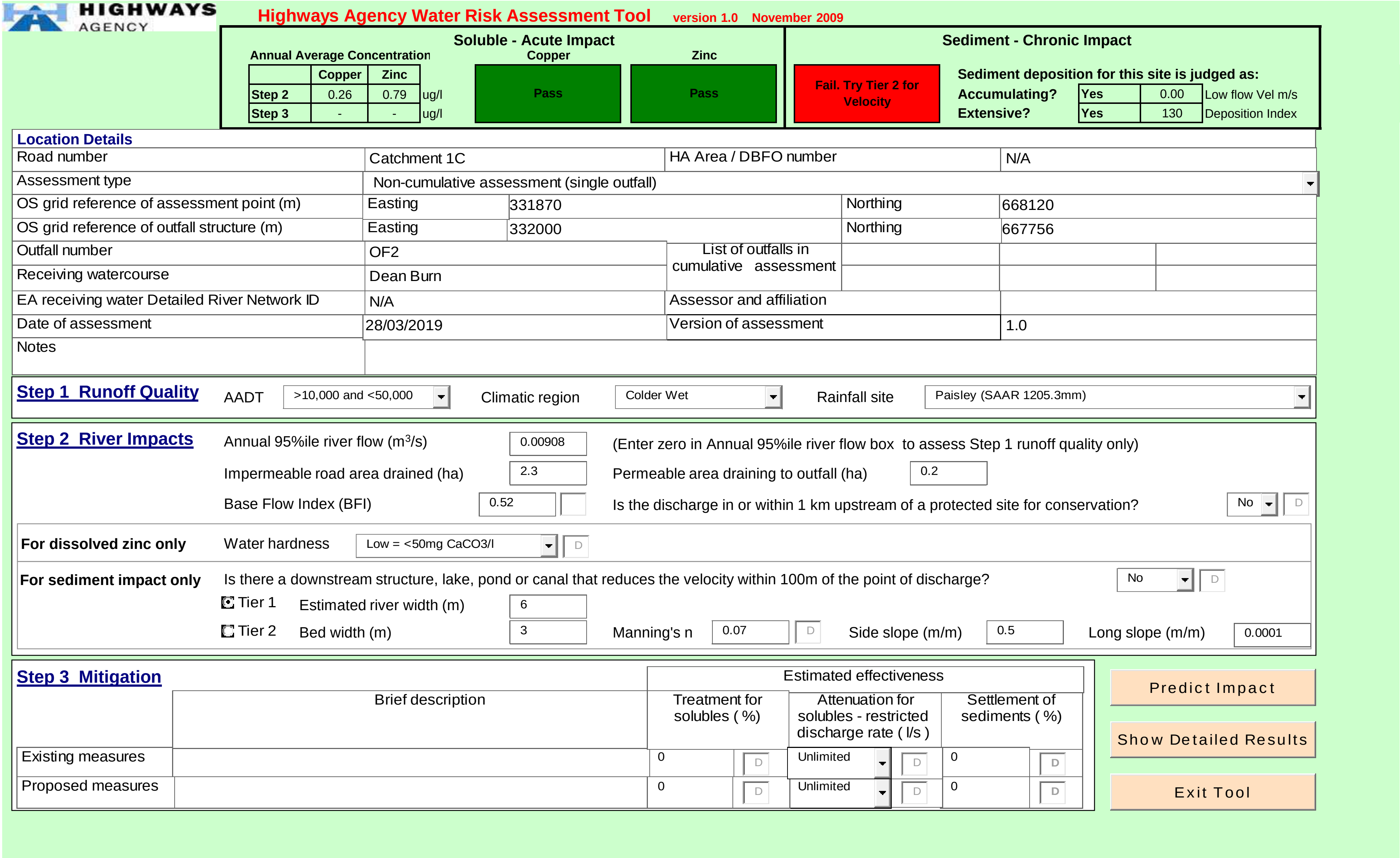
From IOH Report, the mean value of Q95 as a percentage of the MF is 16.9%

Q95 m^3/s = 0.00908

	Treatment Efficiency			
Treatment Train	Dissolved Cu	Dissolved Zn	TSS	*Risk reduction factor applied for treatment performance of secondary and tertiary levels
1 Filter Drain	0	45	60	
2 Retention Pond	40	30	76	
3 Retention Pond	40	30	76	

Estimated effectiveness of Mitigation

Treatment of Cu%	52
Treatment of Zn%	60
Settlement of Sediments %	85
Discharge Rate (l/s)	32.36



Highways Agency Water Risk Assessment Tool version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.26	0.79	ug/l
Step 3	-	-	ug/l

Copper: 🟩 Pass

Zinc: 🟩 Pass

Sediment - Chronic Impact

🟥 Fail. Try Tier 2 for Velocity

Sediment deposition for this site is judged as:

Accumulating?	Yes	0.00	Low flow Vel m/s
Extensive?	Yes	130	Deposition Index

Location Details

Road number	Catchment 1C	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331870	Northing	668120
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 2.3

Permeable area draining to outfall (ha): 0.2

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No D

For dissolved zinc only

Water hardness: Low = <50mg CaCO3/l D

For sediment impact only

Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No D

● Tier 1 Estimated river width (m): 6

○ Tier 2 Bed width (m): 3

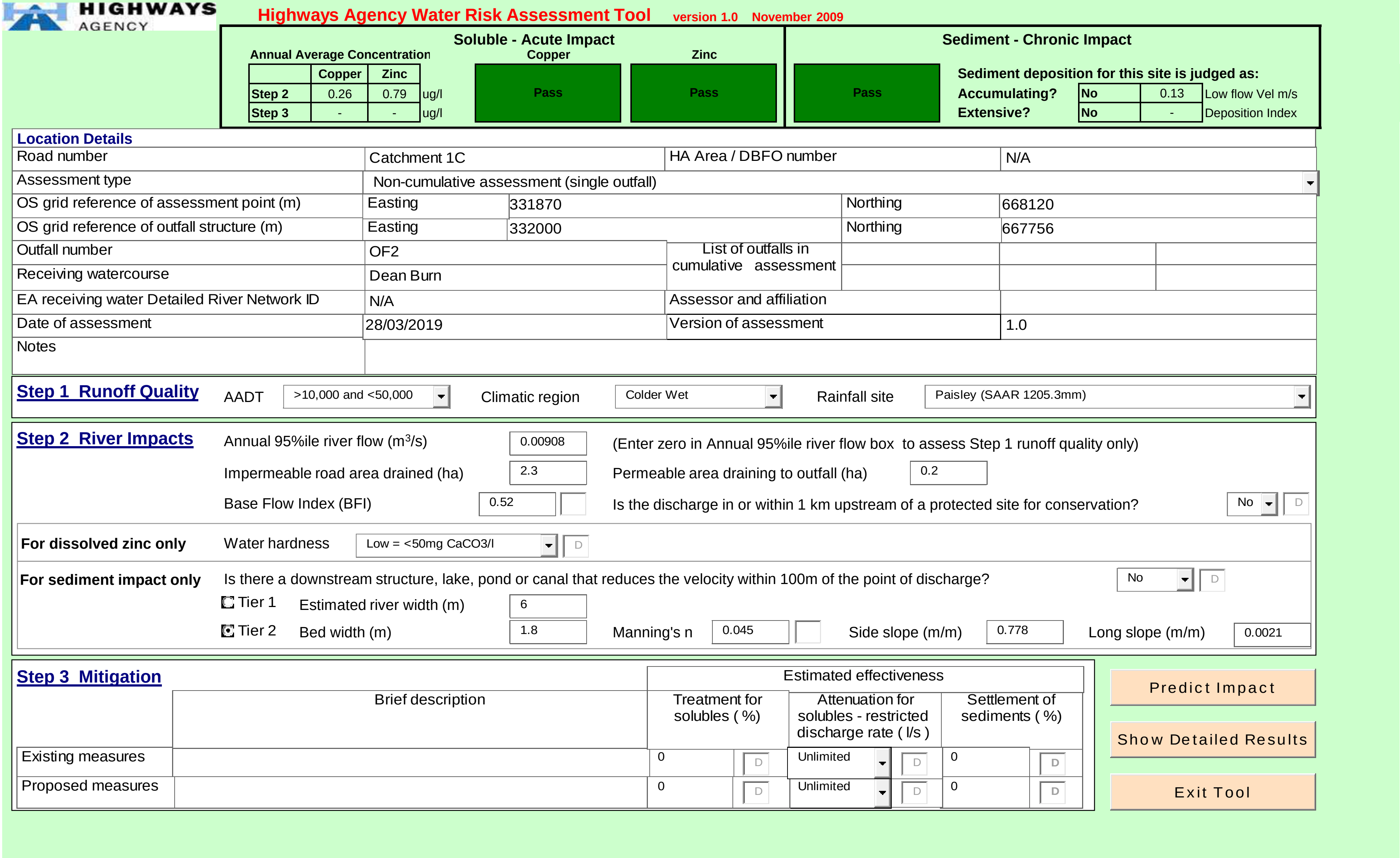
Manning's n: 0.07 D

Side slope (m/m): 0.5

Long slope (m/m): 0.0001

Step 3 Mitigation

	Brief description	Estimated effectiveness Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0 D	Unlimited D	0 D
Proposed measures		0 D	Unlimited D	0 D



Highways Agency Water Risk Assessment Tool

version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.26	0.79	ug/l
Step 3	-	-	ug/l

Copper	Zinc
Pass	Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	No	0.13	Low flow Vel m/s
Extensive?	No	-	Deposition Index

Location Details

Road number	Catchment 1C	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331870	Northing	668120
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 2.3

Permeable area draining to outfall (ha): 0.2

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No

For dissolved zinc only Water hardness: Low = <50mg CaCO3/l

For sediment impact only Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No

○ Tier 1 Estimated river width (m): 6

● Tier 2 Bed width (m): 1.8 Manning's n: 0.045 Side slope (m/m): 0.778 Long slope (m/m): 0.0021

Step 3 Mitigation

	Brief description	Estimated effectiveness Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures		0	Unlimited	0

Highways Agency Water Risk Assessment Tool

version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.26	0.79	ug/l
Step 3	0.12	0.38	ug/l

Copper	Zinc
Pass	Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	**No**	0.13	Low flow Vel m/s
Extensive?	**No**	-	Deposition Index

Location Details

Road number	Catchment 1C	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331870	Northing	668120
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 2.3

Permeable area draining to outfall (ha): 0.2

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No D

For dissolved zinc only Water hardness: Low = <50mg CaCO3/l D

For sediment impact only Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No D

○ Tier 1 Estimated river width (m): 6

● Tier 2 Bed width (m): 1.8

Manning's n: 0.045

Side slope (m/m): 0.778

Long slope (m/m): 0.0021

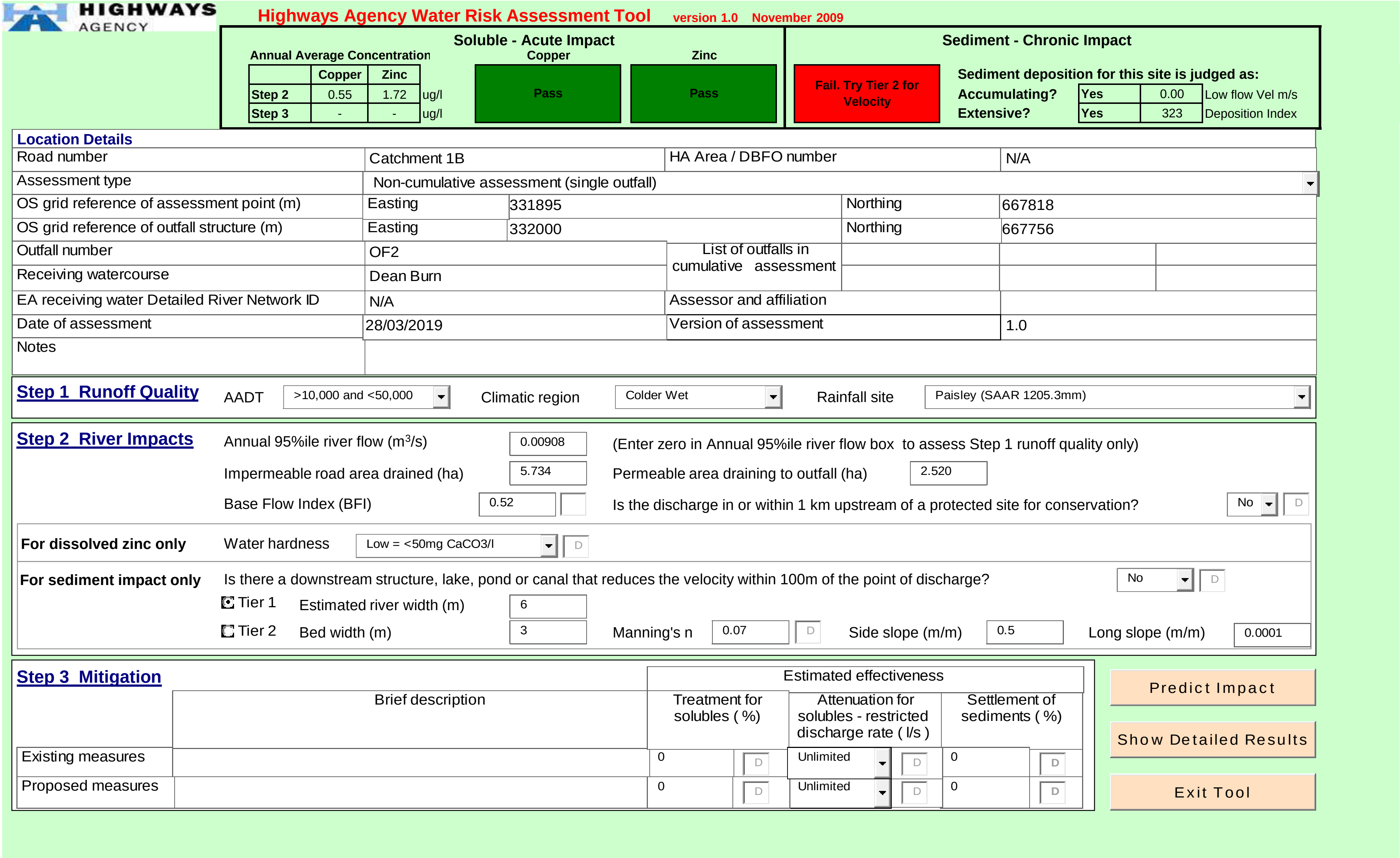
Step 3 Mitigation

	Brief description	Estimated effectiveness Treatment for solubles (%)		Attenuation for solubles - restricted discharge rate (l/s)		Settlement of sediments (%)	
Existing measures		0	D	Unlimited	D	0	D
Proposed measures		52		32.36		85	

Predict Impact

Show Detailed Results

Exit Tool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Highways Agency Water Risk Assessment Tool version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.55	1.72	ug/l
Step 3	-	-	ug/l

Copper	Zinc
🟩 Pass	🟩 Pass

Sediment - Chronic Impact

🟥 Fail. Try Tier 2 for Velocity

Sediment deposition for this site is judged as:

Accumulating?	Yes	0.00	Low flow Vel m/s
Extensive?	Yes	323	Deposition Index

Location Details

Road number	Catchment 1B	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331895	Northing	667818
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 5.734

Permeable area draining to outfall (ha): 2.520

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No

For dissolved zinc only

Water hardness: Low = <50mg CaCO3/l

For sediment impact only

Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No

● Tier 1 Estimated river width (m): 6

○ Tier 2 Bed width (m): 3

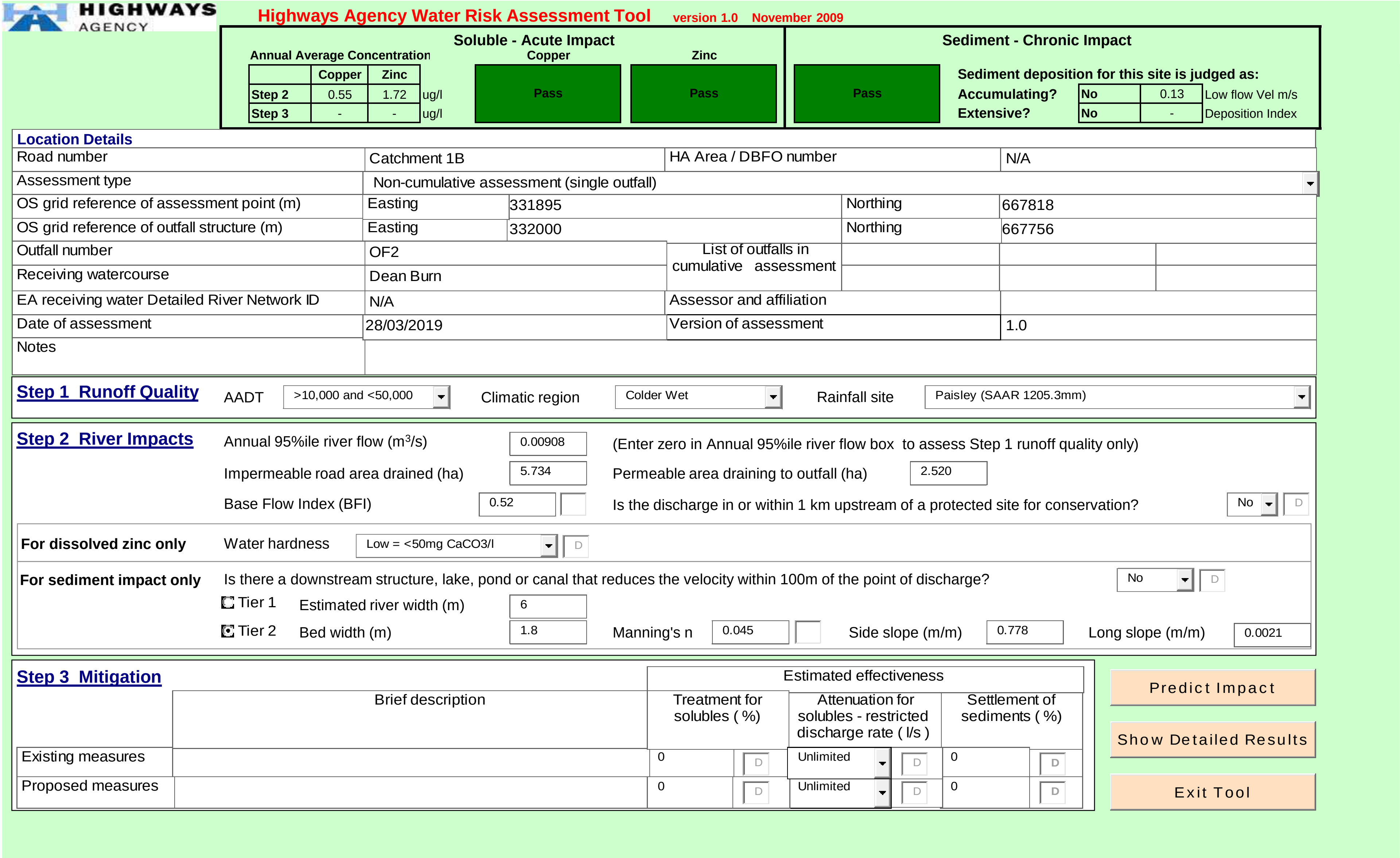
Manning's n: 0.07

Side slope (m/m): 0.5

Long slope (m/m): 0.0001

Step 3 Mitigation

	Brief description	Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
		Estimated effectiveness		
Existing measures		0	Unlimited	0
Proposed measures		0	Unlimited	0



HIGHWAYS AGENCY

Highways Agency Water Risk Assessment Tool version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.55	1.72	ug/l
Step 3	-	-	ug/l

Copper	Zinc
Pass	Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	No	0.13	Low flow Vel m/s
Extensive?	No	-	Deposition Index

Location Details

Road number	Catchment 1B	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331895	Northing	667818
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 5.734

Permeable area draining to outfall (ha): 2.520

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No

For dissolved zinc only Water hardness: Low = <50mg CaCO3/l

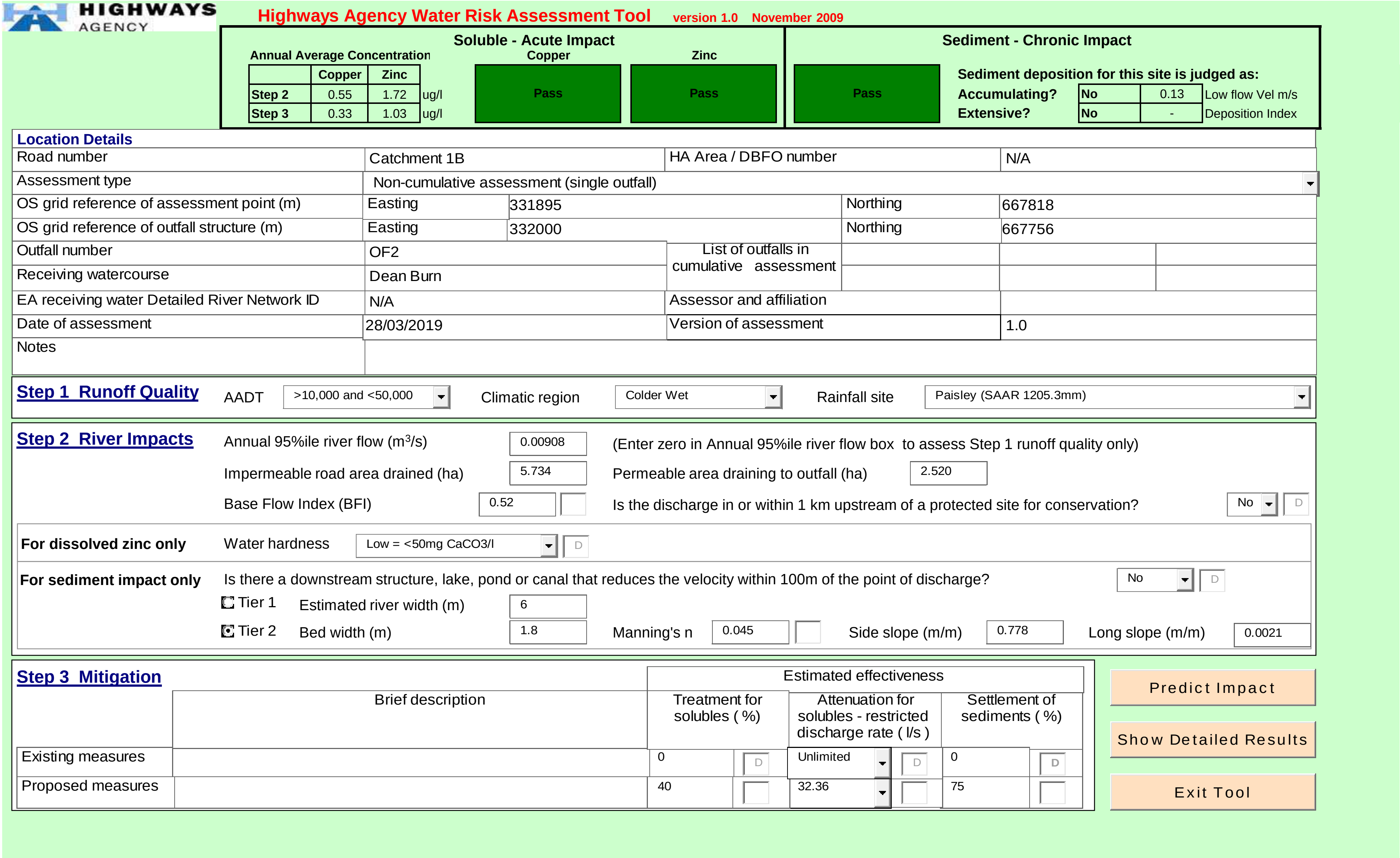
For sediment impact only Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No

○ Tier 1 Estimated river width (m): 6

● Tier 2 Bed width (m): 1.8 Manning's n: 0.045 Side slope (m/m): 0.778 Long slope (m/m): 0.0021

Step 3 Mitigation

	Brief description	Estimated effectiveness Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures		0	Unlimited	0



Highways Agency Water Risk Assessment Tool

version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.55	1.72	ug/l
Step 3	0.33	1.03	ug/l

Copper	Zinc
Pass	Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	**No**	0.13	Low flow Vel m/s
Extensive?	**No**	-	Deposition Index

Location Details

Road number	Catchment 1B	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331895	Northing	667818
OS grid reference of outfall structure (m)	Easting 332000	Northing	667756
Outfall number	OF2	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000 ▾
Climatic region: Colder Wet ▾
Rainfall site: Paisley (SAAR 1205.3mm) ▾

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908
(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)
Impermeable road area drained (ha): 5.734
Permeable area draining to outfall (ha): 2.520
Base Flow Index (BFI): 0.52
Is the discharge in or within 1 km upstream of a protected site for conservation?: No ▾ D

For dissolved zinc only
Water hardness: Low = <50mg CaCO3/l ▾ D

For sediment impact only
Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge?: No ▾ D
○ Tier 1 Estimated river width (m): 6
● Tier 2 Bed width (m): 1.8
Manning's n: 0.045
Side slope (m/m): 0.778
Long slope (m/m): 0.0021

Step 3 Mitigation

Brief description		Estimated effectiveness Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0 D	Unlimited ▾ D	0 D
Proposed measures		40	32.36 ▾	75

Watercourse	Catchment 4		
Outfall Number	1		
Site Location (Easting)	331884	Bed Width (m)	1.8
Site Location (Northing)	667778	Mannings n	0.045
Base Flow Index	0.52	Side Slope	0.778
Estimated River Width (m)	6	Long Slope	0.0021
Impermeable Area (Ha)	3.0523 ha		
Permeable Area (Ha)	2.5397 ha		

To calculate the Q95 value as set out in the IOH Report No. 108, the mean flow in the river must be determined. This is done using equations from the FEH & IOH Report

From the IOH Report No. 108, the mean flow is given by:

$MF = 2.7 \times 10^{-7} \times (AREA^{1.02}) \times (SAAR^{1.82}) \times (PE^{-0.284})$

The river characteristics SAAR and AREA are gained from the FEH

Where…

Catchment Area (km^2) =	6.19
SAAR (mm) =	685

PE is taken as approximately 1/3 of total rainfall

PE =	228

Therefore…

MF =	0.05370

Is a gauging station available to allow a low flow curved to be derived specific to this river?	NO

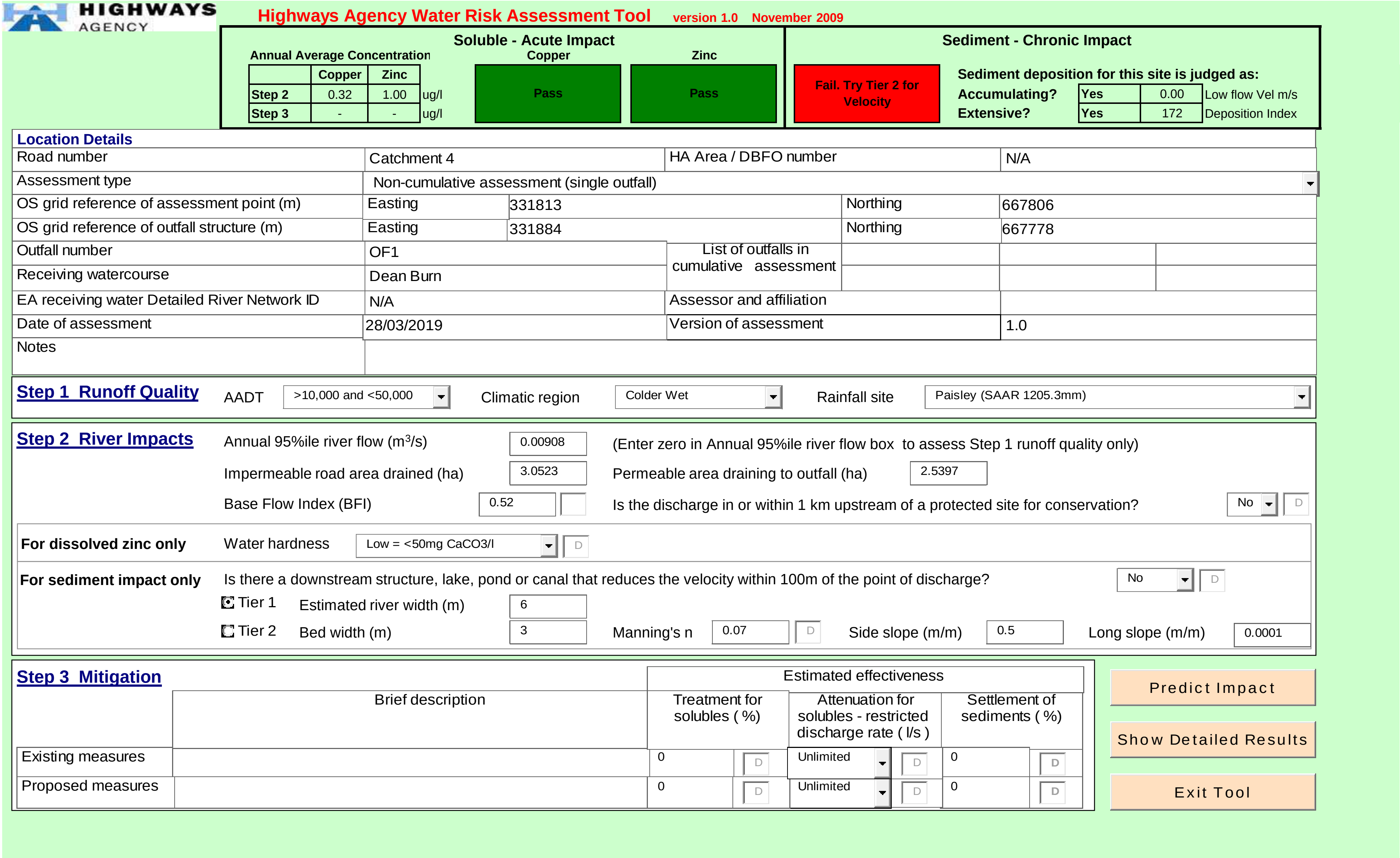
From IOH Report, the mean value of Q95 as a percentage of the MF is 16.9%

Q95 m^3/s =	0.00908

		Treatment Efficiency			
	Treatment Train	Dissolved Cu	Dissolved Zn	TSS	*Risk reduction factor applied for treatment performance of secondary and tertiary levels
1	Filter Drain	0	45	60	
2	Retention Pond	40	30	76	

Estimated effectiveness of Mitigation

Treatment of Cu%	40
Treatment of Zn%	53
Settlement of Sediments %	75
Discharge Rate (l/s)	6.61



Highways Agency Water Risk Assessment Tool version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.32	1.00	ug/l
Step 3	-	-	ug/l

Copper	Zinc
🟩 Pass	🟩 Pass

Sediment - Chronic Impact

🟥 Fail. Try Tier 2 for Velocity

Sediment deposition for this site is judged as:

Accumulating?	Yes	0.00	Low flow Vel m/s
Extensive?	Yes	172	Deposition Index

Location Details

Road number	Catchment 4	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331813	Northing	667806
OS grid reference of outfall structure (m)	Easting 331884	Northing	667778
Outfall number	OF1	List of outfalls in cumulative assessment	
Receiving watercourse	Dean Burn		
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
Date of assessment	28/03/2019	Version of assessment	1.0
Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 3.0523

Permeable area draining to outfall (ha): 2.5397

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No

For dissolved zinc only Water hardness: Low = <50mg CaCO3/l

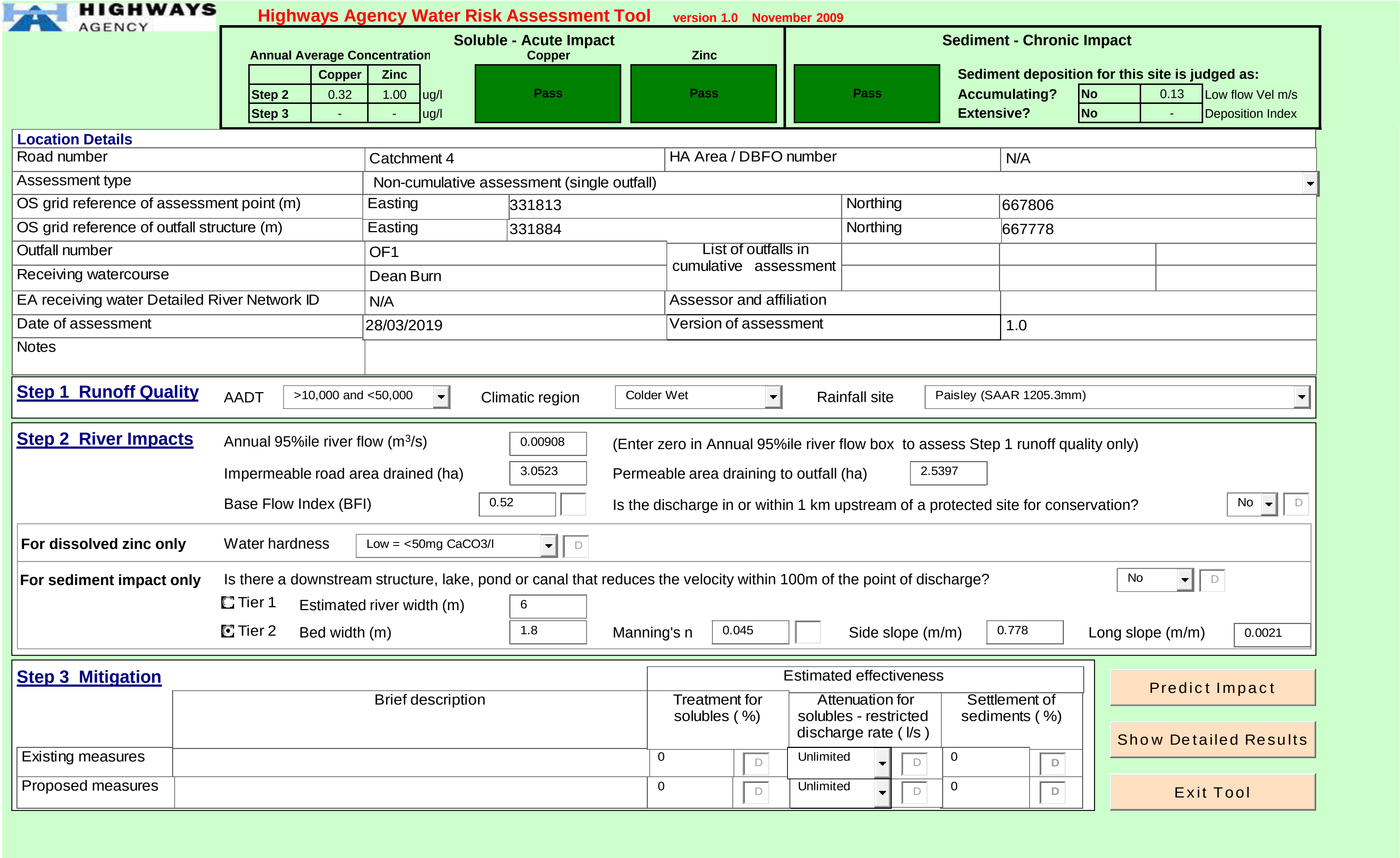
For sediment impact only Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No

☑ Tier 1 Estimated river width (m): 6

☐ Tier 2 Bed width (m): 3 Manning's n: 0.07 Side slope (m/m): 0.5 Long slope (m/m): 0.0001

Step 3 Mitigation

	Brief description	Treatment for solubles (%)	Attenuation for solubles - restricted discharge rate (l/s)	Settlement of sediments (%)
Existing measures		0	Unlimited	0
Proposed measures		0	Unlimited	0



HIGHWAYS AGENCY

Highways Agency Water Risk Assessment Tool version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.32	1.00	ug/l
Step 3	-	-	ug/l

Copper	Zinc
Pass	Pass

Sediment - Chronic Impact

Pass

Sediment deposition for this site is judged as:

Accumulating?	No	0.13	Low flow Vel m/s
Extensive?	No	-	Deposition Index

Location Details

Road number	Catchment 4	HA Area / DBFO number	N/A
Assessment type	Non-cumulative assessment (single outfall)		
OS grid reference of assessment point (m)	Easting 331813	Northing	667806
OS grid reference of outfall structure (m)	Easting 331884	Northing	667778
Outfall number	OF1	List of outfalls in cumulative assessment	
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EA receiving water Detailed River Network ID	N/A	Assessor and affiliation	
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Notes			

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 3.0523

Permeable area draining to outfall (ha): 2.5397

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No D

For dissolved zinc only Water hardness: Low = <50mg CaCO3/l D

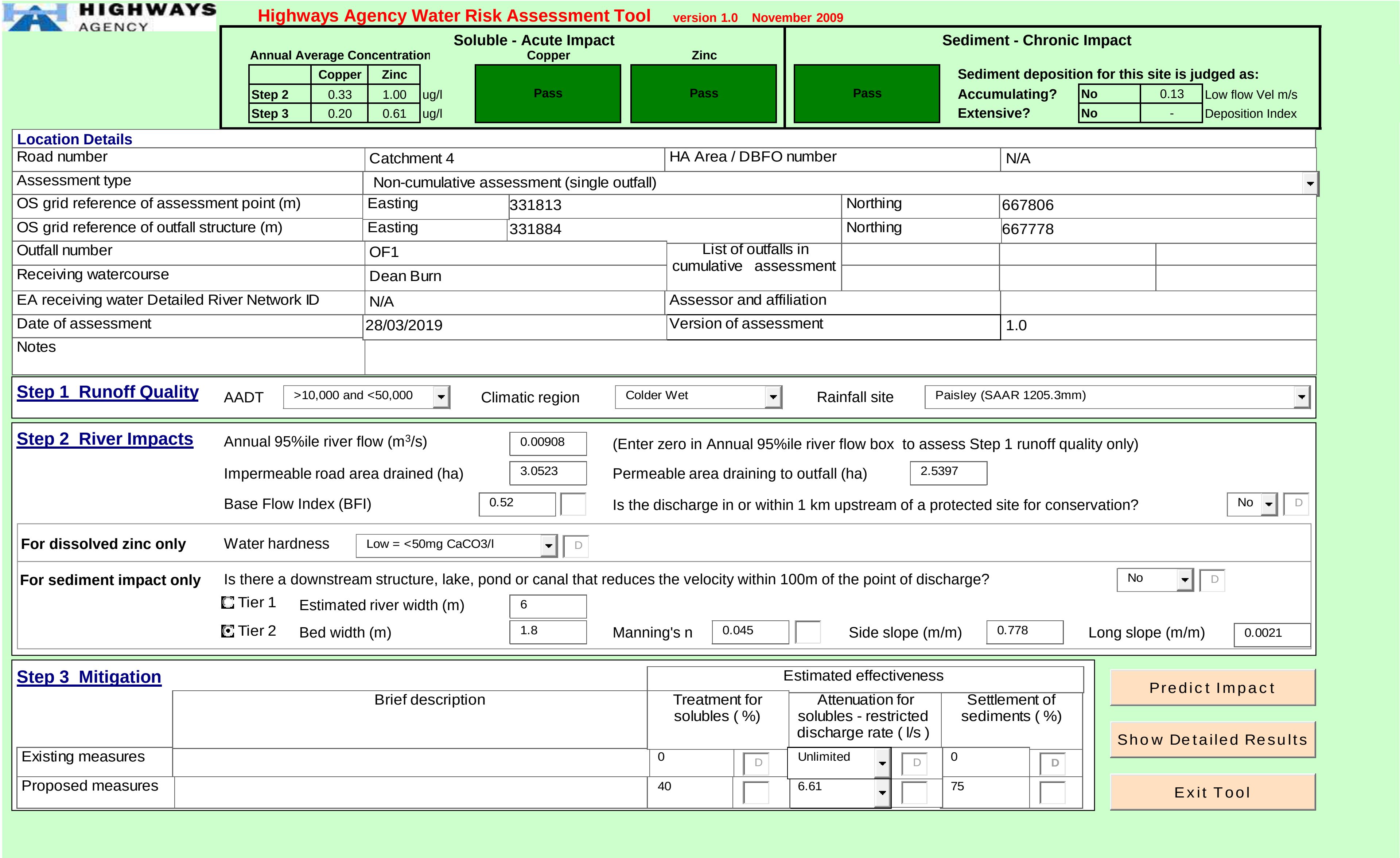
For sediment impact only Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No D

○ Tier 1 Estimated river width (m): 6

● Tier 2 Bed width (m): 1.8 Manning's n: 0.045 Side slope (m/m): 0.778 Long slope (m/m): 0.0021

Step 3 Mitigation

	Brief description	Estimated effectiveness Treatment for solubles (%)		Attenuation for solubles - restricted discharge rate (l/s)		Settlement of sediments (%)	
Existing measures		0	D	Unlimited	D	0	D
Proposed measures		0	D	Unlimited	D	0	D



Highways Agency Water Risk Assessment Tool version 1.0 November 2009

Soluble - Acute Impact

Annual Average Concentration

	Copper	Zinc	
Step 2	0.33	1.00	ug/l
Step 3	0.20	0.61	ug/l

Copper: 🟩 Pass

Zinc: 🟩 Pass

Sediment - Chronic Impact

🟩 Pass

Sediment deposition for this site is judged as:

Accumulating?	**No**	0.13	Low flow Vel m/s
Extensive?	**No**	-	Deposition Index

Location Details

Road number	Catchment 4	HA Area / DBFO number	N/A	
Assessment type	Non-cumulative assessment (single outfall)			
OS grid reference of assessment point (m)	Easting	331813	Northing	667806
OS grid reference of outfall structure (m)	Easting	331884	Northing	667778
Outfall number	OF1	List of outfalls in cumulative assessment		
Receiving watercourse	Dean Burn			
EA receiving water Detailed River Network ID	N/A	Assessor and affiliation		
Date of assessment	28/03/2019	Version of assessment	1.0	
Notes				

Step 1 Runoff Quality

AADT: >10,000 and <50,000

Climatic region: Colder Wet

Rainfall site: Paisley (SAAR 1205.3mm)

Step 2 River Impacts

Annual 95%ile river flow (m^3/s): 0.00908

(Enter zero in Annual 95%ile river flow box to assess Step 1 runoff quality only)

Impermeable road area drained (ha): 3.0523

Permeable area draining to outfall (ha): 2.5397

Base Flow Index (BFI): 0.52

Is the discharge in or within 1 km upstream of a protected site for conservation? No D

For dissolved zinc only Water hardness: Low = <50mg CaCO3/l D

For sediment impact only Is there a downstream structure, lake, pond or canal that reduces the velocity within 100m of the point of discharge? No D

○ Tier 1 Estimated river width (m): 6

● Tier 2 Bed width (m): 1.8

Manning's n: 0.045

Side slope (m/m): 0.778

Long slope (m/m): 0.0021

Step 3 Mitigation

	Brief description	Estimated effectiveness Treatment for solubles (%)		Attenuation for solubles - restricted discharge rate (l/s)		Settlement of sediments (%)	
Existing measures		0	D	Unlimited	D	0	D
Proposed measures		40		6.61		75	

Appendix 11.2 – Dean Burn Diversion Hydromorphology Design Technical Note

Technical Note

Client: Transport Scotland

Subject A720 Sheriffhall Junction Improvement – Dean Burn Diversion Hydromorphology Design

Prepared by:	Sally Homoncik	Date: 06/03/2019
Checked by:	Morag Hutton	Date: 07/03/2019
Approved by:	George Heritage	Date: 08/03/2019

Background and channel characteristics

Transport Scotland has appraised a number of options to reconfigure the Sheriffhall roundabout on the A720 Edinburgh City Bypass with the aim of relieving traffic pressure. The work is now at Stage 3 DMRB (EIA) and part of the design involves the diversion of the Dean Burn to accommodate the earthworks for the realigned/widened road. The proposed planform is shown on Figure 1 below.

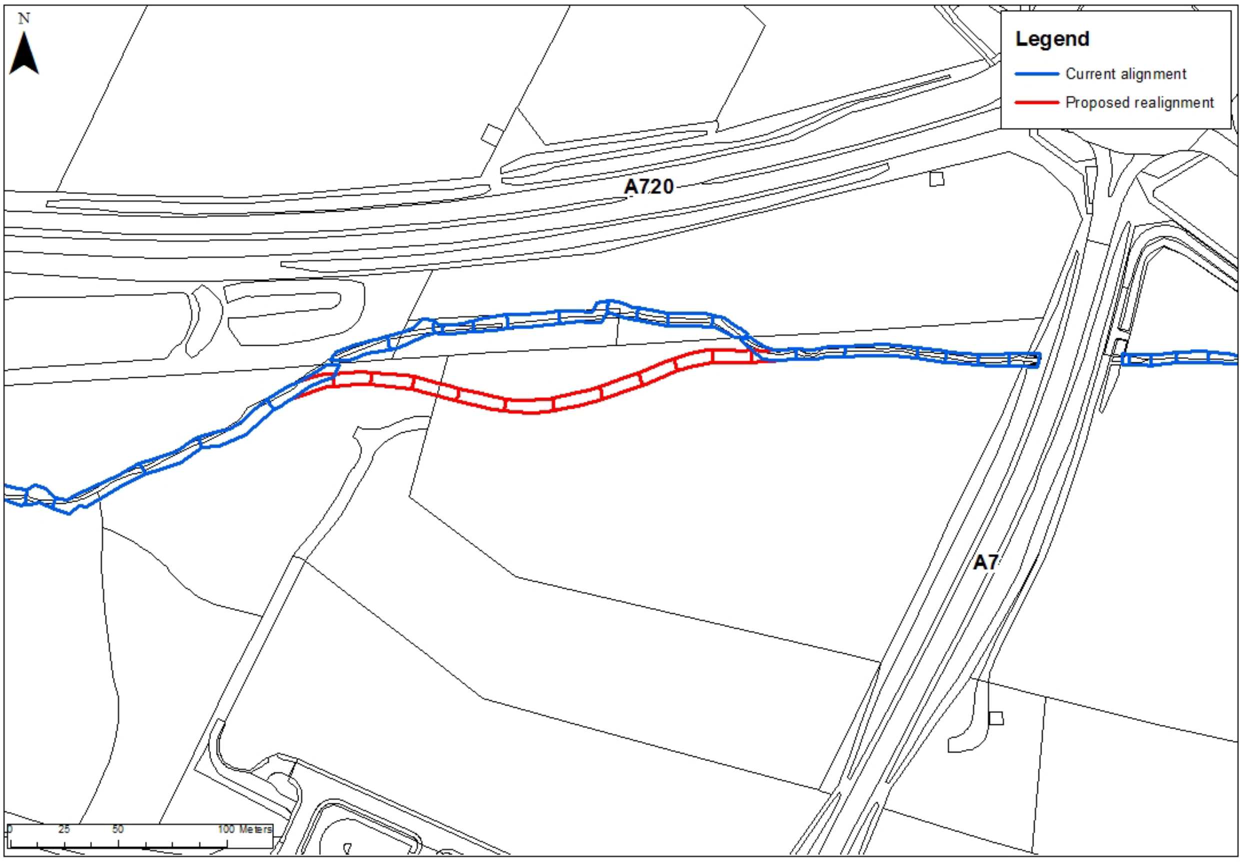


Figure 1 Proposed new planform (the lines represent the bank lines)

The Dean Burn is a minor tributary of the River North Esk and rises as the May Burn at the Pentland Industrial Estate, flowing from west to east, to the south of the A720. The burn is highly impacted by realignment, with a straightened planform, culverting, canalisation and lack of natural bed features along its length. Historic maps show that the Dean Burn has changed little since the OS maps of the 1800s were created. The banks comprise very soft, erodible sandy material, as the superficial geology in this area is dominated by glacial sand and gravel deposits. There is no significant alluvial floodplain present suggesting only minor reworking of this material. The burn is a low activity, locally sinuous, single thread, riffle-pool-plain bed system. There is a general lack of gravel bedload to the channel and an excessive input of fines. This is related to diffuse inputs linked to the management of the system (agriculture, industrial areas and road runoff), as well as the local erosion of bank material containing a high proportion of fines. Where there is more coarse bed material, this appears to be immobile, and in places has become indurated into the bed (as evidenced by the presence of embedded brick and rubble debris).

Where the channel has been able to begin naturalising, there is evidence of increased local sinuosity and the development of some bed features (Figure 2 and Figure 3). Grossly over-wide sections have seen subsequent development of low level fine sediment berms which have become vegetated. These provide beneficial diversity to the flow and marginal habitat in these reaches.

Figure 2 Naturalising reach

Figure 3 Erosion of bank upstream of pond and fine sediment berm formation

The Dean Burn flows through an area of woodland at Lugton Bogs, before entering farmland. The woodland is poorly managed, with large volumes of woody debris in the channel; see Figure 4. The presence of this material in the channel has helped to create a somewhat morphologically diverse channel, with some steps and pools, and erosion and deposition processes evident. However, it is likely that woody debris could be transported downstream during high flows as the majority has been stripped of branches and is unanchored.

Figure 4 Dean Burn in the woodland area

The burn is more confined in the wooded reach, with some steep banks in sinuous sections, acting as a local source of fine sediment and some smaller gravels (Figure 5 to Figure 7). Some deeper pools have formed in these areas, which would normally be indicative of active transport of material, flushing out and maintaining the pools. It is likely in this case that finer material is flushed through the pools in higher flows but undersupply of the coarser bedload has inhibited infilling.

Figure 5 Erosion and deposition features

Figure 6 In channel sediment with local sinuosity

Figure 7 In channel deposition in woodland area with fallen trees (or wood dumped in) and dropping out of fines.

Downstream of the woodland, the watercourse is realigned and deepened through agricultural land and subsequently culverted below the A720, A6106 and the Borders Railway (see Figure 8 and Figure 9).

Figure 8 Modified reach of the Dean Burn

Figure 9 A7 road culvert looking downstream

Channel design

The capacity of the channel has been designed to match the existing channel so as not to increase flood risk. This has been tested within the existing 1D-2D ISIS Tuflow hydraulic model (see Appendix to Chapter 6 – A720 Sheriffhall Junction Improvement: Flood Risk Assessment). The planform of the low flow channel has been developed to mimic the tight bends seen in upstream sections, which display morphological diversity and includes riffle features at strategic locations to create the expected features and to ensure no disruption to sediment transport continuity following construction. The width of this low flow channel is approximately 1.5m, within the wider cross section (approx. 5.5m wide). The proposed indicative planform is shown in Figure 10.

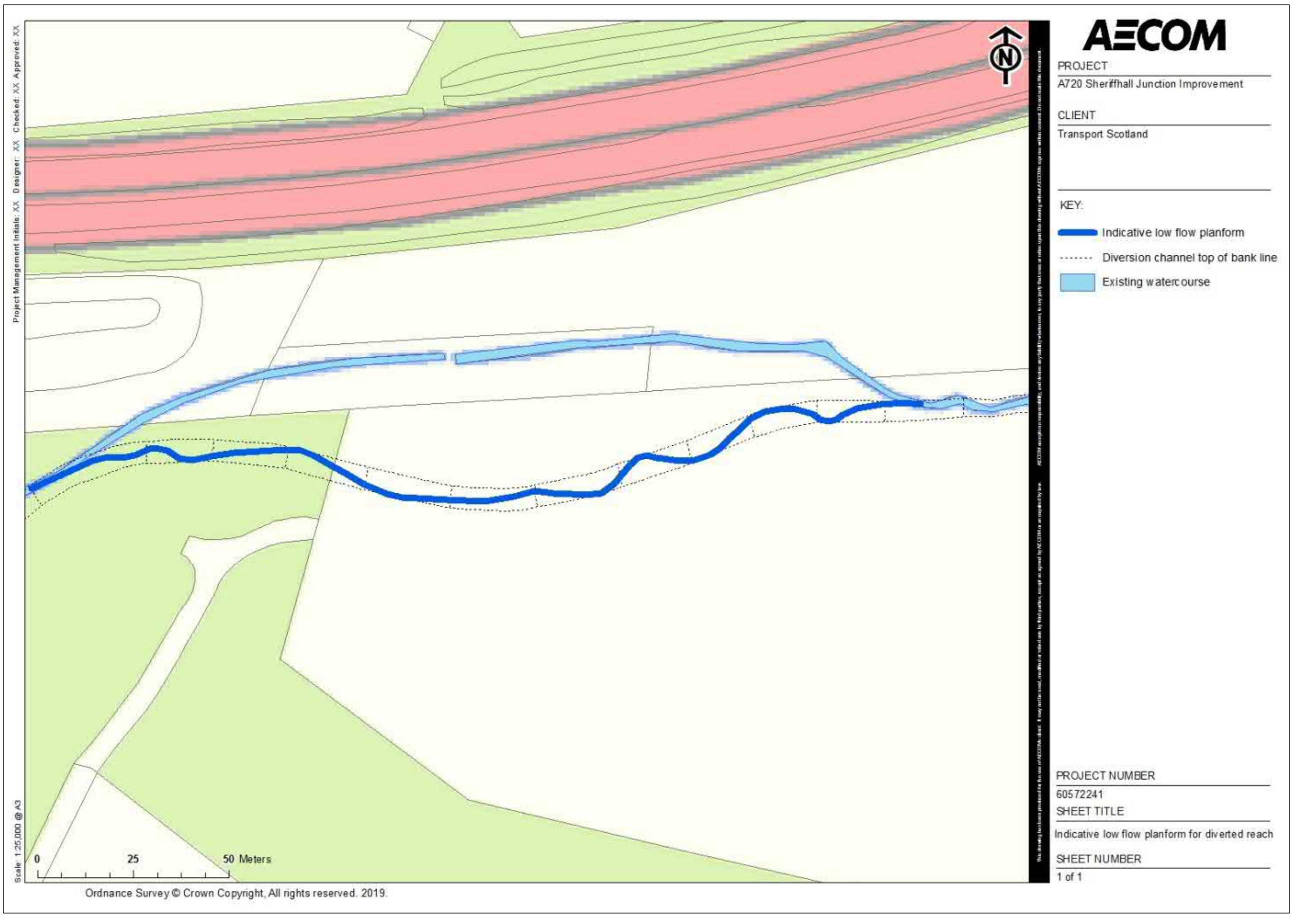


Figure 10 Indicative planform of the low flow channel for the Dean Burn

A two stage channel design is proposed, to allow for some enhancement of the watercourse where it has been canalised and straightened historically. This allows for a low flow channel proportioned to convey approximately the 1 in 2 year flow and a wider channel above this to convey higher flood flows. The bed features introduced to the diverted channel would be sustainable within the low flow channel and the flood flows would be contained in the wider channel area.

A typical cross section profile recommended for the Dean Burn realigned reach is shown in Figure 11 below.

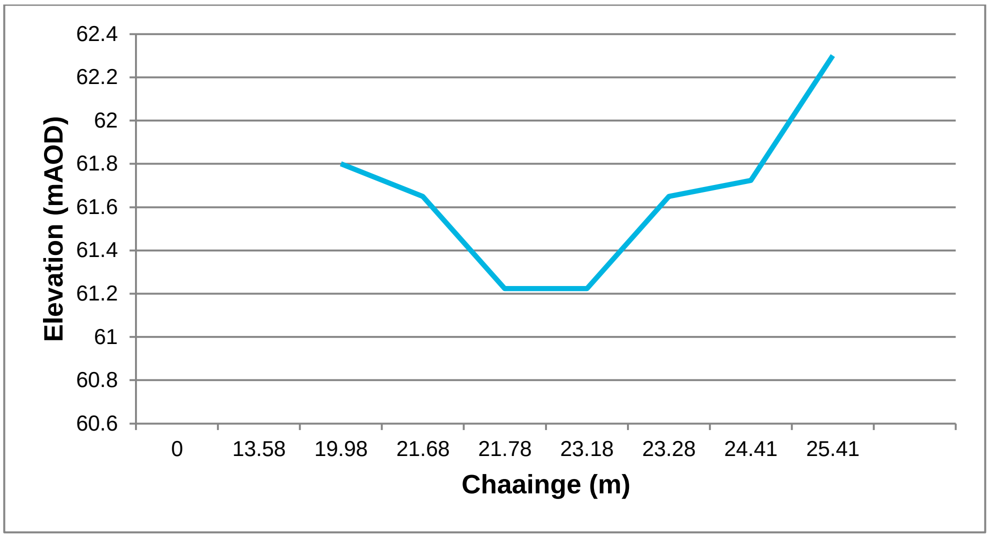


Figure 11 Typical cross section used in the hydraulic model for the diverted reach

Riffle and pool sequence

The ability of a watercourse to transport sediment is indicated by the bed shear stress values. This is a function of the water density, water depth and channel slope.

Baseline maximum cross section shear stress values range from 20-78 (N/m^2) in a 1:2 year event, 22-93 (N/m^2) in a 1:5 year event and 24-103 (N/m^2) in a 1:10 year event. This indicates that the watercourse is capable of transporting material up to coarse gravel to fine cobble.

Grain sizes seen in the channel bed and in the banks of the burn upstream indicate that there is a dominance of fine material, with little mobile gravel. Therefore it is anticipated that riffles will become choked with fine sediment input leaving only a coarse surface layer above a matrix of sand and fine gravels. This is not an ideal outcome but is related to the wider management of the Dean Burn system. The channel should be narrowed and deepened slightly between the riffles to increase the diversity.

The recommended design of the pools and riffles proposed is given in Figure 12 and Figure 13.

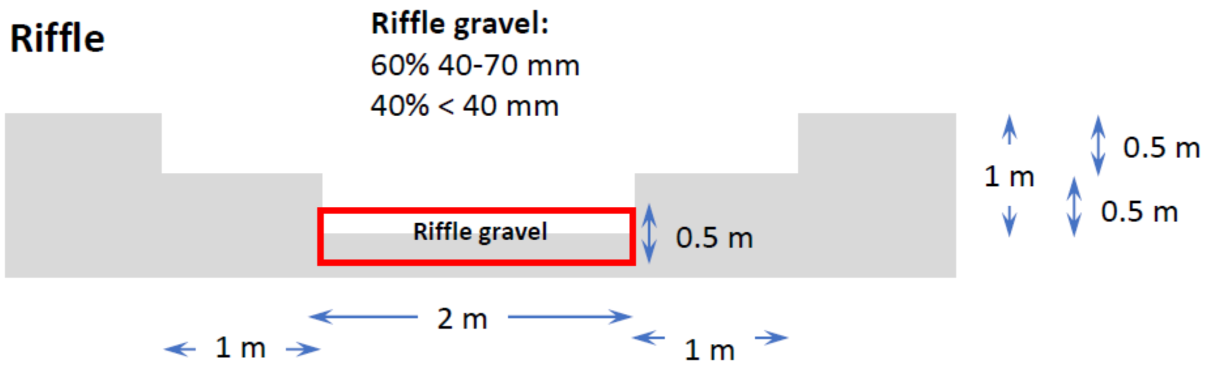


Figure 12 Recommended riffle design

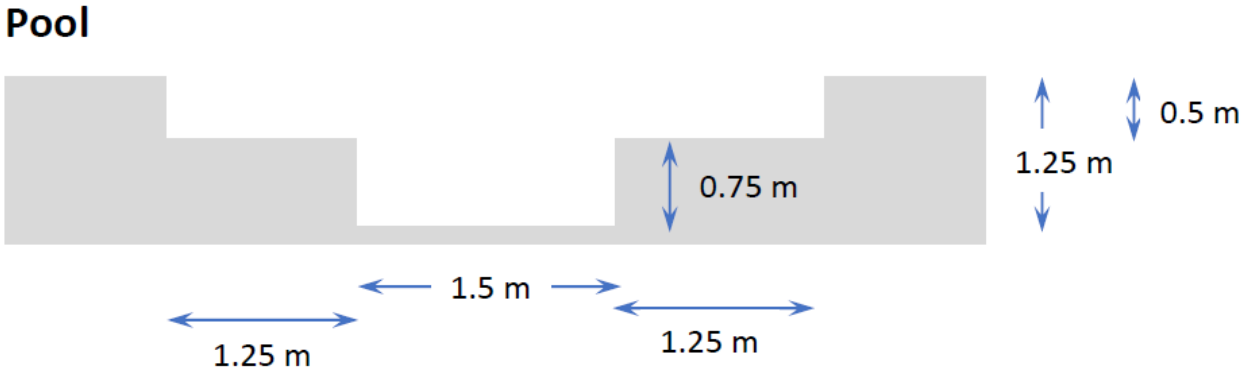


Figure 13 Recommended pool design

Construction would be undertaken by simple placement of appropriate gravel in the required locations and grading to the specified height. The indicative locations of riffles are provided in Figure 14.

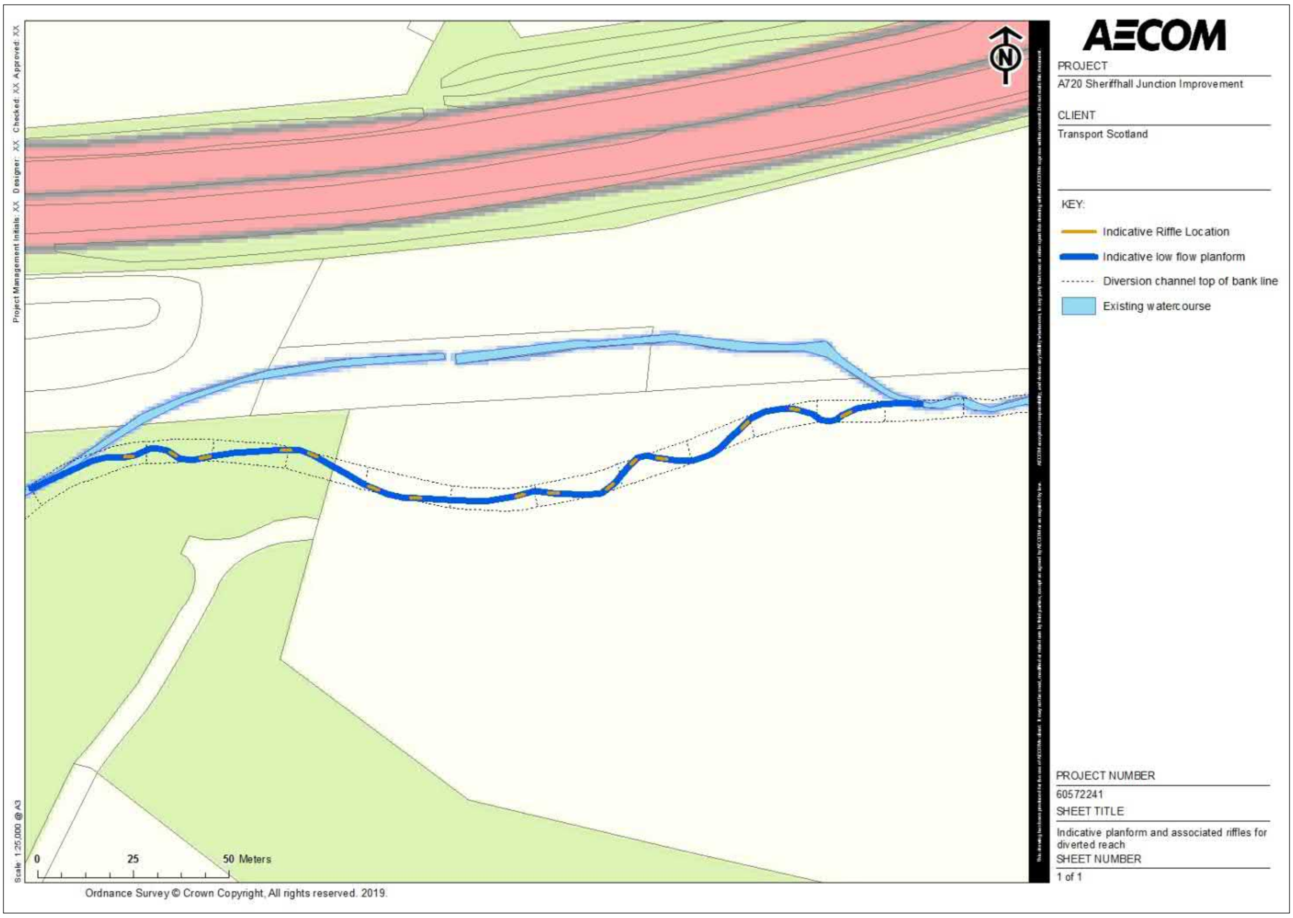


Figure 14 Indicative riffle locations on realigned reach of the Dean Burn

Conclusion

The Dean Burn is a modified watercourse, which suffers from high fine sediment input and little active transport of coarse material. The realigned channel design should include features to improve the morphological diversity where possible, while maintaining channel capacity and stability.

The assessment of the existing channel morphology and hydraulic modelling results has allowed recommendation to be made regarding the channel design. These recommendations include the provision of a two stage channel, with a series of riffles and pools designed to withstand flood flows, within a planform mimicking that seen in upstream reaches.

Appendix 11.3 – Flood Risk Assessment

AECOM

A720 Sheriffhall Junction Improvement

Flood Risk Assessment

05 March 2019

Quality information

Prepared by	Checked by	Approved by
Morag Hutton Senior Hydrologist	Aisling Marlow Engineer	Dylan Huws Associate Director

Revision History

Revision	Revision date	Details	Authorized	Name	Position
01		Draft baseline conditions for review			
02		Baseline FRA with updates based on SEPA comments			

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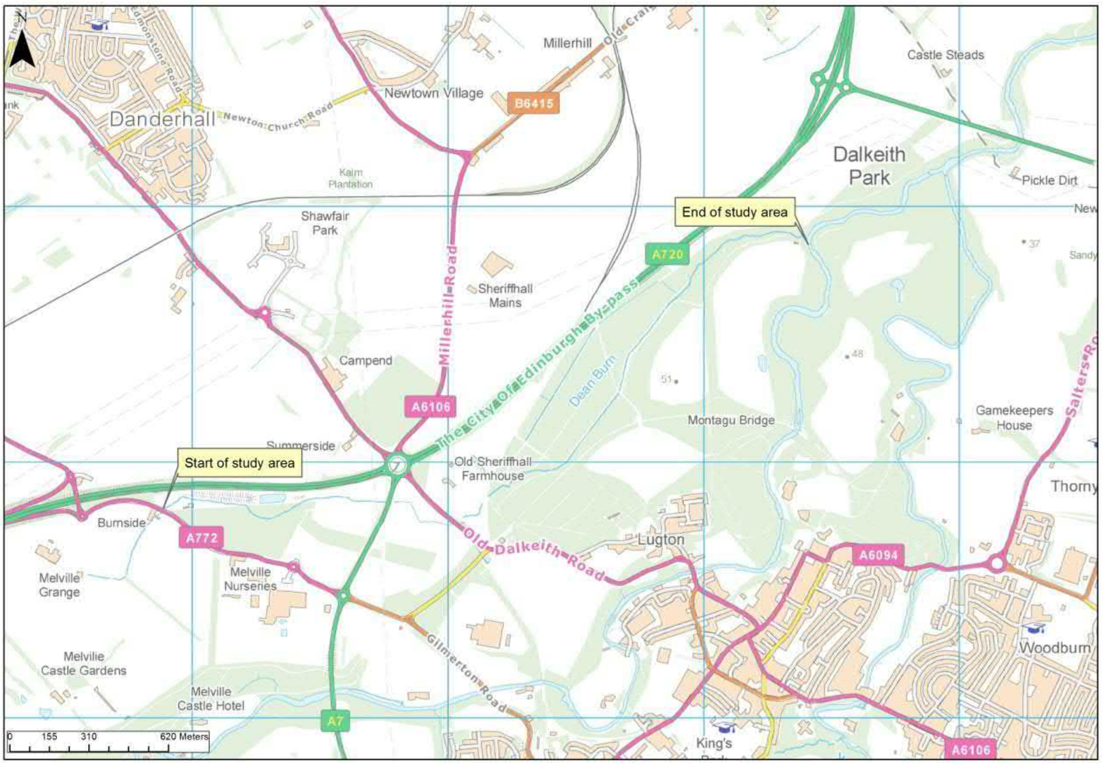
Figures

Tables

1. Introduction

AECOM was commissioned by Transport Scotland to undertake a Flood Risk Assessment (FRA) as part of the wider A720 Sheriffhall Junction improvements that will feed into the Environmental Impact Assessment (EIA). The Sheriffhall roundabout is located at 331803, 667984 and the proposed development includes a flyover for the A720 bypass, with a roundabout connecting the A roads underneath. The works will also include additional cycle network provision. The study area is shown in Figure 1-1.

The aim of the FRA is to assess the current flood risk to the site from the Dean Burn which runs parallel to the A720, assess the impact of the development (if any), and to develop mitigation options if required to ensure that flood risk is not adversely affected elsewhere as a result of the development.



Ordnance Survey © Crown Copyright, All rights reserved. 2019

Figure 1-1: Site location

2. Data collection and Site Appraisal

2.1 Site description

The Sheriffhall roundabout is located to the south east of Edinburgh and connects the A720 with the A7, Old Dalkeith Road and Millerhill Road. It is surrounded on all sides by open fields and forested areas.

The Dean Burn runs almost parallel to the A720 throughout the duration of the study area before joining the North Esk 1.5km downstream. The route of the watercourse appears to have been modified from natural, although the current alignment can be seen on historic mapping as far back as 1850. The channel is set relatively deep compared to the floodplain, with moderately steep, densely vegetated banks throughout. The bed of the channel is comprised of rocky material of varying sizes with frequent obstructions such as tree roots and terrestrial debris. A mixture of rough grazing and forest upstream of the Old Dalkeith Road is observed on the floodplain, before changing to dense forest as the watercourse runs through Dalkeith Country Park.

The Dean Burn runs through several inline structures in the study area. These include openings under dividing walls, the culverts under the A7, Old Dalkeith Road and Borders Railway line, as well as various smaller footbridge and access crossings in Dalkeith Country Park.

Upstream of the site, the catchment is predominately rural, with a section of the town of Loanhead occupying the northern extent.

Site topography can be seen in Appendix C.

2.2 Site visit

A site walkover was undertaken in August 2018 to establish the general topography and constraints on the Dean Burn, review possible flood flow routes and assess the viability of potential mitigation options should they be required.

The area in and around the Dean Burn was seen to be overgrown and numerous natural channel obstructions, such as tree roots, leaves and branches were observed. Areas of bank erosion, specifically around the wooded areas at the irrigation pond, were seen to result in localised lowering of the banks. The channel was seen to be very irregular, with changes in width between approximately 1 – 5m.

A number of culverts and crossings had blockages which would affect conveyance at higher flows. No blockages were noted at the culverts running under the A7 and Old Dalkeith Road. These culverts were very large and likely oversized.

Photographs can be found in Appendix A.

2.3 Review of flooding

2.3.1 Historic flooding

There were no historic flood records available at the site and surrounding areas. This does not however mean that the area has not experienced flooding in the past.

Whilst ground investigation works were being undertaken as part of the wider project, out of bank flow was observed downstream of the irrigation pond on the left hand bank. This flow was sufficient to halt works although may have been somewhat exacerbated by pumping and operations in the area at the time.

2.3.2 SEPA floodmaps

The most recent SEPA flood risk maps were published in March 2015. The maps cover the whole of Scotland, and provide a strategic level of information on the potential sources and impacts of flooding, including coastal, fluvial, surface water (pluvial) flooding. They also show the Potentially Vulnerable Areas identified by SEPA as part of the flood risk management process under the Flood Risk Management (Scotland) Act 2009. Because the maps have been developed on a national scale, there are limitations in the data used, and they should be viewed as indicative only at local scale.

The fluvial flood maps were developed for all catchments greater than 3 km^2. Flooding is seen to be fairly well contained to the channel along much of the study reach. The mapping indicates flooding in the woodland around the irrigation pond. Out of bank ponding is also observed in a low lying area on the right hand bank upstream of the A7 culvert. A flow pathway extends across the left hand bank between the A7 and Old Dalkeith Road, with the potential for some localised ponding. Downstream of the Old Dalkeith Road, flow exits the channel and runs along the southern edge of the Borders Railway embankment.

Surface water flood maps are derived from pluvial model results. Pluvial modelling assumes losses due to drainage networks in urban areas. Pluvial flooding is shown across much of the same extent as in the fluvial mapping.

Fluvial and surface water flooding can be viewed on SEPA's website: http://map.sepa.org.uk/floodmap/map.htm

2.4 Proposed works

The Sheriffhall roundabout upgrade will include construction of a flyover for the A720, with the remaining roads joining into a roundabout underneath. Sunken further from this, a new cycle and footpath network will be created. The works are classed as 'Essential infrastructure' and SEPA's Flood Risk and Land Use Vulnerability Guidance states that it is generally suitable to develop this land use type in areas at medium to high risk for operational reasons or if an alternative is not available. It is noted that the design should remain operational during floods.

These works will include road realignments and elevation changes, creation of new foot and cycle paths, and widening of the existing A720 and associated embankments to account for the flyover. The design also includes several SuDS features, to treat and attenuate the increased hardstanding, which have spatial constraints relating to tie in levels and discharge locations.

Where possible, and using an iterative approach, the layout has been designed to avoid the functional floodplain. However, there are areas where this is not possible.

Mitigation measures may be required if the scheme is seen to affect flood risk out with the site.

3. Hydrology

3.1 Methodology overview

The Flood Estimation Handbook (FEH) gives guidance on rainfall and river flood frequency estimation in the UK and also provides methods for assessing the rarity of notable rainfalls or floods. A number of methods of flood estimation are presented, including the FEH statistical method and the FEH rainfall-runoff method. Subsequent publications have presented the ReFH and ReFH 2 rainfall-runoff method, updating the FEH rainfall-runoff method.

The statistical method relies on deriving a representative growth curve for the subject site from a pooled group of hydrologically similar catchments for which there is gauging information. This means that the accuracy of the method and resulting flow estimate depends on there being a sufficient number of similar catchments contained in the gauging station database. The method assumes that the flood statistics within the periods of record in the pooling group are representative of the flooding regime in the future, i.e. that the data is stationary. However, the method is based on actual observed flood data, and is therefore considered to be more robust than the more conceptual rainfall-runoff methods.

The statistical method consists of two parts; estimation of the median annual flood (QMED), i.e. the flood event with an annual exceedance probability of 50% (1 in 2 year return period), and the derivation of a pooled or single-site growth curve. The growth curve is then multiplied by the QMED estimate to provide a flood frequency curve for the subject site.

The best estimate of QMED is determined using flood data at the site if such local data exists. Alternatively if no such data exists, QMED can be estimated from FEH catchment descriptors and improved by data transfer from a suitably hydrologically similar donor gauge.

WINFAP-FEH is a software tool that supports the statistical flood frequency estimation methods as presented in Volume 3 of the FEH. It provides single-site and pooled group methods of frequency analysis based on annual maxima data from a database of gauged catchments. WINFAP-FEH files (Version 6) gauging station data was used to generate a hydrologically similar pooling group of sites using WINFAP-FEH v4 software. The database contains the annual maximum (AMAX) series data for each station in the database giving AMAX series up to and including the 2015 water year for the majority of UK gauges. Each station within the pooling group was checked and found to have AMAX series up to and including the 2015 water year. Similarity is judged using a distance measure derived from the difference in floodplain extent (FPEXT), rainfall (SAAR) and catchment area (AREA) between the subject site and the gauging station sites. The total data record from the resulting group should amount to around 500 years of data as recommended in *Science Report SC050050*. The pooling group is then used to predict a growth curve, which is combined with the index flood QMED to provide flow estimates for flood events of varying severity.

The FEH rainfall-runoff method has been updated with the ReFH2 rainfall-runoff method. This method utilised catchment specific descriptors to assess catchment functioning and runoff. ReFH2 is now accepted by SEPA as it incorporates a larger Scottish dataset, includes more small-catchment data, utilises the most up to date 2013 rainfall DDF (Depth, Duration, Frequency) model data and incorporates an improved method for assessing urban losses.

Given the size of the catchment, 6.2km^2, both the statistical and ReFH2 methods were undertaken for a comparison before finalising the choice of method. Flow estimates for the Dean Burn catchment were determined for the total catchment at the downstream extent of the study area for input into the hydraulic model.

3.2 FEH catchment characteristics

3.2.1 Standard updates

Catchment characteristics for the Dean Burn study area were extracted from the FEH Web-Service and are presented in Table 3-1. These values were updated where appropriate. The area of the catchment was modified slightly from the delineation provided by the FEH Web-service to account for differences in terrain identified using LiDAR. The original area of the catchment was 6.99 km^2. Figure 3-1 displays the FEH default and the amended catchment area. DPLBAR was updated due to the change of catchment area as the two are inherently linked. URBEXT was also uplifted to current day.

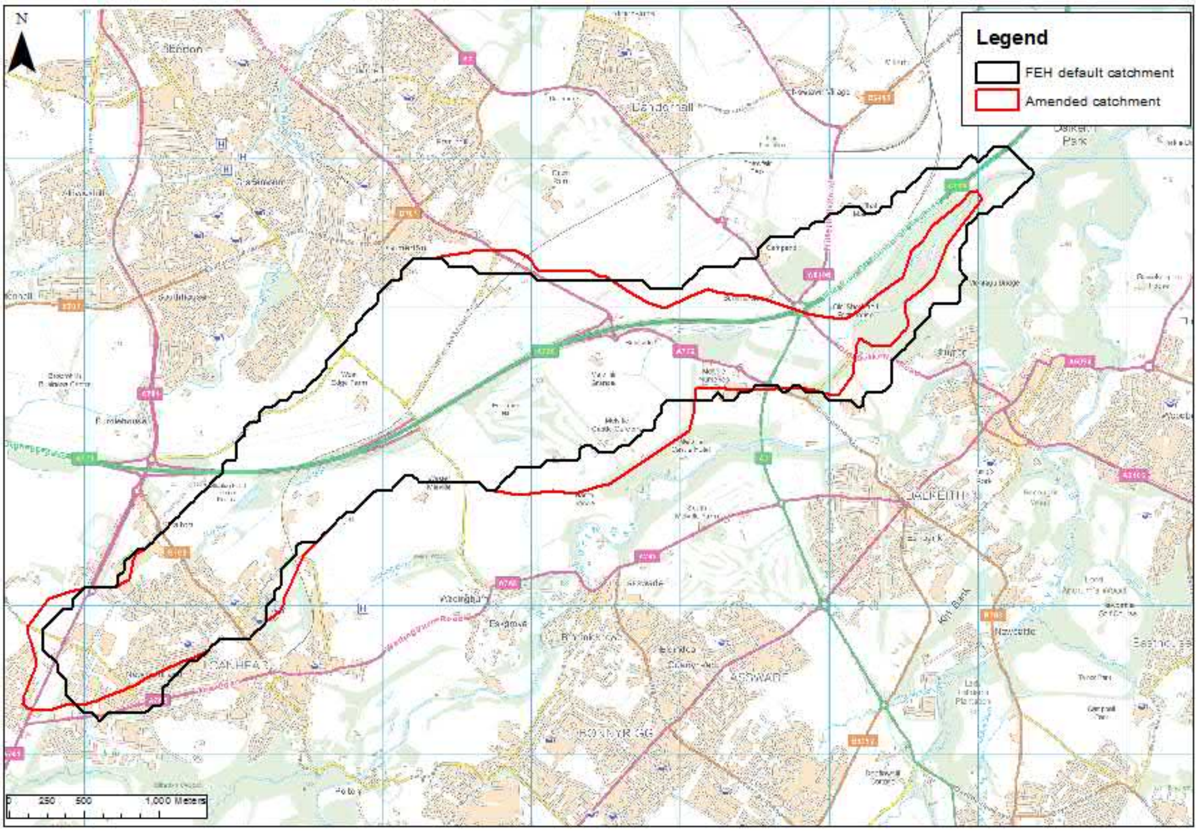


Figure 3-1: Catchment delineations

3.2.2 BFIHOST update

The BFIHOST value obtained from the FEH download was unusually high for this area. Whilst this FEH value is based on geological and soil maps and should therefore give a relatively accurate indication of catchment responsiveness, it was felt, that after correspondence with SEPA as well as further investigation, that this value should be reduced to tie in with the surrounding catchments.

The Dean Burn catchment is not gauged and therefore is not represented in the Institute of Hydrology's Base Flow Index map of Scotland. The surrounding catchment's BFI values ranged from 0.4 -0.64.

Bedrock and superficial deposit maps were then considered to determine the most similar local gauged catchment to the Dean Burn as a catchment with similar underlying geology is likely to have a similar BFI. The Dean Burn catchment bedrock consists of sedimentary rock, largely limestone, with superficial deposits of sedimentary glaciofluvial and till.

The local catchments with lower BFI values around 0.4 were seen to extend over areas of igneous bedrock with minimal superficial deposits, making them relatively impermeable. These catchments are unlikely to react to rainfall in the same manner as the Dean Burn catchment and were discounted from this assessment.

The bed rock and superficial deposits of the North Esk catchment were consistent with the Dean Burn catchment. The Dean Burn also flows into the North Esk and the BFI for this watercourse is between 0.5-0.54. The default Dean Burn BFIHOST value of 0.719 was updated to 0.52 based on its similarity to the North Esk catchment underlying geology.

3.2.3 SPRHOST update

Given the inherent link between BFIHOST and runoff, the SPRHOST value was also updated. This was done by applying the following equation from the Flood Estimation Handbook, vol3:

$$RESHOST = BFIHOST + 1.30\left(\frac{SPRHOST}{100}\right) - 0.987$$

Table 3-1: FEH Catchment Parameters for Dean Burn at Downstream Extent of Subject Site

Catchment Parameters	
NGR	NT 33350 68900
AREA (km^2)	*6.19* updated from default catchment of 6.99*
SAAR (mm)	*685*
FPEXT	*0.0533*
BFIHOST	*0.52* updated from default catchment of 0.719*
SPRHOST (%)	*41.64* updated from default catchment of 26.33*
FARL	*0.992*
PROPWET	*0.49*
DPLBAR (km)	*2.72* updated from default catchment of 4.66*
DPSBAR (m/km)	*37.4*
ALTBAR (m)	*102*
ASPBAR (degrees)	*73*
ASPVAR	*0.51*
LPD (km)	*9.23*
RMED-1H (mm)	*8*
RMED-ID (mm)	*29.5*
RMED-2D (mm)	*43.3*
SAAR4170 (mm)	*686*
URBEXT2000	*0.0952* updated to current day*

3.3 Statistical analysis

Statistical analysis was undertaken on the Dean Burn to establish peak flow estimates. Given the size of the catchment, there are inherent uncertainties using this method as there are only a small number of similar small catchments in the data set.

3.3.1 QMED estimation

QMED is defined as the median annual flood, i.e. the flood event with an annual exceedance probability (AEP) of 50% (1 in 2 year return period).

With no gauged data at the upstream extent of the model, the FEH recommended method to derive QMED is by data transfer from a hydrologically similar donor catchment. This donor transfer was carried out within the WIN-FAP v4 software, using both the multiple station method and the single station method. The single site donor urbanised adjustment method has been selected as the preferred method because the single donor catchment was very similar to the Dean Burn and therefore a strong candidate. The donor catchment used is the West Peffer Burn @ Luffness. Details of the donor selection can be found in Appendix B. Transferred QMED values are shown in Table 3-2.

Table 3-2- QMED Donor Adjustment

Water Course	QMEDcd	QMEDadj (6 sites)	QMEDadj (1 site)	**QMEDadj (1 site)(urbanised)**
Dean Burn	1.23	1.47	1.09	**1.25**

3.3.2 Pooled growth curve

The resulting default pooling group was then reviewed in WINFAP and a number of adjustments were made. This mainly comprised of removing sites with short records, low BFIHOST values and poor suitability comments. Details of the default and reviewed pooling groups are included in Appendix B.

The best fitting statistical distribution was the GL (Generalised Logistic), and the heterogeneity measure H_2 was 1.86, possibly heterogeneous.

Table 3-3 shows the flood frequency curve for the Dean Burn using the pooling group.

Table 3-3-Growth Curve and Flood Frequency Curve for Dean Burn

Return Periods	Pooling group growth curve for Dean Burn (GL)	Peak flows for Dean Burn (m^3/s)
2	1.000	1.25
5	1.370	1.72
10	1.649	2.07
20	1.957	2.45
30	2.156	2.70
50	2.433	3.05
100	2.861	3.58
200	3.361	4.21
500	4.158	5.21
1000	4.883	6.12

3.4 ReFH2

The Revitalised Flood Hydrograph Method 2 (ReFH2) was undertaken as a comparison to the flow estimates generated using the Statistical method. ReFH2 is now accepted by SEPA and is suitable to use on a catchment of this size. This ReFH2 method has also included improvements on how permeable catchments are considered.

Catchment descriptors and delineations were obtained from the FEH Web Service and updated as set out in Section 3.2. ReFH2 software, using the winter storm profile given the rural nature of the catchment, was used.

Peak flows from the analysis are shown in Table 3-4.

Table 3-4: ReFH2 Peak Flow Results

Return Period (yr)	Peak flows for Dean Burn (m^3/s)
2	1.41
5	1.85
10	2.19
20	2.57
30	2.83
50	3.22
100	3.90
200	4.69
500	5.87
1000	6.86

3.5 Method selection

The REFH2 results gave higher peak flow estimates than the Statistical method, which is conservative. Due to the small size of the Dean Burn catchment, it is also difficult to find similar sized gauged catchments for use in the statistical method, which reduces certainty in the results. For these reasons, the REFH2 method was used for establishing peak flows in the Dean Burn.

The standard ReFH2 derived hydrograph was used as there was no gauged data on the watercourse to be used to generate an alternative.

Table 3-5 displays the comparison of the Statistical analysis and ReFH2 peak flow estimates.

Table 3-5- Summary of peak flows for the statistical and ReFH2 method

Return Periods	Statistical peak flows for Dean Burn (m^3/s)	**ReFH2 peak flows for Dean Burn (m^3/s)**
2	1.25	**1.41**
5	1.72	**1.85**
10	2.07	**2.19**
20	2.45	**2.57**
30	2.70	**2.83**
50	3.05	**3.22**
100	3.58	**3.90**
200	4.21	**4.69**
200 +CC	5.09	**5.87**
500	5.21	**6.86**
1000	6.12	**6.86**

3.6 Climate change

The United Kingdom Climate Projections 2018 (UKCP18) dataset was published in December 2018 and outlines updated probabilistic projections of climate change impact for the 2020's, 2050's and 2080's based on various emissions scenarios and probability percentiles. United Kingdom Climate Projections (UKCP09[1]) is a previous version of the projections and since little guidance has been provided on how these new 2018 uplifts in rainfall relate to increases in flow, the UKCP09 flow uplifts are still considered to be the most appropriate.

Outlined in their Flood Modelling Guidance for Responsible Authorities, SEPA commissioned CEH to undertake a study assessing Scottish catchments vulnerability to climate change. Within this study the UKCP09 projections were run through models to provide flow uplift for hydraulic basins. This provides a more accurate representation of the increase to fluvial flows.

Based on the medium emission scenario 2080s, 50th percentile, the study area is reported to have a 21% change in flood peak as shown in table 10-1 of the SEPA Flood Modelling guidance. For the purpose of this flood study, a 21% uplift has been adopted for climate change scenario to come in line with SEPA's Technical Flood Risk Guidance. The medium emission scenario 2080, 90th percentile change in flood peak will also be applied to the modelling to assess sensitivity. This is reported to be 40% for the study area.

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[1] UK Climate Projections, *United Kingdom Climate Projections (UKCP09) Rainfall Maps*, June 2009

4. Hydraulic Modelling

4.1 Baseline model build

A single hydraulic model has been constructed for the Dean Burn and surrounding areas at Sheriffhall consisting of a one dimensional element representing the river channel built in Flood Modeller and a two dimensional element representing the floodplain constructed in Tuflow.

4.1.1 One dimensional channel model

A one dimensional model of the Dean Burn was constructed using surveyed cross sections and inline structures. Details of the sections and structures can be found in Appendix C. The survey was undertaken as part of this study and was used to represent the channel geometry and to define the top of bank. The model consists of 50 surveyed river sections, 2 bridges, and 4 culverts. The openings under the dividing wall upstream of the A7 were not surveyed but were included in the model based on photographs. All structures in the modelled reach were included in the model with trash screens applied where appropriate. When the downstream section of the bridge was not surveyed, a copy of the upstream face was used. During the baseline model runs, all structures were assumed to be clear of obstruction. No changes to default structure parameters were made.

The modelled reach extends from the A722 at Burndale to 500m downstream of the Old Dalkeith Road. Section labelling around the site can be seen in Figure 4-1 and will be referenced later in the report to describe flood risk at certain locations. A full schematisation of the river sections and 2D domain can be seen in Appendix C.

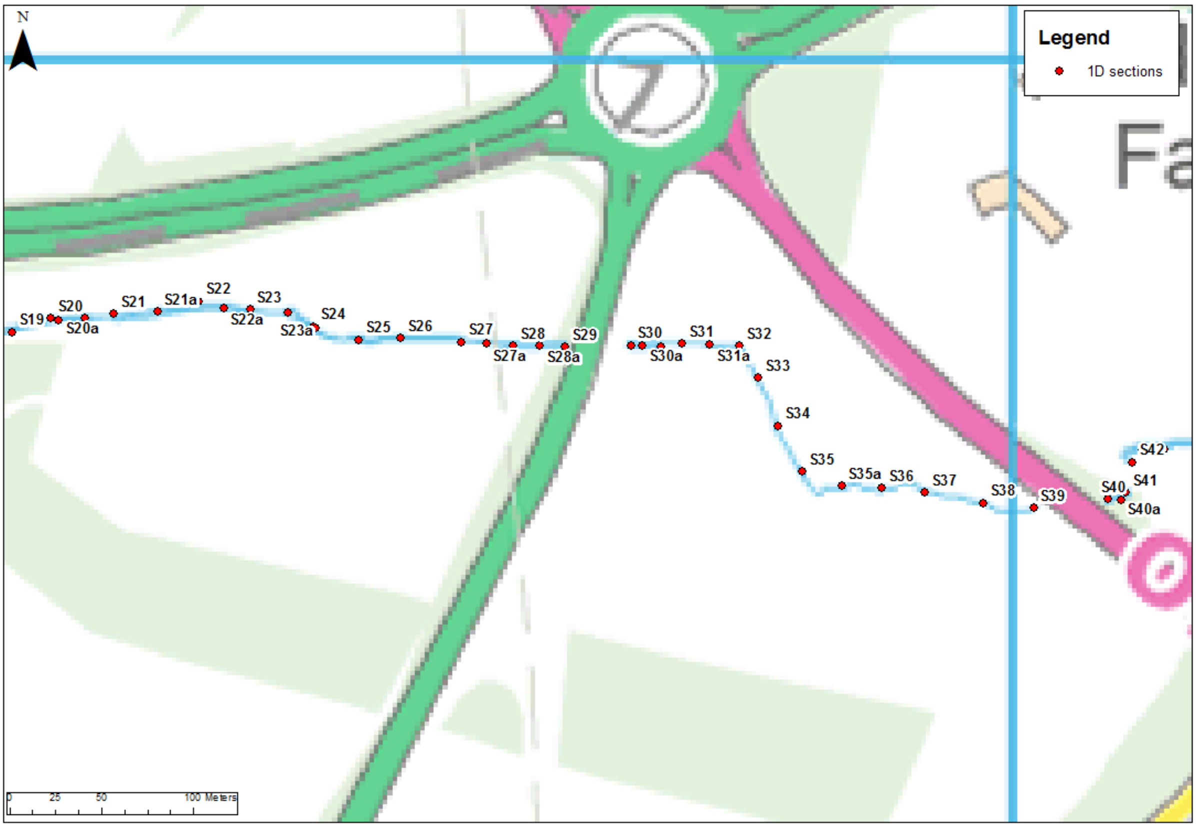

Figure 4-1: Cross section labels around the site

The inflow hydrograph, as calculated in Section 3.5, was applied at the upstream extent of the model. The downstream boundary was represented as a normal depth boundary, based on channel bed gradient, to allow flow to leave the model. A normal depth boundary was deemed appropriate as the influence of the River North Esk would not affect water levels at the site of interest due to the steep nature of the channel. The normal depth boundary in its location further upstream from the North Esk also did not affect water levels at the site.

Channel and bank Manning’s ‘n’ roughness values were selected based on photographs and the site visit. The channel is predominantly natural along its reach. Due to the weedy stony nature of the channel, bed roughness was set between 0.045 and 0.05. Only minor sections of floodplain and banks were represented in the 1D model as the majority of the top of bank was represented in the 2D domain. Intermittent long grass banks were set at 0.04 and denser vegetated banks set at 0.045.

4.1.2 Two dimensional floodplain model

The 1D channel model was linked to a 2D domain (ground surface model) so that the overland flood mechanisms could be assessed. The 2D hydraulic model contained the following elements:

- Ground surface using 1m LiDAR Digital Terrain Model (DTM);
- Topography modifications where LiDAR does not accurately represent the ground surface – primarily between the A7 and A6106;
- 1D/2D links to allow free flow between the river channel and floodplain based on surveyed top of bank elevations. Downstream of Old Dalkeith Road, top of bank was not surveyed and is based on LiDAR;
- Roughness layer depicting different surfaces based on OS Mastermap data representing buildings (n = 0.5), roads (n= 0.02), fields (n=0.045), wooded areas (n=0.1) and water (n=0.03). A default roughness of 0.06 was applied to all other surfaces to represent short to medium grass contained by fences and hedges;
- Downstream boundary – Automatic HQ (head/flow) boundary applied to the downstream extent of the floodplain to allow water to escape the domain and not cause artificial ponding;
- The LiDAR was found to adequately represent the road and rail embankments and no modifications to topography were made;
- A field diving wall was added into the 2D domain as a z-line in the upstream section of the model and was assumed to remain standing. The Dean Burn flows under this wall at 3 locations and these openings were represented by orifice units based on site photographs.

4.1.3 Model run parameters

The 2D domain was set at a 2m grid size so that the channel and flow pathways could be accurately represented.

The model was run using a 0.5 second 1D timestep and a 1 second 2D timestep, with no changes to default run parameters. The 1D/2D model was run unsteady, i.e. time varying flow, for the required return periods set out in Section 3. This allowed for the flood progression to be fully assessed in both the 1D channel and the 2D floodplain.

4.2 Scheme model build

Where possible, and using an iterative approach, the layout has been designed to avoid the functional floodplain identified in the baseline modelling. However, there are areas where this is not possible due to topographic or space constraints. A drawing displaying the proposed scheme is shown in Appendix C.

The proposed development was modelled to determine how the design affected flood risk when compared to the baseline scenario. This run contains no mitigation measures and is to be used purely to assess how the proposed roundabout upgrades affect flood risk in the surrounding area.

To form the with scheme model, the following modifications were undertaken to the baseline model:

- Sections of the proposed development were stamped onto the LiDAR in areas where the design encroached into the flood extent. The existing ground levels within the footprint of the road embankments were raised to account for the changes in levels associated with the development as this could affect floodplain storage and flood mechanism. Raising levels from the toe of the embankment is slightly conservative;
- The area where SuDS ponds was to be located were also raised in the 2D domain as flood water would no longer be able to enter (due to insufficient capacity for river flows) and would therefore be removed from the functional floodplain;
- The culvert under the A7 was lengthened to accommodate the additional footpath and road realignment.

Figure 4-2 displays the locations of the main DTM modifications made during the with scheme modelling

Figure 4-2: Notable areas of DTM modifications due to design within functional floodplain

4.3 Mitigation assessment

4.3.1 Requirement for mitigation

It is best practice to avoid land raising in the function floodplain. This approach has been applied throughout the design process, however in some cases it has not been possible to avoid development within sections of the functional floodplain. In these instances, outlined below, land raising will need to be mitigated up to the 1 in 200yr design level to ensure no detrimental flood risk.

The main SuDS pond between the A7 and A6106 is to provide a large percentage of the attenuation and treatment requirements of the proposed works and therefore has significant area requirements. Additional constraints such as the Dean Burn and the local topography, which affects where ponds can be located due to network outfalls and discharge locations generally requiring gravity, areas where this large pond could be located were limited. Smaller ponds to the north are used earlier in an event to stagger the peak storms and provide additional storage, however the large pond had to be located in the area between the A7 and A6106. This area is seen to flood and will require compensatory storage to mitigate this loss.

Small sections of the A720 approach road embankments are proposed to run very close to the Dean Burn, in an area of floodplain that is also seen to flood during the baseline scenario. This embankment and approach road is constrained by maximum gradients along the road and also maximum side slopes on the embankment. Given the proximity of the embankment toe to the watercourse, and the potential erosion issues this could cause, it is proposed that the burn be diverted 40m to the south. Realignment of this burn provides an opportunity for river restoration along a reach that is currently canalised and overly deep. The channel would be installed as a restored 2 stage meandering channel created to improve watercourse function and habitat. Compensatory storage will also be provided to account for the loss of floodplain storage. Further details of the design of this diverted stretch of watercourse can be found in the technical note ‘A720 Sheriffhall Junction Improvement: Dean Burn diversion hydromorphology design’ and Figure 5-2.

SEPA’s Technical Flood Risk Guidance for Stakeholders, 2018 outlines a recommended approach for providing compensatory storage if functional floodplain is lost elsewhere as a result of the development. It is noted in this guidance that development within the functional floodplain should be avoided but in certain cases it can be appropriate if compensatory storage is provided so that the development does not affect the ability of the functional flooding to store and convey water. This guidance recommends that ‘like for like’ direct storage is the preferred option for mitigating land raising, with a modelling approach potentially being suitable if it is shown that ‘like for like’ is not a suitable method.

The ‘like for like’ method is applicable where only floodplain capacity is lost and does not take into account a loss in floodplain flow pathway or if the watercourse alignment is altered. To mitigate against a loss of floodplain that contains a flow pathway, and to assess storage loss as a result of watercourse diversion, modelling must be undertaken to assess the relative change in floodplain volume over a range of return periods.

4.3.2 Mitigation assessment and modelling

4.3.2.1 Like for like slice calculations

A total of three areas will be removed from the functional floodplain as a result of the scheme and are shown in Figure 4-3.

It is SEPA’s preferred method to use a ‘like for like’ slice approach and each of the areas was assessed to determine whether this approach was suitable.

It was found that the loss of floodplain in areas 1 and 2 was attributed to the channel diversion and that a ‘like for like’ slice assessment would not be appropriate in these areas due to the significant change in bed and bank levels of the realigned channel. Matching volume at each elevation slice would be unlikely to provide the same flood mechanism given the significant change in topography.

It was also found that due to the flow pathway running through area 3 that a ‘like for like’ slice assessment would also not be appropriate as it would underestimate the floodplain loss downstream caused by cutting of the flow pathway. Matching volume at each elevation on the opposite bank would not take into account the area to the south and may result in a net loss of storage.

Hydraulic modelling was therefore deemed the most appropriate way to determine compensatory storage requirements.

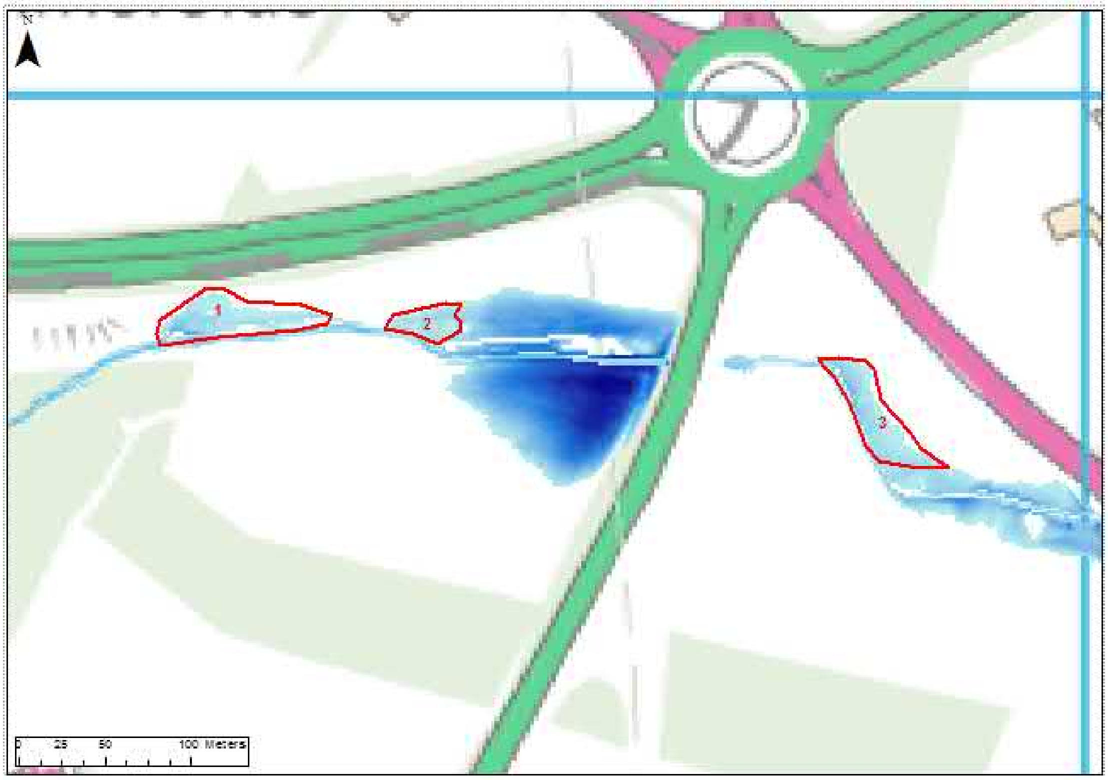

Figure 4-3: Areas that will be removed from the function floodplain

4.3.2.2 Hydraulic modelling of compensatory storage

Modelling was undertaken for all areas shown in Figure 4-3 to ensure that the compensatory storage was adequate, and that it replicated the baseline flood mechanism as closely as possible.

The compensatory storage requirements at the Dean Burn diversion, upstream of the A7 is complex as the river channel will be significantly altered from its original state. The change in alignment, long section and cross section means that the loss and provision of storage must be assessed using the hydraulic model as providing like for like storage is unlikely to adequately account for the changes in the floodplain and channel as elevations have changed significantly.

The compensatory storage at the SuDS pond will also be assessed using the hydraulic model as removing the SuDS pond from the functional floodplain will cut off a flow pathway which currently feeds an area of floodplain that will remain unaltered. Like for like calculations could therefore potentially underestimate the required storage as it would not take into account the flow mechanism and area of unaltered floodplain to the south.

To assess the compensatory storage requirements using the hydraulic model, the LiDAR was lowered along the meander of the realigned channel on both banks as well as in the area on the opposite bank of the main SuDS pond to mimic the lost floodplain storage in all areas. Given the flow path across the left hand bank at the SuDS pond will be cut off, minor lowering of the left bank to the south of the pond was also undertaken to allow flow into this area at the same time in the event as the baseline. The time in the event that spill occurs was matched with the baseline model run to ensure this new area of storage acted as similarly to the baseline scenario as possible. Ensuring that spill occurs at the same time in the baseline and with scheme scenarios means that floodplain storage will not be used too early or late in an event.

The sharp right angle bend in the channel is unnatural and acts as a constriction in the channel. This angle was smoothed in the model to provide an added river functioning benefit as well as less of a constriction to the SuDS pond.

An iterative approach was then undertaken that involved changing bank levels and modifying the elevation and size of the LiDAR modifications until the modelled compensatory storage provided increased attenuation when compared to the baseline. This ensures that like for like is provided based on magnitude of event and total floodplain volume.

4.4 Sensitivity testing

Sensitivity checks were carried out on the hydraulic model parameters where they were considered to be inherently uncertain to explore the effect on model results.

The aim is to understand the range of model results that could be obtained with variation of these parameters. The intention is not to evaluate an accuracy range or otherwise quantify uncertainty; but to give an indication of the influence certain parameters have and identify if there are significant or disproportionate influences.

In line with SEPA guidance, the model parameters tested were:

- Flow,
- Manning’s Roughness,
- Structure Blockages.

Sensitivity to changes in the downstream boundary was not tested as the downstream extent of the model was 500m downstream, with bed levels 6m lower than at the site. It was deemed sufficiently far downstream that the downstream boundary did not influence levels at the site.

4.4.1 Flow

Model sensitivity to flow was tested with a 40% increase for the 1 in 10yr and 1 in 200yr events. This uplift corresponded to the medium emission scenario 2080, 90th percentile change in flood peak.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 1 Appendix D.

Increasing the flow by 40% increased the 1 in 10yr channel water levels by a maximum of 260mm and the 1 in 200yr channel water levels by up to 600mm. These maximum increases are observed immediately upstream of the A7 culvert. Increases in levels are experienced to varying degrees along the length of the modelled reach with the smallest increases being 70mm and 90mm for the 1 in 10yr and 1 in 200yr respectively.

During the 1 in 10yr event, out of bank flow observed in the area upstream of the A7 culvert on the left hand bank is seen to increase. Depths increases in this area reach a maximum of 250mm. Additional flooding that was not observed in the baseline scenario is also observed on the left hand bank between the A7 and the A6106. Flooding locations and extents are seen to increase with a 40% uplift in flow during the 1 in 200yr event. Depths are seen to increase by up to 600mm in the area upstream of the A7 culvert. The area of flooding between the A7 and Old Dalkeith Road has smaller increases in floodplain depths in the order of 200-300mm.

Channel water levels are seen to increase as a result of an uplift in flow. However, it should be noted that location and overall extent of flooding remains comparable, particularly in the lower return periods. Whilst the increases in floodplain depths are not insignificant, the flows used in the baseline model are deemed to be appropriate as they are based on best practice methodologies.

4.4.2 Manning's Roughness

In line with SEPA's modelling guidance Manning's 'n' roughness was increased by 40% in both the 1D channel and 2D floodplain for the 1 in 10yr and 1 in 200yr events.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 1 Appendix D.

Increasing the roughness by 40% increased the 1 in 10yr channel water levels by a maximum of 140mm and the 1 in 200yr channel water levels by up to 440mm. These maximum increases are observed around the A6106 culvert. Increases in levels are experienced to varying degrees along the length of the modelled reach with the smallest increases being 10mm and 25mm for the 1 in 10yr and 1 in 200yr respectively.

During the 1 in 10yr event, very minimal increases to flood extent are observed upstream of the A7. Increases to depths in this area reach a maximum of 25mm. Additional flooding is observed on the left hand bank between the A7 and the A6106. Flooding locations are not seen to change markedly with a 40% uplift in roughness during the 1 in 200yr event. Depths and extents are seen to increase by up to 40mm in the area upstream of the A7 culvert. The area of flooding between the A7 and Old Dalkeith Road has larger increases in floodplain depths in the order of 100-200mm.

Channel water levels are seen to increase as a result of an increase in roughness. The increases are more apparent in the 1 in 200yr event, where extents are increased be approximately 12m in the area between the A7 and A6106. However, the roughness values used in the baseline model are deemed to be appropriate based on channel type and geometry and an increase roughness of 40% would be expected to result in significant uplifts.

4.4.3 Blockages

Blockage scenarios were tested for the1 in 200yr event to assess the impacts on flooding should a structure become partially blocked during a flood event. A total of 3 structures (Figure 4-4) were identified around the site as having the potential to cause increased flooding if they became partially blocked. There were no anecdotal accounts of any blockages at any of the structures. On the site visit undertaken as part of this survey, no blockages were observed in structures 1 and 2 and both were considered to be oversized and unlikely to block significantly. Structure 3 is a much smaller structure and the inlet was seen to be partially blocked by small branches and leaves. Using a conservative approach, all structures were modelled in separate simulations as partially blocked to 50% of the flow area by reducing the cross sectional area accordingly.

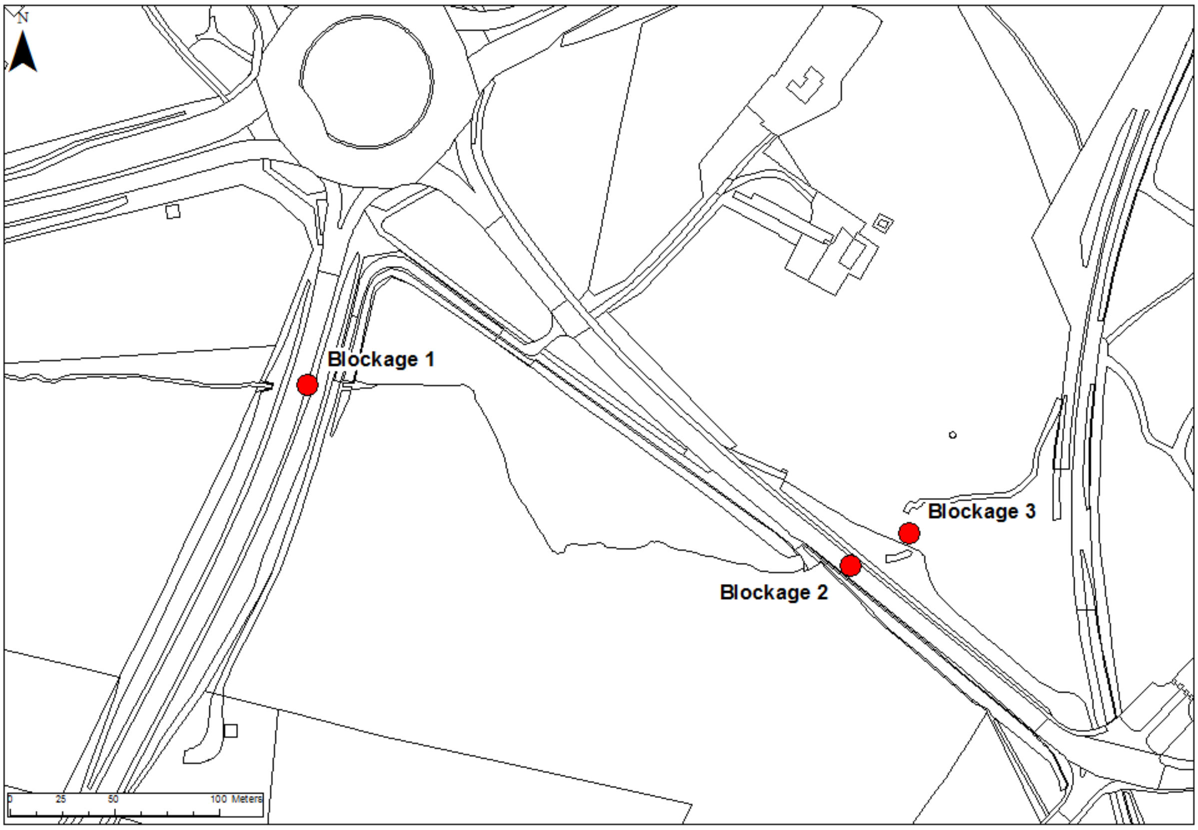

Figure 4-4: Blockage locations

Each blockage scenario was run separately and tabulated results with changes to channel water elevations at various locations are displayed in Table 2 Appendix D.

Decreasing the cross sectional area separately at the 3 structures increased channel water levels by 500mm, 300mm and 600mm for blockage scenarios 1, 2 and 3 respectively.

During blockage scenario 1, in channel water levels were increased by approximately 500mm upstream of the A7 culvert. Floodplain depths and extents were also increased in this location on both banks by approximately 500mm. Out with this area, no other increases to depths are shown. Due to additional flow being held upstream of the A7, out of bank spill is seen to decrease upstream of Old Dalkeith Road by approximately 100mm. The backwater effect is experienced approximately 200m upstream of the culvert inlet. Blockage of this culvert is seen to increase levels near the A7 but does not cause flooding on the carriageway. Due to the size of the culvert, it is also very unlikely that a 50% blockage would occur.

During blockage scenario 2, in channel water levels were increased by approximately 300mm upstream of Old Dalkeith Road culvert. Floodplain depths and extents were also increased in this location on both banks by approximately 300mm. Out with this area, no other increases to depths are shown. The backwater effect is experienced approximately 220m upstream of the culvert inlet. Blockage of this culvert is seen to increase levels near the A6106 but does not cause flooding on the carriageway which is significantly higher.

During blockage scenario 3, in channel water levels were increased by up to 600mm in the area between Old Dalkeith and the railway embankment. The floodplain in this location did not previously flood. During the blockage scenario, depths and extents increased in this location on both banks by approximately 300mm. Flood depths and extents were also seen to have increased upstream of Old Dalkeith Road by approximately 400mm. The backwater effect is experienced approximately 250m upstream of the culvert inlet. Blockage of this culvert is seen to increase levels near the A6106 but does not cause flooding on the carriageway which is significantly higher.

From this testing, it can be seen that increases in channel flood depths are apparent in all blockage scenarios. Floodplain depths and extents are also seen to increase. The increases observed during blockage scenario 1 are not however seen to affect key receptors. The increases during scenario 2 and 3 have the potential to affect flooding around the SuDS ponds. Increased levels as a result of blockage do not cause flooding on either of the carriageways.

This sensitivity analysis is not an analysis on the likelihood of blockage, but an assessment of the severity of flooding impacts should a blockage occur at a particular structure. Identifying the structures where blockage may result in increased flooding, is useful for identifying structures that would benefit from either extra maintenance or additions such as trash screens.

It is recommended that structures are regularly monitored and maintained.

5. Results

5.1 Baseline

During the 1 in 200yr plus climate change event, flooding first occurs on the right hand bank, immediately upstream of the A7 culvert with out of bank flow spreading into a low lying area. Flood depths reach a maximum of 1.65m in this area. As the event progresses, flooding occurs at section 20, downstream of the irrigation pond on the left hand bank. Flood waters travel along the floodplain, parallel to the watercourse, to depths ranging from 50 - 200mm, before re-entering the channel at section 22. At the same time, a flow pathway occurs across the left hand bank between section 32 and 37, equating to 0.4m^3/s at its peak.

Flow exits the channel at section 32 and spreads across the floodplain. The majority of the out of bank spill re-enters the channel between sections 36 and 38. Maximum flood depths in this area reach 280mm. At approximately the same time, flow spills out of bank on the left hand bank upstream of the A7 and the right hand bank upstream of the A6106. Flood depths reach a maximum of 900mm and 500mm upstream of the A7 and A6106 respectively. The flooding extent for this event can be seen in Figure 5-1. Minor flooding is observed on the right hand bank immediately downstream of the A6106 to depths of 300mm.

The remainder of the flow is contained within channel. No out of bank spill is observed downstream of the access track leading onto Old Dalkeith Road.

The A7 and the A6106 were not seen to be at flood risk during a 1 in 200yr plus climate change event.

The flood mechanism is largely replicated in lower return periods, with the first instance of spill at the various locations noted above occurring at different return periods. Flooding is observed in the area upstream of the A7 from the 1 in 5yr event. The onset of flooding for the area around section 20 and flow pathway at section 32 starts from the 1 in 30yr event.

Although there is no historic flood accounts in this rural area, the baseline flood maps tie in well with SEPA flood mapping as also with observed flow routes on site during GI investigations.

A full range of baseline floodmaps for all modelled return periods, with and without climate change, can be found in Appendix E.

Maximum stage in the 1D channel for a range of return periods can also be found in Table 3 Appendix D.

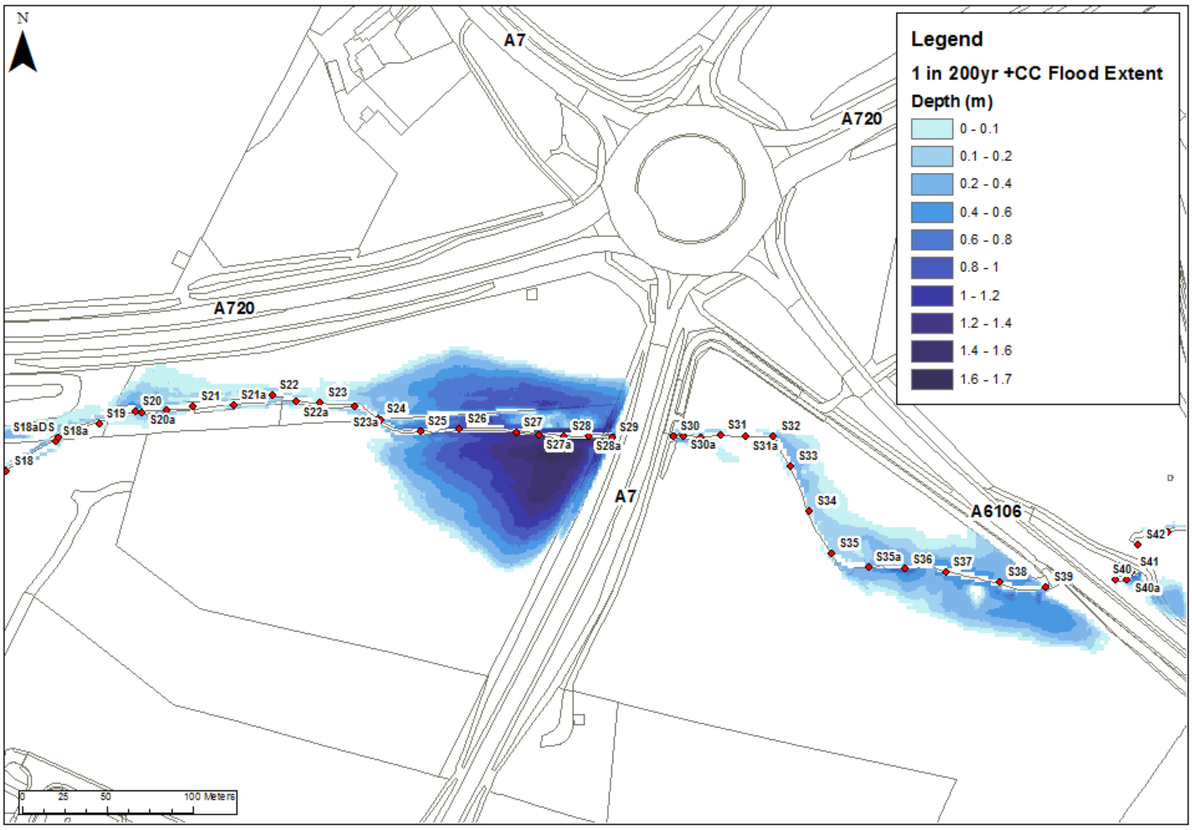

Figure 5-1: 1 in 200yr plus climate change flood depths

5.2 With Scheme

The with scheme model results demonstrates that without mitigation, the proposed scheme has a negative impact on flood risk as a result of loss of floodplain and flow area and is therefore not in line with planning policy.

Floodplain depths upstream of the A7 and the A6106 were increased by approximately 5- 10mm during the 1 in 200yr event and 5-10mm in the 1 in 200yr plus climate change event. Pass forward flows were increased by 0.03m^3/s and 0.025m^3/s through the A6106 culvert for the 1 in 200yr and 1 in 200yr plus climate change events respectively.

Table 5-1 displays the changes in channel water levels at a selection of sections for the 1 in 200yr event. A maximum increase in water level of 50mm is noted at section 32 where out of bank flow originally occurred in the baseline model but is blocked within the scheme model to account for the SuDS pond.

Table 5-1: Channel water levels with and without scheme during the 1 in 200yr event.

Location	Cross section	Baseline maximum stage (mAOD)	With scheme maximum stage (mAOD)
	Section 18	62.82	62.82 (+0.00)
	Section 20	61.99	62.02 (+0.03)
	Section 22	60.57	60.57 (+0.00)
	Section 24	59.99	60.00 (+0.01)
	Section 26	59.68	59.69 (+0.01)
Upstream of A7	Section 28	59.68	59.68 (+0.00)
	Section 30	58.2	58.17* (-0.03)
	Section 32	57.81	57.86 (+0.05)
	Section 34	57.47	57.49 (+0.02)
	Section 36	57.08	57.08 (+0.00)
Upstream of A6106	Section 38	56.99	57.00 (+0.01)
	Section 40	56.69	56.70 (+0.01)

* This decrease related to change in node location and does not represent an actual decrease in water level

The scheme results in a loss of floodplain storage as a result of land raising. The modelling has demonstrated that the proposed scheme increases water levels and pass forward flows and requires mitigation measures to ensure the design complies with planning policy.

5.3 Compensatory storage modelling

5.3.1 Floodplain volumes

The total floodplain volumes at the 2 sections at the realigned channel and on the opposite bank to the SuDS pond were calculated for the baseline and with scheme scenario. The areas of floodplain loss and proposed compensatory storage locations are shown in Figure 5-2. Full details of the land reprofiling are presented in Appendix F.

The proposed compensatory storage for each areas was provided in locations as close as possible to the floodplain loss from the baseline. Due to the river realignment, area 2 is not seen to flood in the with scheme scenario and the compensatory storage has been provided in the same location, with flow filling the area from east. As stated in previous chapters, ground levels were lowered in a manner to ensure that the timings of spill were replicated as closely as possible to the baseline.

Calculating the floodplain volumes for the baseline and with scheme scenarios ensures that at each return period, there is equal to or increased storage from the baseline in the with scheme scenario. Incremental increases between return periods for baseline and with scheme were also calculated. Table 5-2 displays the floodplain volumes in the baseline and with scheme scenarios for the full range of return periods. It is demonstrated that with scheme floodplain volume storage has been increased at every return period from baseline volumes, and that the incremental increases between return periods is also increased. This demonstrates like for like floodplain storage volume at all return periods.

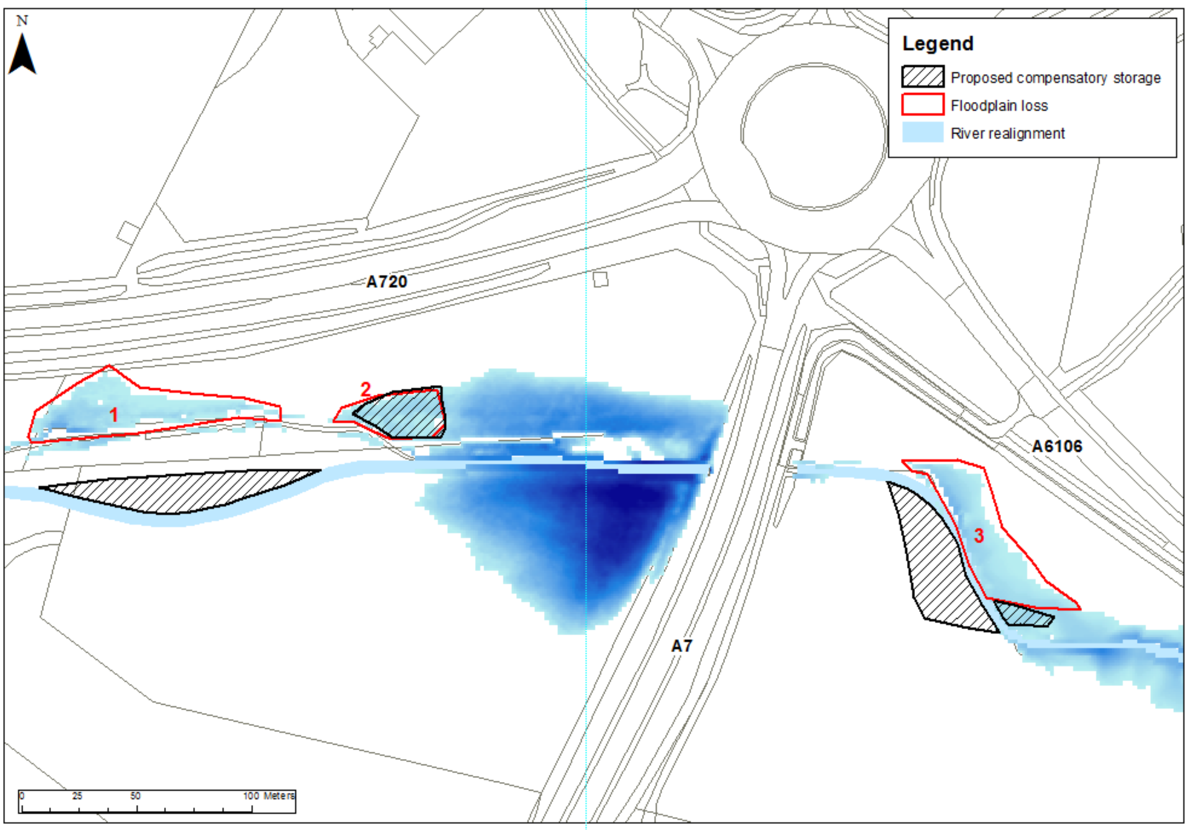

Figure 5-2: Floodplain loss and proposed compensatory storage locations

Table 5-2: Baseline and with scheme floodplain volumes

Return period	Baseline floodplain volume (m^3)	With scheme floodplain volume (m^3)	Change in floodplain storage between baseline and with scheme(m^3)	Baseline incremental change in floodplain volume (m^3)	With scheme incremental change in floodplain volume (m^3)	Incremental change in floodplain volume between baseline and with scheme(m^3)
2	0.0	0.0	+0.0	-	-	-
5	3.6	6.2	+2.6	+3.6	+6.2	+2.6
10	10.7	13.5	+2.8	+7.1	+7.3	+0.2
30	60.3	80.7	+20.4	+49.6	+67.2	+17.6
50	116.2	158.8	+42.6	+55.9	+78.1	+22.2
75	176.9	232.2	+55.3	+60.7	+73.4	+12.7
100	225.4	283.8	+58.4	+48.5	+51.6	+3.1
200	430.0	506.4	+76.4	+204.6	+222.6	+18.0

5.3.2 Impact of Compensatory storage on levels and flow

As well as demonstrating increases storage volumes on the floodplain, the mitigation measures are seen to decrease channel water levels. Table 5-3 displays the top water levels for the 1 in 30yr and 1 in 200yr events. The increases observed at sections 18-22 are as a result of the channel diversion as bed levels and channel cross section have been altered significantly and top water levels between the two scenarios are therefore not comparable. All other river sections display a neutral impact or reduction in water level of between 10-50mm with the mitigation measures in place.

Flood risk to the carriageways was also assessed to ensure they could remain operational during a 1 in 200yr plus climate change event and that they had freeboard to account for any uncertainty.

Flood risk to the two carriageways that cross the Dean Burn was also assessed. The A7 southbound will be lowered from its original elevation and realigned in some locations. The lowest level on the carriageway is 60.45mAOD, which is 500mm above the 1 in 200yr plus climate change flood level in the floodplain upstream of culvert. The A6106 is proposed to remain raised on an embankment, with the lowest level on the carriageway being 59.7mAOD, which is 2.5m above the 1 in 200yr plus climate change flood level upstream of culvert. It is therefore shown that both the A7 and the A6106 can remain operational during a 1 in 200yr plus climate change flood event and that freeboard is provided to account for any uncertainty.

Full tabulated model results can be found in Appendix D. Floodmaps for the 1in 30yr and 1 in 200yr event can be found in Appendix E.

Table 5-3: Baseline and with scheme change in top water levels

Location	Cross section	1 in 30yr baseline maximum stage (mAOD)	1 in 30yr with scheme maximum stage (mAOD)	1 in 200yr baseline maximum stage (mAOD)	1 in 200yr with scheme maximum stage (mAOD)
	Section 18	62.56	62.87* (+0.31)	62.82	63.11* (+0.29)
	Section 20	61.85	61.91* (+0.06)	61.99	62.01* (+0.02)
	Section 22	60.38	60.66* (+0.28)	60.57	60.81* (+0.24)
	Section 24	59.68	59.53 (-0.15)	59.99	59.76 (-0.23)
	Section 26	59.10	59.10 (+0.0)	59.68	59.65 (-0.03)
Upstream of A7	Section 28	59.09	59.08 (-0.01)	59.68	59.65 (-0.03)
	Section 30	58.00	57.98 (-0.02)	58.2	58.15 (-0.05)
	Section 32	57.67	57.65 (-0.02)	57.81	57.75 (-0.06)
	Section 34	57.38	57.36 (-0.02)	57.47	57.44 (-0.03)
	Section 36	56.83	56.83 (+0.0)	57.08	57.07 (-0.01)
Upstream of A6106	Section 38	56.68	56.68 (+0.0)	56.99	56.98 (-0.01)
	Section 40	56.31	56.31 (+0.0)	56.69	56.67 (-0.02)

* These increases are a result of the channel realignment where both section location and elevation have changed

To fully assess the effectiveness of the compensatory storage provided, pass forward flows were also assessed to ensure the scheme has no negative impact on flood risk downstream. Table 5-4 displays the peak flows through the A7 and the A6106 culverts. In all return periods, flow is seen to either be equal to or less than the baseline, representing a neutral or betterment to pass forward flows. Although compensatory storage is only required to be provided up to the 1 in 200yr design event, it can be seen in Table 5-4 that pass forward flow in the 1 in 200yr plus climate change event is also reduced from baseline.

Maximum stage in the 1D channel for a range of return periods can also be found in Table 4 Appendix D.

Table 5-4: Flows at the A7 and A6106 culverts – baseline and with scheme

	2	5	10	30	50	75	100	200	200CC
A7 Culvert Baseline	1.41	1.85	2.17	2.79	3.16	3.51	3.69	4.31	5.00
A7 Culvert With scheme	1.41 (0.00)	1.85 (0.00)	2.17 (0.00)	2.78 (-0.01)	3.14 (-0.02)	3.48 (-0.03)	3.67 (-0.02)	4.25 (-0.06)	4.93 (-0.07)
A6106 Culvert Baseline	1.41	1.85	2.17	2.79	3.14	3.50	3.69	4.30	4.94
A6106 Culvert With scheme	1.41(0.00)	1.85 (0.00)	2.17 (0.00)	2.78 (-0.01)	3.13 (-0.01)	3.48 (-0.02)	3.67 (-0.02)	4.25 (-0.05)	4.89 (-0.05)

As well as matching peak flows, it is also important that the full hydrographs are similar in the baseline and with scheme scenarios to demonstrate that floodplain storage is storing and conveying flood waters in a similar manner. Figure 5-3 displays the 1 in 200yr baseline and with scheme hydrograph upstream of the A6106 culvert. The hydrographs are seen to be very similar on the rising and receding limbs, with the main variation around the peak due to the increase in floodplain storage provided as part of the scheme design.

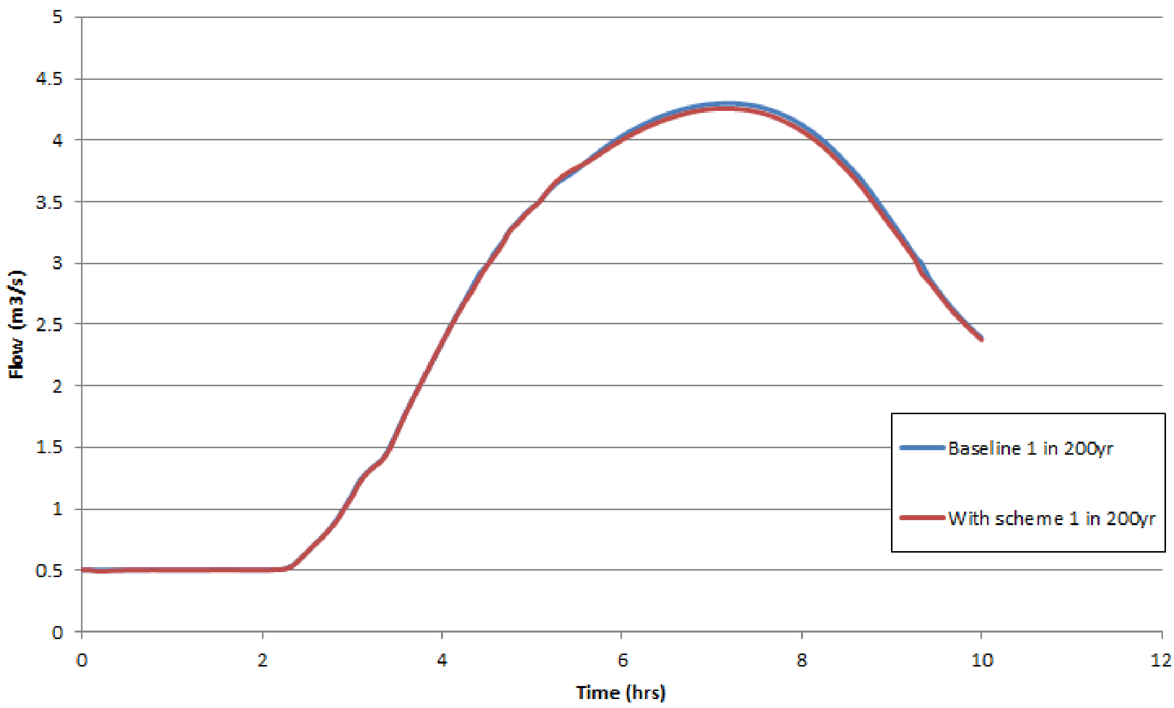

Figure 5-3: 1 in 200yr hydrograph – baseline and with scheme at downstream end of scheme extent

Using the hydraulic model, it has been demonstrated that the proposed compensatory storage delivers increased floodplain volume, decreased top water levels and decreased or matched peak flows at all return period.

6. Conclusion

6.1 Introduction

AECOM was commissioned by Transport Scotland to undertake a Flood Risk Assessment (FRA) as part of the wider A720 Sheriffhall Junction improvements that will feed into the Environmental Impact Assessment (EIA). The Sheriffhall roundabout is located to the south of Edinburgh and the proposed development includes a flyover for the A720 bypass, with a roundabout connecting the A roads underneath and cycle network provision. The design also includes several SuDS features, to treat and attenuate the increased hardstanding.

The works are classed as ‘Essential infrastructure’ and SEPA’s Flood Risk and Land Use Vulnerability Guidance states that it is generally suitable to develop this land use type in areas at medium to high risk for operational reasons or if an alternative is not available. It is noted that the design should remain operational during floods.

The aim of the FRA is to assess the current flood risk to the site from the Dean Burn which runs parallel to the A720, assess the impact of the development (if any), and to develop mitigation options if required to ensure that flood risk is not adversely affected elsewhere as a result of the development.

6.2 Baseline flood risk

Out of bank flow is seen to occur from the 1 in 5yr event upstream of the A7 culvert during current day conditions. Flood extent is seen to increase in this area as event magnitude increases, with maximum flood depths in the 1 in 200yr event plus climate change event of 1.65m.

Other notable areas of out of bank spill are located on the left hand bank downstream of the irrigation pond and across the left hand bank between the A7 and Old Dalkeith Road. The spill in these locations begins from the 1 in 30yr event. Flood depths are shallower in these locations, in the order of 200-300mm during a 1 in 200yr plus climate change event.

Later in the event, further spill is observed on the left bank upstream of the A7 and the right bank upstream of the A6106 to depths of approximately 900mm and 500mm respectively.

The A7 and A6106 carriageways were shown to not be at risk during a 1 in 200yr plus climate change event.

6.3 Proposed scheme flood risk

Where possible, and using an iterative approach, the layout has been designed to avoid the functional floodplain identified in the baseline modelling. However, there are areas where this is not possible due to topographic or space constraints.

The proposed development was modelled to determine how the design affected flood risk when compared to the baseline scenario. This run contains no mitigation measures and is to be used purely to assess how the proposed roundabout upgrades affect flood risk in the surrounding area.

The with scheme model demonstrates that without mitigation, the proposed development has a negative impact on flood risk out with the site and is therefore not in line with planning policy.

Floodplain depths upstream of the A7 and the A6106 were increased by approximately 5- 10mm during the 1 in 200yr event and 5-10mm in the 1 in 200yr plus climate change event. Pass forward flows were increased by 0.03m^3/s and 0.025m^3/s through the A6106 culvert for the 1 in 200yr and 1 in 200yr plus climate change events respectively.

The modelling of scheme demonstrated that the proposals increase water levels and pass forward flows and will require mitigation measures to ensure the design complies with planning policy.

6.4 Mitigation measures

6.4.1 Requirements

It is best practice to avoid land raising in the function floodplain. This approach has been applied throughout the design process, however in some cases it has not been possible to avoid development within sections of the functional floodplain.

The areas where it has not been possible to remove scheme elements from the function floodplain are along a stretch of the Dean Burn that runs close to the A720 embankment and an area between the A7 and the A6106 that is required for a SuDS pond. The with scheme model has demonstrated that removing these areas from the floodplain negatively affects flood risk and land raising will need to be mitigated up to the 1 in 200yr design level to ensure no detrimental flood risk.

SEPA's Technical Flood Risk Guidance for Stakeholders, 2018 outlines a recommended approach for mitigating land raising by providing compensatory storage elsewhere. It is noted in this guidance that development within the functional floodplain should be avoided but in certain cases it can be appropriate if compensatory storage is provided so that the development does not affect the ability of the functional flooding to store and convey water.

In addition to providing compensatory storage, two further mitigation measures are suggested on the Dean Burn. It is proposed that the Dean Burn be realigned upstream of the A7 given the proximity of the embankment toe to the watercourse, and the potential erosion issues this could cause. It is proposed that the burn be diverted 40m to the south. Realignment of this burn provides an opportunity for river restoration along a reach that is currently canalised and overly deep. The channel would be installed as a restored 2 stage meandering channel created to improve watercourse function and habitat. A further channel improvement between the A7 and the A6106 is the proposal to remove the sharp right angle bend in the channel as it is unnatural and acts as a constriction in the channel. This angle will be smoothed to provide an added river functioning benefit as well as less of a constriction to the SuDS pond.

6.4.2 Provision

The areas of floodplain loss that required compensatory storage, were modelled as they were too complex to assess on a 'like for like' elevation slice basis.

The total floodplain volumes at the realigned channel and on the opposite bank to the SuDS pond were calculated for the baseline and with scheme scenario to ensure that at each return period, there was equal to or increased storage from the baseline in the with scheme scenario. Incremental increases between return periods for baseline and with scheme were also calculated. It was demonstrated that with scheme floodplain volume storage has been increased at every return period from baseline volumes, and that the incremental increases between return periods was also increased. This ensures that like for like is provided based on magnitude of event and total floodplain volume.

As well as demonstrating increases storage volumes on the floodplain, the compensatory storage provision in the with scheme scenario is also seen to provide a neutral impact or decrease to channel water levels and flow at all modelled return periods. Hydrograph shape at the downstream extent of the scheme is comparable to the baseline hydrograph, demonstrating that floodplain storage is functioning in a similar manner.

Flood risk to the two carriageways that cross the Dean Burn was also assessed. Based on lowest levels on the carriageway, and top water levels in the 1 in200yr plus climate change event, it was shown that both the A7 and the A6106 can remain operational during a 1 in 200yr plus climate change flood event and that freeboard is provided to account for any uncertainty.

Using the hydraulic model, it has been demonstrated that the provided compensatory storage delivers increased floodplain volume, decreased top water levels and decreased or matched peak flows when compared to the baseline scenario at all return periods.

6.5 Recommendations

In order to mitigate against the loss of floodplain storage as a result land raising, it is recommended that compensatory storage be provided in the three areas outlined in this report. Full details of the extent and contours of the land reprofiling can be found in Appendix F.

The SuDS pond is required to be removed from the function floodplain as there is insufficient capacity in the pond for river flows. This can be achieved by forming a small bund in the order of 100-200mm around the western and southern edges of the pond.

The channel diversion should be constructed in line with the cross sections and guidance set out in the river restoration technical note ‘A720 Sheriffhall Junction Improvement: Dean Burn diversion hydromorphology design’.

Appendix 11.4 – WFD Water Classification

A720 Sheriffhall Junction Improvement

Flood Risk Assessment

05 March 2019

Quality information

Prepared by	Checked by	Approved by
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Revision History

Revision	Revision date	Details	Authorized	Name	Position
01		Draft baseline conditions for review			
02		Baseline FRA with updates based on SEPA comments			

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Tables

1. Introduction

AECOM was commissioned by Transport Scotland to undertake a Flood Risk Assessment (FRA) as part of the wider A720 Sheriffhall Junction improvements that will feed into the Environmental Impact Assessment (EIA). The Sheriffhall roundabout is located at 331803, 667984 and the proposed development includes a flyover for the A720 bypass, with a roundabout connecting the A roads underneath. The works will also include additional cycle network provision. The study area is shown in Figure 1-1.

The aim of the FRA is to assess the current flood risk to the site from the Dean Burn which runs parallel to the A720, assess the impact of the development (if any), and to develop mitigation options if required to ensure that flood risk is not adversely affected elsewhere as a result of the development.

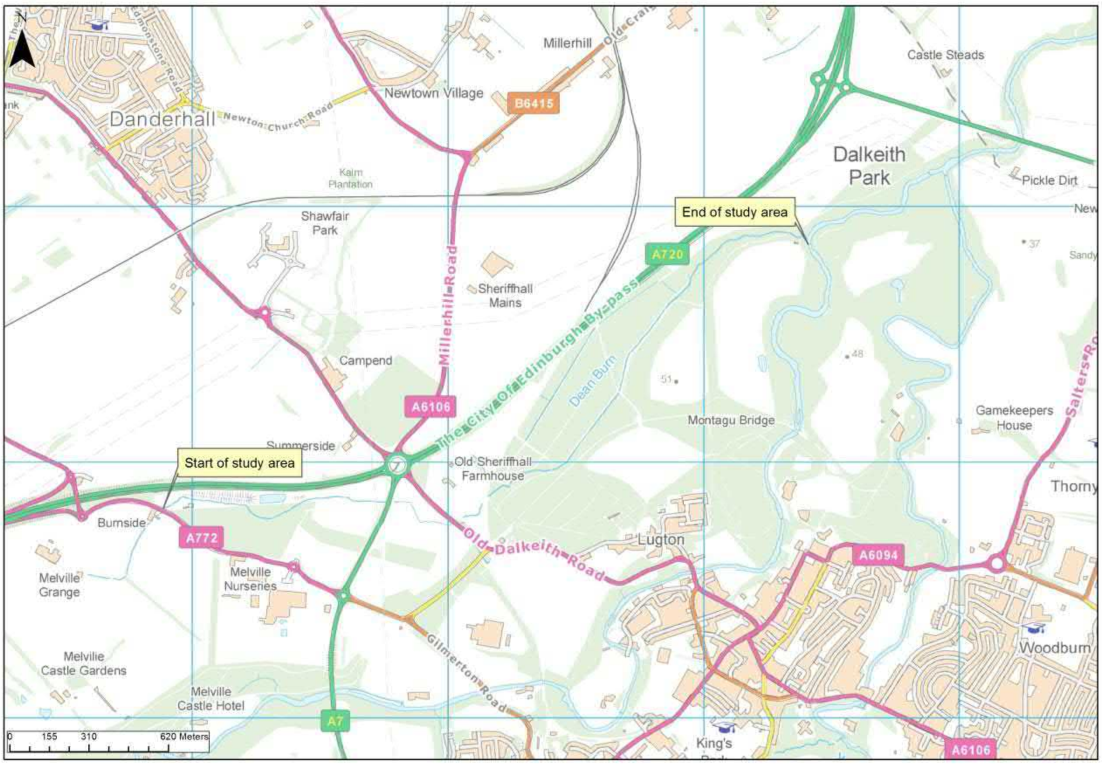

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Figure 1-1: Site location

2. Data collection and Site Appraisal

2.1 Site description

The Sheriffhall roundabout is located to the south east of Edinburgh and connects the A720 with the A7, Old Dalkeith Road and Millerhill Road. It is surrounded on all sides by open fields and forested areas.

The Dean Burn runs almost parallel to the A720 throughout the duration of the study area before joining the North Esk 1.5km downstream. The route of the watercourse appears to have been modified from natural, although the current alignment can be seen on historic mapping as far back as 1850. The channel is set relatively deep compared to the floodplain, with moderately steep, densely vegetated banks throughout. The bed of the channel is comprised of rocky material of varying sizes with frequent obstructions such as tree roots and terrestrial debris. A mixture of rough grazing and forest upstream of the Old Dalkeith Road is observed on the floodplain, before changing to dense forest as the watercourse runs through Dalkeith Country Park.

The Dean Burn runs through several inline structures in the study area. These include openings under dividing walls, the culverts under the A7, Old Dalkeith Road and Borders Railway line, as well as various smaller footbridge and access crossings in Dalkeith Country Park.

Upstream of the site, the catchment is predominately rural, with a section of the town of Loanhead occupying the northern extent.

Site topography can be seen in Appendix C.

2.2 Site visit

A site walkover was undertaken in August 2018 to establish the general topography and constraints on the Dean Burn, review possible flood flow routes and assess the viability of potential mitigation options should they be required.

The area in and around the Dean Burn was seen to be overgrown and numerous natural channel obstructions, such as tree roots, leaves and branches were observed. Areas of bank erosion, specifically around the wooded areas at the irrigation pond, were seen to result in localised lowering of the banks. The channel was seen to be very irregular, with changes in width between approximately 1 – 5m.

A number of culverts and crossings had blockages which would affect conveyance at higher flows. No blockages were noted at the culverts running under the A7 and Old Dalkeith Road. These culverts were very large and likely oversized.

Photographs can be found in Appendix A.

2.3 Review of flooding

2.3.1 Historic flooding

There were no historic flood records available at the site and surrounding areas. This does not however mean that the area has not experienced flooding in the past.

Whilst ground investigation works were being undertaken as part of the wider project, out of bank flow was observed downstream of the irrigation pond on the left hand bank. This flow was sufficient to halt works although may have been somewhat exacerbated by pumping and operations in the area at the time.

2.3.2 SEPA floodmaps

The most recent SEPA flood risk maps were published in March 2015. The maps cover the whole of Scotland, and provide a strategic level of information on the potential sources and impacts of flooding, including coastal, fluvial, surface water (pluvial) flooding. They also show the Potentially Vulnerable Areas identified by SEPA as part of the flood risk management process under the Flood Risk Management (Scotland) Act 2009. Because the maps have been developed on a national scale, there are limitations in the data used, and they should be viewed as indicative only at local scale.

The fluvial flood maps were developed for all catchments greater than 3 km^2. Flooding is seen to be fairly well contained to the channel along much of the study reach. The mapping indicates flooding in the woodland around the irrigation pond. Out of bank ponding is also observed in a low lying area on the right hand bank upstream of the A7 culvert. A flow pathway extends across the left hand bank between the A7 and Old Dalkeith Road, with the potential for some localised ponding. Downstream of the Old Dalkeith Road, flow exits the channel and runs along the southern edge of the Borders Railway embankment.

Surface water flood maps are derived from pluvial model results. Pluvial modelling assumes losses due to drainage networks in urban areas. Pluvial flooding is shown across much of the same extent as in the fluvial mapping.

Fluvial and surface water flooding can be viewed on SEPA's website: http://map.sepa.org.uk/floodmap/map.htm

2.4 Proposed works

The Sheriffhall roundabout upgrade will include construction of a flyover for the A720, with the remaining roads joining into a roundabout underneath. Sunken further from this, a new cycle and footpath network will be created. The works are classed as 'Essential infrastructure' and SEPA's Flood Risk and Land Use Vulnerability Guidance states that it is generally suitable to develop this land use type in areas at medium to high risk for operational reasons or if an alternative is not available. It is noted that the design should remain operational during floods.

These works will include road realignments and elevation changes, creation of new foot and cycle paths, and widening of the existing A720 and associated embankments to account for the flyover. The design also includes several SuDS features, to treat and attenuate the increased hardstanding, which have spatial constraints relating to tie in levels and discharge locations.

Where possible, and using an iterative approach, the layout has been designed to avoid the functional floodplain. However, there are areas where this is not possible.

Mitigation measures may be required if the scheme is seen to affect flood risk out with the site.

3. Hydrology

3.1 Methodology overview

The Flood Estimation Handbook (FEH) gives guidance on rainfall and river flood frequency estimation in the UK and also provides methods for assessing the rarity of notable rainfalls or floods. A number of methods of flood estimation are presented, including the FEH statistical method and the FEH rainfall-runoff method. Subsequent publications have presented the ReFH and ReFH 2 rainfall-runoff method, updating the FEH rainfall-runoff method.

The statistical method relies on deriving a representative growth curve for the subject site from a pooled group of hydrologically similar catchments for which there is gauging information. This means that the accuracy of the method and resulting flow estimate depends on there being a sufficient number of similar catchments contained in the gauging station database. The method assumes that the flood statistics within the periods of record in the pooling group are representative of the flooding regime in the future, i.e. that the data is stationary. However, the method is based on actual observed flood data, and is therefore considered to be more robust than the more conceptual rainfall-runoff methods.

The statistical method consists of two parts; estimation of the median annual flood (QMED), i.e. the flood event with an annual exceedance probability of 50% (1 in 2 year return period), and the derivation of a pooled or single-site growth curve. The growth curve is then multiplied by the QMED estimate to provide a flood frequency curve for the subject site.

The best estimate of QMED is determined using flood data at the site if such local data exists. Alternatively if no such data exists, QMED can be estimated from FEH catchment descriptors and improved by data transfer from a suitably hydrologically similar donor gauge.

WINFAP-FEH is a software tool that supports the statistical flood frequency estimation methods as presented in Volume 3 of the FEH. It provides single-site and pooled group methods of frequency analysis based on annual maxima data from a database of gauged catchments. WINFAP-FEH files (Version 6) gauging station data was used to generate a hydrologically similar pooling group of sites using WINFAP-FEH v4 software. The database contains the annual maximum (AMAX) series data for each station in the database giving AMAX series up to and including the 2015 water year for the majority of UK gauges. Each station within the pooling group was checked and found to have AMAX series up to and including the 2015 water year. Similarity is judged using a distance measure derived from the difference in floodplain extent (FPEXT), rainfall (SAAR) and catchment area (AREA) between the subject site and the gauging station sites. The total data record from the resulting group should amount to around 500 years of data as recommended in *Science Report SC050050*. The pooling group is then used to predict a growth curve, which is combined with the index flood QMED to provide flow estimates for flood events of varying severity.

The FEH rainfall-runoff method has been updated with the ReFH2 rainfall-runoff method. This method utilised catchment specific descriptors to assess catchment functioning and runoff. ReFH2 is now accepted by SEPA as it incorporates a larger Scottish dataset, includes more small-catchment data, utilises the most up to date 2013 rainfall DDF (Depth, Duration, Frequency) model data and incorporates an improved method for assessing urban losses.

Given the size of the catchment, 6.2km^2, both the statistical and ReFH2 methods were undertaken for a comparison before finalising the choice of method. Flow estimates for the Dean Burn catchment were determined for the total catchment at the downstream extent of the study area for input into the hydraulic model.

3.2 FEH catchment characteristics

3.2.1 Standard updates

Catchment characteristics for the Dean Burn study area were extracted from the FEH Web-Service and are presented in Table 3-1. These values were updated where appropriate. The area of the catchment was modified slightly from the delineation provided by the FEH Web-service to account for differences in terrain identified using LiDAR. The original area of the catchment was 6.99 km^2. Figure 3-1 displays the FEH default and the amended catchment area. DPLBAR was updated due to the change of catchment area as the two are inherently linked. URBEXT was also uplifted to current day.

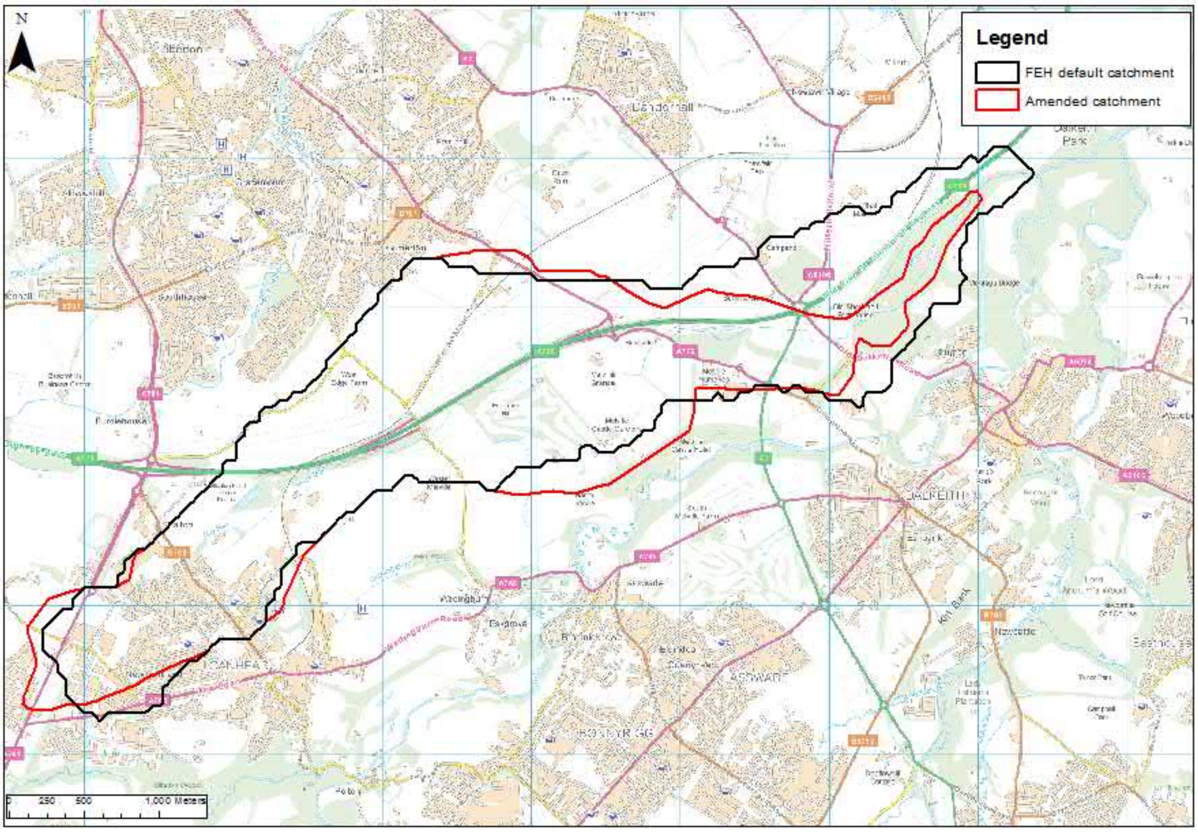

Figure 3-1: Catchment delineations

3.2.2 BFIHOST update

The BFIHOST value obtained from the FEH download was unusually high for this area. Whilst this FEH value is based on geological and soil maps and should therefore give a relatively accurate indication of catchment responsiveness, it was felt, that after correspondence with SEPA as well as further investigation, that this value should be reduced to tie in with the surrounding catchments.

The Dean Burn catchment is not gauged and therefore is not represented in the Institute of Hydrology's Base Flow Index map of Scotland. The surrounding catchment's BFI values ranged from 0.4 -0.64.

Bedrock and superficial deposit maps were then considered to determine the most similar local gauged catchment to the Dean Burn as a catchment with similar underlying geology is likely to have a similar BFI. The Dean Burn catchment bedrock consists of sedimentary rock, largely limestone, with superficial deposits of sedimentary glaciofluvial and till.

The local catchments with lower BFI values around 0.4 were seen to extend over areas of igneous bedrock with minimal superficial deposits, making them relatively impermeable. These catchments are unlikely to react to rainfall in the same manner as the Dean Burn catchment and were discounted from this assessment.

The bed rock and superficial deposits of the North Esk catchment were consistent with the Dean Burn catchment. The Dean Burn also flows into the North Esk and the BFI for this watercourse is between 0.5-0.54. The default Dean Burn BFIHOST value of 0.719 was updated to 0.52 based on its similarity to the North Esk catchment underlying geology.

3.2.3 SPRHOST update

Given the inherent link between BFIHOST and runoff, the SPRHOST value was also updated. This was done by applying the following equation from the Flood Estimation Handbook, vol3:

$$RESHOST = BFIHOST + 1.30\left(\frac{SPRHOST}{100}\right) - 0.987$$

Table 3-1: FEH Catchment Parameters for Dean Burn at Downstream Extent of Subject Site

Catchment Parameters	
NGR	NT 33350 68900
AREA (km^2)	*6.19* updated from default catchment of 6.99*
SAAR (mm)	*685*
FPEXT	*0.0533*
BFIHOST	*0.52* updated from default catchment of 0.719*
SPRHOST (%)	*41.64* updated from default catchment of 26.33*
FARL	*0.992*
PROPWET	*0.49*
DPLBAR (km)	*2.72* updated from default catchment of 4.66*
DPSBAR (m/km)	*37.4*
ALTBAR (m)	*102*
ASPBAR (degrees)	*73*
ASPVAR	*0.51*
LPD (km)	*9.23*
RMED-1H (mm)	*8*
RMED-ID (mm)	*29.5*
RMED-2D (mm)	*43.3*
SAAR4170 (mm)	*686*
URBEXT2000	*0.0952* updated to current day*

3.3 Statistical analysis

Statistical analysis was undertaken on the Dean Burn to establish peak flow estimates. Given the size of the catchment, there are inherent uncertainties using this method as there are only a small number of similar small catchments in the data set.

3.3.1 QMED estimation

QMED is defined as the median annual flood, i.e. the flood event with an annual exceedance probability (AEP) of 50% (1 in 2 year return period).

With no gauged data at the upstream extent of the model, the FEH recommended method to derive QMED is by data transfer from a hydrologically similar donor catchment. This donor transfer was carried out within the WIN-FAP v4 software, using both the multiple station method and the single station method. The single site donor urbanised adjustment method has been selected as the preferred method because the single donor catchment was very similar to the Dean Burn and therefore a strong candidate. The donor catchment used is the West Peffer Burn @ Luffness. Details of the donor selection can be found in Appendix B. Transferred QMED values are shown in Table 3-2.

Table 3-2- QMED Donor Adjustment

Water Course	QMEDcd	QMEDadj (6 sites)	QMEDadj (1 site)	**QMEDadj (1 site)(urbanised)**
Dean Burn	1.23	1.47	1.09	**1.25**

3.3.2 Pooled growth curve

The resulting default pooling group was then reviewed in WINFAP and a number of adjustments were made. This mainly comprised of removing sites with short records, low BFIHOST values and poor suitability comments. Details of the default and reviewed pooling groups are included in Appendix B.

The best fitting statistical distribution was the GL (Generalised Logistic), and the heterogeneity measure H_2 was 1.86, possibly heterogeneous.

Table 3-3 shows the flood frequency curve for the Dean Burn using the pooling group.

Table 3-3-Growth Curve and Flood Frequency Curve for Dean Burn

Return Periods	Pooling group growth curve for Dean Burn (GL)	Peak flows for Dean Burn (m^3/s)
2	1.000	1.25
5	1.370	1.72
10	1.649	2.07
20	1.957	2.45
30	2.156	2.70
50	2.433	3.05
100	2.861	3.58
200	3.361	4.21
500	4.158	5.21
1000	4.883	6.12

3.4 ReFH2

The Revitalised Flood Hydrograph Method 2 (ReFH2) was undertaken as a comparison to the flow estimates generated using the Statistical method. ReFH2 is now accepted by SEPA and is suitable to use on a catchment of this size. This ReFH2 method has also included improvements on how permeable catchments are considered.

Catchment descriptors and delineations were obtained from the FEH Web Service and updated as set out in Section 3.2. ReFH2 software, using the winter storm profile given the rural nature of the catchment, was used.

Peak flows from the analysis are shown in Table 3-4.

Table 3-4: ReFH2 Peak Flow Results

Return Period (yr)	Peak flows for Dean Burn (m^3/s)
2	1.41
5	1.85
10	2.19
20	2.57
30	2.83
50	3.22
100	3.90
200	4.69
500	5.87
1000	6.86

3.5 Method selection

The REFH2 results gave higher peak flow estimates than the Statistical method, which is conservative. Due to the small size of the Dean Burn catchment, it is also difficult to find similar sized gauged catchments for use in the statistical method, which reduces certainty in the results. For these reasons, the REFH2 method was used for establishing peak flows in the Dean Burn.

The standard ReFH2 derived hydrograph was used as there was no gauged data on the watercourse to be used to generate an alternative.

Table 3-5 displays the comparison of the Statistical analysis and ReFH2 peak flow estimates.

Table 3-5- Summary of peak flows for the statistical and ReFH2 method

Return Periods	Statistical peak flows for Dean Burn (m^3/s)	**ReFH2 peak flows for Dean Burn (m^3/s)**
2	1.25	**1.41**
5	1.72	**1.85**
10	2.07	**2.19**
20	2.45	**2.57**
30	2.70	**2.83**
50	3.05	**3.22**
100	3.58	**3.90**
200	4.21	**4.69**
200 +CC	5.09	**5.87**
500	5.21	**6.86**
1000	6.12	**6.86**

3.6 Climate change

The United Kingdom Climate Projections 2018 (UKCP18) dataset was published in December 2018 and outlines updated probabilistic projections of climate change impact for the 2020's, 2050's and 2080's based on various emissions scenarios and probability percentiles. United Kingdom Climate Projections (UKCP09[1]) is a previous version of the projections and since little guidance has been provided on how these new 2018 uplifts in rainfall relate to increases in flow, the UKCP09 flow uplifts are still considered to be the most appropriate.

Outlined in their Flood Modelling Guidance for Responsible Authorities, SEPA commissioned CEH to undertake a study assessing Scottish catchments vulnerability to climate change. Within this study the UKCP09 projections were run through models to provide flow uplift for hydraulic basins. This provides a more accurate representation of the increase to fluvial flows.

Based on the medium emission scenario 2080s, 50th percentile, the study area is reported to have a 21% change in flood peak as shown in table 10-1 of the SEPA Flood Modelling guidance. For the purpose of this flood study, a 21% uplift has been adopted for climate change scenario to come in line with SEPA's Technical Flood Risk Guidance. The medium emission scenario 2080, 90th percentile change in flood peak will also be applied to the modelling to assess sensitivity. This is reported to be 40% for the study area.

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[1] UK Climate Projections, *United Kingdom Climate Projections (UKCP09) Rainfall Maps*, June 2009

4. Hydraulic Modelling

4.1 Baseline model build

A single hydraulic model has been constructed for the Dean Burn and surrounding areas at Sheriffhall consisting of a one dimensional element representing the river channel built in Flood Modeller and a two dimensional element representing the floodplain constructed in Tuflow.

4.1.1 One dimensional channel model

A one dimensional model of the Dean Burn was constructed using surveyed cross sections and inline structures. Details of the sections and structures can be found in Appendix C. The survey was undertaken as part of this study and was used to represent the channel geometry and to define the top of bank. The model consists of 50 surveyed river sections, 2 bridges, and 4 culverts. The openings under the dividing wall upstream of the A7 were not surveyed but were included in the model based on photographs. All structures in the modelled reach were included in the model with trash screens applied where appropriate. When the downstream section of the bridge was not surveyed, a copy of the upstream face was used. During the baseline model runs, all structures were assumed to be clear of obstruction. No changes to default structure parameters were made.

The modelled reach extends from the A722 at Burndale to 500m downstream of the Old Dalkeith Road. Section labelling around the site can be seen in Figure 4-1 and will be referenced later in the report to describe flood risk at certain locations. A full schematisation of the river sections and 2D domain can be seen in Appendix C.

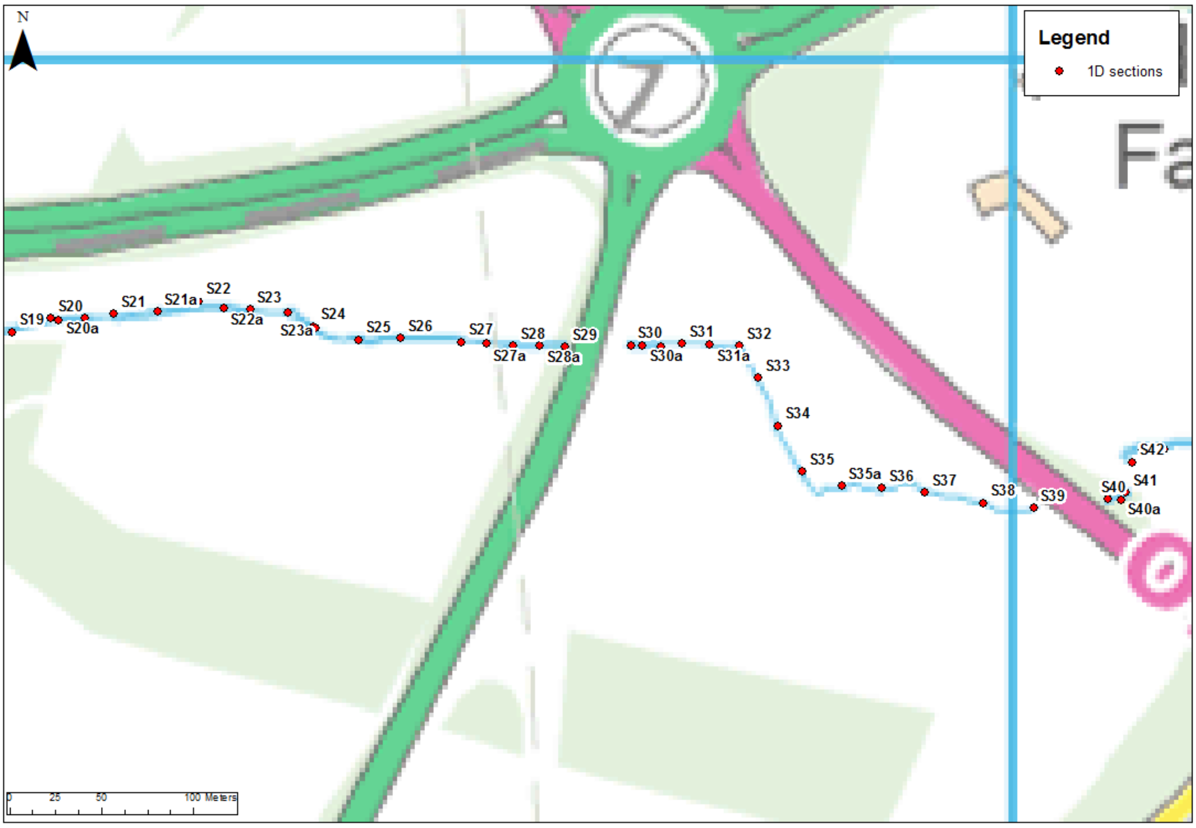


Figure 4-1: Cross section labels around the site

The inflow hydrograph, as calculated in Section 3.5, was applied at the upstream extent of the model. The downstream boundary was represented as a normal depth boundary, based on channel bed gradient, to allow flow to leave the model. A normal depth boundary was deemed appropriate as the influence of the River North Esk would not affect water levels at the site of interest due to the steep nature of the channel. The normal depth boundary in its location further upstream from the North Esk also did not affect water levels at the site.

Channel and bank Manning's 'n' roughness values were selected based on photographs and the site visit. The channel is predominantly natural along its reach. Due to the weedy stony nature of the channel, bed roughness was set between 0.045 and 0.05. Only minor sections of floodplain and banks were represented in the 1D model as the majority of the top of bank was represented in the 2D domain. Intermittent long grass banks were set at 0.04 and denser vegetated banks set at 0.045.

4.1.2 Two dimensional floodplain model

The 1D channel model was linked to a 2D domain (ground surface model) so that the overland flood mechanisms could be assessed. The 2D hydraulic model contained the following elements:

- Ground surface using 1m LiDAR Digital Terrain Model (DTM);
- Topography modifications where LiDAR does not accurately represent the ground surface – primarily between the A7 and A6106;
- 1D/2D links to allow free flow between the river channel and floodplain based on surveyed top of bank elevations. Downstream of Old Dalkeith Road, top of bank was not surveyed and is based on LiDAR;
- Roughness layer depicting different surfaces based on OS Mastermap data representing buildings (n = 0.5), roads (n= 0.02), fields (n=0.045), wooded areas (n=0.1) and water (n=0.03). A default roughness of 0.06 was applied to all other surfaces to represent short to medium grass contained by fences and hedges;
- Downstream boundary – Automatic HQ (head/flow) boundary applied to the downstream extent of the floodplain to allow water to escape the domain and not cause artificial ponding;
- The LiDAR was found to adequately represent the road and rail embankments and no modifications to topography were made;
- A field diving wall was added into the 2D domain as a z-line in the upstream section of the model and was assumed to remain standing. The Dean Burn flows under this wall at 3 locations and these openings were represented by orifice units based on site photographs.

4.1.3 Model run parameters

The 2D domain was set at a 2m grid size so that the channel and flow pathways could be accurately represented.

The model was run using a 0.5 second 1D timestep and a 1 second 2D timestep, with no changes to default run parameters. The 1D/2D model was run unsteady, i.e. time varying flow, for the required return periods set out in Section 3. This allowed for the flood progression to be fully assessed in both the 1D channel and the 2D floodplain.

4.2 Scheme model build

Where possible, and using an iterative approach, the layout has been designed to avoid the functional floodplain identified in the baseline modelling. However, there are areas where this is not possible due to topographic or space constraints. A drawing displaying the proposed scheme is shown in Appendix C.

The proposed development was modelled to determine how the design affected flood risk when compared to the baseline scenario. This run contains no mitigation measures and is to be used purely to assess how the proposed roundabout upgrades affect flood risk in the surrounding area.

To form the with scheme model, the following modifications were undertaken to the baseline model:

- Sections of the proposed development were stamped onto the LiDAR in areas where the design encroached into the flood extent. The existing ground levels within the footprint of the road embankments were raised to account for the changes in levels associated with the development as this could affect floodplain storage and flood mechanism. Raising levels from the toe of the embankment is slightly conservative;
- The area where SuDS ponds was to be located were also raised in the 2D domain as flood water would no longer be able to enter (due to insufficient capacity for river flows) and would therefore be removed from the functional floodplain;
- The culvert under the A7 was lengthened to accommodate the additional footpath and road realignment.

Figure 4-2 displays the locations of the main DTM modifications made during the with scheme modelling

Main areas of DTM modifications due to design within functional floodplain

Figure 4-2: Notable areas of DTM modifications due to design within functional floodplain

4.3 Mitigation assessment

4.3.1 Requirement for mitigation

It is best practice to avoid land raising in the function floodplain. This approach has been applied throughout the design process, however in some cases it has not been possible to avoid development within sections of the functional floodplain. In these instances, outlined below, land raising will need to be mitigated up to the 1 in 200yr design level to ensure no detrimental flood risk.

The main SuDS pond between the A7 and A6106 is to provide a large percentage of the attenuation and treatment requirements of the proposed works and therefore has significant area requirements. Additional constraints such as the Dean Burn and the local topography, which affects where ponds can be located due to network outfalls and discharge locations generally requiring gravity, areas where this large pond could be located were limited. Smaller ponds to the north are used earlier in an event to stagger the peak storms and provide additional storage, however the large pond had to be located in the area between the A7 and A6106. This area is seen to flood and will require compensatory storage to mitigate this loss.

Small sections of the A720 approach road embankments are proposed to run very close to the Dean Burn, in an area of floodplain that is also seen to flood during the baseline scenario. This embankment and approach road is constrained by maximum gradients along the road and also maximum side slopes on the embankment. Given the proximity of the embankment toe to the watercourse, and the potential erosion issues this could cause, it is proposed that the burn be diverted 40m to the south. Realignment of this burn provides an opportunity for river restoration along a reach that is currently canalised and overly deep. The channel would be installed as a restored 2 stage meandering channel created to improve watercourse function and habitat. Compensatory storage will also be provided to account for the loss of floodplain storage. Further details of the design of this diverted stretch of watercourse can be found in the technical note ‘A720 Sheriffhall Junction Improvement: Dean Burn diversion hydromorphology design’ and Figure 5-2.

SEPA’s Technical Flood Risk Guidance for Stakeholders, 2018 outlines a recommended approach for providing compensatory storage if functional floodplain is lost elsewhere as a result of the development. It is noted in this guidance that development within the functional floodplain should be avoided but in certain cases it can be appropriate if compensatory storage is provided so that the development does not affect the ability of the functional flooding to store and convey water. This guidance recommends that ‘like for like’ direct storage is the preferred option for mitigating land raising, with a modelling approach potentially being suitable if it is shown that ‘like for like’ is not a suitable method.

The ‘like for like’ method is applicable where only floodplain capacity is lost and does not take into account a loss in floodplain flow pathway or if the watercourse alignment is altered. To mitigate against a loss of floodplain that contains a flow pathway, and to assess storage loss as a result of watercourse diversion, modelling must be undertaken to assess the relative change in floodplain volume over a range of return periods.

4.3.2 Mitigation assessment and modelling

4.3.2.1 Like for like slice calculations

A total of three areas will be removed from the functional floodplain as a result of the scheme and are shown in Figure 4-3.

It is SEPA’s preferred method to use a ‘like for like’ slice approach and each of the areas was assessed to determine whether this approach was suitable.

It was found that the loss of floodplain in areas 1 and 2 was attributed to the channel diversion and that a ‘like for like’ slice assessment would not be appropriate in these areas due to the significant change in bed and bank levels of the realigned channel. Matching volume at each elevation slice would be unlikely to provide the same flood mechanism given the significant change in topography.

It was also found that due to the flow pathway running through area 3 that a ‘like for like’ slice assessment would also not be appropriate as it would underestimate the floodplain loss downstream caused by cutting of the flow pathway. Matching volume at each elevation on the opposite bank would not take into account the area to the south and may result in a net loss of storage.

Hydraulic modelling was therefore deemed the most appropriate way to determine compensatory storage requirements.

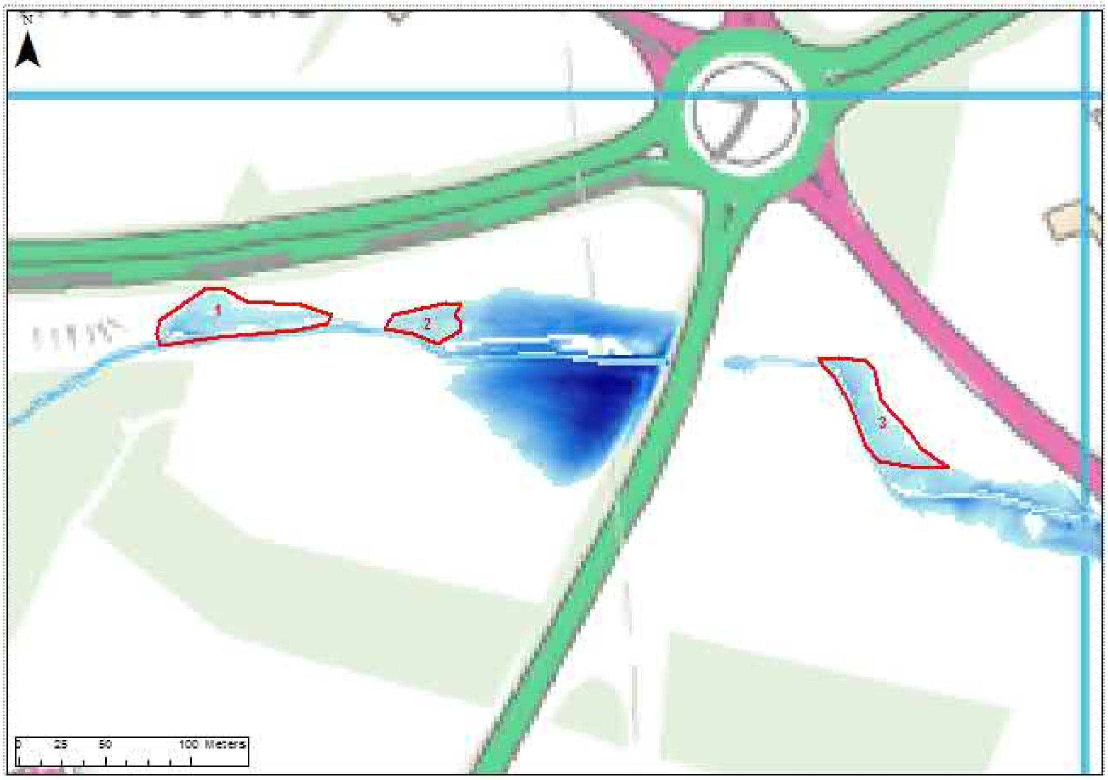


Figure 4-3: Areas that will be removed from the function floodplain

4.3.2.2 Hydraulic modelling of compensatory storage

Modelling was undertaken for all areas shown in Figure 4-3 to ensure that the compensatory storage was adequate, and that it replicated the baseline flood mechanism as closely as possible.

The compensatory storage requirements at the Dean Burn diversion, upstream of the A7 is complex as the river channel will be significantly altered from its original state. The change in alignment, long section and cross section means that the loss and provision of storage must be assessed using the hydraulic model as providing like for like storage is unlikely to adequately account for the changes in the floodplain and channel as elevations have changed significantly.

The compensatory storage at the SuDS pond will also be assessed using the hydraulic model as removing the SuDS pond from the functional floodplain will cut off a flow pathway which currently feeds an area of floodplain that will remain unaltered. Like for like calculations could therefore potentially underestimate the required storage as it would not take into account the flow mechanism and area of unaltered floodplain to the south.

To assess the compensatory storage requirements using the hydraulic model, the LiDAR was lowered along the meander of the realigned channel on both banks as well as in the area on the opposite bank of the main SuDS pond to mimic the lost floodplain storage in all areas. Given the flow path across the left hand bank at the SuDS pond will be cut off, minor lowering of the left bank to the south of the pond was also undertaken to allow flow into this area at the same time in the event as the baseline. The time in the event that spill occurs was matched with the baseline model run to ensure this new area of storage acted as similarly to the baseline scenario as possible. Ensuring that spill occurs at the same time in the baseline and with scheme scenarios means that floodplain storage will not be used too early or late in an event.

The sharp right angle bend in the channel is unnatural and acts as a constriction in the channel. This angle was smoothed in the model to provide an added river functioning benefit as well as less of a constriction to the SuDS pond.

An iterative approach was then undertaken that involved changing bank levels and modifying the elevation and size of the LiDAR modifications until the modelled compensatory storage provided increased attenuation when compared to the baseline. This ensures that like for like is provided based on magnitude of event and total floodplain volume.

4.4 Sensitivity testing

Sensitivity checks were carried out on the hydraulic model parameters where they were considered to be inherently uncertain to explore the effect on model results.

The aim is to understand the range of model results that could be obtained with variation of these parameters. The intention is not to evaluate an accuracy range or otherwise quantify uncertainty; but to give an indication of the influence certain parameters have and identify if there are significant or disproportionate influences.

In line with SEPA guidance, the model parameters tested were:

- Flow,
- Manning's Roughness,
- Structure Blockages.

Sensitivity to changes in the downstream boundary was not tested as the downstream extent of the model was 500m downstream, with bed levels 6m lower than at the site. It was deemed sufficiently far downstream that the downstream boundary did not influence levels at the site.

4.4.1 Flow

Model sensitivity to flow was tested with a 40% increase for the 1 in 10yr and 1 in 200yr events. This uplift corresponded to the medium emission scenario 2080, 90th percentile change in flood peak.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 1 Appendix D.

Increasing the flow by 40% increased the 1 in 10yr channel water levels by a maximum of 260mm and the 1 in 200yr channel water levels by up to 600mm. These maximum increases are observed immediately upstream of the A7 culvert. Increases in levels are experienced to varying degrees along the length of the modelled reach with the smallest increases being 70mm and 90mm for the 1 in 10yr and 1 in 200yr respectively.

During the 1 in 10yr event, out of bank flow observed in the area upstream of the A7 culvert on the left hand bank is seen to increase. Depths increases in this area reach a maximum of 250mm. Additional flooding that was not observed in the baseline scenario is also observed on the left hand bank between the A7 and the A6106. Flooding locations and extents are seen to increase with a 40% uplift in flow during the 1 in 200yr event. Depths are seen to increase by up to 600mm in the area upstream of the A7 culvert. The area of flooding between the A7 and Old Dalkeith Road has smaller increases in floodplain depths in the order of 200-300mm.

Channel water levels are seen to increase as a result of an uplift in flow. However, it should be noted that location and overall extent of flooding remains comparable, particularly in the lower return periods. Whilst the increases in floodplain depths are not insignificant, the flows used in the baseline model are deemed to be appropriate as they are based on best practice methodologies.

4.4.2 Manning’s Roughness

In line with SEPA’s modelling guidance Manning’s ‘n’ roughness was increased by 40% in both the 1D channel and 2D floodplain for the 1 in 10yr and 1 in 200yr events.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 1 Appendix D.

Increasing the roughness by 40% increased the 1 in 10yr channel water levels by a maximum of 140mm and the 1 in 200yr channel water levels by up to 440mm. These maximum increases are observed around the A6106 culvert. Increases in levels are experienced to varying degrees along the length of the modelled reach with the smallest increases being 10mm and 25mm for the 1 in 10yr and 1 in 200yr respectively.

During the 1 in 10yr event, very minimal increases to flood extent are observed upstream of the A7. Increases to depths in this area reach a maximum of 25mm. Additional flooding is observed on the left hand bank between the A7 and the A6106. Flooding locations are not seen to change markedly with a 40% uplift in roughness during the 1 in 200yr event. Depths and extents are seen to increase by up to 40mm in the area upstream of the A7 culvert. The area of flooding between the A7 and Old Dalkeith Road has larger increases in floodplain depths in the order of 100-200mm.

Channel water levels are seen to increase as a result of an increase in roughness. The increases are more apparent in the 1 in 200yr event, where extents are increased be approximately 12m in the area between the A7 and A6106. However, the roughness values used in the baseline model are deemed to be appropriate based on channel type and geometry and an increase roughness of 40% would be expected to result in significant uplifts.

4.4.3 Blockages

Blockage scenarios were tested for the1 in 200yr event to assess the impacts on flooding should a structure become partially blocked during a flood event. A total of 3 structures (Figure 4-4) were identified around the site as having the potential to cause increased flooding if they became partially blocked. There were no anecdotal accounts of any blockages at any of the structures. On the site visit undertaken as part of this survey, no blockages were observed in structures 1 and 2 and both were considered to be oversized and unlikely to block significantly. Structure 3 is a much smaller structure and the inlet was seen to be partially blocked by small branches and leaves. Using a conservative approach, all structures were modelled in separate simulations as partially blocked to 50% of the flow area by reducing the cross sectional area accordingly.

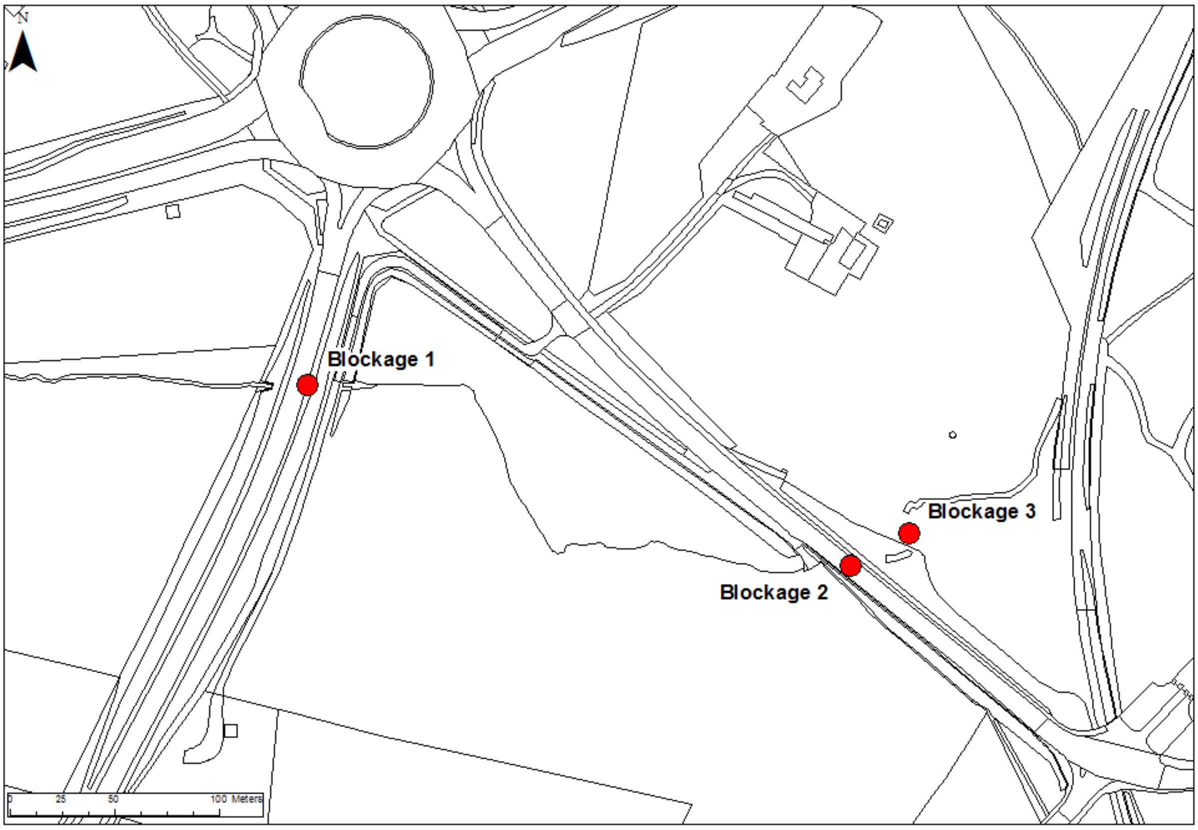


Figure 4-4: Blockage locations

Each blockage scenario was run separately and tabulated results with changes to channel water elevations at various locations are displayed in Table 2 Appendix D.

Decreasing the cross sectional area separately at the 3 structures increased channel water levels by 500mm, 300mm and 600mm for blockage scenarios 1, 2 and 3 respectively.

During blockage scenario 1, in channel water levels were increased by approximately 500mm upstream of the A7 culvert. Floodplain depths and extents were also increased in this location on both banks by approximately 500mm. Out with this area, no other increases to depths are shown. Due to additional flow being held upstream of the A7, out of bank spill is seen to decrease upstream of Old Dalkeith Road by approximately 100mm. The backwater effect is experienced approximately 200m upstream of the culvert inlet. Blockage of this culvert is seen to increase levels near the A7 but does not cause flooding on the carriageway. Due to the size of the culvert, it is also very unlikely that a 50% blockage would occur.

During blockage scenario 2, in channel water levels were increased by approximately 300mm upstream of Old Dalkeith Road culvert. Floodplain depths and extents were also increased in this location on both banks by approximately 300mm. Out with this area, no other increases to depths are shown. The backwater effect is experienced approximately 220m upstream of the culvert inlet. Blockage of this culvert is seen to increase levels near the A6106 but does not cause flooding on the carriageway which is significantly higher.

During blockage scenario 3, in channel water levels were increased by up to 600mm in the area between Old Dalkeith and the railway embankment. The floodplain in this location did not previously flood. During the blockage scenario, depths and extents increased in this location on both banks by approximately 300mm. Flood depths and extents were also seen to have increased upstream of Old Dalkeith Road by approximately 400mm. The backwater effect is experienced approximately 250m upstream of the culvert inlet. Blockage of this culvert is seen to increase levels near the A6106 but does not cause flooding on the carriageway which is significantly higher.

From this testing, it can be seen that increases in channel flood depths are apparent in all blockage scenarios. Floodplain depths and extents are also seen to increase. The increases observed during blockage scenario 1 are not however seen to affect key receptors. The increases during scenario 2 and 3 have the potential to affect flooding around the SuDS ponds. Increased levels as a result of blockage do not cause flooding on either of the carriageways.

This sensitivity analysis is not an analysis on the likelihood of blockage, but an assessment of the severity of flooding impacts should a blockage occur at a particular structure. Identifying the structures where blockage may result in increased flooding, is useful for identifying structures that would benefit from either extra maintenance or additions such as trash screens.

It is recommended that structures are regularly monitored and maintained.

5. Results

5.1 Baseline

During the 1 in 200yr plus climate change event, flooding first occurs on the right hand bank, immediately upstream of the A7 culvert with out of bank flow spreading into a low lying area. Flood depths reach a maximum of 1.65m in this area. As the event progresses, flooding occurs at section 20, downstream of the irrigation pond on the left hand bank. Flood waters travel along the floodplain, parallel to the watercourse, to depths ranging from 50 - 200mm, before re-entering the channel at section 22. At the same time, a flow pathway occurs across the left hand bank between section 32 and 37, equating to 0.4m^3/s at its peak.

Flow exits the channel at section 32 and spreads across the floodplain. The majority of the out of bank spill re-enters the channel between sections 36 and 38. Maximum flood depths in this area reach 280mm. At approximately the same time, flow spills out of bank on the left hand bank upstream of the A7 and the right hand bank upstream of the A6106. Flood depths reach a maximum of 900mm and 500mm upstream of the A7 and A6106 respectively. The flooding extent for this event can be seen in Figure 5-1. Minor flooding is observed on the right hand bank immediately downstream of the A6106 to depths of 300mm.

The remainder of the flow is contained within channel. No out of bank spill is observed downstream of the access track leading onto Old Dalkeith Road.

The A7 and the A6106 were not seen to be at flood risk during a 1 in 200yr plus climate change event.

The flood mechanism is largely replicated in lower return periods, with the first instance of spill at the various locations noted above occurring at different return periods. Flooding is observed in the area upstream of the A7 from the 1 in 5yr event. The onset of flooding for the area around section 20 and flow pathway at section 32 starts from the 1 in 30yr event.

Although there is no historic flood accounts in this rural area, the baseline flood maps tie in well with SEPA flood mapping as also with observed flow routes on site during GI investigations.

A full range of baseline floodmaps for all modelled return periods, with and without climate change, can be found in Appendix E.

Maximum stage in the 1D channel for a range of return periods can also be found in Table 3 Appendix D.

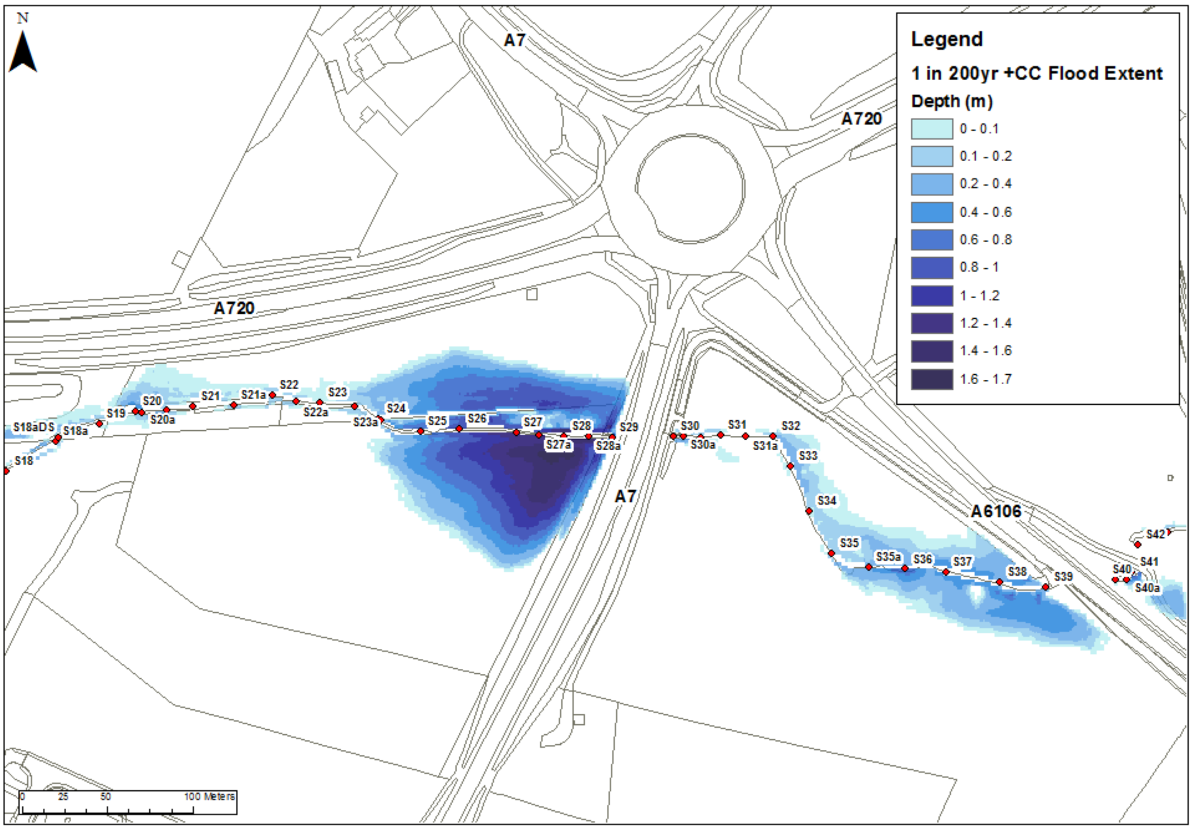


Figure 5-1: 1 in 200yr plus climate change flood depths

5.2 With Scheme

The with scheme model results demonstrates that without mitigation, the proposed scheme has a negative impact on flood risk as a result of loss of floodplain and flow area and is therefore not in line with planning policy.

Floodplain depths upstream of the A7 and the A6106 were increased by approximately 5- 10mm during the 1 in 200yr event and 5-10mm in the 1 in 200yr plus climate change event. Pass forward flows were increased by 0.03m^3/s and 0.025m^3/s through the A6106 culvert for the 1 in 200yr and 1 in 200yr plus climate change events respectively.

Table 5-1 displays the changes in channel water levels at a selection of sections for the 1 in 200yr event. A maximum increase in water level of 50mm is noted at section 32 where out of bank flow originally occurred in the baseline model but is blocked within the scheme model to account for the SuDS pond.

Table 5-1: Channel water levels with and without scheme during the 1 in 200yr event.

Location	Cross section	Baseline maximum stage (mAOD)	With scheme maximum stage (mAOD)
	Section 18	62.82	62.82 (+0.00)
	Section 20	61.99	62.02 (+0.03)
	Section 22	60.57	60.57 (+0.00)
	Section 24	59.99	60.00 (+0.01)
	Section 26	59.68	59.69 (+0.01)
Upstream of A7	Section 28	59.68	59.68 (+0.00)
	Section 30	58.2	58.17* (-0.03)
	Section 32	57.81	57.86 (+0.05)
	Section 34	57.47	57.49 (+0.02)
	Section 36	57.08	57.08 (+0.00)
Upstream of A6106	Section 38	56.99	57.00 (+0.01)
	Section 40	56.69	56.70 (+0.01)

* This decrease related to change in node location and does not represent an actual decrease in water level

The scheme results in a loss of floodplain storage as a result of land raising. The modelling has demonstrated that the proposed scheme increases water levels and pass forward flows and requires mitigation measures to ensure the design complies with planning policy.

5.3 Compensatory storage modelling

5.3.1 Floodplain volumes

The total floodplain volumes at the 2 sections at the realigned channel and on the opposite bank to the SuDS pond were calculated for the baseline and with scheme scenario. The areas of floodplain loss and proposed compensatory storage locations are shown in Figure 5-2. Full details of the land reprofiling are presented in Appendix F.

The proposed compensatory storage for each areas was provided in locations as close as possible to the floodplain loss from the baseline. Due to the river realignment, area 2 is not seen to flood in the with scheme scenario and the compensatory storage has been provided in the same location, with flow filling the area from east. As stated in previous chapters, ground levels were lowered in a manner to ensure that the timings of spill were replicated as closely as possible to the baseline.

Calculating the floodplain volumes for the baseline and with scheme scenarios ensures that at each return period, there is equal to or increased storage from the baseline in the with scheme scenario. Incremental increases between return periods for baseline and with scheme were also calculated. Table 5-2 displays the floodplain volumes in the baseline and with scheme scenarios for the full range of return periods. It is demonstrated that with scheme floodplain volume storage has been increased at every return period from baseline volumes, and that the incremental increases between return periods is also increased. This demonstrates like for like floodplain storage volume at all return periods.

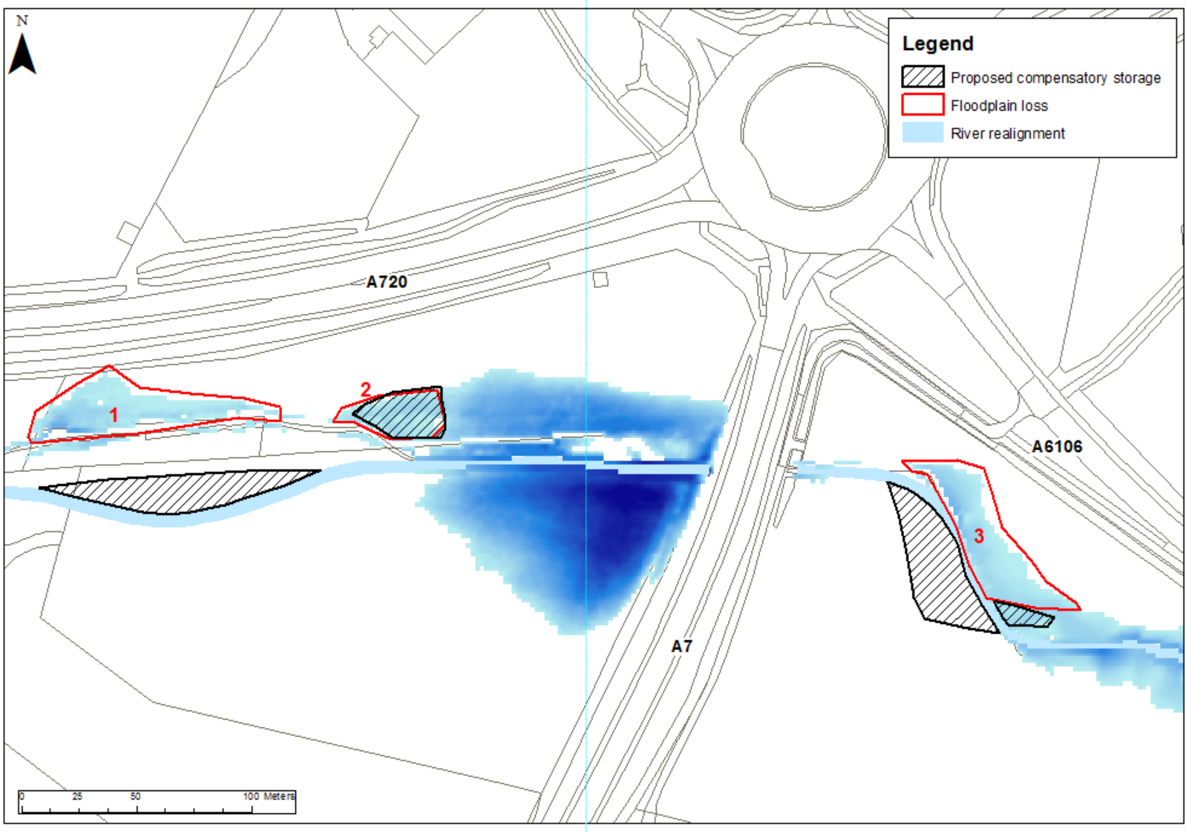


Figure 5-2: Floodplain loss and proposed compensatory storage locations

Table 5-2: Baseline and with scheme floodplain volumes

Return period	Baseline floodplain volume (m^3)	With scheme floodplain volume (m^3)	Change in floodplain storage between baseline and with scheme(m^3)	Baseline incremental change in floodplain volume (m^3)	With scheme incremental change in floodplain volume (m^3)	Incremental change in floodplain volume between baseline and with scheme(m^3)
2	0.0	0.0	+0.0	-	-	-
5	3.6	6.2	+2.6	+3.6	+6.2	+2.6
10	10.7	13.5	+2.8	+7.1	+7.3	+0.2
30	60.3	80.7	+20.4	+49.6	+67.2	+17.6
50	116.2	158.8	+42.6	+55.9	+78.1	+22.2
75	176.9	232.2	+55.3	+60.7	+73.4	+12.7
100	225.4	283.8	+58.4	+48.5	+51.6	+3.1
200	430.0	506.4	+76.4	+204.6	+222.6	+18.0

5.3.2 Impact of Compensatory storage on levels and flow

As well as demonstrating increases storage volumes on the floodplain, the mitigation measures are seen to decrease channel water levels. Table 5-3 displays the top water levels for the 1 in 30yr and 1 in 200yr events. The increases observed at sections 18-22 are as a result of the channel diversion as bed levels and channel cross section have been altered significantly and top water levels between the two scenarios are therefore not comparable. All other river sections display a neutral impact or reduction in water level of between 10-50mm with the mitigation measures in place.

Flood risk to the carriageways was also assessed to ensure they could remain operational during a 1 in 200yr plus climate change event and that they had freeboard to account for any uncertainty.

Flood risk to the two carriageways that cross the Dean Burn was also assessed. The A7 southbound will be lowered from its original elevation and realigned in some locations. The lowest level on the carriageway is 60.45mAOD, which is 500mm above the 1 in 200yr plus climate change flood level in the floodplain upstream of culvert. The A6106 is proposed to remain raised on an embankment, with the lowest level on the carriageway being 59.7mAOD, which is 2.5m above the 1 in 200yr plus climate change flood level upstream of culvert. It is therefore shown that both the A7 and the A6106 can remain operational during a 1 in 200yr plus climate change flood event and that freeboard is provided to account for any uncertainty.

Full tabulated model results can be found in Appendix D. Floodmaps for the 1in 30yr and 1 in 200yr event can be found in Appendix E.

Table 5-3: Baseline and with scheme change in top water levels

Location	Cross section	1 in 30yr baseline maximum stage (mAOD)	1 in 30yr with scheme maximum stage (mAOD)	1 in 200yr baseline maximum stage (mAOD)	1 in 200yr with scheme maximum stage (mAOD)
	Section 18	62.56	62.87* (+0.31)	62.82	63.11* (+0.29)
	Section 20	61.85	61.91* (+0.06)	61.99	62.01* (+0.02)
	Section 22	60.38	60.66* (+0.28)	60.57	60.81* (+0.24)
	Section 24	59.68	59.53 (-0.15)	59.99	59.76 (-0.23)
	Section 26	59.10	59.10 (+0.0)	59.68	59.65 (-0.03)
Upstream of A7	Section 28	59.09	59.08 (-0.01)	59.68	59.65 (-0.03)
	Section 30	58.00	57.98 (-0.02)	58.2	58.15 (-0.05)
	Section 32	57.67	57.65 (-0.02)	57.81	57.75 (-0.06)
	Section 34	57.38	57.36 (-0.02)	57.47	57.44 (-0.03)
	Section 36	56.83	56.83 (+0.0)	57.08	57.07 (-0.01)
Upstream of A6106	Section 38	56.68	56.68 (+0.0)	56.99	56.98 (-0.01)
	Section 40	56.31	56.31 (+0.0)	56.69	56.67 (-0.02)

* These increases are a result of the channel realignment where both section location and elevation have changed

To fully assess the effectiveness of the compensatory storage provided, pass forward flows were also assessed to ensure the scheme has no negative impact on flood risk downstream. Table 5-4 displays the peak flows through the A7 and the A6106 culverts. In all return periods, flow is seen to either be equal to or less than the baseline, representing a neutral or betterment to pass forward flows. Although compensatory storage is only required to be provided up to the 1 in 200yr design event, it can be seen in Table 5-4 that pass forward flow in the 1 in 200yr plus climate change event is also reduced from baseline.

Maximum stage in the 1D channel for a range of return periods can also be found in Table 4 Appendix D.

Table 5-4: Flows at the A7 and A6106 culverts – baseline and with scheme

	2	5	10	30	50	75	100	200	200CC
A7 Culvert Baseline	1.41	1.85	2.17	2.79	3.16	3.51	3.69	4.31	5.00
A7 Culvert With scheme	1.41 (0.00)	1.85 (0.00)	2.17 (0.00)	2.78 (-0.01)	3.14 (-0.02)	3.48 (-0.03)	3.67 (-0.02)	4.25 (-0.06)	4.93 (-0.07)
A6106 Culvert Baseline	1.41	1.85	2.17	2.79	3.14	3.50	3.69	4.30	4.94
A6106 Culvert With scheme	1.41(0.00)	1.85 (0.00)	2.17 (0.00)	2.78 (-0.01)	3.13 (-0.01)	3.48 (-0.02)	3.67 (-0.02)	4.25 (-0.05)	4.89 (-0.05)

As well as matching peak flows, it is also important that the full hydrographs are similar in the baseline and with scheme scenarios to demonstrate that floodplain storage is storing and conveying flood waters in a similar manner. Figure 5-3 displays the 1 in 200yr baseline and with scheme hydrograph upstream of the A6106 culvert. The hydrographs are seen to be very similar on the rising and receding limbs, with the main variation around the peak due to the increase in floodplain storage provided as part of the scheme design.

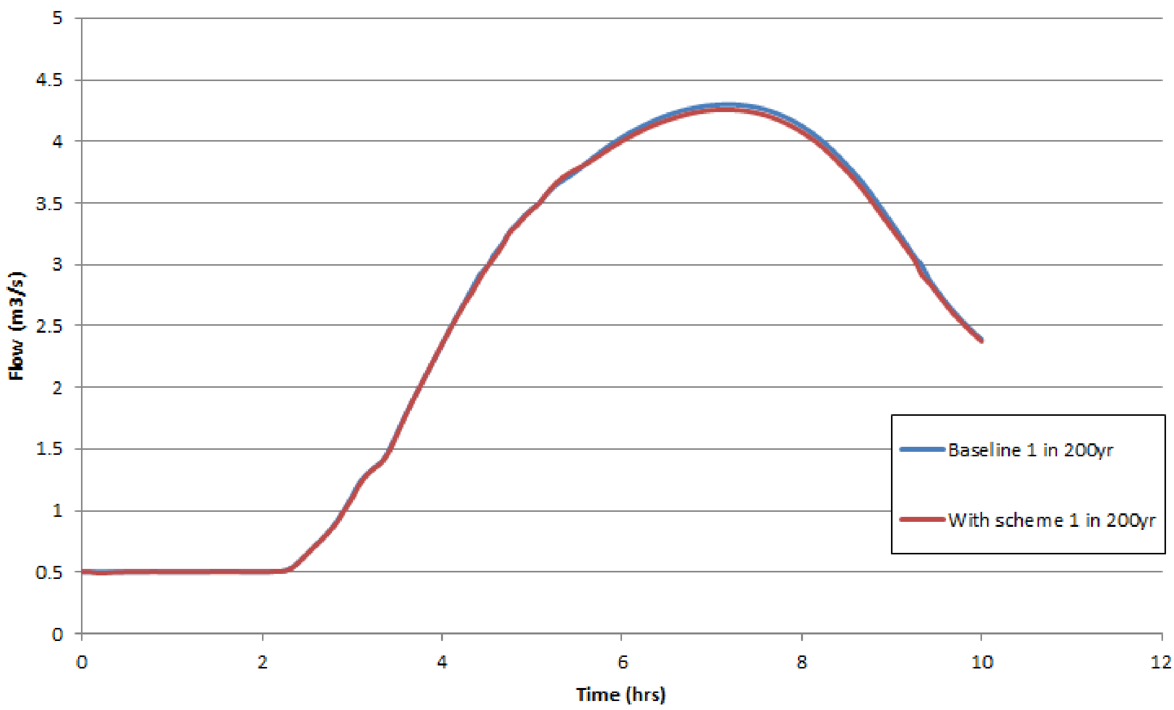


Figure 5-3: 1 in 200yr hydrograph – baseline and with scheme at downstream end of scheme extent

Using the hydraulic model, it has been demonstrated that the proposed compensatory storage delivers increased floodplain volume, decreased top water levels and decreased or matched peak flows at all return period.

6. Conclusion

6.1 Introduction

AECOM was commissioned by Transport Scotland to undertake a Flood Risk Assessment (FRA) as part of the wider A720 Sheriffhall Junction improvements that will feed into the Environmental Impact Assessment (EIA). The Sheriffhall roundabout is located to the south of Edinburgh and the proposed development includes a flyover for the A720 bypass, with a roundabout connecting the A roads underneath and cycle network provision. The design also includes several SuDS features, to treat and attenuate the increased hardstanding.

The works are classed as 'Essential infrastructure' and SEPA's Flood Risk and Land Use Vulnerability Guidance states that it is generally suitable to develop this land use type in areas at medium to high risk for operational reasons or if an alternative is not available. It is noted that the design should remain operational during floods.

The aim of the FRA is to assess the current flood risk to the site from the Dean Burn which runs parallel to the A720, assess the impact of the development (if any), and to develop mitigation options if required to ensure that flood risk is not adversely affected elsewhere as a result of the development.

6.2 Baseline flood risk

Out of bank flow is seen to occur from the 1 in 5yr event upstream of the A7 culvert during current day conditions. Flood extent is seen to increase in this area as event magnitude increases, with maximum flood depths in the 1 in 200yr event plus climate change event of 1.65m.

Other notable areas of out of bank spill are located on the left hand bank downstream of the irrigation pond and across the left hand bank between the A7 and Old Dalkeith Road. The spill in these locations begins from the 1 in 30yr event. Flood depths are shallower in these locations, in the order of 200-300mm during a 1 in 200yr plus climate change event.

Later in the event, further spill is observed on the left bank upstream of the A7 and the right bank upstream of the A6106 to depths of approximately 900mm and 500mm respectively.

The A7 and A6106 carriageways were shown to not be at risk during a 1 in 200yr plus climate change event.

6.3 Proposed scheme flood risk

Where possible, and using an iterative approach, the layout has been designed to avoid the functional floodplain identified in the baseline modelling. However, there are areas where this is not possible due to topographic or space constraints.

The proposed development was modelled to determine how the design affected flood risk when compared to the baseline scenario. This run contains no mitigation measures and is to be used purely to assess how the proposed roundabout upgrades affect flood risk in the surrounding area.

The with scheme model demonstrates that without mitigation, the proposed development has a negative impact on flood risk out with the site and is therefore not in line with planning policy.

Floodplain depths upstream of the A7 and the A6106 were increased by approximately 5- 10mm during the 1 in 200yr event and 5-10mm in the 1 in 200yr plus climate change event. Pass forward flows were increased by 0.03m^3/s and 0.025m^3/s through the A6106 culvert for the 1 in 200yr and 1 in 200yr plus climate change events respectively.

The modelling of scheme demonstrated that the proposals increase water levels and pass forward flows and will require mitigation measures to ensure the design complies with planning policy.

6.4 Mitigation measures

6.4.1 Requirements

It is best practice to avoid land raising in the function floodplain. This approach has been applied throughout the design process, however in some cases it has not been possible to avoid development within sections of the functional floodplain.

The areas where it has not been possible to remove scheme elements from the function floodplain are along a stretch of the Dean Burn that runs close to the A720 embankment and an area between the A7 and the A6106 that is required for a SuDS pond. The with scheme model has demonstrated that removing these areas from the floodplain negatively affects flood risk and land raising will need to be mitigated up to the 1 in 200yr design level to ensure no detrimental flood risk.

SEPA's Technical Flood Risk Guidance for Stakeholders, 2018 outlines a recommended approach for mitigating land raising by providing compensatory storage elsewhere. It is noted in this guidance that development within the functional floodplain should be avoided but in certain cases it can be appropriate if compensatory storage is provided so that the development does not affect the ability of the functional flooding to store and convey water.

In addition to providing compensatory storage, two further mitigation measures are suggested on the Dean Burn. It is proposed that the Dean Burn be realigned upstream of the A7 given the proximity of the embankment toe to the watercourse, and the potential erosion issues this could cause. It is proposed that the burn be diverted 40m to the south. Realignment of this burn provides an opportunity for river restoration along a reach that is currently canalised and overly deep. The channel would be installed as a restored 2 stage meandering channel created to improve watercourse function and habitat. A further channel improvement between the A7 and the A6106 is the proposal to remove the sharp right angle bend in the channel as it is unnatural and acts as a constriction in the channel. This angle will be smoothed to provide an added river functioning benefit as well as less of a constriction to the SuDS pond.

6.4.2 Provision

The areas of floodplain loss that required compensatory storage, were modelled as they were too complex to assess on a 'like for like' elevation slice basis.

The total floodplain volumes at the realigned channel and on the opposite bank to the SuDS pond were calculated for the baseline and with scheme scenario to ensure that at each return period, there was equal to or increased storage from the baseline in the with scheme scenario. Incremental increases between return periods for baseline and with scheme were also calculated. It was demonstrated that with scheme floodplain volume storage has been increased at every return period from baseline volumes, and that the incremental increases between return periods was also increased. This ensures that like for like is provided based on magnitude of event and total floodplain volume.

As well as demonstrating increases storage volumes on the floodplain, the compensatory storage provision in the with scheme scenario is also seen to provide a neutral impact or decrease to channel water levels and flow at all modelled return periods. Hydrograph shape at the downstream extent of the scheme is comparable to the baseline hydrograph, demonstrating that floodplain storage is functioning in a similar manner.

Flood risk to the two carriageways that cross the Dean Burn was also assessed. Based on lowest levels on the carriageway, and top water levels in the 1 in200yr plus climate change event, it was shown that both the A7 and the A6106 can remain operational during a 1 in 200yr plus climate change flood event and that freeboard is provided to account for any uncertainty.

Using the hydraulic model, it has been demonstrated that the provided compensatory storage delivers increased floodplain volume, decreased top water levels and decreased or matched peak flows when compared to the baseline scenario at all return periods.

6.5 Recommendations

In order to mitigate against the loss of floodplain storage as a result land raising, it is recommended that compensatory storage be provided in the three areas outlined in this report. Full details of the extent and contours of the land reprofiling can be found in Appendix F.

The SuDS pond is required to be removed from the function floodplain as there is insufficient capacity in the pond for river flows. This can be achieved by forming a small bund in the order of 100-200mm around the western and southern edges of the pond.

The channel diversion should be constructed in line with the cross sections and guidance set out in the river restoration technical note ‘A720 Sheriffhall Junction Improvement: Dean Burn diversion hydromorphology design’.

Appendix A – Site Photographs

Photograph 1: Typical section through the the wooded area adjacent to irrigation pond

Photograph 2: Typical section through the the wooded area adjacent to irrigation pond

Photograph 3: Area upstream of A7 culvert

Photograph 4: Area upstream of the A7 culvert

Photograph 5: A7 culvert inlet

Photograph 6: A7 culvert outlet

Photograph 7: Inlet of Old Dalkeith Road culvert

Photograph 8: Culvert leading into Dalkeith Country Park

Photograph 9: Typical section through Dalkeith Country Park

Appendix B – Hydrology

Donors assessed in QMED calculations taken from WINFAP selection

Station name	***Station no.***	***Area***	***SAAR***	***BFIHOST***	***SPRHOST***	***FARL***
Dean Burn – subject catchment		*6.19*	*685*	*0.52*	*41.64*	*0.992*
DONORS:						
Tweed @ Glenbreck	*21029*	*34.4*	*1532*	*0.353*	*49.11*	*1.0*
Fruid Water @ Fruid	*21001*	*22.01*	*1702*	*0.392*	*45.21*	*0.779*
West Peffer Burn@ Luffness	***20002***	***25.51***	***616***	***0.47***	***31.99***	***0.995***

Acceptable / Not acceptable

Default Pooling group						
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27051 (Crimple @ Burn Bridge)	0.73	45	4.564	0.221	0.144	0.123
45816 (Haddeo @ Upton)	1.193	24	3.489	0.306	0.387	0.408
26802 (Gypsey Race @ Kirby Grindalythe)	1.353	18	0.108	0.316	0.217	0.342
25019 (Leven @ Easby)	1.353	39	5.677	0.34	0.377	0.602
28033 (Dove @ Hollinsclough)	1.432	38	4.225	0.234	0.405	0.791
49005 (Bollingey Stream @ Bolingey Cocks Bridge)	1.595	7	5.777	0.282	0.189	3.62
49006 (Camel @ Camelford)	1.764	11	11.154	0.124	-0.185	2.861
27010 (Hodge Beck @ Bransdale Weir)	1.774	41	9.42	0.224	0.293	0.286
47022 (Tory Brook @ Newnham Park)	1.806	24	6.651	0.265	0.138	0.258
25011 (Langdon Beck @ Langdon)	1.828	28	15.878	0.238	0.318	0.661
44008 (South Winterbourne @ Winterbourne Steepleton)	1.863	38	0.434	0.417	0.336	1.483
203046 (Rathmore Burn @ Rathmore Bridge)	1.987	35	10.72	0.147	0.144	0.627
76011 (Coal Burn @ Coalburn)	2.083	40	1.84	0.166	0.31	1.126
27073 (Brompton Beck @ Snainton Ings)	2.093	36	0.816	0.203	0.06	0.462
36010 (Bumpstead Brook @ Broad Green)	2.111	50	7.543	0.371	0.177	1.852
71003 (Croasdale Beck @ Croasdale Flume)	2.119	37	10.9	0.212	0.323	0.499
Total		511				

Weighted means				0.256	0.240	

Removed stations from default pooling group. All stations added as a result of removal were checked for all parameters to ensure suitability

Station no.	***Reason***
49005	*Short record*
49006	*Short record*
47022	*Low FARL*
36010	*Low PROPWET – dissimilar to site*
26802	Permeable catchment (low SRPHOST) – dissimilar to site
27073	Permeable catchment (low SRPHOST) – dissimilar to site
76011	Dissimilar BFIHOST
44008	Dissimilar BFIHOST
71003	Site comments – may not be suitable for pooling
25011	Excess years – removed least similar catchment

Amended pooling group						
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27051 (Crimple @ Burn Bridge)	0.73	45	4.564	0.221	0.144	0.864
45816 (Haddeo @ Upton)	1.193	24	3.489	0.306	0.387	0.881
25019 (Leven @ Easby)	1.353	39	5.677	0.34	0.377	1.395
28033 (Dove @ Hollinsclough)	1.432	38	4.225	0.234	0.405	0.996
27010 (Hodge Beck @ Bransdale Weir)	1.774	41	9.42	0.224	0.293	0.248
203046 (Rathmore Burn @ Rathmore Bridge)	1.987	35	10.72	0.147	0.144	1.214
206006 (Annalong @ Recorder)	2.134	48	15.33	0.189	0.052	1.95
20002 (West Peffer Burn @ Luffness)	2.153	41	3.299	0.292	0.015	2.22
27032 (Hebden Beck @ Hebden)	2.307	51	4.052	0.204	0.247	0.7
49003 (de Lank @ de Lank)	2.409	51	14.324	0.225	0.206	0.418

72014 (Conder @ Galgate)	2.421	49	16.283	0.22	0.111	0.885
48004 (Warleggan @ Trengoffe)	2.439	48	9.983	0.258	0.257	0.229
Total		510				
Weighted means				0.24	0.216	

Appendix C – Model Schematisations & Site Topography


A720
(E)
FRENCH DRAIN
COMMEMORATIVE PLAQUE

1D model cross sections

	X	Y			X	Y
S1				S30		
	1.4	69			0	59.043
	3.05	68.534			4.746	58.973
	5.24	68.365			6.67	58.67
	5.6	67.748			8.366	58.37
	7.24	67.737			10.172	58.186
	9.13	68.523			10.491	57.995
	10	69			10.581	58.003
S2					11.457	57.711
	3.56	69			11.679	57.639
	3.96	68.5			11.812	57.4
	4.45	67.877			11.825	57.358
	6.66	67.511			12.224	57.261
	7.7	68			13.064	57.254
	8.77	68.077			13.769	57.259
	10.14	68.573			13.823	57.303
S3					13.91	57.332
	1	68.5			14.464	57.877
	1.78	68.037			14.533	57.879
	2.48	67.381			15.418	57.976
	3.7	67.38				
	3.84	67.615		S31		
	5.42	68.397			0	57.922
					0.596	57.5
S4					1.353	56.965
	0	68.429			3.62	57.193
	5.19	68.025			3.97	58

	7.81	66.687			4.59	58.03
	9.3	66.7				
	9.53	67.062		S32		
	10.48	67.965			0	57.67
S5					1.26	57
	-0.7	67.34			1.83	56.797
	0.2	67.1			3.23	56.6
	3.1	66.53			4.06	57
	3.25	66.5			5	57.68
	3.25	66.5				
	3.42	66.292		S33		
	4.22	66.359			-1	57.5
	4.37	66.5			0	57.418
	4.5	68			0.89	57
S6					1.52	56.701
	0	67			3.12	56.63
	1.08	66.5			3.54	57
	2.04	66.15			3.96	57.69
	3.22	66.15			5	57.5
	3.65	67				
S7				S34		
	0	66.5			-0.7	57.4
	0.568	66			0	57.32
	0.77	65.823			0.54	57
	2.67	65.719			1.2	56.562
	2.88	66			2.78	56.57
	3.53	66.5			3.07	57
					4.38	57.582
S8						

				S35		
	0	66.595			-1	57.3
	1.73	66			0	57.117
	3.18	65.5			0.84	56.5
	3.62	65.348			0.99	56.41
	3.81	65.196			2.63	56.3
	5.88	65.233			2.93	56.5
	6.02	65.5			3.74	57.172
	6.38	66			5	57.2
	6.76	66.61				
S9				S36		
	3	66.05			0	56.91
	3.93	65.958			0.67	56.5
	4.28	64.805			1.55	55.97
	5.66	64.8			3.49	55.85
	5.95	65.064			3.64	56
	7.82	65.351			3.96	56.453
	8.61	65.737			4.31	56.45
S10						
	0	65.781		S37		
	0.648	65.5			-0.3	56.8
	1.26	65			0	56.699
	1.63	64.64			0.367	56.5
	3.5	64.55			1.29	56
	3.94	65			1.86	55.687
	5.59	65.189			3.68	55.859
	6.1	65.4			4.27	56.5
					5.2	56.75

					5.5	56.8
S11						
	0	65.831		S38		
	4.09	65.526			-0.5	56.87
	5.71	64.5			0.92	56
	5.84	64.359			1.81	55.512
	7.54	64.288			3.31	55.512
	7.61	64.5			3.7	56.271
	7.91	64.944			4.49	56.5
	10.29	65.5			4.89	56.8
S11a				S39		
	0	65.2			0	59.336
	0.5	64.18			3.97	58
	4.1	64.18			4.676	56.22
	5.07	65			5.184	55.978
	6.3	65.2			5.777	55.497
					6.635	55.467
S11aDS					7.564	55.47
	0	65.2			8.555	55.775
	0.5	64.18			8.676	55.874
	4.1	64.18			10.179	56.873
	5.07	65			11.976	56.865
	6.3	65.2				
				S40		
					0	57.203
S11b					3.123	57.08
	0	64.94			4.006	57.03
	0.9	63.9			5.175	56.574

	2.09	63.98			5.623	56.445
	2.32	64.2			5.838	56.285
	3.44	64.3			5.856	56.241
	4.6	64.5			6.606	56.111
	5.5	65.2			6.652	55.885
					6.959	56.045
S12					7.131	55.677
	0	65.433			7.567	55.621
	1.44	64.5			8.252	55.55
	2.6	64.255			8.93	55.683
	2.88	63.74			9.162	55.631
	5.06	63.713			10.219	56.708
	5.219	64			10.235	56.876
	5.49	64.5			13.39	59.205
	7.66	65				
				S40a		
					-2.1	56
S13					0	55.7
	0	64.5			0.2	55.5
	3.8	64.3			0.8	55.5
	4.57	64.159			1.4	56.4
	4.92	63.503				
	8.858	63.709		S41		
	9.28	64			0	56.865
	9.86	64.388			2.243	56.176
					6.224	55.886
S14					6.351	55.784
	0	64.494			8.243	55.243
	1.86	63.999			8.323	55.27

	2.5	63.908			10.613	55.222
	2.58	63.328			10.695	55.22
	5.61	63.449			11.422	55.275
	6.23	63.906			11.92	56.112
	7.4	63.96			13.694	57.145
	8.41	64			15.889	57.086
S15				S42		
	0	63.68			0	56.406
	2.08	63.426			0.95	56.643
	2.15	62.87			4.928	56.354
	4.69	62.63			6.098	56.236
	4.93	63			6.163	56.22
	5.35	64.263			7.011	55.401
					7.467	55.185
					7.823	55.162
S16					8.365	55.059
	0	64.011			8.533	55.065
	1.07	63.5			9.189	55.028
	1.76	63.164			9.589	55.189
	1.91	62.302			9.732	55.181
	4.9	62.552			10.138	55.686
	5.81	63			10.324	55.669
	6.93	63.55			11.076	56.023
					11.161	55.675
S17					12.279	56.076
	0	63.66			12.884	56.54
	2	63			14.131	56.696
	2.46	62.14				

	5.21	62.13		S43		
	5.67	63			0	56.984
	6.1	63.51			4.527	56.879
					7.082	55.727
					8.593	55.594
S18					9.794	55.29
	0	63.188			10.176	54.693
	1.6	63			11.263	54.536
	2.16	62.927			11.982	54.436
	2.54	61.9			12.17	54.164
	5.73	61.874			12.386	54.123
	6.13	62.685			12.709	54.066
	7.93	63.152			13.073	54.046
					13.212	54.261
					13.784	55.198
S18a					14.039	55.752
	-1.5	62.5			16.849	56.014
	0	62.3				
	1.2	61.5		S44		
	3.7	61.5			1.047	54.643
	5.7	62.9			4.208	54.688
					6.788	54.5
S18aDS					9.102	54.667
	0	62.1			9.181	54.552
	1.2	61.5			9.657	54.39
	3.7	61.5			9.918	54.169
	5.7	62.3			10.131	54.22
					11.557	54.109
					12.881	54.106

S19					12.918	55.627
	0	62.31			12.939	56.072
	3	61.96			14.942	55.762
	4.228	61.942				
	4.56	61.5		S45		
	4.71	61.359			0	56.954
	8.94	61.567			4.117	56.808
	9.36	62			5.415	56.612
	9.51	62.121			7.846	55.331
					9.242	54.059
S20					10.366	53.759
	0	61.726			11.419	53.883
	6	61.64			11.689	57.157
	7.2	61.623			11.698	57.282
	7.429	61.06				
	11.06	61.208		S46		
	11.52	61.5			0	56.102
	11.67	61.59			2.766	56.215
	12.7	61.9			4.355	55.866
					5.124	54.028
S20a					5.762	53.486
	-1.5	61.4			6.323	53.367
	0	61.3			9.57	53.599
	0.4	61.01			10.033	53.812
	1.6	61.01			10.332	54.759
	1.9	61.56			10.349	55.601
	2.8	61.8			11.614	55.793
					13.865	55.76

S20b				S47		
					0	54.425
					4.862	54.469
	-1.3	61.5			7.028	54.369
	0.4	61			7.331	54.115
	2.7	60.8			7.635	52.893
	3.3	61.35			10.15	52.989
					11.924	52.987
					12.469	52.539
S21					13.111	52.555
	0	61.33			16.456	52.758
	1.19	61.32			16.924	53.951
	1.43	60.55			17.213	54.496
	4.709	60.52			20.345	54.71
	5.06	61.01				
	6.5	61.2				
	8.699	61.5		S48		
					0	54.327
S22					4.083	54.319
	0	60.73			6.284	54.247
	3.6	60.5			6.854	54.089
	4.407	60.548			7.999	53.524
	4.95	59.858			8.22	53.442
	7.67	59.82			8.477	52.279
	7.91	60			10.382	52.151
	8.99	60.5			11.003	53.082
					11.944	53.125
S23					14.053	54.24
	-1.1	60.25			15.363	54.43

	0	60.025			18.873	54.454
	0.528	59.132				
	2.16	59.156		S48DS		
	2.6	60.049			0	54.327
	4.3	60.5			4.083	54.319
					6.284	54.247
S24					6.854	54.089
					7.999	53.524
					8.22	53.442
	0	59.6			8.477	52.279
	0.7	58.9			10.382	52.151
	3.2	58.8			11.003	53.082
	5	59.8			11.944	53.125
					14.053	54.24
S24DS					15.363	54.43
	0	59.6			18.873	54.454
	0.7	58.9				
	3.2	58.8		S49		
	5	59.9			0	53.385
					5.264	53.497
					9.232	53.69
S25					9.979	53.476
	0	59.25			11.357	51.478
	1.21	58.5			12.071	51.393
	1.51	58.33			13.9	51.685
	3.2	58.3			14.459	51.91
	3.43	58.5			15.77	52.065
	4.66	59.545			16.884	53.483
					19.395	53.744

					22.291	53.784
S26						
	0	59.011		S50		
	0.905	58.115			0	52.617
	1.77	58.08			3.787	52.792
	3.605	58.09			5.979	52.765
	3.8	59			6.793	52.464
	4.7	59.02			8.301	51.596
					8.59	51.658
S27					8.798	50.649
	0	59.261			9.589	50.615
	1.356	58.5			10.489	50.814
	2.249	58			10.646	51.218
	2.54	57.836			11.567	51.563
	4	57.79			12.958	51.666
	4.35	58			13.149	51.688
	5.15	58.5			13.292	52.641
	5.54	58.739			13.552	52.904
					17.809	52.958
S28						
	0	58.5				
	0.98	58				
	1.81	57.7				
	3.32	57.7				
	3.84	58				
	4.76	58.566				
S29						
	0	58.928				

	3.588	58.895				
	4.779	58.974				
	5.567	58.448				
	5.907	58.331				
	6.991	58.199				
	7.009	58.15				
	7.09	57.804				
	7.348	57.762				
	7.777	57.7				
	8.43	57.739				
	8.964	57.787				
	9.16	57.779				
	9.215	58.07				
	9.223	58.105				
	10.613	58.477				
	11.035	58.664				

Structures in 1D model

Table 1: summary of structures in model

	Type	Opening width (m)	Opening height (m)
S11a	Orifice	2	1.5
S18a	Orifice	2	1.5
S24	Orifice	2	1.5
S29	Circular culvert	1.75	1.75
S39	Arch culvert	2.4	1.8
S41	Arch culvert	2.1	0.79
S43	Arch bridge	2.912	1.32 (maximum)
S45	Arch culvert	2.4	2
S48	Arch bridge	2.25	1.66 (maximum)

Figure 1-Culvert 29

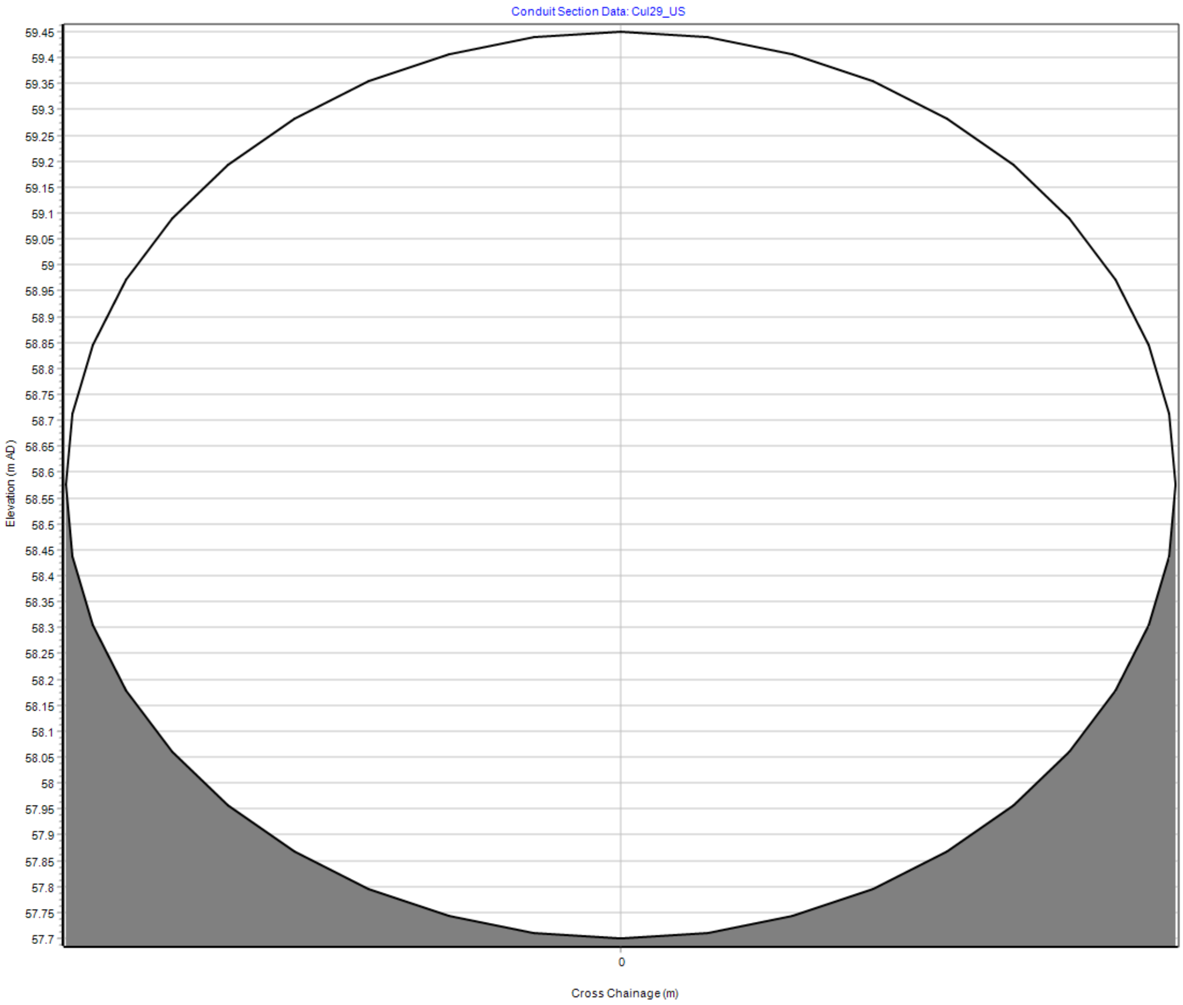


Figure 2-Culvert 39

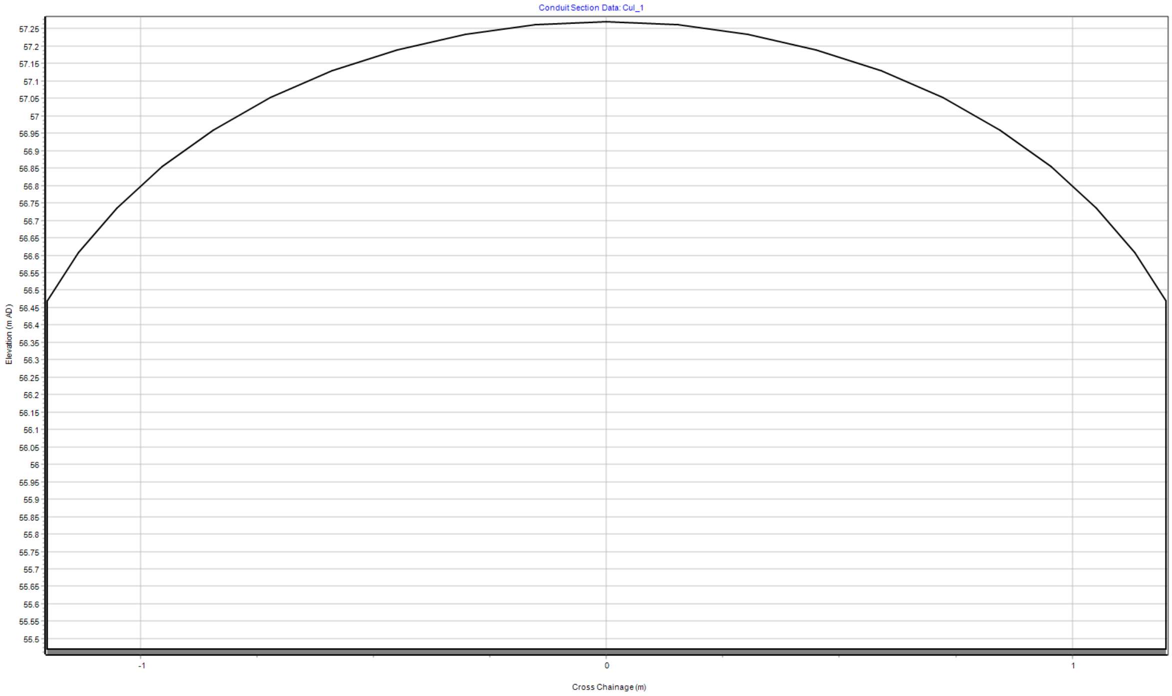


Figure 3-Culvert 41

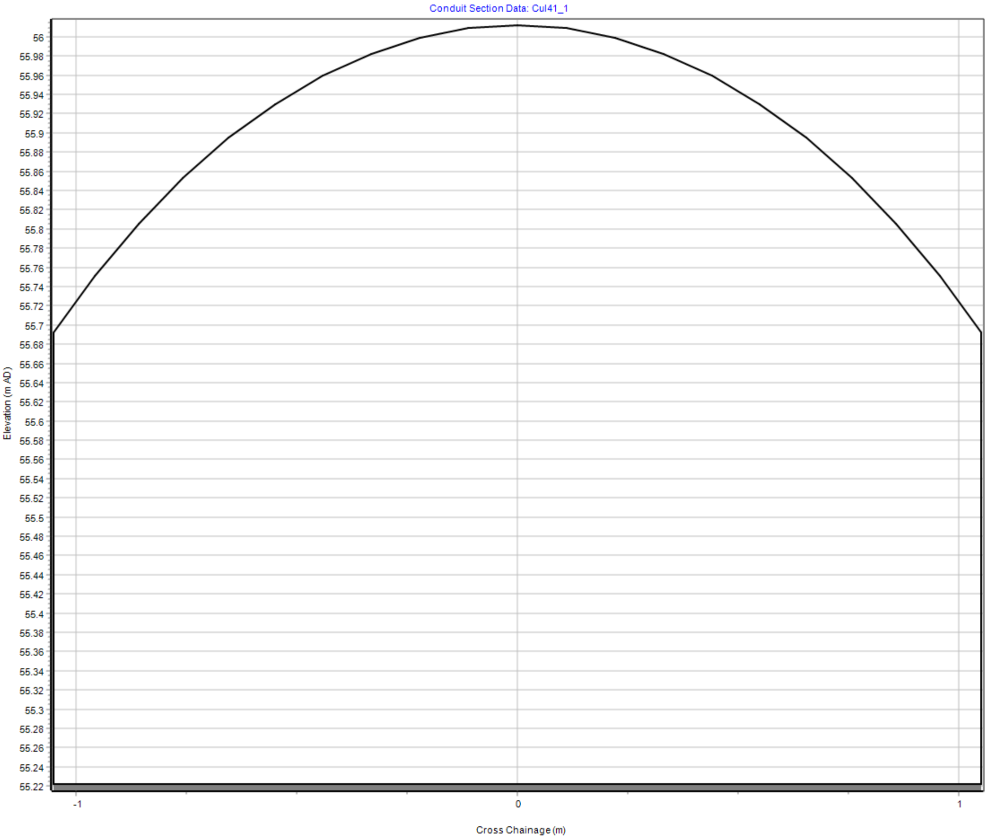


Figure 4-Bridge 43

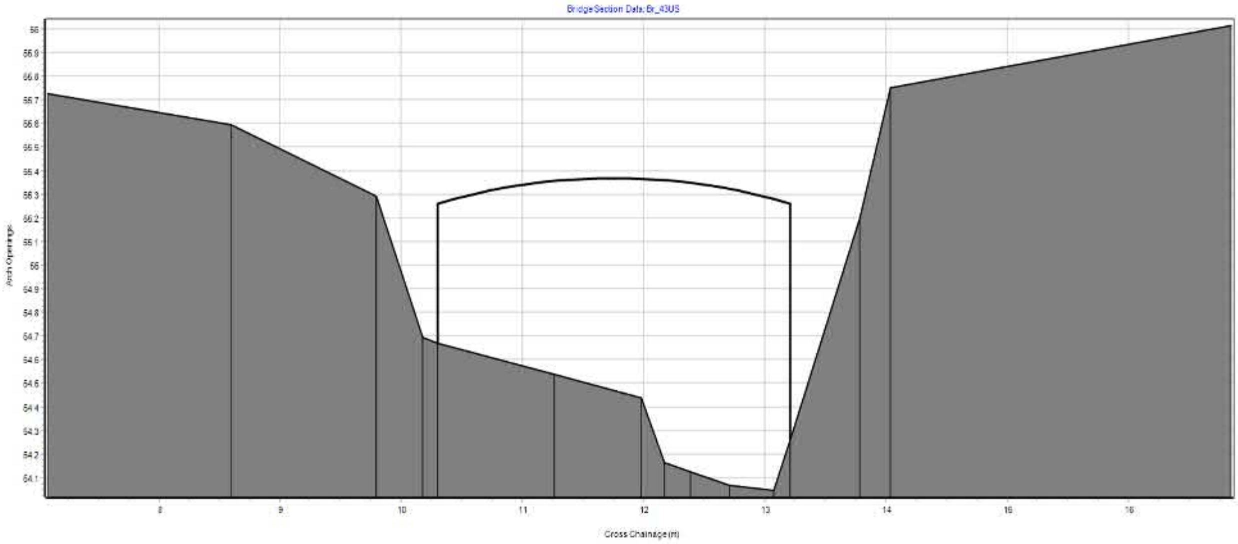


Figure 5-Culvert 45

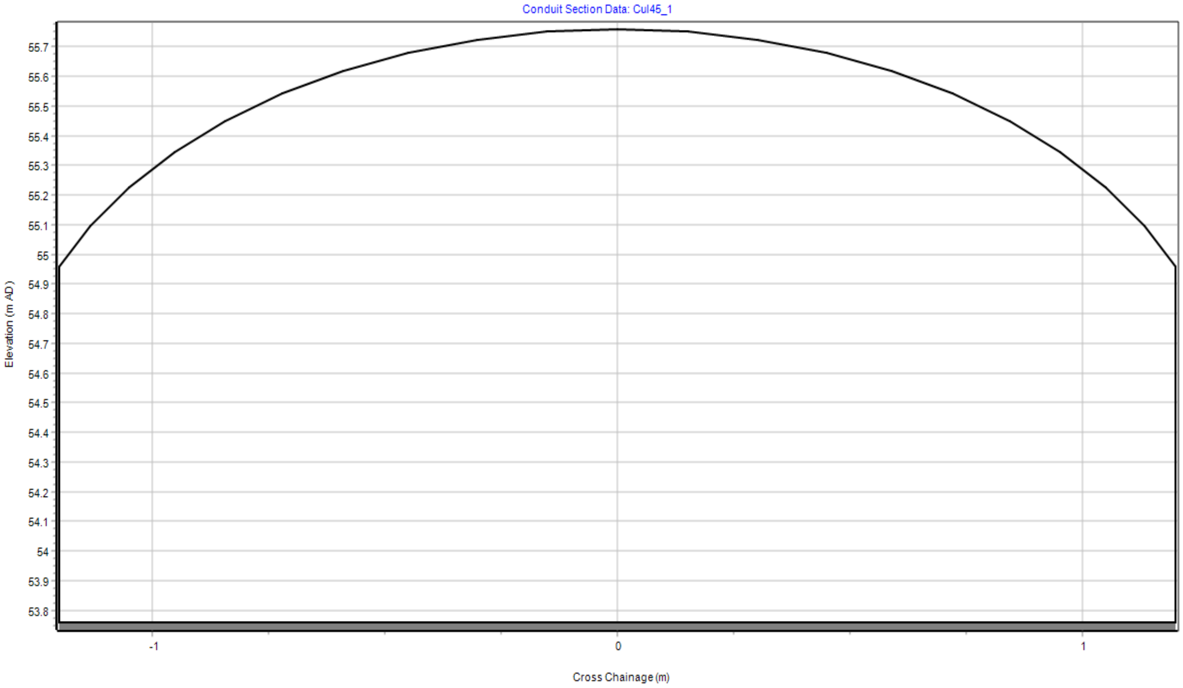
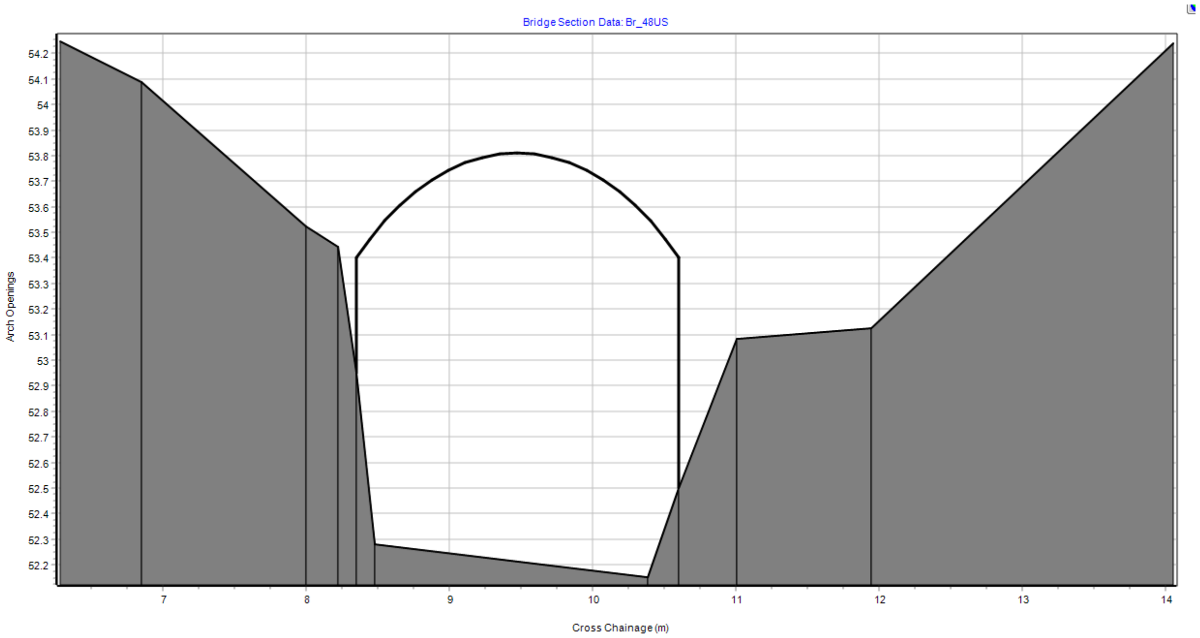
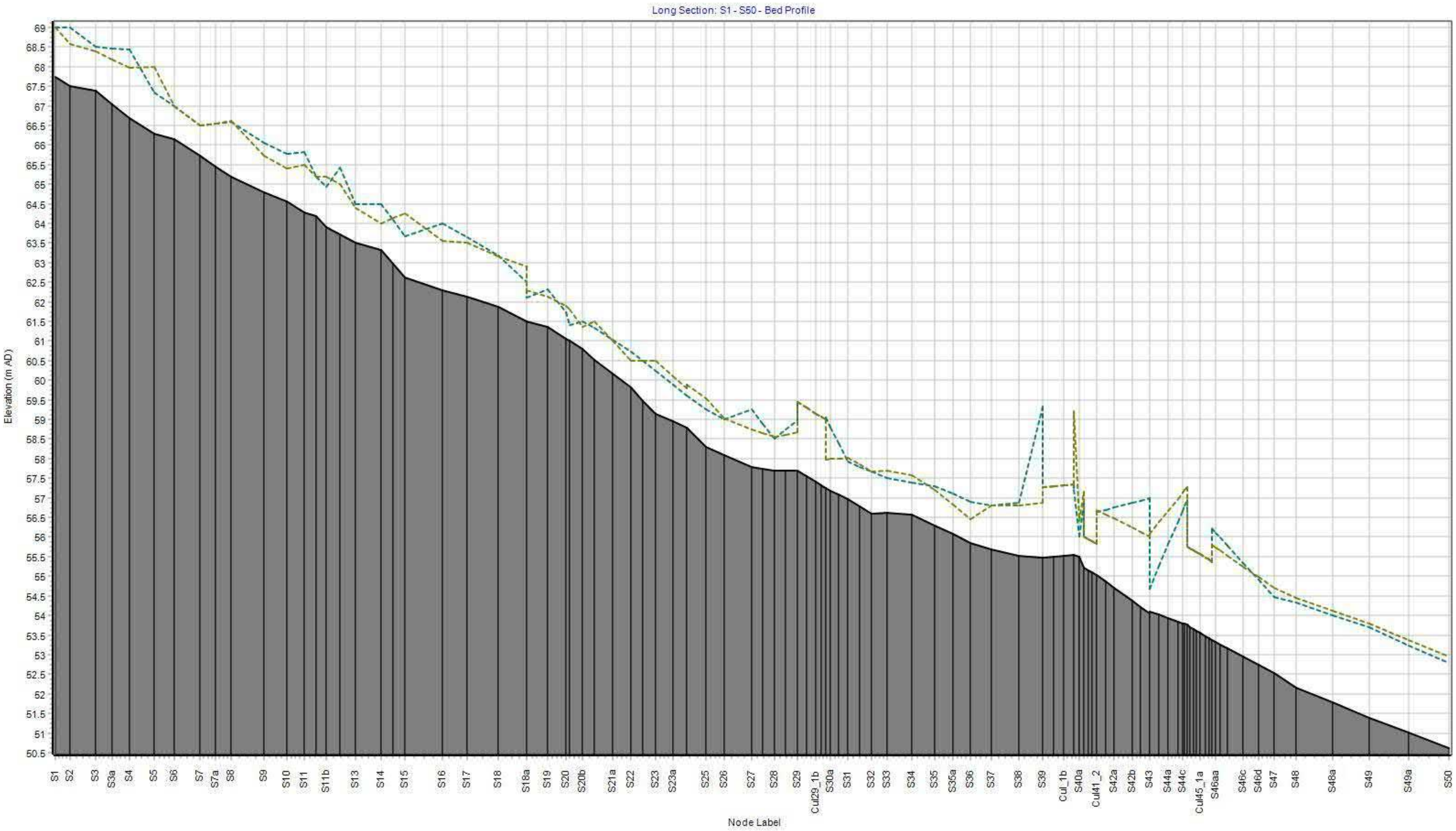
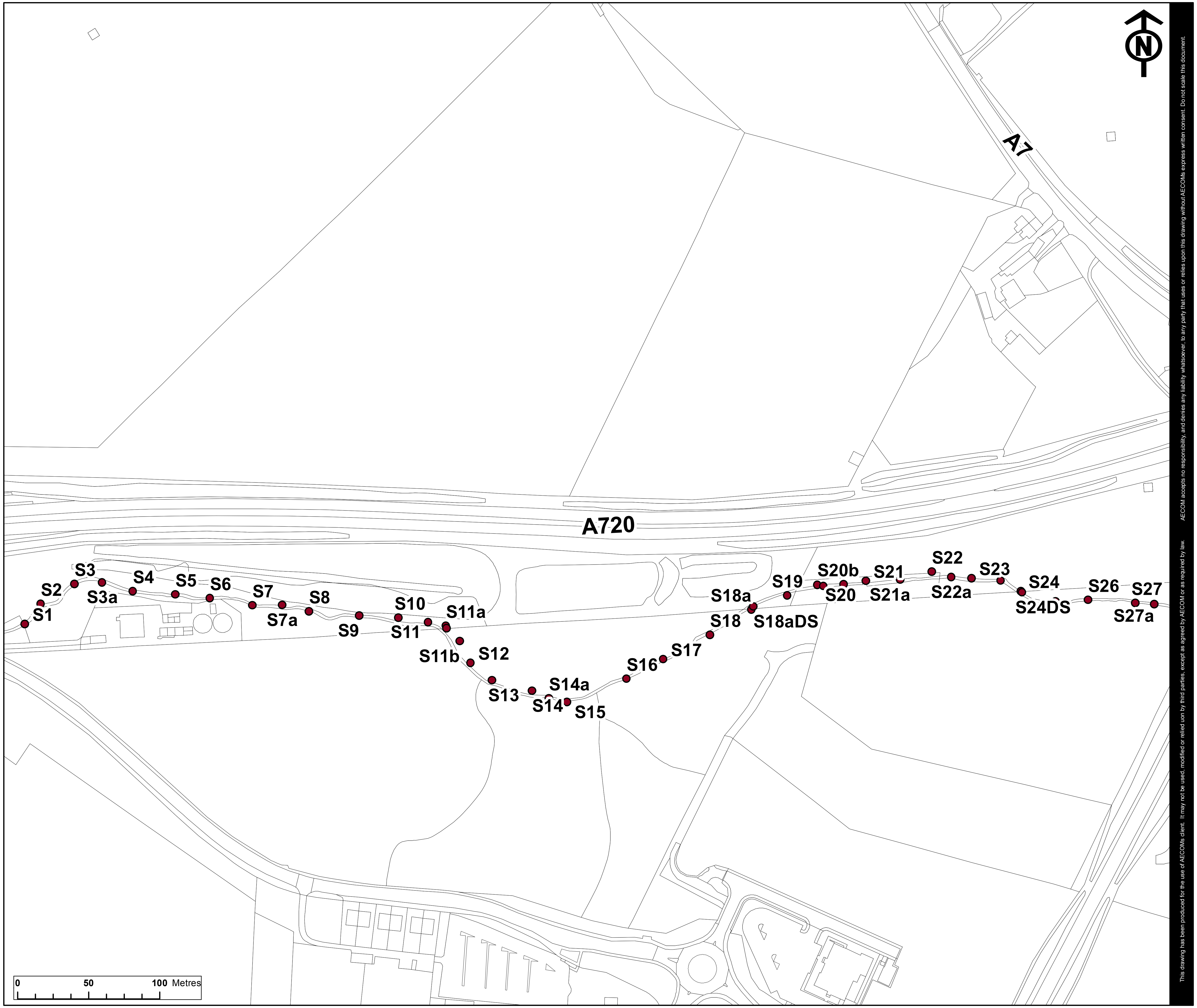


Figure 6-Bridge 48




Long Section: S1 - S50 - Bed Profile
Elevation (m AD)
69
68.5
68
67.5
67
66.5
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
54.5
54
53.5
53
52.5
52
51.5
51
50.5
S1
S2
S3
S3a
S4
S5
S6
S7
S7a
S8
S9
S10
S11
S11b
S13
S14
S15
S16
S17
S18
S18a
S19
S20
S20b
S21a
S22
S23
S23a
S25
S26
S27
S28
S29
Cul29_1b
S30a
S31
S32
S33
S34
S35
S35a
S36
S37
S38
S39
Cul_1b
S40a
Cul41_2
S42a
S42b
S43
S44a
S44c
Cul45_1a
S46aa
S46c
S46d
S47
S48
S48a
S49
S49a
S50
Node Label

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



AECOM

PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

● 1D river sections

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

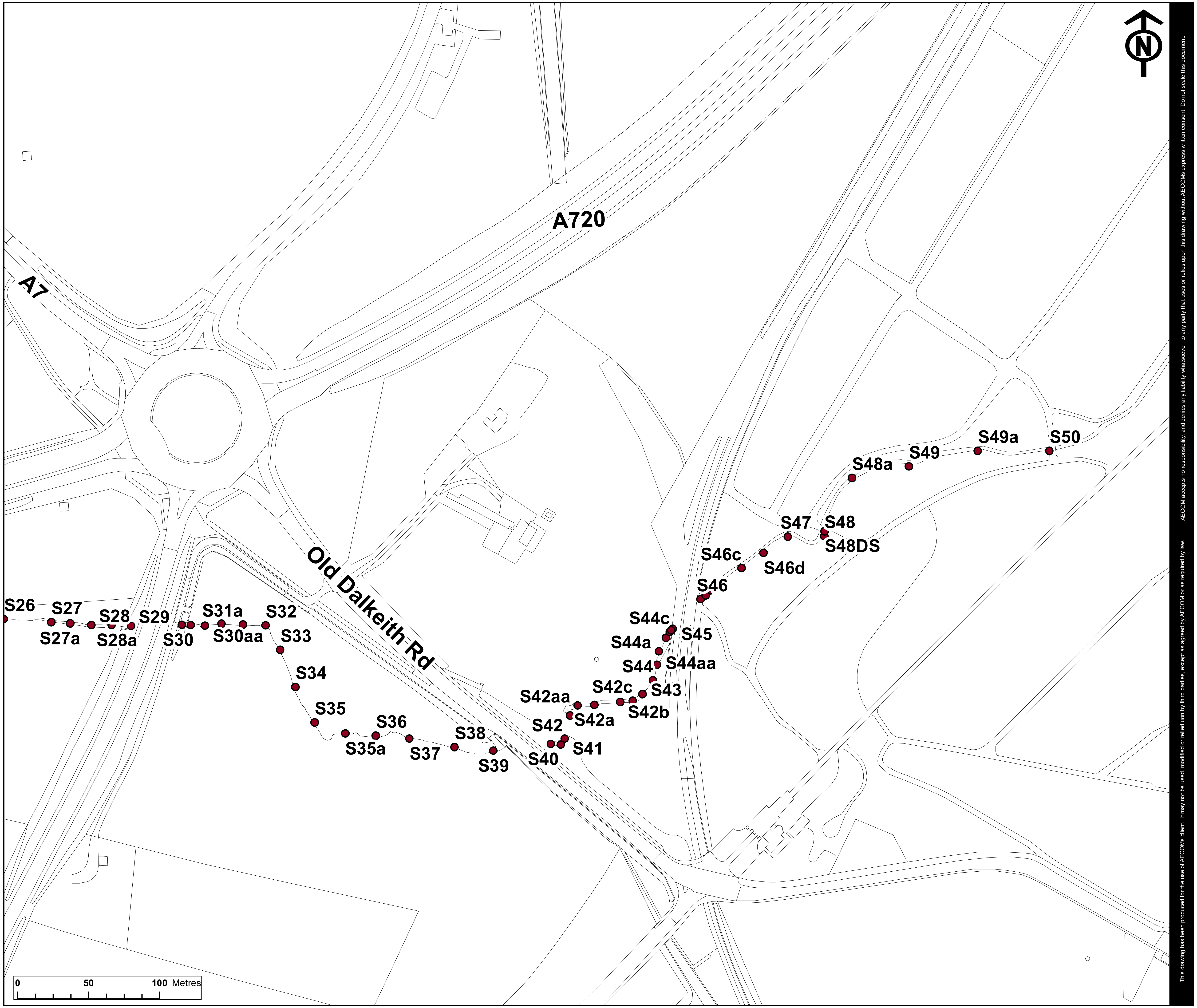
SHEET TITLE

Figure 1: 1D node locations

SHEET NUMBER

1 of 2

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

● 1D river sections

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

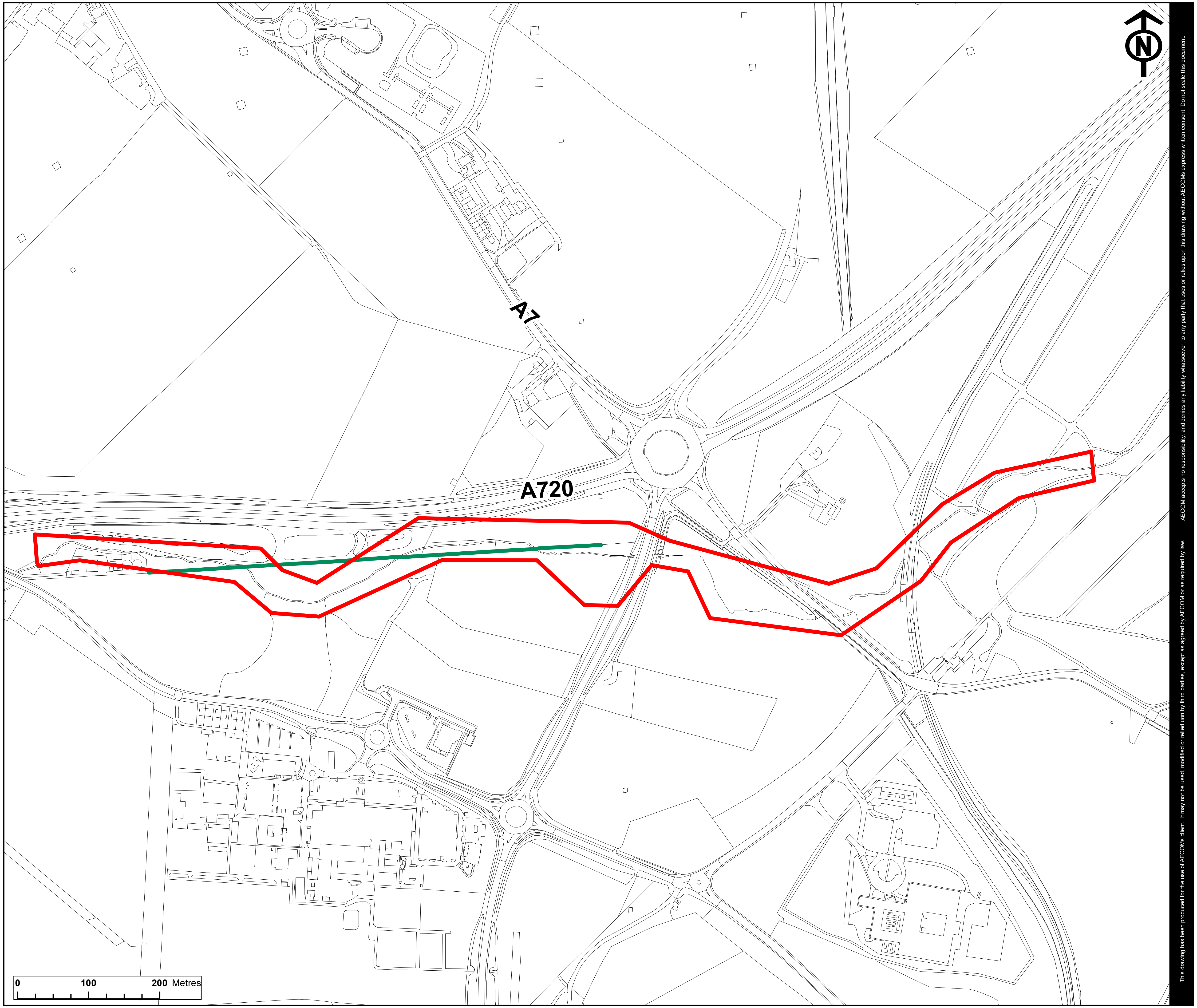
SHEET TITLE

Figure 2: 1D node locations

SHEET NUMBER

2 of 2

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



AECOM

PROJECT

A720 Sheriffhall Junction
Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

🟥 2D domain

▬ Dividing wall

Scale @ A3 - 1:5,000

PROJECT NUMBER

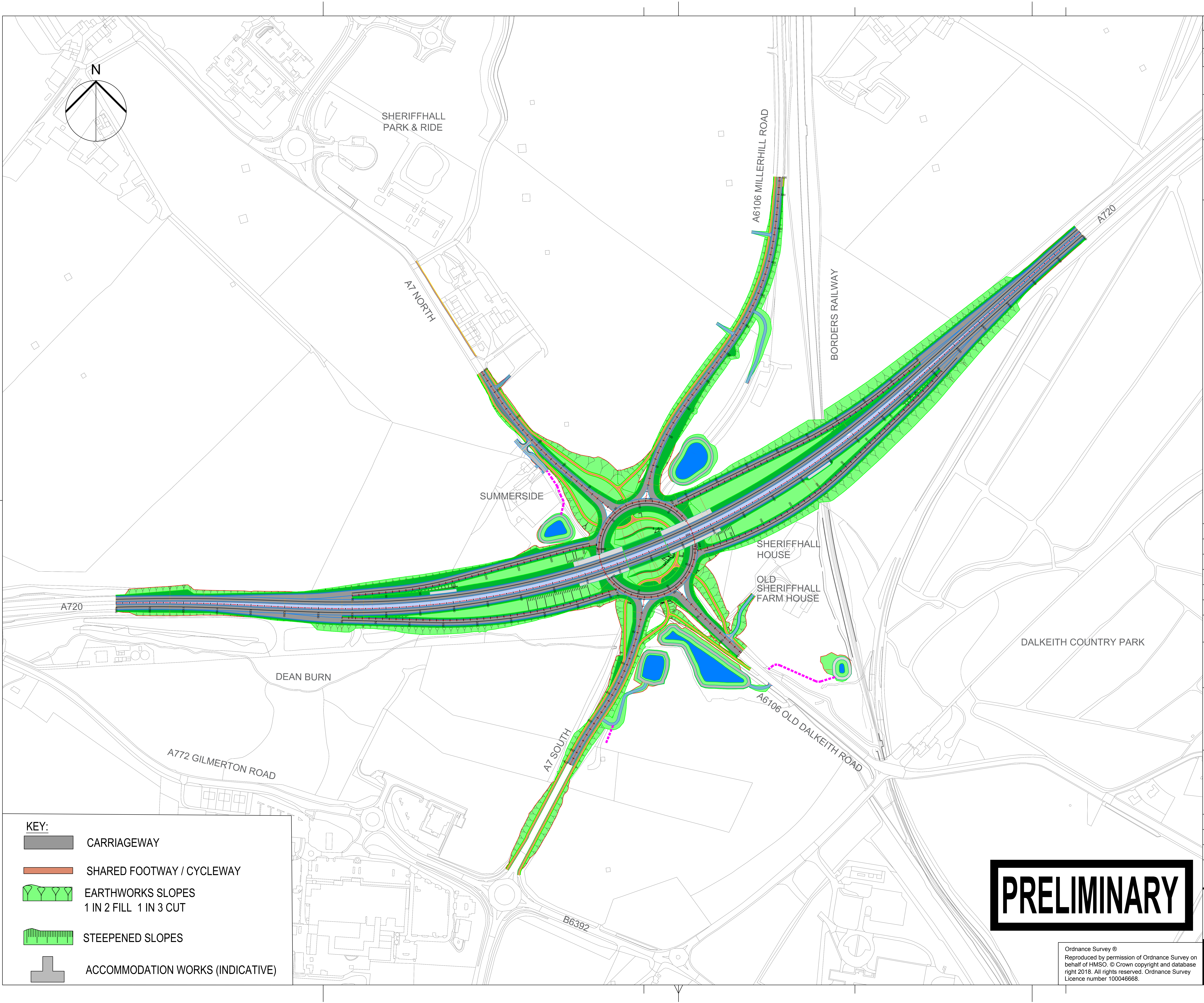
60572241

SHEET TITLE

Figure 3: 2D domain

SHEET NUMBER

1 of 1



PRELIMINARY

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION BOX

IT IS ASSUMED THAT ALL WORKS ON THIS DRAWING WILL BE CARRIED OUT BY A COMPETENT CONTRACTOR WORKING, WHERE APPROPRIATE, TO AN APPROPRIATE METHOD STATEMENT.

THIS DRAWING IS TO BE USED ONLY FOR THE PURPOSE OF ISSUE THAT IT WAS ISSUED FOR AND IS SUBJECT TO AMENDMENT.

EXCEPTIONAL RISKS RELATING TO THE WORKS ASSOCIATED WITH THIS DRAWING ARE IDENTIFIED BELOW.

CONSTRUCTION

MAINTENANCE / OPERATION / DECOMMISSIONING / DEMOLITION

NOTES

1. SUDS PONDS ARE INDICATIVE
2. ACCOMMODATION WORKS LAYOUTS ARE INDICATIVE
3. DRAFT LAYOUT SUBJECT TO CHANGE

Revision Details	By / Check	Date	Suffix
SCHEME LAYOUT UPDATED	LB / AR	25/02/19	C
SCHEME LAYOUT UPDATED	LB / AR	07/01/19	B
ANNOTATIONS AND DRAWING TITLE AMENDED	AR / JI	01/11/18	A

Purpose of issue
FOR INFORMATION

Client
TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

Project Title
A720 SHERIFFHALL ROUNDABOUT

Drawing Title
STAGE 3
PROPOSED SCHEME
LAYOUT PROPOSALS
(DRAFT)

Designed	Drawn	Checked	Approved	Date
AR	LB	SS	JI	25/02/19

Internal Project No.: 60572241
Suitability:
Scale @ A1: 1:2500
Zone: HIGHWAYS

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Registered office: Midpoint, Alencon Link,
Basingstoke, Hampshire RG21 7PP

Drawing Number
Project No. | Originator | Volume
60470009-SK-B-147
Location | Type | Role | Number
Rev
C

Plot Time :
Plot Date :
File Name :

Appendix D – Stability and Tabulated model results

Sensitivity Results

Table 1: Sensitivity to increases in flow and roughness

Section Labels	1 in 10yr Baseline	1 in 10yr +N40%	1 in 10yr +Q40%	1 in 200yr Baseline	1 in 200yr +N40%	1 in 200yr +Q40%
	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)
S1	68.468	68.612	68.584	68.767	68.981	68.968
S2	68.419	68.551	68.527	68.708	68.923	68.915
S3	68.027	68.135	68.138	68.322	68.501	68.505
S3a	67.628	67.769	67.762	67.937	68.118	68.116
S4	67.371	67.507	67.5	67.665	67.839	67.824
S5	67.118	67.231	67.25	67.418	67.557	67.57
S6	66.82	66.947	66.956	67.143	67.317	67.36
S7	66.341	66.458	66.453	66.619	66.796	66.782
S7a	66.037	66.171	66.155	66.32	66.519	66.489
S8	65.851	65.976	65.982	66.17	66.345	66.356
S9	65.488	65.604	65.603	65.789	65.955	65.948
S10	65.234	65.346	65.382	65.596	65.713	65.756
S11	65.033	65.071	65.211	65.471	65.514	65.611
S11a	65.016	64.987	65.206	65.475	65.467	65.646
S11aDS	64.84	64.798	64.977	65.151	65.133	65.256
S11b	64.56	64.669	64.68	64.828	64.992	64.919
S12	64.309	64.449	64.417	64.555	64.684	64.644
S13	64.226	64.337	64.344	64.391	64.531	64.473
S14	63.811	63.914	63.922	64.055	64.206	64.139
S14a	63.565	63.694	63.688	63.859	64.057	63.97
S15	63.426	63.553	63.555	63.724	63.921	63.84
S16	63	63.132	63.141	63.338	63.531	63.471
S17	62.725	62.865	62.872	63.076	63.27	63.216
S18	62.437	62.561	62.599	62.816	62.964	62.994

S18a	62.287	62.359	62.465	62.717	62.796	62.921
S18aDS	62.089	62.192	62.203	62.349	62.466	62.508
S19	61.864	61.975	61.968	62.045	62.147	62.126
S20	61.761	61.847	61.873	61.987	62.039	62.089
S20a	61.636	61.766	61.733	61.861	61.944	61.956
S20b	61.303	61.383	61.396	61.524	61.609	61.654
S21	60.972	61.07	61.069	61.216	61.336	61.358
S21a	60.652	60.737	60.738	60.882	61.004	61.026
S22	60.285	60.407	60.403	60.566	60.726	60.736
S22a	60.059	60.205	60.226	60.406	60.575	60.581
S23	59.8	59.957	59.953	60.158	60.29	60.426
S23a	59.606	59.707	59.778	59.998	60.066	60.293
S24	59.543	59.592	59.729	59.993	60.017	60.353
S24DS	59.291	59.395	59.409	59.718	59.79	60.358
S25	59.013	59.126	59.222	59.68	59.714	60.325
S26	58.937	59.003	59.166	59.679	59.708	60.332
S27	58.893	58.921	59.16	59.678	59.707	60.345
S27a	58.89	58.913	59.159	59.678	59.707	60.313
S28	58.889	58.906	59.16	59.678	59.706	60.322
S28a	58.868	58.878	59.14	59.677	59.703	60.301
S29	58.859	58.86	59.129	59.656	59.678	60.272
Cul29_US	58.25	58.366	58.362	58.517	58.7	58.658
Cul29_1a	58.118	58.242	58.236	58.398	58.574	58.536
Cul29_1b	58.007	58.137	58.131	58.294	58.459	58.426
Cul29_1c	57.961	58.092	58.086	58.248	58.403	58.374
Cul29_DS	57.922	58.054	58.047	58.206	58.351	58.325
S30	57.909	58.041	58.034	58.195	58.34	58.315
S30a	57.852	57.991	57.983	58.147	58.29	58.267

S30aa	57.768	57.917	57.908	58.072	58.207	58.188
S31	57.672	57.822	57.811	57.948	58.083	58.04
S31a	57.604	57.737	57.737	57.854	57.965	57.928
S32	57.57	57.686	57.698	57.813	57.897	57.877
S33	57.494	57.607	57.618	57.741	57.816	57.83
S34	57.273	57.403	57.407	57.465	57.539	57.495
S35	56.982	57.13	57.121	57.244	57.44	57.427
S35a	56.793	56.941	56.942	57.121	57.417	57.413
S36	56.703	56.842	56.877	57.078	57.405	57.406
S37	56.63	56.754	56.807	57.03	57.393	57.397
S38	56.548	56.651	56.73	56.988	57.391	57.399
S39	56.512	56.594	56.695	56.946	57.352	57.346
Cul_1	56.392	56.525	56.552	56.86	57.323	57.295
Cul_1a	56.358	56.486	56.51	56.819	57.276	57.254
Cul_1b	56.314	56.435	56.459	56.772	57.229	57.211
Cul_2	56.248	56.363	56.377	56.712	57.181	57.166
S40	56.231	56.35	56.356	56.688	57.168	57.145
S40a	56.074	56.169	56.243	56.601	57.122	57.065
S41	55.951	56.123	56.208	56.673	57.149	57.135
Cul41_1	55.829	56.042	56.045	56.471	57.028	56.903
Cul41_1a	55.778	55.95	55.955	56.287	56.701	56.611
Cul41_1b	55.731	55.86	55.866	56.102	56.375	56.319
Cul41_2	55.688	55.773	55.778	55.917	56.049	56.028
S42	55.664	55.759	55.756	55.9	56.04	56.013
S42a	55.383	55.489	55.484	55.643	55.796	55.759
S42aa	55.524	55.622	55.618	55.77	55.904	55.862
S42b	55.111	55.229	55.229	55.396	55.571	55.554
S42c	54.981	55.101	55.109	55.282	55.45	55.437

S43	54.803	54.934	54.964	55.176	55.342	55.357
Br_43US	54.803	54.934	54.964	55.176	55.342	55.357
Br_43DS	54.791	54.927	54.945	55.144	55.322	55.311
S44	54.791	54.927	54.945	55.144	55.322	55.311
S44a	54.645	54.771	54.79	54.98	55.142	55.134
S44aa	54.724	54.856	54.875	55.07	55.24	55.232
S44b	54.53	54.656	54.665	54.848	55.008	54.991
S44c	54.42	54.572	54.548	54.721	54.913	54.865
S44d	54.368	54.512	54.492	54.661	54.849	54.802
S45	54.298	54.404	54.427	54.602	54.747	54.748
Cul45_1	54.259	54.378	54.376	54.536	54.704	54.666
Cul45_1a	54.101	54.204	54.21	54.357	54.5	54.475
Cul45_1aa	54.171	54.288	54.287	54.444	54.603	54.57
Cul45_1aaa	54.214	54.332	54.331	54.489	54.653	54.618
Cul45_1ai	54.132	54.245	54.247	54.4	54.552	54.522
Cul45_1b	54.065	54.13	54.158	54.281	54.394	54.382
Cul45_1c	54.054	54.098	54.143	54.25	54.339	54.336
Cul45_2	54.045	54.07	54.131	54.228	54.282	54.292
S46	53.886	53.971	53.966	54.072	54.185	54.149
S46aa	53.775	53.854	53.85	53.954	54.065	54.026
S46a	53.83	53.912	53.908	54.013	54.124	54.087
S46b	53.668	53.739	53.735	53.831	53.954	53.909
S46c	53.441	53.521	53.511	53.64	53.795	53.775
S46d	53.245	53.373	53.388	53.563	53.715	53.726
S47	53.166	53.308	53.349	53.541	53.68	53.71
S48	52.92	53.072	53.083	53.316	53.462	53.494
Br_48US	52.92	53.072	53.083	53.316	53.462	53.494
Br_48DS	52.903	53.06	53.052	53.227	53.396	53.347

S48a	52.462	52.585	52.568	52.734	52.907	52.852
S48DS	52.903	53.06	53.052	53.227	53.396	53.347
S49	52.132	52.261	52.259	52.431	52.588	52.553
S49a	51.867	52.017	52.025	52.173	52.321	52.29
S50	51.531	51.697	51.694	51.822	51.982	51.94

Table 2: Sensitivity to blockage

Section Labels	**1 in 200yr Baseline**	**1 in 200yr blockage 1**	**1 in 200yr blockage 2**	**1 in 200yr blockage 3**
	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)
S1	68.767	68.768	68.768	68.768
S2	68.708	68.708	68.708	68.708
S3	68.322	68.322	68.322	68.322
S3a	67.937	67.937	67.937	67.937
S4	67.665	67.665	67.665	67.665
S5	67.418	67.418	67.418	67.418
S6	67.143	67.143	67.143	67.143
S7	66.619	66.619	66.618	66.618
S7a	66.32	66.32	66.32	66.32
S8	66.17	66.17	66.17	66.17
S9	65.789	65.789	65.789	65.789
S10	65.596	65.596	65.596	65.596
S11	65.471	65.471	65.471	65.471
S11a	65.475	65.475	65.475	65.475
S11aDS	65.151	65.151	65.151	65.152
S11b	64.828	64.828	64.828	64.828
S12	64.555	64.555	64.555	64.555
S13	64.391	64.391	64.391	64.391

S14	64.055	64.055	64.055	64.055
S14a	63.859	63.859	63.859	63.859
S15	63.724	63.723	63.724	63.724
S16	63.338	63.338	63.338	63.338
S17	63.076	63.076	63.076	63.076
S18	62.816	62.816	62.817	62.816
S18a	62.717	62.717	62.717	62.717
S18aDS	62.349	62.349	62.349	62.349
S19	62.045	62.050	62.045	62.045
S20	61.987	61.987	61.987	61.987
S20a	61.861	61.863	61.861	61.861
S20b	61.524	61.524	61.524	61.524
S21	61.216	61.217	61.216	61.216
S21a	60.882	60.881	60.882	60.882
S22	60.566	60.57	60.566	60.566
S22a	60.406	60.412	60.406	60.406
S23	60.158	60.246	60.158	60.158
S23a	59.998	60.194	59.998	59.998
S24	59.993	60.232	59.993	59.993
S24DS	59.718	60.197	59.718	59.718
S25	59.68	60.190	59.68	59.68
S26	59.679	60.178	59.679	59.679
S27	59.678	60.188	59.678	59.678
S27a	59.678	60.177	59.678	59.678
S28	59.678	60.169	59.678	59.678
S28a	59.677	60.167	59.677	59.677
S29	59.656	60.152	59.656	59.656
Cul29_US	58.517	58.623	58.517	58.517

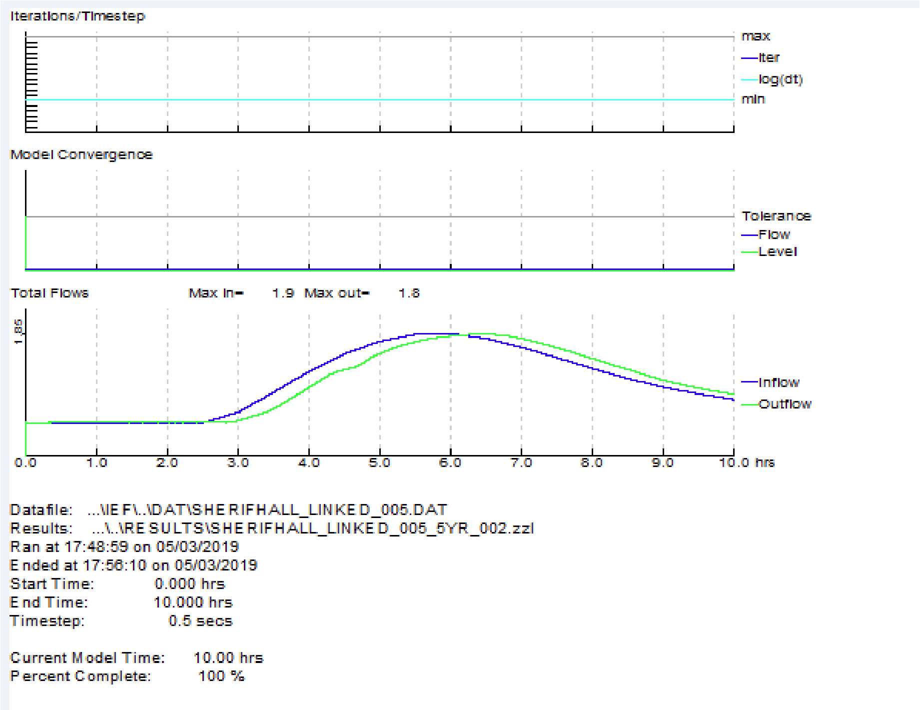
Cul29_1a	58.398	58.47	58.397	58.397
Cul29_1b	58.294	58.315	58.294	58.294
Cul29_1c	58.248	58.233	58.247	58.247
Cul29_DS	58.206	58.148	58.206	58.205
S30	58.195	58.143	58.195	58.194
S30a	58.147	58.095	58.146	58.146
S30aa	58.072	58.017	58.07	58.069
S31	57.948	57.899	57.944	57.942
S31a	57.854	57.816	57.858	57.854
S32	57.813	57.78	57.821	57.817
S33	57.741	57.695	57.762	57.751
S34	57.465	57.454	57.443	57.455
S35	57.244	57.205	57.329	57.406
S35a	57.121	57.056	57.307	57.397
S36	57.078	57.003	57.299	57.392
S37	57.03	56.943	57.289	57.386
S38	56.988	56.877	57.289	57.388
S39	56.946	56.838	57.255	57.357
Cul_1	56.86	56.736	57.156	57.332
Cul_1a	56.819	56.695	57.011	57.308
Cul_1b	56.772	56.644	56.866	57.283
Cul_2	56.712	56.576	56.679	57.258
S40	56.688	56.552	56.665	57.246
S40a	56.601	56.398	56.572	57.196
S41	56.673	56.492	56.647	57.246
Cul41_1	56.471	56.303	56.447	57.131
Cul41_1a	56.287	56.157	56.268	56.715
Cul41_1b	56.102	56.011	56.089	56.299

Cul41_2	55.917	55.865	55.91	55.883
S42	55.9	55.846	55.893	55.878
S42a	55.643	55.587	55.636	55.646
S42aa	55.77	55.715	55.763	55.787
S42b	55.396	55.339	55.388	55.389
S42c	55.282	55.217	55.273	55.266
S43	55.176	55.101	55.165	55.157
Br_43US	55.176	55.101	55.165	55.157
Br_43DS	55.144	55.074	55.134	55.126
S44	55.144	55.074	55.134	55.126
S44a	54.98	54.914	54.971	54.964
S44aa	55.07	55.002	55.061	55.053
S44b	54.848	54.784	54.839	54.832
S44c	54.721	54.66	54.713	54.706
S44d	54.661	54.601	54.652	54.646
S45	54.602	54.54	54.594	54.587
Cul45_1	54.536	54.48	54.528	54.522
Cul45_1a	54.357	54.308	54.351	54.345
Cul45_1aa	54.444	54.39	54.437	54.43
Cul45_1aaa	54.489	54.434	54.482	54.476
Cul45_1ai	54.4	54.347	54.393	54.387
Cul45_1b	54.281	54.241	54.275	54.27
Cul45_1c	54.25	54.22	54.245	54.242
Cul45_2	54.228	54.204	54.225	54.222
S46	54.072	54.04	54.068	54.064
S46aa	53.954	53.92	53.95	53.946
S46a	54.013	53.98	54.008	54.005
S46b	53.831	53.799	53.827	53.824

S46c	53.64	53.591	53.633	53.628
S46d	53.563	53.496	53.553	53.545
S47	53.541	53.469	53.531	53.522
S48	53.316	53.236	53.305	53.296
Br_48US	53.316	53.236	53.305	53.296
Br_48DS	53.227	53.17	53.22	53.213
S48a	52.734	52.676	52.726	52.72
S48DS	53.227	53.17	53.22	53.213
S49	52.431	52.373	52.424	52.417
S49a	52.173	52.123	52.167	52.161
S50	51.822	51.775	51.815	51.809

Model Stability

Baseline - 1 in 5yr event



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Results:    ...\..\RESULTS\SHERIFHALL_LINKED_005_5YR_002.zzl
Ran at 17:48:59 on 05/03/2019
Ended at 17:56:10 on 05/03/2019
Start Time:          0.000 hrs
End Time:           10.000 hrs
Timestep:              0.5 secs

Current Model Time:     10.00 hrs
Percent Complete:        100 %
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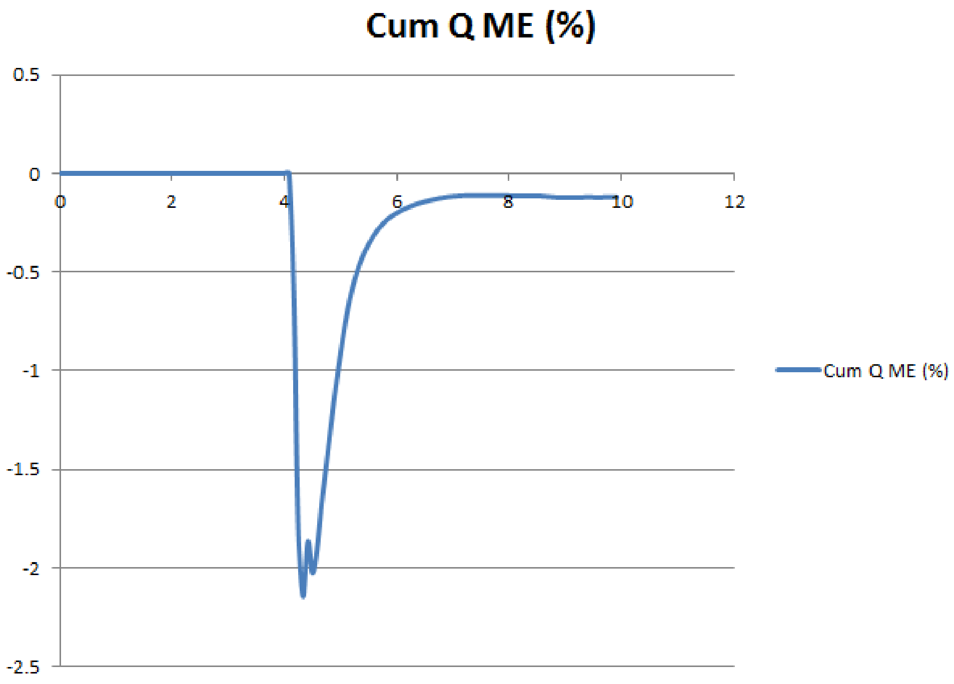
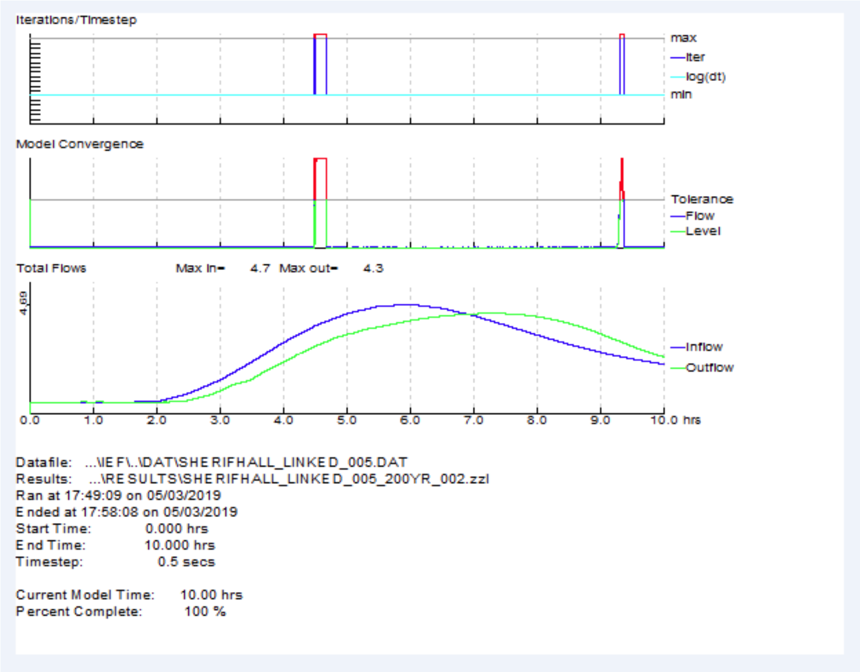


Baseline - 1 in 200yr



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Current Model Time:     10.00 hrs
Percent Complete:        100 %
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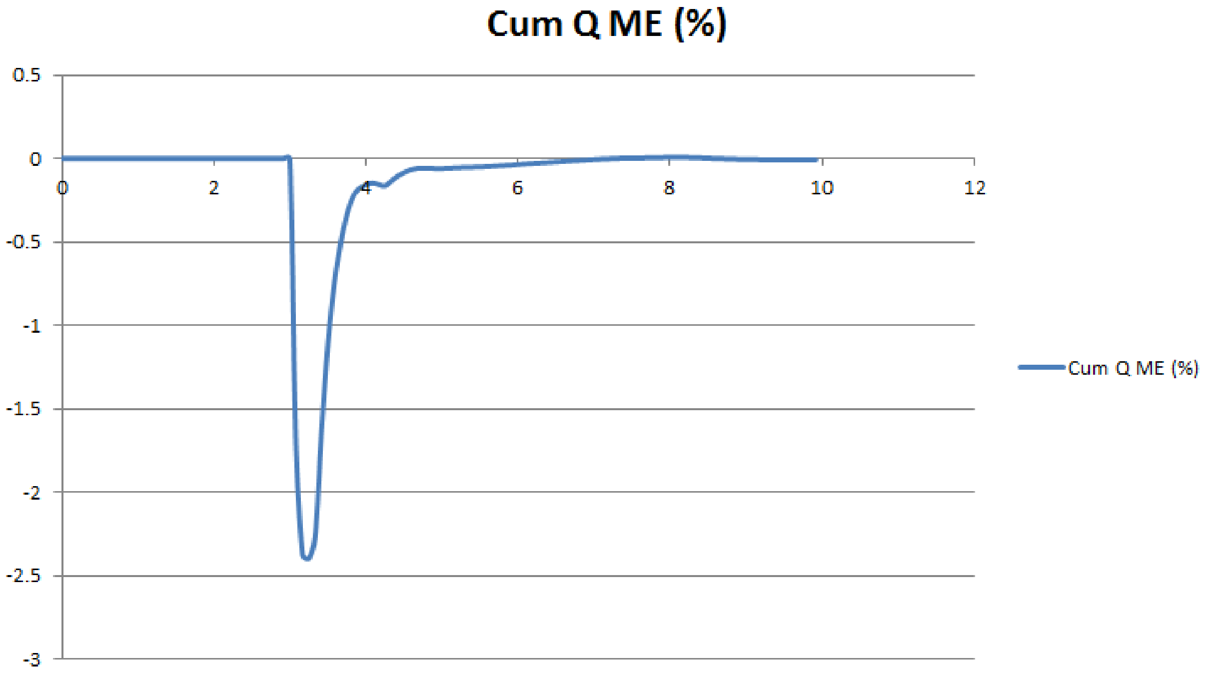
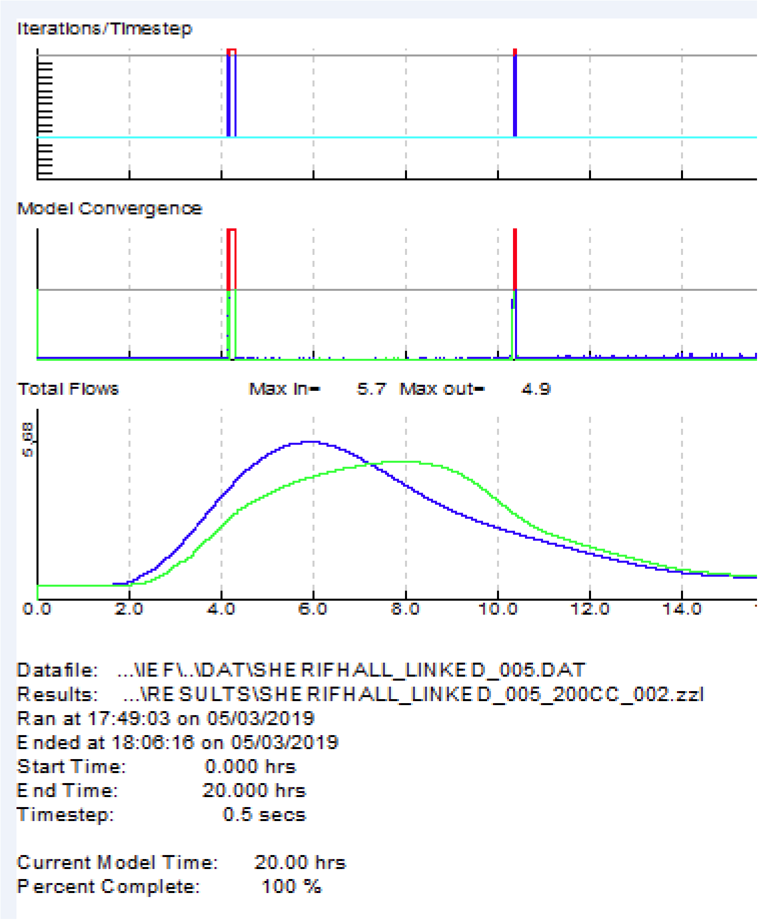


Baseline - 1 in 200yr+CC



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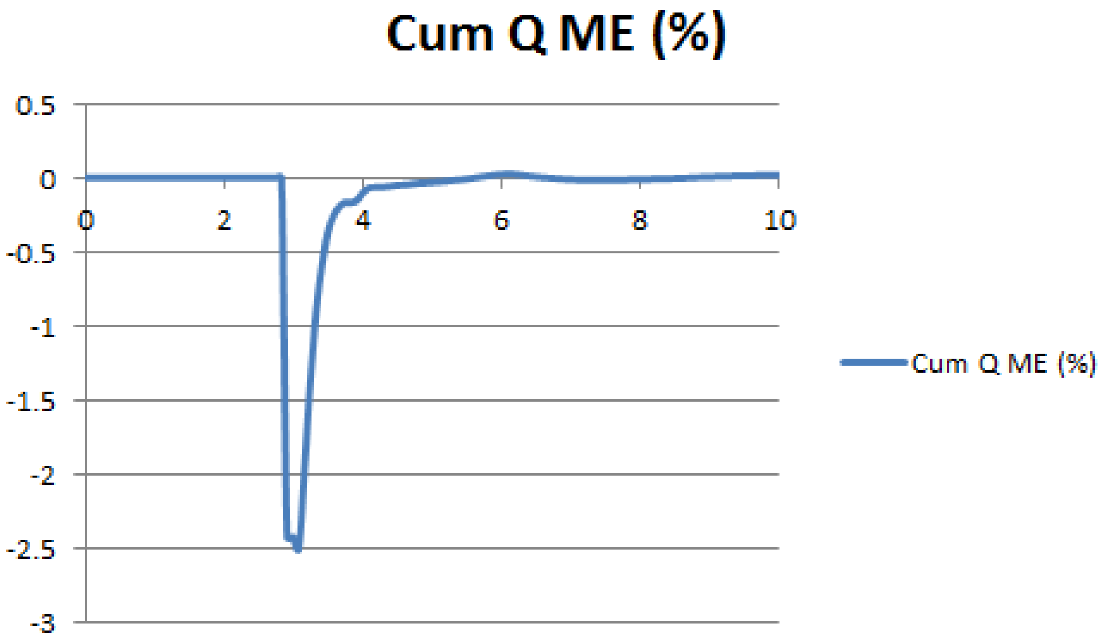
Results: ...\RESULTS\SHERIFHALL_LINKED_005_200CC_002.zzl
Ran at 17:49:03 on 05/03/2019
Ended at 18:06:16 on 05/03/2019
Start Time: 0.000 hrs
End Time: 20.000 hrs
Timestep: 0.5 secs

Current Model Time: 20.00 hrs
Percent Complete: 100 %



Baseline Results

Table 3: Baseline maximum stage

Section Label	1 in 2yr event	1 in 5yr event	1 in 10yr event	1 in 30yr event	1 in 50yr event	1 in 75yr event	1 in 100yr event	1 in 200yr event	1 in 200yr +CC event
	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)
S1	68.3	68.397	68.468	68.558	68.602	68.645	68.678	68.767	68.878
S2	68.241	68.343	68.419	68.502	68.545	68.587	68.62	68.708	68.82
S3	67.859	67.955	68.027	68.113	68.156	68.199	68.233	68.322	68.427
S3a	67.473	67.563	67.628	67.731	67.782	67.823	67.854	67.937	68.038
S4	67.219	67.311	67.371	67.465	67.521	67.563	67.593	67.665	67.751
S5	66.965	67.064	67.118	67.214	67.275	67.321	67.35	67.418	67.491
S6	66.687	66.768	66.82	66.92	66.98	67.025	67.056	67.143	67.257
S7	66.217	66.298	66.341	66.423	66.474	66.52	66.549	66.619	66.704
S7a	65.916	65.993	66.037	66.123	66.176	66.219	66.25	66.32	66.407
S8	65.73	65.799	65.851	65.947	66.004	66.05	66.087	66.17	66.267
S9	65.376	65.445	65.488	65.571	65.625	65.67	65.707	65.789	65.877
S10	65.081	65.185	65.234	65.34	65.406	65.455	65.496	65.596	65.686
S11	64.845	64.964	65.033	65.163	65.243	65.31	65.362	65.471	65.554
S11a	64.814	64.939	65.016	65.156	65.239	65.308	65.361	65.475	65.572
S11aDS	64.687	64.786	64.84	64.94	65.001	65.045	65.079	65.151	65.213
S11b	64.436	64.518	64.56	64.644	64.696	64.739	64.773	64.828	64.878
S12	64.198	64.266	64.309	64.394	64.423	64.465	64.5	64.555	64.604
S13	64.118	64.179	64.226	64.321	64.343	64.343	64.358	64.391	64.431
S14	63.709	63.766	63.811	63.89	63.935	63.975	64.003	64.055	64.102
S14a	63.409	63.494	63.565	63.655	63.703	63.749	63.786	63.859	63.92
S15	63.24	63.348	63.426	63.517	63.574	63.616	63.651	63.724	63.787

S16	62.845	62.935	63	63.1	63.164	63.218	63.259	63.338	63.411
S17	62.609	62.674	62.725	62.83	62.895	62.957	62.996	63.076	63.153
S18	62.289	62.372	62.437	62.557	62.625	62.682	62.723	62.816	62.91
S18a	62.105	62.21	62.287	62.421	62.491	62.557	62.607	62.717	62.824
S18aDS	61.965	62.035	62.089	62.178	62.218	62.259	62.287	62.349	62.427
S19	61.742	61.814	61.864	61.947	61.982	62.007	62.02	62.045	62.086
S20	61.626	61.709	61.761	61.846	61.89	61.924	61.945	61.987	62.035
S20a	61.516	61.587	61.636	61.711	61.747	61.785	61.812	61.861	61.91
S20b	61.188	61.253	61.303	61.375	61.41	61.445	61.471	61.524	61.582
S21	60.857	60.92	60.972	61.046	61.085	61.123	61.152	61.216	61.291
S21a	60.535	60.611	60.652	60.713	60.756	60.797	60.828	60.882	60.942
S22	60.173	60.241	60.285	60.375	60.422	60.469	60.503	60.566	60.648
S22a	59.91	59.994	60.059	60.184	60.255	60.321	60.356	60.406	60.476
S23	59.67	59.743	59.8	59.912	59.981	60.04	60.073	60.158	60.254
S23a	59.446	59.536	59.606	59.733	59.808	59.876	59.923	59.998	60.07
S24	59.355	59.465	59.543	59.681	59.761	59.836	59.887	59.993	60.125
S24DS	59.168	59.252	59.291	59.375	59.434	59.505	59.555	59.718	59.997
S25	58.817	58.934	59.013	59.163	59.268	59.377	59.44	59.68	59.995
S26	58.711	58.848	58.937	59.101	59.218	59.35	59.424	59.679	59.992
S27	58.647	58.79	58.893	59.089	59.214	59.349	59.423	59.678	59.993
S27a	58.631	58.779	58.89	59.088	59.213	59.348	59.422	59.678	59.992
S28	58.62	58.776	58.889	59.088	59.214	59.349	59.423	59.678	59.99
S28a	58.607	58.76	58.868	59.064	59.199	59.34	59.416	59.677	59.991
S29	58.592	58.749	58.859	59.056	59.185	59.323	59.398	59.656	59.969
Cul29_US	58.135	58.203	58.25	58.333	58.38	58.424	58.446	58.517	58.592
Cul29_1a	57.995	58.068	58.118	58.207	58.256	58.301	58.325	58.398	58.472

Cul29_1b	57.875	57.955	58.007	58.1	58.151	58.198	58.223	58.294	58.365
Cul29_1c	57.826	57.909	57.961	58.055	58.106	58.153	58.178	58.248	58.316
Cul29_DS	57.787	57.871	57.922	58.016	58.066	58.113	58.138	58.206	58.271
S30	57.774	57.858	57.909	58.003	58.054	58.101	58.126	58.195	58.261
S30a	57.717	57.799	57.852	57.951	58.004	58.053	58.079	58.147	58.214
S30aa	57.635	57.711	57.768	57.874	57.929	57.978	58.002	58.072	58.14
S31	57.52	57.608	57.672	57.779	57.829	57.87	57.89	57.948	58.001
S31a	57.434	57.538	57.604	57.708	57.754	57.79	57.807	57.854	57.9
S32	57.396	57.504	57.57	57.67	57.715	57.751	57.768	57.813	57.855
S33	57.326	57.427	57.494	57.592	57.631	57.663	57.681	57.741	57.802
S34	57.133	57.214	57.273	57.375	57.419	57.443	57.45	57.465	57.478
S35	56.846	56.923	56.982	57.089	57.137	57.173	57.192	57.244	57.303
S35a	56.641	56.73	56.793	56.905	56.967	57.012	57.037	57.121	57.248
S36	56.526	56.631	56.703	56.832	56.906	56.952	56.98	57.078	57.227
S37	56.442	56.554	56.63	56.758	56.838	56.886	56.918	57.03	57.205
S38	56.359	56.47	56.548	56.679	56.764	56.812	56.849	56.988	57.199
S39	56.324	56.434	56.512	56.643	56.73	56.774	56.81	56.946	57.148
Cul_1	56.252	56.341	56.392	56.505	56.582	56.659	56.702	56.86	57.087
Cul_1a	56.229	56.312	56.358	56.465	56.538	56.617	56.661	56.819	57.049
Cul_1b	56.201	56.276	56.314	56.412	56.488	56.565	56.609	56.772	57.008
Cul_2	56.162	56.224	56.248	56.332	56.402	56.492	56.539	56.712	56.961
S40	56.15	56.209	56.231	56.312	56.382	56.469	56.516	56.688	56.938
S40a	55.941	56.022	56.074	56.203	56.252	56.331	56.366	56.601	56.877
S41	55.751	55.861	55.951	56.129	56.256	56.376	56.442	56.673	56.933
Cul41_1	55.654	55.752	55.829	55.976	56.088	56.196	56.256	56.471	56.711
Cul41_1a	55.606	55.706	55.778	55.902	55.989	56.074	56.121	56.287	56.467

Cul41_1b	55.57	55.666	55.731	55.829	55.891	55.952	55.985	56.102	56.223
Cul41_2	55.545	55.633	55.688	55.755	55.792	55.829	55.85	55.917	55.979
S42	55.523	55.609	55.664	55.732	54.394	55.81	55.831	55.9	55.963
S42a	55.262	55.342	55.383	55.457	55.501	55.546	55.569	55.643	55.719
S42aa	55.388	55.479	55.524	55.593	55.634	55.676	55.698	55.77	55.815
S42b	55.008	55.068	55.111	55.199	55.247	55.296	55.321	55.396	55.474
S42c	54.865	54.926	54.981	55.08	55.126	55.173	55.199	55.282	55.368
S43	54.651	54.739	54.803	54.923	54.989	55.049	55.079	55.176	55.274
Br_43US	54.651	54.739	54.803	54.923	54.989	55.049	55.079	55.176	55.274
Br_43DS	54.645	54.73	54.791	54.905	54.969	55.025	55.053	55.144	55.235
S44	54.645	54.73	54.791	54.905	54.969	55.025	55.053	55.144	55.235
S44a	54.504	54.587	54.645	54.753	54.813	54.869	54.895	54.98	55.064
S44aa	54.578	54.663	54.724	54.837	54.899	54.955	54.982	55.07	55.158
S44b	54.4	54.476	54.53	54.63	54.686	54.74	54.765	54.848	54.926
S44c	54.296	54.368	54.42	54.516	54.569	54.619	54.643	54.721	54.8
S44d	54.245	54.316	54.368	54.46	54.511	54.56	54.584	54.661	54.738
S45	54.166	54.244	54.298	54.395	54.446	54.496	54.521	54.602	54.683
Cul45_1	54.139	54.21	54.259	54.347	54.394	54.44	54.463	54.536	54.608
Cul45_1a	54.002	54.06	54.101	54.182	54.227	54.271	54.292	54.357	54.423
Cul45_1aa	54.053	54.122	54.171	54.258	54.305	54.351	54.373	54.444	54.514
Cul45_1aaa	54.094	54.164	54.214	54.301	54.349	54.394	54.417	54.489	54.561
Cul45_1ai	54.022	54.085	54.132	54.217	54.264	54.309	54.331	54.4	54.468
Cul45_1b	53.978	54.029	54.065	54.134	54.174	54.211	54.229	54.281	54.337
Cul45_1c	53.971	54.02	54.054	54.12	54.157	54.193	54.209	54.25	54.297
Cul45_2	53.966	54.013	54.045	54.108	54.145	54.179	54.194	54.228	54.261
S46	53.804	53.853	53.886	53.946	53.979	54.011	54.028	54.072	54.114

S46a	53.696	53.745	53.775	53.831	53.862	53.892	53.908	53.954	53.993
S46aa	53.75	53.799	53.83	53.888	53.92	53.952	53.968	54.013	54.053
S46b	53.588	53.635	53.668	53.72	53.745	53.773	53.788	53.831	53.87
S46c	53.374	53.425	53.441	53.488	53.525	53.558	53.576	53.64	53.712
S46d	53.152	53.204	53.245	53.35	53.409	53.453	53.477	53.563	53.654
S47	53.008	53.094	53.166	53.304	53.371	53.422	53.449	53.541	53.636
S48	52.765	52.852	52.92	53.042	53.109	53.178	53.211	53.316	53.412
Br_48US	52.765	52.852	52.92	54.923	53.109	53.178	53.211	53.316	53.412
Br_48DS	52.759	52.84	52.903	54.905	53.075	53.127	53.151	53.227	53.292
S48a	52.351	52.422	52.462	52.54	52.586	52.633	52.658	52.734	52.799
S48DS	52.759	52.84	52.903	53.015	53.075	53.127	53.151	53.227	53.292
S49	52.014	52.086	52.132	52.227	52.278	52.328	52.354	52.431	52.498
S49a	51.693	51.789	51.867	51.993	52.041	52.084	52.106	52.173	52.236
S50	51.329	51.445	51.531	51.664	51.707	51.742	51.761	51.822	51.886

Table 4: Max Froude

Section Label	**1 in 2yr event**	**1 in 5yr event**	**1 in 10yr event**	**1 in 30yr event**	**1 in 50yr event**	**1 in 75yr event**	**1 in 100yr event**	**1 in 200yr event**	**1 in 200yr +CC event**
	Max Fr	**Max Fr**	**Max Fr**	**Max Fr**	**Max Fr**	**Max Fr**	**Max Fr**	**Max Fr**	**Max Fr**
S1	0.49	0.51	0.526	0.561	0.561	0.561	0.562	0.562	0.562
S2	0.344	0.345	0.345	0.347	0.359	0.366	0.367	0.368	0.369
S3	0.839	0.844	0.846	0.847	0.851	0.855	0.858	0.862	0.865
S3a	0.834	0.835	0.835	0.835	0.835	0.835	0.835	0.834	0.835
S4	0.57	0.573	0.581	0.615	0.628	0.629	0.633	0.652	0.671
S5	0.599	0.599	0.599	0.599	0.599	0.599	0.599	0.6	0.601
S6	0.66	0.669	0.672	0.672	0.672	0.672	0.673	0.673	0.673
S7	0.705	0.706	0.723	0.749	0.757	0.758	0.761	0.777	0.786
S7a	0.731	0.731	0.732	0.734	0.734	0.74	0.745	0.75	0.75
S8	0.511	0.522	0.527	0.533	0.537	0.537	0.537	0.537	0.537
S9	0.608	0.612	0.612	0.618	0.619	0.619	0.619	0.619	0.619
S10	0.664	0.664	0.664	0.664	0.664	0.664	0.664	0.664	0.664

S11	0.672	0.672	0.673	0.672	0.672	0.673	0.673	0.673	0.672
S11a	0.233	0.233	0.233	0.241	0.245	0.245	0.245	0.245	0.245
S11aDS	0.328	0.329	0.329	0.342	0.348	0.362	0.371	0.392	0.406
S11b	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
S12	0.594	0.637	0.671	0.717	0.77	0.798	0.812	0.833	0.847
S13	0.295	0.328	0.346	0.365	0.414	0.448	0.457	0.496	0.51
S14	0.91	0.91	0.91	0.91	0.91	0.942	0.979	0.98	0.981
S14a	0.796	0.796	0.796	0.796	0.796	0.796	0.796	0.796	0.796
S15	0.479	0.48	0.48	0.511	0.537	0.569	0.589	0.604	0.605
S16	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
S17	0.604	0.604	0.604	0.604	0.604	0.604	0.604	0.604	0.604
S18	0.764	0.764	0.764	0.764	0.764	0.764	0.764	0.764	0.764
S18a	0.304	0.31	0.312	0.318	0.325	0.326	0.326	0.327	0.327
S18aDS	0.435	0.457	0.467	0.47	0.475	0.485	0.488	0.5	0.507
S19	0.767	0.767	0.767	0.767	0.767	0.767	0.767	0.768	0.776
S20	0.35	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384
S20a	0.789	0.789	0.79	0.79	0.79	0.789	0.79	0.79	0.79
S20b	1.07	1.069	1.07	1.069	1.07	1.07	1.07	1.07	1.069
S21	0.869	0.869	0.869	0.869	0.869	0.869	0.869	0.868	0.868
S21a	0.676	0.676	0.679	0.722	0.732	0.74	0.743	0.772	0.799
S22	0.841	0.841	0.841	0.841	0.841	0.841	0.842	0.842	0.841
S22a	0.954	0.954	0.954	0.954	0.954	0.954	0.954	0.954	0.954
S23	0.755	0.755	0.755	0.755	0.755	0.755	0.755	0.799	0.868
S23a	0.595	0.595	0.595	0.595	0.595	0.595	0.595	0.595	0.595
S24	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488
S24DS	1.061	1.061	1.061	1.061	1.061	1.061	1.061	1.061	1.061
S25	0.735	0.736	0.736	0.735	0.736	0.736	0.736	0.736	0.736
S26	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401
S27	0.265	0.269	0.273	0.278	0.28	0.283	0.284	0.287	0.286
S27a	0.22	0.23	0.233	0.238	0.24	0.242	0.244	0.246	0.245
S28	0.186	0.186	0.187	0.187	0.187	0.187	0.187	0.188	0.188
S28a	0.222	0.222	0.222	0.221	0.222	0.222	0.222	0.223	0.222
S29	0.788	0.912	0.996	1.145	1.227	1.302	1.341	1.468	1.603
Cul29_US	1.732	1.733	1.734	1.735	1.735	1.735	1.735	1.735	1.736
Cul29_1a	1.724	1.725	1.725	1.726	1.726	1.725	1.725	1.726	1.737
Cul29_1b	1.635	1.635	1.635	1.635	1.635	1.635	1.635	1.635	1.635
Cul29_1c	1.567	1.567	1.567	1.567	1.567	1.567	1.567	1.567	1.567
Cul29_DS	1.352	1.352	1.352	1.352	1.352	1.352	1.352	1.352	1.352
S30	0.582	0.602	0.636	0.672	0.672	0.672	0.672	0.673	0.673
S30aa	0.567	0.586	0.596	0.601	0.602	0.602	0.603	0.603	0.604
S30a	0.578	0.596	0.624	0.645	0.645	0.646	0.646	0.646	0.647
S31	0.717	0.717	0.717	0.717	0.717	0.717	0.717	0.717	0.717
S31a	0.504	0.504	0.504	0.504	0.504	0.504	0.504	0.525	0.553
S32	0.315	0.316	0.318	0.339	0.347	0.355	0.361	0.384	0.411

S33	0.363	0.385	0.414	0.418	0.425	0.435	0.436	0.436	0.437
S34	0.523	0.554	0.571	0.604	0.616	0.624	0.638	0.697	0.759
S35	0.628	0.628	0.629	0.628	0.628	0.628	0.678	0.7	0.701
S35a	0.684	0.684	0.684	0.684	0.684	0.684	0.684	0.684	0.684
S36	0.415	0.416	0.417	0.418	0.419	0.418	0.418	0.419	0.42
S37	0.336	0.337	0.339	0.347	0.354	0.354	0.357	0.354	0.357
S38	0.276	0.297	0.303	0.304	0.307	0.308	0.312	0.309	0.309
S39	0.573	0.664	0.723	0.819	0.882	0.917	0.94	1.012	1.081
Cul_1	0.271	0.302	0.326	0.35	0.357	0.359	0.362	0.362	0.359
Cul_1a	0.298	0.333	0.361	0.389	0.405	0.405	0.405	0.406	0.406
Cul_1b	0.335	0.376	0.411	0.443	0.449	0.456	0.456	0.456	0.456
Cul_2	0.391	0.443	0.496	0.537	0.568	0.569	0.569	0.569	0.569
S40	0.523	0.587	0.656	0.677	0.678	0.678	0.678	0.678	0.678
S40a	1.509	1.509	1.509	1.509	1.509	1.509	1.509	1.509	1.509
S41	0.546	0.627	0.684	0.783	0.837	0.887	0.909	0.979	1.048
Cul41_1a	0.714	0.715	0.715	0.715	0.715	0.715	0.715	0.715	0.715
Cul41_1b	0.651	0.651	0.651	0.651	0.651	0.651	0.651	0.651	0.651
Cul41_2	0.557	0.558	0.558	0.558	0.558	0.558	0.557	0.558	0.558
Cul41_1	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.754	0.754
S42	0.669	0.669	0.669	0.696	0.704	0.708	0.709	0.71	0.722
S42a	0.653	0.67	0.698	0.708	0.709	0.709	0.709	0.709	0.709
S42aa	0.659	0.66	0.686	0.704	0.708	0.711	0.711	0.711	0.741
S42b	0.664	0.701	0.705	0.706	0.706	0.706	0.706	0.706	0.706
S42c	0.713	0.722	0.723	0.724	0.724	0.724	0.724	0.724	0.724
S43	1.055	1.056	1.056	1.056	1.056	1.057	1.057	1.057	1.057
Br_43US	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.407
Br_43DS	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.407
S44	0.406	0.407	0.407	0.407	0.407	0.407	0.407	0.408	0.408
S44aa	0.422	0.429	0.43	0.431	0.431	0.431	0.431	0.432	0.435
S44a	0.46	0.472	0.477	0.481	0.481	0.483	0.483	0.488	0.493
S44b	0.564	0.581	0.59	0.596	0.597	0.599	0.599	0.6	0.606
S44c	0.756	0.773	0.773	0.774	0.774	0.774	0.774	0.774	0.774
S44d	0.889	0.895	0.895	0.895	0.895	0.895	0.895	0.895	0.896
S45	0.453	0.519	0.565	0.642	0.682	0.721	0.741	0.806	0.869
Cul45_1	0.8	0.811	0.817	0.824	0.826	0.829	0.83	0.836	0.842
Cul45_1aaa	0.788	0.801	0.808	0.816	0.819	0.822	0.824	0.832	0.839
Cul45_1aa	0.763	0.784	0.794	0.805	0.809	0.813	0.815	0.826	0.836
Cul45_1ai	0.713	0.754	0.771	0.788	0.794	0.8	0.804	0.819	0.831
Cul45_1a	0.644	0.701	0.733	0.763	0.772	0.781	0.787	0.809	0.826
Cul45_1b	0.51	0.58	0.622	0.679	0.701	0.722	0.735	0.777	0.809
Cul45_1c	0.452	0.523	0.568	0.629	0.655	0.68	0.694	0.752	0.796
Cul45_2	0.403	0.473	0.517	0.582	0.61	0.637	0.652	0.717	0.779
S46	0.626	0.635	0.653	0.674	0.682	0.687	0.689	0.708	0.728
S46aa	0.63	0.64	0.658	0.679	0.687	0.692	0.695	0.71	0.73

S46a	0.633	0.645	0.663	0.684	0.692	0.698	0.7	0.712	0.731
S46b	0.64	0.66	0.663	0.686	0.705	0.713	0.716	0.731	0.744
S46c	0.656	0.66	0.711	0.737	0.737	0.738	0.738	0.738	0.738
S46d	0.691	0.719	0.72	0.721	0.722	0.722	0.722	0.723	0.724
S47	0.631	0.631	0.631	0.631	0.631	0.631	0.631	0.631	0.631
S48	0.618	0.618	0.618	0.618	0.618	0.629	0.629	0.629	0.629
Br_48US	0.706	0.706	0.706	0.706	0.706	0.706	0.706	0.706	0.706
Br_48DS	0.706	0.706	0.706	0.706	0.706	0.706	0.706	0.706	0.706
S48DS	0.618	0.618	0.618	0.618	0.618	0.677	0.677	0.677	0.677
S48a	0.544	0.556	0.58	0.607	0.614	0.618	0.62	0.647	0.656
S49	0.5	0.5	0.5	0.501	0.502	0.502	0.502	0.502	0.502
S49a	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492	0.492
S50	0.507	0.507	0.512	0.608	0.613	0.614	0.614	0.614	0.614

Table 5: Baseline Max Velocity

	1 in 2yr event	**1 in 5yr event**	**1 in 10yr event**	**1 in 30yr event**	**1 in 50yr event**	**1 in 75yr event**	**1 in 100yr event**	**1 in 200yr event**	**1 in 200yr +CC event**
Section Label	**Max Velocity**	**Max Velocity**	**Max Velocity**	**Max Velocity**	**Max Velocity**	**Max Velocity**	**Max Velocity**	**Max Velocity**	**Max Velocity**
S1	1.001	1.06	1.062	1.097	1.12	1.137	1.15	1.176	1.179
S2	0.673	0.706	0.723	0.817	0.866	0.903	0.929	0.985	1.036
S3	1.595	1.682	1.731	1.817	1.882	1.929	1.962	2.035	2.099
S3a	1.559	1.641	1.69	1.768	1.801	1.856	1.893	1.982	2.075
S4	1.154	1.228	1.288	1.42	1.48	1.521	1.557	1.661	1.771
S5	1.086	1.126	1.179	1.228	1.246	1.284	1.322	1.423	1.549
S6	1.272	1.389	1.45	1.537	1.583	1.629	1.665	1.726	1.736
S7	1.342	1.433	1.527	1.669	1.735	1.792	1.845	1.991	2.138
S7a	1.313	1.423	1.495	1.588	1.632	1.693	1.738	1.856	1.97
S8	0.975	1.081	1.131	1.209	1.25	1.291	1.319	1.403	1.498
S9	1.089	1.17	1.241	1.342	1.382	1.431	1.461	1.548	1.651
S10	1.164	1.166	1.195	1.204	1.206	1.224	1.232	1.255	1.336
S11	1.231	1.272	1.276	1.286	1.29	1.291	1.292	1.292	1.343
S11a	0.531	0.573	0.606	0.643	0.659	0.677	0.69	0.719	0.744
S11aDS	0.682	0.734	0.788	0.873	0.915	0.958	0.986	1.049	1.1
S11b	1.299	1.324	1.371	1.42	1.443	1.482	1.507	1.608	1.684
S12	1.218	1.378	1.466	1.59	1.715	1.785	1.824	1.918	1.987
S13	0.627	0.727	0.779	0.848	0.966	1.054	1.095	1.215	1.287
S14	1.363	1.501	1.564	1.686	1.733	1.75	1.751	1.781	1.805
S14a	1.367	1.418	1.425	1.485	1.501	1.508	1.509	1.541	1.579
S15	1.023	1.097	1.141	1.238	1.282	1.342	1.379	1.442	1.482
S16	0.997	1.07	1.115	1.187	1.217	1.236	1.247	1.297	1.331

S17	0.985	1.119	1.193	1.29	1.334	1.373	1.412	1.481	1.521
S18	1.04	1.115	1.149	1.205	1.24	1.284	1.306	1.348	1.364
S18a	0.668	0.724	0.758	0.779	0.799	0.806	0.809	0.82	0.821
S18aDS	0.829	0.918	0.968	1.034	1.091	1.141	1.172	1.254	1.318
S19	1.091	1.132	1.165	1.245	1.297	1.373	1.43	1.539	1.702
S20	0.708	0.742	0.773	0.812	0.824	0.844	0.845	0.849	0.849
S20a	1.313	1.398	1.444	1.523	1.567	1.571	1.571	1.604	1.61
S20b	1.616	1.7	1.743	1.822	1.858	1.88	1.89	1.944	1.984
S21	1.262	1.373	1.42	1.517	1.572	1.611	1.632	1.685	1.724
S21a	1.201	1.277	1.367	1.507	1.558	1.599	1.624	1.735	1.855
S22	1.327	1.428	1.481	1.526	1.572	1.602	1.626	1.688	1.733
S22a	1.318	1.38	1.407	1.435	1.435	1.436	1.438	1.567	1.704
S23	1.374	1.549	1.642	1.771	1.83	1.893	1.93	1.967	2.058
S23a	1.151	1.206	1.23	1.275	1.301	1.319	1.324	1.375	1.425
S24	0.839	0.866	0.888	0.914	0.925	0.936	0.944	0.955	0.96
S24DS	1.452	1.501	1.567	1.636	1.658	1.674	1.684	1.713	1.734
S25	1.162	1.192	1.204	1.218	1.226	1.232	1.237	1.264	1.292
S26	0.746	0.778	0.81	0.868	0.89	0.906	0.918	0.946	0.968
S27	0.599	0.628	0.64	0.653	0.664	0.671	0.675	0.685	0.698
S27a	0.527	0.554	0.566	0.58	0.588	0.593	0.598	0.608	0.613
S28	0.453	0.462	0.463	0.465	0.466	0.466	0.467	0.468	0.468
S28a	0.479	0.491	0.501	0.516	0.518	0.519	0.52	0.522	0.524
S29	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542
Cul29_US	3.01	3.226	3.36	3.56	3.659	3.739	3.778	3.914	4.062
Cul29_1a	2.945	3.12	3.237	3.411	3.501	3.576	3.611	3.752	3.915
Cul29_1b	2.675	2.827	2.945	3.121	3.219	3.298	3.336	3.498	3.69
Cul29_1c	2.483	2.639	2.764	2.952	3.057	3.144	3.185	3.362	3.572
Cul29_DS	2.266	2.435	2.573	2.778	2.893	2.987	3.033	3.225	3.453
S30	1.143	1.234	1.286	1.332	1.344	1.352	1.356	1.401	1.463
S30aa	1.108	1.219	1.256	1.297	1.325	1.355	1.371	1.43	1.499
S30a	1.134	1.229	1.276	1.317	1.331	1.345	1.354	1.409	1.472
S31	1.127	1.181	1.216	1.291	1.348	1.41	1.443	1.554	1.677
S31a	0.894	0.941	0.984	1.076	1.142	1.201	1.234	1.346	1.463
S32	0.69	0.733	0.773	0.858	0.906	0.952	0.977	1.071	1.178
S33	0.8	0.882	0.913	0.977	1.038	1.085	1.096	1.111	1.116
S34	1.071	1.176	1.237	1.3	1.323	1.376	1.416	1.56	1.711
S35	1.206	1.302	1.35	1.417	1.455	1.468	1.474	1.477	1.475
S35a	1.091	1.161	1.203	1.268	1.292	1.295	1.296	1.301	1.307
S36	0.84	0.879	0.9	0.913	0.92	0.929	0.937	0.946	0.95
S37	0.736	0.782	0.806	0.843	0.859	0.859	0.867	0.87	0.873
S38	0.658	0.72	0.747	0.789	0.819	0.834	0.838	0.846	0.849
S39	0.483	0.536	0.569	0.618	0.643	0.669	0.679	0.696	0.697
Cul_1	0.749	0.883	0.982	1.124	1.177	1.234	1.257	1.324	1.366
Cul_1a	0.799	0.941	1.05	1.2	1.291	1.303	1.324	1.379	1.407

Cul_1b	0.864	1.021	1.145	1.308	1.354	1.4	1.415	1.451	1.461
Cul_2	0.957	1.14	1.298	1.488	1.621	1.627	1.627	1.627	1.627
S40	1.047	1.19	1.338	1.436	1.509	1.512	1.512	1.512	1.513
S40a	2.144	2.161	2.162	2.163	2.163	2.163	2.163	2.164	2.164
S41	0.658	0.678	0.679	0.679	0.679	0.679	0.679	0.679	0.681
Cul41_1a	1.496	1.617	1.718	1.968	2.17	2.424	2.553	2.984	3.427
Cul41_1b	1.407	1.557	1.684	1.98	2.17	2.424	2.553	2.984	3.427
Cul41_2	1.299	1.487	1.642	1.991	2.195	2.424	2.553	2.984	3.427
Cul41_1	1.549	1.667	1.747	1.958	2.17	2.424	2.553	2.984	3.427
S42	1.246	1.318	1.381	1.516	1.571	1.617	1.637	1.694	1.765
S42a	1.219	1.336	1.415	1.526	1.57	1.605	1.62	1.676	1.683
S42aa	1.241	1.313	1.403	1.523	1.574	1.614	1.632	1.686	1.809
S42b	1.214	1.349	1.42	1.502	1.541	1.574	1.589	1.649	1.686
S42c	1.258	1.377	1.411	1.469	1.518	1.56	1.578	1.614	1.645
S43	1.672	1.673	1.673	1.674	1.674	1.674	1.675	1.675	1.674
Br_43US	0.508	0.508	0.508	0.508	0.508	0.508	0.508	0.508	0.508
Br_43DS	0.508	0.508	0.508	0.508	0.508	0.508	0.508	0.508	0.508
S44	0.838	0.923	0.973	1.047	1.081	1.121	1.142	1.205	1.263
S44aa	0.89	0.983	1.039	1.122	1.161	1.203	1.226	1.295	1.358
S44a	0.974	1.078	1.143	1.24	1.285	1.327	1.352	1.427	1.498
S44b	1.158	1.281	1.36	1.472	1.524	1.573	1.598	1.674	1.752
S44c	1.448	1.592	1.663	1.771	1.822	1.874	1.905	1.984	2.049
S44d	1.638	1.779	1.852	1.954	2.003	2.053	2.084	2.172	2.231
S45	2.065	2.116	2.162	2.251	2.302	2.342	2.351	2.382	2.42
Cul45_1	1.543	1.705	1.81	1.978	2.063	2.141	2.181	2.309	2.43
Cul45_1aaa	1.527	1.692	1.797	1.967	2.051	2.13	2.171	2.301	2.424
Cul45_1aa	1.495	1.667	1.776	1.948	2.033	2.114	2.156	2.291	2.418
Cul45_1ai	1.429	1.624	1.741	1.921	2.008	2.091	2.135	2.277	2.409
Cul45_1a	1.336	1.547	1.683	1.879	1.971	2.059	2.105	2.258	2.398
Cul45_1b	1.143	1.363	1.509	1.738	1.849	1.954	2.011	2.2	2.365
Cul45_1c	1.055	1.273	1.42	1.653	1.767	1.876	1.936	2.152	2.34
Cul45_2	0.977	1.19	1.334	1.569	1.685	1.796	1.858	2.084	2.307
S46	1.033	1.157	1.241	1.369	1.43	1.484	1.511	1.618	1.722
S46aa	1.03	1.149	1.231	1.356	1.415	1.469	1.495	1.593	1.696
S46a	1.028	1.141	1.222	1.344	1.402	1.454	1.48	1.57	1.672
S46b	1.023	1.134	1.193	1.314	1.384	1.437	1.462	1.551	1.641
S46c	1.007	1.09	1.204	1.312	1.318	1.342	1.347	1.352	1.353
S46d	1.023	1.107	1.11	1.113	1.113	1.115	1.115	1.116	1.117
S47	0.817	0.818	0.818	0.819	0.819	0.819	0.819	0.819	0.819
S48	1.16	1.29	1.356	1.461	1.499	1.504	1.504	1.504	1.504
Br_48US	0.605	0.605	0.605	0.605	0.605	0.605	0.605	0.605	0.605
Br_48DS	0.605	0.605	0.605	0.605	0.605	0.605	0.605	0.605	0.605
S48DS	1.175	1.316	1.392	1.515	1.576	1.622	1.635	1.683	1.757
S48a	1.101	1.2	1.291	1.418	1.47	1.515	1.535	1.598	1.652

S49	0.894	0.976	1.022	1.067	1.092	1.115	1.126	1.173	1.232
S49a	0.914	0.948	0.956	0.994	1.044	1.096	1.121	1.192	1.246
S50	1.119	1.198	1.24	1.26	1.291	1.334	1.353	1.411	1.458

Mitigation results

Table 6: Mitigation scenario top water levels

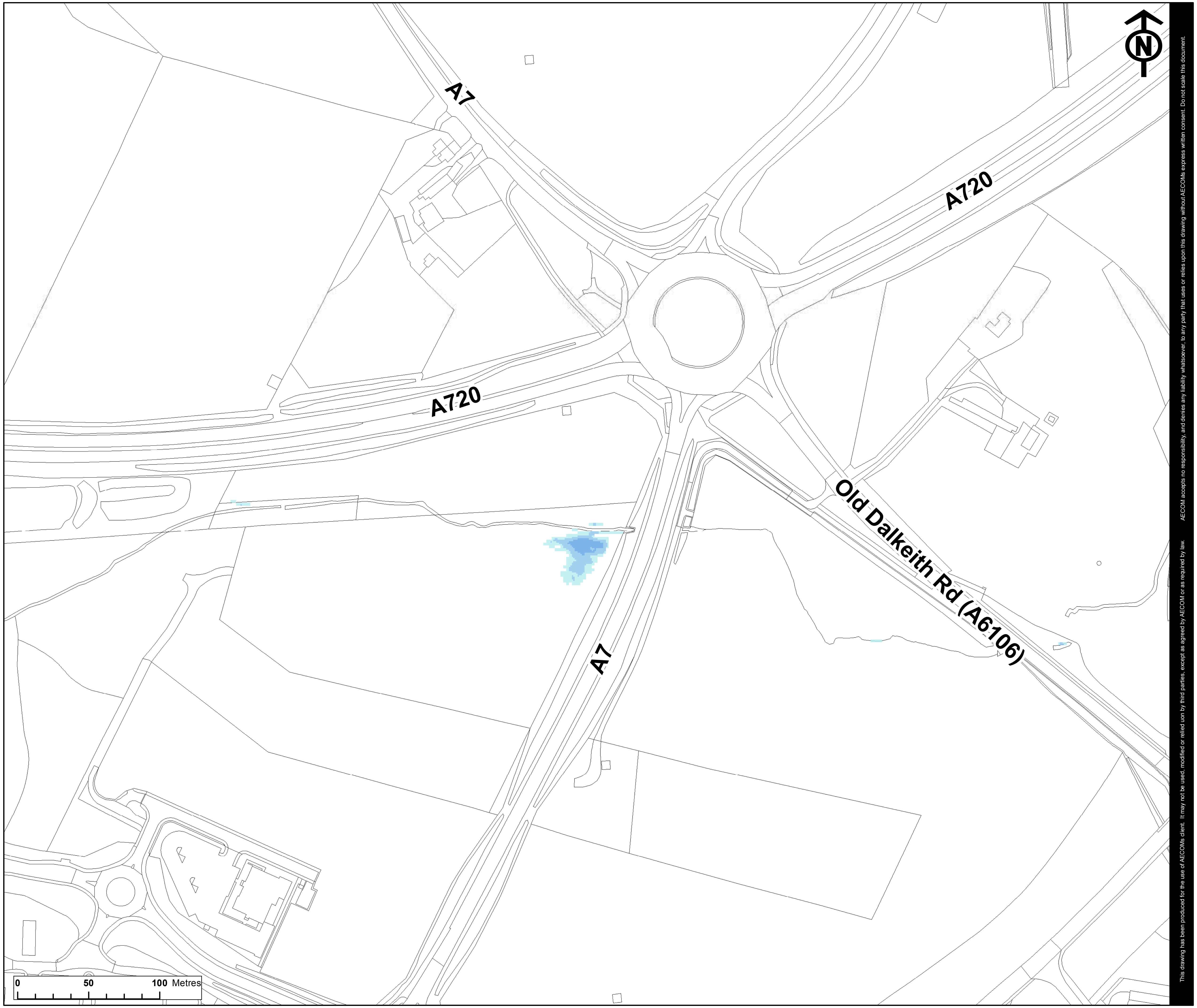
	1 in 2yr event	1 in 5yr event	1 in 10yr event	1 in 30yr event	1 in 50yr event	1 in 75yr event	1 in 100yr event	1 in 200yr event	1 in 200yr +CC event
	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)	Max Stage (mAOD)
S1	68.3	68.397	68.468	68.558	68.602	68.645	68.678	68.768	68.878
S2	68.241	68.343	68.419	68.502	68.545	68.587	68.62	68.708	68.82
S3	67.859	67.955	68.027	68.113	68.156	68.199	68.233	68.322	68.427
S3a	67.473	67.563	67.628	67.731	67.782	67.823	67.854	67.937	68.038
S4	67.219	67.311	67.371	67.465	67.521	67.563	67.593	67.665	67.751
S5	66.965	67.064	67.118	67.214	67.275	67.321	67.35	67.418	67.491
S6	66.687	66.768	66.82	66.92	66.98	67.025	67.056	67.143	67.257
S7	66.217	66.298	66.341	66.423	66.474	66.52	66.549	66.619	66.704
S7a	65.916	65.993	66.037	66.123	66.177	66.219	66.249	66.32	66.407
S8	65.73	65.799	65.851	65.948	66.004	66.05	66.087	66.17	66.267
S9	65.376	65.445	65.488	65.571	65.625	65.67	65.707	65.789	65.877
S10	65.081	65.185	65.234	65.34	65.406	65.455	65.496	65.596	65.686
S11	64.845	64.964	65.033	65.163	65.243	65.309	65.362	65.471	65.554
S11a	64.814	64.939	65.016	65.156	65.239	65.308	65.361	65.475	65.572
S11aDS	64.687	64.786	64.84	64.94	65.001	65.044	65.079	65.152	65.213
S11b	64.436	64.518	64.56	64.645	64.696	64.739	64.773	64.828	64.878
S12	64.198	64.266	64.309	64.394	64.423	64.465	64.5	64.555	64.604
S13	64.118	64.179	64.226	64.321	64.343	64.343	64.358	64.391	64.432
S14	63.71	63.766	63.812	63.89	63.934	63.974	64.003	64.056	64.103
S14a	63.408	63.493	63.559	63.654	63.7	63.747	63.785	63.86	63.923
S15	63.237	63.345	63.413	63.513	63.564	63.612	63.651	63.728	63.795
S16	62.862	62.975	63.037	63.148	63.206	63.257	63.297	63.387	63.461
S17	62.697	62.813	62.869	62.971	63.03	63.082	63.123	63.211	63.281
S18	62.619	62.736	62.783	62.871	62.924	62.975	63.017	63.106	63.175
S18a	62.361	62.44	62.482	62.563	62.613	62.659	62.686	62.748	62.804
S19	62.156	62.202	62.243	62.316	62.361	62.404	62.431	62.493	62.548
S20	61.803	61.848	61.871	61.911	61.934	61.955	61.971	62.006	62.036
S20a	61.312	61.387	61.424	61.476	61.503	61.526	61.542	61.573	61.598
S21	60.969	61.055	61.12	61.193	61.229	61.26	61.283	61.34	61.386

S21a	60.748	60.855	60.922	60.992	61.027	61.055	61.072	61.092	61.112
S22	60.41	60.54	60.593	60.661	60.694	60.727	60.752	60.807	60.844
S22a	60.11	60.197	60.24	60.31	60.35	60.389	60.421	60.481	60.546
S23	59.877	59.931	59.976	60.065	60.117	60.166	60.198	60.263	60.308
S23a	59.641	59.736	59.788	59.881	59.921	59.962	59.993	60.064	60.123
S24	59.215	59.324	59.411	59.53	59.576	59.623	59.66	59.755	59.963
S25	58.817	58.934	59.013	59.16	59.262	59.369	59.433	59.656	59.952
S26	58.711	58.848	58.937	59.098	59.211	59.34	59.415	59.654	59.952
S27	58.647	58.791	58.892	59.085	59.207	59.339	59.414	59.653	59.952
S27a	58.631	58.78	58.889	59.084	59.206	59.338	59.413	59.653	59.952
S28	58.62	58.777	58.888	59.084	59.207	59.339	59.414	59.653	59.951
S28a	58.607	58.761	58.867	59.06	59.191	59.33	59.406	59.650	59.952
S29	58.592	58.749	58.858	59.052	59.177	59.313	59.389	59.631	59.932
Cul29_US	58.135	58.203	58.249	58.331	58.376	58.417	58.439	58.506	58.582
Cul29_1a	57.995	58.066	58.116	58.203	58.249	58.291	58.314	58.383	58.460
Cul29_1b	57.874	57.951	58.004	58.095	58.141	58.183	58.206	58.275	58.352
Cul29_1c	57.824	57.902	57.956	58.048	58.094	58.135	58.158	58.226	58.302
Cul29_DS	57.767	57.845	57.9	57.991	58.035	58.074	58.095	58.162	58.235
S30	57.754	57.832	57.887	57.978	58.022	58.061	58.083	58.151	58.225
S30a	57.723	57.8	57.854	57.948	57.993	58.034	58.056	58.125	58.199
S30aa	57.635	57.708	57.764	57.862	57.912	57.956	57.979	58.049	58.119
S31	57.516	57.603	57.664	57.76	57.806	57.843	57.861	57.914	57.970
S31a	57.427	57.53	57.594	57.685	57.723	57.751	57.764	57.799	57.838
S32	57.389	57.496	57.56	57.645	57.679	57.703	57.715	57.741	57.771
S33	57.322	57.422	57.488	57.584	57.625	57.654	57.668	57.709	57.749
S34	57.126	57.213	57.277	57.359	57.392	57.414	57.424	57.443	57.464
S35	56.843	56.934	56.995	57.078	57.124	57.157	57.176	57.226	57.291
S35a	56.641	56.736	56.798	56.903	56.968	57.009	57.033	57.113	57.232
S36	56.526	56.631	56.703	56.829	56.904	56.949	56.978	57.071	57.210
S37	56.442	56.555	56.629	56.755	56.836	56.882	56.915	57.021	57.186
S38	56.359	56.471	56.548	56.676	56.762	56.808	56.845	56.975	57.179
S39	56.324	56.435	56.512	56.641	56.728	56.77	56.807	56.934	57.128
Cul_1	56.252	56.341	56.392	56.502	56.58	56.654	56.699	56.847	57.065
Cul_1a	56.229	56.312	56.358	56.462	56.536	56.613	56.657	56.806	57.027
Cul_1b	56.201	56.276	56.314	56.41	56.486	56.56	56.605	56.758	56.985
Cul_2	56.162	56.224	56.247	56.329	56.4	56.487	56.535	56.698	56.938
S40	56.15	56.21	56.231	56.31	56.38	56.464	56.511	56.673	56.915
S40a	55.941	56.023	56.073	56.199	56.251	56.328	56.363	56.583	56.853
S41	55.751	55.861	55.951	56.125	56.253	56.369	56.436	56.656	56.910
Cul41_1	55.654	55.752	55.828	55.972	56.085	56.189	56.251	56.456	56.693
Cul41_1a	55.606	55.706	55.778	55.899	55.987	56.069	56.117	56.275	56.453
Cul41_1b	55.57	55.666	55.731	55.826	55.889	55.948	55.982	56.094	56.214
Cul41_2	55.545	55.633	55.687	55.753	55.791	55.827	55.848	55.913	55.974
S42	55.523	55.61	55.664	55.731	55.77	55.807	55.829	55.895	55.958

S42a	55.262	55.342	55.383	55.455	55.5	55.543	55.567	55.638	55.714
S42aa	55.388	55.479	55.523	55.592	55.633	55.673	55.696	55.766	55.813
S42b	55.008	55.068	55.111	55.196	55.246	55.293	55.319	55.391	55.468
S42c	54.865	54.926	54.98	55.078	55.125	55.171	55.196	55.277	55.362
S43	54.651	54.739	54.803	54.92	54.988	55.046	55.076	55.169	55.266
Br_43US	54.651	54.739	54.803	54.92	54.988	55.046	55.076	55.169	55.266
Br_43DS	54.645	54.73	54.791	54.903	54.967	55.022	55.051	55.138	55.228
S44	54.645	54.73	54.791	54.903	54.967	55.022	55.051	55.138	55.228
S44a	54.504	54.587	54.645	54.751	54.812	54.866	54.893	54.974	55.058
S44aa	54.578	54.663	54.724	54.834	54.897	54.952	54.979	55.064	55.152
S44b	54.4	54.477	54.529	54.628	54.685	54.737	54.763	54.842	54.921
S44c	54.296	54.368	54.42	54.513	54.567	54.616	54.64	54.716	54.795
S44d	54.245	54.316	54.367	54.458	54.51	54.558	54.582	54.655	54.732
S45	54.166	54.244	54.298	54.392	54.445	54.493	54.519	54.597	54.677
Cul45_1	54.139	54.21	54.259	54.345	54.393	54.437	54.461	54.531	54.603
Cul45_1aaa	54.094	54.165	54.213	54.299	54.348	54.392	54.415	54.485	54.555
Cul45_1aa	54.053	54.122	54.17	54.256	54.304	54.348	54.371	54.439	54.509
Cul45_1ai	54.022	54.086	54.132	54.215	54.263	54.307	54.329	54.395	54.463
Cul45_1a	54.002	54.06	54.101	54.18	54.226	54.269	54.291	54.353	54.418
Cul45_1b	53.978	54.029	54.065	54.133	54.172	54.209	54.227	54.277	54.333
Cul45_1c	53.971	54.02	54.053	54.118	54.156	54.191	54.208	54.247	54.294
Cul45_2	53.966	54.013	54.045	54.107	54.144	54.177	54.192	54.226	54.258
S46	53.804	53.853	53.886	53.944	53.978	54.01	54.027	54.069	54.111
S46aa	53.75	53.799	53.83	53.887	53.919	53.95	53.967	54.01	54.05
S46a	53.696	53.745	53.775	53.83	53.861	53.891	53.907	53.951	53.99
S46b	53.588	53.635	53.668	53.719	53.744	53.771	53.786	53.828	53.866
S46c	53.374	53.425	53.441	53.487	53.524	53.556	53.574	53.636	53.706
S46d	53.151	53.204	53.244	53.347	53.407	53.45	53.475	53.557	53.647
S47	53.008	53.095	53.166	53.3	53.37	53.419	53.446	53.534	53.629
Br_48US	52.765	52.852	52.919	53.039	53.107	53.174	53.209	53.309	53.405
Br_48DS	52.759	52.841	52.903	53.013	53.073	53.125	53.149	53.222	53.288
S49a	51.693	51.789	51.866	51.991	52.04	52.082	52.104	52.169	52.232
S50	51.329	51.445	51.53	51.662	51.706	51.74	51.759	51.818	51.881

Appendix E – Floodmaps

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



AECOM

PROJECT

A720 Sheriffhall Junction
Improvement

CLIENT

TRANSPORT
SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 2yr Flood Extent

Depth (m)

▨ 0 - 0.1

▨ 0.1 - 0.2

▨ 0.2 - 0.38

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

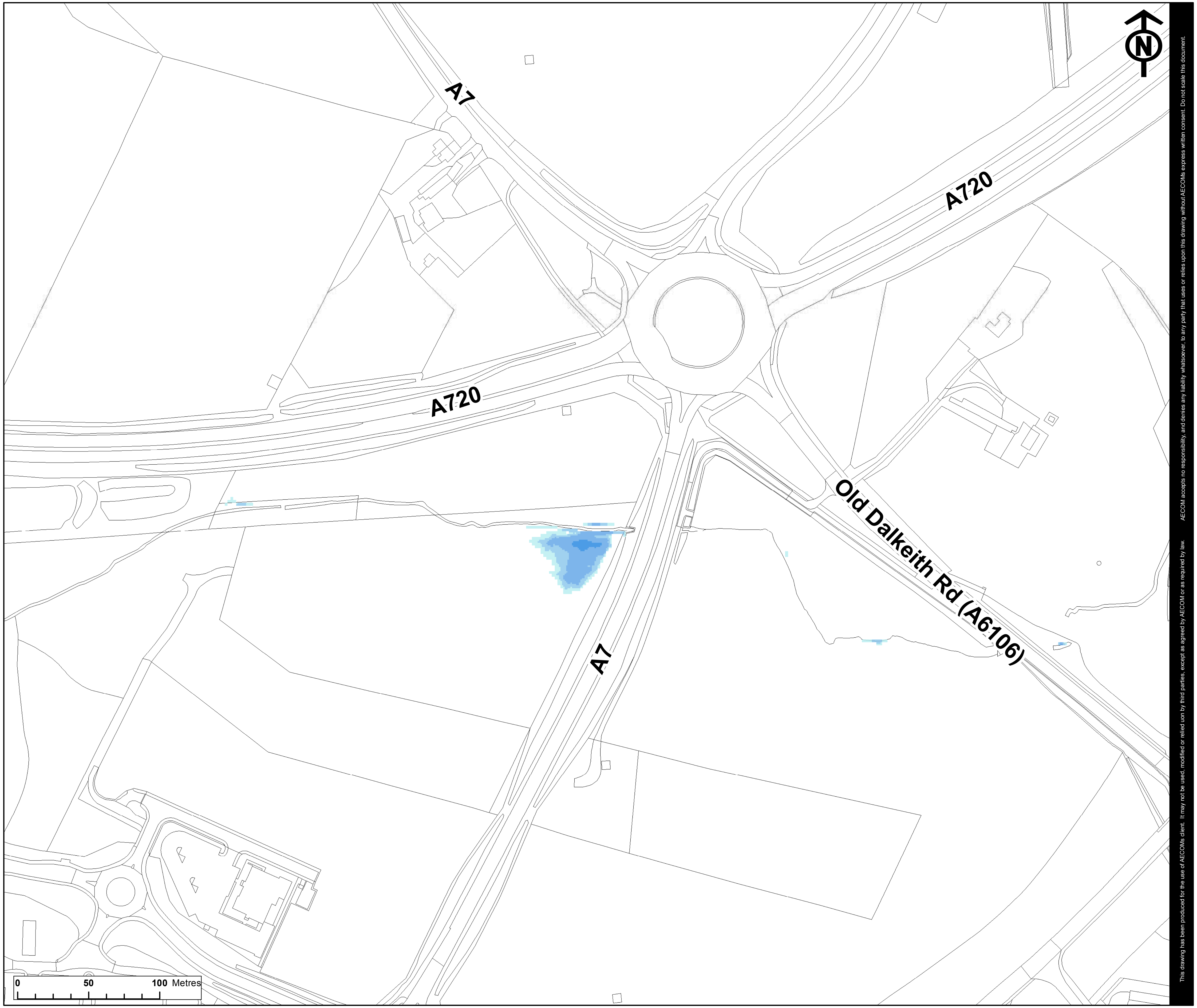
SHEET TITLE

Figure 1: 1 in 2yr Baseline
Flood Extent

SHEET NUMBER

1 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



AECOM

PROJECT

A720 Sheriffhall Junction
Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 5yr Flood Extent

Depth (m)

🟦 0 - 0.1
🟦 0.1 - 0.2
🟦 0.2 - 0.4
🟦 0.4 - 0.53

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

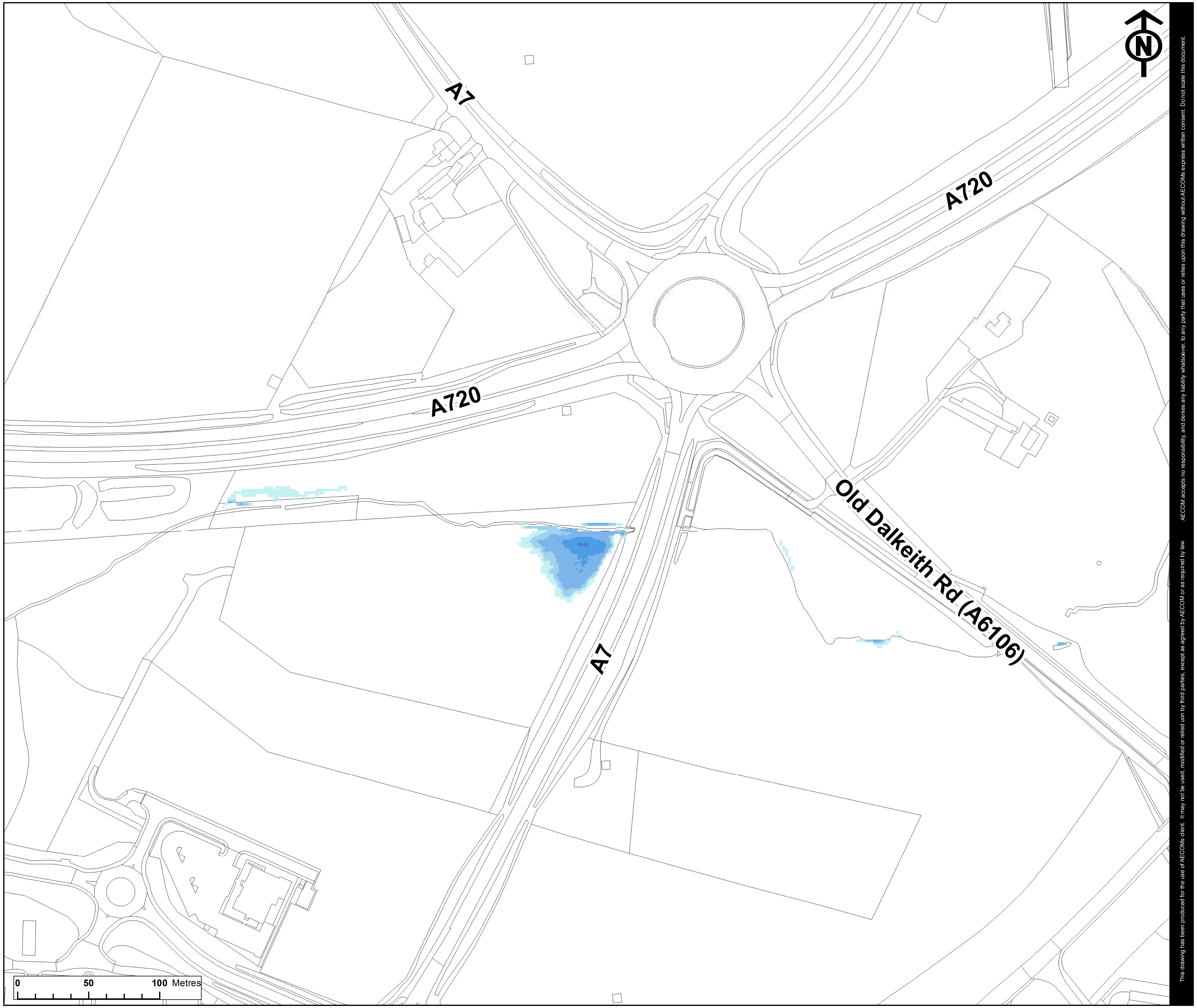
SHEET TITLE

Figure 2: 1 in 5yr Baseline
Flood Extent

SHEET NUMBER

2 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



AECOM

PROJECT

A720 Sheriffhall Junction
Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 10yr Flood Extent

Depth (m)

- ▭ 0 - 0.1
- ▭ 0.1 - 0.2
- ▭ 0.2 - 0.4
- ▭ 0.4 - 0.6
- ▭ 0.6 - 0.65

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

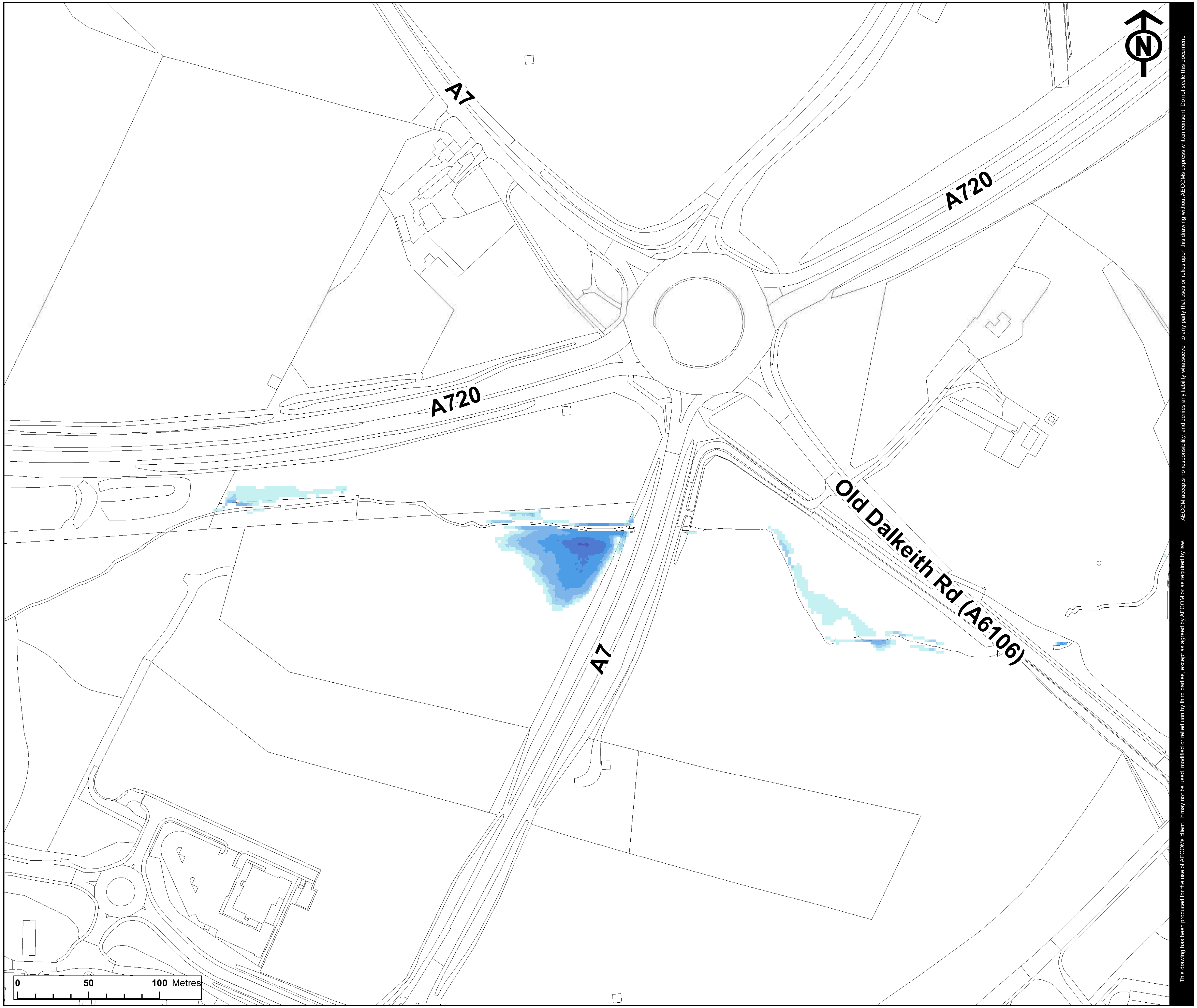
SHEET TITLE

Figure 3: 1 in 10yr Baseline
Flood Extent

SHEET NUMBER

3 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



AECOM

PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 30yr Flood Extent

Depth (m)

▨	0 - 0.1
▨	0.1 - 0.2
▨	0.2 - 0.4
▨	0.4 - 0.6
▨	0.6 - 0.8
▨	0.8 - 0.84

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

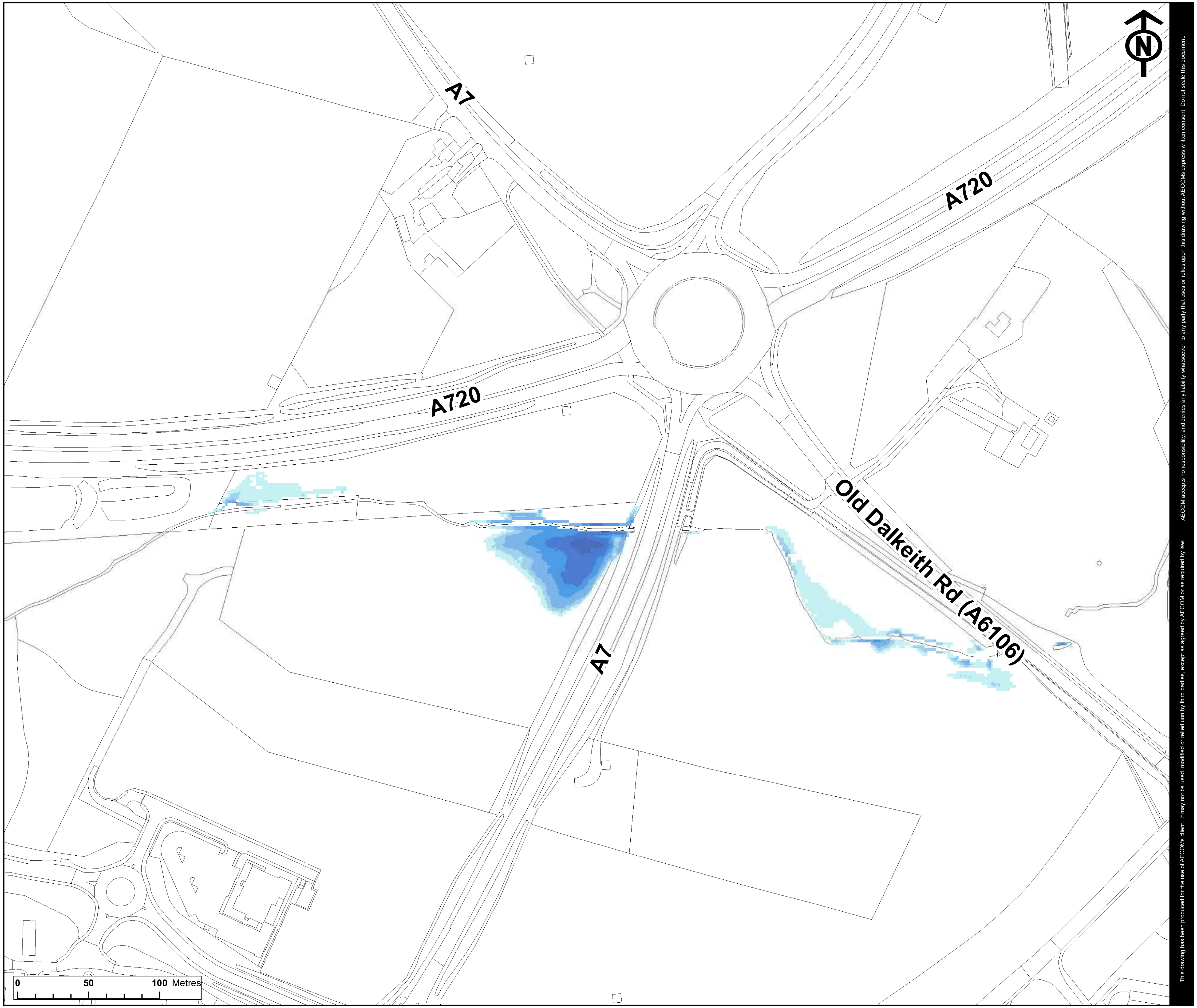
SHEET TITLE

Figure 4: 1 in 30yr Baseline Flood Extent

SHEET NUMBER

4 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



AECOM

PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 50yr Flood Extent

Depth (m)

- 🟦 0 - 0.1
- 🟦 0.1 - 0.2
- 🟦 0.2 - 0.4
- 🟦 0.4 - 0.6
- 🟦 0.6 - 0.8
- 🟦 0.8 - 0.97

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

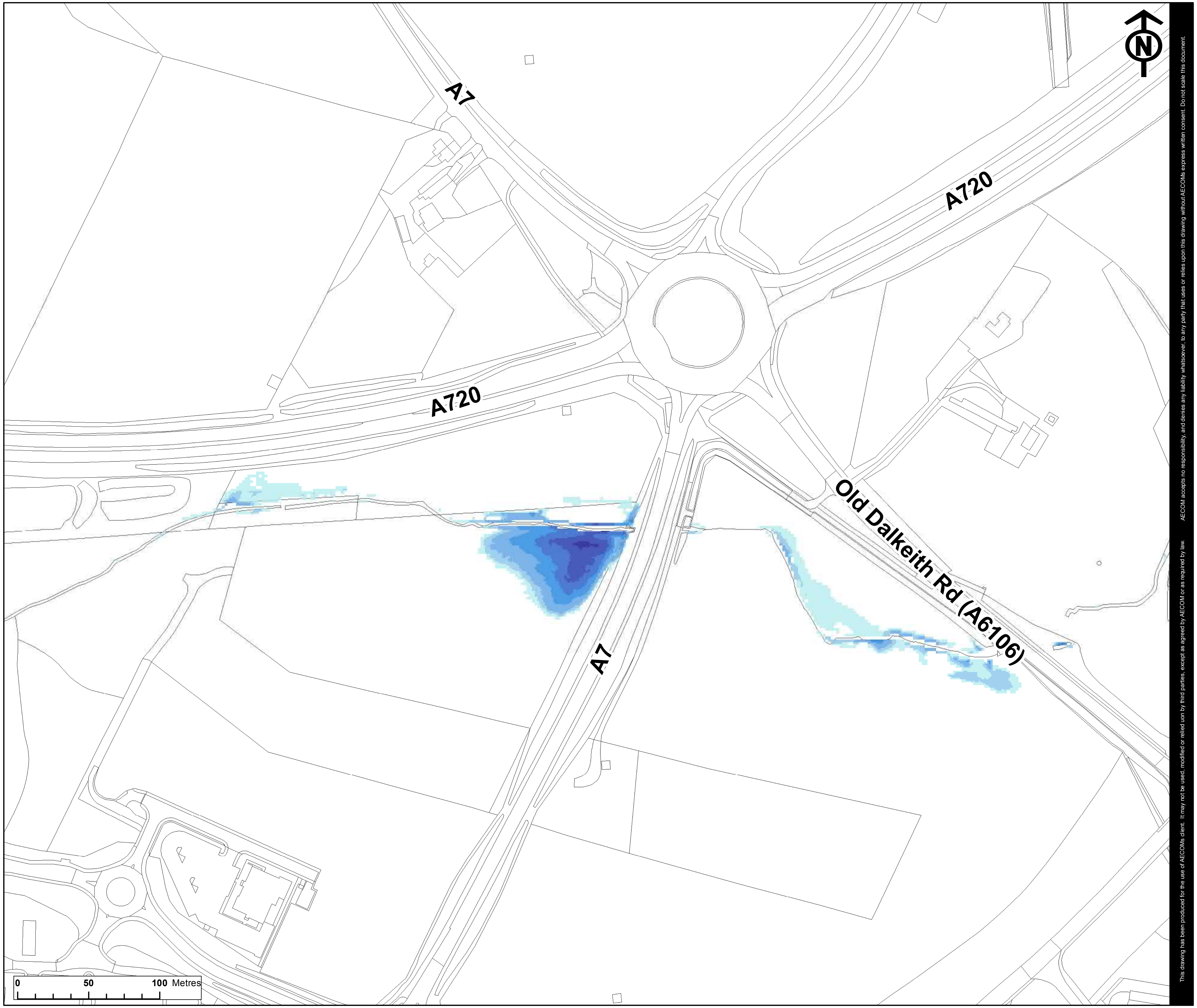
SHEET TITLE

Figure 5: 1 in 50yr Baseline Flood Extent

SHEET NUMBER

5 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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AECOM

PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 75yr Flood Extent

Depth (m)

▨ 0 - 0.1
▨ 0.1 - 0.2
▨ 0.2 - 0.4
▨ 0.4 - 0.6
▨ 0.6 - 0.8
▨ 0.8 - 1.0
▨ 1.0 - 1.10

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

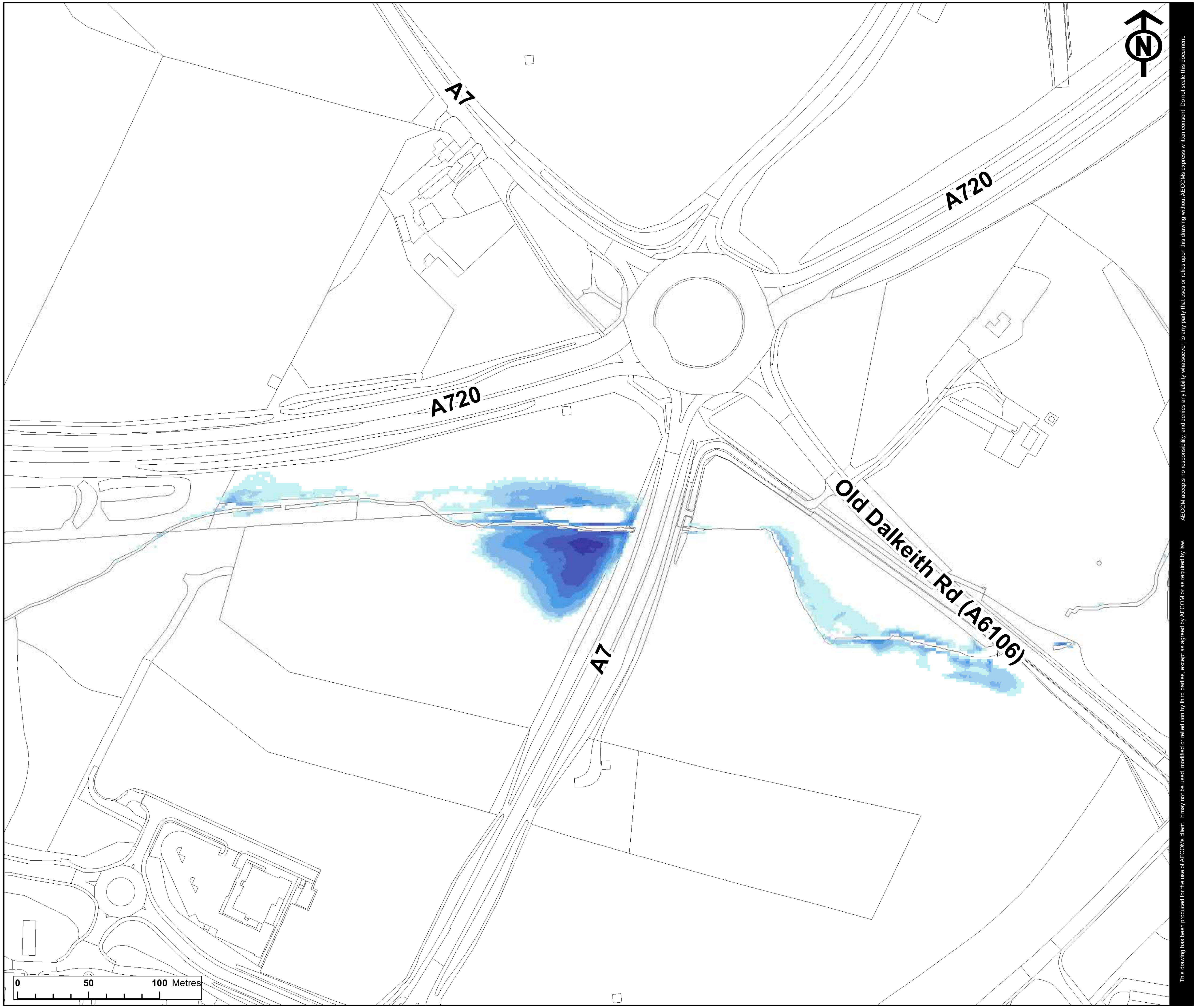
SHEET TITLE

Figure 6: 1 in 75yr Baseline Flood Extent

SHEET NUMBER

6 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 100yr Flood Extent

Depth (m)

- 🟦 0 - 0.1
- 🟦 0.1 - 0.2
- 🟦 0.2 - 0.4
- 🟦 0.4 - 0.6
- 🟦 0.6 - 0.8
- 🟦 0.8 - 1.0
- 🟦 1.0 - 1.18

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

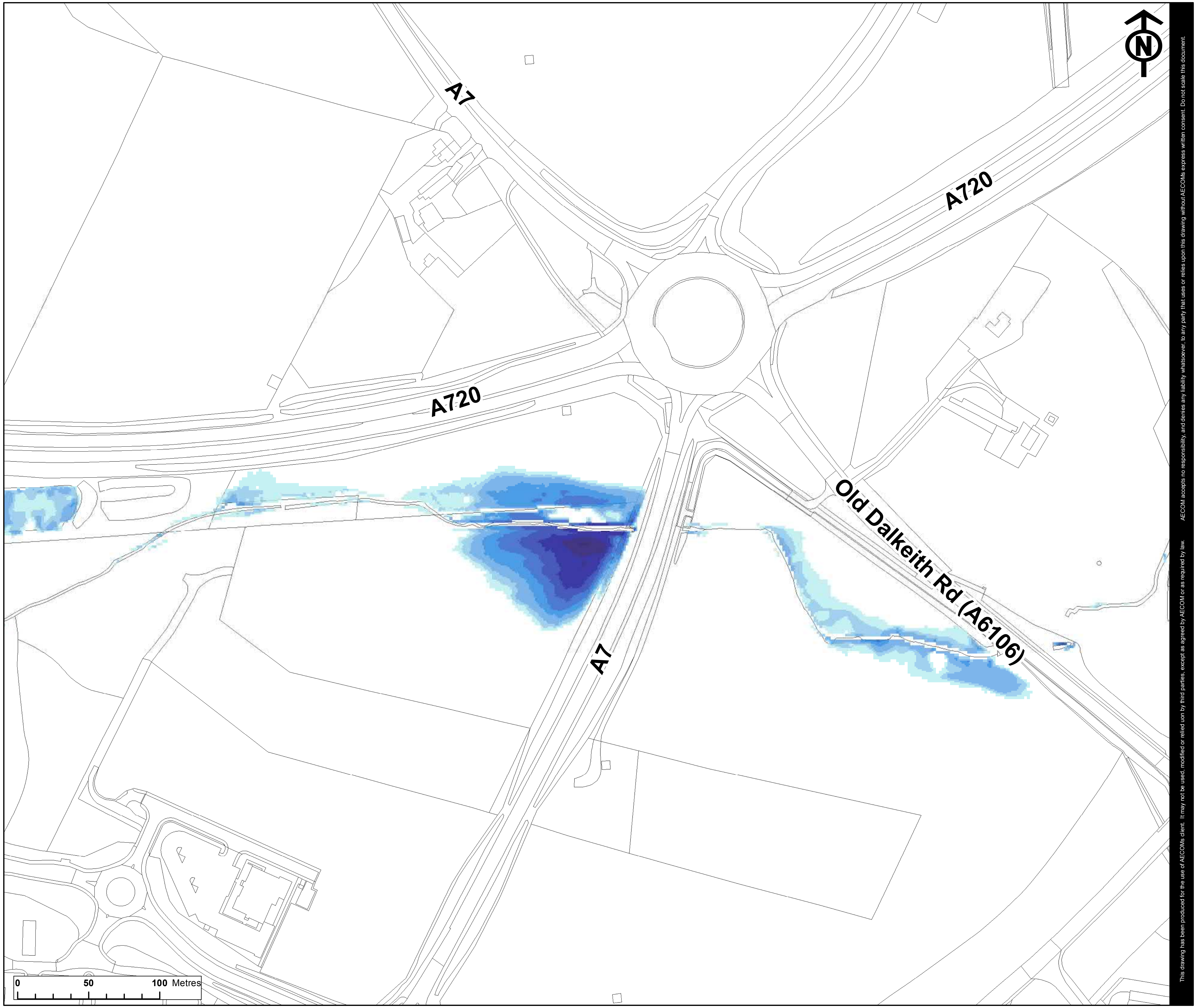
SHEET TITLE

Figure 7: 1 in 100yr Baseline Flood Extent

SHEET NUMBER

7 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 200yr Flood Extent

Depth (m)

- ■ 0 - 0.1
- ■ 0.1 - 0.2
- ■ 0.2 - 0.4
- ■ 0.4 - 0.6
- ■ 0.6 - 0.8
- ■ 0.8 - 1.0
- ■ 1.0 - 1.2
- ■ 1.2 - 1.4
- ■ 1.4 - 1.43

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

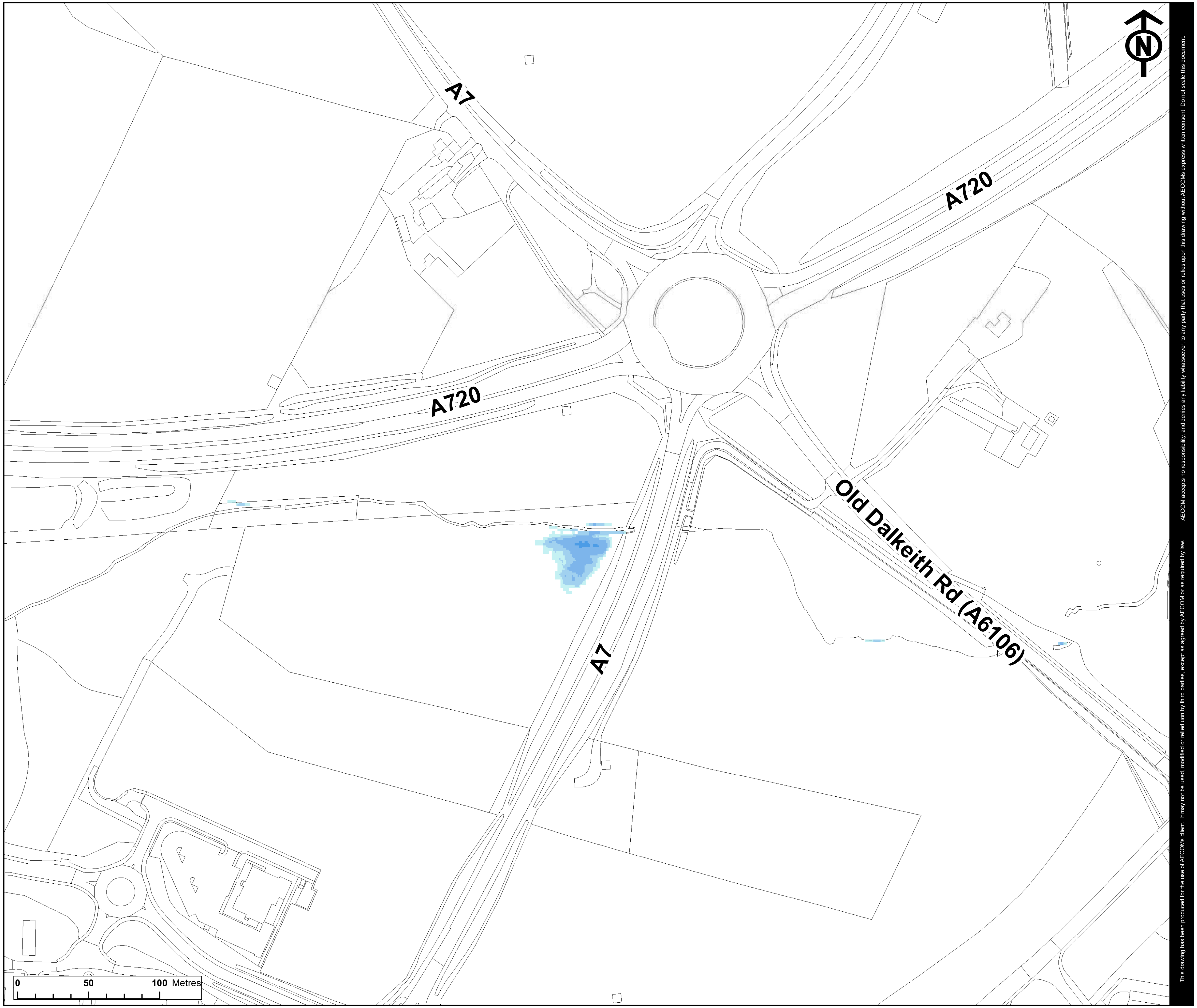
SHEET TITLE

Figure 8: 1 in 200yr Baseline Flood Extent

SHEET NUMBER

8 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 2yr +CC Flood Extent

Depth (m)

■ 0 - 0.1
■ 0.1 - 0.2
■ 0.2 - 0.4
■ 0.4 - 0.48

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

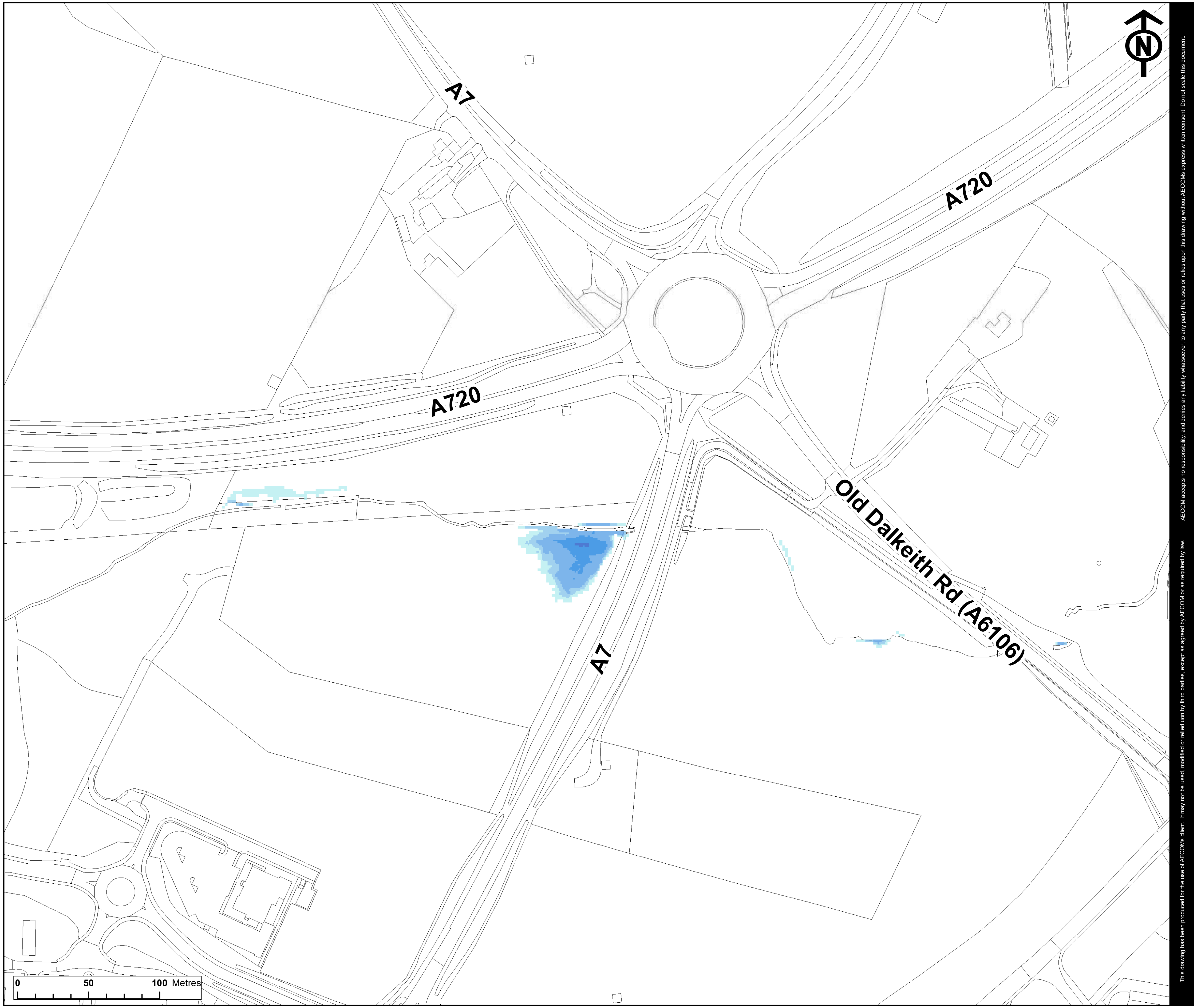
SHEET TITLE

Figure 9: 1 in 2yr + CC Baseline Flood Extent

SHEET NUMBER

9 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction
Improvement

CLIENT

KEY:

1 in 5yr +CC Flood Extent

Depth (m)

▨	0 - 0.1
▨	0.1 - 0.2
▨	0.2 - 0.4
▨	0.4 - 0.6
▨	0.6 - 0.66

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

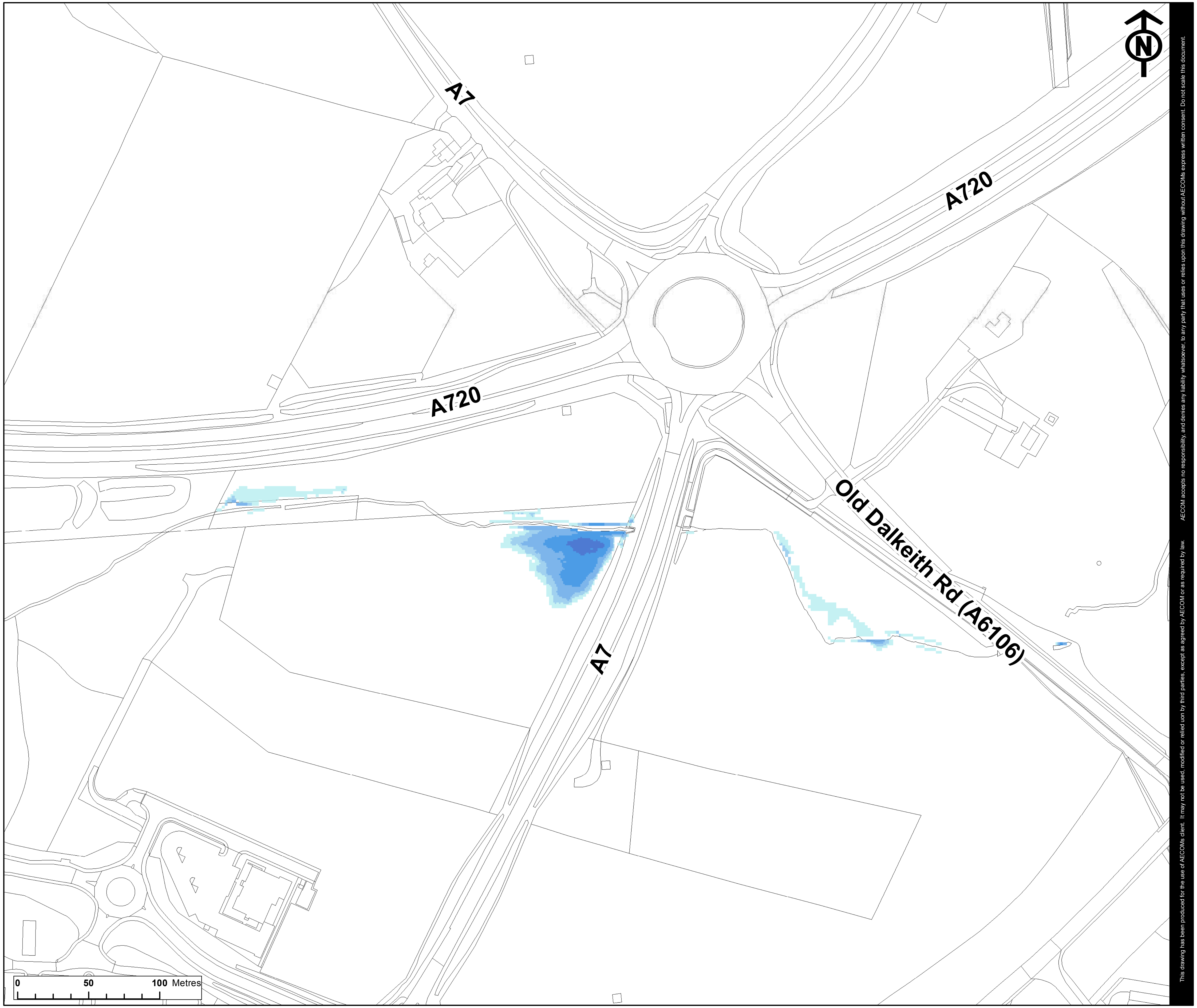
SHEET TITLE

Figure 10: 1 in 5yr + CC Baseline
Flood Extent

SHEET NUMBER

10 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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AECOM

PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 10yr +CC Flood Extent

Depth (m)

- ▨ 0 - 0.1
- ▨ 0.1 - 0.2
- ▨ 0.2 - 0.4
- ▨ 0.4 - 0.6
- ▨ 0.6 - 0.79

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

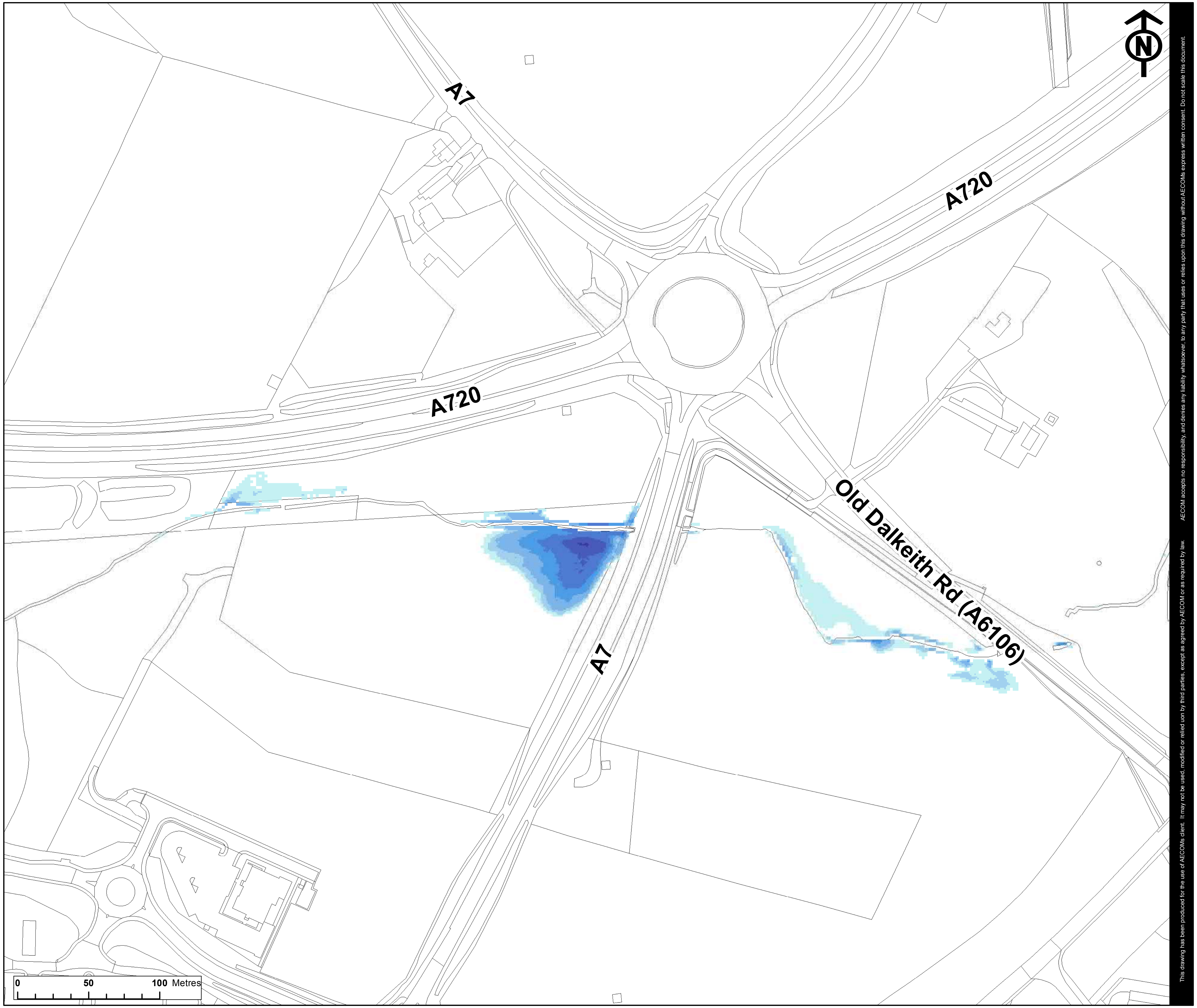
SHEET TITLE

Figure 11: 1 in 10yr + CC Baseline Flood Extent

SHEET NUMBER

11 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



AECOM

PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 30yr +CC Flood Extent

Depth (m)

▨	0 - 0.1
▨	0.1 - 0.2
▨	0.2 - 0.4
▨	0.4 - 0.6
▨	0.6 - 0.8
▨	0.8 - 1.0
▨	1.0 - 1.04

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

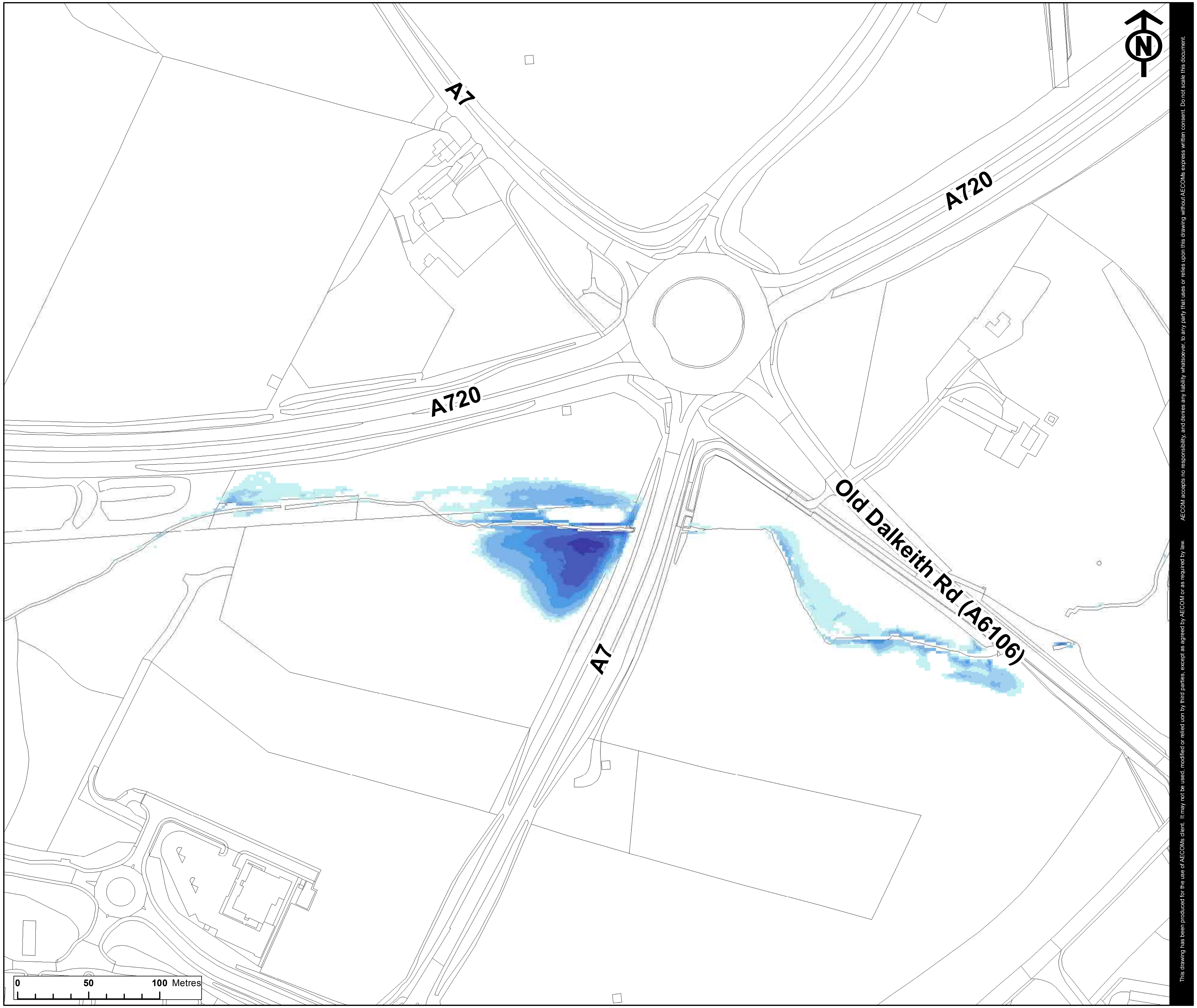
SHEET TITLE

Figure 12: 1 in 30yr + CC Baseline Flood Extent

SHEET NUMBER

12 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction
Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 50yr +CC Flood Extent

Depth (m)

🟦	0 - 0.1
🟦	0.1 - 0.2
🟦	0.2 - 0.4
🟦	0.4 - 0.6
🟦	0.6 - 0.8
🟦	0.8 - 1.0
🟦	1.0 - 1.18

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

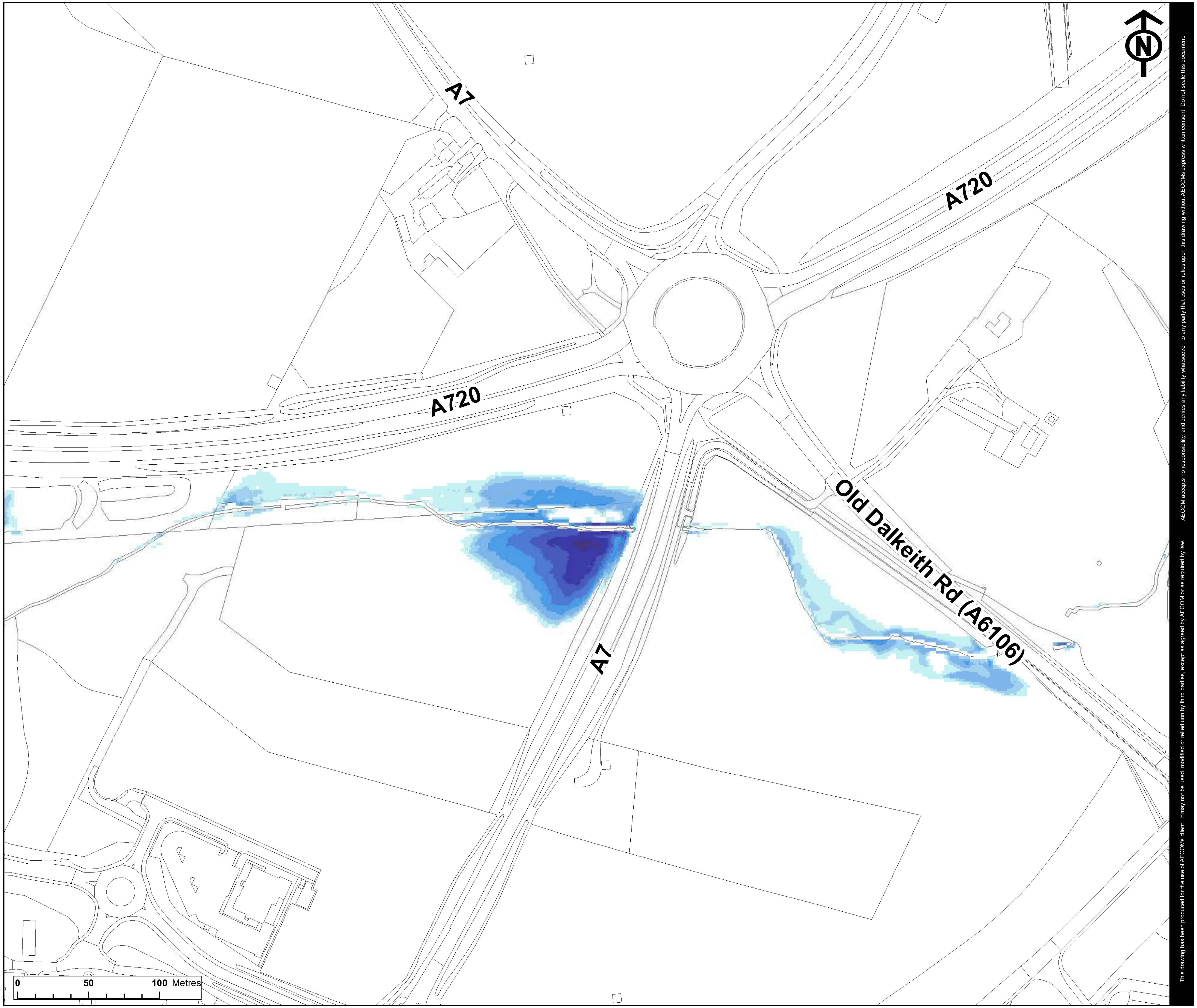
SHEET TITLE

Figure 13: 1 in 50yr + CC Baseline
Flood Extent

SHEET NUMBER

13 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 75yr +CC Flood Extent

Depth (m)

- ▨ 0 - 0.1
- ▨ 0.1 - 0.2
- ▨ 0.2 - 0.4
- ▨ 0.4 - 0.6
- ▨ 0.6 - 0.8
- ▨ 0.8 - 1.0
- ▨ 1.0 - 1.2
- ▨ 1.2 - 1.34

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

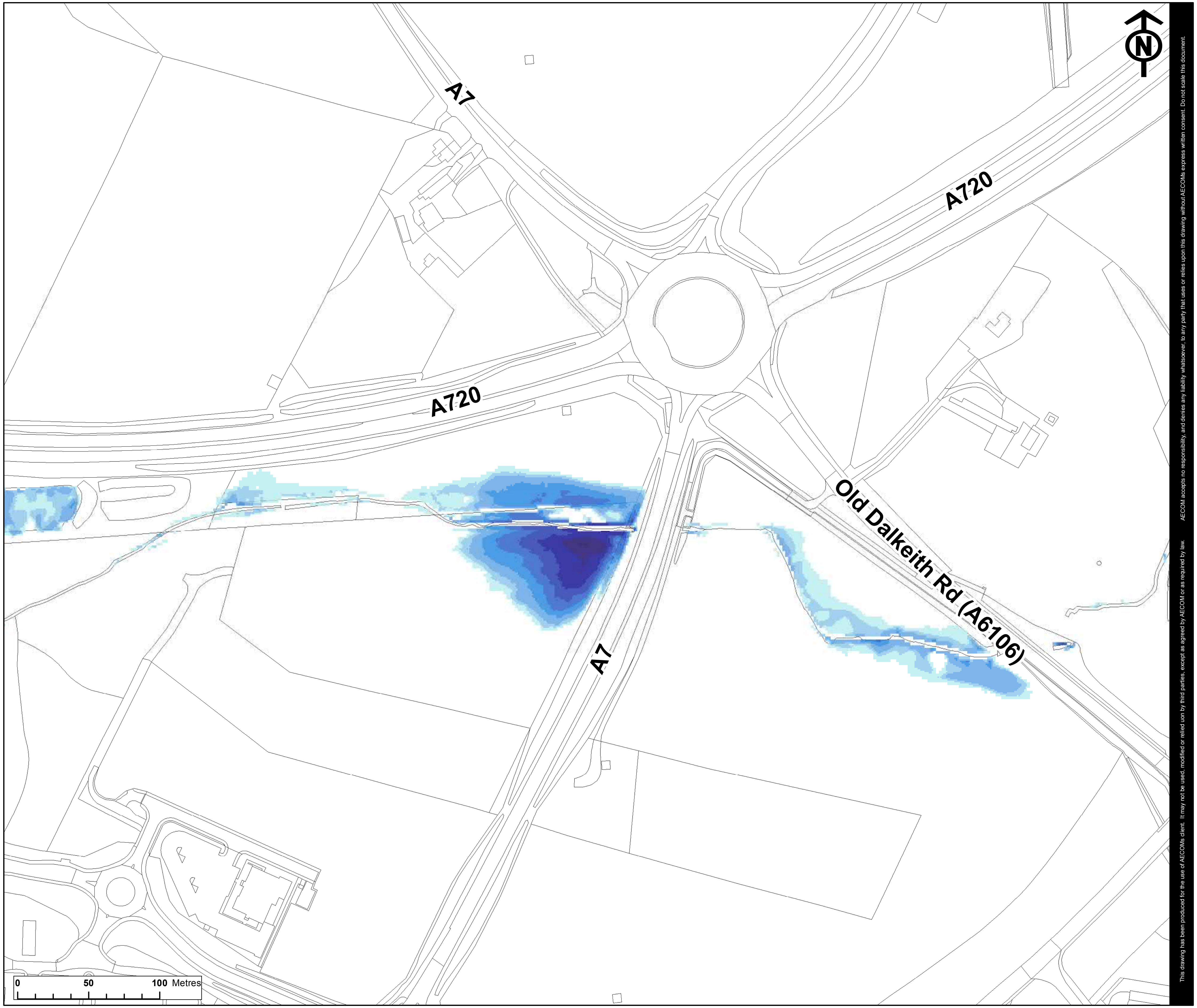
SHEET TITLE

Figure 14: 1 in 75yr + CC Baseline Flood Extent

SHEET NUMBER

14 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



AECOM

PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 100yr +CC Flood Extent

Depth (m)

▨	0 - 0.1
▨	0.1 - 0.2
▨	0.2 - 0.4
▨	0.4 - 0.6
▨	0.6 - 0.8
▨	0.8 - 1.0
▨	1.0 - 1.2
▨	1.2 - 1.4
▨	1.4 - 1.44

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

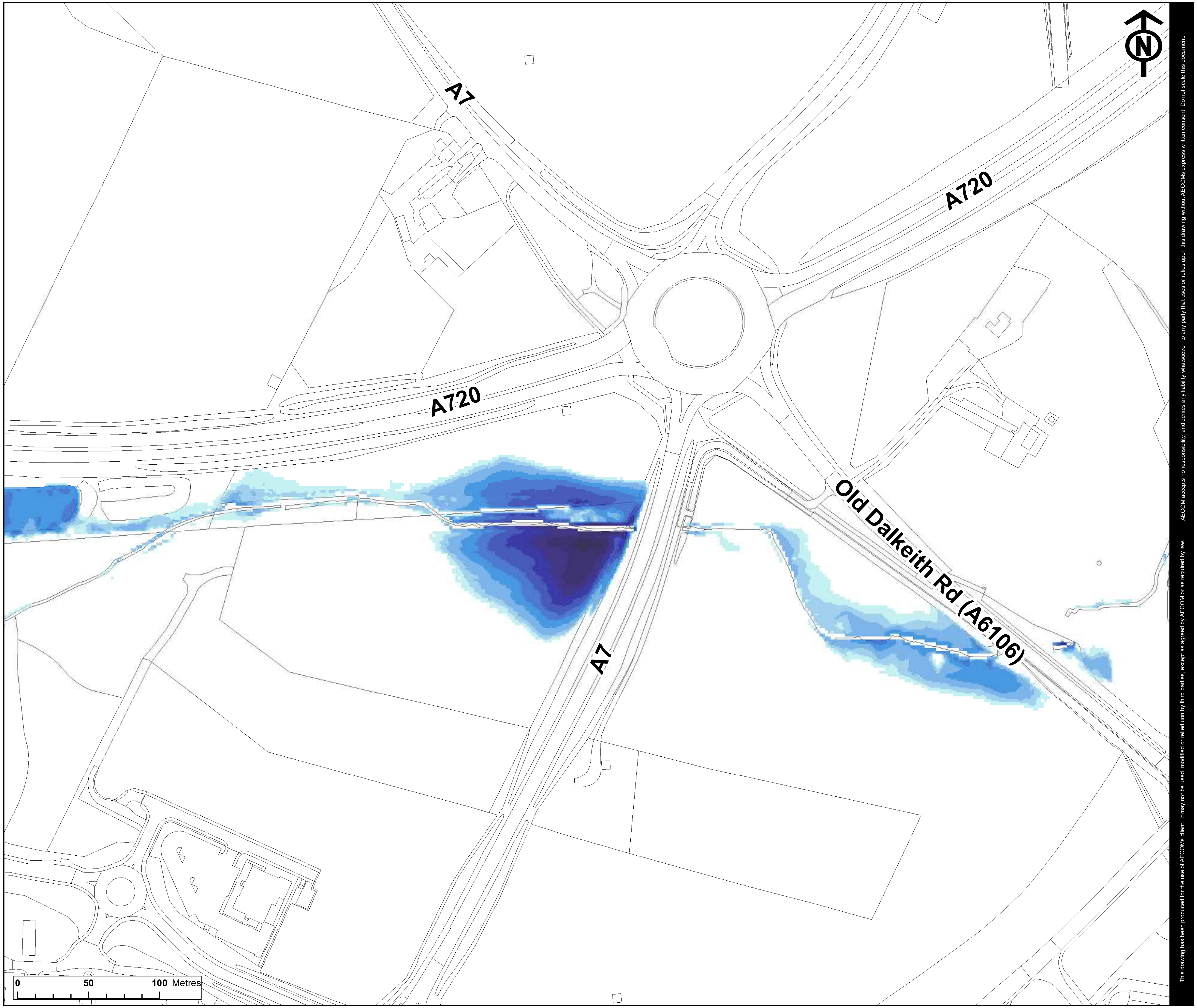
SHEET TITLE

Figure 15: 1 in 100yr + CC Baseline Flood Extent

SHEET NUMBER

15 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 200yr +CC Flood Extent

Depth (m)

- ▨ 0 - 0.1
- ▨ 0.1 - 0.2
- ▨ 0.2 - 0.4
- ▨ 0.4 - 0.6
- ▨ 0.6 - 0.8
- ▨ 0.8 - 1
- ▨ 1 - 1.2
- ▨ 1.2 - 1.4
- ▨ 1.4 - 1.6
- ▨ 1.6 - 1.7

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

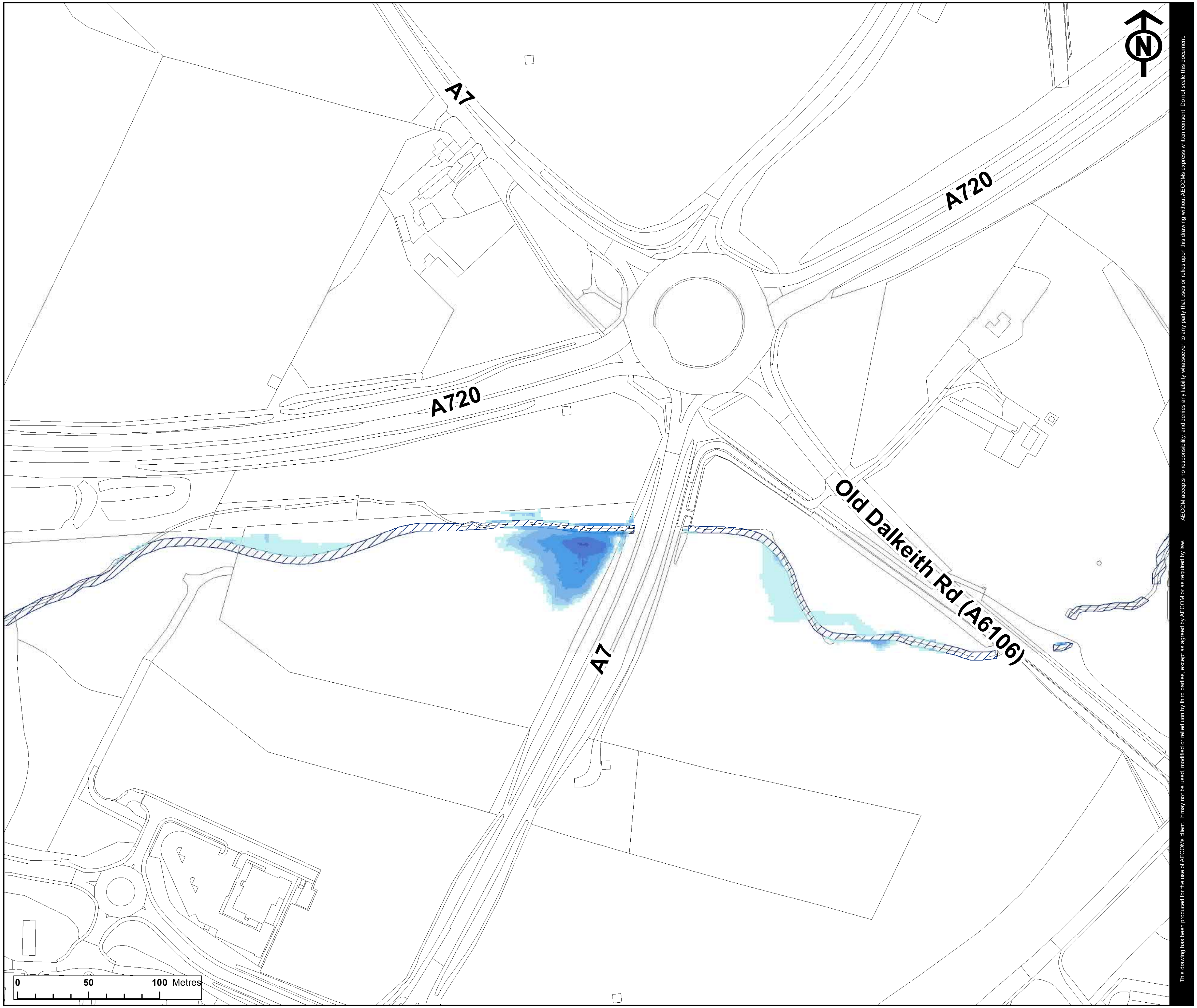
SHEET TITLE

Figure 16: 1 in 200yr + CC Baseline Flood Extent

SHEET NUMBER

16 of 16

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction
Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 30yr with mitigation

Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 0.84
- ▨ Realigned channel

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

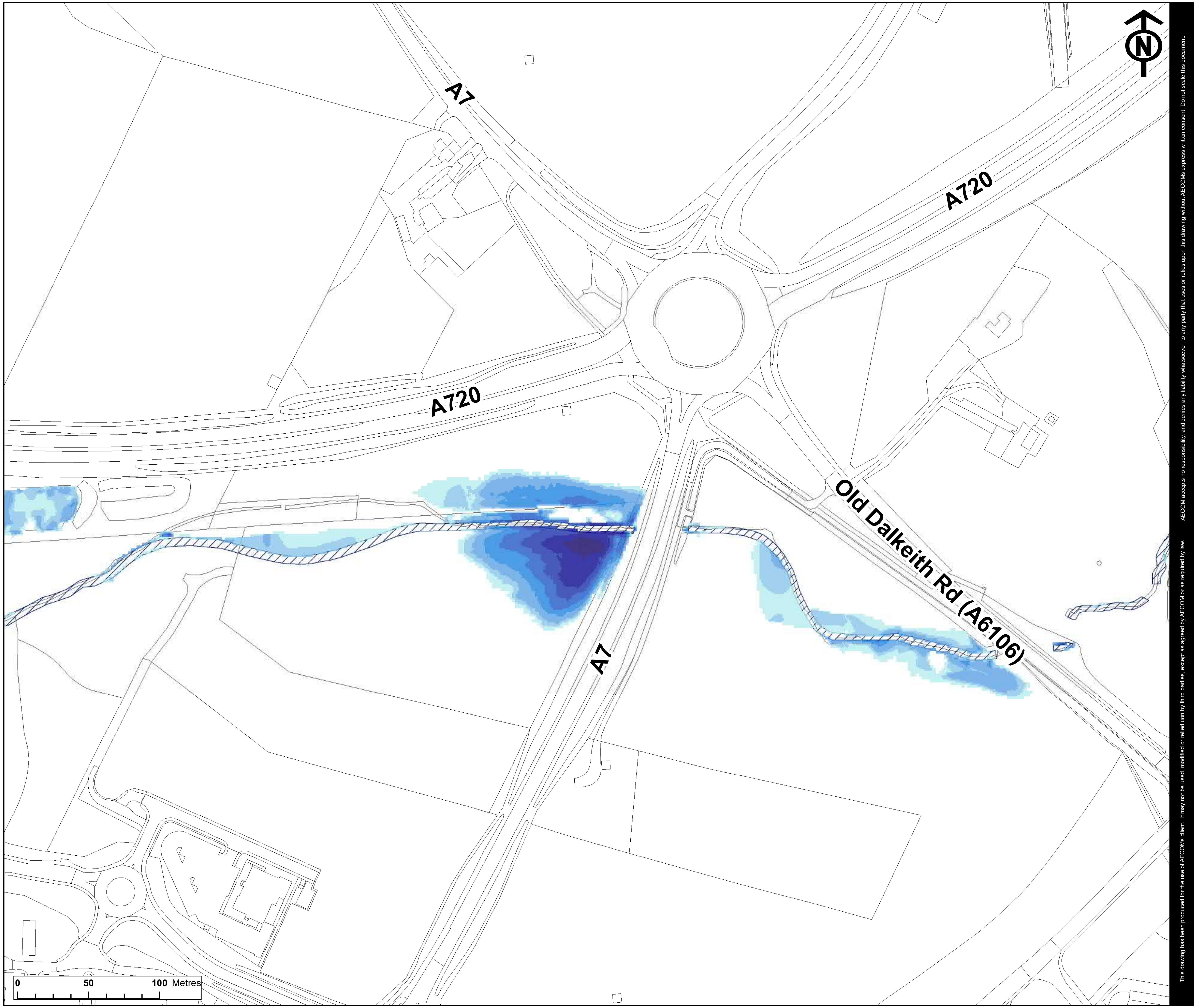
SHEET TITLE

Figure 17: 1 in 30yr with Mitgation
Flood Extent

SHEET NUMBER

1 of 2

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction
Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

1 in 200yr with mitigation

Depth (m)

🟦	0 - 0.1
🟦	0.1 - 0.2
🟦	0.2 - 0.4
🟦	0.4 - 0.6
🟦	0.6 - 0.8
🟦	0.8 - 1.0
🟦	1.0 - 1.2
🟪	1.2 - 1.4
🟪	1.4 - 1.41
▨	Realigned channel

Scale @ A3 - 1:2,500

PROJECT NUMBER

60572241

SHEET TITLE

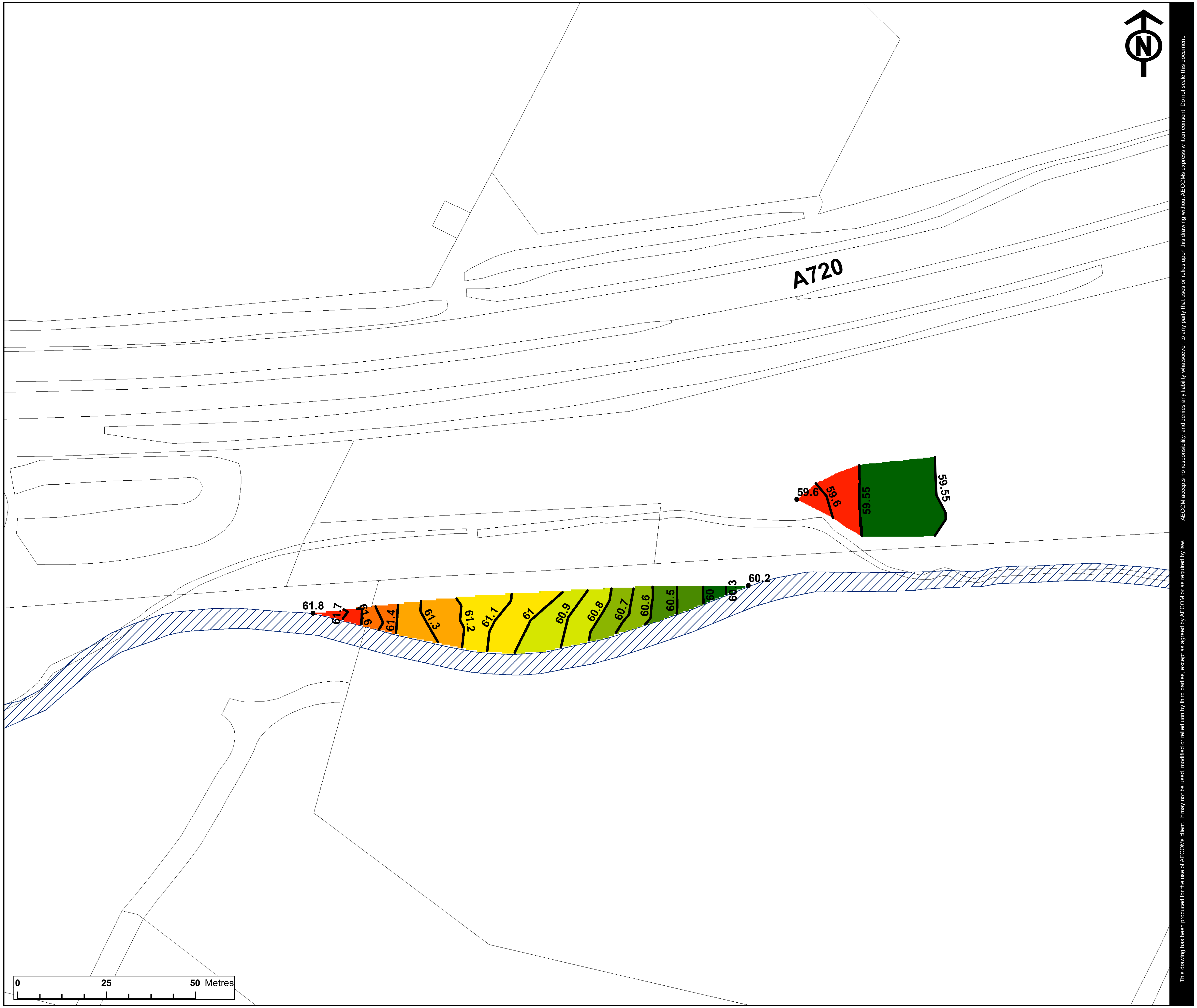
Figure 18: 1 in 200yr with mitigation
Flood Extent

SHEET NUMBER

2 of 2

Appendix F – Land re-profiling – compensatory storage

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH



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PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

▨ Realigned channel

* slopes leading up from the compensatory storage areas to existing ground levels should be designed at a suitable gradient

Scale @ A3 - 1:1,000

PROJECT NUMBER

60572241

SHEET TITLE

Figure 19: Compensatory storage provision

SHEET NUMBER

1 of 2

Project Management Initials: ZM Designer: MH Checked: HH Approved: DH

AECOM

PROJECT

A720 Sheriffhall Junction Improvement

CLIENT

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

KEY:

▨ Realigned channel

* slopes leading up from the compensatory storage areas to existing ground levels should be designed at a suitable gradient

Scale @ A3 - 1:500

PROJECT NUMBER

60572241

SHEET TITLE

Figure 20: Compensatory storage provision

SHEET NUMBER

2 of 2

Appendix G – SEPA checklist

Flood Risk Assessment (FRA) Checklist

(SS-NFR-F-001 - Version 13 - Last updated 15/04/2015

This document should be attached within the front cover of any flood risk assessments issued to Local Planning Authorities (LPA) in support of a development proposal which may be at risk of flooding. The document will take only a few minutes to complete and will assist SEPA in reviewing FRAs, when consulted by LPAs. This document should not be a substitute for a FRA.

Development Proposal

Site Name		Sheriffhall Junction Improvement				
Grid Reference	Easting:	331803	Northing:	667984		
Local Authority		Midlothian Council				
Planning Reference number (if known)						
Nature of the development		Infrastructure	If residential, state type:			
Size of the development site		25	Ha			
Identified Flood Risk	Source:	Fluvial	Source name:	Dean Burn		

Supporting Information

Have clear maps / plans been provided within the FRA (including topographic and flood inundation plans)		Yes				
Has a historic flood search been undertaken?		Yes				
Is a formal flood prevention scheme present?		No	If known, state the standard of protection offered			
Current / historical site use		partially greenfield, partially existing infrastructure				

Hydrology

Area of catchment		6.19	km^2			
Qmed estimate		1.41	m^3/s	Method:	Catchment Descriptors	
Estimate of 200 year design flood flow		4.69	m^3/s			
Estimation method(s) used *		Rainfall-runoff	If other (please specify methodology used):	statistical undertaken too		
			If Pooled analysis have group details been included	Yes		

Hydraulics

Hydraulic modelling method		Linked 1D 2D	Software used:	TuFlow		
If other please specify		Flood modeller/Tuflow				
Modelled reach length		1600	m			
Any structures within the modelled length?		Combination	Specify, if combination	bridges and culverts		
Brief summary of sensitivity tests, and range:						
variation on flow (%)		10+200yr - +40	%			
variation on channel roughness		10 +200yr - +40				
blockage of structure (range of % blocked)		50 - 3 scenarios	%	Reference CIRIA culvert design guide R168, section 8.4		
boundary conditions:		**Upstream**		**Downstream**		
(1) type		Flow		Normal depth		
	Specify if other		Specify if other			
(2) does it influence water levels at the site?		Yes		No		
Has model been calibrated (gauge data / flood records)?		No				
Is the hydraulic model available to SEPA?		Yes				
Design flood levels	200 year	N/A	m AOD	200 year plus climate change	N/A	m AOD

Flood Risk Assessment (FRA) Checklist

(SS-NFR-F-001 - Version 13 - Last updated 15/04/2015)

Coastal

Estimate of 200 year design flood level			m AOD			
Estimation method(s) used		Select from List	If other (please specify methodology used):			
Allowance for climate change (m)			m			
Allowance for wave action etc (m)			m			
Overall design flood level			m AOD			

Development

Is any of the site within the functional floodplain? (refer to SPP para 255)		Yes		If yes, what is the net loss of storage	389	m^3
Is the site brownfield or greenfield		Greenfield				
Freeboard on design water level (m)		N/A	m			
Is the development for essential civil infrastructure or vulnerable groups?		Select from List		If yes, has consideration been given to 1000 year design flood?	Select from List	
Is safe / dry access and egress available?		Vehicular and Pedestrian		Min access/egress level		m AOD
If there is no dry access, what return period is dry access available?			years			
If there is no dry access, what is the impact on the access routes?	Max Flood Depth @ 200 year event:		m	Max Flood Velocity:		m/s
Design levels	Ground level	N/A	m AOD	Min FFL:	N/A	mAOD

Mitigation

Can development be designed to avoid all areas at risk of flooding?	No
Is mitigation proposed?	Yes
If yes, is compenstory storage necessary?	Yes
Demonstration of compensatory storage on a "like for like" basis?	Yes
Should water resistant materials and forms of construction be used?	No

Comments

Any additional comments:	compensatory storage has been demonstrated using like for like where applicable. Modelling has also been used to demonstrate volume provision at channel diversions and loss of flow pathways

Approved by:
Organisation:
Date:

Note: Further details and guidance is provided in 'Technical Flood Risk Guidance for Stakeholders' which can be accesssed here:- **CLICK HERE**

**** ReFH2 is now accepted by SEPA for flow estimates in Scotland. Any use of this method should be compared with other accepted methods.***

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Appendix 11.5 – Hydrogeological Assessment Technical Note

A720 Sheriffhall Junction Improvement

Hydrogeological Assessment

Transport Scotland

60572241

11 July 2019

COMMERCIAL IN CONFIDENCE

Quality information

Prepared by	Checked by	Approved by
Rachel Pugh Graduate Hydrogeologist	Philip Smart Technical Director (Hydrogeology)	Neil Mackenzie Technical Director

Revision History

Revision	Revision date	Details	Authorized	Name	Position
0	28.03.2019	Draft		Rachel Pugh	Graduate Hydrogeologist
1.1	11.07.2019	Updated with audit comments		Rachel Pugh	Graduate Hydrogeologist

1. Introduction

This hydrogeological assessment has been prepared to accompany Chapter 11 – Road Drainage and Water Environment of this ES., however reference is also made to this assessment in Chapter16 – Geology and Soils.

2. Baseline Conditions

2.1 Geology

The geology of the area comprises made ground overlying superficial deposits of variable thickness, which overlie the Carboniferous Coal Measures. The superficial geology in the area is composed predominantly of glacial till comprising of sandy gravelly clay with occasional cobbles and boulders, and glaciofluvial deposits comprising of sand and gravel with varying proportions of clay and silt. The glaciofluvial deposits have been identified from ground investigation works at the site to lie extensively under the existing Sheriffhall roundabout. Significant deposits of boulder clay (glacial till) have also been identified during site investigation. The superficial deposits have been shown to vary in thickness between approximately 1m and 24m, with an average thickness of approximately 11.1m. The superficial deposits are typically thickest in the southern part of the area. They have been identified to a maximum depth of approximately 31mAOD. Across the majority of the area, the superficial deposits are overlain by significant deposits of made ground, up to 7m thick, which have been identified during ground investigations at the site.

The underlying bedrock geology comprises of rocks belonging to the Scottish Middle Coal Measures in the north and Lower Coal Measures in the south of the area, both members of the Carboniferous Coal Measures Formation. This formation typically comprises of cyclical deposits of sandstone, siltstone and mudstone, in addition to bands of coal often in excess of 0.3m thick. From ground investigation works at the site, the top of the bedrock has been identified at between approximately 31mAOD and 63mAOD, varying between 1m and 30m below ground level. Based on the BGS sheet, it is inferred that the Carboniferous bedrock dips towards the north-east, with the surface of the bedrock typically shown to be shallowest in the west of the area and deepest towards the north-east. A number of coal seams are recorded to outcrop within the local area and due to their shallow depth, many have been extensively worked. However during the ground investigations in the study area, coal was often recovered and only infrequently listed as a void on driller's logs.

The ground in the vicinity of the proposed development has been significantly faulted, most notably by the east – west trending Sheriffhall Fault which passes through the centre of the area, which downthrows strata to the north by approximately 175m. Several additional minor faults have also been recorded within the area, including another south-east to north-west trending fault approximately 450m to the east of the proposed development

A detailed assessment of the geology is discussed in the full A720 Sheriffhall Junction Improvement Environmental Statement.

2.2 Hydrogeological Characterisation

The Coal Measures are classified by the Scottish Environmental Protection Agency (SEPA) as the 'Dalkeith Bedrock' groundwater body. The strata are further classified by SEPA as being moderately permeable, with variable permeability and thickness of overlying superficial deposits. The BGS (British Geological Survey) classifies the bedrock in the area as a moderately productive aquifer, in which flow is virtually all through fractures and other discontinuities. Within both the Middle and Lower Coal Measures, it is likely that the sandstone strata are the main water bearing units. The mudstones, siltstones and coals typically act as low permeability barriers to flow, confining the groundwater in underlying sandstone units where the bands are laterally continuous. Groundwater flow also takes place through fractures and fissures within the bedrock, which may have been enhanced following coal mining activities. The Dalkeith Bedrock groundwater body has an overall Water Framework Directive (WFD) status of Poor, due to the effects of extensive coal mining and the resultant degraded water quality. The water quantity and flow of the groundwater have a WFD status of Good. Whilst mine drainage through the former coal workings may be impacting on the hydrogeological conditions in the bedrock, it is understood that there are no active mine drainage schemes currently in operation in the area. Active pumping from the old coal workings ceased at the Monktonhall Colliery, approximately 2.1km north-east of the area in 2009.

Aquifer property data from the joint BGS and SEPA Groundwater Science Programme differentiates between Carboniferous sedimentary rocks that have been extensively mined for coal and those that have not. This is due to unmined coal seams acting as a low permeability layers and restricting flow between sandstone aquifer units, potentially forming a series of hydrogeologically discrete units. In contrast, mine voids, shafts and tunnels can artificially increase aquifer transmissivity and link previously separate flow systems laterally and vertically. Aquifer property data for Carboniferous sedimentary aquifers extensively mined for coal, estimate a wide transmissivity between 10-1000m^2/d and a specific capacity between 48-132m^3/d/m.

Glaciofluvial sand and gravel, and mixed deposits are classified as having a high productivity rating, with borehole supplies in excess of 10l/s, by the BGS. The BGS also assumes flow through all superficial deposits will be granular, though acknowledges that flow may occur in fractures in certain tills. The glaciofluvial deposits in the proposed development area typically have a high intergranular permeability in the sand and gravel units which facilitates groundwater flow. Falling head permeability tests completed in the superficial deposits in March 2019, calculated a permeability of 1.59x10^{-5}m/s for a sand and gravel deposit, and a permeability between 1.4x10^{-6} m/s and 6.0x10^{-8} m/s for clay deposits. Due to the variability of the lithology and the presence of low permeability clay-rich units including boulder clay (till) in these deposits, water bearing horizons may be discontinuous and perched aquifers may be encountered.

It is unlikely that there is a significant direct hydrogeological connection between the superficial aquifer and the bedrock due to the presence of low permeability (boulder) clay, siltstone and mudstone strata, all of which limit the vertical hydraulic connectivity through the aquifers. There is no obvious correlation in groundwater level fluctuations between those piezometers measuring the bedrock and those measuring the superficial deposits. There is no hydraulic continuity between groundwater in the superficial deposits and that in the bedrock, with the groundwater level in the Coal Measures being on average approximately 12m lower.

2.3 Groundwater Levels and Flow

Based on the results of groundwater level monitoring, it is considered that groundwater flow in the superficial deposits is approximately east/north-east towards local surface water features, which are assumed to be in hydraulic continuity with groundwater in the superficial deposits. Groundwater in the superficial deposits provides baseflow discharge to the watercourses. It is known from the Borders Railway construction that the ground conditions in the vicinity of Sheriffhall comprised sands with a high groundwater level, which resulted in ‘running sands’ in the cutting excavation.

Groundwater flow in the bedrock is likely to be approximately down-dip towards the north-east. Historic mine workings, water treatment and dewatering operations in the former coal workings are likely to have significantly disrupted the bedrock hydrogeological conditions and the natural direction of groundwater flow. Information from the Coal Authority has shown that the groundwater level in the former workings has rebounded in this area from approximately 20mAOD in 2012, to 40m to 46mAOD currently.

Groundwater level monitoring was initially completed in 107 piezometers, installed as part of the ground investigation works at the site between July 2018 and February 2019. Subsequently an additional 15 piezometers were installed, in which groundwater level monitoring was completed between April 2019 and May 2019. Analysis has been undertaken of all the available groundwater level monitoring data. Typically, the maximum groundwater level recorded in each piezometer has been used for assessment. The full set of monitoring results is provided in the A720 Sheriffhall Junction Improvement Environmental Statement Appendices.

17 of the piezometers installed as part of the ground investigation phase of works, monitor the groundwater levels in the Coal Measures strata. Water levels were monitored in a number of units in the Coal Measures, and the monitored groundwater level ranges from approximately 18mAOD to 61mAOD. Seven of these piezometers, six of which are located adjacent to the existing roundabout, were recorded as dry on each monitoring occasion, with the lowest levels below 42.1m AOD. The majority of these boreholes are located in the centre of the study area, in line with the existing A720 bypass and roundabout. Groundwater levels in the Coal Measures to the south of the Sheriffhall Fault indicate a maximum groundwater level of approximately 47mAOD. The recorded groundwater level varies between 16.2m and 21.3m below ground. It is likely that previously worked coal seams below this level are flooded. Maximum monitored groundwater levels in the Coal Measures to the north of the Sheriffhall Fault are more variable. This includes the highest recorded water level in the Coal Measures at 56.09mAOD, 3.92m below ground level. This was recorded in the deep piezometer installed in borehole BH17, monitoring a zone of medium strong, grey fine grained sandstone from 48mAOD to 49mAOD, above the coal seams. BH17 is situated adjacent to the westbound carriageway of the A720, approximately 100m from the centre of the existing roundabout. Water levels in the Coal Measures in boreholes BH28-M and BH26-M, to the north-east of the site and east of the Sheriffhall Fault, were considerably lower at 27.36mAOD and 28.67mAOD respectively. These boreholes however monitor lower strata at approximately 18mAOD and 27mAOD. Information received from the Coal Authority shows that recent groundwater levels in the former coal workings are in the range 40m to 46m AOD.

Across the area groundwater conditions in the bedrock are typically confined, with an average maximum pressure head of 5.38m. Notably borehole BH17 recorded a maximum groundwater level approximately 6.1m above the top of the bedrock, into the superficial deposits. During the eight month period of monitoring, the average groundwater level fluctuation was 0.96m and the maximum groundwater level fluctuation was 1.81m. Figure 1 shows the groundwater levels recorded in the bedrock. Based on the groundwater levels in Figure 1, the groundwater flow direction in the bedrock is inferred to be approximately east/north-east. It is unclear as to whether the Sheriffhall Fault has a major impact on the groundwater flow in the Coal Measures.

94 of the piezometers installed as part of the ground investigation phase of works, monitor the groundwater level in the superficial deposits, of these 27 piezometers were recorded as dry on each monitoring occasion. The majority of the dry boreholes were monitoring clay-rich strata or shallow (<5mbgl) sand and gravel deposits. The highest recorded water level during the period of monitoring was 68.62mAOD. This was recorded in the piezometer installed in borehole BH73. BH73 is situated adjacent to the A7, approximately 450m from the centre of the proposed development and facilitates monitoring of the sand and gravel. During the initial eight month period of monitoring, the average groundwater level fluctuation was 0.56m and the maximum groundwater level fluctuation was 2.97m. The minimum monitored depth to water table varied between 0.04mbgl (59.95m AOD) in Borehole BH65 (located in the south of the area), and 11.16mbgl (50.35m AOD) in Borehole BH82 (located adjacent to the southern portion of the existing roundabout). Figure 2 shows the groundwater levels recorded in the superficial deposits. Typically the water levels are highest in the south and west of the area, and lowest in the north-east of the area. This indicates an approximate east/north-east flow direction. However due to the variability of the superficial deposits, groundwater is likely to be present in discrete pockets of granular deposits and may not be vertically or laterally continuous.

Five of the piezometers installed as part of the ground investigation phase of works, monitor the groundwater level in the made ground. The maximum recorded water levels vary between 67.08mAOD (5.30m below ground) to the west of the study area and 51.32mAOD (1.50m below ground) to the north-east of the study area. Figure 3 shows the groundwater levels recorded in the made ground.

The remaining 6 piezometers installed as part of the groundwater investigation phase of the works, are screened against both the bedrock and overlying superficial deposits. One of these piezometers were recorded as dry on each monitoring occasion, with levels below approximately 48mAOD. The remaining six piezometers had a maximum recorded water level between 36.14mAOD and 59.86mAOD. As these boreholes facilitate monitoring of both the bedrock and the superficial deposits, the relevance of these levels is unclear.

2.4 Groundwater Quality

Groundwater associated with historic mining activity in the area tends to be poor quality with a low pH and elevated sulphate, iron and fluoride concentrations. The Dalkeith Bedrock groundwater body has an overall WFD status of Poor, due to the extensive former coal mining works and resultant degraded water quality.

In-situ groundwater quality monitoring was completed in June 2018 on samples from Boreholes BH05-M, BH26-M, BH28-M, BH41-M, BH45-M, BH55-M, BH59-M and BH80-M in the bedrock, and Boreholes BH28A, BH29, BH40, BH50, BH62-M, BH70A, BH74, BH76 in the superficial deposits. This included observations for LNAPL and DNAPL presence, turbidity, redox potential (ORP), dissolved oxygen, electrical conductivity (EC), temperature and pH. None of the samples indicated the presence of LNAPLs or DNAPLs. The pH ranged from 6.26 to 7.94 in the bedrock and from 6.66 to 7.76 in the superficial deposits. The average EC recorded in the bedrock was 953µs/cm. The average EC recorded in the superficial deposits was 1060µs/cm.

Additional in-situ groundwater quality monitoring was completed in May 2019 on samples from Borehole BH89, BH90, BH91, BH93 and BH110 in the superficial deposits. No LNAPLs or DNAPLS were detected. The pH ranged from 6.39-7.93.

It is understood that no further groundwater quality monitoring, including of groundwater in the made ground, has been undertaken.

2.5 Groundwater Abstractions

There are six BGS registered water wells within 2km of the study area. Three of these exploit the Coal Measures formation and have depths between approximately 103m and 122m. Details for the remaining three boreholes are not available. The presence of a BGS well record is not indicative of an active groundwater abstraction. Information provided by the Midlothian Council Environmental Health Officer indicated that there are no private water supplies in the vicinity of the proposed works.

2.6 Groundwater Surface Water Interactions

A small watercourse, Dean Burn, runs to the south and east of the study area flowing north-east towards the River North Esk. It is located at its closest point approximately 100m south of the existing A720. The water quality appears to be poor, with iron rich deposits on the bed of the Burn and cloudy water noted at the time of the site visits. It has been reported that historically an outflow from a constructed wetland used to treat contaminated drainage from Gilmerton Coal Bing, located approximately 1.9km west of the roundabout and to the north of the A720, also entered the Dean Burn. It is understood that the Bing has now been removed and replaced by a scrap yard. There is also an outfall into the Dean Burn from an old sewage treatment works located to the south side of the Dean Burn, approximately 800m west of the roundabout.

The River North Esk runs to the south and east of the study area, flowing north-east towards the confluence with the River South Esk. It is located at its closest point approximately 900m south of the existing roundabout. The River North Esk has a Poor WFD status. The River South Esk runs approximately 2km to the east of the area and also flows north towards the confluence with the River North Esk. The confluence of the River South Esk and River North Esk is approximately 2.4km north east of the site. Two SEPA flow monitoring stations are located on the River North Esk (NT332675) and River South Esk (NT338677), approximately 1.45km and 2km east of the area respectively. As superficial glacial deposits have an extensive coverage in the wider area, it is likely the watercourses are in hydraulic continuity with the superficial deposits.

There is a small pond located approximately 430m west of the Sheriffhall Roundabout, immediately to the south of the A720 embankment. The pond is recorded as approximately 110m long and 50m wide. Review of the available information has identified the pond has been formed post construction of the A720. This is a private pond whose primary purpose is supply water via an underground pipe to the agricultural fields to the north of the A720. There is presence of small hides which are utilised for shooting activities. The pond is supplied by water directly from the Dean Burn. There are inlet and outlet metal pipes were identified during a site walkover in 2018.

The nearest mapped springs according to the Scottish Wetland Inventory are approximately 3.6km south-west of the area. No mine discharges in the vicinity of the existing roundabout have been identified. There is also a mine water treatment scheme at Monktonhall, approximately 2.1km north-east of the study area.

There is one Site of Special Scientific Interest (SSSI) located in proximity to the study area. Dalkeith Oakwood is an ancient relict oak woodland located within the Dalkeith Country Estate, approximately 1.8km north east of the project site. The SSSI is not water dependant. There are no RAMSAR sites, designated wetlands or local nature reserves within 2km.

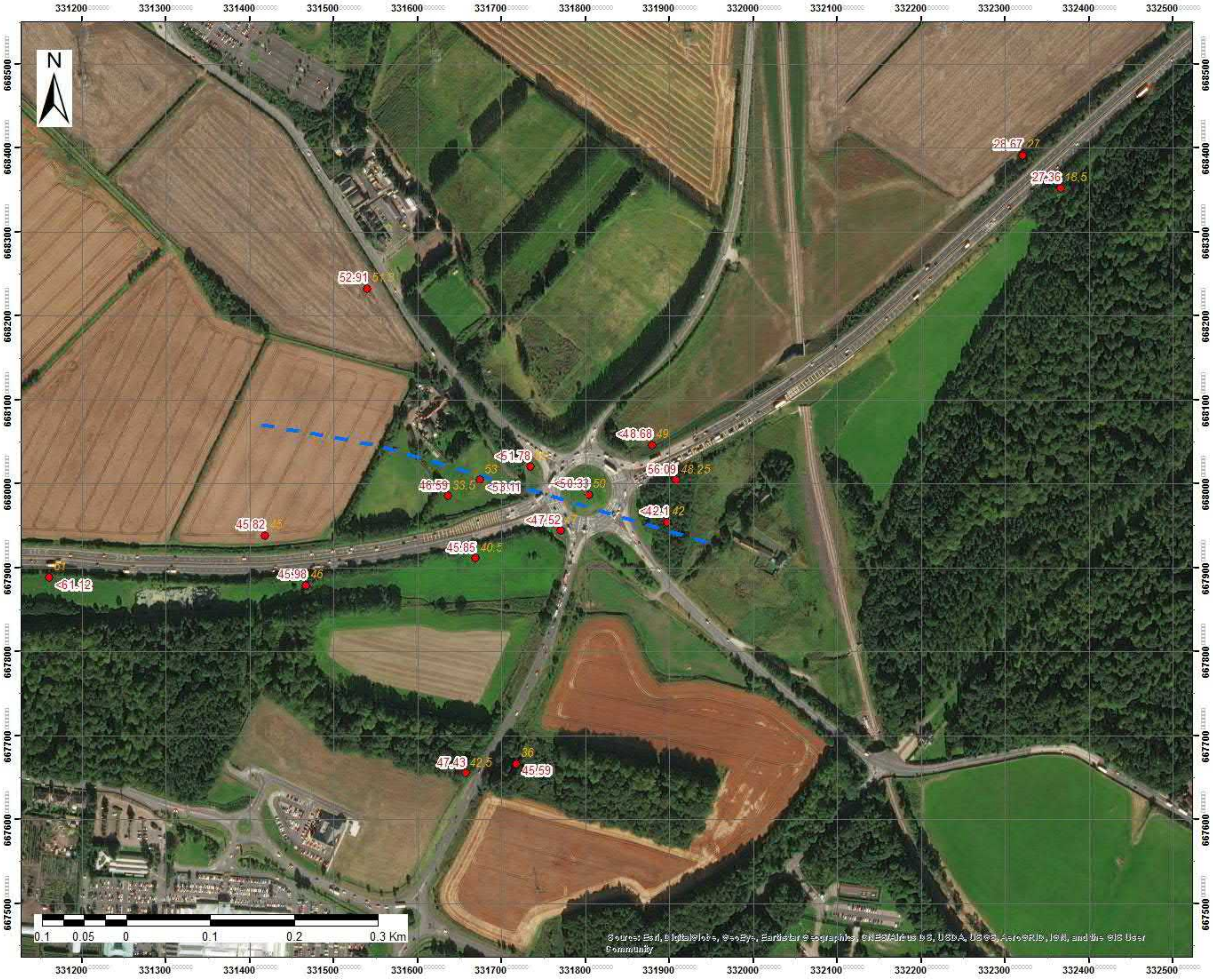
2.7 Historic Mine Workings

The Sheriffhall area has been subjected to extensive underground coal mining. Local mining activities have been identified in the vicinity of the area, from data sourced from the Coal Authority's Coal Mining Report and the BGS Environmental Geology Map. These indicate a total of 40 mine entries within the immediate vicinity of the site, 16 of which are considered to be directly affected by the proposed scheme and thus pose a risk to surface stability. There also remains potential for unrecorded mine entries.

Available mine plans relating to the site have been reviewed and confirmed the presence of workings beneath the site in eleven coal seams (from shallowest to deepest): the Diamond, Musselburgh Jewel, Little Splint, Cowpits Five Foot, Salters (Whitehall Rough), Nine Foot (Whitehill Splint), Fifteen Foot (combined Pinkie Three Foot and Six Foot), Six Foot (Whitehall Jewel), Great Seam, Stairhead and Parrot Seam. These dip approximately north-east towards the River Esk, downstream of the confluence between the River North Esk and River South Esk. It is understood from ground investigation that these workings have largely collapsed. There are no identified adits in the mine working areas proposed for grouting treatment as part of the construction works.

There is a mine water treatment scheme at Monktonhall, approximately 2.1km north-east of the study area. Correspondence with the Coal Authority indicates that there are several proposed mine water treatment sites in the vicinity of the study area. Their proposed locations are approximately 0.9km south, 2.0km south-east and 3.1km south-east of the study area.

There are currently no active local groundwater/mine water control operations reported by the Coal Authority. Groundwater pumping at Monktonhall ceased in 2009.



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LEGEND

● Maximum Bedrock Water Level (mAOD)

● *Upper Monitored Section (mAOD)*

▬ ▬ Approximate Location of Sheriffhall Fault

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Purpose of Issue

TECHNICAL NOTE

Project Title

HYDROGEOLOGICAL ASSESSMENT FOR A720 SHERIFFHALL JUNCTION IMPROVEMENT

Drawing Title

MAXIMUM MONITORED GROUNDWATER LEVELS IN THE BEDROCK

Drawn	Checked	Approved	Date
RP	PS	PS	03/07/2019

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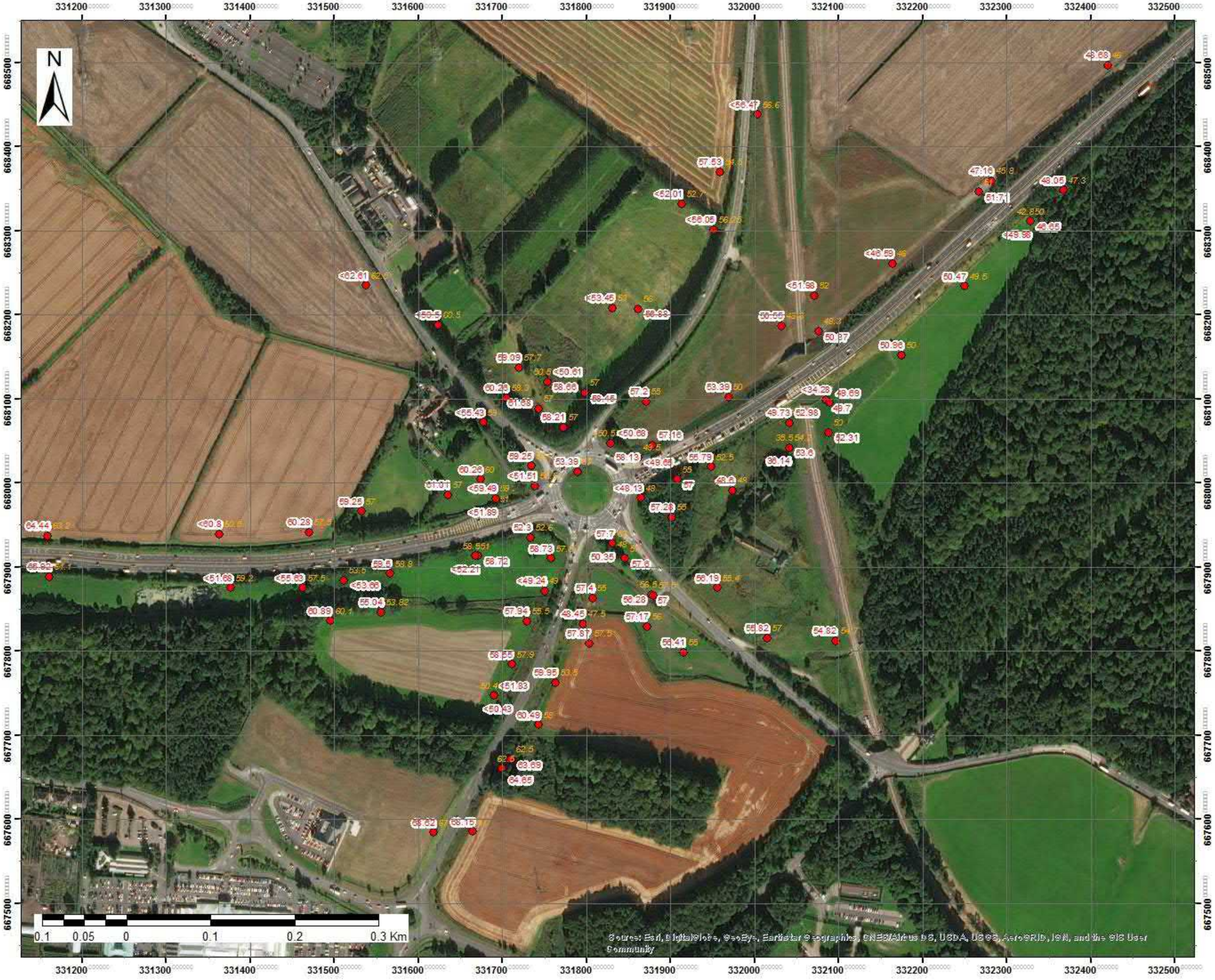
FIGURE 1	1



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LEGEND

● Maximum Groundwater Level Superficial Deposits (mAOD)

● *Upper Monitored Section (mAOD)*

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Purpose of Issue

TECHNICAL NOTE

Project Title

HYDROGEOLOGICAL ASSESSMENT FOR A720 SHERIFFHALL JUNCTION IMPROVEMENT

Drawing Title

MAXIMUM MONITORED GROUNDWATER LEVELS IN THE SUPERFICIAL DEPOSITS

Drawn	Checked	Approved	Date
RP	PS	PS	08/07/2019

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LEGEND

● Maximum Made Ground Water Level (mAOD)

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Purpose of Issue
TECHNICAL NOTE

Project Title
HYDROGEOLOGICAL ASSESSMENT FOR A720 SHERIFFHALL JUNCTION IMPROVEMENT

Drawing Title
MAXIMUM MONITORED GROUNDWATER LEVELS IN THE MADE GROUND

Drawn	Checked	Approved	Date
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FIGURE 3

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3. Assessment of Potential Impacts

3.1 Introduction

The proposed scheme has potential to cause adverse impacts on the groundwater conditions, both in respect to groundwater flow and groundwater quality. Adverse impacts on the groundwater system could also result in associated impacts on local surface water features. The assessment has been split into two phases; construction which is expected to last from 2022 to 2024, and operation thereafter. An assessment of impacts has been completed for each phase. In order to assess the potential impacts of the project on the hydrogeological conditions, a conceptual hydrogeological model of the project site has been prepared. The conceptual model forms the basis of a qualitative risk assessment of the potential impacts of the construction and operation of the project on groundwater flow and quality.

3.2 Conceptual Hydrogeological Model

Based on the assessment of the baseline information on geology, aquifer properties and groundwater levels, an initial conceptual hydrogeological model has been developed for the area. A summary is given below.

- The local geology consists of superficial deposits of variable thickness, up to approximately 30m, comprising glacial sand, gravel, silt and clay (till) in varying proportions.
- Underlying the superficial deposits is the Carboniferous Coal Measures Formation, comprising the Scottish Middle Coal Measures Formation to the north and the Scottish Lower Coal Measures Formation to the south. These are both comprised of cyclical deposits of sandstone, siltstone and mudstone and coal. The strata dip approximately to the north-east.
- The area is significantly faulted, most notably by the east - west trending Sheriffhall Fault which passes through the centre of the study area. It is estimated to down throw strata by approximately 175m, terminating many of the identified shallow coal seams on the western side of the fault.
- The area has been extensively mined and several mine entries have been identified in the vicinity of the project area. It is understood that where present, the coal seam workings have largely collapsed underneath the project site.
- Groundwater levels have been monitored in the superficial deposits. Some monitored boreholes were recorded as dry on all monitoring occasions. Maximum recorded groundwater levels varied between 46.65mAOD and 68.62mAOD. Due to the heterogeneity of the glacial deposits and the abundance of clay in the sequence, there may not be lateral or vertical hydraulic continuity within the superficial deposits.
- It is inferred that groundwater flow in the superficial deposits is generally to the east-north-east towards local surface water features, which are assumed to be in hydraulic continuity with groundwater in the superficial deposits.
- Areas of made ground are also present at the site. Groundwater is present in the made ground.
- Groundwater levels have been monitored in the bedrock formation. Within both the Middle and Lower Coal Measures, the sandstone units form the main water bearing units. The mudstones, siltstones and coal strata typically act as low permeability barriers to flow, confining the groundwater in the sandstones where the lower permeability bands are laterally continuous. Flow will also occur through fractures and fissures within the bedrock. Where the coal seams have been worked, any remaining voids will be flooded where they are below the water table and in hydraulic continuity with the sandstone strata.
- Monitored groundwater levels to the south of the Sheriffhall Fault indicate a maximum groundwater level of approximately 47mAOD, with a typical maximum water level between 45mAOD and 47mAOD. Maximum monitored groundwater levels to the east of the fault are more variable, ranging from 27.36mAOD to 56.09mAOD. Over 40% of the monitored boreholes were recorded as dry to levels of less than 42.1mAOD on all monitoring occasions; these boreholes are typically located around the centre of the project site.
- Across the study area, bedrock groundwater conditions are typically confined, with an average maximum pressure head of 5.38m. Borehole BH17 showed a pressure head of 6.1m above the top of the bedrock into the superficial deposits.

- Groundwater flow in the bedrock can be very approximately assumed to be in the direction of dip, to the east-north-east. Localised faulting may act as a barrier to groundwater flow. Bedrock groundwater discharge points have not been explicitly identified in the vicinity of the site.
- It is unlikely that there is significant hydrogeological connection between the superficial aquifer and the bedrock due to the presence of (boulder) clay, siltstone and mudstone strata which limits vertical hydraulic connectivity between both aquifers. This is confirmed by the significant difference in the groundwater level in the superficial deposits and those in the bedrock.

3.3 Receptor Assessment

3.3.1 Introduction

The methodology adopted for the hydrogeological impact assessment has been based on the source-pathway-receptor approach. For there to be an identifiable impact, there must be a source i.e. a contaminant or an activity; a receptor; and, a pathway, which allows the source to impact on a receptor. All three elements must be present before a plausible linkage and a potential impact can be realised.

Key groundwater receptors have been identified and assessed based on their perceived sensitivity, the magnitude of the potential impacts and the significance of the effects in line with the DMRB Volume 11, Section 2 ‘Assessment and Management of Environmental Effects’. Effects of minor and negligible significance are considered acceptable. For those impacts of moderate or high significance, a detailed assessment has been carried out and the need for mitigation measures addressed. When assessing the importance of each receptor the criteria and examples outlined in Table 3-1 have been followed.

Table 3-1 Estimating the Sensitivity of the Water Environment

Importance	Criteria	Typical Examples
Very High	Very high importance and rarity, international scale and very limited potential for substitution	**Surface Water:** EC Designated Salmonid/Cyprinid fishery; WFD Class ‘High’; Site protected/designated under EC or UK habitat legislation (SAC, SPA, ASSI, RAMSAR site, salmonid water) / Species protected by EC legislation. **Groundwater:** Principal aquifer providing a regionally important resource or supporting a site protected under EC and UK habitat legislation. Important groundwater abstraction within impact area. Very good water quality.
High	High importance and rarity, national scale and limited potential for substitution	**Surface Water:** WFD Class ‘Good’; Major Cyprinid Fishery; Species protected under EC or UK habitat legislation. **Groundwater:** Principal aquifer providing locally important resource or supporting river ecosystem. Good water quality.
Medium	High or medium importance and rarity, regional scale, limited potential for substitution	**Surface Water:** WFD Class ‘Moderate’. **Groundwater:** Aquifer providing water for agricultural or industrial use with limited connection to surface water. Poor to good water quality.
Low	Low or medium importance and rarity, local scale	**Surface Water:** WFD Class ‘Poor/Bad’. **Groundwater:** Unproductive strata. Poor water quality where present.
No Change	Very low importance and rarity, local scale.	**Surface Water:**

WFD Class 'Poor'/unspecified

3.3.2 Superficial Aquifers

Superficial glacial till and glaciofluvial deposits underlie the proposed scheme. It is assumed that the deposits are in hydraulic continuity with the nearby surface water features. There are no known abstractions from the superficial deposits in the study area. The superficial aquifer is considered to be of Medium importance.

3.3.3 Bedrock Aquifers

The Scottish Middle and Lower Coal Measures, known as the Dalkeith Bedrock Aquifer, underlie the proposed scheme. There are no known abstractions from this aquifer in the area. The Dalkeith Bedrock groundwater body is classified under the WFD. It has a current status of Poor, due to legacy mining activities negatively impacting on groundwater quality. However the quantity and flow of the groundwater have a WFD status of Good. The Dalkeith bedrock aquifer is therefore considered to be of Medium importance.

3.3.4 Surface Water Features

It is assumed that local surface water features including the small pond, Dean Burn, River North Esk and River South Esk, are in hydraulic continuity with the superficial glacial deposits. The surface water features in the area are considered to be of Medium importance.

3.3.5 Designated and Non-Designated Sites

Dalkeith Oakwood SSSI is situated approximately 1.8km north-east of the study area. It is considered to be of High importance. The woodland is not assessed as groundwater dependant and is located a significant distance from the proposed works. It has therefore ben discounted from further discussion as the proposed scheme is assessed as having no impact.

3.4 Construction Phase

3.4.1 Discussion

Impacts on the groundwater environment are likely to be most pronounced during the construction phase, due to the high level of activity and opportunity for the release of contaminants and disruption of groundwater flow. The main elements of this stage of the project which potentially could impact on groundwater are associated with:

- Fuel and chemical storage and use;
- Storage of wastes (hazardous and non-hazardous);
- Discharge of surface runoff and dewatering water, potentially containing high levels of suspended solids;
- Filling of small pond by proposed earthworks;
- Realignment of Dean Burn;
- Construction of site investigation and dewatering boreholes, trenches and other excavations;
- Excavation below superficial groundwater level for construction of SuDS ponds and NMU routes;
- Ingress of confined groundwater from the Coal Measures, following excavation of confining superficial deposits;
- Piling, retaining wall foundations and other permanent below ground structures impacting on groundwater flow;
- Grouting of below ground structures including old mine workings;
- Dewatering of superficial deposits; and
- Dewatering of the bedrock aquifer in order to control confined groundwater pressures and minimise the risk of heave.

Impacts on groundwater quality in both the superficial and bedrock aquifers could result from spillages and leaks of fuels and chemicals from bulk storage, and vehicle and plant usage and the associated contaminated surface run-off. Existing mine shafts, and the construction of further ground investigation boreholes or excavations into the superficial or bedrock aquifer could create pathways for near-surface pollutants to reach the groundwater in the Coal Measures. The high water table makes groundwater in the superficial deposits especially susceptible to pollution, as the pathway length for a surface contaminant to reach groundwater generally is very short and hence minimises any potential for attenuation.

As discussed in the full A720 Sheriffhall Junction Improvement Environmental Statement there are five proposed SuDS ponds constructed to assist with road and NMU (Non-Motorised User) drainage from the project site and the development. The ponds are assumed to be lined and then drain under gravity to the local watercourses. Impacts to surface water quality may occur from possible contaminated site drainage water, in addition to construction activity at the small pond, Dean Burn and River North Esk. This could result in a deterioration of the groundwater quality in the superficial deposits, which are assumed to be in hydraulic continuity with the surface water system.

The discharge of surface run-off with a high concentration of suspended solids from site runoff but also from dewatering of excavations has the potential to impact on the quality of groundwater and surface water bodies.

The lowest point across all proposed infrastructure is approximately 57.1mAOD, on the NMU (Non-Motorised User) route. The lowest proposed level of the SuDS ponds is 55.1mAOD. This is a small NMU drainage pond located in the south-eastern part of the scheme. The nearest boreholes monitoring groundwater level in the superficial deposits are BH89 and BH90 located in the immediate vicinity of the proposed SuDS pond. These recorded a maximum groundwater level of 54.82mAOD and 55.82mAOD respectively. It is therefore possible that minimal groundwater dewatering of the superficial deposits will be required to facilitate construction activities including excavation and installation of the SuDS ponds and carriageways in this part of the site. Inadequate provision for the pre-treatment and disposal of extracted groundwater, which may have a high concentration of suspended solids, has the potential to impact on local surface water quality.

Piling is required in the proposed scheme of works for several structures. The piles are assumed to be of significant depth and will penetrate through the overlying superficial deposits and at least 6m into competent layers of the bedrock aquifer. A maximum bedrock groundwater level has been recorded at 56.09mAOD (approximately 6.1m above the top of the bedrock aquifer) in Borehole BH17. BH17 is situated adjacent to the westbound carriage way of the A720, approximately 100m from the centre of the study area. Where located below the bedrock water table, the piles will act as a low permeability barrier to groundwater flow and may cause change to groundwater levels, flow rates and flow directions. Providing that there is a reasonable thickness of aquifer below the base of the piles, impacts will be localised. The placement of grout in the piles may impact on groundwater quality, as there will be direct contact between the grout and the groundwater. Where the piles terminate above the bedrock groundwater level, there will be no impacts to bedrock groundwater flow and negligible impacts on bedrock groundwater quality. There may be localised impacts to superficial groundwater flow and quality.

Retaining walls and foundations for the NMU routes are only proposed to extend into the superficial deposits, potentially causing changes to superficial groundwater conditions but not affecting the groundwater conditions in the bedrock aquifer.

Permanent excavations are not expected to extend below the superficial deposits. Groundwater confined in the bedrock aquifer has been shown to have pressure heads of up to 6.1m into the superficial deposits. Excavation of the overlying superficial deposits may result in ground heave of excavations and uncontrolled groundwater inflow from the bedrock aquifer. Dewatering may therefore be required in order to control the confined water pressure in the bedrock aquifer. Inadequate provision for the pre-treatment and disposal of extracted groundwater, which may have a high concentration of suspended solids, has the potential to impact local water quality.

The proposed scheme of works details extensive grouting of the Coal Measures aquifer beneath the area in order to achieve ground stabilisation and remediate the significant historic shallow mining activity. The proposed extent of grouting activity is discussed in the full A720 Sheriffhall Junction Improvement Environmental Statement. The area of grout treatment includes a section approximately 325m in length and 100m wide under the eastern portion of the A720, and an extensive area under the current western portion of the Sheriffhall roundabout, approximately 1500m in length and up to 700m wide. Grouting in the shallower coal seams under both the central and eastern sections is proposed; including the Whitehall Upper, Whitehall Great, Whitehall Rough, Whitehall Split, Whitehall Parrot Rough and Whitehall Jewel, and Splint and Rough respectively. Monitored water levels in the bedrock predominantly represent groundwater within the sandstone units. Water levels within the coal seams have not been explicitly monitored. However it is expected that where these seams are below the groundwater level in the Coal Measures that they are in continuity with the groundwater and have a similar groundwater level.

The use of grout in mine working treatment, including these coal seams, or as part of other below ground structures, could impact temporarily the groundwater quality as a result of leaching from the cement slurry. This could result in a short-term release of contaminants, such as chromium, into the groundwater. Once the grout has cured, further contamination is unlikely. Displacement of groundwater from voids along the grouted coal seams will occur. It is likely that any groundwater within these seams is already of poor quality; however water quality within the coal seams has not been explicitly monitored.

Grouting also has the potential to disrupt and/or act as a barrier to local groundwater flow. It is understood from ground investigations that many of the coal workings have collapsed, reducing the potential volume of groundwater. However it is likely that the hydraulic conductivity of mining voids is significantly greater than that of the surrounding non-mined strata. Grouting will therefore remove or reduce the existing artificial flow paths through the worked seams, and could also block any fractures and fissures though which groundwater movement currently occurs. Any displaced groundwater will travel along alternative flow paths offering the least resistance in the bedrock. This may include adits and untreated workings, although no additional features have been identified outside the area targeted for treatment. This may lead to a diversion of groundwater flow either under or around the grouted zones. Typically groundwater would be expected to rise locally on the upstream side of the grouted areas and to be lower on the downstream side of the grouted areas. There is also the potential for contaminated groundwater to be mobilised towards local surface water features, such as the River North Esk or Dean Burn, or to the surface via grout treatment holes and untreated mine entrances. Groundwater in certain units within the Coal Measures has been monitored and shows high confined pressures.

3.4.2 Assessment of Superficial Aquifer

Groundwater levels in the superficial deposits have been monitored at a higher level than the proposed formation levels for the scheme and it is therefore assumed that the superficial deposits will require dewatering in order to enable construction. Impacts on groundwater flow are expected to be localised. The high water table also makes the superficial aquifer susceptible to contamination from surface activities during construction. Piling and excavations, associated with the scheme’s engineering works, also have the potential to impact on superficial groundwater flow locally.

The proposed scheme is considered to have a **Moderate magnitude impact** on the quality of the groundwater in the superficial deposits during construction due to surface potentially contaminative activities, such as the leakage and spillages of fuels and chemicals. This produces a **Moderate significance of effect** on the superficial groundwater quality during construction.

The proposed scheme is considered to have a **Minor magnitude impact** on the groundwater flow of the superficial aquifer during construction as impacts on groundwater flow are expected to be localised. This produces a **Slight significance of effect** on groundwater flow in the superficial deposits during construction.

3.4.3 Assessment of Bedrock Aquifer

The proposed scheme’s deep engineering works, specifically piling and the grouting of mine workings, have the potential to impact on both the quality and flow of groundwater in the Coal Measures aquifer. Impacts on groundwater flow are expected to be localised compared to the overall aquifer extent. Contamination of bedrock groundwater from surface activities is also possible via pathways from mine workings. Excavation of the bedrock aquifer is not expected to be required.

The proposed scheme is considered to have a **Minor magnitude impact** on the groundwater quality of the Coal Measures aquifer during construction. This produces a **Slight significance of effect** on the quality of the groundwater in the bedrock during construction.

The proposed scheme generally is considered to have a **Minor magnitude impact** on groundwater flow in the Coal Measures aquifer during construction, but locally in the vicinity of the grouting works, impacts are considered **Moderate**. Overall, this produces a **Slight significance of effect** on the groundwater flow in the bedrock during construction.

3.4.4 Assessment of Surface Water Bodies

Surface run-off and site drainage during construction may result in degradation of surface water quality. Temporary dewatering of the superficial deposits and possibly the Coal Measures may result in changes to groundwater/surface water interactions and a deterioration in surface water quality. Mobilisation and discharge of contaminated groundwater in the Coal Measures aquifer, as a result of the piling and grouting operations, may impact on the quality and flow of surface water bodies.

The proposed scheme is assessed as having a **Minor magnitude impact** on the surface water bodies in the area during construction. This produces a **Slight significance of effect** on surface water during construction.

3.5 Operational Phase

The main elements of this stage of the project which potentially could impact on groundwater are associated with:

- Permanent dewatering of the superficial deposits, via gravity flow;
- Permanent below ground features, such as pilings, foundations or grouted workings disrupting groundwater flow.

External groundwater conditions which potentially could impact on the operational phase of the project include:

- Changes to local mine treatment and dewatering operations.

It is possible that groundwater will need to be permanently dewatered from the superficial deposits in the areas of the NMU routes. It is understood that this is will be completed via a gravity drainage system, discharging to the south of the project site.

As discussed in the full A720 Sheriffhall Junction Improvement Environmental Statement there are five proposed SuDS ponds which capture drainage from the Proposed Scheme. Superficial groundwater levels higher than the proposed base of the SuDS ponds may cause the uplift of the pond lining, in the case that no residual water remains after drainage. It is assumed that ponds will act as settlement / attenuation / treatment basins to remove the bulk of any contamination and reduce impacts to surface water quality from possible contaminated drainage water; which could result in a degradation of the groundwater in the superficial aquifers which are assumed to be in hydraulic continuity.

It is considered unlikely that operation of the proposed scheme will have any additional impacts on the groundwater level or quality in the deeper Coal Measures aquifer.

3.5.1 Assessment of Superficial Aquifer

Groundwater levels in the superficial deposits have been monitored at a higher level than the completed levels of parts of the proposed scheme and it is therefore assumed that the superficial deposits may require permanent dewatering locally for operation. Impacts on groundwater flow are expected to be localised. Permanent piling, associated with the scheme's engineering works, also have the potential to impact on superficial groundwater flow locally.

The proposed scheme is considered to have a **Minor magnitude impact** on the quality of groundwater in the superficial deposits during operation. This produces a **Slight significance of effect** on the groundwater quality in the superficial deposits during operation.

The proposed scheme is considered to have a **Minor magnitude impact** on the groundwater flow in the superficial aquifer during operation as impacts on groundwater flow are expected to be localised. This produces a **Slight significance of effect** on groundwater flow in the superficial deposits during operation.

3.5.2 Assessment of Bedrock Aquifer

The deep piling and the grouting of mine workings as part of the construction phase, have the potential to cause a long term impact on the flow of groundwater in the bedrock aquifer. These impacts on groundwater flow are discussed in Section 2.4.3 and are expected to be localised compared to the overall aquifer extent.

The proposed scheme is considered to have a **Negligible magnitude impact** on the groundwater quality of the bedrock aquifer during operation. This produces a **Neutral significance of effect** on the bedrock groundwater during operation.

The proposed scheme is considered to have a **Minor magnitude impact** on the groundwater flow of the bedrock aquifer during operation, but locally in the vicinity of the site grouting, impacts are considered **Moderate**. This produces a **Slight significance of effect** on the bedrock groundwater during operation.

3.5.3 Assessment of Surface Water Bodies

Surface run-off and site drainage during operation may result in degradation of surface water quality. However this impact will be reduced through settlement in the SuDS pond reducing the bulk of the contamination.

The proposed scheme is assessed as having a **Minor magnitude impact** on the surface water bodies in the area during operation. This produces a **Slight significance of effect** on surface water bodies during operation.

4. Mitigation

4.1 Introduction

Mitigation measures have been recommended and designed, in particular where the assessment has indicated an impact of High or Moderate significance on groundwater. These include standard site mitigation measures, as well as project specific mitigation works.

4.2 Construction Phase

Appropriate mitigation will be required, primarily during construction, to ensure that potential impacts are minimised wherever possible.

This will include appropriate site layout and design, with the aim to minimise the potential for fuel or other contaminant leakage and uncontrolled site runoff. For example, containment of all fuel storage tanks in bunded areas; controlled refuelling operations; contained area for cement washout; appropriate storage of chemicals in contained areas; and appropriate treatment of surface water and dewatering water prior to discharge. This should follow SEPA environmental guidance for site layout.

Standard mitigation during construction will be provided in a Construction Environmental Management Plan (CEMP) which will include an Erosion Prevention and Sediment Control Plan in order to minimise sediment mobilisation or release of pollutants into the adjacent watercourses, or risk of contamination to groundwater.

Prior to the commencement of excavations and below-ground construction, the current groundwater quality should be established. A contaminated land survey should also be completed to identify any potential historic contamination and the potential for the presence of contaminated ground that may be excavated as part of the scheme. Dewatering activities should require groundwater discharges to be directed into settlement lagoons, to reduce the suspended solids concentration, before subsequent discharge to surface watercourses. Any groundwater dewatering required from the bedrock aquifer should also be adequately treated before discharge, as it may be of poor quality and potentially contaminated.

A major part of the mitigation measures will be to ensure the control of grout during the mine workings treatment. Measures should be implemented during both the design and construction phases of the works. This will include controlling grout run-off on the ground surface and prevent grout reaching agricultural soils, watercourses or causing contamination of groundwater. Care should also be taken to prevent the grout extending past the target zone. This may be controlled by measures such as the use of gravel to form curtain walls to the grout. If practicable, large voids should initially be filled with permeable granular materials, such as gravel, to allow some groundwater flow to remain and minimise hydraulic obstruction. Existing or potential mine water discharges should be identified via a water features survey and a review of abandoned coal working plans prior to construction and a regular visual monitoring assessment should be implemented to observe for areas of seepage of migrated groundwater arising from grouting activities.

All piles should be installed in accordance with EA / SEPA methodology. This is of particular importance where the proposed piles terminate below the groundwater level in the Coal Measures. Where the piles terminate above the groundwater level in the bedrock, there will be no impacts on groundwater flow and negligible impacts on bedrock groundwater quality. A piling risk assessment may be required.

In order to assess the impacts of the proposed scheme on groundwater level and quality, a programme of regular groundwater level and quality monitoring should be established and implemented prior to the commencement of any construction works. Monitoring for potential impacts, including groundwater level and quality monitoring in both the superficial and bedrock aquifers, and surface water discharges, will allow for timely maintenance, remediation and restoration to minimise potential direct and indirect impacts. This is especially important before and during grouting operations to observe for any adverse effects on groundwater. Guidance from the Coal Authority and SEPA including *Stabilising mine workings with PFA grouts. Environmental code of practice 2nd Edition, BRE Report 509*, should be adopted throughout the design and construction process to minimise impacts on groundwater during these operations.

4.3 Operational Phase

Potential operational impacts can also be mitigated through an effectively designed drainage scheme which discharges surface run-off away from the site. Any permanent dewatering activities, such as in the vicinity of the NMU, should also require groundwater discharges to be settled to reduce suspended solids concentration before subsequent discharge to surface watercourses. The current design of the SuDS pond will enable this.

There are not expected to be any operational impacts to the existing or proposed mine treatment works close to the site which may impact on the hydrogeological conditions at the site. Guidance from the Coal Authority and SEPA should be referred to as required if changes are later proposed.

5. Residual Impact Assessment

5.1 Introduction

The residual impact on receptors after the implementation of mitigation measures are discussed only where the pre-mitigation assessment of the receptors has indicated an impact on groundwater of High or Moderate significance.

5.2 Superficial Aquifer

After implementation of the appropriate mitigation measures detailed above, the significance of the residual effect on groundwater quality and flow in the superficial deposits during construction is assessed as **Slight**.

5.3 Summary

After mitigation, all receptors (superficial quality, superficial flow, bedrock quality, bedrock flow and surface water features) are assessed as having a slight or neutral residual impact. A summary of the assessment of potential impacts is shown in Table 5-1.

Table 5-1 Summary of the Assessment of Potential Impacts

Receptor	Importance	Magnitude of Impact during Construction	Magnitude of Impact during Operation	Significance of Effect during Construction	Significance of Effect during Operation	Residual Significance of Effect during Construction	Residual Significance of Effect during Operation
Superficial Aquifer - Quality	Medium	Moderate	Minor	Moderate	Slight	Slight	Slight
Superficial Aquifer - Flow	Medium	Minor	Minor	Slight	Slight	Slight	Slight
Bedrock Aquifer - Quality	Medium	Minor	Negligible	Slight	Neutral	Slight	Neutral
Bedrock Aquifer - Flow	Medium	Minor	Minor	Slight	Slight	Slight	Slight
Surface Water Features	Medium	Minor	Minor	Slight	Slight	Slight	Slight

6. Conclusions and Recommendations

Based on the assessment, it is concluded that following the implementation of appropriate mitigation measures, there are no residual impacts on groundwater in both the superficial deposits and in the Coal Measures aquifer during both construction and operations with a significance greater than **Slight**.