A9.3 Hydraulic Modelling and Input to Design

1 Introduction

1.1 Introduction

1.1.1 This appendix presents the methodology and results of a hydraulic analysis along Niddry Burn and Swine Burn for the proposed scheme. The appendix includes the following sections:

- hydrological assessment of the contributing catchments;
- mathematical river modelling and estimation of flood levels for the existing scenario;
- mathematical river modelling and estimation of flood levels for post-development scenarios;
- culvert sizing for the proposed development;
- sizing of Swine Burn realigned channel (refer to Appendix A9.4: Fluvial Geomorphology); and
- assessment of compensatory storage requirements for areas of floodplain encroachment due to proposed culvert extensions or new culvert installations.

1.1.2 Additional watercourses that could potentially be affected by the proposed scheme were identified in the flood risk review, namely Tributary of Niddry Burn, Ferry Burn, Tributary of Swine Burn, Dolphington Burn and Linn Mill Burn. Preliminary hydraulic desktop calculations were carried out to assess potential flood risk issues for these watercourses, however detailed hydraulic models were not developed for these watercourses due the their small catchment size and the expected limited impact of the proposed scheme on the flood risk associated to these watercourses. For more details on the baseline flood risk for those watercourses please refer to Appendix A9.2.

1.1.3 For the River Almond, immediately to the south of the proposed scheme, flood level data from a previous modelling exercise for this watercourse were provided by the City of Edinburgh Council. The construction of a new mathematical river model was not deemed necessary for the River Almond as analysis for this project was restricted to assessment of compensatory storage requirements, for which flood levels provided by the City of Edinburgh Council were deemed suitable. Compensatory storage requirements have also been assessed where encroachment of the floodplain is being proposed within the existing floodplains of the Tributary of Niddry Burn and of the River Almond.

1.2 Background

1.2.1 Niddry Burn, located to the west of Kirkliston, is a tributary of the River Almond and has a catchment area of approximately 21km^2. The burn, which is approximately 7km in length, flows in a general easterly direction through a predominantly rural catchment.

1.2.2 Niddry Burn reach analysed for the purposes of this study is located between an area approximately 0.5km upstream of the M9 and the River Almond. In addition to a number of small farm crossings, Niddry Burn is culverted under the M9 and the B800, as shown on Diagram 1.1.

1.2.3 Swine Burn has a catchment area of approximately 10km^2 and is a tributary of the River Almond. The burn, which is approximately 8km in length, flows in a southeasterly direction through a predominantly rural catchment which includes mixed and broadleaf woodland and agricultural land.

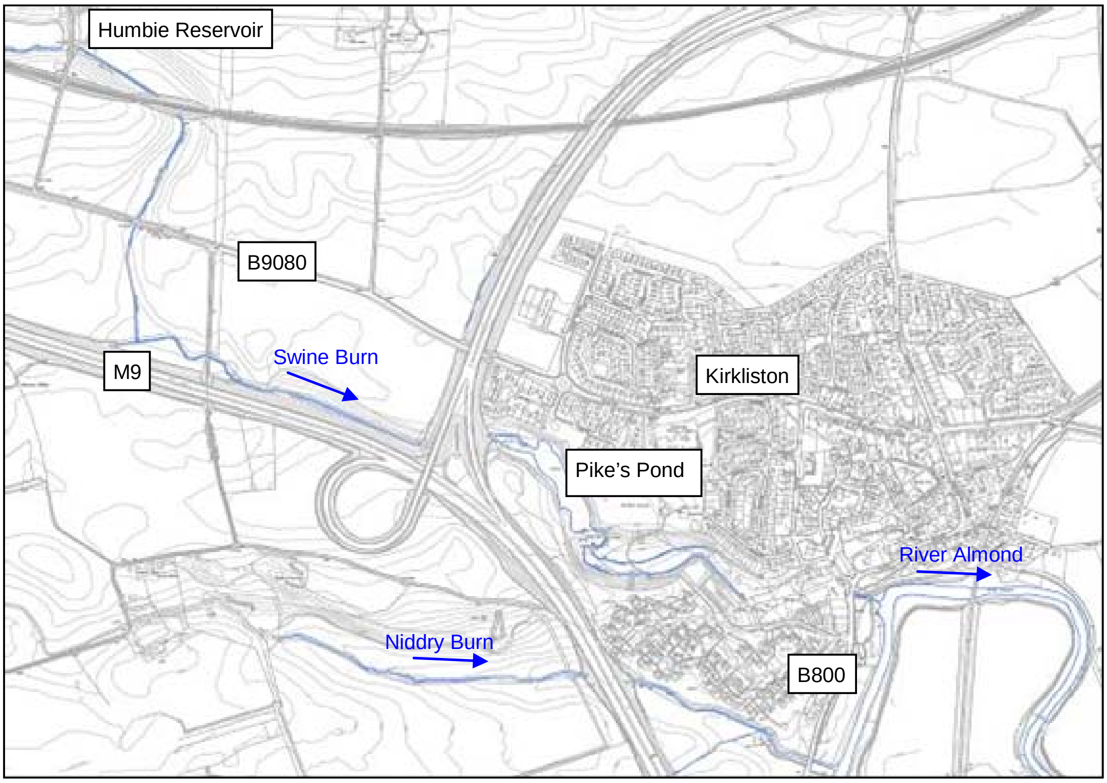
1.2.4 Swine Burn has hydrological connectivity with the Hopetoun fishery pond located within Swineburn Wood, the Humbie Reservoir and a reservoir located downstream of the existing M9 Spur culvert (hereafter referred to as Pike's Pond in this report).

1.2.5 Swine Burn reach analysed for the purposes of this study is located between the Humbie Reservoir and the outlet of Pike's Pond. The outlet of Pike's Pond was deemed a suitable downstream boundary to the model as there is a large drop in riverbed elevations downstream of the existing sluice gate at the outlet of Pike's Pond. There are a number of existing structures along this length of Swine Burn, namely:

- culvert under railway line;
- culvert under B9080;
- Overton Road bridge; and
- culvert under M9 Spur.

1.2.6 The locations of the watercourse reaches considered in this assessment are shown on Diagram 1.1.

Diagram 1.1: Location Plan



2 Hydrological Model Inputs

2.1 Introduction

2.1.1 The hydrological information for Niddry Burn and Swine Burn was developed using the Flood Estimation Handbook CD-ROM v.2 (Centre for Ecology and Hydrology, 2006). Through site visits, it was identified that a bifurcation (split/fork) of Niddry Burn was historically installed to direct flow from Niddry Burn into Swine Burn for water supply to a distillery in Kirkliston. The flow from Niddry Burn was conveyed towards Swine Burn by way of a channel located to the south of the M9.

However, site visit observations proved that this historical connection has been infilled and the two catchment areas are hydraulically separated.

2.2 Catchment Descriptors

2.2.1 As the historical connection between Niddry Burn and Swine Burn has been infilled, the current FEH CD-ROM dataset does not reflect the actual drainage pattern of the Swine and Niddry catchments and does not account for existing drainage patterns. The catchment boundaries were therefore manually amended and the areas calculated using GIS software (Arcview).

2.2.2 The catchment descriptors as collected from FEH and Arcview are shown in Table 2.1.

Table 2.1: Catchment Descriptors

Catchment Descriptor	Swine Burn	Niddry Burn
AREA (km^2)	9.85	21.01
BFIHOST	0.352	0.339
FARL	0.969	0.992
SAAR (mm)	816	845
SPRHOST	39.63	38.85
URBEXT2000	0.02	0.001

2.3 Historic Flooding Information

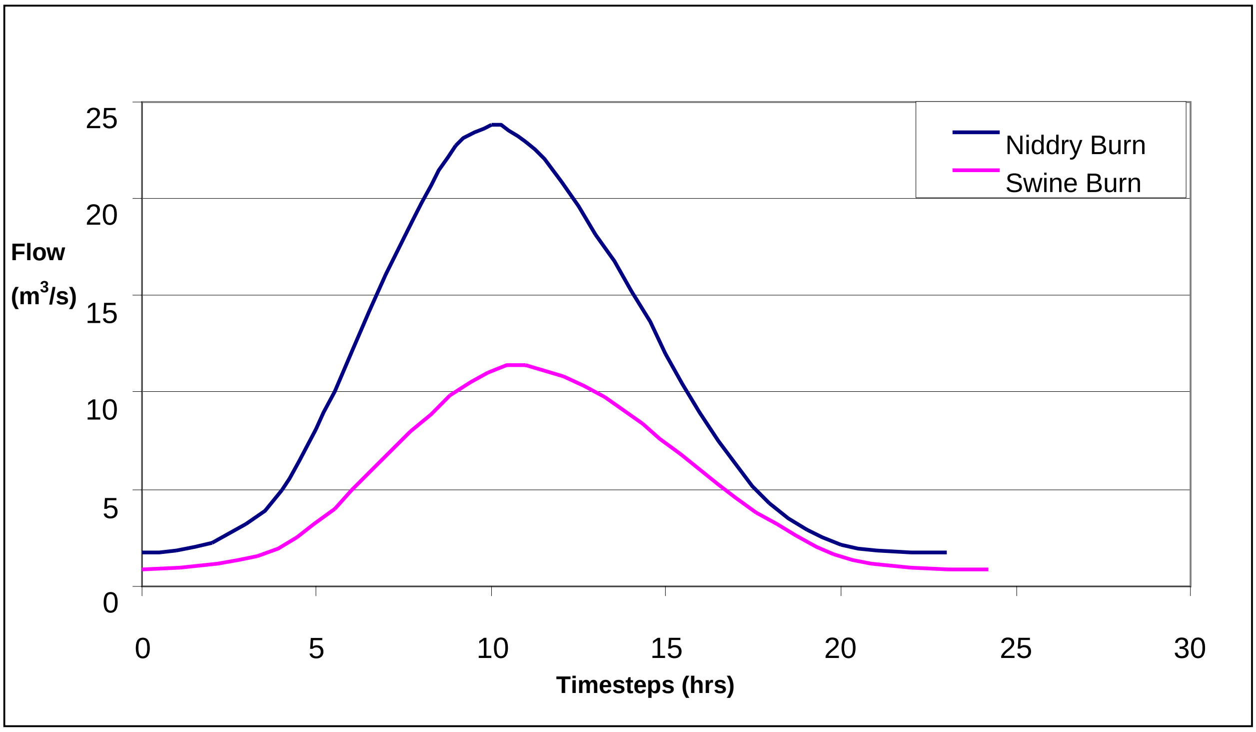
2.3.1 Based on consultations with City of Edinburgh Council, historical flooding was identified at the lower reaches of Niddry Burn and Swine Burn near their respective crossings under the B800. The impacted areas are largely open field areas; however, some residential property located between the B800 roadway and the banks of the River Almond are known to be affected by flood events. It is believed that flooding has occurred in these reaches of Niddry Burn and Swine Burn as a result of high water levels in the River Almond.

2.4 Determination of Flood Frequency

2.4.1 Standard application of the FEH statistical pooling group method was used on these catchments to determine flood frequency curves for each burn. Design flows for the following Annual Exceedance Probabilities (AEP) were estimated: 50%, 20%, 10%, 4%, 2%, 1%, 0.5% AEP (i.e. design return periods: 2, 5, 10, 25, 50, 100, 200 years respectively).

2.4.2 Design hydrographs were derived by the FEH Rainfall-Runoff method and parameterisation was based on catchment descriptors. The peak flows of the hydrographs were scaled to the FEH statistical pooling results. The 0.5% AEP flood hydrographs are shown on Diagram 1.2.

Diagram 2.1: 0.5% AEP Design Hydrographs (Input to the ISIS model)



2.4.3 This methodology provides baseline conditions of these two watercourses along the proposed scheme.

2.5 Design Flows

2.5.1 The design flows used as an input for the ISIS model are shown in Table 2.2.

Table 2.2: Design Flows

AEP	Design Flows (m^3/s)	
	Swine Burn	Niddry Burn
50%	3.6	7.6
20%	4.9	10.3
10%	5.8	12.3
4%	7.2	15.1
2%	8.4	17.6
1%	9.8	20.5
0.5%	11.3	23.8

2.6 Comparison of Pre- and Post-development Flows for Potentially Affected Watercourses

2.6.1 The pre- and post-development 0.5% AEP flows for Swine Burn and Niddry Burn were derived by the standard application of the FEH statistical pooling group method. For the Tributary of Niddry Burn, Ferry Burn, Tributary of Swine Burn, Dolphington Burn and Linn Mill Burn, a range of methodologies were applied to estimate the pre and post-development flows. These methodologies included the FEH statistical pooling and the Rainfall-Runoff methodology. For River

Almond gauged data are available. The most appropriate results were established by critical review of the results and are presented below.

2.6.2 The flows from each catchment area are presented below in Table 2.3. These values are reprehensive of expected flows at the downstream boundary of the respective catchment areas. For this reason, the flows presented below in Table 2.3 are considered conservative and do not necessarily represent the expected flows at different outfall and/or culvert locations along these watercourses as used in other sections of this study. Therefore the values presented below should be used for comparative purposes only.

Table 2.3: Comparison of Pre and Post Development Flows at Downstream end of Watercourses

Catchment	0.5% AEP Design Flow (m^3/s)		% Difference
	Pre-Development	Post-Development	
Swine Burn	11.4	11.5	0.9%
Tributary of Swine Burn	0.8	0.9	1%
Niddry Burn	23.8	24	0.8%
Tributary of Niddry Burn	1.28	1.32	3.1%
Ferry Burn	1.91	1.97	3.1%
Linn Mill Burn	3.7	3.73	2.4%
Dolphington Burn	3.0	3.0	0%
River Almond	279	279	0%

3 Mathematical Hydraulic Modelling

3.1 General

3.1.1 Two one-dimensional (1-D) hydraulic models were constructed, to include the principal hydraulic features within the study area, have been constructed using the ISIS river modelling software package. Niddry Burn and Swine Burn have been modelled independently of each other.

3.1.2 ISIS is a river modelling software package adapted to describe both steady and unsteady flows in networks of open channels and floodplains. ISIS also predicts flow characteristics for a wide variety of hydraulic structures, including culverts and bridges.

3.1.3 The 50%, 20%, 10%, 4%, 2%, 1% and 0.5% AEP design flows were used to derive respective flood levels and assess extent of flooding along the banks of Niddry Burn and Swine Burn.

3.2 Model Construction

3.2.1 The representation of Niddry Burn and Swine Burn in the respective river models has been based on recently collected river survey information, which includes river cross-sections at a maximum interval of 200m and hydraulic structures, and recently collected geodetic survey information to characterise out-of-bank topography.

3.2.2 The survey information was supplemented by measurements taken during site walkover inspections, with site observations used to assess roughness parameters.

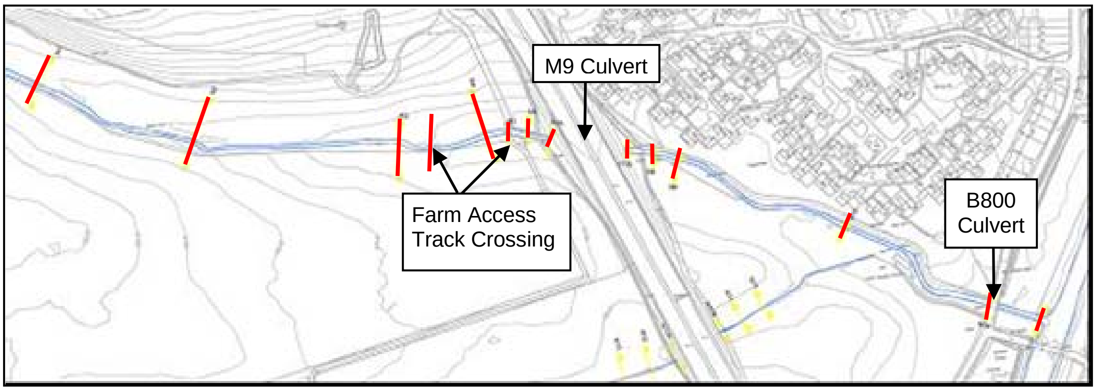
3.2.3 Channel dimensions for a reach between two cross-sections have been modelled representative of the surveyed upstream cross-section.

Niddry Burn

3.2.4 The model contains cross-section information based on river survey data including: (i) 14 channel cross-sections and (ii) 3 hydraulic structures, which may affect the flow characteristics in the studied watercourse reach during high flow events. These structures are (i) 2 farm access track crossings (of which one is disused), and (ii) the M9 culvert.

3.2.5 The location of cross-sections and the hydraulic structures in the hydraulic model are shown on Diagram 3.1.

Diagram 3.1: Niddry Burn Cross-Sections



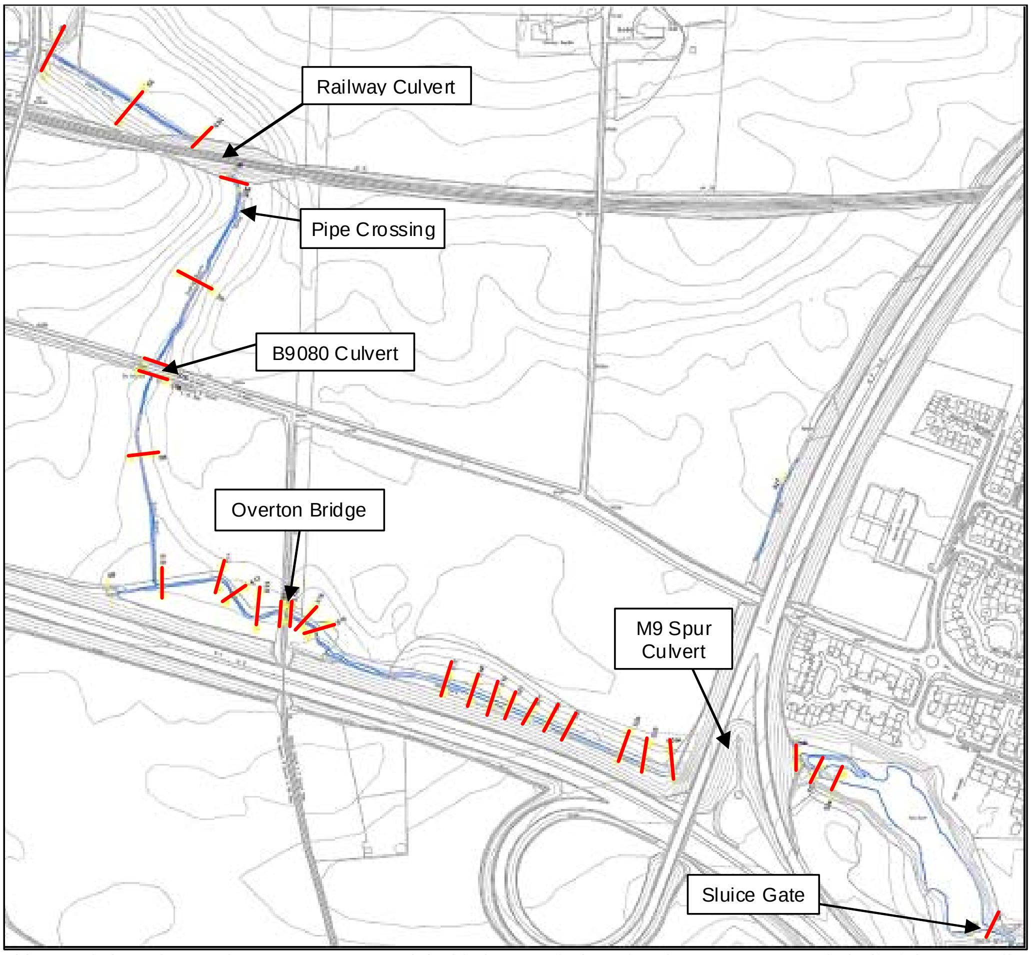
Swine Burn

3.2.6 The model contains cross-section information based on river survey data including: (i) 30 channel cross-sections, and (ii) 6 hydraulic structures, which may affect the flow characteristics in the studied watercourse reach during high flow events. These are:

- railway culvert;
- pipe crossing;
- B9080 culvert;
- Overton Bridge;
- M9 Spur culvert (twin rectangular); and
- Pike's Pond sluice gate.

3.2.7 The location of cross-sections and the hydraulic structures in the hydraulic model are shown on Diagram 3.2.

Diagram 3.2: Swine Burn Cross Sections



3.3 Model Assumptions

3.3.1 The following assumptions have been adopted for the assessment:

- Channel banks have been extended to include the floodplain, which assumes flow of floodwater downstream through the main channel and the floodplain areas. It is assumed that the floodplain area adjacent to the watercourse is not separated hydraulically from the watercourse, as observed during the site walkover.
- Areas of depression within the floodplain area have not been represented in detail outside of the cross-section information. It is assumed that there is a uniformity of terrain between cross-sections.
- The channel roughness (Manning's n) values for Swine Burn and Niddry Burn channels are assumed to be between 0.035-0.050 which were representative of channel conditions during the site walkover.
- The effect of Humbie Reservoir has been excluded from the Swine Burn model, but it is expected that this reservoir has a minimal impact on peak flows based on preliminary routing assessments. The minimal attenuation capacity of the Humbie Reservoir is explained by its small size and little active storage. Detailed information related to the volume of the reservoir and spillway configuration were not available for this analysis; however it is recommended that the reservoir's attenuation capacity be reviewed should further information become available.
- The effect of the B800 culvert (New Liston Bridge) has been excluded from the Niddry Burn model as it is considered that water levels in the River Almond control the flow at this location. Through the modelling exercise, it was found that the high water levels in the River Almond outflanked the B800 culvert on the right hand bank and rendered the hydraulic restrictions by the culvert negligible during high flow events.
- Flood extents at the confluence of the River Almond with Niddry Burn were found to be controlled by high water levels within the River Almond. High water levels along the River Almond were used to establish the downstream boundary of the Niddry Burn model, and the flood extents were based on overtopping from the banks of Niddry Burn. Through the modelling programme, it was shown that influence on water levels in the Niddry Burn from the River Almond during extreme flood events does not extend as far upstream as the M9 culvert due to the presence of the B800 crossing. Water level increases in the Niddry Burn upstream of the M9 crossing during high flow events are not influenced by water levels in the River Almond.
- The railway culvert, Overton Road bridge and M9 Spur culvert have been modelled to not overtop on Swine Burn. Flow is restricted to passage through these culverts within the models. This assumption is reasonable based on elevations of the bridge parapets.
- The M9 culvert has been modelled to not overtop on Niddry Burn. Flow is restricted to passage through the culvert. This assumption is reasonable based on elevations of the bridge parapet.
- Inflow from the tributary of Swine Burn has been included into the Swine Burn model as part of the upstream boundary of the model. A separate inflow source was not included in the model for the Tributary of Swine Burn due to its small catchment area, its small contribution to peak flows, and its proximity to the upstream boundary.

3.4 Model Boundaries

Niddry Burn

3.4.1 The upstream boundary of Niddry Burn is located approximately 540m upstream of the M9 culvert and its hydrology is represented by a flow hydrograph in accordance with the hydrology as described previously in Section 2 (Hydrological Model Inputs).

3.4.2 The downstream boundary of Niddry Burn is located directly upstream of the confluence with the River Almond. Water levels within the River Almond are based on observed and modelled water levels within the River Almond, provided by City of Edinburgh Council. The water levels for different return periods used in this analysis are shown in Table 3.1.

Table 3.1: Predicted River Almond Water Levels at Niddry Burn Confluence

Return Period (% AEP)	Predicted Water Level (mOD)
50	32.00
20	32.35
10	32.60
4	32.90
2	33.09
1	33.29
0.5	33.48
0.5 + 20% Climate Change	33.92

Swine Burn

3.4.3 The upstream boundary for Swine Burn is located immediately downstream of Humbie Reservoir and is represented by a flow hydrograph in accordance with the hydrology as described previously in Section 2 (Hydrological Model Inputs).

3.4.4 The downstream boundary for Swine Burn model has been fixed at the existing sluice gate elevation at the outlet of Pike's Pond. It is considered that the top of spillway elevations may change in the future as it currently is in poor structural condition.

3.4.5 The flood extents along Swine Burn have only been presented to the M9 Spur culvert inlet in Figure 9.4 (please refer to Chapter 9) due to lack of detailed geodetic information on the grounds surrounding Pike's Pond.

3.5 Model Calibration

3.5.1 Ideally, it is desirable to calibrate mathematical model parameters against observations of peak water levels during past high flow events. The calibration process increases the level of confidence in model predictions.

3.5.2 As there are no observed water levels for either Niddry Burn or Swine Burn, calibration could not be undertaken. However, in the absence of observed water levels in Niddry Burn and Swine Burn, model simulations were carried out to assess the sensitivity of model predictions to changes in certain model parameters including channel roughness coefficients, downstream boundaries, and flood breach scenarios.

3.6 Sensitivity Analysis

3.6.1 A sensitivity analysis has been undertaken on both Niddry Burn and Swine Burn to assess the impact of channel roughness on predicted water levels. The potential hydraulic resistance of vegetation within the floodplain has been characterised in the model by adjustment of the Manning's n values i.e. increasing the Manning's n values (in-bank and out-of-bank) by 20%.

3.6.2 Two further scenarios were run to assess the impact of blockages/failure of the Overton Road culvert along Swine Burn. These assessments were performed on the Overton Road culvert as model findings proved that this culvert is an important hydraulic restriction upstream of the reach of Swine Burn to be impacted by new roadway construction works. These scenarios included:

- Overton Bridge 90% blocked; and

- Overton Bridge removed.

3.6.3 Due to some uncertainties in future elevations of the sluice gate at Pike's Pond and water levels in the River Almond, a sensitivity analysis was undertaken on the Swine Burn and the Niddry Burn downstream boundaries where water levels were increased by 0.5m in both cases.

3.6.4 Further information on the sensitivity analyses of Niddry Burn and Swine Burn is presented in Section 4.2 and 4.3 respectively.

4 Hydraulic Modelling Results

4.1 General

4.1.1 A comparison of the predicted flood extents for the 0.5% AEP flood flows for Niddry Burn and Swine Burn against the 0.5% AEP SEPA Indicative River and Coastal Flood Map was undertaken by comparing Figure 9.4 (refer to Chapter 9) to the SEPA indicative flood extents (SEPA, 2009).

4.1.2 Review of available information identified a substantial difference between the predicted flood extents from the ISIS modelling results and those shown on the SEPA Flood Map. However, it is considered that the predicted flood extents estimate more accurately the flood effects along Niddry Burn and Swine Burn over the SEPA flood mapping due to:

- more refined hydrology and understanding of hydraulic connectivity;
- more accurate representation of the watercourse dimensions;
- more accurate representation of hydraulic structures; and
- more accurate assessment of backwater effects of hydraulic structures on upstream water levels.

4.1.3 Predicted peak water levels for all cross-sections within the models are presented in Annex A.

4.2 Niddry Burn

Existing Scenario

4.2.1 Model simulations of the existing scenario on Niddry Burn have been undertaken for a range of design flood flows. The predicted peak water levels at key locations along Niddry Burn are shown in Table 4.1.

Table 4.1: Niddry Burn Existing Scenario Water Levels

Location	Model Node	Maximum Predicted Water Level (mOD) for Design Flood Flows (%AEP)						
		50	20	10	4	2	1	0.5
Upstream boundary	N1	44.30	44.42	44.48	44.54	44.60	44.65	44.70
Upstream of farm access track 1	N3A	37.90	38.03	38.24	38.54	38.65	38.75	38.88
Upstream of farm access track 2	N5	37.09	37.33	37.57	37.78	38.02	38.40	38.80
Upstream of M9 culvert	N7A	36.88	37.16	37.36	37.62	37.89	38.36	38.78
Upstream of B800 culvert	N16	32.01	32.35	32.60	32.90	33.09	33.29	33.48
Downstream boundary	N17	32.00	32.35	32.60	32.90	33.09	33.29	33.48

4.2.2 The associated flood depths for the maximum predicted water levels on Niddry Burn are shown in Table 4.2.

Table 4.2: Niddry Burn Existing Scenario Flood Depths

Location	Model Node	Maximum Predicted Flood Depths (m) for Design Flood Flows (%AEP)						
		50	20	10	4	2	1	0.5
Upstream boundary	N1	0.74	0.85	0.92	0.98	1.04	1.09	1.14
Upstream of farm access track 1	N3A	1.00	1.13	1.34	1.64	1.75	1.85	1.98
Upstream of farm access track 2	N5	0.94	1.18	1.42	1.63	1.87	2.25	2.65
Upstream of M9 culvert	N7A	1.22	1.50	1.70	1.96	2.23	2.70	3.12
Upstream of B800 culvert	N16	1.44	1.78	2.03	2.33	2.52	2.72	2.91
Downstream boundary	N17	1.98	2.33	2.58	2.88	3.07	3.27	3.46

4.2.3 For each flood event, the greatest flood depth increase is predicted to occur upstream of the M9 culvert; however, it should be noted that increases in water levels along the reach downstream of the M9 culvert are attributed in large part to high water levels in the River Almond. For the extreme flood flows, the M9 culvert is considered to be under capacity and restricts flow, increasing water levels upstream due to backwater effects. In addition, it is considered that under high flows the farm access track crossings do not impact on water levels upstream as they become drowned with overtopping of their bridge decks.

4.2.4 Figure 1 in Annex B shows the variation of predicted peak water levels along the modelled reach of Niddry Burn for the 0.5% AEP flood event.

Sensitivity

(a) Roughness

4.2.5 The sensitivity analysis results for a 20% increase in roughness are shown in Table 4.3 below.

Table 4.3: Niddry Burn Roughness Sensitivity

Location	Model Node	Existing Scenario 0.5% AEP (mOD)	Roughness + 20% 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	N1	44.70	44.77	+70
Upstream of farm access track 1	N3A	38.88	38.89	+10
Upstream of farm access track 2	N5	38.80	38.81	+10
Upstream of M9 culvert	N7A	38.78	38.78	0
Upstream of B800 culvert	N16	33.48	33.49	+10
Downstream boundary	N17	33.48	33.48	0

4.2.6 Based on the above results, the model is relatively insensitive to roughness at the location of the M9 culvert.

(b) Downstream Boundary

4.2.7 The sensitivity analysis results for a 0.5m increase in the downstream boundary i.e. River Almond water levels, are presented in Table 4.4 below.

Table 4.4: Niddry Burn Downstream Boundary Sensitivity

Location	Model Node	Existing Scenario 0.5% AEP (mOD)	Downstream Boundary + 0.5m 0.5% AEP mOD)	Difference (mm)
Upstream boundary	N1	44.70	44.70	0
Upstream of farm access track 1	N3A	38.88	38.88	0
Upstream of farm access track 2	N5	38.80	38.80	0
Upstream of M9 culvert	N7A	38.78	38.78	0
Upstream of B800 culvert	N16	33.48	33.98	+500
Downstream boundary	N17	33.48	33.98	+500

4.2.8 Based on the above results, the reach of Niddry Burn upstream of the M9 culvert (i.e. proposed location of potential roadway works) is shown to be insensitive to increases in the downstream boundary water levels.

4.3 Swine Burn

Existing Scenario

4.3.1 Model simulations of the existing scenario on Swine Burn have been undertaken for a range of design flood flows. The predicted peak water levels at key locations are presented in Table 4.5.

Table 4.5: Swine Burn Existing Scenario Water Levels

Location	Model Node	Maximum Predicted Water Level (mOD) for Design Flood Flows (%AEP)						
		50	20	10	4	2	1	0.5
Upstream boundary	S1	61.13	61.24	61.31	61.40	61.48	61.56	61.65
Upstream of railway culvert	S3A	58.86	59.03	59.14	59.30	59.43	59.57	59.75
Upstream of pipe crossing	S4	58.60	58.68	58.72	58.79	58.83	58.88	58.93
Upstream of B9080 culvert	S7A	55.86	56.12	56.33	56.48	56.55	56.58	56.58
Upstream of Overton Bridge	S14A	52.30	52.48	52.62	52.83	53.00	53.19	53.40
Upstream of M9 spur culvert	S26A	47.66	47.87	48.00	48.19	48.35	48.52	48.71
Pike’s Pond	S29	45.84	45.91	45.95	46.01	46.05	46.12	46.22

4.3.2 The associated flood depths for the maximum predicted water levels on Swine Burn are presented in Table 4.6.

Table 4.6: Swine Burn Existing Scenario Flood Depths

Location	Model Node	Maximum Predicted Flood Depths (m) for Design Flood Flows (%AEP)						
		50	20	10	4	2	1	0.5
Upstream boundary	S1	0.82	0.93	1.00	1.09	1.17	1.25	1.34
Upstream of railway culvert	S3A	1.02	1.19	1.30	1.46	1.59	1.73	1.91
Upstream of pipe crossing	S4	1.11	1.19	1.23	1.30	1.34	1.39	1.44
Upstream of B9080 culvert	S7A	1.14	1.40	1.61	1.76	1.83	1.86	1.86
Upstream of Overton Bridge	S14A	0.72	0.90	1.04	1.25	1.42	1.61	1.82
Upstream of M9 spur culvert	S26A	0.89	1.10	1.23	1.42	1.58	1.75	1.94
Pike’s Pond	S29	0.60	0.67	0.71	0.77	0.81	0.88	0.98

4.3.3 For the lower return period flood events, the greatest flood depth increases are predicted to occur upstream of the B9080 culvert. For the 0.5% AEP flood event, similar flood depth increases are predicted upstream of the railway culvert, the B9080 culvert, the Overton Road culvert, and the M9 Spur culvert.

4.3.4 For the 0.5% AEP flood event flow, the M9 Spur culvert, B9080 culvert and Overton Bridge are considered to be under capacity and restrict flow, increasing water levels upstream due to backwater effects.

4.3.5 Figure 2 in Annex B shows the variation of predicted peak water levels along the modelled reach of Swine Burn for the 0.5% AEP flood event.

Sensitivity

<u>Roughness</u>

4.3.6 The sensitivity analysis results for a 20% increase in roughness are presented in Table 4.7 below.

Table 4.7: Swine Burn Roughness Sensitivity

Location	Model Node	Existing Scenario 0.5% AEP (mOD)	Roughness + 20% 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	S1	61.65	61.74	+90
Upstream of railway culvert	S3A	59.75	59.85	+100
Upstream of pipe crossing	S4	58.93	58.93	0
Upstream of B9080 culvert	S7A	56.58	56.64	+60
Upstream of Overton Bridge	S14A	53.40	53.41	+10
Upstream of M9 spur culvert	S26A	48.71	48.71	0
Pike’s Pond	S29	46.22	46.24	+20

4.3.7 Based on the above results, the model is relatively insensitive to changes in roughness. The greatest depth increases due to roughness increases were assessed in the reach upstream of the railway culvert.

<u>(b) Overton Bridge 90% Blocked</u>

4.3.8 The sensitivity analysis results for a 90% blockage of Overton Bridge are presented in Table 4.8 below.

Table 4.8: Swine Burn Overton Bridge 90% Blocked

Location	Model Node	Existing Scenario 0.5% AEP (mOD)	Bridge 90% Blocked 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	S1	61.65	61.65	0
Upstream of railway culvert	S3A	59.75	59.75	0
Upstream of pipe crossing	S4	58.93	58.93	0
Upstream of B9080 culvert	S7A	56.58	56.58	0
Upstream of Overton Bridge	S14A	53.40	54.95	+1,550
Upstream of M9 spur culvert	S26A	48.71	48.72	+10
Pike’s Pond	S29	46.22	46.22	0

4.3.9 Based on the above results any reduction in capacity at Overton Bridge has a localised impact on upstream water levels with a maximum increase in water level of 1.5m.

4.3.10 The impact of the blockage is predicted to extend upstream as far as the downstream end of the B9080 culvert. The results in Table 4.8 show only a minor impact on water levels downstream of Overton Bridge. Predicted peak water levels at each of the model cross-sections are set out in Table A6 of Annex A.

4.3.11 Based on this assessment, any potential blockage of Overton Bridge is not expected to impact on water levels outwith the immediate vicinity of the Overton Bridge.

(c) Overton Bridge Removed

4.3.12 The sensitivity analysis results for the removal of Overton Bridge (to represent a breach of the structure) are presented in Table 4.9 below.

Table 4.9: Swine Burn Overton Bridge Removed (Breach Scenario)

Location	Model Node	Existing Scenario 0.5% AEP (mOD)	Bridge Removed 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	S1	61.65	61.65	0
Upstream of railway culvert	S3A	59.75	59.75	0
Upstream of pipe crossing	S4	58.93	58.93	0
Upstream of B9080 culvert	S7A	56.58	56.58	0
Upstream of Overton Bridge	S14A	53.40	52.86	-540
Upstream of M9 spur culvert	S26A	48.71	48.72	+10
Pike's Pond	S29	46.22	46.22	0

4.3.13 As a result of removing Overton Bridge from the model, the flow restriction at this section is also reduced. This results in a localised impact on the water levels, with a reduction of up to 540mm immediately upstream of the Overton Bridge.

4.3.14 Based on this assessment, any potential breach of the Overton Bridge structure is not expected to impact on water levels outwith the immediate vicinity of the Overton Bridge.

(d) Increase in elevation of sluice gate on Pike's Pond

4.3.15 As noted in paragraph 3.4.4, due to the poor condition of the sluice gate at the outlet of Pike's Pond, it is anticipated that it will be upgraded in the future (although this is not required by, or as part of, the proposed scheme assessed and reported in this ES). Due to this uncertainty, potential increases in sluice gate levels up to 0.5m above existing levels were assessed using the hydraulic model. Results of this analysis indicate that these increases in sluice gate levels would not be expected to impact water levels at the existing M9 Spur culvert (based on current understanding of Pike's Pond dimensions, elevation drop from culvert outlet to Pike's Pond and potential attenuation capacity of Pike's Pond).

4.4 Climate Change Sensitivity Testing

4.4.1 The United Kingdom Climate Impacts Programme (UKCIP02) (UK Climates Impact Programme, 2009) reports that future changes to average precipitation are likely to occur due to climate change. UKCIP02 scenarios suggest that the 2 year daily winter rainfall is predicted to increase by between 10% and 20% (range of medium low and medium high emissions scenario). Therefore to account for future variation in precipitation, the 0.5% AEP flow has been increased by 20% to allow for climate change and sensitivity to be assessed.

4.4.2 In October 2006, DEFRA released a Supplementary Note to Operating Authorities regarding Climate Change Impacts (DEFRA, 2006). An allowance of 20% is consistent with this guidance which is current at the time of preparing this appendix.

4.4.3 Also, recent guidance issued by SEPA 'Technical Flood Risk Guidance for Stakeholders' (Version 2, 30/01/08) also recommends a +20% allowance for climate change onto the 0.5% AEP flood event. Although this is not national policy, Scottish Planning Policy 7: Planning and Flooding (SPP7) (Scottish Executive, 2004) and SEPA recognises that such advice is useful for Local Authorities in consideration of climate change impacts.

4.4.4 Following the above discussion, the impacts of climate change on water levels have been estimated for Niddry Burn and Swine Burn using the respective hydraulic models for the 0.5% AEP +20% flood event. The results of this analysis are presented below for discussion purposes. For design purposes, new culvert sizing (along Swine Burn) has been undertaken in accordance with guidance provided by CIRIA Report 168 – Culvert Design Guide (CIRIA, 1997), and has considered the 0.5% AEP flood event.

Niddry Burn

4.4.5 The increases in predicted peak water levels at the key areas as a result of a 20% increase in design flow for Niddry Burn are shown on Table 4.10. Predicted peak water levels for all cross-sections within the model are set out in Table A8, Annex A.

Table 4.10: Niddry Burn Climate Change

Location	Model Node	Existing Scenario 0.5% AEP (mOD)	Climate Change 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	N1	44.70	44.77	+70
Upstream of farm access track 1	N3A	38.88	39.50	+620
Upstream of farm access track 2	N5	38.80	39.49	+690
Upstream of M9 culvert	N7A	38.78	39.48	+700
Upstream of B800 culvert	N16	33.48	33.92	+440
Downstream boundary	N17	33.48	33.92	+440

4.4.6 It is considered that Niddry Burn model is relatively sensitive to potential increases in flow as a result of climate change. Water levels are predicted to increase by a maximum of 700mm within the model upstream of the existing M9 culvert.

Swine Burn

4.4.7 The increases in predicted peak water level at the key areas as a result of a 20% increase in design flow for Swine Burn are presented in Table 4.11. Predicted peak water levels for all cross-sections within the model are set out in Table A9, Annex A.

Table 4.11: Swine Burn Climate Change

Location	Model Node	Existing Scenario 0.5% AEP (mOD)	Climate Change 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	S1	61.65	61.72	+70
Upstream of railway culvert	S3A	59.75	60.00	+250
Upstream of pipe crossing	S4	58.93	59.00	+70
Upstream of B9080 culvert	S7A	56.58	56.63	+50
Upstream of Overton Bridge	S14A	53.40	53.70	+300
Upstream of M9 spur culvert	S26A	48.71	48.97	+260
Pike's Pond	S29	46.22	46.36	+140

4.4.8 It is considered that Swine Burn model is sensitive to potential increases in flow as a result of climate change. Water levels are predicted to increase by a maximum of 300mm within the model upstream of Overton Road.

5 Culvert Sizing

5.1 Introduction

5.1.1 The determination of culvert sizing for the proposed new crossing of Swine Burn was carried out using existing hydrological assessment of 0.5% AEP flood event flows, channel cross-section information and mathematical modelling techniques.

5.1.2 The culvert hydraulics have been assessed and designed in accordance with CIRIA Report 168 Culvert Design Guide (CIRIA, 1997) as recommended by DMRB guidance (The Highways Agency et al. (2004) In addition, based on our recent experience, it was considered that the flow capacity of the culvert should be reviewed using a mathematical model of the culverted reach.

5.1.3 Further details of the hydrological analysis and model construction, as previously described, are set out in Sections 2 (Hydrological Model Inputs) and Section 3 (Mathematical Hydraulic Modelling) respectively.

5.1.4 It is a requirement of SPP7 (Scottish Executive, 2004) that new culverts, where unavoidable, must be designed to maintain or improve existing flow conditions and aquatic life.

5.1.5 For design purposes, the new culvert has been designed to pass the predicted 0.5% AEP design flows. Although a sensitivity analysis was performed on the water levels of the Swine Burn and Niddry Burn models, the culvert sizing exercise has not included allowance for climate change above the 0.5% AEP design flows. The existing M9 culverts along Swine Burn and Niddry Burn, which are to be extended, currently control peak flows downstream. As such, the inclusion of climate change impact on the design of the proposed culvert along Swine Burn is likely to increase flood risk along the reach of the Swine Burn between the proposed culvert and the existing M9 culvert. For this reason, it is considered detrimental to include the provision of climate change in the design of the new culvert.

5.1.6 The design parameters adopted in this assessment are listed in the Table 5.1, together with any assumptions.

Table 5.1: Design Parameters

Parameter	Comment
Culvert Flow	Predicted peak 0.5% AEP flow is 11.3m^3/s for Swine Burn. See Table 5.2: Culvert Dimensions.
Fisheries Water (Y/N)	No information provided to confirm this, so assumed not to be a fisheries watercourse.
Design Freeboard (m)	CIRIA Report 168 (page 41) (CIRIA, 1997) guidance recommends 300mm freeboard above the 0.5% AEP flood level.
Embedment Depth (m)	0.3m as recommended by DMRB (Highways Agency et al., 2003).
Culvert Manning's 'n'	It is assumed that the culvert will be constructed with pre-cast concrete units i.e. roughness value of 0.3m.
Inlet Structure Design Coefficients	The inlet structure arrangement acts to minimise the head loss at the inlet to the culvert barrel as it provides a smooth transition from the upstream channel to the culvert entrance. An inlet structure comprising a concrete headwall and concrete wingwalls at 30 degrees – 75 degrees to barrel/square edge has been adopted.
Outlet Structure Design Coefficients	It is assumed that the outlet structures will include headwalls and wingwalls hence an outlet loss coefficient of 0.7 is assumed.
Mammal Ledges	The culvert design has to accommodate mammal ledges based on current DMRB guidance (HA81/99) (Highways Agency et al., 1999).

Parameter	Comment
Flow Condition	Free Flow i.e. flow is not pressurised through the culvert
Culvert Type	Box

5.2 Culvert Scenario Results

5.2.1 Following the methodology presented in CIRIA Report 168 (CIRIA. 1997) and the input parameters presented above, the standard pre-cast culvert size required to pass the design flow, assuming 'free flowing' conditions within the culvert barrel is presented in Table 5.2.

Table 5.2: Culvert Dimensions

Culvert ID	0.5% AEP Design Flow (m^3/s)	Standard Sizes	
		Culvert Width (m)	Culvert Depth (m)
Swine Burn	11.3	6.0	2.4

5.2.2 A low flow channel within the culvert, formed by concrete benching, of width 1.5m is considered appropriate as this is similar in width to the upstream realigned channel cross-section, hence minimising the impact of the transition from the open channel upstream to the culvert entrance. The culvert height has been determined so as to allow a minimum headroom of 600mm between the predicted mammal ledge level and the culvert soffit, a minimum freeboard of 0.3m between the 0.5% AEP water level and the culvert soffit, and an embedment depth of 0.3m.

5.3 Recommendations

5.3.1 A culvert size of opening 6.0m wide and 2.4m high is recommended for the proposed new Swine Burn culvert, based on standard pre-cast concrete rectangular culverts.

5.3.2 The design of a new culvert should be based on the following principles as stated in CIRIA Report 168 (CIRIA, 1997), which include the following:

- The use of durable materials;
- No bends in the culvert alignment;
- No steps or changes of cross-section within the culvert;
- No other obstructions within the barrel; and
- Provision of access to inspect the inlet and outlet and, where the culvert is large enough, to gain entry into the barrel.

5.3.3 CIRIA Report 168 (CIRIA, 1997) states that improvements to the hydraulics can be achieved by modifying the geometry of the culvert entrance and exit.

5.3.4 Therefore, it is recommended that consideration be given to providing a smooth transition from the open channel to the culvert which minimises head loss i.e. by providing an inlet structure. The more dramatic and abrupt the change to the flow of water in the channel (in direction, depth or width) the greater the head loss, resulting in increased upstream water levels.

5.3.5 An example is to construct wingwalls at an angle of between 35 degrees – 75 degrees to the culvert. The presence of an inlet structure i.e. headwall and wingwalls will also help to prevent local scour which may lead to undermining or outflanking of the structure.

5.3.6 CIRIA Report 168 (CIRIA, 1997) also recommends that the outlet provides a transition from the culvert to the open channel. This is necessary as the magnitude of the flow velocity exiting the culvert may be higher than the channel velocity downstream. Therefore there is an increased risk of erosion in the channel immediately downstream of the culvert, to both the bed and the banks.

5.3.7 The form of the outlet structure is usually similar to that of the inlet structure. It may be necessary to provide bank protection downstream of the culvert outlet so that any erosion of the river bank doesn't result in the undermining or outflanking of the outfall structure.

6 Channel Realignment

6.1 Introduction

6.1.1 To inform the design of the channel realignment and address flood risk issues along Swine Burn, the proposed realigned reach of Swine Burn was included within the hydraulic model. Various iterations of design were modelled, with the realignment detail included in the Stage 3 design and reported here having the following key features:

- length of reach = 451.5m;
- length of culvert = 50m;
- location of culvert inlet (upstream of existing M9 Spur culvert) = 133m;
- width of floodplain channel = 10m;
- dimensions of low flow channel = 2.5m width at top of bank, 1.5m width at channel bottom, 0.5m depth;
- floodplain side-slopes = 1V:3H; and
- assuming the culvert sizing as presented in Section 5 (Culvert Sizing).

6.1.2 The flood depths of the channel realignment to the flood depths along the reach of the existing Swine Burn channel adjacent to the realignment were then compared.

6.2 Results

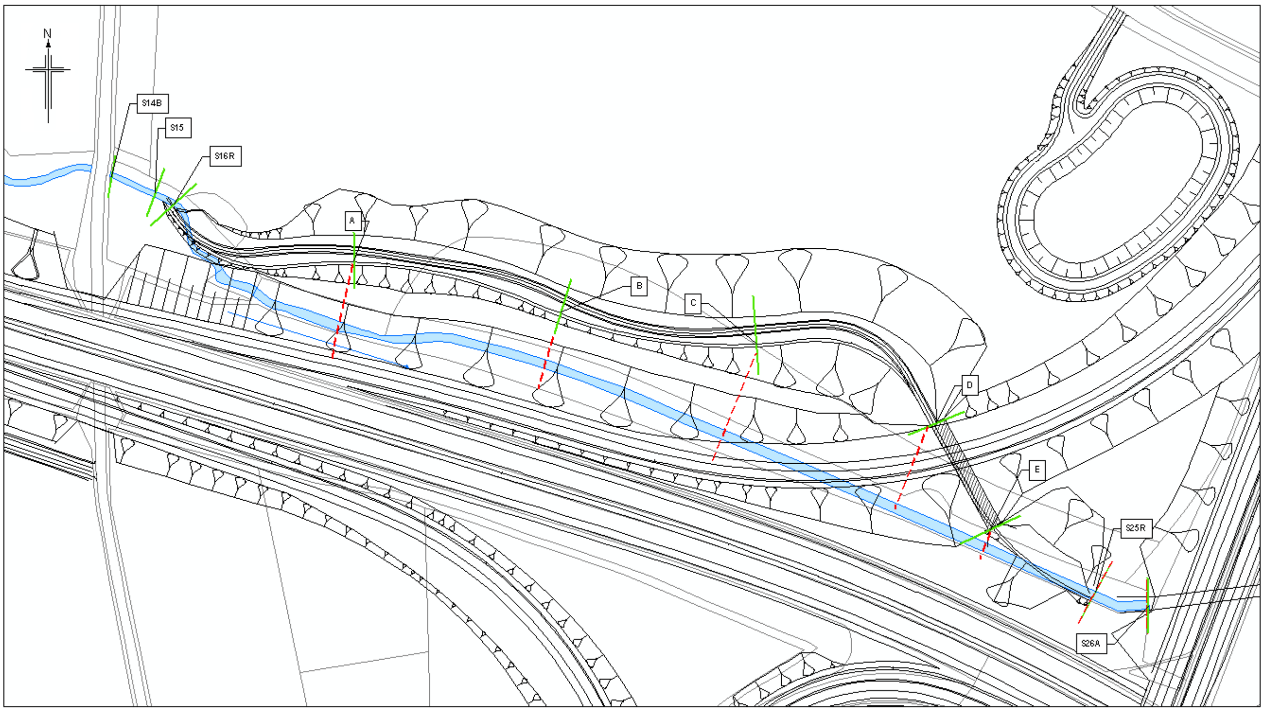
6.2.1 A comparison of the 0.5% AEP flood depths along the channel realignment compared to the flood depths along the reach of the existing Swine Burn channel adjacent to the realignment are presented in Table 6.1 below.

Table 6.1: Realignment Comparison (0.5% AEP)

Section	Existing			Realignment			Flood Depth Difference (change from Existing (m))
	Bed Level (mOD)	Max Predicted Flood Level (mOD)	Flood Depth (m)	Bed Level (mOD)	Max Predicted Flood Level (mOD)	Flood Depth (m)	
S14B	51.56	52.79	1.23	51.56	52.61	1.05	-0.18
S15	51.31	52.76	1.45	51.31	52.27	0.96	-0.49
S16R	51.22	52.63	1.41	51.22	52.15	0.93	-0.48
A	50.14	51.54	1.40	50.44	51.40	0.96	-0.44
B	49.09	50.52	1.43	49.66	50.58	0.92	-0.51
C	48.29	49.95	1.66	48.88	49.89	1.01	-0.65
D	47.72	49.40	1.68	48.10	49.67	1.57	-0.11
E	47.57	49.24	1.67	47.66	49.25	1.59	-0.08
S25R	47.20	48.90	1.70	47.20	48.91	1.71	+0.01
S26A	46.77	48.71	1.94	46.77	48.71	1.94	0

6.2.2 Diagram 6.1 indicates locations of comparisons in water depth between existing and realigned channels. As presented in Table 6.1, the 0.5% AEP flood depths along the realigned section of Swine Burn are expected to decrease by up to 650mm when compared to the adjacent section of the existing channel and generally show a decrease in flood depths along the realignment. In addition, the flood depths at the upstream and downstream extents of the proposed realignment show little change in flood depths from the existing scenario. Based on these results, the flood risk along Swine Burn realignment and directly upstream and downstream of the realignment is not expected to increase if the realigned channel is constructed using the configuration details presented above.

Diagram 6.1: Swine Burn Comparison Locations



6.3 Recommendations

6.3.1 A realigned channel which includes a 10m floodplain width and a 1.5m low flow channel (2.5m width at top of bank, 1.5m width at channel bottom, 0.5m depth) is considered adequate to address flood risk storage requirements along the realigned reach of the channel. Using this channel configuration, flood risk along the channel realignment and directly upstream and downstream of the realignment is not expected to increase.

6.3.2 Further refinement of the width of the floodplain channel has not been provided due to geomorphological considerations at the site. However, further narrowing of the floodplain channel may be possible if both flood risk and geomorphology requirements are met for a narrower floodplain channel.

7 Assessment of Compensatory storage Requirements

7.1 Introduction

7.1.1 The proposed scheme design as assessed and reported in the ES includes widening of the M9 roadway in vicinity of the Swine Burn, Niddry Burn, Tributary of Niddry Burn and River Almond. As a result, portions of the functional floodplain for each of these watercourses may be infilled. SEPA guidance (SEPA, 2008) suggests that ‘compensatory storage’ should be provided to mitigate against the lost conveyance capacity/storage volume and counteract the displacement of flood water.

7.1.2 Under current technical flood risk SEPA guidance (SEPA, 2008), any compensatory storage should be provided as close as possible to that lost, provide the same volume, and be at the same level as that lost (i.e. become effective at the same point within a flood event as the area that is lost). Such requirements are commonly termed ‘level for level’ compensatory storage.

7.1.3 In general, direct compensatory storage can be provided through direct connection between the watercourse and the floodplain by regrading the channel/floodplain profile.

7.1.4 The predicted compensatory volumes required for each watercourse have been determined in accordance with SEPA recommendations. Guidance contained within CIRIA C624 (CIRIA, 2004). has also been followed.

7.1.5 The methodology used in the determination of compensatory storage volumes is outlined below:

- Representative topographical information of river cross-sections of the existing channel and adjacent floodplain areas for the impacted area was collected.
- The estimation of volume of encroachment of existing functional floodplain along a channel was performed by first estimating its cross-sectional area. This estimation included consideration of the area between the 0.5% AEP floodwater levels and the ground elevations adjacent to the channel based on representative topographical information. The ground elevations of interest represent the ‘out-of-bank’ ground elevations from the ‘top of bank’ to the 0.5% AEP level. The ‘top of bank’ elevation of the existing channel has been defined as the bank elevations of the main channel.
- The predicted peak water levels at the impacted area for the 0.5% AEP event were extracted from available flood modelling results for the respective watercourses.
- The total area between top of bank and the 0.5% AEP water level was divided into a number of slices. The total number of slices varied depending on the distance between the ‘top of bank’ elevation and the 0.5% AEP levels, but generally included 5 – 10 increments.
- The cross-sectional area for each slice was then estimated.

- The volume representing each slice was estimated with consideration of the length along the channel and the gradient of the channel.

7.1.6 Compensatory storage has been proposed to include compensatory storage at a volume equal or greater for each slice of infilled area.

7.2 Swine Burn

7.2.1 The proposed scheme design includes realignment of the Swine Burn channel upstream of the M9 Spur carriageway. The realigned channel design includes a 10m wide floodplain to provide compensatory storage for a 20m wide extension of the M9 Spur culvert and a new culvert approximately 50m in length located approximately 60m upstream of inlet of the culvert extension.

7.2.2 This assessment included estimation of the floodplain volume lost for slices of various levels between the top of bank level and the 0.5% AEP flood level. This volume was then compared to the estimated volume gained by implementation of the realigned channel (volume in realigned channel - volume of existing channel).

7.2.3 A desktop volumetric check was performed to assess whether the compensatory storage within the realigned channel (between the proposed new culvert and the existing) would be adequate to mitigate against the volume lost by the floodplain encroachment following culvert extension. The results of this assessment for the culvert extension are presented in Table 7.1.

7.2.4 In addition, a volumetric check was performed to assess whether the compensatory storage within the realigned channel (for short reaches upstream and downstream of the proposed new culvert) would be adequate to mitigate against the volume lost by floodplain encroachment following construction of the new culvert. Results of this assessment for the proposed new culvert are presented in Table 7.2.

Table 7.1: Results of Assessment of Changes in Floodplain Storage along Swine Burn for Pre and Post Development Conditions with Consideration of the Proposed Extension to the Existing Culvert

Increment	Volume Gained in Realignment (m^3)	Volume Lost from Infill (m^3)	Difference in Floodplain Volume (m^3)
47.27 – 47.33mOD	0.4	2.7	-2.3
47.33 – 47.63mOD	6.7	18.3	-11.7
47.63 – 47.93mOD	66.1	26.4	39.7
47.93 – 48.23mOD	110.3	31.0	79.3
48.23 – 48.53mOD	129.7	38.0	91.7
48.53 – 48.83mOD	131.4	50.2	81.2

Table 7.2: Results of Assessment of Changes in Floodplain Storage along Swine Burn for Pre and Post Development Conditions with Consideration of the Proposed New Culvert Construction

Increment	Volume Gained in Realignment (m^3)	Volume Lost from Infill (m^3)	Difference in Floodplain Volume (m^3)
48.10 – 48.20mOD	10.5	2.78	8.2
48.20 – 48.30mOD	19.9	9.26	10.6
48.30 – 48.40mOD	26.4	16.5	9.9
48.40 – 48.50mOD	32.9	24.6	8.3
48.50 – 48.60mOD	39.4	33.6	5.8
48.60 – 48.70mOD	49.3	33.5	15.8
48.70 – 48.80mOD	63.6	36.1	27.5
48.80 – 48.90mOD	70.9	39.5	31.4
48.90 – 49.00mOD	72.8	42.9	29.9

Increment	Volume Gained in Realignment (m^3)	Volume Lost from Infill (m^3)	Difference in Floodplain Volume (m^3)
49.00 – 49.10mOD	74.7	46.6	28.1
49.10 – 49.20mOD	76.5	49.8	26.7
49.20 – 49.30mOD	78.4	53.0	25.4
49.30 – 49.40mOD	81.3	56.2	25.1

7.2.5 Table 7.1 presents the volumes gained along the proposed realigned channel directly upstream of the extended culvert, as compared to the floodplain lost due to the culvert extension. As indicated by Table 7.1, only the lower two slices lack sufficient compensatory storage volume. However, these levels are lower than the 'top-of-bank' levels at the location directly upstream of the proposed culvert extension. For geomorphology reasons it is not considered beneficial to widen the normal channel width. In addition, the larger volumes provided for slices at higher elevations are expected to mitigate against increased flood risk. It is therefore considered that the Swine Burn channel realignment provides sufficient compensatory storage for the proposed culvert extension. Provision of additional compensatory storage is not required for the proposed culvert extension.

7.2.6 Table 7.2 presents the volumes gained along the proposed new culverted section of the Swine Burn (including short reaches of realigned channel directly upstream and downstream of the proposed new culvert), as compared the existing floodplain volumes along the existing watercourse for the reach adjacent to the proposed culvert. As indicated by Table 7.2, adequate compensatory storage is provided for all increment levels. It is therefore concluded that the Swine Burn channel realignment together with the proposed culvert dimensions provide sufficient flood storage volume for the new proposed culvert location. Provision of additional compensatory storage is not required for the proposed new culvert construction.

7.3 Niddry Burn

7.3.1 The estimated compensatory storage volumes required for the Niddry Burn are presented in Tables 7.3 and 7.4 for upstream and downstream of the M9 respectively. These volumes were estimated based on an expected encroachment of 7m upstream and 7m downstream of the existing M9 crossing for the levels between top of bank height and 0.5% AEP flood levels, at both the upstream and downstream locations.

Table 7.3: Niddry Burn Compensatory Storage (Upstream of M9)

Increment	Compensatory Storage Volume Required (m^3)
37.0 – 37.3mOD	29.0
37.3 – 37.6mOD	63.9
37.6 – 37.9mOD	84.5
37.9 – 38.2mOD	103.8
38.2 – 38.5mOD	119.9
38.5 – 38.8mOD	131.1

Table 7.4: Niddry Burn Compensatory Storage (Downstream of M9)

Increment	Compensatory Storage Volume Required (m^3)
35.5 – 35.6mOD	4.5
35.6 – 35.7mOD	7.6
35.7 – 35.8mOD	13.2
35.8 – 35.9mOD	18.0
35.9 – 36.0mOD	22.3

7.3.2 The areas available for environmental mitigation as presented in Figure 12.4(m) upstream and downstream of the M9 culvert along Niddry Burn are deemed suitable to provide adequate compensatory storage along the banks of Niddry Burn both upstream and downstream of the M9 culvert based on a preliminary desktop analysis. For the purposes of this study, a detailed assessment of compensatory storage sizing has not been undertaken. It is expected that the area required for the compensatory storage would be smaller than those areas presented in Figure 12.4(m). However, it is proposed that compensatory storage areas be provided within the boundaries of the areas presented in Figure 12.4(m), so as to be located as close as possible to the points of lost floodplain.

8 Tributary of Niddry Burn

8.1 Introduction

8.1.1 The estimated compensatory storage volumes required for the Tributary of Niddry Burn are presented in Table 8.1 below. These volumes were estimated based on an expected encroachment of 5m upstream (where encroachment of the existing floodplain is expected). Although roadway widening is planned downstream of the culvert, floodplain encroachment is not expected in this location due to flow containment within the main channel. This assessment considered levels between top of bank height and the 0.5% AEP flood levels directly upstream of the existing M9 culvert.

Table 8.1: Tributary of Niddry Burn Compensatory Storage Requirements

Increment	Compensatory Storage Volume Required (m^3)
38.1 - 38.2mOD	23.1
38.2 - 38.3mOD	26.6
38.3 - 38.4mOD	29.7
38.4 - 38.5mOD	32.7
38.5 – 38.6mOD	35.6
38.6 – 38.7mOD	38.5
38.7 – 38.8mAOD	41.1

8.1.2 The areas presented for environmental mitigation in Figure 12.4(m) upstream of the M9 culvert along the Tributary of Niddry Burn are deemed suitable to provide adequate compensatory storage for the Tributary of Niddry Burn based on a preliminary desktop analysis. For the purposes of this study, a detailed assessment of compensatory storage sizing has not been undertaken. However, it is proposed that compensatory storage areas be provided within the boundaries of the areas presented in Figure 12.4(m), so as to be located as close as possible to the points of lost floodplain.

8.2 River Almond

8.2.1 The compensatory storage volume requirements along the River Almond have been estimated based on an assumed motorway widening of 5m on the western side of the embankment on the approach road to the bridge crossing the River Almond. A 0.5% AEP flood level of 35.2mOD in the undeveloped area north of the B800 west of the M9 was assumed based on flood levels within the River Almond as provided by City of Edinburgh Council. Using available topographical mapping of the floodplain area, the volume of required compensatory storage was estimated, as presented in Table 8.2.

Table 8.2: River Almond Compensatory Storage

Increment	Compensatory Storage Volume Required (m^3)
34.0 – 34.2mOD	55.4
34.2 – 34.4mOD	60.7
34.4 – 34.6mOD	66.0
34.6 – 34.8mOD	71.3
34.8 – 35.0mOD	76.6
35.0 – 35.2mOD	80.5

8.2.2 The area presented for environmental mitigation in Figure 12.4(m) upstream of the River Almond bridge crossing is deemed suitable to provide adequate compensatory storage for the River Almond based on a preliminary desktop analysis. For the purposes of this study, a detailed assessment of compensatory storage sizing has not been undertaken. However, it is proposed that compensatory storage areas be provided within the boundaries of the area presented in Figure 12.4(m), so as to be located as close as possible to the points of lost floodplain.

9 Conclusions

9.1.1 This appendix has been prepared as part of the culvert sizing assessments and flood modelling along Niddry Burn and Swine Burn for the proposed scheme.

9.1.2 One-dimensional (1D) hydraulic models to include the hydraulic features within the study areas have been constructed using the ISIS river modelling software package. Niddry Burn and Swine Burn have been modelled independently of each other as it was concluded during site inspections that the two watercourses are hydraulically separated.

9.1.3 The representation of Niddry Burn and Swine Burn in the respective river models has been based on recently collected river survey information, which includes river cross-sections at a maximum interval of 200m and hydraulic structures, and recently collected geodetic survey information to characterise out-of-bank topography. The survey information was supplemented by measurements taken during site walkover inspections, with site observations used to assess roughness parameters.

9.1.4 The flood levels along Niddry Burn have been shown to be most affected by the existing hydraulic structure at the M9, while those along Swine Burn have been shown to be most affected by the existing hydraulic structures at the railway bridge, at the B9080, at the Overton Bridge, and at the M9 Spur.

9.1.5 Through sensitivity analyses of Niddry Burn and Swine Burn it was found that:

- The hydraulic models were shown to be relatively insensitive to increases in channel roughness along the respective reaches upstream of the existing M9 crossings.
- The assessment of a potential blockage or breach of the Overton Bridge on Swine Burn showed that neither is expected to impact water levels outwith the immediate vicinity of the Overton Bridge.
- Sensitivity analysis on the downstream boundaries of Niddry Burn and Swine Burn models showed that increases in water levels at their respective downstream boundaries are not expected to impact water levels upstream of the M9 culverts in the vicinity of the proposed works.

9.1.6 The flood levels within both Niddry Burn and Swine Burn are considered to be relatively sensitive to a 20% increase in flood event flows attributed to climate change. However, it is considered detrimental to include climate change impacts in the design flow of the new culvert along Swine Burn, as doing so could exacerbate flood risk along the reach of the Swine Burn between the proposed culvert and the existing M9 culvert.

9.1.7 The predicted results developed in this study estimate more accurately the flood effects along Niddry Burn and Swine Burn over the SEPA flood mapping due to:

- more refined hydrology and understanding of hydraulic connectivity;
- more accurate representation of the watercourse dimensions;
- more accurate representation of hydraulic structures; and
- more accurate assessment of backwater effects of hydraulic structures on upstream water levels.

9.1.8 A culvert size of opening 6.0m wide and 2.1m high (with 0.3m embedded material) is recommended for the proposed new Swine Burn culvert, based on standard pre-cast concrete rectangular culverts.

9.1.9 A channel realignment which includes a 10m wide floodplain and a 1.5m wide low flow channel (2.5m wide at top of bank, 1.5m wide at bed level and 0.5m depth) has been included in the hydraulic model. Based on the results of this assessment, the 0.5% AEP flood levels are not expected to increase from pre-development levels along the full length of the realignment or directly upstream or downstream of the realignment. These channel dimensions are considered appropriate to provide sufficient flood storage along the full reach of the realigned channel.

9.1.10 Compensatory storage volumes for slices at different levels should be provided as presented above for the Niddry Burn, the Tributary of Niddry Burn and River Almond to mitigate against increases in flood risk in areas where floodplain encroachment is proposed.

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Annex A: Simulation Results

Table A1: Niddry Burn Existing Scenario Water Levels

Location	Model Node	Bed Level	Soffit Level	Maximum Predicted Water Level (mOD) for Design Flood Flows (%AEP)						
		(mOD)	(mOD)	50	20	10	4	2	1	0.5
Upstream boundary	N1	43.56	-	44.30	44.42	44.48	44.54	44.60	44.65	44.70
	N2	40.83	-	41.74	41.83	41.89	41.96	42.01	42.06	42.11
	N3	37.33	-	38.40	38.52	38.59	38.72	38.85	38.93	39.02
Upstream of farm access track 1	N3A	36.90	-	37.90	38.03	38.24	38.54	38.65	38.75	38.88
	N3B	36.87	-	37.85	37.99	38.07	38.18	38.32	38.52	38.81
	N4	36.35	-	37.33	37.56	37.69	37.85	38.06	38.41	38.81
Upstream of farm access track2	N5	36.15	-	37.09	37.33	37.57	37.78	38.02	38.40	38.80
	N6	35.80	-	36.98	37.26	37.49	37.72	37.97	38.38	38.79
Upstream of M9 culvert	N7A	35.66	37.46	36.88	37.16	37.36	37.62	37.89	38.36	38.78
	N7B	34.80	36.60	35.72	35.90	35.98	36.10	36.19	36.30	36.41
	N8	34.63	-	35.34	35.50	35.58	35.69	35.79	35.89	36.00
	N9	33.77	-	35.14	35.32	35.41	35.53	35.61	35.73	35.85
	N10	32.46	-	33.54	33.69	33.78	33.89	34.00	34.11	34.23
Upstream of B800 culvert	N16	30.57	32.35	32.01	32.35	32.60	32.90	33.09	33.29	33.48
Downstream boundary	N17	30.02	-	32.00	32.35	32.60	32.90	33.09	33.29	33.48

Table A2: Niddry Burn Roughness Sensitivity Water Levels

Location	Model Node	Bed Level (mOD)	Soffit Level (mOD)	Existing Scenario 0.5% AEP (mOD)	Roughness +20% 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	N1	43.56	-	44.70	44.77	+70
	N2	40.83	-	42.11	42.17	+60
	N3	37.33	-	39.02	39.04	+20
Upstream of farm access track 1	N3A	36.90	-	38.88	38.89	+10
	N3B	36.87	-	38.81	38.83	+20
	N4	36.35	-	38.81	38.81	0
Upstream of farm access track 2	N5	36.15	-	38.80	38.81	+10
	N6	35.80	-	38.79	38.80	+10
Upstream of M9 culvert	N7A	35.66	37.46	38.78	38.78	0
	N7B	34.80	36.60	36.41	36.54	+130
	N8	34.63	-	36.00	36.07	+70
	N9	33.77	-	35.85	36.00	+150
	N10	32.46	-	34.23	34.36	+130
Upstream of B800 culvert	N16	30.57	32.35	33.48	33.49	+10
Downstream boundary	N17	30.02	-	33.48	33.48	0

Table A3: Niddry Burn Downstream Boundary Sensitivity Water Levels

Location	Model Node	Bed Level (mOD)	Soffit Level (mOD)	Existing Scenario 0.5% AEP (mOD)	Downstream Boundary +0.5m 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	N1	43.56	-	44.70	44.70	0
	N2	40.83	-	42.11	42.11	0
	N3	37.33	-	39.02	39.02	0
Upstream of farm access track 1	N3A	36.90	-	38.88	38.88	0
	N3B	36.87	-	38.81	38.81	0
	N4	36.35	-	38.81	38.81	0
Upstream of farm access track 2	N5	36.15	-	38.80	38.80	0
	N6	35.80	-	38.79	38.79	0
Upstream of M9 culvert	N7A	35.66	37.46	38.78	38.78	0
	N7B	34.80	36.60	36.41	36.41	0
	N8	34.63	-	36.00	35.99	-10
	N9	33.77	-	35.85	35.83	-20
	N10	32.46	-	34.23	34.30	+70
Upstream of B800 culvert	N16	30.57	32.35	33.48	33.98	+500
Downstream boundary	N17	30.02	-	33.48	33.98	+500

Table A4: Swine Burn Existing Scenario Water Levels

Location	Model Node	Bed Level	Soffit Level	Maximum Predicted Water Level (mOD) for Design Flood Flows (%AEP)						
		(mOD)	(mOD)	50	20	10	4	2	1	0.5
Upstream boundary	S1	60.31	-	61.13	61.24	61.31	61.40	61.48	61.56	61.65
	S2	58.82	-	59.47	59.59	59.68	59.79	59.88	59.99	60.13
Upstream of railway culvert	S3A	57.84	60.57	58.86	59.03	59.14	59.30	59.43	59.57	59.75
	S3B	57.76	60.49	58.61	58.70	58.74	58.80	58.85	58.90	58.95
Upstream of pipe crossing	S4	57.49	-	58.60	58.68	58.72	58.79	58.83	58.88	58.93
	S5	57.38	-	58.00	58.10	58.16	58.25	58.29	58.35	58.40
	S6	55.76	-	56.50	56.61	56.66	56.73	56.78	56.82	56.85
Upstream of B9080 culvert	S7A	54.72	56.26	55.86	56.12	56.33	56.48	56.55	56.58	56.58
	S7B	54.73	-	55.52	55.62	55.68	55.76	55.82	55.89	55.95
	S8	53.63	-	54.41	54.54	54.62	54.73	54.81	54.90	54.98
	S10	52.63	-	53.33	53.41	53.46	53.53	53.60	53.67	53.77
	S11	52.17	-	53.06	53.17	53.23	53.33	53.42	53.54	53.70
	S12	52.12	-	52.92	53.06	53.13	53.24	53.35	53.49	53.66
	S13	51.84	-	52.64	52.79	52.88	53.05	53.23	53.43	53.62
Upstream of Overton Bridge	S14A	51.58	53.54	52.30	52.48	52.62	52.83	53.00	53.19	53.40
	S14B	51.56	-	52.24	52.37	52.44	52.54	52.62	52.70	52.79
	S15	51.31	-	52.21	52.37	52.46	52.57	52.64	52.72	52.76
	S16	51.17	-	52.04	52.16	52.23	52.31	52.37	52.47	52.56
	S17	49.16	-	50.01	50.12	50.19	50.29	50.36	50.47	50.57
	S18	48.72	-	49.61	49.73	49.81	49.93	50.03	50.14	50.25
	S19	48.43	-	49.42	49.57	49.67	49.83	49.95	50.07	50.18
	S20	48.34	-	49.33	49.47	49.57	49.70	49.80	49.91	50.02
	S21	48.16	-	49.22	49.35	49.44	49.56	49.65	49.75	49.87
	S22	48.06	-	49.02	49.15	49.22	49.34	49.43	49.53	49.65

Location	Model Node	Bed Level (mOD)	Soffit Level (mOD)	Maximum Predicted Water Level (mOD) for Design Flood Flows (%AEP)						
				50	20	10	4	2	1	0.5
	S23	47.77	-	48.87	49.00	49.06	49.17	49.25	49.35	49.45
	S24	47.50	-	48.46	48.53	48.63	48.77	48.88	49.01	49.17
	S25	47.23	-	48.05	48.19	48.29	48.43	48.56	48.74	48.93
Upstream of M9 Spur culvert	S26A	46.77	48.58	47.66	47.87	48.00	48.19	48.35	48.52	48.71
	S26B	45.66	47.61	46.51	46.59	46.65	46.72	46.77	46.83	46.88
	S28	45.35	-	46.19	46.25	46.28	46.32	46.35	46.40	46.45
Pike's Pond	S29	45.24	-	45.84	45.91	45.95	46.01	46.05	46.12	46.22

Table A5: Swine Burn Roughness Sensitivity Water Levels

Location	Model Node	Bed Level (mOD)	Soffit Level (mOD)	Existing Scenario 0.5% AEP (mOD)	Roughness +20% 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	S1	60.31	-	61.65	61.74	+90
	S2	58.82	-	60.13	60.25	+120
Upstream of railway culvert	S3A	57.84	60.57	59.75	59.85	+100
	S3B	57.76	60.49	58.95	58.97	+20
Upstream of pipe crossing	S4	57.49	-	58.93	58.93	0
	S5	57.38	-	58.40	58.48	+80
	S6	55.76	-	56.85	56.92	+70
Upstream of B9080 culvert	S7A	54.72	56.26	56.58	56.64	+60
	S7B	54.73	-	55.95	56.08	+130
	S8	53.63	-	54.98	55.01	+30
	S10	52.63	-	53.77	53.88	+110
	S11	52.17	-	53.70	53.76	+60
	S12	52.12	-	53.66	53.71	+50
	S13	51.84	-	53.62	53.65	+30
Upstream of Overton Bridge	S14A	51.58	53.54	53.40	53.41	+10
	S14B	51.56	-	52.79	52.78	-10
	S15	51.31	-	52.76	52.71	-50
	S16	51.17	-	52.56	52.62	+60
	S17	49.16	-	50.57	50.64	+70
	S18	48.72	-	50.25	50.36	+110
	S19	48.43	-	50.18	50.27	+90
	S20	48.34	-	50.02	50.13	+110
	S21	48.16	-	49.87	49.99	+120
	S22	48.06	-	49.65	49.78	+130
	S23	47.77	-	49.45	49.59	+140
	S24	47.50	-	49.17	49.28	+110
	S25	47.23	-	48.93	49.02	+90
Upstream of M9 Spur culvert	S26A	46.77	48.58	48.71	48.71	0
	S26B	45.66	47.61	46.88	46.97	+90
	S28	45.35	-	46.45	46.49	+40
Pike's Pond	S29	45.24	-	46.22	46.24	+20

Table A6: Swine Burn Overton Bridge 90% Blocked Water Levels

Location	Model Node	Bed Level (mOD)	Soffit Level (mOD)	Existing Scenario 0.5% AEP (mOD)	Bridge 90% Blocked 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	S1	60.31	-	61.65	61.65	0
	S2	58.82	-	60.13	60.13	0
Upstream of railway culvert	S3A	57.84	60.57	59.75	59.75	0
	S3B	57.76	60.49	58.95	58.95	0
Upstream of pipe crossing	S4	57.49	-	58.93	58.93	0
	S5	57.38	-	58.40	58.40	0
	S6	55.76	-	56.85	56.85	0
Upstream of B9080 culvert	S7A	54.72	56.26	56.58	56.58	0
	S7B	54.73	-	55.95	55.93	-20
	S8	53.63	-	54.98	55.22	+240
	S10	52.63	-	53.77	54.96	+1,190
	S11	52.17	-	53.70	54.97	+1,270
	S12	52.12	-	53.66	54.97	+1,310
	S13	51.84	-	53.62	54.97	+1,350
Upstream of Overton Bridge	S14A	51.58	53.54	53.40	54.95	+1,550
	S14B	51.56	-	52.79	52.79	0
	S15	51.31	-	52.76	52.74	-20
	S16	51.17	-	52.56	52.57	+10
	S17	49.16	-	50.57	50.58	+10
	S18	48.72	-	50.25	50.24	-10
	S19	48.43	-	50.18	50.19	+10
	S20	48.34	-	50.02	50.02	0
	S21	48.16	-	49.87	49.87	0
	S22	48.06	-	49.65	49.65	0
	S23	47.77	-	49.45	49.45	0
	S24	47.50	-	49.17	49.17	0
	S25	47.23	-	48.93	48.94	+10
Upstream of M9 Spur culvert	S26A	46.77	48.58	48.71	48.72	+10
	S26B	45.66	47.61	46.88	46.88	0
	S28	45.35	-	46.45	46.45	0
Pike's Pond	S29	45.24	-	46.22	46.22	0

Table A7: Swine Burn Overton Bridge Removed Water Levels (Breach Scenario)

Location	Model Node	Bed Level	Soffit Level	Existing Scenario 0.5% AEP	Bridge Removed 0.5% AEP	Difference
		(mOD)	(mOD)	(mOD)	(mOD)	(mm)
Upstream boundary	S1	60.31	-	61.65	61.65	0
	S2	58.82	-	60.13	60.13	0
Upstream of railway culvert	S3A	57.84	60.57	59.75	59.75	0
	S3B	57.76	60.49	58.95	58.95	0
Upstream of pipe crossing	S4	57.49	-	58.93	58.93	0
	S5	57.38	-	58.40	58.40	0
	S6	55.76	-	56.85	56.85	0
Upstream of B9080 culvert	S7A	54.72	56.26	56.58	56.58	0
	S7B	54.73	-	55.95	55.94	-10
	S8	53.63	-	54.98	55.00	+20
	S10	52.63	-	53.77	53.68	-90
	S11	52.17	-	53.70	53.50	-200
	S12	52.12	-	53.66	53.37	-290
	S13	51.84	-	53.62	53.14	-480
Upstream of Overton Bridge	S14A	51.58	53.54	53.40	52.86	-540
	S14B	51.56	-	52.79	52.79	0
	S15	51.31	-	52.76	52.76	0
	S16	51.17	-	52.56	52.58	+20
	S17	49.16	-	50.57	50.58	+10
	S18	48.72	-	50.25	50.24	-10
	S19	48.43	-	50.18	50.18	0
	S20	48.34	-	50.02	50.03	+10
	S21	48.16	-	49.87	49.88	+10
	S22	48.06	-	49.65	49.64	-10
	S23	47.77	-	49.45	49.45	0
	S24	47.50	-	49.17	49.18	+10
	S25	47.23	-	48.93	48.94	+10
Upstream of M9 Spur culvert	S26A	46.77	48.58	48.71	48.72	+10
	S26B	45.66	47.61	46.88	46.89	+10
	S28	45.35	-	46.45	46.45	0
Pike's Pond	S29	45.24	-	46.22	46.22	0

Table A8: Niddry Burn Climate Change Water Levels (+20% Flow Increase)

Location	Model Node	Bed Level (mOD)	Soffit Level (mOD)	Existing Scenario 0.5% AEP (mOD)	Climate Change 0.5% AEP (mOD)	Difference (mm)
Upstream boundary	N1	43.56	-	44.70	44.77	+70
	N2	40.83	-	42.11	42.16	+50
	N3	37.33	-	39.02	39.50	+480
Upstream of farm access track 1	N3A	36.90	-	38.88	39.50	+620
	N3B	36.87	-	38.81	39.49	+680
	N4	36.35	-	38.81	39.49	+680
Upstream of farm access track 2	N5	36.15	-	38.80	39.49	+690
	N6	35.80	-	38.79	39.48	+690
Upstream of M9 culvert	N7A	35.66	37.46	38.78	39.48	+700
	N7B	34.80	36.60	36.41	36.55	+140
	N8	34.63	-	36.00	36.13	+130
	N9	33.77	-	35.85	35.94	+90
	N10	32.46	-	34.23	34.41	+180
Upstream of B800 culvert	N16	30.57	32.35	33.48	33.92	+440
Downstream boundary	N17	30.02	-	33.48	33.92	+440

Table A9: Swine Burn Climate Change Water Levels (+20% Flow Increase)

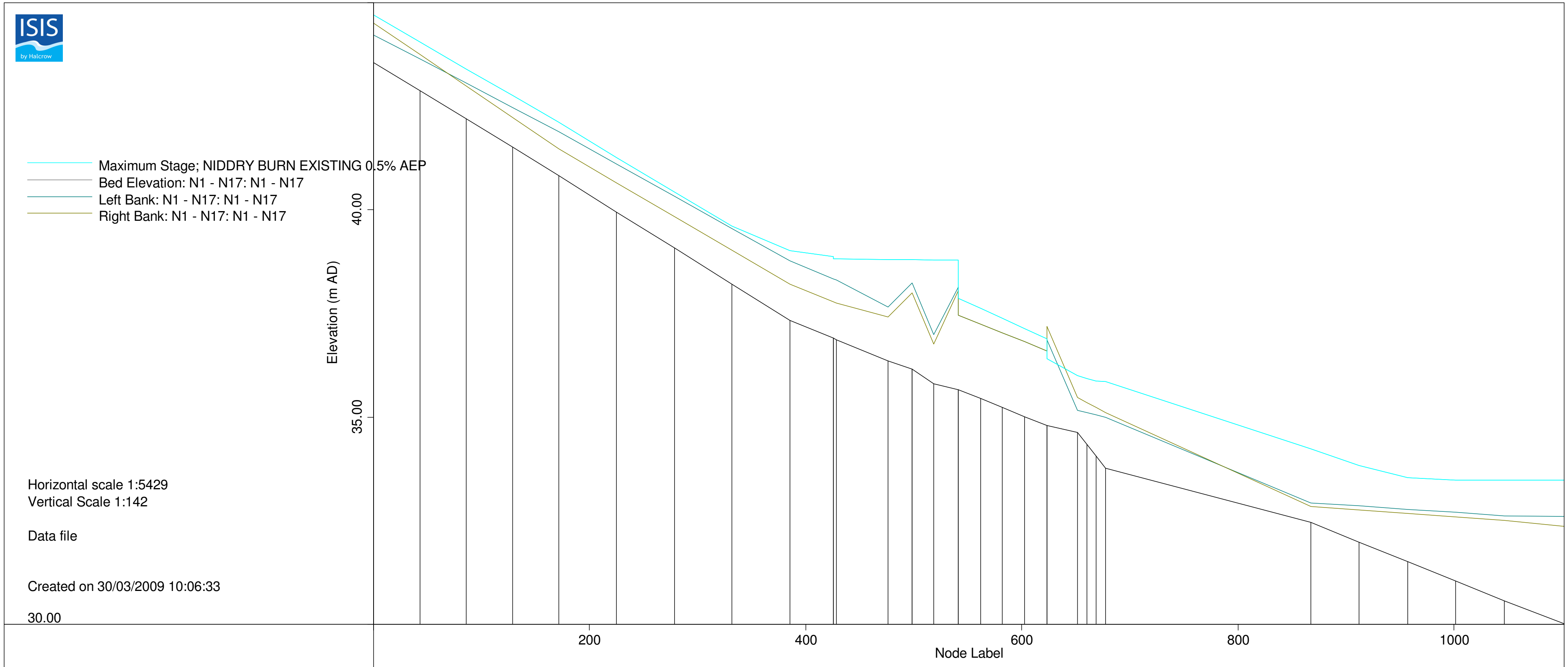
Location	Model Node	Bed Level	Soffit Level	Existing Scenario 0.5% AEP	Climate Change 0.5% AEP	Difference
		(mOD)	(mOD)	(mOD)	(mOD)	(mm)
Upstream boundary	S1	60.31	-	61.65	61.72	+70
	S2	58.82	-	60.13	60.29	+160
Upstream of railway culvert	S3A	57.84	60.57	59.75	60.00	+250
	S3B	57.76	60.49	58.95	59.01	+60
Upstream of pipe crossing	S4	57.49	-	58.93	59.00	+70
	S5	57.38	-	58.40	58.48	+80
	S6	55.76	-	56.85	56.91	+60
Upstream of B9080 culvert	S7A	54.72	56.26	56.58	56.63	+50
	S7B	54.73	-	55.95	56.02	+70
	S8	53.63	-	54.98	55.08	+100
	S10	52.63	-	53.77	53.96	+190
	S11	52.17	-	53.70	53.94	+240
	S12	52.12	-	53.66	53.92	+260
	S13	51.84	-	53.62	53.89	+270
Upstream of Overton Bridge	S14A	51.58	53.54	53.40	53.70	+300
	S14B	51.56	-	52.79	52.89	+100
	S15	51.31	-	52.76	52.85	+90
	S16	51.17	-	52.56	52.68	+120
	S17	49.16	-	50.57	50.67	+100
	S18	48.72	-	50.25	50.38	+130
	S19	48.43	-	50.18	50.31	+130
	S20	48.34	-	50.02	50.16	+140
	S21	48.16	-	49.87	50.02	+150
	S22	48.06	-	49.65	49.78	+130
	S23	47.77	-	49.45	49.59	+140
	S24	47.50	-	49.17	49.37	+200
	S25	47.23	-	48.93	49.20	+270
Upstream of M9 Spur culvert	S26A	46.77	48.58	48.71	48.97	+260
	S26B	45.66	47.61	46.88	46.96	+80
	S28	45.35	-	46.45	46.53	+80
Pike’s Pond	S29	45.24	-	46.22	46.36	+140

Annex B: Existing Scenario Figures

Figure 1 - Niddry Burn 0.5% AEP Existing Scenario

Long Section: N1 - N17 - Maximum Stage

Node: N1

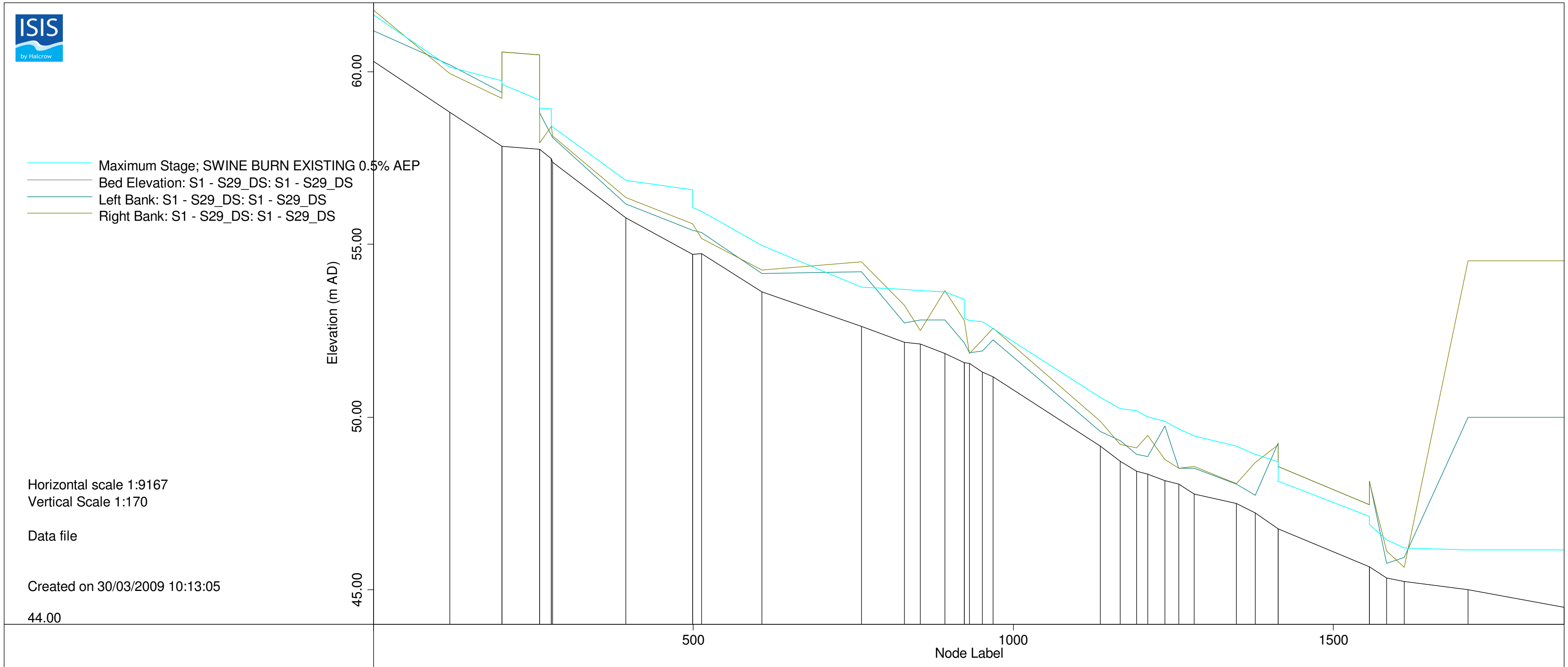


Label	Chainage	Maximum Stage; NIDDRY BURN EXISTING 0.5% AEP	Bed Elevation: N1 - N17: N1 - N17	Left Bank: N1 - N17: N1 - N17	Right Bank: N1 - N17: N1 - N17
N1	0	44.70	43.56	44.22	44.51
I_1A	43	44.05	42.88	43.64	43.75
I_1B	86	43.40	42.19	43.06	42.99
I_1C	128	42.76	41.51	42.47	42.23
N2	171	42.11	40.83	41.89	41.47
I_2A	225	41.26	39.96	41.11	40.65
I_2B	278	40.44	39.08	40.33	39.84
I_2C	332	39.61	38.21	39.55	39.03
N3	385	39.02	37.33	38.77	38.21
N3A	425	38.88	36.90	38.34	37.78
N4	476	38.81	36.35	37.66	37.42
N5	498	38.80	36.15	38.23	38.00
N6	518	38.79	35.80	36.99	36.76
N7A	541	38.78	35.66	38.13	38.05
R1	562	37.63	35.44	37.24	37.24
R2	582	37.38	35.23	37.03	37.03
R3	603	37.13	35.01	36.81	36.81
CULV_7LHDS	623	36.88	34.80	36.60	36.60
N8	651	36.00	34.63	35.16	35.47
N8_IB	669	35.88	34.06	35.05	35.23
N10	867	34.23	32.46	32.93	32.84
N10_IA	912	33.83	31.99	32.85	32.76
N10_IB	957	33.53	31.51	32.78	32.67
N10_IC	1002	33.48	31.04	32.70	32.59
N16	1046	33.48	30.57	32.62	32.51
N17	1102	33.48	30.02	32.60	32.36

Figure 2 - Swine Burn 0.5% AEP Existing Scenario

Long Section: S1 - S29_DS - Maximum Stage

Node: S1



Chainage	0	119	201	259	394	499	607	763	830	854	893	923	951	1136	1167	1193	1237	1283	1349	1377	1413	1557	1583	1611	1711	1861
Maximum Stage; SWINE BURN EXISTING 0.5% AEP	61.65	60.13	59.75	59.19	56.85	56.58	54.98	53.77	53.70	53.66	53.62	53.40	52.76	50.57	50.25	50.18	49.87	49.45	49.17	48.93	48.71	47.12	46.45	46.22	46.17	46.16
Bed Elevation: S1 - S29_DS: S1 - S29_DS	60.31	58.82	57.84	57.76	55.76	54.72	53.63	52.63	52.17	52.12	51.84	51.58	51.31	49.16	48.72	48.43	48.16	47.77	47.50	47.23	46.77	45.66	45.35	45.24	45.00	44.50
Left Bank: S1 - S29_DS: S1 - S29_DS	61.19	60.20	59.40	60.49	56.18	55.41	54.16	54.20	52.72	52.81	52.82	52.15	51.91	49.59	49.32	48.93	49.74	48.52	48.06	47.73	49.25	47.46	45.76	45.94	50.00	50.00
Right Bank: S1 - S29_DS: S1 - S29_DS	61.78	59.94	59.24	60.49	56.37	55.60	54.26	54.50	53.23	52.51	53.66	52.80	52.23	49.87	49.22	49.11	48.78	48.56	48.07	48.69	49.20	47.46	46.12	45.64	54.52	54.52
Label	S1	S2	S3A	RAIL_DS	S6	S7A	S8	S10	S11	S12	S13	S14A	S15	S17	S18	S19	S21	S23	S24	S25	S26A	CULV_7RHDS	S28	S29	S29_US	S29_DS