Dean Moor
Solar Farm

Environmental Statement: Appendix 2.4 – Flood Risk Assessment and Outline Drainage Strategy Appendix D Hydraulic Modelling

on behalf of **FVS Dean Moor Limited**

26 August 2025
Prepared by: Stantec UK Ltd
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Revision: 1

DEAN MOOR SOLAR FARM

FRA AND ODS APPENDIX D

HYDRAULIC ANALYSIS OF FLOOD FLOWS IN ORDINARY WATERCOURSES

PLANNING INSPECTORATE REFERENCE EN010155

PREPARED ON BEHALF OF FVS DEAN MOOR LIMITED

Regulation: 5(2)a

Project Ref:	**EN010155/FRA and ODS Appendix D**
Status	Final
Issue/ Rev:	1
Date:	August 2025

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1 Introduction

1.1.1 This Hydraulic Analysis of Flood Flows in Ordinary Watercourses is provided as Appendix D to the Flood Risk Assessment (FRA) and Outline Drainage Strategy (ODS) [AS-013] which has been prepared to support the application for a Development Consent Order (DCO) for the Dean Moor Solar Farm (the Proposed Development) on approximately 276.50ha of land located between the villages of Gilgarran and Branthwaite in West Cumbria (the Site) which sits in the administrative area of Cumberland Council (the Council).

1.1.2 A number of ordinary watercourses flow across the Site. The Environment Agency (EA) Risk of Flooding from Surface Water (RoFSW) mapping, updated in January 2025 with the outputs of the EA National Flood Risk Assessment (NaFRA) Study[1], has been used within the FRA as a proxy for the fluvial flood risk, in the absence of 'detailed' hydraulic modelling over the Site and surrounding area.

1.1.3 This approach taken in the FRA was (and remains) robust on the basis that (i) the flood risk areas are generally well defined along the key land drainage channels through the Site, (ii) it was proportionate given the nature of the Proposed Development, the general low flood risk, and the level of detail available at this stage (i.e. maximum parameters defining acceptable uses in strategic areas), and (iii) the provision of minimum 8m buffers along watercourses through the Site to minimise impacts to flow routes. This approach has been agreed with the Council) as the Lead Local Flood Authority (LLFA), who stated in their DCO Additional Submission (AS) response (dated 22nd May 2025) [**AS-004**] that:

'*The FRA & ODS is a very comprehensive document and includes all the necessary measures and procedures as previously discussed and agreed. I am satisfied that with the measures considered and proposed at this stage for surface water management the development will not increase flood risk to the site nor downstream.*'

[1] UK Government (2025). Flood Map for Planning. Available at: https://flood-map-for-planning.service.gov.uk/ Accessed June 2025

1.1.4 The EA have maintained concerns that a more detailed analysis will enable verification of the suitability of the RoFSW mapping in the absence of detailed fluvial modelling in the area where the ordinary watercourses converge before discharging off-Site and becoming a main river (Lostrigg Beck).

1.1.5 This hydraulic analysis technical note (TN) has been prepared to address this matter and is included as Appendix D in the updated FRA (August 2025).

2 Background

2.1.1 The EA's DCO Relevant Representation (RR) [RR-017] dated 17th June 2025 provided feedback to the DCO application submission, which included the FRA and ODS. In their response the EA raised the following:

'The Applicant relies on Flood Zone 1 classification from the Flood Map for Planning (FMfP) and Risk of Flooding from Rivers and Sea (RoFRS) mapping without site-specific hydraulic modelling. This is problematic because both FMfP and RoFRS contain evidence gaps, particularly for catchments under 3km²…

…The Applicant should carry out an assessment of fluvial flood risk to address the evidence gap. This will inform the design, ensure that a sequential approach is properly applied, and allow appropriate mitigation such as siting sensitive equipment or providing freeboard relative to the design flood level.

Clarify the intended use and limitations of the NaFRA2 and FMfP datasets. Reassess fluvial flood risk for all relevant watercourses using appropriate methodologies for small catchments.'

2.1.2 The RR also set out a proposed methodology and estimated flows for the catchment area that could be utilised to provide a greater level of reassurance to verify that the EA's national scale mapping was broadly accurate across the Site.

2.1.3 A meeting was held with the EA planning and modelling teams on 17th July 2025. It was agreed that a hydraulic analysis based on the generation of rating curves, and utilising the EA-advised flows, would be a proportionate way to address the matter, Subsequent correspondence confirmed the approach as follows (refer to emails dated 21st and 22nd July 2025 in Annex A):

- Extract approx. 5 no. cross sections from the topographic survey (FRA Appendix B), across floodplain/watercourses at downstream end of the Site (i.e. in the vicinity of Work No. 2 (Grid Connection Infrastructure) and downstream);
- Generate estimates of watercourse gradient and roughness coefficients from the survey and photos;
- Undertake rating curve analysis in Flood Modeller software to generate flow – level relationship at each section i.e. Manning's equation analysis;
- Sensitivity tests on roughness coefficients, to understand impact on estimated flood levels; and
- Produce figure(s) showing extent of flooding at each section for advised peak flow, for comparison with RoFSW mapping.

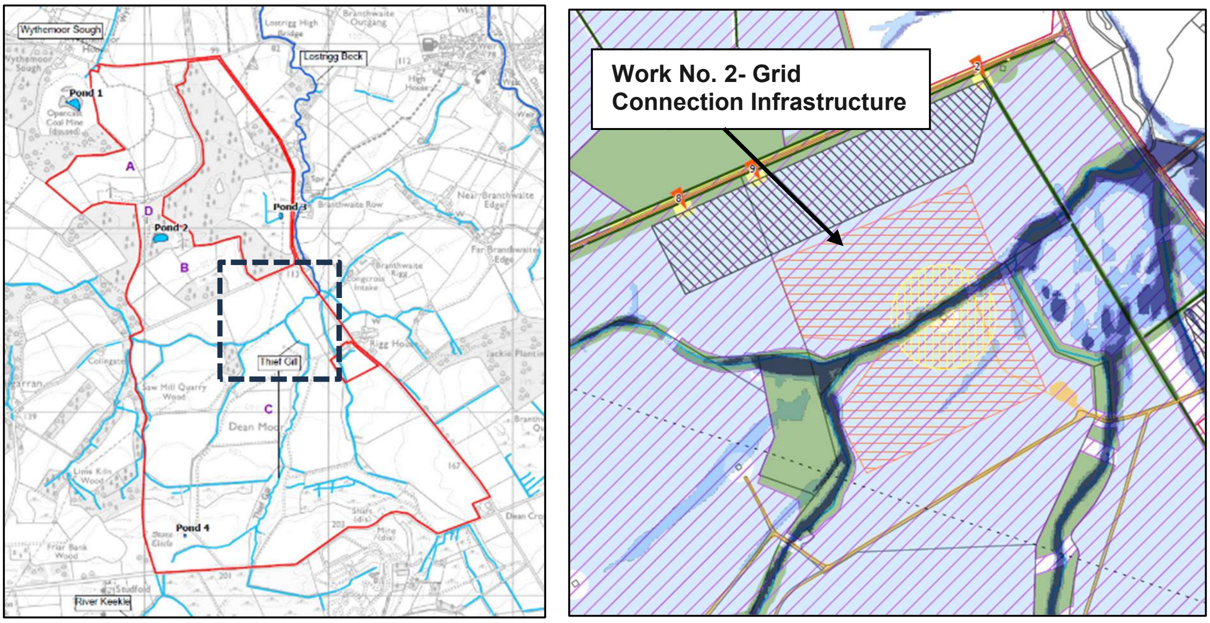
2.2 Location of Analysis

2.2.1 The EA confirmed that their primary interest is around the downstream end of the ordinary watercourses within the Site, where the channels converge and the Work Plans [**APP-007**] identifies Work No. 2 Grid Connection Infrastructure which is identified via the orange hatched square in Figure 1 of this TN (adapted from the ES Figure 3.4 Parameter Plan [**APP-049**]), stating:

‘We note that solar panels are placed in this area which is shown to be at risk in the updated Risk of Flooding from Surface Water (RoFSW) mapping. In addition, just upstream of this area an ordinary watercourse runs through the proposed grid connection infrastructure.

Please incorporate evidence within the Flood Risk Assessment that the RoFSW mapping is a suitable proxy for fluvial flood risk in this area and that flows would remain in bank in the design flood event, particularly in the vicinity of the grid connection infrastructure.’

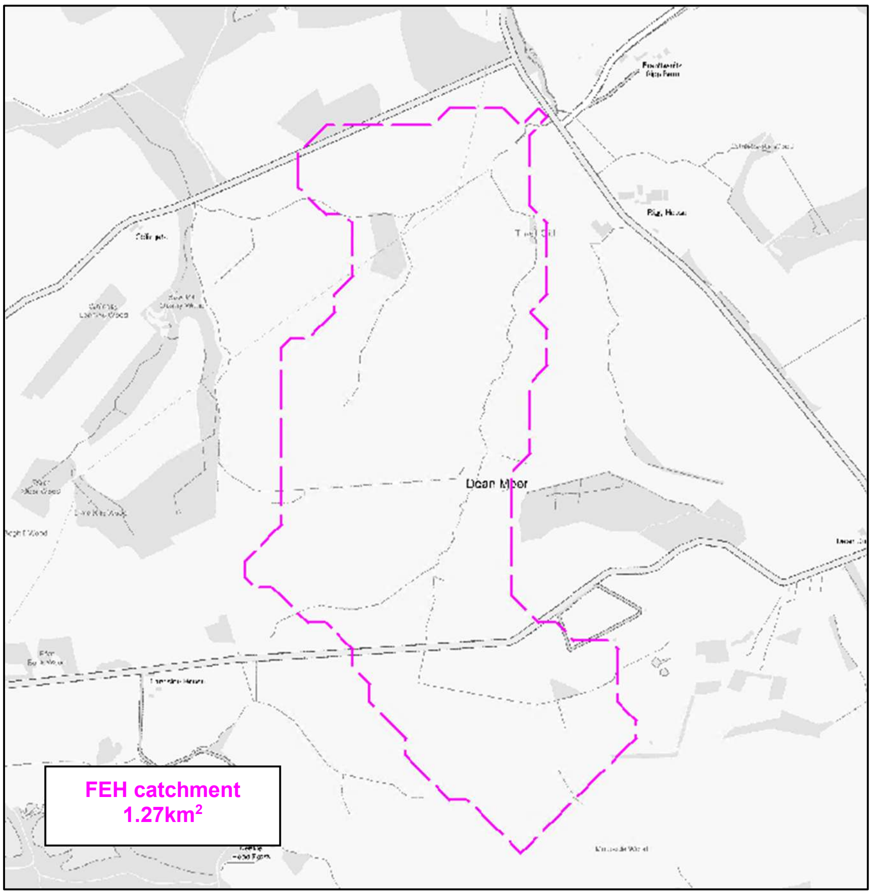
Figure 1 – Site Location (left) and Inset Area extract showing Parameter Plan and EA RoFSW Map Overlay (right)



3 Flood Flows

3.1.1 As part of the EA's RR [RR-017], estimated flood flows were provided for both Revitalised Flood Hydrograph (ReFH2)[2] and Flood Estimation Handbook (FEH)[3] Statistical hydrological methods for the catchment to grid reference 304,900m E, 523,650m N. This coordinate is located at Branthwaite Edge Road which forms the eastern boundary of Area C of the Site, at the downstream end of the Site, and was indicated as a catchment area of 1.27km^2 (based on the entered coordinate in the FEH Web Service)[4] as shown in Figure 2 of this TN.

Figure 2 – FEH Catchment Output over the Site



3.1.2 The EA analysis identified that the 1 in 100 Annual Probability (AP) FEH statistical flow at this location (4.5m3/s) was higher than the ReFH2 estimate

[2] Wallingford Hydrosolutions (2025) Revitalised Flood Hydrograph software (version 4.2)

[3] Wallingford Hydrosolutions (2024) Flood Estimation Handbook WINFAP 5 software

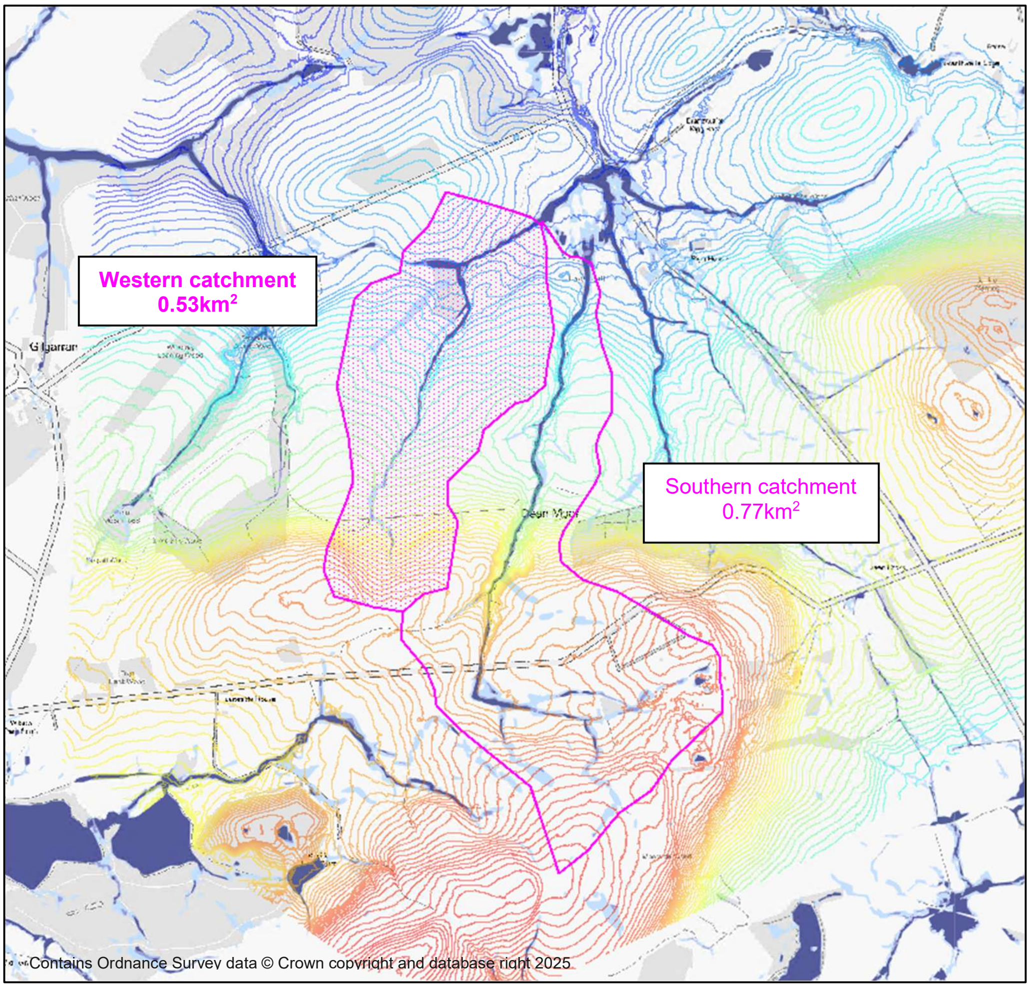
[4] Wallingford Hydrosolutions (2025) Flood Estimation Webservice. Available at www.fehweb.ac.uk. Accessed August 2025.

(2.65m3/s) and it was therefore agreed that the higher FEH statistical flow would be used as the basis for this high-level assessment as a precautionary ‘worst case’.

3.1.3 To assess the western branch of the catchment (i.e. the channel flowing east through and past Work No. 2) with the appropriate flow. It has been with the EA modelling team that the FEH Statistical flow should be scaled pro-rata to the smaller catchment area at this location due to the similarity of the catchment and its descriptors. This smaller catchment is not specifically included within FEH; therefore, the EA’s climate change surface water extents and 2022 composite LiDAR have been utilised to estimate an appropriate catchment area for this watercourse.

3.1.4 Figure 3 of this TN displays the EA RoFSW climate change extents, contours from the EA’s LiDAR and estimated catchment area for the key western watercourse, along with the southern watercourse (see Figure 3.1 in the FRA and Figure 1 of this TN for hydrological context of watercourses). It is evident that the catchment extent compares favourably with the FEH catchment in Figure 2 of this TN, as does the total combined catchment area of 1.3km^2.

Figure 3 – Site Catchments derived from EA LiDAR



3.1.5 **Table 1** below shows the area ratio of the FEH and western/southern catchments, along with the adjusted statistical flows.

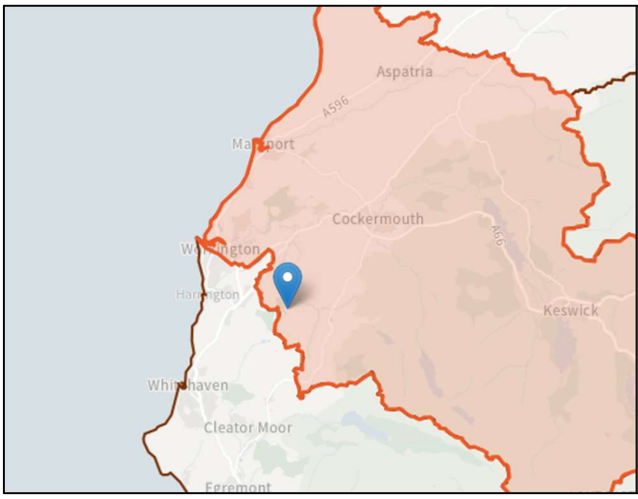
Table 1 – Catchment areas and adjusted 1 in 100 AP flows

Catchment Source	Area (km^2)	Ratio	1 in 100 AP flow (m^3/s)
FEH	*1.27*	*-*	*4.50*
***Western** (based on LiDAR)*	*0.53*	*0.42*	*1.88*
Southern (based on LiDAR)	0.77	0.61	2.73

3.1.6 The appropriate 1 in 100 AP flows will be scaled by the relevant 'Higher Central' and 'Upper End' climate change allowances to generate 'design' flood flows to consider in the analysis.

3.1.7 The area of concern lies in the ‘Derwent North West’ Management Catchment, where the applicable peak river flow climate change allowances are displayed in Figure 4 below.

Figure 4 – EA Climate Change Allowance (extract from online guidance)



Derwent North West Management Catchment peak river flow allowances

	Central	Higher	Upper
2020s	15%	19%	28%
2050s	23%	31%	49%
2080s	40%	51%	80%

3.1.8 As noted in the FRA, the scheme is assumed to have a 40-year design life and as such the projections would effectively be applicable to the end of the ‘2050s’ epoch (i.e. to the year 2069). However, as per the EA’s request the analysis will consider the more precautionary 2080s allowances as follows:

- Assess design using the 2080s ‘Higher Central’ allowance of +51%; and
- Sensitivity test using the 2080s ‘Upper End’ allowance of +80% (on the basis that the Proposed Development is classed as ‘Nationally Significant Infrastructure’).

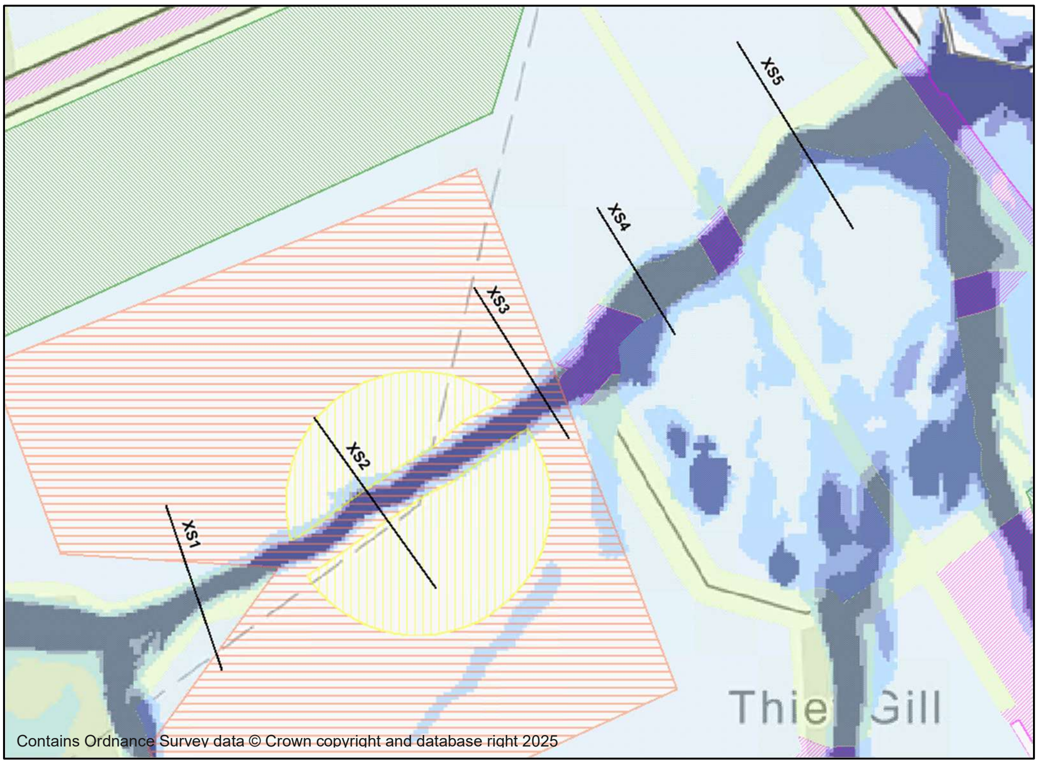
4 Rating Curve Analysis

4.1.1 To undertake the rating curve analysis, five cross sections have been extracted from the available topographic survey of the Site, to cover the approximate reach between the western end of Work No. 2 and the Branthwaite Edge Road downstream.

4.1.2 The extracted reach is 416m in total length.

4.1.3 The location of these sections is shown on Figure 5 of this TN.

Figure 5 – Location of Cross Sections for Rating Curve Analysis



4.1.4 For the majority of the cross sections a left bank, channel bed, and right bank level was provided within the detailed Topographic Survey over the Site. However, for one section (XS4), the EA's 2022 composite LiDAR data was used to supplement missing left bank level information.

4.1.5 It should be noted that a good consistency between the Topographic Survey and LiDAR was observed. The cross sections are provided in Annex B for reference.

4.1.6 The five sections were input into Flood Modeller software[5] with the following processes carried out to obtain rating curves and estimate 1 in 100 AP plus climate change flood levels:

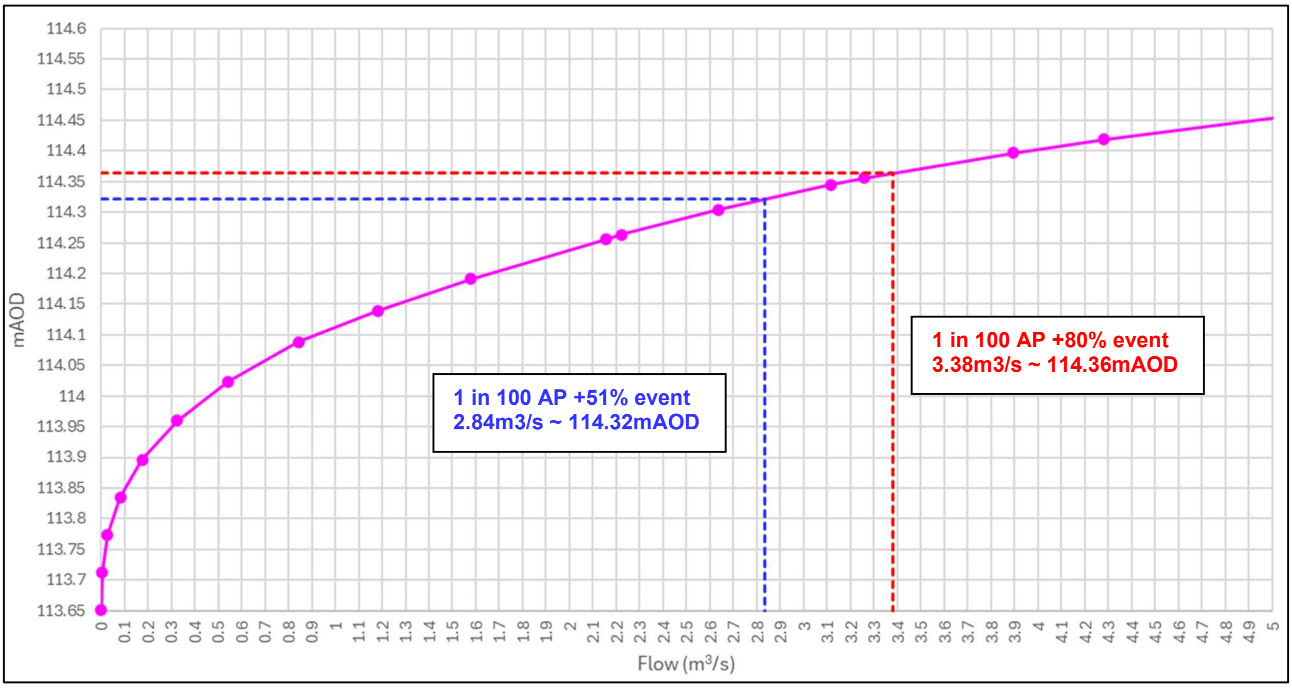
- Following a review of available Site / aerial photos and the recommended values given in Chow[6] for channels and floodplains, a Manning's 'n' value of 0.05 has been selected as a suitable roughness value for all the sections (see photos of typical conditions in Figure 6 of this TN). This has been applied for both in-channel and the floodplain. A sensitivity test has been carried out to increase this value by 20%, to understand the impact on estimated flood levels. It is considered that 0.05 for the in-channel roughness value is a slightly conservative estimate, where values down to 0.04 could also be appropriate.
- Panel markers have been included in each section, to ensure the conveyance curves are appropriate. This includes panel markers for the left and right banks of the channel.
- Bed slopes were estimated based on the extracted cross sections. The estimated slopes ranged from 1 in 37.8 – 1 in 69.5, with the slope values reducing moving downstream. The relevant slopes were assigned to each section within Flood Modeller, to inform the Manning's / rating analysis. For comparison, the calculated average slope from the first and last cross section is approximately 1 in 50.
- The 'tabulate cross section properties' tool was utilised to obtain the flow vs stage rating curves at each cross section (based on the section profile, Manning's 'n' and relevant bed slope).
- Interrogate rating curves, based on the relevant catchment flows / interpolation, and estimate flood level. An example of this process is shown in Figure 7 of this TN, with all sections provided in Annex B.

[5] Jacobs (2025) Flood Modeller Pro software version 7.3

[6] Ven Te Chow, Open Channel Hydraulics (1959)

Figure 6 – Photos along ordinary watercourse at the Site

Figure 7 – Rating Curve Analysis Example, Section XS2



4.1.7 Calculated flood levels for each section are shown in **Table 2** below, along with the relevant catchment flows. Based on a review of the OS mapping and LiDAR data, the southern catchment enters between XS3 and XS4. Therefore, the flows for the western catchment are relevant for XS1 – XS3, with the whole catchment flow relevant for XS4 and XS5.

4.1.8 It can be seen that the differences between the +51% and +80% climate change events are relatively small (i.e. less than 100mm).

Table 2 – Calculated Climate Change Flood Levels

Cross Section	1 in 100 AP + 51% Flood Level (mAOD) Design event	1 in 100 AP + 80% Flood Level (mAOD) Sensitivity Test	Difference (m)
Applicable flow (west catchment only)	*2.84m^3/s*	*3.38 m^3/s*	*0.54 m^3/s*
XS1	117.06	117.09	+0.03
XS2	114.32	114.36	+0.04
XS3	112.14	112.16	+0.02
Applicable flow (west and south catchment)	*6.80m^3/s*	*8.10m^3/s*	*1.3 m^3/s*
XS4	110.92	110.95	+0.03
XS5	109.50	109.59	+0.09

4.1.9 Results from the +20% Manning's 'n' sensitivity test are shown below for the design event in **Table 3**. The test shows the flood levels are relatively insensitive to the higher roughness, and the resulting sensitivity test flood levels (and degree of change from the design event across the sections) are very similar to the results for the 'Upper End' climate change scenario.

Table 3 - Roughness Sensitivity test – 1 in 100 AP +51% climate change event

Cross Section	Design Flood Level - Manning's 'n' = 0.05 (mAOD)	Sensitivity Test - Manning's 'n' = 0.06 (+20%) (mAOD)	Difference (m)
XS1	117.06	117.09	+0.03
XS2	114.32	114.37	+0.05
XS3	112.14	112.16	+0.02
XS4	110.92	110.96	+0.04
XS5	109.50	109.60	+0.10

4.1.10 The estimated flood levels have been utilised to create the Higher Central and Upper End flood extents over the study area, as discussed in Section 5.

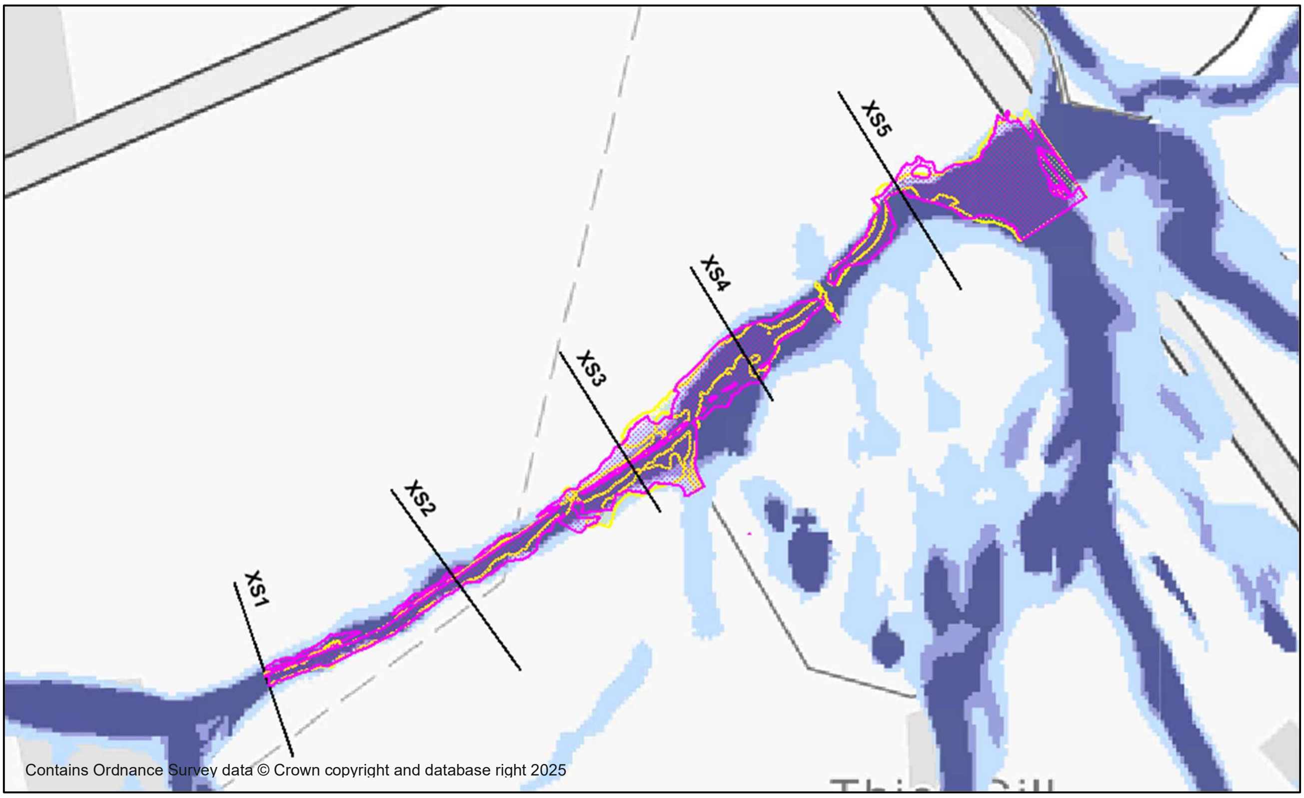
5 Extent of Flooding

5.1.1 Floodplain mapping has been carried out using the following process within MapInfo GIS:

- Assign the 1 in 100 AP +51% and +80% climate change flood levels to relevant cross sections utilising the calculated flood levels from Table 2. As a conservative assessment, the flood level at XS5 was also assigned to the area downstream of the section as far as the road at the Site boundary.
- Create triangular irregular network (TIN) to create water surfaces for both climate change scenarios.
- Subtract topographic survey digital terrain model (DTM) from the water surfaces to create depth grids.
- Contour depth grid at zero to create the extent of flooding and 'clean' as required

5.1.2 This process has also been carried out using the EA's 2022 Composite LiDAR DTM to provide a comparison with the topographic survey generated flood extent.

Figure 8 – 1 in 100 AP +51% flood extents – Topographic Survey = Magenta | LiDAR = Yellow



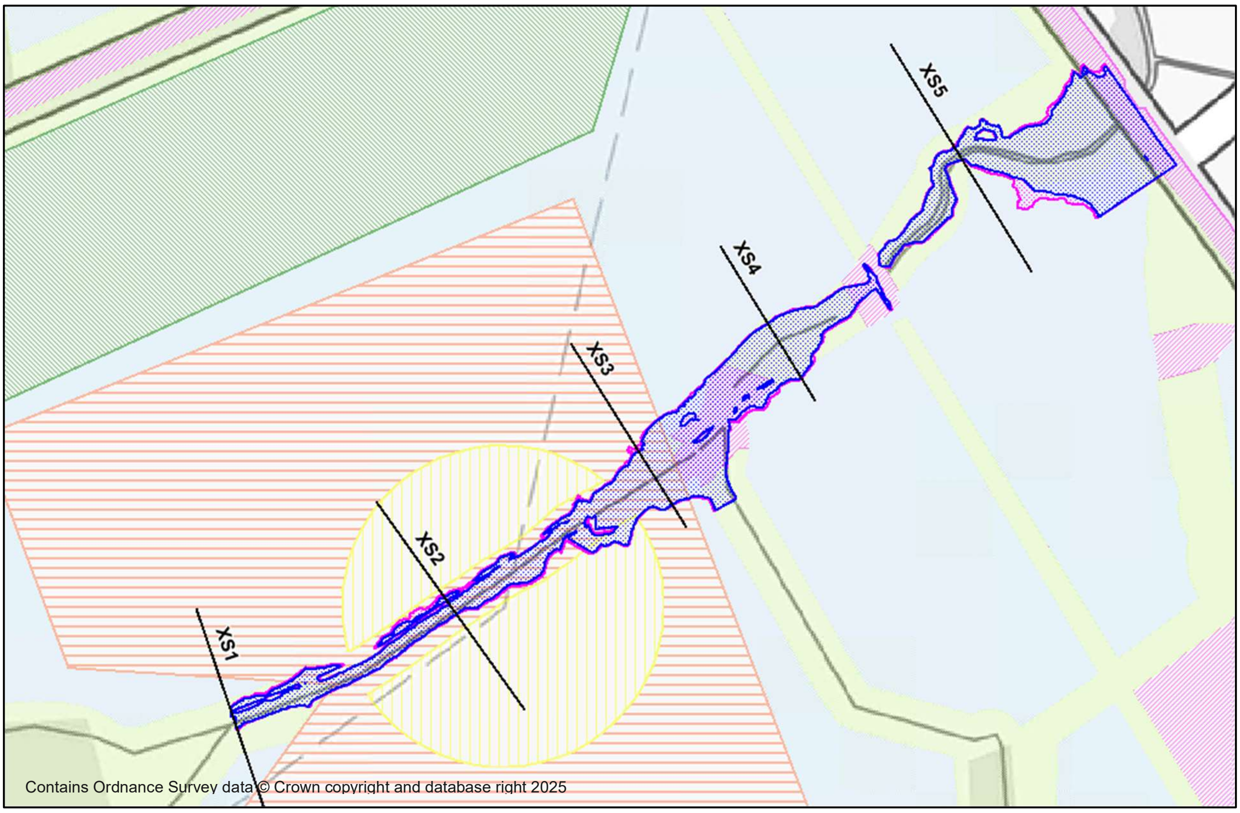
5.1.3 The 1 in 100 AP +51% extents from both 'topographic survey' (magenta) and from 'LiDAR' (yellow) flood extents are shown in Figure 8 of this TN, indicating both extents are very similar from both survey sources.

5.1.4 In addition, the outlines are also overlaid on the EA's RoFSW including climate change maps. The overlay shows that the outlines are very similar to the surface water maps, reconfirming the original FRA position that the surface water maps are a suitable proxy for fluvial flood risk when assessing the Proposed Development.

5.1.5 To provide a further level of precaution to the analysis, the final flood extents have been generated as a composite of the 'Topo' and 'LiDAR' flood extents, so that the outline would show the larger of the two extents.

5.1.6 The +51% Higher Central (design event) and +80% Upper End (sensitivity event) 'merged' climate change flood extents are overlaid with the parameter plan in Figure 9 of this TN.

Figure 9 – Final 1 in 100 AP plus climate change flood extents – +51% Higher Central = Blue | +80% Upper End =Magenta



6 Summary

6.1.1 The hydraulic analysis has been undertaken in accordance with a methodology agreed with the EA to verify the accuracy of the RoFSW mapping as proxy for fluvial flood risk through the central part of the Site, prior to the watercourses flowing off-Site where the channel becomes a main river (Lostrigg Beck).

6.1.2 The analysis has generated rating curves to consider against the precautionary FEH flows provided by EA, with a pro-rata scaling applied for sub-catchments within the Site.

6.1.3 The analysis confirms that the calculated 1 in 100 AP plus climate change allowances, using precautionary 'Higher Central' and 'Upper End' 2080s climate change allowances, show a very close agreement with the EA RoFSW flood extents. As such, the analysis re-affirms that the approach taken within the FRA is proportionate and appropriate for the Proposed Development.

6.1.4 It should be reiterated that the Works Plans [**APP-007**] set out 'Work Area' extents to define acceptable uses across the Site. They do not specify Site level detail, such as proposed building/infrastructure specifications or locations within these Work Areas, although some additional parameters for equipment in each work area are specified in the Design Parameters Document (DPD) [**APP-028**], and additional commitments that constrain and/or refine the form and manner of implementation and maintenance are provided by the control documents such as the Outline Construction Environmental Management Plan (OCEMP) [**APP-108**]. The final details (layout, elevations, etc.) will be specified post-consent within the envelope provided by the application's parameters, and the details of the proposed drainage to be consented will also be in accordance with the Outline Drainage Strategy in the FRA and ODS.

Annex A - EA Correspondence - Proposed Methodology

Stantec email to EA dated 21st July 2025

EA email reply dated 22nd July 2025

[redacted]

Hi Both,

Following on from our call, the Applicant has approved the following Scope for further assessment to inform the flood risk assessment, to respond to our discussion on Thursday last week. If you have any comments on this, please let us know.

1. Liaise with EA to confirm required flows for hydraulic analysis
2. Extract approx. 5 no. cross sections from topographic survey, across floodplain/watercourses at downstream end of site (i.e. in vicinity of proposed Grid Infrastructure area and downstream)
3. Generate estimates of watercourse gradient and roughness coefficients from survey and photos;
4. Undertake rating curve analysis in Flood Modeller software to generate flow – level relationship at each section ie Manning's equation analysis
5. Sensitivity tests on roughness coefficients, to understand impact on estimated flood levels.
6. Produce figure(s) showing extent of flooding at each section for advised peak flow, and impact relative to parameter plan boundaries;
7. Produce Technical Note summary of methodology/results
8. Update FRA to cross reference results and append Technical Note into new appendix

We will update the next iteration of the SoCG to confirm that we are progressing this (along with capturing other points in the Relevant Representations).

This would be undertaken with the aim to have completed the work, and shared it with the EA ahead of Deadline 2, on the 22nd of August.

If there are any design conclusions which arise as a result of this modelling, we would be seeking to commit to addressing this within the design to be submitted post consent, and secured by DCO Requirement.

[redacted]ope you enjoy your holiday!

KR,

[redacted]RTPI
Associate Planner

RE: Dean Moor Solar Farm - Flood Risk Assessment - Additional hydraulic analysis

[redacted]

Reply | Reply All | Forward | ...

Tue 22/07/2025 11:07

You forwarded this message on 22/07/2025 17:23.

Some people who received this message don't often get email fro[redacted]environment-agency.gov.uk. Learn why this is important

Hi [redacted]

This seems reasonable from our perspective. Please see below our comments in blue

1. Liaise with EA to confirm required flows for hydraulic analysis. Our view would be that given the uncertainties on estimating flows in ungauged catchments it would be sensible to take the more precautionary of the FEH Statistical and ReFH2 peak flows for the catchment to the road (304900,523650). As discussed in the meeting it would be reasonable to scale the flows by catchment area depending on the location that flow inputs are calculated for as the catchment for the watercourses to the road is uniform in terms of catchment descriptors. Peak flows should be calculated for the 1% (1 in 100) annual exceedance probability (AEP) scenario and should be scaled by the higher central allowance for climate change for the 2080's epoch for the Derwent North West Management catchment and a sensitivity test should be undertaken for the Upper climate change scenario as the development is classed as Nationally Significant Infrastructure.
2. Extract approx. 5 no. cross sections from topographic survey, across floodplain/watercourses at downstream end of site (i.e. in vicinity of proposed Grid Infrastructure area and downstream). This seems reasonable
3. Generate estimates of watercourse gradient and roughness coefficients from survey and photos; This is reasonable. The channel survey or publicly available Lidar data from the Defra Data Services platform online at Defra Survey Data Download could be used to inform channel slope.
4. Undertake rating curve analysis in Flood Modeller software to generate flow – level relationship at each section ie Manning's equation analysis. This is reasonable
5. Sensitivity tests on roughness coefficients, to understand impact on estimated flood levels. This is reasonable
6. Produce figure(s) showing extent of flooding at each section for advised peak flow, and impact relative to parameter plan boundaries; This is reasonable. It would be useful if the water levels at each section could be used to generate a triangular irregular network (TIN) showing water surface elevation. This could then be superimposed on Lidar data to generate a flood outline for the 1% (1 in 100) annual exceedance probability plus higher central and upper climate change scenarios.
7. Produce Technical Note summary of methodology/results. This is reasonable
8. Update FRA to cross reference results and append Technical Note into new appendix. This is reasonable

Let me know if you need any further information

Kind regards,

[redacted]

Planning Specialist – National Infrastructure Team
Environment Agency | Sentinel House, 9 Wellington Crescent, Fradley Park, Lichfield, Staffordshire, WS13 8RR

[redacted] www.gov.uk/environment-agency

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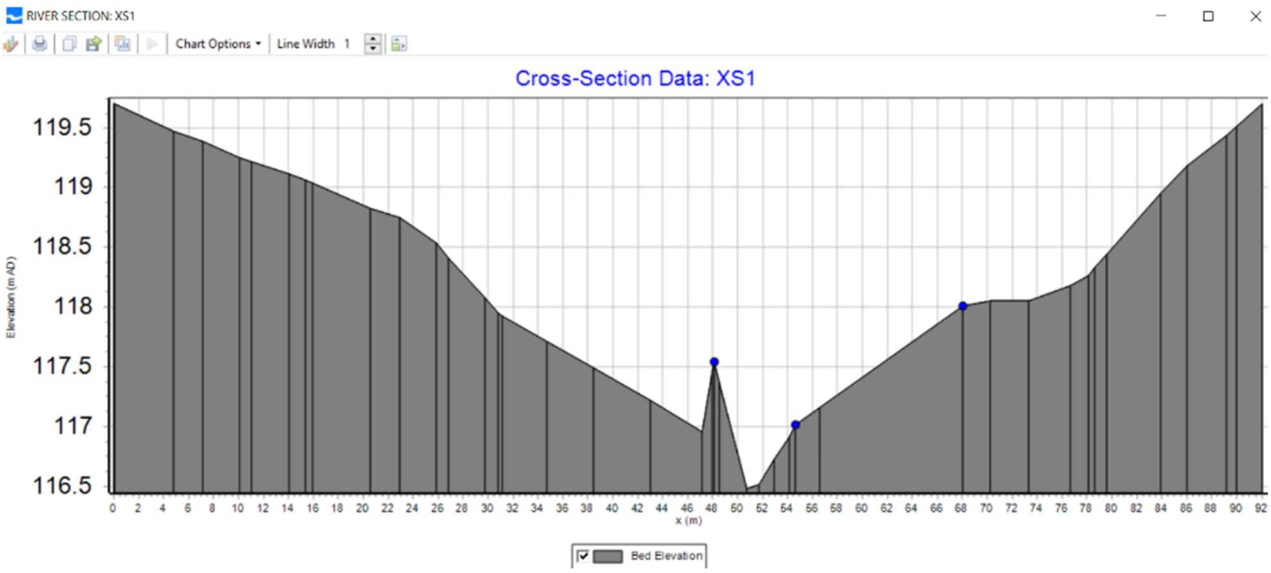
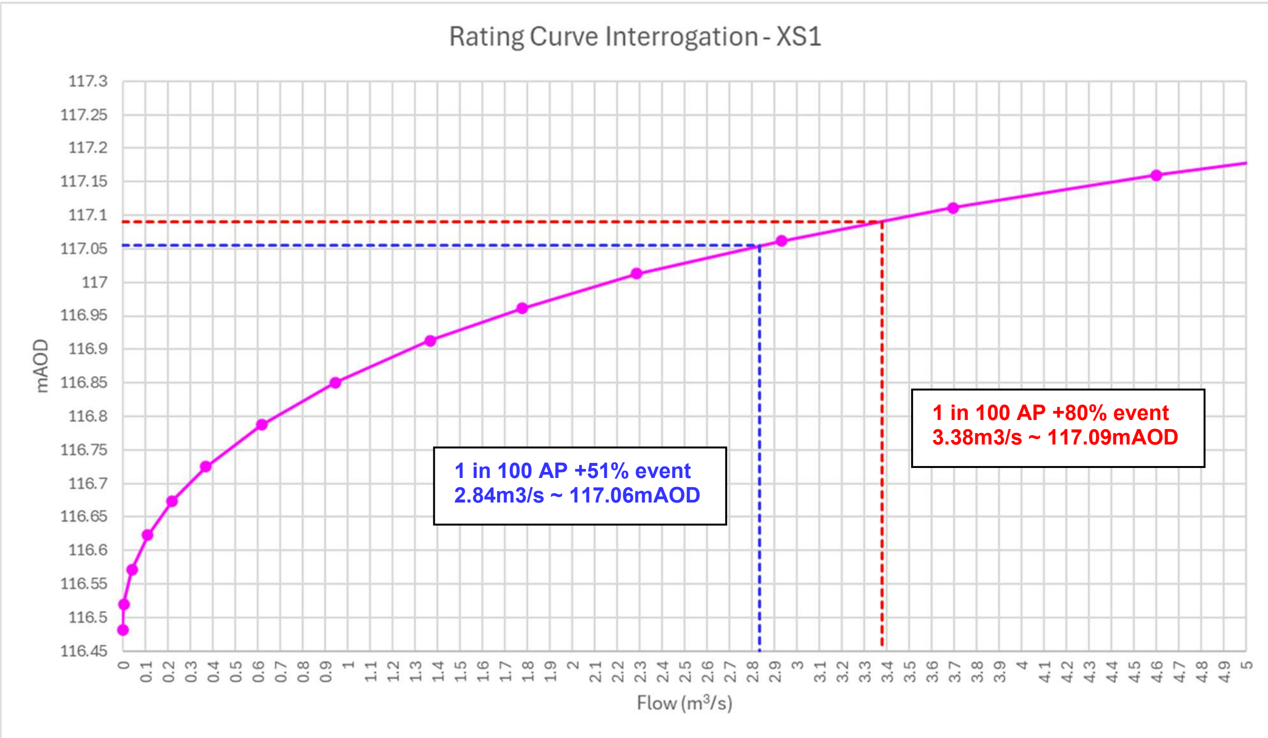
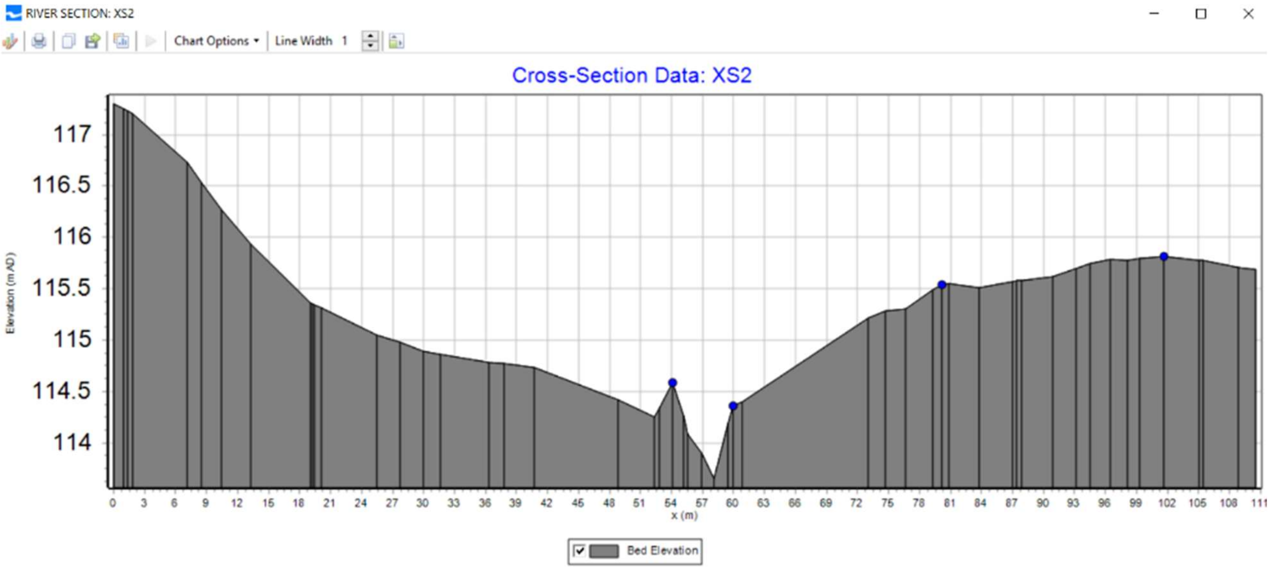
Annex B - Cross Sections & Rating Curves

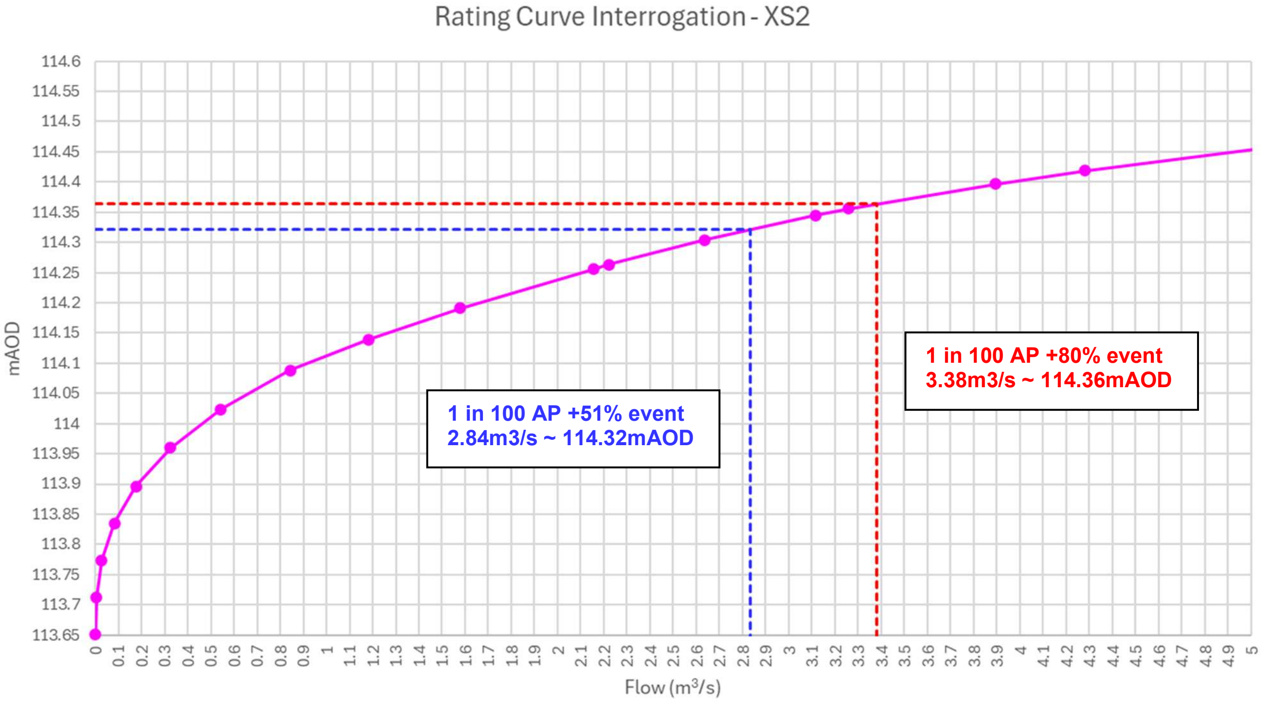
XS1





XS2


RIVER SECTION: XS2
Chart Options
Line Width 1
Cross-Section Data: XS2
Elevation (m AD)
x (m)
Bed Elevation


Rating Curve Interrogation - XS2
mAOD
Flow (m3/s)
1 in 100 AP +51% event
2.84m3/s ~ 114.32mAOD
1 in 100 AP +80% event
3.38m3/s ~ 114.36mAOD

XS3

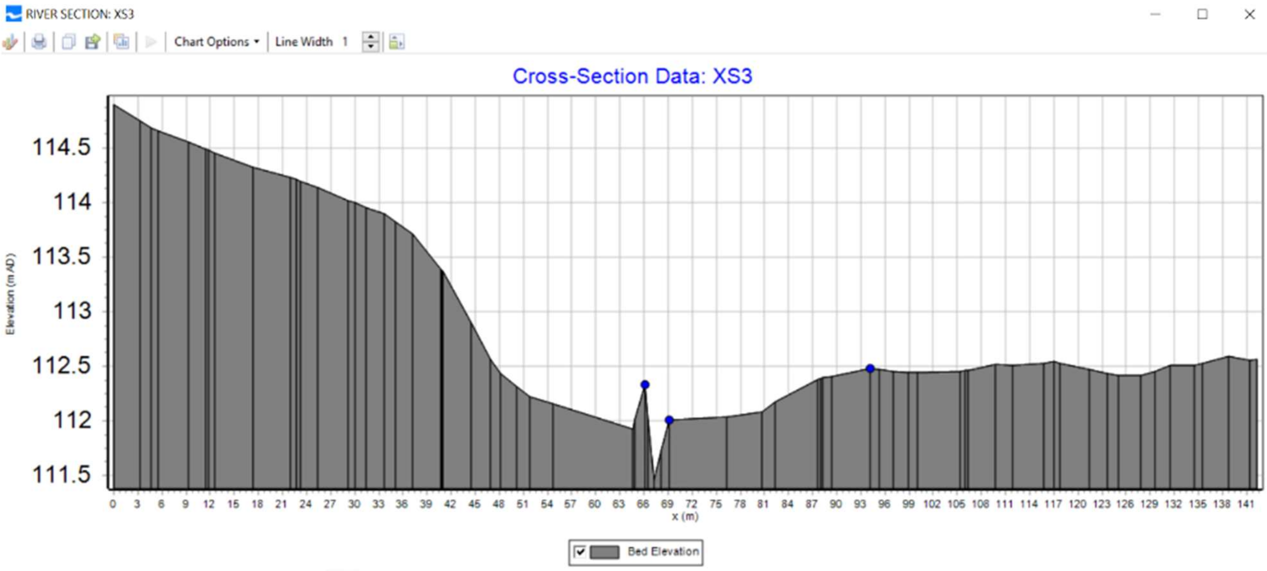

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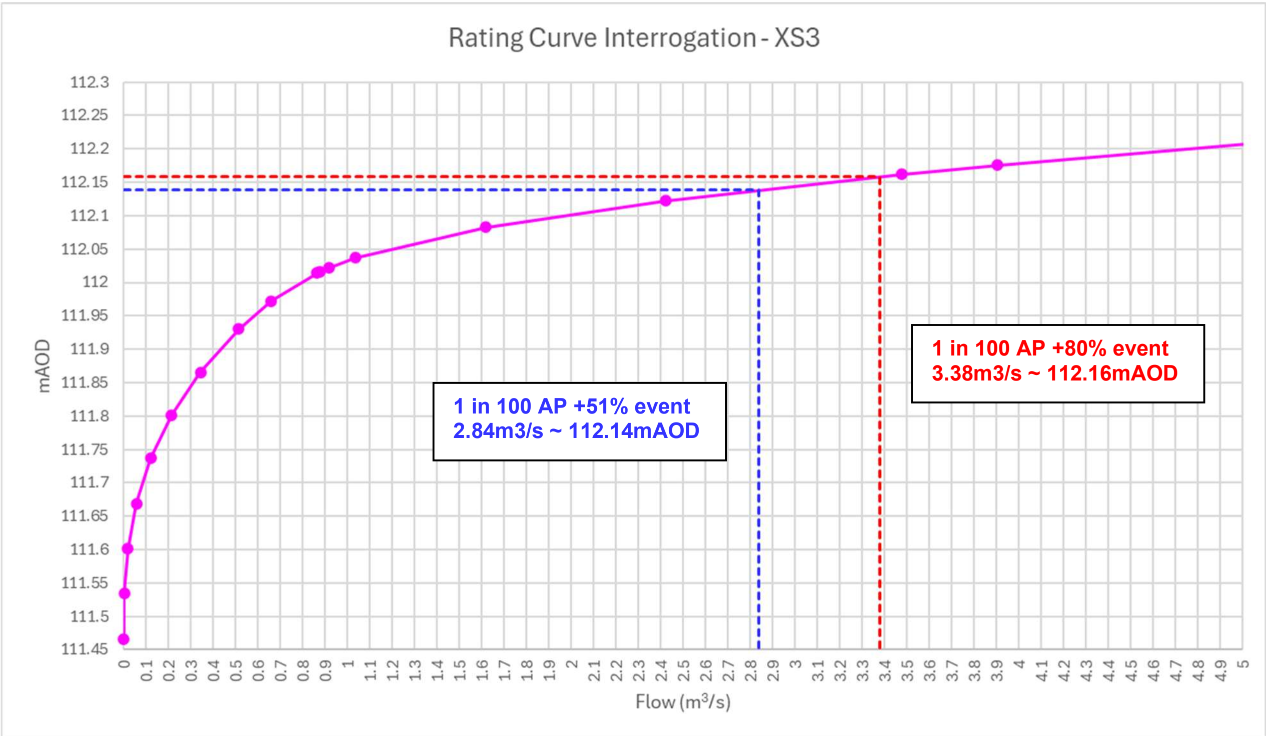
Chart Options
Line Width 1
Cross-Section Data: XS3
Elevation (m AD)
x (m)
Bed Elevation


Rating Curve Interrogation - XS3
mAOD
Flow (m3/s)
1 in 100 AP +51% event
2.84m3/s ~ 112.14mAOD
1 in 100 AP +80% event
3.38m3/s ~ 112.16mAOD

XS4

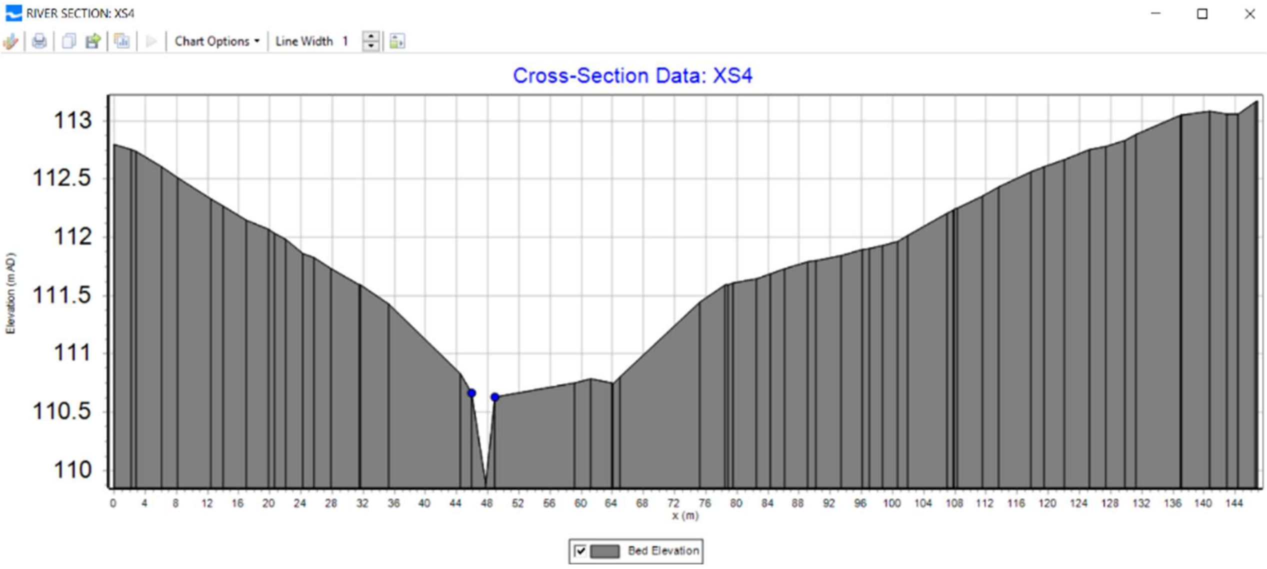

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Chart Options
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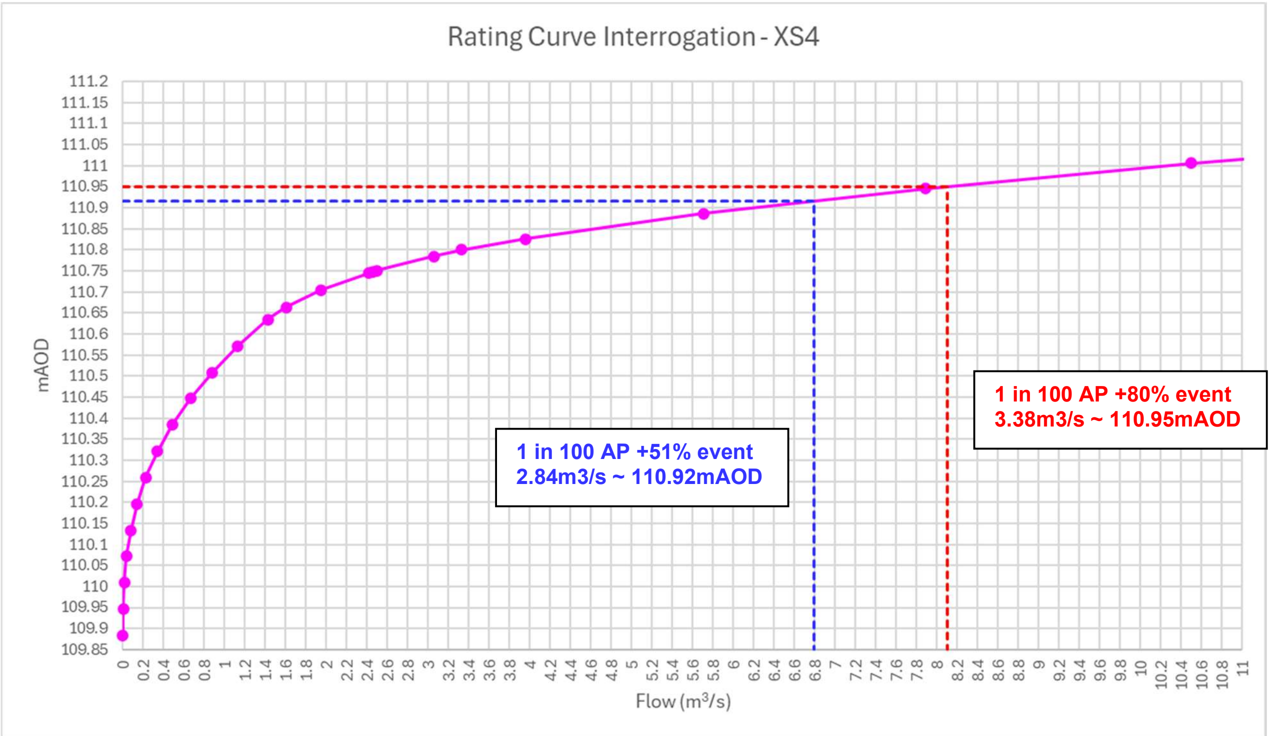
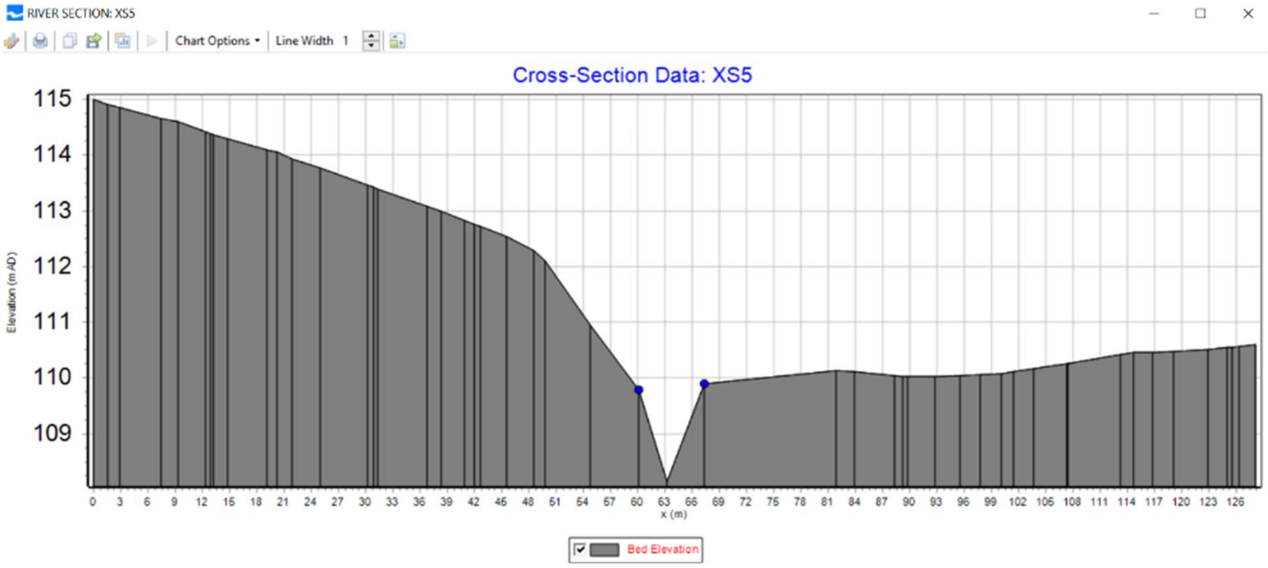
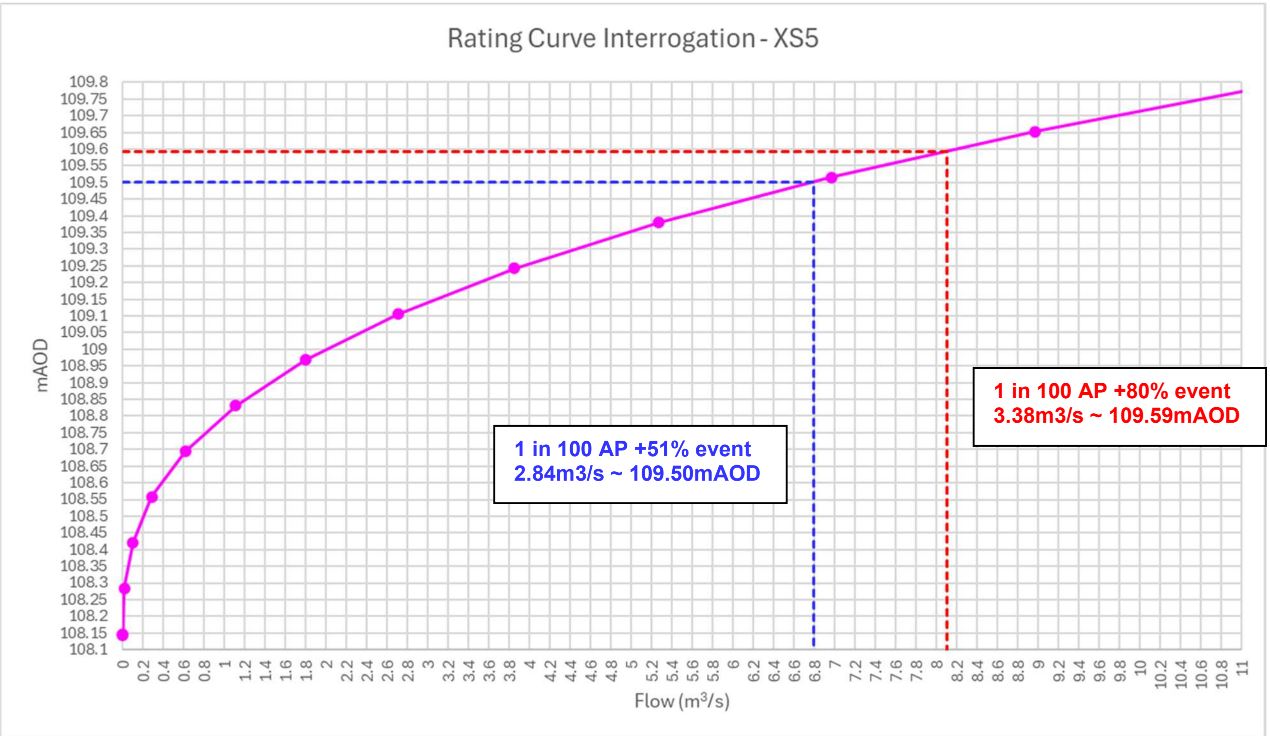
Cross-Section Data: XS4
Elevation (m AD)
x (m)
Bed Elevation


Rating Curve Interrogation - XS4
mAOD
Flow (m3/s)
1 in 100 AP +51% event
2.84m3/s ~ 110.92mAOD
1 in 100 AP +80% event
3.38m3/s ~ 110.95mAOD

XS5



RIVER SECTION: XS5
Chart Options
Line Width 1
Cross-Section Data: XS5
Elevation (m AD)
x (m)
Bed Elevation



Rating Curve Interrogation - XS5
mAOD
Flow (m3/s)
1 in 100 AP +51% event
2.84m3/s ~ 109.50mAOD
1 in 100 AP +80% event
3.38m3/s ~ 109.59mAOD