

Natural Resources Wales

NRW Consultancy – S4T2 Glascoed

Hydraulic Model – Development and Findings

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Executive Summary

This Report documents the fluvial hydraulic model review and model development carried out in order to inform fish pass scour improvements at the Glascoed Fish Bypass Channel. The Bypass Channel was constructed in Autumn 2014 and soon after the bypass channel was opened it became apparent that there were design and/or construction related issues resulting in erosion control matting becoming loose, scour pools developing and general instability of the new feature. There was significant risk that erosion could lead to the channel migrating outside of the land leased by NRW and, consequently the bypass channel was closed by NRW. An improved design is required to address the current scour issue and prevent it from reoccurring in the future.

The aim of the modelling study is to calculate the expected peak velocity in the channel at the location of the inlet structure to the fish pass channel. This velocity estimate will be used to identify appropriate solutions to reduce local scour, and for calculation of sediment movement. The hydraulic assessment comprises a 1D steady state model in Flood Modeller Pro (FMP) of the Afon Cynllaith channel through the reach adjacent to the fish pass inlet.

No gauged or observed flow, level or velocity data is available to calibrate or validate the model and thus the model uses several assumptions and simplifications which place a number of limitations on the model of relevance to the study:

- The lack of gauged flow data means the assumed Manning's roughness coefficient cannot be refined through calibration.
- NRW flood mapping suggests the possibility of water spilling out upstream and flowing through the valley bottom floodplain but, because derived peak flows have been inserted into the modelled river channel, any losses due to upstream spills will not have been accounted for, which may lead to an overestimate of the maximum flow and velocity through the watercourse in the model.
- The watercourse is noted to be perched above the valley bottom. Water exceeding the right bank top in the channel would therefore spill down into the floodplain and not return to the watercourse until further downstream. The right bank beyond the bank top crest has been deactivated in the channel cross-sections, having the effect of constraining all flows into the modelled channel through the reach, especially because of the lack of representation of the bypass channel itself. This will likely result in the hydraulic model over-estimating the water levels and velocities through the reach, in addition to the possible over-estimate of peak flow being inserted into the model, which is considered conservative from the point of view of informing design.

Due to the limitations above predicted velocities from the model are expected to be conservative. These all may have an impact on the ability of the hydraulic assessment to accurately capture the hydraulics for use in detailed scour assessment or design and specification of scour protection products. Refinement of the modelling would necessitate additional data and modelling, such as flow gauging data required to validate the inflow hydrology to the model, in particular to ensure the flows inserted into the channel itself are accurate. Understanding of the hydraulic roughness and refinement of the channel cross-section where loss of definition in the channel shape has been encountered and extension of the survey downstream and across the floodplain (to represent credible losses from overtopping of the channel) would also aid refinement.

Additional information would allow the model to inform the design with a higher level of certainty. NRW is currently intending to undertake a temporary flow gauging exercise for the 2023/2024 winter months which will allow calibration of the hydrology calculations and refinement of the hydraulic model. This will provide model outputs with improved suitability to inform a proportionate and sustainable design for the scour remediation and protection.

1. Introduction

This Report documents the fluvial hydraulic model review and model development carried out in order to inform fish pass scour improvements at the Glascoed Fish Bypass Channel.

1.1 Project background

The Glascoed Fish Bypass Channel was constructed in Autumn 2014 for Natural Resources Wales (NRW) ‘Salmon for Tomorrow’ programme, to provide smoother passage for fish on the Afon Cynllaith, around 750 m east from Llansilin village, Wales (OS Grid Reference: SJ 21714 28311). The watercourse has a large weir which had been constructed to divert flow into a mill race for the Glascoed Mill downstream. The mill is no longer active, and the mill race has been mostly removed, making the weir redundant and a barrier to fish passage.

Soon after the bypass channel was opened it became apparent that there were design and/or construction related issues resulting in erosion control matting becoming loose, scour pools developing and general instability of the new feature. There was significant risk that erosion could lead to the channel migrating outside of the land leased by NRW and, consequently the bypass channel was closed by NRW. An improved design is required to address the current scour issue and prevent it from reoccurring in the future.

1.2 Previous studies

Prior to this scheme, there were not any existing hydraulic models covering this portion of the river. A hydraulic design for the bypass channel was undertaken by Halcrow for Natural Resource Wales in 2014. However, there are no available reports which refer to any modelling done during the development of these structural design, though it is assumed that a low-flows assessment was conducted at the time.

1.3 Study area

The constructed bypass channel diverts some flow around a broad-crested weir on the Afon Cynllaith watercourse (Figure 1), which had likely been constructed for the purposes of diverting water into a millrace for a water wheel and mill downstream. The Afon Cynllaith as it flows through the site also appears to be perched above the majority of the floodplain, probably indicating that the channel may have historically realigned to follow the contour more closely to maximise the hydraulic head at the weir and water wheel.

Tributaries contributing to Afon Cynllaith upstream of the site include Nant Pengwely, Afon Ogau and Afon Ysgwennant. The upper catchment also includes the Pen-y-gwely Reservoir. At the location of the bypass on the Afon Cynllaith, two smaller unnamed tributaries join from the northwest from Wenffrwd and Bodlith, and flow into the bypass channel close to where it re-joins the Afon Cynllaith.

For this portion of the catchment, the topography ranges from 145mAOD to 165mAOD and it sits over a low productivity aquifer. According to British Geological Survey (BGS) data, the bedrock in this location is ‘Caradoc Rocks’ – an undifferentiated mixture of mudstone, siltstone, and sandstone.

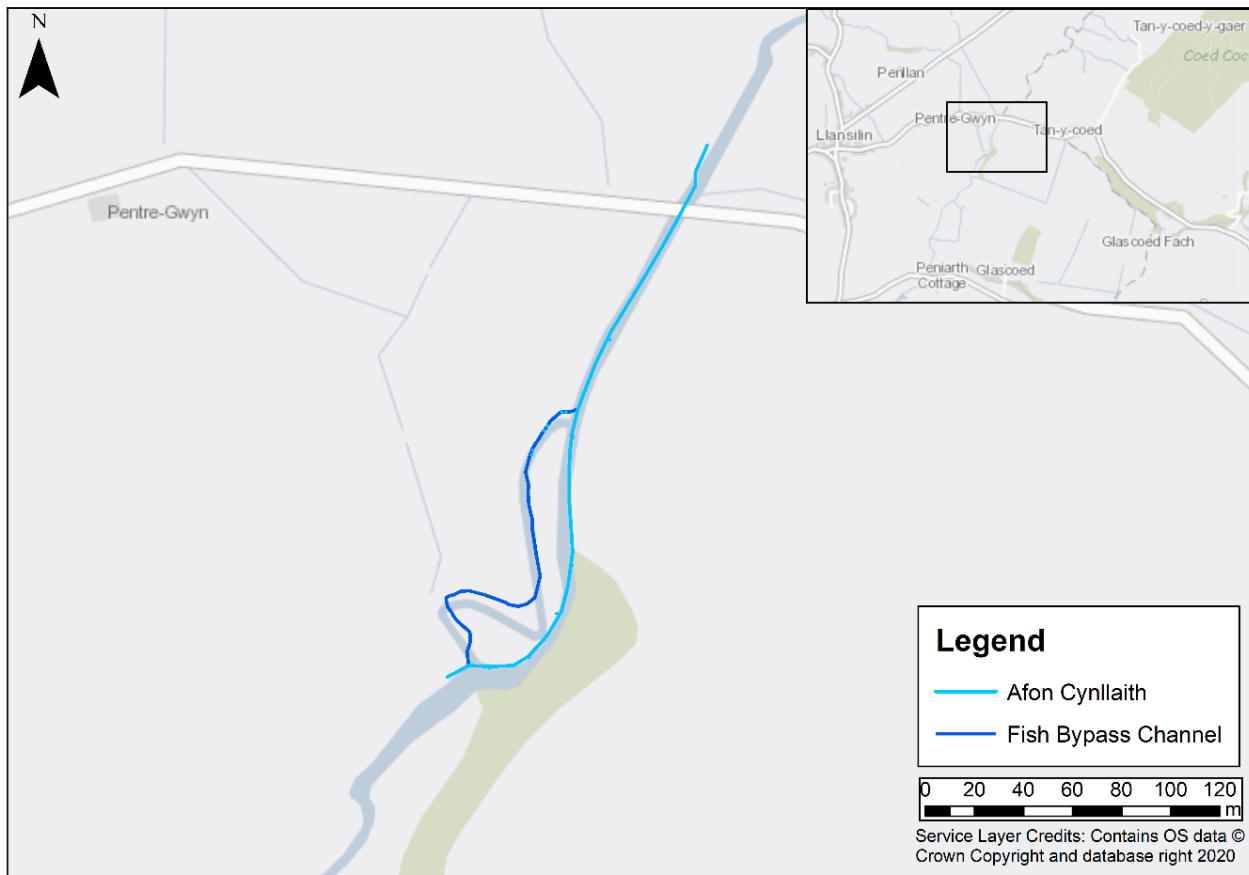


Figure 1 The study area extent, indicating the main watercourse (Afon Cynllaith) and the bypass channel.

2. Model development

2.1 Modelling aims

The aim of the modelling study is to calculate the expected peak velocity in the channel at the location of the inlet structure to the fish pass channel. This velocity estimate will be used to identify appropriate solutions to reduce local scour, and for calculation of sediment movement.

2.2 Conceptualisation

The hydraulic assessment comprises a 1D steady state model in Flood Modeller Pro (FMP) of the Afon Cynllaith channel through the reach adjacent to the fish pass inlet (Figure 2). This is an appropriate level of detail in the modelling given the aim of predicting peak flows in the main channel only. Higher precision 2D in-channel modelling capable of predicting the variation in flows and velocities and eddy currents within the channel in the vicinity of the inlet was discounted as disproportionate at this initial stage given the available data and likely scale of the engineering solution. Similarly, a linked 1D-2D model of the watercourse, bypass channel and the connectivity across the wider floodplain was also discounted, on the basis of the primary interest being in the channel at the bypass inlet.

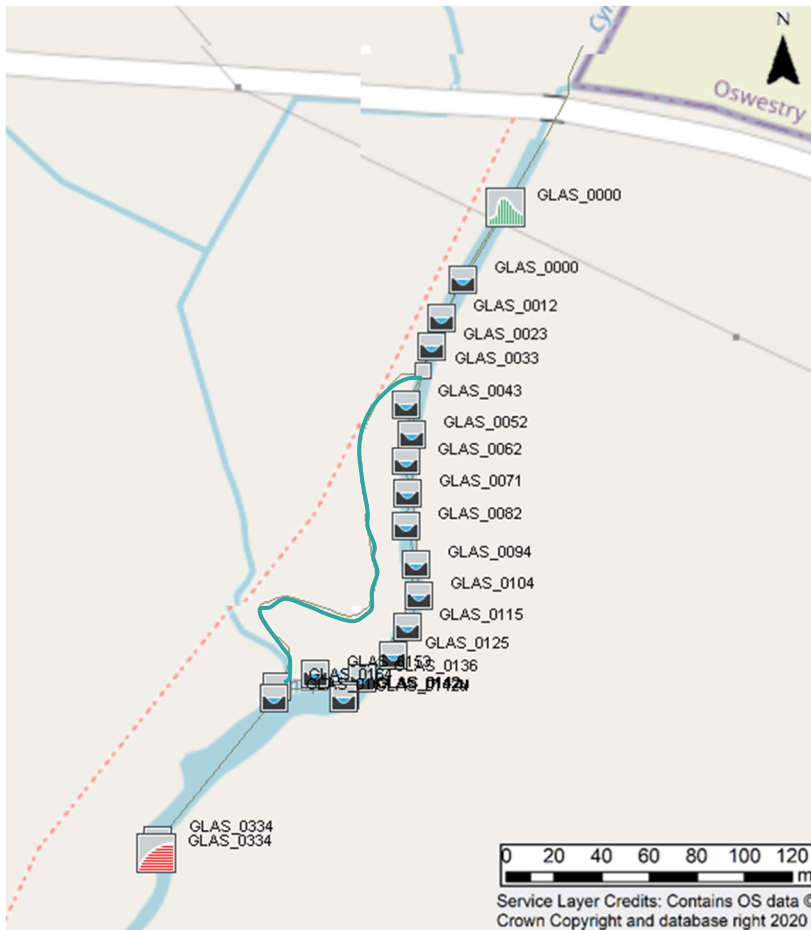


Figure 2 Glascoed model, showing the 1D node network.

In the chosen 1D model approach, the bypass channel itself is not explicitly represented, as only the flows and velocities in the main channel at the location of the inlet are required. Because the wider floodplain is also not represented, this may have the effect of potentially over-estimating the peak velocities in the channel, because more of the water will be contained in the modelled channel and not be allowed to spill out. This is considered conservative for purposes of design of any scour protection.

The model is run for a range of storm event magnitudes in steady state to calculate water level, flow, velocity and Froude number.

2.3 Input data

The following data was used in this assessment:

- Topographical survey (provided by Usk Land Survey Ltd, conducted on 2nd May 2023), with point elevations of the channel and environs, including physical features such as the check weirs, provided in CAD format.
- Cross-section and long-section data derived by Usk Land Survey from the topographical survey, at 1m increments along the channel length and width at selected locations. Note this is not a typical formal channel cross-section survey.
- Photographs and observations from a site visit by Arup engineers and fluvial geomorphologists (conducted on 30th May 2023).

2.4 Hydrology

For the original fish pass design, a low flows assessment for estimating the flows through the Afon Cynllaith had been undertaken. Using low flows techniques for estimating peak flows may potentially have underestimated the actual flows expected in the channel. Therefore, Arup undertook a revised flood

estimation¹. In summary, the peak flows for the range of return periods considered are shown below in Table 1. A climate change uplift of 25% on peak flows has been calculated for the 1% AEP event, which represents the central estimate for the total change anticipated by the 2080s for the Welsh Severn River Basin.

Table 1 Peak Flow Estimates obtained from hydrology, used as input data in the hydraulic model. *Climate change is represented by a 25% increase in peak flow.

AEP (%)	50%	20%	10%	5%	4%	3.3%	2%	1.3%	1%	1% +CC*	0.5%	0.1%
Flow (m ³ /s)	8.57	11.79	13.92	15.97	16.62	17.16	18.64	19.81	20.65	25.81	24.21	33.52

2.5 Software

This 1D model was produced in FMP, Version 5.1.

2.6 Baseline model

Channel nodes were placed at approximately 10 m intervals through the modelled reach, with cross section data extracted from the topographic survey. An interpolate unit was required at the location of the bypass inlet (model node GLAS_0033), because of uncertainty in the topographic survey at this point.

The weir is represented as a spill unit (node GLAS_0142u), with cross-section data and spill crest level inferred from the topographic survey at the upstream and downstream point. The weir coefficient C_d is set at 1.7, based on comparing the weir photographs to typical values for a round nosed horizontal crested weir (Figure 3). This has not been verified, and sensitivity testing has been undertaken on this value to understand its impact on model results – see Section 3.1.

¹ Arup (2023) Glascoed flood estimation calculation record. [Glascoed_NRW-GN008-flood-estimation-calculation-record-v3_DA.docx](#)



Figure 3 Glascoed weir on the Afon Cynllaith

The downstream boundary is defined as a ‘normal depth’ boundary based on the bed slope. To reduce the risk of these assumptions on the point of interest at GLAS_0033, the most downstream surveyed cross-section at GLAS_0167 was duplicated and applied to a “dummy” node at GLAS_0334, effectively doubling the modelled reach length. The overall gradient over the surveyed reach was taken and applied to GLAS_0334 by reducing the elevations down uniformly. Because the downstream channel is un-surveyed, a sensitivity test has been undertaken to explore sensitivity of the downstream channel gradient (and therefore the downstream boundary condition) on the results at the bypass inlet.

The upstream boundary condition is an inflow hydrograph just downstream of where the Afon Cynlliath is crossed by the road from Llansilin, at the approximate location of the peak flow estimate. A Manning’s n hydraulic roughness value of 0.040 was uniformly taken across the channel throughout the model, based on the middle value for a clean, winding channel with some pools and shoals, from Chow 1959. This has been broadly sense-checked from photographs of the site.

As discussed in Section 2.2, the bypass channel is not represented.

2.7 Calibration and validation

No gauged or observed flow, level or velocity data is available to calibrate or validate the model. The model has been broadly verified by a sense check from engineers attending the site and from site photographs.

2.8 Assumptions and limitations

The assumptions described in the previous sections regarding the schematisation of the Afon Cynlliath and the bypass channel place a number of limitations on the model of relevance to the study:

1. The lack of gauged flow data means the assumed Manning’s roughness coefficient cannot be refined through calibration.

2. NRW flood mapping suggests the possibility of water spilling out upstream and flowing through the valley bottom floodplain (Figure 4). Because derived peak flows have been inserted into the modelled river channel, any losses due to upstream spills will not have been accounted for. This may lead to an overestimate of the maximum flow and velocity through the watercourse in the model, which is considered conservative from the point of view of informing design. This is further reflected in the modelled bank full capacity in some locations being significantly less than the peak flow for the 50% AEP event ($8.57 \text{ m}^3/\text{s}$), despite anecdotal evidence from the client that suggests the channel has not been observed to overtop.
3. The watercourse is noted to be perched above the valley bottom (Figure 5). Water exceeding the right bank top in the channel would therefore spill down into the floodplain and not return to the watercourse until further downstream. The right bank beyond the bank top crest has been deactivated in the channel cross-sections, having the effect of constraining all flows into the modelled channel through the reach, especially because of the lack of representation of the bypass channel itself. This will likely result in the hydraulic model over-estimating the water levels and velocities through the reach, in addition to the possible over-estimate of peak flow being inserted into the model, which is considered conservative from the point of view of informing design.

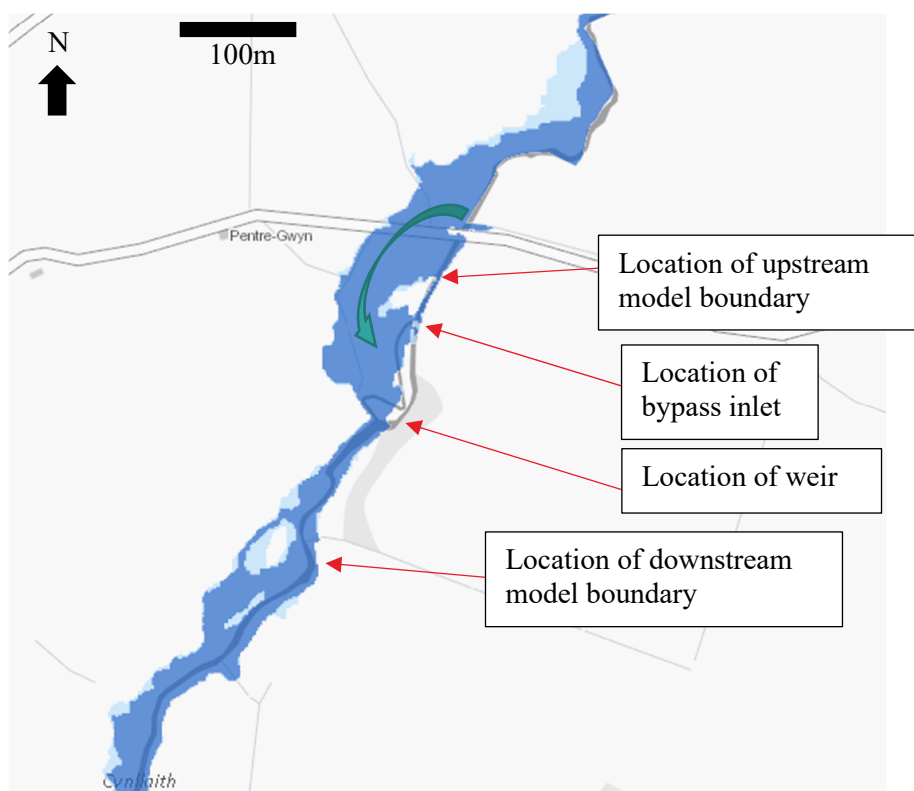


Figure 4 Flood map for planning, NRW, showing the possibility of flow bypassing the watercourse itself and flowing through the valley bottom in flood events.

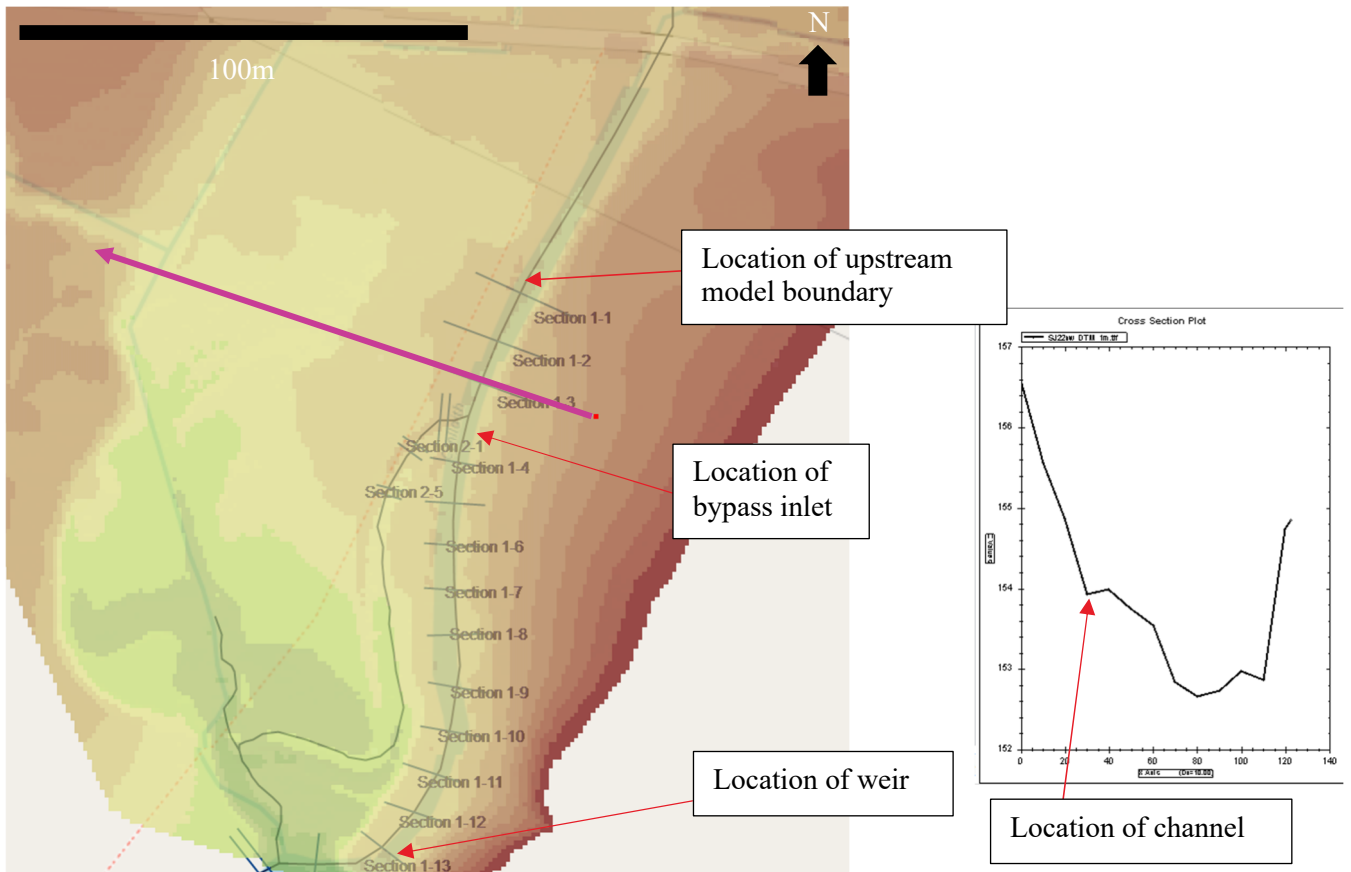


Figure 5 LiDAR image showing the channel perched at the eastern edge of the valley, likely due to historical realignment for water power, with an indicative cross-section (purple) showing the likelihood that any water spilling over the right bank of the channel would likely flow away from the channel.

3. Results

3.1 Sensitivity testing

3.1.1 Hydraulic roughness

The base model assumes a plausible roughness value from Chow's Manning's n tables (1959) of $n=0.040$. Given the lack of calibration data, and uncertainties in the representation of the channel, a sensitivity test has been conducted using plausible upper and lower roughness values for the channel, instead of a $\pm 20\%$ test.

For the "smooth" test, a lower value of $n=0.018$ was selected as representation of the low range of a straight, uniform, earthen dredged channel. For the "rough" test, an upper value of $n=0.100$ was selected as the middle value for a channel that has very weedy reaches, deep pools, or floodways with a heavy stand of timber and underbrush.

The water levels and velocities for smooth, baseline and rough versions at the inlet structure (GLAS_0033) are provided in Table 2 below.

Table 2 Sensitivity test results for the location at the bypass inlet (GLAS_0033)

Model version	Manning's <i>n</i>	10% AEP Water level (mAOD)	1% AEP Water level (mAOD)	10% AEP Peak velocity (m/s)	1% AEP Peak velocity (m/s)
Smooth	0.018	154.49	154.66	2.19	2.54
Baseline	0.040	154.85	155.10	1.34	1.54
Rough	0.100	155.36	155.71	0.83	0.95

The model is sensitive to hydraulic roughness. Higher roughness reduces water levels and increases the velocity. In the absence of more data to calibrate the model and refine the roughness estimate, the velocities predicted for scour below will be reported for the range of smooth to rough models.

3.1.2 Downstream boundary

The model assumes a normal depth boundary at the downstream end of the hydraulic model, and the use of a dummy cross-section at GLAS_0334 (duplicating the last surveyed section at GLAS_0167) with the same overall channel gradient as over the length of the study reach. A sensitivity test has been used to determine the impact on the predicted flows at the bypass inlet, by changing the distance-to-next of final node to double and then to half its current. This has the effect of altering the calculated bed slope used in the downstream boundary unit.

Table 3 Sensitivity test results for the downstream boundary

Model version	Gradient	10% AEP Water level (mAOD)	1% AEP Water level (mAOD)	10% AEP Peak velocity (m/s)	1% AEP Peak velocity (m/s)
Shallow	Half gradient	154.85	155.10	1.34	1.54
Baseline	Same as overall	154.85	155.10	1.34	1.54
Steep	Double gradient	154.85	155.10	1.34	1.54

The model results at the location of the bypass inlet (GLAS_0033) are not sensitive to the downstream boundary assumption. The weir acts as the primary hydraulic control, limiting the effect of the changes to water level on velocity caused by the change in downstream boundary gradient to downstream of the weir only, even in the largest modelled event (Figure 6).

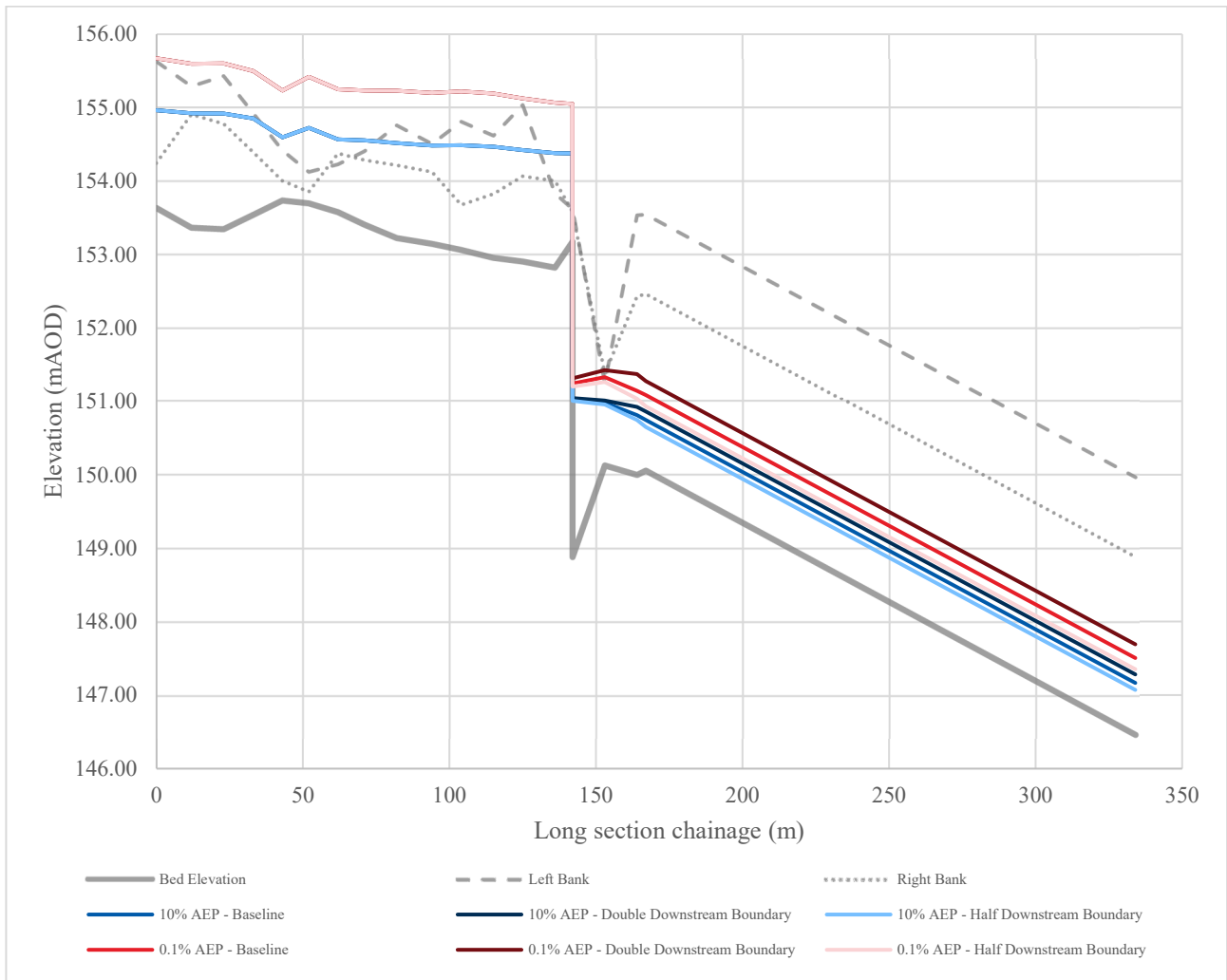


Figure 6 Long section profile results for the downstream boundary sensitivity test, showing the maximum water levels for the 10% AEP baseline (mid blue) against the shallower gradient (dark blue, doubling the distance-to-next of the final dummy node) and steeper gradient (light blue, halving the distance-to-next), and for the 0.1% AEP baseline (mid red), shallower gradient (dark red) and steeper gradient (light red).

3.1.3 Glascoed weir coefficient of discharge

Without flow data for the site, the C_d cannot be determined directly and relies on modelling judgment from typical values, with 1.7 selected in the baseline case as typically representative of a broad nosed weir crest. The sensitivity of the model to these values has been tested to represent plausible limits of those parameter values, with a highly efficient weir ($C_d = 1.85$) and highly inefficient weir ($C_d = 1.20$). The results at the location of the bypass inlet (GLAS_0033) are sensitive to the parameter value of the weir spill coefficient used (Table 4). This is because the backwater effect of the weir extends beyond the location of the bypass inlet, given the size of the weir in relation to the gradient and size of the channel. The effect of glass-walling the model will exacerbate this, especially at larger events.

Table 4 Sensitivity test results for the weir coefficient of discharge

Model version	C_d	10% AEP Water level (mAOD)	1% AEP Water level (mAOD)	10% AEP Peak velocity (m/s)	1% AEP Peak velocity (m/s)
Efficient	1.85	154.85	155.08	1.35	1.56
Baseline	1.70	154.85	155.10	1.34	1.54
Inefficient	1.20	154.89	155.17	1.29	1.44

3.1.4 Glass-walling

As outlined in Figure 5, the limitations of the topographic surveys on defining the channel shape, particularly the right bank, suggest very low bank heights on the watercourse. In the model, because the water is not allowed to spill out of the channel, FMP addresses this by adding a virtual “glass wall” onto the cross-sections of theoretically unlimited height.

Figure 7 provides the long-section maximum water levels for all modelled events for the baseline case, against bed and bank elevations. This illustrates the low spot on the right bank requiring this “glass-walling” treatment, even at the 50% AEP, the smallest modelled event. On this basis, all of the results derived from the model will be conservative from the point of view of potentially overestimating the flow, water level, and velocities through the reach.

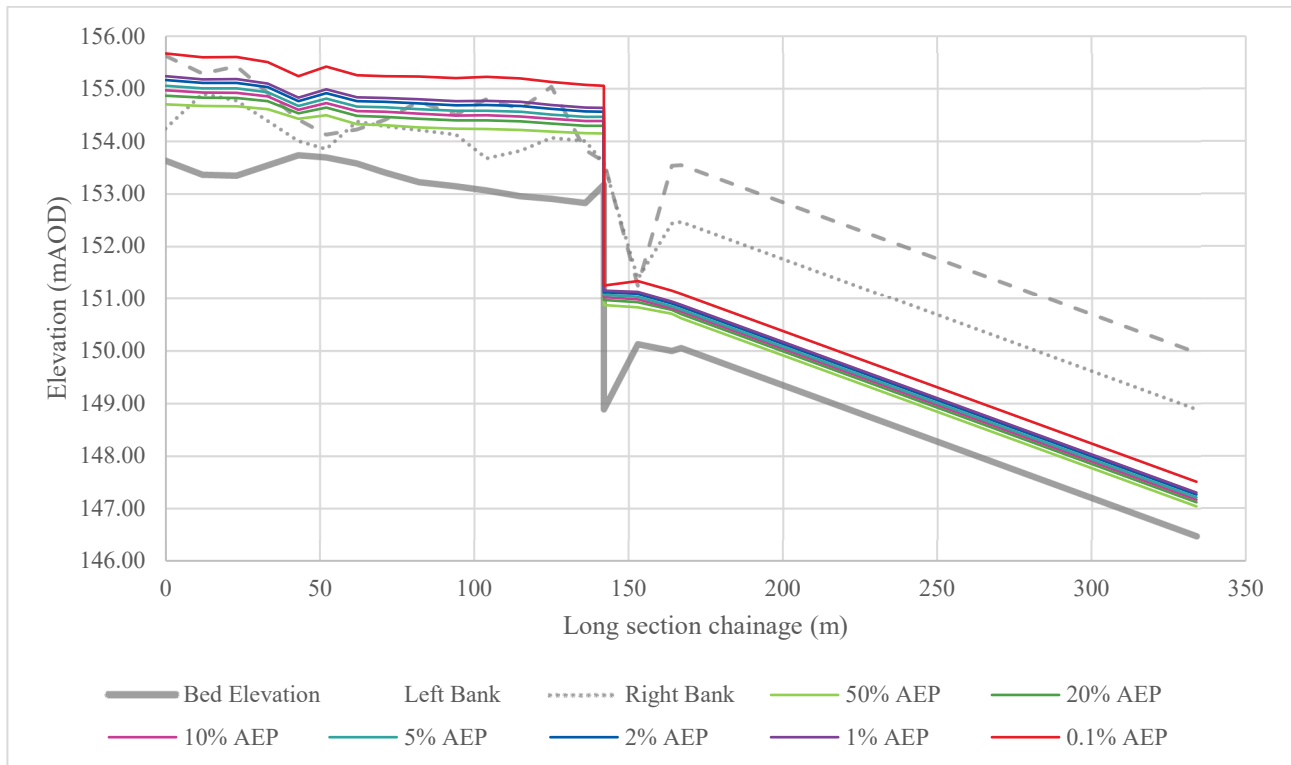


Figure 7 Glass walling in the model, showing modelled baseline events exceeding bank top and being artificially contained in the modelled channel.

3.2 Results for scour assessment

Calculated peak velocities and Froude numbers are provided for a range of flows in Figure 8 and Figure 9. Given the uncertainties in the peak flows outlined above, for the purposes of informing design of scour protection, the results are presented against peak flow, rather than being linked to the event magnitude itself. The six events plotted span the 50% to 0.1% AEP.

The maximum modelled velocity near the inlet to the fish bypass channel across all modelled roughness and events does not exceed 3 m/s. At the node immediately downstream, this maximum is 3.6 m/s. The model predicts sub-critical flow in the channel at the inlet across all events.

Full tabulated results are provided in Appendix A.

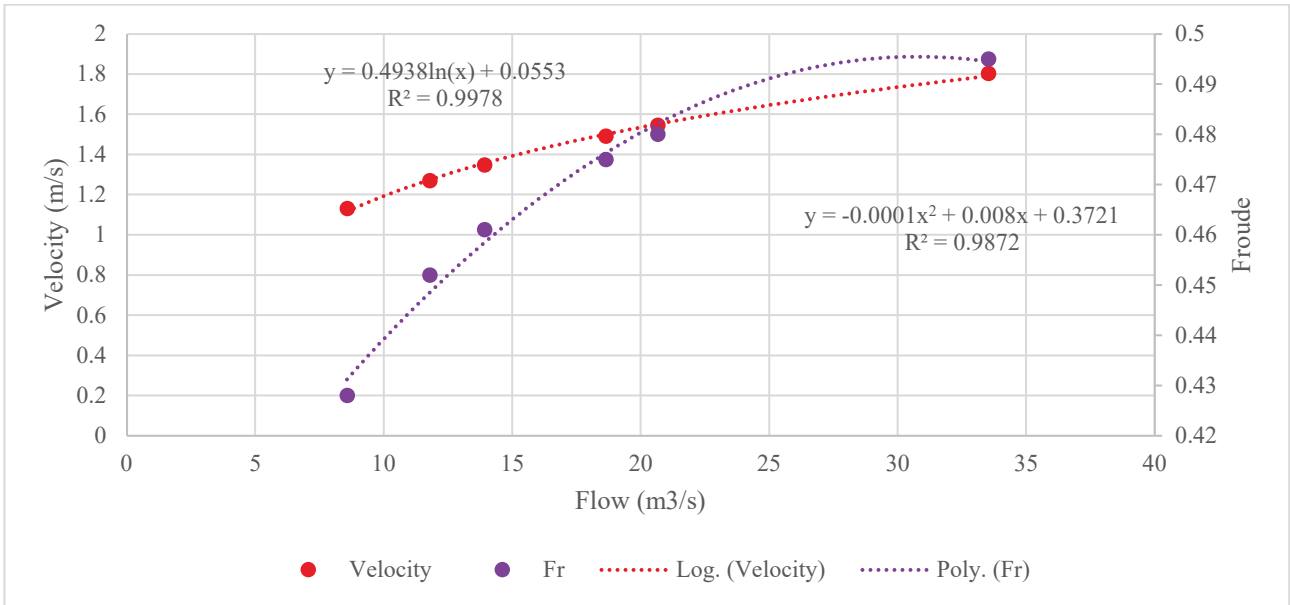


Figure 8 Calculated velocity and Froude number at the bypass inlet (GLAS_0033) for a range of modelled inflows.

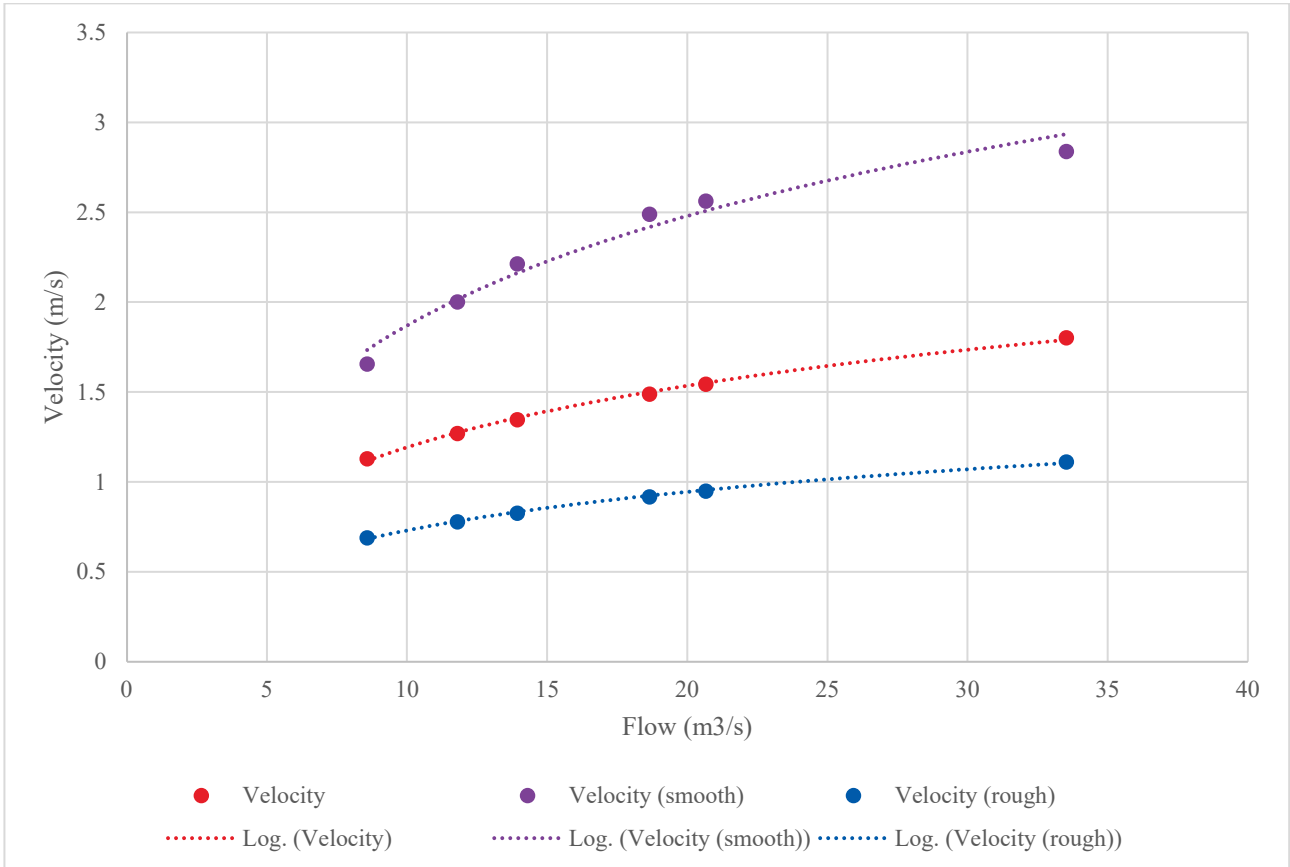


Figure 9 Calculated velocities at the bypass inlet (GLAS_0033) for a range of modelled inflows, for the base model, as well as the smooth and rough models.

4. Conclusions and recommendations

The predicted velocities from the model are expected to be conservative, as outlined in Section 2.7. The model uses a number of assumptions and simplifications. These all may have an impact on the ability of the hydraulic assessment to accurately capture the hydraulics for use in detailed scour assessment or design and specification of scour protection products.

Refinement of the modelling would necessitate additional data and modelling. In particular:

- Flow gauging data required to validate the inflow hydrology to the model, in particular to ensure the flows inserted into the channel itself are accurate, for example by accounting for any losses at the reach in question that have spilled out and bypassed through the floodplain.
- Refined understanding of the hydraulic roughness, for example using the Conveyance Estimation System, in combination with observed flow data, including discretisation of varying roughness in the channel and river bank zones.
- Refinement of the channel cross-section survey and topographic data, where loss of definition in the channel shape has been encountered when extracting from the existing coarse topographic survey points.
- Extension of the survey downstream and across the floodplain, to represent credible losses from overtopping of the channel. Creation of a combined 1D model of the channel linked to a 2D floodplain model, or use of 1D spill and dummy “reservoir” units to represent losses from overtopping into the bypass channel and the floodplain.
- Fundamentally, a 1D hydraulic model calculates depth-averaged and width-averaged velocities and cannot account for complex localised hydraulic effects such as eddy circulation or the effect of gravel bars within the channel. If within-channel hydraulic complexity was an issue and considered critical for design of scour protection, then an in-channel 2D model or 3D Computational Fluid Dynamics model may be required.

It is recommended to conservatively assume up to 3 m/s velocity in the channel at the location of the inlet structure. An additional factor of safety could also be applied if this is to be used to inform design.

In conclusion, additional information would allow to refine the model to inform a design with a lower level of uncertainty. NRW is currently intending to undertake a temporary flow gauging exercise, including the 2023/2024 winter months, which would allow calibration of the hydrology calculations and refinement of the hydraulic model. This would provide outputs that with improved suitability to inform a proportionate and sustainable design for the scour remediation and protection.

Appendix A

Tabulated hydraulic results

Base model (n=0.040)

Label	Bed Elevation	2yr				5yr				10yr				50yr				100yr				1000yr			
		Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity
GLA S_00_00	153.63	8.57	154.70	0.40	0.94	11.79	154.86	0.38	0.99	13.92	154.97	0.36	1.02	18.64	155.16	0.36	1.10	20.65	155.23	0.35	1.13	33.52	155.67	0.35	1.28
GLA S_00_12	153.36	8.57	154.67	0.34	0.97	11.79	154.82	0.37	1.12	13.92	154.92	0.39	1.19	18.64	155.10	0.41	1.34	20.65	155.17	0.41	1.39	33.52	155.59	0.47	1.59
GLA S_00_23	153.34	8.57	154.66	0.30	0.84	11.79	154.82	0.32	0.95	13.92	154.92	0.33	1.01	18.64	155.10	0.35	1.12	20.65	155.18	0.35	1.16	33.52	155.60	0.37	1.33
GLA S_00_33	153.54	8.57	154.61	0.43	1.13	11.79	154.75	0.46	1.28	13.92	154.85	0.46	1.34	18.64	155.03	0.47	1.49	20.65	155.10	0.48	1.54	33.52	155.50	0.49	1.79
GLA S_00_43	153.73	8.57	154.42	0.81	1.91	11.79	154.52	0.89	2.22	13.92	154.59	0.91	2.34	18.64	154.76	0.92	2.50	20.65	154.83	0.91	2.54	33.52	155.23	0.79	2.68
GLA S_00_52	153.69	8.57	154.49	0.42	1.06	11.79	154.63	0.44	1.18	13.92	154.72	0.44	1.25	18.64	154.91	0.44	1.35	20.65	154.98	0.43	1.39	33.52	155.42	0.42	1.60
GLA S_00_62	153.57	8.57	154.32	0.85	1.82	11.79	154.47	0.77	1.84	13.92	154.57	0.73	1.87	18.64	154.76	0.67	1.95	20.65	154.83	0.66	1.99	33.52	155.25	0.61	2.24
GLA S_00_71	153.4	8.57	154.30	0.56	1.37	11.79	154.46	0.55	1.49	13.92	154.55	0.54	1.56	18.64	154.75	0.54	1.70	20.65	154.82	0.53	1.76	33.52	155.23	0.54	2.08
GLA S_00_82	153.22	8.57	154.26	0.49	1.26	11.79	154.42	0.50	1.38	13.92	154.52	0.50	1.45	18.64	154.72	0.50	1.56	20.65	154.79	0.50	1.61	33.52	155.23	0.48	1.85
GLA S_00_94	153.14	8.57	154.23	0.39	1.11	11.79	154.39	0.42	1.27	13.92	154.48	0.44	1.35	18.64	154.68	0.46	1.50	20.65	154.76	0.47	1.55	33.52	155.20	0.46	1.77
GLA S_01_04	153.06	8.57	154.23	0.33	0.91	11.79	154.39	0.35	1.04	13.92	154.49	0.36	1.11	18.64	154.69	0.37	1.23	20.65	154.77	0.38	1.27	33.52	155.22	0.37	1.48
GLA S_01_15	152.95	8.57	154.21	0.32	0.88	11.79	154.37	0.34	1.01	13.92	154.47	0.34	1.08	18.64	154.66	0.36	1.20	20.65	154.74	0.36	1.25	33.52	155.19	0.37	1.49

GLA S_01 25	152.9	8.57	154. 18	0.3 6	1.02	11.7 9	154. 33	0.3 9	1.19	13.9 2	154. 42	0.4 0	1.27	18.6 4	154. 61	0.4 3	1.43	20.6 5	154. 68	0.4 3	1.49	33.5 2	155. 12	0.4 5	1.75
GLA S_01 36	152.82	8.57	154. 14	0.3 8	1.06	11.7 9	154. 29	0.4 1	1.23	13.9 2	154. 38	0.4 2	1.32	18.6 4	154. 56	0.4 5	1.49	20.6 5	154. 64	0.4 5	1.55	33.5 2	155. 07	0.4 7	1.84
GLA S_01 42u	153.17	8.57	154. 14	0.3 3	0.95	11.7 9	154. 29	0.3 6	1.12	13.9 2	154. 38	0.3 7	1.21	18.6 4	154. 56	0.3 9	1.39	20.6 5	154. 63	0.4 0	1.46	33.5 2	155. 05	0.4 3	1.80
GLA S_01 42d	148.88	8.57	150. 87	0.2 4	0.93	11.7 9	150. 97	0.3 0	1.20	13.9 2	151. 02	0.3 4	1.37	18.6 4	151. 11	0.4 3	1.73	20.6 5	151. 15	0.4 6	1.88	33.5 2	151. 24	0.6 9	2.89
GLA S_01 53	150.13	8.57	150. 83	0.5 0	1.16	11.7 9	150. 93	0.5 4	1.36	13.9 2	150. 98	0.5 7	1.48	18.6 4	151. 08	0.6 2	1.72	20.6 5	151. 12	0.6 4	1.82	33.5 2	151. 33	0.7 5	2.34
GLA S_01 64	149.99	8.57	150. 71	0.7 6	1.50	11.7 9	150. 78	0.8 3	1.73	13.9 2	150. 81	0.9 0	1.92	18.6 4	150. 90	0.9 3	2.14	20.6 5	150. 94	0.9 4	2.22	33.5 2	151. 14	0.9 7	2.63
GLA S_01 67	150.05	8.57	150. 62	0.9 8	1.83	11.7 9	150. 70	1.0 1	2.05	13.9 2	150. 75	1.0 2	2.18	18.6 4	150. 84	1.0 5	2.41	20.6 5	150. 88	1.0 6	2.50	33.5 2	151. 09	1.1 0	2.94
GLA S_03 34	146.47	8.57	147. 04	0.9 8	1.83	11.7 9	147. 12	1.0 1	2.06	13.9 2	147. 17	1.0 2	2.18	18.6 4	147. 26	1.0 5	2.41	20.6 5	147. 30	1.0 6	2.50	33.5 2	147. 51	1.1 0	2.94

Smooth model (n=0.018)

Label	Bed Elevation	2yr				5yr				10yr				50yr				100yr				1000yr			
		Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity
GLA S_00_00	153.63	8.57	154.36	0.94	1.91	11.79	154.51	0.90	1.90	13.92	154.61	0.82	1.79	18.64	154.79	0.69	1.74	20.65	154.86	0.66	1.74	33.52	155.27	0.55	1.78
GLA S_00_12	153.36	8.57	154.43	0.51	1.33	11.79	154.54	0.57	1.56	13.92	154.61	0.60	1.69	18.64	154.73	0.67	1.95	20.65	154.78	0.69	2.05	33.52	155.13	0.70	2.34
GLA S_00_23	153.34	8.57	154.45	0.43	1.12	11.79	154.57	0.48	1.29	13.92	154.65	0.50	1.38	18.64	154.79	0.53	1.55	20.65	154.85	0.54	1.61	33.52	155.24	0.53	1.79
GLA S_00_33	153.54	8.57	154.36	0.69	1.65	11.79	154.44	0.80	1.99	13.92	154.49	0.86	2.19	18.64	154.60	0.94	2.47	20.65	154.66	0.95	2.54	33.52	155.00	0.89	2.76
GLA S_00_43	153.73	8.57	154.24	1.36	2.77	11.79	154.35	1.35	3.02	13.92	154.42	1.34	3.14	18.64	154.55	1.33	3.35	20.65	154.61	1.32	3.42	33.52	154.94	1.23	3.57
GLA S_00_52	153.69	8.57	154.19	0.95	1.91	11.79	154.30	0.91	2.02	13.92	154.39	0.86	2.03	18.64	154.56	0.79	2.06	20.65	154.64	0.76	2.07	33.52	155.09	0.61	2.06
GLA S_00_62	153.57	8.57	154.13	1.50	2.86	11.79	154.25	1.40	2.91	13.92	154.32	1.36	2.91	18.64	154.47	1.23	2.92	20.65	154.53	1.17	2.93	33.52	154.87	1.00	3.10
GLA S_00_71	153.4	8.57	154.06	1.01	2.15	11.79	154.19	0.98	2.27	13.92	154.27	0.97	2.33	18.64	154.43	0.92	2.44	20.65	154.51	0.88	2.45	33.52	154.95	0.74	2.56
GLA S_00_82	153.22	8.57	154.09	0.71	1.66	11.79	154.23	0.72	1.81	13.92	154.32	0.71	1.87	18.64	154.51	0.68	1.96	20.65	154.59	0.67	1.99	33.52	155.03	0.60	2.13
GLA S_00_94	153.14	8.57	154.13	0.48	1.26	11.79	154.27	0.51	1.45	13.92	154.36	0.52	1.55	18.64	154.54	0.55	1.71	20.65	154.61	0.55	1.77	33.52	155.05	0.54	1.96
GLA S_01_04	153.06	8.57	154.16	0.38	1.01	11.79	154.31	0.39	1.14	13.92	154.40	0.41	1.22	18.64	154.59	0.42	1.34	20.65	154.67	0.42	1.39	33.52	155.12	0.41	1.58
GLA S_01_15	152.95	8.57	154.16	0.35	0.95	11.79	154.31	0.37	1.08	13.92	154.40	0.38	1.16	18.64	154.59	0.39	1.28	20.65	154.67	0.39	1.33	33.52	155.11	0.39	1.57

GLA S_01 25	152.9	8.57	154. 14	0.3 9	1.07	11.7 9	154. 28	0.4 2	1.24	13.9 2	154. 37	0.4 3	1.34	18.6 4	154. 55	0.4 5	1.50	20.6 5	154. 63	0.4 6	1.56	33.5 2	155. 06	0.4 8	1.82
GLA S_01 36	152.82	8.57	154. 13	0.3 9	1.07	11.7 9	154. 27	0.4 2	1.25	13.9 2	154. 36	0.4 3	1.34	18.6 4	154. 54	0.4 6	1.51	20.6 5	154. 62	0.4 6	1.57	33.5 2	155. 04	0.4 8	1.87
GLA S_01 42u	153.17	8.57	154. 14	0.3 3	0.95	11.7 9	154. 29	0.3 6	1.12	13.9 2	154. 38	0.3 7	1.21	18.6 4	154. 56	0.3 9	1.39	20.6 5	154. 63	0.4 0	1.46	33.5 2	155. 05	0.4 3	1.80
GLA S_01 42d	148.88	8.57	150. 70	0.2 8	1.04	11.7 9	150. 77	0.3 6	1.36	13.9 2	150. 80	0.4 1	1.58	18.6 4	150. 84	0.5 3	2.05	20.6 5	150. 84	0.5 9	2.27	33.5 2	150. 81	0.9 9	3.78
GLA S_01 53	150.13	8.57	150. 59	1.1 2	2.04	11.7 9	150. 66	1.1 8	2.32	13.9 2	150. 70	1.2 2	2.49	18.6 4	150. 77	1.2 8	2.82	20.6 5	150. 80	1.3 1	2.96	33.5 2	150. 95	1.4 6	3.71
GLA S_01 64	149.99	8.57	150. 50	1.7 0	2.81	11.7 9	150. 56	1.7 6	3.11	13.9 2	150. 59	1.8 2	3.30	18.6 4	150. 67	1.8 7	3.60	20.6 5	150. 69	1.9 1	3.76	33.5 2	150. 83	2.0 7	4.45
GLA S_01 67	150.05	8.57	150. 45	2.0 7	3.25	11.7 9	150. 51	2.1 2	3.56	13.9 2	150. 54	2.1 4	3.73	18.6 4	150. 61	2.1 8	4.04	20.6 5	150. 64	2.2 1	4.21	33.5 2	150. 77	2.2 9	4.98
GLA S_03 34	146.47	8.57	146. 87	2.0 7	3.25	11.7 9	146. 93	2.1 2	3.56	13.9 2	146. 96	2.1 4	3.73	18.6 4	147. 03	2.1 8	4.04	20.6 5	147. 06	2.2 1	4.21	33.5 2	147. 19	2.2 9	4.98

Rough model (n=0.100)

Label	Bed Elevation	2yr				5yr				10yr				50yr				100yr				1000yr			
		Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity	Max Flow	Max Stage	Max Fr	Max Velocity
GLA S_00_00	153.63	8.57	155.14	0.17	0.51	11.79	155.37	0.17	0.57	13.92	155.51	0.17	0.60	18.64	155.78	0.18	0.66	20.65	155.88	0.18	0.68	33.52	156.44	0.18	0.76
GLA S_00_12	153.36	8.57	155.10	0.19	0.62	11.79	155.32	0.20	0.70	13.92	155.45	0.22	0.74	18.64	155.72	0.23	0.79	20.65	155.82	0.23	0.81	33.52	156.39	0.21	0.92
GLA S_00_23	153.34	8.57	155.07	0.17	0.53	11.79	155.29	0.18	0.60	13.92	155.42	0.18	0.64	18.64	155.68	0.19	0.70	20.65	155.78	0.19	0.72	33.52	156.35	0.19	0.85
GLA S_00_33	153.54	8.57	155.02	0.22	0.69	11.79	155.23	0.23	0.78	13.92	155.36	0.24	0.83	18.64	155.61	0.24	0.92	20.65	155.71	0.25	0.95	33.52	156.28	0.25	1.11
GLA S_00_43	153.73	8.57	154.92	0.33	0.94	11.79	155.13	0.32	1.04	13.92	155.25	0.32	1.09	18.64	155.50	0.33	1.21	20.65	155.59	0.33	1.26	33.52	156.14	0.33	1.50
GLA S_00_52	153.69	8.57	154.87	0.21	0.65	11.79	155.08	0.22	0.73	13.92	155.21	0.22	0.77	18.64	155.46	0.22	0.86	20.65	155.56	0.23	0.90	33.52	156.11	0.24	1.09
GLA S_00_62	153.57	8.57	154.78	0.30	0.87	11.79	154.99	0.30	0.97	13.92	155.12	0.30	1.03	18.64	155.36	0.30	1.15	20.65	155.46	0.31	1.20	33.52	155.99	0.32	1.45
GLA S_00_71	153.4	8.57	154.71	0.26	0.81	11.79	154.92	0.27	0.92	13.92	155.04	0.27	0.99	18.64	155.28	0.29	1.12	20.65	155.37	0.29	1.17	33.52	155.89	0.31	1.45
GLA S_00_82	153.22	8.57	154.62	0.26	0.79	11.79	154.84	0.27	0.88	13.92	154.96	0.27	0.94	18.64	155.19	0.28	1.05	20.65	155.28	0.28	1.10	33.52	155.79	0.30	1.34
GLA S_00_94	153.14	8.57	154.54	0.25	0.79	11.79	154.74	0.27	0.89	13.92	154.86	0.28	0.95	18.64	155.09	0.29	1.06	20.65	155.18	0.29	1.10	33.52	155.68	0.30	1.34
GLA S_01_04	153.06	8.57	154.48	0.22	0.69	11.79	154.68	0.24	0.78	13.92	154.80	0.24	0.83	18.64	155.03	0.25	0.93	20.65	155.12	0.25	0.97	33.52	155.62	0.27	1.18
GLA S_01_15	152.95	8.57	154.42	0.23	0.69	11.79	154.61	0.24	0.80	13.92	154.73	0.25	0.85	18.64	154.95	0.26	0.97	20.65	155.04	0.26	1.01	33.52	155.53	0.28	1.25

GLA S_01 25	152.9	8.57	154. 34	0.2 8	0.85	11.7 9	154. 52	0.3 0	0.98	13.9 2	154. 63	0.3 1	1.05	18.6 4	154. 84	0.3 3	1.19	20.6 5	154. 93	0.3 4	1.23	33.5 2	155. 39	0.3 5	1.48
GLA S_01 36	152.82	8.57	154. 21	0.3 4	0.97	11.7 9	154. 37	0.3 6	1.13	13.9 2	154. 47	0.3 7	1.21	18.6 4	154. 67	0.3 9	1.37	20.6 5	154. 74	0.4 0	1.42	33.5 2	155. 19	0.4 2	1.71
GLA S_01 42u	153.17	8.57	154. 14	0.3 3	0.95	11.7 9	154. 29	0.3 6	1.12	13.9 2	154. 38	0.3 7	1.21	18.6 4	154. 56	0.3 9	1.39	20.6 5	154. 63	0.4 0	1.46	33.5 2	155. 05	0.4 3	1.80
GLA S_01 42d	148.88	8.57	151. 14	0.1 9	0.78	11.7 9	151. 29	0.2 4	0.99	13.9 2	151. 38	0.2 6	1.12	18.6 4	151. 55	0.3 1	1.37	20.6 5	151. 61	0.3 3	1.47	33.5 2	151. 95	0.4 4	2.03
GLA S_01 53	150.13	8.57	151. 10	0.2 8	0.78	11.7 9	151. 24	0.3 0	0.91	13.9 2	151. 32	0.3 2	0.98	18.6 4	151. 49	0.3 4	1.12	20.6 5	151. 55	0.3 5	1.17	33.5 2	151. 90	0.3 8	1.47
GLA S_01 64	149.99	8.57	150. 96	0.3 7	0.89	11.7 9	151. 10	0.3 8	0.99	13.9 2	151. 18	0.3 8	1.04	18.6 4	151. 34	0.3 9	1.15	20.6 5	151. 40	0.3 9	1.20	33.5 2	151. 74	0.4 1	1.41
GLA S_01 67	150.05	8.57	150. 89	0.4 2	1.01	11.7 9	151. 03	0.4 4	1.13	13.9 2	151. 11	0.4 4	1.19	18.6 4	151. 26	0.4 5	1.31	20.6 5	151. 32	0.4 5	1.35	33.5 2	151. 66	0.4 7	1.57
GLA S_03 34	146.47	8.57	147. 31	0.4 2	1.01	11.7 9	147. 45	0.4 4	1.13	13.9 2	147. 53	0.4 4	1.19	18.6 4	147. 68	0.4 5	1.31	20.6 5	147. 74	0.4 5	1.35	33.5 2	148. 08	0.4 7	1.57