Phil Worthing

LECKWITH QUAY

Hydraulic Modelling Report

3561-C-RP-004
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CONFIDENTIAL

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1 INTRODUCTION & BACKGROUND

1.1 PROJECT REQUIREMENTS

WSP UK Ltd (WSP) were commissioned by Phil Worthing (the client) to undertake flood studies at Leckwith Quay, Vale of Glamorgan in support of a proposed development.

The development proposals are for a residential development (target of up to 250 residences) along with associated public open space, amenities and includes a new highway link via a bridge across the Afon Elái, with the existing B4267 bridge being demolished along with the existing business units. The development is split into two parcels on either side of the proposed new bridge crossing referred to as the northern (1.3 ha) and the southern plateaus (6.4 ha). It is proposed to raise the development parcels above the flood level to reduce the risk of onsite flooding. Figure 1-1 below shows the redline boundary and masterplan (Appendix B) provided by Loyn + Co Architects. It must be noted that the proposals shown in the figure have evolved from those simulated in the model which discussed in Appendix A.

Given the magnitude of the Scheme and the changes that are proposed within and adjacent to the floodplain it was deemed appropriate to undertake a Level 3 FCA to provide a robust evidence base to support the planning application. This modelling report should be read alongside the FCA [ref:3561-C-RP-003-04-FCA].

1.2 PREVIOUS RELEVANT STUDIES

1.2.1 HYDRAULIC MODELS & NRW DEVELOPER ADVICE SERVICE

Natural Resources Wales (NRW) hold a hydraulic model, the *'Ely Mills Scheme Model (ARUP 2013)'* (herein the 'Paper Mills Model'), which simulates the interaction between the currently under construction Ely Paper Mills Scheme and its associated works to the riparian system and the Afon Elái (only); however, this representation does not include the site at Leckwith Quay or the Afon Taf, which are within a separate Cardiff-wide model the '*Cardiff VDM Update 1D-2D Model (MOTT MACDONALD DEC 2012)'* (herein the 'VDM') that does not currently include the Ely Paper Mills Scheme. Both of these models and their associated reports are of interest to this study. In order to inform the analysis of the flood risk at this location, discussions were held with NRW via their Developer Advice Service (DAS). The key outcomes of the DAS were:

- Confirmation of the range and general configuration of the scenarios and events required to provide a robust understanding of the fluvial risk at this location, and;
- An agreement as to how to incorporate the most appropriate representation of the Paper Mills Scheme, given various unknowns and uncertainties.

1.3 LOCATION

Leckwith Quay is a 7.7 ha site located between the A4232, Leckwith Road and the Afon Elái (River Ely) on the outskirts of Cardiff in the Vale of Glamorgan CF11 8AU. The site extends approximately 890 m along the Elái riverbank in the Vale of Glamorgan (with the opposite bank within Cardiff City) it extends some 100 m into Vale of Glamorgan from the river bank. There are currently two river crossings at this location:

- Leckwith Road (B4267) roadbridge has a single span concrete arch conveying the channel itself with a springing level of 4.8 m AOD and soffit of 9.26 m AOD and includes a series of nine additional spans over the western bank as the road climbs to the higher ground.
- Historic Roadbridge (Grade II*) is a single track, triple arch, rough masonry viaduct with pedestrian refuges between each arch. The bridge sits lower than its more modern companion with each soffit approximately 7 m AOD and the parapet generally below 9.0 m AOD.

The site is some 3 km upstream of the Afon Elái's outfall into Cardiff Bay, behind the Cardiff Bay Barrage and some 700 m upstream of the A432 Roadbridge. Upstream from the site by circa 490 m is another A432 Roadbridge as well as an Ely Trail Footbridge approximately 690 m upstream.

Current site levels are understood to be around 7.0 m AOD along the Afon Elái's top of bank and rising to the west.

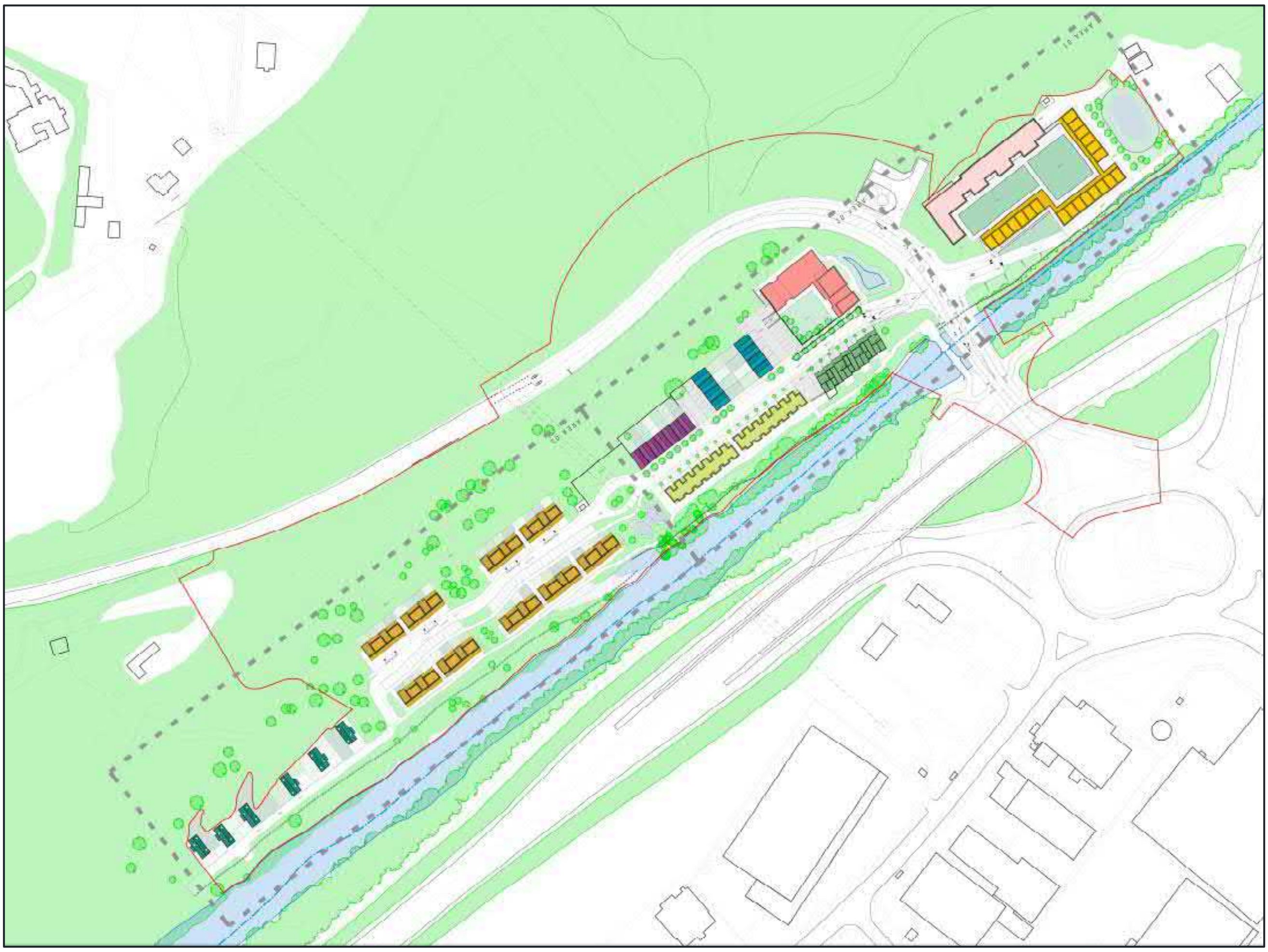


Figure 1-1: Proposed Development

1.4 BACKGROUND DATA

1.4.1 HYDRAULIC MODELLING STUDIES

As set out in Section 1.2 above, there are two specific previous models of interest to this study, the Paper Mills Model and the VDM. The Paper Mills Model, covering a more detailed area within the VDM coverage, has been incorporated into the WSP model developed for this study. Details regarding this process are set out within Section 3 and Appendix A. However, NRW have voiced uncertainty regarding the Paper Mills Scheme which is still under construction. Whilst surveys (advised as-built) which have been obtained by the client show that the Paper Mills Scheme has been constructed in general agreement with the proposal as represented in the Paper Mills Model, NRW consider that there are discrepancies and disagreement on some specifics. Unfortunately, this additional available data regarding the Paper Mills Scheme: does not cover the entire works, is unavailable in a format suitable for the hydraulic model and neither the client nor WSP have permission to rely on the information. The uncertainty regarding the Paper Mills Scheme, increases the uncertainty associated with any model seeking to understand the flood risk in and around the maximum flood extents in Cardiff. The client and WSP have progressed the hydraulic modelling for the Scheme to the best position available given the data constraints. It is deemed that this approach is appropriate for the purposes of determining this application.

1.4.2 TOPOGRAPHIC DATA

Outputs from hydraulic models are dependent on how accurately the channel sections are represented and whether any obstructions to flow or structures have been described. An appropriate survey is therefore an important component of any hydraulic model. This model primarily relies on the topographic data used to build the original models.

1.4.2.1 River Cross Sections

The original river cross section data used to build the VDM is no longer available. No additional river cross sections have been collected. Additional information on the representation of 1D structures is discussed in Section 3 and Appendix A.

1.4.2.2 Site Surveys

There are two site surveys of interest, a general survey of the site (Appendix C) which has been used to identify ground levels at the site in the model by creating a 3D surface of the recorded points. The surface has also been used to update the river bank-top zln as well as a zln of the road through the northern plateau area to form a preferential flowpath. The second survey (Appendix C) consists of an elevation of the existing crossing (B4267) which has been used to configure the 2D flowpath under this structure.

1.4.2.3 LiDAR Data

The 2D domain has been updated with the latest available 1m DTM LiDAR, which can be seen in Figure 1-2 below. The available LiDAR is from both 2011 and 2017, the age of the tiles in the model is shown in the image below with green shading as 2011 and blue shading as 2017. This is of note as the VDM dates from 2016 and hence the area in blue is more recent than the VDM.

The DTM consists of an array of points with elevations representing the surface and forms the basis on which structures and relevant features can be added. The DTM has been patched and amended by additional files, in the baseline/existing model these include only those from the merged models, plus the available topographic data on site and a set of small targeted patches which overwrite null values located in gaps in the updated LiDAR file. Additional information on the representation of the 2D domain is discussed in Section 3 and Appendix A.

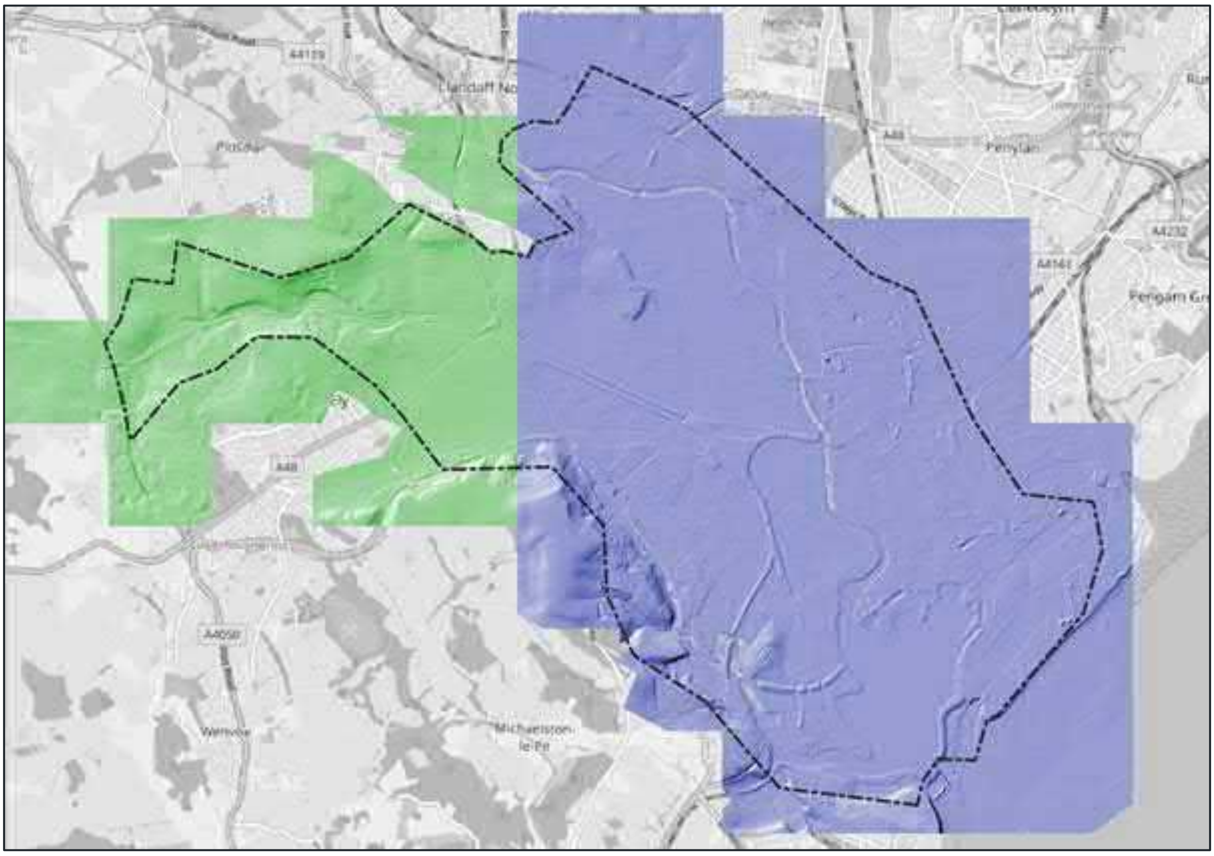


Figure 1-2: Available LiDAR

1.4.3 HISTORICAL DATA

Data on historical flood or flow events have not been used for this study. It is understood that the NRW VDM has been previously compared to or calibrated against historic events, however given the scale of the changes that have occurred since and the agreements previously reached with NRW on the scope of this model study their specific consideration are not deemed a requirement.

1.5 APPROACH TO THE STUDY

A 1D-2D hydraulic model of the Afon Elái and the Afon Taf have been constructed by merging together the VDM and Paper Mils Model, as well as incorporating more recent LiDAR and topographic survey information from the site of interest. Given the age of the two models additional improvements and changes have been incorporated. This includes:

- implementing newer software versions
- converting Cardiff Bay to a 1D representation
- alterations to structure representations discussed with NRW
- application of a finer grid resolution around the site in question
- updating topographic information to account for more recent LiDAR data

Additional information on the representation of changes to the provided models is discussed in Section 3 and Appendix A.

2 HYDROLOGY

There are a number of ways in which the likelihood or probability of a flood can be described. It is standard practice within the UK to refer to a flood in terms of its Return Period (RP), which is the average interval in years between consecutive events exceeding a specified magnitude. It is also possible to express an event in terms of its Annual Exceedance Probability (AEP). The AEP is the percentage chance that a flood of a specified magnitude or greater may occur in any given year. The equivalence between the two methods of describing the rarity of events is shown in Table 2-1 below.

Table 2-1: Annual Exceedance Probability - Return Period Equivalence

AEP (%)	50	20	10	4	3.3	2	1	0.1
RP (1 in *X* years)	2	5	10	25	30	50	100	1000

The equivalence[1] reported in the above table holds for return periods substantially greater than one year.

As part of discussions with NRW it was agreed that WSP would include flows derived as part of NRW's hydrological study of Cardiff. These inflows were provided as peak flow estimates in March 2020; therefore, they have been used to scale the hydrographs which accompanied the model.

Table 2-2 below states the design flows for periods of interest where CE denotes that the central estimate uplift for climate change has been applied. Figure 2-1 beneath shows an extract of the hydrographs themselves.

It should be noted that NRW provided FEH values only, the estimate for the 0.1% AEP event has been estimated via the Morris method using the originally supplied ReFH values resulting in an uplift to the peak of 15 cumecs (7%). Additionally, previous correspondence with NRW has questioned the shape of the hydrograph applied to the Afon Taf noting deformation from a standard curve in the higher return period events. It is understood that this is likely the result of the inflow hydrograph being derived from the outputs of a NRW model upstream. This would also explain the presence of the 2D flowpath added to the upstream extent of the Taf (2d_bc_TAF_FP_001.MIF).

The downstream boundary remains unchanged from the VDM model.

[1] The equivalence $AEP \approx \left(\frac{1}{RP}\right) * 100$ as reported in table can be more accurately derived as $AEP = \left(1 - e^{(-1/RP)}\right) * 100$

Table 2-2: Peak Flow Values per Return Period & AEP

AEP (%)	50	20	10	3.3	1	1CE	0.1
RP (1 in *X* years)	2	5	10	30	100	100CE	1000
Flow (m^3/s)	53.7	68.8	80.1	100.4	128.4	166.9	222.4

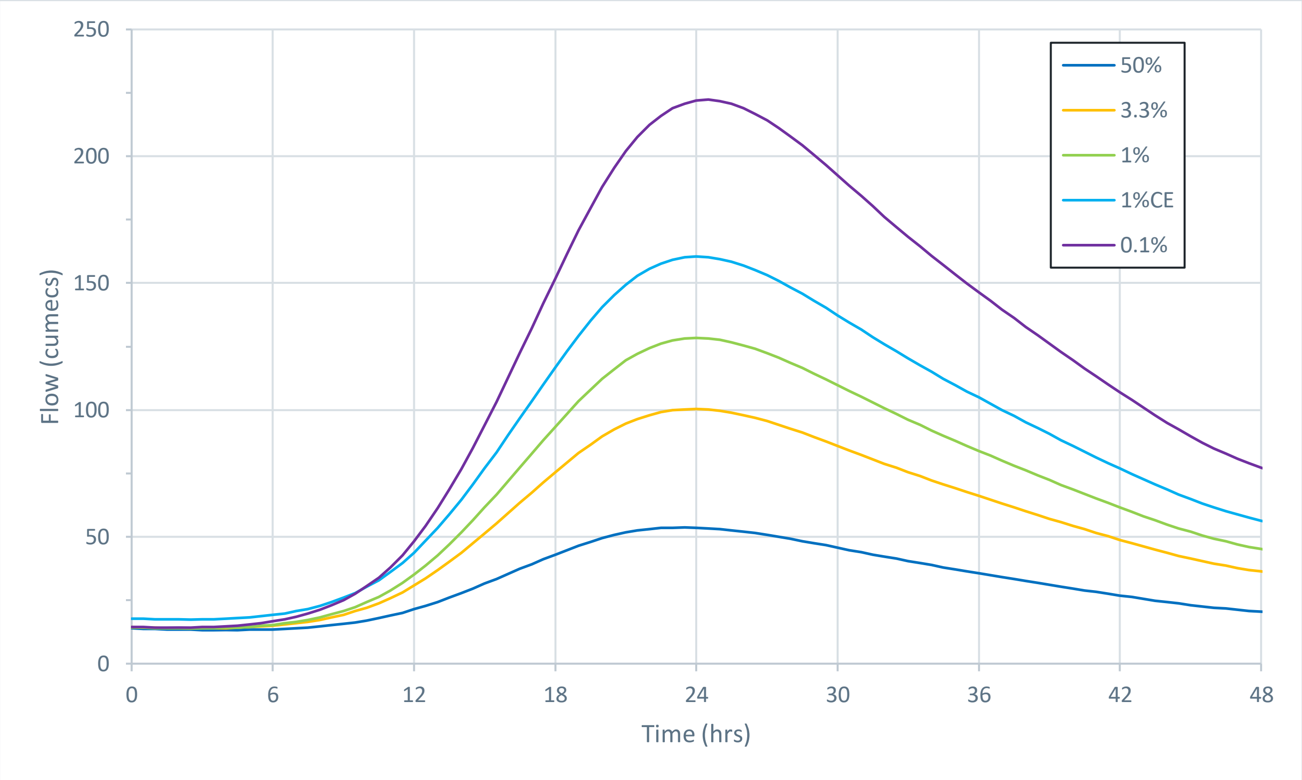


Figure 2-1: Example Hydrographs Afon Elái

3 HYDRAULIC MODEL SIMULATIONS

This section describes the simulated scenario configurations and provides a table setting out each of the simulations undertaken. Details of the hydraulic model construction and associated parameters are provided in Appendix A.

3.1 EXISTING SCENARIO

The Existing Scenario is the Baseline model and hence only incorporates those changes required to update the model and as agreed with NRW. These changes are summarised in Section 1.5 above and discussed in the relevant sections of Appendix A.

3.2 VARIATION D SCENARIO

The Variation D Scenario is the most recent iteration of the proposed development. It has been configured to represent the proposed development in a suitable manner. No changes have been required for software parameters; however, changes have been made to both the 2D and 1D domains. The below subsections summarise these changes

3.2.1 VARIATION D SCENARIO 2D

To represent the proposed scenario, ground surfaces provided by the project team representing the proposed surfaces have been used to overwrite the default roughness applied within the developable boundary. Land development parcels and the banktop have been set in accordance with the masterplan as provided in Appendix B and set via ‘Zln’,‘Za’ and ‘Zsh’ files, the bridge has been represented as a surface feature as directly translated from the 3D surface provided by the project team. A number of additional files have been applied to the control files in order to facilitate linking to the 1D domain, (e.g. nodes, WLL, HX, etc) as required to accommodate the changes described below.

3.2.2 VARIATION D SCENARIO 1D

A number of changes have been required in FMP and Estry to represent the proposed configuration.

3.2.2.1 Variation D FMP

The required changes to FMP include removing the current Leckwith roadbridge and inserting the Proposed Leckwith Bridge resulting in the proposed bridge being named ELY32550.

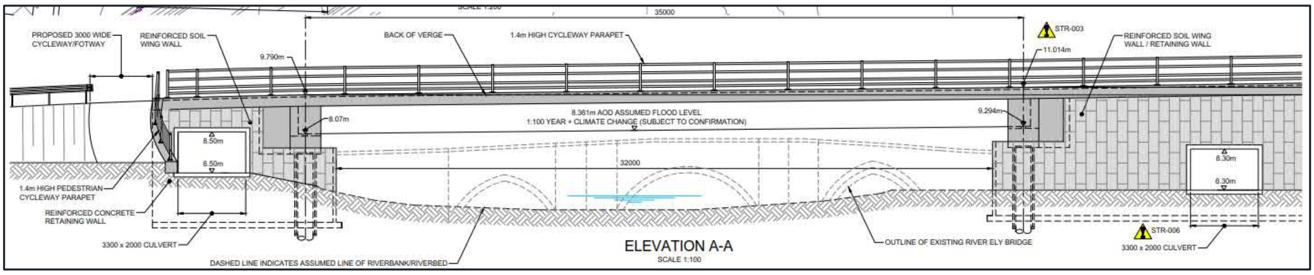
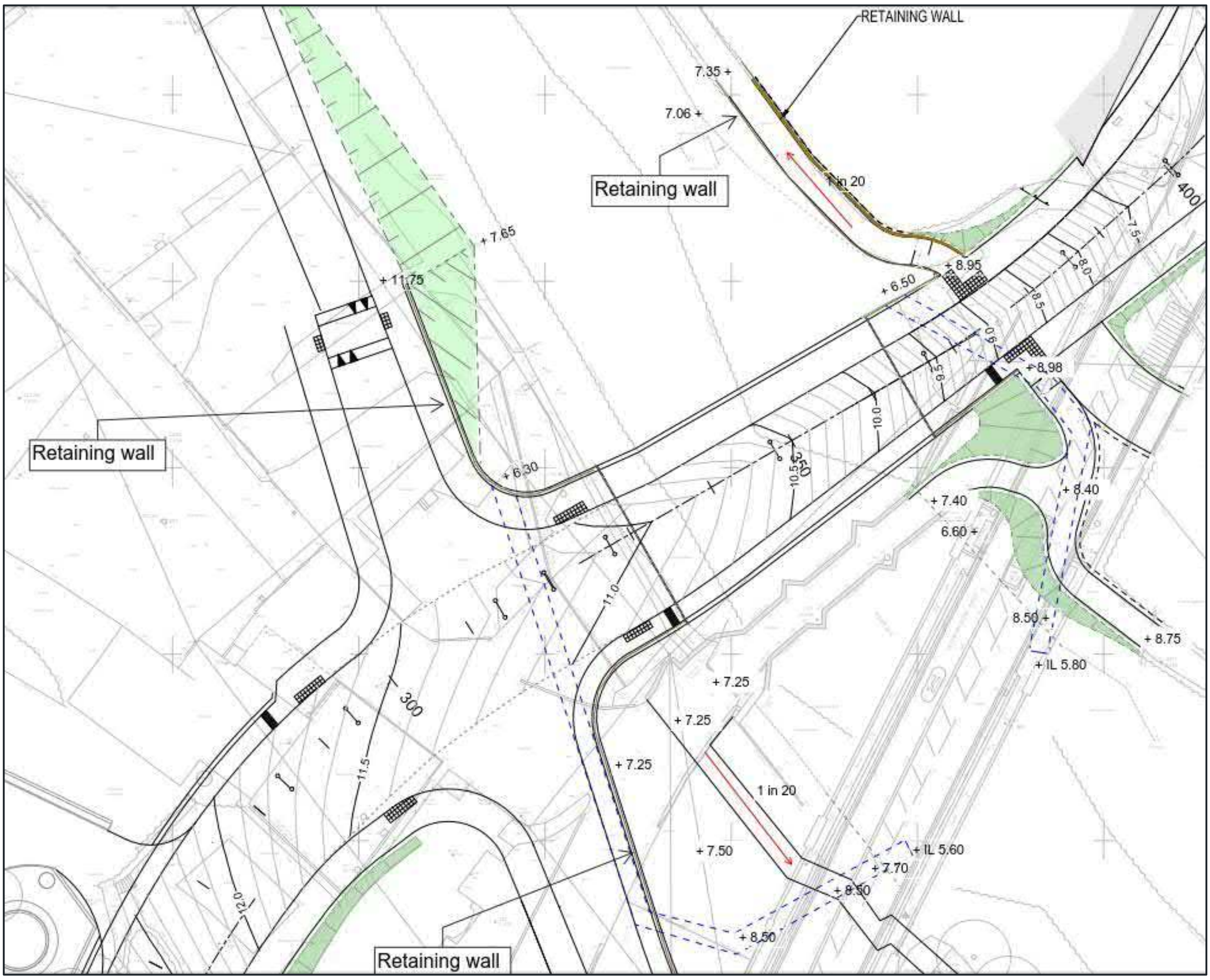


Figure 3-1: Proposed Viaduct Elevation

The above figure is an extract from the drawing *'Leckwith Quay Bridge Proposed General Arrangement'* 70053561-002-P03 September 2021 which is provided in Appendix B.

The below figure is an extract from the drawing '*B4267 Leckwith Road Highway Improvements Levels And Contours*' 70053561-WSP-XX-XX-CR-DE-600 September 2019 and is also provided in Appendix B.



The proposed bridge includes a number of assumptions concerning the final configuration and has been modelled as a USBPR bridge type unit given the 'thinness' of the expected structure. The associated spill has been set to the provided ground surface and assumes no significant impediment through the railings. A single span structure has been assumed with the aperture 32 m width noted with a skew angle of 0 degrees. Given the proximity to the Historic Bridge the ground profile has been replicated from that section and extended on the left hand bank, the top of bank has been set at the levelled off invert of the proposed bypass culverts on either side of the bridge to allow the transfer of water into this arrangement. The bridge definition also includes an orifice transition distance of 0.1 m on either side of the soffit.

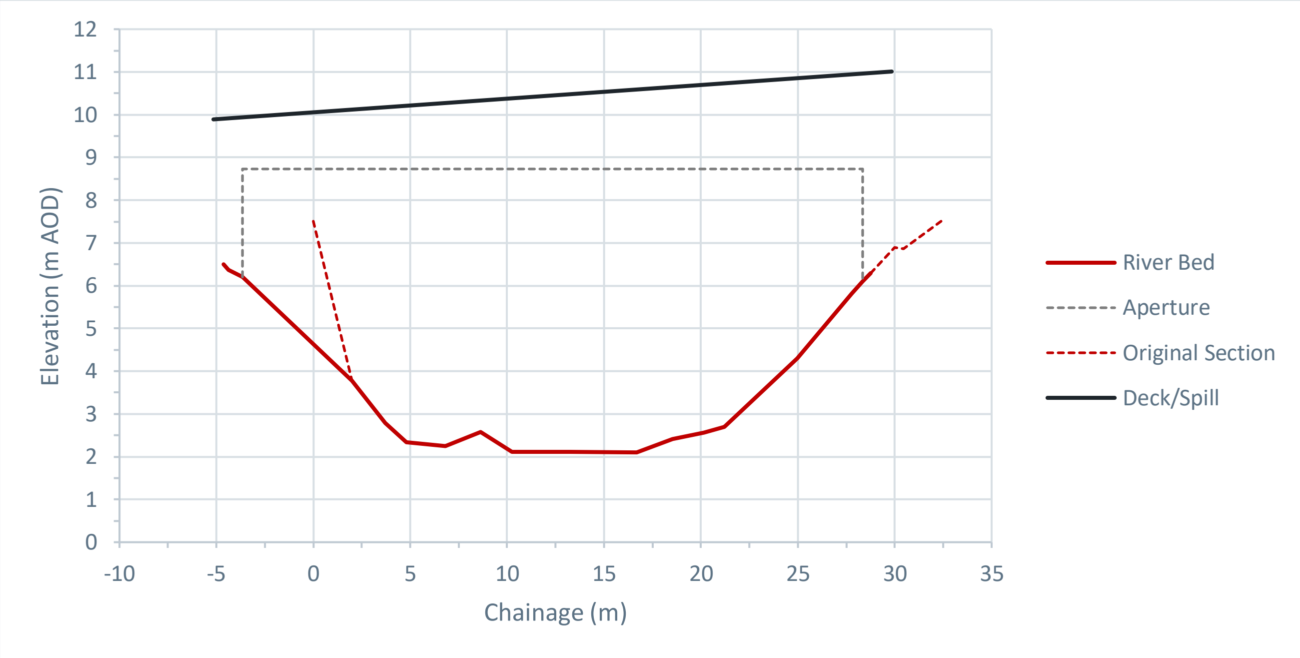


Figure 3-2: Representation of Proposed Viaduct (Sans Bypass Culverts)

3.2.2.2 Variation D Estry

The proposed bridge includes bypass culverts, these have been simulated in Estry. The two bypass culverts are 3.3 m by 2 m rectangular culverts, with one through either bank. The left bank culvert has an upstream invert of 6.5 m AOD and a downstream invert of 5.65 m AOD. The right bank culvert has an upstream invert of 6.3 m AOD and a downstream invert of 5.45 m AOD. Both culverts connect from the upstream face of the proposed viaduct and reconnect downstream of the historic bridge a mannings value of 0.02 has been applied assuming a concrete construction.

3.3 BLOCKAGE SCENARIOS

The Blockage Scenarios consist of modifying the underlying model scenario (i.e. Baseline/Existing or Developed) model but includes a blockage at the Historic Leckwith Bridge and, if relevant, a blockage on both bypass culverts. The blockage configuration assumes that the central arch of the Historic Bridge is 80% blocked (equivalent to 36.1% total) from the commencement of the model is represented via a 'blockage unit' in FMP. In the Variation D scenario this is combined with a 30% blockage to the upper section of both bypass culverts, this is achieved by reading in a modified '1d_nwk' with a pblock value of 30. It is noted that this configuration is not fully compliant with NRW guidance on modelling blockages; however, this is in accordance with NRW requests. No other changes in the model parameters were applied.

3.4 SENSITIVITY TESTS

A number of sensitivity scenarios are required to confirm the appropriateness of the model results and better understand the uncertainty, the applied model changes agreed to each are described in the relevant sub-sections below.

3.4.1 MANNINGS (ROUGHNESS) SENSITIVITY

The Mannings Sensitivity Tests will change the mannings roughness in the FMP 1D domain of both the Afon Elái and the Afon Taf by +/- 20% as well as the Estry roughness values of the floodplain features and the Tuflow roughness for the entire 2D domain.

3.4.2 INFLOW SENSITIVITY

The Inflow Sensitivity Tests changed the peak flow value provided by NRW by +/- 20% for the 1% AEP event (100yr return period) for the inflows (other than the baseflow) applied to both the Afon Elái and the Afon Taf.

3.4.3 BOUNDARY (OUTFLOW) SENSITIVITY

Whilst it may be typical to include boundary or outflow sensitivity tests, given that Cardiff Bay is controlled water body it was agreed with NRW that this sensitivity test was not required.

Table 3-1: Model Simulations

Scenario		Fluvial Event	Tidal Event	Sensitivity	Completed
Site	Blockage				
Baseline	Clear	50	MHWS		✓
		20	MHWS		✓
		10	MHWS		✓
		3.3	MHWS		✓
		1	MHWS		✓
		1	MHWS	(+20% Flow)	✓
		1	MHWS	(-20% Flow)	✓
		1	MHWS	(+20% Mannings)	✓
		1	MHWS	(-20% Mannings)	✓
		1CE	MHWScc		✓
		0.1	MHWS		✓
	Occluded	3.3	MHWS		✓
		1CE	MHWScc		✓
		0.1	MHWS		✓
Variation D	Clear	50	MHWS		✓
		20	MHWS		✓
		10	MHWS		✓
		3.3	MHWS		✓
		1	MHWS		✓
		1CE	MHWScc		✓
		0.1	MHWS		✓
	Occluded	3.3	MHWS		✓
		1CE	MHWScc		✓
		0.1	MHWS		✓

In the above table:

- The Site Scenario is either Baseline (Existing) or Variation D.
  - The Baseline variation describes the site in its current state;
  - The Variation D configuration describes the site in its proposed state with building structures and a new viaduct with bypass culverts.
- The Blockage Scenario is either Clear or Occluded.
  - The Clear version assumes no obstructions;
  - The Occluded variation assumes that the central arch of the Historic Bridge is 80% blocked (equivalent to 36.1% total). In the Variation D scenario this is combined with a 30% blockage to the upper section of the bypass culverts. This is in accordance with NRW requests.
- Fluvial event describes the annual exceedance probability (AEP) in flow applied to both the Afon Taf and the Afon Elái. CE denotes Central Estimate uplift for climate change.
- Tidal Event describes the downstream boundary. Each fluvial event is combined with a Mean High Water Springs tide (with or without climate change as appropriate).
- Sensitivity identifies whether the sensitivity of the model is being investigated for its inputs by either varying flow or roughness (mannings) by the agreed amount.

3.5 EXCLUDED SCENARIOS

In addition to the Boundary Sensitivity (S3.4.3) Scenario other scenarios have been considered during this project and excluded. For completeness these are described below:

- Undefended Scenario – this is a configuration which removes the defence features from the model. Previous model reports have included this Scenario and found that with floodwaters having less restricted access to upstream flood plains, the water level through the reach of interest ends up lower. It has been agreed with NRW that this model scenario is not required for this project.
- Paper Mills Discounted – this is a configuration which removes the works associated with the Paper Mills Scheme. The purpose of the Discounted Scenarios is to better understand the effect of the Paper Mills Scheme on flood risk and consequences to the proposed development and to better understand any uncertainty in this risk which may result from unknown matters associated with said scheme. At time of writing these scenarios have not been simulated.

4 HYDRAULIC MODELLING RESULTS

4.1 BASELINE MODEL RESULTS

The baseline model was run for all return periods listed in Table 3-1. Flood maps showing the maximum extents and depths for the key design (1%CE AEP) and extreme (0.1% AEP) events have been produced, which are contained in Appendix D.

The results of this model study are used to inform the FCA and therefore this section summaries key results from the events of interest. The primary source of the results reported in this document are extracted directly from FMP nodes, the location of these nodes in relation to the site is illustrated below. (N.B. OS data for river sections is not provided within the licenced data for each node and thus the locations should be considered as indicative).

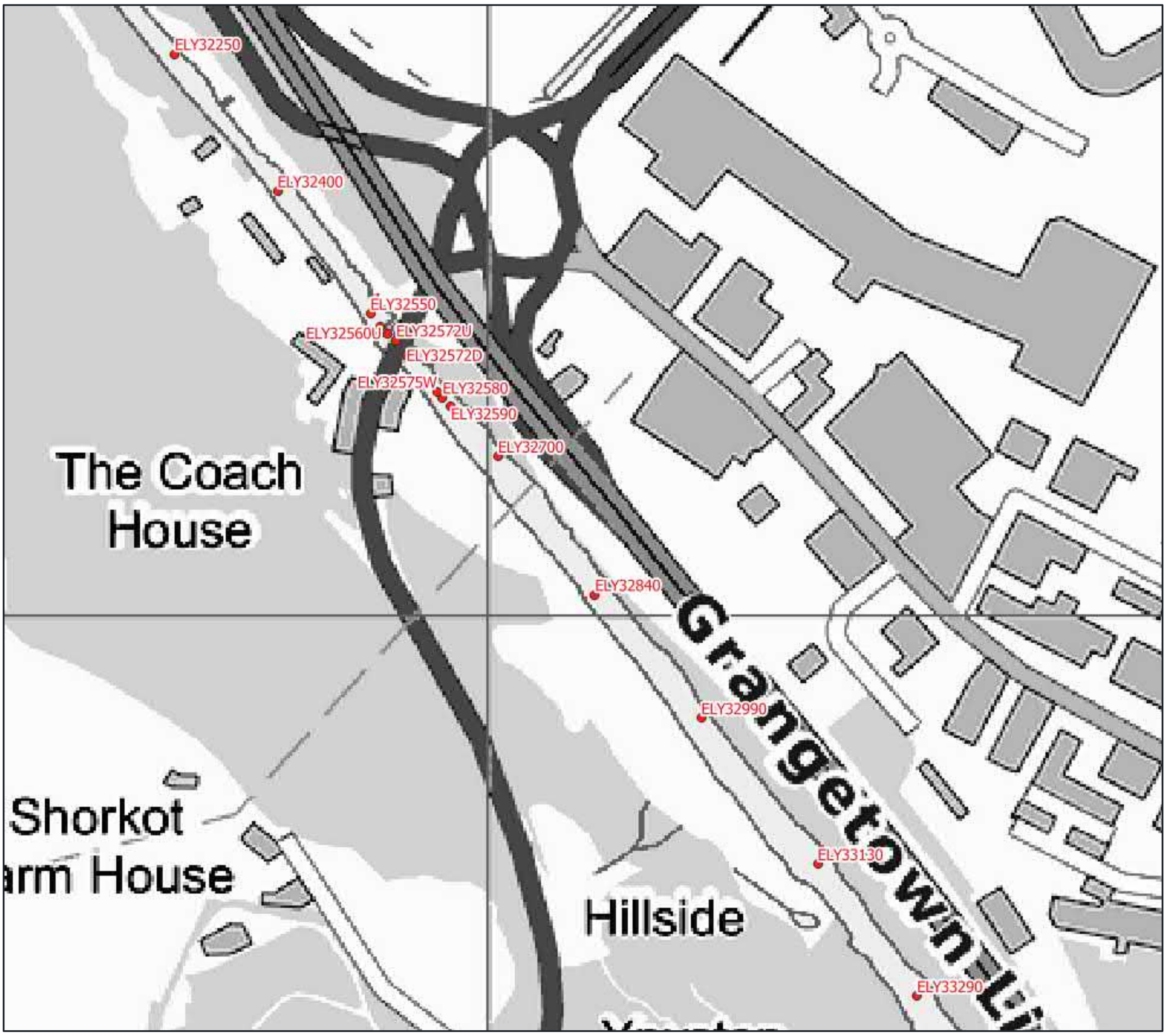


Figure 4-1: FMP Node Locations

The results suggest that the river reaches bankfull at the 1% event around the site but only floods with the addition of climate change or in less probable events. This event does cause wider flooding in Sanitorium Park, the South Wales Mainline and around Cowbridge Road. The existing site floods in the design 1%CE event.

The flood mechanism in the area of interest is that during the 1%CE event, waters overtop the banks on either side of the river at the site and on either side of the bridges by 25 hours into the simulation. This corresponds to the peak inflow and peak water level within the Bay causing a rapid increase in the volume of floodwaters within the system as outflows are throttled by the tide levels. Flood levels peak at over a metre deep on site with higher levels tending to be at the upstream face of the existing Leckwith Roadbridge. Once the driving floodwater level subsides some 5 hours later the majority of water flows back into the river leaving relatively shallow flooding, generally less than 10 cm but with pockets up to 40 cm, across low lying areas of the site for the remainder of the simulation.

Table 4-1: Extracted Baseline Defended Clear Results

Stage Levels (m AOD) for the Key Reach

Label	AEP		
	1%	1%CE	0.1%
ELY32400	7.491	8.419	8.476
ELY32550	7.482	8.411	8.460
ELY32560U	7.480	8.421	8.474
ELY32560D	6.995	8.016	7.431
ELY32572U	7.003	8.013	7.427
ELY32572D	6.986	7.994	7.397
ELY32575W	6.985	7.993	7.392
ELY32580	6.939	7.966	7.289
ELY32590	6.911	7.952	7.224
ELY32700	6.904	7.950	7.214
ELY32840	6.859	7.928	7.118
ELY32990	6.844	7.923	7.093
ELY33130	6.831	7.919	7.075

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge. The nodes named *ELY32572U* and *ELY32572D* are on either side of the Current Leckwith Bridge.

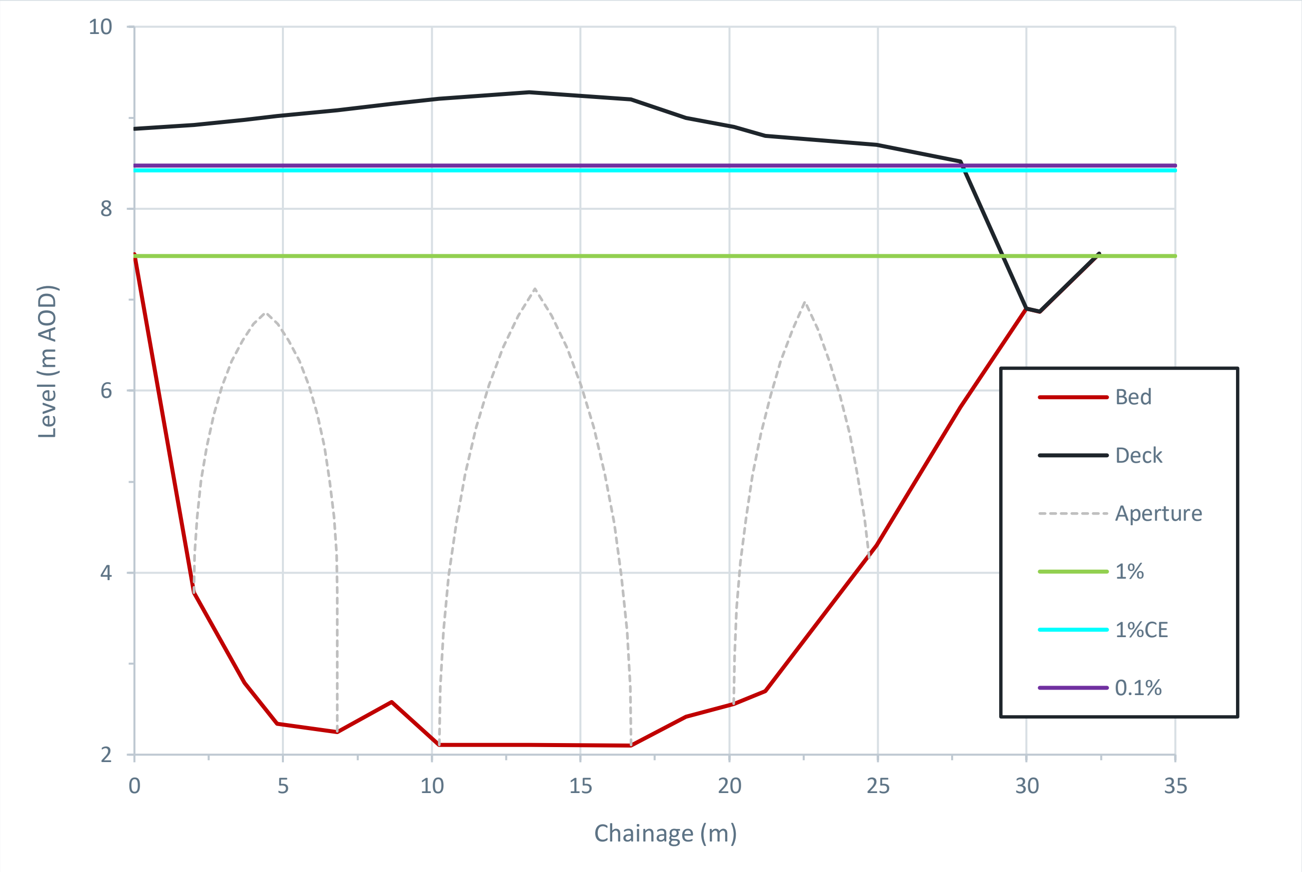


Figure 4-2: Baseline Defended Clear Section Upstream of Historic Bridge

4.1.1 BASELINE BLOCKAGE SCENARIO

This subsection reports the simulated effects of a blockage at the Historic Leckwith Bridge as described in Section 3.3.

Table 4-2: Extracted 3.3% Baseline Defended Blockage Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	3.3% Clear	3.3% Blocked	Difference
ELY32400	7.239	7.487	0.248
ELY32550	7.228	7.481	0.253
ELY32560U	7.227	7.480	0.253
ELY32560D	6.947	6.891	-0.056
ELY32572U	6.953	6.896	-0.057
ELY32572D	6.939	6.883	-0.056
ELY32575W	6.938	6.882	-0.056
ELY32580	6.903	6.852	-0.051

Label	AEP		
	3.3% Clear	3.3% Blocked	Difference
ELY32590	6.882	6.834	-0.048
ELY32700	6.875	6.829	-0.046
ELY32840	6.841	6.799	-0.042
ELY32990	6.830	6.787	-0.043
ELY33130	6.820	6.779	-0.041

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge which is either clear or blocked.

Table 4-3: Extracted 1%CE Baseline Defended Blockage Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	1%CE Clear	1%CE Blocked	Difference
ELY32400	8.419	8.557	0.138
ELY32550	8.411	8.550	0.139
ELY32560U	8.421	8.563	0.142
ELY32560D	8.016	7.957	-0.059
ELY32572U	8.013	7.951	-0.062
ELY32572D	7.994	7.933	-0.061
ELY32575W	7.993	7.930	-0.063
ELY32580	7.966	7.902	-0.064
ELY32590	7.952	7.887	-0.065
ELY32700	7.950	7.885	-0.065
ELY32840	7.928	7.864	-0.064
ELY32990	7.923	7.858	-0.065
ELY33130	7.919	7.853	-0.066

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge which is either clear or blocked.

Table 4-4: Extracted 0.1% Baseline Defended Blockage Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	1%CE Clear	1%CE Blocked	Difference
ELY32400	8.476	8.682	0.206
ELY32550	8.460	8.666	0.206
ELY32560U	8.474	8.689	0.215

Label	AEP		
	1%CE Clear	**1%CE Blocked**	**Difference**
ELY32560D	7.431	7.316	-0.115
ELY32572U	7.427	7.305	-0.122
ELY32572D	7.397	7.280	-0.117
ELY32575W	7.392	7.270	-0.122
ELY32580	7.289	7.191	-0.098
ELY32590	7.224	7.137	-0.087
ELY32700	7.214	7.124	-0.090
ELY32840	7.118	7.046	-0.072
ELY32990	7.093	7.025	-0.068
ELY33130	7.075	7.010	-0.065

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge which is either clear or blocked.

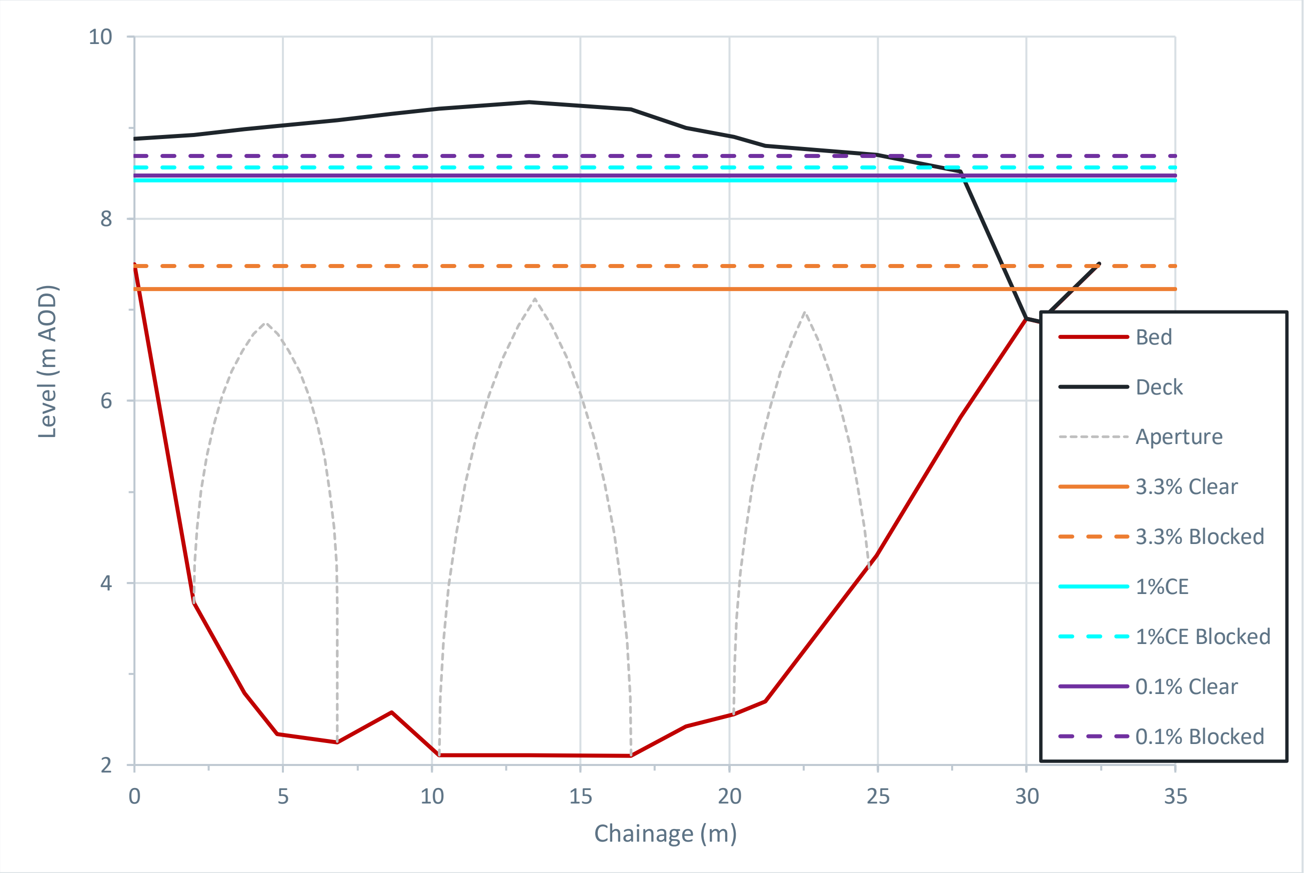


Figure 4-3: Baseline Defended Blockage Section Upstream of Historic Bridge

The results suggest that the modelled blockage at the historic bridge results in a significant increase in afflux which would be expected.

4.2 PROPOSED (VARIATION D) SCHEME RESULTS

The Proposed development Scheme consists of a residential development (target of up to 250 residences) along with associated public open space, amenities and includes a new highway link via a bridge across the Afon Elái, with the existing B4267 bridge being demolished along with the existing business units. The development is split into two parcels on either side of the proposed new bridge crossing referred to as the northern (1.3 ha) and the southern plateaus (6.4 ha). It is proposed to raise the development parcels above the flood level to reduce the risk of onsite flooding. A summary of the changes required to the model is provided in Section 3.2.

The baseline model was run for all return periods listed in Table 3-1. Flood maps showing the maximum extents and depths for the key design (1%CE) and extreme (0.1%) events have been produced, which are contained in Appendix D.

The results suggest that the site remains flood free, excepting the river and bypass culvert channels, in all modelled flood events. Assuming flows are unimpeded through the historic bridge and bypass culverts (i.e. unblocked). The bypass culverts are predicted to be utilised in each event modelled including the Qmed event; however, this event only channels flow in the hour around the peak with 0.002 cumecs (2 l/s) reported as the peak flow diverted through the left bank culvert and 0.4 cumecs (400 l/s) as the peak flow diverted through the right bank culvert.

Table 4-5: Extracted Variation D Defended Clear Results

Stage Levels (m AOD) for the Key Reach

Label	AEP		
	1%	1%CE	0.1%
ELY32400	7.432	8.361	8.388
ELY32550	7.441	8.381	8.424
ELY32550D	7.435	8.377	8.415
ELY32560U	7.435	8.376	8.415
ELY32560D	7.010	7.991	7.468
ELY32572D	7.017	7.994	7.480
ELY32575W	7.005	7.981	7.436
ELY32580	6.956	7.950	7.324
ELY32590	6.926	7.935	7.256
ELY32700	6.919	7.932	7.247
ELY32840	6.871	7.908	7.144
ELY32990	6.855	7.900	7.117
ELY33130	6.843	7.895	7.098

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge. The node named *ELY32572U* was removed from the model as the Current Leckwith Bridge does not form part of the proposals. The nodes named *ELY32550* and *ELY32550D* are on either side of the Proposed Leckwith Bridge.

Table 4-6: Extracted Baseline - Variation D Defended Clear Results

Change in Water level (m) for the Key Reach

Label	AEP		
	1%	1%CE	0.1%
ELY32400	-0.059	-0.058	-0.088
ELY32550	-0.041	-0.030	-0.036
ELY32550D	-	-	-
ELY32560U	-0.045	-0.045	-0.059
ELY32560D	0.015	-0.025	0.037
ELY32572D	-	-	-
ELY32575W	0.031	0.000	0.083
ELY32580	0.020	-0.012	0.044
ELY32590	0.017	-0.016	0.035
ELY32700	0.015	-0.017	0.032
ELY32840	0.015	-0.018	0.033
ELY32990	0.012	-0.020	0.026
ELY33130	0.011	-0.023	0.024

The above tables show that Variation D reduces the afflux upstream of the proposed bridge compared to the Baseline Scenario. There is a corresponding increase in in-channel downstream water levels resulting from the increased conveyance, excepting in the 1%CE event. This apparent discrepancy is likely due to the application of the MHWScc tide on this simulation.

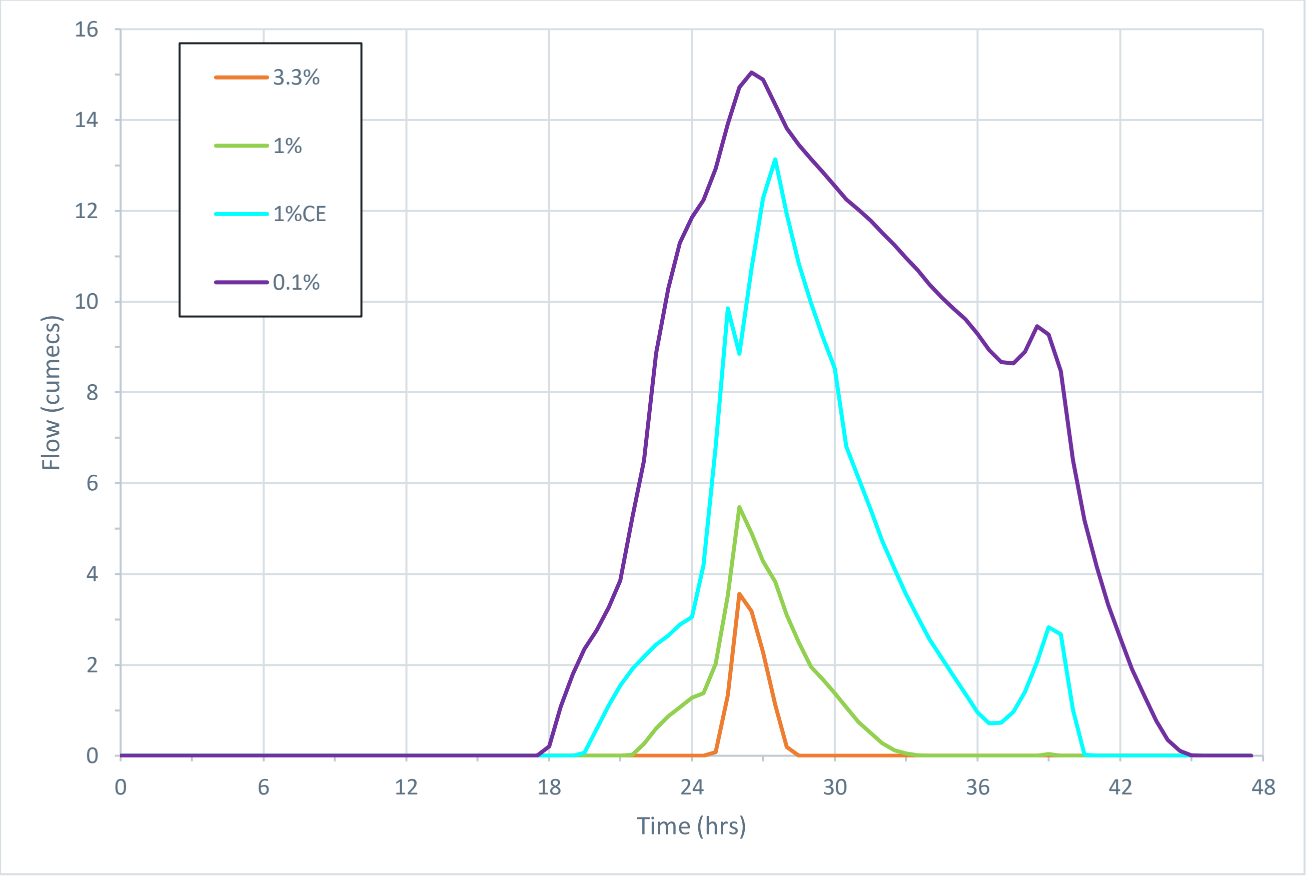


Figure 4-4: Variation D Defended Clear Flow through Bypass Culvert (Right Bank)

The above figure illustrated the functionality of the bypass culverts, noting that the right bank culvert, having a lower invert conveys larger flows more readily than the left bank culvert. The effect of the high tide at 36 hours is clearly discernible in the two larger events.

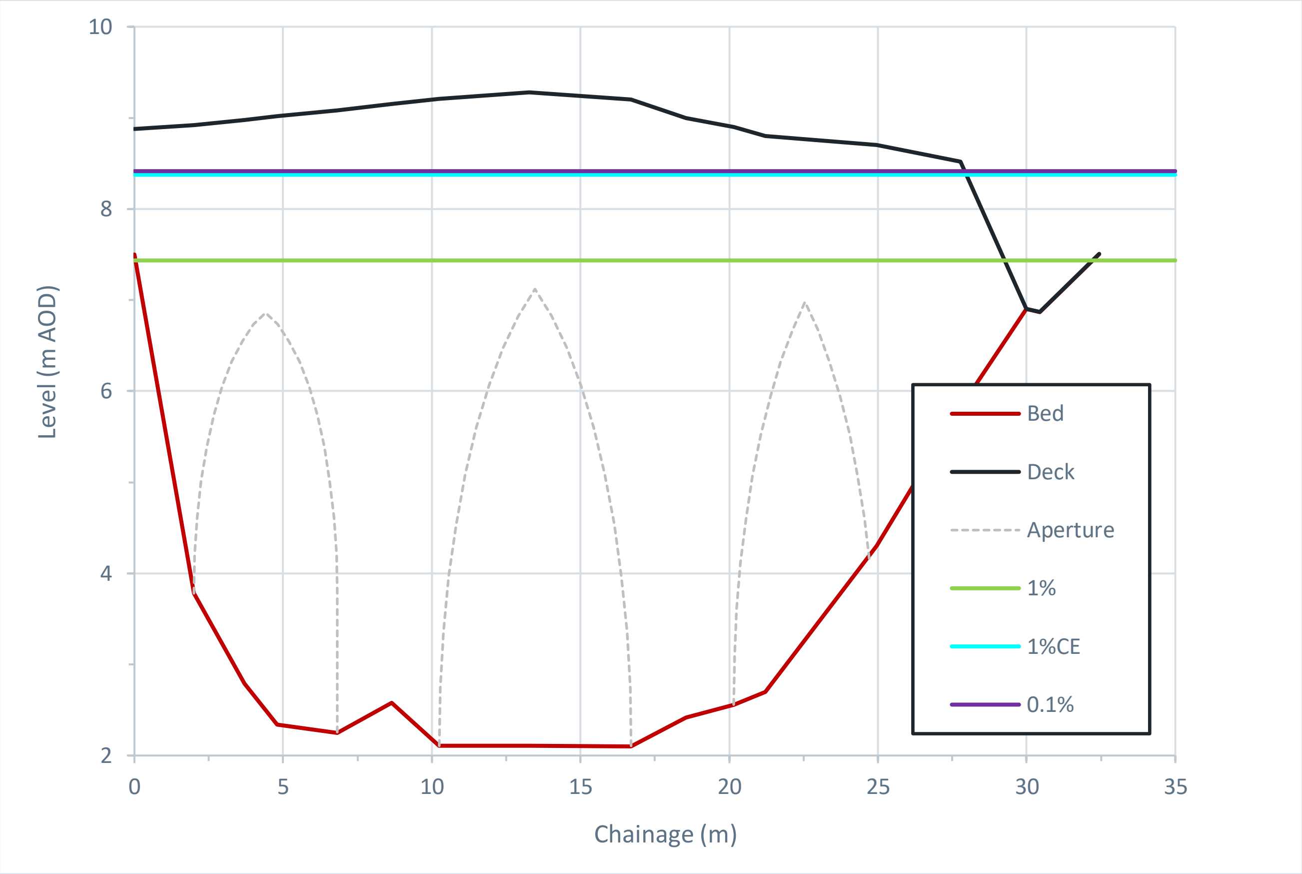


Figure 4-5: VarD Defended Clear Section Upstream of Historic Bridge

The above figure illustrates the predicted peak water level at the upstream face of the historic bridge. Proposed ground levels for the development are 8.5 m AOD.

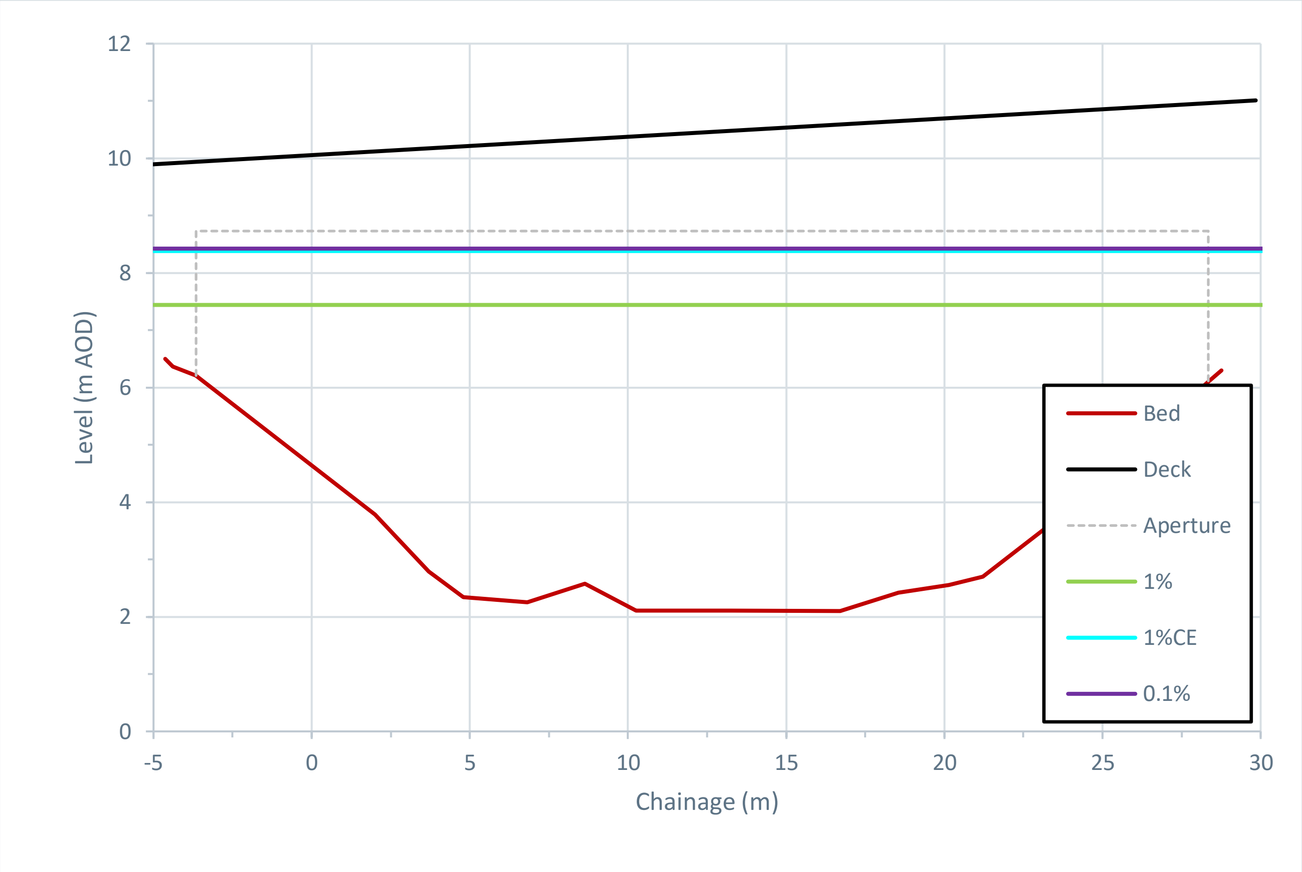


Figure 4-6: VarD Defended Clear Section Upstream of Proposed Bridge

The above figure illustrates the predicted peak water level at the upstream face of the historic bridge. Proposed ground levels for the development are 8.5 m AOD, higher than the water level. The soffit level is above both modelled flood levels though freeboard is reduced to 0.3 m in the extreme event.

In general Variation D results in lower water levels upstream of the site and higher levels downstream; upstream of the site this translates to shallower depths on the developed and undeveloped floodplain and downstream results in higher levels in the river channel down to Cardiff Bay. These results are in accordance with expectations of the effect of reducing the existing choke point of the Historic Bridge by introducing bypass culverts.

In the 3.3% AEP there is limited flooding predicted, the Variation D configuration is observed to slightly lower water levels in Sanitorium Park by generally 5 cm, though up to 9 cm in areas. The effect of this lower afflux has essentially resolved by the Cowbridge Road West bridge, although there are some marginal changes in water level further upstream in the order of a couple of millimetres.

In the 1% AEP flooding is predicted to be more widespread, the Variation D configuration is observed to lower water levels in Sanitorium Park by generally 9 cm. The effect of this lower afflux has essentially resolved by the Cowbridge Road West bridge, although the flowpath southeast along the railway and A4161 also indicate lower water levels of circa 1 cm. Downstream from the historic bridge an increase in water levels is noted for some 1.1 km downstream, this reduced from 3 cm to 1 cm at the southern end of the site. This is principally constrained to the river channel, except immediately downstream of the site an increase of 1 cm is observed on the right bank.

In the design event (1%CE AEP) the Variation D configuration is observed to lower water levels across the developed floodplain. The reduction in afflux still extends to the Cowbridge Road West bridge and the reduction in level in Sanatorium Park and Paper Mills Development is only circa 3 cm. However, there are significant reductions further into Leckwith (11 to 14 cm), around Riverside (9 to 11 cm) and Grangetown (6 to 7 cm) as well as the A4161 and Victoria Park (4 cm). This is illustrated in Figure 4-7 below.

In the extreme event (0.1% AEP) the reduction in upstream flood levels is less than in the design event but over a wider area of developed floodplain. The reduction in afflux still extends to the Cowbridge Road West bridge and the reduction in level in Sanatorium Park and Paper Mills Development remains only circa 3 cm. However, there are also reductions further into Leckwith (5 cm), around Riverside (4 cm) and Grangetown (8 cm) as well as the A4161 and Victoria Park (3 cm). Upstream of the Cowbridge Road West bridge, there is limited influence from the scheme as would be expected, however there is some 'mottling' effects noted likely resulting from oscillations in the model converging on a iterative solution, these are identifiable alongside the 1D domain in the undeveloped floodplain (e.g. Horses Field) and are often associated with a corresponding reduction in channel, the 'mottling' visible indicates variability in the peak level at the defined tolerable limits (i.e. +/- 5 mm), as such these are considered more artefacts of the modelling than a predicted effect. Downstream from the historic bridge an increase in water levels is noted to Cardiff Bay, this reduced from 3 cm to 2 cm at the southern end of the site and further reduces to 8 mm by Cardiff Bay. This is principally constrained to the river channel, except immediately downstream of the site an increase of 2 cm is observed on the right bank. This is illustrated in Figure 4-8 beneath.

	>30cm reduction		Less than 0.5 cm change		≥ 0.5 cm increase
	≥ 25 cm reduction		Was Dry Now Wet		≥ 5 cm increase
	≥ 20 cm reduction		Was Wet Now Dry		≥ 10 cm increase
	≥ 15 cm reduction				≥ 15 cm increase
	≥ 10 cm reduction				≥ 20 cm increase
	≥ 5 cm reduction				≥ 25 cm increase
	≥ 0.5 cm reduction				≥ 30 cm increase

Figure 4-7: VarD-Existing 1%CE MHWSCC Maximum Flood Stage Comparison Map

>30cm reduction	Less than 0.5 cm change	≥ 0.5 cm increase
≥ 25 cm reduction	Was Dry Now Wet	≥ 5 cm increase
≥ 20 cm reduction	Was Wet Now Dry	≥ 10 cm increase
≥ 15 cm reduction		≥ 15 cm increase
≥ 10 cm reduction		≥ 20 cm increase
≥ 5 cm reduction		≥ 25 cm increase
≥ 0.5 cm reduction		≥ 30 cm increase

Figure 4-8: VarD-Existing 0.1% MHWS Maximum Flood Stage Comparison Map

4.2.1 VARIATION D BLOCKAGE SCENARIO

This subsection reports the simulated effects of a blockage at the Historic Leckwith Bridge and proposed bypass culverts as described in Section 3.3.

Table 4-7: Extracted 3.3% Variation D Defended Blockage Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	3.3% Clear	3.3% Blocked	Difference
ELY32400	7.175	7.432	0.257
ELY32550	7.176	7.437	0.261
ELY32550D	7.172	7.433	0.261
ELY32560U	7.171	7.433	0.262
ELY32560D	6.936	6.903	-0.033
ELY32572D	6.942	6.907	-0.035
ELY32575W	6.935	6.900	-0.035
ELY32580	6.898	6.868	-0.030
ELY32590	6.875	6.849	-0.026
ELY32700	6.868	6.843	-0.025
ELY32840	6.831	6.811	-0.020
ELY32990	6.817	6.799	-0.018
ELY33130	6.806	6.789	-0.017

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge. The node named *ELY32572U* was removed from the model as the Current Leckwith Bridge does not form part of the proposals. The nodes named *ELY32550* and *ELY32550D* are on either side of the Proposed Leckwith Bridge.

Table 4-8: Extracted 1%CE Variation D Defended Blockage Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	1%CE Clear	1%CE Blocked	Difference
ELY32400	8.361	8.541	0.180
ELY32550	8.381	8.556	0.175
ELY32550D	8.377	8.553	0.176

Label	AEP		
	1%CE Clear	1%CE Blocked	Difference
ELY32560U	8.376	8.553	0.177
ELY32560D	7.991	7.948	-0.043
ELY32572D	7.994	7.950	-0.044
ELY32575W	7.981	7.936	-0.045
ELY32580	7.950	7.906	-0.044
ELY32590	7.935	7.891	-0.044
ELY32700	7.932	7.890	-0.042
ELY32840	7.908	7.870	-0.038
ELY32990	7.900	7.866	-0.034
ELY33130	7.895	7.863	-0.032

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge. The node named *ELY32572U* was removed from the model as the Current Leckwith Bridge does not form part of the proposals. The nodes named *ELY32550* and *ELY32550D* are on either side of the Proposed Leckwith Bridge.

Table 4-9: Extracted 0.1% Variation D Defended Blockage Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	0.1% Clear	0.1% Blocked	Difference
ELY32400	8.388	8.677	0.289
ELY32550	8.424	8.697	0.273
ELY32550D	8.415	8.683	0.268
ELY32560U	8.415	8.683	0.268
ELY32560D	7.468	7.293	-0.175
ELY32572D	7.480	7.302	-0.178
ELY32575W	7.436	7.268	-0.168
ELY32580	7.324	7.184	-0.140
ELY32590	7.256	7.133	-0.123
ELY32700	7.247	7.125	-0.122
ELY32840	7.144	7.048	-0.096
ELY32990	7.117	7.028	-0.089
ELY33130	7.098	7.013	-0.085

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge. The node named *ELY32572U* was removed from the model as the Current Leckwith Bridge does not form part of the proposals. The nodes named *ELY32550* and *ELY32550D* are on either side of the Proposed Leckwith Bridge.

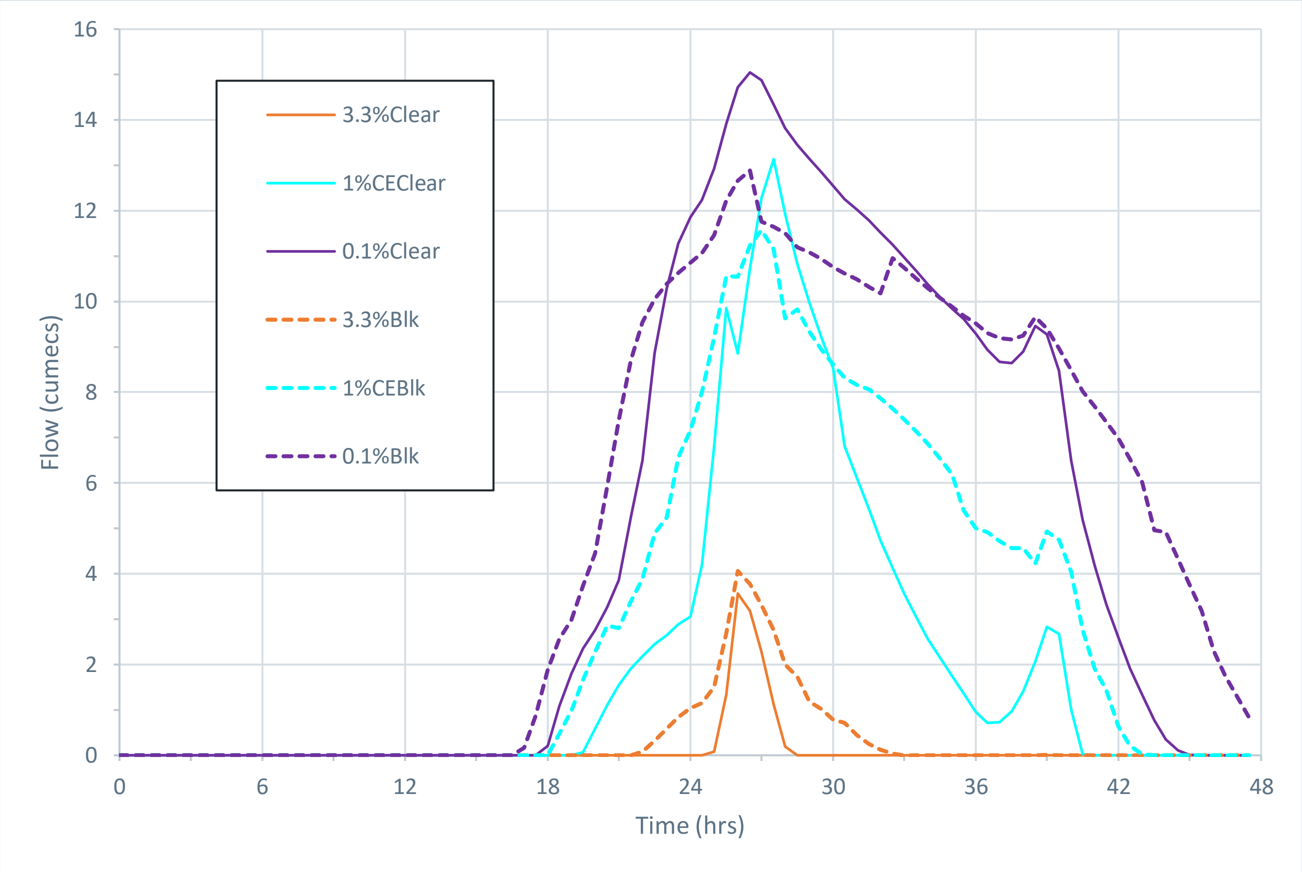


Figure 4-9: Variation D Defended Blocked Flow through Bypass Culvert (Right Bank)

The above figure illustrates that the blockage scenarios result in a hydrograph with a wider base as a result of flows being throttled through this choke point. In the 1%CE and 0.1% events the peak of the conveyed flow is also reduced by the presence of the blockage; however, in the 3.3% event a slightly higher peak flow is observed. The explanation for this is likely due to the fact that the stage levels on the upstream face of the culvert provides additional driving head, noting that the culvert in this event, unlike the other simulated events, does not become drowned.

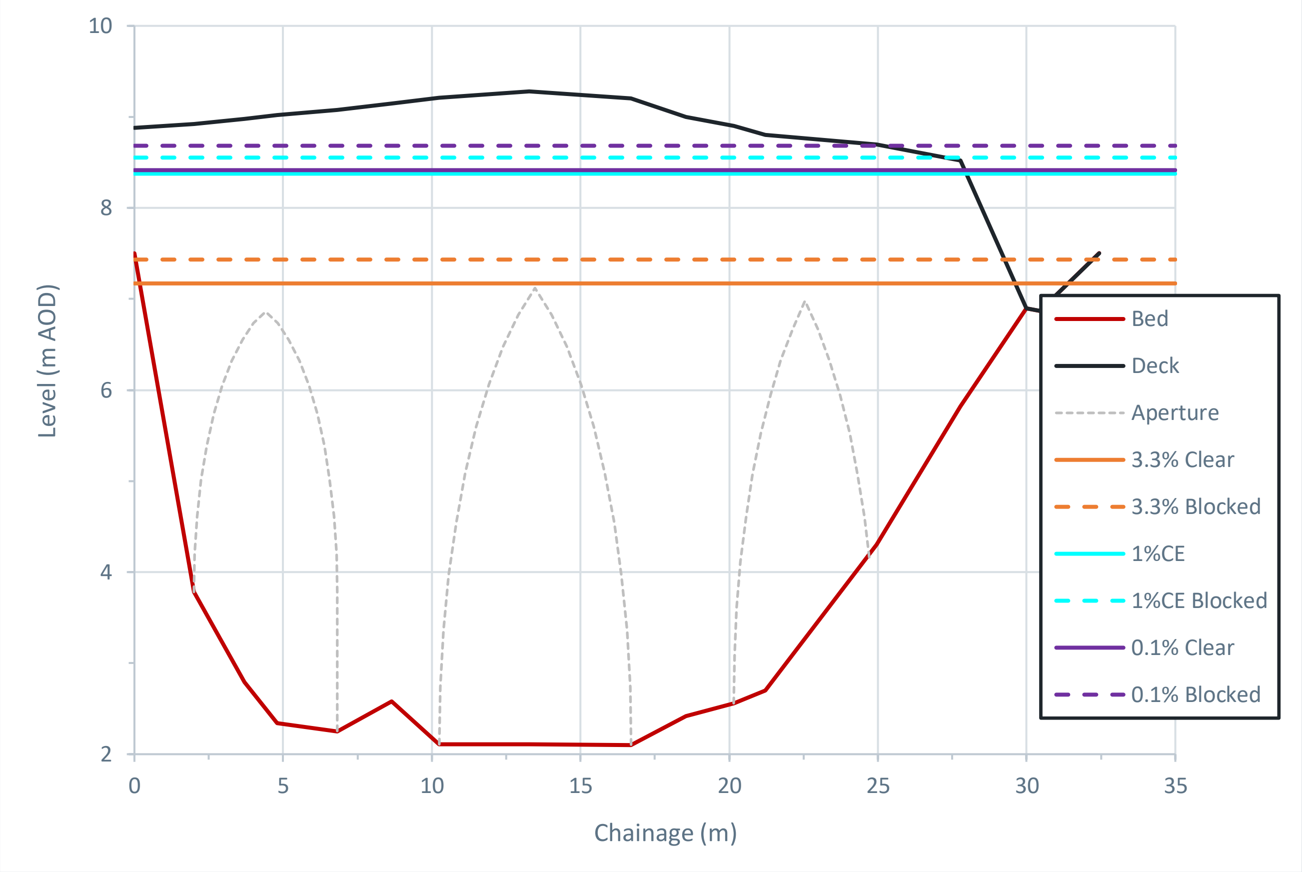


Figure 4-10: Variation D Defended Blockage Section Upstream of Historic Bridge

The results suggest that the modelled blockage at both the historic bridge and the bypass culverts results in a significant increase in afflux which would be expected. As ground levels are 8.5 m AOD in the northern plateau of the proposed development flood waters are predicted to reach circa 5 cm deep in the 1%CE event (with blockage) and under 20 cm in the 0.1% event (with blockage).

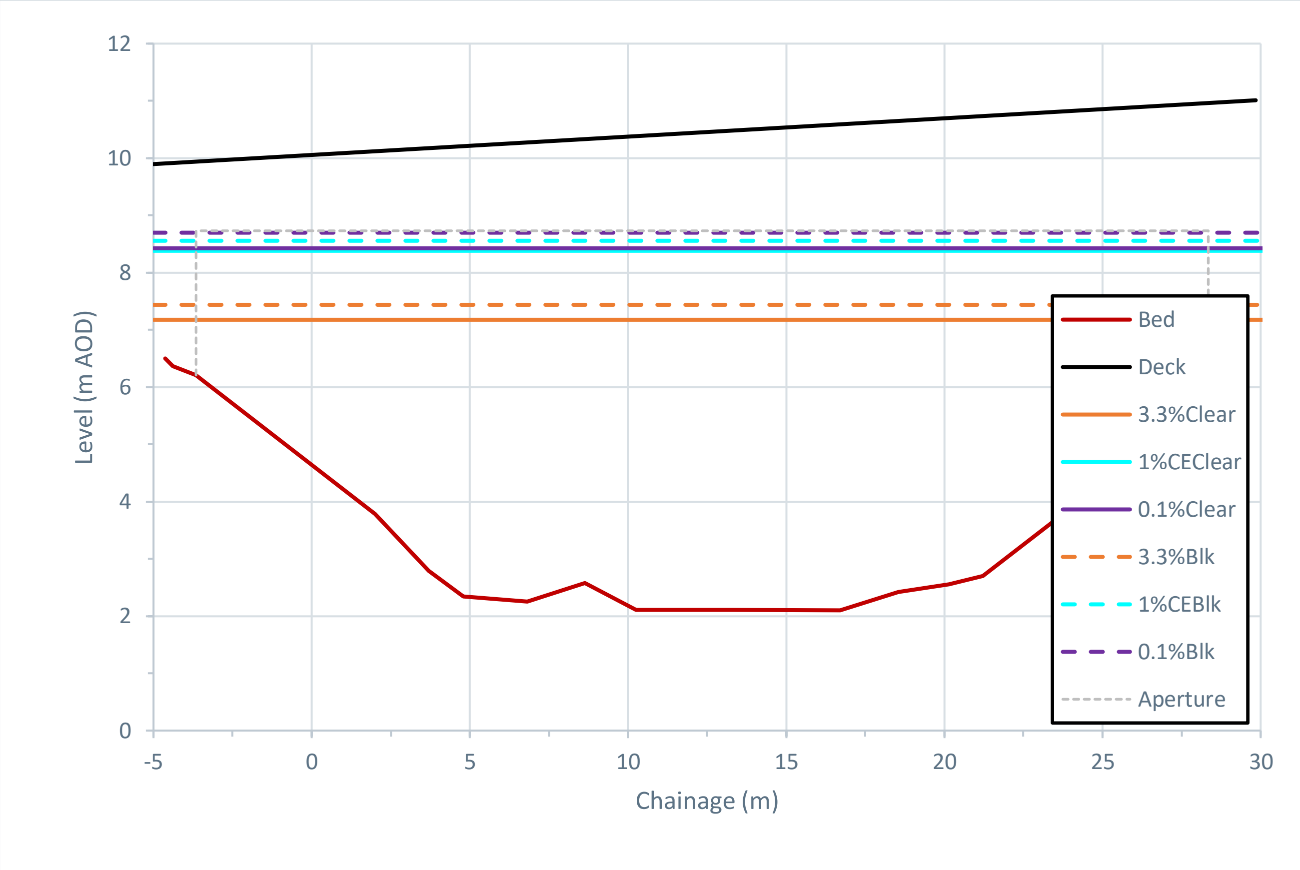


Figure 4-11: VarD Defended Blocked Section Upstream of Proposed Bridge

The results suggest that the modelled blockage at both the historic bridge and the bypass culverts results in a significant increase in afflux which would be expected. Whilst this is not sufficient for either event to reach the soffit of the proposed bridge, the freeboard in the 0.1% event is circa 3 cm.

Table 4-10: Extracted Baseline - Variation D Defended Blockage Results

Change in Water level (m) for the Key Reach

Label	AEP		
	3.3%	1%CE	0.1%
ELY32400	-0.055	-0.016	-0.005
ELY32550	-0.044	0.006	0.031
ELY32550D	-	-	-
ELY32560U	0.047	0.010	0.006
ELY32560D	-0.012	0.009	0.023
ELY32572D	-	-	-
ELY32575W	-0.024	-0.017	-0.022
ELY32580	-0.018	-0.006	0.002
ELY32590	-0.016	-0.004	0.007
ELY32700	-0.015	-0.004	0.004

Label	AEP		
	3.3%	1%CE	0.1%
ELY32840	-0.014	-0.005	-0.001
ELY32990	-0.012	-0.006	-0.002
ELY33130	-0.012	-0.008	-0.003

The above table illustrates that the maximum predicted water levels the Baseline Scenario with a blockage at the historic bridge is essentially comparable to Variation D scenario with blockage at the historic bridge and bypass culverts.

The effects observed in the results of the Variation D blockage scenarios are less apparent and more ambiguous than in the clear scenarios.

In the blockage 3.3% AEP where there is limited flooding predicted and the bypass culverts do not become drowned, the results are more similar to the clear scenarios than the other blockage events modelled. The Variation D configuration is observed to slightly lower water levels in Sanitorium Park by generally 13 cm. The effect of this lower afflux extends further than in the clear simulation and is generally resolved by Mill Place circa 2.5 km upstream, although there are some marginal changes in water level immediately upstream of up to 1 cm in channel. Downstream from the historic bridge an increase in water levels is noted to for some 800 m in channel, this reduces from 2.5 cm to 1 cm at the southern end of the site. This is principally constrained to the river channel, except immediately downstream of the site an increase of 1 cm is observed on the right bank

In the blockage 1%CE AEP the Variation D configuration is observed to lower water levels across the developed Elái floodplain. The reduction in afflux still extends to the Cowbridge Road West bridge and the reduction in level in Sanatorium Park and Paper Mills Development is only circa 8 mm. However, there are also reductions further into Leckwith (4 cm), around Riverside (5 cm) and Grangetown (4 to 9 cm) as well as the A4161 and Victoria Park (5 cm). Downstream from the historic bridge an increase in water levels is noted along essentially the remaining reach to Cardiff Bay, this reduces from 1.5 cm to 0.5 cm within 50 m, then increases further downstream to the Penarth Road crossing before reducing again downstream to Cardiff Bay. A similar effect is noted in the Afon Taf suggesting higher levels in Cardiff Bay propagating upstream, this higher water level results in increased levels around Cardiff Bridge of between 8 to 16 cm as well as additional overflow around Stuart Street adjacent to Cardiff Bay suggesting increases of circa 1.5 cm. As ground levels are 8.5 m AOD in the northern plateau of the proposed development flood waters are predicted to reach circa 5 cm deep in external and ancillary areas, albeit with a low hazard classification.

In the blockage 0.1% AEP an afflux in noted upstream of the Historic Bridge, this dissipates at the A4232 crossing upstream, but some minor effects are noted on the Sanitorium Park floodplain and the edge of the Paper Mills Scheme. These increased water levels occur in isolated pockets at the measurable limit of the model circa 5 mm. However, there are reductions noted around Riverside (1 cm) and Grangetown (2.5 cm). Downstream from the historic bridge an increase in water levels is absent, though an in-channel increase of up to 1.2 cm centred on the A4232 crossing by Grangemoor Park is noted. A similar effect is noted in the Afon Taf suggesting higher levels in Cardiff Bay propagating upstream, this effect essentially remains in-channel dissipating 400 m downstream of the Penarth Road bridge though an isolated increase in water levels at the measurable limit (i.e. 5 mm is noted around Cardiff Central station. As ground levels as 8.5 m AOD in the northern plateau of the proposed development flood waters are predicted to be less than 20 cm in external and ancillary areas, albeit with a low hazard classification.

4.3 SENSITIVITY TESTING

The results from the Sensitivity Tests suggest that the sensitivity of the model at this location may be amplified by the constriction at the Historic Bridge particularly to an increase in flow which as shown in Figure 4-2 appears to be consistent with the bridge becoming a more significant obstacle at flows around the 1% flow event.

4.3.1 MANNINGS SENSITIVITY BASELINE

This subsection reports the sensitivity test on the Baseline Scenario for a +/- 20% change in mannings roughness value in the model as described in Section 3.4.1. The results suggest that the model is more sensitive to an increase in roughness than a decrease, with an average increase in water level through the reach of interest +6 cm which is a small percentage change in predicted water level. These values help with the understanding of uncertainty in the results and should be given due consideration when determining suitable freeboard allowances.

Table 4-11: Extracted 1% Baseline +20% Mannings Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	1% Baseline	1% +20% Mannings	Difference
ELY32400	7.491	7.669	0.178
ELY32550	7.482	7.644	0.162
ELY32560U	7.480	7.641	0.161
ELY32560D	6.995	7.036	0.041
ELY32572U	7.003	7.042	0.039
ELY32572D	6.986	7.025	0.039
ELY32575W	6.985	7.024	0.039
ELY32580	6.939	6.979	0.040
ELY32590	6.911	6.950	0.039
ELY32700	6.904	6.932	0.028
ELY32840	6.859	6.873	0.014
ELY32990	6.844	6.846	0.002
ELY33130	6.831	6.827	-0.004
Average	7.055	7.114	0.060

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge.

The results in the table above clearly show the effect of the Historic Bridge acting as a constriction within the reach of interest with the increase in water levels on the upstream side significantly greater than those on the downstream side and it is of interest to note that this increase in level is similar to that which results from a blockage at the bridge. An alternative hypothesis is that the location of the bridge is on the transition point between more fluvial dominant upstream and more tidally dominant downstream (i.e. the downstream effect may be dampened by the influence of the water level in the Bay).

Table 4-12: Extracted 1% Baseline -20% Mannings Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	1% Baseline	1% -20% Mannings	Difference
ELY32400	7.491	7.475	-0.016
ELY32550	7.482	7.475	-0.007
ELY32560U	7.480	7.474	-0.006
ELY32560D	6.995	6.961	-0.034
ELY32572U	7.003	6.970	-0.033
ELY32572D	6.986	6.953	-0.033
ELY32575W	6.985	6.952	-0.033
ELY32580	6.939	6.904	-0.035
ELY32590	6.911	6.874	-0.037
ELY32700	6.904	6.877	-0.027
ELY32840	6.859	6.840	-0.019
ELY32990	6.844	6.835	-0.009
ELY33130	6.831	6.829	-0.002
Average	7.055	7.032	-0.022

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge.

The results in the table above show the average decrease in water level through the reach of interest is 2 cm which is a small percentage change in predicted water level. This is significantly less than the increase in roughness sensitivity test.

4.3.2 FLOW SENSITIVITY BASELINE

This subsection reports the sensitivity test on the Baseline Scenario for a +/- 20% change in the peak flow applied to the model as described in Section 3.4.2. The results suggest that the model is slightly more sensitive to an increase in flow than a decrease, with an average increase in water level through the reach of interest between +20 and -17 cm which is a modest percentage change in predicted water level. These values help with the understanding of uncertainty in the results and should be given due consideration when determining suitable freeboard allowances.

Table 4-13: Extracted 1% Baseline +20% Flow Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	1% Baseline	1% +20% Flow	Difference
ELY32400	7.491	8.009	0.518
ELY32550	7.482	8.000	0.518
ELY32560U	7.480	8.000	0.520
ELY32560D	6.995	7.134	0.139
ELY32572U	7.003	7.143	0.140
ELY32572D	6.986	7.120	0.134
ELY32575W	6.985	7.118	0.133
ELY32580	6.939	7.046	0.107
ELY32590	6.911	7.001	0.090
ELY32700	6.904	6.993	0.089
ELY32840	6.859	6.924	0.065
ELY32990	6.844	6.904	0.060
ELY33130	6.831	6.890	0.059
Average	7.055	7.252	0.198

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge.

The results in the table above clearly show the effect of the Historic Bridge acting as a constriction within the reach of interest with the increase in water levels on the upstream side significantly greater those on the downstream side and it is of interest to note that this increase in level is greater than that which results from a blockage at the bridge. An alternative hypothesis is that the location of the bridge is on the transition point between more fluvial dominant upstream and more tidally dominant downstream (i.e. the downstream effect may be dampened by the influence of the water level in the bay).

Table 4-14: Extracted 1% Baseline -20% Flow Results

Stage Levels (m AOD) and change in metres for the Key Reach

Label	AEP		
	1% Baseline	1% -20% Flow	Difference
ELY32400	7.491	7.203	-0.288
ELY32550	7.482	7.191	-0.291
ELY32560U	7.480	7.190	-0.290
ELY32560D	6.995	6.866	-0.129
ELY32572U	7.003	6.873	-0.130
ELY32572D	6.986	6.857	-0.129
ELY32575W	6.985	6.856	-0.129
ELY32580	6.939	6.812	-0.127
ELY32590	6.911	6.784	-0.127
ELY32700	6.904	6.776	-0.128
ELY32840	6.859	6.730	-0.129
ELY32990	6.844	6.715	-0.129
ELY33130	6.831	6.703	-0.128
Average	7.055	6.889	-0.166

The above table is ordered from upstream to downstream. The nodes named *ELY32560U* and *ELY32560D* are on either side (upstream and downstream respectively) of the Historic Leckwith Bridge.

The results in the table above show the average decrease in water level through the reach of interest is 17 cm which is a small percentage change in predicted water level. This is slightly less than the increase in flow sensitivity test.

4.4 MODEL STABILITY

4.4.1 MASS BALANCE

Model simulations are within the generally acceptable +/- 1 % mass balance limits.

Figure 4-12 below shows an example mass balance error plot as recorded in the 2D Tuflow domain. This shows that the values remain within the generally considered acceptable limits of +/- 1%.

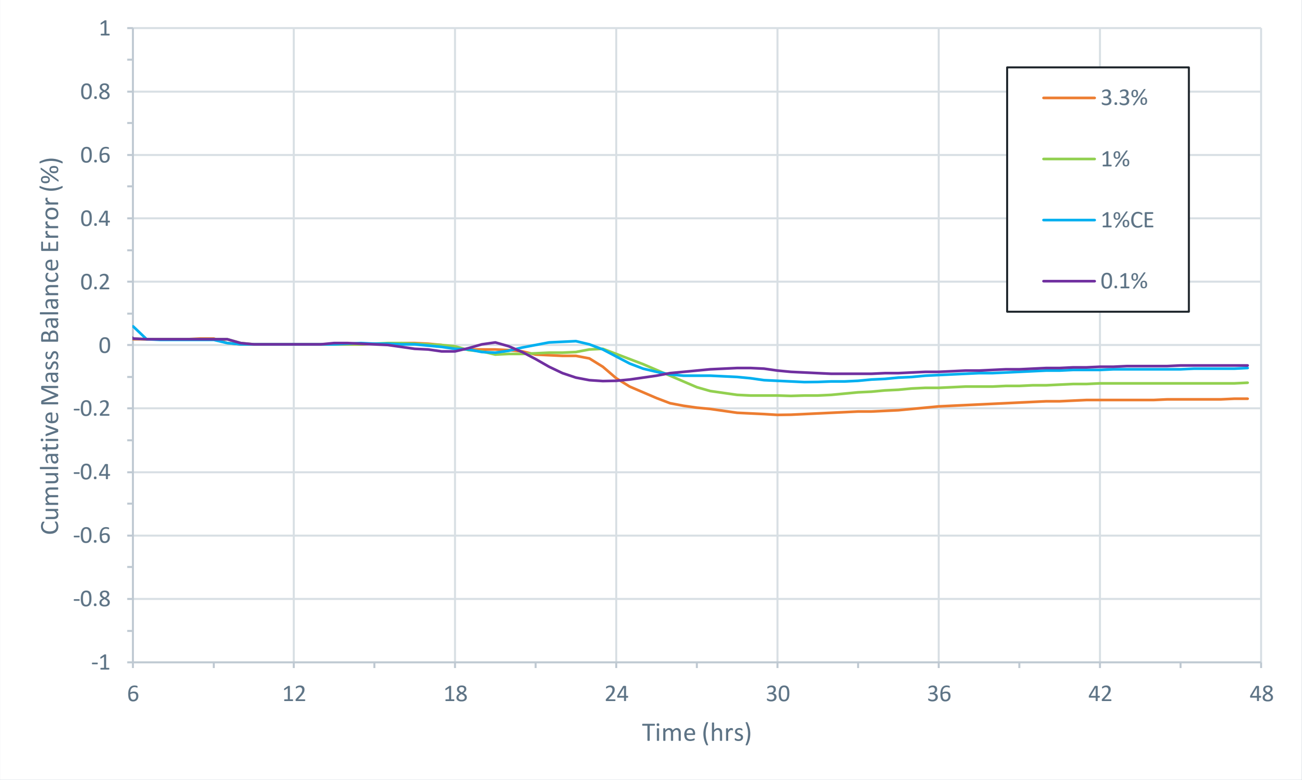


Figure 4-12: Example Mass Balance Error Plot (Existing Scenario)

4.4.2 VOLUME CHANGE

An additional measure of model stability is the change in volume plot, where a smoother curve tends to correlate to a more stable model. Figure 4-13 below, whilst showing some fluctuations is generally indicative of a healthy model.

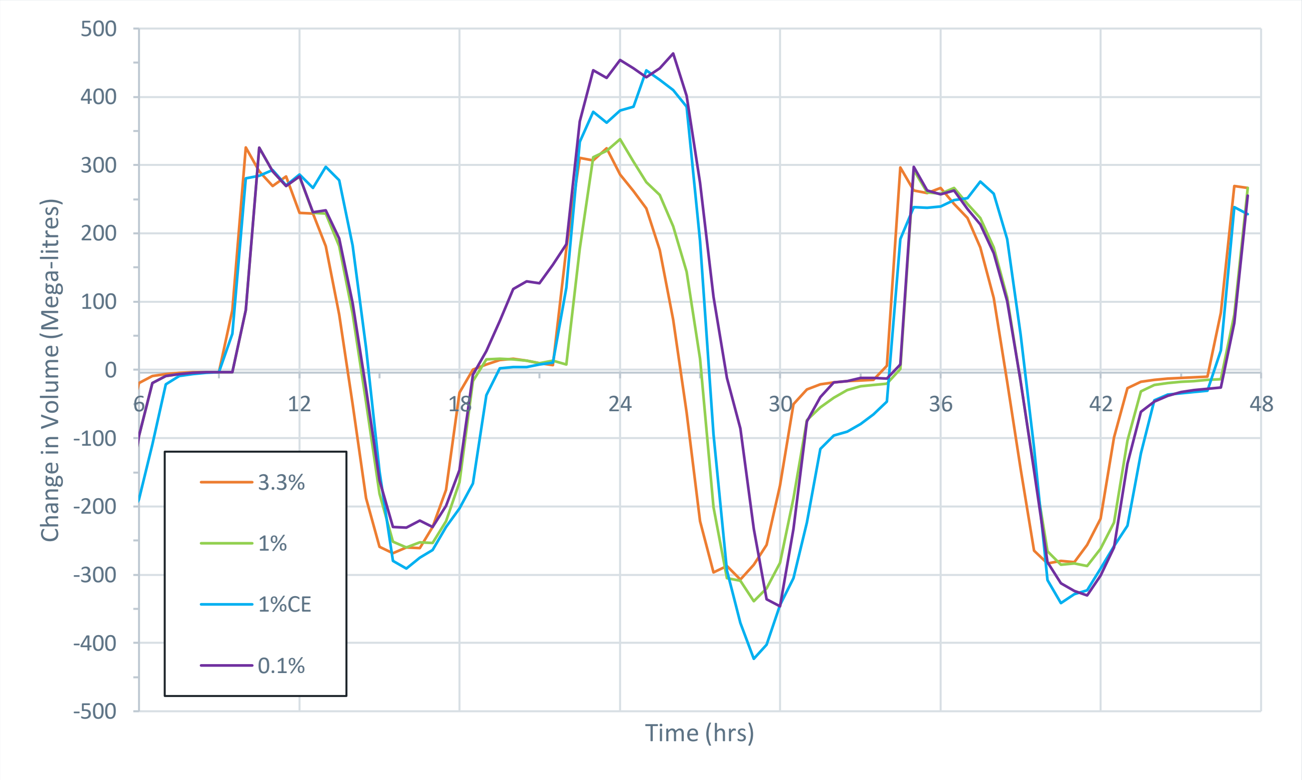


Figure 4-13: Example Change in Volume Plot (Existing Scenario)

4.4.3 1D FMP FLOW FLUCTUATIONS

It is noted that the representation of the Cardiff Bay Barrage in the licenced model, in particular the automated sluice gates result in flow oscillations. This is not an atypical result of the movement of such features in FMP. This effect is largest within Cardiff Bay itself and the effect reduces upstream. The impact on stage levels can be seen within the bay when water levels are 4.5 m AOD, the resulting fluctuation in stage level around 4.5 m AOD rapidly diminishes upstream as the bed level of the river channel exceeds this level. The oscillation in flow, however, does propagate further upstream; by the downstream end of the site this fluctuation has diminished to a couple of cumecs and reduces further upstream through the key reach of interest. Therefore, given the small % change in flow and the smooth hydrograph of stage, whilst due care is required, the results are considered usable to inform this project.

Appendix A

MODEL TECHNICAL DETAILS

CONTENTS

TABLES

FIGURES

A. MODEL TECHNICAL DETAILS

This model log forms an Appendix of, and should be read in conjunction with, the Hydraulic Modelling Report. As well as the model log and the associated reports of the NRW licenced models incorporated into this study.

A.1 TOPOGRAPHIC DATA

The sources of topographic survey data used to inform the modelling include:

- Cross section data contained in NRW's licenced models.
- Site survey. February 2019 Gwalia Surveyors 2786-T-001 to -010
- Existing Viaduct Elevation Survey. March 2019 Gwalia Surveyors 2786-E-001

Unfortunately, the original survey data used to create the models licenced from NRW are no longer available. Survey information was obtained and reviewed for the Paper Mills Scheme, but as noted in the main report cannot be applied to this project.

A.2 MODEL SCHEMATISATION

A.2.1 MODELLING APPROACH AND CHOICE OF SOFTWARE

The watercourses modelled is urban in nature, with limited areas of natural floodplain. The Afon Taf and Afon Elái display elements of constrained channel profiles and structures where urban features dominate the landscape. There are various features, which require modelling in these catchments both in-channel and out-of-channel. These are discussed in the relevant following subsections.

The original approach discussed with NRW was for a 'light touch' incorporating the Paper Mills Scheme into the VDM which had been previously approved and calibrated to include only changes considered necessary and required to update information around the site and the proposed development. Unfortunately, given the age of the model a substantial number of updates were required.

A hydraulically linked 1D Flood Modeller Pro (FMP) and 2D TUFLOW model has been used for the purpose of this study. The choice of software reflects the need to accurately represent the combination of an urban catchment mixed with natural floodplain features and important overland flow paths, as well as industry experience in the UK in the development of fluvial floodplain models. Furthermore, the models licenced from NRW rely on these software.

It has been agreed with NRW based on the current understanding of the construction methodology that no representation of interim phases of construction or demolition are currently required, so only the pre-development and post-development scenarios have been considered.

A.2.2 MODEL SCHEMATISATION

The Afon Taf and Afon Elái are both modelled as 1D (FMP) in-channel flows throughout the model up to and including a downstream tidal boundary, without any intervening 2D representation. Seaward of the Cardiff Barrage the tidal levels are also represented in 2D via a HT. Additionally there is an overland inflow near the upstream end of the Afon Taf which is active in the 0.1% AEP. It is understood that the associated hydrograph has been derived from the results of a model upstream. Details of the representation of the proposed scheme are provided in Section A.5.

A.2.3 LABELLING CONVENTION

The labelling convention inherited from the licenced model has largely been followed.

A.2.3.1 1D FMP & Estry

Watercourse channel sections have been assigned a label for each watercourse, CRCS for the Afon Taf and ELY for the Afon Elái. The Afon Taf river sections are then numbered from downstream to upstream with a two digit count excepting what appears to be an extension towards Cardiff Bay at the downstream end which has a single digit count in the opposite direction. The Afon Elái is followed by a 5 digit count from upstream to downstream with the count referencing the chainage in metres starting (lowest) at the upstream end with 25630. What appears to be a 'dummy' watercourse on the seaward side of the Cardiff Barrage is labelled TF_DS_001 / 002.

Additional suffixes have been assigned to the watercourse chainage label to describe non river channel units as follows:

- On the Afon Elái 'U' suffixed denotes a non-river unit (e.g. bridge or weir) and/or the river unit and junction upstream of a non-river unit.
- On the Afon Elái 'A' suffixed denotes a spill over a non-river unit.
- On the Afon Elái 'D' suffixed denotes the river unit and junction downstream of a non-river unit.
- On the Afon Elái 'K' suffixed denotes a blockage unit added to the model for this study.
- On the Afon Elái 'i' suffixed denotes an interpolate section added to the model for this study.
- In Cardiff Bay 'S' suffixed denotes a spill out of the bay.
- On the Afon Taf 'A' or 'B' suffixed denotes a structure in the watercourse

A.2.3.2 2D Tuflow

The standard labelling convention and folder structure for TUFLOW models has been applied. Control files (.tcf, .tgc, .tbc, .tmf) have been prefixed with Lek or Leck and a two digit version number and or date (YYMMDD) associated with the model iteration. GIS files are saved in the Model/mi folder and prefixed with the TUFLOW ascribed codes and suffixed with a version number and or date followed by a letter denoting the shapefile geometry type (point, line or region). Surfaces are saved in the Model\DTM folder.

A.3 BASELINE MODEL REPRESENTATION

A number of alterations have been made to the baseline model as a result of merging the two NRW models together alongside discussions with NRW on model performance and representation. The primary source should be considered the model build log; however this HMR provides an overview of these changes. The following subsections are split between the 2D and 1D domains.

A.3.1 FMP & ESTRY 1D MODEL REPRESENTATION

This model contains elements from both FMP and Estry. FMP is used to represent the main river channels and associated structures, whereas Estry is used to represent structures in the floodplain.

A.3.1.1 1D Simulation Parameters & Miscellanea

For the FMP aspect of the 1D domain, version 4.5.1.6163 single precision was used with a 0.5 second timestep, the timestep is 0.25 seconds in Estry. Model simulations have been run for 48 hours. Alterations have also been made to the 1D domain, which consist of alterations to the Afon Elái, no changes were made to the Afon Taf. A number of additional tweaks and alterations were required to merge the two models (VDM & Paper Mills) and incorporate improvements and facilitate the model simulation. New initial conditions were created for FMP and the minitir value increased to 6 and the maxitir value increased to 23.

A.3.1.2 1D Channel Roughness

No additional channel survey has been undertaken, the licenced models from NRW apply atypical values for mannings roughness. It is presumed that these have been iterated in order to improve model calibration. A review of the applied values identified no reason for concern being within typical ranges of manning roughness. This does not mean no changes have been made. A review of the conveyance curves plotted in FMP identified a number of cross sections likely to result in model instabilities, additional panel markers have been applied in order to smooth the conveyance curves and improve the model.

A.3.1.3 1D Hydraulic Structures

No additional channel survey has been undertaken, therefore with several exceptions, hydraulic structures within the 1D model have been retained as previously represented. No alterations have been made to the structures on the Afon Taf, for ease of reporting the structures discussed below have been split into predominantly FMP and predominantly Estry.

- FMP Structures, Sections & Features
  From upstream to downstream:
  - 25786U - A4232
    This structure represents the A4232 Bridge. It has been modelled as a USBPR type unit, with no 1D overspill. No changes have been made to the representation.
  - 26555U – Railway Bridge
    This structure represents the Railway Bridge. It has been modelled as a USBPR type unit, with an associated 1D overspill. An orifice transition has been added to the structure with upper and lower distances of 0.1 m and a discharge coefficient of 1.0. No other changes have been made to the representation.
  - 26592U – Disused Railway Bridge
    This structure represents the Disused Railway Bridge. It has been modelled as an Arch type unit, with an associated 1D overspill. An orifice transition has been added to the structure with upper and lower distances of 0.1 m and a discharge coefficient of 1.0. No other changes have been made to the representation.
  - 27235U – St Fagan’s Road Bridge
    This structure represents the St Fagan’s Road Bridge. It has been modelled as an Arch type unit, with an associated 1D overspill. An orifice transition has been added to the structure with upper and lower distances of 0.1 m and a discharge coefficient of 1.0. No other changes have been made to the representation.
  - 27425U – St Fagans Gauging Station
    This structure represents St Fagans Gauging Station. It has been modelled as a Flat-V Weir type unit, with a 1D overspill. No changes have been made to the representation.
  - 27925U – Railway Bridge
    This structure represents the Railway Bridge. It has been modelled as a USBPR type unit, with an associated 1D overspill. An orifice transition has been added to the structure with upper and

lower distances of 0.1 m and a discharge coefficient of 1.0. No other changes have been made to the representation.

- 28245U – Railway Bridge
  This structure represents the Railway Bridge. It has been modelled as a USBPR type unit, with an associated 1D overspill. An orifice transition has been added to the structure with upper and lower distances of 0.1 m and a discharge coefficient of 1.0. No other changes have been made to the representation.
- 28825U – Railway Bridge
  This structure represents the Railway Bridge. It has been modelled as an Arch type unit, with an associated 1D overspill. An orifice transition has been added to the structure with upper and lower distances of 0.1 m and a discharge coefficient of 1.0. No other changes have been made to the representation.
- ELY29434 – Weir
  This structure represents a weir. It has been modelled as an inline spill unit. No changes have been made to the representation.
- 29645U – Footbridge
  This structure represents the Footbridge. It has been modelled as an Arch type unit, with an associated 1D overspill. An orifice transition has been added to the structure with upper and lower distances of 0.1 m and a discharge coefficient of 1.0. No other changes have been made to the representation.
- 30292U – Cowbridge Road
  This structure represents the Cowbridge Road crossing. It has been modelled as a USBPR type unit, with no 1D overspill. An orifice transition has been added to the structure with upper and lower distances of 0.1 m and a discharge coefficient of 1.0. No other changes have been made to the representation.
- ELY30320 – Weir
  This structure represents a weir. It has been modelled as an inline spill unit. No changes have been made to the representation.
- ELY30840 – Wiggins Teape Sluice/Weir
  There is a comment at this location in the model noting that this structure has been removed. No changes have been made to the representation.
- ELY 31730 – Sanitorium Park Footbridge
  At approximately this location there is understood to be a footbridge over the river. This is not included in either the VDM or the Paper Mills model. No additional survey information has been collected. Based on the fact that this feature has been omitted previously and its distance from the site it is considered that it does not require explicit consideration for this project.
- ELY 31730 – A4232 Roadbridge
  At approximately this location the A4232 crosses the river. This is not included in either the VDM or the Paper Mills model. No additional survey information has been collected. Based on the fact that this feature has been omitted previously it is considered that the soffit must be significantly higher then the maximum water level recorded in either model and it is noted that the abutments are significantly wider than the channel at this location. As maximum water levels do not significantly increase for this project it has been considered that the omission of this feature remains acceptable. Representation is included in the 2D domain as discussed in the relevant subsection below.

- 32560U – Historic Leckwith Bridge
  This structure represents the Historic Leckwith Bridge. It has been modelled as a USBPR type unit, with an associated 1D overspill. An orifice transition has been added to the structure with upper and lower distances of 0.1 m and a discharge coefficient of 1.0. A blockage unit has been included in readiness for Scenarios which require a blockage at this location.
- 32572U – Current Leckwith Road Bridge
  This structure represents the A4232 Bridge. It has been modelled as an Arch type unit, with a 1D overspill. No changes have been made to the representation.
- ELY32575W
  This structure represents a weir. It has been modelled as an inline spill unit. No changes have been made to the representation.
- ELY32590 (and downstream)
  From this river unit downstream, interpolates have been added such that the chainage between sections is circa 100 metres or less. These features have been linked to the 2D domain via CN/HX connections, network lines and WLLS have been updated to reflect the new nodes. They have been added to improve model performance and stability, with particular reference to Cardiff Bay.
- ELY34265i – A4232
  At approximately this location the A4232 crosses over the river. This is not included in either the VDM or the Paper Mills model. No additional survey information has been collected. Based on the fact that this feature has been omitted previously and its distance from the site it is considered that it does not require explicit consideration for this project.
- ELY34500
  There is a comment in this location in the model noting that Penarth Road Bridge is not explicitly included. No changes have been made to the representation.
- 35185U – Railway Bridge
  This structure represents the Railway Bridge. It has been modelled as a USBPR type unit, with no 1D overspill. No changes have been made to the representation.
- 35725i – A4232
  At approximately this location the A4232 crosses over the river. This is not included in either the VDM or the Paper Mills model. No additional survey information has been collected. Based on the fact that this feature has been omitted previously and its distance from the site it is considered that it does not require explicit consideration for this project.
- 36380 – A4055
  At approximately this location the A4055 crosses over the river. This is not included in either the VDM or the Paper Mills model. No additional survey information has been collected. Based on the fact that this feature has been omitted previously and its distance from the site it is considered that it does not require explicit consideration for this project.
- 36605i – Pont Werin
  At approximately this location the Pont Werin lifting bridge crosses the river. This is not included in either the VDM or the Paper Mills model. No additional survey information has been collected. Based on the fact that this feature has been omitted previously and its distance from the site it is considered that it does not require explicit consideration for this project.
- ELY37430 – Cardiff Bay

The representation of Cardiff Bay within the model has been translated from the 2D domain into the FMP 1D domain. The original representation of the Bay was in the 2D domain with the mouths of the Afon Taf and Afon Eláі terminating in a SX line across their entire width. Due to changes in the Tuflow methodology of calculating these features, by updating the engine this connectivity required a restart file recorded after the commencement of the model to prevent the simulation from crashing. Significant 'mottling' and fluctuations were noted within the Cardiff Bay area. Therefore, it was decided to translate this representation into the 1D domain for improved stability. A Reservoir unit was connected via an inline spill to the ends of each river. The geometry for the inline spill was taken from the final cross sections on each river and the geometry for the reservoir unit was taken from contouring the resulting surface in the licenced model. It is noted that the resulting surface may not be wholly accurate at low elevations, given the alterations to the surface from the received model and the penetration of LiDAR through the water column, however this level is below the water level at the onset of the simulation and should not significantly affect results. Where water is able to overtop the bay, connectivity has been provided into the 2D domain based on spill units connected to the reservoir unit and dummy HT units that provide 2D connectivity via CN and SX lines along the edge of the Bay based on the flood extents of previous simulations. The geometry of these spill units has been extracted from LiDAR as follows:

- Ferry Road (85 m wide at 7.85 m AOD),
- Roath Basin (26 m, 7.68 m AOD),
- Stuart Street (60 m, 7.3 m AOD),
- Havana Street North (31 m, 7.64 m AOD),
- Havana Street South (30 m, 7.90 m AOD) and
- Landsea Gardens (40 m, 7.35 m AOD).

As can be seen in Figure A-1 the provided results files which represent the Bay as a 2D feature striations and mottling across the bay are evident when coloured against NRW's 5 mm difference criteria. Such mottling patterns are not typically indicative of a good performing model and introduce additional noise when trying to understand outcomes. Additionally, it is noted that large volumes of (static) water in the 2D domain can mask MB errors when considering model performance. The conversion resulted in a limited change in maximum stage levels through the site of interest as a result of the model refinements, with differences tending to a couple of centimetres if not a couple of millimetres. Therefore, the representation of the bay in the 2D domain being an aspect which is not a focus for this project, given its controlled nature and relation to the site, it can be considered an unnecessary computational and analytical burden. Whilst there remain minor issues with the 1D representation, (Section 4.4.3 of the main report) the stage – time plot has reduced fluctuations and the conversion is considered an improvement for this project.

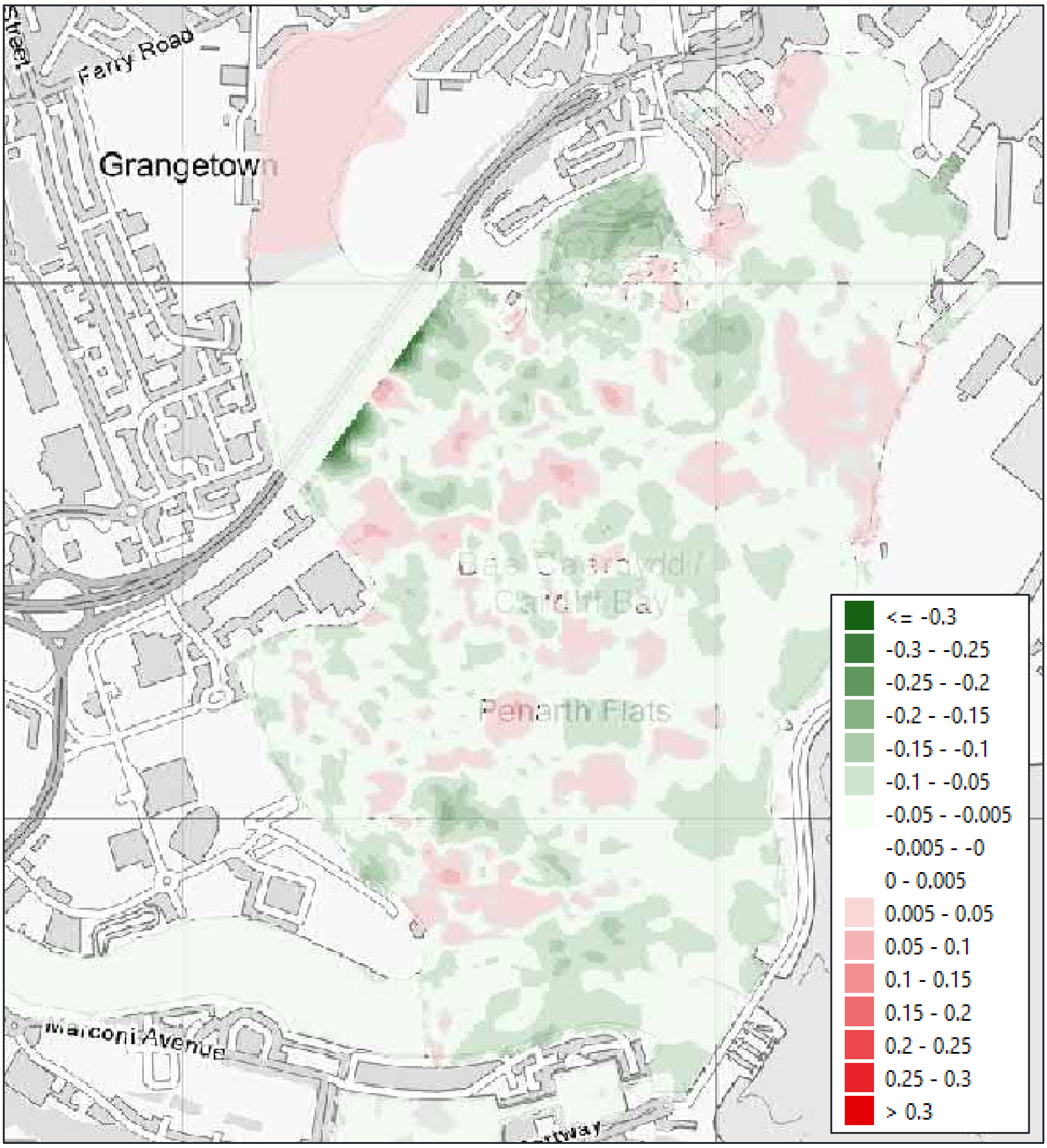


Figure A-1: 2D Cardiff Bay Representation showing 'mottling' – licenced results.

- TF_DS – Cardiff Barrage
  This structure represents the connectivity of Cardiff Bay through the Cardiff Barrage to the open coast. It has been modelled as a Vertical Sluice Gate with no separate 1D overspill / bypass. It is connected directly to the 1D Cardiff Bay Reservoir unit on its upstream side and to what is understood to be a dummy reach of river on its downstream side, which terminates in a HT unit containing a description of the relevant tidal event. No changes have been made to the representation.
- Orifice Transition
  In neither inherited model were orifice transitions used at structures. Discussions with NRW have identified that these are now considered to be standard inclusions, requiring justification

where omitted and as such have been applied at the following sections based on the identified maximum water level.

- 26555U
- 26592U
- 27235U
- 27925U
- 28245U
- 28825U
- 29645U
- 30292U
- 32560U

- Changes to Section widths
  It was agreed with NRW to revise the 2D sections widths to better reflect the 1D section data within Flood Modeller along the key reach of interest between the two A4232 crossings. For three of the reviewed sections based on LiDAR and aerial data it was found that a better fit could be made by trimming the 1D data sets. The three sections were:

  - ELY31930, four points removed from the left bank totalling 17.51 m
  - ELY32400, one point removed from the right bank totalling 15.43 m
  - ELY33440, one point removed from the right bank totalling 12.53 m

  The original cross section data is noted in the model log with the removed data presented in a red font.

A number of features which were previously in the FMP domain, have been translated to alternative representation and will be discussed in the relevant section and identified in the model log. The following features have been removed entirely:

- No features have been wholly removed as part of this project.

- Estry Structures, Sections & Features
  In the current baseline model there are twenty features contained within the '1D_nwke' unit read from the .ecf. Each of these are rectangular culverts representing flowpaths through impermeable embankments, typically in the form of underpasses. Whilst the underlying LiDAR has been updated across much of the model, it was considered that the invert levels of the '1D_nwke' as provided within the licenced NRW model would not be updated without good reason as the original LiDAR should provide reasonable data at these locations. In alphanumerical order of their 'ID' field (unchanged from the licenced model):

  - 1 – Cardiff Central, Station Underpass
    This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required.
  - 2 – Cardiff Central, Penarth Road, Railway Underpass
    This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required.
  - 3 – Cardiff Central, Saint Mary Street, Railway Underpass
    This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required.

- 4 – Bute Street, Railway Underpass
  This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required.
- 5 – Dock Feeder Canal, Railway Underpass, Cardiff Bay Branch
  This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required
- 6 – Adams Street, Railway Underpass
  This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required
- 7 - Dock Feeder Canal, Railway Underpass, South Wales Mainline
  This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required.
- 12 – Sanitorium Road, Railway Underpass, South Wales Mainline
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, no modifications to this feature have been considered as required.
- 13 – Sanitorium Road, Railway Underpass, Cardiff City Line
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, as the southern end is now located within the nested subgrid of the Tuflow model, it was decided that the length of the 'HX' should be amended to better reflect the culvert width on a per cell basis. No other modifications to this feature have been considered as required.
- 14 – Paper Mill Road, Railway Underpass, Cardiff City Line
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, as the southern end is now located within the nested subgrid of the Tuflow model, it was decided that the length of the 'HX' should be amended to better reflect the culvert width on a per cell basis. No other modifications to this feature have been considered as required.
- 15 – South Wales Mainline, Railway Underpass, Cardiff City Line
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, as the western end is now located within the nested subgrid of the Tuflow model, it was decided that the length of the 'HX' should be amended to better reflect the culvert width on a per cell basis. No other modifications to this feature have been considered as required.
- 16 – Cowbridge Road East, Railway Underpass, Cardiff City Line
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, as the western end is now located within the nested subgrid of the Tuflow model, it was decided that the length of the 'HX' should be amended to better reflect the culvert width on a per cell basis. No other modifications to this feature have been considered as required.
- 17 – South Wales Mainline, Road Underpass, Cowbridge Road West
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, as both ends are now located within the nested subgrid of the Tuflow model, it was decided that the length of the 'HX' should be amended to better reflect the culvert width on a per cell basis. No other modifications to this feature have been considered as required.
- 18 – Ely Trail, Pedestrian Railway Underpass
  This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required, for an unknown reason the VDM and Mills models applied different mannings values to this culvert. The value from the Mills Model has been applied.

- A48 – Gabalfa Avenue, Pedestrian Road Underpass, A48
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, no modifications to this feature have been considered as required.
- FLEET – Fleet Way, Disbanded Railway Underpass, VoG Line
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, as the western end is now located within the nested subgrid of the Tuflow model, it was decided that the length of the 'HX' should be amended to better reflect the culvert width on a per cell basis. No other modifications to this feature have been considered as required.
- STFAGANS – Mill Leat Railway Underpass near St Fagans Park
  This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required.
- TAFF1 – Clare Road, Railway Underpass
  This culvert is connected to the 2D domain via an 'SX' and 'CN' arrangement, no modifications to this feature have been considered as required.
- TAFF2 – Virgil Street, Railway Underpass
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, as the western end is now located within the nested subgrid of the Tuflow model, it was decided that the length of the 'HX' should be amended to better reflect the culvert width on a per cell basis. No other modifications to this feature have been considered as required.
- TAFF3 – Penarth Road Grangetown, Railway Underpass
  This culvert is connected to the 2D domain via an 'HX' and 'CN' arrangement, as the western end is now located within the nested subgrid of the Tuflow model, it was decided that the length of the 'HX' should be amended to better reflect the culvert width on a per cell basis. No other modifications to this feature have been considered as required.

A number of features which were previously in the Estry domain, have been translated to alternative representation and will be discussed in the relevant section and identified in the model log. The following features have been removed entirely:

- No features have been wholly removed as part of this project.

A.3.1.4 1D Model Boundaries

Not including the Dummy 'HT' linking FMP to Tuflow the 1D model contains: three hydrological inflow boundaries and one downstream tidal boundary located within FMP. There are no hydrological boundaries as part of the Estry model, the 2D hydrological boundaries in Tuflow are discussed later in this report. The two main hydrological inflow boundaries in FMP are located at the upstream reaches of the Afon Taf (Taff_US_QT) and Afon Elái (ELY25630) and are represented as QT units, the secondary inflow is a lateral flow spread over the upper reaches of the Afon Elái (INT1) as a ReFH unit. Each inflow has its own flow/time profile for each event modelled. There is a single downstream boundary (TF_DS_002) represented as a 'HT' unit. This unit is connected to the downstream end of the dummy river unit downstream of the Cardiff Barrage. There are two downstream boundaries applied to the model a Mean High Water Springs tide and the same but with sea level rise and climate change included. As noted previously all hydrological inflows have been provided by NRW and all units are read in as .ied files for the relevant event via the .ief.

A.3.2 TUFLOW 2D MODEL REPRESENTATION

This model contains a 2D environment in which the 1D elements from both FMP and Estry are embedded and linked. Whilst FMP is used to represent the main river channels and associated structures and Estry is used to represent structures in the floodplain, many features are represented within the 2D domain.

A.3.2.1 2D Simulation Parameters & Miscellanea

For this Tuflow model, version 2018-03-AD-iSP-w64 was used with a 1 second timestep. Whilst the reports provided by NRW suggest a timestep of between 4 and 2 seconds, the log and parameter files appear to indicate 1 second. It is unknown how or why this change occurred. Model simulations have been run for 48 hours. Alterations have been made to the software parameters which include implementing the latest software versions, noting that improvements to the software engine, suppress or render obsolete some commands (e.g. *'Cell Side Wet/Dry Depth == '* and *'Structure Losses == FIX'*). The 2D PO points and lines from the licenced model have been removed and new features added at likely points of interest for this project. It has been noted that when automatically generated 'check files' produced by Tuflow are included within a simulation the model terminates at 0.0 hours into the simulation, therefore a 'Dummy' event has been configured with the sole purpose of generating these check files.

The NRW model was simulated using an older version of the software, the 2018-03-AD version used for this project to date was released in March 2019. No significant changes in moving to more recent engines are anticipated, noting however that such a change did break NRW's provided model. The release notes as part of the latest software engine from Tuflow 2020-10 note corrections in the application of SX lines and zln gullies.

- The release note concerning SX lines advises that SX lines using a Z flag lower cell centres only. Whilst the majority of SX connectors in the model utilise a Z flag these are either on already set ground levels (e.g. the approach to the bypass culverts) or connect open areas in which LiDAR representation tends to be reasonably suitable and therefore any 'bucketing' effect should be limited or in line with actual flowpaths away from modelled features.
- The release note concerning zln gullies notes that these do not apply correct ground levels. There is a single zln gully feature in this model representing the Mill Leat, given the distance from the site and the underlying data, this is not anticipated to significantly affect the findings of this project.

Whilst it is recommended that future studies apply more recent software versions it is considered that 2018-03-AD-iSP-w64 remains appropriate for this project,

A.3.2.2 Model Grid Resolution, Terrain, Structures & Features

Additional topographic survey has been undertaken at the site, therefore the representation of the site has been updated, but with several exceptions features elsewhere within the floodplain have been retained as previously represented.

In order to better define flowpaths around the site, a sub-domain on a 4 metre grid has been inserted around the site with the intent of better defining flood flows and volumes within this area. The sub-grid has been centred on the site and bounds higher ground where possible to reduce artefacts from the head only transfer of water between grids. Figure A-2 below shows the location of this grid. For ease of reporting the features discussed below have been split into predominantly domain grid (the larger cell size and predominantly subgrid (the smaller cell size).

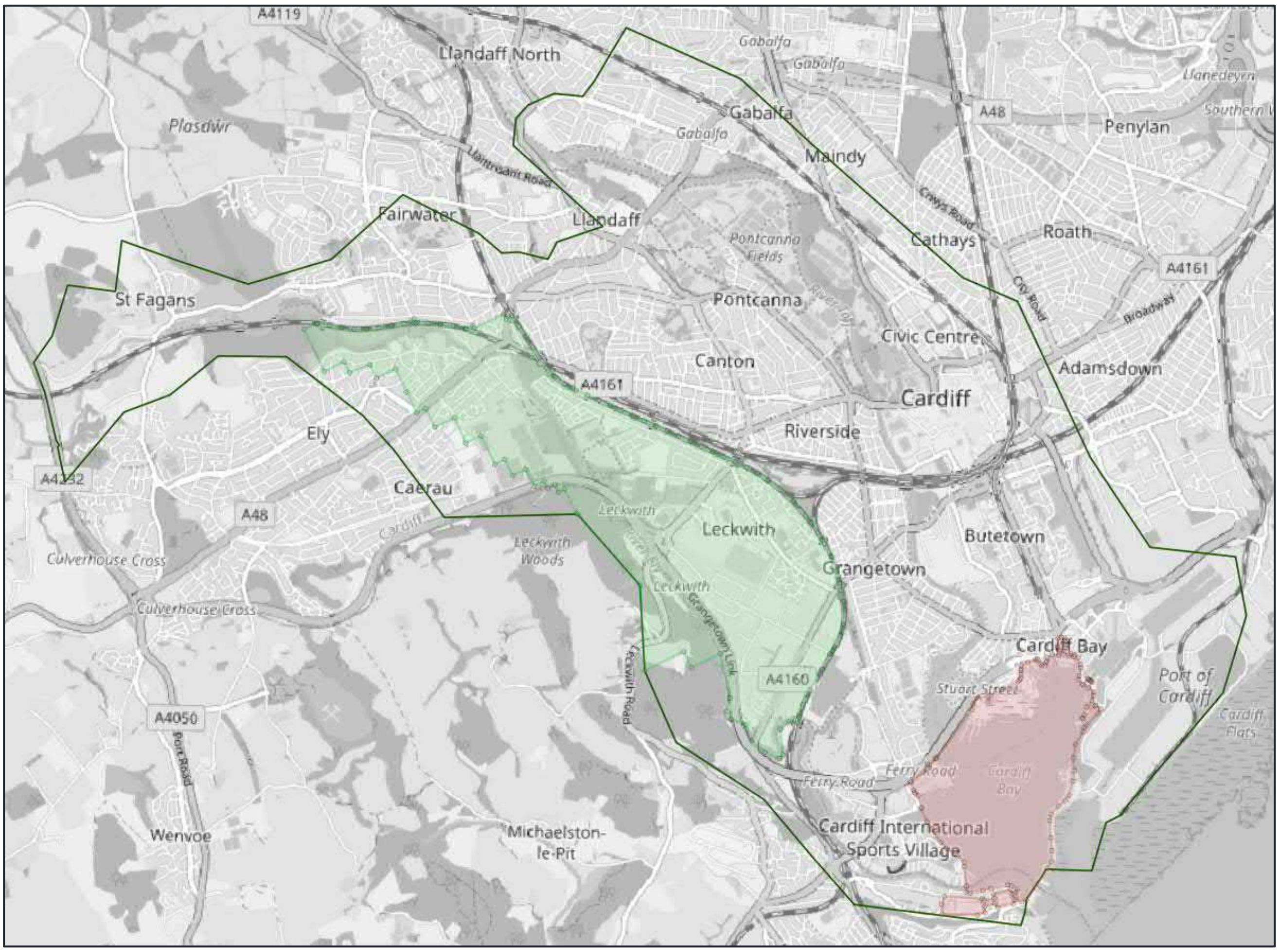


Figure A-2: Subgrid (4m cell) extents

Where: the green unshaded polygon denotes the 8m DomainGrid, the shaded green polygon denotes the 4m SubGrid and the red shaded polygon denotes the inactive (1D) Cardiff Bay area.

- Domain Grid Structures, Sections & Features
  In read order from the .tgc:
  - The base grid is set up with the size and orientation of the VDM with the same cell size of 8 metres.
  - All zpts within the domain are set to 9,999 m AOD
    the above command facilitates locating gaps in surface grids (e.g. LiDAR)
  - 1mDTM_LiDAR_7005-3561_Leck.asc
    This entry reads in the latest LiDAR information at time of model construction, significant areas are more recent than included in the VDM as discussed in the main report.
  - 2d_za_7005-3561_Overwrite.mif
    This entry reads in 'za' patches which overwrite the LiDAR where gaps exist in the .asc that are within the active domain. These are in general less than a single cell size and based on adjacent zpt values. There are two main areas, one on the South Wales Main Line near St Fagans Castle and the second around the keep and dock feeder canal, Cardiff Castle.
  - Active & Inactive Code

The whole model is firstly set into an inactive state, the area of the model is activated, this area is based on the active area from the VDM, the area of the subgrid is then deactivated by applying the inverted command on the subgrid active area file. Then the area of the rivers as covered by the 1D FMP domain are also deactivated to avoid double counting the conveyance.

- 2d_za_CBAY.mif
  This entry sets the levels within the bay area (those that are active). Areas of the Bay between the yacht club on the Afon Elái, Butetown Link over the Afon Taf, the Roath Basin, Roath Dock and Queen Alexandra Dock sets levels to 4 m AOD. With the seaward side of Queen Alexandra Dock set to -3 m AOD, resulting in a significant drop in this location. Whilst the underlying LiDAR has been updated, it was considered that this representation is suitable for this project given the underlying data and distance from the site of interest and this entry remains as inherited from the VDM.
- 2d_za_RAIL_001.mif
  This entry sets the railway level to 14.2 m AOD over the St Fagans mill leat underpass (Estry structure described above). This entry remains as inherited from the VDM.
- 2d_zln_Infrastructure_003a.mif
  This entry sets the railway level around Cardiff Central, whilst the underlying LiDAR has been updated, it was considered that this representation is suitable for this project given the underlying data and distance from the site of interest and this entry remains as inherited from the VDM.
- 2d_zsh_CBAY_001.mif
  This entry splits Cardiff Bay (excluding docks) in half the western half is set to 4 m AOD and the easter half slopes down to -2.2 m AOD around the perimeter. This is now predominantly in an inactive portion of the model as the representation of Cardiff Bay has been translated into the 1D domain. Whilst the underlying LiDAR has been updated, it was considered that this representation is suitable for this project given the underlying data and distance from the site of interest and this entry remains as inherited from the VDM.
- 2d_zln_TAF_Defences_008.mif
  This entry sets the riverbank levels of the Afon Taf as well as the feature around Pontcanna Fields. Whilst the underlying LiDAR has been updated, it was considered that this representation is suitable for this project given the underlying data and distance from the site of interest and this entry remains as inherited from the VDM.
- 2d_zln_7005-3561_Lek_Infrastructure_DomainGrid_210720_P.mif | L
  This entry sets the levels of the railway embankments through the active model reinforcing the LiDAR information. It is based on the zln performing the same function in the VDM, except as requested from NRW it has been split to exclude areas covered by the subgrid domain. Whilst the underlying LiDAR has been updated, it was considered that this representation is suitable for this project given the underlying data and distance from the site of interest and this entry remains as inherited from the VDM.
- 2d_zln_7005-3561_Lek_ELY_Defences_DomainGrid_210920_P.mif | L
  This entry sets the levels of the Afon Elái including bankside defences, it has been based on a merger of the VDM and the Paper Mills Model. Following discussions with NRW it has been split to exclude areas covered by the subgrid domain and levels have been updated based on the more recent LiDAR information between the site and the A4232 downstream of the site, excepting where 1D bank levels take precedent. Otherwise, levels remain as inherited from the

VDM as it was considered that this representation is suitable for this project given the underlying data and distance from the site of interest.

- 2d_zln_7005-3561_Lek_NinianPark_UPass_001_P.mif | L
  This entry sets the level of the Leckwith Road Underpass through both the South Wales Mainline and the Cardiff City Line Railways. Previously these were modelled as the other underpasses (i.e. Estry Culverts see above), however discussions with NRW noted a preference against culverts in this location and these have been translated into 2D z-lines opening a gap through the ground surface based on the width of the underpass and the LiDAR values on either side. The lines have been drawn taking into consideration the grid orientation and hence 'saw-tooth'.
- 2d_zln_MillLeat_002.mif
  This feature enforces a flowpath modifying u and V points only along the route of a leat within the model, it is not orientated with the model grid. Commencing from its western edge neat St Michael's Church it flows northeast connecting into the 1D Estry feature (ID: St Fagans), on the opposite side of the railway it continues east to Michaelstone Road where it is interrupted, recommencing on the south side of the railway and opposite side of the road it continues circa 325 m east before turning north and terminating on the immediate north of the railway. This entry remains as inherited from the VDM but according to the release note no longer correctly applies the intended ground surface; however, this is considered suitable for this project given the underlying data and distance from the site of interest.
- 2d_fcsh_MillLeat_001.mif
  This entry connects to the zln described in the above feature. It represents a flow constriction at the eastern end of said feature where it turns northwards under the railway prior to termination., The flow constriction sets the invert and soffit of an underpass at this location alongside a blockage of 80%, no additional losses are applied either above or below the soffit. This entry remains as inherited from the VDM which is considered suitable for this project given the underlying data and distance from the site of interest.
- 2d_zln_7005-3561_Lek_QA_Channel_P.mif | L
  This entry has been added to the model as the abrupt change in ground level at the Queen Alexandra Dock gate (c.f. 2d_za_CBAY.mif) from +4 m AOD to -3 m AOD was resulting in negative depths due to critical weiring in the simulation. Therefore, this entry enforces a more gradual change in ground level over 100m length and based on the width of the feature. It is noted that neither representation is wholly accurate of the action of this gate. However, it is understood that this gate may be opened in advance of high tides and the ground levels are typically lower than initial water levels. Thus, given the underlying data, inherited representation based on an approved NRW model as well as the distance from the site of interest and improvements in model stability this representation is considered suitable for this project.
- Materials and roughness values are discussed in Section A.3.2.3 below.

■ Subgrid Structures, Sections & Features
In read order from the .tgc:

- The base grid is set up with the orientation as the VDM, but covering a smaller area (as the subgrid covers a smaller area and has a finer grid cell size of 4 metres).
- All zpts within the domain are set to 9,999 m AOD
  the above command facilitates locating gaps in surface grids (e.g. LiDAR)
- 1mDTM_LiDAR_7005-3561_Leck.asc

This entry reads in the latest LiDAR information at time of model construction, significant areas are more recent that included in the VDM.

- 2d_zsh_7005-3561_Lek_A4232_Patch_210920_P.mif | R
  This entry patches a gap in the LiDAR near the site for A4232 embankment, it is based on LiDAR and translates from the previous zln for better representation in the 4m subgrid.
- DTM_Ely_TopoSurvey.asc
  This entry was incorporated from the Paper Mills Model, it was provided only as a grid of zpts which did not align with the VDM 8 m grid so a surface was created from the points to enable their inclusion into the model.
- 2d_zpt_4m_Ely_topo.asc
  This entry was incorporated from the Paper Mills Model, it was provided only as a grid of zpts which did not align with the VDM 8 m grid so a surface was created from the points to enable their inclusion into the model.
- 2d_zpt_4m_Broadstairs_topo.asc
  This entry was incorporated from the Paper Mills Model, it was provided only as a grid of zpts which did not align with the VDM 8 m grid so a surface was created from the points to enable their inclusion into the model.
- 2d_Zpt_7005-3561_Leck_ExSurveySurface2.asc
  This entry consists of a surface created from the onsite topographical survey. This survey was not collected in order to result in such a grid and does not include full coverage of the site; however, it has been agreed with NRW that this surface is considered preferable to the LiDAR as representing this surface in the model.
- 2d_zln_7005-3561_Lek_Survey_rd_CL_210920_L.mif | P
  This entry has been included in the model to ensure the preferential flowpath of the access road forms a complete flowpath in the model the centreline of the road has been used to set the points. In order to ensure a continuous flowpath the line has been drawn taking into consideration the grid orientation and hence ‘saw-tooth’.
- Active & Inactive Code
  The whole model is firstly set into an inactive state, the area of the subgrid model is activated, Then the area of the rivers as covered by the 1D FMP domain are deactivated to avoid double counting the conveyance.
- 2d_zln_7005-3561_Lek_Infrastructure_SubGrid_210720_L.mif | P
  This entry sets the levels of the railway embankments through the active model reinforcing the LiDAR information. It is based on the zln performing the same function in the VDM, except as requested from NRW it has been split to exclude areas covered by the Domain grid. Whilst the underlying LiDAR has been updated, it was considered that this representation is suitable for this project given the underlying data and distance from the site of interest and this entry remains as inherited from the VDM.
- The following files are topographic modifications from the Paper Mills model. No changes have been identified as required. It is understood that these should accurately reflect the approved model from NRW and hence the associated development. Given this minimal commentary is considered required:
  - 2d_zln_bridge_spill_001.MIF
  - 2d_zln_MoreData2011
  - 2d_zln_MoreData2011B

- 2d_zln_surveyMILL1
- 2d_zln_surveyMILL2
- 2d_zln_MoreData2011C
- 2d_zln_surveyData2011
  The above 7 entries are understood to comprise survey information collected to support the Paper Mills Scheme. None of the entries have been considered to require alterations, it is presumed that this data supersedes LiDAR.
- 2d_zpt_MillEntry.mif
- 2d_zpt_MillNorth.mif
- 2d_zpt_MillContours.mif
- 2d_zpt_MillCTR01.mif
- 2d_zpt_MillCTR02.mif
- 2d_zpt_MillCTR03.mif
- 2d_zpt_MillCTR04.mif
- 2d_zpt_MillCTR05.mif
- 2d_zpt_MillCTR06c.mif
- 2d_zpt_MillRoadWide.mif
- 2d_zpt_MillRoad.mif
- 2d_zpt_MillOpen04.mif
- 2d_zpt_MillChannel02.mif
- 2d_zln_bund01.mif
- 2d_zln_cutPile_09.mif
- 2d_zln_ELY_Defences_005.mif
  The above sixteen entries are understood to comprise the proposed development as part of the Paper Mills model which this project presumes as a significant committed development will be completed by the time this site completes. None of the entries have been considered to require alterations. It is presumed the licenced model suitably captures the eventual built development. Any deviation that may result between the as-built drawings and the approved NRW model are outside of the purview of this project.

- 2d_zln_7005-3561_Lek_ELY_Defences_SubGrid_220124_P.MIF | L
  This feature sets the bank levels of the Afon Elái through the subgrid domain. The elevations of the points between the two A4232 crossings on either side of the site have been taken from 1D cross section bank levels, site survey levels or the latest LiDAR in that order of preference. The updated values place a data point at approximately 4 or 5 cell intervals. The bank levels further away from the site have been inherited either from the Paper Mills model or the VDM in that order of preference.
  Reportedly as part of the Paper Mills scheme, the flood defences alongside the site of interest were raised. There is no record of this in either the licenced Product 5 information (reporting) or Product 7 information (model). The client notes that works were undertaken which raised ground levels over an area and that these should be captured in the topographic survey. As the baseline model includes a ground surface of the site built from this topographical data which is used preferentially over LiDAR in the creation of this feature/surface, whilst it is accepted this is an anecdotal data source, in the absence of more accurate information it is considered that these defences are accurately represented.

- 2d_zsh_amend_zpts_leckbundN.mif
  The above entry is understood to form part of the Paper Mills model. It is not considered to require updating or alteration for this project.
- 2d_zsh_amend_zpts_leckbundS.mif
  The above entry is understood to form part of the Paper Mills model. It is not considered to require updating or alteration for this project.
- 2d_zsh_7005-3561_Lek_NinianPark_UPass_210920_P.mif | R
  In the Paper Mills and VDM model the railway underpass on Leckwith Road at Ninian Park was represented as a 1D culvert. Discussions with NRW identified that this flowpath should not be represented as a culvert. Therefore, the representation of this flowpath was altered to be a free flowing overland flow route. A zsh has been used to represent this flowpath with the elevations of each corner taken from LiDAR in order to patch a flowpath through the railway embankment. The width of the feature has been identified from LiDAR and satellite imagery.
- 2d_zsh_7005-3561_Lek_TrelaiPark_UPass_210920_P.mif | R
  Upstream of the site the A4232 crosses the Afon Elái. In the Paper Mills model the flowpath under the bridge in the 2D domain was not modelled but floodplain waters were collected and transferred into the 1D domain. Following discussions with NRW it was agreed to represent the overland flowpath in the 2D domain. Therefore, a zsh has been used to set ground levels (removing the embanked road), the levels have been set based on LiDAR a sufficient distance from the embankment and the widths have been based on satellite imagery which shows the abutment locations. The assumption remains (see 1D section on this feature) that the soffit level of the feature is significantly higher than the maximum water level at this location and so no additional losses have been applied or requested.
- 2d_zsh_7005-3561_Lek_Leckwith_UPass_210920_P.mif | R
  In the licenced model the passage of the B4257 under the A4232 was represented as a connection directly into the 1D Afon Elái. This was not considered appropriate for this project and following discussions with NRW neither was an Estry culvert, similar to other underpasses in the model. Discussions concluded that a suitable representation given the dimensions of the feature was to allow a 2D flowpath unimpeded through the A4232. These features enable this flowpath and sets the width and ground levels based upon surveyed data (Appendix C).
- 2d_zln_7005-3561_Lek_Leckwith_UPass_210920_P.mif | L
  The A4232 has on and off ramps passing under the road itself at this location. Previously the on ramp was represented as a connection directly into the 1D Afon Elái. This was not considered appropriate for this project. This has been modelled as a 2D flowpath, the levels have been set based on LiDAR a sufficient distance from the embankment and the widths have been based on satellite imagery which shows the abutment locations. The lines have been drawn taking into consideration the grid orientation and hence ‘saw-tooth’.
- 2d_zln_7005-3561_Lek_Site_UPass_220124_P | L
  This entry enforces a 2D flowpath under the B4267, at this location an access road passes under the B4267 via one of the floodplain arches. As this arch is substantially clear a zln is considered a suitable representation. Levels have been based on surveyed data (Appendix C). The lines have been drawn taking into consideration the grid orientation and hence ‘saw-tooth’.
- 2d_zsh_7005-3561_Lek_Site_SpansGLs_210920_R.mif | P

This entry corrects the ground levels through the B4267 where there are arches over the floodplain. It sets ground levels based on surveyed data (Appendix C) removing the surface of the B4267 at these locations.

- 2d_zln_7005-3561_Lek_Site_SpansWall_220124_L.mif | P
  This entry represents a blockwork wall which effectively severs the flowpath through the north face of the two easternmost floodplain arches of the B4267 apparently built into the structure. The levels are based surveyed data (Appendix C).
- 2d_lfcsh_7005-3561_Lek_Site_Spans_220124_R.mif
  This entry supplies an additional loss factor through the floodplain arches based on the fact that they have been built through, in front of and over. Blockage percentages, obverts and flow losses have been applied to reflect the data collected in the topographic survey, in particular the longsection of the bridge.
- Materials and roughness are discussed in Section A.3.2.3 below.

A number of features which were previously in the Tuflow domain, have been translated to alternative representation and will be discussed in the relevant section and identified in the model log. The following features have been removed entirely:

- No features have been wholly removed as part of this project.

A.3.2.3 Floodplain Roughness

In both the Domain Grid and the Subgrid, the manning's roughness coefficient was set at 0.05 for the entire area before being overwritten based upon land use classifications from Mastermap data inherited from the licenced models and based on the classifications used for the VDM model. In line with NRW's guidance at time of modelling the roughness values for buildings has been increased to 0.7. The values have also been amended to 'default' under the existing Leckwith bridge to better represent the roughness values anticipated. All other roughness values are considered appropriate, do not vary with depth and remain as inherited from the licenced models Table A-1 below provides these values.

Table A-1: Tuflow roughness Values

Classification	Mannings Value
Buildings	0.700
Roads	0.038
Wood	0.080
Inland Water	0.040
Default	0.050
(unused)	0.100
Dock Feeder	0.022

Classification	Mannings Value
Cardiff Bay	0.022
Stabilisation	2.000

A.3.2.4 2D Model Boundaries

- FMP 1D links

The TUFLOW 2D domain is linked to the FMP 1D river channels of both the Afon Taf and Afon Elái, using a HX boundary along the left and right bank top of the channels. This boundary has predominantly been inherited from the licenced models, no changes have been made to the HX lines associated with the Afon Taf. The HX lines following the riverbank of the Afon Elái have been reviewed, it is noted that between the two crossings of the A4232 on either side of the site the channel width of the 2D and 1D domains were generally within a single cell width difference when applying the 8 metre grid, but the transition to the 4 metre grid suggests that these discrepancies should be corrected. Unfortunately, NRW no longer hold the original survey data so it is unclear where the 1D bank tops are located in a geocoordinated space. Discussions with NRW agreed that in general the 1D widths should be considered as more accurate than the 2D widths and the CN/HX lines corrected to better match the widths in the 1D domain. The following sections have had their widths updated in the 2D domain. The locations of the revised banktops are based on the width specified in the 1D domain and the bank top levels in the 1D domain compared to the levels noted LiDAR. Table A-2 below identifies these corrections. It is noted that the widths do not match exactly and that the locations of the FMP nodes within the VDM & Ely Mills model more be mis-coordinated, however the resulting fit is considered reasonable based on the informing data sets.

Table A-2: Corrected Tuflow Section Widths (m)

Section Name	1D Width	Old 2D Width	New 2D Width
ELY31930	35.74	65.0	37.3
ELY32250	44.29	64.3	44.7
ELY32550	37.80	40.0	37
ELY32560D	32.44	41.0	36
ELY32572U	35.27	45.0	34.5
ELY32572D	35.27	53.0	32.8
ELY32575W	35.27	56.7	34.2
ELY32580	32.70	57.0	33.6

Section Name	1D Width	Old 2D Width	New 2D Width
ELY32590	28.69	56.0	31.8
ELY32700	44.51	59.8	48.5
ELY32840	61.10	56.5	61.4
ELY32990	75.22	63.3	75.5
ELY33130	48.54	67.0	48.6
ELY33290	59.19	74.0	55.9
ELY33440	89.60	85.0	88.7
ELY33540	117.78	82.0	112.6
ELY33710	82.61	67.5	78.3
ELY33920	47.47	50.0	40.5
ELY34190	87.67	64.0	88.2

CN lines communicate the in-channel water levels to the HX lines. These lines have been split between the Domain grid and the subgrid. WLLs do not effect model results, these have been updated to account for the new cell widths.

As noted previously the representation of Cardiff Bay has been translated from the 2D domain into the 1D FMP domain to improve model stability. Additional information is provided in the above section on 1D FMP structures. Where water is able to overtop the bay connectivity has been provided into the 2D domain based on spill units connected to the 2D Domain Grid via CN and SX lines along the edge of the Bay based on the flood extents of previous simulations.

- Estry 1D links

A number of 1D Estry culverts have been embedded within the 2D domain, these are connected via HX or SX links, dependant on providence. Where the connected end is now in the subgrid, the length of the SX lines has been updated to better reflect the width of the feature. An early version of the combined VDM and Mills Model required Z flags added to the Mill Lane and Fleet Lane culverts for stability. No other changes have been incorporated into their representation. A number of these entities have been translated from 1D-2D links to 2D flowpaths, these are noted in the discussion on 2D structures.

- 2D only Boundaries

The presence of two separate grids with two separate cell size requires a 2D-2D boundary line in order to allow the transfer of water between the two grids. The two grids have the same orientation and are a suitable change in cell size between the two. In order to transfer water between the two domains a 2D-2D_BC line has been used which transfers head between the two domains. The boundary has been configured to follow the higher ground of the railway embankment in order to reduce model inaccuracies resulting from the head only transfer of water. This line follows the boundary of the Subgrid with the Domain grid, in accordance with current guidance the 'D' attribute is not less than 3 times the size of the coarse 2D domain.

As noted in the Hydrology section of the main report, inherited from the VDM is a 2D overland flood flowpath 2d_bc_TAF_FP_001.MIF near the upstream end of the Afon Taf. No changes have been made to this boundary.

On the seaward side of Cardiff Bay and Queen Alexandra Docks is a HT boundary, this allows the tide to work its way upstream through the docks and into Cardiff Bay. This feature has been inherited from the VDM and no changes have been identified as required for this arrangement.

A.3.2.5 Checks, Warnings & Error Messages

One Hundred and Fourteen messages are generated in total of which forty-three are Warnings, seventy-one Checks and zero are Errors. These have been reviewed and are considered acceptable.

- Warnings

There are 43 Warnings covering 8 codes

- 0307 - No GIS Projection specified. No output .prj file will be created.
  This warning is generated twice, once for each domain. The project continues with the inherited projection as used in the licenced model and the lack of a .prj is of no concern.
- 1317 - WLL does not cross (2 point WLL only) or snap to 1D channel
  This warning is generated 9 times, 7 of which relate to the Taf and 2 the Elái. WLLs are cosmetic only for the mapping of 1D results and therefore given the distance from the site are of no significant concern to this project.
- 2079 - 3D breakline failed to modify any Zpts. Check elevations, snapping and correct GIS projection.
  This warning is generated 3 times and is associated with the Mill Leat, these warnings are inherited from the licenced model and may represent an error as noted in the release notes (S A.3.2.1); however this feature is a significant distance from the area of interest and sufficiently represented in the LiDAR for the purposes of this project.
- 2117 - Inactive 2D cell made active by 2D SX link.
  This warning is generated 15 times and is associated with the 1D-2D boundary of the spills set up to connect Cardiff Bay. A review of the grd check file identifies that these are suitably located and connected along the edge of the active/inactive domain.
- 2118 - Lowered SX ZC Zpt by #m to 1D node bed level.
  This warning is generated 10 times and relates to the 'Z' flags applied to the railway underpasses. These have been reviewed and, noting that the invert levels of the culverts remains unchanged from the licenced model, are considered to be performing as desired.
- 2218 - Manning's n value of # for Material # is unusually low or high
  This warning is generated 4 times, twice for each model domain. It identifies the mannings value for the roughness stability patch inherited from the licenced model .tmf but not applied for this

project and the value requested by NRW to representing buildings. Therefore, none of these warnings are of concern for this project.

- 2380 - Elevations above 1000 detected. Double Precision version of TUFLOW may be required
  This warning is generated once and is associated with the set zpts command used to highlight gaps in the LiDAR coverage. A review of the resulting ground surface and final zpts identify that these are generally within the inactive channel or sufficiently distant from the site of interest to be of no concern for this project.
- 2400 - Hidden node not allocated as a primary node to a 2D2D link cell in 2D Domain Site_SubGrid. Review 2D2D link line shape and check vertex spacing is not too close
  This warning is generated twice the 2D2D interchange has been reviewed and is considered to be performing satisfactorily.

- Checks

There are 71 Checks covering 6 codes

- 2097 - FC obvert (soffit) is below ZV Zpt. ZV cell side blocked.
  This check is generated 3 times, each of which concern the mill leat, the configuration of which is inherited from the licenced model and it is presumed that the configuration remains sufficiently accurate to be of no concern for this project.
- 2099 - Ignored repeat application of boundary to 2D cell.
  This check is generated 9 times, 7 for HX and twice for SX. 3 HX relate to the Afon Taf, 4 on the Elái and the two SX relate to the dock feeder canal underpass. A review of the bcc check file identifies that the boundary cells are appropriately connected.
- 2109 - Raised HX ZC Zpt by #m to 1D bed level
  This check is generated 8 times and relates to the ‘Z’ flags applied at the railway underpasses. These have been reviewed and, noting that the invert levels of the culverts remains unchanged from the licenced model, are considered to be performing as desired.
- 2118 - Lowered SX ZC Zpt by #m to 1D node bed level.
  This check is generated 33 times and relates to the ‘Z’ flags applied to the railway underpasses and the Cardiff Dock - Roath Basin 1D/2D interchange. These have been reviewed and, noting that the invert levels of the culverts remains unchanged from the licenced model, are considered to be performing as desired.
- 2370 - Ignoring coincident point found in ORIGINAL layer
  This check is generated 18 times, the majority of which relate to the setting of levels alongside the Taf with two associated with the railway embankment. A review of the levels identifies that the configuration remains sufficiently accurate to be of no concern for this project.
- 2380 - Elevations above 1000 detected. Double Precision version of TUFLOW may be required
  This check is generated once and is associated with the set zpts command used to highlight gaps in the LiDAR coverage. A review of the resulting ground surface and final zpts identify that these are generally within the inactive channel or sufficiently distant from the site of interest to be of no concern for this project.

- Errors

There are no error messages recorded in the automatic check file.

A.4 BASELINE BLOCKAGE MODEL REPRESENTATION

No additional details or changes are required to explain the configuration of the blockage scenarios beyond those identified in the main report.

A.5 PROPOSED (VARIATION D) MODEL REPRESENTATION

The proposed scheme is summarised in the FCA. The site is under consideration for a residential development (target of up to 250 residences) along with associated public open space, amenities and includes a new highway link via a bridge across the Afon Elái with the existing bridge being demolished along with the existing business units. The development is currently split into two parcels on either side of the proposed new bridge crossing referred to as the northern (1.3 ha) and the southern plateaus (6.4 ha). It has been proposed to raise the development parcels above the flood level to reduce the risk of onsite flooding and to include bypass culverts under each riverbank to alleviate the choke point formed by the Historic Bridge.

A.5.1 DATA INFORMING THE VARIATION D MODEL REPRESENTATION

The data sources used to inform the development of the proposed model include:

- Architect's layout 1844/S.102C October 2021.
- *'Leckwith Quay Bridge Proposed General Arrangement'* 70053561-002-P03 September 2021.
- *B4267 Leckwith Road Highway Improvements Levels And Contours*' 70053561-WSP-XX-XX-CR-DE-600 September 2019.

A.5.2 FMP & ESTRY 1D MODEL REPRESENTATION

This model contains elements from both FMP and Estry. FMP is used to represent the main river channels and associated structures, whereas Estry is used to represent structures in the floodplain.

A.5.2.1 1D Simulation Parameters & Miscellanea

No changes to simulation parameters were required to represent the proposed (Variation D) configuration.

A.5.2.2 1D Channel Roughness

No changes to roughness values were required to represent the proposed (Variation D) configuration. For the new bypass culverts a mannings value of 0.02 has been applied assuming a concrete construction.

A.5.2.3 1D Hydraulic Structures

Limited changes are proposed to the watercourse itself and therefore the majority of hydraulic structures within the 1D model have been retained as previously represented. No alterations have been made to the structures on the Afon Taf, for ease of reporting the structures discussed below have been split into predominantly FMP and predominantly Estry.

- Changes to FMP Structures, Sections & Features
  From upstream to downstream:
  - 32550U – Proposed B4267 Viaduct

This is a newly added structure, which has been inserted to represent the proposed bridge. The existing cross section ELY32550 was, according to the coordinates of its node in the 2D domain, located at the upstream face of this structure. Therefore, this node has had its chainage reduced to zero in order to insert the desired structure, the 10m chainage assigned which have been removed were reallocated with a 50-50 split to the upstream and downstream nodes (Table A-3 below). The position of the bridge across the existing section has been based on how the section in '*Leckwith Quay Bridge Proposed General Arrangement*' 70053561-002-P03 September 2021 fits against this section and the downstream representation of the Historic Bridge visible in section A-A on that drawing. This has necessitated some modification to bank levels in order to coordinate the section and allow for the bank overtopping between the 1D FMP domain and the 2D domain at the approach to the Estry bypass culverts. These changes are clearly evident in Figure A-3 below. The structure has been modelled as a USBPR type bridge unit. Based on the information from the design and provided in the appendices, the bridge has been modelled with no skew, default abutments and a flat soffit. Whilst the soffit is not entirely flat, given the limitations of the modelling software and the small gradient, a mid-point value has been taken to represent the average soffit level. Whilst the full bridge opening may be 35 m wide, given the small height between the soffit and the abutment gantry a decision has been made to consider the full span in the 1D domain to be the span between the abutments.

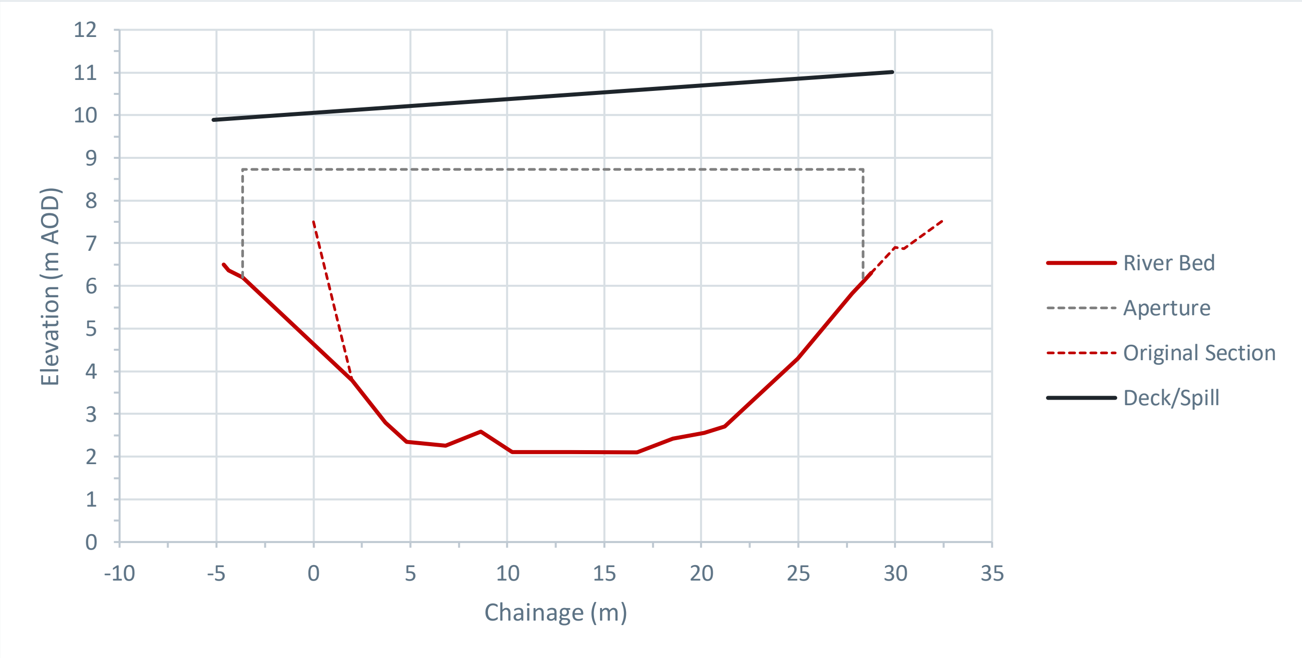


Figure A-3: Representation of Proposed Viaduct (Sans Bypass Culverts)

- 32550K – Proposed B4267 Viaduct Blockage Unit
  This unit has been included in FMP to facilitate the application of a blockage on the proposed bridge should that scenario configuration be considered desirable. Notwithstanding that it is currently considered superfluous for the purposes of this study.
- 32550A – Proposed B4267 Viaduct Spill Unit
  As indicated in Figure A-3 above, a spill unit has been applied to allow any flood water reaching the deck level of the bridge to weir over into the downstream cross section. Notwithstanding that

results generated to date show water levels do not reach this height, default parameters are applied for this spill unit and thus assumes that the parapet remains unblocked in such an event and that flood water will have reached a level on the lower left bank to result in no substantial diversion of flow perpendicular to the channel were flood water to reach said level.

- 32572U - B4267 Existing Bridge
  This structure and the associated upstream zero chainage river cross section have been deleted from the model as the presumption is these will be demolished and removed.

Table A-3: FMP Chainage through key reach

Label	Chainage (m)	
	Baseline	Proposed
ELY32100	150	150
ELY32250	150	150
ELY32400	150	155
ELY32550	10	0
ELY32550D	-	5
ELY32560U	0	0
ELY32560D	12	12
ELY32572U	0	-
ELY32572D	8	8
ELY32575W	0	0
ELY32580	10	10
ELY32590	110	110
ELY32700	140	140
ELY32840	150	150
ELY32990	140	140
ELY33130	160	160
Total	1190	1190

- Estry Structures, Sections & Features
  No changes have been required for the existing Estry units within the Baseline model in order to represent the proposed scenario. However, the proposed bypass culverts are represented within Estry.

  - C01L, C02L, C03L – Left Bank Bypass Culverts
    This culvert (1d_nwk_7005-3561_Lek_VarCCulverts_210920_L) is connected to the 2D domain on the upstream end via an 'SX' and 'CN' arrangement. Routes, lengths, dimensions and inverts are as set out in *Leckwith Quay Bridge Proposed General Arrangement'* 70053561-002-P03 September 2021. Standard losses have been applied to each segment of the culvert. A sealed system has been assumed with no connectivity to the overlying topography via surface water connections, surcharging manholes, etc. In-channel storage is active and a Mannings roughness of 0.02 to represent the concrete finish has been assumed. The downstream end of the culvert connects directly into the downstream FMP node via a 1D head transfer of water. As the lengths are defined in the culvert parameters the extension to connect the 1d_nwk does not over-estimate the volume the culverts, there is a marginal change (c. 4°) in the angle of the final unit which will have a corresponding effect on the losses calculated in Estry, but these are considered to be negligible.
  - C01R, C02R, C03R – Right Bank Bypass Culverts
    This culvert (1d_nwk_7005-3561_Lek_VarCCulverts_210920_L) is connected to the 2D domain on the upstream end via an 'SX' and 'CN' arrangement. Routes, lengths, dimensions and inverts are as set out in *Leckwith Quay Bridge Proposed General Arrangement'* 70053561-002-P03 September 2021. Standard losses have been applied to each segment of the culvert. A sealed system has been assumed with no connectivity to the overlying topography via surface water connections, surcharging manholes, etc. In-channel storage is active and a Mannings roughness of 0.02 to represent the concrete finish has been assumed. The downstream end of the culvert connects directly into the downstream FMP node via a 1D head transfer of water. As the lengths are defined in the culvert parameters the extension to connect the 1d_nwk does not over-estimate the volume the culverts, there is a marginal change (c. 3°) in the angle of the final unit which will have a corresponding effect on the losses calculated in Estry, but these are considered to be negligible.

A.5.2.4 1D Model Boundaries

Notwithstanding the new 1DHX connection between Estry and FMP at the ends of the Bypass Culverts, no changes to the 1D model boundaries have been required to represent the proposed configuration.

A.5.3 TUFLOW 2D MODEL REPRESENTATION

In order to represent the 2D configuration changes have been required within the 2D model domain.

A.5.3.1 2D Simulation Parameters & Miscellanea

No changes to simulation parameters were required to represent the proposed (Variation D) configuration.

A.5.3.2 Model Grid Resolution, Terrain, Structures & Features

As mentioned in the main report the development of the proposed model is based on the architect's layout (1844/S.102C), this has since been superseded by 102F, we have been assured that this will not affect the flood model. Both layouts have been provided in the appendices and the changes have been summarised as:

- Strengthening/widening of the 'green wedges' for ecological benefit. Some blocks on the southern plateau have been shifted to accommodate this.
- Reconfiguration of blocks along the riverside of the southern plateau to create sufficient acoustic shadows where outdoor amenity space can be situated.
- Area 03 (Block Es) has revised road, building and parking layout to accommodate the above acoustic and ecological requirements, as well as improve efficiency.

For ease of reporting the features discussed below have been split into predominantly domain grid (the larger cell size and predominantly subgrid (the smaller cell size).

- Domain Grid Structures, Sections & Features
  In read order from the .tgc:
  - All changes required in order to represent the proposed scenario are contained within the Subgrid.
- Subgrid Structures, Sections & Features
  In read order from the .tgc:
  - Active & Inactive Code
    The whole model is firstly set into an inactive state, the area of the subgrid model is activated, Then the area of the rivers as covered by the 1D FMP domain are deactivated to avoid double counting the conveyance. The inactive area for the proposed model has been modified in order to account for the change in cross sections, allowing the bypass culverts to connect to the 2D domain on their upstream end and facilitating the changes required to CN & HX lines.
  - 2d_zln_7005-3561_Lek_ELY_Defences_SubGrid_VarD_210920_P.mif | L
    This feature sets the bank levels of the Afon Elái through the subgrid domain. The majority of levels are as per the baseline scenario, however the zln has been modified to represent the changes resulting from the placement of structures through the reach of interest and the bank levels alongside the proposed bypass culverts. Given the level of detail provided concerning the level design of the proposed development it is assumed in large part that the levels raised for the development plateaus will slope to existing river bank levels where there is space to do so and utilise retaining features, erosion protection and slope stabilisation methods where required.
  - 2d_za_7005-3561_Lek_VarD_220224_R.mif
    This entry represents the flat areas of the development plateaus, undercroft parking is presumed to preclude the ingress of flood waters. Levels have been set as per the architect's layout 1844/S.102C and 70053561-WSP-XX-XX-CR-DE-600.
  - 2d_zsh_7005-3561_Lek_VarC_220224_R.mif |
  - 2d_zsh_7005-3561_Lek_VarD_220224_P.mif
    This entry represents the graded areas of the development plateaus. Levels have been set as per the architect's layout 1844/S.102C and 70053561-WSP-XX-XX-CR-DE-600.
  - 2d_Zpt_7005-3561_Leck_PropSurface_200403.asc

This entry reads a ground surface provided by the highways team representing the surface of the proposed viaduct.

- 2d_za_7005-3561_Lek_VarC_CulvEntry_210920_R.mif
  This entry ensures that the ground levels at the entry to the bypass culverts and from the river banks (1D-2D link) at this location is set to the correct ground level.
- Materials and roughness are discussed in Section A.5.3.3 below.

A number of features which were previously in the Baseline Tuflow domain are no longer relevant for the proposed configuration and thus are omitted via the use “If Scenario” clauses. The following features have been removed entirely:

- 2d_zln_7005-3561_Lek_Survey_rd_CL_210920_L.mif | P
  This entry represented a flowpath through the existing access road through the site, given the proposed layout it is considered superfluous and is not read in the proposed simulation.
- 2d_zln_7005-3561_Lek_Site_UPass_220124_P | L
  This entry enforced a 2D flowpath under the B4267, at this location an access road passes under the B4267 via one of the floodplain arches. As this bridge will be demolished it is considered superfluous and is not read in the proposed simulation.
- 2d_zsh_7005-3561_Lek_Site_SpansGLs_210920_R.mif | P
  This entry corrects the ground levels through the B4267 where there are arches over the floodplain. As this bridge will be demolished it is considered superfluous and is not read in the proposed simulation.
- 2d_zln_7005-3561_Lek_Site_SpansWall_220124_L.mif | P
  This entry represents a blockwork wall which effectively severs the flowpath through the north face of the two easternmost floodplain arches of the B4267 apparently built into the structure. As this bridge will be demolished it is considered superfluous and is not read in the proposed simulation.
- 2d_lfcsh_7005-3561_Lek_Site_Spans_220124_R.mif
  This entry supplies an additional loss factor through the floodplain arches based on the fact that they have been built through, in front of and over. As this bridge will be demolished it is considered superfluous and is not read in the proposed simulation.

A.5.3.3 Floodplain Roughness

No changes to the mannings classification file (.tmf) were required to represent the proposed configuration. Changes to the floodplain roughness were required to represent the proposed (Variation D) configuration at the site itself, as such all alterations occur within the subgrid domain. The area covering the site is first read in as a constant value (2d_mat_7005-3561_Lek_PropUnderlay_R.mif) as the default floodplain roughness vale (5, 0.050) this is then overwritten with roughness classifications based on the proposed layout developed by the project architects (Appendix B) (2d_mat_7005-3561_Lek_VarC_220224_R.mif) with codes for buildings, roads and inland water as appropriate based on the proposed layout (Table A-1).

A.5.3.4 2D Model Boundaries

- FMP 1D links
  The TUFLOW 2D domain is linked to the FMP 1D river channels of both the Afon Taf and Afon Elái, using a HX boundary along the left and right bank top of the channels. This boundary has

predominantly been inherited from the licenced models, no changes have been made to the HX lines associated with the Afon Taf. CN lines communicate the in-channel water levels to the HX lines. These lines have been split between the Domain Grid and the Subgrid, however all changes required to represent the proposed model occur within the Subgrid. The principal changes are:

- a narrowing of the cross section at the upstream face of the proposed bridge in order to accommodate the proposed bypass culverts.
- A removal of the gap which previously accommodated the current Leckwith Bridge which is to be demolished as part of these proposals.
- An upstream extension of the gap for the Historic Leckwith Bridge to accommodate the gap required to represent the proposed viaduct. As the chainage between these two features is circa 5 m and the cell size is 4 m it is not practical to link the river reach between the two features to the 2D domain, the aperture of the structure and the spill in the 1D domain over the parapet remain the controlling effect of the water level and it is noted that this may result in a conservative estimate of upstream water levels.
- WLLs do not effect model results, these have been updated to account for the new cell widths.

- Estry 1D links

  No changes to the Estry 1D links are required for the baseline model. However, the two bypass culverts are connected to the 2D domain via CN and SX lines allowing the transfer of water between the two domains. Although ground levels are set using the 'za' noted in Section A.5.3.2 a 'Z' flag is still utilised. Given the size of the structure (3.3 x 2 m) a single 4 m cell is linked, the cell is at the location noted from 70053561-WSP-XX-XX-CR-DE-600 and allows for a single cell gap between the FMP HX connection and the SX. This arrangement is replicated on both sides of the Afon Elái.
- 2D only Boundaries

  No changes to the 2D boundaries are required to represent the proposed scenario.

A.5.3.5 Checks, Warnings & Error Messages

One Hundred and twenty-three messages are generated in total of which forty-three are Warnings, eighty Checks and zero are Errors. The majority of these are the same as those from the baseline model as would be expected. This section focuses on messages new to this scenario, original error messages are covered in the relevant section of this report above. The messages have been reviewed and are considered acceptable.

- Warnings

There are no new warning messages

- Checks

There are 9 new Checks covering 5 codes, two of which, the first two in the bullets below, are new:

- 1393 - Node C03L.2 linked to external 1D scheme Node ELY32572D using a X1DH link
  This check advises the new connection to between Estry and FMP as part of the Bypass culverts has established via a X1DH, this is as desired.
- 1402 - More than one culvert connected but could not create manhole at Node "C03L.2"
  This check advises that Estry has not generated an automatic manhole at the downstream end of the Bypass culverts, which is also as desired.
- 2118 - Lowered SX ZC Zpt by #m to 1D node bed level.

This check is newly generated 2 additional times and relates to the ‘Z’ flags applied to bypass culverts. These have been reviewed and are considered to be performing as desired.

- 2370 - Ignoring coincident point found in ORIGINAL layer
  This check is newly generated 5 additional times, 4 of which have no geocoordinated information to track down and one is located at the end of the road grading down form the proposed bridge to the southern plateau. A review of the levels associated with the new features via the check files identifies that the configuration remains sufficiently accurate to the provided layout.

- Errors

There are no error messages recorded in the automatic check file.

A.6 PROPOSED BLOCKAGE MODEL REPRESENTATION

No additional details or changes are required to explain the configuration of the blockage scenarios beyond those identified in the main report.

Appendix B

PROPOSALS

CONFIDENTIAL

Appendix B.1

PROPOSED DEVELOPMENT LAYOUT

DWELLING MIX + GIFA

BLOCK A

50no. 2B 4P apartments.
Dwelling size average: 70m2

BLOCK B

19no. 3B 5P houses (HOUSE TYPE B).
Dwelling size average: 116m2
18no. 2B 4P duplex (Duplex Dwelling Type 7)
Dwelling size average: 73m2

BLOCK C

31no. 2B 4P apartments.
Dwelling size average: 70m2

BLOCK D

28no. 2B 4P duplex
(Duplex Dwelling Types 1 + 2)
Dwelling size average: 94m2

BLOCK E

54no. 3B 5P duplex (Duplex Dwelling Types 3 + 4)
Dwelling size average: 113m2

HOUSE TYPE A

7no. 3B 5P houses
Dwelling size average: 125m2

HOUSE TYPE C

8no. 3B 5P houses
Dwelling size average: 96m2

HOUSE TYPE D

6no. 4B 7P houses
Dwelling size average: 165m2

HOUSE TYPE E

7no. 3B 5P houses
Dwelling size average: 178m2

DWELLING MIX:

Apartments	81
Duplex Dwelling	100
Houses	47
TOTAL	228

REVISIONS

A	10.09.2020 GE LEVELS UPDATED TO NORTHERN PLATEAU
B	30.10.2020
C	05.10.2021 AREA 3 LAYOUT UPDATED
D	24.02.2022 BLOCKS D AND E UPDATED
E	08.04.2022 LEVELS UPDATED
F	12.04.2022 LEVELS UPDATED

PLANNING

1844/S.102F

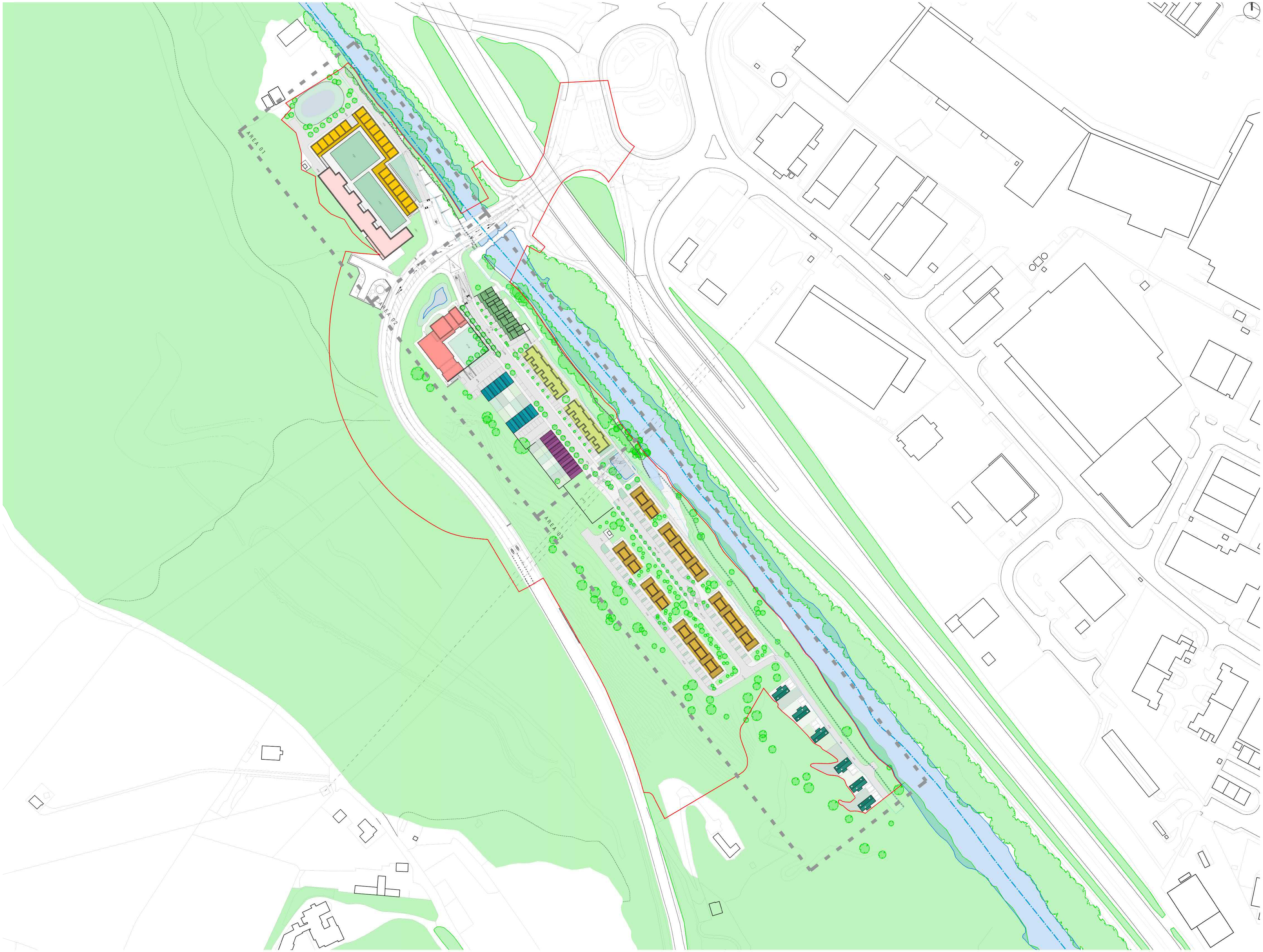
LECKWITH QUAY

PROPOSED MASTERPLAN

1:1250@A1 APR 22

LOYN + CO
ARCHITECTS

02920 711432 | architecture@loyn.co.uk
88 Glebe Street Penarth CF64 1EF | loyn.cc.uk



DWELLING MIX + GIFA

BLOCK A

50no. 2B 4P apartments.
Dwelling size average: 70m2

BLOCK B

19no. 3B 5P houses (HOUSE TYPE B).
Dwelling size average: 116m2
18no. 2B 4P duplex (Duplex Dwelling Type 7)
Dwelling size average: 73m2

BLOCK C

31no. 2B 4P apartments.
Dwelling size average: 70m2

BLOCK D

28no. 2B 4P duplex
(Duplex Dwelling Types 1 + 2)
Dwelling size average: 94m2

BLOCK E

54no. 3B 5P duplex (Duplex Dwelling Types 3 + 4)
Dwelling size average: 113m2

HOUSE TYPE A
7no. 3B 5P houses
Dwelling size average: 125m2

HOUSE TYPE C
8no. 3B 5P houses
Dwelling size average: 96m2

HOUSE TYPE D
6no. 4B 7P houses
Dwelling size average: 165m2

HOUSE TYPE E
7no. 3B 5P houses
Dwelling size average: 178m2

DWELLING MIX:

Apartments	81
Duplex Dwelling	100
Houses	47
TOTAL	228

A 10.09.2020 GE
LEVELS UPDATED TO NORTHERN PLATEAU
B 30.10.2020
C 05.10.2021
AREA 3 LAYOUT UPDATED

REVISIONS 1

PLANNING

1844/S.102C

LECKWITH QUAY

PROPOSED MASTERPLAN

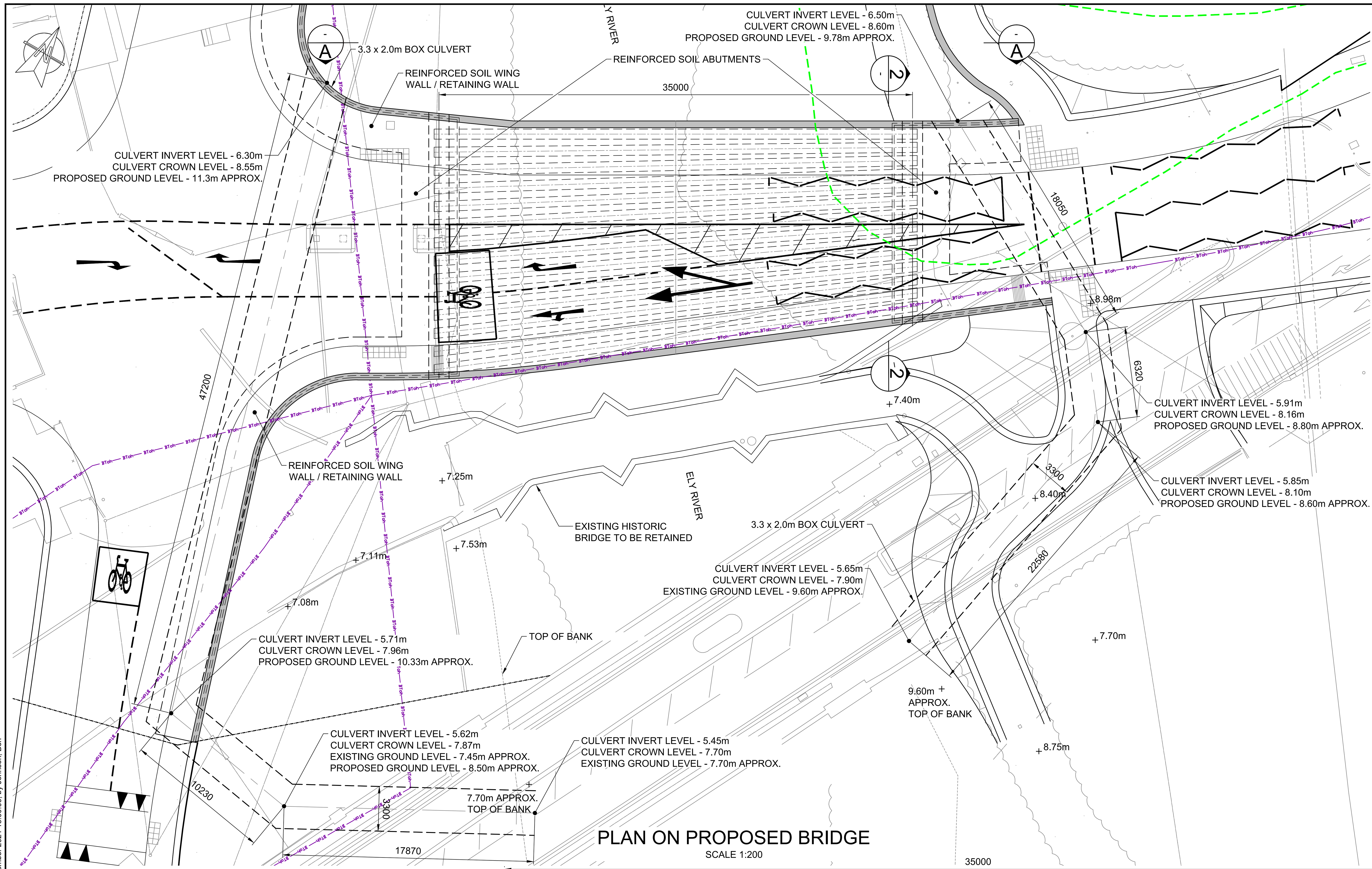
1:1250@A1 OCT 21

LOYN+CO
ARCHITECTS

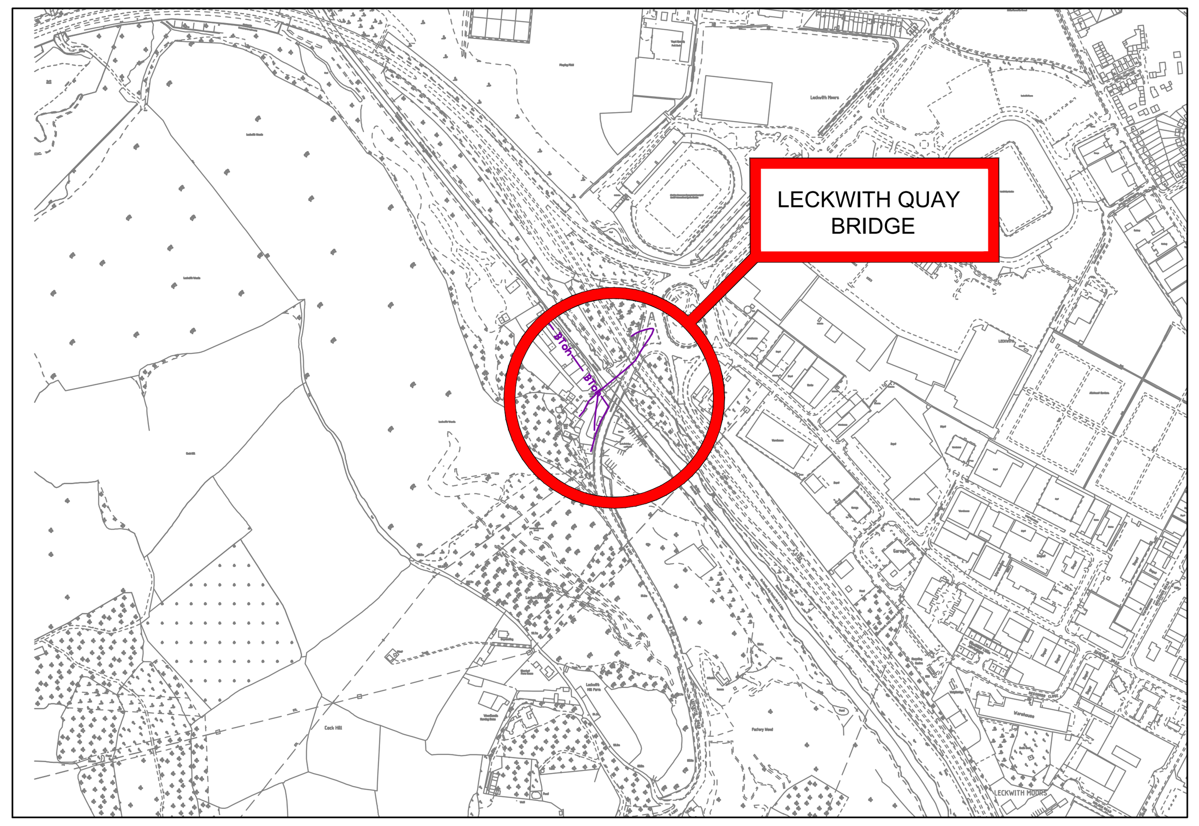
02920 711432 | architecture@loyn.co.uk
88 Glebe Street Penarth CF64 1EF | loyn.cc.uk

Appendix B.2

PROPOSED VIADUCT LAYOUT



PLAN ON PROPOSED BRIDGE
SCALE 1:200



LOCATION PLAN
SCALE 1:10,000

DO NOT SCALE

NOTES:

1. DO NOT SCALE FROM THIS DRAWING - USE ONLY VALUES OF STATED DIMENSIONS.
2. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE SHOWN.
3. ALL EXISTING STATUTORY INFORMATION SHOWN HAS BEEN PROVIDED BY THE RELEVANT STATUTORY AUTHORITIES. THE CONTRACTOR SHALL CONFIRM THE LOCATIONS AND OWNERSHIP OF THE SERVICES PRIOR TO ANY WORKS BEING CARRIED OUT. ANY DIVERSIONS REQUIRED ARE TO BE CARRIED OUT IN ACCORDANCE WITH THE REQUIREMENTS OF THE RELEVANT STATUTORY AUTHORITY PRIOR TO CONSTRUCTION.

KEY

BT OPENREACH

WESTERN POWER HV (33kV)

Health and Safety Symbols Legend

All Risks are Recorded in the Significant Residual Design H&S Risk Schedule Document Number: 70053561-***

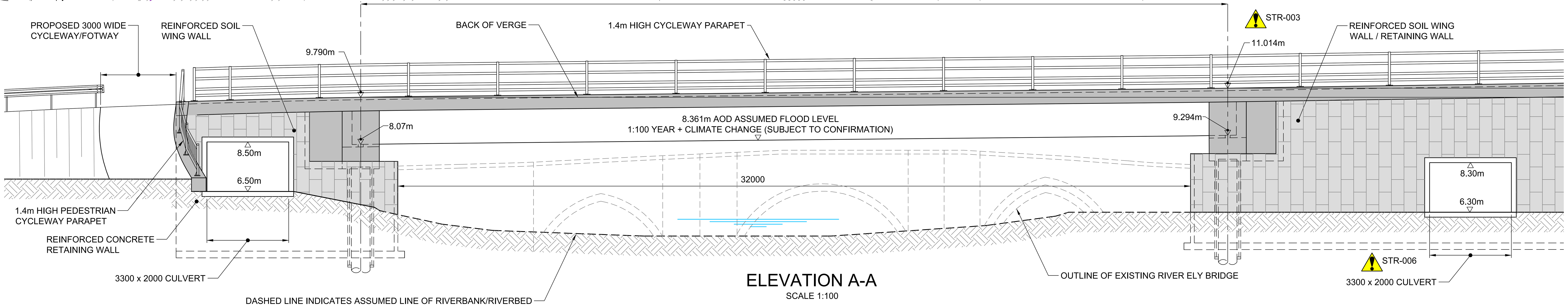
1. INDICATES A RESIDUAL RISK AS A WARNING.

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS

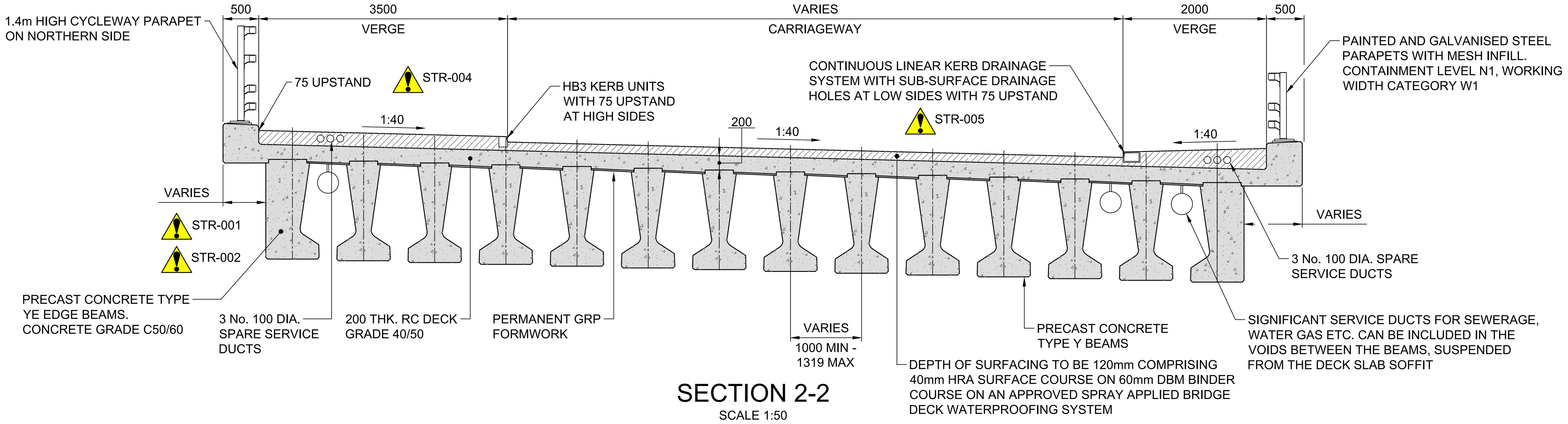
Construction Risks - STR001 - Lifting of pre-cast beams.
STR002 - Landing of pre-cast beams onto capping beam.
STR003 - Superstructure construction.
STR004 - Proximity of existing Statutory Undertakers apparatus.
STR005 - Deck Construction
STR006 - Wingwall construction.
STR007 - Fixing reinforcement.
STR008 - Fixing reinforcement (piles).

Maintenance Risks - No significant maintenance risks identified.

Demolition/Adapation Risks - No significant demolition risks identified.



ELEVATION A-A
SCALE 1:100



SECTION 2-2
SCALE 1:50

REV	DATE	BY	DESCRIPTION	CHK	APP
P03	24/09/2021	BJ	CULVERT DIMENSIONS/LEVELS ADJUSTED	SH	SS
P02	27/08/2020	BJ	SPAN INCREASED	SH	SS
P01	21/10/2019	BJ	FIRST ISSUE	SH	SS

DRAWING STATUS: S0 - WORK IN PROGRESS

wsp

1 Capital Quarter, Tyndall St, Cardiff, CF10 4BZ, UK
T+ 44 (0) 292 076 9200
wsp.com

CLIENT:

ARCHITECT:

SITE/PROJECT: LECKWITH QUAY DEVELOPMENT

TITLE: LECKWITH QUAY BRIDGE PROPOSED GENERAL ARRANGEMENT

SCALE @ A1: AS SHOWN	CHECKED: SH		APPROVED: SS
PROJECT NO: 70053651	DESIGNED: SS	DRAWN: BJ	DATE: September 21
DRAWING No: 70053561-002			REV: P03

File name \\UK.WSPGROUP.COM\CENTRAL DATA\PROJECTS\700535XX\70053561 - LECKWITH QUAY, CARDIFF\02 WIP\STRUCTURES\DRAWINGS\70053561-002.DWG, printed on 24 September 2021 15:00:06, by Johnson, Ben

DO NOT SCALE

NOTES
1. DO NOT SCALE FROM THIS DRAWING, USE FIGURED DIMENSIONS ONLY.
2. ALL LEVELS ARE IN METRES ABOVE ORDNANCE DATUM (AOD)
3. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE STATED.
4. THIS DRAWING IS FOR PLANNING PURPOSES ONLY AND IS SUBJECT TO DETAILED DESIGN
5. HIGHWAY GEOMETRY & DESIGN IS SUBJECT TO TECHNICAL APPROVAL OF THE ADOPTING HIGHWAY AUTHORITIES

KEY:
- 1:2 FILL SLOPE*
- 1:1 CUTTING SLOPE (ROCK CUTTING/ STRENGTHENED CUT)*
- 1:2 CUTTING SLOPE*

*SUBJECT TO CONFIRMATION OF GROUND CONDITIONS

DRAWING STATUS: FOR PLANNING

wsp

1 Capital Quarter
Tyndall St
Cardiff
CF10 4BZ, UK

T+ 44 (0) 292 076 9200
wsp.com

CLIENT:	PHILIP WORTHING
ARCHITECT:	LOYN ARCHITECTS
PROJECT:	LECKWITH QUAY
TITLE:	B4267 LECKWITH ROAD HIGHWAY IMPROVEMENTS LEVELS AND CONTOURS

SCALE @ A1:	CHECKED:	APPROVED:
1:500	SID	GW

PROJECT No:	DESIGNED:	DRAWN:	DATE:
70053561	SID	GS	September 19

DRAWING No:	REV:
70053561-WSP-XX-XX-CR-DE-600	-

File name \\UK.WSPGROUP.COM\CENTRAL DATA\PROJECTS\700535XX\70053561 - LECKWITH QUAY, CARDIFF\02 WIP\CIVILS\DRAWINGS\70053561-WSP-XX-XX-CR-DE-600 LEVELS & CONTOURS.DWG printed on 28 February 2020 16:23:20, by Davies, Sion

Appendix C

TOPOGRAPHIC SURVEY DATA

Coordinate System

This survey has been oriented to the Ordnance Survey (OS) National Grid and Datum using GPS observations and the OS Active Network.

A true OS coordinate was established near to the centre of the site. This survey has been correlated to this point. Further OS coordinates were established to create a true OS bearing for angle orientation.

No scale factor has been applied to this survey. The coordinates shown are arbitrary and not true OS coordinates which do have a scale factor applied.

Notes

1. Dimensions should not be scaled. All dimensions should be verified on site prior to construction.
2. All dimension and levels are in metres unless otherwise stated.
3. Some detail may have been obscured by parked vehicles, stored materials, overgrown vegetation, and leaf litter.
4. All data shall remain Copyright of Gwalia Surveyors unless formally agreed otherwise.
5. The surveyed boundary features may not be legal boundaries.
6. Gwalia Surveyors cannot accept any responsibility for any damage to computer systems from viruses which may be contained in the data/files supplied.

Key to Abbreviations

Inspection Covers & Chambers

AV	Air Valve
BH	Borehole
BT	British Telecom Cover
CDP	Cable Draw Pit
CW	Combined Water
Dr.Ch.	Drainage Channel
Elec.	Electric Inspection Cover
ER	Earth Rod
FH	Fire Hydrant
FW	Foul Water
G	Gully
GC	Gas Cock
GV	Gas Valve
IC	Inspection Cover
KO	Kerb Outlet
MH	Manhole
RE	Rodding Eye
SC	Stop Cock
SV	Stop Valve
SW	Storm Water
TV	Cable Television Cover
UL	Uplighter
UTL	Unable to Lift
WM	Water Meter
WO	Washout

Ground Surface Types

Asp.	Asphalt
B/P	Block Paviors
Conc.	Concrete
Pav.	Concrete Paving
Tac.	Tactile Paving

Measurement Descriptions

CL	Cover Level
d	Depth (m)
dia.	Diameter (mm)
FFL	Finished Floor Level
h	Feature Height (m)
IL	Invert Level
SL	Sump Level
Soff.	Soffit Level
WL	Water Level

Walls & Fence Types

Bl.	Block Wall
Br.	Brick Wall
B/W	Barbed Wire Fence
C/B	Close Boarded Fence
C/I	Corrugated Iron Fence
C/L	Chain Link Fence
C/P	Concrete Post
Gab.	Gabion Wall
H/R	Hand Rail
I/R	Iron Railings
Pal.	Pallisade Fence
P/R	Post & Rail Fence
P/W	Post & Wire Fence
Ret.	Retaining Wall
St.	Stone Wall

Street Furniture

B	Bollard
BB	Belisha Beacon
DP	Down Pipe
EP	Electricity Pole
FB	Flower Bed
JB	Junction Box
LP	Lamp Post
MP	Marker Post
P	Post
PB	Post Box
RS	Road Sign
RWP	Rain Water Pipe
SP	Sign Post
Stay	Stay Wire
SVP	Soil Vent Pipe
TCB	Telephone Call Box
TL	Traffic Light
TP	Telegraph Pole
VP	Vent Pipe

Linetypes & Symbols

Banks
Buildings
Building Overhead
Change of Surface
Fences
Kerbs
Overhead Cables
Ridges & Eaves
Steps
Walls
Vegetation
Tree Canopy
CW Combined Water
FW Foul Water
SW Storm Water

Banking
Flow Direction
Gate
Survey Station
Tree

Sheet Layout

N

Rev.	Date	Drawn	Details
A	17.01.2019	JT	Survey updated.

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LAND | UTILITIES | BUILDING | BOUNDARY | BIM

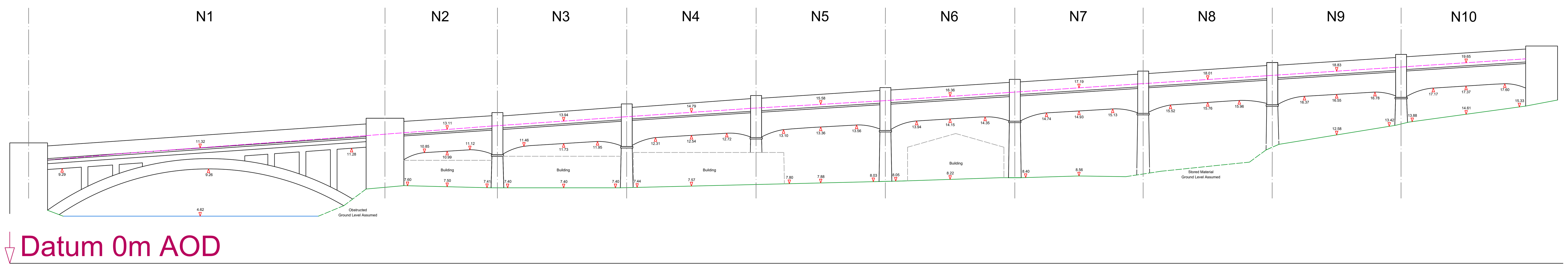
Title: Topographical Survey

Project: Leckwith

Client: Gareth Davies Project Services

Drawn:	JT,DB,JF	Checked:	DR
Date:	21.12.2018	Scale:	N.T.S.

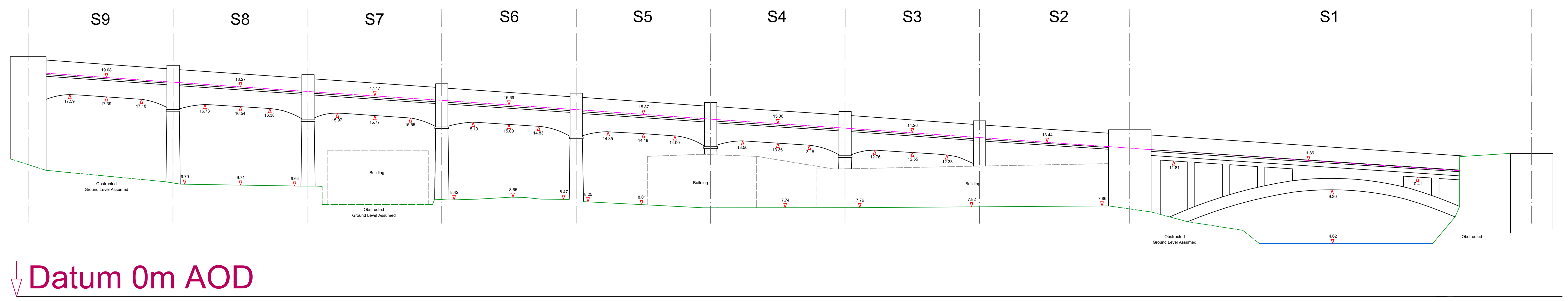
Drawing Number: 2786-T-PRELIMINARY
Rev. A



North Elevation

This is a flattened elevation view

Scale-1:200 @ A0

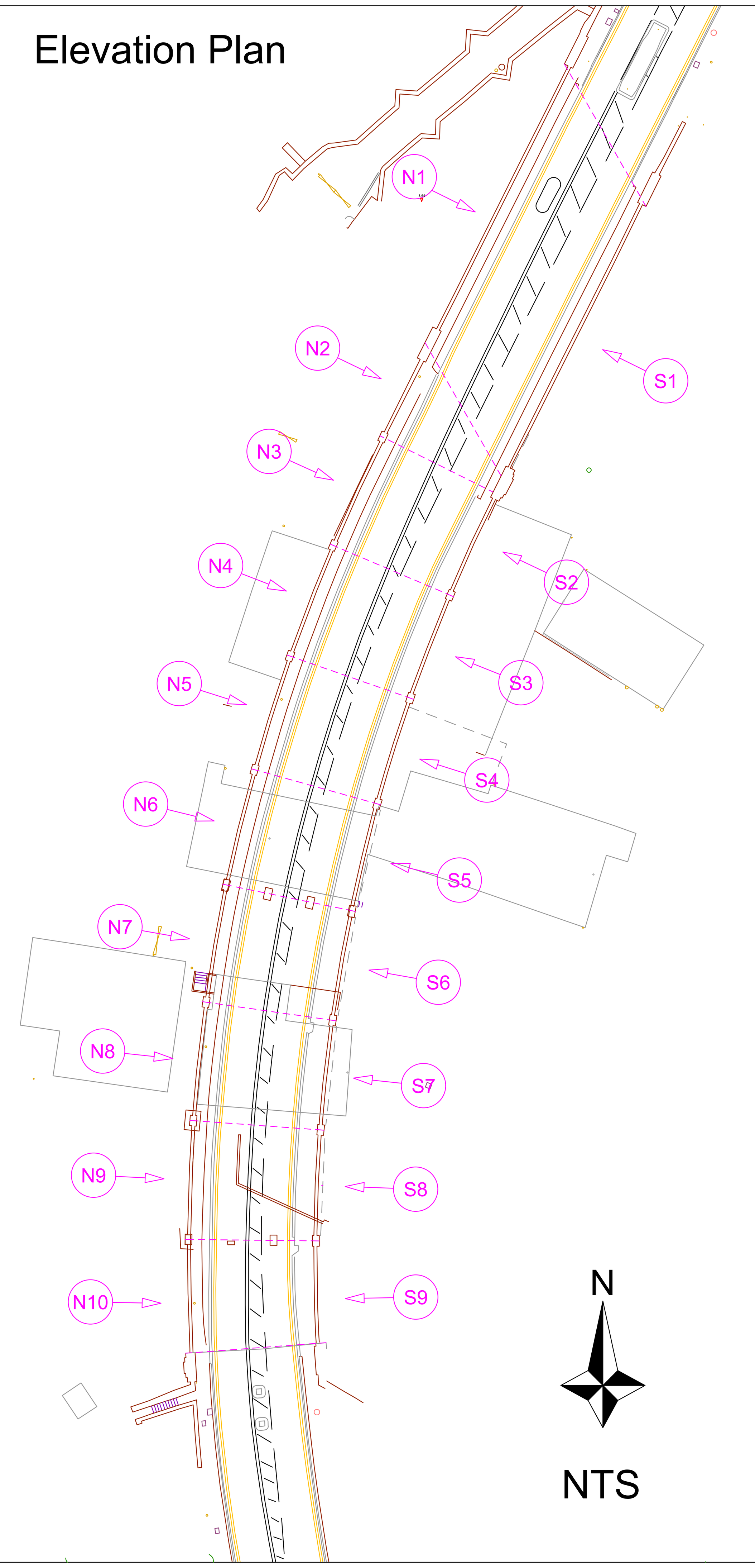


South Elevation

This is a flattened elevation view

Scale-1:200 @ A0

Elevation Plan



Key

	Highway Channel
	Ground Profile
	Assumed Ground Level
	Water Level
10.00	Level
N1	Elevation ID

Coordinate System

This survey has been oriented to the Ordnance Survey (OS) National Grid and Datum using GPS observations and the OS Active Network.

A true OS coordinate was established near to the centre of the site. This survey has been correlated to this point. Further OS coordinates were established to create a true OS bearing for angle orientation.

No scale factor has been applied to this survey. The coordinates shown are arbitrary and not true OS coordinates which do have a scale factor applied.

Notes

1. Dimensions should not be scaled. All dimensions should be verified on site prior to construction.
2. All dimension and levels are in metres unless otherwise stated.
3. Some detail may have been obscured by parked vehicles, stored materials, overgrown vegetation, and leaf litter.
4. All data shall remain Copyright of Gwalia Surveyors unless formally agreed otherwise.
5. The surveyed boundary features may not be legal boundaries.
6. Gwalia Surveyors cannot accept any responsibility for any damage to computer systems from viruses which may be contained in the data/files supplied.

Key to Abbreviations

Inspection Covers & Chambers

AV	Air Valve
BH	Borehole
BT	British Telecom Cover
CDP	Cable Draw Pit
CW	Combined Water
Dr.Ch.	Drainage Channel
Elec.	Electric Inspection Cover
ER	Earth Rod
FH	Fire Hydrant
FW	Foul Water
G	Gully
GC	Gas Cock
GV	Gas Valve
IC	Inspection Cover
KO	Kerb Outlet
MH	Manhole
RE	Rodding Eye
SC	Stop Cock
SV	Stop Valve
SW	Storm Water
TV	Cable Television Cover
UL	Uplighter
UTL	Unable to Lift
WM	Water Meter
WO	Washout

Ground Surface Types

Asp.	Asphalt
B/P	Block Paviors
Conc.	Concrete
Pav.	Concrete Paving
Tac.	Tactile Paving

Measurement Descriptions

CL	Cover Level
d	Depth (m)
dia.	Diameter (mm)
FFL	Finished Floor Level
h	Feature Height (m)
IL	Invert Level
SL	Sump Level
Soff.	Soffit Level
WL	Water Level

Walls & Fence Types

Bl.	Block Wall
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RWP	Rain Water Pipe
SP	Sign Post
Stay	Stay Wire
SVP	Soil Vent Pipe
TCB	Telephone Call Box
TL	Traffic Light
TP	Telegraph Pole
VP	Vent Pipe

Rev.	Date	Drawn	Details

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LAND | UTILITIES | BUILDING | BOUNDARY | BIM

Title:	Elevations
Project:	Leckwith Bridge
Client:	G.D Project Services
Drawn: KB	Checked: DR
Date: 28.03.2019	Scale:
Drawing Number: 2786-E-001	Rev.