VALE of GLAMORGAN
BRO MORGANNWG

Agenda Item: 9

Meeting of:	**Cabinet**
Date of Meeting:	**Thursday, 29 September 2022**
Relevant Scrutiny Committee:	Learning and Culture
Report Title:	Proposal to add St Richard Gwyn to the Capital Programme
Purpose of Report:	Outline the proposed changes to St Richard Gwyn Project within the Sustainable Communities for Learning Programme and changing the project from a Mutual Investment Model (MIM) to a Capital Scheme.
Report Owner:	Cabinet Member for Education, Arts, and the Welsh Language
Responsible Officer:	Paula Ham, Director of Learning and Skills
Elected Member and Officer Consultation:	Officers Consulted: Matt Bowmer: Head of Finance/Section 151 Officer Gemma Jones: Operational Manager, Accountancy Trevor Baker: Head of Strategy, Community Learning & Resources Lisa Lewis: Operational Manager, Strategy and Resources Nathan Slater: Project Manager, Sustainable Communities for Learning
Policy Framework:	This is a matter for Executive decision by the Cabinet

Executive Summary:

- On 18th August, 2022, the Council was notified that that the revised strategic outline programme submitted to Welsh Government had been approved which reviewed and amended the intervention rates for projects, by type, to ensure that over the programme the Council was contributing the correct intervention rate and removed projects which were not required in Band B.
- St Richard Gwyn RC High School has been identified as an urgent project due to the implications relating to the viability of the scheme due to the requirements of the new TAN 15 guidance set to be adopted in June 2023. To deliver the project within the required timeframe, the scheme will be added to the Council's Band B capital programme. A variation to the strategic outline programme will be required to approve the change and will need to be submitted to Welsh Government by 14th October, 2022.

- The project will increase the Council's contribution by £8.250m. This will be funded through unallocated s.106 monies, reserves and borrowing. £466k is required to be invested in the scheme before the variation to the strategic outline programme is determined to ensure the design and planning works are addressed before the new TAN 15 guidance is adopted in June 2023.

Recommendations

1. That Cabinet notes the position relating to the Council's Sustainable Communities for Learning Band B Programme.

2. That Cabinet approves the amended Band B profile of the Council's Sustainable Communities for Learning Programme and submission to Welsh Government.

3. That Cabinet approves the inclusion of initial design and feasibility works in relation to the 3-16 Faith School Project and include a budget of £466k into the 2022/23 Capital Programme.

4. That the use of article 15.14.2 A(ii) of the Council's Constitution (urgent decision procedure) be authorised in respect of Recommendations (2) and (3) above.

Reasons for Recommendations

1. To inform Cabinet of the current position with regards to the Sustainable Communities for Learning, Band B programme.

2. To ensure the Council can deliver a more robust Band B programme and continue to deliver improvements to schools within the Vale of Glamorgan that reflect pupil demand and school condition.

3. To allow initial feasibility works on the scheme to be progressed.

4. To allow the Council to progress with the design and planning consultancy costs for the project as soon as possible in order to minimise risk to the Council due to the implications of the new TAN 15 guidance being released in June 2023.

1. Background

1.1 The Sustainable Communities for Learning Programme is a unique collaboration between Welsh Government and Local Authorities. It is a major long term strategic capital investment programme with the aim of creating a generation of modern Schools in Wales. The programme was previously known as the 21st Century Schools Programme.

1.2 In July 2017, the Council submitted its Strategic Outline Programme (SOP) for Welsh Government approval, identifying the priorities included within the Band B programme. The SOP was approved by Welsh Government on 10th November, 2017. Since the approval there have been several revisions to the SOP which changed the scope of projects such as St Nicholas CiW Primary School from a refurbishment scheme to a new school scheme and changes to the intervention rate for different types of schools, for example the Welsh Government community school intervention rate increased from 50% to 65%.

1.3 In January 2019, the Council's Cabinet determined to remove the 3-16 Faith School scheme from the proposed Band B capital programme. This allowed the Council to fund the increased costs associated with Pencoedtre High School, the Centre for Learning & Well-being, and the Ysgol Y Deri Expansion. It was determined that the 3-16 Faith School scheme would be brought forward under the tranche of funding for the programme referred to as Band C.

1.4 A SOP Variation was submitted to remove the 3-16 Faith School Scheme to Welsh Government, however, on 5 April 2019, the Council was notified that the variation had not been approved by the Minister for Education as it would result in the funding envelope being increased. Initially, the Council questioned this decision, as officers were of the view that the funding envelope had not been increased.

1.5 However, following further clarification, Welsh Government confirmed that it considers the Council's capital funding envelope excluded the funding allocated to the 3-16 faith school scheme as this scheme was identified as being delivered using Welsh Government's Mutual Investment Model (MIM). As MIM is a revenue funded programme, Welsh Government stated the value of the project should not be included within the Council's capital funding envelope and the funding could not therefore be reallocated to fund alternative capital schemes if it is removed.

1.6 Consequently, as the 3-16 faith scheme would not impact the Council's capital budget for the scheme it was retained within the Band B programme as a MIM project.

1.7 In July 2022, the Council submitted a SOP Variation which reviewed and amended the intervention rates for projects, by type, to ensure that over the programme the Council was contributing the correct intervention rate as detailed in the following table:

65:35 Intervention Rate	75:25 Intervention Rate	85:15 Intervention Rate
Whitmore High School	Centre for Learning and Well-being	St David's Primary School
Pencoedtre High School	Ysgol Y Deri Expansion	
Ysgol Gymraeg Bro Morgannwg		
Barry Waterfront		
Llancarfan Primary School		
St Nicholas Primary School		
Cowbridge Primary Provision		

1.8 The intervention rates for the projects under the different types have varied over the course of the programme due to rising costs on individual projects. These additional costs have been met by the Council to ensure the timely delivery of the schemes. This has resulted in the Council providing a higher amount of match funding than required to deliver the projects within the programme. In addition to amending the intervention rate, the project known as Nursery Provision for

Penarth was removed from the programme following the Cabinet decision to amalgamate nursery provision in Penarth on 11th April, 2022 which addressed the lack of nursery provision at Evenlode and Cogan Primary Schools. Furthermore, the scheme Penarth Primary Provision was removed from the funding envelope due to uncertainties surrounding the likely final cost and ensure the robustness of the contribution amendments, however, the project will remain in the programme.

1.9 The SOP Variation was approved by Welsh Government on 18th August, 2022. The programme envelope has been reduced by £671k and the total envelope for the programme is now £136.844m. This total excludes the increases relating to St Nicholas and Ysgol Y Deri projects as these would be subject to separate business cases which would require approval from Welsh Government. Based on the final costs for the outstanding 2 projects the overall programme would increase to £148.813m. The increase in the Council's contribution for these projects will be funded from the funds released by the SOP Variation. Accounting for these increases £3.920m funds would remain within the programme for future schemes.

1.10 Should the St Richard Gwyn scheme feasibility and design works identify that the scheme is unviable the cost incurred to date would need to be funded by the Council to allow these funds to be released back into the Sustainable Communities for Learning Programme.

2. Key Issues for Consideration

2.1 St Richard Gwyn RC High School has been highlighted as a school for redevelopment. The project was identified as a MIM scheme under Band B of the Sustainable Communities for Learning Programme. The MIM scheme is a new revenue funded model which was launched in September 2020 following the appointment of the strategic partner and the creation of WEPCo. MIM is a Public-Private Partnership arrangement with a strategic partner. Meridiam was appointed as the strategic partner following a 12-month long competitive procurement process.

2.2 MIM would not require an initial capital contribution from the Council but would be funded via a revenue cost over the 25yr agreement. The building would be fully maintained over the 25yr agreement period, and the building would transfer to the Council at the end of the agreement period. MIM does not require an initial capital outlay and the building would be maintained throughout the 25yr agreement period.

2.3 The preferred option to re-develop St Richard Gwyn was to create a 3-16 Although School by amalgamating St Helen's RC Primary School with St Richard Gwyn. This would include 72 part-time nursery places, 315 primary places and 900 secondary places based upon the projected demand at the time. This would be delivered on the existing St Richard Gwyn school site. The cost comparison to deliver this option via MIM or capital is shown in the table below:

Option	Overall Council Cost – MIM (£)	Overall Council Cost – Capital (£)
Amalgamation of St Helen's and St Richard Gwyn with rounded capacity	12,978,750	4,994,550

2.4 However, MIM does not require an initial capital outlay and the building would be maintained throughout the 25yr agreement period. The capital scheme would still require maintenance and the capital funding streams would need to be identified. In order to provide a fair comparison, annual revenue costs have been identified to construct the scheme via capital. These costs are compared against the MIM annual revenue costs in the table below:

Option	Annual Revenue Cost – MIM (£)	Annual Revenue Cost – Capital Scheme (£)
Amalgamation of St Helen's and St Richard Gwyn with rounded capacity	519,150	605,952.40

2.5 The annual revenue cost associated with delivering a scheme via capital is higher than the annual MIM revenue cost. This is to be expected as Welsh Government would be part funding life cycle, maintenance and borrowing costs. Whilst this provides a useful comparison, it does not reflect the reality of newly developed schools. For example, the assumption is made that the Council would spend more than £350k per annum maintaining the new building. However, Cowbridge Comprehensive School was completed approx. 12 years ago, and the main building has not had any significant capital investment. Likewise, Penarth Learning Community was completed approx. 9 years ago and has also not have any significant capital expenditure. The borrowing costs would also be reduced if the Council identified alternative funding streams such as S106, reserves, capital receipts and general capital funding.

2.6 Since the preferred option was identified in 2021, further feasibility work has been undertaken which has identified flooding on the St Richard Gwyn School site. This restricts the amount of land within the site which could be developed. Consequently, it is proposed that the 3-16 Faith School Scheme is amended to remove the All-through School element and focus on the redevelopment of the Secondary School only. Based on the current pupil projections it is proposed a 1050 capacity secondary school is delivered. Furthermore, the construction sector has experienced increased costs due to recent global events. This has had a significant impact on the costs being received from contractors to deliver construction projects. Therefore, although the scheme is smaller in scale the costs to deliver the scheme are higher for both the MIM and capital funding route and maybe subject to further increases which will need to be considered during the design and feasibility phase. The table below shows the new costs for the revised option for St Richard Gwyn:

Option	Overall Council Cost – MIM (£)	Overall Council Cost – Capital (£)
Amalgamation of St Helen's and St Richard Gwyn with rounded capacity	13,188,285	8,250,000

2.7 In relation to the associated revenue costs for the revised project, the table below compares the MIM and Capital Route:

Option	Annual Revenue Cost – MIM (£)	Annual Revenue Cost – Capital Scheme (£)
Amalgamation of St Helen's and St Richard Gwyn with rounded capacity	607,308	708,851

2.8 The annual revenue costs for the MIM project are approximately £100k cheaper than predicted for the capital scheme. However, the annual revenue costs are unlikely to begin immediately on capital schemes. This is based on previously completed schemes such as Cowbridge Comprehensive and Penarth Learning Community which have not required significant maintenance investment since being completed. It is estimated the total annual revenue costs reflected in the table above will begin after 25 years following the completion of the project. The MIM scheme requires annual maintenance payments as the building is maintained by the contractor regardless of the condition of the school. A capital scheme does allow for more flexibility in utilising revenue costs on maintenance helping to reduce the cost over the long term.

2.9 In addition to the cost comparison, the site represents a greater risk to contractors applying for the scheme through the MIM route. This is due to the site's location within a flood zone which increases the risk of flooding on the site. This increases the risk to a potential contractor who would be responsible for the 25-year maintenance commitment as part of a MIM scheme. Therefore, it is considered unlikely that the project would be successful even if flood mitigations were included in the scheme as the MIM scheme would be inflated to reflect the associated insurance premiums the contractor would need to accommodate. The scheme will include flood mitigation methods which address the flood zone area. The Council has undertaken feasibility testing which included a Hydraulic Modelling Report. The Report reviewed 5 potential options managing and/or alleviating flood risk to the developed area of St Richard Gwyn School. Option 5 was considered to be appropriate as it intercepts flooding from the two key flowpaths which from Coldbrook and attenuates floodwater on site through a series of basins and ditches. Once water has entered these storage features, ditches will be designed to convey water around the southern perimeter of the site in an anti-clockwise direction, re-connecting with the baseline flowpath to the east of the site to ensure flood depths do not increase within third party land. Natural Resources Wales (NRW) have reviewed the model and agree to the proposal in principle subject to the detailed design modelling stage.

2.10 Consequently, based on the estimated costs associated with both the MIM and capital funding routes and the high risk associated with the MIM route it is proposed the scheme is amended to capital funding project. A capital scheme is predicted to offer greater savings over the long term in relation the maintenance costs and overall project costs. There is available capital funding for the scheme, but the majority of funding will be required from borrowing. This has implications on the revenue costs for the capital scheme, the borrowing will result in an additional £213k in revenue costs per annum over a 50-year period. Although the £709k revenue costs relating to maintenance will unlikely be required over the next 25 years, £475k per annum over the next 50 years would need to be accounted for in relation to revenue costs associated with borrowing. In terms of the flooding risk this would be addressed through a robust mitigation strategy as part of the project.

2.11 It is proposed the St Richard Gwyn School scheme is added to the Band B programme via a SOP Variation which will be submitted to Welsh Government for approval in due course. Currently the estimated total cost for the project is £55m. Accounting for the Welsh Government intervention rate for Voluntary Aided faith schools of 85%, the Council would need to contribute 15% to the project which equates to £8.250m. This would be funded from the following sources outlined in the table below:

Funding Source	**Amount (£,000)**
S.106	105
Education Capital Receipts	0
Reserves	586
Borrowing	7,559
Total	**8,250**

2.12 The majority of Council funds used to cover the intervention rate for the scheme are safeguarded within the Band B programme. However, an additional £3.390m would be required in borrowing to meet the full intervention rate requirement. Furthermore, this would use all available funding currently within the Band B programme. The Council would need to identify alternative funding resources for other schemes which come forward as the programme progresses. The full amount of Council funding required (£8.250m) will not be committed until Welsh Government confirm the project can be added to the capital programme and the results of the initial design and feasibility works identify that the scheme is viable. This will be submitted to Welsh Government to be considered by their investment panel on 14th October, 2022.

2.13 The estimated borrowing requirement for the additional £3.390m will result in additional revenue costs of £213k per annum to fund the repayment of the loan. This will put an additional revenue burden on budgets at a time of significant inflationary and budgetary pressures at an unprecedented level.

2.14 Due to the implications on the Council's funding resources, if the scheme did not progress under the MIM route there was an expectation the project would come forward as part of the next tranche of funding in the Sustainable Communities for Learning Programme referred to as Band C. However, it is considered the redevelopment of the site cannot be delayed. This is due to the flooding implications on the site. As noted above the Council have undertaken hydraulic modelling to identify a flood mitigation scheme to address the flooding issue on the site. This shows that there is a workable option that can alleviate flooding to the site in line with national planning policy. The report recommended that the proposal be progressed to the outline design stage where more accurate dimensions of the proposed attenuation features and associated bunds can be confirmed. This will be included within the survey work required for the planning application. The Hydraulic Modelling Report can be viewed at Appendix 1a and 1b.

2.15 In relation to the onsite flooding implications, the site has been reviewed under the current Technical Advice Note 15: Development, flooding, and coastal erosion (2004) which is the active flooding guidance to inform proposed developments. Welsh Government have confirmed this guidance will be replaced in June 2023. The school is within a flooding zone, under the current TAN 15 guidance development can progress on sites in a flood zone subject to the proposal including appropriate mitigations to address the flooding issues. Natural Resources Wales (NRW) has reviewed the proposed flooding mitigations for the project and has agreed these would be suitable in principle under the current guidance. These works and the school development proposal can be undertaken under one planning application. However, the new TAN 15 guidance requires developers to mitigate the flooding issues on a site prior to a planning application for development being determined. This would mean the Council would have to fund the flood mitigation works, implement the measures, and seek NRW's permission to remove the flooding area from the site before a planning application for the new school could be determined. This would increase the front-end costs for the Council to cover the flood mitigation works, significantly delay the project, and increase the level of risk associated with the scheme as there is not a guarantee that NRW will accept.

2.16 Due to the impacts of the new TAN 15 guidance to be released in June 2023 would have on the viability of the project it is proposed the scheme is brought forward under Band B. Furthermore, to ensure planning consent is achieved under the current TAN 15 guidance, it is recommended the design and planning works for the project are commissioned in October 2022 to allow for sufficient time for consultants to submit a planning application and receive a determination prior to June 2023. The costs for the design and planning works are outlined below:

Stage	Consultant	Role	Fees
1	Surveys	Allowance for Survey work	£75k
2	HLM	RIBA Stage 1 & 2 Architectural Design	£205k
3	Hydrock	RIBA Stage 1 & 2 C&S Design	£63k
4	Hydrock	RIBA Stage 1 & 2 M&E Design	£103k
5	The Urbanists	Planning Consultant (Outline Planning)	£20k
	Total Fees (excluding PM & CM costs)		**£466k**

2.17 The full £466k will not be required as one lump sum. The costs associated with the planning work will be kept under review as they progress and will come forward in stages. This will ensure any arising issues from the initial surveys can be considered before continuing with additional costs. This approach will allow the project team to manage the risks associated with the project and limit the amount of Council funding committed to the scheme if following a certain stage further risks are identified, and the scheme becomes unviable. The progress of the feasibility will be monitored closely by the programme board and an exit from the feasibility works should be agreed should the scheme fall behind programme required to secure planning permission for the scheme within the required timeframe or if the scheme is judged unviable by the School Investment Programme Board.

2.18 Work on the project is required to start in October to ensure the proposal is determined prior to the new TAN 15 being released. However, the SOP Variation will not be determined until early November 2022. This means the Council would be responsible for funding the £466k costs. These would be included within the total costs of the project that would be subject to the Welsh Government intervention rate of 85%, however, until the SOP Variation is determined the £466k costs will be at risk for approximately 1-2 months. The risk associated with the design and planning costs is considered to be low. Welsh Government have been made aware of the Council’s potential proposals and no objections were raised to the proposal in principle.

3. How do proposals evidence the Five Ways of Working and contribute to our Well-being Objectives?

3.1 The Well-being of Future Generations Act 2015 ("the 2015 Act") requires the Council to think about the long-term impact of their decisions, to work better with people, communities, and each other and to prevent persistent problems such as poverty, health inequalities and climate change.

3.2 The Council has committed as part of the Corporate Plan 2020-2025 to achieving a vision of 'Working Together for a Brighter Future'. This plan is reflective of the Welsh Government's Well-being of Future Generations Act and is comprised of four Well-being objectives to deliver this vision:

- Objective 1 - To work with and for our communities
- Objective 2 - To support learning, employment, and sustainable economic growth
- Objective 3 - To support people at home and in their community
- Objective 4 - To respect, enhance and enjoy our environment

3.3 To make sure we are all working towards the same purpose, the 2015 Act puts in place seven well-being goals on the Council. The 2015 Act makes it clear the listed public bodies must work to achieve all the goals, not just one or two, these being:

- A prosperous Wales
- A resilient Wales
- A healthier Wales
- A more equal Wales
- A Wales of cohesive communities
- A Wales of vibrant culture and Welsh Language
- A globally responsible Wales

3.4 The Sustainable Communities for Learning Programme contributes to achieving the wellbeing goals by:

- Generating financial savings to ensure a more efficient financial model for education in the Vale.
- Ensuring a fairer distribution of funding across the Vale.
- Improving sustainability of school buildings through the creation of BREEAM Excellent accommodation.
- Ensure an efficient supply and demand of school places across the Vale of Glamorgan through effective forecasting of future demand.
- Providing additional school places to meet increased demand as a result of recent and proposed housing developments.

- Providing facilities available for community use.

3.5 The 2015 Act imposes a duty on all public bodies in Wales to carry out "sustainable development", defined as being, "The process of improving the economic, social, environmental and cultural well-being of Wales by taking action, in accordance with the sustainable development principle, aimed at achieving the well-being goals." The action that a public body takes in carrying out sustainable development includes setting and publishing well-being objectives and taking all reasonable steps in exercising its functions to meet those objectives.

3.6 The 2015 Act sets out five ways of working needed for the Council to achieve the seven well-being goals, these being:

- The importance of balancing short-term needs with the needs to safeguard the ability to also meet long-term needs.
- Considering how the Council's objectives impact upon each of the wellbeing goals listed above.
- The importance of involving people with an interest in achieving the well-being goals and ensuring that those people reflect the diversity of the area which the Council services.
- Acting in collaboration with other persons and organisations that could help the Council meet its wellbeing objectives.
- Acting to prevent problems occurring or getting worse.

3.7 The Sustainable Communities for Learning Programme meets the five ways of working by:

- Responding to the need to ensure that there is a well-managed balance of supply and demand of school places across the Vale.
- Developing schools that will have an environment reflective of the national mission for education in Wales and future curriculum.
- Ensuring that schools remain sustainable, reflects the needs of local communities, and are equipped with the best possible learning environments.
- Delivering rigorous consultation with open communication channels and numerous opportunities for stakeholders to engage throughout the process.
- Ensuring that schools are of the right size, in the right places and serving the educational needs of their local communities as part of the school organisation process.

4. Climate Change and Nature Implications

4.1 There are no direct climate change and nature implications as a result of the revised programme. However, St Richard Gwyn project would be net zero carbon in operation and include biodiversity enhancements as part of the proposal in accordance with Welsh Government and Council requirements and national and local planning policy.

5. Resources and Legal Considerations

Financial

5.1 There will be an £8.250m increase to the Council match funding contribution to deliver the St Richard Gwyn School project. The proposed sources for this funding are outlined in the table below:

Funding Source	Amount (£,000)
S.106	105
Education Capital Receipts	0
Reserves	586
Borrowing	7,559
Total	**8,250**

5.2 The majority of Council funds used to cover the intervention rate for the scheme are safeguarded within the Band B scheme. However, an additional £3.390m would be required in borrowing to meet the full intervention rate requirement. The estimated borrowing requirement for the additional £3.390m will result in additional revenue costs of £213k per annum to fund the repayment of the loan. Overall, the borrowing of £7.559m will result in a total revenue repayment cost of £475k per annum over the next 50 years. This will put an additional revenue burden on budgets at a time of significant inflationary and budgetary pressures at an unprecedented level.

5.3 Should the St Richard Gwyn scheme feasibility and design works identify that the scheme is unviable the cost incurred to date would need to be funded by the Council to allow these funds to be released back into the Sustainable Communities for Learning Programme. Therefore, the decision points in the feasibility stage should be utilised to minimise the exposure of the Council to spending at risk on this scheme.

5.4 Furthermore, this would use all available funding currently within the Band B programme. The Council would need to identify alternative funding sources for other schemes which come forward as the programme progresses. £391k will remain in the programme contingency to cover any additional costs that arise on outstanding project that go beyond the estimated project contingency.

5.5 There is currently £105k s106 available to fund the Richard Gwyn RC High School scheme. The s.106 funding comes from the following schemes:

- Cog Road, Sully
- Former St Cyres School, Murch Road, Dinas Powys
- Land adjacent to Llantwit Major By-pass

5.6 St Richard Gwyn is a denominational school and has a large catchment area. The amount of s.106 funds from the developments has been allocated based upon the likely number of pupils attending St Richard Gwyn from the area each development is located. The table below outlines the s.106 funds being used based upon the percent of pupils who attend St Richard Gwyn from each area:

Scheme	Unallocated s.106 funds	% of pupils attending St Richard Gwyn	S.106 funds allocated to St Richard Gwyn	S.106 funds remaining
	£m	%	£k	£m
Cog Road, Sully	4.535	1	45	4.490
Former St Cyres School, Murch Road, Dinas Powys	1.193	4	48	1.145
Land adjacent to Llantwit Major (Phase 1 and 2)	608	2	12	596
Total	**6.336**	**-**	**105**	**£6.231**

5.7 The scheme relates to a Voluntary Aided Faith School which benefits from an intervention rate of 85% from Welsh Government.

5.8 The full scheme will be considered alongside the various bids coming forward in the Capital Strategy for the 2023/24 Capital Programme.

Employment

5.9 There are no direct employment implications as a result of the revised programme. Individual projects would be subject to Cabinet approval and employment implications would be considered on a project-by-project basis.

Legal (Including Equalities)

5.10 Individual proposals would be subject to Equality Impact Assessment as part of the consultation exercise which is undertaken in line with the School Standards and Organisation (Wales) Act 2013 and the School Organisation Code (2018).

5.11 The programme would increase the opportunities for learning through the medium of Welsh and ensure accessibility of education through the medium of Welsh.

5.12 All new buildings would be fully accessible and compliant with the Equality Act 2010.

5.13 The Council must comply with the public sector equality duty (section 149) of the Equality Act 2010.

6. Background Papers

6.1 None.

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Coldbrook (St. Richard Gwyn)

Optioneering Modelling Report

Vale of Glamorgan Council

Project Number: 60603495
Revision P03

October 2021

Quality information

Prepared by	Checked by	Approved by
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Revision History

Revision	Revision date	Details	Approved	Position
P01	May 2020	Draft	Mark Davin	Associate Director
P02	June 2020	Final	Mark Davin	Associate Director
P03	October 2021	Draft following NRW comments	Mark Davin	Associate Director

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1. Introduction

1.1. Project Context and Commission

In June 2019, AECOM Limited (AECOM) were commissioned by Vale of Glamorgan Council (VoGC) (hereafter referred to as the Client) to undertake a review of the 'As-Built' hydraulic model created as part of VoGC's Coldbrook Catchment Flood Risk Management Scheme (2018). The objective of this review was to assess whether the Coldbrook hydraulic model was suitable to undertake optioneering at the St Richard Gwyn Catholic High School (hereafter referred to as St Richard Gwyn School) in Barry, as part of a Flood Consequence Assessment (FCA).

The review undertaken by AECOM identified a number of limitations that were adversely impacting the ability of the model to accurately represent the current level of flood risk in proximity to St Richard Gwyn School. In particular, there were significant issues with simulating the received 2018 model in the most up to date versions of the equivalent modelling software without instabilities occurring.

In October 2019, AECOM were commissioned to re-build and update the Coldbrook hydraulic model, including the hydrology, in line with recommendations from the model review[1]. By improving the representation and robustness of the model, and therefore the accuracy of the baseline results, it is now considered suitable for assessing various flood mitigation options at the St Richard Gwyn School.

This model was subsequently reviewed by Natural Resources Wales (NRW) in March 2021 who provided a number of further improvements before the model and associated results could be approved and used as part of a site-specific FCA.

On the 26th March 2021, a meeting was arranged between AECOM, NRW and VoGC to discuss the model review comments and further actions. AECOM created a comments register following the meeting which detailed the improvements required to the model to satisfy NRW's comments. On the 23rd April 2021 NRW confirmed they were happy with AECOM's approach to the hydraulic model updates. AECOM were commissioned by VoGC in June 2021 to carry out the updates recommended by NRW.

This Optioneering Modelling Report presents these potential options and appraises them as to their advantages and disadvantages to create a high level optioneering assessment to be taken forward to detailed assessment and outline design. As a conclusion of this stage, the hydraulic model results are presented, discussed and a single preferred option has been recommended.

1.2. Aims and Objectives

In March 2020, VoGC commissioned AECOM to identify several solutions that could mitigate flooding at the St Richard Gwyn School which would be compliant with the requirements of national planning policy, including Planning Policy Wales[2] and Technical Advice Note 15: (TAN15) Development and Flood Risk[3]. This report presents a breakdown of available options using a multi-criteria assessment which has been adopted to evaluate shortlisted options, clearly discussing the benefits, higher risk aspects and rationale for any discounting (where required) of each option, concluding with a single preferred option (with a number of subtle variations). This preferred option has then been modelled to demonstrate how this could be incorporated into any future design of the St Richard Gwyn School which could alleviate flooding at the site without increasing risk to third party land.

In order to meet the objectives of this study, the following elements were undertaken:

- A site visit to review and confirm project limitations, restrictions and to discuss with the Client what options could potentially meet the objectives of the study. This site visit was undertaken on 11 March 2020 and was attended by consultants from AECOM, the Project Manager from VoGC and representatives from St Richard Gwyn School. This allowed AECOM to establish existing flood risk mechanisms, recent flood history (February 2020) and also confirm 'what matters most' to the Client and what development restrictions (in terms of land use and future aspirational masterplans) may exist to assist in manipulating any proposed engineering solutions.
- A shortlist of potential solutions involving a detailed review of each option using the multi-criteria assessment requirements;

[1] AECOM (13th September 2019), "Richard Gwyn School – Coldbrook Hydraulic Model Review".
[2] Welsh Government (December 2018), "Planning Policy Wales".
[3] Welsh Government (July 2044), "Planning Policy Wales Technical Advice Note 15: Development and Flood Risk"

- Conclusion of the multi-criteria assessment and refinements to a single preferred option;
- Modelling of the preferred option to undertake an assessment of the potential benefits and documenting of key risk aspects for three AEP events (5% AEP, 1% AEP and 1% AEP +30% climate change event). It should be noted that this option has been developed to create a working concept. Outline or detailed design of this option has not been undertaken, and as such the current dimensions/figures should be considered as indicative. Further refinements will be required should the preferred option be taken forward by VoGC; and,
- Production of an Optioneering Modelling Report containing the multi-criteria assessment which also summarises the modelling process and presents results of the preferred option.

1.3. Site Overview

The St Richard Gwyn School is located approximately 4km north-east of the centre of Barry, located along Argae Lane, off the Barry Docks Link Road (A4231). The Coldbrook watercourse runs parallel to Argae Lane (Figure 1-1) and presents a fluvial flood risk to the school site.

The Coldbrook, which flows within 15m of the site, is approximately 6km in length and rises in the Merthyr Dyfan area of Barry where it then flows through Gibbonsdown and Cadoxton before flowing beneath the Barry Docks Link Road (A4231) and past St Richard Gwyn School. From here the Coldbrook flows through agricultural fields before confluencing with the Cadoxton River.

Most of the catchment of this watercourse was originally greenfield but has now been developed for residential and commercial use following the construction of Barry Docks in the 1880s. As a result of localised development in the catchment, significant lengths of the watercourse have been culverted which has gradually 'closed in' sections of the watercourse. This has increased conveyance resulting in a potential exacerbation of flood risk in specific areas where the culverted watercourse become overwhelmed.

In 2007, following intense rainfall, areas of Gibbonsdown, Cadoxton and Palmerston suffered severe flooding which resulted in approximately 100 properties and four schools being inundated with floodwater. Consequently, this led to various flood studies within the area and in 2016 the Coldbrook Flood Alleviation Scheme began construction with the aim of reducing the risk of flooding to over 200 properties and three schools in the Barry area[4].

Figure 1-1 shows an overview of St Richard Gwyn School which includes the reach of the Coldbrook and other important features. The school currently consists of a main building with several smaller buildings located to the east (shown in orange on Figure 1-1). To the rear of the school development and around the existing car park is a raised bund which is assumed to offer protection during a flood event. These bunds also protect a set of manholes located to the west of the main development. The area to the south of the raised bund includes sports pitches which are also located within the site boundary that is being considered as part of this study.

[4] Available at: https://www.valeofglamorgan.gov.uk/en/living/Flooding/Flood-and-Coastal-Erosion/Coldbrook/Coldbrook-Flood-Alleviation-Works.aspx. Accessed: January 2020.

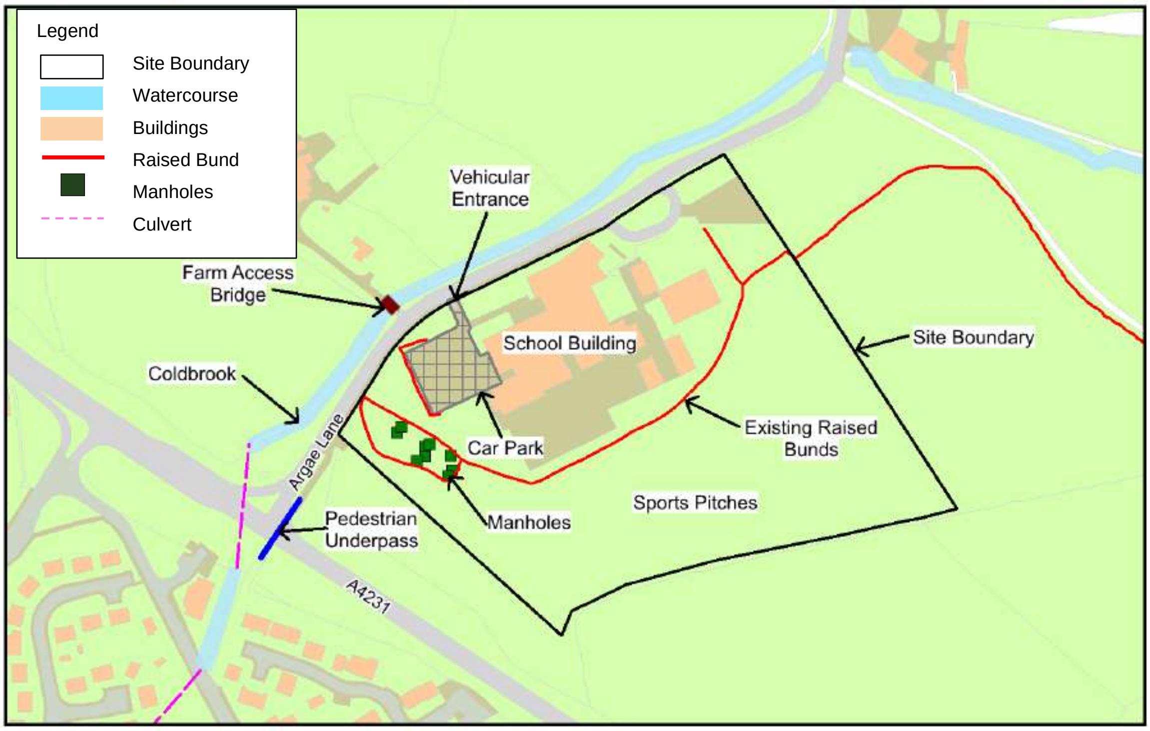

Figure 1-1: Overview of St Richard Gwyn School

1.4. Flood Mechanism

When assessing fluvial flood risk at St Richard Gwyn School, the 2019 baseline model results indicate there are two key flowpaths from the Coldbrook that need to be considered. Firstly, overtopping of the Coldbrook occurs at the farm access bridge opposite the school site which results in floodwater propagating across Argae Lane and into the site. Floodwater bypasses the bund around the car park and flows through the site inundating the main school building (Flowpath 1). Secondly, overtopping occurs along the right bank of the Coldbrook west of the A4231, propagating along the underpass and eastwards towards the site. Eventually water overtops onto the school sports pitches, flowing east and into the adjacent fields (Flowpath 2). Floodwater is also shown to overtop the raised bund to the south of the site (south to north from the sports pitches), causing elevated flood depths around the main building footprint. These flowpaths are shown on Figure 1-2, which are overlaid onto the flood extent for the 1% AEP +30% climate change event.

To alleviate flooding to both the developed area of the school (main building footprint, car park and playground) and also the sports pitches, an option is required which manages floodwater from both the flowpaths which are identified within Figure 1-2.

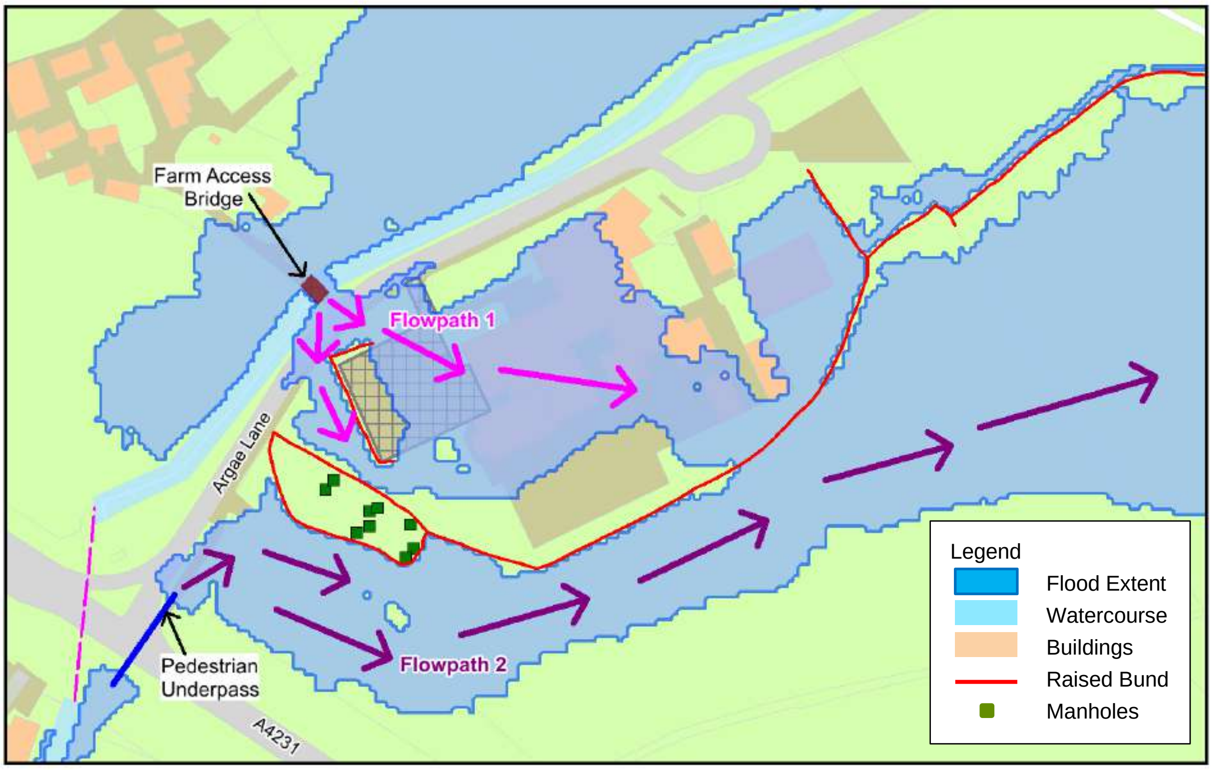

Figure 1-2: Flowpaths at St Richard Gwyn School (1% AEP +30% Climate Change event)
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1.5. Historical Flooding

Since the Flood Alleviation Scheme was completed in 2016, there have been limited flood events to calibrate/validate the model results. However, VoGC were able to provide anecdotal evidence and telemetry data from a number of recent events to assist in verifying the model results. Further information on the historical flooding at the site and model verification is discussed in the Hydraulic Modelling Report[5].

[5] AECOM (September 2021) "Coldbrook (Richard Gwyn) Hydraulic Modelling Report P02"

2. Multi-Criteria Assessment

A shortlist of options that could potentially alleviate flooding at St Richard Gwyn School were developed through a desk study using model results from the updated Coldbrook baseline model (2019) and through a site visit by key project team members (including flood risk specialists and engineers), the Client and representatives from St Richard Gwyn School. This shortlist process included a review of options along the Coldbrook, options adjacent to Argae Lane and within the St Richard Gwyn School boundary. Each of these options are discussed below and are presented within the multi-criteria assessment table (Table 2-1) which demonstrates why certain options were discounted and which has greatest potential and has therefore been taken forward for hydraulic modelling testing.

It should be noted that following discussions with the Client, many of the shortlisted options were discounted due to construction and masterplan issues, as well as potential landowner conflicts. There were also concerns regarding flood risk increases to third parties neighbouring the boundary of the school. These are reflected within Table 2-1.

As part of this assessment, the following criteria has been considered for each option and assessed using a green, amber or red 'traffic light' system to denote whether the option has been viewed as favourable or progressively less favourable in relation to the assessment criteria. Please refer to Table 2-1 for more information on the 'traffic light' system.

- Flood Risk Management
- Cost
- Environmental Impacts
- Technical Feasibility
- Health and Safety
- Residual Risk
- Maintenance
- Stakeholder Objectives

2.1. Option 1 – Minor Interventions to Existing Infrastructure

This option does not involve any form of construction or change to the development at the site. There is minimal intervention and the option focuses on monitoring flood risk alongside flood proofing measures of the existing development. It could be beneficial to assess whether there is an option of holding more flow further upstream in the catchment (through the operation of the Coldbrook Flood Alleviation Scheme) so that during a flood event, less flow reaches St Richard Gwyn School and instead gets stored and released at a controlled rate. There is an operating sluice gate at the Flood Storage Area in Gibbons Down which could be explored i.e. this could be closed during certain events to store more floodwater, reducing flow further downstream. The only concern is that there is still a large catchment between this storage area and the school and therefore any changes in this location may not affect flooding at the school.

Advantages: With no construction taking place there should be no new technical challenges to consider as the existing situation shall be continued. As such, the cost will be comparatively lower to other options where construction is required. Maintaining the existing situation with minor interventions will not increase flood risk to third parties, which is a significant aspect to consider in relation to national planning policy.

Disadvantages: With only minor intervention, this option does not provide flood alleviation to the site and the school will therefore continue to experience flooding which has been shown to impact on the current operation of the school and is likely to hinder aspirations for future development. Existing flood mechanisms could occur more frequently and with greater magnitude when considering the impact of climate change over time. Furthermore, with more frequent flood events it is likely that more repair works will be required and the number of school closures may increase.

2.2. Option 2 – Enhancements to Coldbrook Banks (adjacent to School)

This option involves increasing the height of the Coldbrook banks in the location where overtopping occurs adjacent to the school. From a review of the baseline modelling results it appears that the Coldbrook overtops at two locations immediately upstream of the farm access bridge, where the banks are naturally lower.

Advantages: This option has the potential to alleviate flooding to the main buildings of the site by removing Flowpath 1. It is likely that the cost of this option will be comparatively less than other options, given that only a small stretch of bank raising would be required. This option alone would not involve any flood mitigation within the site boundary and therefore land take for any onsite features will not need to be considered as part of the overall masterplan.

Disadvantages: By preventing overtopping at the farm access bridge adjacent to the school it is likely that floodwater will be retained within the channel and will therefore overtop at a different location further downstream. This is likely to increase flood risk to third parties and would therefore be considered unacceptable to the Lead Local Flood Authority and Natural Resources Wales (NRW). This option would need to be modelled with further mitigation on third party land likely if flood risk is shown to increase elsewhere. The Coldbrook is also Main River in this location and therefore any alterations to the watercourse would need support and agreement with NRW.

Furthermore, this option would potentially mitigate flooding to the main building footprints but would not address the flowpath that occurs across the sports pitches to the rear of the school (Flowpath 2). To manage this area of risk, either the right bank of the Coldbrook would need to be raised west of the A4231 pedestrian underpass (which could cause landowner issues and subsequent increases in flood risk further downstream) or additional attenuation would need to be provided within the school grounds, as discussed in Option 5.

2.3. Option 3 – Enhancements to Coldbrook Channel (adjacent to School)

This option involves modifying the current Coldbrook channel adjacent to the school to allow more capacity. By providing more storage in the channel in the vicinity of the school, it may be possible to retain more flow and consequently less water will overtop into the site. This would likely involve lowering the bed of the channel or increasing the width depending on land ownership and would take place from the A4231 (upstream limit) to the location at which Argae Lane cross the Coldbrook (downstream limit).

Advantages: This option has the potential to alleviate flooding to the main buildings of the site by removing Flowpath 1. This option alone would not involve any flood mitigation within the site boundary and therefore land take for any onsite features will not need to be considered as part of the overall masterplan.

Disadvantages: By increasing the capacity of the Coldbrook adjacent to the school it is likely that more flow will be conveyed downstream and could therefore overtop at a different location. This is likely to increase flood risk to third parties and would therefore be considered unacceptable to the Lead Local Flood Authority and NRW. This option would need to be modelled to assess the impact with further mitigation likely on third party land if flood risk is increased elsewhere. Modelling would also need to confirm whether the modifications to the channel are substantial enough to prevent the secondary flowpath from the underpass (Flowpath 2). If this is not achievable, either the right bank of the Coldbrook would need to be raised by the A4231 pedestrian underpass (which could cause landowner issue and increases in flood risk further downstream) or additional attenuation would need to be provided within the school grounds, as discussed in Option 5. The Coldbrook is also Main River in this location and therefore any alterations to the watercourse would need support and agreement with NRW. Furthermore, through amending the channel dimensions, there may be geomorphological and ecological aspects which need to be studied in greater detail to ensure that no detriment results.

2.4. Option 4 – Reprofiling of Argae Lane

This option involves reprofiling Argae Lane in the vicinity of the school, conveying floodwater away from the site and back into the Coldbrook further downstream where there is increased capacity. This could involve raised speedbumps to prevent water entering the school and a natural fall to the north and east to prevent any overtopping into the school.

Advantages: This option has the potential to alleviate flooding to the main buildings of the site by removing Flowpath 1. This option alone would not involve any flood mitigation within the site boundary and therefore land take for any onsite features will not need to be considered as part of the overall masterplan.

Disadvantages: By conveying more floodwater along Argae Lane, flood depths are likely to increase along the highway and it may become impassable. Redirecting flow back towards the Coldbrook may also increase flood risk downstream of the site. Flood risk to third parties could therefore increase if appropriate mitigation is not provided which is unlikely to be acceptable to the Lead Local Flood Authority and NRW. There may also be constraints relating to any highways work and this would need to be confirmed with Welsh Government and the local highway agency (VoGC).

Furthermore, this option would potentially mitigate flooding to the building footprints but would not address the flowpath that occurs across the sports pitches to the rear of the school (Flowpath 2). To manage this area of risk, either the right bank of the Coldbrook would need to be raised by the A4231 pedestrian underpass (which could cause landowner issues and subsequent increases in flood risk further downstream) or additional attenuation would need to be provided within the school grounds, as discussed in Option 5.

2.5. Option 5 – Onsite Attenuation

This option involves attenuating floodwater on site and conveying it around the perimeter of the sports pitches to the south of the current development. It is envisaged that floodwater from the Coldbrook (Flowpath 1) can be intercepted by an attenuation basin to the west of the current car park, which would then outfall to a ditch that would convey water around the southern perimeter of the site. These features would also provide enough capacity to intercept floodwater from Flowpath 2, preventing inundation of the sports pitches.

Advantages: This option would maintain the current flood mechanism from the Coldbrook but would attenuate floodwater on site. This option has the potential to alleviate flooding to the entire school site and would manage both flowpaths discussed in Section 1.4. By maintaining the current flood mechanism from the Coldbrook, and rerouting floodwater around the perimeter of the school and then back to its existing flow route within the fields to the east of the site, mitigation can be developed such that there will not be any increase in flood risk to third party land. There is also a benefit that no works would be required off site or within an existing watercourse, which could otherwise present significant obstacles in relation to approval, permits and programme. There is also potential flexibility in the design of the ditches which is discussed in more detail within Section 3. With this option there is also a social benefit in that pupils of the school could be involved with the design and learn about sustainable approaches to managing fluvial flood risk. With floodwater managed on site and ensuring that runoff rates do not exceed current values, there is unlikely to be any landowner issues.

Disadvantages: Cost likely to be greater than other options as excavation will be required to provide a new attenuation basin along with conveyance ditches. It is also likely that modifications to vehicular and pedestrian access routes will be required to allow construction of the attenuation features. The location of the attenuation basin is restricted due to the Client's request to keep the car park at its current location and also due to the bunded manholes located to the east of the site (Figure 1-1). It is important to note that there is also a 700mm diameter combined sewer located within the sports pitches which would need to be considered as part of any excavation within this area. Further liaison with the utility company is required to confirm what is likely to be feasible in the area of the combined sewer.

2.6. Multi-Criteria Assessment Conclusion

By undertaking a multi-criteria assessment (Table 2-1) of the shortlisted options discussed above, it was concluded that there may be only one option for the St Richard Gwyn School which could feasibly be taken forward to the hydraulic modelling phase without significant off site issues or those which could require third party landowner discussions. While Option 2 – 4 presented within Table 2-1 are achievable from a technical perspective in that they would alleviate flooding to the developed area of the site, the majority of these result in additional flow being passed downstream which is likely to increase risk to third party land. This is unlikely to be considered favourably by stakeholders such as NRW and these options have therefore been discounted.

Option 5, which involves attenuation basins and conveyance ditches within the boundary of the site, has therefore been taken forward as the preferred option and has been modelled to assess whether flooding on site can be managed without increasing risk to both the site and third party land. The modelling approach and results are discussed within Section 3.

Table 2-1: Multi-Criteria Assessment	**Proposed recommendation regarding short-listing.** Red - option unlikely to be feasible and therefore discounted from short-list. Amber - has potential, however other options likely to more feasible. Green - based on the results of the multi-criteria assessment, this options is recommended for hydraulic modelling testing.	**Flood risk management** Does the option provide the level of resilience required (1% AEP +30%CC) without increasing flood risk to third parties. Red - fails to address / mitigate risk or makes worse Amber - partially addresses / mitigates risk Green - improves protection and/or significantly mitigates risk	**Cost (relative)** Anticipated scheme cost and ongoing maintenance relative to other proposed options. Red - significant cost Amber - moderate cost Green - low cost	**Environmental Impacts** Anticipated environmental impacts of scheme relative to current situation. Red - environmentally detrimental (significant) Amber - environmental benefits but also env drawbacks, or doesn't make significant difference to present condition Green - environmental enhancement	**Technical feasibility** Review of constructability, associated risks, temporary impact on highways network and sustainability of solution. Red - option is technically very challenging or difficult to implement / construct Amber - option presents some technical challenges to implement / construct Green - no significant technical challenges to implement / construct	**Health and Safety** Review of proposed scheme in relation to health and safety regulations. Red - significant risk to the public, operatives in construction and/or operation Amber - potential health and safety implications which could be addressed Green - no health and safety risks / improves in comparison to the existing condition	**Maintenance** Review of ongoing maintenance requirements Red - requires significant level of on-going maintenance Amber - some scheduled maintenance required Green - maintenance free / minimal maintenance	**Stakeholder Objectives** Review of anticipated stakeholder objectives. Red - potential for major objections or goes against feedback received Amber - likely to be support for and against or meets some feedback received but not all. Green - helps achieve majority stakeholder needs / addresses main concerns
Option 1 - Minor interventions to existing infrastructure.	This option is only viable if the site is not redeveloped within the existing floodplain. If a planning application for a new development is submitted, flood mitigation will be required to alleviate flooding to the site without increasing flood risk to third parties. This option involves minor interventions to the existing infrastructure only.	Red - does not provide flood alleviation to the site during the 1% AEP +30% climate change event. Flood events likely to become more frequent with effects of climate change. Green - does not increase risk to third parties.	Red - inundation of the school will incur more frequent economic impact over time with repeat closures and repairs (especially when considering the effects of climate change). Green - relative low costs in comparison to other schemes proposed.	Amber - no anticipated adverse or betterment when considering environmental impacts.	Green - no technical challenges given no construction or excavation being undertaken. May be challenges if existing development requires flood proofing.	Red - existing condition allows for the school to become inundated during a large storm event. Potential health and safety risks to those using the school.	Red - it is likely that the school will experience more frequent closures and repair works associated with flood events.	Red - planning application for any new development on site will be rejected if the site is located within an existing floodplain. Some form of mitigation will be required to ensure the site does not flood without increasing risk to third parties.
Option 2 - Enhancements to Coldbrook banks in the overtopping location adjacent to the St Richard Gwyn School.	Although this option would alleviate flooding at the main school site, it is likely that flood risk would be increased to third parties further downstream and would therefore not be considered acceptable to stakeholders.	Red - by preventing overtopping at this location more flow will be passed downstream and it is likely that there will be an increase in flood risk to third parties. Amber - does not address flowpath across the sports pitches. Green - likely to provide flood alleviation to the main school site during the 1% AEP +30% climate change event.	Green - comparative cost to other proposed options are low due to the fact that only a small stretch of the watercourse banks will need to be raised.	Red - by increasing flow it could have an environmental impact further downstream. Red - will be difficult to achieve 'buy in' from Lead Local Flood Authority or NRW due to detrimental impact elsewhere. Amber - anticipated that material delivery for increasing bank heights will have a minor adverse impact.	Amber - option presents some technical challenges with raising banks of watercourse adjacent to the site to specific height. Amber - this option would alleviate flooding to the main school site only. The sports pitches would still flood and therefore further mitigation would be required to manage flooding from this separate flowpath.	Amber - option would involve working near water. Green - reduced risk to those using the site as school would not flood during a storm event.	Amber - would require routine maintenance of raised bank. Watercourse technically Main River in this location and responsibilities would therefore need to be discussed with NRW.	Red - has the potential to increase flood risk to third parties downstream which would not be supported by Lead Local Flood Authority or NRW. Amber - the Coldbrook is Main River in this location and therefore any alterations to the watercourse could present issues with NRW. Any changes would need the support and agreement by NRW.
Option 3 - Enhancements to Coldbrook channel along the stretch of watercourse from the A4231 to the Argae Lane crossing (adjacent to the school).	Although this option would alleviate flooding at the main school site, it is likely that flood risk would be increased to third parties further downstream and would therefore not be considered acceptable to stakeholders.	Red - by preventing overtopping at this location more flow will be passed downstream and it is likely that there will be an increase in flood risk to third parties. Amber - does not address flowpath across the sports pitches. Green - likely to provide flood alleviation to the main school site during the 1% AEP +30% climate change event.	Amber - potential for higher comparative costs due to significant reprofiling of watercourse.	Red - by increasing flow it could have an environmental impact further downstream. It is likely that geomorphological and ecological aspects will need to be assessed in greater detail. Red - will be difficult to achieve 'buy in' from Lead Local Flood Authority or NRW due to detrimental impact elsewhere	Amber - option presents some technical challenges with reprofiling of watercourse. Amber - this option may alleviate flooding to the main school site only (to be confirmed by modelling). It is possible that the sports pitches would still flood and therefore further mitigation would be required to manage flooding from this separate flowpath.	Amber - option would involve working near water. Green - reduced risk to those using the site as school would not flood during a storm event.	Green - minimal maintenance required although this would need to be discussed with NRW. Monitoring may be required to ensure the channel is not blocked by large debris during a storm event.	Red - has the potential to increase flood risk to third parties downstream which would not be supported by Lead Local Flood Authority or NRW. Amber - the Coldbrook is Main River in this location and therefore any alterations to the watercourse could present issues with NRW. Any changes would need the support and agreement by NRW.
Option 4 - Reprofiling of Argae Lane on the stretch of highway adjacent to St Richard Gwyn school.	Although this option would alleviate flooding at the main school site, it is possible that flood depths along Argae Lane will increase and flood risk increased to third parties if appropriate mitigation is not provided. Likely to be constraints with local highways agency.	Red - has the potential to increase flood depths along Argae Lane and to areas further downstream if appropriate mitigation not included. Amber - does not address flowpath across the sports pitches. Green - likely to provide flood alleviation to the main school site during the 1% AEP +30% climate change event.	Amber - potential for higher comparative costs due to reprofiling of highway.	Red - by redirecting flow along Argae Lane and back towards the Coldbrook, detrimental flood risk to others and third party land owners could result. Will be difficult to achieve 'buy in' from Lead Local Flood Authority or NRW. Amber - no anticipated adverse or betterment when considering environmental impacts.	Amber - option presents some technical challenges with reprofiling of highway and ensuring risk is not increased to third parties. Amber - this option may alleviate flooding to the main school site only (to be confirmed by modelling). It is possible that the sports pitches would still flood and therefore further mitigation would be required to manage flooding from this separate flowpath.	Amber - during construction there will be a reduced service along Argae Lane and the need for traffic management. Green - reduced risk to those using the site as school would not flood during a storm event.	Green - minimal maintenance required.	Red - flood depths likely to increase along Argae Lane. Has the potential to increase flood risk to third parties downstream (if appropriate mitigation is not provided) which would not be supported by Lead Local Flood Authority or NRW. Amber - could be constraints relating to highways work and would need to be agreed with Welsh Government and local highways agency.

Table 2-1: Multi-Criteria Assessment	Proposed recommendation regarding short-listing. Red - option unlikely to be feasible and therefore discounted from short-list. Amber - has potential, however other options likely to more feasible. Green - based on the results of the multi-criteria assessment, this options is recommended for hydraulic modelling testing.	**Flood risk management** Does the option provide the level of resilience required (1% AEP +30%CC) without increasing flood risk to third parties. Red - fails to address / mitigate risk or makes worse Amber - partially addresses / mitigates risk Green - improves protection and/or significantly mitigates risk	**Cost (relative)** Anticipated scheme cost and ongoing maintenance relative to other proposed options. Red - significant cost Amber - moderate cost Green - low cost	**Environmental Impacts** Anticipated environmental impacts of scheme relative to current situation. Red - environmentally detrimental (significant) Amber - environmental benefits but also env drawbacks, or doesn't make significant difference to present condition Green - environmental enhancement	**Technical feasibility** Review of constructability, associated risks, temporary impact on highways network and sustainability of solution. Red - option is technically very challenging or difficult to implement / construct Amber - option presents some technical challenges to implement / construct Green - no significant technical challenges to implement / construct	**Health and Safety** Review of proposed scheme in relation to health and safety regulations. Red - significant risk to the public, operatives in construction and/or operation Amber - potential health and safety implications which could be addressed Green - no health and safety risks / improves in comparison to the existing condition	**Maintenance** Review of ongoing maintenance requirements Red - requires significant level of on-going maintenance Amber - some scheduled maintenance required Green - maintenance free / minimal maintenance	**Stakeholder Objectives** Review of anticipated stakeholder objectives. Red - potential for major objections or goes against feedback received Amber - likely to be support for and against or meets some feedback received but not all. Green - helps achieve majority stakeholder needs / addresses main concerns
Option 5 - Onsite attenuation in the form of basins and conveyance ditches.	Alleviates flooding to the school buildings and maintains the existing flowpath to the east of the site. Manages floodwater from both flowpaths. Small increase in flood depth and extent along Argae Road to be addressed during detailed design modelling phase.	Green - likely to provide flood alleviation to the main school site during the 1% AEP +30% climate change event. Small increase in flood depth and extent along Argae Road to be addressed during detailed design modelling phase.	Amber - potential for higher comparative costs due to the excavation associated with ditches and attenuation basins. Bunds will also need to be constructed as well as reprofiling of main access vehicular route.	Green - has the potential to provide environmental benefits by creating habitats as part of the new attenuation ditches.	Amber - there could be technical issues regarding the 700mm diameter combined sewer that is located within the sports pitches in the area where attenuation is proposed. Amber - there could be technical issues surrounding manholes on site. Green - this option manages floodwater from both flowpaths. By managing floodwater around the southern perimeter of the site, this option maximises developable space. Green - flexibility in the size of the proposed ditches. Green - this option involves construction onsite only and therefore there will be no landownership issues.	Amber - there may be health and safety risks relating to access i.e. pupils entering ditches, unless appropriate mitigation in the form of fences etc are implemented around the attenuation features.	Amber - routine maintenance of ditches and attenuation basins required to ensure no blockages occur.	Amber - small increase in flood depth and extent along Argae Road which will need to be addressed during the detailed design modelling phase. Green - potential to involve pupils of the school in educating about sustainable flood mitigation.

3. Preferred Option Development (Option 5)

3.1. Hydraulic Modelling Approach

The updated Coldbrook hydraulic model (2019) has been used to assess the impact associated with Option 5. For all information on how the baseline model was created (including roughness values, hydrology, boundary conditions etc) please refer to the Coldbrook Hydraulic Modelling Report[6].

According to NRW's Guidance for FCA's: Climate Change Allowance[7], the site is located within the West Wales River Basin District and in line with this guidance, the central estimate for the 2080s has been used to assess the potential impact of climate change. To assess whether Option 5 is therefore feasible, the 1% AEP +30% climate change event has been used for the concept design of the attenuation features and forms the main discussion throughout the rest of this Section.

In September 2021, the hydrological analysis was updated following comments received from NRW as detailed in the Hydraulic Modelling Report[5]. As a result, Option 5 was re-modelled with the updated hydrological flows. The update to the hydrology as recommended by NRW resulted in a slight increase in the model inflows, compared with the previous hydrological analysis and therefore there is now more floodwater to be managed by the proposed option. The results for the preferred option are discussed in Section 3.3, however it should be noted that the preferred option modelled previously is now noted as Option 5a and an additional model run has been simulated to account for the increase in flows within the model which is referred to as Option 5b.

3.2. Hydraulic Modelling Option 5

During the site visit, Option 5 was discussed with the Client as a possibility and a walkover of the area designated for attenuation was undertaken. The Client confirmed that should a new masterplan be taken forward, the current main vehicular access route and car park would need to be retained and therefore any options would have to be designed around these features.

While undertaking the site walkover, a number of manholes located to the west of the car park (protected by raised bunds) were discovered which have also been considered when assessing attenuation options on site. From a review of available asset data[8] provided by the Client and also a topographic survey of the site, it was concluded that the bund protecting this area could be moved to allow attenuation features within the area. Figure 3-1 shows the location of the existing car park and the realignment of bunds alongside the new attenuation features being proposed.

[6] AECOM (September 2021) "Coldbrook (Richard Gwyn) Hydraulic Modelling Report P02"
[7] Natural Resources Wales (2016) "Climate Change Guidance for FCAs"
[8] Welsh Water (March 2020) "DCWW Network" for St Richard Gwyn School

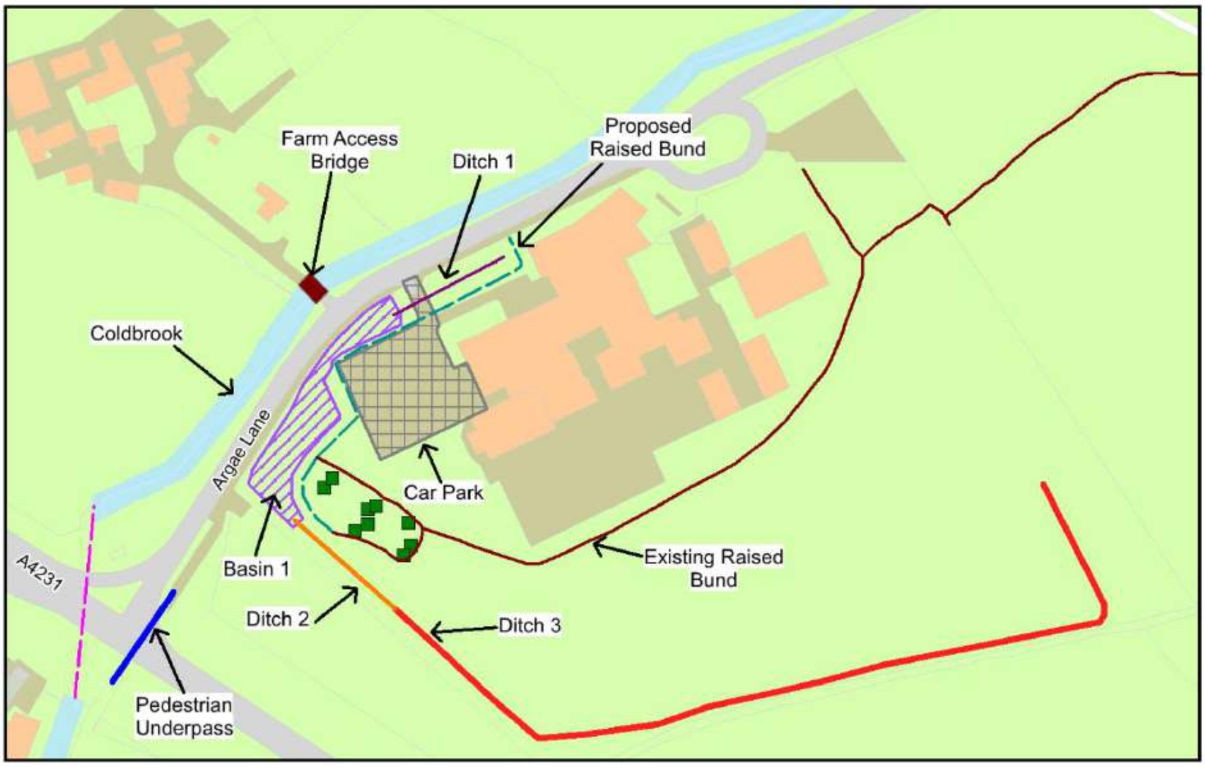

Figure 3-1: Proposed Attenuation Features (Option 5)
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Within the model set-up, the attenuation features have been designed to intercept floodwater which overtops the Coldbrook at the farm access bridge (Flowpath 1) while also providing enough storage to intercept floodwater which flows from the pedestrian underpass beneath the A4231 (Flowpath 2). It should be noted that outline or detailed design of the proposed attenuation features have not been undertaken at this stage, with further refinements required if this option is taken forward by the Client. The features modelled are conceptually represented to inform whether they provide flood alleviation benefits which reduce flooding without increasing flood risk to third parties. Any dimensions or extents of attenuation features are currently indicative and are subject to refinements and further modelling following Client confirmation.

3.2.1. Option 5a

Figure 3-2 shows the representation of the proposed attenuation features for Option 5a with indicative lengths, widths and depths which are subject to change. To summarise:

- Ditch 1 (45m x 2m): This ditch will intercept any water that flows across Argae Lane and enter the site boundary from the north west and the main vehicular access route to the school. It is envisaged that this ditch will flow beneath the vehicular access route through either an open ditch or a uni-directional culvert which would then connect into Basin 1. A 'cattle grid' style interceptor system could be placed across the vehicular access, allowing any floodwater from the road to flow directly into this ditch, preventing inundation of the school buildings and car park within this area. The ditch is located within an area of open green space which will also be used to attenuate floodwater during the higher magnitude events. It is likely that a bund/raised speedbump will be required adjacent to this ditch to provide additional protection to the school. This may involve reprofiling of the vehicular access route as part of any redevelopment.

- Basin 1: An irregular shaped basin which stores 700m^3 of floodwater during the 1% AEP +30% climate change event. This has been designed around the existing car park configuration and manhole locations; and will also be located beneath an existing pedestrian access route. This basin will store the majority of floodwater from both Flowpath 1 and 2, where it first enters the site boundary. To the north, Ditch 1 will outfall into the basin and to the south, Ditch 2 will provide a conveyance route in a south easterly direction away from the basin and anticlockwise around the southern perimeter of the school site.

- Ditch 2 (50m x 4m) and Ditch 3 (340m x 5m): Ditch 2 conveys floodwater from Basin 1 away from the main developable area of the site. This connects to Ditch 3 which is slightly wider to provide additional storage and conveys floodwater around the southern perimeter of the school site. This ditch eventually levels out to existing ground levels at the location of the baseline flood flowpath to the east of the site as shown in Figure 1-2. The reason behind this is to retain the current flood mechanism and flowpath within this area so that flood risk to third parties is not increased.

- Raised bunds: Existing bunds have been retained (where required) however a small raised bund will be required near the car park to provide additional protection. This will include a raised feature, such as a speedbump or similar, across the main vehicular access to the school. The height of this proposed bund has been modelled at 10.50m AOD but it is likely that this could be refined during the detailed modelling phase following confirmation on the preferred option by the Client.

All these features that have been included within the proposed Option 5a model have been represented using z-shape files which are designed to increase/decrease existing ground levels within the 2D model.

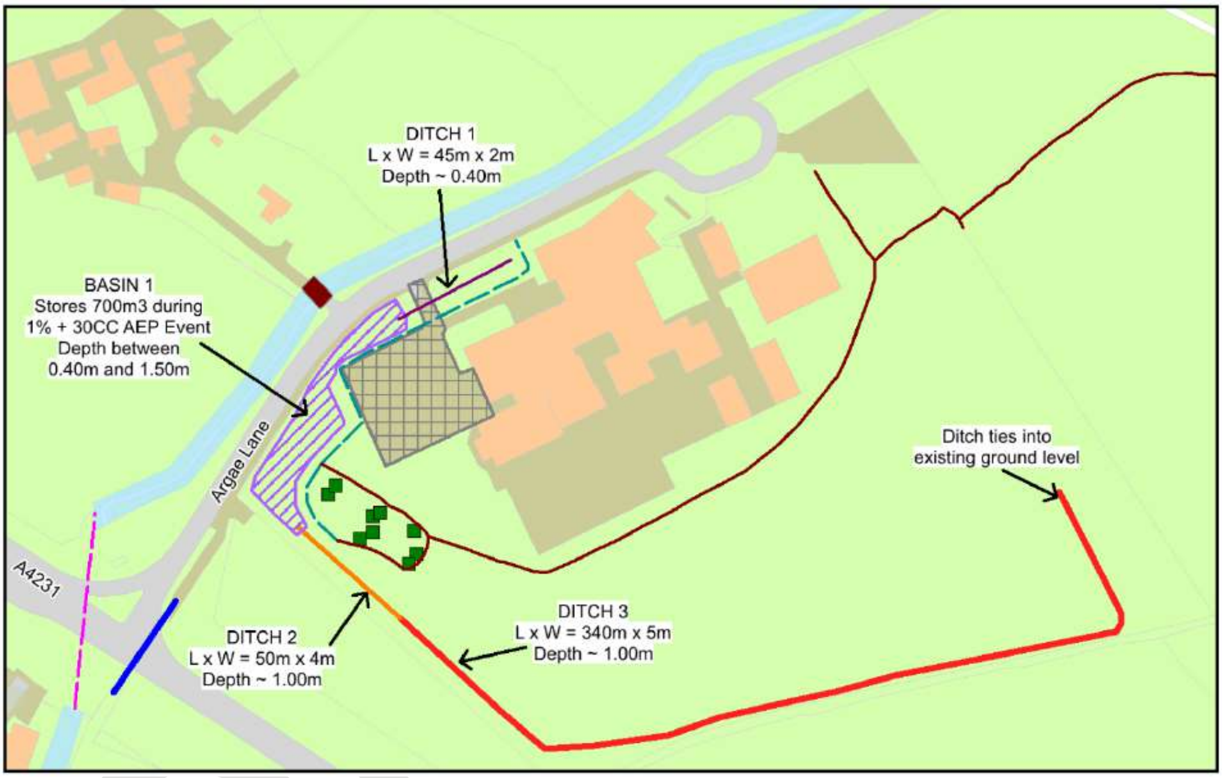

Figure 3-2: Indicative Dimensions for Proposed Attenuation Features (Option 5a)
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3.2.2. Option 5b

As discussed in Section 3.1, the hydrological analysis was updated as recommended by NRW in September 2021 and the flows within the model have slightly increased for each of the AEP events. Therefore, an additional model run was undertaken for the preferred option whereby the width of Ditch 3 was increased from 5m (Option 5a) to 8m to manage the additional flow within the model. This is the only difference between Options 5a and 5b and the results are discussed in Section 3.3.

3.3. Results

3.3.1. Option 5a

Design Event

During the 1% AEP +30% climate change event for Option 5a, the first sign of the Coldbrook overtopping occurs approximately 3 hours 10 minutes into the simulation at the location of the farm access bridge which crosses the watercourse. Water propagates across Argae Lane and flows into the onsite attenuation basin located to the west of the existing car park. Floodwater continues to fill the attenuation basin and is conveyed around the southern perimeter of the school site via the conveyance ditch (Ditch 2 and Ditch 3).

As more flow enters the attenuation system, the amount of floodwater increases within Ditch 3 and approximately 3 hours 45 minutes into the simulation, water spills out at the end of the ditch (located to the east of the sports field) in the location of the existing (baseline) flowpath. Approximately 4 hours into the simulation, floodwater appears from the pedestrian underpass beneath the A4231 and begins to propagate across the field immediately to the west of St Richard Gwyn School. Floodwater flows into the conveyance ditch (Ditch 2) and the level in the attenuation basin increases.

Approximately 3 hours 55 minutes into the simulation, Ditch 1 receives flow that is propagating across Argae Lane (along the main vehicular access route to the school) while backing up also occurs from the attenuation basin. At this location the ditch is approximately 2m wide which stores water during the lower magnitude events. However, during the higher magnitude events, water overtops this ditch and is stored within the grassy area in the immediate vicinity. A small amount of floodwater also overtops onto the road. Floodwater is prevented from flowing onto the school site by the raised bund in this area and the cattle grid interceptor system across the access road. Depths do however increase along Argae Road in this location by up to 100mm. This will need to be addressed during the detailed design modelling stage.

With a large amount of water already in the attenuation system, at approximately 4 hours 20 minutes into the model simulation, the left bank of Ditch 2 is overtopped and water begins to flow across the sports pitches at the back of the school site. The water from this pathway then joins with floodwater flowing out of the end of Ditch 3 at approximately 4 hours 35 minutes into the model simulation. It should be noted that although the school sports pitches are shown to be wet during the design event with the updated hydrology, the school buildings remain dry.

Figure 3-3 shows the baseline maximum flood depth map for the 1% AEP +30% climate change event. This figure shows where the existing site is flooded and how floodwater propagates across the sports fields. Figure 3-4 shows the proposed maximum flood depth map for the same event and demonstrates how the proposed attenuation features are intercepting floodwater, preventing flooding across the site. This figure shows that within Ditch 1, depths increase to approximately 0.80m, while in the attenuation basin and Ditches 2 and 3, depths increase to approximately 1.20m. The water depth on the sports pitches is approximately 0.15m.

Finally, Figure 3-5 shows the depth difference map which compares the baseline and proposed results for the 1% AEP +30% climate change event. It should be noted that this figure shows the maximum flood extent in light blue, but it focuses on showing areas where differences in flood depth have occurred. Increases and decreases in flood depth are depicted by red/pink/yellow and green colours respectively.

Figure 3-5 clearly demonstrates a significant increase in flood depth (red) in the areas of the site where attenuation is being provided (as expected). Consequently, there are significant decreases in flood depth (green) across the majority of the site where floodwater has been removed. Although the sports fields still flood, there is a reduction in flood depths of approximately -0.10m when compared with the baseline. Most importantly for this event is that within the fields to the east of the site (in the location of the existing flowpath) there are no significant increases in flood depth which demonstrates that the proposed option is alleviating flooding on site without significantly increasing risk to third party land. As discussed above however, there is a small increase in flood extent and depth along Argae Road which will need to be addressed during the detailed design modelling.

Other AEP Events

During the 5% and 1% AEP event, the flood mechanism is similar to the 1% AEP +30% climate change event, although to a lesser magnitude. During the 5% AEP event, the attenuation features intercept floodwater from Argae Lane as floodwater does not flow out of the pedestrian underpass towards the school site. During the 1% AEP, the attenuation features intercept floodwater from both flowpaths and prevent the school and sports pitches from flooding. There is no increase in flood depth along Argae Road during these events. The maximum flood depth maps and depth difference figures for these AEP events, are included within Appendix B and C of this document.

As discussed in Section 2.9 of the hydraulic modelling report, the model was trimmed to enable the 0.1% AEP event to be simulated. The maximum flood depth maps and depth difference figures for the trimmed model during the 0.1% AEP event, are included within Appendix B and C of this document. Appendix B-3 shows that the school buildings are dry, however there is flooding on the sports pitches of up to 0.30m. The maximum flood depth difference map, Appendix C-3, shows a similar area where there is an increase/decrease in flood depths at the school site when compared to the 1% AEP +30% climate change event discussed above. However, this map does show an increase in flood depths of up to +20mm on the left bank of the Coldbrook, downstream of the farm access bridge and along Argae Road (+100mm).

Alternative Configurations

As part of this optioneering modelling, several configurations of the attenuation features have been modelled whereby the ditches at the attenuation basin outfall (Ditch 2 and Ditch 3) have been increased in size. The results produced are very similar to what is presented within this document. This indicates that there is a degree of flexibility for the Client in terms of what can be designed. There is Option 5a which has been reported in Section 3.3.1 where these ditches have been designed to be narrower (~5m) but consequently deeper (~1m) to attenuate floodwater, which in turn has maximised the developable area of the site but may present health and safety risks when it comes to access. There is also the issue of flooding on the school fields with depths reaching 0.25m during the 1% AEP +30% climate change event. There is also an option to design these ditches to be wider (~8m) but consequently shallower (~0.5m), however this will take up more space within the sports fields. There is also an opportunity with this option of providing other environmental benefits/uses within these areas as these attenuation ditches will only be used during high magnitude flood events.

3.3.2. Option 5b

As discussed in Section 3.3.1, as a result of the updated hydrology in the model, the preferred option presented in June 2020 (referred to as Option 5a) no longer captures all the flow within the attenuation features during the 1% AEP plus 30% climate change event such that there is water up to depths of 0.30m on the sports fields around the back of the school. The school buildings remain dry, but the field does experience flooding. To determine if the preferred option still provides a potential solution i.e. where no flooding occurs across the site, a model scenario was simulated whereby Ditch 3 was widened from 5m to 8m (referred to as Option 5b).

The maximum flood depth and depth difference results are shown in Figures 3-6 and 3-7. The maximum flood depth map shows that the flow is now captured within the ditch around the back of the school during the 1% AEP plus 30% climate change event and the sports fields remain dry. This therefore shows that by increasing the width of Ditch 3 to 8m, the attenuation features capture all the flow during the design event which includes the updated hydrology. There is however an increase in flood extent and depth along Argae Road of up to 100mm when compared to the baseline. This will need to be addressed during the detailed design modelling stage.

During the 0.1% AEP flood event, the school buildings remain dry, however even with a wider Ditch 1 width of 8m, there is still flooding on the school fields of up to 0.25m. The maximum flood depth difference map shows that there is minimal increases to third party land, although flood extents and depths increase along Argae Road (up to 100mm).

The maximum flood depth maps and depth differences for the 5%, 1% and 0.1% AEP events are included in Appendix D and E respectively.

As discussed in Section 3.3.1, there is some flexibility with this preferred option with how wide or deep the ditches can be to provide the same flood risk benefit. It is therefore recommended that the client considers whether they would prefer the ditches to be smaller in size but as a consequence the school field still floods in an extreme flood event (whilst the school buildings remain dry), or whether the ditches are constructed wider, to attenuate all the flow. Further work could be carried out to understand and incorporate the client's preferences for the preferred option if required.

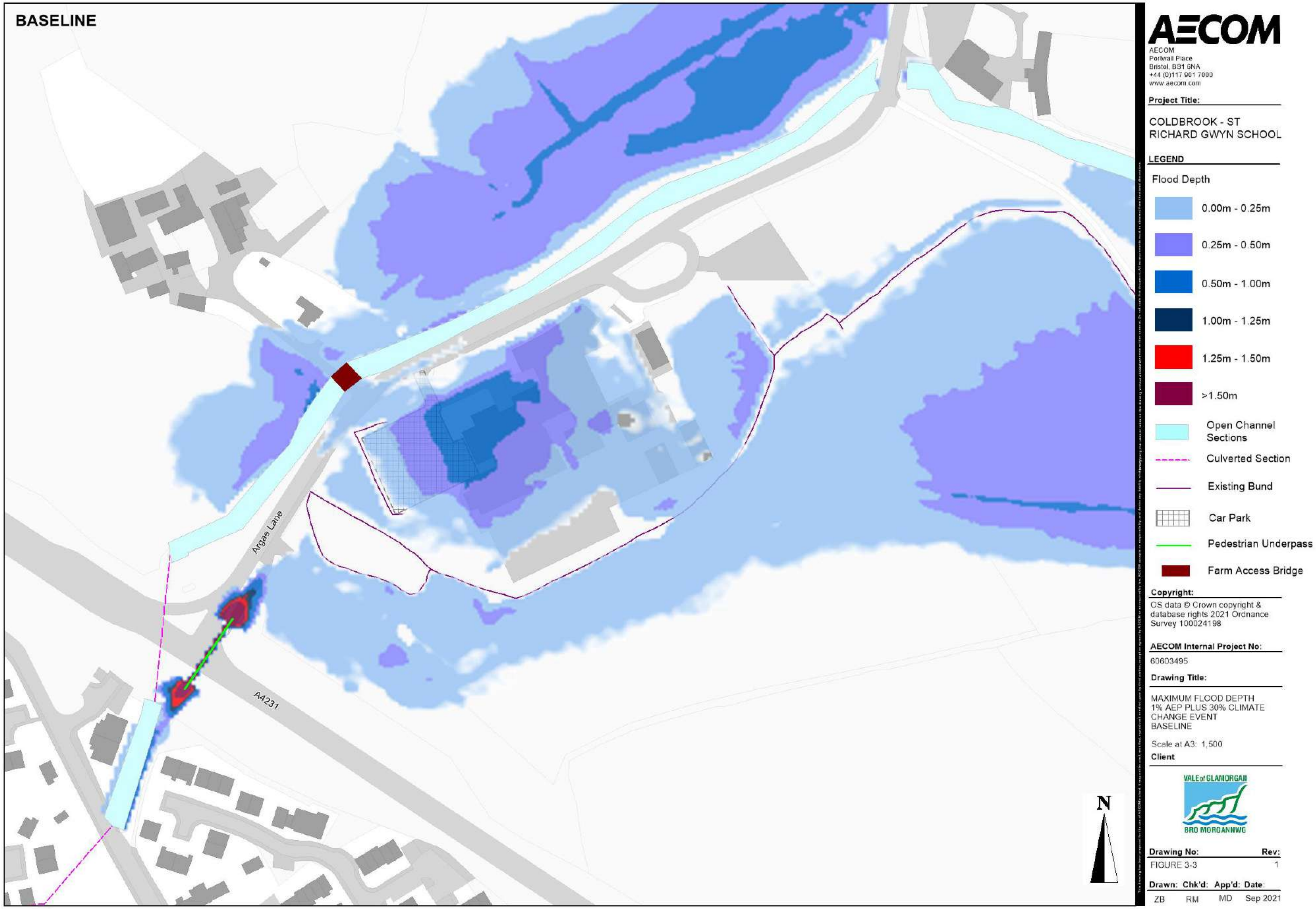


Figure 3-3: Maximum Flood Depth Map (Baseline) 1% AEP +30% Climate Change Event

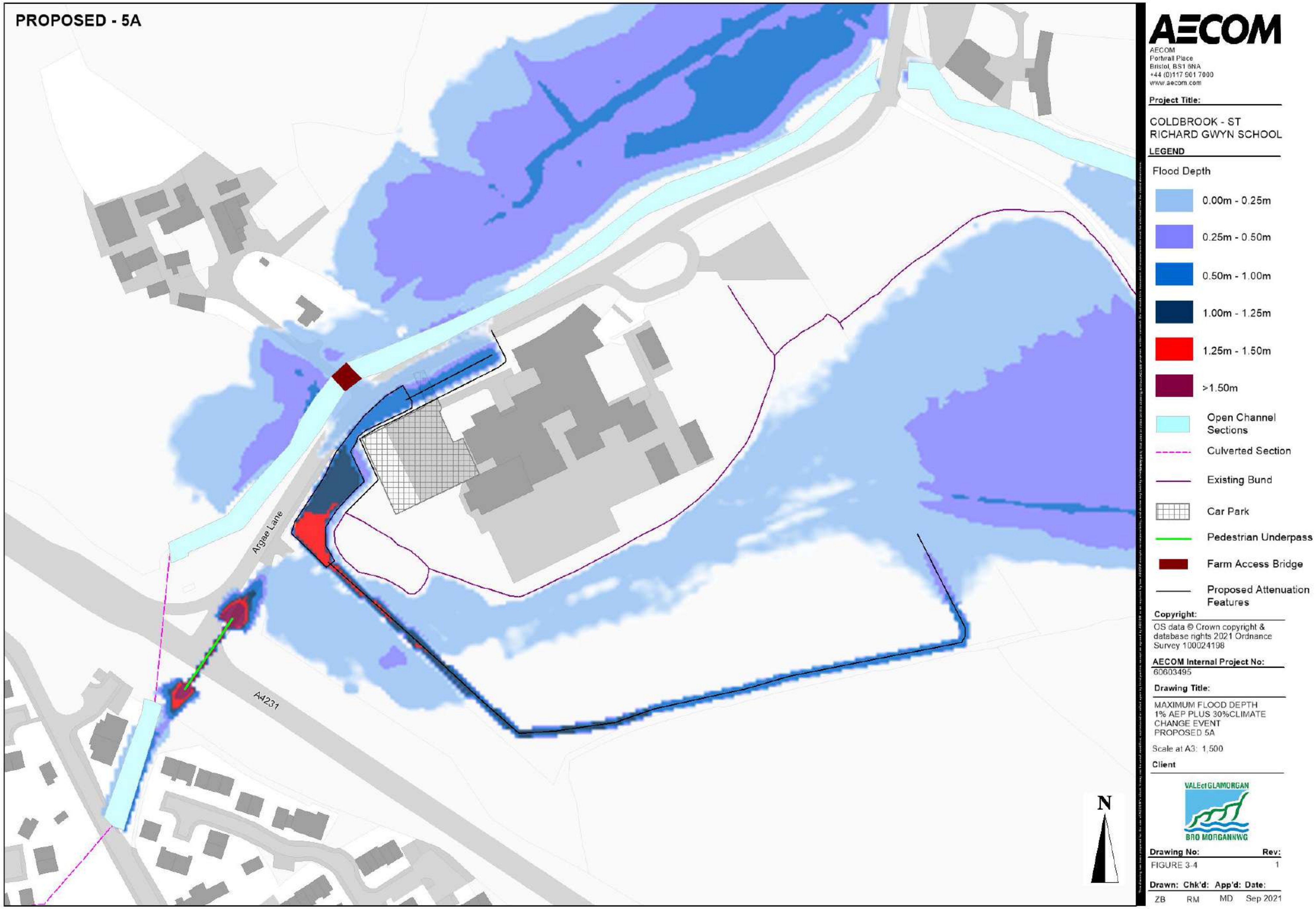


Figure 3-4: Maximum Flood Depth Map (Proposed) 1% AEP +30% Climate Change Event (Option 5a)

Figure 3-5: Depth Difference Flood Map 1% AEP plus 30% climate change (Option 5a)

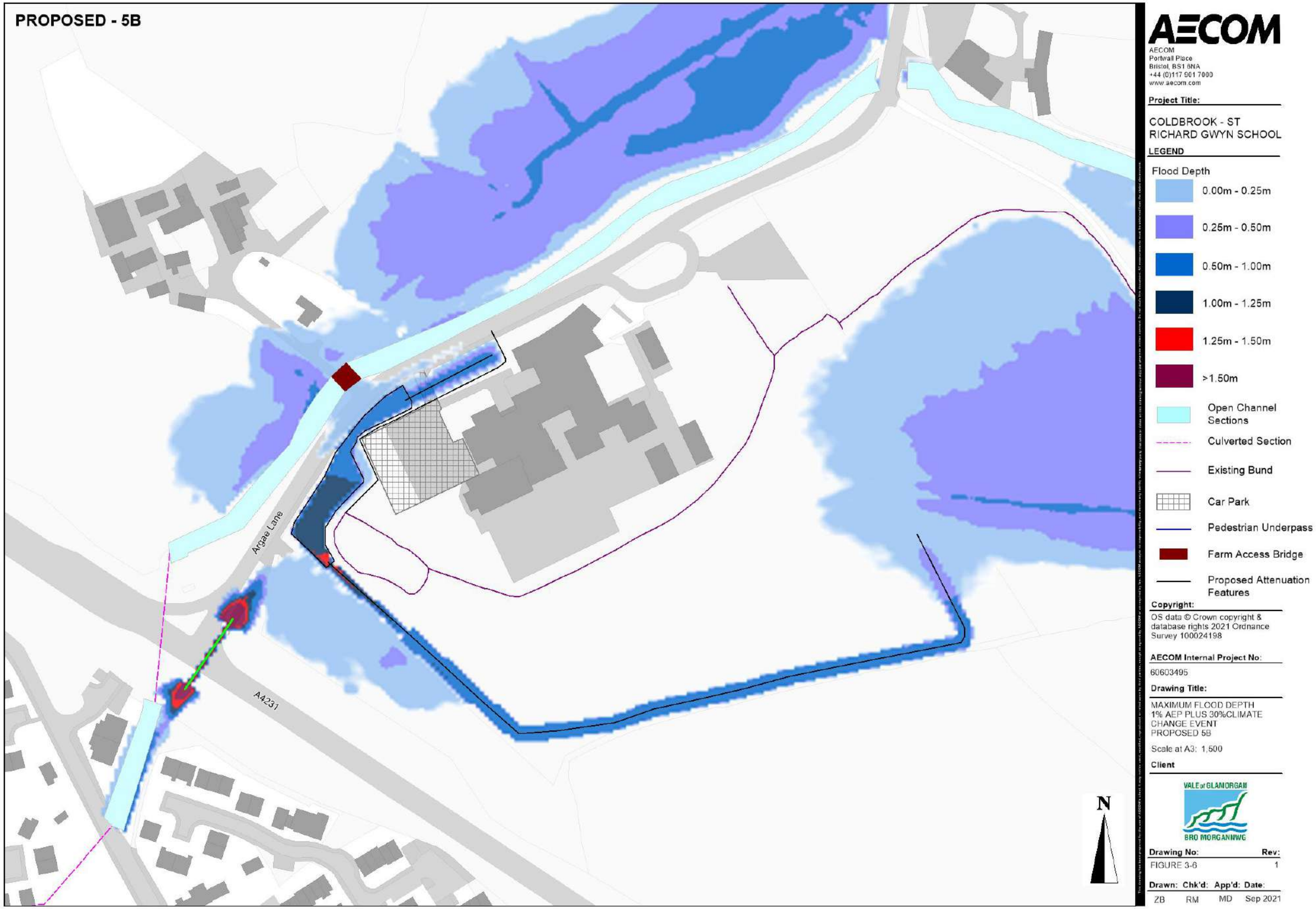


Figure 3-6: Maximum Flood Depth Map (Proposed) 1% AEP +30% Climate Change Event (Option 5b)

Figure 3-7: Depth Difference Flood Map 1% AEP plus 30% climate change (Option 5b)

4. Limitations and Recommendations

When considering the results and discussion throughout this report, it is important to understand the limitations and uncertainties with the model and its outputs which are documented within the Coldbrook Hydraulic Modelling Report. For this optioneering phase, the key limitations and recommendations surrounding both the model and the preferred option include:

- The preferred Option 5 includes a number of attenuation basins and ditches which convey water away from the site. Results have shown that these features successfully alleviate flooding at the site and do not significantly increase risk to third parties. There are however localised increases, such as along Argae Road where flood extents and depths increase (up to 100mm) during the 1% AEP +30% climate change event and 0.1% AEP event. The features that have been modelled should be considered indicative at this stage and subject to change during the detailed design modelling stage. This modelling has demonstrated that there is an option which conceptually works to alleviate flooding at the site, however the finer detail regarding the size of ditches and the amount of storage required will need to be refined once the Client has confirmed that this option works (in principle) as part of any redevelopment aspirations.

- From a review of Welsh Water data provided by the Client, there does not appear to be any constraints when considering attenuation features near to the manholes shown in Figure 1-1. However, it is recommended that the Client liaises with the utility company to ensure that no below ground features are present within this location, which may affect the amount of attenuation that can be provided in this area.

- The Welsh Water data provided by the Client has confirmed that a 700mm diameter combined sewer is located within the sports pitches, in an area which is proposed for attenuation. It is recommended that the Client liaises with the utility company to confirm the depth of this sewer and whether attenuation in this area is likely to be feasible or if optimising the layout would prove to be sufficient.

- This modelling has not considered ground conditions, groundwater or any other environmental assessments. These may be required to understand more about the underlying conditions before attenuation features can be confirmed as feasible. It is recommended that further liaison is undertaken with NRW to confirm these requirements.

5. Conclusions

This Optioneering Modelling Report has presented a total of five options which are considered to be potentially viable in managing and/or alleviating flood risk to the developed area of St Richard Gwyn School. However, through an assessment of these options against a number of key criteria (Table 2-1), only one option was considered appropriate to be taken forward for hydraulic modelling testing.

The majority of the options proposed as part of the shortlist exercise have the potential to increase flood risk to third party land further downstream, which would not be considered favourably by stakeholders. They also only address flood risk from Flowpath 1, while flooding from Flowpath 2 would continue to inundate the sports pitches.

Option 5 was therefore taken forward as this intercepts out of bank flooding from the two key flowpaths of overtopping from the Coldbrook and attenuates floodwater on site through a series of basins and ditches. Once water has entered these storage features, ditches have been designed to convey water around the southern perimeter of the site in an anti-clockwise direction, re-connecting with the baseline flowpath to the east of the site to ensure flood depths do not increase within third party land. The model has been simulated for the 5% AEP, 1% AEP, 1% AEP +30% climate change and 0.1% AEP events and during each event the proposed option alleviates flood risk to the main school site and does not significantly increase flood risk elsewhere. The only exception is during the 1% AEP +30% climate change and 0.1% AEP events where flood extents and depths increase along Argae Road (up to 100mm).

Further work has been undertaken in September 2021 following model updates to address NRW's model review comments, which included an update to the hydrological analysis. This has resulted in a slight increase in the flows within the model during each of the AEP events and therefore more water must be attenuated within the preferred option. Option 5 still has the potential to function as the preferred scheme, and the results discussed in Section 3.3 suggest that Option 5a results in the school buildings remaining dry, however the sports pitches around the back of the school experience flood depths of up to 0.25m during the design event. An additional model run has been simulated whereby the width of Ditch 3 has been increased from 5m (Option 5a) to 8m (Option 5b). The results show that floodwater from both flowpaths is captured within the attenuation features in Option 5b. It is therefore recommended that the Client considers as part of future work whether they would accept any flooding on the school fields during the larger AEP events or would they prefer to have all flow captured within the attenuation features. As discussed above flood depths increase by up to 100mm along Argae Road during both these options during the higher AEP events and would need to be addressed during the detailed design modelling stage.

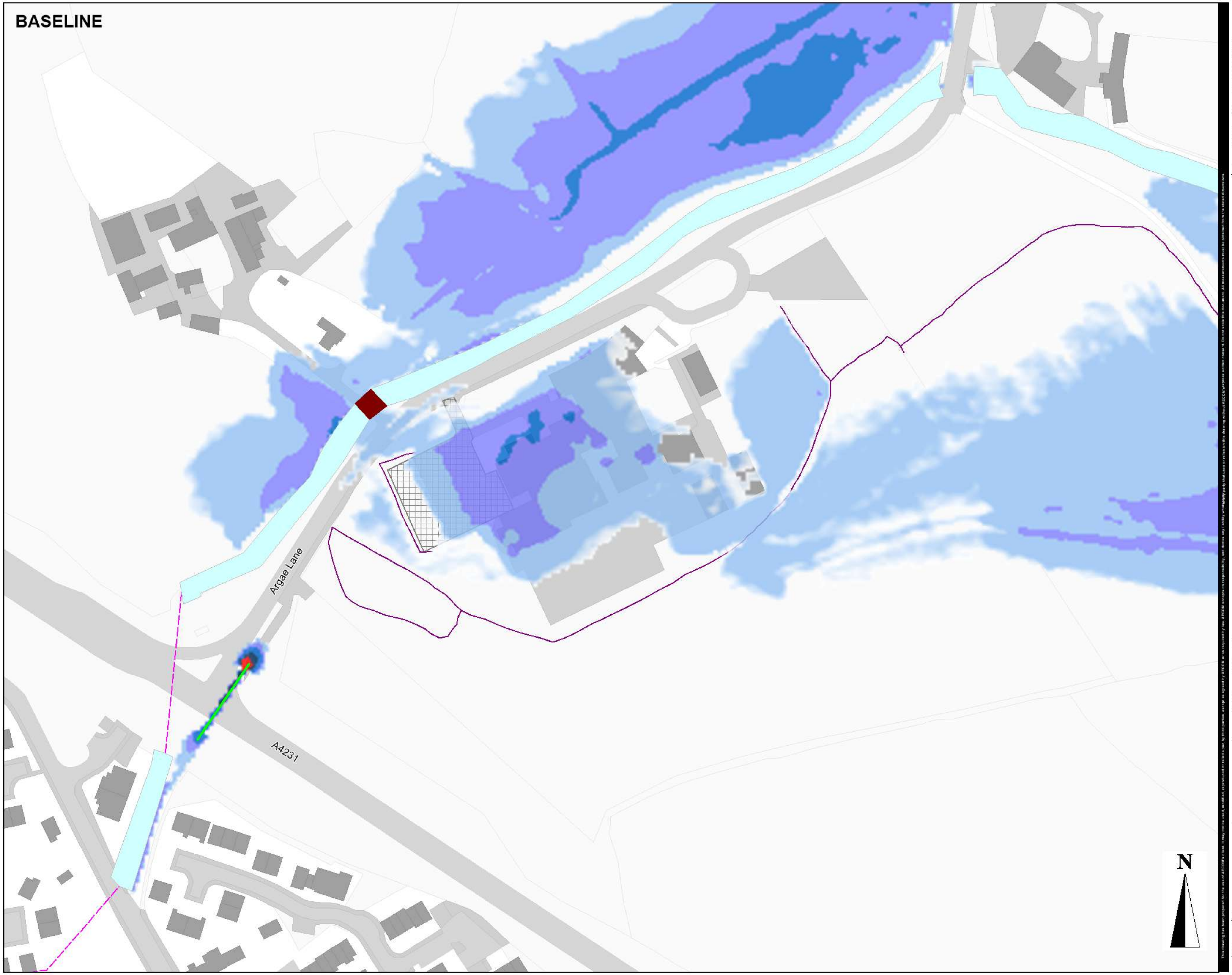
Results from this optioneering modelling phase have essentially shown that there is a workable option that can alleviate flooding to the site (in line with national planning policy), thus increasing the amount of developable land. It is recommended that the Client reviews the option proposed within this document and if considered acceptable and in line with any aspirational masterplan, is taken forward to the outline design stage where more accurate dimensions of the proposed attenuation features and associated bunds can be confirmed. While this option works from a flood risk perspective (subject to a few minor modifications), further investigation regarding other environmental issues (i.e. groundwater, ground conditions) and planning requirements may be required, alongside further liaison with various stakeholders such as NRW and Welsh Water.

Appendix A – Maximum Flood Depth Maps (Baseline)

Appendix A-1 – 5% AEP Event

Appendix A-2 – 1% AEP Event

Appendix A-3 – 0.1% AEP Event



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Project Title:

COLDBROOK - ST RICHARD GWYN SCHOOL

LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
5% AEP EVENT
BASELINE

Scale at A3: 1,500

Client

VALE of GLAMORGAN
BRO MORGANNWG

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APPENDIX A1	1

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LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
1% AEP EVENT
BASELINE

Scale at A3: 1,500

Client

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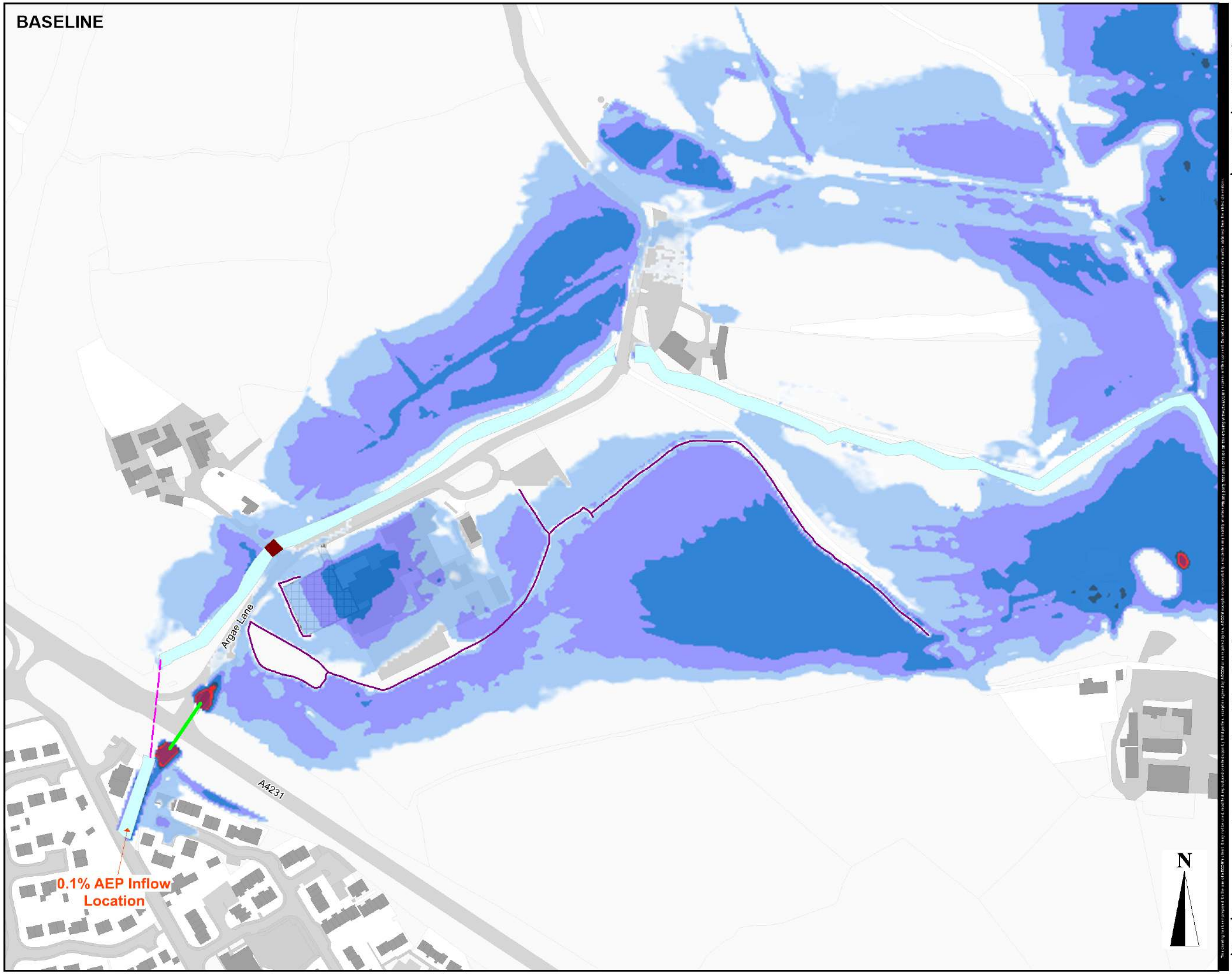

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LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
0.1% AEP EVENT
BASELINE

Scale at A3: 2,500

Client

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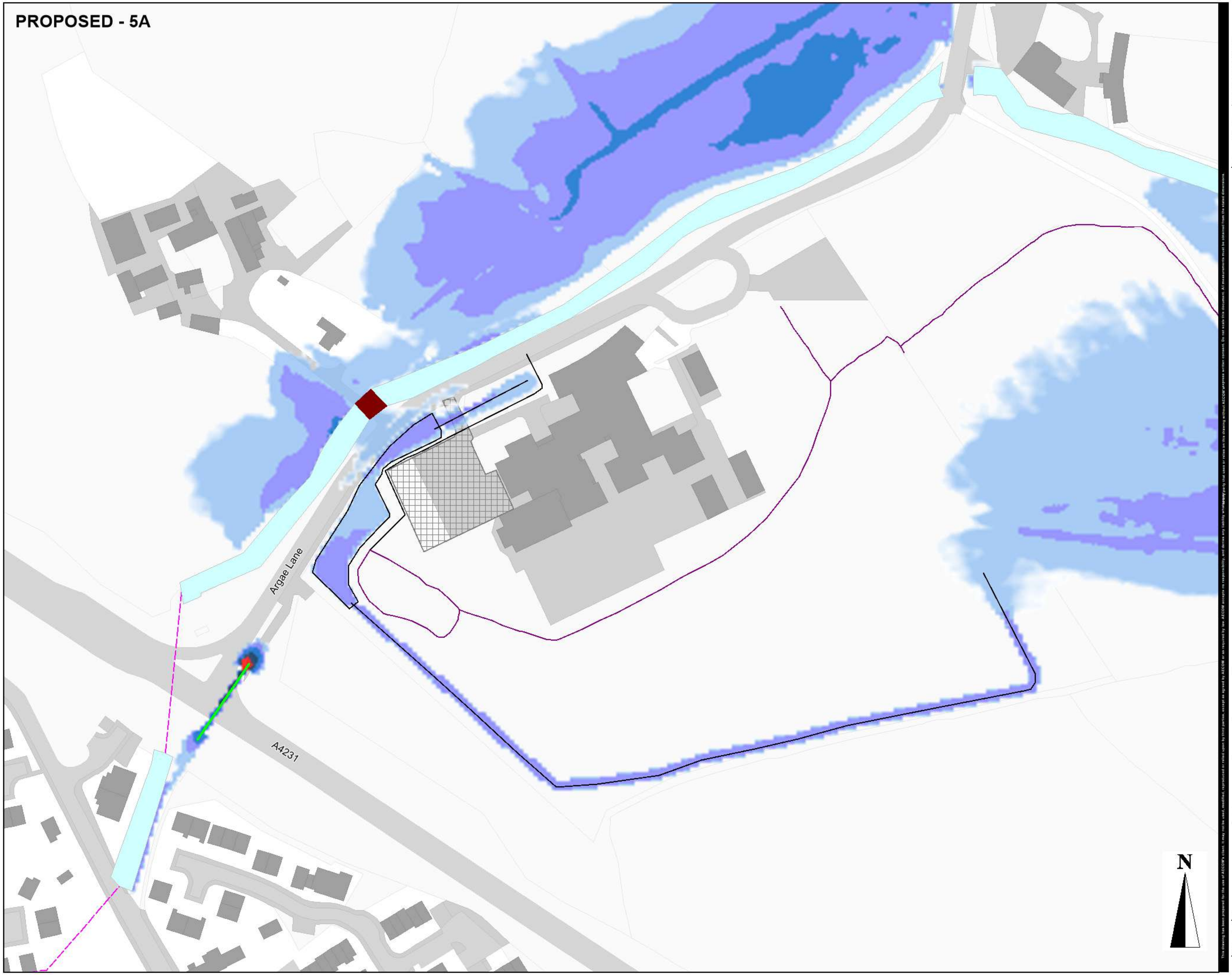
Appendix B – Maximum Flood Depth Maps (Proposed 5A)

Appendix B-1 – 5% AEP Event

Appendix B-2 – 1% AEP Event

Appendix B-3 – 0.1% AEP Event



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LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
5% AEP EVENT
PROPOSED 5A

Scale at A3: 1,500

Client

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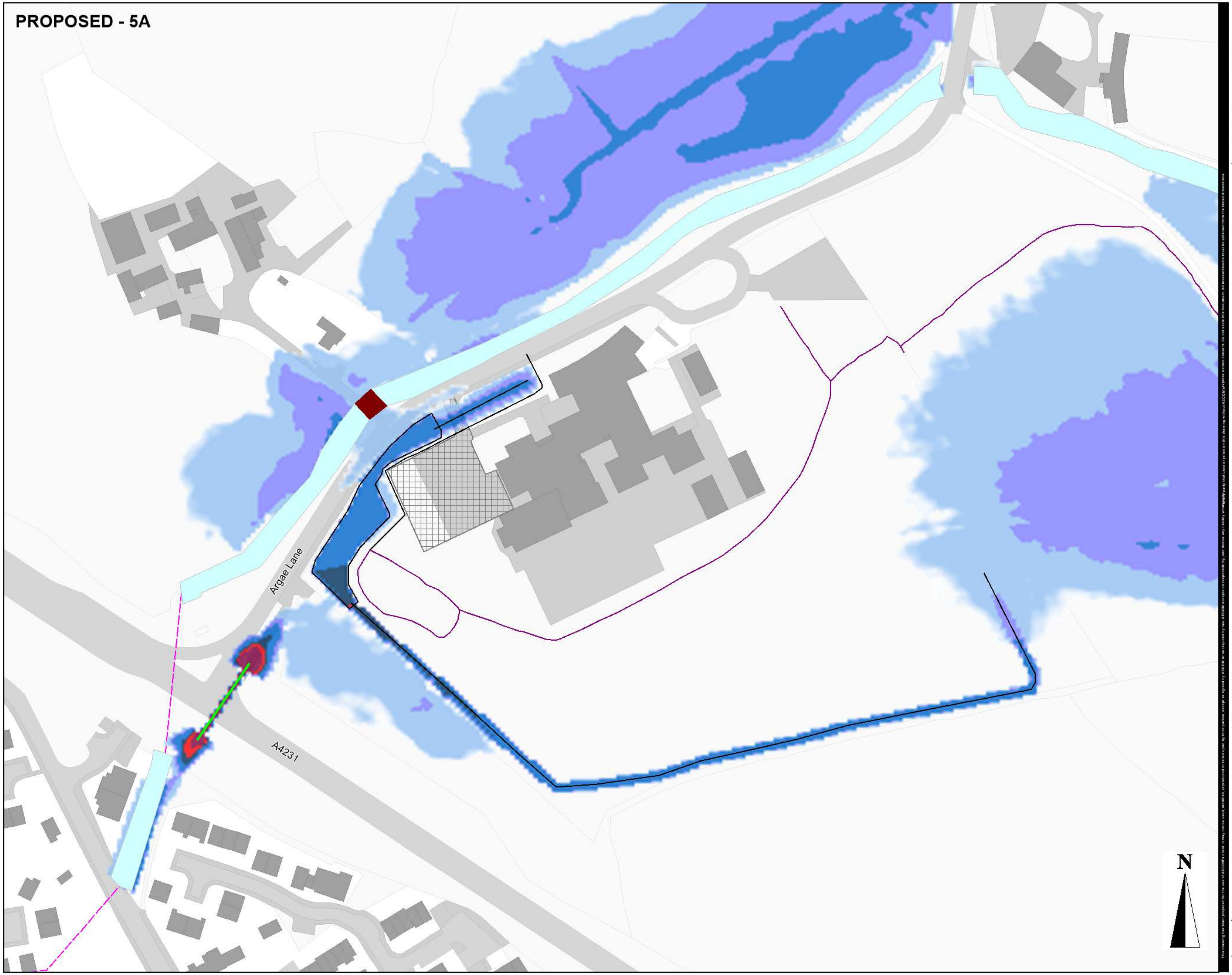

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LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
1% AEP EVENT
PROPOSED 5A
Scale at A3: 1,500

Client

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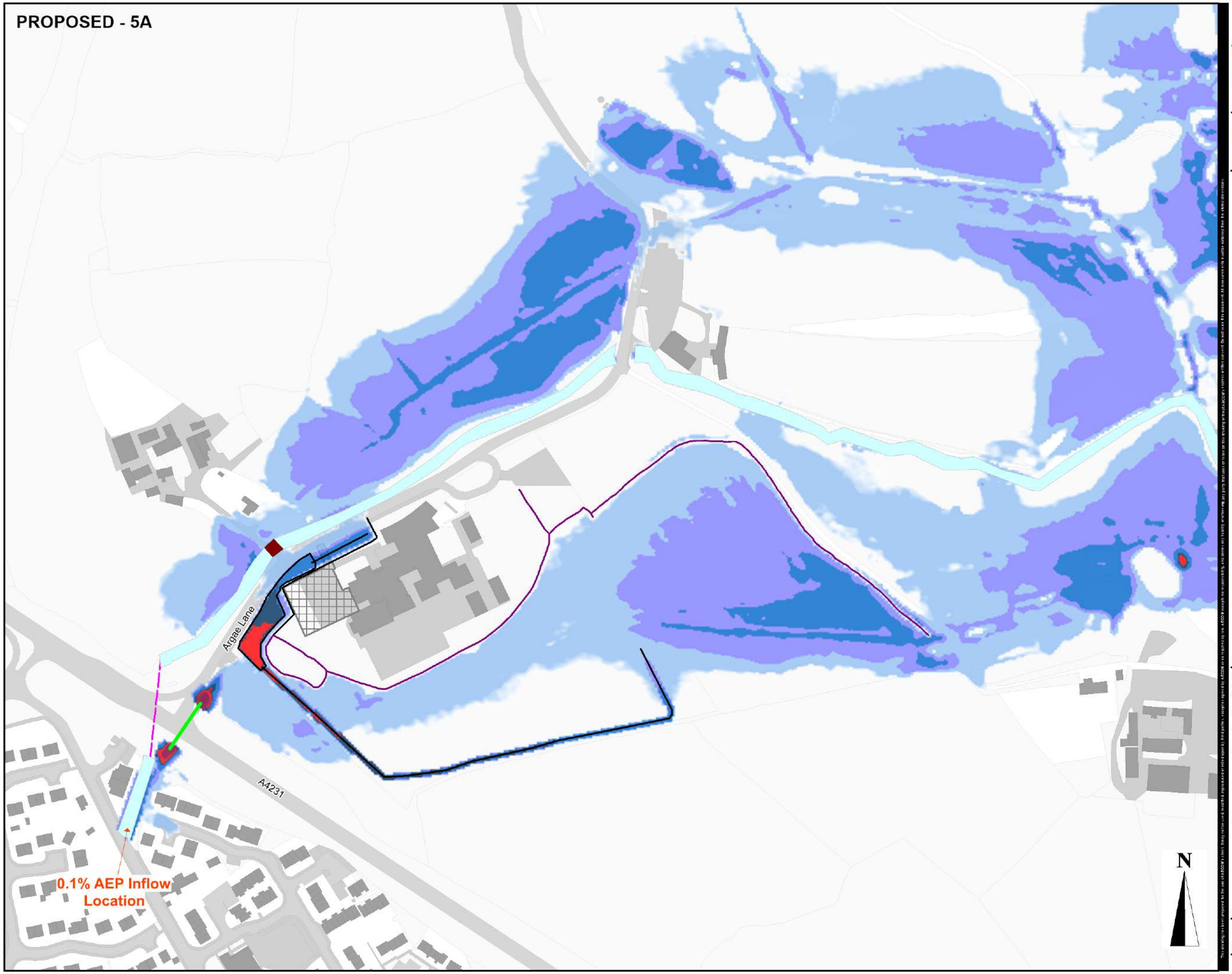

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Project Title:

COLDBROOK - ST RICHARD GWYN SCHOOL

LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features

AECOM Internal Project No:
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Drawing Title:
MAXIMUM FLOOD DEPTH
0.1% AEP EVENT
PROPOSED - 5A

Scale at A3: 2,500

Client

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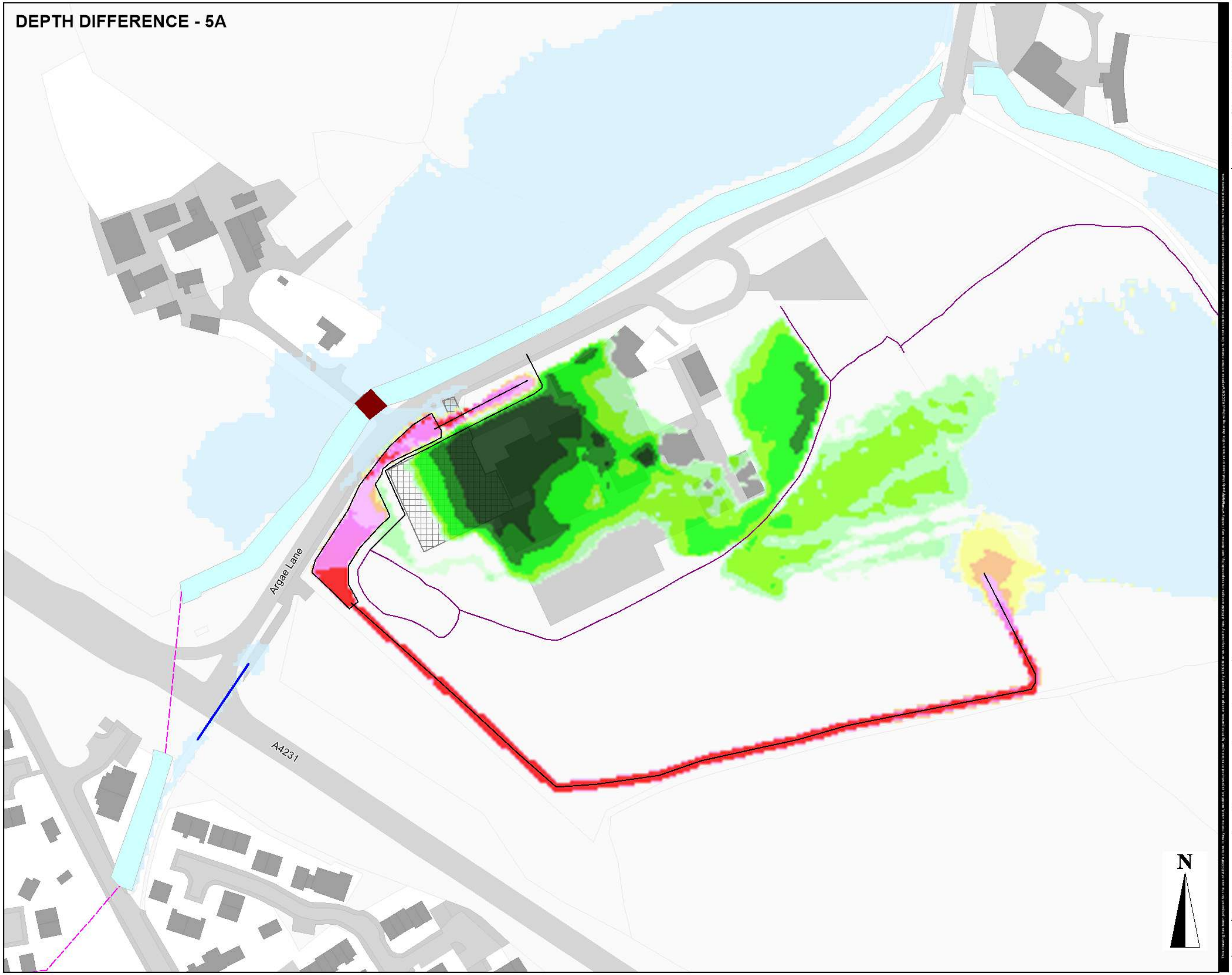
Appendix C – Depth Difference Maps (Proposed 5A)

Appendix C-1 – 5% AEP Event

Appendix C-2 – 1% AEP Event

Appendix C-3 – 0.1% AEP Event

DEPTH DIFFERENCE - 5A



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Project Title:

COLDBROOK - ST RICHARD GWYN SCHOOL

LEGEND

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10to <+20
- >-10to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features
- Proposed Maximum Flood Extent

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Drawing Title:

MAXIMUM FLOOD DEPTH
5% AEP
DEPTH DIFFERENCE
OPTION 5A

Scale at A3: 1,500

Client

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DEPTH DIFFERENCE - 5A

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LEGEND

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10to <+20
- >-10to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features
- Proposed Maximum Flood Extent

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AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
1% AEP
DEPTH DIFFERENCE
OPTION 5A

Scale at A3: 1,500

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DEPTH DIFFERENCE - 5A

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Project Title:

COLDBROOK - ST RICHARD GWYN SCHOOL

LEGEND

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10to <+20
- >-10to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features
- Proposed Maximum Flood Extent

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
0.1% AEP
DEPTH DIFFERENCE
OPTION 5A

Scale at A3: 2,500

Client

VALE of GLAMORGAN
BRO MORGANNWG

Drawing No:	Rev:
APPENDIX C3	1

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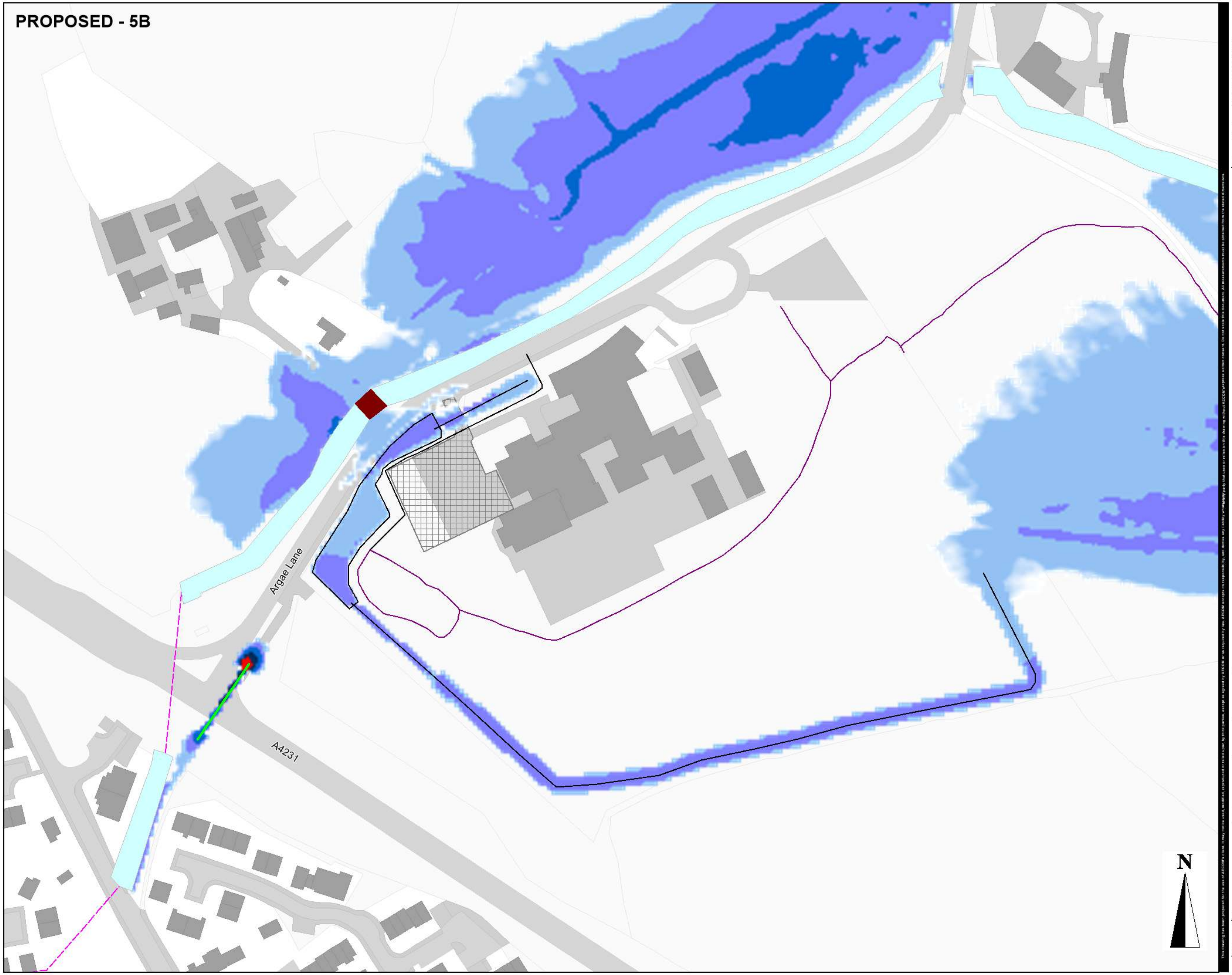
ZB	RM	MD	Sep 2021

Appendix D – Maximum Flood Depth Maps (Proposed 5B)

Appendix D-1 – 5% AEP Event

Appendix D-2 – 1% AEP Event

Appendix D-3 – 0.1% AEP Event



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Project Title:

COLDBROOK - ST RICHARD GWYN SCHOOL

LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features

Copyright:

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
5% AEP EVENT
PROPOSED 5B

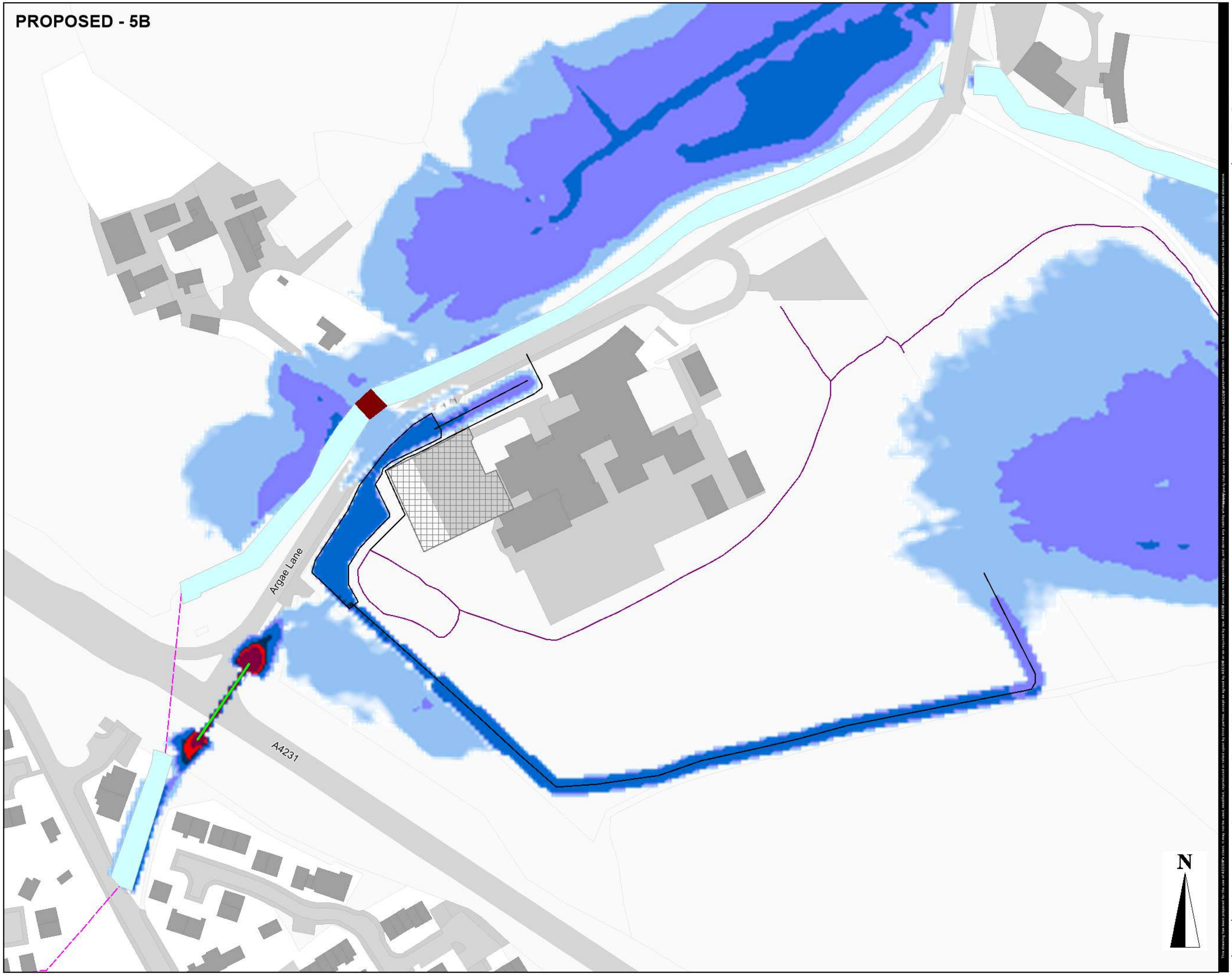
Scale at A3: 1,500

Client

VALE of GLAMORGAN
BRO MORGANNWG

Drawing No:	Rev:
APPENDIX D1	1

Drawn:	Chk'd:	App'd:	Date:
ZB	RM	MD	Sep 2021



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Project Title:

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LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features

AECOM Internal Project No:

60603495

Drawing Title:

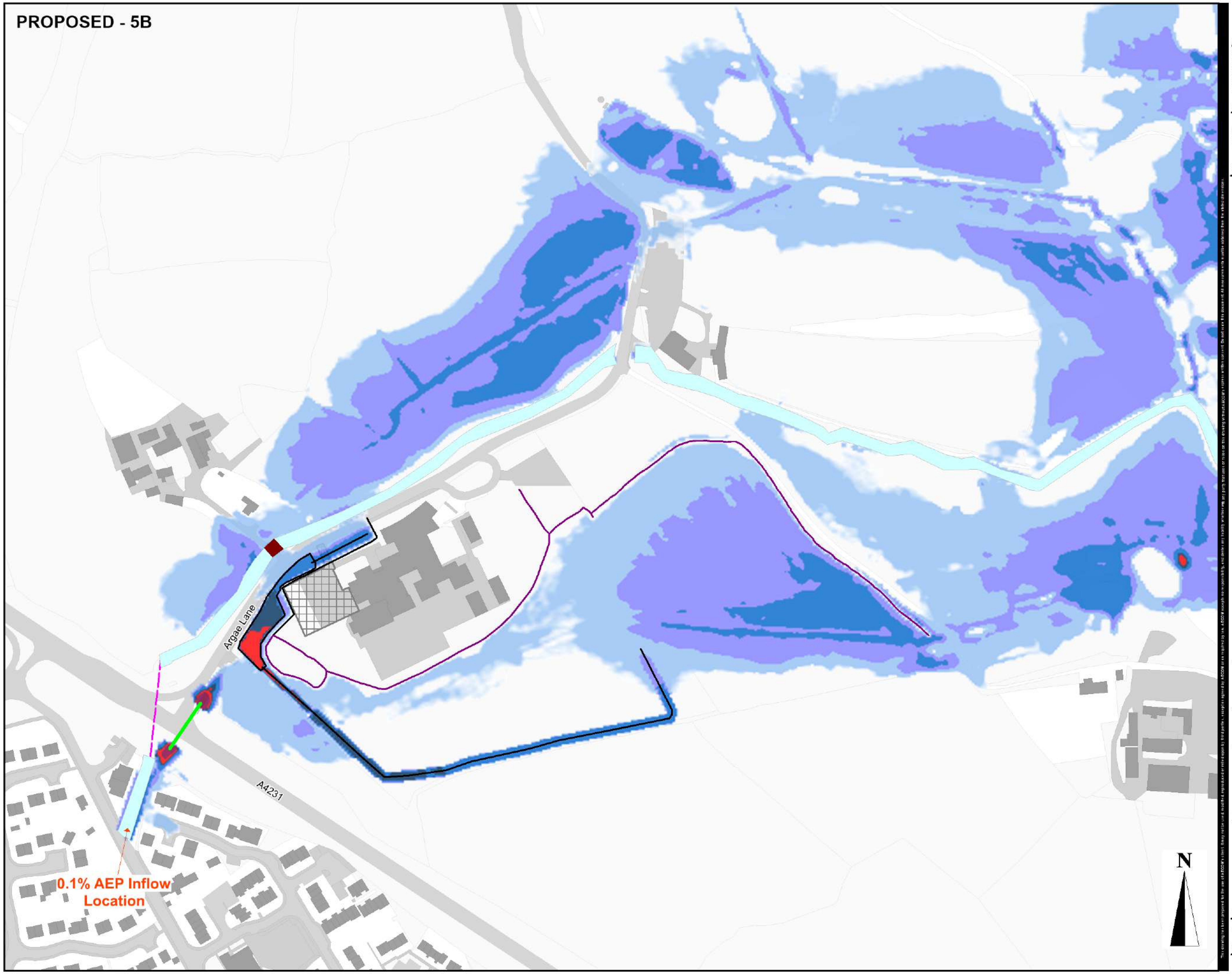
MAXIMUM FLOOD DEPTH
1% AEP EVENT
PROPOSED 5B
Scale at A3: 1,500

Client

VALE of GLAMORGAN
BRO MORGANNWG

Drawing No:	Rev:
APPENDIX B2	1

Drawn:	Chk'd:	App'd:	Date:
ZB	RM	MD	Sep 2021



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Project Title:

COLDBROOK - ST RICHARD GWYN SCHOOL

LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features

AECOM Internal Project No:
60603495

Drawing Title:
MAXIMUM FLOOD DEPTH
0.1% AEP
PROPOSED 5B

Scale at A3: 2,500

Client

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Drawing No:	Rev:
APPENDIX D3	1

Drawn:	Chk'd:	App'd:	Date:
ZB	RM	MD	Sep 2021

Appendix E – Depth Difference Maps (Proposed 5B)

Appendix E-1 – 5% AEP Event

Appendix E-2 – 1% AEP Event

Appendix E-3 – 0.1% AEP Event

DEPTH DIFFERENCE - 5B

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Project Title:

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LEGEND

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10to <+20
- >-10to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features
- Proposed Maximum Flood Extent

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
5% AEP
DEPTH DIFFERENCE
OPTION 5B

Scale at A3: 1,500

Client

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Drawing No:	Rev:
APPENDIX E1	1

Drawn:	Chk'd:	App'd:	Date:
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DEPTH DIFFERENCE - 5B

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LEGEND

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10to <+20
- >-10to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features
- Proposed Maximum Flood Extent

Copyright:

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
1% AEP
DEPTH DIFFERENCE
OPTION 5B

Scale at A3: 1,500

Client

VALE of GLAMORGAN
BRO MORGANNWG

Drawing No:	Rev:
APPENDIX E2	1

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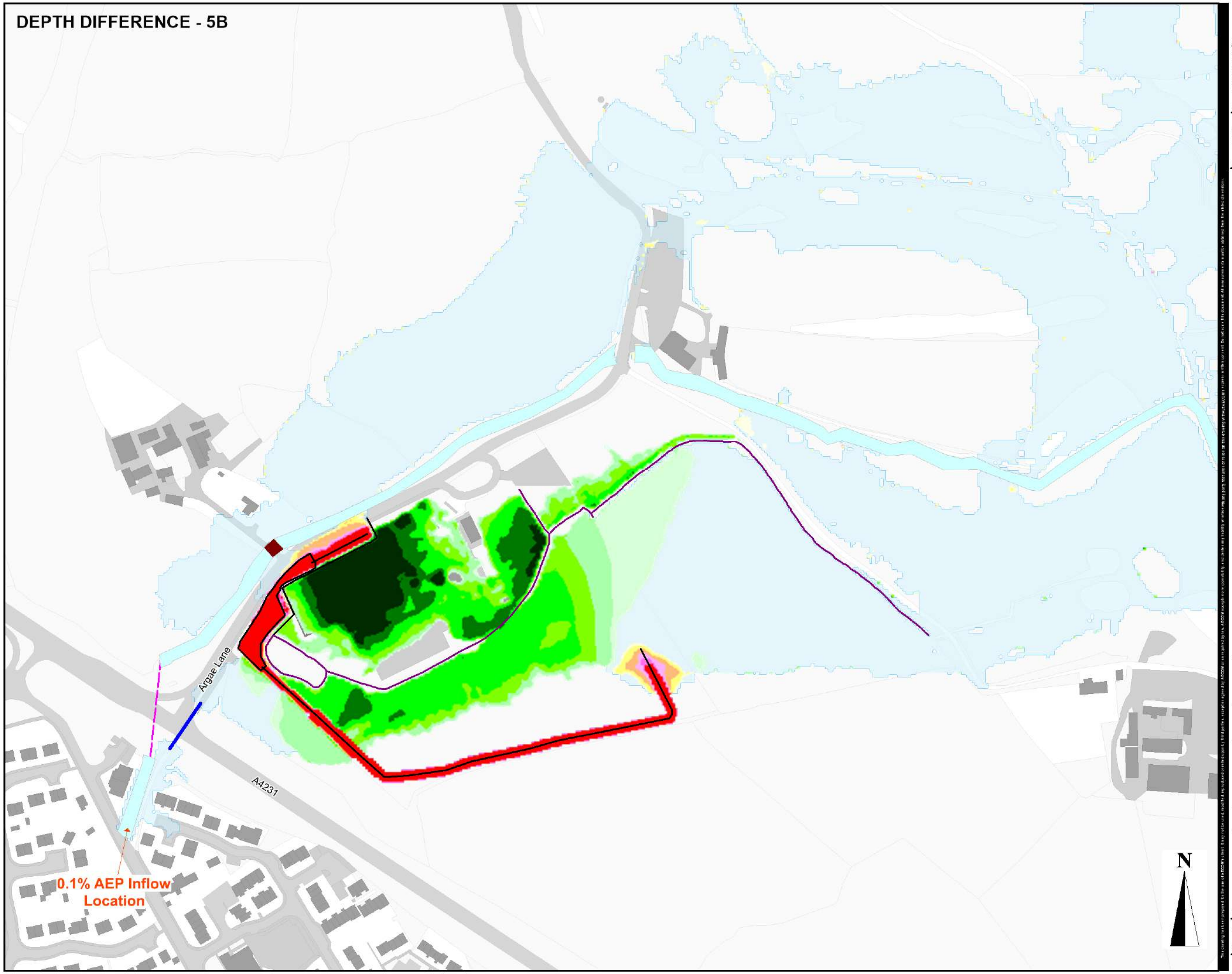

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Project Title:

COLDBROOK - ST RICHARD GWYN SCHOOL

LEGEND

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10to <+20
- >-10to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge
- Proposed Attenuation Features
- Proposed Maximum Flood Extent

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
0.1% AEP
DEPTH DIFFERENCE
OPTION 5B

Scale at A3: 2,500

Client

VALE of GLAMORGAN
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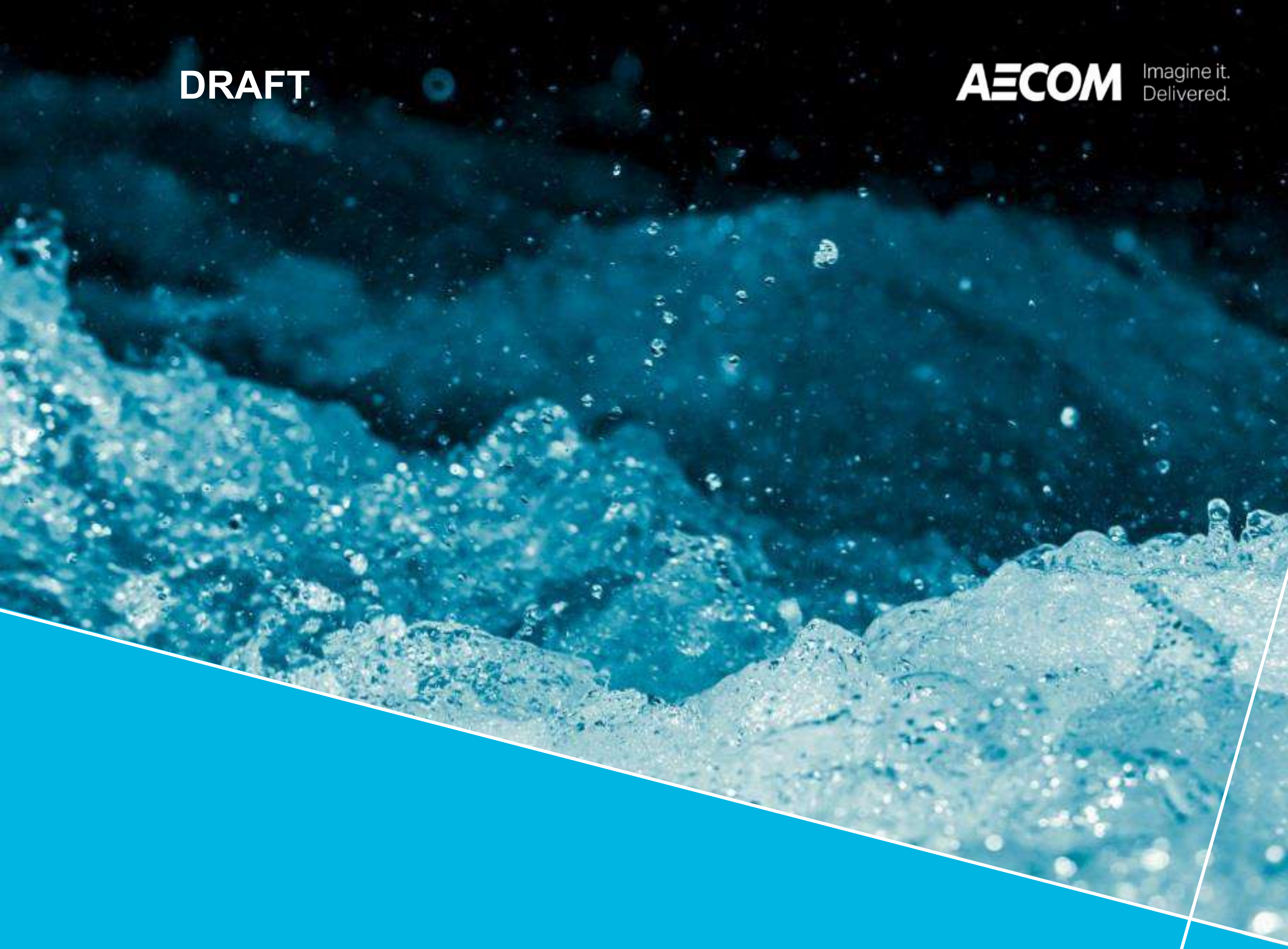
Drawing No:	Rev:
APPENDIX E3	1

Drawn:	Chk'd:	App'd:	Date:
ZB	RM	MD	Sep 2021



DRAFT

AECOM Imagine it. Delivered.

Coldbrook (Richard Gwyn)

Hydraulic Modelling Report

Vale of Glamorgan Council

Project Number: 60603495
Revision P02

October 2021

Quality information

Prepared by	Checked by	Approved by
Zoe Ball Engineer	Richard Moore Senior Consultant	Mark Davin Associate Director

Revision History

Revision	Revision date	Details	Approved	Position
P01	January 2020	Draft	Mark Davin	Associate Director
P02	October 2021	Draft following NRW comments	Mark Davin	Associate Director

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Table of Contents

1. Introduction

1.1. Project Context and Commission

In June 2019, AECOM Limited (AECOM) were commissioned by Vale of Glamorgan Council (VoGC) to undertake a review of the 'As-Built' hydraulic model created as part of VoGC's Coldbrook Catchment Flood Risk Management Scheme (2018). The objective of this review was to assess whether the Coldbrook hydraulic model was suitable to undertake optioneering at the St Richard Gwyn Catholic High School (hereafter referred to as St Richard Gwyn School) in Barry, as part of a Flood Consequence Assessment (FCA).

The review undertaken by AECOM identified a number of limitations that were adversely impacting the ability of the model to accurately represent the current level of flood risk in proximity to St Richard Gwyn School. In particular, there were significant issues with simulating the received 2018 model in the most up to date versions of the equivalent modelling software without instabilities occurring.

It was therefore recommended by AECOM that further work should be undertaken to update the hydrological assessment and hydraulic model to represent the Coldbrook Flood Alleviation Scheme and to improve the robustness of the model and increase the accuracy associated with the representation of flood risk in the vicinity of St Richard Gwyn School (to inform a future site specific FCA for the site) and throughout the modelled extent.

Following the initial model suitability review, VoGC commissioned AECOM to undertake the model update in October 2019. This model was subsequently reviewed by Natural Resources Wales (NRW) in March 2021 who provided a number of further improvements before the model and associated results could be approved and used as part of a site-specific FCA.

On the 26th March 2021, a meeting was arranged between AECOM, NRW and VoGC to discuss the model review comments and further actions. AECOM created a comments register following the meeting which detailed the improvements required to the model to satisfy NRW's comments. On the 23rd April 2021, NRW confirmed they were happy with AECOM's approach to the hydraulic model updates and AECOM were subsequently commissioned by VoGC in June 2021 to carry out the updates recommended by NRW.

This hydraulic modelling report has been produced to describe the methodology behind updating the received 1D and 2D model in line with the recommendations made in the AECOM model review (2019)[1] and NRW's comments (2021).

1.2. Report Structure

The approach and methodology that has been used to rebuild the Coldbrook model is outlined in Section 2. This summarises how the model has been updated and developed from the received 2018 model.

The baseline model results and the flooding mechanism within the area surrounding St Richard Gwyn School are summarised in Section 3, followed by a summary of the model sensitivity analyses undertaken in Section 4.

A statement of the limitations associated with the hydraulic modelling work that has been undertaken is included within Section 5, along with recommendations that could increase the confidence in the modelling results. The conclusions of this study are outlined in Section 6.

1.3. Site Overview

The Coldbrook is approximately 6km in length and rises in the Merthyr Dyfan area of Barry where it then flows through Gibbonsdown and Cadoxton before flowing beneath the A4231 (Barry Docks Link Road) and past St Richard Gwyn School. From here the Coldbrook flows through agricultural fields before confluencing with the Cadoxton River. St Richard Gwyn School is located approximately 4km north-east of the centre of Barry and is located adjacent to the Coldbrook, separated by Argae Lane.

Most of the catchment of this watercourse was originally greenfield but has now been developed for residential and commercial use following the construction of Barry Docks in the 1880s. As a result of localised development in the catchment, significant lengths of the watercourse have been culverted which has gradually 'closed in' sections of the watercourse and has increased conveyance resulting in a potential exacerbation of flood risk in specific areas where the culverted watercourse become overwhelmed.

[1] AECOM (13th September 2019), "Richard Gwyn School – Coldbrook Hydraulic Model Review".

In 2007, following intense rainfall, areas of Gibbonsdown, Cadoxton and Palmerston suffered severe flooding which resulted in approximately 100 properties and four schools being inundated with floodwater. Consequently, this led to various flood studies within the area and in 2016 the Coldbrook Flood Alleviation Scheme began construction with the aim of reducing the risk of flooding to over 200 properties and three schools in the Barry area[2].

Figure 1-1 shows an overview of the Coldbrook catchment and identifies the key features that relate to flood risk within the area.

[2] Available at: https://www.valeofglamorgan.gov.uk/en/living/Flooding/Flood-and-Coastal-Erosion/Coldbrook/Coldbrook-Flood-Alleviation-Works.aspx. Accessed: January 2020.

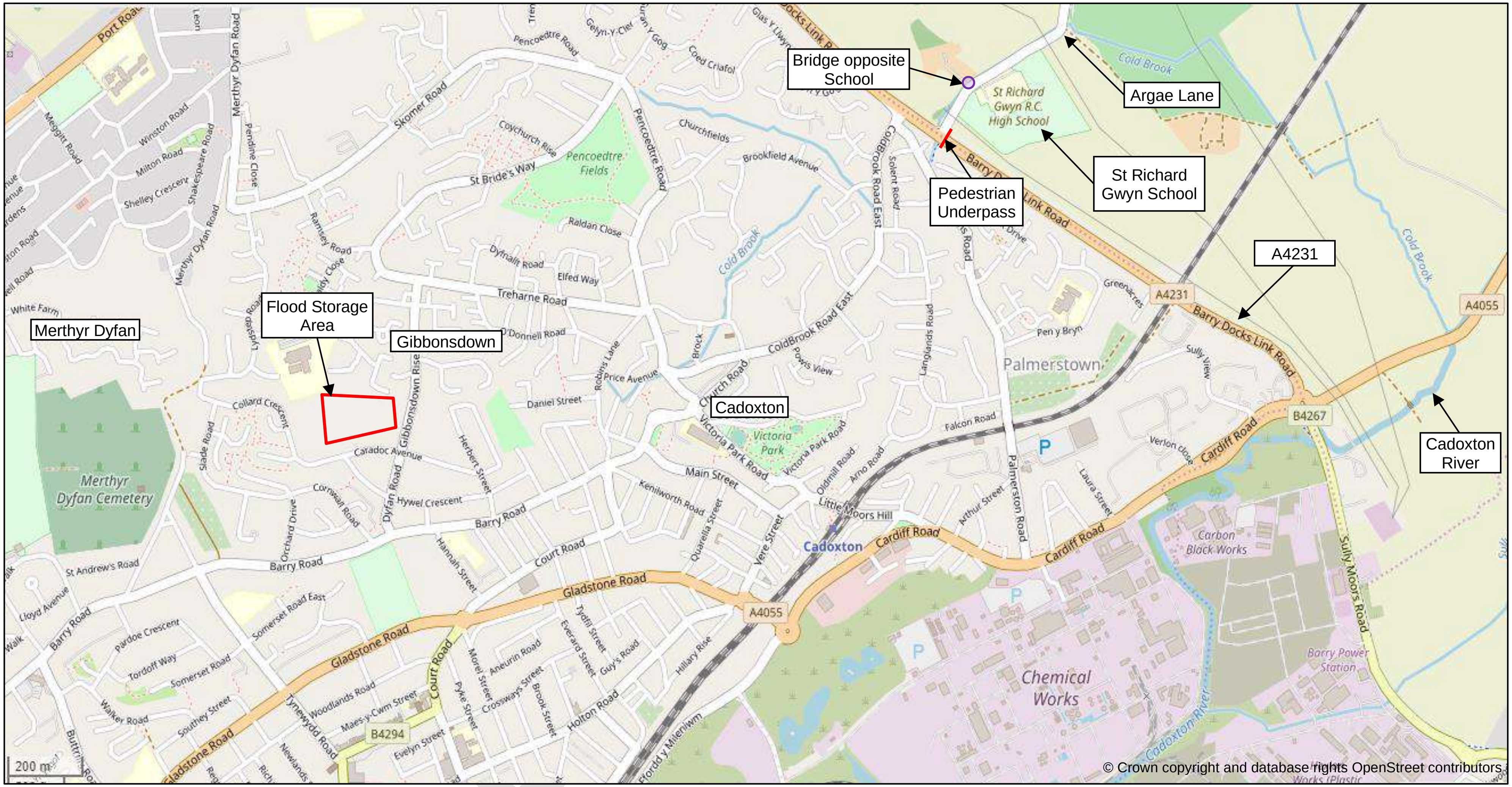


Figure 1-1: Site Location Map
Source: Open Street Map, January 2020

2. Hydraulic Modelling Methodology

2.1. Overview

AECOM were provided the Coldbrook hydraulic model by VoGC which was created as part of the Coldbrook Catchment Flood Risk Management Scheme (2018). This model was built using a superseded version of 1D hydraulic modelling software (ISIS) and did not simulate in the most recent Flood Modeller Pro (FMP) software. This section describes the hydraulic model setup and methodology, and how the received 2018 model information has been incorporated into this updated model.

2.2. Received Model

The original Coldbrook Catchment Flood Risk Management Scheme design and hydraulic modelling was undertaken by Martin Wright Associates between 2011 and 2014 to address flooding that occurred in July 2007. This original hydraulic model was constructed using ISIS version 3.6 and TUFLOW build 2009. In July 2018 Betts Hydro Consulting Engineers (BHCE) updated this model to test the As-Built scenario[3], retaining the use of the ISIS modelling software while using a 2016 version of the TUFLOW software (Section 2.3).

AECOM were supplied with model files and results for the 1% Annual Exceedance Probability (AEP) plus 20% climate change design event for both a 12hr and a 24hr model run time. As part of the model review, AECOM attempted to simulate these received 2018 model files in 1D FMP version 4.4 and 2D TUFLOW version 2018-03-AD software, however the model did not successfully simulate, with instabilities occurring during the opening timesteps.

Key findings from the AECOM model review are discussed within the Coldbrook Hydraulic Model Review[4] report, where the majority of which have been addressed as part of this 2019 model update. The key recommendations made by AECOM are summarised as:

- The model should be re-built and simulated in the most recent hydraulic modelling software. An iterative approach should be applied, improving the initial conditions associated with the model each time a new model section is updated;
- The 2013 Martin Wright Associates hydrological assessment should be updated to be inclusive of the most up to date climate change guidance[5], the latest Revitalised Rainfall-Runoff Method (ReFH2) software and the most recent Flood Estimation Handbook (FEH13) rainfall dataset;
- The 1D FMP model should be updated including improvements to 1D cross-sections (widths, roughness values and panel marker placement), reduction of minimum flows, improvement to structure representation and checks against survey data;
- The representation of the Flood Storage Area (FSA) in Merthyr Dyfan should be improved (Section 2.4);
- There is uncertainty regarding the modelled representation of the Barry Docks Link Road pedestrian underpass and a bund around St Richard Gwyn School. The representation of these structures should be checked against up to date survey and improved as they have the potential to critically influence the propagation of floodwater and therefore the modelled flood outlines in the area of interest;
- The LiDAR data should be updated with the more recent dataset; and,
- There is discrepancy between 1D and 2D model cross-section extents that should be reviewed as this is resulting in double counting of floodwater volumes.

The model extent has remained the same as the received 2018 model and is shown in Figure 2-1.

[3] Betts Hydro Consulting Engineers (July 2018), As-built Model Hydraulic Assessment, Coldbrook Catchment Flood Risk Management Scheme, Barry, Vale of Glamorgan
[4] AECOM (September 2019) 'Coldbrook Hydraulic Model Review'.
[5] Natural Resources Wales Climate Change Guidance for FCAs (2016). Available at: https://gov.wales/sites/default/files/publications/2018-11/flood-consequence-assessments.pdf.

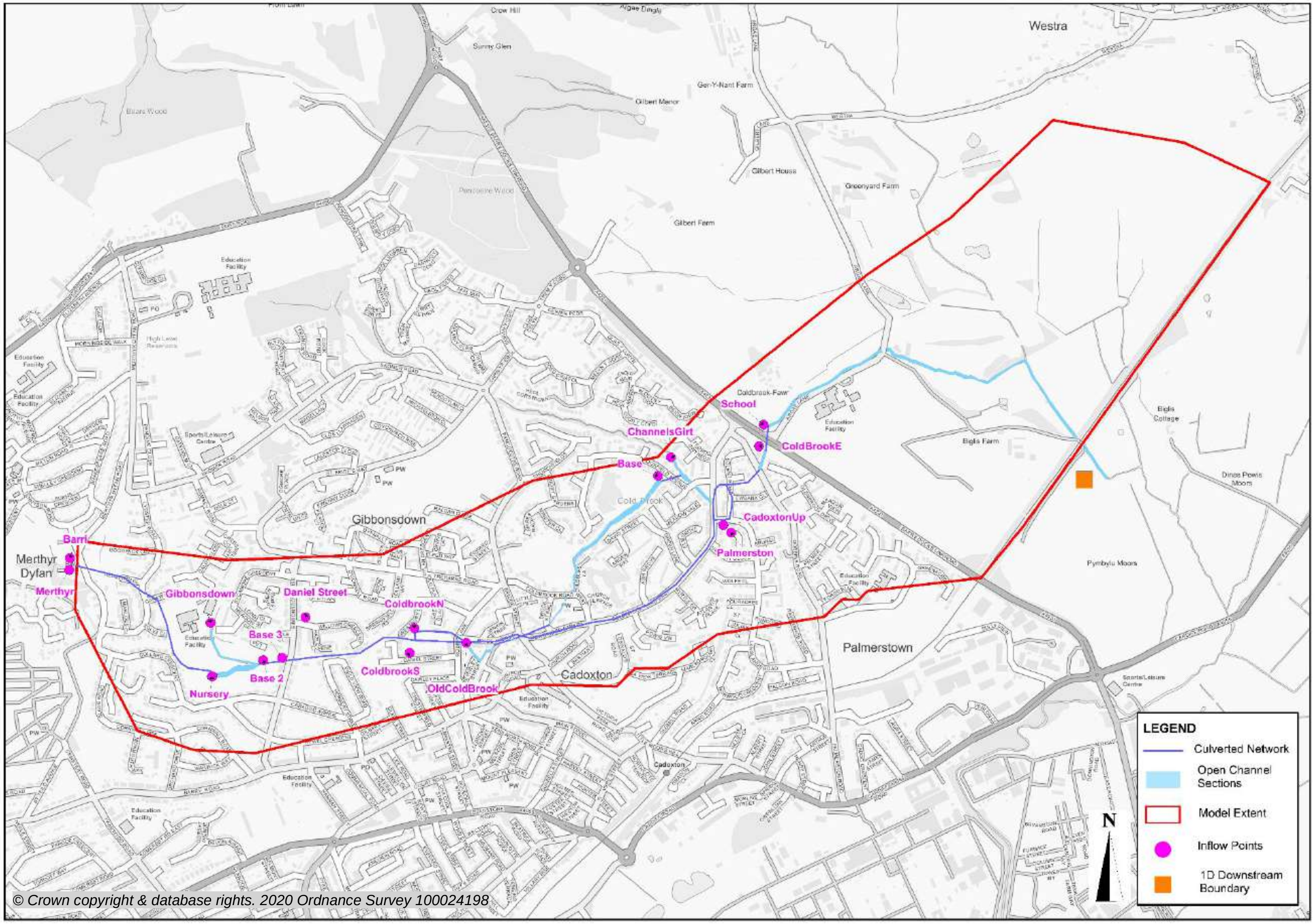


Figure 2-1: Coldbrook Model Extent

2.3. Modelling Software

The one-dimensional (1D) network of the 2019 model has been represented in FMP which is a 1D package used for modelling river channels, including bridges, culverts, weirs and other structures. The varying water levels within the channel and the associated transfer of flow to the two-dimensional (2D) part of the model is calculated by FMP.

TUFLOW is a 2D hydraulic modelling package that simulates hydrodynamic behaviour of floodwater across the land surface using a grid based approach. Combining FMP and TUFLOW allows for full hydraulic linking between the channel and the floodplain allowing the water from the channel (1D) to enter the floodplain (2D) and vice versa.

It should be noted that the pedestrian underpass under Barry Docks Link Road (A4231) has been represented using ESTRY which is a 1D modelling software provided by TUFLOW and provides the link between the 1D and 2D model domains in a similar way as FMP.

The models have been simulated using what is considered to be the most up to date versions of the software at the time the study was undertaken. The software versions used in this study are FMP version 4.6 and TUFLOW version 2020-01-AA.

2.4. Model Updates

Aligned with the recommendations made during the hydraulic model review, the following key updates have been made to the received hydraulic model:

- The 1D cross-sections were reviewed and updated against survey data provided by VoGC where possible. The widths and bank elevations of the 1D cross-sections were updated to be accurately represented in the 2D domain;
- The culvert at the outlet of the FSA has a sluice gate which has been set at 460mm above the invert of the culvert in accordance with Reservoir Operational Data - Dyfan Road POS[6], provided by VoGC (Appendix A);
- The pedestrian underpass under Barry Docks Link Road (A4231) has been updated using survey provided by VoGC and forms a key flow path onto the school site. The representation of the pedestrian underpass has been tested using both ESTRY (1D culvert representation) and 2D only, in an attempt to improve model stability. When represented in ESTRY, the water level in the most extreme flood events upstream and downstream of the pedestrian underpass is lower than the A4231 road level and therefore there is an opportunity to represent this feature in 2D only. Furthermore, a review of the flow at the upstream and downstream ends of the ESTRY culvert was undertaken which showed significant stability issues as shown in Figure 2-2. Consequently, the pedestrian underpass was modelled in the 2D which proved to be more stable without sacrificing accuracy (Figure 2-2). The 2D flood results were also compared between the two options and there was negligible difference between the results. Therefore, the pedestrian underpass has been represented in the 2D only;

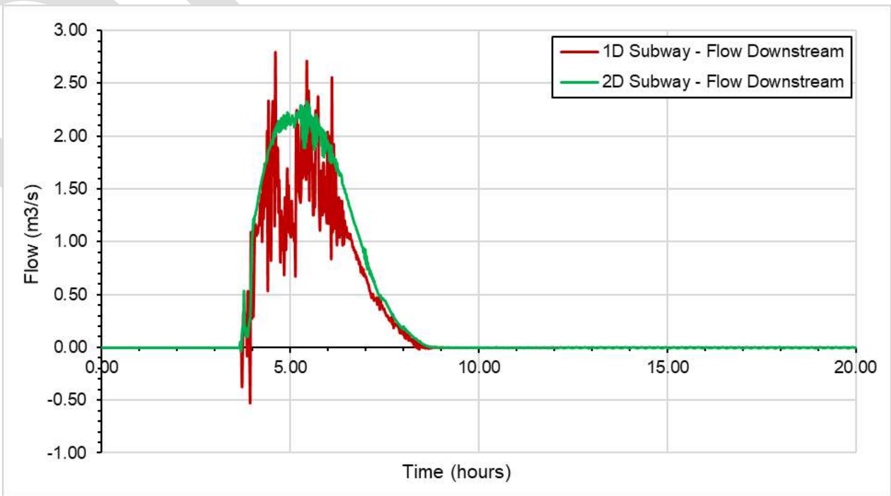


Figure 2-2: Comparison of flow at the downstream end of the A4231 pedestrian underpass (1% AEP event)

- The Channel's Girt tributary was only represented in the 1D domain in the received 2018 model and it has now been hydraulically linked to the 2D model;

[6] Vale of Glamorgan Council, June 2019. DATA SHEET C Reservoir Operational Data.

- Orifice flow has been enabled on all bridge structures within the model. This approach has been adopted for consistency with other bridges within the received model;
- The representation of the FSA has been improved, such that the 1D channel is hydraulically linked to the 2D model domain (floodplain). Within the received 2018 model, the FSA was represented by extended cross-sections within the 1D model domain, as well as being represented in the 2D domain, which resulted in the storage in this area being ‘double-counted’ and therefore misrepresented. The cross-sections within this area are no longer extended to represent the floodplain, with this feature now represented within the 2D model only. The representation of the floodplain in the FSA has been retained from the received model as no additional survey was provided as part of this study. Representing the FSA in 2D only was considered (removing the representation within the 1D model), however given the location and representation of the sluice gate at the outlet of the FSA, a consistent approach has been maintained by representing in 1D-2D (as per the received model);
- The manholes within the received 2018 model have been represented using spill units in the 1D FMP model and are all hydraulically linked to the 2D model. This enables water to flow from a 1D surcharged culvert into the 2D model domain (floodplain), and vice versa where water on the floodplain comes into contact with the manholes in the 1D model, water can flow into the 1D model. The manholes were included in the original 2014 model (before the Flood Alleviation Scheme was constructed in 2018) and therefore these manholes would have surcharged in previous versions of the model as the out of bank flooding was more severe before the Flood Alleviation Scheme was constructed. Now that the Flood Alleviation Scheme has been constructed and is included in the updated model, the surcharge of these manholes no longer occurs. For consistency, these manholes have been retained within the model if higher flows are simulated through the model in the future;
- The 2D grid resolution has been refined from 4m in the received 2018 model to 2m in the updated model. This was due to several sections of the watercourse having a cross-section width of less than one grid cell. The refinement of the 2D grid resolution allows for a more detailed and accurate representation of the study area and the flooding mechanisms within the Coldbrook catchment;
- The LiDAR used to generate ground elevations within the 2D model has been updated with the most recent dataset (when the model was built in January 2020);
- The Coldbrook channel between the A4231 and the farm access bridge was improved in line with available channel survey[7]. A cross-section was added at the A4231 culvert outlet and bank levels along this stretch up to the farm access bridge were improved using survey data and LiDAR information. The bridge deck level of the farm access track was also improved using this channel survey while representation of Argae Lane was improved using a provided topographic survey[8]. These changes improved the representation of out of bank flooding (when compared with photographic and anecdotal evidence of flooding around the site) and therefore the overall accuracy of the model outputs;
- The initial conditions have been improved during the model build and the minimum flow values have been improved compared to the received model (Section 4.1);
- The 1D bank levels have been compared with the LiDAR levels in the area of interest to ensure that the bank representation is correct. Figure 2-3 shows the comparison of these bank levels and the LiDAR; and,

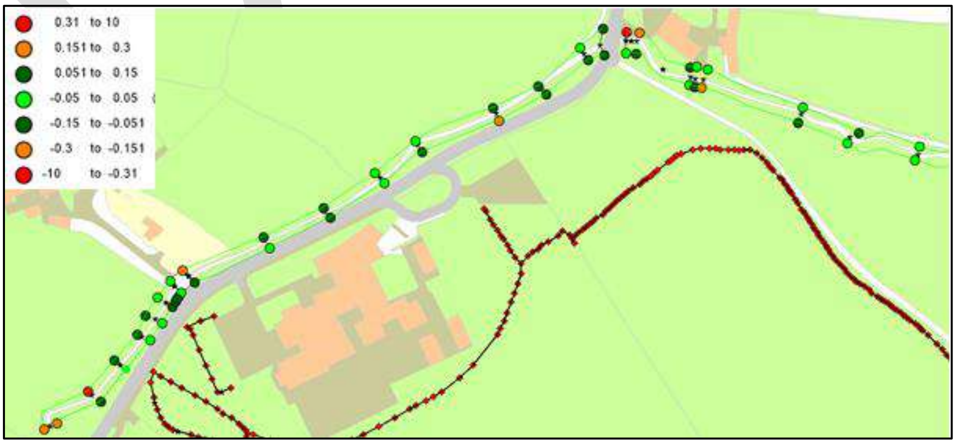


Figure 2-3: Comparison of 1D bank levels and LiDAR (difference shown in m)

[7] Environment Agency (April 2008) “Topographic Survey – Coldbrook at Argae Lane, Barry”
[8] Alpine Land Surveyors Ltd (November 2018) “Topographic Survey at Lower Coldbrook, Barry”

- The representation of the bund around St Richard Gwyn School has been improved and checked against detailed Topographic Survey provided by VoGC.

2.5. Manning's Roughness Coefficients

Manning's Roughness Coefficients specified within the received 2018 model have been reviewed and updated where required. Within the 1D FMP model, the Manning's Roughness Coefficients in the received 2018 model were checked against observations made during a site visit on 30th October 2019 and these were also assessed against the descriptions in Open Channel Hydraulics (Chow, 1959)[9].

Within the 2D model OS MasterMap was used to define floodplain land cover, retained from the received 2018 model. To assist in presentation of chosen roughness coefficients used throughout the channel and floodplain, Table 2-1 details the specification adopted within the Coldbrook model for both the 1D and 2D model domains. The Manning's Roughness Coefficient values have been determined based on the received model and checked against survey information where possible. Site visits have also been undertaken to confirm the specified values.

It should be noted that the buildings are represented using flow constriction cells, which means that the cell side flow widths are significantly reduced. This means that the amount of water that can flow across the building footprint is reduced. This was the modelled approach within the received model and was therefore retained for consistency.

Figure 2-4 and Figure 2-5 show two typical channel cross-sections identified within the Coldbrook watercourse. Additionally, it should be noted that the photographs were taken during a site visit on 30th October 2019. Figure 2-5 is located within the upper catchment of the watercourse and is located immediately upstream of the first culvert in the model. Figure 2-5 is located on Coldbrook Road West upstream of where this watercourse passes under the road. Additionally, Figure 2-6 was taken further downstream and shows an example of a culvert that has been constructed as part of the Coldbrook Flood Alleviation Scheme and this photo was taken on Brookfield Avenue, which is west of Coldbrook Road East. The FSA is shown in Figure 2-7.

Table 2-1: Manning's Roughness Coefficients

1D or 2D Roughness Element	Material	Manning's Roughness Coefficient
1D	Natural Channel Bed	0.03 / 0.04
1D	Densely Vegetated Channel Bed	0.05
1D	Natural Channel Banks	0.05
1D	Densely Vegetated Channel Banks	0.06 / 0.07
1D	Culverts	0.03
2D	Grass	0.04
2D	Gardens	0.05
2D	Footpaths and Paved Areas	0.025
2D	Manmade	0.03
2D	Buildings	1.00
2D	Unclassified	0.04

[9] Ven Te Chow, 1959. Open Channel Hydraulics.

Figure 2-4: Typical Channel Cross Section

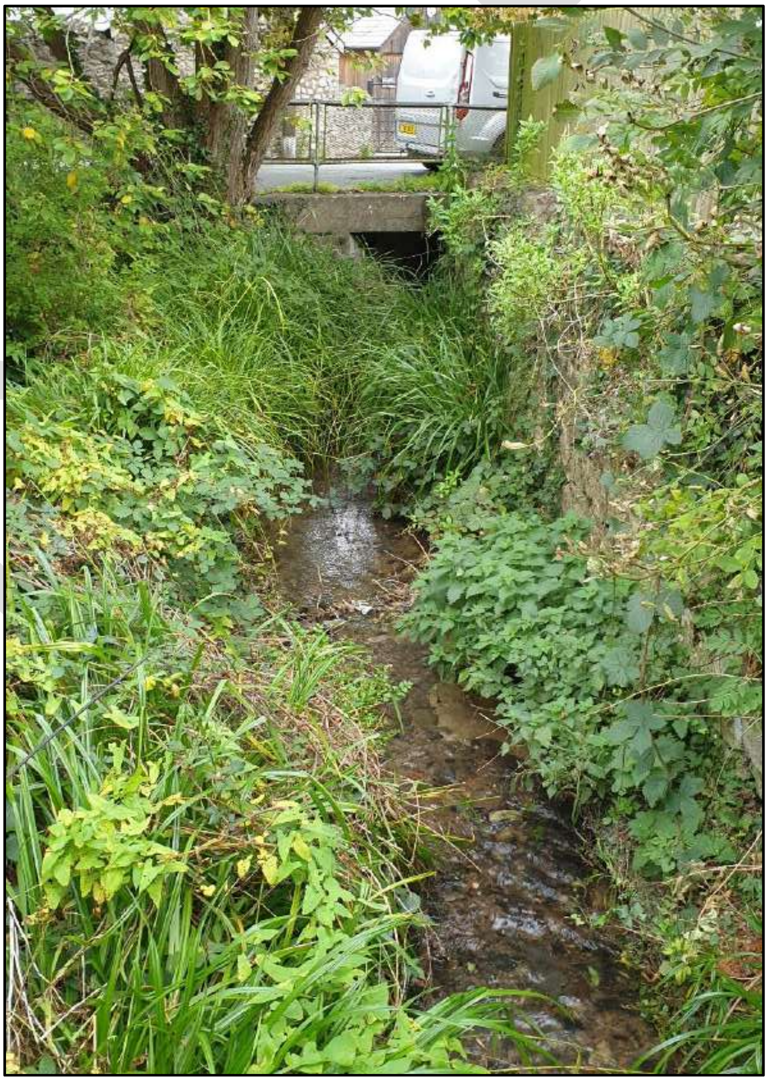


Figure 2-5: Typical Channel Cross Section and Bridge Structure

Figure 2-6: Typical Culvert Structure of the Coldbrook Flood Alleviation Scheme

Figure 2-7: Coldbrook Flood Storage Area

2.6. Topography

The LiDAR data used within this model study has been obtained from the Environment Agency Data Share site[10]. This LiDAR Digital Terrain Model (DTM) data consists of a 2m grid resolution and has a vertical accuracy of +/-150mm. The date that this LiDAR was flown is unknown from the downloaded data, however it is considered to be the most up to date LiDAR for the area when the model was constructed.

In addition to the LiDAR data, survey data provided by VoGC has been updated into the model to improve the representation of specific features throughout the 2D model. The surveys that have been included within the 2D model are:

- Topographic survey of the FSA (date of survey unknown, obtained from the received 2018 model);
- Topographic survey of the ground levels upstream and downstream of the pedestrian underpass under the A4231 (August 2010);
- Topographic survey of the floodwall at CS1034 (upstream of the A4231 pedestrian underpass) has been included within the model. The floodwall at this location does not extend along the entire bank of the Coldbrook. From Dobbins Road to the floodwall (approximately 50m) there is no raised defence and right bank levels are approximately 11.09m AOD i.e. at pavement level. The floodwall has been constructed approximately 25m upstream of the pedestrian underpass to a level of 11.71m AOD. Floodwater bypasses this floodwall when water levels overtop the right bank of the watercourse upstream of the wall before flowing into the pedestrian underpass. This wall is shown in Figure 2-8; and,
- Topographic survey of St Richard Gwyn School site, including the bund around the school (November 2018).

Figure 2-8: Floodwall upstream of the A4231 pedestrian underpass

2.7. Upstream Inflows

The 2013 Martin Wright Associates hydrological assessment[11] has been updated by AECOM as part of this hydraulic modelling study. The primary aim of updating the hydrological assessment was to ensure that the model hydrology reflects new methods, datasets and guidance that have been introduced since the original assessment in 2013. For further details of how the hydrological analysis was undertaken, the Coldbrook Hydrology Update Report is included within Appendix B. This was reviewed by NRW in March 2021, with updates undertaken in July 2021 in response to review comments.

The 16 inflows into the model are shown in Figure 2-1. It should be noted that three inflows shown in this figure (Base, Base 2 and Base 3), were in the received 1D model and have been retained within the updated 2019 model. Therefore, a total of 13 inflows are part of the hydrological analysis and three inflows are not included within the calculations.

[10] Environment Agency LiDAR Data (2019) Available at: https://data.gov.uk/dataset/002d24f0-0056-4176-b55e-171ba7f0e0d5/lidar-composite-dtm-2m. Accessed: October 2019
[11] Martin Wright Associate (2013) 'Coldbrook Flood Risk Management Scheme: Hydrology Technical Note'

2.8. Model Runs

Annual Exceedance Probabilities (AEPs) of: 20%, 10%, 5%, 1% and 1% plus 30% climate change, were simulated for the Coldbrook model to generate baseline results as part of the original study (June 2020). However, as part of the update to the hydrology following comment from NRW, only the AEP events where out of bank flooding occurs at the school have been reproduced. The AEP events modelled in the most recent study are therefore 5%, 1% and 1% plus 30% climate change. It should be noted that because the 0.1% AEP event flows are a lot larger than the other AEP events modelled (as shown in Table 2-2), the hydraulic model becomes unstable due to the culverted nature of the catchment. The hydraulic model was therefore trimmed in order to get the model to simulate. This is discussed in Section 2.9.

Table 2-2: Peak flow for the modelled flood events (m^3/s)

Flood Event	5% AEP	1% AEP	1% AEP + 30% CC	0.1% AEP
2021 peak flow estimate	6.8	10.3	13.4	20.1

The results from these simulations will confirm the baseline flood map for the school site and surrounding area for each of the AEP events. The model has been simulated for a 20 hour flood event with the peak of the event occurring at approximately 5 hours. This has been extended following NRW's review and is considered a suitable run time which ensures that the peak water level is achieved across the model domain and water levels across the floodplain begin to recede.

To account for climate change, the 1% AEP plus 30% climate change event was simulated in line with NRW's Guidance for FCA's: Climate Change Allowance[12]. The site is located within the West Wales River Basin District and the central estimate has been used because it is recommended by NRW that the central estimate for the 2080s should be used to assess the potential impact of climate change as part of an FCA.

2.9. 0.1% AEP Event

Following the model review by NRW, one of the comments related to running the model for the 0.1% AEP event. This AEP event had not been simulated in any previous versions of the model and the hydrology had not previously been estimated for this flood event. As part of NRW's future requirements for an FCA, the 0.1% AEP event should be simulated to determine how a proposed scheme would work in this extreme scenario. Therefore, flow hydrographs were produced for the 0.1% AEP event.

As shown in Table 2-2, the peak flow during the 0.1% AEP event is almost double that of the 1% AEP event (this is discussed further in the hydrology report, Appendix B). The model was simulated for the 0.1% AEP event, however because of the large flows and culverted nature of the model, it became unstable. Consequently, to enable the model to run, several updates were made to the model:

- The model was trimmed at node CS1035 (an open channel section upstream of the pedestrian underpass) at Dobbins Road which removed the majority of culverts within the model;
- One inflow point into the open-channel cross-section was included in the model and the other inflow points were removed. To estimate the flow at this location, the flow hydrograph from the 1% AEP plus 30% climate change event was extracted and scaled to match the peak of the 0.1% AEP event. Although the peak of the 0.1% AEP event is 20.10m^3/s, this was reduced to 12.91m^3/s to account for the water stored within the upstream FSA. This was calculated based on the amount of water stored during the 1% AEP plus 30% climate change event, with an appropriate scaling factor applied. This is considered to be a conservative approach as this does not consider other areas of out of bank flooding within the upstream catchment;
- A roughness patch with a Manning's Roughness Coefficient value of 0.06 was added to the model upstream and across the pedestrian underpass to improve model stability; and
- For stability reasons, the pedestrian underpass has been represented in ESTRY, rather than within the 2D domain. It should be noted that an attempt was made to simulate the whole model for the 0.1% AEP event with the culvert represented in ESTRY, however the model became unstable. This indicates that the model needs to be trimmed to Dobbins Road for the 0.1% AEP event to simulate.

[12] Natural Resources Wales (2016) 'Guidance for Flood Consequence Assessments: Climate Change Allowances.' Accessed: January 2020

2.10. Model Stability

A bitmap of the updated Coldbrook model FMP convergence plot for the 1% AEP plus 30% climate change simulation is presented within Figure 2-9. It can be seen that there are limited convergence issues in this model. At approximately 4 and 7 hours into the simulation, the model convergence exceeds the non-convergence tolerance of the model. Additionally, Figure 2-10 shows the FMP convergence plot for the received 2018 model during the 1% AEP plus 20% climate change event. A comparison of the two convergence plots indicates that there is a significant improvement in the stability of the updated model in comparison with the received model. The number of non-convergence peaks has been significantly reduced from 8 in the received model, to 3 in the updated model. Additionally, the received model shows that there is more convergence 'noise' throughout the model simulation, whereas the 'noise' shown in the updated model convergence plot is more substantial around the peak of the flood event than the rest of the model simulation.

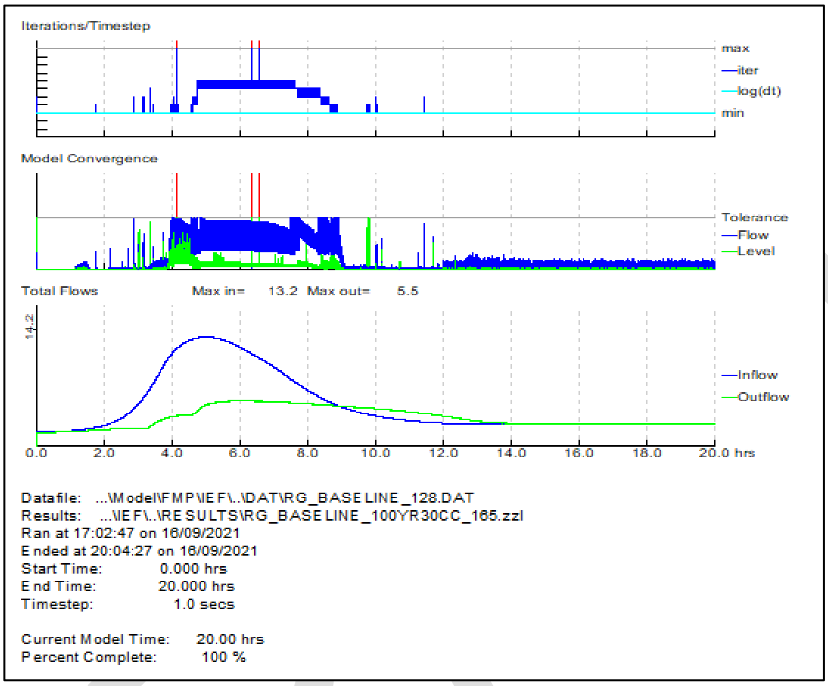


Figure 2-9: Flood Modeller Pro Convergence Plot – 1% AEP plus 30% Climate Change

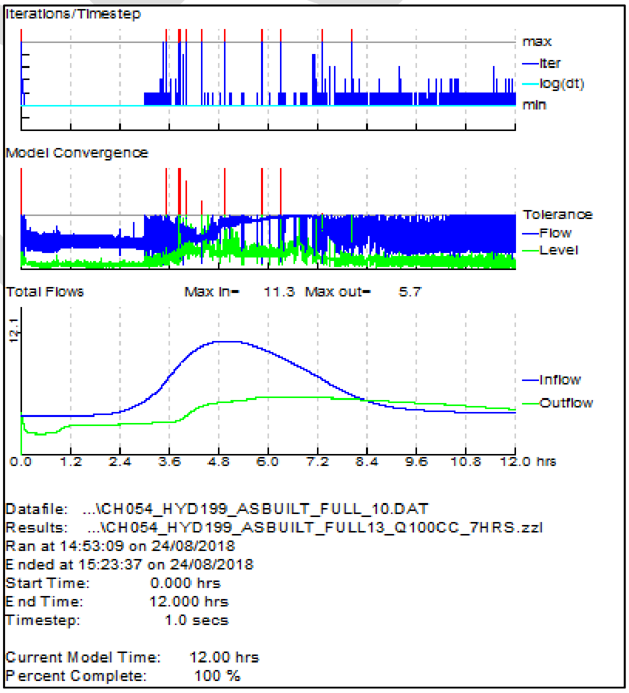


Figure 2-10: Received 2018 Model ISIS Convergence Plot – 1% AEP plus 20% Climate Change

The updated 1D model results have been reviewed within the long section to determine what may cause this increase in model convergence in the updated model. The results suggest that the 'noise' and non-convergence shown in Figure 2-9 is associated with the large flood depths that occur in the FSA, which causes a continuous transfer of water between the 1D and 2D model domain. This is particularly apparent in this location given that two 1D watercourses are located within close proximity and confluence within the FSA.

The reason for the fluctuations in the model convergence is also confirmed to be related to the large flood depths in the FSA because a review of the bitmap for the lower AEP events show that there is less 'noise' within the convergence plot and the non-convergence tolerance is not exceeded. During the lower AEP event (5% AEP), less water overtops from the 1D channel into the FSA, than during the higher AEP events, and therefore flood depths in the FSA are smaller. This also means that the transfer of flow between the 1D and 2D models is less than that during the higher AEP events where the capacity of the 1D channel is exceeded.

To try to reduce the rate of transfer of water between the 1D and 2D model domain, the 'a' parameter in the 1D-2D model link was increased from 0 to 0.5. This 'a' parameter allows a constriction of flow to be applied over the 1D-2D model link and can be adjusted to control the transfer of water between the 1D and 2D model domains. Increasing the value of 'a' can reduce the volumes of water transferred between the 1D and 2D models and is a method employed to enhance model stability.

The 2D Mass Balance Error for all modelled simulations is within +/-1.0%, with the exception of the 1% AEP plus 30% climate change event (-1.03%). The Cumulative Mass Error and the change in total volume of water (dVol) within the 2D model domain plots are shown in Figures 2-11 and 2-12, and both of these graphs present a change at approximately 4.8 hours into the model simulation. These two model outputs have been examined as they can be used as health indicators of the model and can highlight if there are any areas where there may be issues with model stability. The model results were reviewed, and this suggested that the drop in the cumulative mass error and dVol is also associated with the large flood depths within the FSA and the close proximity of the two 1D watercourses and therefore the continuous transfer of water between the 1D and 2D model domain. As mentioned in Section 2.4, alternative options of representing the FSA were considered (i.e. in 2D only), however given the location and representation of the sluice gate at the outlet of the FSA, a consistent approach has been maintained by representing in 1D-2D (as per the received model). It is not considered that this will affect the model results because the build-up of water occurs in the FSA which is a localised area and the affect shown in the two graphs is not observed elsewhere in the 1D model. Additionally, the FSA is not located in close proximity to the area surrounding St Richard Gwyn School.

It should be noted that it was attempted to run the model using double precision, as suggested by NRW, to improve the model performance. However, this caused the model to go unstable and so the model has been simulated using single precision.

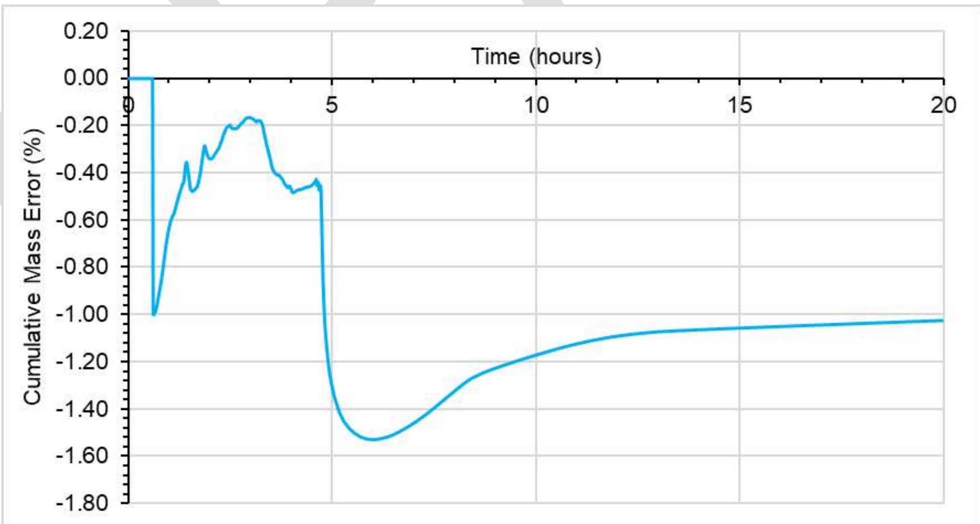


Figure 2-11: Cumulative Mass Balance Error, 1% AEP plus 30% Climate Change Event

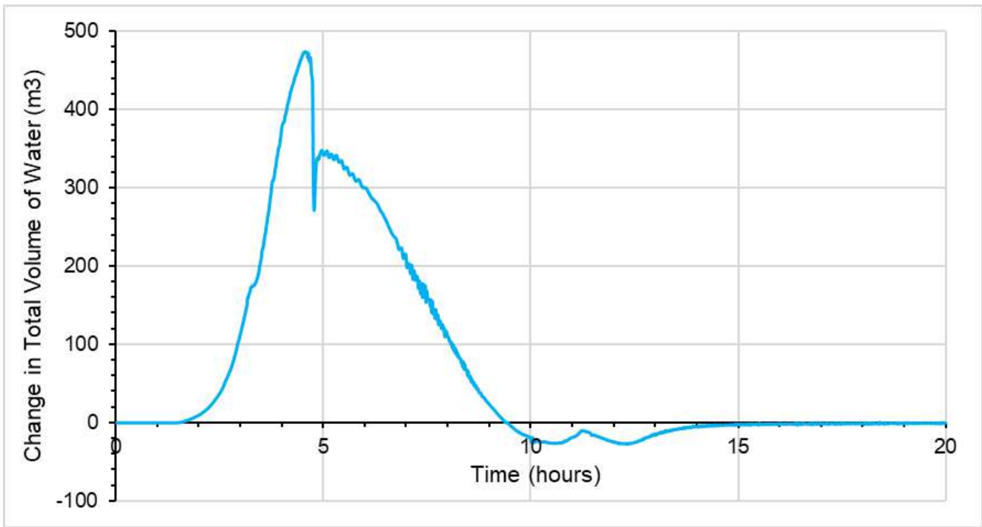


Figure 2-12: Change in Total Volume of Water - 1% AEP plus 30% Climate Change Event

3. Baseline Model Results

3.1. Overview

Following the rebuild of the received 2018 model discussed in Section 2, the baseline model has been simulated using a 20 hour storm duration for the events listed in Section 2.8 and represents the current situation. This section discusses the mechanism of flooding within the Coldbrook catchment and presents the results for the modelled AEP events.

3.2. Flooding Mechanism

A review of the 2D modelling results indicates that there are two areas within the Coldbrook model that experience out of bank flooding: the FSA and the area surrounding St Richard Gwyn School. Water levels increase in the FSA when the culvert at the outlet of the FSA reaches capacity. As discussed in Section 2.4, this culvert has a sluice gate which is set at 460mm above the culvert invert level, which controls the amount of water that is conveyed out of the FSA, and therefore how much water remains within the FSA.

The second location within the model where the Coldbrook overtops is at the downstream extent of the model in the area surrounding St Richard Gwyn School. The process by which flooding occurs in this area is progressively demonstrated by Figure 3-1 to 3-4. These figures illustrate the magnitude of water velocity that is experienced within the area surrounding the school during the 1% AEP plus 30% climate change event, alongside the velocity vectors which also demonstrate the direction of flow and the areas at which overtopping occurs.

Figure 3-1 illustrates the approximate time that the Coldbrook first reaches capacity near to the school site. This occurs adjacent to the school buildings (on the opposite side of Argae Lane) where the left bank of the watercourse overtops downstream of the farm access bridge which crosses the Coldbrook. Once overtopping occurs, floodwater propagates to the north-east across the undeveloped floodplain. It can also be seen that the Coldbrook has overtopped the right bank in two locations, approximately 450m east of the school.

Figure 3-2 demonstrates the timestep in the model where the capacity of the Coldbrook is exceeded on the right bank, upstream of the bridge, where water flows over Argae Lane and propagates south-east onto the school site. This figure also illustrates that water has continued to overtop the left bank of the watercourse downstream of the farm access bridge and water propagates across the undeveloped floodplain. Additionally, the access track to Biglis Farm prevents water that has propagated from the right bank of the watercourse, from flowing onto the school site.

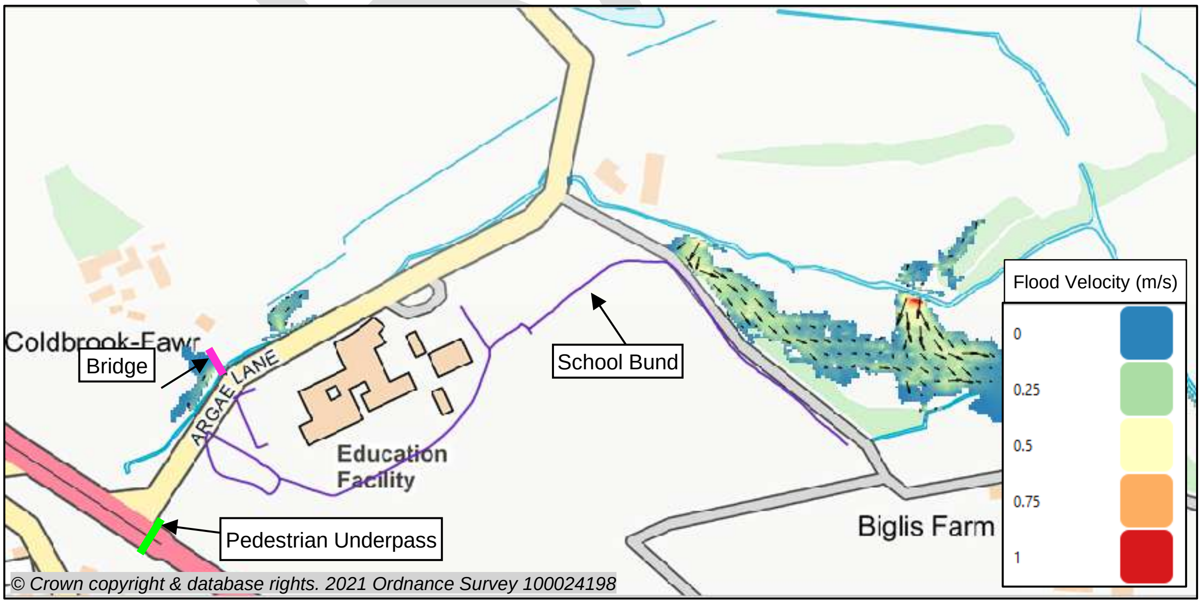


Figure 3-1: 1% AEP plus 30% Climate Change Flood Velocity Map at 2 hours and 45 minutes into Model Simulation
Water first overtops the left bank of Coldbrook adjacent to St Richard Gwyn School

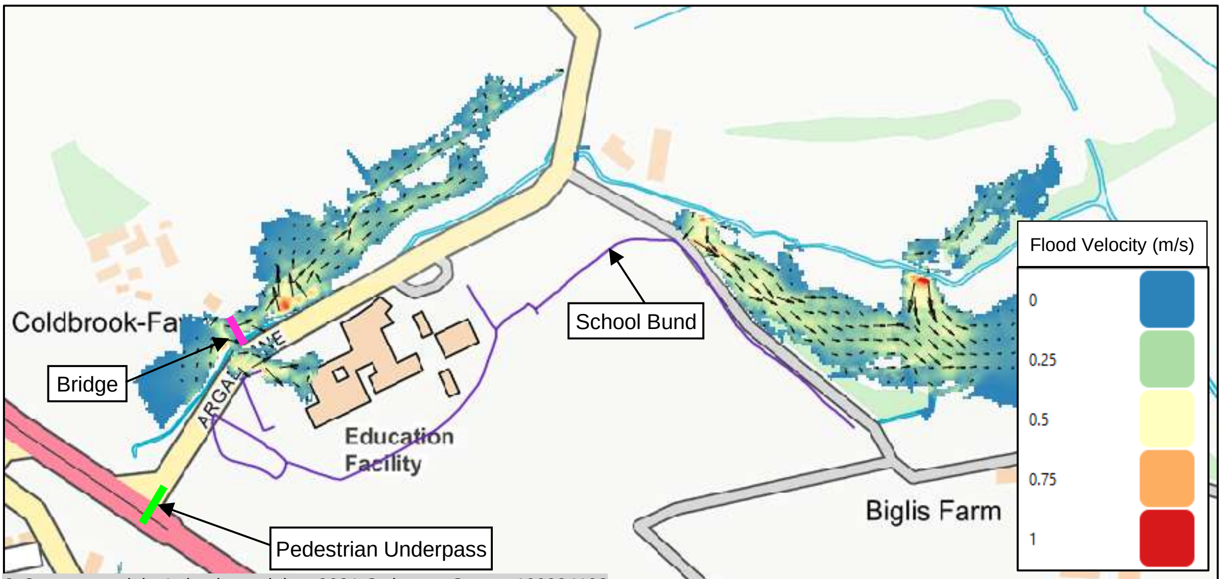


Figure 3-2: 1% AEP plus 30% Climate Change Flood Velocity Map at 3 hours and 15 minutes into Model Simulation
Water first overtops the right bank of Coldbrook and flows onto St Richard Gwyn School

Water continues to flow onto the school site from the right bank of the Coldbrook, adjacent to the school, as shown in Figure 3-3 where the extent of flooding increases as the model simulation continues. This figure also shows that the capacity of the Coldbrook has been exceeded upstream of the A4231 (Barry Docks Link Road) and water has overtopped the right bank and propagated into the pedestrian underpass under the A4231. The water then propagates east onto the school field. Flooding from these two locations continues to progress, with the flood extent increasing throughout the model simulation, as shown by Figures 3-4.

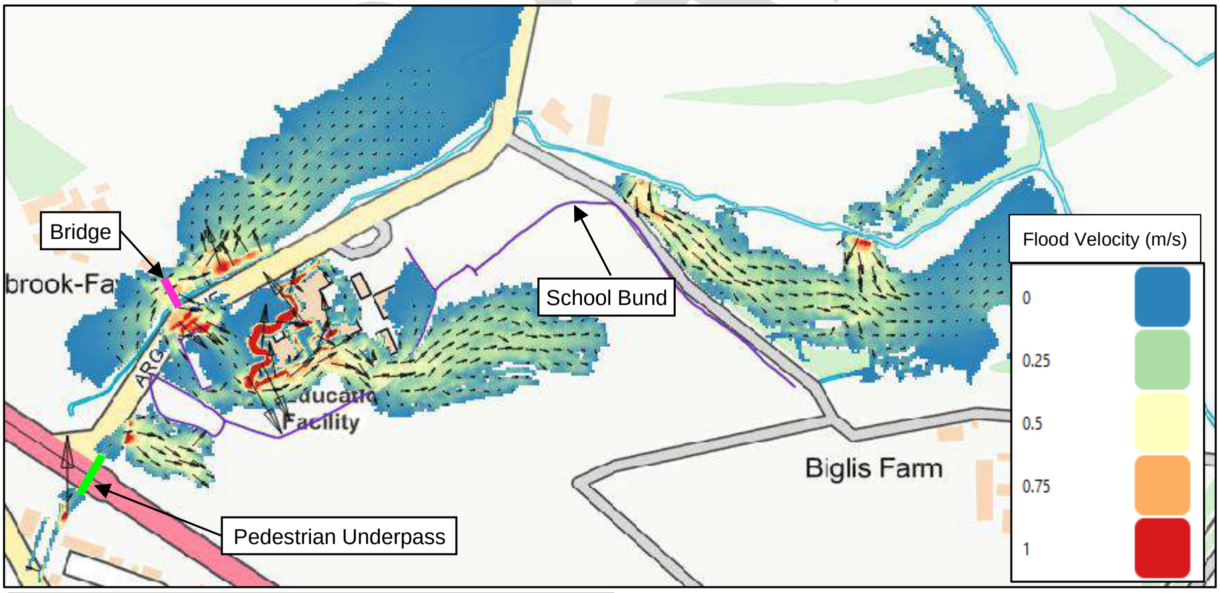


Figure 3-3: 1% AEP plus 30% Climate Change Flood Velocity Map at 4 hours into Model Simulation
Water flows from the pedestrian underpass under the A4231 onto St Richard Gwyn School site

Figure 3-4 shows how the bund around the school functions when there is flooding on site. The largest section of the bund that spans the south of the site prevents water that has propagated through the A4231 pedestrian underpass from inundating the main school site. The figures also indicate that the main source of flooding at the school site is a result of the right bank of the Coldbrook, upstream of the farm access bridge being overtopped by floodwater which propagates onto the school site. It can be seen from the velocity vectors that the water that has overtopped the right bank of the Coldbrook flows over Argae Lane and it then builds up behind the small bund perpendicular to the road where it either overtops this bund or is redirected around the bund and onto the school site. This suggests that the bund in this location may not be functioning as intended.

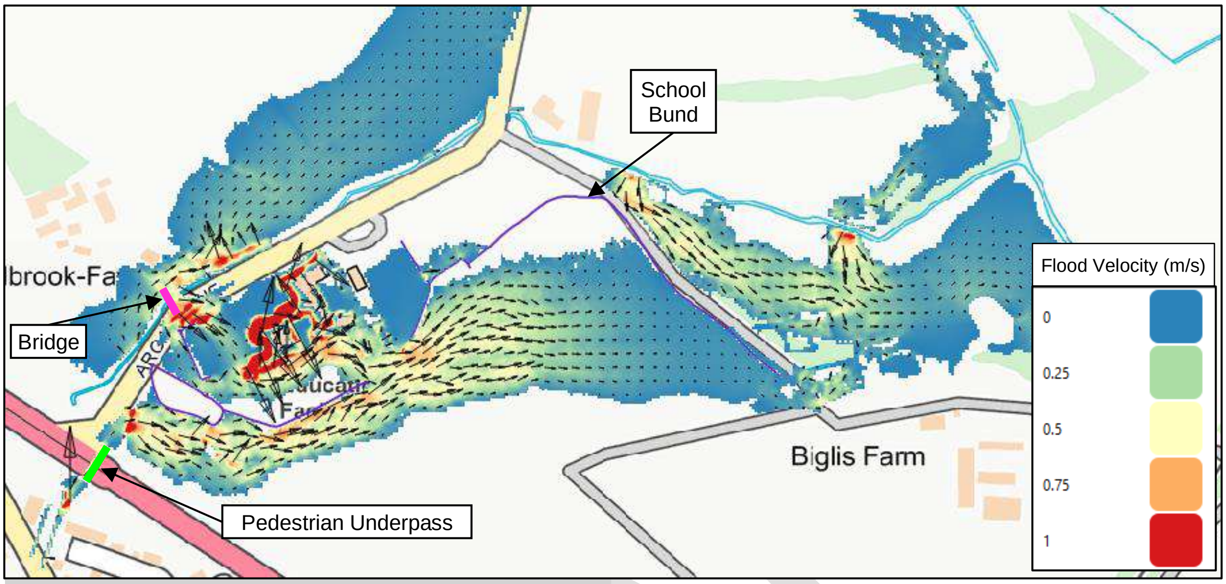


Figure 3-4: 1% AEP plus 30% Climate Change Flood Velocity Map at 4 hours and 30 minutes into Model Simulation
Water from the pedestrian underpass flows behind the bund on site and does not overtop onto the school buildings. This is near the peak of the model simulation and it shows water overtopping the bund behind the school

It should be noted that a similar mechanism of flooding occurs for all AEP events, and the extent and magnitude of flooding increases naturally with an increasing magnitude event, as expected. The results for the modelled AEP events are discussed in more details in Section 3.3.

3.3. Flood Depths and Extents

The baseline results have been used to create maximum flood depth maps of the whole model (Appendix C) and for the area surrounding St Richard Gwyn School (Appendix D). A summary of the results during the modelled AEP events (5%, 1%, 1% plus 30% climate change and 0.1%) are:

- Appendix C-1 indicates that during the 5% AEP event, out of bank flooding occurs and flood depths within the FSA during this event reach approximately 1.00m. Appendix D-1 demonstrates that during the 5% AEP event, there is flooding on the St Richard Gwyn School site of up to 0.50m. The extent of flooding during the 5% AEP event shows that water flows across the school and overtops the bund around the back of the school with depths up to 0.25m.
- During the 1% AEP event, there is flooding in the FSA with water depths of up to 1.50m as shown in Appendix C-2. Flooding also occurs on the school site with depths of up to 1.00m, as shown by Appendix D-2, while flood depths to the south of the bund around the school are up to 0.25m.
- During the 1% AEP plus 30% climate change event, flood depths within the FSA are greater than 1.50m, as shown in Figure 3-5. Additionally, the maximum depth and extent of flooding in the area surrounding the school site during the 1% AEP plus 30% climate change event is shown in Figure 3-6. This shows that the maximum flood depths at the school site are up to 1.00m within the main school building. In the agricultural field to the north of the school, on the left bank of the Coldbrook, flood depths reach up to 1.00m. The flood depths on the sports pitches are up to 0.25m.
- Appendix D-3 shows the maximum flood depths and extent for the trimmed model during the 0.1% AEP event. In the agricultural field to the north of the school, on the left bank of the Coldbrook, flood depths reach up to

1.00m. The maximum flood depths at the school site are also up to 1.00m within the main school building and 0.50m on the sports pitches.

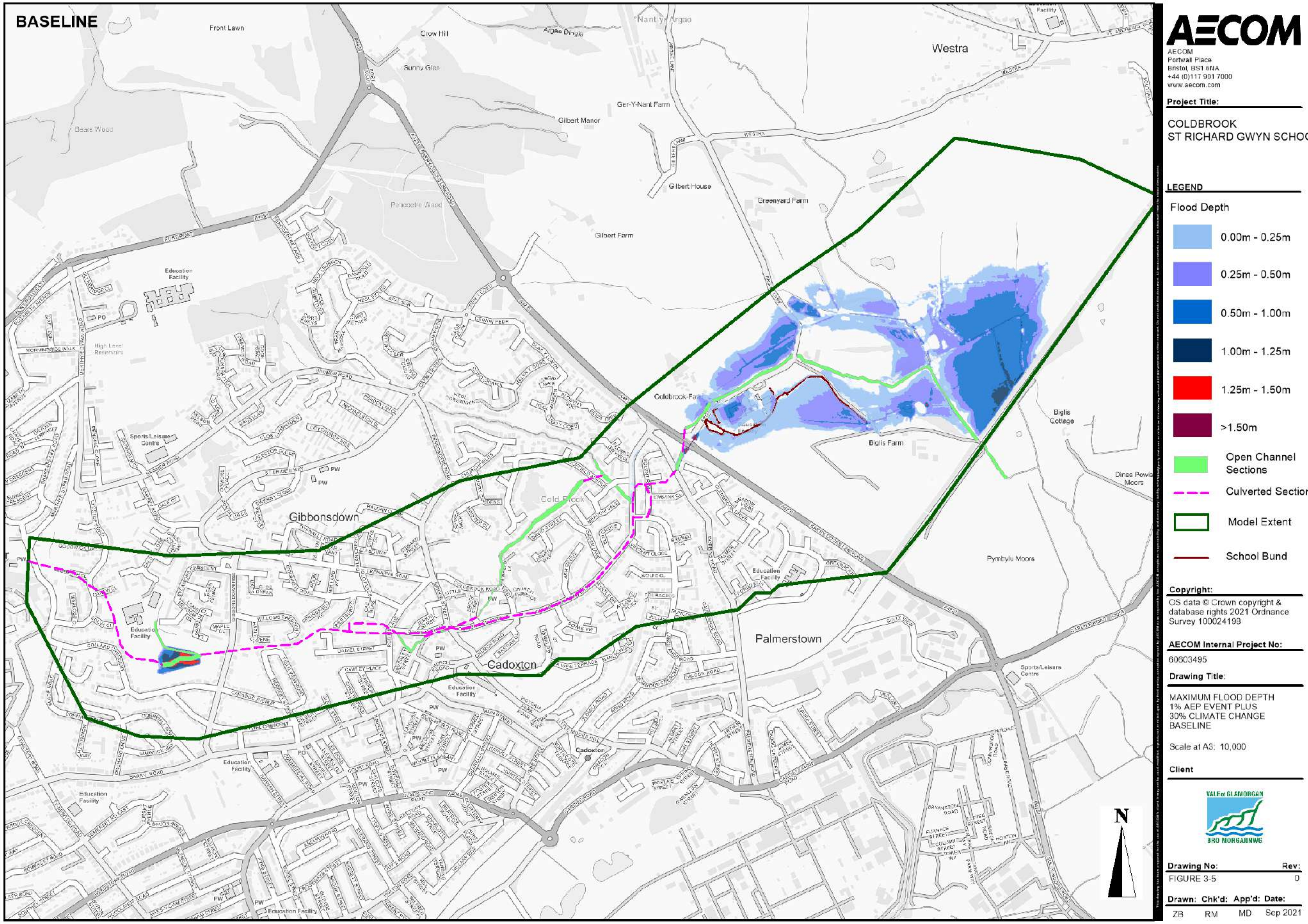


Figure 3-5: Maximum Flood Depth Whole Model (1% AEP plus 30% Climate Change Event)

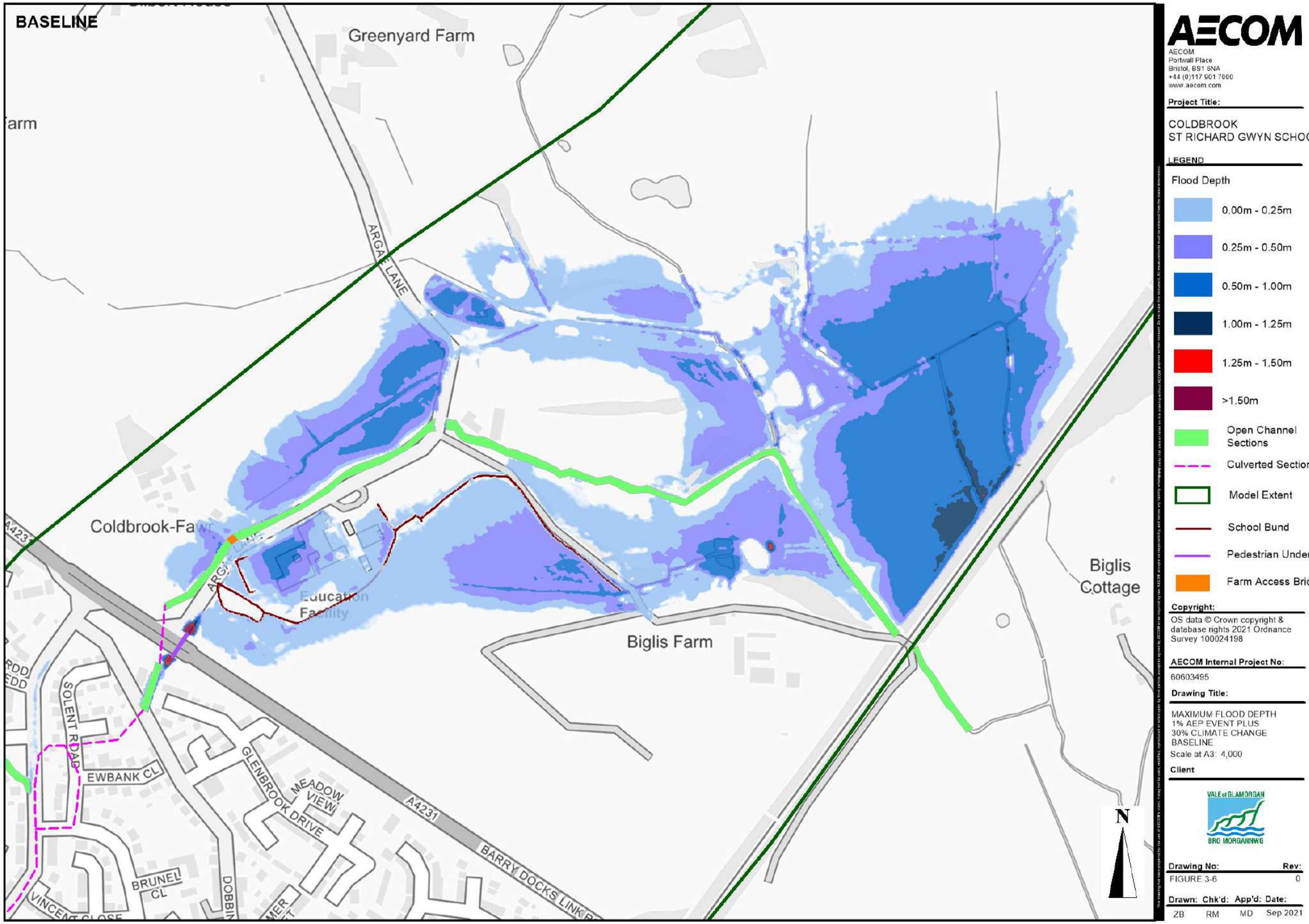


Figure 3-6: Maximum Flood Depth Area Surrounding St Richard Gwyn School (1% AEP plus 30% Climate Change Event)

3.4. Model Validation

Calibration and validation are important aspects of the model proving process. These steps are important in improving the quality of hydraulic models and understanding the uncertainties and limitations. Calibration is broadly defined as the process by which model parameters are adjusted so that resulting model outputs fit as closely as possible to observed datasets.

Model validation refers to the process whereby a model is assessed with observed datasets in order to provide an indication of the accuracy of the model outputs. It should be noted that the model validation can be broadly separated into two types:

- Quantitative validation – this involves rigorous objective comparison of model outputs with precise observed data. For example, data from river gauges and/or comparison of modelled flood extent with observed flood extent measured from aerial photography. Photos containing metadata i.e. time, date and location can also be considered as observed data suitable for quantitative validation.
- Qualitative validation – this involves comparison of model outputs to anecdotal observations and is generally more subjective than a quantitative validation exercise. For example, this includes personal accounts of a particular event and photos that do not contain appropriate metadata.

The Coldbrook hydraulic model has only been partially validated as it has been based on very limited available information and therefore only the flowpaths have been validated. The only information available to validate the model included one quantitative source (telemetry data) and a couple of qualitative sources (anecdotal reports/photographs).

3.4.1. *Available Data*

Since the Flood Alleviation Scheme was completed in 2016, there have been limited flood events to validate the model results. VoGC provided AECOM with the data that they had at the time of writing this report, which included telemetry data from the level gauge at the Coldbrook farm access bridge opposite the school, for the following events. Peak water depth is presented in m aSD which is assumed to be metres above standard datum (however the datum is unknown):

- 29th February 2020 (Peak depth = 1.46m aSD)
- 19th June 2020 (Peak depth = 1.45m aSD)
- 23rd December 2020 (Peak depth = 1.40m aSD)
- 29th January 2021 (Peak depth = 1.33m aSD)
- 2nd February 2021 (Peak depth = 1.00m aSD)

The telemetry data logger at this location notifies when the water depth reaches 1.00m aSD and 1.40m aSD which is the reason that the flood events above have been highlighted. According to VoGC, the 23rd December 2020 flood event has been analysed to be between a 5% and 3.33% AEP event. This was calculated by JBA using gauging data from DCWW Cog Moors Treatment Works plus other rain gauges in the area although a report was unavailable for review as part of this study. According to the telemetry data, the peak water depth during this event is slightly lower than the 29th February 2020 and 19th June 2020 events.

It should be noted that anecdotal evidence to support the telemetry data, such as photos, were not available for the majority of these events (except the 29th February 2020) as these occurred during the Covid-19 pandemic while the work from home guidance was in place by the UK government. It was therefore not possible for VoGC to visit the site and take photos during this period.

3.4.2. *Historic Flooding at St Richard Gwyn School*

In July 2007 and February 2020, St Richard Gwyn School experienced surface water flooding and fluvial flooding from the Coldbrook. Since 2007, the Coldbrook Flood Alleviation Scheme has been constructed which has been reported to have reduced the frequency of flood events in the area. However, ion 29th February 2020 extreme rainfall combined with a saturated catchment resulted in the Coldbrook overtopping at the farm access bridge opposite the school which resulted in floodwater inundating the site leading to a temporary closure. Although the school buildings were not inundated (albeit very close to reaching building threshold levels), the car park and the entrance to the main building were flooded and the school was therefore not considered safe for pupils.

The model results discussed in this modelling report have been assessed against the 29th February 2020 flood event as VoGC were able to provide some photographic evidence for this event as well as telemetry data.

3.4.3. February 2020 Flood Event

With the aim of comparing similar AEP events, the model results for the 5% AEP event have been compared with the evidence provided to AECOM for the February 2020 flood event by VoGC. As discussed above, JBA considered the 23rd December 2020 event to be between a 5% and 3.33% AEP event, and the peak water depth at the gauge for this event is similar to the 29th February 2020 event. Below provides a comparison of the modelled results against the data provided for the February 2020 event:

- The location of overtopping at the farm access bridge is confirmed by Figure 3-7 as this is the same overtopping location shown by the modelled 5% AEP results.
- During the February 2020 flood event, floodwater naturally flows towards the school where ground levels are lower, ponding against the kerb as shown in Figure 3-8. Eventually water overtops the kerb and flows through the car park towards the main school building. Floodwater also flows east along Argae Lane with water entering the main vehicular access route to the school. The photos have been useful to confirm and verify the overtopping locations shown by the baseline model. The model results also shown the same propagation of floodwater as described above.
- It should be noted that during this February 2020 flood event, there was no reported flooding from the pedestrian underpass and therefore the sports pitches to the rear of the school were not inundated. However, according to the modelled 5% AEP event, the maximum flood depth maps (Appendix D-1) shows flooding within the school building of up to 0.50m and the floodwater is shown to overtop the bund around the back of the school.
- There is no evidence of a flowpath from the pedestrian underpass onto the school site during the February 2020 event which is reflected within the 5% AEP modelling results.

The flooding at the school building suggests that the modelled 5% AEP flood extents and depths are greater than those shown in the photographs. However, it is important to note that it is unknown when these photographs were taken compared with the peak of the flood event: the maximum flood depth maps capture the peak flood depth within each grid cell during the whole model simulation. It could be possible that the peak of the event wasn't captured by the photographs. Furthermore, no detailed information regarding maximum flood extents was provided for this event.

The telemetry data from 29th February 2020 suggests that the peak water depth experienced was 1.46m aSD. The in-channel peak water depth upstream and downstream of the farm access bridge for the modelled 5% AEP event is 1.59m and 1.30m respectively. If the telemetry data has been interpreted correctly such that the water depth downstream of the farm access bridge was 1.46m aSD then the model results are showing a larger flood depth within the channel than the recorded telemetry data (that is expected to be between a 5% and 3.33% AEP event). This is the same conclusion that has been made regarding the flood extents when comparing the February 2020 event with the modelled 5% AEP event.

In conclusion, anecdotal evidence and telemetry data from a flood events have been used to verify the flood mechanism from the hydraulic model results. While the results from the 5% AEP event differ slightly from what was reported and observed during the 29th February 2020 event (which has been estimated to be between a 5% AEP and 3.33% AEP event), the model has shown the mechanism of flooding to be consistent with real life events. It is important to note that there are elements that have not been included within this hydraulic model which may have an impact on flood extents and depths i.e. the inclusion of drainage networks, representation of ground saturation etc, which should be considered as limitations to the model.

In the absence of gauged flow data, it has not been possible to fully calibrate and validate the hydraulic model.

Figure 3-7: February 2020 Event - Farm access bridge, taken from right bank of Coldbrook

Source: VoGC

Figure 3-8: February 2020 Event – Argae Lane, facing eastwards from right bank of Coldbrook

Source: VoGC

4. Sensitivity Analysis

4.1. Overview

Sensitivity testing of the model was undertaken to assess the influence of parameter assumptions made during the model development. The following elements were recommended by NRW to assess the model sensitivity and therefore the potential impact on maximum flood depth for the baseline 1% AEP plus 30% climate change event:

- Manning's Roughness Coefficient values +/-20% in 1D and 2D values; and,
- Variation in the setup of the downstream boundary.

Sensitivity analysis for Manning's Roughness Coefficient values has been carried out, however the modelled downstream boundary is located more than 1km away from the St Richard Gwyn site. It is not envisaged that any changes to the representation will impact the results at the St Richard Gwyn site and therefore it is not considered that a sensitivity analysis of a variation of the downstream boundary will provide any benefit to the study. This was discussed with NRW during the meeting on 26th March 2021 and this sensitivity has therefore not been undertaken.

4.2. Manning's Roughness

Manning's Roughness Coefficient sensitivity was conducted by applying a +20% and -20% value to all 1D (open channel) and 2D (floodplain) elements as specified in the 1D FMP DAT file and 2D materials layer respectively. This effectively creates either a rougher (+20%) or smoother (-20%) path for water to propagate through the hydraulic model. It should be noted that the global edit feature was used in FMP to apply the roughness changes and this feature changes the Manning's Roughness Coefficient values in open channel sections only and therefore any structures are retained as per the baseline. It is not expected that this would change the results of the sensitivity significantly.

To understand the impact of changing the roughness parameter, in-channel water levels were extracted throughout the model to help identify key areas that were sensitive to the changes. Table 4-1 shows the change in water levels for several locations throughout the model.

Table 4-1: 1D Maximum Water Levels

1D Node Label	Location Description	Maximum Stage at Node				
		Baseline (m AOD)	+20% Roughness Sensitivity (m AOD)	Difference (m)	-20% Roughness Sensitivity (m AOD)	Difference (m)
COLD2A_0180D	Upstream of FSA	32.99	32.96	-0.03	32.94	-0.05
COLD4_0233	Open channel north of David Street	14.89	14.97	+0.08	14.80	-0.09
CS1034	Upstream of A4231 pedestrian underpass	11.72	11.72	0.00	11.72	0.00
CS1024	Upstream of Argae Lane Farm Bridge	11.06	11.09	+0.03	11.04	-0.02
CS1021	Adjacent to School Building	10.62	10.63	+0.01	10.60	-0.02
CS1008	East of School	9.67	9.68	+0.01	9.67	0.00

Table 4-1 demonstrates that there is generally negligible change in the maximum water levels within the 1D channel at the nodes shown in the table. The largest change in maximum water levels is experienced at Node COLD4_0233, however this node is located approximately 1km upstream of the St Richard Gwyn School and there is no out of bank flooding that occurs in this location. Additionally, the model extents and depths in the 2D domain have been compared and there is negligible change in the area of interest. There is a slight change in the 2D flood extent on Coldbrook Road East (whereby roughness factor of -20% and +20% causes a small reduction and increase of the flood extents respectively), however the change is insignificant and the extent of flooding remains on the road with no properties affected. Therefore, it can be concluded that the model is insensitive to changes in the roughness parameters in the 1D and 2D domain.

5. Model Limitations and Recommendations

5.1. Limitations

When considering the results and discussion throughout this report, it is important to understand the limitations and uncertainties associated with the model and its outputs. The key limitations identified as part of the modelling process are discussed below:

- The Manning's Roughness Coefficient parameters have been reviewed and updated within the 1D model, however the OS MasterMap within the 2D model domain has not been updated from the received 2018 model. It is not considered that this will affect the modelling results as it doesn't appear that there have been significant development changes within the catchment.
- The model was simulated for the same AEP events as those simulated in the received 2018 model when the model was initially updated. However, as part of the update to the hydrology following comment from NRW, only the AEP events where out of bank flooding occurs at the school have been reproduced. The AEP events modelled in the most recent study are therefore 5%, 1% and 1% plus 30% climate change. The main change between the AEP events is that the climate change allowance applied to the 1% AEP event has been updated in line with the most recent climate change guidance. The climate change allowance used as part of this modelling study is the central climate change allowance (30%) for the West Wales river basin district. If the model is required to be simulated with higher flows, such as the upper climate change allowance (75%), further model amendments may be required to ensure the model remains stable.
- It should be noted that the 0.1% AEP flows were created following NRW comments, however the model became unstable during this event because of the large amount of flow in the model and culverted nature of the catchment. The model has therefore been trimmed, as discussed in Section 2.9 to enable the model to run for this flood event.
- The minimum flows specified in the IED input file (the file that specifies the flow for each AEP event) were reduced where possible i.e. where the 1D model allowed and the channel did not run dry. The minimum flows for the majority of the inflow locations were reduced to be significantly lower than the peak flow during the 20% AEP event (lowest modelled AEP event). There are two exceptions to this: the minimum flows at the inflow point 'Merthyr' are set at 0.11m^3/s which is larger than the peak flow of 0.057m^3/s during the 20% AEP event; and the minimum flows at the inflow point 'ColdbrookN' are 0.50m^3/s and the peak flow during the 20% AEP event is 0.882m^3/s. It is not considered that this will have an impact on the model results as the flows are insignificant in comparison to the total flow in the model.
- Where As-Built survey of the Coldbrook Flood Alleviation Scheme was available, this was checked against the received model and updated where required. However, As-Built survey for the whole model was not available and therefore it has been assumed that the representation in the received 2018 model is correct.
- The model does not include any representation of the drainage network or other factors such as ground saturation. This may therefore have an impact on results when comparing to past flood events.
- In the absence of gauged flow data, it has not been possible to fully calibrate and validate the hydraulic model.

5.2. Recommendations

When considering the limitations stated in Section 5.1, there are several recommendations that would potentially improve confidence of the modelling results. These include:

- If the most recent OS MasterMap becomes available, it is recommended that this is updated into the 2D model (potentially during the optioneering phase for the St Richard Gwyn School), however this is not considered to adversely impact the model results.
- Should As-Built survey of the Coldbrook Flood Alleviation Scheme become available, it is recommended that this is updated into the model where required.
- If further evidence of historic or future flood events become available, it is recommended that a further model validation exercise is undertaken as the information available at the time of writing this report was limited. If gauged flow data is available, this could also be utilised to calibrate the model.

- To allow the whole model to simulate with higher flows (i.e. 0.1% AEP event) it may be necessary to convert the model to ESTRY-TUFLOW. Models built using ESTRY are usually more stable when representing heavily culverted catchments and low flows.

6. Conclusions

The model has been updated based on survey information provided by VoGC and it now simulates in the most recent modelling software at the time of writing this report. This has improved the robustness of the model and the representation of flood risk in the vicinity of St Richard Gwyn School. Additionally, the hydrological assessment has been updated in line with the most recent climate change guidance which enables the model results to be used to support future FCAs within the Coldbrook catchment.

As part of the model updates following model review comments from NRW, the hydrology has since been updated for the AEP events where out of bank flooding occurs at St Richard Gwyn School. Other model updates have also taken place as detailed in this report.

The baseline model results conclude that there are two key areas within the Coldbrook catchment that experience out of bank flooding: the FSA in Merthyr Dyfan and the area surrounding St Richard Gwyn School. During the 5% AEP, 1% AEP, 1% AEP plus 30% climate change and 0.1% AEP events, there is flooding within the school site, up to a depth of 1.00m. The extent and depth of flooding increases with event magnitude as expected.

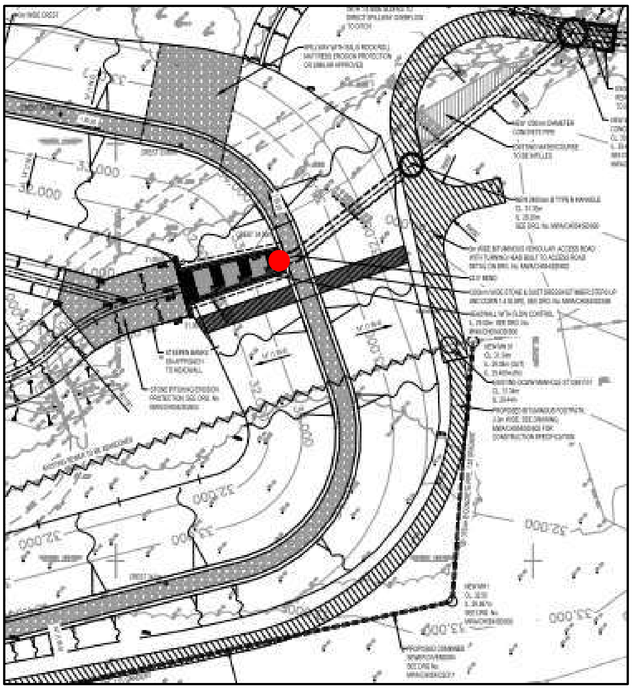
It can be concluded that this hydraulic modelling study has created a model that represents the Coldbrook Flood Alleviation Scheme such that it can be used to support future development within the Coldbrook catchment.

Appendix A – FSA Culvert Sluice Gate Information

DATA SHEET C – Reservoir Operational Data

Location Details

Location:	Dyfan Road Public Open Space, Barry, with the nearest postcode being CF63 1DP.
Grid reference:	ST 12009 69191
A4 Location / directions map with scale:	See map attached in Section 1
A4 Sketch of Penstock location:	See plan below with valve location marked by red spot.



Details of Dam

Name:	Coldbrook Attenuation Pond
Use:	Flood storage
Type:	Earth fill
Date built:	2017
Height:	3m approx. maximum height measured from the lowest natural level of the surrounding land contiguous to it, to the top of the embankment
Crest length:	395 m approx.
Overflow / top water level:	33.85m AOD
Design top water level:	33.68m AOD
Dam Crest Level	34m AOD

Water depth:	2.85m approx. measured from the lowest natural level of the surrounding land contiguous to it, to top water level
Total storage capacity:	19,812m^3
Design flood category:	Category A

Valve

Type:	1200 mm ∅ low level discharge penstock
Set partially open:	460mm above invert – position marked on site
Discharge Capacities:	2.48 cumecs (normal operating water level 33.68m AOD)

Reservoir Capacities

The As-Built Model has been used to prepare the table below, which shows the drawdown data for the Pond with the time taken in hours and minutes from the peak of the 1 in 100 year event + climate change of 20%. This is with flood water still being fed into the Pond as defined by the original hydrology and with the penstock in its partially open position.

Draw down from TWL	Water level (mAOD)	Max. Discharge (m^3/s)	Time taken for draw-down
0.0 m down	33.68	2.48	00:00
0.5 m down	33.18	2.19	02:00
1.0 m down	32.68	1.96	03:35
1.5 m down	32.18	1.76	05:25
2.0 m down	31.68	1.54	08:10
2.4 m down	31.26	1.35	16:30

NB: 31.26m AOD is being taken as the general ground level within the Pond area at the base of the embankment.

The Average drawdown rate is: 3 hrs for 0.5m

Reservoir Operation

Reservoir use:	Attenuation pond on the Coldbrook catchment, which is part of a scheme to provide 1 in 100 year + 20% climate change

Impact of Failure on Undertaker Operations

Loss of flood storage will increase the risk of flooding downstream.

Appendix B – Hydrological Assessment

Technical Note

Project:	Coldbrook Hydraulic Model Update	Job No:	60603495
Subject:	Revisiting urban expansion area		
Version:	2		
Prepared by:	Ed Malone	Date:	19/08/21
Checked by:	Rob Sweet	Date:	31/08/21

1. Introduction

The purpose of this technical note is the provision of updated peak flow estimates (5% AEP, 1% AEP and 1% AEP + CC, 0.1% AEP) generated using a revised urban area value for the Coldbrook Catchment.

This technical note is supplementary to the Cold Brook Hydrology Update[1], please refer to this document for greater detail and justification into the methods used.

2. Overview of current urban representation

Following review and discussion with NRW in order to reflect the urban expansion in the north eastern corner of the Coldbrook catchment (Figure 2-1), the urban area value in the ReFH2 urbanisation parameters was increased from the catchment descriptor based 1.91 km^2 to 2.78 km^2.

However, such a direct measurement of the developed area is likely to overestimate urbanisation (and therefore URBEXT2000) as there is no differentiation between ‘Urban’, ‘sub-urban’ and ‘Inland Bare Ground’ that make up URBEXT2000, equation 1[2]:

$$URBEXT2000 = URBEXT + 0.5\,SUBURBEXT + 0.8\,IBGEXT$$

This overestimation results in greater peak flow estimates[1], and the proposed scheme design is no longer viable based on hydraulic model outputs.

To address this, we propose that a more realistic differentiation of the urban expansion area will better represent the true characteristics of the catchment.

[1] 20210714_Cold Brook Hydrology Update_v7
[2] R&D Technical Report FD1919/TR (2006)

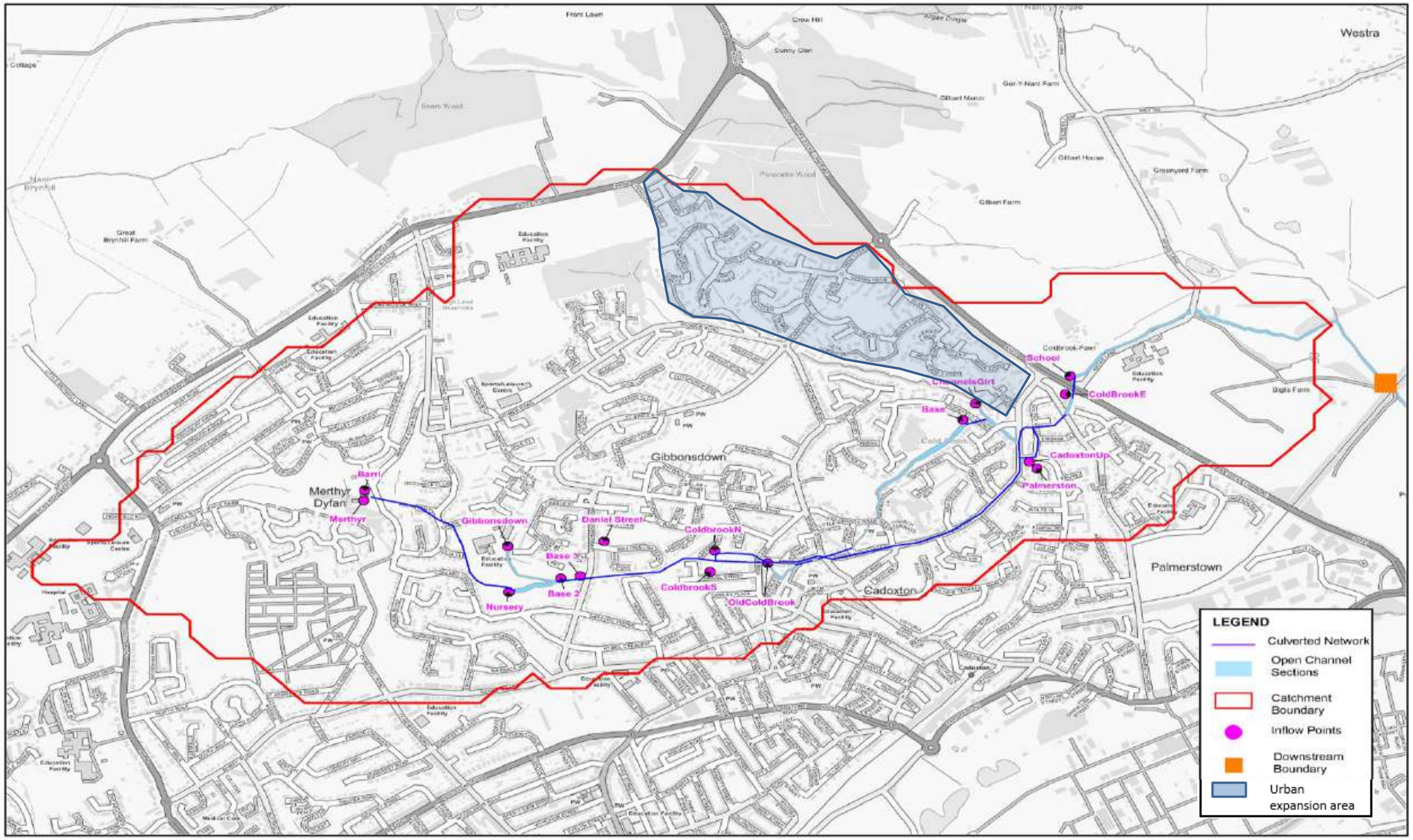


Figure 2.1: Coldbrook Catchment Map

3. Method updates and results

3.1. URBEXT2000

The land cover type of the urban expansion area was assessed using areal imagery[3], with the majority of the area determined to be suburban (0.27 km^2), with a small area of urban (0.006 km^2). This was also cross checked against the LCM2019[4] data, which shows the expansion area as wholly suburban, therefore providing further justification for our choice of classification.

The new and existing areas were digitised in GIS software according to their type, and the respective area extents extracted. The combined values (original URBEXT2000 area + urban expansion) for each classification (URBext 0.23, SUBURBext 2.259 and IBGext 0.01) were then used in the URBEXT equation to give an updated URBEXT2000 value of 0.3506, with a revised urban catchment area value of 2.14 km^2.

As a check on the accuracy of the GIS digitisation method, a comparison with the catchment descriptor URBEXT2000 value was also undertaken excluding the expansion area (Table 1).

Table 1. URBEXT2000 value comparison

URBEXT2000 source	Value
Catchment descriptors	0.3133
GIS excluding expansion	0.3145
GIS including expansion	0.3506

As can be seen in table 1, the comparison between CDs and the GIS determined URBEXT2000 value is very close, leading credibility to the updated value that included the urban expansion area.

3.2. *ReFH2*

The updated URBEXT2000 value was used in ReFH2.3 software (BFIHOST19, FEH2013 rainfall model) to generate the new set of lumped catchment flow estimates (Table 2). Under the urbanisation parameter, the new urban area based on the update URBEXT2000 value was calculated to be 2.14 km^2, which is an intermediate value compared to the original CD value of 1.91 km^2 and the NRW value of 2.78 km^2.

Table 2: Flood peak estimates (m^{3}s^{-1}), and scaling factors.

	20	100	100 + 30% CC	1000
2021 estimate	6.8	10.3	13.4	20.1
MWA 2013	6.16	9.48	-	-

[3] Google Maps, Imagery 2021

[4] CEH Land Cover, LCM2019

Table 2: Flood peak estimates (m^3s^{-1}), and scaling factors.

	20	100	100 + 30% CC	1000
Scaling factor	1.10	1.09	1.41	2.12

The new 1% AEP peak flow of 10.3 m^3s^{-1} also sits between the NRW based flows estimate of 11.08 m^3s^{-1}, and the earlier MWA (2013) estimate of 9.48 m^3s^{-1}.

As part of this modelling, only the 'central estimate' (30%) has been applied as CC to the 1% AEP estimate as this is the scenario that will require consideration for future development[5].

Further details of the ReFH2 parameters can be found in the attached ReFH2 report (appendix).

4. Summary

The lumped catchment flow estimates and associated scaling factors to be applied to the corresponding MWA (2013) model inflows are presented in Table 2. This technical note provides a robust and evidence based approach to updating URBEXT2000, and should therefore be used in the analysis.

[5] NRW (2016) Flood Consequence Assessments: Climate Change Allowances

UK Design Flood Estimation

Generated on Thursday, August 19, 2021 10:48:39 AM by Ed.Malone
Printed from the ReFH2 Flood Modelling software package, version 3.2.7650.24314

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH2)

Site details Checksum: DB12-AD07

Site name: FEH_Catchment_Descriptors_314250_170050(updatedURBEXT)

Easting: 314250

Northing: 170050

Country: England, Wales or Northern Ireland

Catchment Area (km^2): 3.9

Using plot scale calculations: No

Model: 2.3

Site description: None

Model run: 2 year

Summary of results

Rainfall - FEH 2013 model (mm):	24.34	Total runoff (ML):	44.71
Total Rainfall (mm):	22.70	Total flow (ML):	77.26
Peak Rainfall (mm):	8.05	Peak flow (m^3/s):	3.35

Parameters

Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.
** Indicates that the user locked the duration/timestep*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hh:mm:ss)	04:30:00	No
Timestep (hh:mm:ss)	00:30:00	No
SCF (Seasonal correction factor)	0.97	No
ARF (Areal reduction factor)	0.96	No
Seasonality	Summer	No

Loss model parameters

Name	Value	User-defined?
Cini (mm)	114.92	No
Cmax (mm)	223.42	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	2.15	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m^3/s)	0.16	No
BL (hr)	25.68	No
BR	0.77	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km^2)	2.14	No
Urbext 2000	0.35	No
Impervious runoff factor	0.7	No
Imperviousness factor	0.4	No
Tp scaling factor	0.75	No
Depression storage depth (mm)	0.5	No
Exporting drained area (km^2)	0.72	Yes
Sewer capacity (m^3/s)	1.85	Yes

Time series data

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (mm)	Net Rain (mm)	Runoff (m^3/s)	Baseflow (m^3/s)	Total Flow (m^3/s)
00:00:00	0.671	0.089	0.304	0.000	0.125	0.125
00:30:00	1.098	0.158	0.519	0.016	0.123	0.139
01:00:00	1.895	0.274	0.905	0.076	0.121	0.197
01:30:00	3.665	0.537	1.784	0.211	0.120	0.331
02:00:00	8.047	1.213	4.067	0.479	0.121	0.600
02:30:00	3.665	0.568	1.921	1.014	0.127	1.141
03:00:00	1.895	0.297	1.010	1.776	0.139	1.915
03:30:00	1.098	0.173	0.590	2.532	0.160	2.691
04:00:00	0.671	0.106	0.363	3.048	0.189	3.237
04:30:00	0.000	0.000	0.000	3.129	0.223	3.353
05:00:00	0.000	0.000	0.000	2.866	0.259	3.125
05:30:00	0.000	0.000	0.000	2.449	0.292	2.741
06:00:00	0.000	0.000	0.000	2.007	0.320	2.327
06:30:00	0.000	0.000	0.000	1.574	0.342	1.915
07:00:00	0.000	0.000	0.000	1.197	0.358	1.555
07:30:00	0.000	0.000	0.000	0.877	0.370	1.246
08:00:00	0.000	0.000	0.000	0.610	0.377	0.988
08:30:00	0.000	0.000	0.000	0.417	0.382	0.799
09:00:00	0.000	0.000	0.000	0.273	0.383	0.655
09:30:00	0.000	0.000	0.000	0.158	0.381	0.539
10:00:00	0.000	0.000	0.000	0.076	0.376	0.452
10:30:00	0.000	0.000	0.000	0.034	0.371	0.405
11:00:00	0.000	0.000	0.000	0.014	0.364	0.378
11:30:00	0.000	0.000	0.000	0.004	0.357	0.362
12:00:00	0.000	0.000	0.000	0.000	0.351	0.351
12:30:00	0.000	0.000	0.000	0.000	0.344	0.344
13:00:00	0.000	0.000	0.000	0.000	0.337	0.337
13:30:00	0.000	0.000	0.000	0.000	0.331	0.331
14:00:00	0.000	0.000	0.000	0.000	0.324	0.324
14:30:00	0.000	0.000	0.000	0.000	0.318	0.318
15:00:00	0.000	0.000	0.000	0.000	0.312	0.312
15:30:00	0.000	0.000	0.000	0.000	0.306	0.306
16:00:00	0.000	0.000	0.000	0.000	0.300	0.300
16:30:00	0.000	0.000	0.000	0.000	0.294	0.294
17:00:00	0.000	0.000	0.000	0.000	0.289	0.289

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (mm)	Net Rain (mm)	Runoff (m^3/s)	Baseflow (m^3/s)	Total Flow (m^3/s)
17:30:00	0.000	0.000	0.000	0.000	0.283	0.283
18:00:00	0.000	0.000	0.000	0.000	0.278	0.278
18:30:00	0.000	0.000	0.000	0.000	0.272	0.272
19:00:00	0.000	0.000	0.000	0.000	0.267	0.267
19:30:00	0.000	0.000	0.000	0.000	0.262	0.262
20:00:00	0.000	0.000	0.000	0.000	0.257	0.257
20:30:00	0.000	0.000	0.000	0.000	0.252	0.252
21:00:00	0.000	0.000	0.000	0.000	0.247	0.247
21:30:00	0.000	0.000	0.000	0.000	0.242	0.242
22:00:00	0.000	0.000	0.000	0.000	0.238	0.238
22:30:00	0.000	0.000	0.000	0.000	0.233	0.233
23:00:00	0.000	0.000	0.000	0.000	0.228	0.228
23:30:00	0.000	0.000	0.000	0.000	0.224	0.224
24:00:00	0.000	0.000	0.000	0.000	0.220	0.220
24:30:00	0.000	0.000	0.000	0.000	0.215	0.215
25:00:00	0.000	0.000	0.000	0.000	0.211	0.211
25:30:00	0.000	0.000	0.000	0.000	0.207	0.207
26:00:00	0.000	0.000	0.000	0.000	0.203	0.203
26:30:00	0.000	0.000	0.000	0.000	0.199	0.199
27:00:00	0.000	0.000	0.000	0.000	0.196	0.196
27:30:00	0.000	0.000	0.000	0.000	0.192	0.192
28:00:00	0.000	0.000	0.000	0.000	0.188	0.188
28:30:00	0.000	0.000	0.000	0.000	0.184	0.184
29:00:00	0.000	0.000	0.000	0.000	0.181	0.181
29:30:00	0.000	0.000	0.000	0.000	0.177	0.177
30:00:00	0.000	0.000	0.000	0.000	0.174	0.174
30:30:00	0.000	0.000	0.000	0.000	0.171	0.171
31:00:00	0.000	0.000	0.000	0.000	0.167	0.167
31:30:00	0.000	0.000	0.000	0.000	0.164	0.164
32:00:00	0.000	0.000	0.000	0.000	0.161	0.161
32:30:00	0.000	0.000	0.000	0.000	0.158	0.158
33:00:00	0.000	0.000	0.000	0.000	0.155	0.155
33:30:00	0.000	0.000	0.000	0.000	0.152	0.152
34:00:00	0.000	0.000	0.000	0.000	0.149	0.149
34:30:00	0.000	0.000	0.000	0.000	0.146	0.146
35:00:00	0.000	0.000	0.000	0.000	0.143	0.143

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (mm)	Net Rain (mm)	Runoff (m^3/s)	Baseflow (m^3/s)	Total Flow (m^3/s)
35:30:00	0.000	0.000	0.000	0.000	0.140	0.140
36:00:00	0.000	0.000	0.000	0.000	0.138	0.138
36:30:00	0.000	0.000	0.000	0.000	0.135	0.135
37:00:00	0.000	0.000	0.000	0.000	0.132	0.132
37:30:00	0.000	0.000	0.000	0.000	0.130	0.130
38:00:00	0.000	0.000	0.000	0.000	0.127	0.127

Appendix

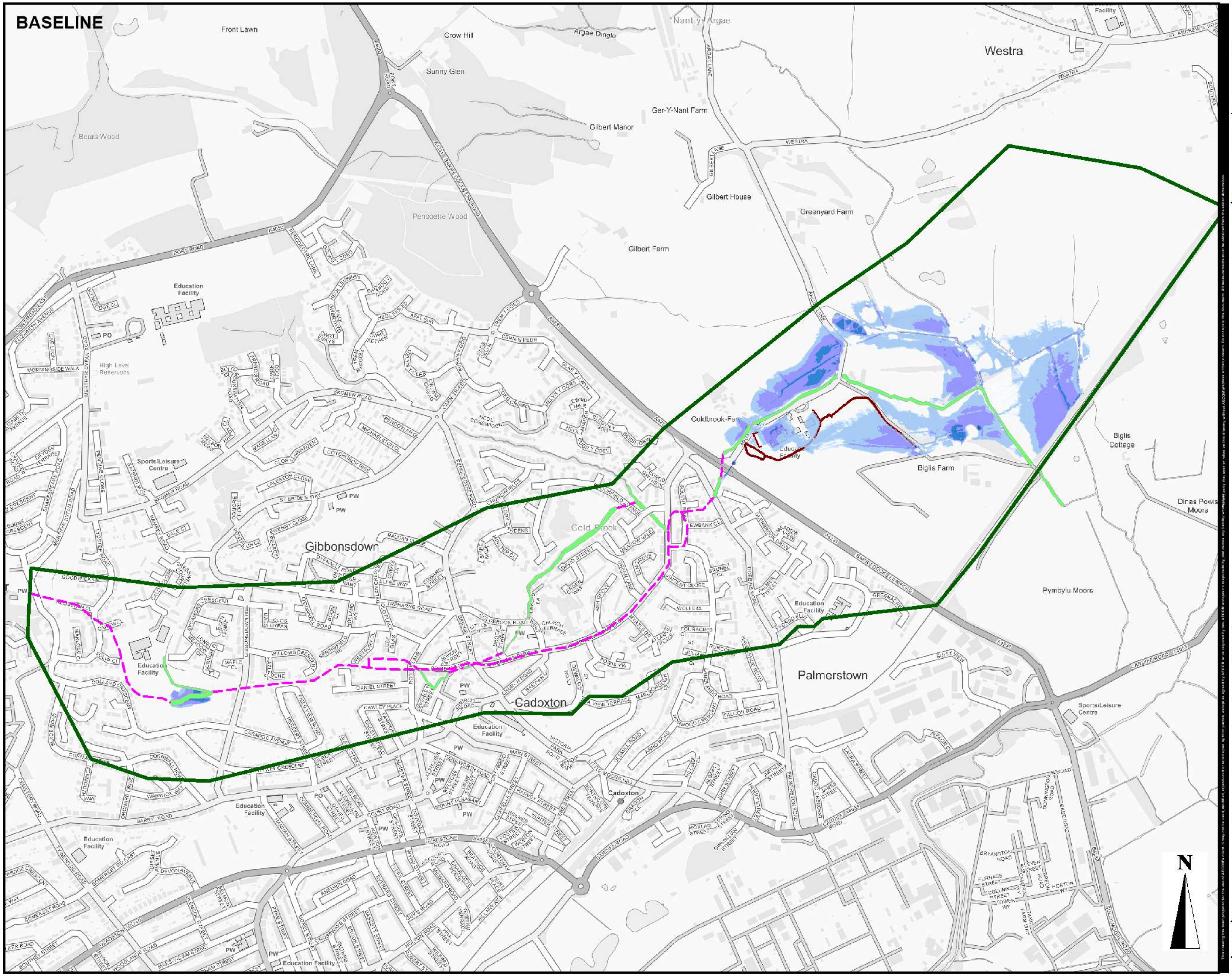
Catchment descriptors

Name	Value	User-defined value used?
Area (km^2)	3.9	No
ALTBAR	48	No
ASPBAR	108	No
ASPVAR	0.42	No
BFIHOST	0.31	No
BFIHOST19	0.29	No
DPLBAR (km)	2.59	No
DPSBAR (mkm^{-1})	58.5	No
FARL	1	No
LDP	4.66	No
PROPWET (mm)	0.47	No
RMED1H	11.5	No
RMED1D	38.4	No
RMED2D	48.2	No
SAAR (mm)	991	No
SAAR4170 (mm)	991	No
SPRHOST	47.48	No
Urbext2000	0.35	No
Urbext1990	0.2	No
URBCONC	0.87	No
URBLOC	1.06	No
DDF parameter C	-0.03	No
DDF parameter D1	0.38	No
DDF parameter D2	0.33	No
DDF parameter D3	0.31	No
DDF parameter E	0.29	No
DDF parameter F	2.51	No
DDF parameter C (1km grid value)	-0.03	No
DDF parameter D1 (1km grid value)	0.38	No
DDF parameter D2 (1km grid value)	0.34	No
DDF parameter D3 (1km grid value)	0.33	No
DDF parameter E (1km grid value)	0.29	No
DDF parameter F (1km grid value)	2.51	No

Appendix C – Maximum Flood Depth Maps, Whole Model

Appendix C-1 – 5% AEP Event

Appendix C-2 – 1% AEP Event



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Project Title:

COLDBROOK
ST RICHARD GWYN SCHOOL

LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Model Extent
- School Bund

AECOM Internal Project No:
60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
5% AEP EVENT
BASELINE

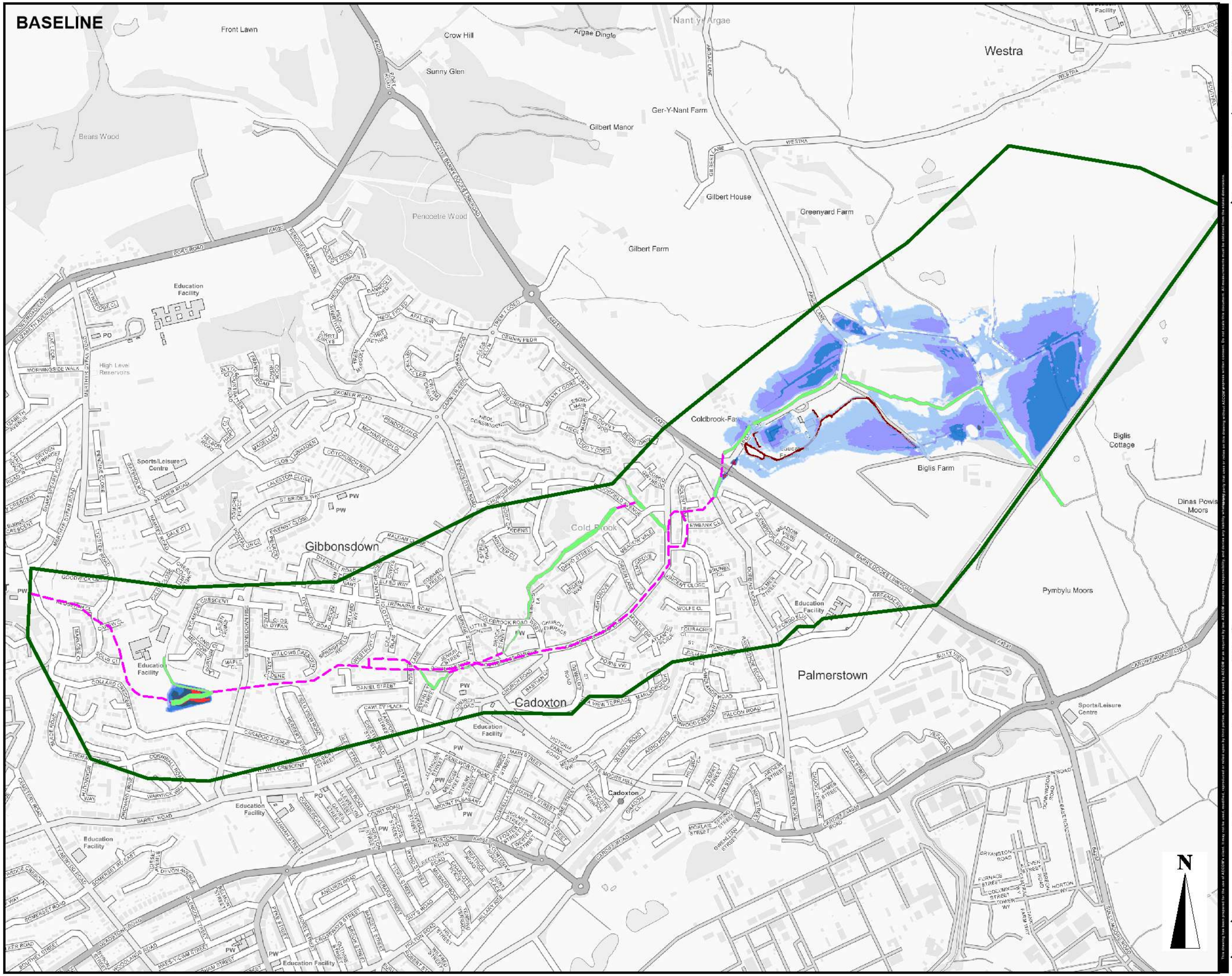
Scale at A3: 10,000

Client

VALE of GLAMORGAN
BRO MORGANNWG

Drawing No:	Rev:
APPENDIX C-1	0

Drawn:	Chk'd:	App'd:	Date:
ZB	RM	MD	Sep 2021



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Project Title:

COLDBROOK
ST RICHARD GWYN SCHOOL

LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Model Extent
- School Bund

AECOM Internal Project No:
60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
1% AEP EVENT
BASELINE

Scale at A3: 10,000

Client

VALE of GLAMORGAN
BRO MORGANNWG

Drawing No:	Rev:
APPENDIX C-2	0

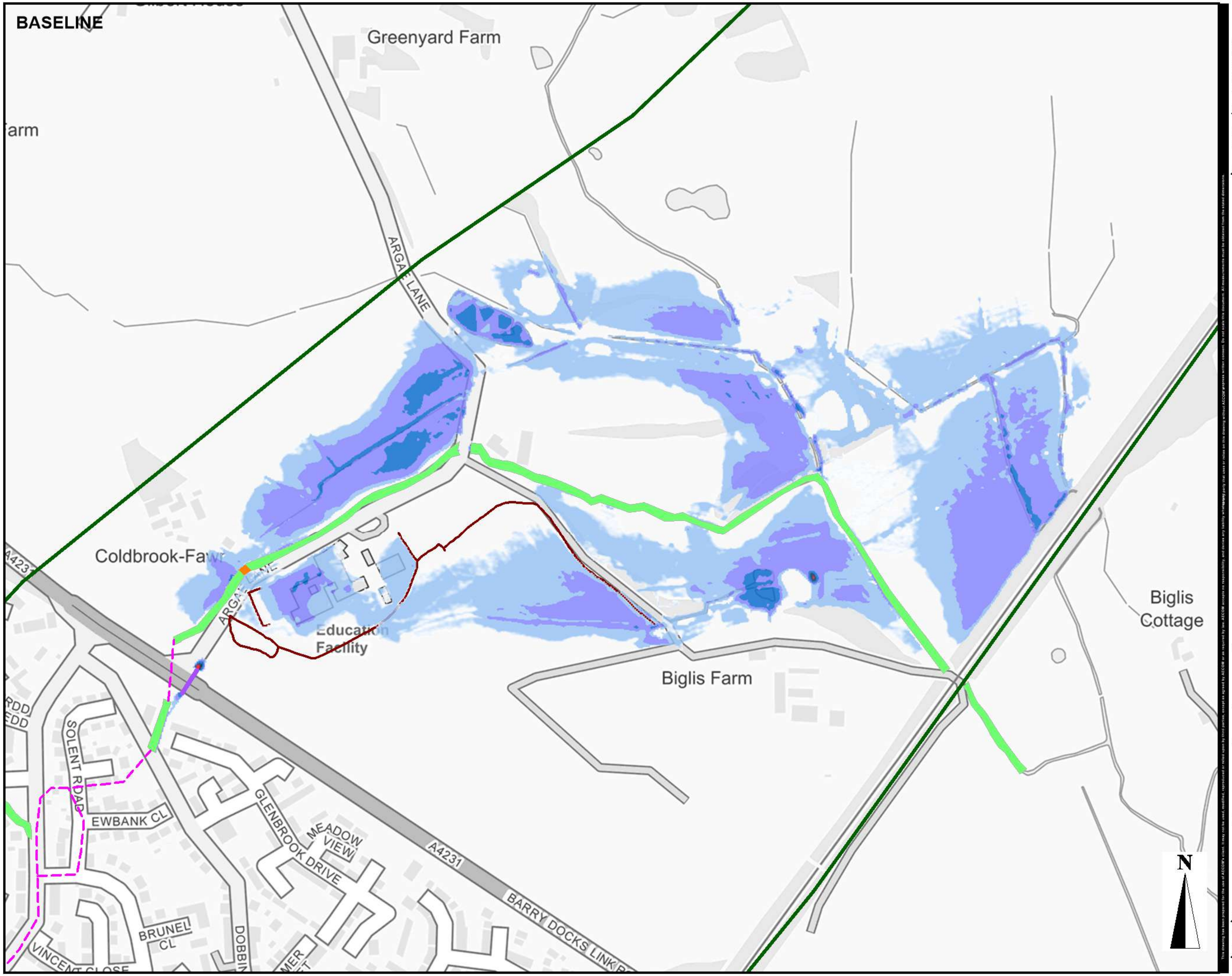
Drawn:	Chk'd:	App'd:	Date:
ZB	RM	MD	Sep 2021

Appendix D – Maximum Flood Depth Maps, School Site

Appendix D-1 – 5% AEP Event

Appendix D-2 – 1% AEP Event

Appendix D-3 – 0.1% AEP Event



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Portwall Place
Bristol, BS1 6NA
+44 (0)117 901 7000
www.aecom.com

Project Title:

COLDBROOK
ST RICHARD GWYN SCHOOL

LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Model Extent
- School Bund
- Pedestrian Underpass
- Farm Access Bridge

AECOM Internal Project No:

60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
5% AEP EVENT
BASELINE

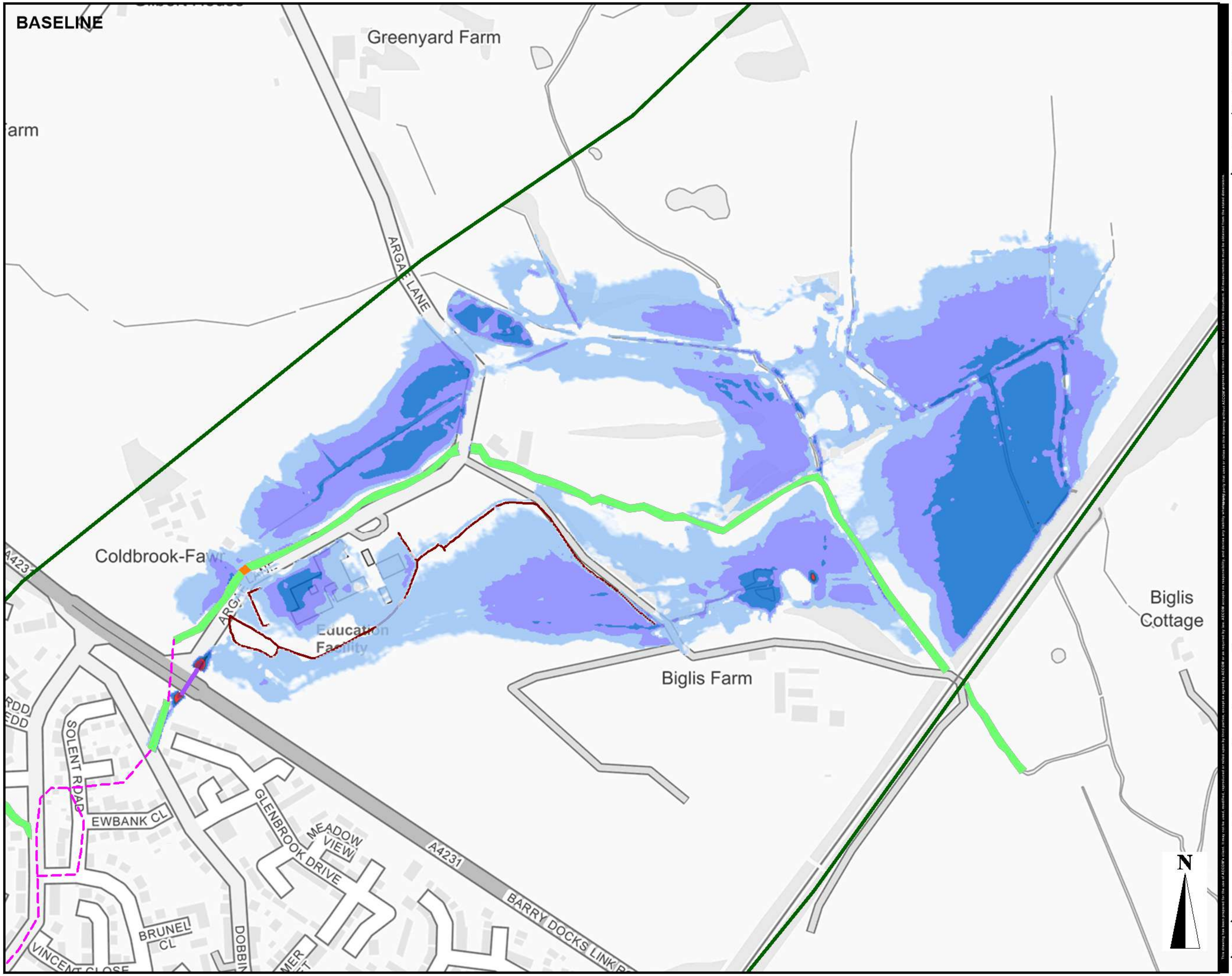
Scale at A3: 4,000

Client

VALE of GLAMORGAN
BRO MORGANNWG

Drawing No:	Rev:
APPENDIX D-1	0

Drawn:	Chk'd:	App'd:	Date:
ZB	RM	MD	Sep 2021



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Project Title:

COLDBROOK
ST RICHARD GWYN SCHOOL

LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Model Extent
- School Bund
- Pedestrian Underpass
- Farm Access Bridge

AECOM Internal Project No:
60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
1% AEP EVENT
BASELINE

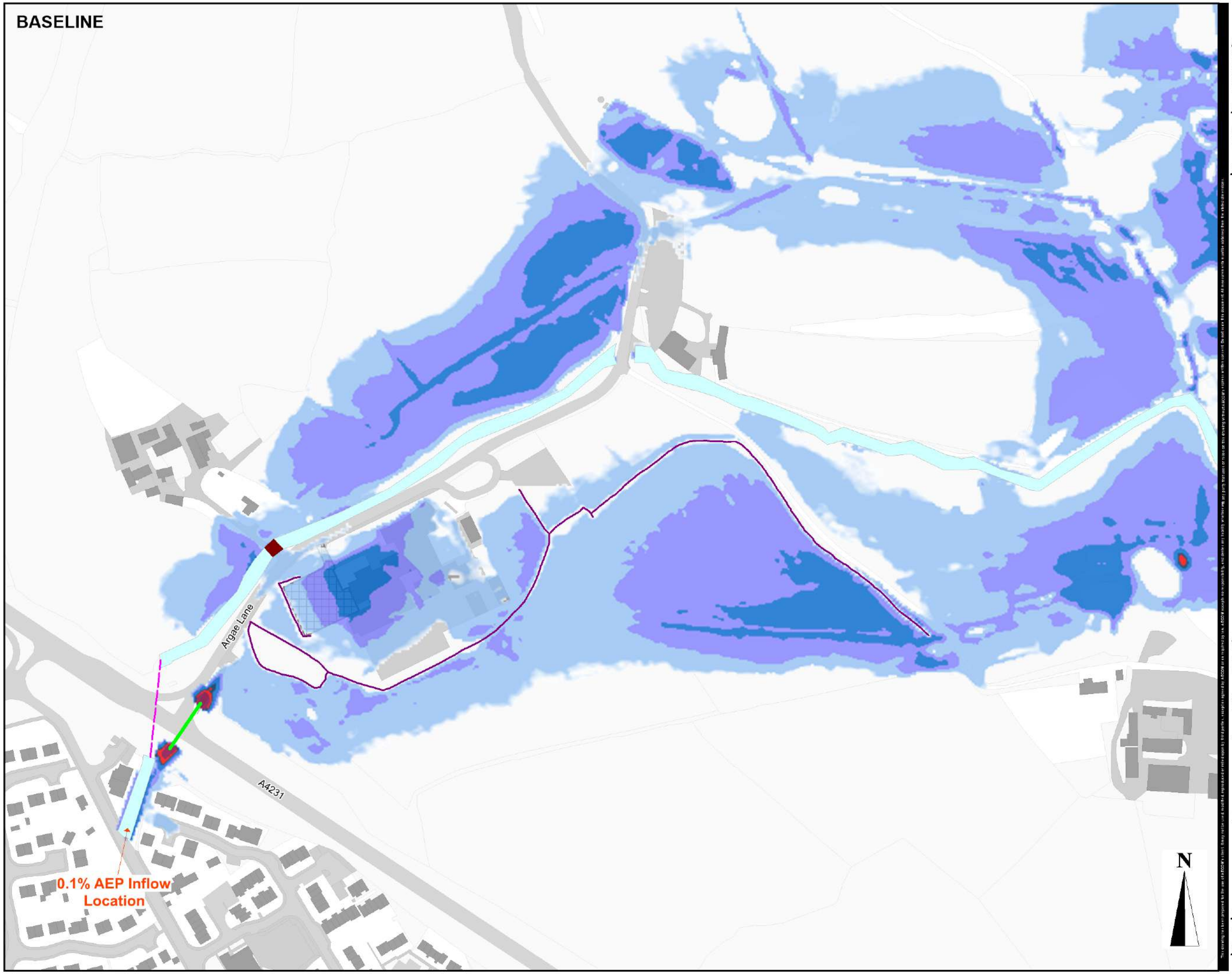
Scale at A3: 4,000

Client

VALE of GLAMORGAN
BRO MORGANNWG

Drawing No:	Rev:
APPENDIX D-2	0

Drawn:	Chk'd:	App'd:	Date:
ZB	RM	MD	Sep 2021



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Project Title:

COLDBROOK - ST RICHARD GWYN SCHOOL

LEGEND

Flood Depth

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- 1.00m - 1.25m
- 1.25m - 1.50m
- >1.50m
- Open Channel Sections
- Culverted Section
- Existing Bund
- Car Park
- Pedestrian Underpass
- Farm Access Bridge

AECOM Internal Project No:
60603495

Drawing Title:

MAXIMUM FLOOD DEPTH
0.1% AEP EVENT
BASELINE

Scale at A3: 2,500

Client

VALE of GLAMORGAN
BRO MORGANNWG

Drawing No:	Rev:
APPENDIX D3	1

Drawn:	Chk'd:	App'd:	Date:
ZB	RM	MD	Sep 2021