REPORT

Greenfield Mill Modelling update

Greenfield Mill, Oldham

Client: Holdgate Consulting on behalf of Purico Group Ltd

Reference: 6859_GreenfieldMill_Oldham

Status: S3/P01.01

Date: 03 February 2023

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Glossary

Term	Definition
AEP	Annual Exceedance Probability is the probability of a rainfall or tidal event occurring within any one year. For example an event of a 100 year return period has an AEP of 1:100 or 1%.
Courant Number	A function of the amount of fluid that crosses the cell in a given time-step. For 2d modelling the Courant Number generally needs to be less than 10 and typically around 5 or less for real-world applications.
Critical Storm Duration	The duration of a specific storm event which creates the largest volume or highest rate of net storm water runoff for typical durations up to and including the 10 day duration event.
ESTRY	Dynamic flow program suitable for mathematic modelling floods and tides (and/or surges) in a virtually unlimited number of combinations.
Flood Defences	Artificial structures maintained to a set operational level designed to protect land people and property from tidal and fluvial flood sources to an established chance of happening in any year threshold.
Flood Source: Fluvial (River)	When flows within watercourses exceed the capacity of the watercourse causing out of bank flows.
Flood Source: Groundwater	Groundwater flooding is usually the result of prolonged wet weather causing groundwater levels to rise sufficiently to either emerge at surface or to cause flooding of below ground infrastructure, such as basements.
Flood Source: Surface Water	When rainfall causes overland flows which exceed the capacity of the drainage network, causing flooding to land that is normally dry.
Flood Source: Tidal	When high tide events overtop the shoreline to cause flooding to land behind.
Flood Zone 1	Low Probability. Land having a less than 0.1% annual probability of river or sea flooding
Flood Zone 2	Medium Probability. Land having between a 1.0% and 0.1% annual probability of river flooding; or land having between a 0.5% and 0.1% annual probability of sea flooding.
Flood Zone 3 (A)	High Probability. Land having a 1.0% or greater annual probability of river flooding; or Land having a 0.5% or greater annual probability of sea.
Flood Zone 3 (B)	Functional Floodplain. According to the Planning Practice Guidance (2022) this zone comprises land where water from rivers or the sea has to flow or be stored in times of flood. The identification of functional floodplain should take account of local circumstances and not be defined solely on rigid probability parameters. Functional floodplain will normally comprise: • land having a 3.3% or greater annual probability of flooding, with any existing flood risk management infrastructure operating effectively; or • land that is designed to flood (such as a flood attenuation scheme), even if it would only flood in more extreme events (such as 0.1% annual probability of flooding). Local planning authorities should identify in their Strategic Flood Risk Assessments areas of functional floodplain and its boundaries accordingly, in agreement with the Environment Agency. (Not separately distinguished from Zone 3a on the Flood Map)
Flood Zone Map	The Environment Agency has produced a mapping data set which covers England and provides the general extents of Flood Zones 1, 2, and 3. However the national data set available online does not differentiate between Flood Zone 3 (A) and 3 (B).
GMSF	Greater Manchester Spatial Framework
LiDAR	Light Detection and Ranging (LIDAR) is an airborne mapping technique, which uses a laser to measure the distance between the aircraft and the ground. Up to 500,000 measurements per

Term	Definition
	second are made of the ground, allowing highly detailed terrain models to be generated at spatial resolutions of between 25cm and 2 metres.
Main River	Defined on the Main River map and relate to river's on which the Environment Agency have powers to carry out flood defence works
Model Event	The Model Event is the AEP storm or flow profile used within each Model Scenario
Model Scenario	Each Model Scenarios considers a range of Model Events to assess the impact of the Scenario, typical Model Scenarios are; base case, post development, post mitigation.
m AOD	Metres Above Ordnance Datum
OS	Ordnance Survey.
Ordinary Watercourse	A watercourse which does not form part of a Main River
PMF	Probable Maximum Flood
'Puddle'	The 'direct rainfall' modelling process can result in water being caught between local ridges and depressions creating "puddles" these artefacts are normally the result of subtle changes in the ground data that has been sampled to create the DEM.
SuDS	*Sustainable Drainage Systems*, which are designed to manage surface water flows in order to mimic the Greenfield run-off from an undeveloped site.
TUFLOW	TUFLOW is one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software. It simulates the complex hydrodynamics of floods and tides using the full 1D St Venant equations and the full 2D free-surface shallow water equations.

1 Introduction

1.1 Appointment & Brief

Holdgate Consulting commissioned Ambiental Environmental Assessment on behalf of Purico Group Ltd to undertake hydraulic modelling services to support the proposed development at Greenfield Mill, Oldham (hereafter referred to as the "Site").

The aim of this report is to demonstrate that the impact of including the network of culverts and collecting boxes present at the Site, excluded from previous hydraulic modelling of the area, and to predict the flood extents more accurately at the Site.

1.2 Purpose of the Report

This report sets out the hydraulic modelling works conducted to date and the methodology from which the model was derived, as well as providing the findings of the modelling.

1.3 Background to the Site

The Robert Fletcher Paper Mill at Greenfield near Oldham has a site area of approximately 17 acres, consisting of over 20 existing buildings with over 400,000 sq ft of footprint. Manufacture at the site ceased in early 2000.

The owners of the site have been in consultation with Oldham Council concerning the future of the Site and it being examined for redevelopment potential in the Greater Manchester Places for Everyone strategy document (Site Allocation 18).

The Client has related to Ambiental that the site needs to create 160 residential units to be commercially viable.

In early 2021, as part of the initial Greater Manchester Spatial Framework (GMSF), a flood risk assessment was produced for the Site (Site Allocation 18) which included flows from a previously unnamed watercourse called "Fletcher's Brook". This model shows that this watercourse flows down the steep hillside from above Bradbury Lane, through the arch in the Hey Top houses, and then overland into the main part of the site.

The consequence of including flows from this watercourse is that the Council believes that the site would likely be restricted to 90 units due to flood risk.

This initial model was undertaken by JBA Consulting but did not include most of the complex network of culverts and collecting boxes across the site. A plan of the network of culverts and collecting boxes provided by the Client is presented in Appendix C (Supporting Information).

Based on the current flood model omitting the culverts and collecting boxes, the current flood model produced by JBA can not be considered representative of the flood flow conditions at the Site, and therefore cannot be used to classify flood risk at the Site.

1.4 Spatial Context

The study area considered during this report and for the latest hydraulic model is indicated on Figure 1, provided below. A larger version of all the figures are appended to this document.

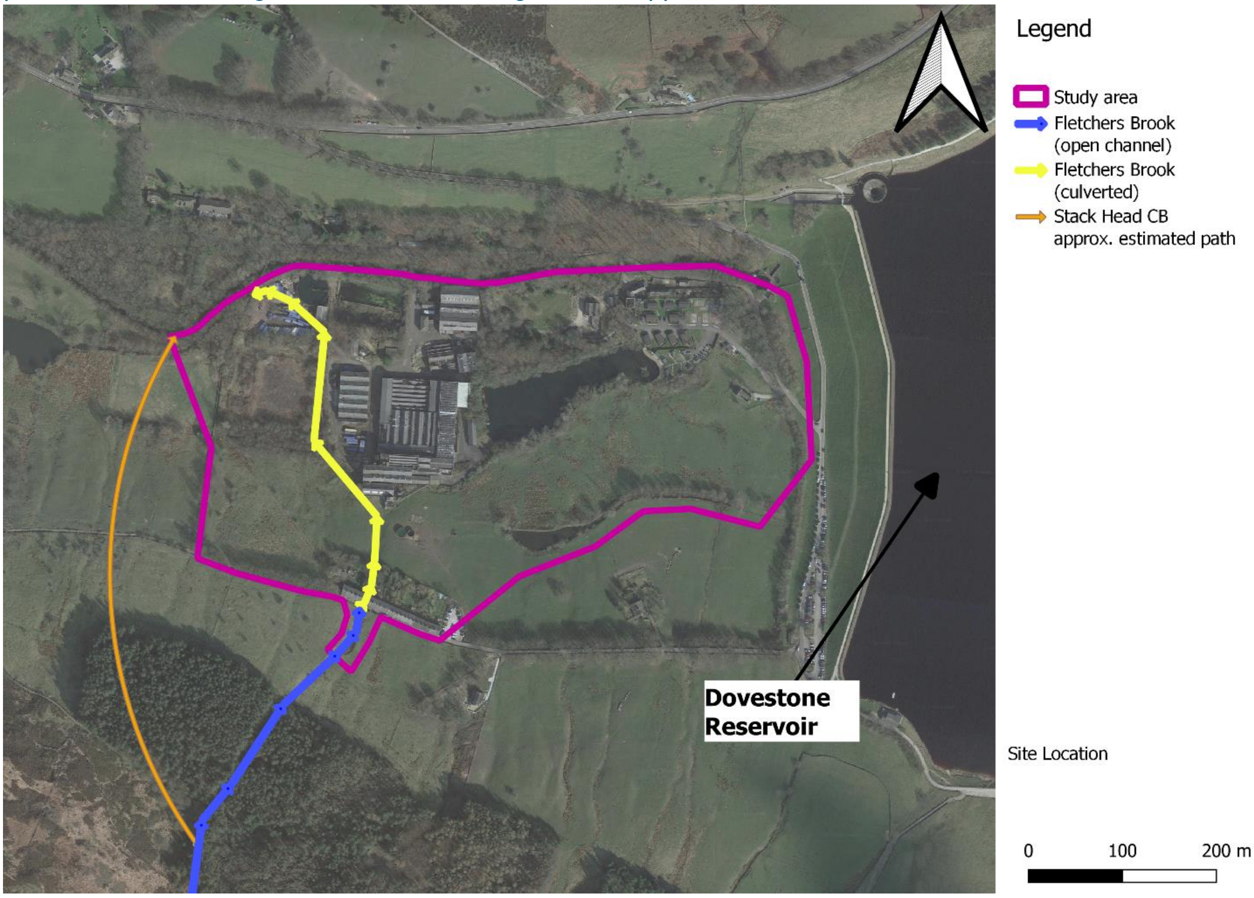

Figure 1: Study area

The site sits on the southern hillside, with the large Dovestone Reservoir directly upstream. As a result the contributing catchment is restricted to the hillsides directly above the development.

A Digital Elevation Model has been prepared using Environment Agency 1m LiDAR and a topographic survey (drawing number PL.TS.01) provided by the client.

1.5 Site Inspections and surveys

To support the initial JBA model (2021), a river survey as well as a CCTV culvert survey were carried out. Copies of these surveys have been provided in Appendix B (Initial JBA model and info).

It was found that the Fletchers Brook enters a culvert on the uphill side of Bradbury Lane and runs directly north, towards the main site and then westwards out into the Chew Brook.

Ambiental have attended a site walkover (25/11/2022). The purpose of this site walkover was to verify several structure and material details of the Site, as well as to understand the overall site context. The key findings of the site visit are as follows:

- The site visit revealed the presence of surplus 450mm diameter pipe sections in a storage yard near the north western edge of the site (Figure 2). In combination with measurements of pipe entrances made with a laser measurer, this provides a reasonable basis for some of the assumptions made in this model update.

- The site visit also provided confirmation of the existence of several ‘collecting boxes’. In particular, the Stack Head Collecting box is situated at the top of Fletchers Brook and diverts water from there down to the Chew. Audible water flow was heard in the divert during the site visit, indicating that it was still functional. Whilst the exact path of this divert is unknown, it is likely that it connects to the culvert, found during the 2021 CCTV survey[1], which is labelled as “coming from hills”.

Figure 2: Surplus pipe sections (450mm dia.)

[1] *EAK-JBAU-XX-XX-FN-HM-0010 – Robert Fletcher Technical Modelling note (Incl CCTV)*

2 Methodology

2.1 Overview

The numerical flood model has made use of the data included in the 2021 JBA model. This data has been supplemented by the site visit observations and the CCTV survey. Any assumptions which have had to be made are based off a conservative and precautionary approach.

2.2 Hydrologic Approach

2.2.1 Approach Adopted

After examination of the previous JBA FEH Calculation Record it was decided that the approach taken from the previous modelling iteration remained sound. Thus, the values from the JBA model iteration were carried forward to this modelling study as they stood. Further detail can be found in that document[2] which is attached to this document as Appendix B.

The one exception to this was that climate change allowances were updated using the latest guidance. There is no gauge data available for this catchment.

Generally, the FEH Statistical method is the preferred method for flood estimation as it makes use of gauged data and is also the Environment Agency's preferred methods for small catchments of less than 0.5km such as Fletchers Brook. It was found that there is close agreement in the flow estimates generated by The ReFH method and the FEH Statistical method, with the ReFH generating slightly higher flows.

Therefore, due to this creating a conservative peak flow estimate, the ReFH method was used as the preferred method for creating the hydrology.

2.2.2 Catchment Map

Figure 3 is an extract from the JBA FEH Calculation Record document (Appendix B) showing the catchment area which is used for calculating the hydrology.

The catchment for Fletchers Brook is approximately 0.55km^2. There are two inflow points calculated, one at the entrance to the culverted section of Fletchers Brook (near Hey Top houses), and one at the confluence of the Fletchers Brook and Chew Brook, as indicated on Figure 3below.

[2] *2020s1058 -GMSF Allocation 18 Flood Risk – Robert Fletchers – FEH Calculation Recordv1.0.docx*

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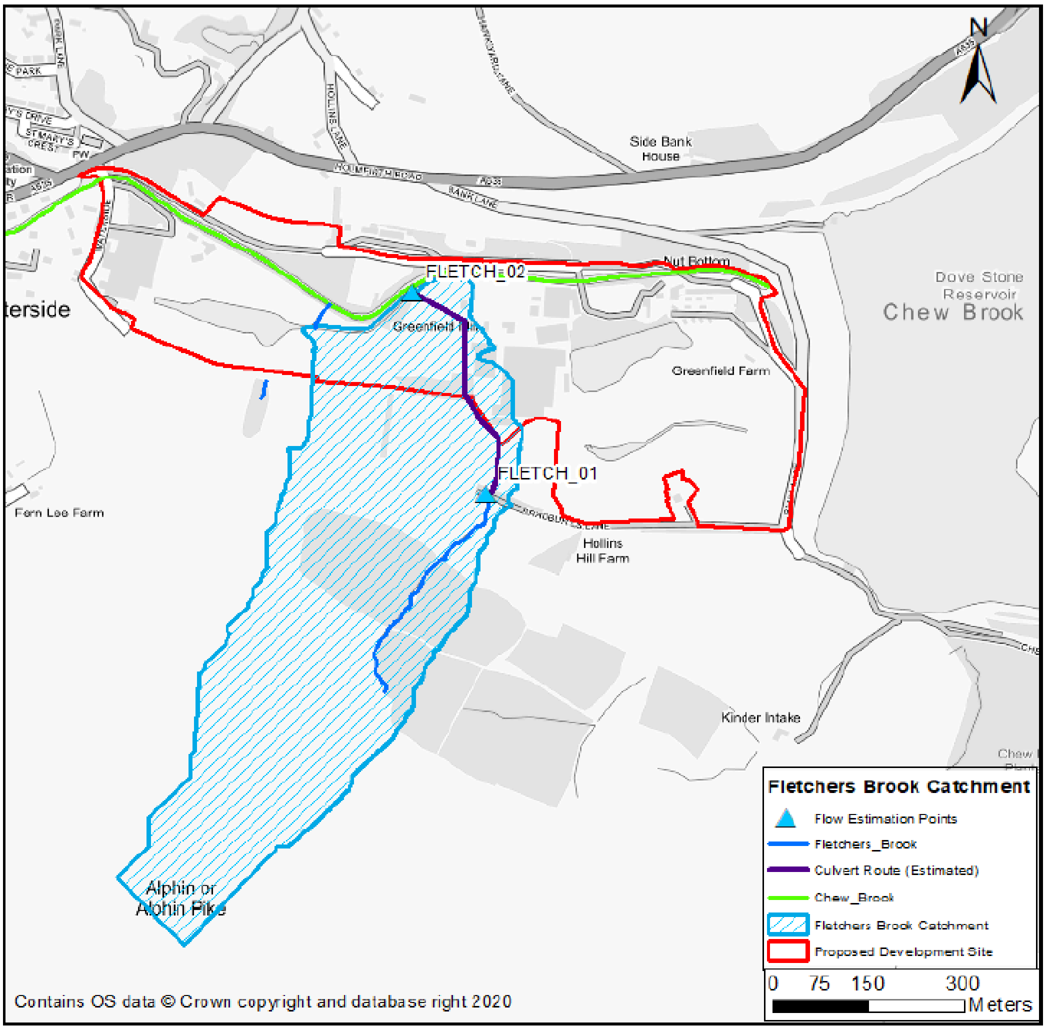

Figure 3: Map showing hydrologic catchment (taken from JBA FEH Calculation Record)

2.2.3 Storm Duration and Time to Peak

Due to the size of the catchments (less than 0.5km), the critical storm durations and time to peak are both less than 1 hour, as summarised below in Table 1

Table 1: Peak inflows for each return period

Site Code		Fletch_01	Fletch_02
Catchment Area (km^2)			
Critical Storm Duration (Hours)		0.85	0.94
Time to Peak (Hours)		0.34	0.37
Flood peak flow rate	2-year RP	0.36 m^{3}s^{-1}	0.67m^{3}s^{-1}
	5-year RP	0.50 m^{3}s^{-1}	0.93m^{3}s^{-1}
	10-year RP	0.62 m^{3}s^{-1}	1.16m^{3}s^{-1}
	20-year RP	0.76 m^{3}s^{-1}	1.40m^{3}s^{-1}

	30-year RP	0.84 m^3s^{-1}	1.55m^3s^{-1}
	50-year RP	0.97 m^3s^{-1}	1.78m^3s^{-1}
	75-year RP	1.08 m^3s^{-1}	1.99m^3s^{-1}
	100-year RP	1.16 m^3s^{-1}	2.15m^3s^{-1}
	100+41%-year RP	1.64 m^3s^{-1}	3.03m^3s^{-1}
	100+53-year RP	1.78 m^3s^{-1}	3.29m^3s^{-1}
	200-year RP	1.43 m^3s^{-1}	2.62m^3s^{-1}
	1,000-year RP	2.38 m^3s^{-1}	4.34m^3s^{-1}

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2.3 Hydraulic Modelling Approach

The JBA model was a linked Flood Modeller-TUFLOW model with all of the 1D elements in this model modelled via Flood Modeller and the 2D domain as TUFLOW. This model included the main Fletchers Brook culvert but did not include the numerous other pipes or collecting boxes around the Site.

To maintain commensurability with the previous JBA model, the Ambiental model carries over the river sections and the various pipe diameters and inverts as they appear in that model. Additional elements have been added where data obtained supports the incorporation of the details.

A marked-up drawing was provided by the client to Ambiental describing the network of pipes within the Site (Appendix C). A critical point is that the East-West pipe connecting the Fletchers Brook pipe and the outflow from the Mill Pond pipe is confirmed to be blocked off due to a collapse in that area.

From review of the data, three critical elements to include which were missed in the initial JBA model.

1. The first is the connection from the Fletchers Brook culvert towards Top Dam lake. This splits from the main culvert around the archway in the Hey Top houses, running underneath the gardens before turning north and connecting to Top Dam in the west. This is assumed to be a 300mm diameter pipe. A manhole was lifted in the gardens behind Hey Top houses however accurate measurement of the exact diameter of the pipe was not possible due to the nature of the chamber.
2. The second is an overland flow inlet just downstream of the archway in Hey Top. This inlet is approximately 1.5m wide and 0.5m high and is designed to collect any flow which might be spilling down the roadway and divert it back into the 300mm dia. main Fletchers brook culvert below. (Figure 5).
3. The third key element is the Stack Head collecting box. This is a collecting box near the extreme uphill limit of Fletchers Brook. It has a connecting pipe which siphons water away off to the west, down the hill, and out of the Fletchers Brook catchment. It is assumed in the model update that this is a 300mm diameter pipe although it is possible that it is larger. This assumption ensures a conservative approach is taken.

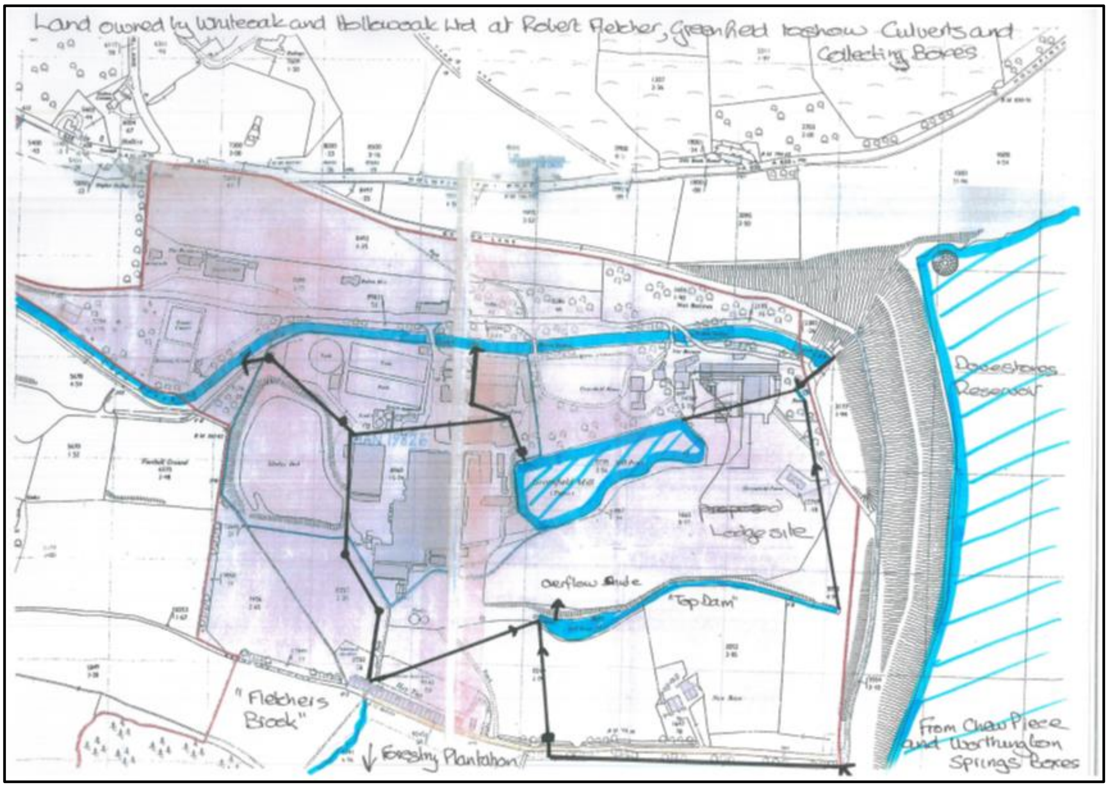

Figure 4: Network of pipes on the Site with the blocked pipe marked by a red line across it

Figure 5: Overland flow capture inlet near Hey Top houses

It was found, during the model build, that adding in these three critical elements introduced very significant errors and instabilities into the model under the previous Flood Modeller/TUFLOW set up. This was likely due to the gradient in that area (approximately 20% slope). As such, the Flood Modeller element was converted to ESTRY for the Site specific model.

The ESTRY-TUFLOW computational engine has been benchmarked by the Environment Agency [1], and is considered suitable for predicting flood levels, flood depths, flow velocities, and flood hazard ratings, associated with fluvial flood inundation.

A benchmarking model run has been undertaken to compare the performance of the Site specific model to the original JBA model. A comparison of the models is provided in Figure 6 demonstrating that there are very few changes between the two models. The few small changes which do occur are attributed to the change in 1m LIDAR as a more recent flight was used for the ESTRY/TUFLOW model.

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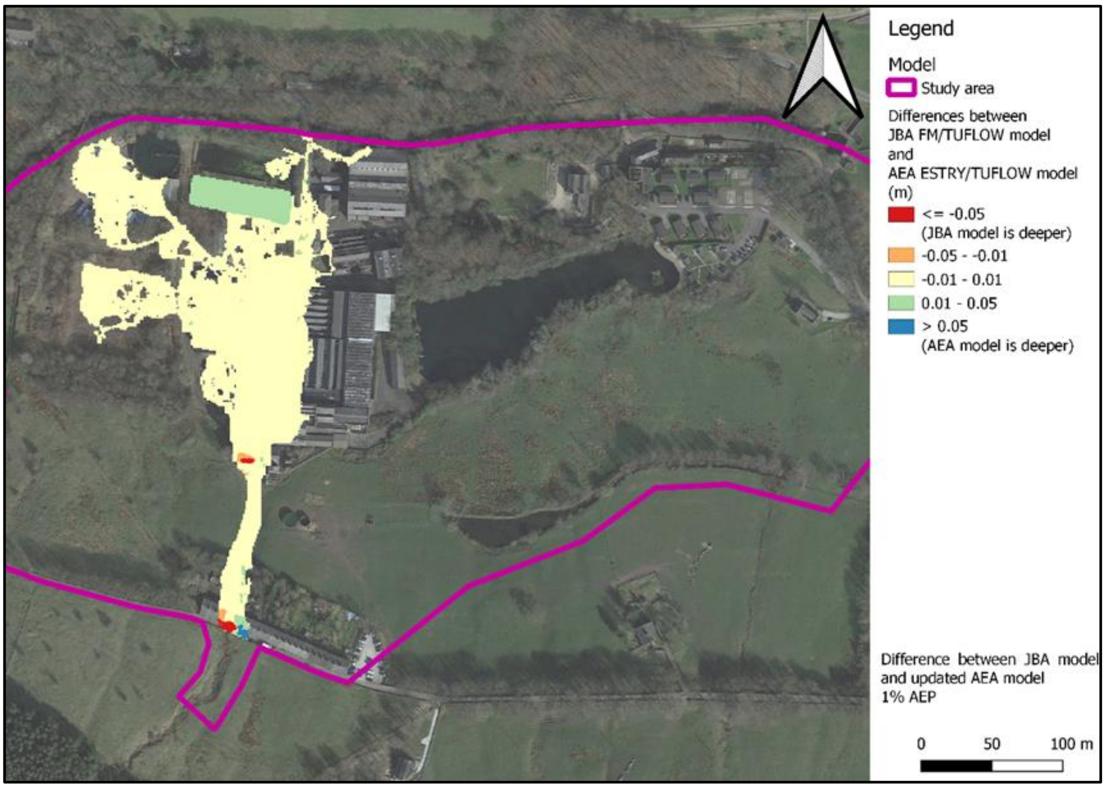

Figure 6: Comparison between the original FM/TUFLOW model and the ESTRY/TUFLOW model

The histograms in Figure 7 shows that most changes are within +/- 0.01m, the mean of differences is +0.0038m, which is considered nominal.

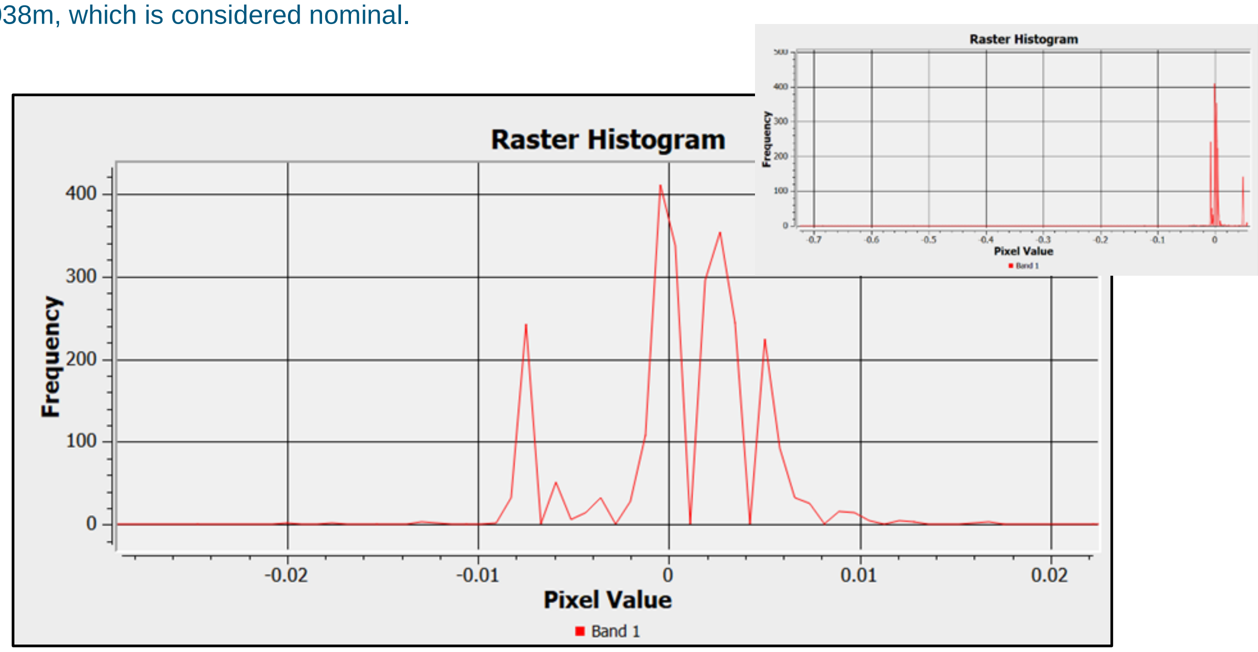

Figure 7: Histogram of differences after conversion to ESTRY/TUFLOW

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3 Model Schematisation

3.1 1D Domain

3.1.1 Structures

The 1D Network represents channels and culverts used within the model. Where the data record is incomplete or the survey ambiguous, a conservative approach has been used to not over emphasise benefits to flood risk provided. The following structures were identified within the surveys as well as during the site walkover (Table 2) and are included within this model update.

Reference	Description	Type	Width /Diameter (m)	Height (m)	Manning's n	Data Source
StackHead	The culvert leading away from the Stack Head collecting box. Discharges into the Chew Brook at the downstream	Culvert (Circular)	0.3	N/A	0.025	Site Walkover/Client onsite knowledge
Flet_406c	Culverted Fletchers Brook. Blocked by 35% to account for bars.	Culvert (Circular)	0.3	N/A	0.015	2021 CCTV Survey/JBA model
Flet_401c	Culverted Fletchers Brook. Connection towards Top Dam occurs at downstream.	Culvert (Circular)	0.3	N/A	0.015	2021 CCTV Survey/JBA model
Flet_381c	Culverted Fletchers Brook. Connection to Top Dam occurs at upstream end. Overland flood capture intake occurs at the downstream.	Culvert (Circular)	0.3	N/A	0.015	2021 CCTV Survey/JBA model
Flet_372c	Culverted Fletchers Brook. Overland flood capture intake occurs at the downstream.	Culvert (Circular)	0.3	N/A	0.015	2021 CCTV Survey/JBA model
Flet_356c	Culverted Fletchers Brook.	Culvert (Circular)	0.3	N/A	0.015	2021 CCTV Survey/JBA model
Flet_306c	Culverted Fletchers Brook.	Culvert (Circular)	0.3	N/A	0.015	2021 CCTV Survey/JBA model
Flet_281c	Culverted Fletchers Brook.	Culvert (Circular)	0.45	N/A	0.015	2021 CCTV Survey/JBA model
Flet_206c	Culverted Fletchers Brook.	Culvert (Circular)	0.45	N/A	0.015	2021 CCTV Survey/JBA model
Flet_156c	Culverted Fletchers Brook.	Culvert (Circular)	0.45	N/A	0.015	2021 CCTV Survey/JBA model
Flet_106c	Culverted Fletchers Brook.	Culvert (Circular)	0.45	N/A	0.015	2021 CCTV Survey/JBA model

Flet_056c	Culverted Fletchers Brook.	Culvert (Circular)	0.45	N/A	0.015	2021 CCTV Survey/JBA model
Flet_030c	Culverted Fletchers Brook. Outlet into the Chew occurs at the downstream.	Culvert (Circular)	0.45	N/A	0.015	2021 CCTV Survey/JBA model
Flet_Dam	Connection from culverted Fletchers Brook, underneath the gardens, into the west of Top Dam	Culvert (Circular)	0.3	N/A	0.025	Site Walkover/Client onsite knowledge
InletBox	Connection into culverted Fletchers Brook via the grate in the roadway near the arch in the Hey Top houses	Culvert (Rectangular)	1.5	0.3	0.025	Site Walkover/Client onsite knowledge
TopDam_East	Connection from Top Dam down to the confluence with the Mill Pond intake	Culvert (Circular)	0.45	N/A	0.015	Site Walkover/Client onsite knowledge
MPondEast	Mill Pond intake taking water from Top Dam	Culvert (Circular)	0.45	N/A	0.015	Site Walkover/Client onsite knowledge
Offlow2Chew	Outflow to the Chew from the Mill Pond Intake/Top Dam outflow confluence	Culvert (Rectangular)	1.0	0.5	0.015	Site Walkover/Client onsite knowledge
MPondWest	Outflow to the Chew from the western edge of Mill Pond	Culvert (Circular)	0.45	N/A	0.015	Site Walkover/Client onsite knowledge

Table 2: Schedule of Culverts and Bridges within the flood model.

The JBA model implemented the culverted Fletchers Brook and acquired details of this from a CCTV survey conducted in 2021. These details were maintained in this model update with no change.

The Stack Head Collecting box culvert is assumed to be a 300mm diameter pipe in order remain conservative. Water was heard flowing through this pipe during the site walkover however physical inspection was not possible. It is likely that this pipe connects to the culvert section found in the CCTV survey which is labelled as “coming from the hills”.

The grated intake underneath the archway was simulated as an HX line which allowed flow back into the culverted watercourse. This was then connected to a specific 1D network point which specified the dimensions of this element.

The connection from the culverted Fletchers Brook to the exit into Top Dam was inspected during the walkover using a laser measurer and this was found to be a 300m diameter pipe. The overall length is assumed from the direction seen from the lifted manhole and the placement of the exit into Top Dam (both seen during site walkover).

The exit from the eastern end of Top Dam down towards the confluence with the Mill Pond intake was measured with a laser measurer during the site walkover at both the upstream intake as well as the downstream exit and was found to be a 450mm diameter pipe in both locations.

The intake into the Mill Pond was measured at the upstream end using a laser measurer and found to be a 450mm diameter pipe. No inspection was possible at the downstream end (outlet into Mill Pond) due to this being submerged.

The outflow from the Mill Pond down to the Chew was located and found to be a 450mm dia. pipe. It was observed that this pipe was free flowing out of the wall directly into the Chew at the downstream. Consequently, a flat Stage/Time outflow was used as the outflow with the level at the downstream set to just above the soffit of the pipe to indicate a submerged entrance. It was assumed that the level in the Chew would be raised during flood.

This confluence at the Mill Pond intake, Top Dam outflow, and connection to the Chew Brook is open and an outflow culvert was present taking any overspill down to the Chew. This was measured as a 1m wide and 0.5m high box culvert at this location via a laser measurer. The outflow was located high up the side of a concrete wall, spilling into the Chew Brook and consequently the outflow level was set to simulate the pipe being approximately half full.

Figure 8: Outflow from Mill Pond into the Chew Brook

3.2 2D Domain

The 2D domain has been developed using Environment Agency 1m resolution LiDAR data and overlain with a topographical survey of the site. A 3D surface was developed from the topographical survey information however due to the occasionally sporadic nature of the measurement points the survey is not representative of the land surface in all locations and so there are places where the lidar was taken preferentially, to prevent long triangulation lines.

The two-dimensional grid size used on this hydraulic model was 1 metres, which is considered suitable due to the steepness of the catchment, and features being considered.

3.2.1 Boundary Conditions

The boundary conditions represent the inflow and outflow conditions around the edge of the modelled domain. The site is bounded by the Chew and a HQ boundary was implemented along this edge to represent water falling into the Chew.

3.2.2 Surface Roughness

Definition of surface roughness within the floodplain is important, especially for areas of shallow flow, where the roughness factor of the ground can have an impact on the flow velocity due to the impacts of friction.

The land use classification has been determined by using Ordnance Survey MasterMap data. The MasterMap layer provided a detailed view of the landscape, including; roads, fields, buildings, trees, paths, etc.

MasterMap includes feature codes which delineate the types of ground surface, these feature codes have been used to determine appropriate surface roughness values with reference to the work of Chow [2], Table 2 provides the feature codes and surface roughness values used.

MasterMap Feature Code	Manning’s Roughness ‘n’	Description
10021	1	Buildings
10053	0.05	Gardens
10054	0.05	General Surface
10056	0.035	Fields (including agricultural land)
10062	0.05	Glasshouse
10089	0.015	Inland Water
10096	0.04	Man made landform
10099	0.05	Natural Landform (Cliff)
10111	0.08	Trees
10119	0.025	Roads tracks and paths
10123	0.025	Paths
10167	0.04	Rail Features
10172	0.025	Road
10183	0.025	Roadside
10185	0.06	Structures including roadside structures
10193	0.06	Structures
10217	0.05	Unclassified Land
1000	0.2	Stability
1001	0.5	Increased stability

Table 2: Definition of Surface Roughness Values with respect to ZoomStack data and Chow.

A Manning’s ‘n’ of 1 is unusually high for buildings however this value was maintained from the initial JBA model to provide consistency.

3.2.3 Infiltration Parameters

Infiltration parameters were not included within the hydraulic modelling for the 2D floodplain, as the effect of infiltration is included within the hydrological model in determining both the fluvial input hydrograph as well as the pluvial “Net Rainfall” input.

3.2.4 Lakes

The lakes (Top Dam and Mill Pond) were digitised by examining the contours which bounded them and finding one which conformed with satellite imagery. The bed level was then set to approximately 2m below the bank top. This conformed with observations made during the site visit.

In two places, one at the western edge of Top Dam and one on the western bank of Mill Pond, the general landscape surface modelled was lower than that shown in the topographic survey. This is due to minor interpolation issues. These lower banks allowed water to spill sooner than might be expected in these locations and so a z-shape line was implemented to apply the correct ground levels in these locations.

3.2.5 Initial Water Levels

The initial water levels were maintained from the JBA model with regards to the Fletchers Brook watercourse.

The lakes initial water level was digitised as at approximately 0.5m below bank top, giving a depth in both lakes of 1.5m. This aligns with the observations from the site visit.

3.2.6 Buildings

The buildings were digitised via extracting the outlines from the MasterMap data.

Previously, in the JBA model, these buildings were only represented via an increased roughness coefficient, with no topographical changes. The updated Ambiental model aims to provide a more accurate representation of these features.

Where a Finished Floor Level (FFL) was available from the topographic survey, and appropriate, this level was used. There were a number of buildings which either; did not have a FFL, or had significant differences within the building FFL from one side to another due to the slope on which the building was set. Where there were internal FFL differences attempts were made to estimate which portion of the buildings these apply to however this was not always possible.

Where FFL was not available for either of the reasons above, a flat 0.15m was added to the surrounding ground level in order to estimate the thresholds.

Walls were digitised surrounding the buildings. These walls were set to 0.6m in order to represent closed doorways and brick walls. It was assumed that at much more than 0.6m of floodwater depth the structural integrity of these features may not be suitable and so above these levels water was allowed to spill into the buildings.

4 Assumptions and Limitations

4.1 Assumptions

In developing numerical hydraulic models, it is necessary to include certain assumptions due to ambiguity in the data, and underlying parameters, such as infiltration potential across a catchment. The key assumptions made as part of this numerical model are:

- The Digital Elevation Model has been derived from filtered Environment Agency LiDAR, it is assumed that this data is representative of the topography.
- Some culvert / structure data has been derived from site inspection. It has been assumed that structure invert levels estimated from site measurements are representative.

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- 2D surface roughness values have been assumed based on MasterMap data. Verification of roughness areas has been undertaken, using online aerial photography and site visits.
- All structures in the model were assumed to be free and clear of debris in the baseline model runs although consideration has been made to account for structural barriers such as grates or bars across drain inlets.

4.2 Limitations

The following limitations of the hydraulic model should be noted:

- The numerical flood model has been produced to determine the flood risk profile on the project site and should not be used by third parties to assess flood risk elsewhere in the model domain.
- The model has been tested on normal design storms only, due to the complexity and variability of real storm events, the flood risk profile determined by this model is a prediction only.
- Due to the ungauged nature of the catchment the hydrology has a confidence limit of between 0.5 to 2.0 times the quoted estimate. Whilst attempts have been made in order to ensure that the hydrology is as accurate as possible there is still a large degree of uncertainty and the stated flows are a central estimate rather than a definitive statement.

5 Model Condition

5.1 Overview

To provide an assessment of the condition of the model, a range of indicators have been reviewed, including undertaking sensitivity testing the impact of blockage on the drainage network.

5.2 Significant Issues

In the development of this numerical flood model, no significant issues have been determined. The model runs within normal operating parameters, and the outputs have been visually verified with topographic data.

There are a small handful of 1D negative depths and no 2D negative depths. The negative depths occur approximate 30 minutes into the simulation at the open river section Flet_408r and resolve themselves within approximately 3 seconds of initial appearance.

Analysis of the mass balance indicates that the TUFLOW mass balance is well within the typical +/-2% limits. The maximum cumulative mass error was 0.38%, occurring during the 5% AEP event.

5.3 Calibration

Calibration is the adjustment of a model’s parameters, such as roughness, and hydraulic structure co-efficients, so that it reproduces observed data to an acceptable accuracy.

No calibration data was available for the model and therefore calibration has not been undertaken.

5.4 Sensitivity Testing

To understand the influence of the above assumptions and limitations on the model results and consequently, the confidence that can be associated with them, a sensitivity test which applies a 50% blockage to the modelled structures has been included.

This has been achieved by setting all 1D network “pblockage” values to 0.5.

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6 Model Results

The addition of the various elements which were not included in the JBA model, and the improved representation of the buildings, serve to reduce the total amount of flooding on site.

This model agrees with the JBA assessment that the culverted Fletchers Brook can take approximately $0.18m^3/s$. The connection from this watercourse down towards Top Dam takes a similar amount. The divert from Stack Head Collecting Box takes approximately $0.1m^3/s$.

The cumulative impact of these three culverts serves to keep approximately $0.4m^3/s$ underground. Comparing against the peak flows from Table 1 we can see that the network of pipes is sufficient to contain around the 20% AEP event (1 in 5 year likelihood). However, above this return period the network becomes overwhelmed. The 1% AEP + 41% climate change (central allowance) has a peak flow of $1.64m^3/s$.

As a result of this culvert surcharging the Robert Fletchers site is predicted to be at risk of overland flows, that gravitate down the catchment and across the Site. This inundation tends to follow the roads where possible although during the climate change runs and the 0.1% AEP event it does also spill over some of the walls into buildings as it runs down the hill.

At the northwest corner of the largest building the road T-junctions. There are several structures, buildings and tanks, present on the far side of that junction. The floodwater passes through this area direct to the settling tank areas on the far side however it is also held up by these structures and is therefore partially diverted to the right, passing down the primary access and out to the gate before spilling into the Chew.

The majority of the inundation on the main Robert Fletcher site is of very low depths, generally less than 0.05m.

The greatest flood depths occur on the upstream face of the largest building on site. The overland flow path runs down the hill from Hey Top and impacts against this building, building up until it can make its way around the building edge or else becomes deep enough to overtop the wall or doors present. Depths against this wall can reach up to 0.75m during the 1% AEP +41% climate change event. It should be noted that the onsite drainage inlets have not been included in the model, which could further reduce the overall flood depths.

Depths along the primary road flow path between the buildings are approximately 0.17m during the 1% AEP +41% climate change event.

There is a sheet of flow, with a maximum depth of approximately 0.02m deep and maximum width of 50m, exiting from the western half of Top Dam down to Mill Pond.

Figure 9 through to Figure 13 shows the updated model results after the application of the additional elements. Figure 14 shows the blockage scenario for the 1% AEP +41% climate change.

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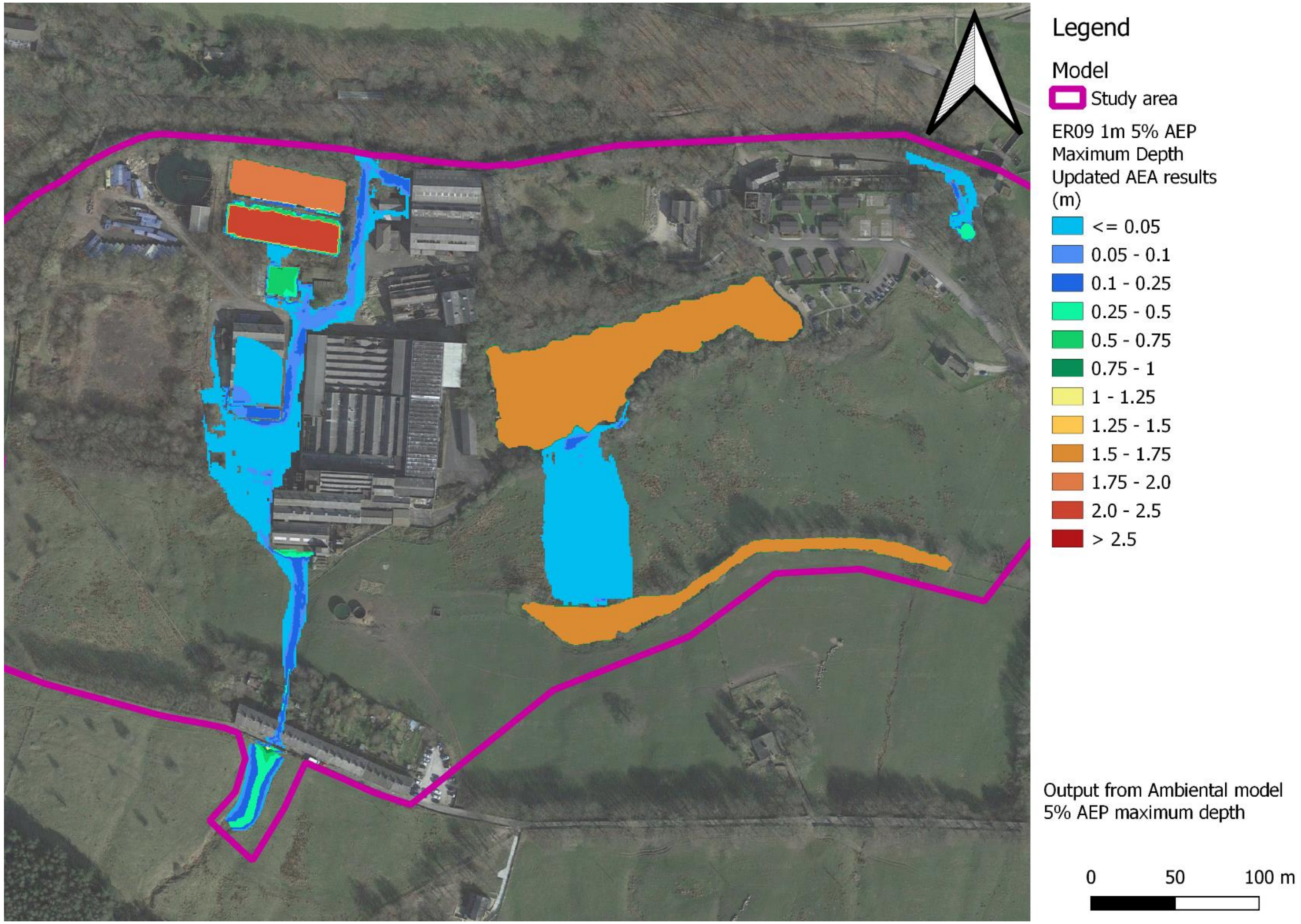

Figure 9: Updated Existing Risk 5% AEP depth

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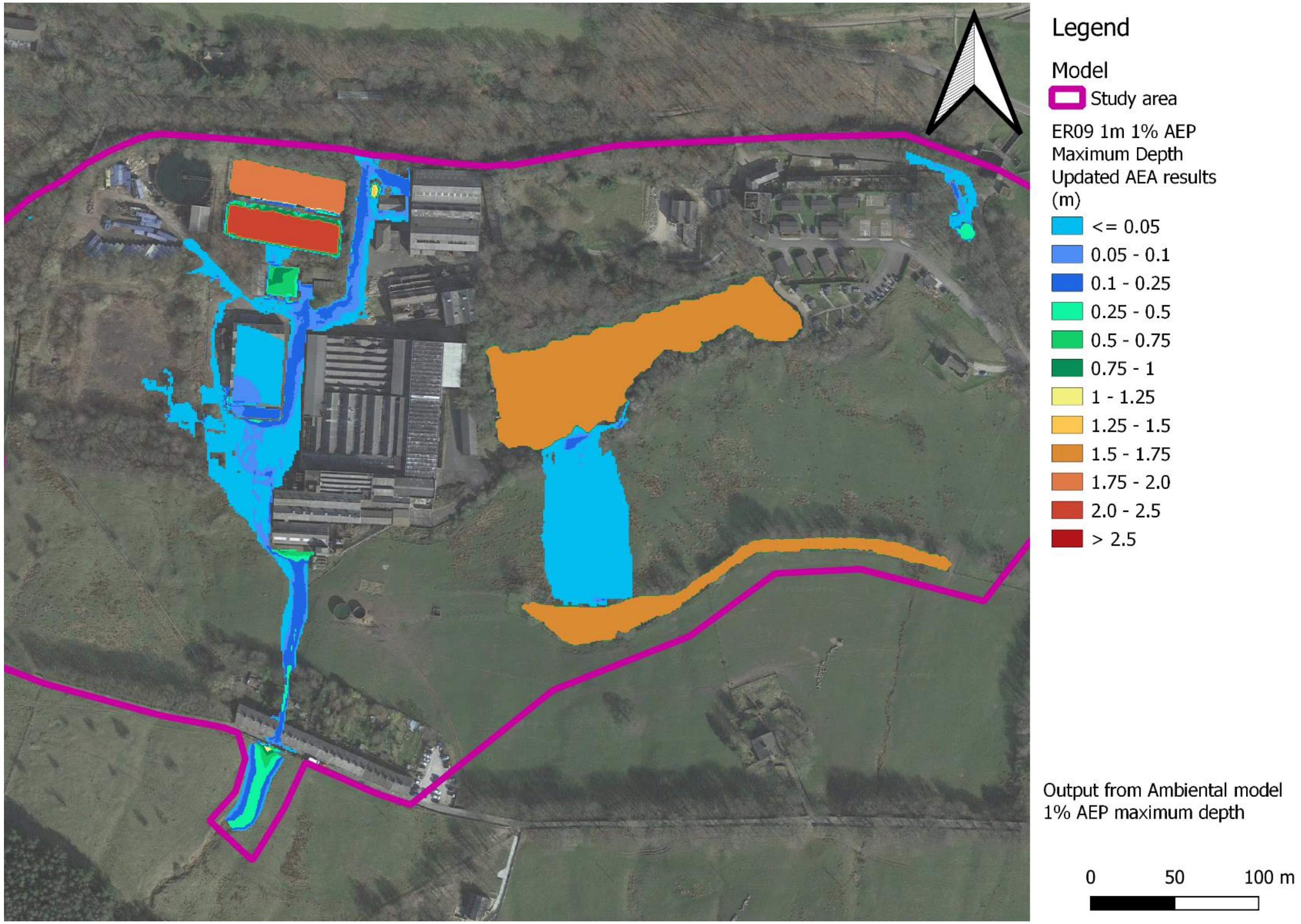

Figure 10: Updated Existing Risk 1% AEP depth

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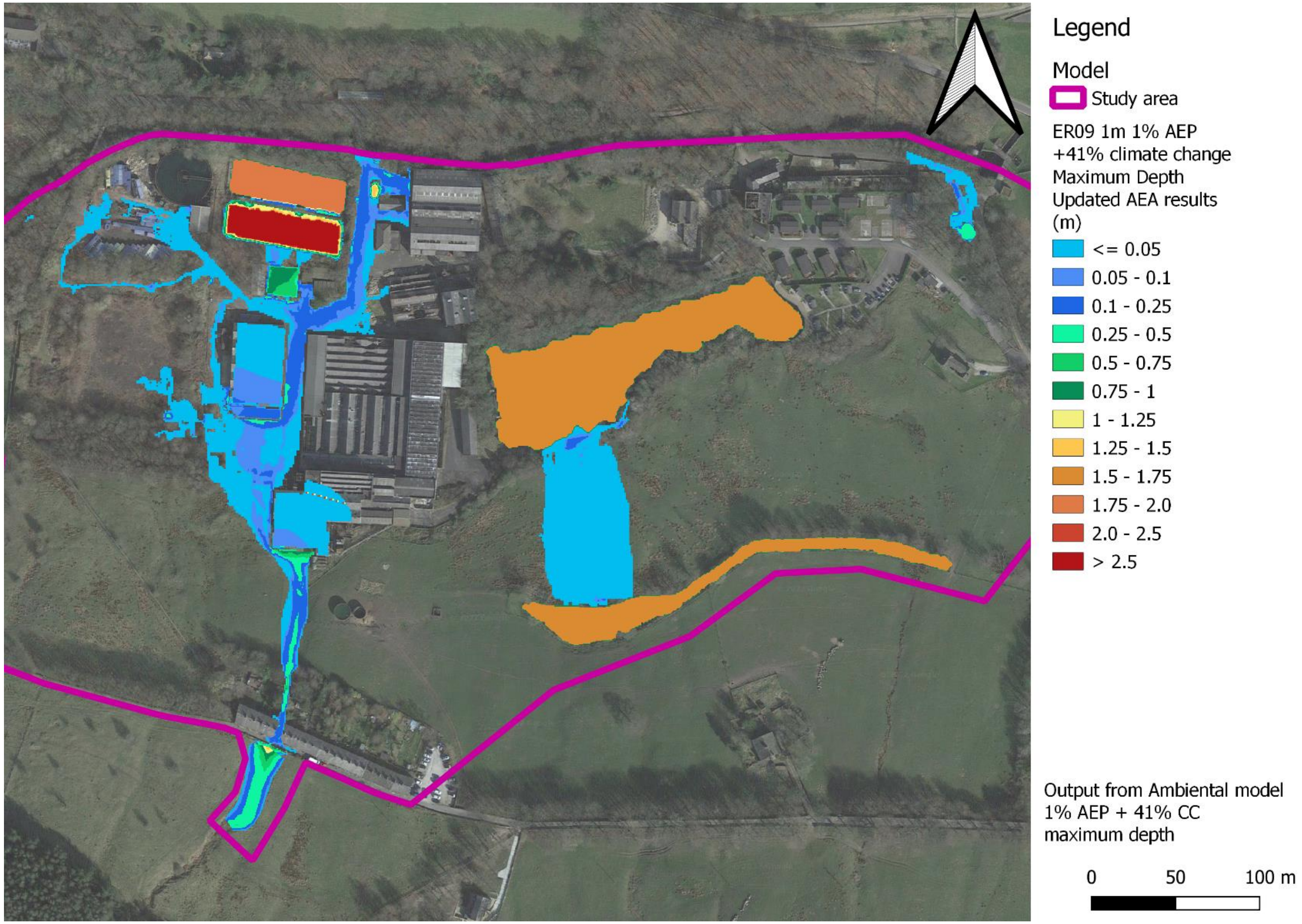

Figure 11: Updating Existing Risk 1% AEP +41% climate change depth

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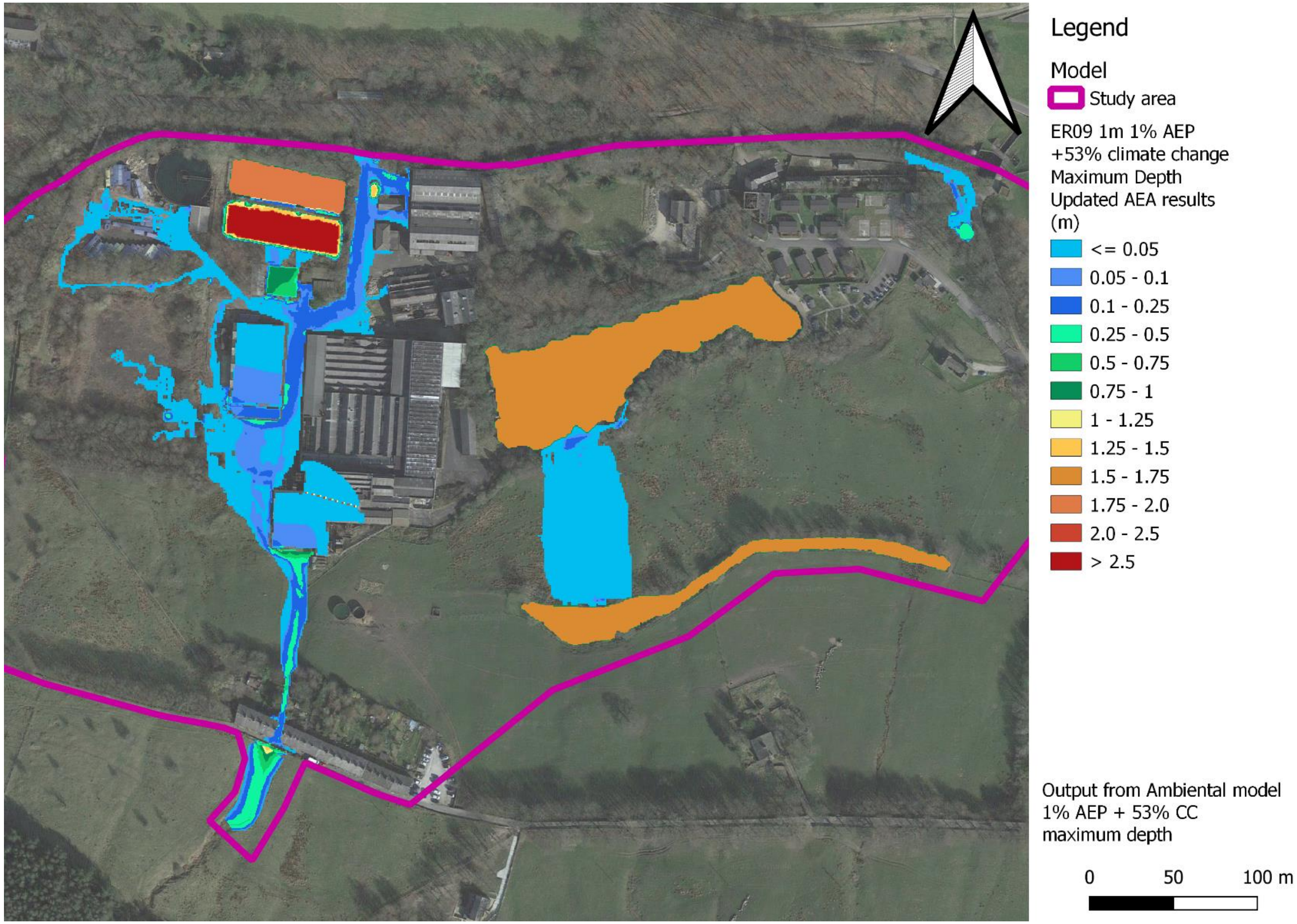

Figure 12: Updated Existing Risk 1% AEP +53% climate change depth

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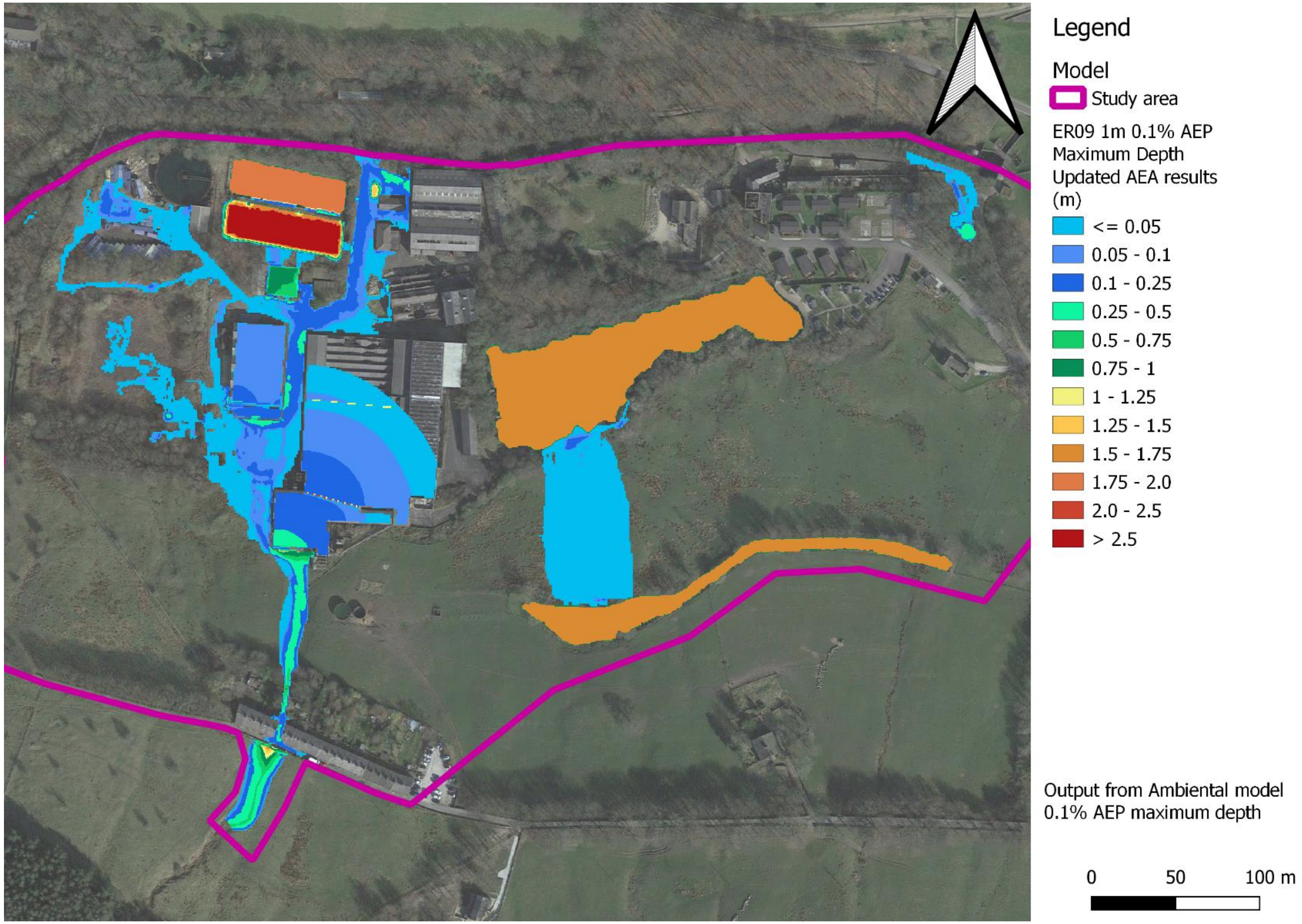

Figure 13: Updated Existing Risk 0.1% AEP depth

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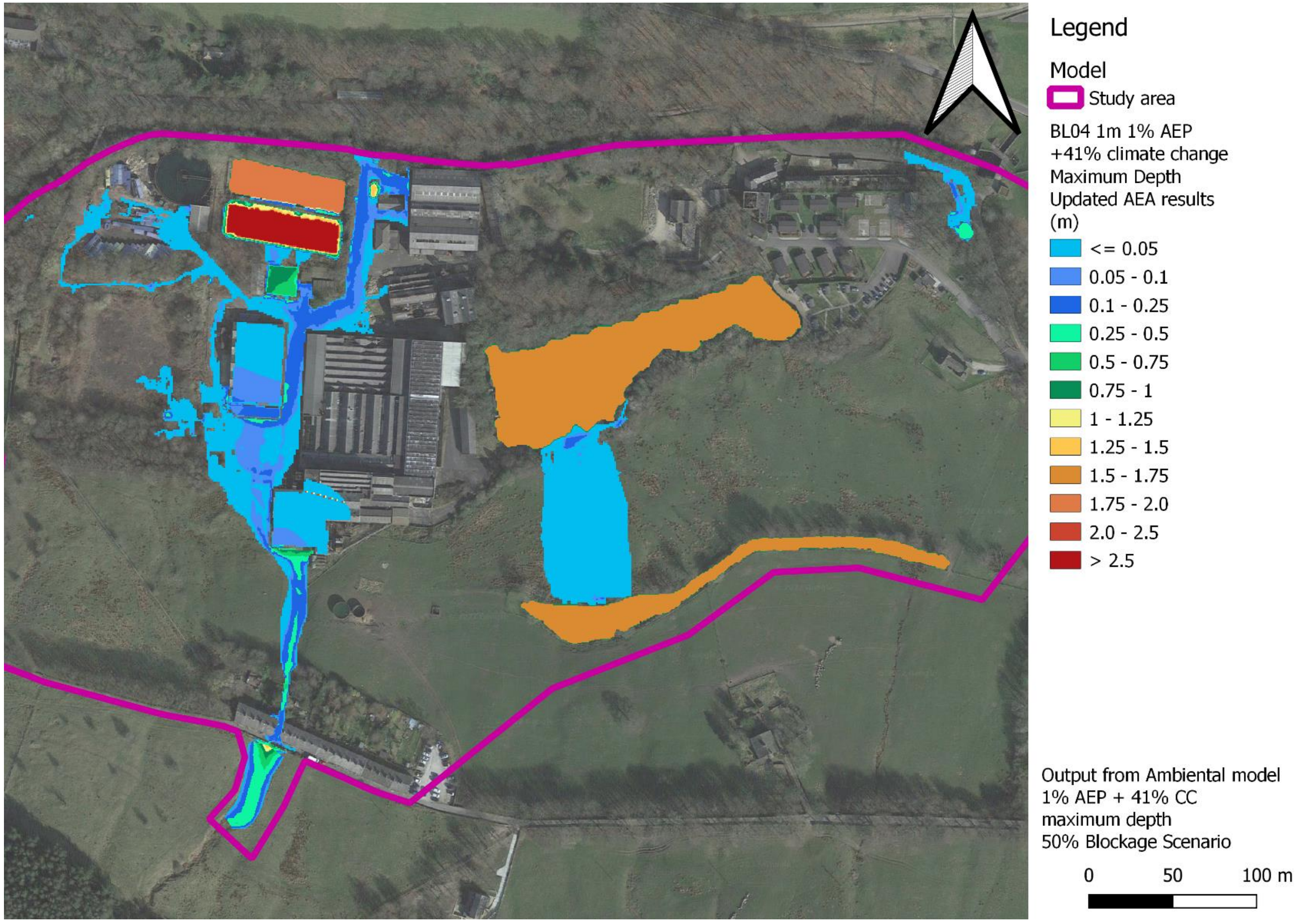

Figure 14: Updated 50% blockage scenario 1% AEP +41% climate change depth

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7 Model Conclusions

Upon review of the model results (Appendix A), Ambiental found that there was still a flood risk posed to the site, even after the implementation of the additional existing elements, with flooding onsite predicted for all modelled return periods from 5% to 0.1% AEP.

As mentioned during the Model Results section the culverted section of the Fletcher's Brook does not have enough capacity to take significant flood flows even after the addition of the overland flow intake and the Top Dam divert pipe.

Even a significant blockage scenario with all pipes blocked by 50% causes a negligible impact on flood depths. This is consistent with the small proportion of flow the culvert can convey relative to the peak flood flows. This also aligns with the findings from the original JBA model.

7.1 Mitigation Options

There are three primary mitigations options which the Site could pursue to consider how to manage the fluvial flood risk in order to enable redevelopment of the Site. These are summarised below.

7.1.1 Upsizing and increasing the culvert network

The first is the upsizing of the existing culvert network as well as potentially the addition of extra pipes.

As demonstrated by the existing pipe, whilst the Fletchers Brook tends to run at very low flow during ordinary operation, during times of flood the flow could spike up to at least 1.6m^3/s. To cope with this amount of water a 1000mm diameter pipe would be required.

It would be a significant undertaking to replace the entire length of existing Fletchers Brook culvert with a pipe of at least this diameter.

Additionally, the hydrology has significant uncertainty and so it is possible that, it to protect against the 1% AEP + 41% climate change event, it would not be a 1000mm dia. pipe but instead a 2000mm dia. pipe which would be required, or multiple smaller pipes or box culverts.

Upsizing the pipe would also not remove the potential for blockage. The Existing Risk baseline model is not sensitive to blockage however if the reliance upon this method was increased the sensitivity of the model to this would also increase.

Figure 5 demonstrates that blockage is not an uncommon occurrence and so a regular and thorough maintenance program would need to be implemented to ensure that this mitigation option actually performed as intended.

Therefore, due to the uncertainty presented as to whether this option would technically accomplish flood risk mitigation, and the ongoing maintenance requirements, it is advised that this is not a feasible solution.

7.1.2 Creation of an attenuation basin

The creation of an attenuation area in the fields downstream of the Hey Top houses but uphill of the largest existing building could intercept the primary overland flow path before it reaches the main area under consideration for development.

The cumulative flow from the 1% AEP +41% climate change hydrograph is 102.1m^3.

It is worth noting again that there is a potential uncertainty factor of 2.0 inherent in the hydrology inputs.

Therefore, accounting for hydrology uncertainty, an attenuation area of 204.2m^3 placed in the path of the flow path would be enough to ensure that all of the overland flooding was captured before it could hit the main site.

An area of 50m wide, 10m long, and 0.5m deep would provide sufficient capacity.

This area would need to straddle two different fields to ensure that it was placed optimally in front of the existing flow path. The area would need to have a connection to the existing Fletchers Brook culvert so that flood water can drain back out once the flood wave had passed.

There are two potential issues with this mitigation option. The first is that construction may be difficult given the topography (~20% slope) in the area. This would entail a large rear retaining wall of at least 2.5m. This is exclusive of any freeboard adjustments which may further lower the basin to prevent the floodwater from spilling over at the front of the attenuation.

The second is that the Land Drainage Act (1991)3 prohibits the obstruction of ordinary watercourses without the express consent in writing of the drainage board concerned.

Obstruction can mean the erection of a mill dam, weir, or other obstruction which would alter the flow of an ordinary watercourse.

This mitigation option accomplishes the technical aspect of removing flood risk from the site.

However, there are potential design considerations with having a large rear retaining wall. Significant design challenges may also present themselves when having to ensure that the basin remained safe (and legislatively compliant) whilst temporarily hold back water on a hill above the residential development.

Further, whilst the Land Drainage Act does not explicitly prohibit such an attenuation area, it does make the process of getting this agreed more difficult, especially if other options are more technically feasible, and until such an agreement is reached the proposed development would remain at risk.

As such, whilst this mitigation option should not be completely discarded, the challenges in implementing this option are significant and it is not recommended to pursue this option as a first course of action.

7.1.3 De-culverting and implementing a naturalised open channel

The third option is to de-culvert the existing Fletcher's Brook culvert and create a natural two stage channel which follows the overland flow route down the hillside, and through the Site.

It is proposed that this option would start downstream of the archway through the Hey Top houses, around the location of the existing overland grated inlet. The existing culvert crossing underneath Bradbury Lane and the connection to Top Dam would be maintained.

Beginning the naturalised channel in this location minimises the constructability and access issues presented by trying fit a wide natural channel underneath the archway and crossing the road.

The channel would then follow the path of the existing flood flow path, meandering down the hillside, and entering the area where the settling tanks are currently located. From this location it would then flow out into the Chew Brook, following approximately the path laid out in Figure 15.

[3] *Land Drainage Act 1991 (legislation.gov.uk)*

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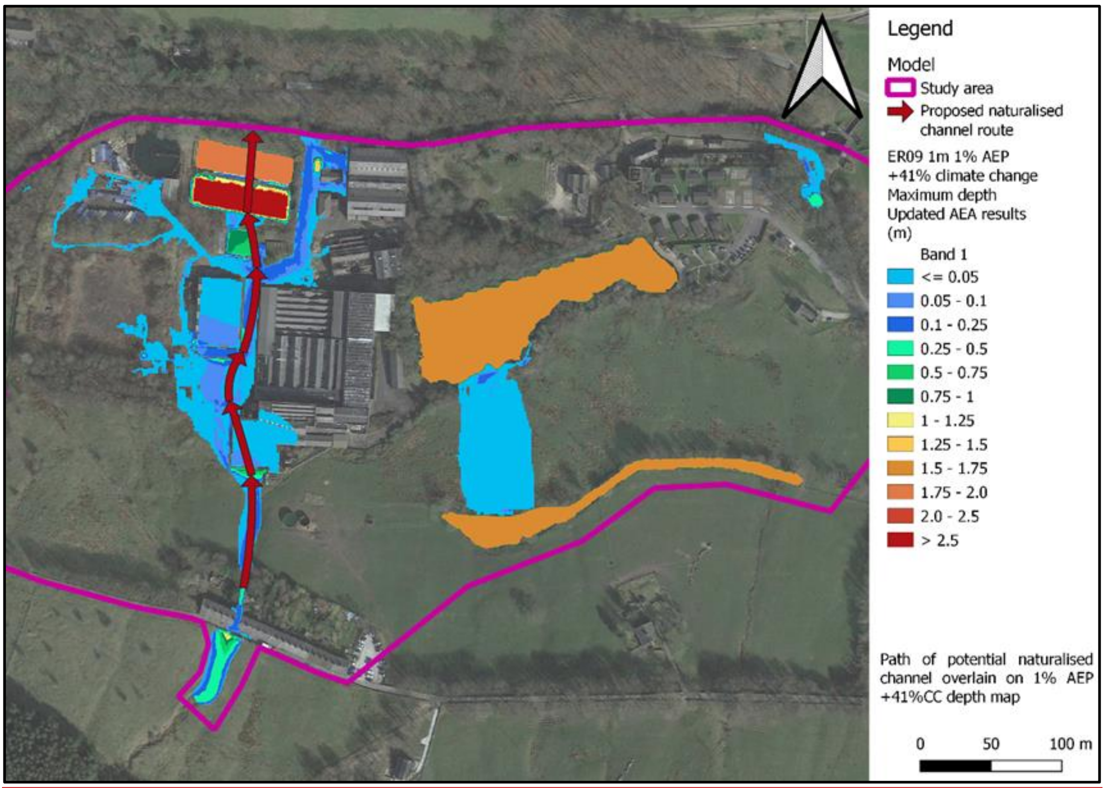

Figure 15: Proposed naturalised channel route

Given the current vacant buildings on site and the proposed redevelopment plan of locating 160 units on the site the presence of existing buildings in the lower part of the site should not be an impediment to this option as it is anticipated that these would be removed during the redevelopment.

It is proposed that a two stage channel would be best suited for this mitigation option as this allows the ordinary low flows to be contained within an appropriately sized channel whilst also allowing greater in channel capacity to accommodate flood events.

The predicted 1% AEP + 41% climate change event has a maximum flow of 1.64m3/s and the hydrology has an uncertainty factor of 2.0.

Therefore, a channel sized to take 3.5m^3/s would certainly be able to contain a design event. Additionally, a channel of this size would also be able to contain a 0.1% AEP event + 41% climate change (using the existing predicted hydrology).

Initial proposals for the channel would be to use 1:3 side slopes, a 'normal' flow channel to accommodate Qbar flows, would be approximately 10 metres wide from top of bank to top of bank. It is important to ensure that such a channel has maintenance access nearby, as such a 4m wide access route on either side of the channel should be provided, however landscaping and amenity improvements could also be planned along this route, to integrate the proposed channel into the design strategy for the Site.

Any crossings over the channel should be either via a free spanning bridge or else via a box culvert. If box culverts are used these should be partly buried with either bed type material or gravel for at least 300mm to enable biodiversity benefits.

Implementing this channel would ensure that all of the flood flows for up to a 0.1% AEP event inclusive of climate change would be contained within the designated areas and therefore would remove the fluvial risk to the development.

In addition to removing the flood risk from the site, this option also provides opportunity to create amenity benefits for the development as well as habitat creation potential. It would also support an Environment Agency aim of de-culverting and re-naturalising watercourses, as well as provide the opportunity to re-use a vacant brownfield Site.

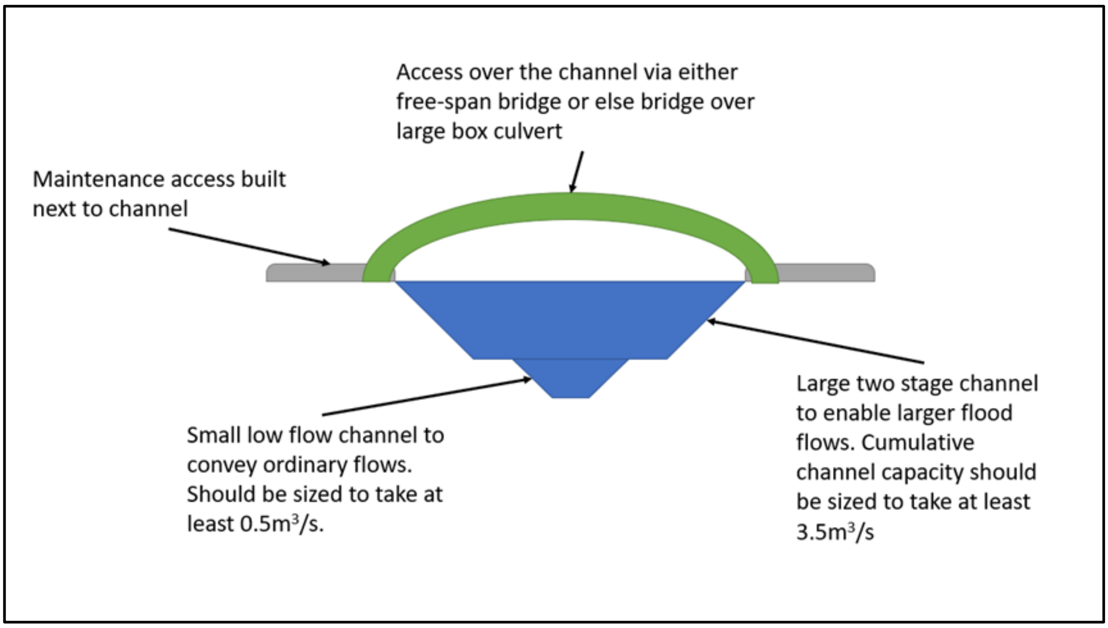

Figure 16: Example cross section of naturalised Fletchers Brook

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8 Summary

Holdgate Consulting (the Client) commissioned Ambiental Environmental Assessment to conduct an updated modelling exercise to study the flood risk from Fletchers Brook and to suggest how this might be mitigated if necessary.

A prior JBA model was completed in 2021 wherein this watercourse was demonstrated to be causing a significant flood risk to the Site. However, this model did not fully account for the complex network of culverts and collecting boxes which are present on site and so it was believed that the results from this 2021 study were over emphasising the risk to the site.

The Client provided Ambiental with a topographic survey, details of these pipes, and invited Ambiental along on a site walkover.

These pieces of information revealed the presence, direction, and approximate dimensions of several key culverts.

- The Stack Head collecting box was confirmed to be operational although inspection of the pipe sizes leading away from here was not possible. A 300mm dia. pipe was assumed in order to take a conservative approach.
- The culvert divert from the Fletchers Brook culvert towards Top Dam was confirmed to be at least 300mm dia. at one location under a manhole in the gardens behind the Hey Top houses.
- The grated intake to Fletchers Brook to capture overland flow was measured and it's placement downstream of the divert towards Top Dam was noted.
- The pipes connecting the two lakes were measured as were the outfalls leading to the Chew Brook.
- The topographic survey provided many Finished Floor Levels which were incorporated into the model ensuring better representation of the existing buildings on site. This survey also provided an improved representation for the general model surface levels.

Due to stability issues the model needed to be converted from the JBA 2021 format of a linked Flood Modeller/TUFLOW set up to an ESTRY/TUFLOW set up. The average difference between the flood depths for the 1% AEP between these two set ups was less than 4mm and therefore the new set up is considered comparable.

Implementing the additional elements and details found that although reduced flood volume on the main portion of the site did decrease, however there was still flooding running down the roadways and even through some buildings.

The Fletchers Brook culvert as it exists now is simply too small to fully accommodate large flood flows and so it overtops leading to overland flooding down into the main site.

Given topography and existing overland flow path, complete environmentally sympathetic mitigation of flood risk may be possible.

Potential mitigation measures / solutions

Based on findings, three different mitigation measures were considered. These were;

1. Changes to the culvert network
2. Creation of an attenuation area, and,
3. De-culverting the Fletchers Brook and creating a naturalised channel leading down to the Chew Brook.

The potential culvert change mitigation option was assessed to not be feasible due to uncertainty as to whether it would be a technically effective option and ongoing maintenance burden.

The attenuation basin option was assessed to be hydraulically effective option however design and constructability challenges, combined with legislative hurdles, mean that this should only be considered as a secondary option.

The de-culverting of the Fletchers Brook culvert downstream of the Top Dam divert and creating a naturalised channel which runs down through the proposed development is considered the best mitigation option.

This manages the fluvial flood risk to the development site as the channel will be able to contain all of the floodwater, upto the 0.1% + Climate Change scenario. Additionally, this allows opportunity for habitat creation as well as potential provision of amenity areas, integrating into the development proposals. Furthermore, this option aligns with the Environment Agency's aspirations for de-culverting of watercourses.

In conclusion, the updated flood modelling demonstrates that the omission of key structures from the JBA flood model, has led to an over-prediction of flood risk to the Site. However, in order to redevelop the vacant brownfield, a flood risk management strategy is likely to require the provision of an open watercourse channel, replacing the existing under-sized culvert. Consequently, it is considered that redevelopment of the site is technically feasible and the opportunities to reduce flood risk and provide environmental and amenity enhancement, align with the National Planning Policy Framework objectives.

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Appendix

A. Model results and files

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Appendix

B. Initial JBA Model and info

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Appendix

C. Supporting Information

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