



WATER LANE ANGMERING

MODELLING REPORT

EDENVALE YOUNG ASSOCIATES LTD.

JULY 27, 2018

Revision A



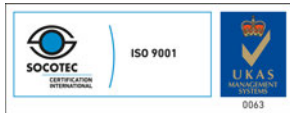
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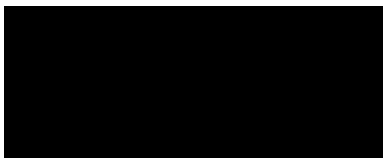
Rydon Homes

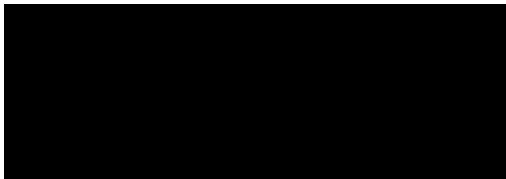
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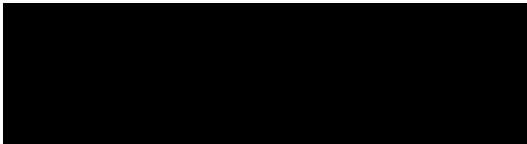
Document Control



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1 Introduction

1.1 Model overview

Edenvale Young has been commissioned by Rydon Homes to undertake hydraulic modelling to assess the impact of changing a signalised junction to a roundabout. The proposed roundabout location is at the junction of A280 Angmering Bypass and Water Lane just to the North-East of Angmering, UK as shown in figure 1.1.

The proposed roundabout is currently has a slightly larger land take, including some land within the flood plain. The slightly larger area of the roundabout compared to the existing signalised junction would impact the catchment storage. Current EA flood zones, as shown in figure 1.2 show that the proposed site is in flood zone 1 but lies close to the watercourse named Black Ditch.

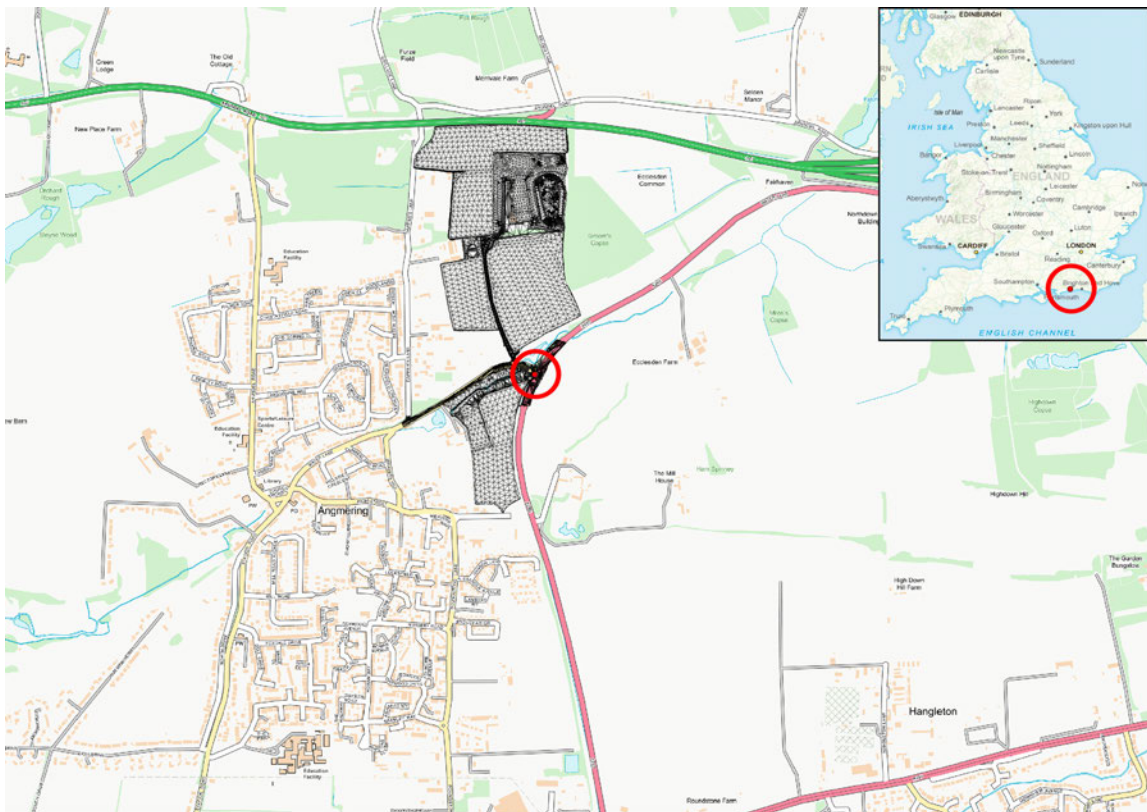


Figure 1.1: New proposed roundabout location

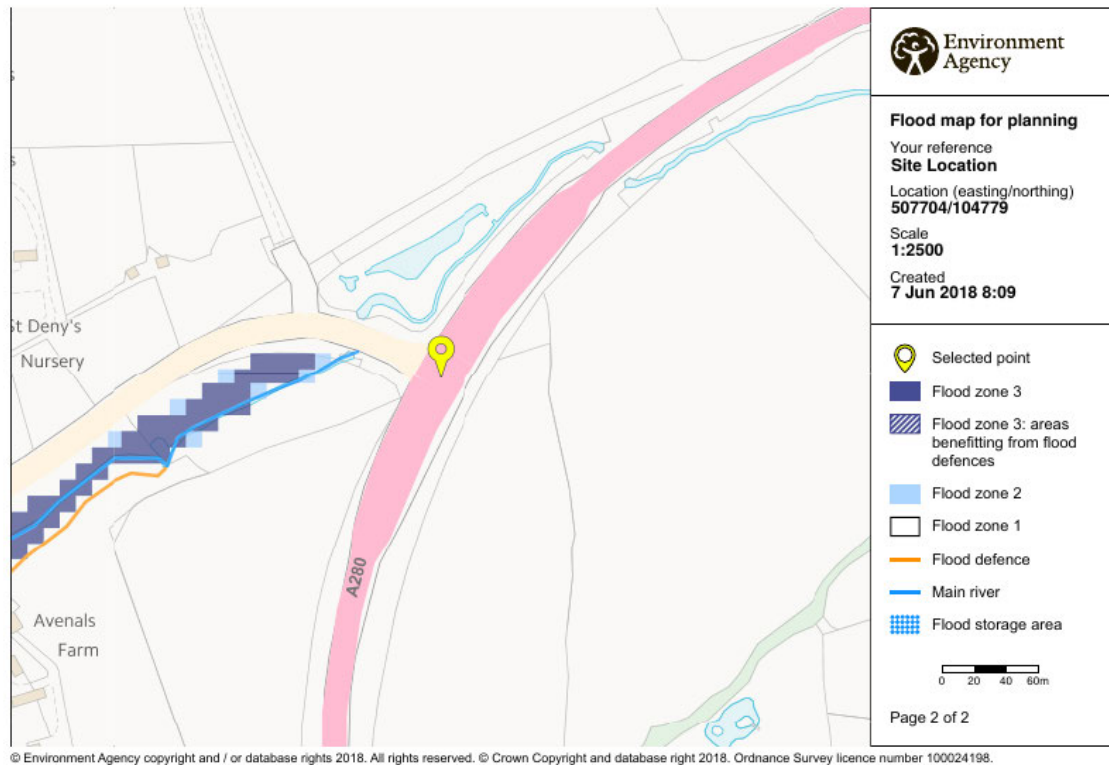


Figure 1.2: Current EA flood zones

Hydraulic modelling was undertaken for 5%, 1%, 1% + climate change and 0.1% Annual Exceedance Probability (AEP) events. The active area of the model is 1.2km² and covers approximately 2.6km of watercourse. Cross section survey data from March 2018 as well topographic survey from April 2017 was used in creation of the hydraulic model. ESTRY-TUFLOW HPC 2018-03-AA was used for all hydraulic modelling.

2 Hydraulic modelling

2.1 General

The hydraulic modelling was undertaken for a total of 1.2km² of model area covering 2.6km of water course as shown in figure 2.3.

The hydraulic model has been used to assess flood risk and the effect of the roundabout development on flood risk in adjacent areas. Inflows into the model were developed using FEH methods, see Appendix A. Modelling has been undertaken for pre- and post-development scenarios for a range of fluvial flow and climate change (CC) events as shown in table 2.1.

AEP (return period)	Pre-development Case-A	Post-development Case-B
5% (1-in-20)	✓	✓
1% (1-in-100)	✓	✓
1% (1-in-100) +10% CC	✓	✓
1% (1-in-100) +20% CC	✓	✓
1% (1-in-100) +35% CC	✓	✓
0.1% (1-in-1000)	✓	✓

Table 2.1: AEPs and cases modelled

2.2 Existing modelling

It is understood that no pre-existing modelling of this area exists and as such, a new model has been built completely from component data with no elements from previous models incorporated.

2.3 Available data

2.3.1 Elevation data

LiDAR data was obtained from the Environment Agency Open Data website¹. For the study area, this was available at 2m and 1m resolutions, and the 1m data was selected for use.

¹ <https://environment.data.gov.uk/ds/survey>

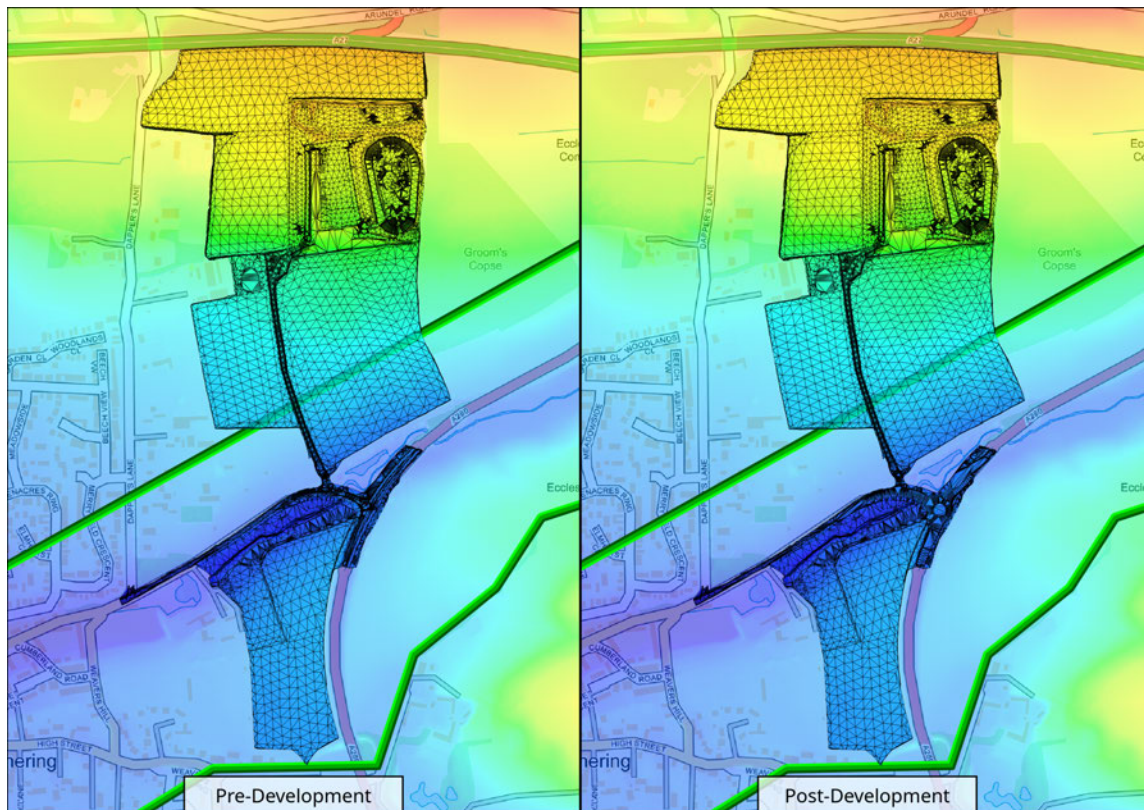


Figure 2.1: Pre and post-development TINs

2.3.2 Channel survey

Hydrographic survey was undertaken for the purposes of this study by Infomap surveys & Mapping Ltd. The scope of the survey met and exceeded the EA National Standard Contract and Specification for Surveying Services (v3.2 and amendments). This included sections of open channel and also structural survey at all bridges and other features within the study reach.

2.3.3 TINs

A Triangulated Irregular Network (TIN) DTM was provided for pre-development scenario in DWG format. The supplied proposed roundabout geometry was processed to create a post-development TIN DTM using AutoCAD Civil 3D 2018. The AutoCAD drawing was then post processed into Aquaveo SMS .tin file format that TUFLOW can read natively. The final TIN can be seen in figure 2.1.

2.3.4 Map data

Land-use data in vector format was derived from the national coverage provided by Ordnance Survey: Open Map-Local (04/2017). This was supplied with sufficient coverage for the full model extent.

2.4 Modelling approach

2.4.1 Software used

The scheme was modelled using the new HPC solver of the widely adopted TUFLOW software. Due to great increase in computation times, the scheme was run on GPU instead of standard CPU.

TUFLOW has been in wide use in the UK for over 10 years and is a stable and extensively tested two-dimensional (2D) modelling package. TUFLOW HPC is becoming the new standard in 2D modelling due to its heavily parallelizable ability, great run time improvements and therefore ability to make models at much higher resolutions. The model incorporates a one-dimensional (1D) model, ESTRY, for the simulation of open channels, culverts and structures.

The 1D and 2D solvers may be coupled and run simultaneously, exchanging data throughout the simulation, permitting utilisation of the strengths of both 1D (best for channels and structures) and 2D (best for floodplains and complex flood paths).

One of the key advantages of the software is its use of standardised and open input and output formats (ASC, SHP, CSV, TXT). This means that model data can be both prepared and inspected/reviewed without a copy of the software and the data can be readily extracted and processed using other, unrelated programs.

The latest version of the software was applied, specifically build 2018-03-AA-iSP-w64 run on GPU (NVidia GeForce 1080's or 1080Ti's).

2.4.2 Terrain

Represented using the 2D portion of the model, the floodplain is split into square elements referred to as 'cells'. The cell size should be small enough to represent flow routes with sufficient detail, however, larger cell sizes are favourable as increases to the number of cells also increases the computational effort in undertaking simulations (halving the cell size results in simulations taking approximately 8 times longer to run). In this instance a 1m resolution was selected as there is no finer resolution LiDAR available.

Refinements were required at some bridge decks as the LiDAR processing that removes buildings from the DTM also tends to filter out bridge decks. These were reinstated within the model using TUFLOW's 'Z shape' capability. Elevations for the bridge decks were obtained from topographic survey.

It was required to carve out the small pond between Weavers Hill road and A280 since the LiDAR picked up the surface of the water. The pond was lowered by 0.5m below the invert of the spill out of the pond. The initial water level in the pond was

then set to the invert of the spill out of the pond to prevent artificially raising the storage in the model.

The LiDAR was sufficiently recent and of sufficiently good quality that no further refinements were considered necessary, as relevant flow routes and obstructions to flow were all well represented.

2.4.3 Surface parameters

In addition to elevations, it is necessary to assign roughness and permeability characteristics to the model domain.

Roughness has been spatially assigned using Ordnance Survey maps, with material IDs being assigned different Manning's n roughness parameters (the industry standard parameterisation of roughness). The values selected are typical values for floodplains in the UK.

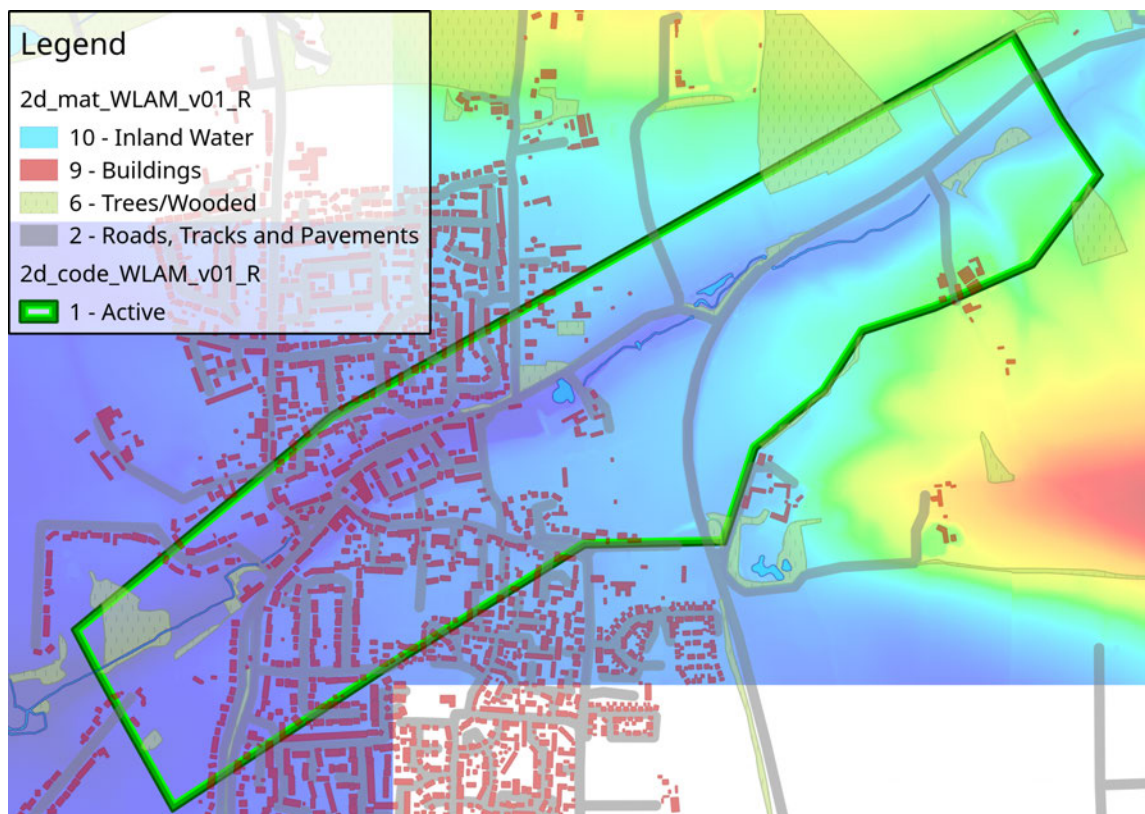


Figure 2.2: Active area and materials used

Figure 2.2 shows the coverage of the different classes, while table 2.2 below shows the roughness parameters applied to the different classes. For some materials depth varying Manning's n was applied. This is done to provide accurate representation of roughness at all scales. For example, grass is going to impede shallow flows to a much greater extent than deep flows over the same grass once the water level rises above the blades of grass. $d1$ and $d2$ are depths in meters for which Manning's values $n1$ and $n2$ respectively are applied. Between $d1$ and $d2$ depths, linear interpolation is used for Manning's n .

Material ID - description	Manning's n	d1	n1	d2	n2
1 - Default. Grazed fields/ shortish grass	0.0500	0.10	0.3000	0.20	0.0500
2 - Roads & concrete	0.0200				
3 - Kept fields (playing fields etc)	0.0400	0.05	0.3000	0.10	0.0400
4 - Covers Urban primarily	0.0800	0.15	0.3000	0.20	0.0800
5 - Scrubland	0.0550	0.10	0.3000	0.30	0.0600
6 - Trees/Wooded	0.1000	0.10	0.3000	0.20	0.1000
9 - Buildings	1.0000				
10 - River channel	0.0350				

Table 2.2: Roughness parameters applied

2.5 Open channel

2.5.1 Features

The watercourses within the area being modelled as 1D elements in ESTRY are identified in figure 2.3, which also indicates the primary flow direction and active area of the model.

Of particular note is the pond between Weavers Hill road and A280. The culvert passing under the road spills into the pond, via an SX boundary that was modelled in 2D. The water is then taken out of the pond via another SX boundary and a WW weir unit from survey.

All the other structures within the model are bridges/conduits, which have been represented using conduit units. High resolution of the model allowed all bridge decks to be represented within the 2D domain.

2.5.2 Parameters

Aside from the geometry, there are a few other parameters that influence flow being passed through a 1D scheme; these were set as follows:

Channel Roughness

Roughness was applied using the Manning's n. Roughness is permitted to vary across the sections and the values (initially provided by the surveyor) were cross-checked against photographs.

In general in-bank roughness is between 0.03 and 0.035, with lined channel sections between 0.015 and 0.02. All out-of-bank areas were trimmed out of the cross sections and modelled in 2D to avoid 'double counting'. These are typical values for 1D channels.

Structure losses

The conduits representing bridges all have contraction, entrance and exit losses applied at default values as recommended within the TUFLOW manual of 0.5 and 1 respectively. Such weirs as are present are represented using 'WW' units within ESTRY, which is

an improved broad weir schematisation; parameters have been left at default in all cases.

2.6.1 Inflows

The location of the inflow is shown in figure 2.4.

A Head-Time (HT) boundary has been applied at the downstream extent of the Black Ditch in the 1D domain as shown in figure 2.4. The elevation of this boundary has been set to 1.91 mAOD—just below top of bank (at 2.15 mAOD). Setting the water level just below top of bank in 1D is considered standard practice when modelling with ESTRY where the downstream water levels are not expected to affect the site, especially as an automatic HQ boundary will be handling out of bank flows in TUFLOW.

Water Lane Angmering-Modelling Report

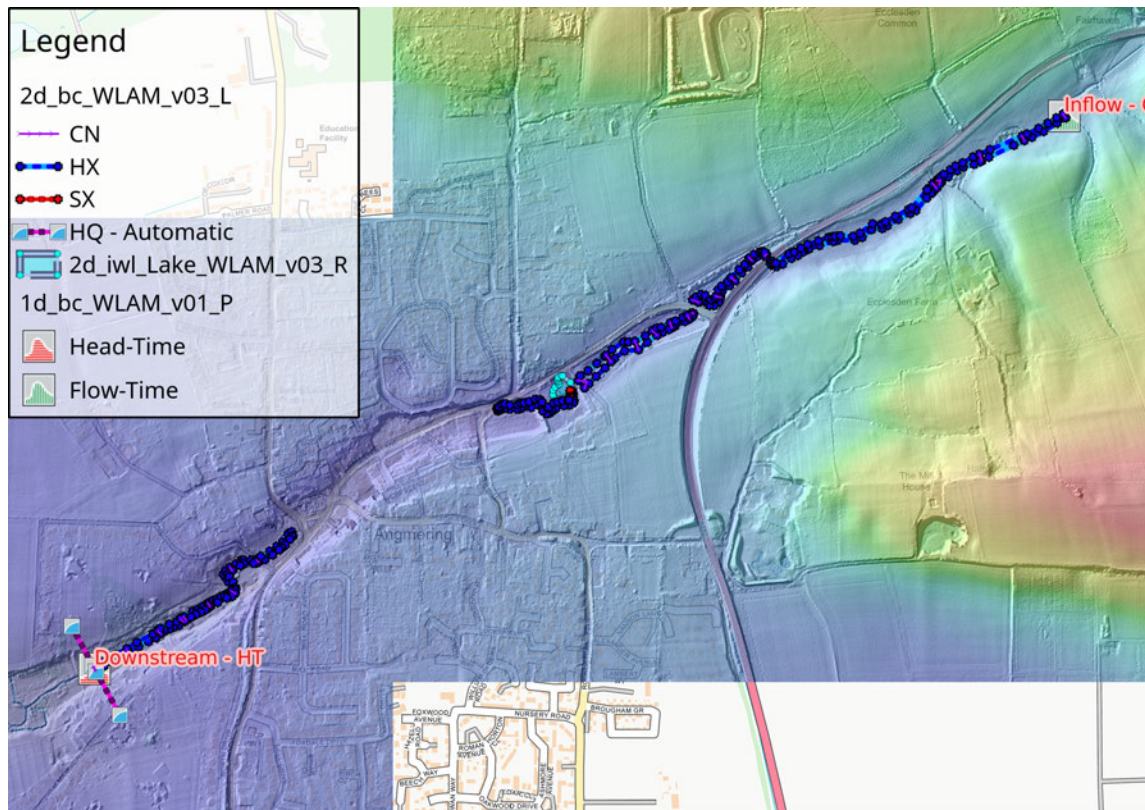


Figure 2.4: 1D & 2D boundary conditions and initial water level

The slopes were calculated from LiDAR data immediately downstream of the respective boundaries.

It is considered the boundaries have been placed far enough away from the area of interest to not have any influence on the modelled results for the site.

2.7 Initial conditions

Both the 1D and 2D domains starts completely dry apart from the small pond between Weavers Hill road and A280. The initial water level in the pond was then set to 9.08 mAOD, the same as the invert of the spill out of the pond to prevent artificially raising the storage in the model.

2.8 Simulation parameters

All simulation parameters have been left at their default values except where discussed above.

3 Results

The following figures (outlined in table 3.1) show the peak modelled flood depths, water levels, differences between pre and post-development scenarios and model stability parameters through the simulation.

The HPC solver uses 3 primary mechanisms to determine the maximum timestep that an explicit solution to the Shallow Water Equations can use:

Nu Courant number, $Nu = \frac{u \Delta t}{\Delta x}$, limit $Nu < 1.0$

Nc Non-dimensional wave speed number, $c = \sqrt{gh}$, $Nc = \frac{c \Delta t}{\Delta x}$
limit $Nc < 1.0$

Nd Non-dimensional diffusion number, $Nd = \frac{v \Delta t}{\Delta x^2}$ limit $Nd \leq 0.3$

Figures 3.31–3.42 show the maximum Nu , Nc and Nd values in the model at any time throughout the simulation. By analysing the Nu , Nc and Nd parameters, you can see which process is the limiting parameter for the timestep. The plots also show the timestep (Δt), fluctuations in timestep could indicate model instability. In addition the plots show number of wet cells in the model ($nWet$) as an indication of the progression of the simulated event.

AEP	Case-A Depths	Case-B Depths	Case-A Levels	Case-B Levels	Case-B minus A Differences	Case-A Stability	Case-B Stability
5%	Fig. 3.1	Fig. 3.7	Fig. 3.13	Fig. 3.19	Fig. 3.25	Fig. 3.31	Fig. 3.37
1%	Fig. 3.2	Fig. 3.8	Fig. 3.14	Fig. 3.20	Fig. 3.26	Fig. 3.32	Fig. 3.38
1% +10% CC	Fig. 3.3	Fig. 3.9	Fig. 3.15	Fig. 3.21	Fig. 3.27	Fig. 3.33	Fig. 3.39
1% +20% CC	Fig. 3.4	Fig. 3.10	Fig. 3.16	Fig. 3.22	Fig. 3.28	Fig. 3.34	Fig. 3.40
1% +35% CC	Fig. 3.5	Fig. 3.11	Fig. 3.17	Fig. 3.23	Fig. 3.29	Fig. 3.35	Fig. 3.41
0.1%	Fig. 3.6	Fig. 3.12	Fig. 3.18	Fig. 3.24	Fig. 3.30	Fig. 3.36	Fig. 3.42

Table 3.1: Results figure index

3.1 Depth maps

3.1.1 Case-A: Pre-development

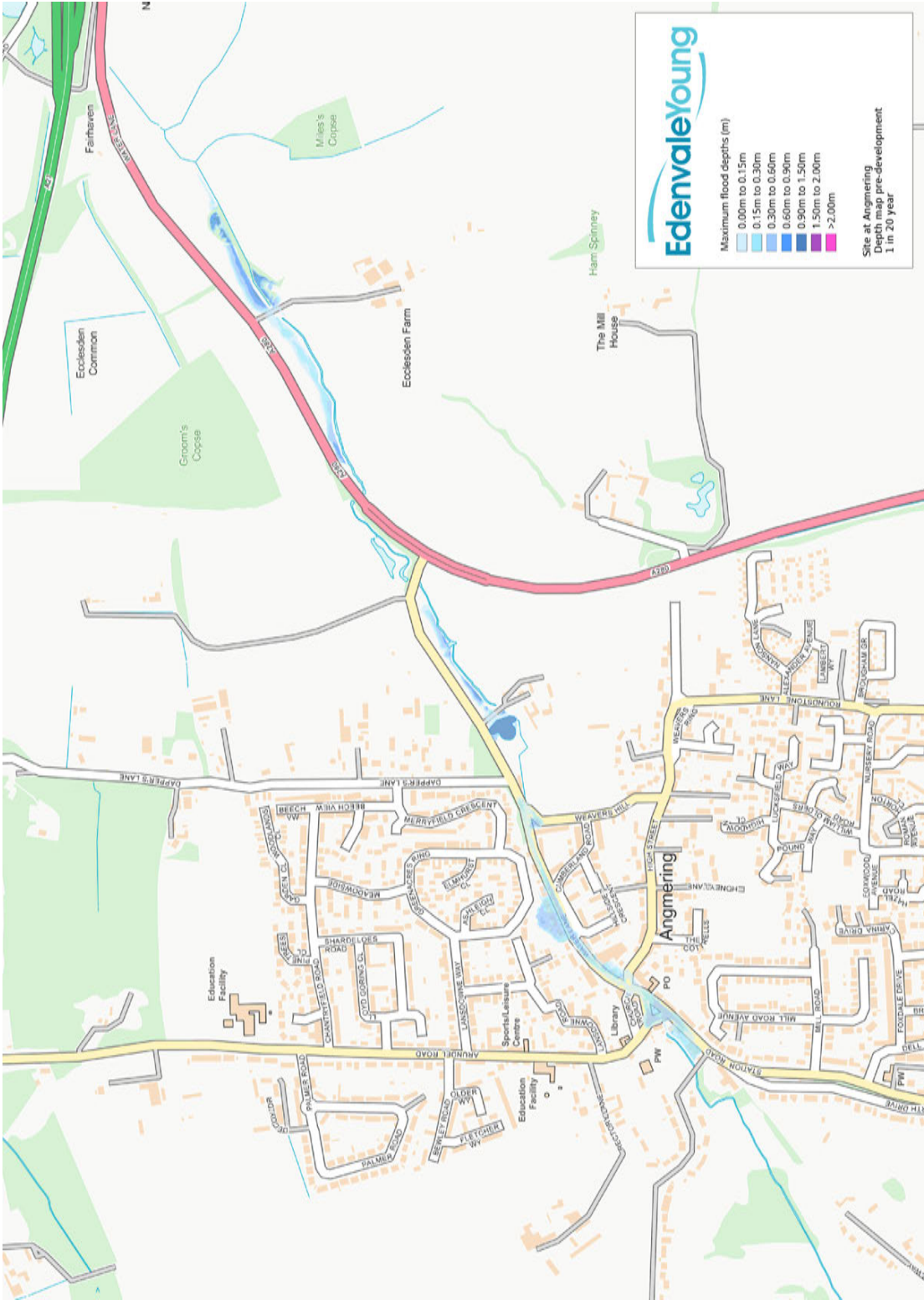


Figure 3.1: Case-A: Pre-development, depth map 5% AEP

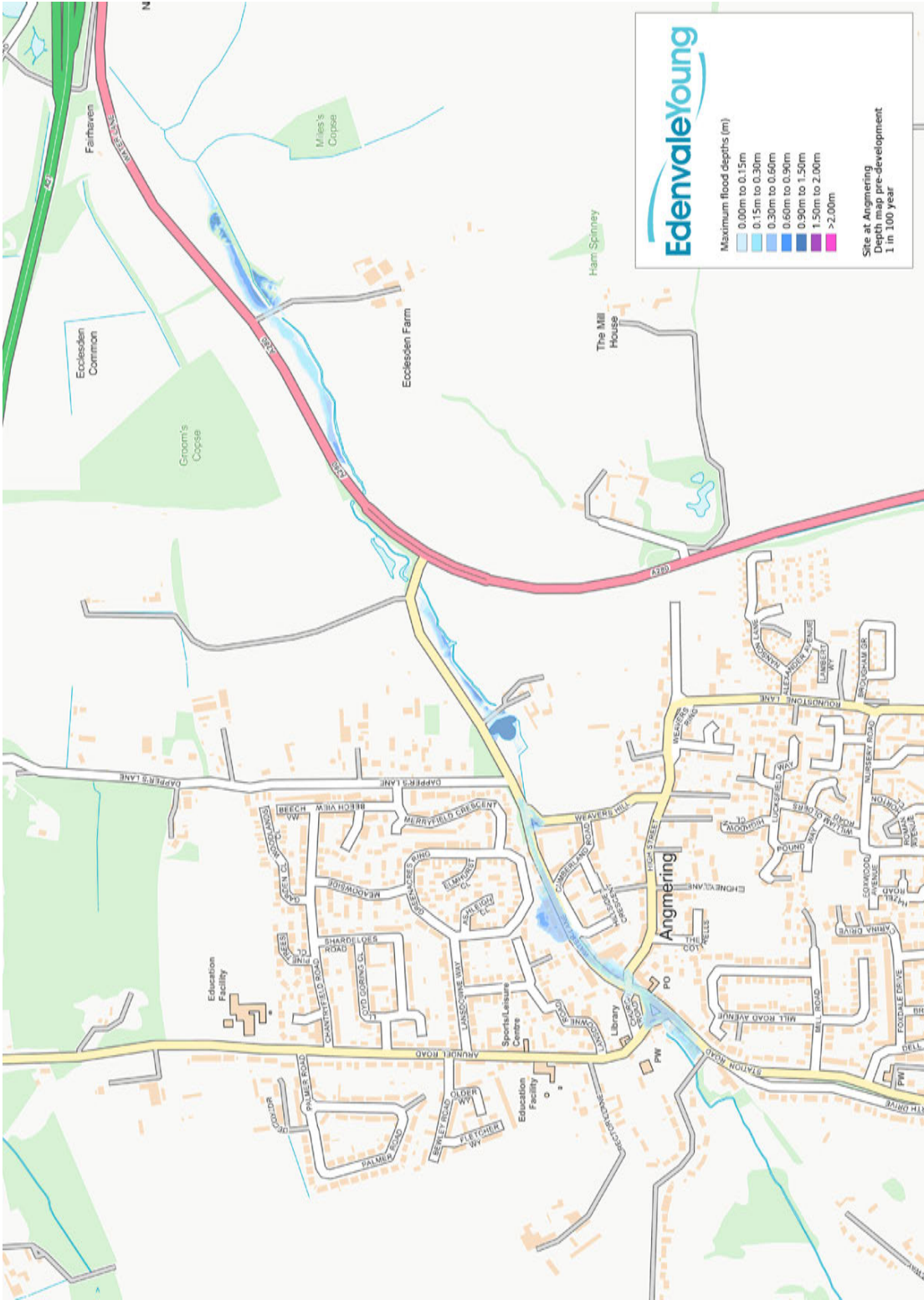


Figure 3.2: Case-A: Pre-development, depth map 1% AEP

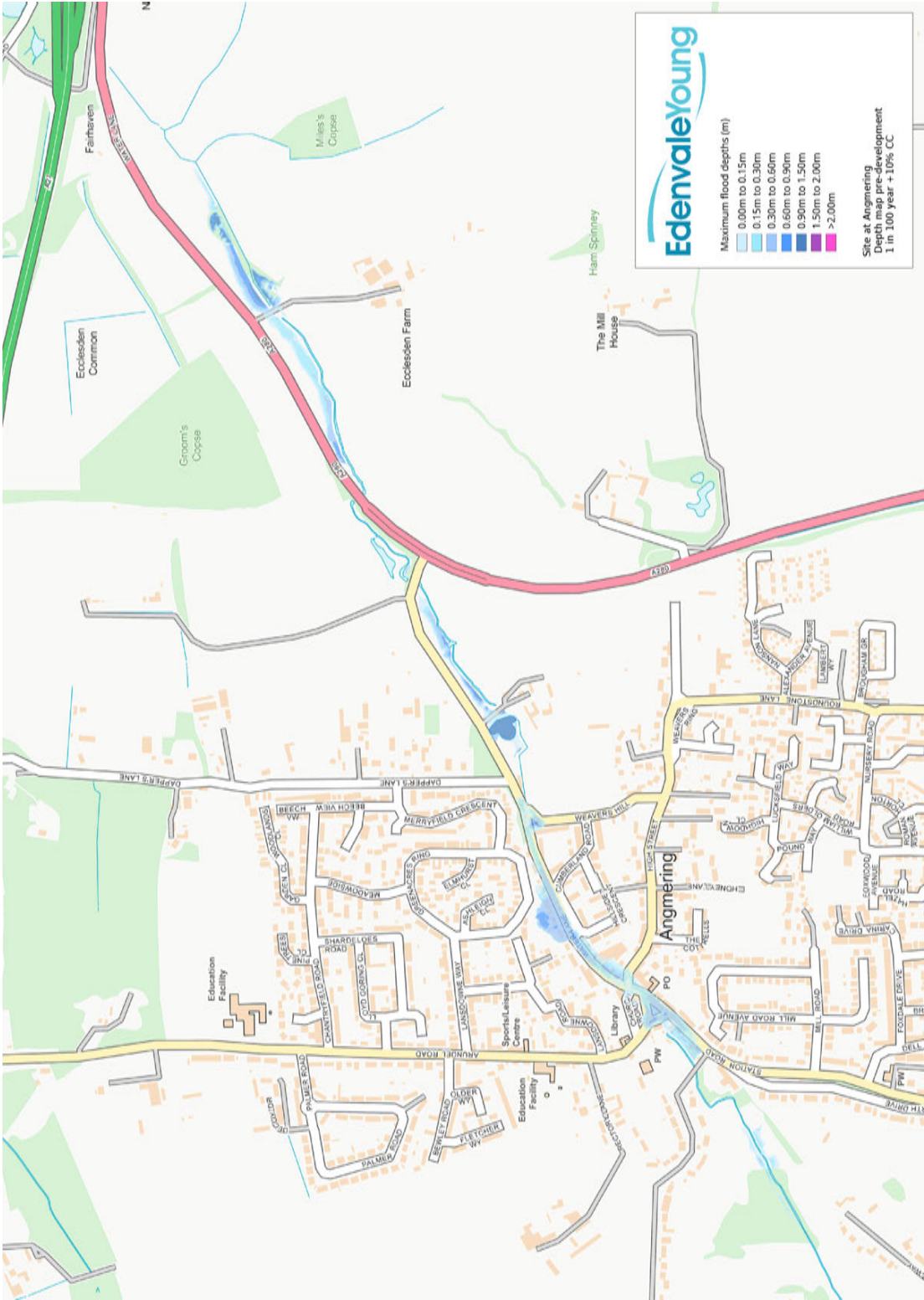


Figure 3.3: Case-A: Pre-development, depth map 1% AEP + 10% climate change

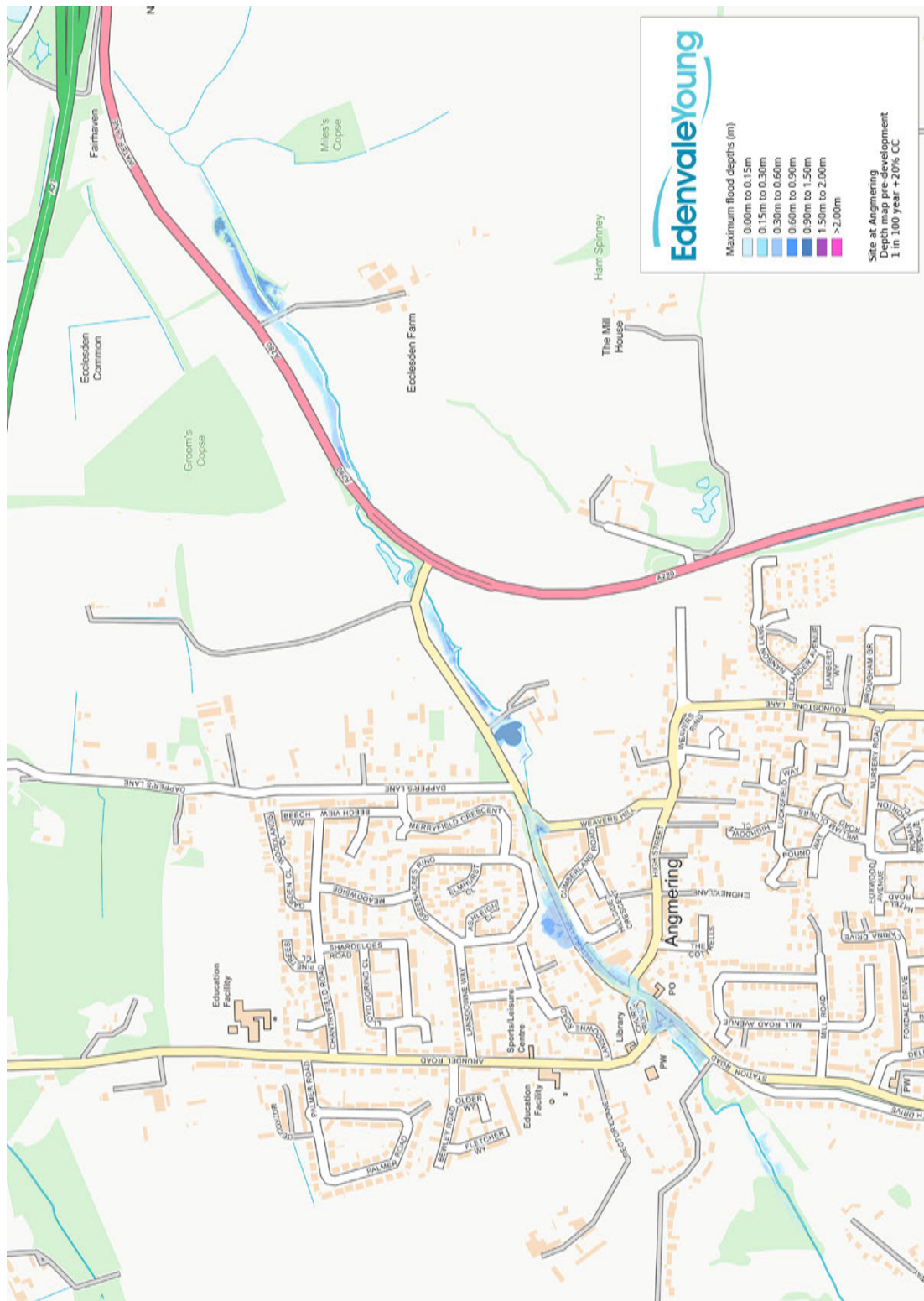


Figure 3.4: Case-A: Pre-development, depth map 1% AEP + 20% climate change

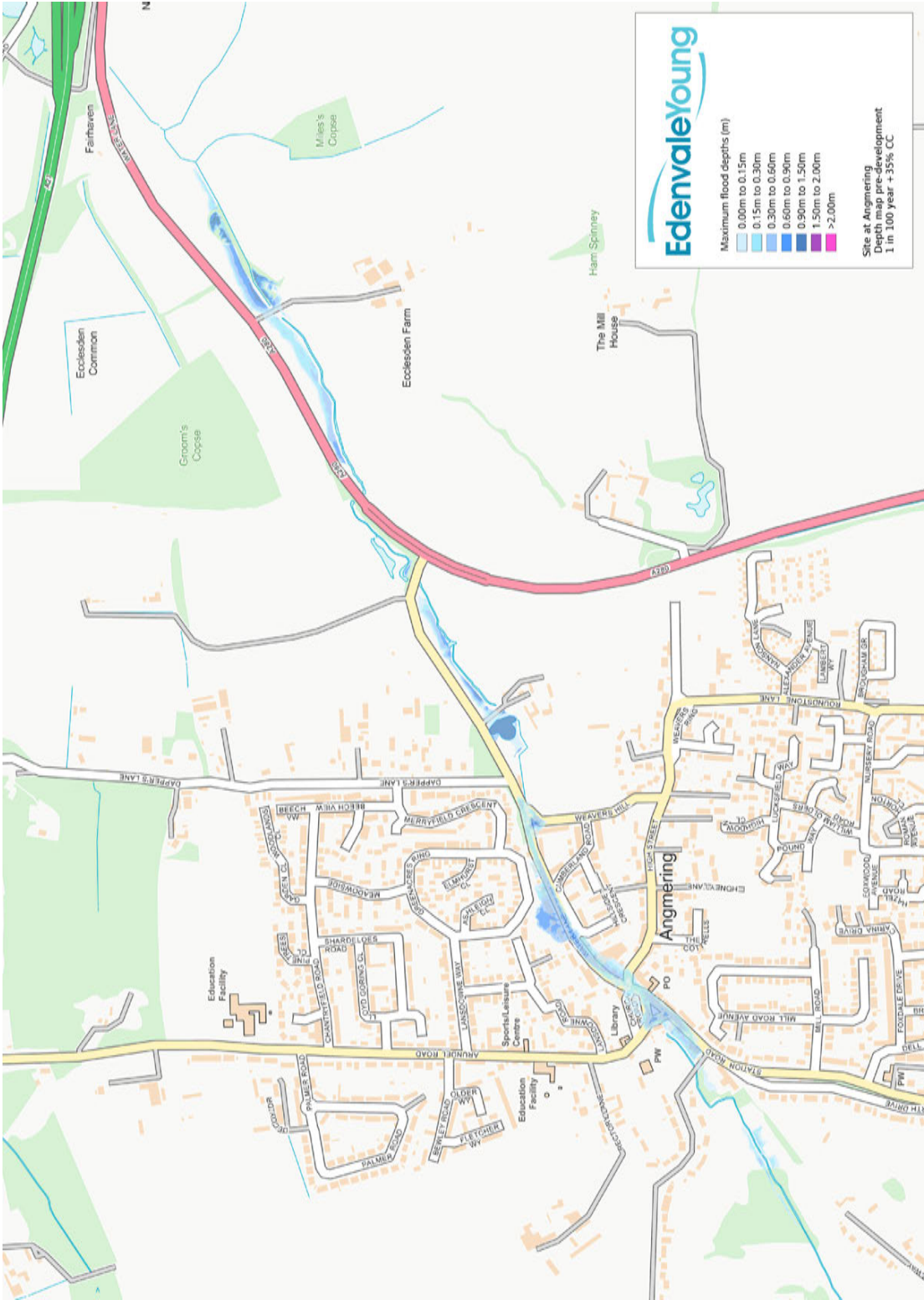


Figure 3.5: Case-A: Pre-development, depth map 1% AEP + 35% climate change

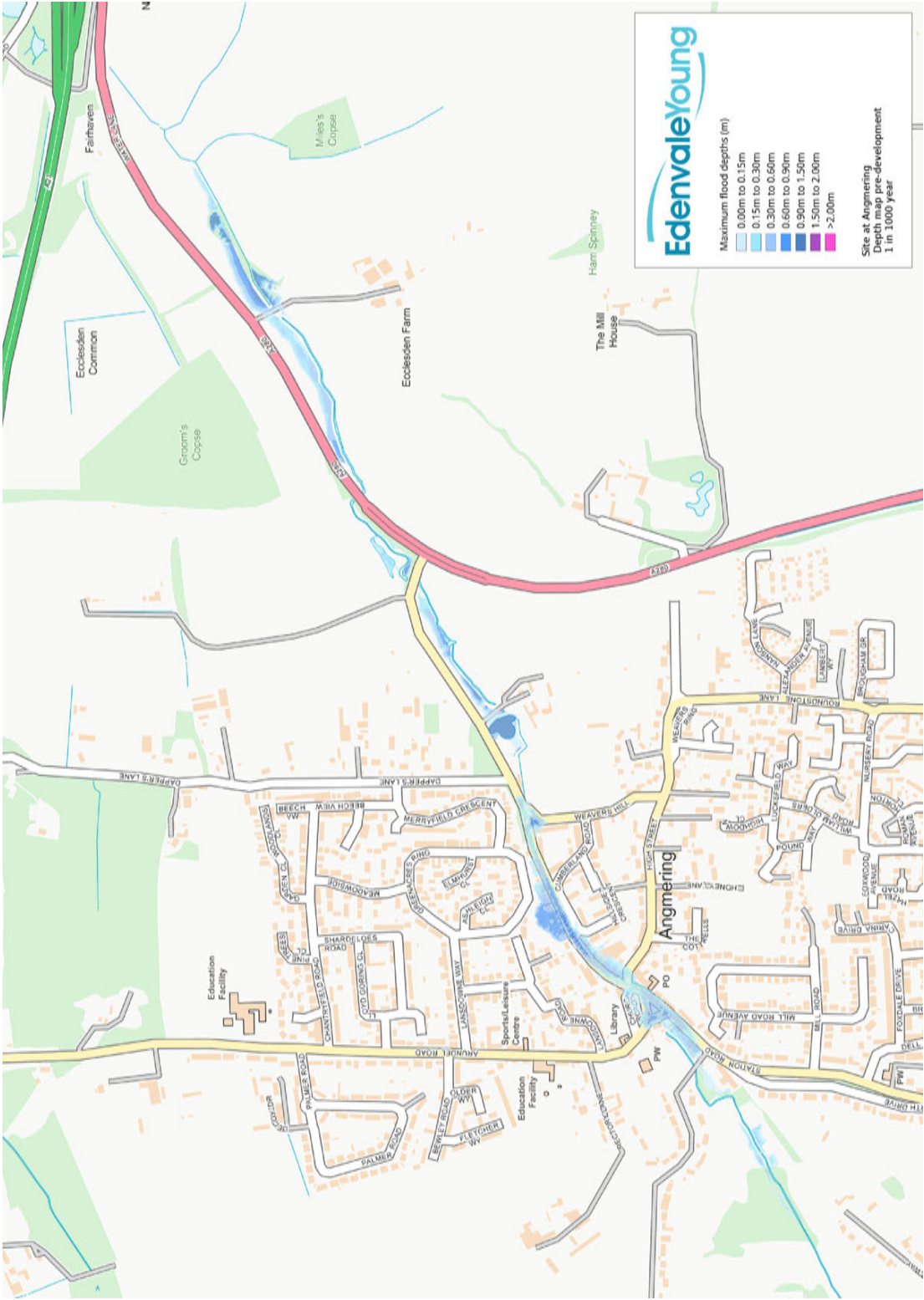


Figure 3.6: Case-A: Pre-development, depth map 0.1% AEP

3.1.2 Case-B: Post-development

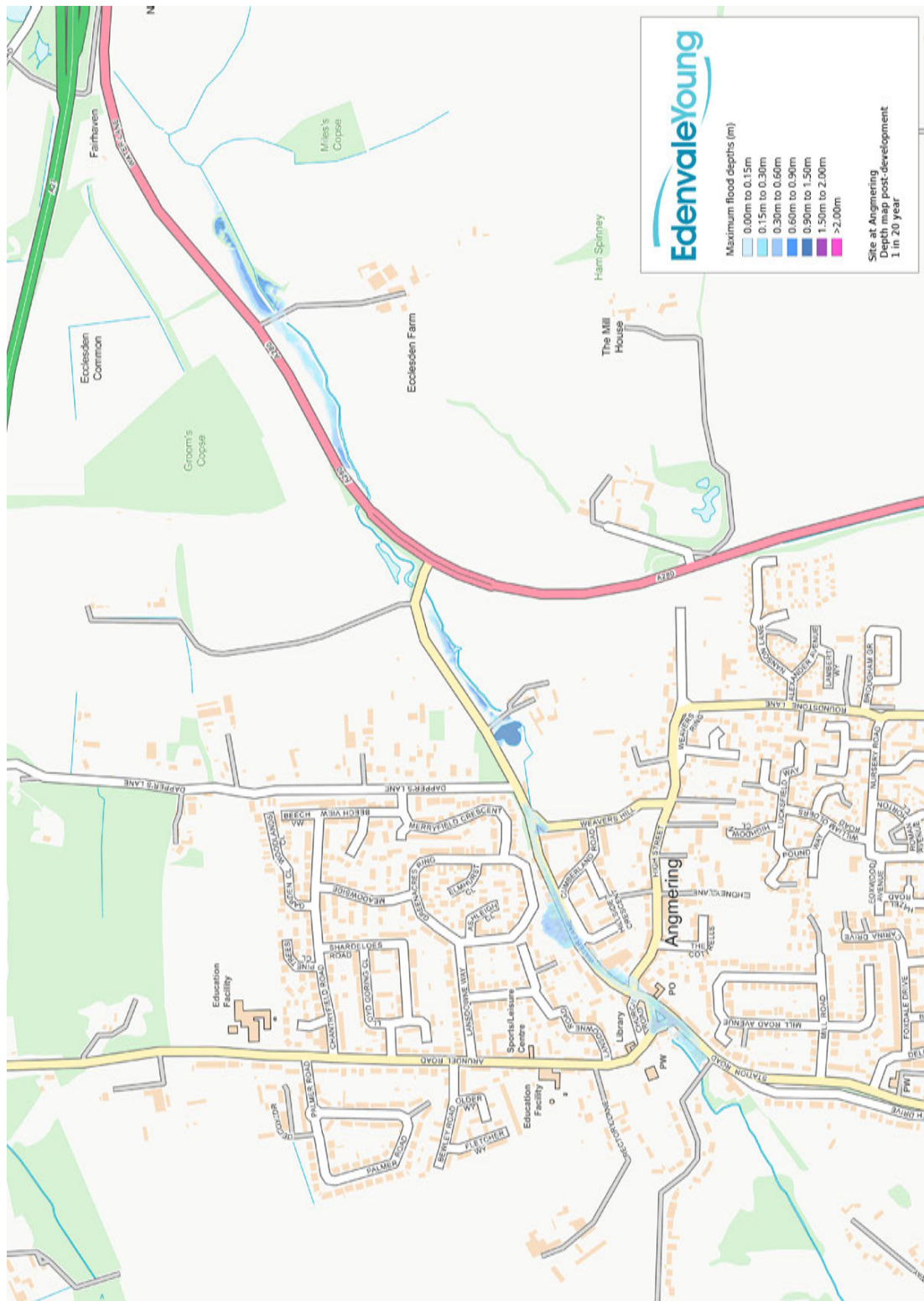


Figure 3.7: Case-B: Pre-development, depth map 5% AEP

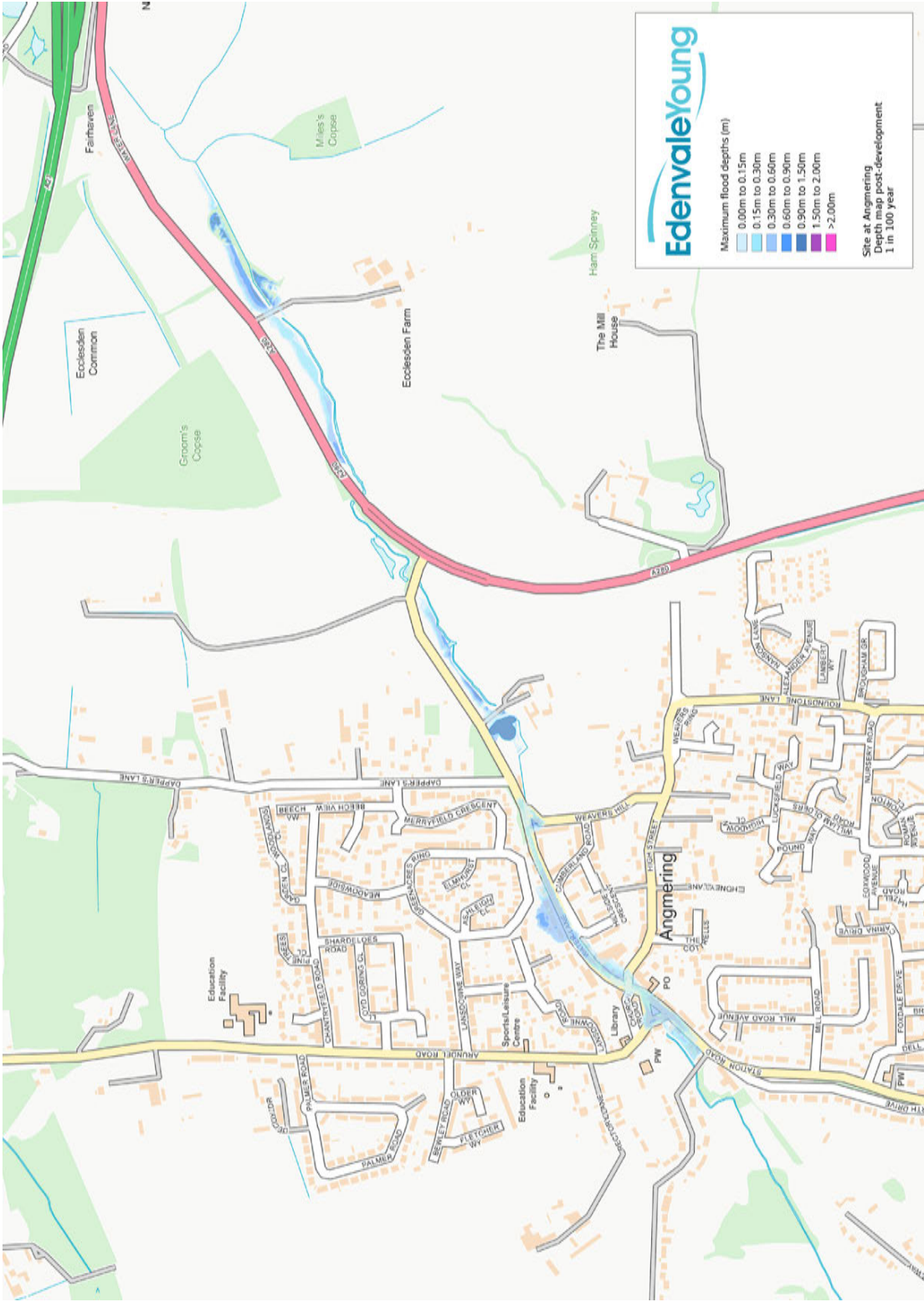


Figure 3.8: Case-B: Pre-development, depth map 1% AEP

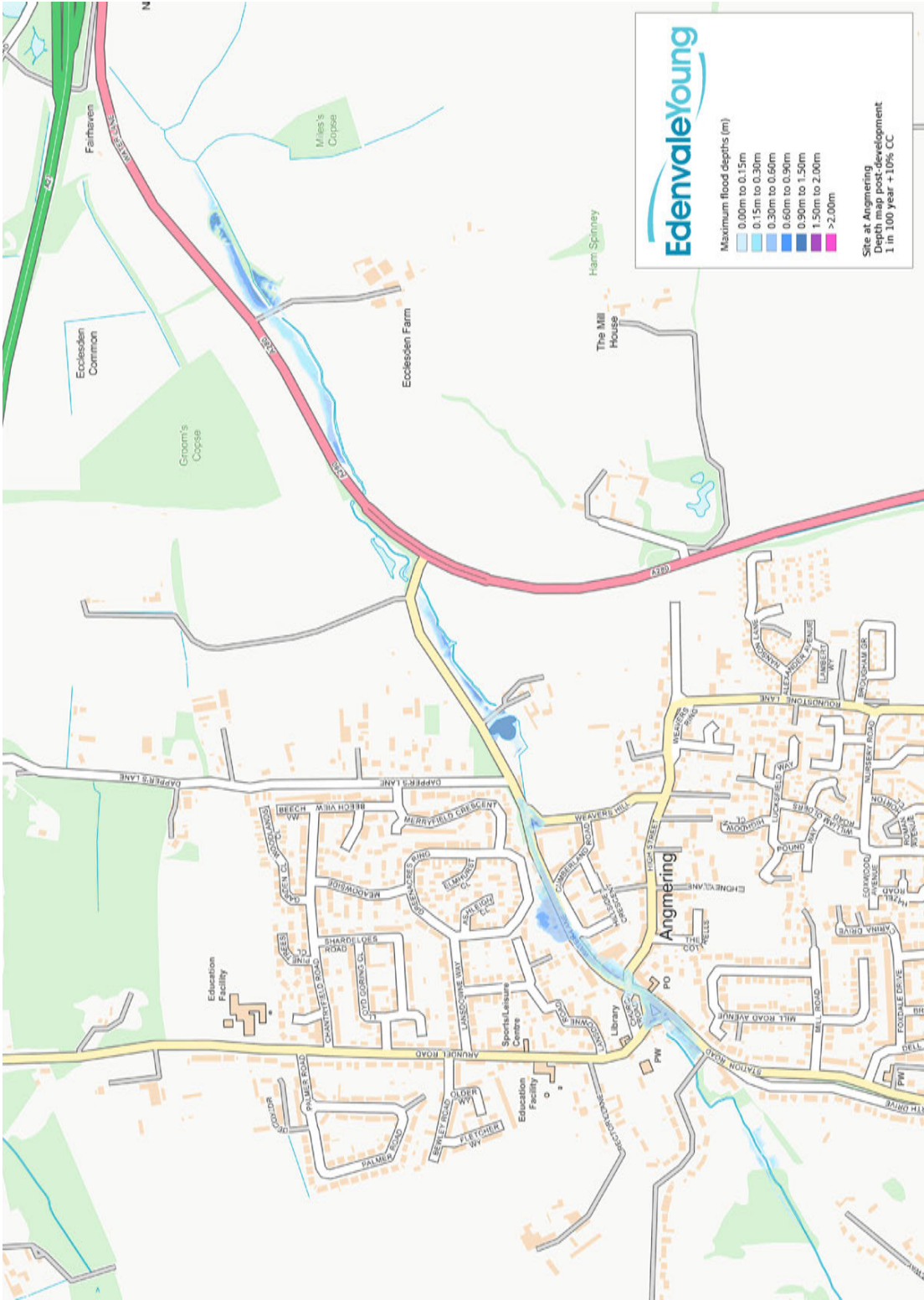


Figure 3.9: Case-B: Pre-development, depth map 1% AEP + 10% climate change

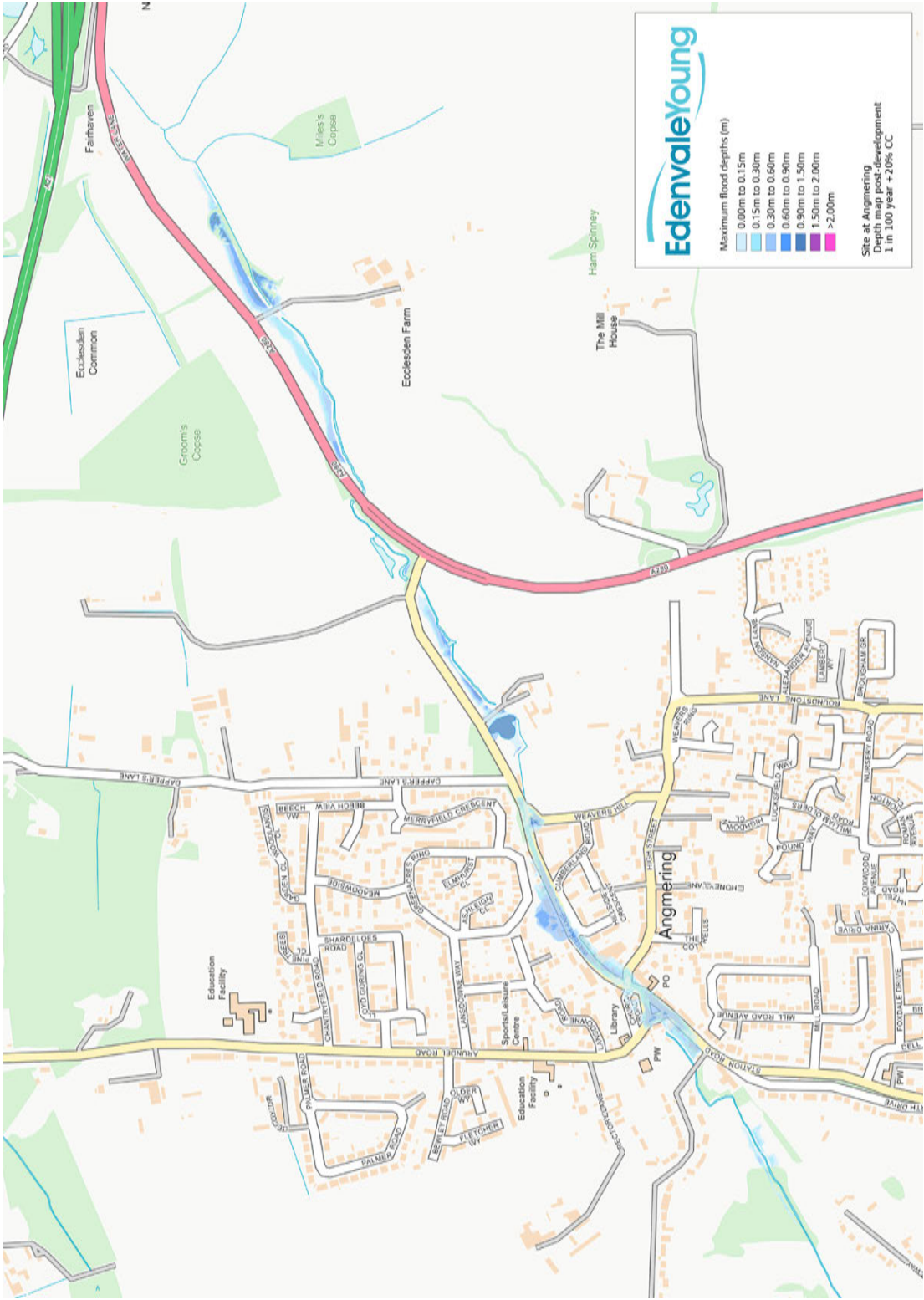


Figure 3.10: Case-B: Pre-development, depth map 1% AEP + 20% climate change

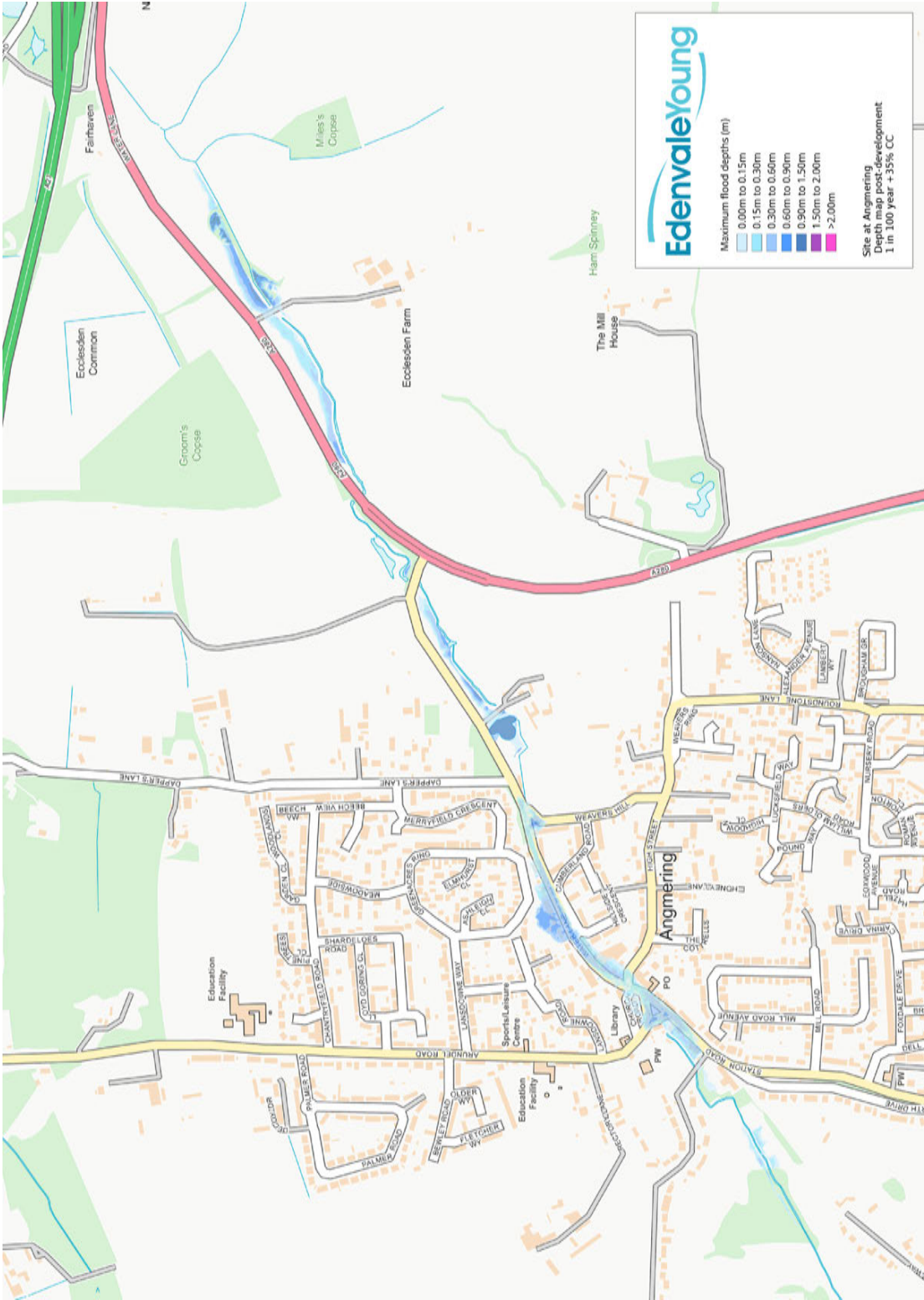


Figure 3.11: Case-B: Pre-development, depth map 1% AEP + 35% climate change

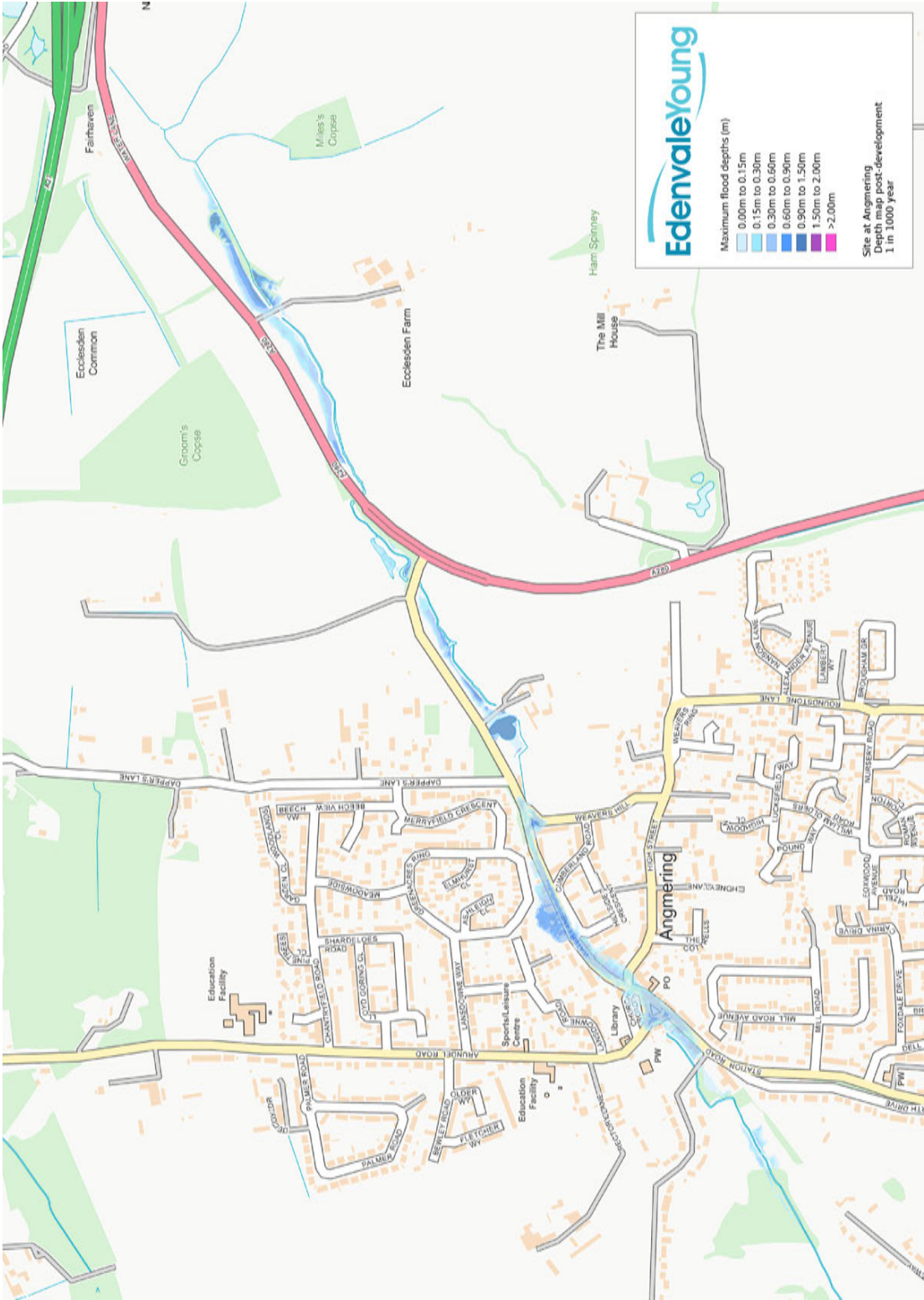


Figure 3.12: Case-B: Pre-development, depth map 0.1% AEP

3.2 Level maps

3.2.1 Case-A: Pre-development

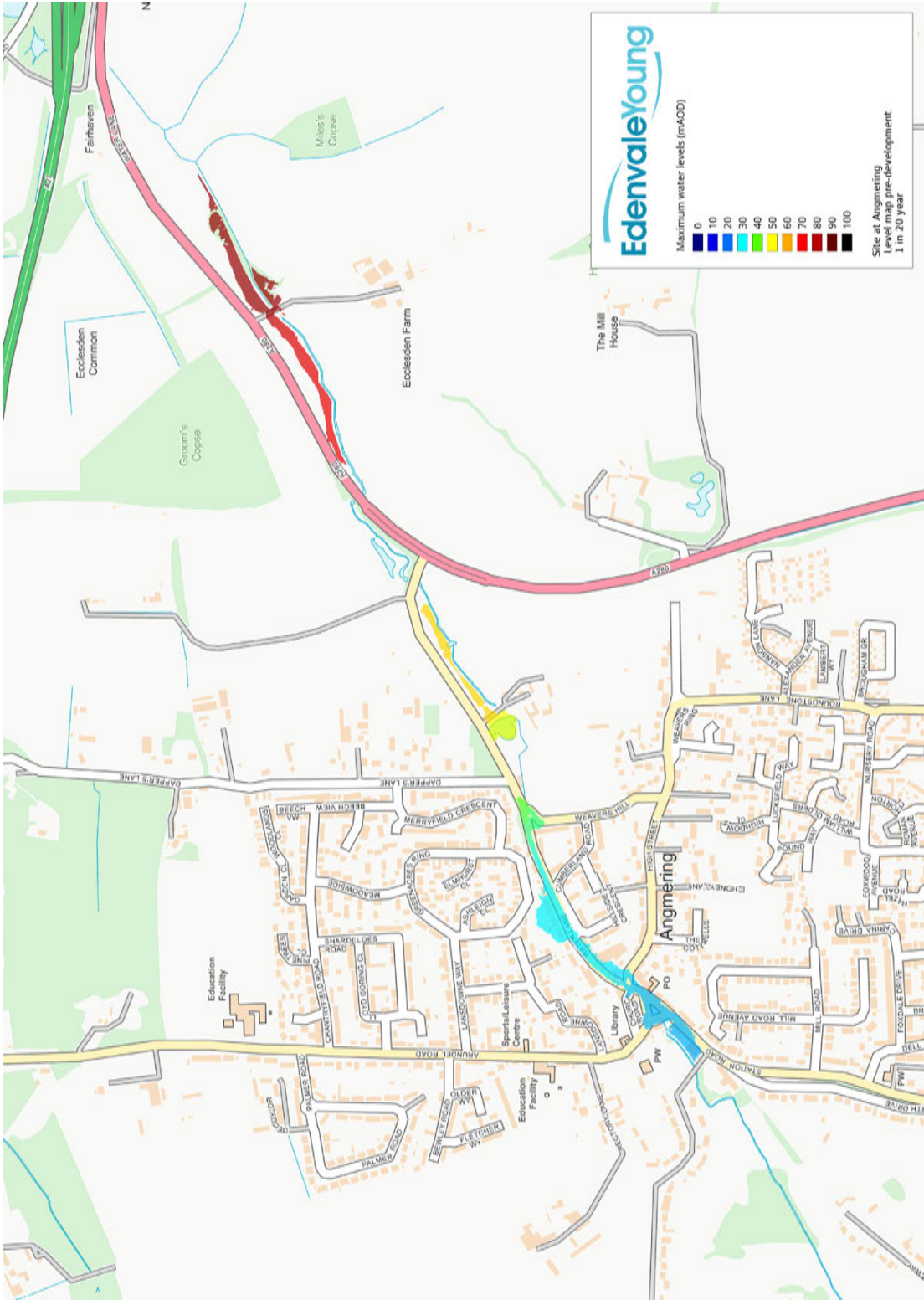


Figure 3.13: Case-A: Pre-development, level map 5% AEP

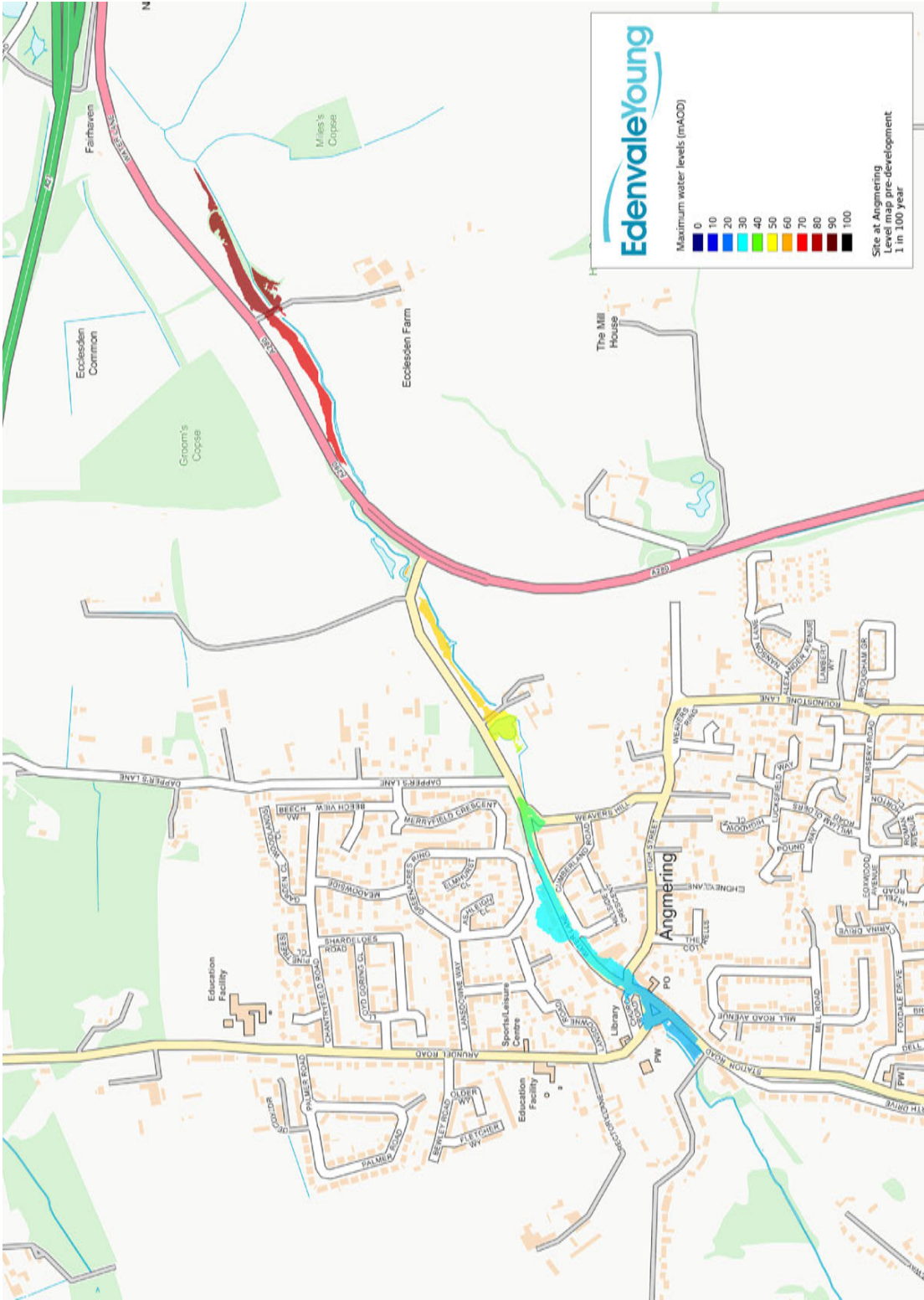


Figure 3.14: Case-A: Pre-development, level map 1% AEP

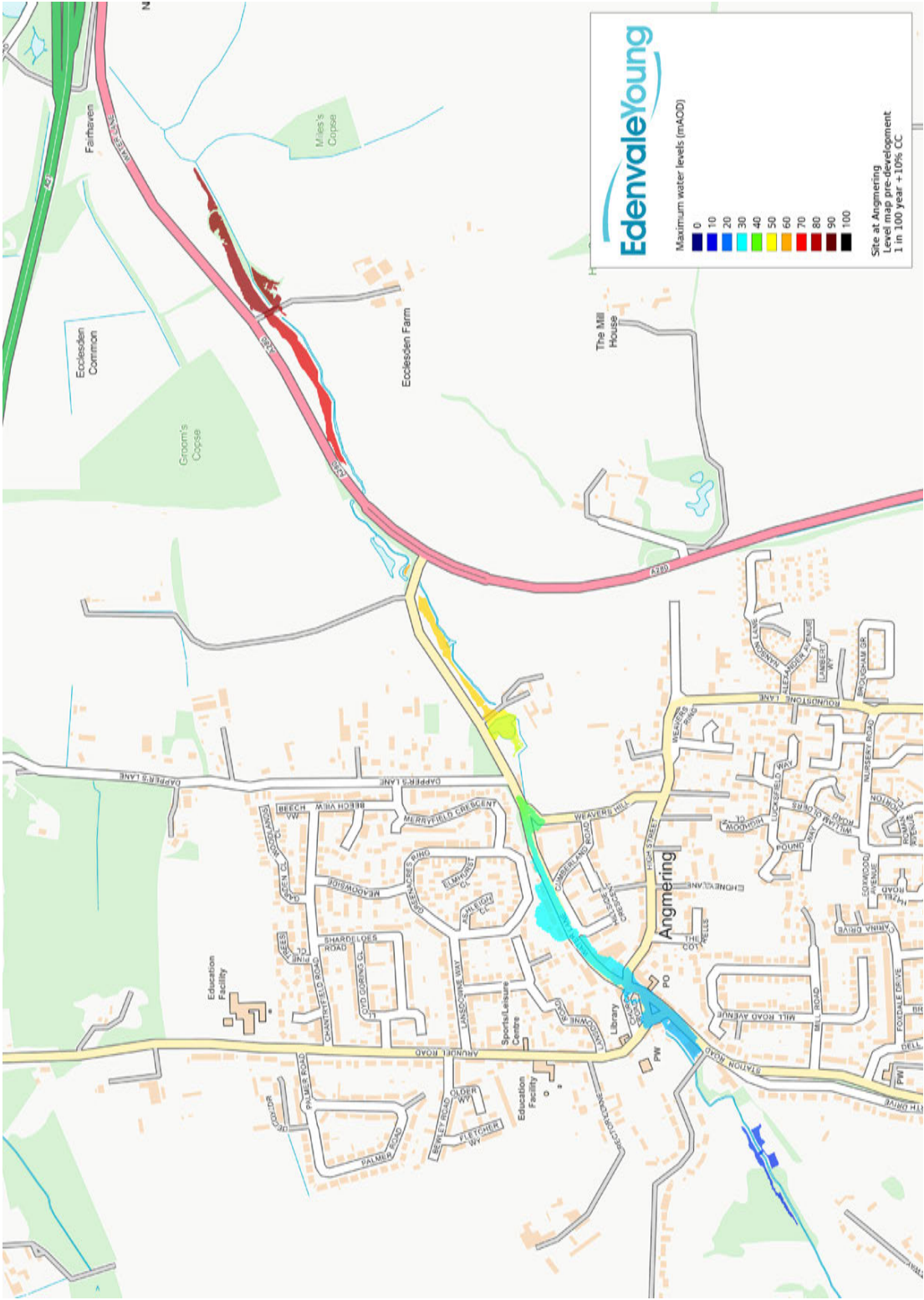


Figure 3.15: Case-A: Pre-development, level map 1% AEP + 10% climate change

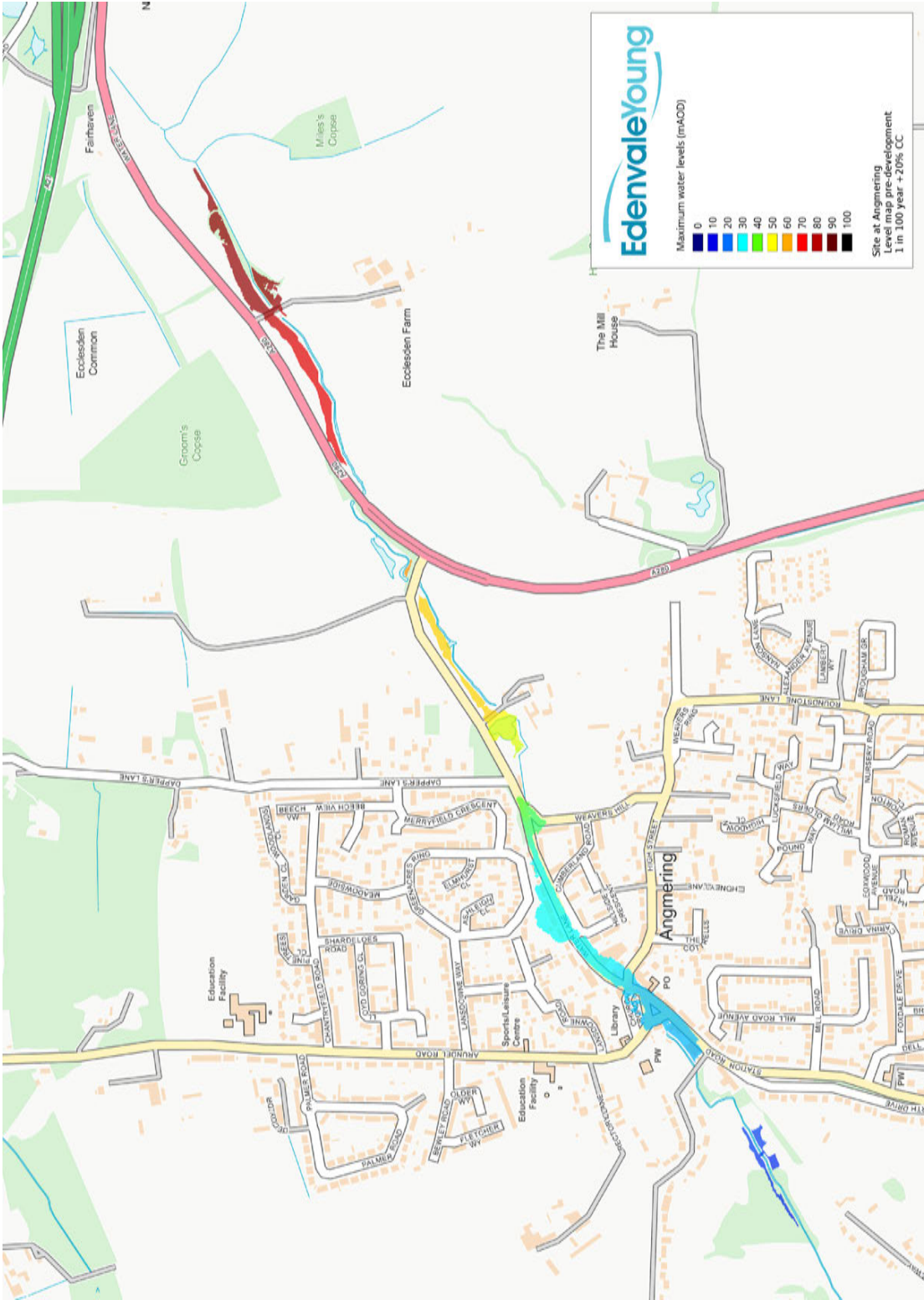


Figure 3.16: Case-A: Pre-development, level map 1% AEP + 20% climate change

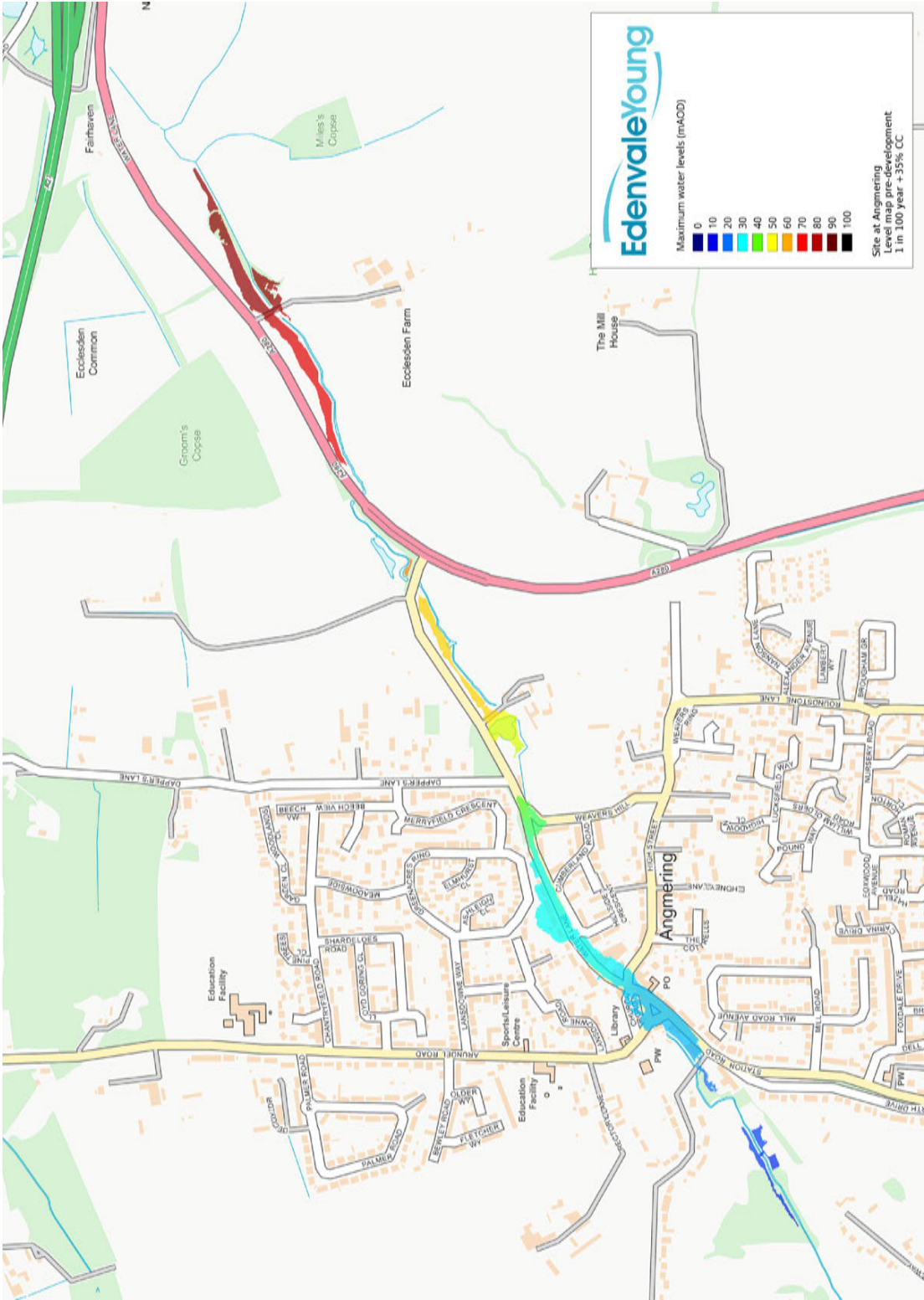


Figure 3.17: Case-A: Pre-development, level map 1% AEP + 35% climate change

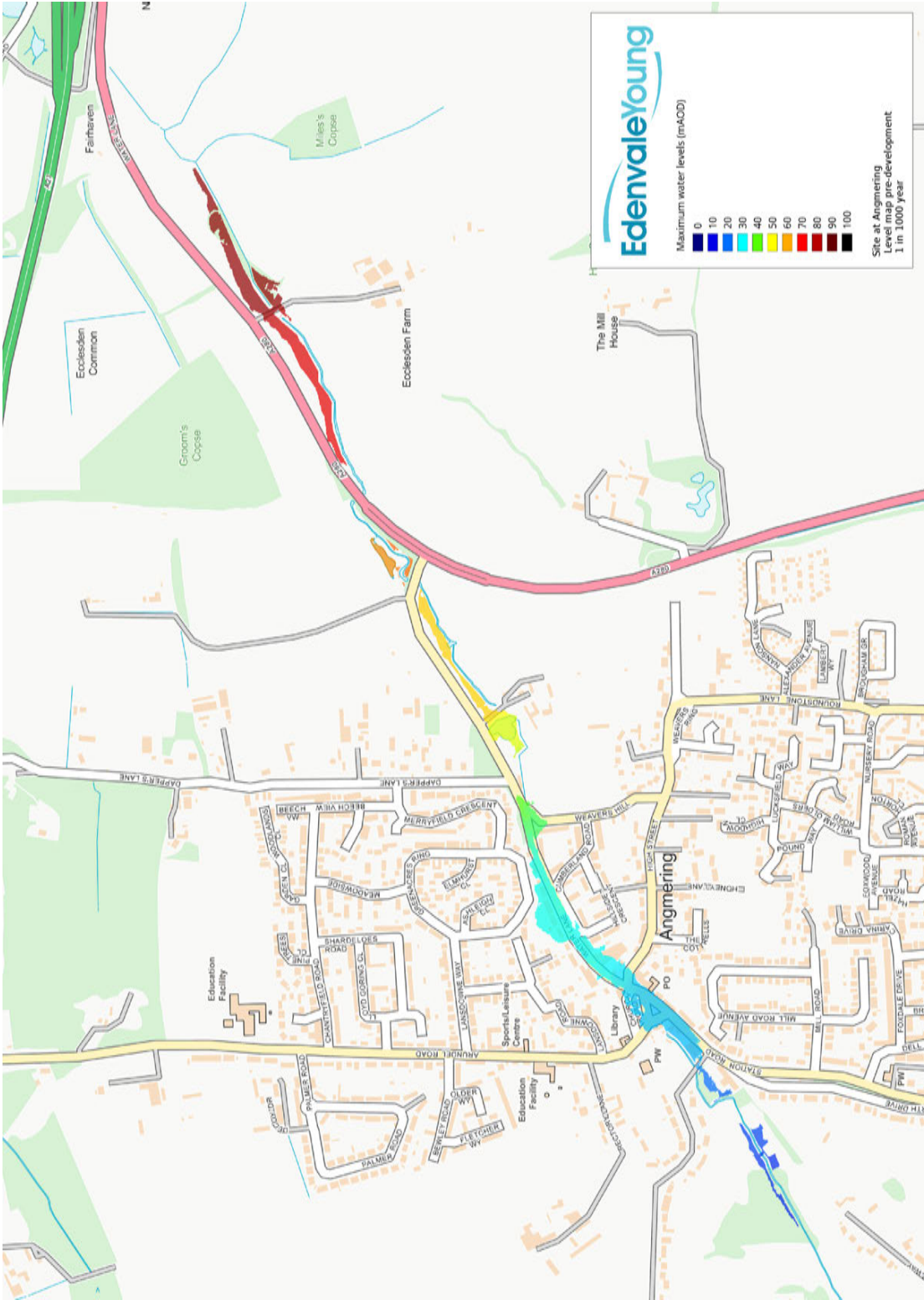


Figure 3.18: Case-A: Pre-development, level map 0.1% AEP

3.2.2 Case-B: Post-development

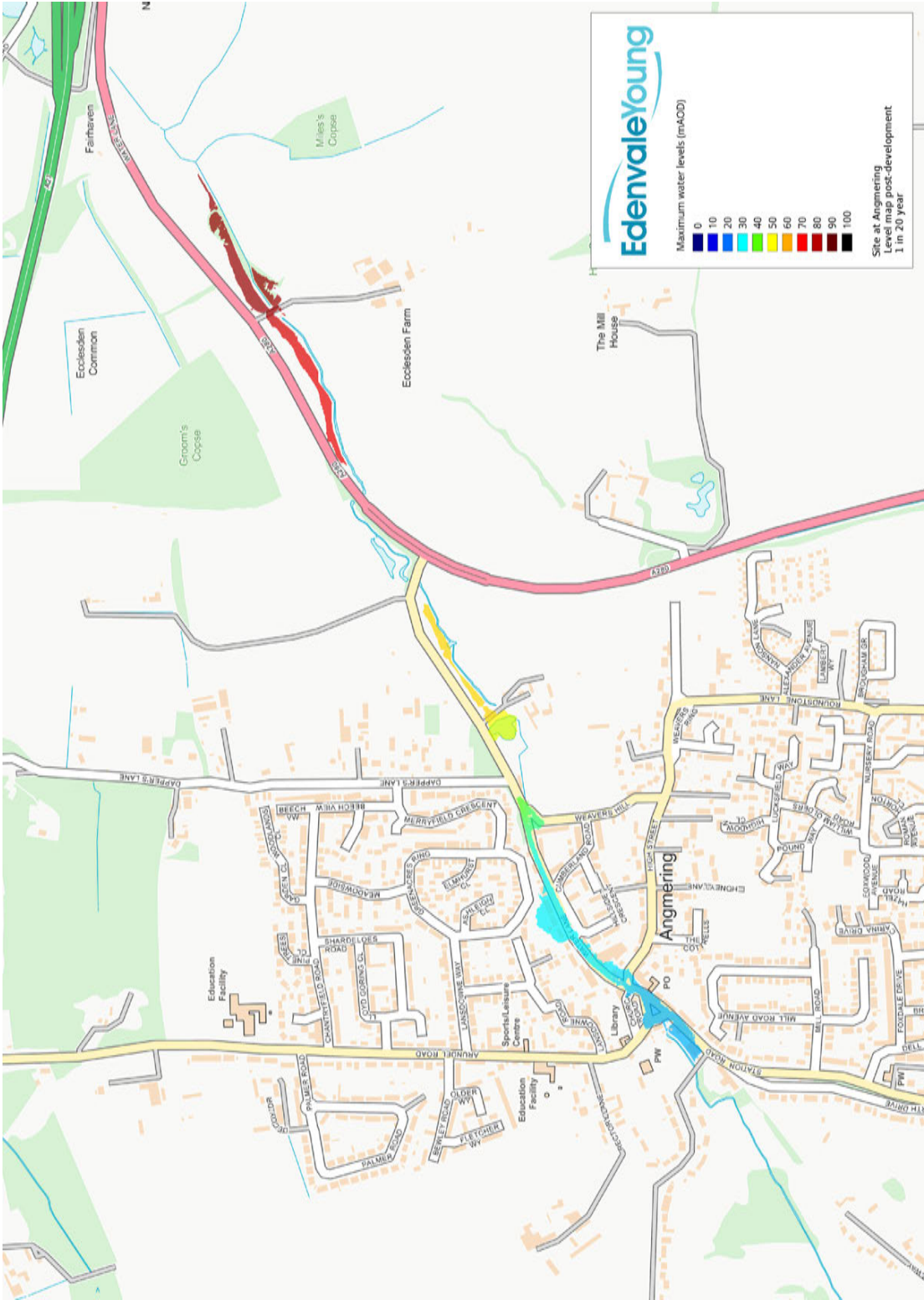


Figure 3.19: Case-B: Pre-development, level map 5% AEP

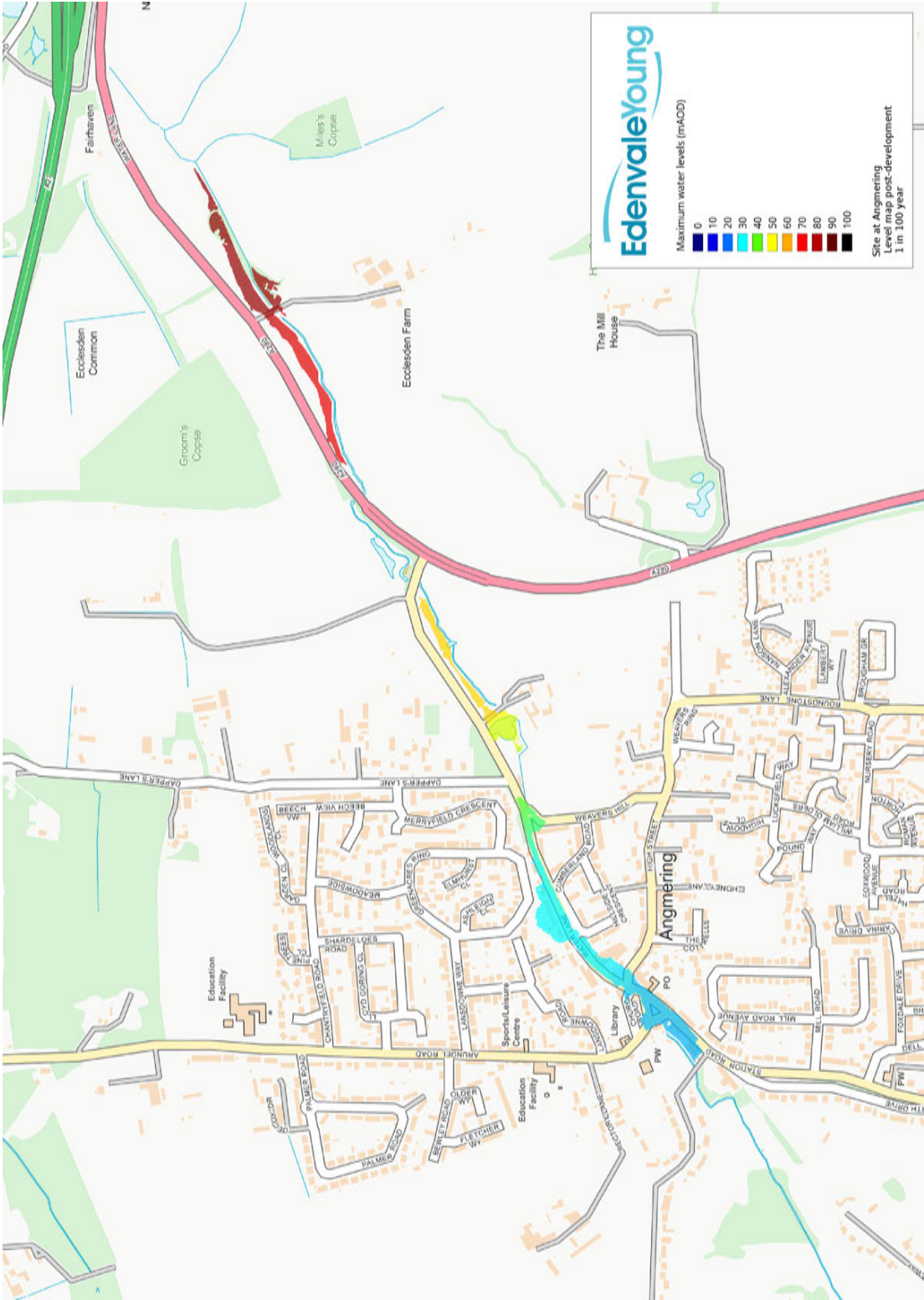


Figure 3.20: Case-B: Pre-development, level map 1% AEP

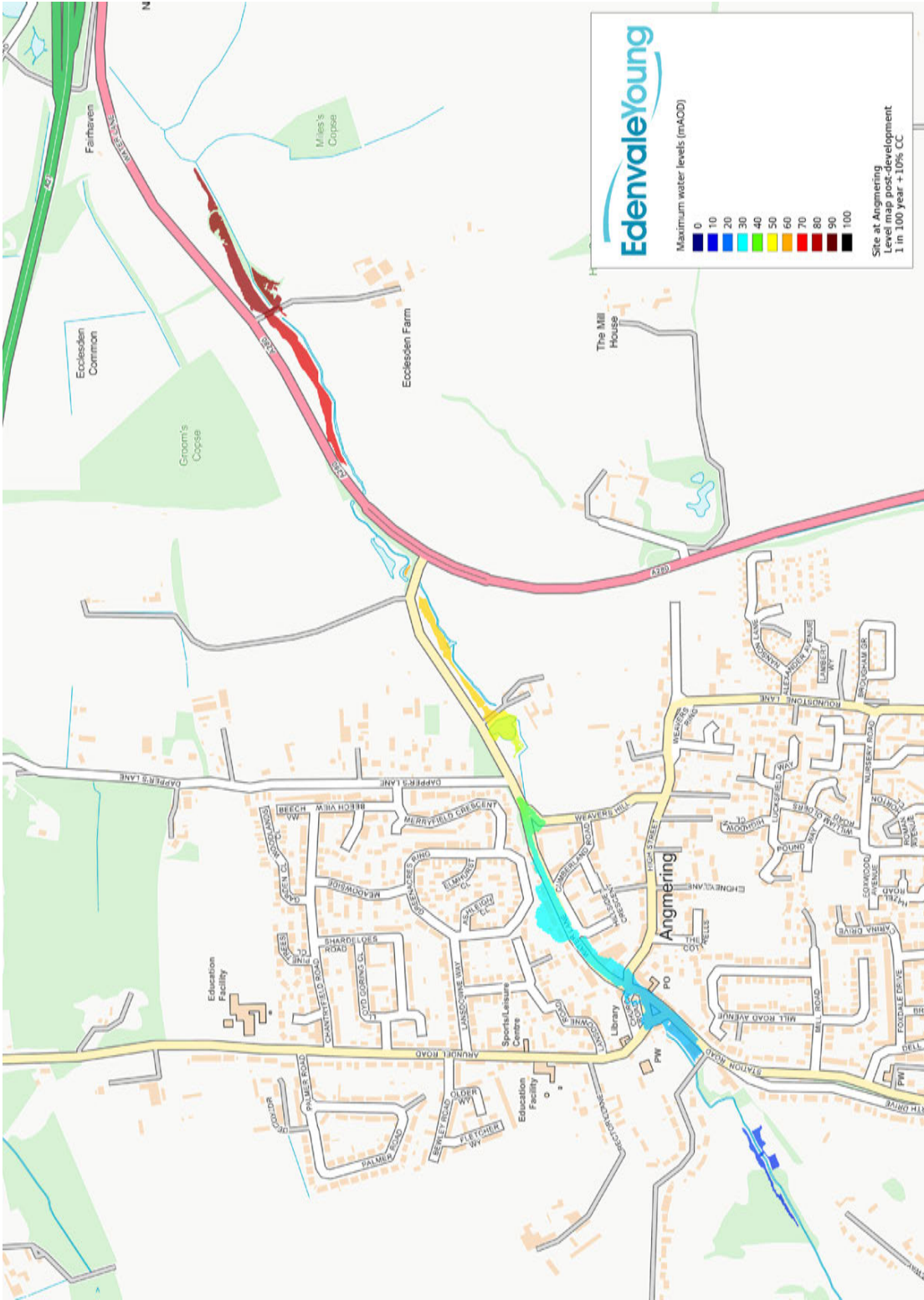


Figure 3.21: Case-B: Pre-development, level map 1% AEP + 10% climate change

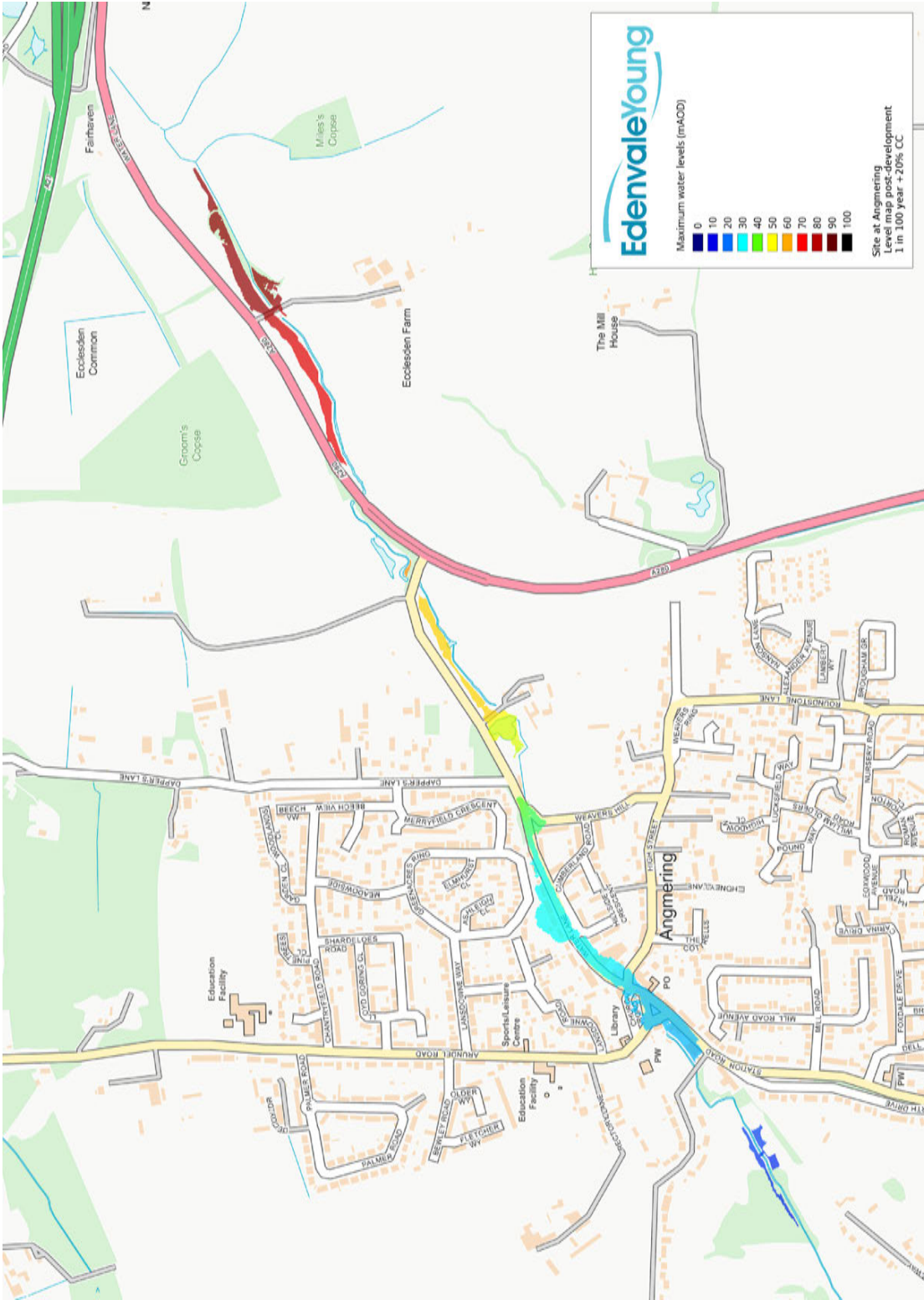


Figure 3.22: Case-B: Pre-development, level map 1% AEP + 20% climate change

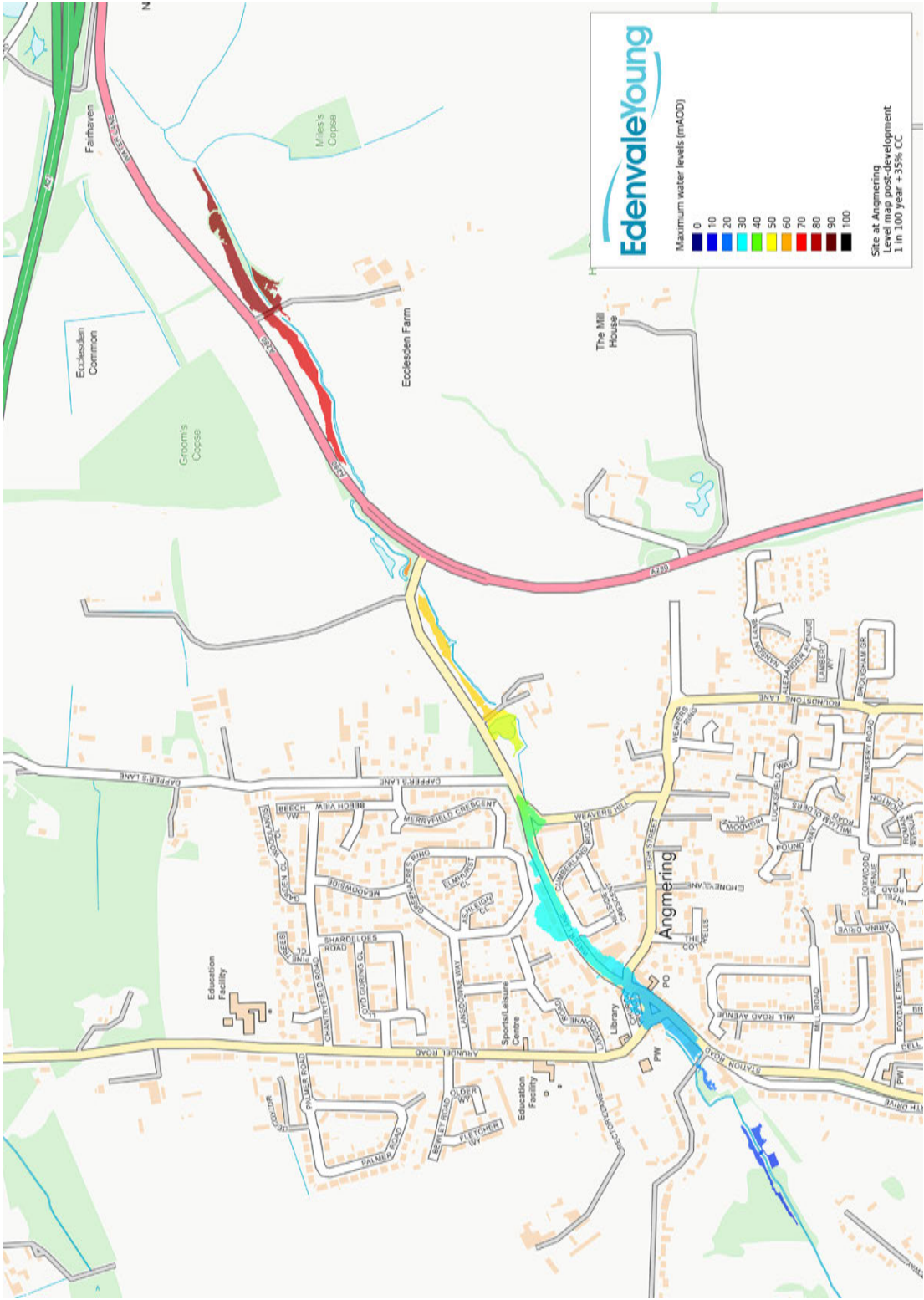


Figure 3.23: Case-B: Pre-development, level map 1% AEP + 35% climate change

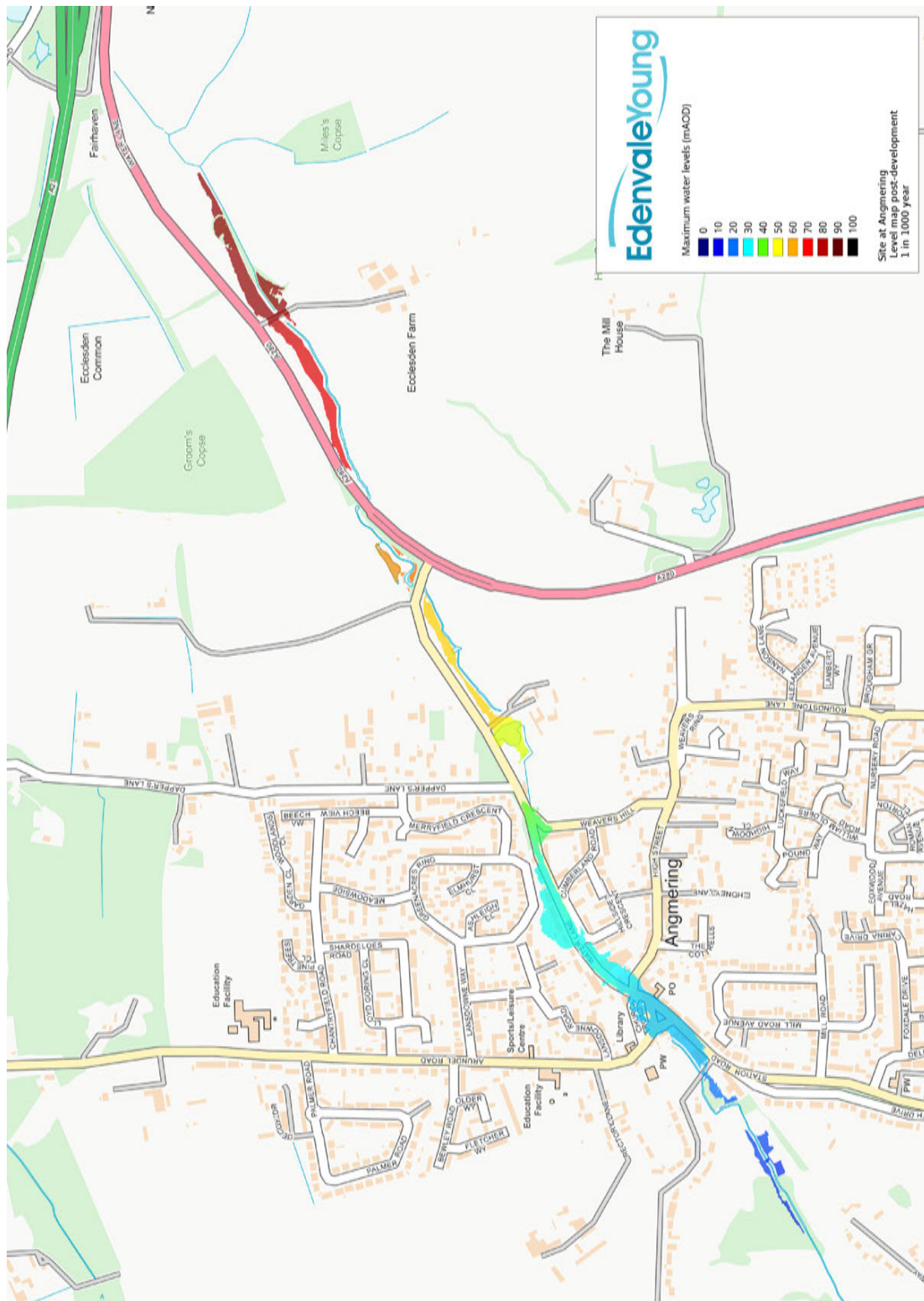


Figure 3.24: Case-B: Pre-development, level map 0.1% AEP

3.3 Difference maps: Case-B minus Case-A, post minus pre-development

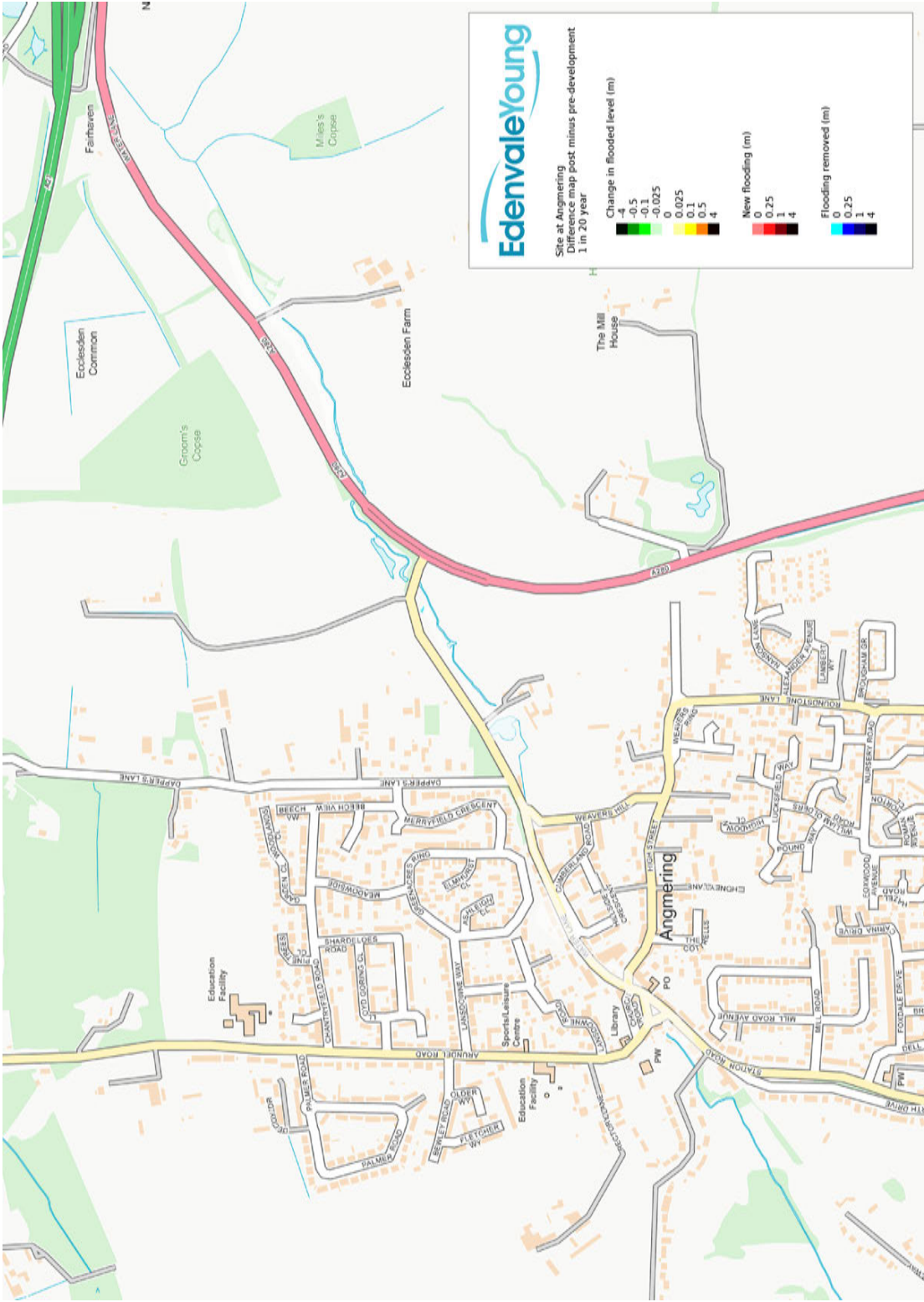


Figure 3.25: Case-B minus Case-A: difference map 5% AEP

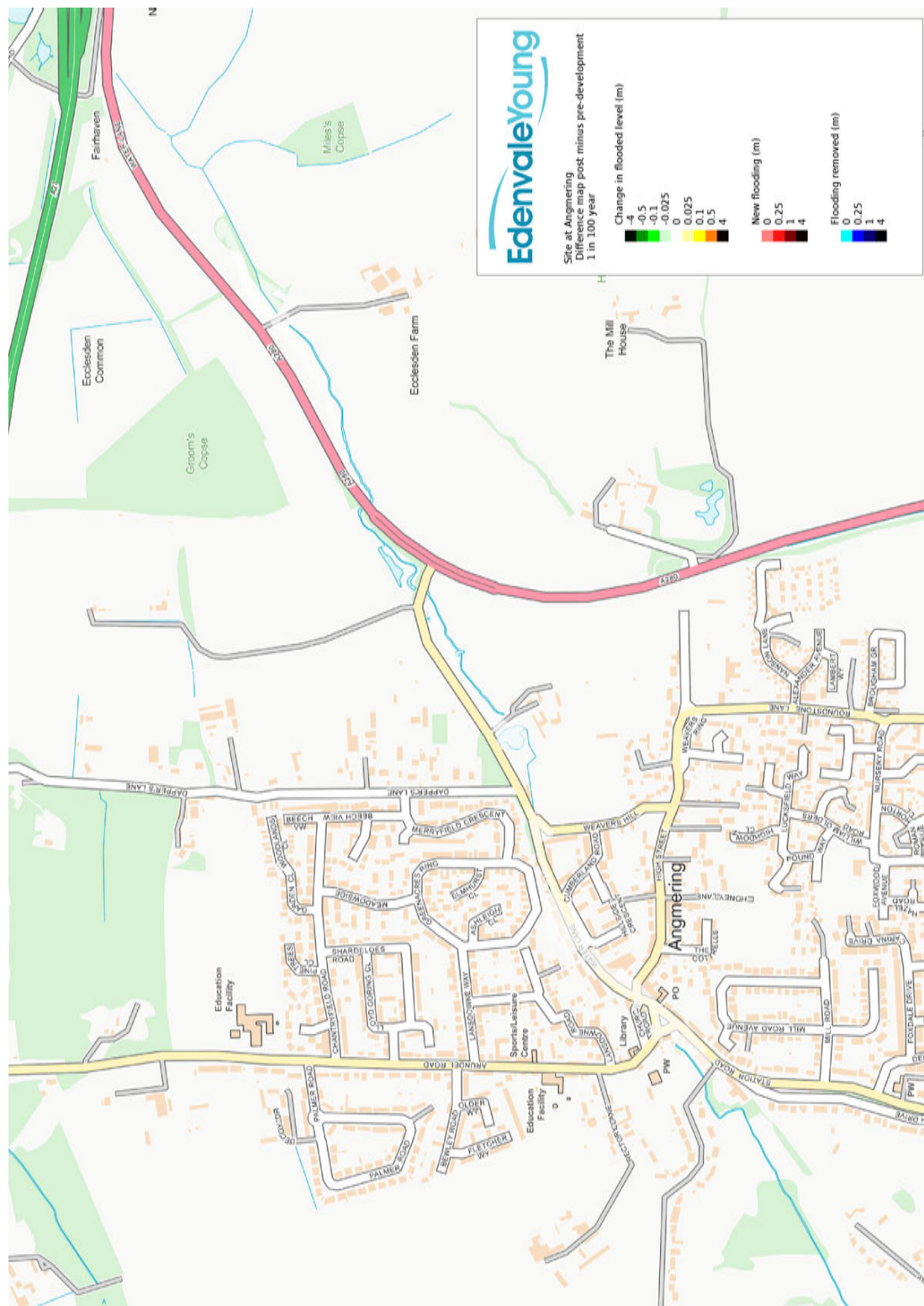


Figure 3.26: Case-B minus Case-A: difference map 1% AEP

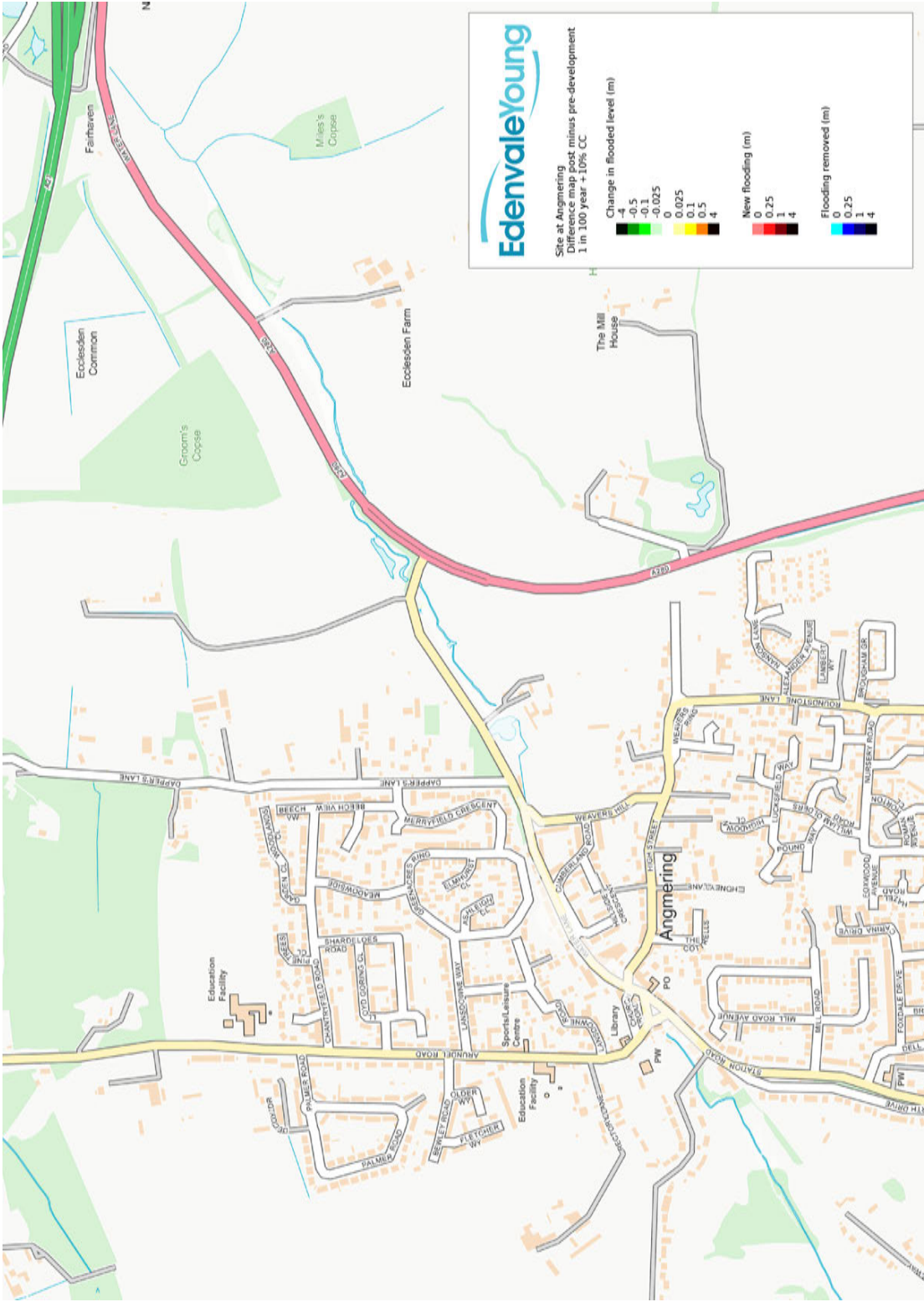


Figure 3.27: Case-B minus Case-A: difference map 1% AEP + 10% climate change

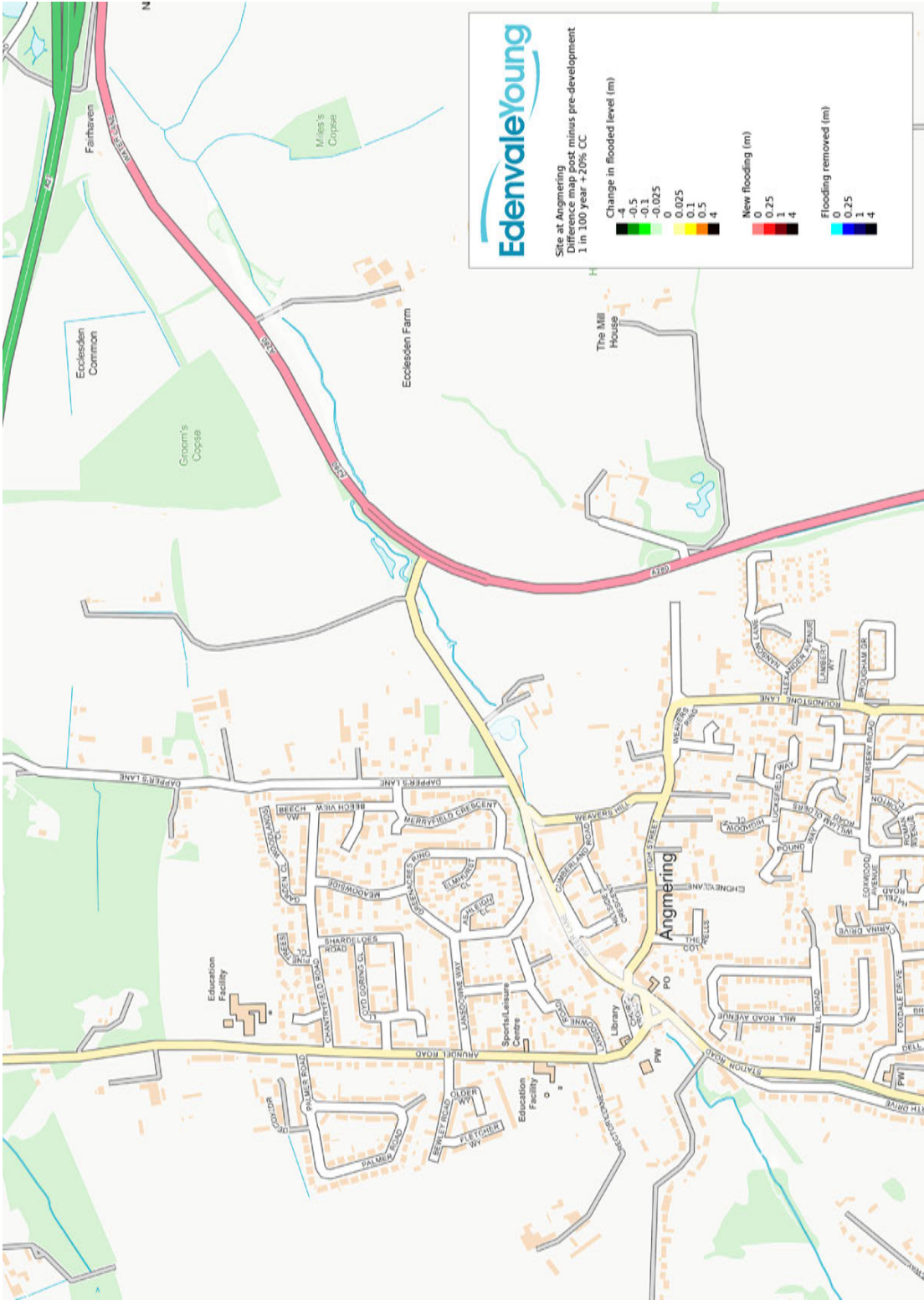


Figure 3.28: Case-B minus Case-A: difference map 1% AEP + 20% climate change

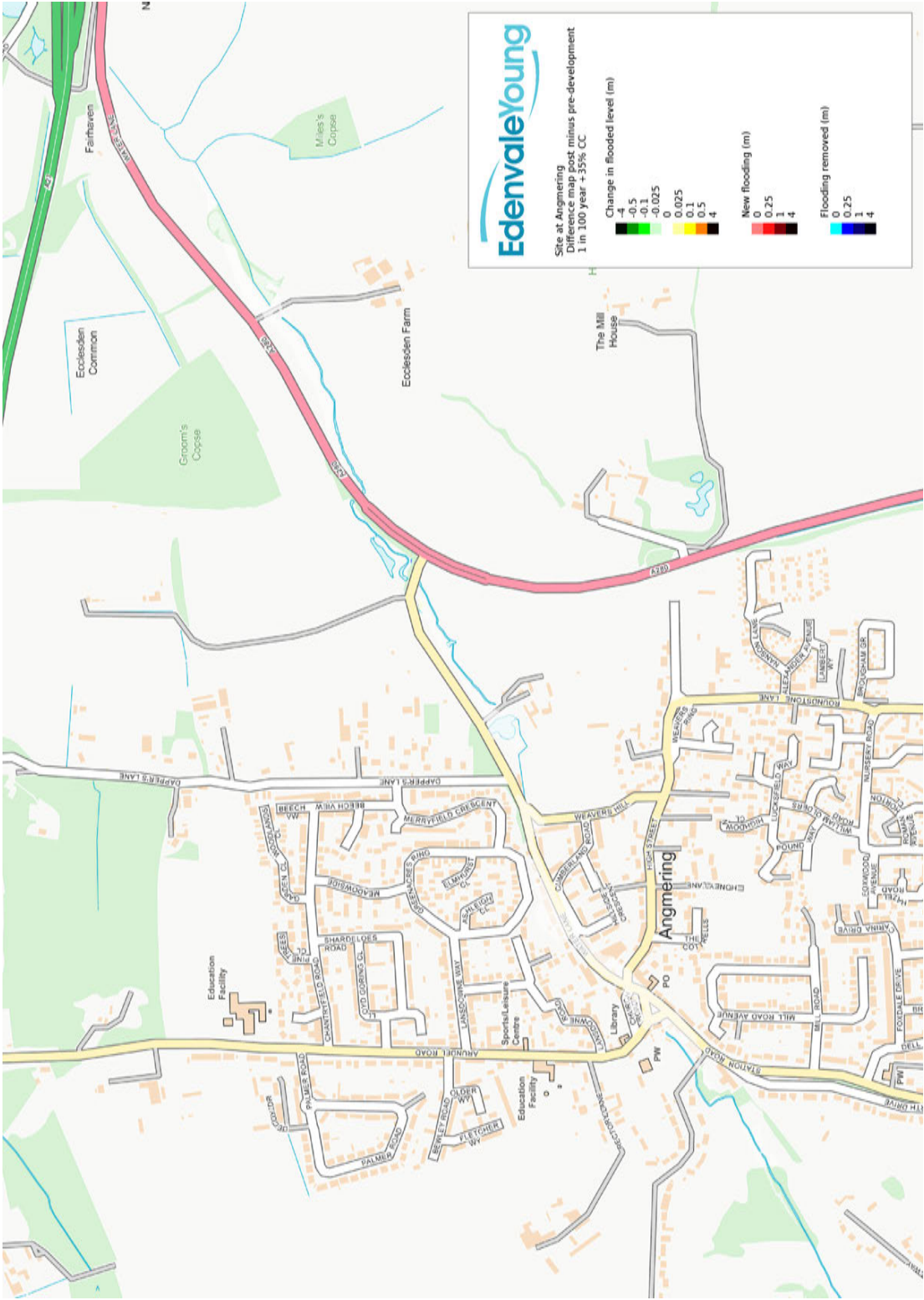


Figure 3.29: Case-B minus Case-A: difference map 1% AEP + 35% climate change

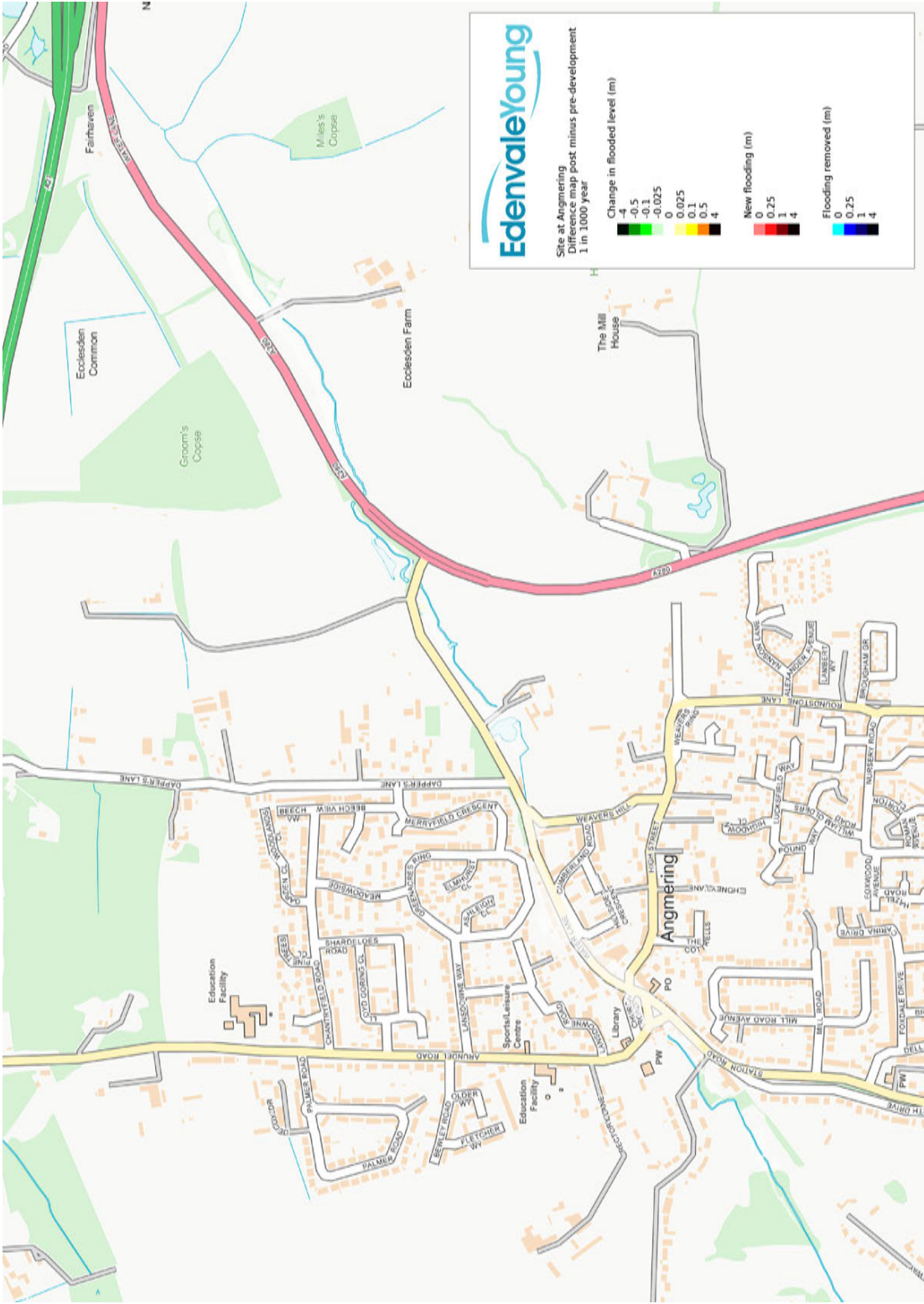


Figure 3.30: Case-B minus Case-A: difference map 0.1% AEP

3.4 Stability plots

3.4.1 Case-A: Pre-development

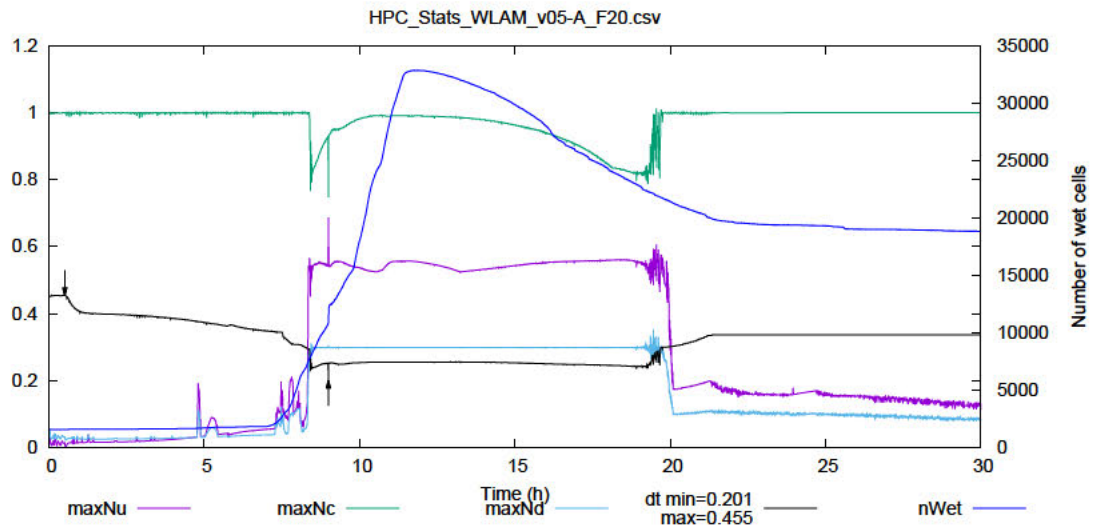


Figure 3.31: Case-A: Pre-development, stability plot 5% AEP

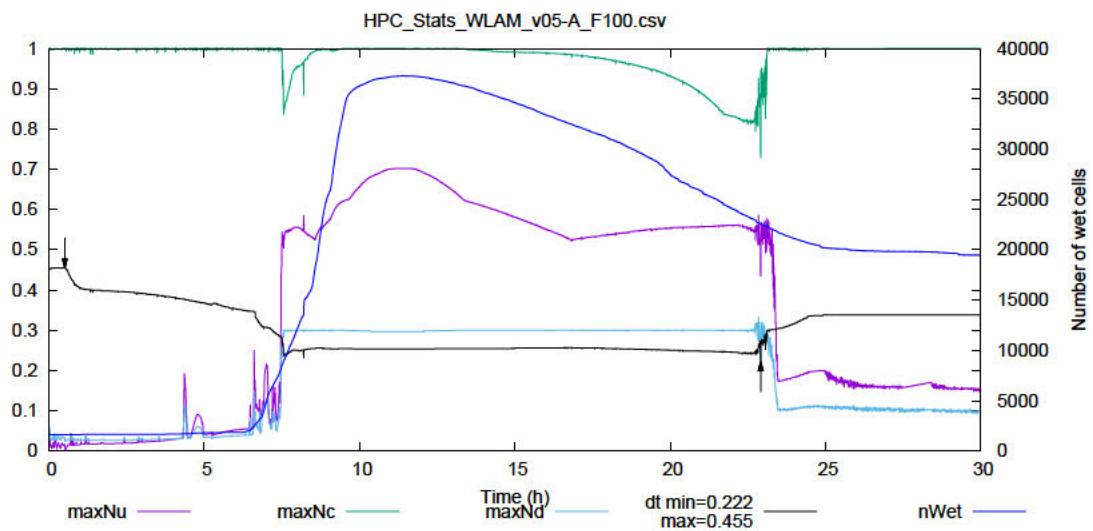


Figure 3.32: Case-A: Pre-development, stability plot 1% AEP

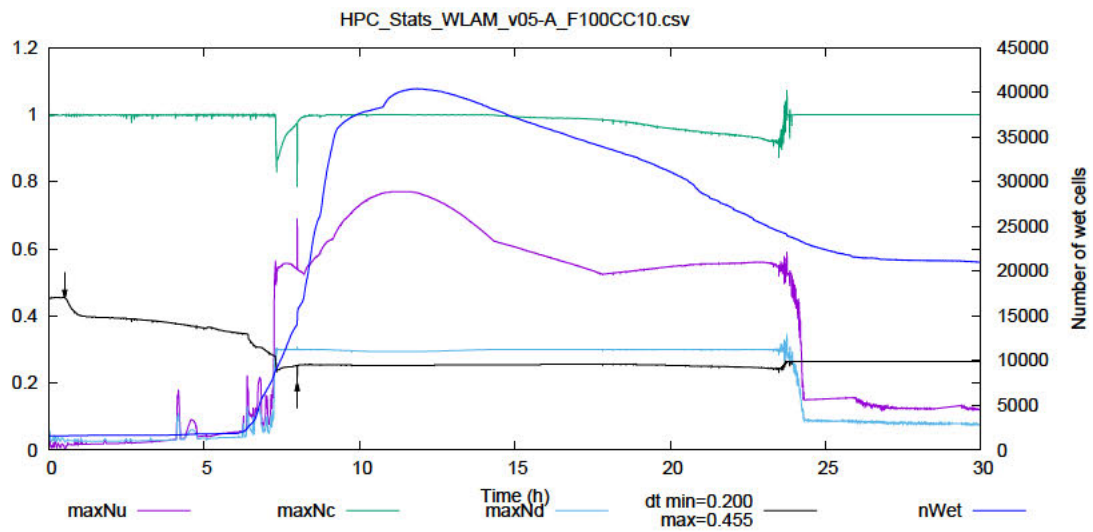


Figure 3.33: Case-A: Pre-development, stability plot 1% AEP + 10% climate change

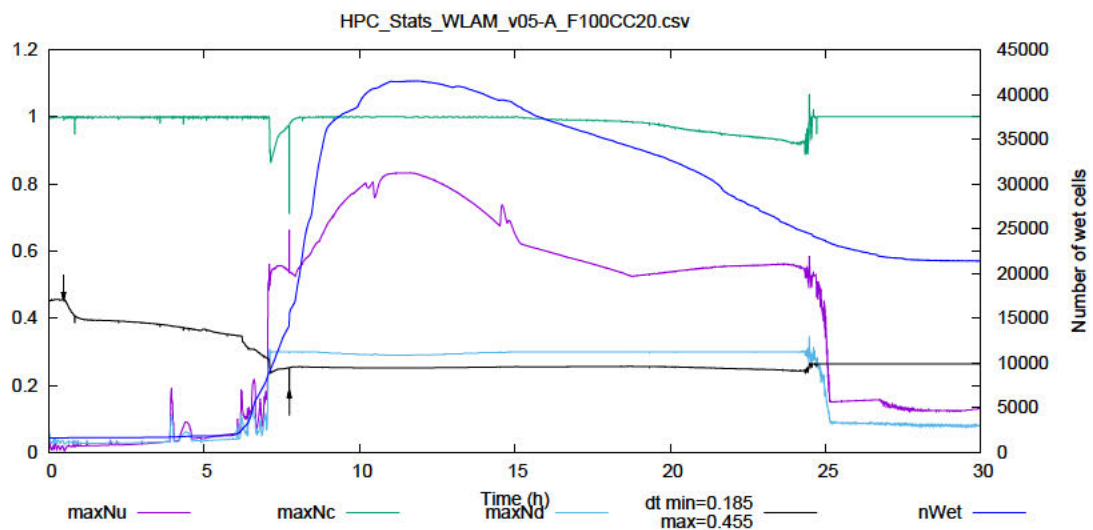


Figure 3.34: Case-A: Pre-development, stability plot 1% AEP + 20% climate change

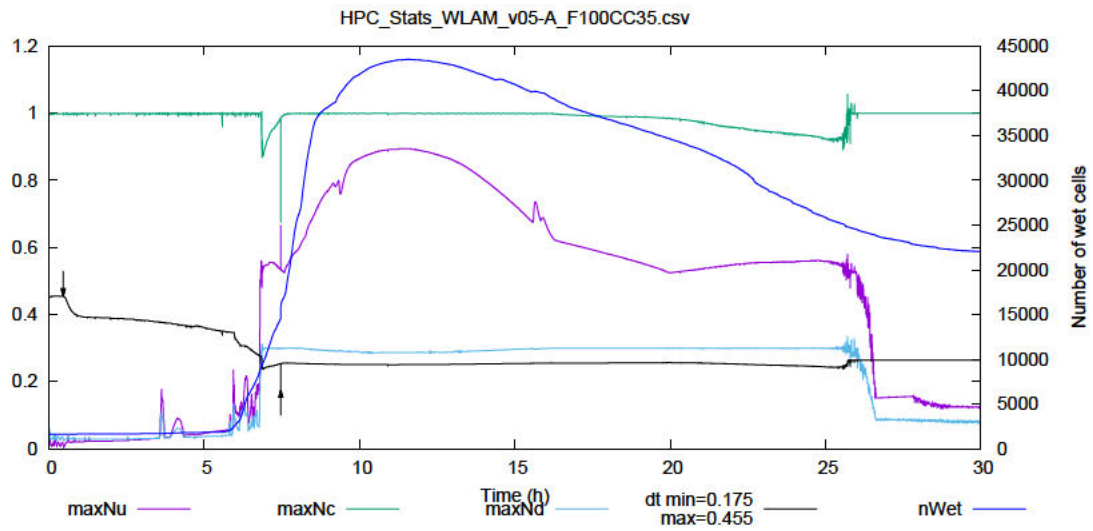


Figure 3.35: Case-A: Pre-development, stability plot 1% AEP + 35% climate change

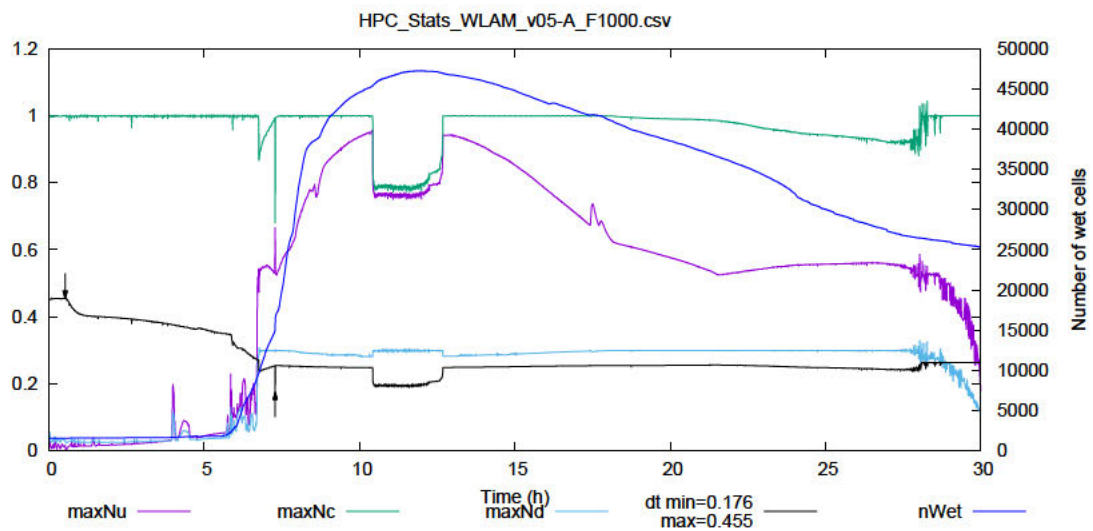


Figure 3.36: Case-A: Pre-development, stability plot 0.1% AEP

3.4.2 Case-B: Post-development

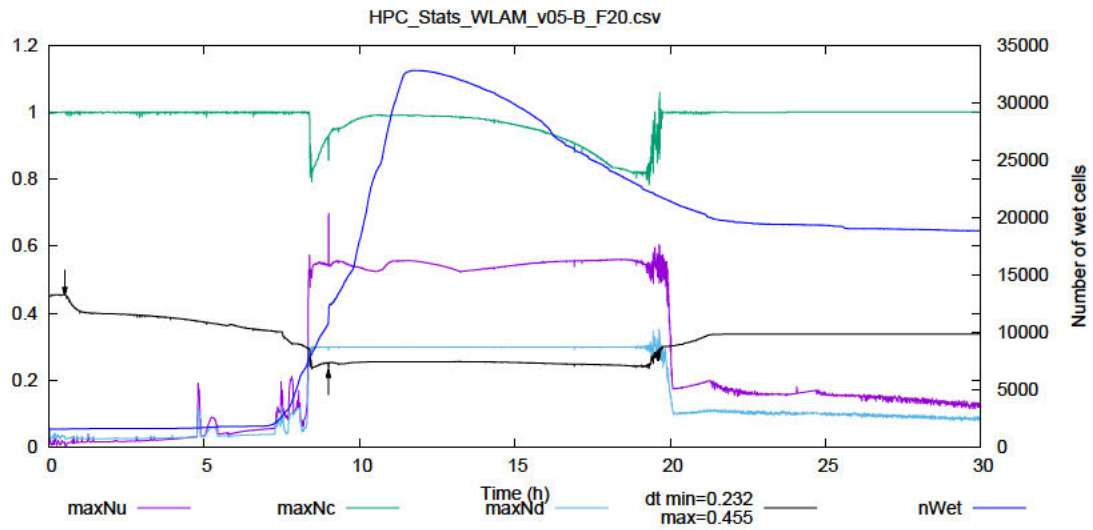


Figure 3.37: Case-B: Post-development, stability plot 5% AEP

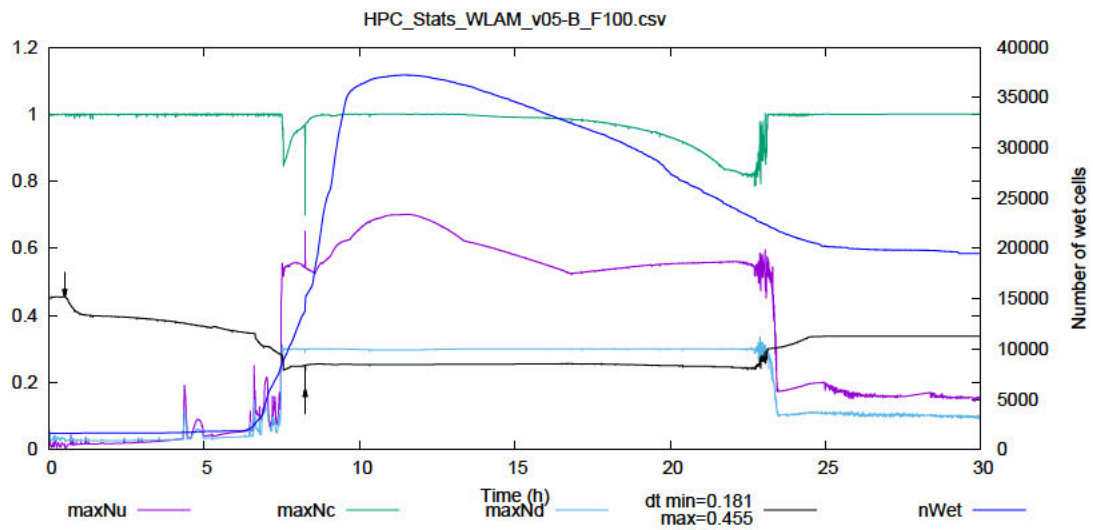


Figure 3.38: Case-B: Post-development, stability plot 1% AEP

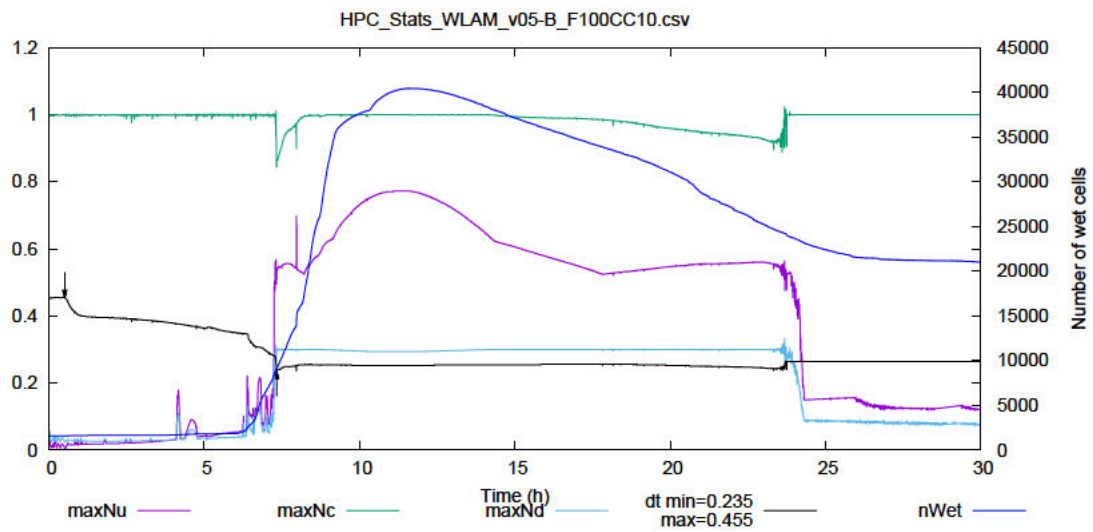


Figure 3.39: Case-B: Post-development, stability plot 1% AEP + 10% climate change

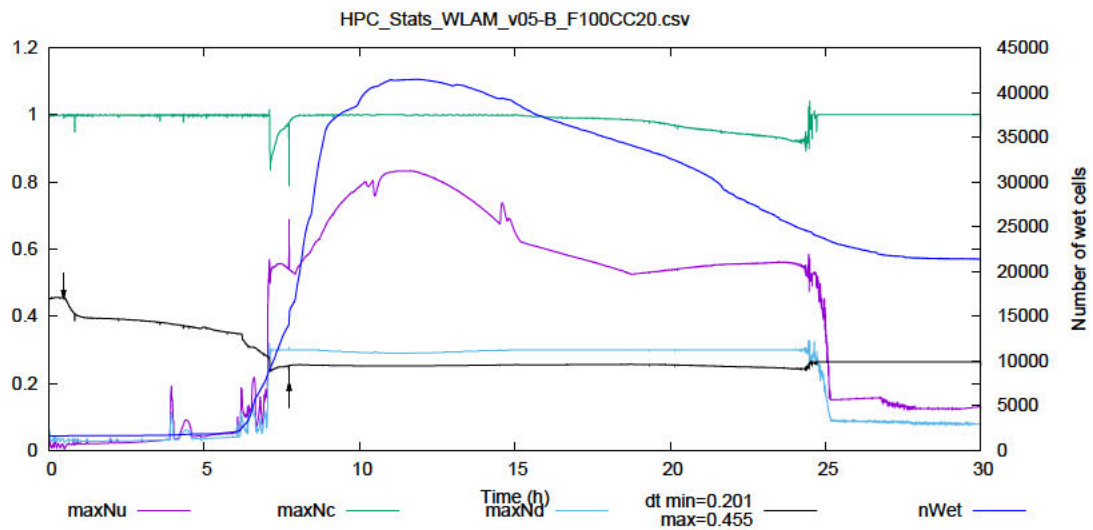


Figure 3.40: Case-B: Post-development, stability plot 1% AEP + 20% climate change

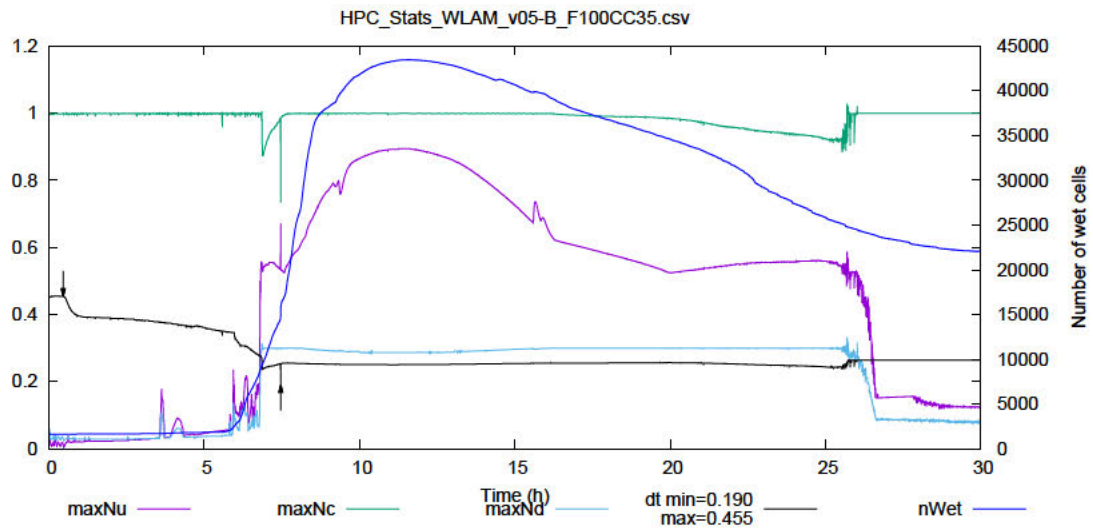


Figure 3.41: Case-B: Post-development, stability plot 1% AEP + 35% climate change

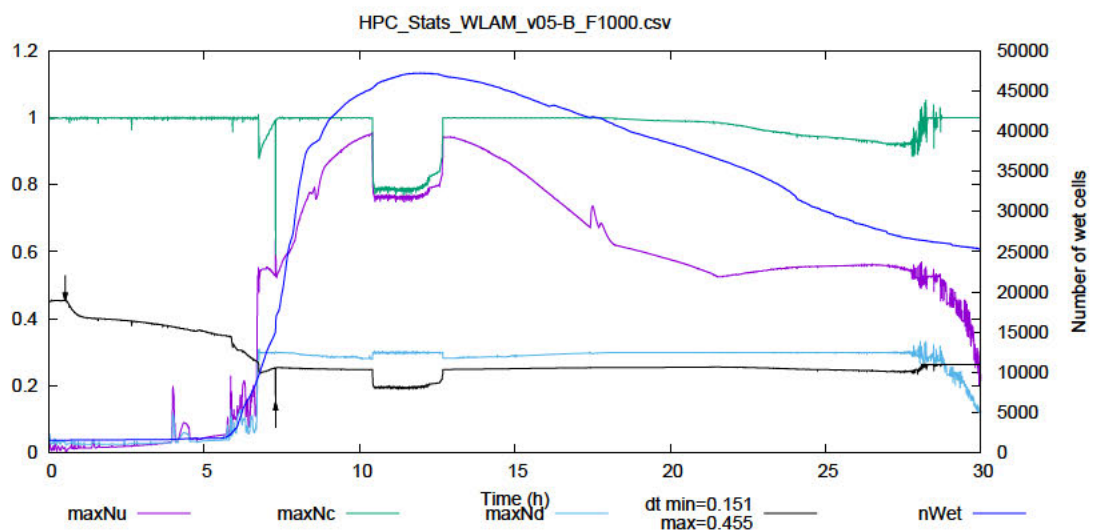


Figure 3.42: Case-B: Post-development, stability plot 0.1% AEP

4 Conclusions

The results using best practice model parameters show that the proposed development site is flood free for all modelled scenarios including the 0.1% annual exceedance probability event.

The slightly larger area of the roundabout compared to the existing signalised junction has negligible impact on the catchment storage and therefore no visible impact on the flood levels.

A Hydrology

Flood estimation calculation record

Introduction

This document is a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at multiple locations.

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2	LOCATIONS WHERE FLOOD ESTIMATES REQUIRED ----- 9
3	STATISTICAL METHOD ----- 10
4	REVITALISED FLOOD HYDROGRAPH (REFH) METHOD ----- 14
5	FEH RAINFALL-RUNOFF METHOD ----- 15
6	DISCUSSION AND SUMMARY OF RESULTS ----- 16
7	ANNEX ----- 19

Approval

	Signature	Name and qualifications	For Environment Agency staff: Competence level (see below)
Calculations prepared by:			
Calculations checked by:			
Calculations approved by:			

Environment Agency competence levels are covered in [Section 2.1](#) of the flood estimation guidelines:

- Level 1 – Hydrologist with minimum approved experience in flood estimation
- Level 2 – Senior Hydrologist
- Level 3 – Senior Hydrologist with extensive experience of flood estimation

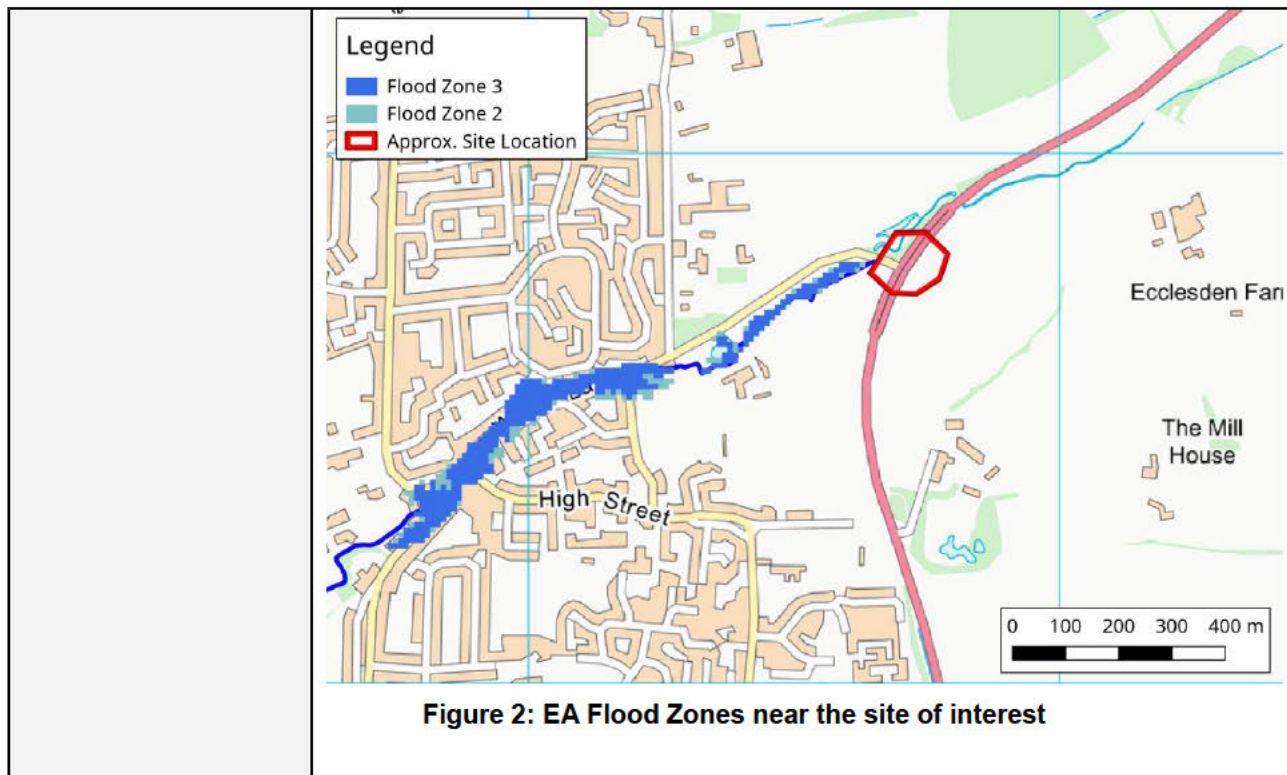
ABBREVIATIONS

AM	Annual Maximum
AREA	Catchment area (km ²)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

1 Method statement

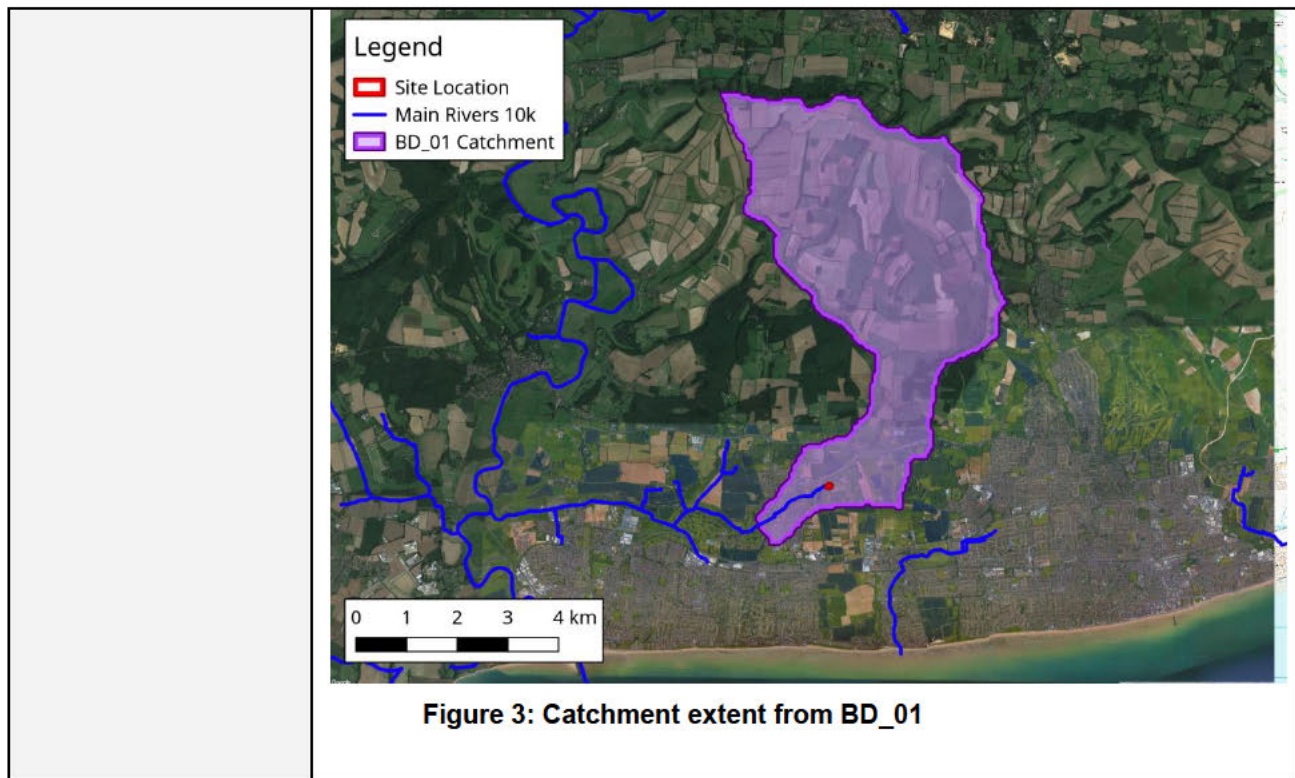
1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: • Purpose of study • Approx. no. of flood estimates required • Peak flows or hydrographs? • Range of return periods and locations • Approx. time available	This document outlines the hydrological analysis of the Black Ditch at the crossroad of the A280 and Water Lane in the village of Angmering, West Sussex. The purpose of this study is to produce hydrological estimates for use in the hydraulic modelling to support the planning documentation for the proposed roadway modifications at the junction of A280 and Water Lane. The approximate location of the proposed road construction is shown below in Figure 1.  Figure 1: Approximate boundary of the proposed road layout changes at the junction of A280 and Water Lane in Angmering. The Black Ditch watercourse constitutes the main potential source of fluvial flooding near the site and for the purpose of this study, hydrological estimates are required for the Black Ditch only. Peak flow estimates are required for the following annual exceedance probabilities (AEPs): 5% (1 in 20 year), 1% (1 in 100 year), 1% plus climate change (1 in 100 year +cc), and the 0.1% (1 in 1000 year). It should be noted that climate change allowances have been determined according to the latest EA guidance on climate change application to Flood Risk Assessments, published in February 2016. The hydrological catchment of interest is located within the boundaries of the South East River Basin District, according to the river basin maps published by the Environment Agency. The proposed development is in Flood Zone 1 according to the EA flood maps for planning (Figure 2). The vulnerability classification of the proposed roadworks is classed as essential infrastructure (Table 2 of the National Planning Practice Guidance). Therefore, the 'Central' climate change allowance for the South East River Basin District in Table 1 of the EA guidance should be considered. Accordingly, for the purpose of this study the 35% climate change allowance has been applied to the 1% AEP peak estimate to assess the impact of climate change.



1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	Permeable, rural The area of interest is located to the east of Angmering, just on the junction of of A280 and Water Lane. The Black Ditch catchment originates about 9km to the north and is set in a very rural area. The Black Ditch catchment downstream of the site of interest at location BD_01 (NGR 506350 104000) in Figure 3 below covers an area of 25.66km². Catchment descriptors indicate that the catchment is very rural, but also somewhat permeable. There are no NRFA river gauges on the Black Ditch, or reasonably nearby.



1.3 Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Version 6, released 22 nd February 2018. WINFAP-FEH release of HiFlows-UK from the NRFA database.
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1.4 Gauging stations (flow or level)

(at the sites of flood estimates or nearby at potential donor sites)

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catchment area (km ²)	Type (rated / ultrasonic / level...)	Start and end of flow record
41023	Lavant at Graylingwell	41023	41023	SU870064	87.2	Flat-V Weir	01/1970-present
41018	Kird at Tanyards	41018	41018	TQ044256	66.8	Crump Profile Weir	01/1969-10/2001
41014	Arun at Pallingham	41014	41014	TQ046229	379	Flat-V Weir	10/1960-present
41022	Lod at Halfway Bridge	41022	41022	SU931222	52	Crump Profile Weir	01/1970-present
Give link/reference to any further data quality checks carried out			None				

1.5 Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
Lavant at Graylingwell	01/05/1981 – 30/09/2016	NA	Yes	Yes	NA	Gauged above QMED
Kird Tanyards	14/07/1970 – 02/09/2001	NA	Yes	No	NA	Hydraulic model simulates QMED well
Arun at Pallingham	01/03/1977 – 30/09/2016	NA	Yes	No	NA	Some scattering in gauging evident, but gauged to 12% of QMED
Lod at Halfway Bridge	01/05/1981 – 30/09/2016	NA	Yes	Yes	NA	Gauged to within 19% of QMED
Give link/reference to any further data quality checks carried out			NA			

1.6 Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
Give link/reference to any rating reviews carried out		Outside scope	

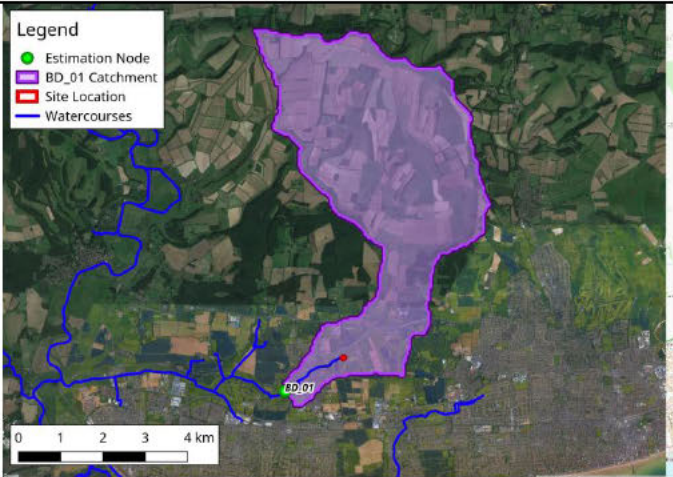
1.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available ?	Source of data and licence reference if from EA	Date obtained	Details
Check flow gaugings (if planned to review ratings)	None available				
Historic flood data – give link to historic review if carried out.	No	Yes, recorded			
Flow data for events	NA				
Rainfall data for events	NA				
Potential evaporation data	NA				
Results from previous studies	Yes	No			

Other data or information (e.g. groundwater, tides)	NA				
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1.8 Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	As the catchment is described as being rural, of a medium size, and permeable, The FEH Guidelines suggest that the FEH approach is an appropriate approach for the hydrological analysis of the Black Ditch at Angmering. As the catchment is permeable, the FEH Guideline suggest that the ReFH methods may be less representative of such a catchment, so the Statistical Method will likely be more acceptable of an estimation.
Outline the conceptual model, addressing questions such as: - Where are the main sites of interest? - What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides...) - Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? - Is there a need to consider temporary debris dams that could collapse?	High peak flows on the Black Ditch are considered to be the main source of fluvial flood risk in the area of the proposed roadworks. Inflows are to be provided for the 1D/2D hydraulic model of this watercourse. While the FEH Guidelines discourage the ReFH method in permeable catchments, both the Statistical method and the ReFH method will be carried out: Statistical Method for estimation of peak flows, and the ReFH method for the development of a hydrograph. Final hydrographs will be derived by implementing the ReFH2 model hydrographs scaled to fit the Statistical method peak flow estimates.
Any unusual catchment features to take into account? e.g. - highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% - highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments - pumped watercourse – consider lowland catchment version of rainfall-runoff method - major reservoir influence (FARL<0.90) – consider flood routing - extensive floodplain storage – consider choice of method carefully	BFIHOST at BD_01 is = 0.863, and thus is considered to be highly permeable. FEH guidelines suggest that in catchments with a BFIHOST>0.65 that the ReFH model is inappropriate, and that the Statistical Method should be used with caution.
Initial <u>choice of method(s)</u> and reasons Will the catchment be split into sub catchments? If so, how?	A lumped inflow will be determined for the Black Ditch catchment at location BD_01 (see Figure 4) and applied to the top of the model (upstream of the site of interest).

	Legend ● Estimation Node ■ BD_01 Catchment ■ Site Location — Watercourses  Figure 4: Location of hydrological estimation node BD_01 and its catchment area The Statistical Method will be carried out for the catchment at location BD_01 in order to derive the peak flows. Typical donor transfer analysis will be carried out within WINFAP4. ReFH2 will be used only to generate hydrograph shapes, which will then have the Statistical peak flows applied to them.
Software to be used (with version numbers)	CEH Web Server WINFAP-FEH v4.0.000 ReFH2 (v2.2) Design Flood Modelling Software

2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km ²)	Revised AREA if altered
Inflow estimation nodes						
BD_01	Black Ditch	Junction of A280 and Water Lane in Angmering, West Sussex	506350	104000	25.6575	NA
Reasons for choosing above locations		Appropriate to the scale of study and to the requirements of the hydraulic modelling. Estimation location 1.5km downstream of area of interest.				
Comments						

2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROP WET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT 2000	FPEXT
BD_01	0.974	0.34	0.863	7.81	84.4	858	11.65	0.0161	0.0291

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	FEH Catchment boundaries have been checked using topographic information from the LiDAR DTM. The FEH catchment boundaries have not been modified.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	URBEXT and FARL have been checked against OS Open Data background maps (1:10000) and have been found to be appropriate.
Source of URBEXT	URBEXT2000
Method for updating of URBEXT	Equation 5.5 of Technical Report FD1919/TR for URBEXT2000

3 Statistical method

3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: - Number of potential donor sites available - Distances from subject site - Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors - Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	QMED at BD_01 is estimated from catchment descriptors and adjusted by donor transfer. Potential donors were selected by the distance and hydrological similarity to the subject site as well as physical distance. Potential donors are listed in Section 1.4. While there were four potential donor sites, after a review of the stations, only three donor sites were deemed appropriate for this study.
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3.2 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)
41023	Chosen: quality station with good gaugings above QMED	AM	NA	1.731	3.255	0.532
41018	Chosen: QMED tested by hydraulic modelling	AM	NA	19.093	17.797	1.073
41014	Rejected: large difference in size of catchment (379km ²)	AM	NA	82.596	69.043	1.196
41022	Chosen: quality structure with high confidence in British standard structure derived rating	AM	NA	16.260	11.225	1.449
Which version of the urban adjustment was used for QMED at donor sites, and why? Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).				Kjeldsen (2010) * urban adjustment was not carried out at donor sites and the rural estimate of QMED was used to estimate the adjustment ratio for the selected essentially rural donor sites (FEH Volume 3, 4.6.1).		

3.3 Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of QMED (m ³ /s)	Data transfer						Final estimate of QMED (m ³ /s)
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d _{ij} (km)	Power term, a	Moderated QMED adjustment factor, (A/B) ^a	If more than one donor		
							Weight	Weighted average adjustment factor	
BD_01	DT	1.365	41023	21.28					1.295 as rural 1.446 as urban (adjusted by UAF= 1.117)
			41018	21.89					
			41022	24.84					
Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?									
Which version of the urban adjustment was used for QMED, and why?						Kjeldsen (2010), EA guidelines recommendation			
Notes Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone. When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added. When QMED is estimated from catchment descriptors, the revised 2008 equation from Science Report SC050050 should be used. If the original FEH equation has been used, say so and give the reason why. The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8). The adjustment method used in WINFAP-FEH v3.0.003 is likely to overestimate adjustment factors for such catchments. In this case the only reliable flood estimates are likely to be derived from local flow data. The data transfer procedure is from Science Report SC050050. The QMED adjustment factor A/B for each donor site is given in Table 3.3. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is (A/B) ^a times the initial estimate from catchment descriptors. If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column.									

3.4 Derivation of pooling groups

The composition of the pooling groups is given in the Annex. Several subject sites may use the same pooling group.

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
BD_01	BD_01	No	The default pooling group is heterogeneous but no site in the default pooling group is discordance (discordancy threshold is 3.0 for the 17 sites). Given the distribution of L-moments within the pooling group, various sites were investigated. Site 44008 was investigated and retained in the pooling group as there is a good correlation of spot flow gaugings to the rating curve. Site 44013 was reviewed and retained as it is gauged to within 25% of AMAX1 with well fitted rating. Site 22003 was reviewed and removed from the pooling group due to uncertainty in high flows due to potential upstream attenuation. Site 28058 was reviewed and retained in the pooling group as the rating has been confirmed by gaugings. Site 203046 was reviewed and retained was the NRFA stated that the measuring authority has a high confidence in the high flow rating. Site 24006 was reviewed and retained in the pooling group at this site has a formal structure and is believed to contain all flow. Site 49005 was removed from the pooling group due to a low number of years of data at the site. Site 36010 was reviewed and removed from the pooling group due to very poor correlation between the spot flow gaugings and the rating. Site 25019 was reviewed and retained as there is high confidence in the modelled rating curve. Sites 24007 and 72014, selected on the basis of their hydrological similarity with the subject site (SDM, measured by AREA, SAAR, FARL, FPEXT), were introduced to the pooling group to achieve the recommended total number of years of flow records ~500. The resulting pooling group was still heterogeneous but no further modifications to the pooling group were required to improve the extrapolation of peak flow estimates at the subject site.	L-CV: 0.250 L-skew: 0.189
Comments:				

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
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Notes

Pooling groups were derived using the revised procedures from Science Report SC050050 (2008). Amend if not applicable.

The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.

3.5 Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group (3.4)	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments	Growth factor for 100-year return period
BD_01	P	BD_01	General Logistic, Z value gave acceptable fit (1.5341)	Urban Adjustment Kjeldsen 2010 (1.117) *	Location: 1 Scale: 0.859 Shape: 0.213	2.867

Notes

*Permeable adjustments were not made in this process. Four of the sixteen pooling group sites were considered permeable. After reviewing their AMAX data, the revised number of years with floods ($AMAX > QMED/2$) was the same as, or very near to, the number of years of record which would have led to $\omega=1$, and would cause the adjustment process to have no effect.

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.

Urban adjustments to growth curves should use the version 3 option in WINFAP-FEH: Kjeldsen (2010).

Growth curves were derived using the revised procedures from Science Report SC050050 (2008).

3.6 Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)								
	2	5	10	20	50	100	200	500	1000
BD_01	1.446	2.030	2.451	2.899	3.567	4.146	4.804	5.811	6.698

4 Revitalised flood hydrograph (ReFH2.2) method

4.1 Parameters for ReFH2.2 model

Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	T _p (hours) Time to peak	C _{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
BD_01	CD	5.195	1048.737	72.709	2.316
Comments					
Brief description of any flood event analysis carried out (further details should be given below or in a project report)					

4.2 Design events for ReFH2.2 method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
BD_01	Urban	Winter	9:30	-
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?				

4.3 Flood estimates from the ReFH2.2 method

Site code	Flood peak (m ³ /s) for the following return periods (in years)								
	2	5	10	20	50	100	200	500	1000
BD_01	1.53	2.02	2.38	2.76	3.33	3.83	4.46	5.60	6.78

5 FEH rainfall-runoff method

5.1 Parameters for FEH rainfall-runoff model

Methods:

- FEA : Flood event analysis
- LAG : Catchment lag
- DT : Catchment descriptors with data transfer from donor catchment
- CD : Catchment descriptors alone
- BFI : SPR derived from baseflow index calculated from flow data

Site code	Rural (R) or urban (U)	Tp(0): method	Tp(0): value (hours)	SPR: method	SPR: value (%)	BF: method	BF: value (m ³ /s)	If DT, numbers of donor sites used (see Section 5.2) and reasons

5.2 Donor sites for FEH rainfall-runoff parameters

N o.	Watercourse	Station	Tp(0) from data (A)	Tp(0) from CDs (B)	Adjustment ratio for Tp(0) (A/B)	SPR from data (C)	SPR from CDs (D)	Adjustment ratio for SPR (C/D)
1								
2								

5.3 Inputs to and outputs from FEH rainfall-runoff model

Site code	Storm duration (hours)	Storm area for ARF (if not catchment area)	Flood peaks (m ³ /s) or volumes (m ³) for the following return periods (in years)							
			2							
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?										

6 Discussion and summary of results

6.1 Comparison of results from different methods

This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Ratio of peak flow to FEH Statistical peak					
	Return period 2 years			Return period 100 years		
	ReFH2.2	Other method	Other method	ReFH2.2	Other method	Other method
BD_01	1.058	NA	NA	0.928	NA	NA

6.2 Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	QMED estimates were calculated from catchment descriptors with donor transfer adjustment. QMED was adjusted for urbanisation (Kjeldsen 2010) as suggested for all catchment by the FEH Guidelines. Final peak flows for all return periods are derived with the statistical method at BD_01, which is recommended by current EA guidelines and the FEH Guidelines for permeable catchments. Final design hydrographs for all AEPs are derived from applying the statistical peaks to the ReFH2 model.
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6.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	- Gauges considered for donor transfer for QMED are judged according to NRFA information - Suitability for pooling is based on HiFlows classification and the assessment of the quality of gauges is based on data and comments in the NRFA.																
Discuss any particular limitations , e.g. applying methods outside the range of catchment types or return periods for which they were developed	Statistical methods used up to the 1000 year return period.																
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	<table><tr><th rowspan="2">Node</th><th rowspan="2">QMED (m³/s)</th><th colspan="2">68% confidence</th><th colspan="2">95% confidence</th></tr><tr><th>Lower</th><th>Upper</th><th>Lower</th><th>Upper</th></tr><tr><td>BD_01</td><td>1.446</td><td>1.010</td><td>2.069</td><td>0.706</td><td>2.961</td></tr></table>	Node	QMED (m ³ /s)	68% confidence		95% confidence		Lower	Upper	Lower	Upper	BD_01	1.446	1.010	2.069	0.706	2.961
Node	QMED (m ³ /s)			68% confidence		95% confidence											
		Lower	Upper	Lower	Upper												
BD_01	1.446	1.010	2.069	0.706	2.961												
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	Results are suitable for the purpose of the assessment of flood levels and extents at the site of interest.																
Give any other comments on the study, for example suggestions for additional work.	The use of local data would improve these estimates if a gauge could be installed on the Black Ditch watercourse.																

6.4 Checks

Are the results consistent, for example at confluences?	NA
What do the results imply regarding the return periods of floods during the period of record?	NA
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	2.867, yes this is realistic
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	1.616, this is within the typical range [1.5-2]
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Outside scope of this project
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	No previous reporting to compare results to.
Are the results compatible with the longer-term flood history?	NA. Outside of scope.
Describe any other checks on the results	No further checks were made.

6.5 Final results

Site code	Flood peak (m ³ /s) for the following return periods (in years)								
	2	5	10	20	50	100	200	500	1000
BD_01	1.446	2.030	2.451	2.899	3.567	4.146	4.804	5.811	6.698

Site code	100+35C C
BD_01	5.597

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	NA
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7 ANNEX

Table 1 Default pooling group at BD_01 (FEH catchment)

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
44008 (South Winterbourne @ Winterbourne Steepleton)	0.514	37	0.448	0.416	0.326	1.036
26803 (Water Forlornes @ Driffield)	0.516	17	0.437	0.3	0.112	0.466
44013 (Piddle @ Little Puddle)	0.544	23	1.103	0.463	0.254	1.849
22003 (Usway Burn @ Shillmoor)	0.547	13	16.17	0.282	0.311	1.785
28058 (Henmore Brook @ Ashbourne)	0.574	12	9.006	0.155	-0.064	1.673
27010 (Hodge Beck @ Bransdale Weir)	0.579	41	9.42	0.224	0.293	0.679
203046 (Rathmore Burn @ Rathmore Bridge)	0.658	34	10.788	0.146	0.136	0.558
28041 (Hamps @ Waterhouses)	0.702	31	26.664	0.22	0.295	1.348
41020 (Bevern Stream @ Clappers Bridge)	0.704	47	13.9	0.205	0.17	0.602
26802 (Gypsey Race @ Kirby Grindalythe)	0.733	17	0.116	0.274	0.24	0.078
24006 (Rookhope Burn @ Eastgate)	0.741	20	24.62	0.152	0.117	0.586
49005 (Bollingey Stream @ Bolingey Cocks Bridge)	0.764	6	6.511	0.265	0.063	1.331
36010 (Bumpstead Brook @ Broad Green)	0.766	49	7.585	0.365	0.173	2.002
49004 (Gannel @ Gwills)	0.769	47	15.022	0.258	0.105	0.345
25019 (Leven @ Easby)	0.77	38	5.333	0.338	0.391	1.076
73015 (Keer @ High Keer Weir)	0.796	25	12.239	0.174	0.191	0.455
51003 (Washford @ Beggearn Huish)	0.801	49	6.12	0.19	0.076	1.129
Total		506				
Weighted means				0.263	0.197	

Table 2 Final pooling group at BD_01 (FEH catchment)

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
44008 (South Winterbourne @ Winterbourne Steepleton)	0.514	37	0.448	0.416	0.326	1.218
26803 (Water Forlornes @ Driffield)	0.516	17	0.437	0.3	0.112	0.634
44013 (Piddle @ Little Puddle)	0.544	23	1.103	0.463	0.254	2.242
28058 (Henmore Brook @ Ashbourne)	0.574	12	9.006	0.155	-0.064	1.713
27010 (Hodge Beck @ Bransdale Weir)	0.579	41	9.42	0.224	0.293	0.738
203046 (Rathmore Burn @ Rathmore Bridge)	0.658	34	10.788	0.146	0.136	0.464
28041 (Hamps @ Waterhouses)	0.702	31	26.664	0.22	0.295	1.544
41020 (Bevern Stream @ Clappers Bridge)	0.704	47	13.9	0.205	0.17	0.704
26802 (Gypsy Race @ Kirby Grindalythe)	0.733	17	0.116	0.274	0.24	0.091
24006 (Rookhope Burn @ Eastgate)	0.741	20	24.62	0.152	0.117	0.563
49004 (Gannel @ Gwills)	0.769	47	15.022	0.258	0.105	0.438
25019 (Leven @ Easby)	0.77	38	5.333	0.338	0.391	1.158
73015 (Keer @ High Keer Weir)	0.796	25	12.239	0.174	0.191	0.429
51003 (Washford @ Beggearn Huish)	0.801	49	6.12	0.19	0.076	1.392
24007 (Browney @ Lanchester)	0.82	15	10.981	0.222	0.212	2.275
72014 (Conder @ Galgate)	0.871	49	16.646	0.212	0.082	0.398
Total		502				
Weighted means		955		0.25	0.189	

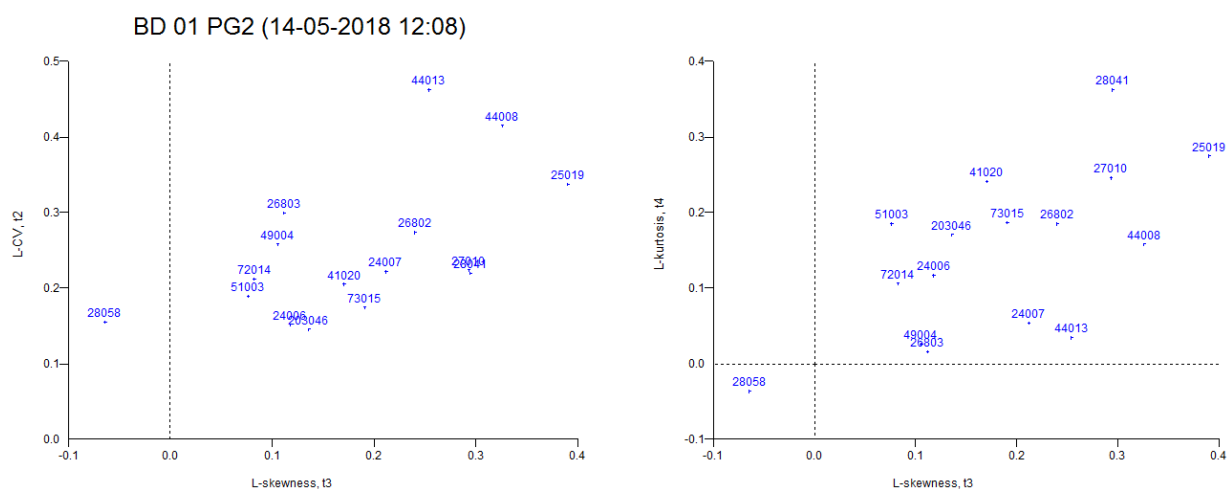


Figure 5: L-moments for final pooling group at site BD_01

BD 01 PG2 (14-05-2018 12:08)
Generalised Logistic

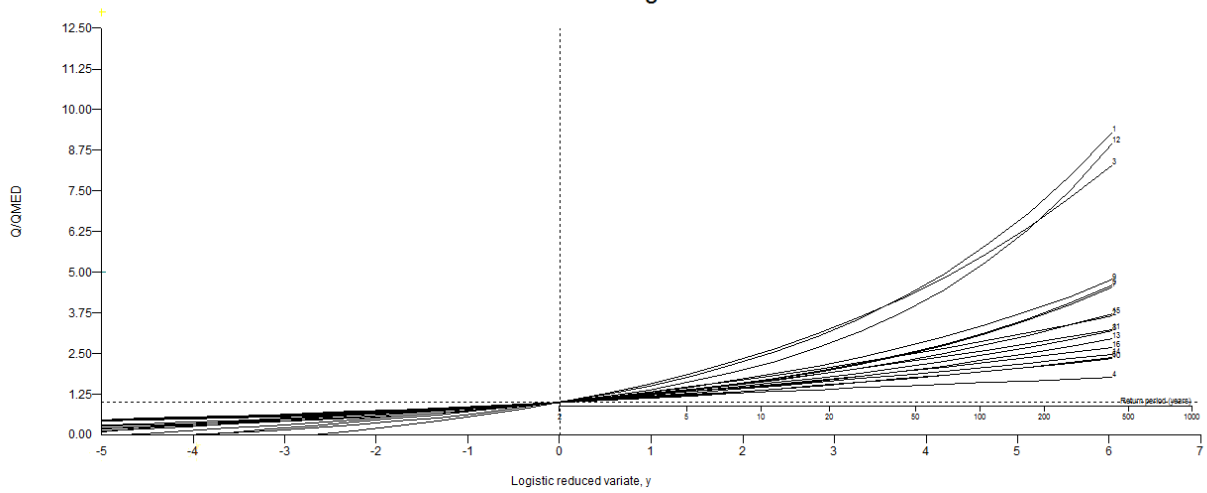


Figure 6 Growth curve for final pooling group at site BD_01

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