Cambridge South East Transport Phase 2

Environmental Statement

Appendix 8.2 Flood modelling report

31st July 2023

Appendix 8.2 Flood modelling report

Introduction

8.2.1 This report has been prepared to document the approach and outcomes of the River Granta flood modelling work. The modelling work has been carried out for the Cambridge South East Transport (CSET) Scheme, hereinafter referred to as "the Proposed Development", to both inform the design and the Flood Risk Assessment.

8.2.2 The Proposed Development crosses the River Granta on a viaduct in two locations, one at Stapleford and the other at Babraham. A hydraulic model of the River Granta was used to model fluvial flood risk for Proposed Development. The model was originally developed by JBA Consulting in 2013 and updated by Mott McDonald in 2021. Further updates have been made by Atkins as detailed in this report, and the Proposed Development has been reassessed.

Flood risk and modelling approach

Review of existing hydraulic models

8.2.3 The initial assessment of Proposed Development carried out by Mott McDonald (reported in 2021) was done using a linked 1D/2D Flood Modeller – TUFLOW model. There was an existing model of the River Granta developed by JBA in 2013 and this was used by Mott McDonald as the base model for their assessment. Mott McDonald made some updates to the model to improve it for the assessment of Proposed Development. The technical note describing the model for the 2021 FRA are included in 0.

8.2.4 Atkins has taken the Mott McDonald model as the basis for the assessment of the updated Proposed Development design. As part of this process Atkins have reviewed the model and made changes to ensure the baseline model and the assessment of the potential impacts of Proposed Development are robust. Details of these changes are provided in Section 0.

Model approach

8.2.5 The basic model schematisation and approach has remained the same as the incoming model (JBA 2013 / Mott McDonald 2021). The model software used is Flood Modeller 5.1 and TUFLOW 2020 AE.

8.2.6 The key changes made to the model are described in **Error! Reference source not found.** below. Details of how these changes have been applied to the model are provided in Section 0.

Table A8.2.1 Hydraulic model updates

Model update	Details and justification
Truncation of the model	A significant proportion of the model was upstream of Proposed Development extent. To avoid needing to resolve issues remote from Proposed Development and to simplify the model and reduce run times, the model has been truncated.
Update floodplain DTM	More recent lidar has become available since the model was produced, therefore the floodplain topographic data has been updated.
Revised hydrology	The hydrology for the model had not been updated since the original model was built in 2013, therefore the inflows have been recalculated using the latest data and methods. This includes updating the climate change allowances to the latest guidance. The hydrology calculation record is given in 0.
Update of schematisation	Several updates were required to improve the schematisation, this included updating the elevations at the 1D/2D linkages and improving the width of the channel in the 2D domain, so that it matched the 1D cross sections.
Proposed Development design	Proposed Development design has been updated and this includes changes to the viaduct embankments crossing the River Granta.

Input data

8.2.7 The definition of the river channels in the River Granta model is unchanged from the original 2013 model. The date of the original channel survey is unknown. The Environment Agency provided data from a channel survey of the River Granta caried out in 2021 to compare to the original survey. Where aligned, the locations of the surveyed and modelled cross sections have been compared. The comparison shows that there is a good match in the datasets, therefore the channel data in the hydraulic model which defines the channels can be considered reliable. Details on the comparison of the datasets is provided in 0.

8.2.8 The floodplain extents have been updated using the latest available Lidar data, downloaded from the defra .gov site1 in 2022.

8.2.9 The latest climate change allowances2 have also been adopted for the flood modelling.

8.2.10 The only other revised input data relates to the latest design for the two viaducts. The design of the viaducts has been taken from Drawing 5212868-ATK-SGN-WHL_AL_SCHME-DR-CB-000003_C01 for Stapleford, and Drawing 5212868-ATK-SGN-WHL_AL_SCHME-DR-CB-000009_C01 for Babraham.

[1] Defra Data Services Platform

[2] Climate change allowances for peak river flow in England (data.gov.uk)

Technical method and implementation

Hydrological assessment

8.2.11 Hydrological inputs to the hydraulic model have been recalculated to provide peak flow estimates and hydrographs for the River Granta and Hobson's Brook.

8.2.12 For the modelling, peak flows and hydrographs are required for three River Granta subcatchments shown in Figure A8.2.1:

- Stapleford
- Babraham
- Bartlow

8.2.13 For the derivation of the hydrology, peak flows and hydrographs are additionally required for the catchment to the Babraham gauge (Bartlow and Babraham catchments combined). The hydrological estimates were carried out using the incoming hydraulic model extents (i.e., from the JBA / Mott Macdonald model). The hydraulic model was truncated as described in Section 2 after the hydrological assessment had been carried out therefore the upper catchment estimates were not used as an input, however it is included in the calculations for completeness. Peak flows and hydrographs were also required for the Hobson's Brook catchment. These catchments are all shown on Figure A8.2.1.

8.2.14 A statistical estimate was required for the catchment to the gauge, shown in Figure A8.2.1. Peak flows and hydrographs were calculated for the full range of flood events. The peak flow estimates for the River Granta are provided in Table A8.2.2. The full calculation record will be provided separately.

Table A8.2.2 Updated peak flow estimates

Site	Flood peak (m3/s) for the following Annual Exceedance Probability (AEP) (%) events									
	50	20	10	5	3.3	2	1.3	1	0.5	0.1
Gauge at Babraham	3.74	5.19	6.21	7.29	8.00	9.04	10.08	10.97	13.83	22.20
Bartlow catchment	5.35	7.12	8.31	9.55	10.34	11.48	12.59	13.55	16.62	25.39
Babraham catchment	1.53	2.17	2.62	3.10	3.42	3.88	4.35	4.75	6.04	9.86
Stapleford catchment	0.48	0.66	0.79	0.92	1.01	1.14	1.27	1.37	1.71	2.66
Hobson's Brook	0.21	0.29	0.36	0.43	0.47	0.54	0.61	0.67	0.85	1.30

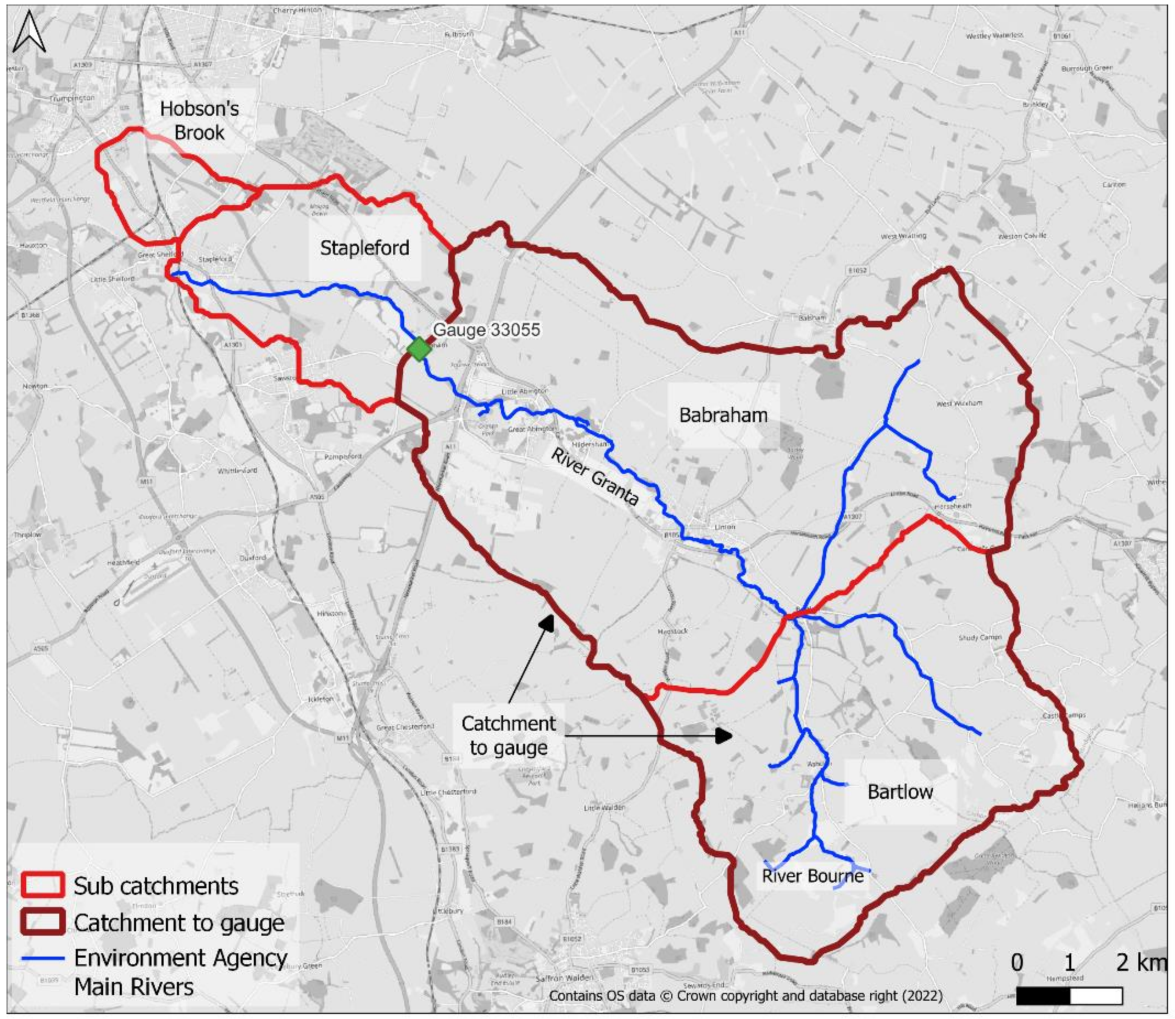


Figure A8.2.1 Subcatchment locations

Hydraulic model build

8.2.15 The updates to the incoming model focused on bringing it in line with current best practice, reducing instabilities and using the updated hydrology.

8.2.16 The model extent and domain has been updated to avoid the need to fix stability issues in reaches of the Granta which would not be affected by Proposed Development and to reduce the run time of simulations. The exiting model extent was from chainage 0 m (downstream extent) to chainage 18047 m (upstream extent). The model has been truncated to chainage 9345 m (2775 m upstream of Babraham crossing).

8.2.17 Figure A8.2.2 shows the changes to the model extent. Figure A8.2.3 presents the current layout of the 1D-2D model of the River Granta, focussed on the Proposed Development area from Babraham to Stapleford.

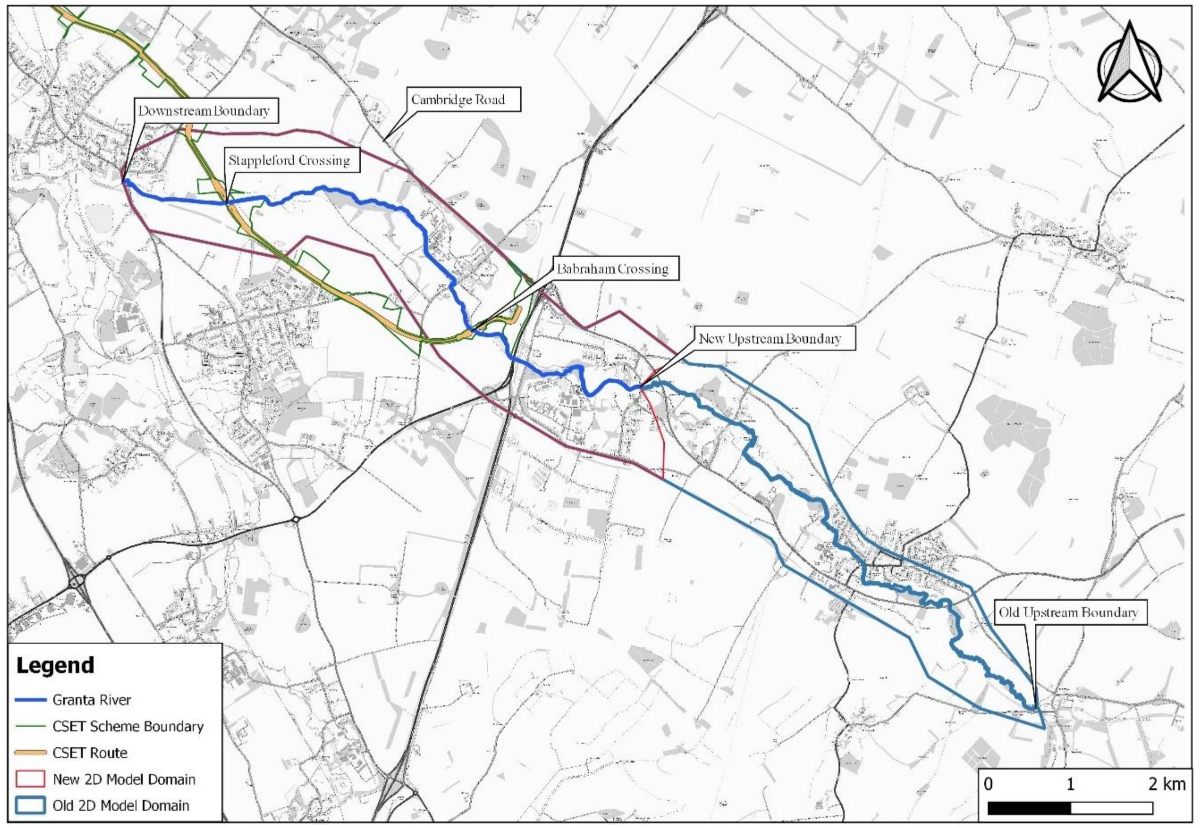


Figure A8.2.2 Revised model extent

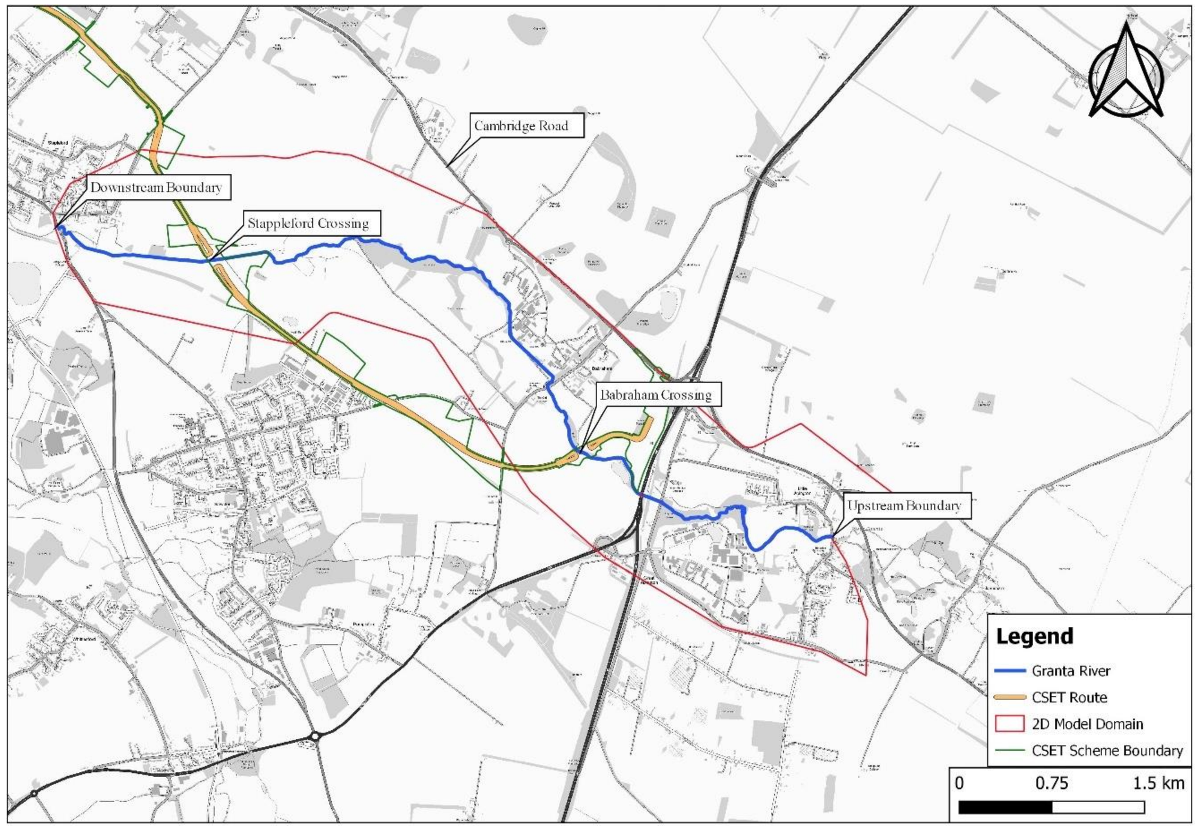


Figure A8.2.3 Plan of the updated model

8.2.18 Updates to the 1D model relate to the width of spill units at structures; corrections to the distances between cross sections; adjusting panel markers and bank levels. The model nodes are referenced by the chainage from the downstream extent, prefixed by 'GR'. References in this report to locations in the model take this form.

8.2.19 Specific updates are listed below:

- Width of the following spill units are updated: GR7918spu, GR9661spu, GR9025spu, GR7918spu, GR7446spu, GR5830SPu, GR5790SPu, GR5190SPu, GR960SPu.
- Chainage correction is applied at many cross sections near structures including: GR6085D/S GR6100 GR6410D/S GR6450 GR6452D/S GR6600 GR6620 GR6800 GR7200DS GR7220 GR7436 GR7912 GR8185 GR8456 GR9345.
- Additional panel marker for improving conveyance applied at GR6452ds, GR6450, GR6410, GR5790, GR5790ds, GR5789, GR5789D, GR940, GR940ds, GR904, GR8224, GR8204.
- Bank level updates at GR7918U, GR7240, GR7220, GR7200ds, GR 7000.

8.2.20 The main change to the 2D model was the update to the lidar data which defined the floodplain ground levels. Other updates related to correcting the width of deactivation areas along the river corridor; updating 1D/2D link spill levels and locations. Specific updates are listed below:

- The existing DEM was updated with new LiDAR 2020 1 m DTM.
- Deactivation width correction: The deactivation width was updated to reflect the changes in the cross section widths in the 1D model.
- Bank points update: The bank points in 1D model were enforced in the TUFLOW model as it came from the river cross section survey and considered to be more representative and accurate.
- Bank line update: Bank line was updated based on the updated cross section widths.

8.2.21 The model has 3 inflow boundaries which have been updated to match the hydrographs from the revised hydrology calculations. The three inflow boundaries are:

- GR9345: This is the upstream boundary of the model which is 90% of the gauge flow.
- LAT 01: Lateral flow between node GR9337 to GR5600 (u/s of model to the Babraham gauge) which is 10% of the gauge flow.
- LAT 02: Lateral flow in Stapleford catchment between nodes GR5450ds to GR50

8.2.22 The downstream boundary is at GR0 which is a head-time (HT) boundary. The downstream boundary is based on levels in the River Cam, however it is sufficiently downstream of the proposed viaduct locations that any uncertainty in the boundary will not affect the conclusions drawn from the model outputs. Sensitivity tests have been carried out to confirm there is no impact.

8.2.23 All roughness values have been applied as Manning's n roughness coefficients and identified using MasterMap land classes values. For 1D and 2D elements of models, the following values for Manning's n roughness are used:

- Agricultural/grass land: 0.04.
- Buildings :0.30
- Roads, tracks, paths: 0.025
- Rail lines: 0.05.
- Water:0.035
- Structures: 0.05
- Trees: 0.15
- Scrub: 0.10

- Stability patch[3]: 0.1

Proposed Development model build

8.2.24 The hydraulic model has been modified to simulate the two Proposed Development viaducts. At each viaduct crossing the 2D DTM has been modified to raise the ground levels to match the approach embankments associated with these crossing. The piers have been modelled using flow constriction layers in the TUFLOW model. These flow constriction layers apply a headloss across the floodplain associated with the piers. The headloss has been calculated based on the Incremental Backwater Coefficient for Piers (Hydraulics of Bridge and Waterways, 1978) approach.

Model results

Model proving

8.2.25 The flow gauge rating at Babraham is unreliable4 at high flows and so calibration / validation to flows has not been carried out for the model.

8.2.26 Model convergence information and mass error data from the present day 1% Annual Exceedance Probability (AEP) baseline simulation are reported below:

- The model completes without any issues relating to model convergence – see Figure A8.2.4.
- The final mass error in the Flood Modeller simulation is -0.12% of the boundary inflow volume.
- The final cumulative mass error in the TUFLOW model is <1%.
- The cumulative mass error in the TULFOW model reaches approximately 4% during the first 20 hours of the simulation, but it is only at around 20 hours where any significant volume spills into the 2D domain (see Figure A8.2.5), therefore the mass errors prior to this time are not significant nor a cause for concern.

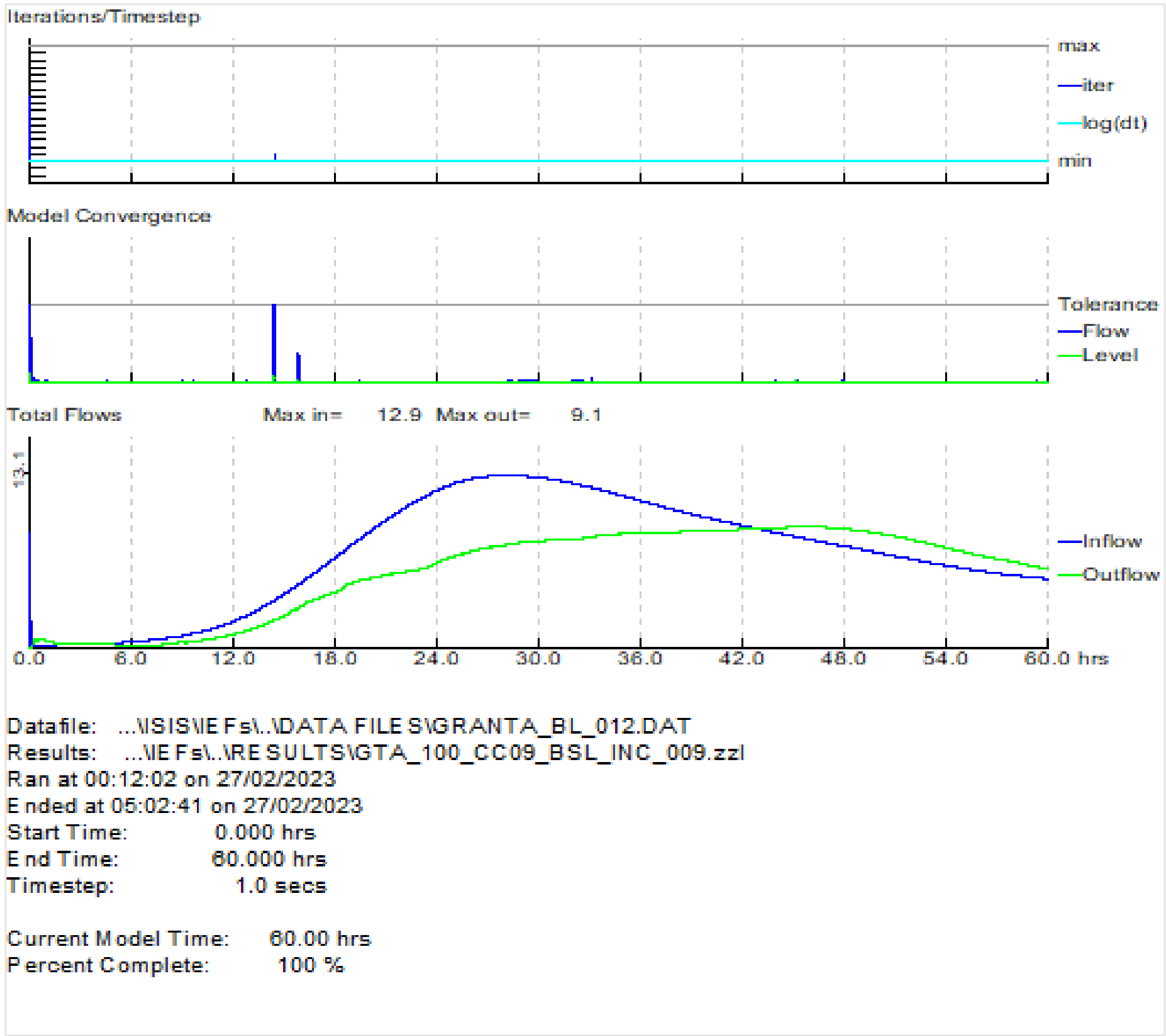


Figure A8.2.4 Flood modeller - Model convergence plot

[3] Small areas of higher roughness to resolve instabilities in the 2D model.

[4] NRFA Station Data for 33055 - Granta at Babraham (ceh.ac.uk)

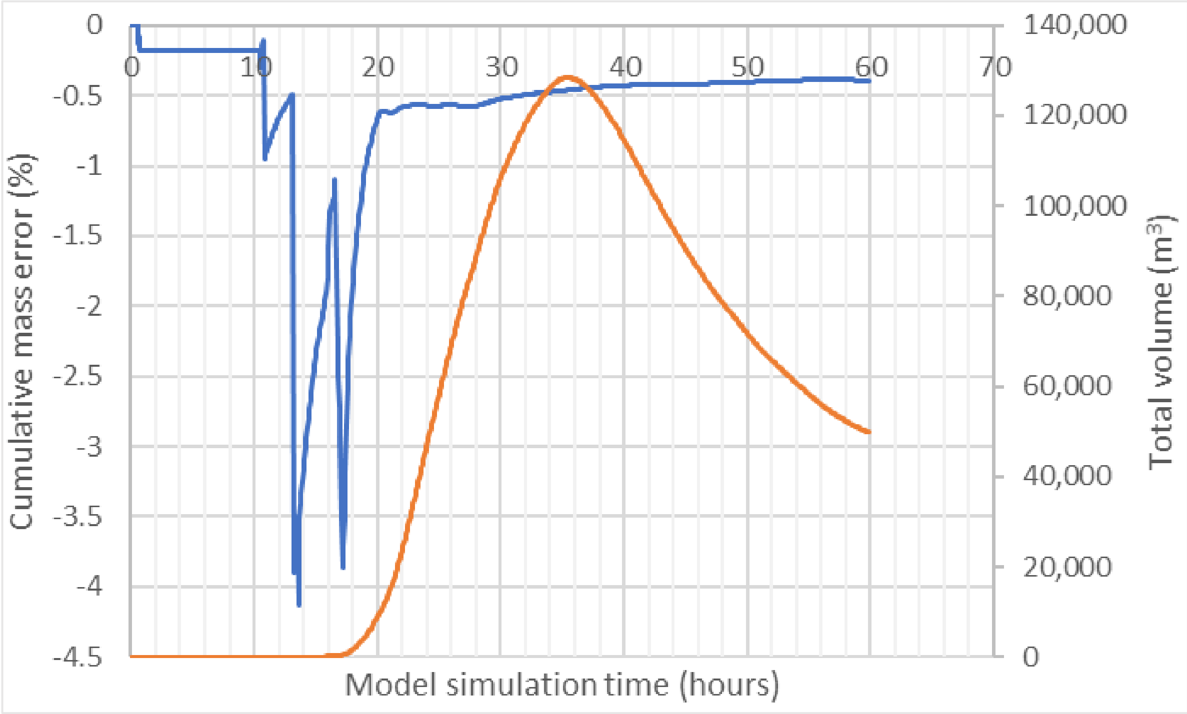


Figure A8.2.5 TUFLOW mass balance plot

Model results

8.2.27 The River Granta peak water levels from the baseline models are provided in Table A8.2.3. The model has been run for flood events ranging from the 50% AEP event up to the 0.1% AEP event. The climate change factors applied to the 1% AEP event are 9%, 16% and 45% for the central, higher central and upper end allowances respectively.

8.2.28 The impact of the Proposed Development is presented in Table A8.2.4, which shows the increase (in millimetres) in water levels from the 1D model.

8.2.29 The impact on the floodplain for each flood event simulated are presented Figure A8.2.6 to Figure A8.2.16.

8.2.30 The model results presented in this report do not include the floodplain compensation storage areas that will be included to offset the loss of floodplain storage capacity associated with the embankments and the piers.

8.2.31 At the Babraham viaduct the results show that there is a negligible change (< 10 mm) in the peak water levels in the channel for all events simulated. Similarly, there is no adverse impact on the floodplain as a result of the Proposed Development.

8.2.32 At the Stapleford viaduct the results show that there is a negligible change (< 10 mm) in the peak water levels in the channel for all events simulated up to and including the 1% AEP event with the upper end climate change allowance. However, there is a 14 mm increase in the 0.1% AEP event event. This increase is only shown at the viaduct location, and upstream of this location the impact reduces to negligible.

8.2.33 The impacts on the floodplain levels are seen in the 3.3% AEP event event and for the more extreme events. The impacts are only on the right bank floodplain for all events, except the most extreme 0.1% AEP event where the left bank also becomes flooded.

8.2.34 In the 3.3% event, there is a very small area affected by Proposed Development, and the increases in flood levels are very localised to within the footprint of the viaduct.

8.2.35 During the design event, which is the 1% AEP event with the higher central climate change allowance, the impact on the right bank is minor adverse (between 10 mm and 50 mm). Outside the corridor width of the viaduct embankment the increase in flood level is less than 20 mm, and this reduces to 0 mm approximately 60 m upstream of the viaduct.

Table A8.2.3 Baseline peak water levels from 1D model (mAOD)

Location	50	20	10	3.3	2	1.3	1	1%C	1%HC	1%UE	0.1
u/s Babraham Viaduct (GR6600)	25.359	25.502	25.557	25.628	25.662	25.68	25.694	25.724	25.749	25.806	25.867
At the Babraham Viaduct (GR6450)	25.017	25.173	25.248	25.337	25.365	25.384	25.401	25.43	25.457	25.521	25.565
d/s of Babraham Viaduct (GR6390)	24.452	24.581	24.659	24.777	24.837	24.879	24.91	24.974	25.029	25.163	25.321
u/s of Stapleford Viaduct (GR2400)	17.255	17.454	17.57	17.654	17.685	17.697	17.706	17.722	17.738	17.783	17.833
At the Stapleford Viaduct (GR2400_i)	17.074	17.274	17.386	17.459	17.486	17.497	17.505	17.519	17.535	17.584	17.641
d/s of Stapleford Viaduct (GR2200)	16.901	17.099	17.196	17.232	17.248	17.255	17.261	17.272	17.286	17.311	17.332

Table A8.2.4 Impact of Proposed Development on peak water levels form 1D model (mm)

Location	50	20	10	3.3	2	1.3	1	1%C	1%HC	1%UE	0.1
u/s Babraham Viaduct (GR6600)	0	0	0	0	0	0	0	0	+1	+1	+1
At the Babraham Viaduct (GR6450)	0	0	0	0	0	0	0	0	0	+1	+1
d/s of Babraham Viaduct (GR6390)	0	0	0	0	0	0	0	0	0	0	0
u/s of Stapleford Viaduct (GR2400)	0	0	0	0	0	0	+1	0	+2	+2	+2
At the Stapleford Viaduct (GR2400_i)	0	0	+1	0	0	0	0	0	+5	+8	+14
d/s of Stapleford Viaduct (GR2200)	0	0	0	0	0	0	0	0	+2	+2	+3

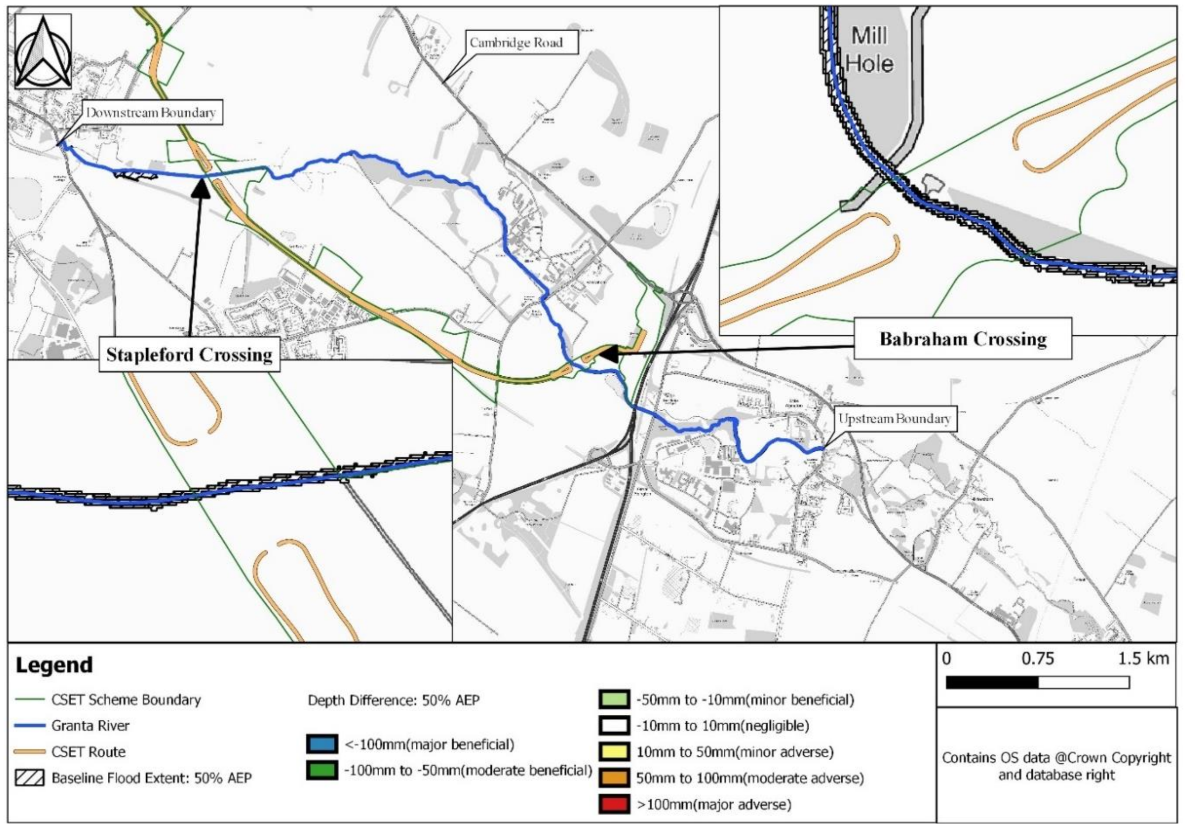


Figure A8.2.6 Depth difference for 50% AEP event

Table A8.2.5 Impact of Proposed Development on peak flood levels for the 50% AEP event in river channel (FM Model)

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.359	25.359	0
At the Babraham Viaduct (Node: GR6450)	25.017	25.017	0
d/s of Babraham Viaduct (Node: GR6390)	24.452	24.452	0
u/s of Stapleford Viaduct (Node: GR2400)	17.255	17.255	0
At the Stapleford Viaduct (Node: GR2400_i)	17.074	17.074	0
d/s of Stapleford Viaduct (Node: GR2200)	16.901	16.901	0

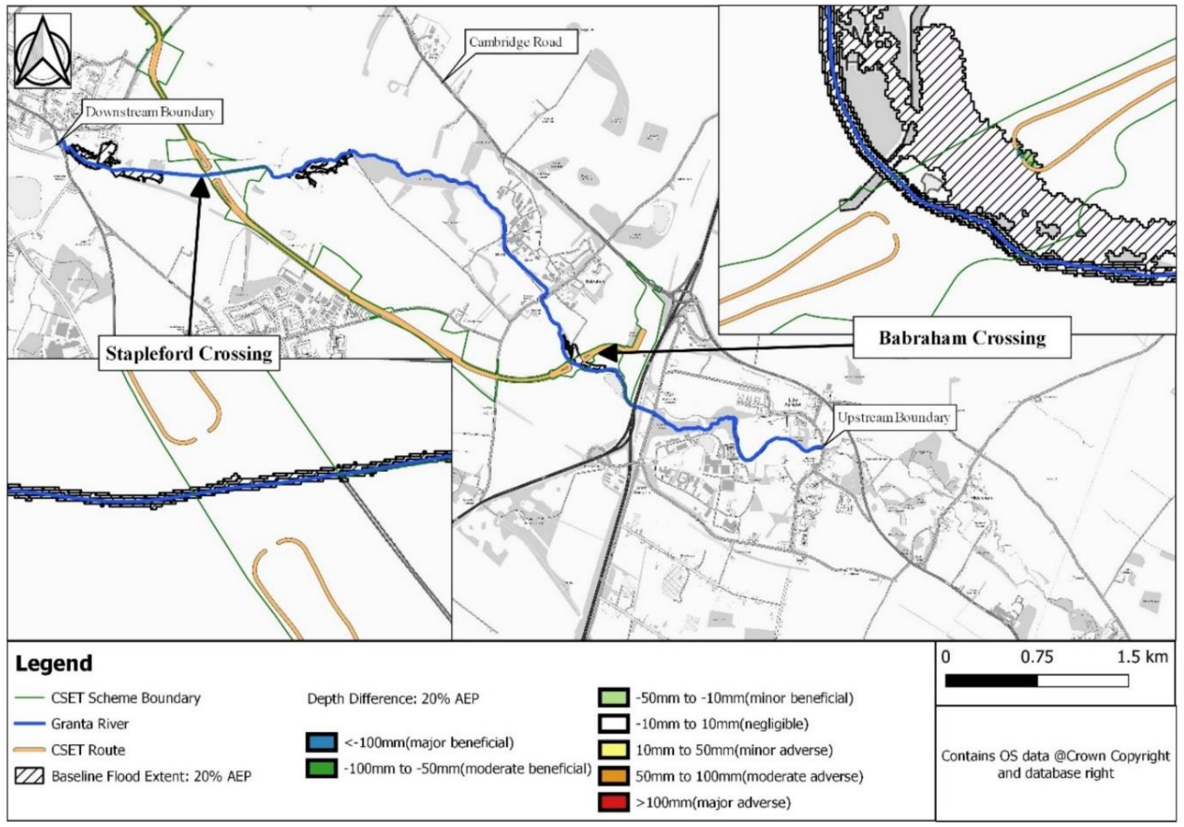


Figure A8.2.7 Depth difference for 20% AEP event

Table A8.2.6 Impact of Proposed Development on peak flood levels for the 20% AEP event in river channel (FM Model)

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.502	25.502	0
At the Babraham Viaduct (Node: GR6450)	25.173	25.173	0
d/s of Babraham Viaduct (Node: GR6390)	24.581	24.581	0
u/s of Stapleford Viaduct (Node: GR2400)	17.454	17.454	0
At the Stapleford Viaduct (Node: GR2400_i)	17.274	17.274	0
d/s of Stapleford Viaduct (Node: GR2200)	17.099	17.099	0

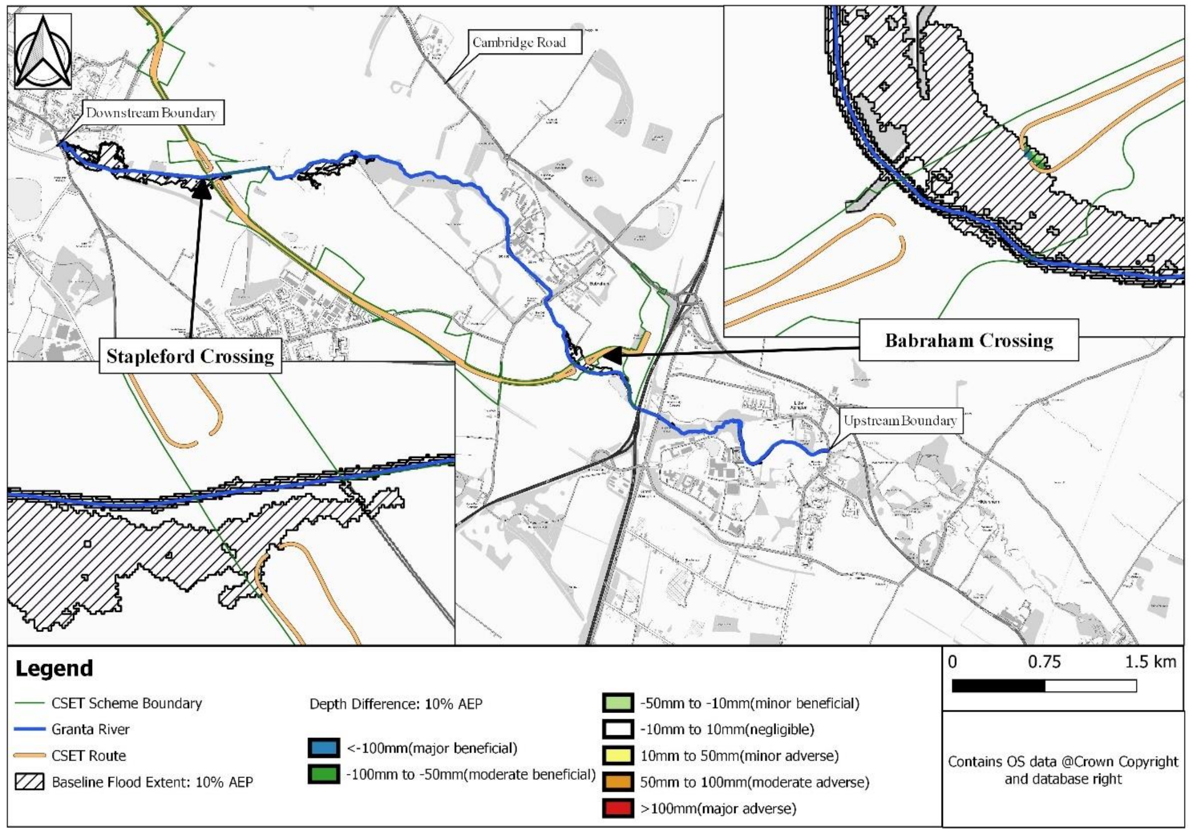


Figure A8.2.8 Depth difference for 10% AEP event

Table A8.2.7 Impact of Proposed Development on peak flood levels for the 10% AEP event in river channel

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.557	25.557	0
At the Babraham Viaduct (Node: GR6450)	25.248	25.248	0
d/s of Babraham Viaduct (Node: GR6390)	24.659	24.659	0
u/s of Stapleford Viaduct (Node: GR2400)	17.57	17.57	0
At the Stapleford Viaduct (Node: GR2400_i)	17.386	17.387	+1
d/s of Stapleford Viaduct (Node: GR2200)	17.196	17.196	0

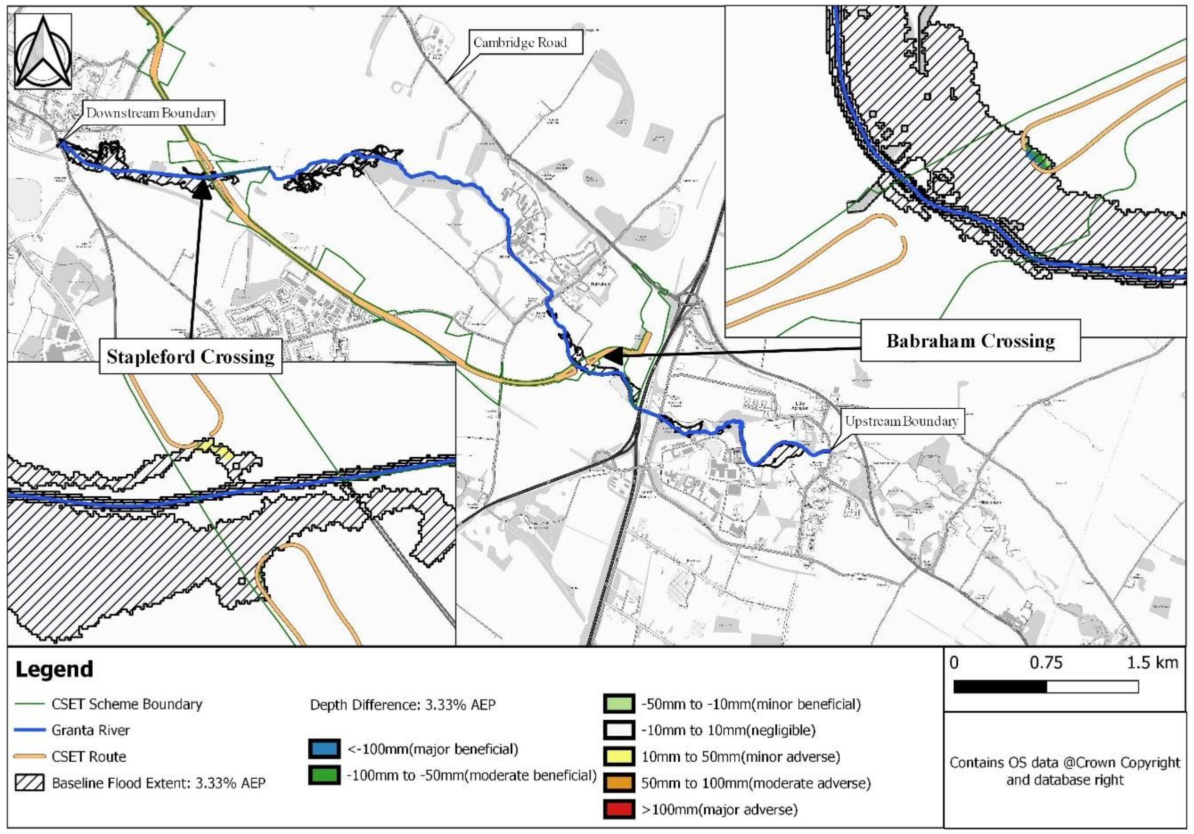


Figure A8.2.9 Depth difference for 3.33% AEP event

Table A8.2.8 Impact of Proposed Development on peak flood levels for the 3.33% AEP event in river channel

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.628	25.628	0
At the Babraham Viaduct (Node: GR6450)	25.337	25.337	0
d/s of Babraham Viaduct (Node: GR6390)	24.777	24.777	0
u/s of Stapleford Viaduct (Node: GR2400)	17.654	17.654	0
At the Stapleford Viaduct (Node: GR2400_i)	17.459	17.459	0
d/s of Stapleford Viaduct (Node: GR2200)	17.232	17.232	0

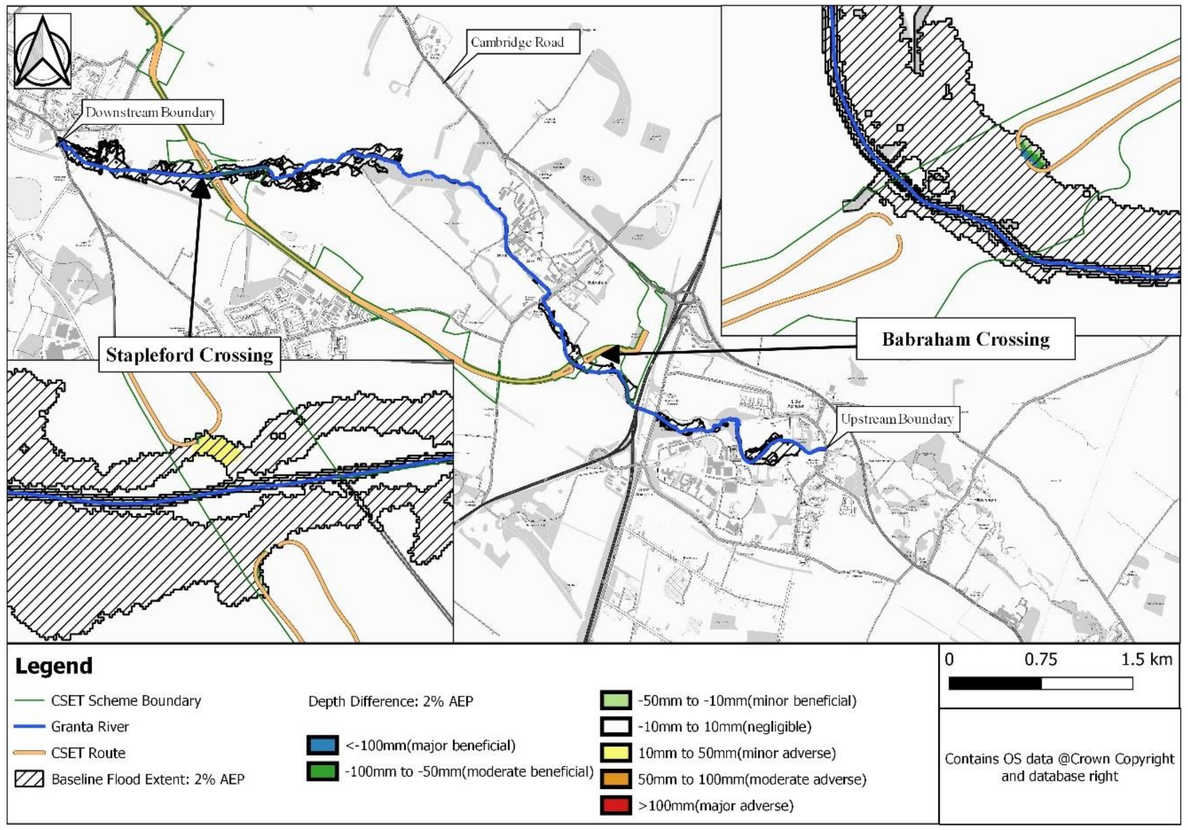


Figure A8.2.10 Depth difference for 2% AEP event

Table A8.2.9 Impact of Proposed Development on peak flood levels for the 2% AEP event in river channel

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.662	25.662	0
At the Babraham Viaduct (Node: GR6450)	25.365	25.365	0
d/s of Babraham Viaduct (Node: GR6390)	24.837	24.837	0
u/s of Stapleford Viaduct (Node: GR2400)	17.685	17.685	0
At the Stapleford Viaduct (Node: GR2400_i)	17.486	17.486	0
d/s of Stapleford Viaduct (Node: GR2200)	17.248	17.248	0

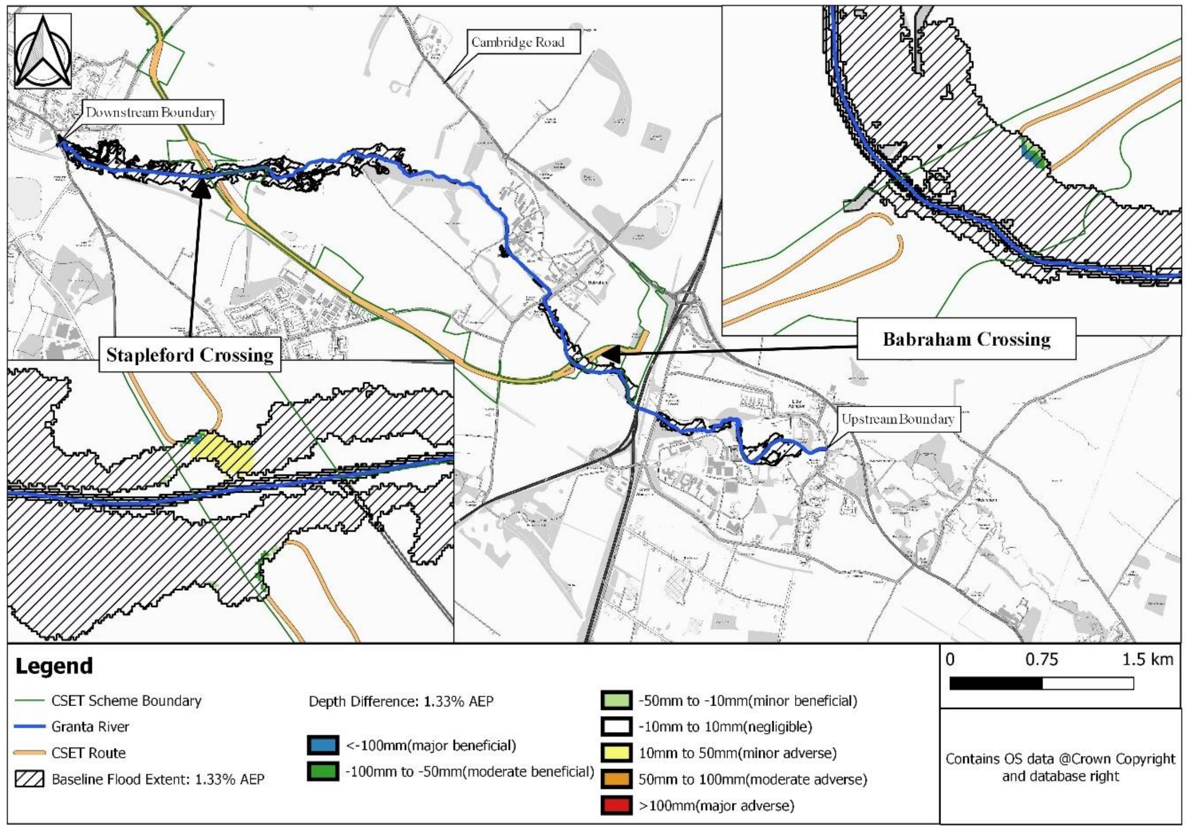


Figure A8.2.11 Depth difference for 1.33% AEP event

Table A8.2.10 Impact of Proposed Development on peak flood levels for the 1.33% AEP event in river channel

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.68	25.68	0
At the Babraham Viaduct (Node: GR6450)	25.384	25.384	0
d/s of Babraham Viaduct (Node: GR6390)	24.879	24.879	0
u/s of Stapleford Viaduct (Node: GR2400)	17.697	17.697	0
At the Stapleford Viaduct (Node: GR2400_i)	17.497	17.497	0
d/s of Stapleford Viaduct (Node: GR2200)	17.255	17.255	0

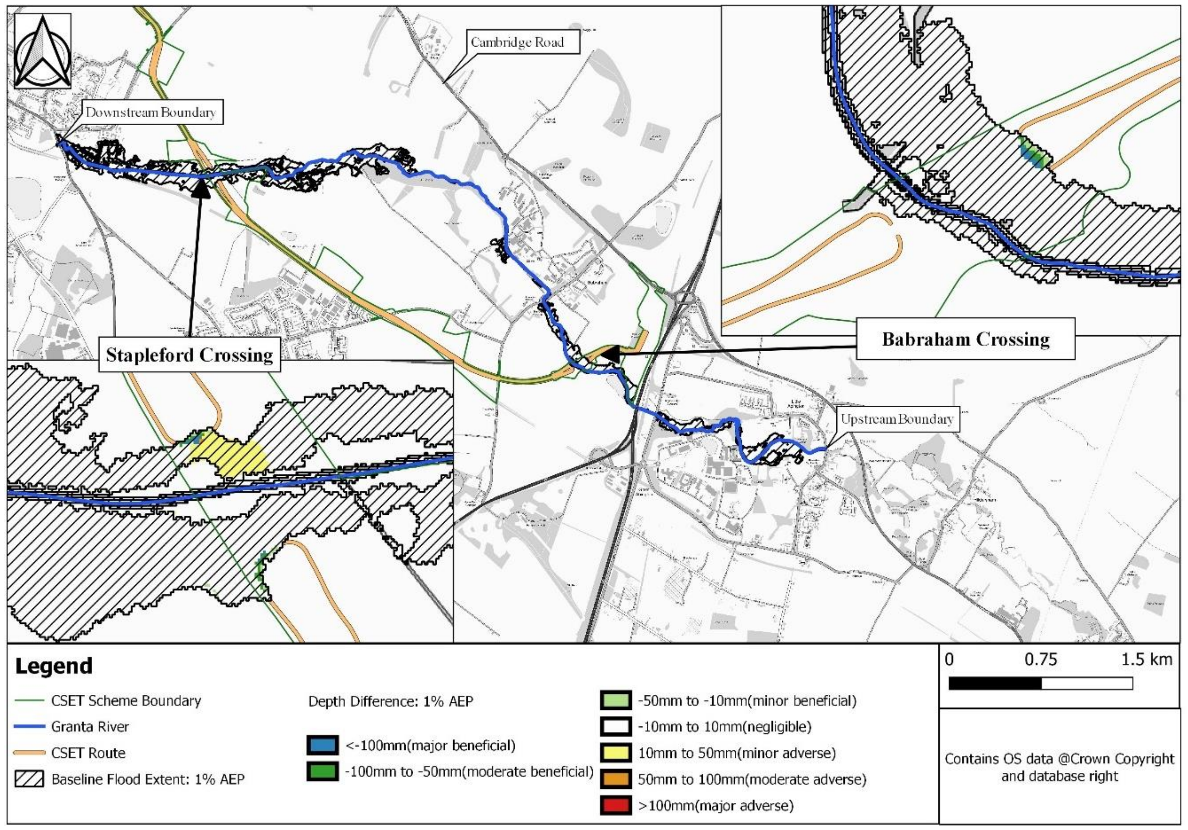


Figure A8.2.12 Depth difference for 1% AEP event

Table A8.2.11 Impact of Proposed Development on peak flood levels for the 1% AEP event in river channel

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.694	25.694	0
At the Babraham Viaduct (Node: GR6450)	25.401	25.401	0
d/s of Babraham Viaduct (Node: GR6390)	24.91	24.91	0
u/s of Stapleford Viaduct (Node: GR2400)	17.706	17.707	+1
At the Stapleford Viaduct (Node: GR2400_i)	17.505	17.505	0
d/s of Stapleford Viaduct (Node: GR2200)	17.261	17.261	0

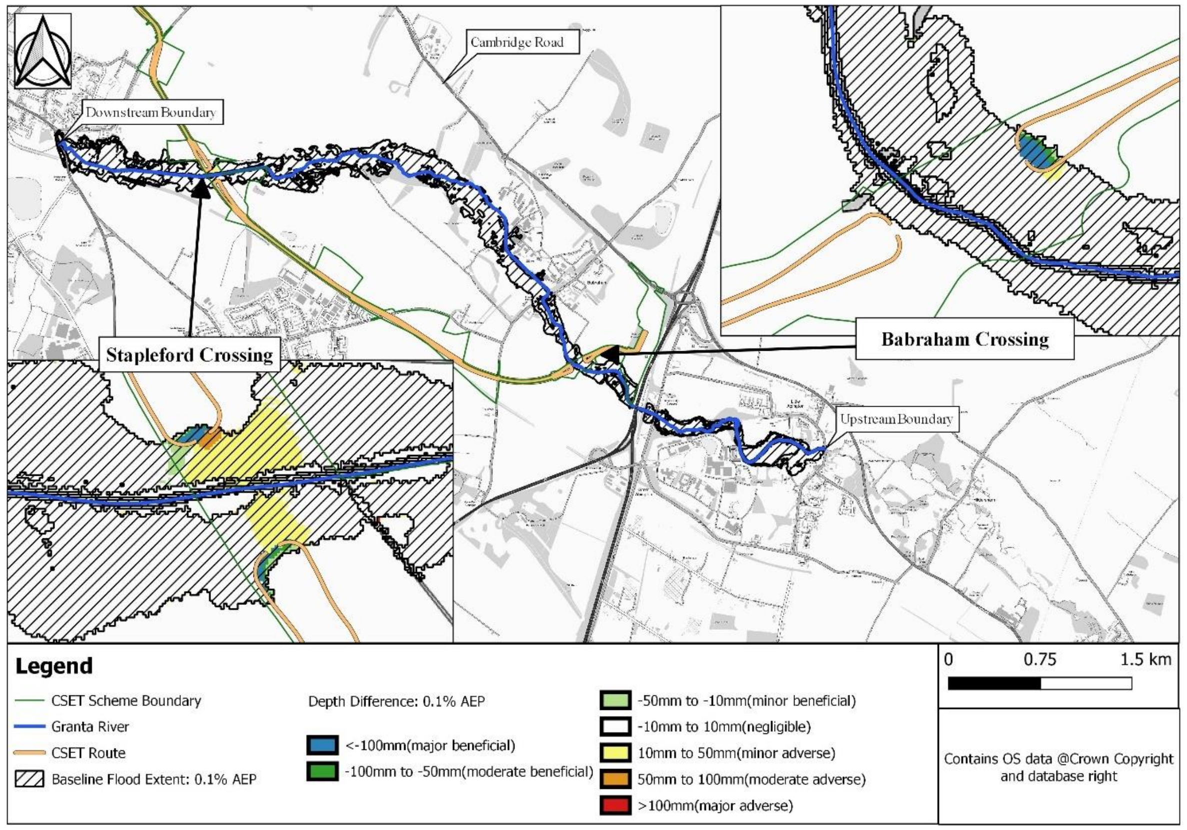


Figure A8.2.13 Depth difference for 0.1% AEP event

Table A8.2.12 Impact of Proposed Development on peak flood levels for the 0.1% AEP event in river channel

Table	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.867	25.868	+1
At the Babraham Viaduct (Node: GR6450)	25.565	25.566	+1
d/s of Babraham Viaduct (Node: GR6390)	25.321	25.321	0
u/s of Stapleford Viaduct (Node: GR2400)	17.833	17.835	+2
At the Stapleford Viaduct (Node: GR2400_i)	17.641	17.655	+14
d/s of Stapleford Viaduct (Node: GR2200)	17.332	17.335	+3

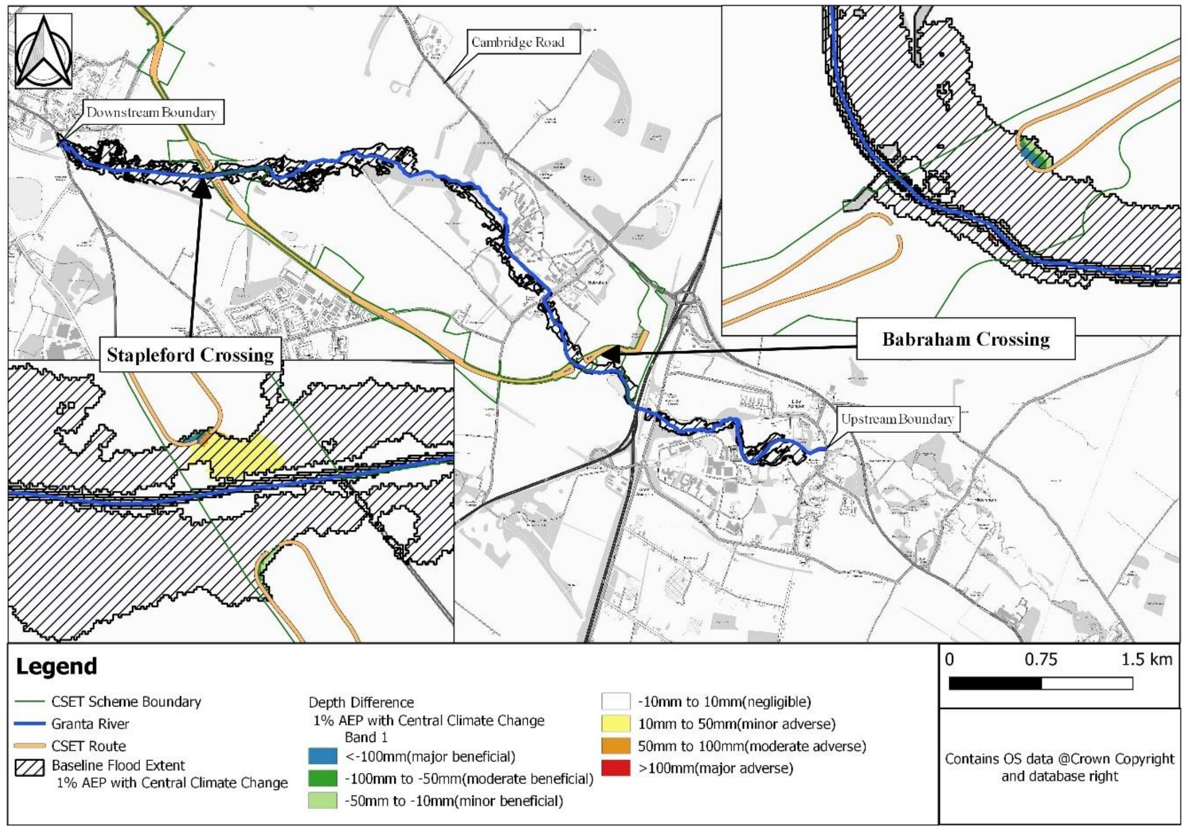


Figure A8.2.14 Depth difference for 1% AEP event with central climate change allowance

Table A8.2.13 Impact of Proposed Development on peak flood levels for the 1% AEP event and central climate change allowance in river channel

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.724	25.724	0
At the Babraham Viaduct (Node: GR6450)	25.43	25.43	0
d/s of Babraham Viaduct (Node: GR6390)	24.974	24.974	0
u/s of Stapleford Viaduct (Node: GR2400)	17.722	17.722	0
At the Stapleford Viaduct (Node: GR2400_i)	17.519	17.519	0
d/s of Stapleford Viaduct (Node: GR2200)	17.272	17.272	0

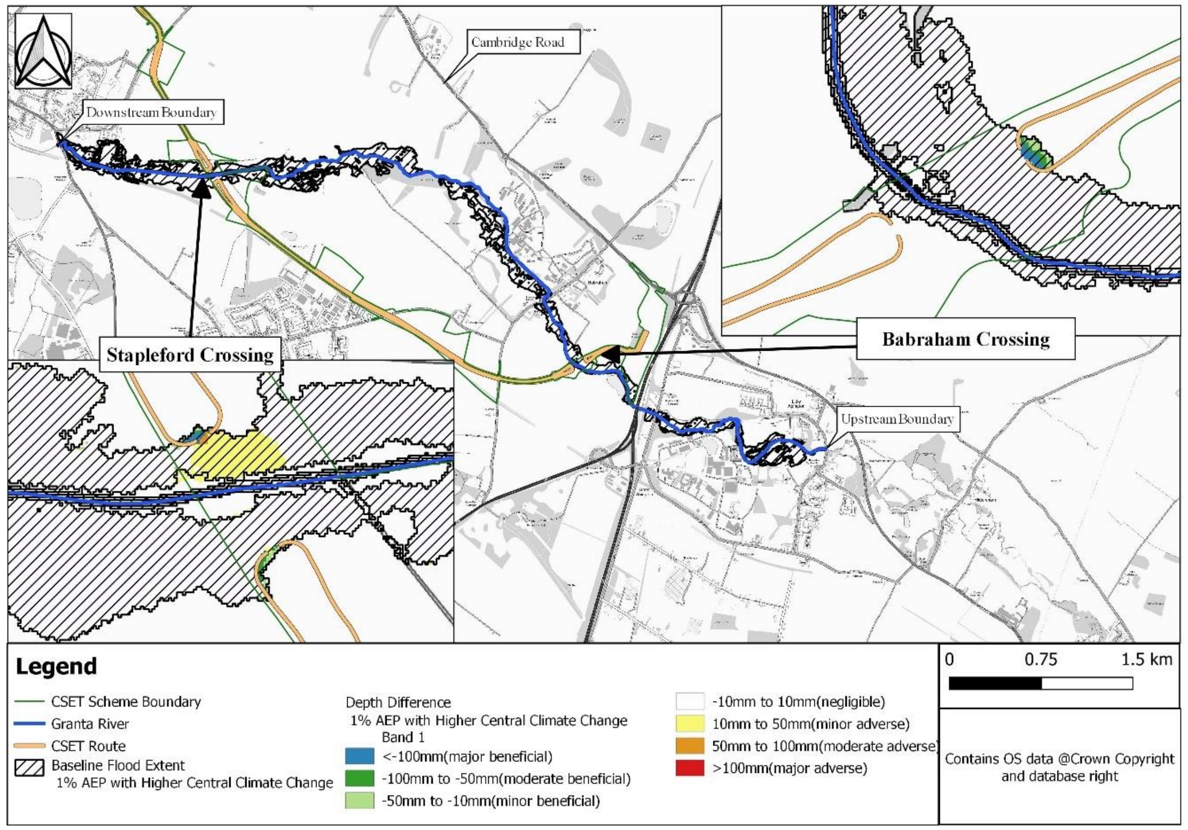


Figure A8.2.15 Depth difference for 1% AEP event with higher central climate change allowance

Table A8.2.14 Impact of Proposed Development on peak flood levels for the 1% AEP event and higher central climate change allowance in river channel

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.749	25.75	+1
At the Babraham Viaduct (Node: GR6450)	25.457	25.457	0
d/s of Babraham Viaduct (Node: GR6390)	25.029	25.029	0
u/s of Stapleford Viaduct (Node: GR2400)	17.738	17.74	+2
At the Stapleford Viaduct (Node: GR2400_i)	17.535	17.54	+5
d/s of Stapleford Viaduct (Node: GR2200)	17.286	17.288	+2

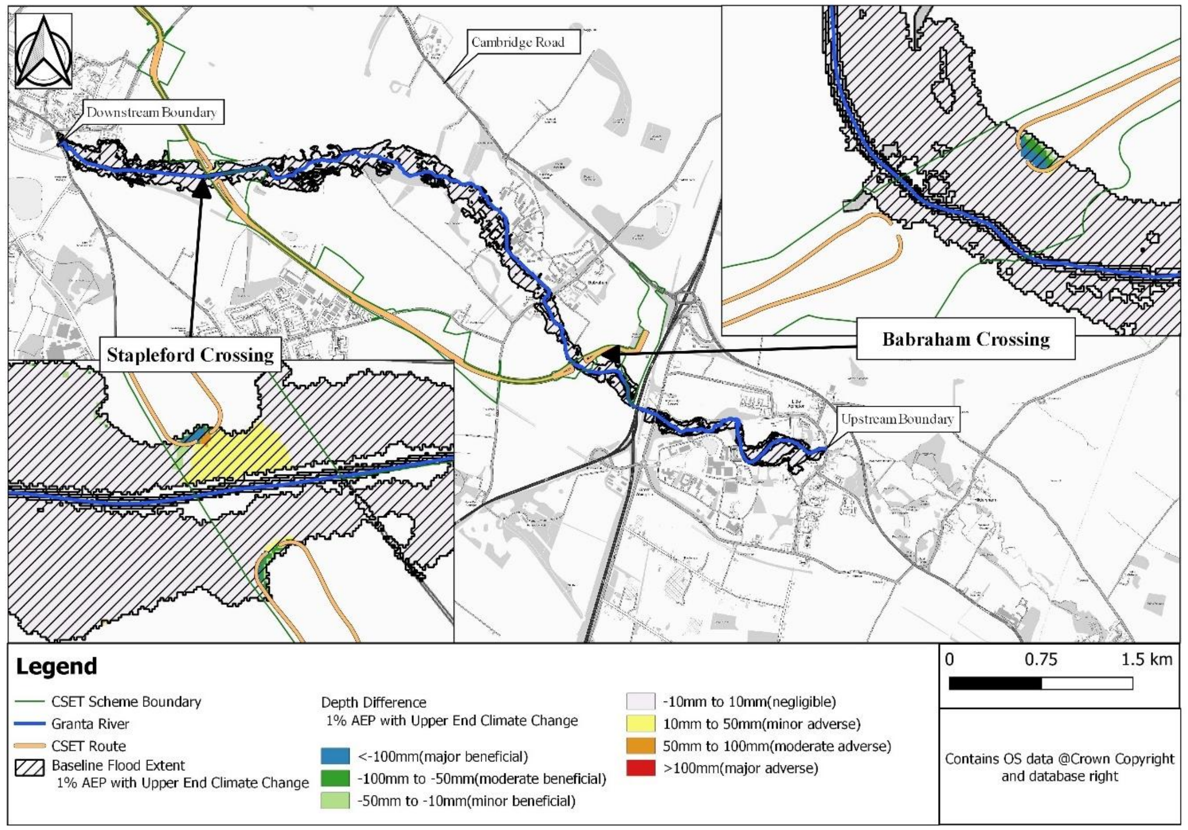


Figure A8.2.16 Depth difference for 1% AEP event with upper end climate change allowance

Table A8.2.15 Impact of Proposed Development on peak flood levels for the 1% AEP event and upper end climate change allowance in river channel

Location	Baseline	Proposed Development	Impact (mm)
u/s Babraham Viaduct (Node: GR6600)	25.806	25.807	+1
At the Babraham Viaduct (Node: GR6450)	25.521	25.522	+1
d/s of Babraham Viaduct (Node: GR6390)	25.163	25.163	0
u/s of Stapleford Viaduct (Node: GR2400)	17.783	17.785	+2
At the Stapleford Viaduct (Node: GR2400_i)	17.584	17.592	+8
d/s of Stapleford Viaduct (Node: GR2200)	17.311	17.313	+2

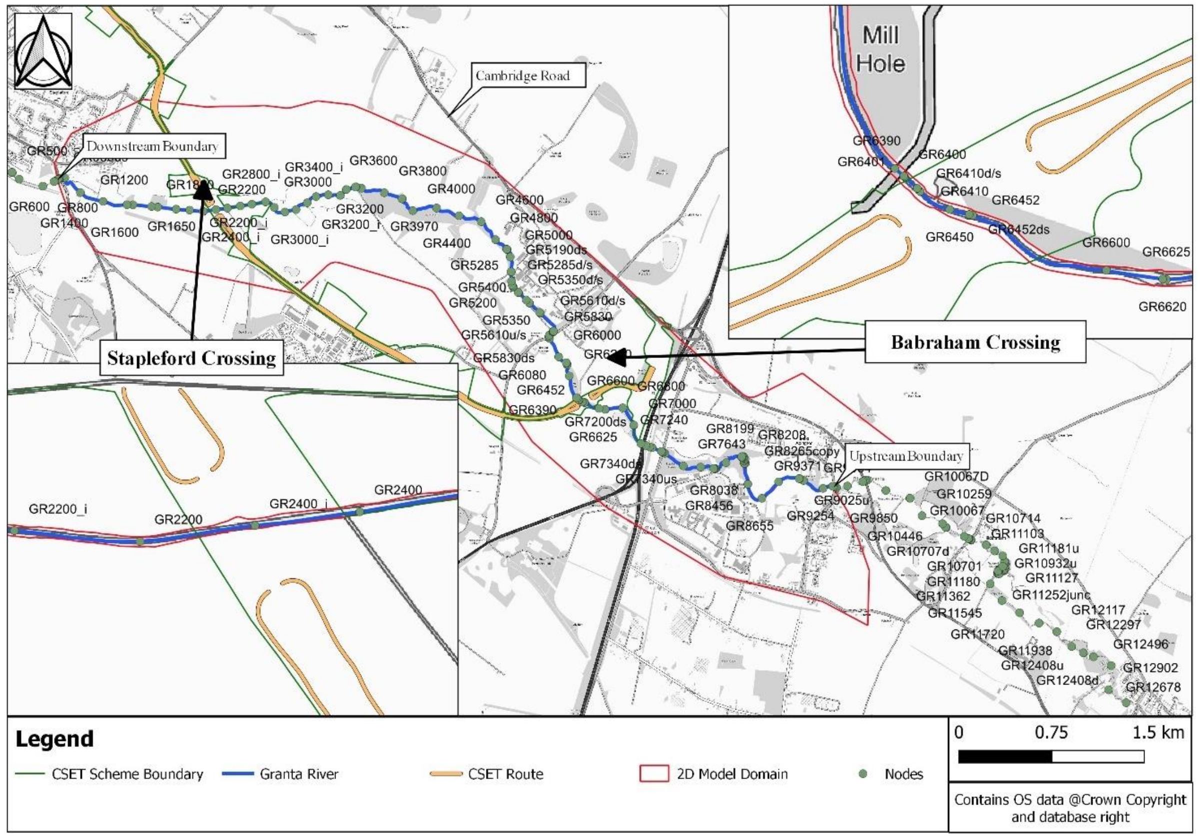


Figure A8.2.17 Locations of nodes where peak water levels are extracted

Sensitivity tests

8.2.36 Sensitivity tests have been run on the present day baseline 1% AEP event . The following tests were simulated:

- 20% increase in depth at downstream boundary.
- 20% increase in roughness in both the channel and floodplain
- 20% increase in boundary inflows.

8.2.37 The model's downstream boundary is a head-time (HT) relationship, therefore the sensitivity test was carried out by increasing the depth by 20% for each given flow in the HT relationship. The impact of this change affects only the most downstream reach of the River Granta and does not affect flows or levels at the two viaduct sites.

8.2.38 The tests on roughness and model inflows showed an increase in flood depths and extents. The change in flood extents is shown in Figure A8.2.18. In each case at the two viaducts sites there is very little change in flood extent. There is an increase in flood depth of less than 100 mm at Stapleford and less than 50 mm at Babraham. There is no fundamental change to the nature of flooding at either site as a result of the sensitivity tests.

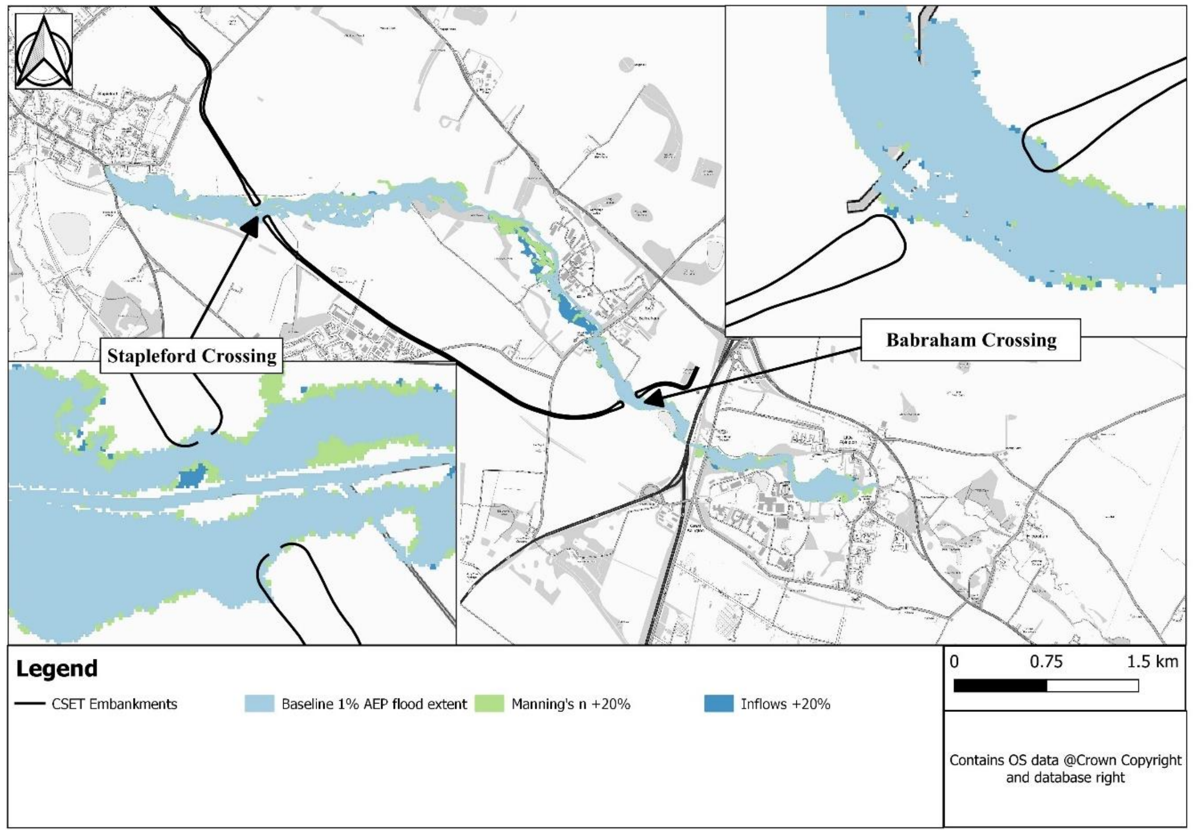


Figure A8.2.18 Sensitivity test results

Flood mitigation

Floodplain storage loss and compensation volumes

8.2.39 The embankments at Stapleford and Babraham encroach into the floodplain, reducing floodplain storage. The results reported in Section 0show that the impacts on flood levels are negligible and only effects areas very locally to the viaducts, therefore the mitigation requirements for Proposed Development relate to the replacement of floodplain storage capacity lost in these locations.

8.2.40 Floodplain compensation losses have been calculated based on the baseline 1% AEP event with the higher central climate change allowance.

Floodplain storage loss and compensation volumes – Stapleford

8.2.41 At Stapleford both the north and south embankment abutments encroach into the floodplain. The lowest flood level that is affected by the embankments is the minimum ground level at the toe of the embankment. The minimum ground level, the maximum 1% AEP event (including climate change) flood level, and the total volume loss between these two levels are given below.

- North embankment
  - Minimum ground levels at toe of embankment: 17.15 mAOD
  - Maximum baseline flood level: 17.44 mAOD
  - Total volume loss: 21.6 m^3
- South embankment
  - Minimum ground levels at toe of embankment: 17.23 mAOD
  - Maximum baseline flood level: 17.47 mAOD
  - Total volume loss: 21.5 m^3

8.2.42 The total volume loss due to both embankments is 43.1m^3. The area shown in Figure A8.2.19 has been identified as an area within the redline boundary of Proposed Development where floodplain compensation can be provided within the current red line boundary. Given the small volume of storage that need to be replaced, a definitive design for the replacement storage has not been carried out to date. The replacement will be accommodated within the general landscaping works defined in the detailed design.

8.2.43 The potential for the provision of floodplain compensation within the areas shown in Figure A8.2.19 has been assessed. Between the ground levels of 17.15 mAOD and 17.45 mAOD the available replacement volume at each 100 mm slice is greater than the total required replacement volume. This allows for opportunities to provide betterment or enhancement.

8.2.44 The storage loss created by the piers is approximately 3.5 m^3. This loss will be at elevations between river bank level and the maximum flood level; however the volume loss is negligible and impractical to compensate for and maintain.

Floodplain storage loss and compensation volumes – Babraham

8.2.45 At Babraham only the east embankment abutments encroach into the floodplain. The lowest flood level that is affected by the embankments is the minimum ground level at the toe of the embankment. The minimum ground level, the maximum 1% AEP event (including climate change) flood level, and the total volume loss between these two levels are given below.

- East embankment
  - Minimum ground levels at toe of embankment: 25.41 mAOD
  - Maximum baseline flood level: 25.70 mAOD
  - Total volume loss: 46.1 m^3
- West embankment
  - Minimum ground levels at toe of embankment: n/a
  - Maximum baseline flood level: n/a
  - Total volume loss: n/a

8.2.46 The total volume loss due to both embankments is 46.1 m^3. The area shown in Figure A8.2.19 has been identified as area within the redline boundary of Proposed Development where floodplain compensation storage can be provided within the current red line boundary. Given the small volume of storage that need to be replaced, a definitive design for the replacement storage has not been carried out to date. The replacement will be accommodated within the general landscaping works defined in the detailed design.

8.2.47 The potential for the provision of floodplain compensation within the areas shown in Figure A8.2.19 has been assessed. Between the ground levels of 25.41 mAOD and 25.70 mAOD the available replacement volume at each 100 mm slice is greater than the total required replacement volume. This allows for opportunities to provide betterment or enhancement.

8.2.48 The storage loss created by the piers is approximately 4.6 m3. This loss will be at elevations between river bank level and the maximum flood level, however the volume loss is negligible and impractical to compensate for and maintain.

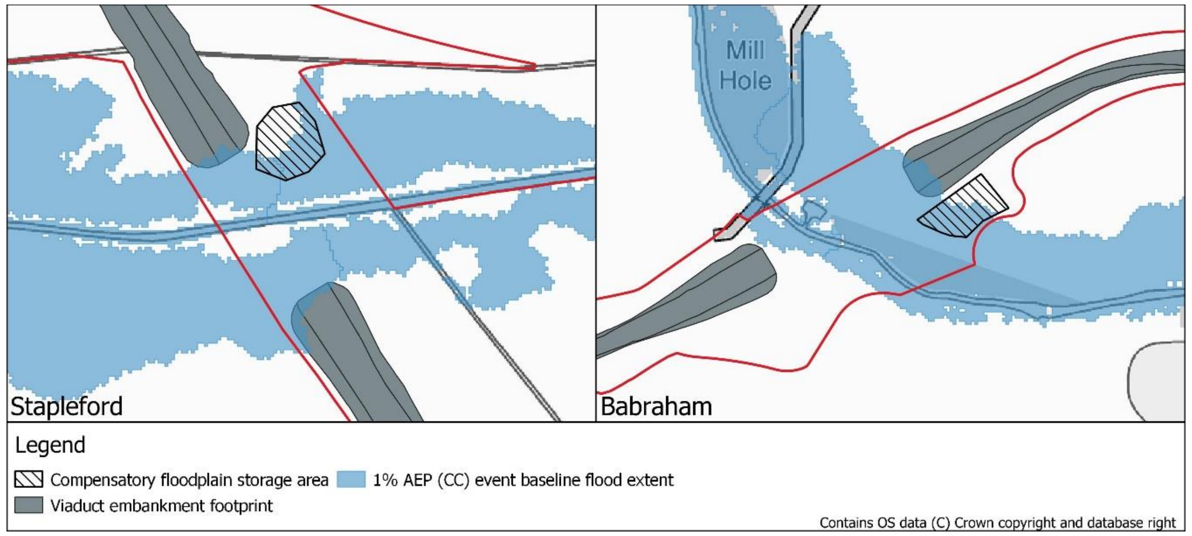


Figure A8.2.19 Floodplain compensation areas

Conclusions and recommendations

8.2.49 The flood model for the River Granta has been updated to determine the potential impact on fluvial flood risk arising from the construction of the Proposed Development. The two proposed viaduct structures crossing the River Granta have been shown to have a negligible impact on flood levels.

8.2.50 There is a loss of floodplain storage capacity where the viaduct embankments encroach into the floodplain. At each viaduct the loss of storage capacity is very small, less than 50 m^3. Floodplain storage compensation will be accommodated for within the landscape design around the viaducts, as the storage volumes required are of a scale where this is possible. There is also a suitable area for the provision of floodplain storage compensation with the current red line boundary of Proposed Development, close to the viaducts. Therefore, this mitigation can be incorporated into the detailed design stage, rather than requiring specific design at this stage. The floodplain compensation provided will be on a volume-for-volume and level-for-level basis, as per Environment Agency guidelines.

8.2.51 Sensitivity testing of the model has shown that there is no significant change in flooding at the two viaduct locations that would warrant a change in the design parameters for Proposed Development. The model has not been calibrated because of the poor quality of the gauge record at high flows. However, the model has been used to simulate the 0.1% AEP event. The inflow in the 0.1 % event is approximately double the flow of the 1% AEP event. In the 0.1 % AEP event the model shows that there is no significant impact of Proposed Development to any receptors. Therefore, any uncertainty relating to the lack of calibration affecting the conclusions from the modelling of the design event (the 1% AEP event) will be within the bounds of the 0.1% AEP event.

8.2.52 Overall, this hydraulic modelling exercise has concluded that there will be very little change to fluvial flood risk as a result of the proposed Proposed Development.

ANNEX 1 MODEL UPDATES (2021)

Channel survey assessment

8.2.53 The definition of the river channel geometry in the River Granta model is unchanged from the original 2013 model. The date of the channel survey is unknown. The Environment Agency provided data from a recent channel survey of the River Granta undertaken in 2021. The 2021 survey covered the lower reach of the River Granta up to the approximate location of the Stapleford viaduct, 2 km from the confluence with the River Cam.

8.2.54 Where the locations of the survey cross sections and modelled approximately coincided a comparison between the two has been carried out. The cross section comparisons are shown in the figures in Table A8.2.16.

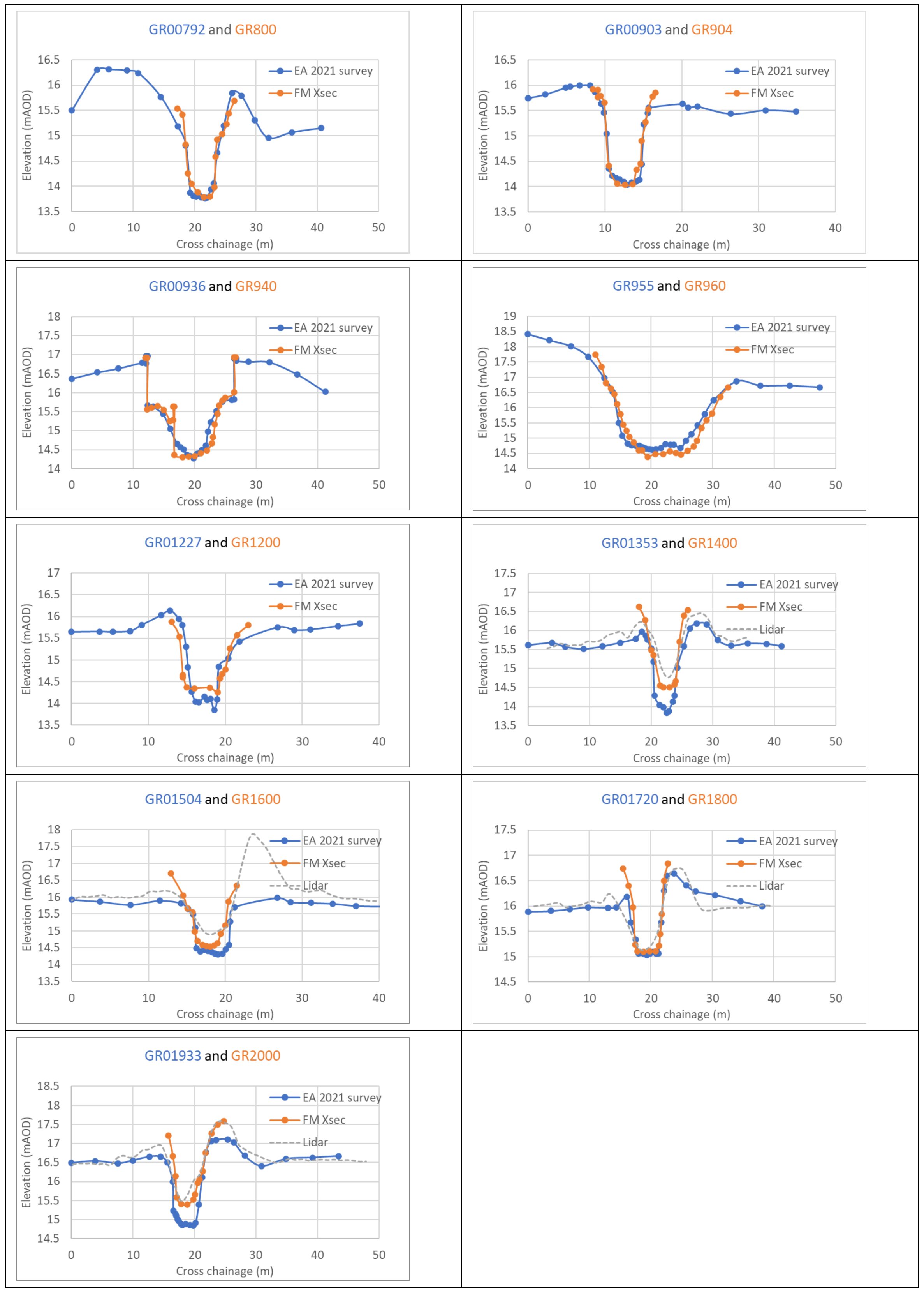
8.2.55 At the first four cross sections the survey and model cross sections are at very similar locations and there is a good match between the two datasets. The cross sections upstream of chainage 1000 are not as close spatially, with up to 100 m distance between the nearest comparable sections.

8.2.56 Where there is a substantial difference between the comparable cross section locations, the lidar data for the approximate locations of the river model cross sections has also been added to the figures.

8.2.57 Bank levels along the channel are highly variable so an exact or near match would only be possible if the cross sections in both data sets were at the same location. Accounting for the difference in cross section locations, the cross section shape, area and hence conveyance match well.

8.2.58 The one significant structure that is within the overlapping reaches of the flood model and the 2021 survey is the Cambridge Road bridge at approximate chainage 950. The spring and soffit points of the arches on the bridge are within about 60 mm of each other in the two datasets. The width of the arches are comparable.

Table A8.2.16 Cross section comparison



ANNEX 2 HYDROLOGY CALCULATION RECORD

Flood estimation report:

River Granta and Hobson's Brook

Introduction

This report template is a supporting document to the Environment Agency's Flood Estimation Guidelines. It provides a record of the hydrological context, the method statement, the calculations and decisions made during flood estimation and the results. This document can be used for one site or multiple sites. If only one site is being assessed, analysts should remove superfluous rows from tables.

Guidance notes (in red text) are included throughout this document in column titles or above tables. These should be deleted before finalising the document. Where relevant, references to specific sections of the Flood Estimation Guidelines document are included to indicate where further useful information can be found.

Note: Column size / page layout can be adapted, where necessary, to best present relevant information, for example, maps do not need to be within the tables if they would be better as a separate page.

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Approval

Revision stage	Analyst / Reviewer name & qualifications	Amendments	Date
Method statement preparation	James Sear BSc	Written first draft of document	12/09/22
Method statement sign-off	Clare Hodgson BA C.WEM CSci	As discussed and agreed	21/09/22
Initial calculations preparation	James Sear BSc	First draft	12/09/22
Initial calculations sign-off	Clare Hodgson BA C.WEM CSci	Minor updates only to finalise numbers	21/09/22
Calculations - Revision 1 preparation			N/A
Calculations - Revision 1 sign-off		N/A	
Calculations - Revision 2 preparation			N/A
Calculations - Revision 2 sign-off		N/A	

Abbreviations

AEP................................ annual exceedance probability

AM.................................. Annual Maximum

AREA .... Catchment area (km²)

BFI .... Base Flow Index

BFIHOST .... Base Flow Index derived using the HOST soil classification

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

OS................................... Ordnance Survey

POT................................. Peaks Over a Threshold

QMED .... Median Annual Flood (with return period 2 years)

ReFH .... Revitalised Flood Hydrograph method

ReFH2 .... Revitalised Flood Hydrograph 2 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 SUMMARY OF ASSESSMENT

1.1 Summary

This table provides a summary of the key information contained within the detailed assessment in the following sections. The aim of the table is to enable quick and easy identification of the type of assessment undertaken. This should assist in identifying an appropriate reviewer and the ability to compare different studies more easily.

The aim of this table is to provide a summary so keep the text to one or two sentences for each point.

Catchment location	River Granta, Cambridge (TL 51000 50400)
Purpose of study and scope e.g. for scope just include whether it is simple, routine, moderate, difficult, very difficult	To calculate inflows for the River Granta hydraulic model. Inflows are required at four locations to represent subcatchments of the River Granta, and additionally (and separately) for a single Hobson's Brook catchment. Given the relatively small number of catchments, this assessment is considered routine.
Key catchment features e.g. permeable, urban, pumped, mined, reservoired	The catchment to the gauge is permeable (BFIHOST19 = 0.709) and predominantly rural (URBEXT2000 = 0.0125). There is no pumping or mining, and no significant flood attenuation features (FARL = 0.999).
Flooding mechanisms e.g. fluvial, surface water, groundwater	Little is know about the predominant flooding mechanisms but they are assumed to be fluvial.
Gauged / ungauged State if there are flow or level gauges and a very brief indication of quality if there are	There is a rated gauge (33055) on the River Granta at Babraham (TL 51000 50400) which is suitable for QMED estimation only.
Final choice of method	River Granta: AMAX series derived from QMED at gauge with pooling group. ReFH 2.3 hydrographs scaled to fit FEH Statistical method peaks calculated at the gauged site. Hobson's Brook: ReFH 2.3 hydrographs only.
Key limitations / uncertainties in results	Potential uncertainty in observed flow at the gauge location. The use of the scaling factor derived for the combination of Bartlow and Babraham catchments is appropriate for all subcatchments. This is not considered to be a significant source of uncertainty because of the gauge location. It is assumed that the default ReFH parameters as calculated from catchment descriptors are representative of the flood response in the catchment.

1.2 Note on flood frequencies

The frequency of a flood can be quoted in terms of a return period, which is defined as the average time between years with at least one larger flood, or as an annual exceedance probability (AEP), which is the inverse of the return period.

Return periods are are output by the Flood Estimation Handbook (FEH) software and can be expressed more succinctly than AEP. However, AEP can be helpful when presenting results to members of the public who may associate the concept of return period with a regular occurrence rather than an average recurrence interval. Results tables in this document contain both return period and AEP titles; both rows can be retained or the relevant row can be retained and the other removed, depending on the requirement of the study.

The table below is provided to enable quick conversion between return periods and annual exceedance probabilities.

Annual exceedance probability (AEP) and related return period reference table

AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.2	0.1
AEP	0.5	0.2	0.1	0.05	0.033	0.02	0.013	0.01	0.005	0.002	0.001
Return period (yrs)	2	5	10	20	30	50	75	100	200	500	1,000

2 METHOD STATEMENT

For all but simple or routine projects, establish a break-point in which the method statement is reviewed before work continues. This creates a valuable opportunity to agree on the intended approach and address any difficulties with availability of data or information from previous work.

2.1 Requirements for flood estimates

Overview

The content and level of detail provided in this section will depend on the scope of the study. The following should be included as a minimum:

- Purpose of study
- Peak flows or hydrographs?
- Design events for which flow estimates are to be made given as AEP (%)
- Climate change allowances with reference to relevant guidance
- Potential number of locations for flow estimation
- The purpose of the document

Atkins has been commissioned to calculate flow estimates for use within the River Granta hydraulic model.

Hydrological inputs to the hydraulic model are required and therefore the purpose of the study is to calculate peak flow estimates and hydrographs for the River Granta and Hobson's Brook.

For the modelling, peak flows and hydrographs are required for three River Granta subcatchments:

- Stapleford;
- Babraham;
- Bartlow;

For the derivation of the hydrology, peak flows and hydrographs are additionally required for the catchment to the gauge (Bartlow and Babraham catchments combined).

Peak flows and hydrographs are also required for the Hobson's Brook catchment.

These catchments are all shown on Figure 1 below.

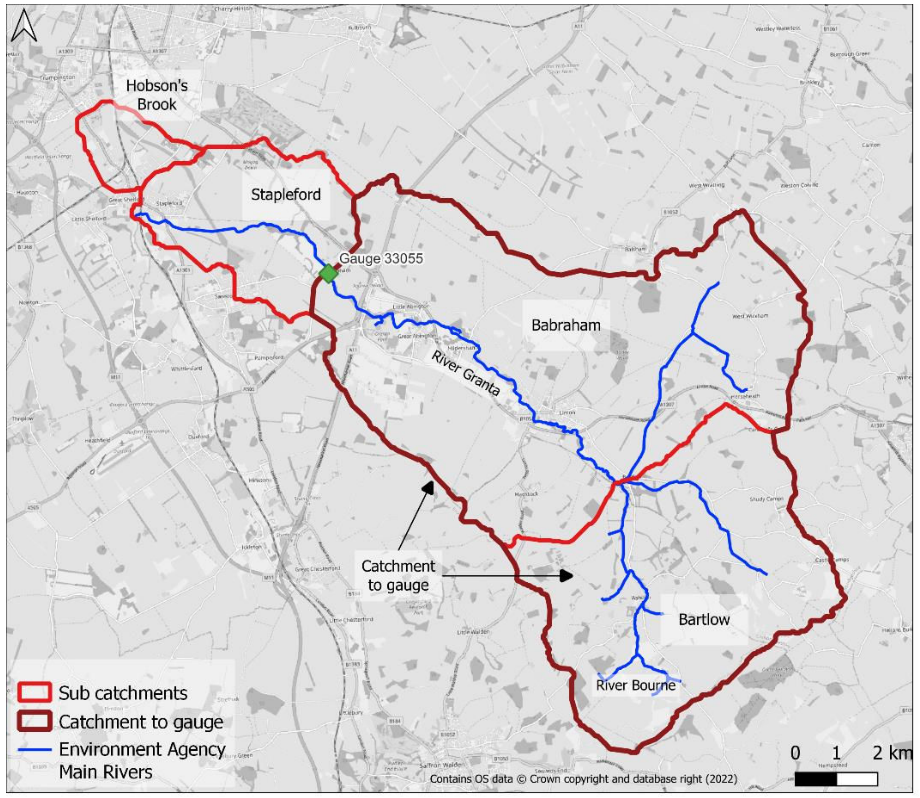


Figure 1 Subcatchment locations

A Statistical estimate was required for the catchment to the gauge, shown in Figure 1. Peak flows and hydrographs were calculated for the following present day AEP events: 50% (1 in 2); 20% (1 in 5); 10% (1 in 10); 5% (1 in 20); 4% (1 in 25); 3.3% (1in 30); 2% (1 in 50); 1.33% (1 in 75); 1% (1 in 100); 0.5% (1 in 200); 0.2% (1 in 500) and 0.1% (1 in 1,000). No climate change AEP events have been calculated but these could be later added using the Environment Agency percentage uplifts for fluvial flows (Environment Agency, 2022).

Project scope What is the complexity of the study – simple, routine, moderate, difficult, very difficult? What analyses need to be included within the study, for example: • Review of existing studies? • Rating reviews / updates? • Simple / detailed flood history review? • ReFH model parameter estimation? • Joint probability?	Given the relatively small number of subcatchments and the need to only test one storm duration, this assessment is considered routine. There are no existing studies that were provided and the scope does not include rating reviews or flood history reviews. All of these things could be done at a later stage if required. Critical storm duration and ARF will be manually calculated, but no other ReFH model parameters will be adjusted. Joint probability is not relevant for this catchment.

2.2 The catchment

Include a map of the catchment in here, at a minimum showing the river network, catchment boundary and gauging stations, and appropriately labelled / referenced in a legend. Additional information which could be included is the model extent or locations of unusual / interesting features, for example. Think about the background mapping being used – scale and colour / greyscale – think about if the reader could easily identify locations from the background mapping.

Include more than one map if that would assist in presenting the information, consider including maps using satellite imagery as background if that would better show key catchment features, and consider including photographs if they would help understanding of features identified in the 'Description' section. For permeable catchments, consider including a hydrogeological map showing groundwater equipotential lines.

Remember to give all figures a number and title and refer to them in the text.

In many cases it will be best to present maps outside of this box. Consider changing the page orientation to landscape and the page size to A3 if necessary.

Description Include topography, climate, geology, soils, land use and any unusual features (e.g. reservoirs, historic mining) that may affect the flood hydrology. In some cases, it may be useful to include reference to things such as amount of modelled reach that is culverted but remember that this is not a hydraulic modelling report and detail on hydraulic features, such as weir and culvert sizes, is not required. Think about what features are going to affect runoff from the contributing catchment reaching the watercourse.	The catchment is shown in Figure 1 in Section 2.1. The total catchment area of the River Granta is 116 km² and the catchment of Hobson's Brook is 3.8 km². The River Granta flows in a northwest direction and despite being relatively rural it has artificial influences in the form of significant groundwater abstractions for industrial and agricultural uses. At its downstream extent, it joins the River Cam which then flows north into Cambridge. The primary land use is arable. The bedrock geology of the catchment is chalk: • Lewis Nodular Chalk Formation bedrock in the upstream catchment; • New Pit Chalk Formation in the downstream catchment; and • Hoylwell Nodular Chalk Formation in the downstream catchment. There are superficial deposits of alluvium (clay, silt, sand and gravel) and river terrace deposit (sand and gravel) along the rivers, with buffer zones of Lowestoft Formation sand and gravel on either side of the channel. The upstream section of the catchment is dominated by superficial deposits of Lowestoft diamicton. The upstream sections of the catchment are predominantly lime-rich loamy and clayey soils with impeded drainage (Soilscape 9). Further downstream, bands of freely draining loamy soils (Soilscape 5) and shallow lime-rich soils over chalk (Soilscape 3) become the common soil types. This information has been taken from British Geological Survey Geology Viewer and LandIS Soilscapes. The catchment has high permeability which increases from upstream to downstream. The FEH web BFIHOST19 is 0.474 for Bartlow and 0.709 for the catchment to the gauge.

2.3 Source of flood peak data

This should be updated to the latest version of the dataset at the time of the assessment.

Source	NRFA peak flows dataset, Version 10, released August 2021. This contains data up to water year 2019-2020.
	Since completion of this study (August 2022) Version 11 of the dataset has been released but at this time, the calculations had already been completed and so the work was not updated.

2.4 Gauging stations (flow or level)

Only need to include gauges at or very near to the sites of flood estimates unless there is an exceptional reason to include other gauges.

Note: If you have data extracted from WISKI the datafile may only provide the digital data period of record, and the actual operating period of the gauge may be longer. It is useful to check this.

Water-course	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level…)	Start of record and end if station closed
River Granta	Granta at Babraham	-	33055	98.7	Rated	01/1976 - present

2.5 Data available at each flow gauging station in Table 2.4

This table can be deleted if the study catchment is ungauged.

A quality check of the data is not required if the gauge is in the NRFA, unless specifically called for in the project brief.

There is no need to repeat everything in the NRFA station description, for example, weir length, wingwall height. Just add the key factors which will affect the quality of flood flow measurement and hence confidence in the data. For more detailed studies consider looking for other sources of information, for example, gauging authority rating review reports, station files held at CEH Wallingford, or reports on earlier flood studies.

Station name	Start and end of NRFA flood peak record	Update for this study?	OK for QMED?	OK for pooling?	Data quality check needed?	Other comments on station and flow data quality
Granta at Babraham	01/1976 - present	No	Yes	No	No	The station is drowned and bypassed at high flows. Current rating accounts for out of bank flow. However, from 12.94 cumecs (0.95m) floodplain flow is over a wide area with great uncertainty in flows, and no gaugings above 0.4m to verify rating. Two ratings applied across period of record, the most recent is valid from January 1979. Information obtained from NRFA website.
Tabulate any updated or revised flood peak series in the Annex and provide a link here. Any flood peak data not in the NRFA (e.g. extra stations, recent data or altered flows) should be provided here or in the Annex. Give link/reference to any further data quality checks carried out. Delete this row if not relevant.						N/A; no changes to the data in the NRFA made.

2.6 Rating equations

The table has been deleted as the gauge is in the NRFA and a rating review has been not requested as part of the project brief.

2.7 Other data available and how it has been obtained

The table has been deleted as no other data has been used for this assessment.

2.8 Hydrological understanding of catchment

The flow data interpretation table has been deleted because it is not required within the scope.

Conceptual model Include information on factors 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?	The main sites of interest are the towns and villages along both the River Granta and Hobson's Brook, including Linton, Hildersham, Great Abingdon, Little Abingdon, Babraham, Stapleford, Great Shelford and Trumpington. Flow estimates here will also support understanding of risk in towns further downstream such as Cambridge. Peak flows and flood volumes are likely to be the main causes of flooding at these locations. There are no specific controls on flood risk such as reservoirs within the catchment. There is no need to consider temporary debris dams that could collapse.
Unusual catchment features Include information on factors such as: • highly permeable • heavily urbanised • pumped watercourse • major reservoir influence (FARL<0.90) • flood storage areas, particularly those which are normally dry • historical mining or operational mining activities Guidance on methods for unusual catchments is contained in Section 7 of the Flood Estimation Guidelines	The catchment to the Gauge at Babraham is permeable (BFIHOST19 = 0.709) and not particularly urbanised (URBEXT2000 = 0.0125). There are no major reservoirs (FARL = 0.999). There are no historical or present day mining influences.

2.9 Initial choice of approach

Is FEH appropriate? (it may not be for extremely heavily urbanised or complex catchments). If not, describe other methods to be used.	FEH Statistical method (WINFAP 5) and ReFH 2.3 are appropriate.
Initial choice of method(s) and reasons Think about: (i) the type of problem, (ii) the type of catchment, and (ii) the type of data available. Which methods are appropriate? If more than one method is appropriate will all be applied, and the results compared before a final decision is made? How will hydrograph shapes be derived if needed? e.g. ReFH1 / ReFH2 shapes, average hydrograph shape from gauge data Will the catchment be split into subcatchments? If so, how? If the hydrological assessment is being undertaken to supply inflows to a hydraulic model, it is likely that a distributed approach will be taken, with the catchment split into subcatchments and design flows routed from each sub-catchment. Think about what the split into subcatchments will be based on, e.g. tributary confluences, changes in geology / urbanisation, key areas of interest, sewer outfalls. Will intervening area hydrographs be required and how will these be derived? If the catchment area changes significantly over the study reach, or tributaries are also being modelled, will different storm durations need to be considered / tested?	The initial method is to calculate a QMED derived from the gauged AMAX series for the catchment to the gauge using the FEH Statistical method. This was then multiplied by growth factors calculated from a pooling group derived growth curve to create a set of peak flows. These peak flows will be compared against the peak flows of a combined Bartlow and Babraham ReFH hydrograph in order to create a scaling factor. This scaling factor will then be applied to the ReFH flows for all subcatchments to fit the ReFH hydrographs to the FEH Statistical peaks. As the gauge is only suitable for QMED and not for pooling, the subject site is treated as ungauged when it comes to the pooling group analysis. The catchment will be split into the subcatchments shown in Figure 1, Section 2.1. These have been modified from the original FEH Web Service download to account for sewer outfalls, urbanisation and topographic changes. A consistent storm duration has been applied for the subcatchments of the River Granta. The Hobson's Brook catchment is ungauged. ReFH hydrographs only have been calculated with a separate storm duration applied.
Software to be used (with version numbers)	FEH Web Service[1] / WINFAP 5[2] / ReFH2.3 / Flood

[1] CEH 2022. The Flood Estimation Handbook (FEH) Online Service, Centre for Ecology & Hydrology, Wallingford, UK.

[2] WINFAP 5 © Wallingford HydroSolutions Limited 2017.

Delete entries in the column on the right as appropriate	Modeller Pro (for calculation of ARF only)

3 LOCATIONS WHERE FLOOD ESTIMATES REQUIRED

Consider including a map here which shows the locations of flood estimate locations.

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

Include any intervening areas required for a distributed approach in here as these are necessary to reproduce results.

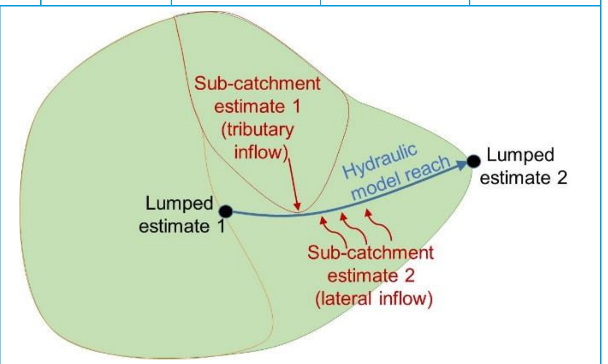
3.1 Summary of subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Watercourse	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
1	L	River Granta	Gauge at Babraham	551000	250400	101.97	101.02
2	S	River Granta	Bartlow catchment	558100	245100	37.27	36.99
3	S	River Granta	Babraham catchment	551000	250400	64.70	64.03
4	S	River Granta	Stapleford catchment	546400	251550	14.51	14.95
5	L	Hobson's Brook	Hobson's Brook	545550	254300	3.15	3.84

Note: Lumped catchments (L) are complete catchments draining to points at which design flows are required.

Subcatchments (S) are catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system. There is no need to report any design flows for subcatchments, as they are not relevant: the relevant result is the hydrograph that the sub-catchment is expected to contribute to a design flood event at a point further downstream in the river system. This will be recorded within the hydraulic model output files. However, catchment descriptors and ReFH model parameters should be recorded for subcatchments so that the results can be reproduced.

The schematic diagram illustrates the distinction between lumped and sub-catchment estimates.



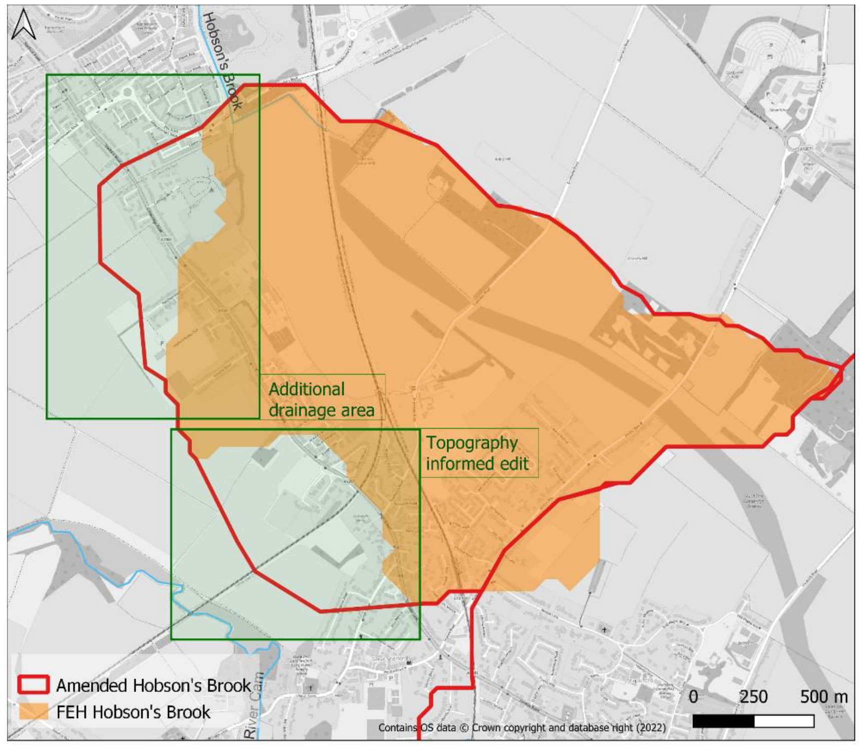
3.2 Important catchment descriptors at each subject site (incorporating any changes made)

Consider using a different colour text / highlighting to identify catchment descriptors which have been changed from the FEH values.

Include any intervening areas required for a distributed approach in here as these are necessary to reproduce results.

Site code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 1990 Delete if not required	URBEXT 2000	FPEXT
1	0.999	0.26	0.709	12.4	35.6	579	0.0126	0.0125	0.062
2	1	0.26	0.474	5	37.2	589	0.00761	0.00761	0.043
3	0.999	0.26	0.844	9.77	34.7	573	0.0151	0.0151	0.072
4	0.999	0.26	0.950	4.40	20.4	547	0.031	0.04	0.203
5	1	0.26	0.895	2.09	19.6	540	0.07	0.109	0.18

3.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes Add maps if needed to aid explanation of any changes If changes are made to the catchment boundary (and hence AREA), identify if any other descriptors will be updated and how	Catchment boundaries were downloaded from the FEH Web Service and mapped in GIS software. The catchment boundaries were verified and amended where necessary by comparing the FEH web catchment boundary with the Environment Agency National LiDAR Programme 1 m LiDAR and drainage ditch mapping. The area for Hobson's Brook catchment was altered by 22%. Given this is a relatively significant change, the amendments are documented in Figure 2 below.  **Figure 2 Hobson's Brook catchment area amendment**
Record how other catchment descriptors were checked and describe any changes.	The soils and geology for each sub catchment were compared against the Soilscapes and BGS datasets and are representative of the BFIHOST19 and SPRHOST values for the catchment. Reverse area weighting was used to derive the catchment descriptors for the two interstation calculations (Babraham catchment site 3 and Stapleford catchment site 4). When reverse area weighting, the original FARL value was kept because FARL cannot be area weighted. DPLBAR was calculated from catchment area for each of these catchments using the FEH formula. Manual estimation of BFIHOST19 for catchment 4 (Stapleford) because the area weighting interstation methodology resulted in a value greater than 1. The value was changed to 0.95 as this is what most closely matches the SPRHOST value.
Source of URBEXT Delete as needed. URBEXT1990 is only used for ReFH1 An alternative is the URBAN50k method if URBEXT values need to be substantially revised due to discrepancies between the FEH urban extent layers and current mapping	URBEXT2000

Method for updating of URBEXT Delete as needed (CPRE formula from FEH Volume 4 is for URBEXT1990) An update to the current year is not required when the URBAN50k method is used as it will be implicitly accounted for in the latest mapping	The urban expansion factor (UEF) equations were used to update both URBEXT values to 2022 values. This is in line with the Environment Agency Flood Estimation Guidelines.

4 STATISTICAL METHOD

4.1 Application of Statistical method

What is the purpose of applying this method? Brief summary of the reasons, specific to this study, for applying the method. For example, lumped estimates at key locations for the purpose of checking modelled peak flow estimates.	The Statistical method was used to derive peak flows for the catchment to the Gauge at Babraham. For this catchment, a QMED value was derived from the AMAX series at the gauge. As the gauge is only suitable for QMED and not for pooling, the subject site was then treated as ungauged and a pooling group created in order to fit a growth curve to this QMED and derive a flood frequency curve.

4.2 Overview of estimation of QMED at each subject site

If more than one donor is 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.

The final estimate of QMED should include any relevant donor and urban adjustment. If QMED is derived directly from AMAX or POT data, an urban adjustment factor should not be applied as this is implicitly included in the estimate and would be double-counted.

Site code	QMED (rural) from CDs (m^3/s)	Final method	Data transfer					Urban adjust-ment factor UAF	Final estimate of QMED (m^3/s)
			NRFA numbers for donor sites used (see 4.3)	Distance between centroids d_{ij} (km)	Moderated QMED adjustment factor, $(A/B)^a$	If more than one donor: Weight	If more than one donor: Weighted ave. adjustment		
1	N/A	AMAX	N/A					N/A	3.964

Are the values of QMED spatially consistent?	N/A. QMED estimated at a single location only.
Method used for urban adjustment for subject and donor sites (delete method in the column to the right as needed)	N/A QMED from gauge data so no urban adjustment undertaken.

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment); BCW – Catchment descriptors and bankfull channel width (add details); LF – Low flow statistics (add details).

The QMED adjustment factor A/B for each donor site 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 (rural) estimate from catchment descriptors.

Important note on urban adjustment

The method used to adjust QMED for urbanisation published in Kjeldsen (2010)**Error! Bookmark not defined.** in which PRUAF is calculated from BFIHOST is not correctly applied in WINFAP-FEH v3.0.003. Significant differences occur only on urban catchments that are highly permeable. This is discussed in Wallingford HydroSolutions (2016)**Error! Bookmark not defined.**.

4.3 Derivation of pooling groups

Try to use as few groups as possible, this avoids step changes in flow estimates between flow estimation points for catchment-wide studies. If all catchments being assessed have AREA <25km^2 and similar SAAR, FARL and FPEXT values, normally use one group.

Section 4.3 of the Flood Estimation Guidelines provides further details on reviewing pooling groups.

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 (if there are no changes just say "None", although it is helpful to provide details of stations which were investigated even if they were ultimately retained)	Weighted average L-moments L-CV and L-skew, (before urban adjustment)
Gauge at Babraham	33055	No	Removed: 33051 (Cam @ Chesterford) – significant GW abstraction 35008 (Gipping @ Stowmarket) – high flows affected by flood relief scheme 37014 (Roding @ High Ongar) – significant GW abstraction 34012 (Burn @ Burnham Overy) – very low SPRHOST Added: 53028 (By Brook @ Middlehill) – good data length and minor artificial influences 21027 (Blackadder Water @ Mouth Bridge) – good data length and natural flow regime 21024 (Jed Water @ Jedburgh) – flows are largely natural and uncontrolled and good data length Permeable stations with non-flood years removed: 43014 (East Avon @ Upavon East) – removed years 1975, 1990, 1995, 2010 and 2018.	L-CV: 0.273 L-Skew: 0.142
Note: Pooling groups were derived using the procedures from Science Report SC050050 (2008).				

4.4 Derivation of flood growth curves at subject sites

Any relevant frequency plots from WINFAP, particularly showing any comparisons between single-site, enhanced single-site and pooled growth curves (including flood peak data on the plot), should be shown here.

An individual urban adjustment should be applied even if the same pooling group (including enhanced single-site analysis) has been applied to several sites, as each site is likely to have a different URBEXT2000 value and hence a different urban adjustment.

For single-site analysis on a permeable catchment, or a pooled analysis for a group consisting largely of permeable catchments, a permeable adjustment should be applied to the growth curve using the technique described in the FEH Volume 3, Chapter 19 for removing flood-free years by adjusting the L-moments.

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group	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 / 1% AEP (delete as needed)
1	P	-	Generalised Logistic	Urban adjustment in WINFAP5	Location: 1 Scale: 0.279 Shape: -0.144	2.821
Notes Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis Urban adjustments are all carried out using the method of Kjeldsen (2010). Growth curves were derived using the procedures from Science Report SC050050 (2008).						

4.5 Flood estimates from the Statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)											
	2	5	10	20	25	30	50	75	100	200	500	1000
	Flood peak (m^3/s) for the following AEP (%) events											
	50	20	10	5	4	3.3	2	1.3	1	0.5	0.2	0.1
1	3.96	5.66	6.83	8.03	8.43	8.76	9.74	10.57	11.18	12.76	15.09	17.08

Note that for the final sets of flows the ratio method will be used to calculate flood peaks for the 0.5% (1 in 200), 0.2% (1 in 500) and 0.1% (1 in 1,000) AEP events. This method has not been applied to the numbers given in the table above.

5 REVITALISED FLOOD HYDROGRAPH 2 (REFH 2.3) METHOD

5.1 Application of ReFH 2.3 method

What is the purpose of applying this method? Brief summary of the reasons, specific to this study, for applying the method. For example, lumped estimates at key locations for the purpose of checking modelled peak flow estimates, distributed approach to apply inflows to a hydraulic model, deriving hydrograph shapes only, extending the flood frequency curve out to extreme events (long return periods).	The ReFH 2.3 method has been applied to all subcatchments and hydrographs calculated. The Bartlow and Babraham ReFH hydrographs will be combined and the resultant peaks compared to the FEH Statistical method peaks. The hydrology for the Hobson's Brook is being calculated directly using ReFH 2.3 only.

5.2 Parameters for ReFH 2.3 model (urban or mixed urban & rural catchments)

Lumped and sub-catchment / intervening areas should be included in this table.

If applying the method in Flood Modeller Pro, Tp_{urban} values are not directly specified by the user; the model works them out from the supplied URBEXT, DPLBAR, etc. It is simpler just to report Tp rather than separate URBEXT, etc, values for rural and urban portions.

Note: ReFH is also implemented in InfoWorks ICM which does not include the urban component.

Site code	Method	Tp_{rural} (hours)	Tp_{urban} (hours)	C_{max} (mm)	PR_{imp} % runoff for impermeable surfaces	BL (hours)	BR
1	L	12.08	Default scaling of 0.75 applied	743.87	Default scaling of 0.7 applied	80.64	2.51
2	S	7.08		404		51.82	2.49
3	S	10.62		1056.31		85.09	3.07
4	S	7.98		1391.15		76.83	3.52
5	L	5.27		1205.94		62.99	3.29

5.3 Design events for ReFH 2.3 method: Lumped catchments

This table can be deleted if ReFH is not being applied for lumped catchments. Note: ReFH may be applied for both lumped catchments and subcatchments in a study; if this is the case both this table and the next should be completed.

Storm durations detailed here should be the values for the individual catchments. Lumped flows should be generated using the storm duration relevant to each lumped catchment for comparison with Statistical estimates.

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)
1	Urban	Winter	25 hours
5	Urban	Winter	8 hours 30 minutes

5.4 Design events for ReFH 2.3 method: Subcatchments and intervening areas

This table can be deleted if ReFH is not being applied for subcatchments.

This table is included to identify the storm which will be applied to all inflows to a distributed model (see Section 6.1 of the Flood Estimation Guidelines) and avoid the scenario of using a different storm for each inflow to the model.

If there are multiple flood risk areas throughout the model it may be necessary to allow for different storms in different parts of the model by carrying out multiple model runs. Each model run should use the same storm applied to all inflows. Use one row for each storm to be applied. If only one storm is to be applied, delete the additional rows.

If storm duration testing using the hydraulic model is being undertaken ensure that the results are included in the last row of this table when the testing is complete, for example, which duration(s) has been selected and why, what the process will be in terms of presenting model results if more than one duration is selected.

Site code	Season of design event	Storm duration (hours)	Storm area for ARF (if not catchment area)	Reason for selecting storm
1	Winter	25 hours	101.97 km² (ARF = 0.944)	Rural catchments (URBEXT < 0.03) therefore winter storm applied. Critical storm duration selected in ReFH 2.3 based on highest flow value obtained for the catchment to the gauge.
2			119.81 km² (ARF = 0.92)	A rural catchment (URBEXT < 0.03) therefore winter storm applied. Critical storm duration selected in ReFH 2.3 based on highest flow value obtained for the catchment to the gauge.
3				
4				
5		8 hours 30 minutes	3.84 km² (ARF = 0.97)	A rural catchment (URBEXT < 0.03) therefore winter storm applied. Critical storm duration selected in ReFH 2.3 based on highest flow value obtained for the catchment to the gauge.
Results of storm duration testing. This row can be deleted if storm duration testing is not being undertaken.				

Ctitical storm duration calculation

Catchment to gauge (1 hr timestep)

Duration	Max flow (m3/s) 50% (1 in 2) AEP	1% (1 in 100) AEP
21	3.79	11.27
23	3.82	11.31
25	**3.84**	**11.33**
27	3.85	11.32

5.5 Flood estimates from the ReFH 2.3 method

Note: This table is for recording results for lumped catchments. There is no need to record peak flows from subcatchments or intervening areas that are being used as inputs to a semi-distributed model of the river system.

Site code	Flood peak (m³/s) for the following return periods (in years)											
	2	5	10	20	25	30	50	75	100	200	500	1000
	Flood peak (m³/s) for the following AEP (%) events											
	50	20	10	5	4	3.3	2	1.3	1	0.5	0.2	0.1
1	3.74	5.19	6.21	7.29	7.67	8.00	9.04	10.08	10.97	13.83	18.50	22.20
2	5.35	7.12	8.31	9.55	9.98	10.34	11.48	12.59	13.55	16.62	21.58	25.39
3	1.53	2.17	2.62	3.10	3.27	3.42	3.88	4.35	4.75	6.04	8.16	9.86
4	0.48	0.66	0.79	0.92	0.97	1.01	1.14	1.27	1.37	1.71	2.24	2.66
5	0.21	0.29	0.36	0.43	0.45	0.47	0.54	0.61	0.67	0.85	1.10	1.30

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 / AEP events. Delete columns which are not required.

The ReFH flows presented here are from the catchment to the gauge on the top row (catchment 1) and for the combined Bartlow and Babraham peak flows (catchment 2 + 3) on the bottom row. This is described further in Section 6.2 below.

Site code	Ratio of peak flow to FEH Statistical peak					
	Return period 2 years / 50% AEP			Return period 100 years / 1% AEP		
	ReFH 2.3	FEH	Ratio	ReFH 2.3	FEH	Ratio
1	3.74	3.96	1.06	10.97	11.18	1.02
2 + 3	6.78	3.96	0.58	17.92	11.18	0.62

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.

As can be seen in the first row of the table in Section 6.1 above, the ReFH and FEH Statistical peak flows match well if calculated only for the entire catchment to the Babraham gauge. However, when splitting this catchment into two subcatchments (Bartlow (2) and Babraham (3)), the ReFH method appears to significantly over-estimate flow. This is most evident from Table 5.5 (raw ReFH peaks) where the peak flow for catchment 2 is greater than for catchment 1, despite catchment 2 being only the upstream portion of catchment 1. It is assumed this strange pattern in peak flow is a result of the very different catchment permeability.

To seek to resolve this issue, ReFH hydrographs were combined for the Bartlow and Babraham catchments and peaks extracted. These were compared to FEH Statistical method peaks to produce a scaling factor for each AEP (see the second row in Table 6.1 above). These were subsequently applied to the ReFH hydrographs for the Bartlow, Babraham and Stapleford subcatchments. Hobson's Brook is a separate watercourse and has no scaling factor applied. For subcatchments of the River Granta, a 25 hour storm duration with a 1 hour timestep was applied. An 8 hour 30 minute storm duration with a 30 minute timestep was applied for Hobson's Brook.

Default parameters were used for ReFH 2.3.

The scaling factors are as follows:

Return period (years)	Bartlow, Babraham and Stapleford scaling factor
2	0.58
5	0.62
10	0.63
20	0.65
25	0.65
30	0.65
50	0.65
75	0.64
100	0.62
200	0.92
500	0.90
1000	0.96

The scaling factors for the more extreme events are markedly different to those for the events up to and including the 1% (1 in 100) AEP. This is because for these more extreme events, the ratio method has been used to update the

calculation of the FEH statistical flood peaks.

The ratio method has been applied for the Statistical method 0.5% (1 in 200), 0.2% (1 in 500) and 0.1% (1 in 1000) AEP events. The ratio used is as follows:

(FEH *{200/500/1000}* / FEH 100) * ReFH 100

Justification for using the combined Bartlow and Babraham ReFH hydrograph to calculate the scaling factor:

The ReFH peak flows for the catchment to the gauge provided a good match to the FEH Statistical method (10% or closer). The ReFH peak flows for the combined Babraham and Bartlow hydrograph are a less good match and provide much higher values. This is possibly a result of the significant variation in permeability through the catchment. Given that the most confidence is in the gauged FEH Statistical flows, the most appropriate scaling factor should align Babraham and Bartlow (the model inflows) to the FEH Statistical peaks calculated at the gauge. Therefore combining these hydrographs and scaling their peaks provides more confidence compared to using the ReFH catchment to gauge peaks. Although tests were undertaken to try and shift the Babraham and Bartlow ReFH hydrographs to better match the FEH Statistical flows by amending Cini, very significant changes in ReFH parameters would be required and so the scaling methodology was taken forward in preference.

The raw ReFH hydrographs have been provided and are much larger than the scaled hydrographs. It is recommended these are used as sensitivity tests in any modelling work.

It is suggested that using the ReFH hydrographs for the catchment to the gauge (scaled to fit the FEH Statistical peak) and manually applying an area weighting to Bartlow and Babraham is a possible alternative flow method. This would not however take account of the difference in permeability between the Bartlow and Babraham catchments.

How will the flows be applied to a hydraulic model?

If relevant. Will model inflows be adjusted to achieve a match with lumped flow estimates, or will the model be allowed to route inflows?

ReFH hydrographs scaled to the statistical peaks will be applied in the hydraulic model as flow-time boundaries. For Hobson's Brook the raw ReFH hydrographs will be applied directly.

6.3 Assumptions, limitations and uncertainty

Careful thought should be put into identifying the specific assumptions and limitations applicable to the design peak flow estimates (and design hydrographs). Assessing and reporting on the uncertainty in the estimates is also very important. These sections should be completed for every study and never left blank.

List the main assumptions made (specific to this study)

This study has assumed that the catchment descriptors from the FEH Web Service are suitable to be used to derive hydrological estimates, using both the FEH Statistical and ReFH2.3 methods. These were, however, checked against LiDAR, soil type and geology information.

No sewer information was made available for the urban portion of the catchment and therefore it has been necessary to assume that the topographic catchment represents the whole of the catchment, and that the sewer network does not add in or remove any significant contributing areas. Given the small urban area, this is considered to be an appropriate assumption.

Area weighting is an appropriate method to calculate interstation catchment descriptors.

	The gauge is suitable for QMED estimation. The use of the scaling factors derived from the FEH statistical flood peaks are appropriate to be used for all three River Granta subcatchments. This is not considered to be a significant source of uncertainty because of the gauge location. Default ReFH parameters as calculated from catchment descriptors are representative of the flood response in the catchment.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed.	The rating has been taken directly from NRFA and a rating review has not been included as it is outside the scope. The gauge is identified as suitable for QMED only. Therefore the growth curve was derived from a pooling group which treated the subject site as ungauged. Manual estimation of BFIHOST19 for catchment 4 (Stapleford) because the area weighting interstation methodology resulted in a value greater than 1. The value was changed to 0.95 as this is what most closely matches the SPRHOST value. This downstream catchment is very permeable and FEH methodologies are less certain when applied to permeable catchments such as this one.
Provide information on the uncertainty in the design peak flow estimates and the methodology used Uncertainty in the peak flow estimates should always be provided. The default is the 95-percentile upper and lower bounds, but other estimates may need to be provided depending on the requirements of the study. Further information can be found in Section 5.4 of the Flood Estimation Guidelines.	It is not possible to directly quantify the uncertainty for the ReFH2.3 method. For the FEH Statistical method the uncertainty will depend on many factors, for example, how unusual the catchment is relative to the pooling group and the uncertainty in flow measurement at other gauges. No uncertainty calculation method is available where the QMED has been derived from AMAX data but the growth factors are from a pooling group. Refer to Section 6.6 which provides an indicative quantification of uncertainty.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes, would a project for scheme design require additional detail, etc.	The hydrology derived for this study is likely to remain appropriate until such a time as either the guidance changes, new data becomes available or there is a significant event which may effect the QMED and growth curve estimation.
Give any other comments on the study, e.g. suggestions for additional work, such as flow monitoring, rating reviews, etc.	Future work could include • Gauge at Babraham rating confirmation and / or review. • Obtaining full gauge record for observed event analysis and / or hydrological calibration. This could inform changes in ReFH paraemters including Tp, Cmax, BL and BR.

6.4 Checks

These checks are important as a way of ensuring that everything has been considered and that the results are sensible. All relevant sections should be completed for every study. Where sections are not relevant (where there are no flow gauges or previous studies, for example) a comment should be added to this effect rather than leaving a blank space.

Are the results consistent, for example at confluences? This will not be relevant for a study where there is only a single flow estimation point.	1% (1 in 100) AEP: Peak flow at catchment to gauge: 11.18 m³/s Peak flow at Bartlow: 8.45 m³/s
What do the results imply regarding the return periods / frequency of floods during the period of record? This will only be relevant where there is flow gauge data.	The observed peak flows from the gauge at Babraham have been compared to the FEH Statistical estimates to provide an indicative return period for each event. Note that the peak flow in 2001 is subject to considerable uncertainty – a high proportion of this was overbank flows so it is not an accurate flow to use for comparison.

Date	Peak flow at Gauge at Babraham (m^3/s)	Return period based on FEH Statistical (m3/s)
22/10/2001	26.275	Larger than a 0.1% (1 in 1000) AEP
30/01/1988	8.055	Between a 5% (1 in 20) AEP and a 4% (1 in 25) AEP
07/02/2014	7.685	Between a 10% (1 in 10) AEP and 5% (1 in 20) AEP

What is the range of 100-year / 1% AEP growth factors? Is this realistic?	The growth factor is 2.821. This is realistic and appropriate as it is between 1 and 4.
If 1000-year / 0.1% AEP flows have been derived, what is the range of ratios for 1000-year / 0.1% AEP flow over 100-year / 1% AEP flow?	Catchment 1: 20.93 / 11.18 = 1.87 Catchment 2: 24.28 / 8.45 = 2.87 Catchment 3: 9.43 / 2.96 = 3.18 Catchment 4: 2.54 / 0.86 = 2.95 Catchment 5: 1.3 / 0.67 = 1.94
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred. This will not be relevant if there are no previous hydrological assessments.	N/A; no other studies made available.
Are the results compatible with the longer-term flood history? This will not be relevant if there is no flow gauge data or historical flooding information.	Yes. As is shown in the table above.

6.5 Final results

Show the final results here for all flow estimation points (unless using a distributed approach, with no lumped catchment flow estimation points, and allowing the hydraulic model to route the flows) and design events, and give any other data or results needed for the next stage of the study.

Site code	Flood peak (m^3/s) for the following return periods (in years)											
	2	5	10	20	25	30	50	75	100	200	500	1000
	Flood peak (m^3/s) for the following AEP (%) events											
	50	20	10	5	4	3.3	2	1.3	1	0.5	0.2	0.1
1	3.96	5.66	6.83	8.03	8.43	8.77	9.75	10.57	11.18	12.52	16.36	20.93
2	3.13	4.41	5.28	6.17	6.46	6.71	7.42	8.02	8.45	15.34	19.50	24.28
3	0.90	1.35	1.67	2.00	2.12	2.22	2.51	2.77	2.96	5.57	7.37	9.43
4	0.28	0.41	0.50	0.60	0.63	0.66	0.74	0.81	0.86	1.58	2.03	2.54
5	0.21	0.29	0.36	0.43	0.45	0.47	0.54	0.61	0.67	0.85	1.10	1.30

6.6 Uncertainty bounds

This table reports the flows derived from the uncertainty analysis detailed in Section 6.3. The 'true' value is more likely to be near the estimate reported in Section 6.5 than the bounds. However, it is possible that the 'true' value could still lie outside these bounds.

The Flood Estimation Guidelines provide a method for uncertainty analysis. This analysis is for either ungauged catchments or gauged catchments with single site or enhanced single site analysis. Given that the gauge used in this calculation record is suitable for QMED but not suitable for pooling, the gauge falls between these two methods. Therefore, the uncertainty analysis set out for ungauged catchments with one donor has been used as a proxy. There is also no established method currently for measuring ReFH uncertainty. The method used has been taken from Table 2, Section 5.4, of the Flood Estimation Guidelines (Environment Agency , 2022).

Complete this table with the flows from the uncertainty analysis. Some key design events have been added to the table, but these can be amended as required.

Site code	Flood peak (m^3/s) for the following return periods (in years)					
	20		100		1,000	
	Flood peak (m^3/s) for the following AEP (%) events					
	5		1		0.1	
	Lower	Upper	Lower	Upper	Lower	Upper
1	5.54 - 11.56	3.85 - 16.62	7.71 - 16.32	5.25 - 23.7	14.02- 31.18	9.42 - 46.67

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, hydraulic model, or reference to table below)	'Model inflow hydrographs.xlsx'

7 ANNEX

Original pooling group

Station	Distance	Years of data	QMED AM	L-CV deurbanised	L-SKEW deurbanised	Discordancy	AREA
37020 (Chelmer @ Felsted)	0.395	51	12.8	0.343	0.191	0.886	133.447
54036 (Isbourne @ Hinton on the Green)	0.402	48	13.578	0.331	0.322	1.21	92.83
38002 (Ash @ Mardock)	0.42	79	6.735	0.301	0.074	0.402	77.995
38004 (Rib @ Wadesmill)	0.444	61	11.621	0.33	0.154	0.658	136.785
33051 (Cam @ Chesterford)	0.462	51	7.86	0.258	-0.102	0.567	140.018
53013 (Marden @ Stanley)	0.464	48	13.392	0.247	0.241	1.489	99.46
35008 (Gipping @ Stowmarket)	0.51	55	14.7	0.299	0.046	2.16	125.853
37014 (Roding @ High Ongar)	0.537	57	10.8	0.248	-0.196	1.655	92.645
34012 (Burn @ Burnham Overy)	0.565	54	1.03	0.249	0.007	0.168	83.868
21016 (Eye Water @ Eyemouth Mill)	0.571	39	36.964	0.275	0.151	1.164	118.93
43014 (East Avon @ Upavon East)	0.579	50	3.668	0.216	0.068	1.286	85.828
39028 (Dun @ Hungerford)	0.603	52	2.18	0.236	-0.012	0.354	100.095

Final pooling group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA
37020 (Chelmer @ Felsted)	0.395	51	12.8	0.34	0.343	0.194	0.191
54036 (Isbourne @ Hinton on the Green)	0.402	48	13.578	0.329	0.331	0.324	0.322
38002 (Ash @ Mardock)	0.42	79	6.735	0.299	0.301	0.076	0.074
38004 (Rib @ Wadesmill)	0.444	61	11.621	0.327	0.33	0.156	0.154
53013 (Marden @ Stanley)	0.464	48	13.392	0.243	0.247	0.246	0.241
21016 (Eye Water @ Eyemouth Mill)	0.571	39	36.964	0.275	0.275	0.151	0.151
43014* (East Avon @ Upavon East)	0.579	45	4.048	0.182	0.183	0.11	0.108
39028 (Dun @ Hungerford)	0.603	52	2.18	0.235	0.236	-0.011	-0.012
53028 (By Brook @ Middlehill)	0.776	39	10.692	0.169	0.17	-0.093	-0.095
21027 (Blackadder Water @ Mouth Bridge)	0.814	32	40.298	0.321	0.322	0.268	0.267
21024 (Jed Water @ Jedburgh)	1.046	34	71.477	0.216	0.217	0.151	0.15

ANNEX 3 STRUCTURES

River Station	Modelling Representation
GR9025bu	Bridge with flat shaped soffit
GR7918bu	Bridge
GR7446bu	Bridge with arch shaped soffit
GR7340Wus	Weir
GR7200Bus	Bridge with arch shaped soffit
GR7000W	Weir
GR6625Wus	Footbridge
GR6410Wus	Sharp crested weir
GR5830Bus	High Street Road Bridge
GR5790Bus	Foot bridge
GR5350Bus	Road Bridge
GR5285Wus	Sharp Crested Weir
GR5190Bus	Road Bridge
GR3550Bus	Love Lane Bridge
GR960Bu	Sawston Road Bridge
GR904W1u	Crump
GR904W2u	Crump
GR904W3u	Crump
GR220Bu	Railway Bridge

ANNEX 4 MODEL HANDOVER LOG

Baseline scenarios

Return Period	Scenarios	FMP .ief file	FMP .dat file	Event File	TUFLOW .tcf file	TUFLOW .tgc file	TUFLOW .tbc file	TUFLOW .tmf file
2	Baseline	GTA_02_BSL_INC_009.ief	Granta_BL_012.dat	GR_02yr_v04.ied	GTA_02_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
5	Baseline	GTA_05_BSL_INC_009.ief	Granta_BL_012.dat	GR_05yr_v04.ied	GTA_05_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
10	Baseline	GTA_10_BSL_INC_009.ief	Granta_BL_012.dat	GR_10yr_v04.ied	GTA_10_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
30	Baseline	GTA_30_BSL_INC_009.ief	Granta_BL_012.dat	GR_30yr_v04.ied	GTA_30_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
30	Baseline Sensitivity Test Inflow increased by 20%	GTA_30_BSL_SEN_Inflowplus20_009.ief	Granta_BL_012.dat	GR_30yr__inflow_20inc_v04.ied	GTA_30_BSL_SEN_inflowplus20_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
30	Baseline Sensitivity Test Depth increased by 20 %	GTA_30_BSL_SEN_Depthplus20_009.ief	Granta_BL_012.dat	GR_30yr_Depth20incrs_v04.ied	GTA_30_BSL_SEN_Depthplus20_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
30	Baseline Sensitivity Test Manning's coefficient increased by 20%	GTA_30_BSL_SEN_ManinNplus20_009.ief	Granta_BL_012_N20%_Increase.dat	GR_30yr_v04.ied	GTA_30_BSL_SEN_ManinNplus20_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001_N20%_increase.tmf
50	Baseline	GTA_50_BSL_INC_009.ief	Granta_BL_012.dat	GR_50yr_v04.ied	GTA_50_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
75	Baseline	GTA_75_BSL_INC_009.ief	Granta_BL_012.dat	GR_75yr_v04.ied	GTA_75_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
100	Baseline	GTA_100_BSL_INC_009.ief	Granta_BL_012.dat	GR_100yr_v04.ied	GTA_100_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
100CC09	Baseline Central Climate Change	GTA_100_CC09_BSL_INC_009.ief	Granta_BL_012.dat	GR_100yr_CC_Central__v04.ied	GTA_100_CC09_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
100CC19	Baseline Higher Central Climate Change	GTA_100_CC19_BSL_INC_009.ief	Granta_BL_012.dat	GR_100yr_CC_HC__v04.ied	GTA_100_CC19_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf

Return Period	Scenarios	FMP .ief file	FMP .dat file	Event File	TUFLOW .tcf file	TUFLOW .tgc file	TUFLOW .tbc file	TUFLOW .tmf file
100CC45	Baseline Upper End Climate Change	GTA_100_CC19_BSL_INC_009.ief	Granta_BL_012.dat	GR_100yr_CC_UE__v04.ied	GTA_100_CC45_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
100	Baseline Sensitivity Test Inflow increased by 20%	GTA_100_BSL_SEN_Inflowplus20_009.ief	Granta_BL_012.dat	GR_100yr_v04_inflow_20inc_.ied	GTA_100_BSL_SEN_inflowplus20_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
100	Baseline Sensitivity Test Depth increased by 20 %	GTA_100_BSL_SEN_Depthplus20_009.ief	Granta_BL_012.dat	GR_100yr_Depth20incrs_v04.ied	GTA_100_BSL_SEN_Depthplus20_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf
100	Baseline Sensitivity Test Manning's coefficient increased by 20%	GTA_100_BSL_SEN_ManinNplus20_009.ief	Granta_BL_012_N20%_Increase.dat	GR_100yr_v04.IED	GTA_100_BSL_SEN_ManinNplus20_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001_N20%_increase.tmf
1000	Baseline	GTA_1000_BSL_INC_009.ief	Granta_BL_012.dat	GR_1000yr_v04.ied	GTA_1000_BSL_INC_009.tcf	granta_014.tgc	granta_013.tbc	Granta_001.tmf

Proposed Development Scenarios

Return Period	Scenarios	FMP .ief file	FMP .dat file	Event File	TUFLOW .tcf file	TUFLOW .tgc file	TUFLOW .tbc file	TUFLOW .tmf file
2	Post Proposed Development	GTA_02_SCH_06.ief	Granta_BL_012.dat	GR_02yr_v04.ied	GTA_02_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
5	Post Proposed Development	GTA_05_SCH_06.ief	Granta_BL_012.dat	GR_05yr_v04.ied	GTA_05_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
10	Post Proposed Development	GTA_10_SCH_06.ief	Granta_BL_012.dat	GR_10yr_v04.ied	GTA_10_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
30	Post Proposed Development	GTA_30_SCH_06.ief	Granta_BL_012.dat	GR_30yr_v04.ied	GTA_30_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
30	Post Proposed Development Sensitivity Test Inflow increased by 20%	GTA_30_SCH_SEN_Inflowplus20_06.ief	Granta_BL_012.dat	GR_30yr__inflow_20inc_v04.ied	GTA_30_SCHEME_SEN_inflowplus20_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
30	Post Proposed Development Sensitivity Test Depth increased by 20 %	GTA_30_SCH_SEN_Depthplus20_06.ief	Granta_BL_012.dat	GR_30yr_Depth20incrs_v04.ied	GTA_30_SCHEME_SEN_Depthplus20_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf

Return Period	Scenarios	FMP .ief file	FMP .dat file	Event File	TUFLOW .tcf file	TUFLOW .tgc file	TUFLOW .tbc file	TUFLOW .tmf file
30	Post Proposed Development Sensitivity Test Manning's coefficient increased by 20%	GTA_30_SCH_SEN_ManinNplus20_06.ief	Granta_BL_012_N20%_Increase.dat	GR_30yr_v04.ied	GTA_30_SCHEME_SEN_ManinNplus20_009.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001_N20%_increase.tmf
50	Post Proposed Development	GTA_50_SCH_06.ief	Granta_BL_012.dat	GR_50yr_v04.ied	GTA_50_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
75	Post Proposed Development	GTA_75_SCH_006.ief	Granta_BL_012.dat	GR_75yr_v04.ied	GTA_75_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
100	Post Proposed Development	GTA_100_SCH_06.ief	Granta_BL_012.dat	GR_100yr_v04.ied	GTA_100_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
100CC09	Post Proposed Development Central Climate Change	GTA_100_CC_09_SCH__06.ief	Granta_BL_012.dat	GR_100yr_CC_Central__v04.ied	GTA_100_CC09_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
100CC19	Post Proposed Development Higher Central Climate Change	GTA_100_CC19_SCH__06.ief	Granta_BL_012.dat	GR_100yr_CC_HC__v04.ied	GTA_100_CC19_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
100CC45	Post Proposed Development Upper End Climate Change	GTA_100_CC19_SCH__06.ief	Granta_BL_012.dat	GR_100yr_CC_UE__v04.ied	GTA_100_CC45_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
100	Post Proposed Development Sensitivity Test Inflow increased by 20%	GTA_100_SCH_SEN_InflowplusS20_06.ief	Granta_BL_012.dat	GR_100yr_v04_inflow_20inc_.ied	GTA_100_SCHEME_SEN_inflowplus20_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
100	Post Proposed Development Sensitivity Test Depth increased by 20 %	GTA_100_SCH_SEN_Depthplus20_06.ief	Granta_BL_012.dat	GR_100yr_Depth20incrs_v04.ied	GTA_100_SCHEME_SEN_Depthplus20_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf
100	Post Proposed Development Sensitivity Test Manning's coefficient increased by 20%	GTA_100_SCH_SEN_ManinNplus20_06.ief	Granta_BL_012_N20%_Increase.dat	GR_100yr_v04.IED	GTA_100_SCHEME_SEN_ManinNplus20_009.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001_N20%_increase.tmf
1000	Post Proposed Development	GTA_1000_SCH_06.ief	Granta_BL_012.dat	GR_1000yr_v04.ied	GTA_1000_SCHEME_006.tcf	granta_Scheme_06.tgc	granta_013.tbc	Granta_001.tmf