The Sizewell C Project

5.5 Two Village Bypass Flood Risk Assessment Appendix A Two Village Bypass Modelling Report

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Planning Act 2008
Infrastructure Planning (Applications: Prescribed
Forms and Procedure) Regulations 2009

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1 Introduction

1.1.1. As part of the Sizewell C proposed development, the two village bypass is proposed with the route comprising a new, permanent, 2.4 kilometre (km) single carriageway road, that would depart from the A12 to the south-west of Stratford St. Andrew before re-joining the A12 to the east of Farnham. As the new carriageway would cross the River Alde, a flood risk assessment (FRA) is required. The FRA will form part of the Environmental Statement to be submitted as part of an application for a Development Consent Order (DCO).

1.1.2. The two village bypass would be constructed in the early years of construction of the Sizewell C project. Once operational, it would be open to the public and would be used by EDF Energy during the construction phase of the Sizewell C main development site.

1.1.3. The aim of this report is to present the outcomes of the hydraulic modelling study to assess flood risk to the proposed carriageway itself and its potential impacts on flood risk off-site.

1.1.4. For the purpose of the study, RHDHV received the Fluvial Alde, Ore and Fromus 1D-2D model report and associated modelling files (Flood Modeller Pro and TUFLOW) for the latest available hydraulic modelling study for the rivers Alde, Ore and Fromus in a rural area of Suffolk (Ref 1).

1.1.5. The supplied model was not calibrated due to lack of calibration data. However, a range of sensitivity tests of the main model parameters has been undertaken to assess the overall model robustness.

2 Methodology

2.1 Overview

2.1.1. The existing model (1D-2D) provided by the Environment Agency was developed by JBA consulting in March 2012, as a part of Fluvial Alde, Ore and Fromus ISIS - TUFLOW flood mapping study. Full details of the model build are available in 'Fluvial Alde, Ore and Fromus ISIS-TUFLOW model' Report (Ref 1).

2.1.2. As part of the current study, the 1D–2D model was first updated to account for any additional information collected for the study and then amended to represent the proposed development and assess its impact on flood risk.

2.1.3. The supplied model was not fully reviewed as a part of this study. Only necessary changes were made to improve model stability and enable the model run for the required range of scenarios, including climate change allowances, as discussed in **section 2.3** and **section 4** respectively.

2.2 Existing model

2.2.1. As stated in **section 1**, the Environment agency has supplied the Fluvial Alde, Ore and Fromus model report and associated modelling files for the 1D-2D Flood Modeller Pro (FMP) and TUFLOW models respectively.

2.2.2. The supplied model is a linked 1D-2D model built using ISIS-TUFLOW and associated results were produced by running the model using TUFLOW version 2011-09-AD-iSP and ISIS version 3.5.

2.2.3. The model extent includes the River Alde from Dennington to Snape Maltings (approximately 25 km) and the River Ore from upstream of Framlingham until the Alde confluence near Stratford St Andrew (17 km), and the River Fromus that flows through the town of Saxmundham and joins the Alde immediately upstream of the tidal sluice at Snape, a model reach of some 13 km.

2.2.4. The study extent also includes the smaller tributary reaches such as Badingham watercourse (2.5 km), Glemham watercourse (3.5 km) The Gull (1 km) and Saxmundham (2 km). The Ore, Badingham, Glemham, Gull and Saxmundham watercourses are modelled in 1D only.

2.2.5. The 2D-TUFLOW domain includes the River Alde floodplain downstream of Screw Bridge (railway bridge north of Blaxhall) and extends to the downstream boundary of the model. On the River Fromus the 2D domain is connected to the 1D channel downstream of the A1094 road bridge at Snape Watering until its confluence with the River Alde.

2.2.6. The upstream extent of the 2D domain for each watercourse ties in with high ground (the railway embankment on the River Alde and the A1094 on the River Fromus) which allows for a straightforward link between the 1D and 1D-2D model domains.

2.2.7. The 2D-TUFLOW model domain is a single domain model with an 8m grid size connected to the 1D-Flood Modeller model via HX links where the channels are open. The supplied 1D-2D model extents are shown in **Plate 2.1** and the location of the watercourses within the study extent are shown in **Plate 2.2**.

Plate 2.1. Extract from ‘Fluvial Alde, Ore and Fromus ISIS -TUFLOW Model Report, Figure 2-2: Hydraulic model domains.

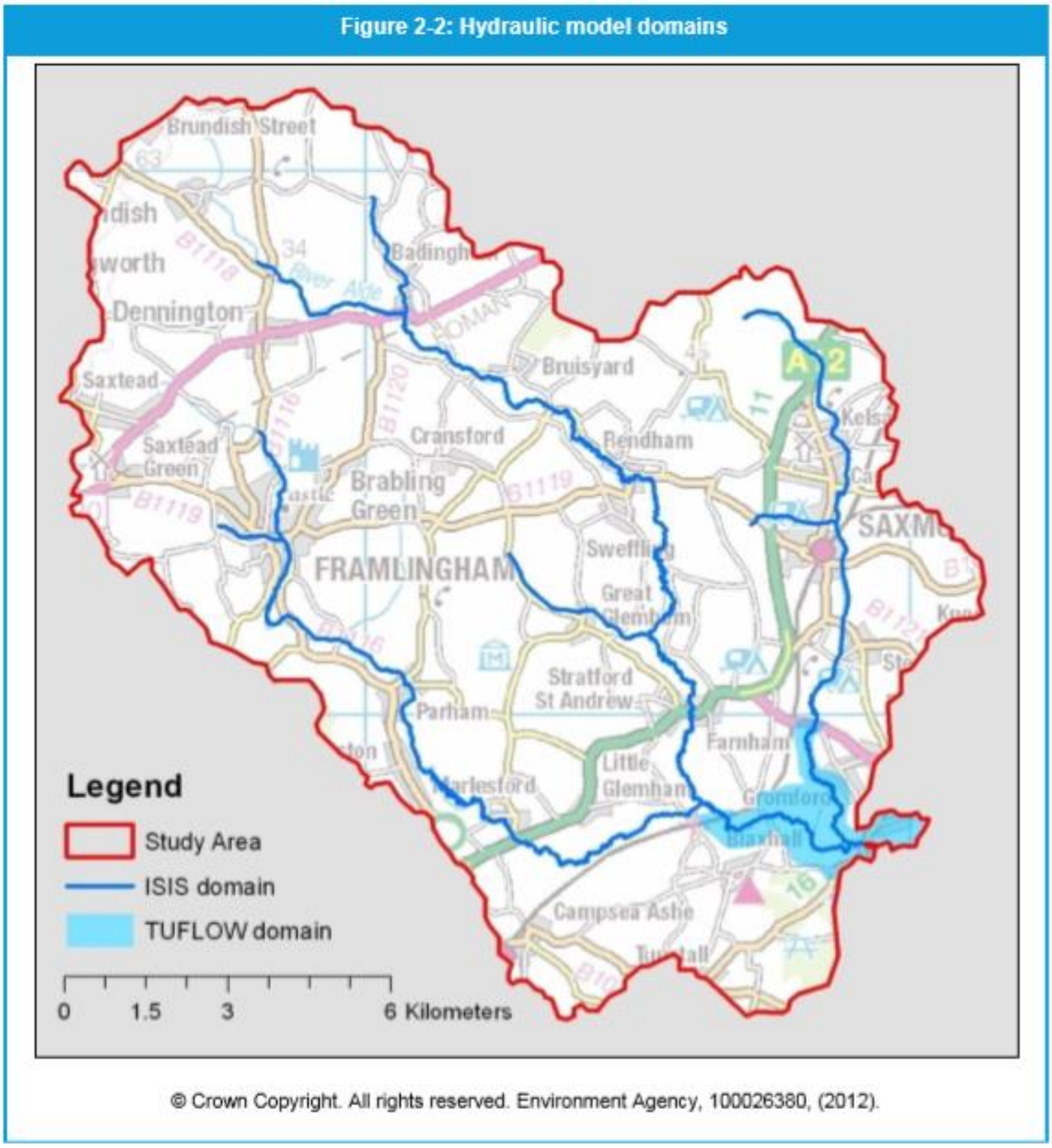

Figure 2-2: Hydraulic model domains

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Plate 2.2. Extract from ‘Fluvial Alde, Ore and Fromus ISIS -TUFLOW Model Report, Figure 3-1: Diagram of model schematisation.

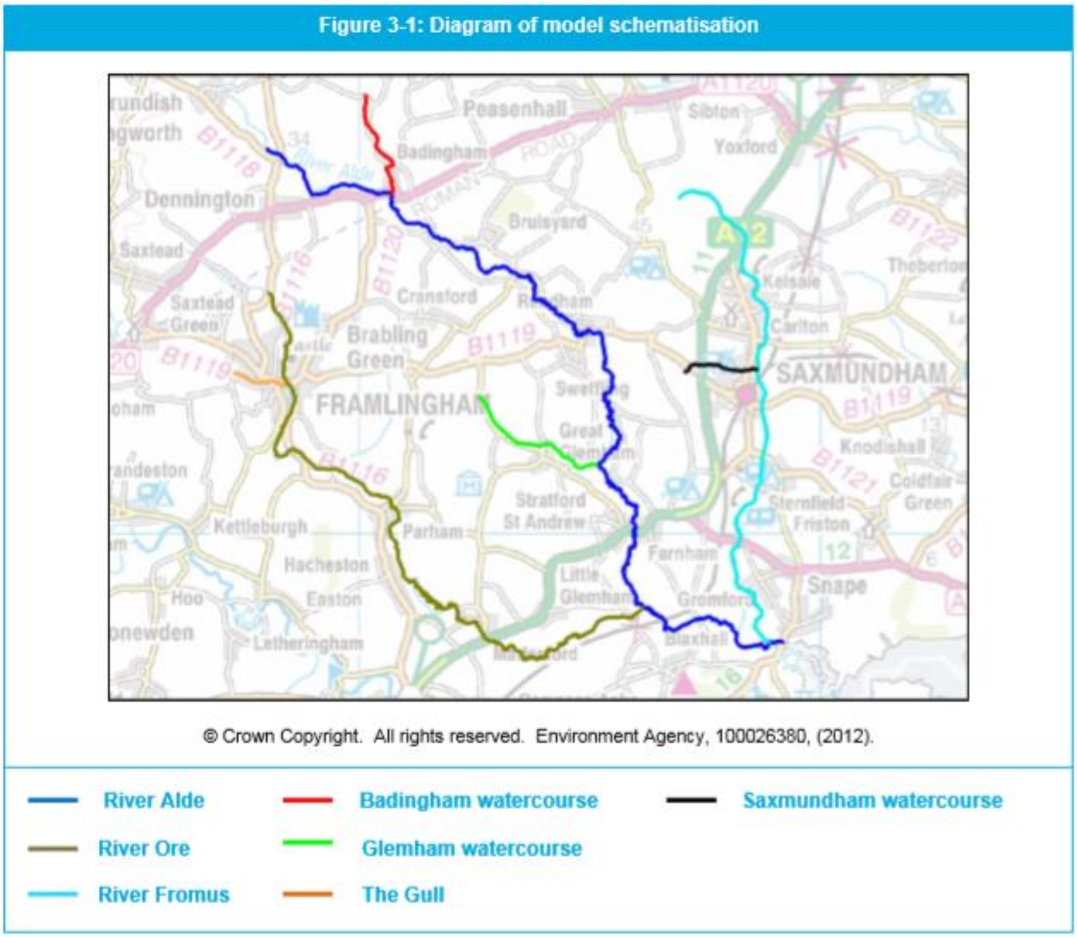

Figure 3-1: Diagram of model schematisation

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2.2.8. The supplied model was previously run for the 1 in 2-year, 1 in 10-year, 1 in 20-year, 1 in 75-year, 1 in 100-year, 1 in 100-year with 20% climate change allowance and 1 in 1,000-year return periods. Details of the peak inflows adopted in the study are provided in **section 4.1**.

2.2.9. The model was not calibrated due to lack of calibration data. However, a range of sensitivity tests of the main model parameters has been undertaken to assess the overall model robustness.

2.2.10. The model uses separate IED files to assign the appropriate inflow boundaries for each modelled event, and an initial condition was read into the DAT file for all the model runs.

2.2.11. The downstream boundary of the model is at Snape Maltings (on the Alde estuary). Timeseries of tide levels corresponding to a low tide return period has been used for all fluvial model runs given the low dependence between extreme fluvial and tidal events on the east coast. Further details on the downstream model boundary are provided in **section 4.2**.

2.2.12. In late 2019, the Environment Agency issued updated the flood modelling for the Rivers Alde, Ore and Fromus (Ref 11). This model was not available in time for this two village bypass FRA study and therefore the previous (2012) model was used and updated as discussed in following sections.

2.3 Model updates

2.3.1. The supplied model was updated to extend the 2D model domain further upstream in order to appropriately represent River Alde floodplain and its connectivity with the river channel in the vicinity of the development. This was done to enable adequate assessment of the impacts of the development on changes in flood risk.

2.3.2. The updated model was used to assess baseline flood conditions (i.e. pre development) and then amended to represent the development. Details of model updates and other changes for the baseline and 'with scheme' model schematisations are discussed in **sections 3.1** and **3.2** respectively.

2.3.3. Following additional data was collected and used in this modelling study:

- 1.0m resolution LiDAR data obtained from Defra's Data Services Platform (Ref 2), used to define the topography of the catchment in the additional 2D-TUFLOW hydraulic model domain;
- River Alde channel survey (Ref 3);
- Mastermap data within the study extent obtained from Ordnance Survey (Ref 4). The data consists of geometric layers representing different features, such as roads, railways, grass, water, buildings, etc., used to assign appropriate roughness coefficients to the material layer of the 2D-TUFLOW model; and
- Two village bypass proposed layout and profile (Ref 5).

3 Model schematisation

3.1 Baseline model

3.1.1. This section outlines the amendments made to the supplied Fluvial Alde, Ore and Fromus 2012 model in order to develop the updated baseline model and the 'with scheme' model that is discussed further in **section 3.2**.

3.1.2. Five additional 1D model cross-sections between A12 Road bridge (Farnham gauge station) and the railway line were added to the model based on the obtained channel survey (Ref 3). The location of the five cross-sections are shown in **Plate 3.1**.

Plate 3.1. Location of the additional River Alde channel survey cross-sections.

3.1.3. The grid size was reduced from 8m to 4m in order to represent sufficient detail in the areas of interest, without making the simulations time too computationally expensive. The initial conditions in the 1D model have been improved to stabilise the model for low probability events runs.

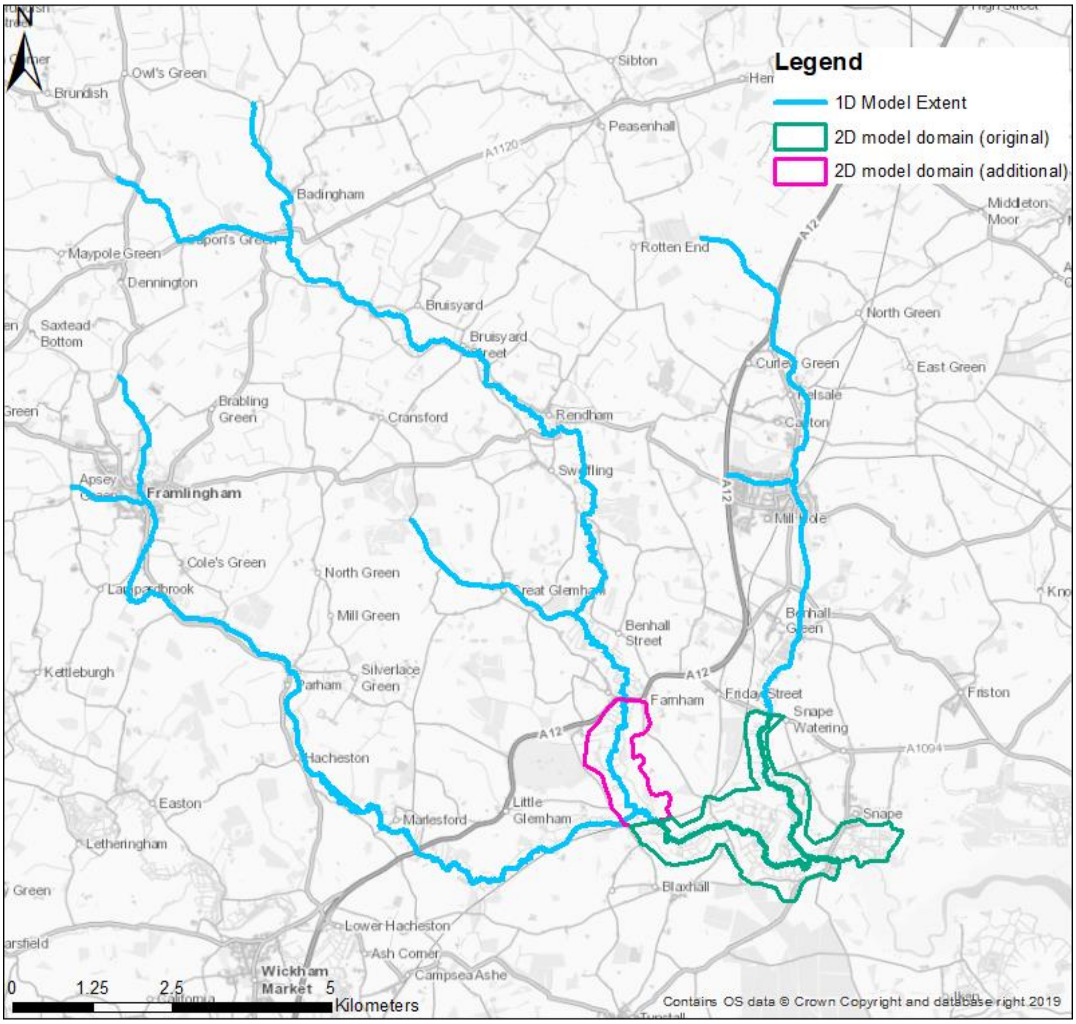
3.1.4. The 2D-Tuflow model domain was extended to cover the area between A12 road (near Farnham) and the railway line near Gorse Farm. The floodplain elements of the cross-sections within the extended 2D domain have been deactivated in the 1D model to avoid double-counting flood storage within the floodplains.

3.1.5. Links between the 1D channel and the extended 2D model domain have been schematised using HX lines digitised along the channel bank tops. The elevation of the TUFLOW grid cell should closely match the bank crest in the connected 1D cross-sections. Therefore, bank levels from the FMP model were applied to the 2D domain along the HX lines using ZP points in the 2d_zline layer. Lines (represented as .zsh) have been used to refine areas of poor Lidar filtering based on the surrounding ground levels to reinforce existing drains.

3.1.6. To reduce model instability, a “stability patch” which contains a high manning’s value (0.85) was applied to the 1D-2D boundaries where highly turbulent flows occurs. This does not impact on the overall model results. The stability patch was included with all the modelled scenarios for consistency. The remaining channel and floodplain roughness values have been adopted as in the original supplied model. No other changes were made to the supplied model.

3.1.7. The extent of the updated baseline model showing 1D and 2D model extent is illustrated in **Plate 3.2**.

Plate 3.2. Updated 1D-2D model extent.

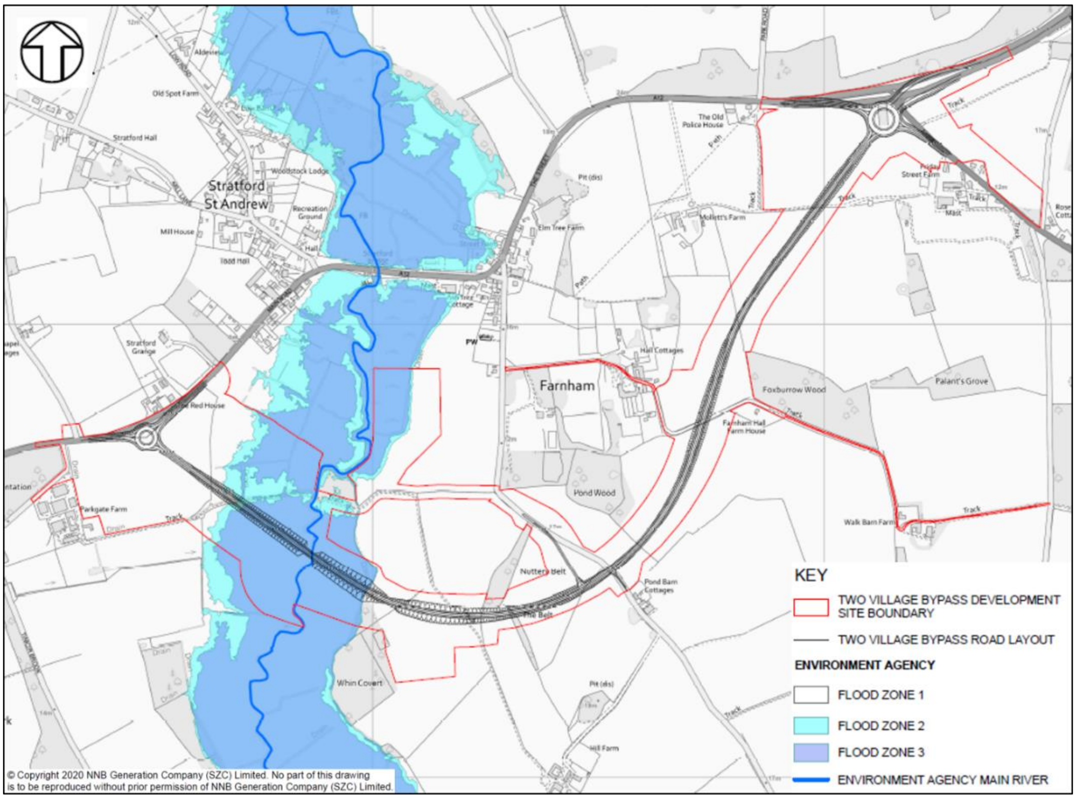


3.2 'With scheme' model

3.2.1. This section outlines the amendments made to the baseline model in order to represent the design of the proposed two village bypass development.

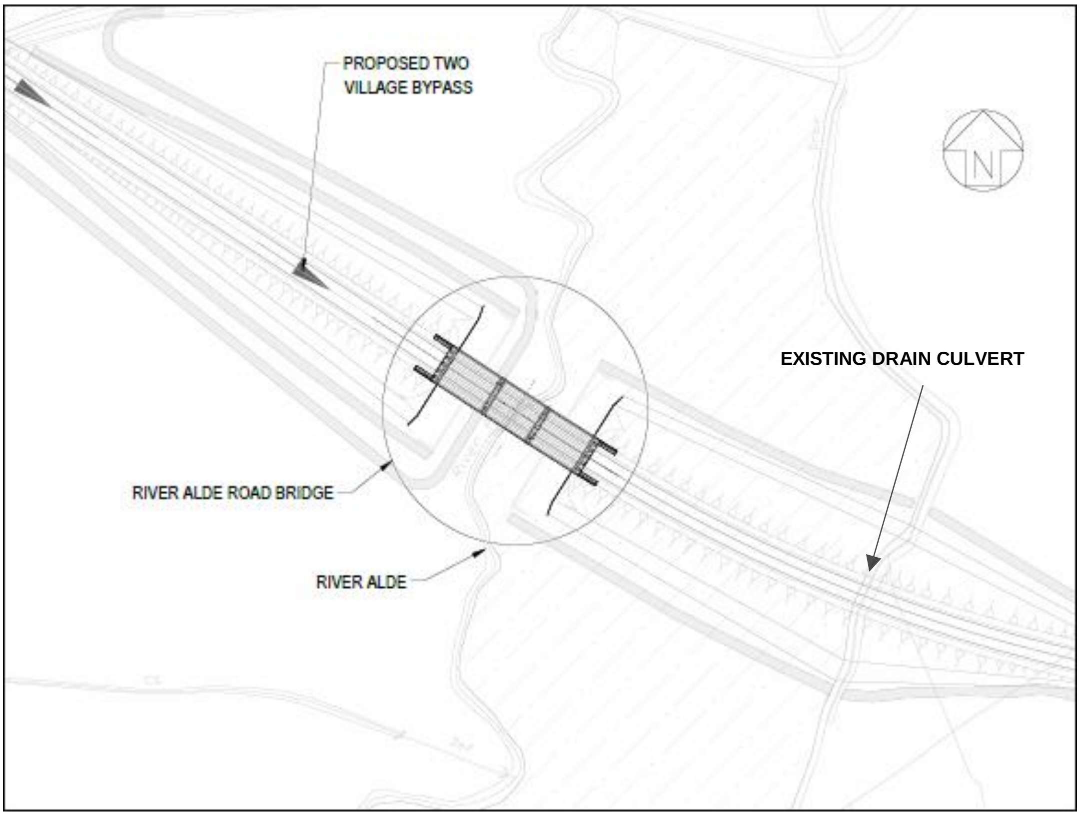
3.2.2. The crossing over the River Alde was added to the baseline model near 1D model node ALDE_06069 (in FMP). The bypass would cross the River Alde approximately 500m from the western end of the proposed route, passing through Flood Zones 2 and 3 (**Plate 3.3**).

Plate 3.3. Environment Agency Flood Zone Map



3.2.3. The proposed two village bypass development comprises the section of the road to bypass the villages of Farnham and Stratford St Andrew and a bridge over the River Alde. In addition, a culvert on an existing drain was included (east of the River Alde) as illustrated in **Plate 3.4**.

Plate 3.4. Extract from EDF Energy two village bypass drawing: SZC-SZ0204-XX-00-DRW-100297 – Location Plan.



3.2.4. Following initial model results it became apparent that road embankment crossing the floodplain would have too significant an impact on flood risk upstream. Therefore, the design was revised to include a larger bridge opening and flood relief culverts to help alleviate water impounded by the embankment.

3.2.5. Following design elements of the two village bypass development were included in the 1D-2D model:

- the carriageway is represented in the 2D model domain using 2d_za layer with average road elevation of 7.0m AOD;
- the road embankments are also represented in the 2D model using 2d_zsh layer so that a slope is created between the road level and the surrounding ground levels;
- the bridge is represented in the 1D model as USBPR bridge unit (model node: ALDE_06069bu) with span width of 60m, soffit level of 6m AOD and 4 circular piers of 0.5m diameter. In the final iteration of the outline design the dimeter of the piers was increased to 1.2m due to structural

requirements (**Plate 3.5**). A sensitivity test was carried out to determine impact of the increased pier size, however results showed no difference in the maximum flood levels (**Plate 3.6** illustrating comparison immediately upstream of the proposed crossing) and therefore it was assumed not necessary to re-run all the modelled scenarios;

- one portal culvert (with no concrete base, so no impact on main channel) at the existing drain (east of the River Alde) that is 5.4m wide and 3.0m high and 70m long. This was represented as rectangular culvert in 1D TUFLOW ESTRY unit (which does not provide option for a portal culvert. The bore area of the box culvert was assumed as per the portal culvert design. This is a slightly more conservative approach as the head loss within the culvert is included;
- three flood relief culverts on the eastern floodplain, two halfway between the River Alde and the drain culvert and one side by side with the existing drain portal culvert. These are standard box culverts (5.4m wide and 3.0m high and 60m long) built at ground level represented in the 1D ESTRY (within TUFLOW domain) using 1d_nwk layer;
- two sets of twin flood relief culverts under the road embankment on the western floodplain represented in the 1D ESTRY (within TUFLOW domain) using 1d_nwk layer. These culverts are each 5.4m wide and 3.0m high and 55m long, placed in the lowest point on the floodplain to maximise their efficiency in passing water through the embankment, illustrated in **Plate 3.7**.

Plate 3.5. Extract from EDF Energy two village bypass drawing: SZC-SZ0204-XX-00-DRW-100297 – Elevation.

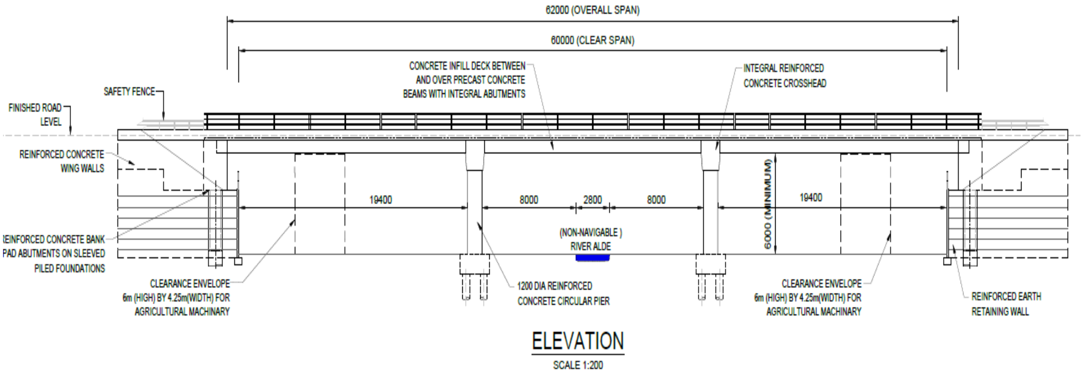
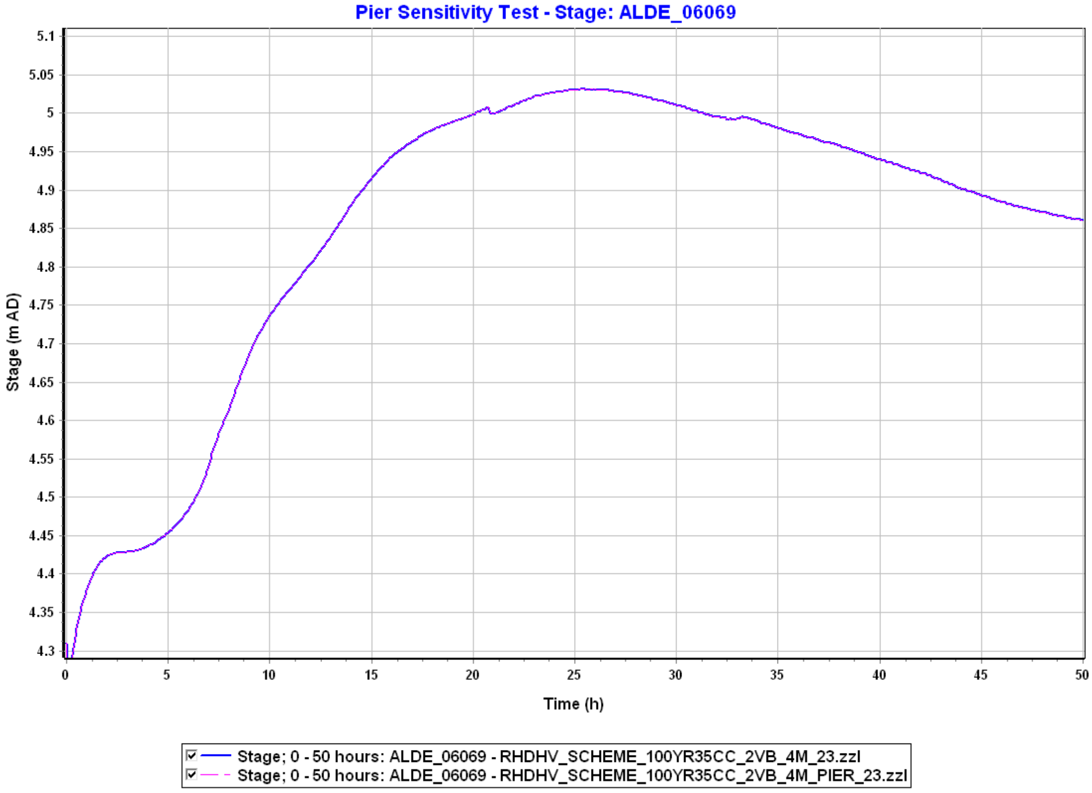


Plate 3.6. Comparison of max water levels – pier sensitivity test



3.2.6. Representation of the bridge structure within the 1D model (in FMP) is shown in **Plate 3.8**.

3.2.7. A mammal crossing to the east of River Alde (**Plate 3.7**) would be located outside of flood extent to provide dry passage at all times. This was not included in the model as not relevant to the resulting flood levels.

Plate 3.7. Extract from EDF Energy two village bypass drawing: SZC-SZ0204-XX-000-DRW-100038 P19 TVB Highway Layout and Profile GA

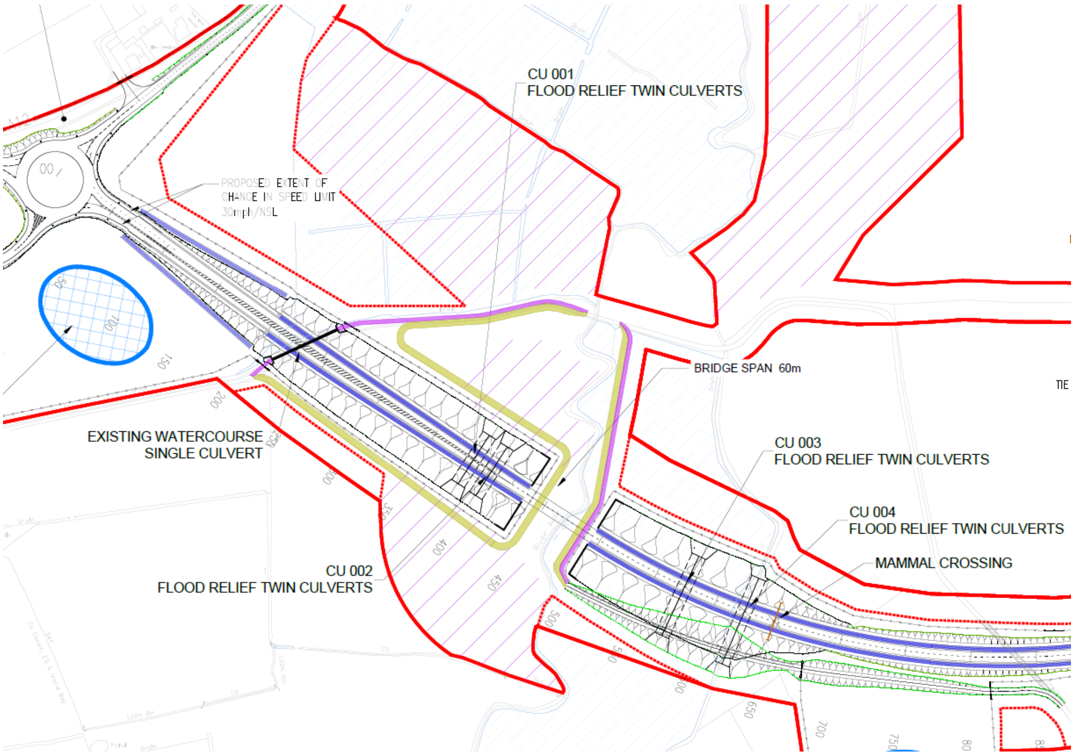
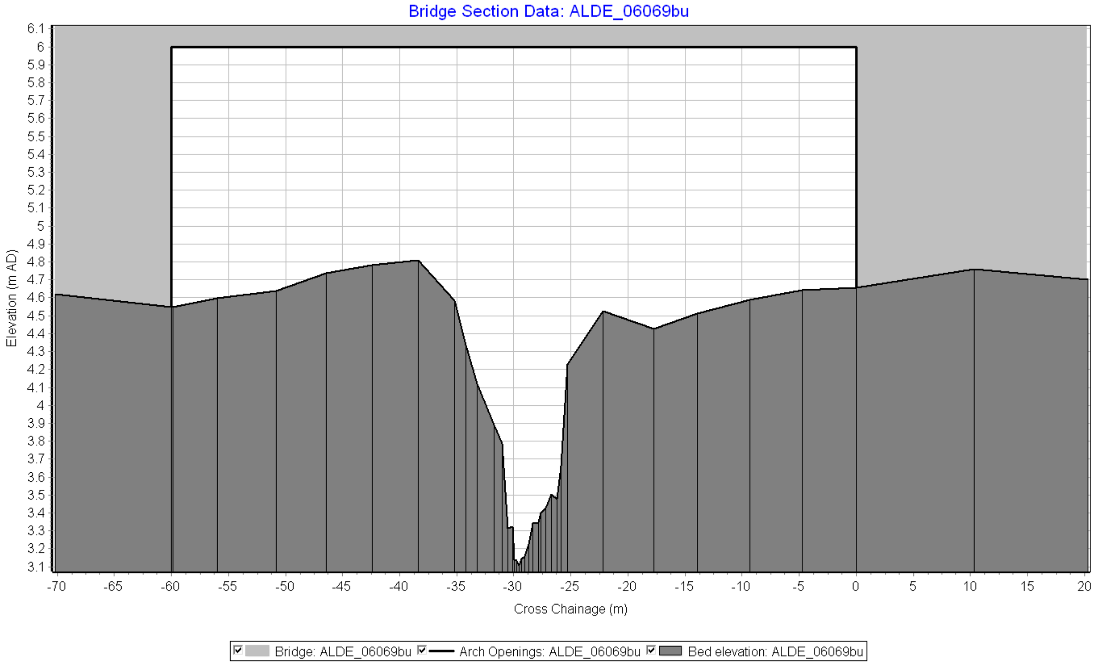


Plate 3.8. Two village bypass bridge representation in the 1D model.



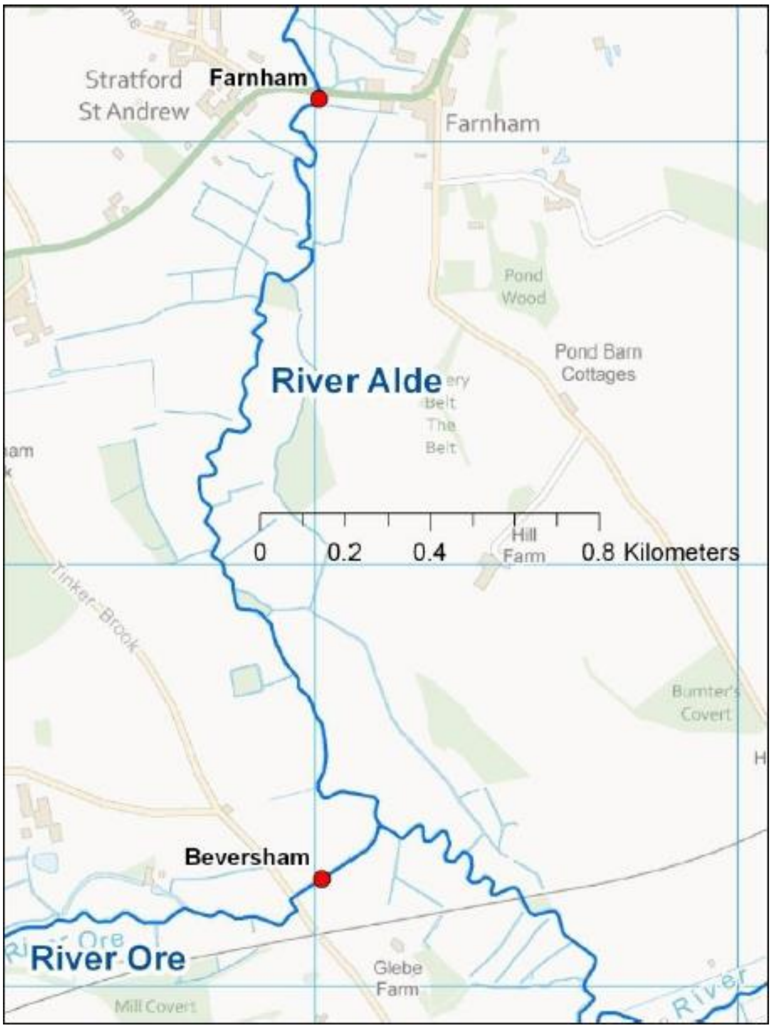
4 Boundary conditions

4.1 Fluvial flows

4.1.1. The hydrological assessment was not updated as a part of this Sizewell C study. Instead, fluvial flows derived in the 2012 study (Ref 1) were adopted.

4.1.2. In the 2012 study, the FEH statistical method has been chosen for estimating inflows to the River Alde, Ore and the other tributaries. Two flow gauges were available in the study area; i.e. Farnham (ID 35003) on the Alde and Beversham (ID 35004) on the Ore (locations shown in **Plate 4.1**). Both gauges are part of the Environment Agency's HiFlows-UK dataset although neither were deemed suitable for the estimation of QMED.

Plate 4.1. Extract from 'Fluvial Alde, Ore and Fromus ISIS -TUFLOW Model Report, Figure 2-1: HiFlows-UK gauge locations on the Alde.



4.1.3. Rating reviews were undertaken at both gauges with results suggesting that despite some uncertainties, the AMAX series would provide a more reliable estimate of QMED than that calculated from catchment descriptors alone. For this reason, both gauges were used as donors on their respective rivers for further flow calculations.

4.1.4. For peak flow estimation, the FEH statistical procedure of "pooled analysis" was undertaken. A pooled growth curve for each group was developed, allowing the QMED estimates to be scaled up to other return periods. Further details on the hydrological assessment are available in the 2012 modelling study report (Ref 1).

4.1.5. Peak flow estimates for the inflows into River Alde adopted in the modelling are presented in **Table 4.1**. Inflows to River Ore and all tributaries are available in the 2012 modelling study report (Ref 1).

Table 4.1. Peak flow estimates for the River Alde, extracted from Fluvial Alde, Ore and Fromus ISIS -TUFLOW Model Report, Appendix A- Flood estimation calculation record – Section 5.4 Final Results

River Alde Inflows	Flood peak (m^3/s) for the following return periods (in years)					
	2	10	20	75	100	1,000
ALD_1	1.8	3.33	3.93	5.07	5.33	9.85
ALD_2	1.93	3.57	4.21	5.44	5.71	10.57
ALD_3	2.23	4.11	4.85	6.25	6.56	12.14
ALD_4	2.39	4.39	5.18	6.69	7.02	12.98
ALD_5	2.6	4.8	5.66	7.3	7.67	14.18
ALD_6	2.69	4.96	5.86	7.56	7.93	14.67
ALD_7	3.89	7.09	8.16	9.98	10.35	18.93
ALD_8	4.16	7.58	8.73	10.68	11.07	20.26
ALD_9	4.65	8.47	9.76	11.94	12.37	22.64
ALD_10	5.08	9.25	10.66	13.03	13.51	24.72
ALD_11	5.59	10.18	11.73	14.34	14.86	27.2
ALD_12	6.06	11.03	12.7	15.53	16.1	29.46
ALD_13	6.54	11.89	13.7	16.75	17.36	31.77
ALD_14	7.07	12.86	14.81	18.11	18.77	34.34
ALD_15	7.33	13.33	15.35	18.77	19.46	35.6
ALD_16	8.24	14.98	17.25	21.1	21.86	40.01
ALD_17	8.29	15.08	17.36	21.23	22	40.26
ALD_18	8.4	15.28	17.6	21.52	22.3	40.81

River Alde Inflows	Flood peak (m^3/s) for the following return periods (in years)					
	2	10	20	75	100	1,000
ALD_19	12.87	20.3	23.02	28.24	29.41	52.06
ALD_20	12.55	19.79	22.44	27.54	28.67	50.75
ALD_21	14.7	23.16	26.25	32.2	33.53	59.35

4.1.6. For the purpose of this Sizewell C study the hydraulic model was simulated for 1 in 20-year, 1 in 100-year and 1 in 1,000-year return period events for the present day and with allowance for climate change scenarios. Adopted climate change allowances are discussed in **section 4.3**

4.1.7. As mentioned in **section 2.2**, in 2019 the Environment Agency issued updated flood modelling for the Rivers Alde, Ore and Fromus (Ref 11). The updates included revised hydrological assessment, which included updating rating curves for the Farnham and Benhall gauging stations and as a result revised QMED and design peak flow estimations. In general, the flows are similar or slightly higher than the previous 2012 study for all rivers above the 1 in 10-year return period event.

4.1.8. Further updates to topography, structures representation and other improvements to model schematisation were made. However, this model was not available in time for this modelling study and therefore derived for the previous (2012) model was used. In order to assess potential impact of the revised hydrology on overall model results and conclusions within this FRA, a comparison of flows and peak water levels at key locations was made and is presented in **section 6.4** of this report.

4.2 Tidal boundary

4.2.1. Similar to the fluvial inflows, the tidal boundary at Snape Maltings (on the Alde estuary) has also been taken from 2012 ISIS-TUFLOW study. The boundary was taken from the TUFLOW model developed as part of the Suffolk Estuaries project (Ref 6). The tide curve was taken from a calibration event very similar to the Highest Astronomical Tide (HAT).

4.2.2. The troughs of the tide in the 2012 model have been truncated at -0.075m AOD to ensure the estuary is wet during low tides. The 2012 model report (Ref 1) states that this low tidal return period event has been used for all fluvial model runs given the low dependence between extreme fluvial and tidal events on the east coast. This was determined with a joint probability assessment, details of which are available in Appendix A of the 2012 study report (Ref 1).

4.2.3. In the updated 2012 model, the troughs of the tide in the model boundary were truncated at -0.075m AOD for the construction phase scenarios and at 1.74m AOD for the future scenarios to account for climate change allowances for sea level rise, as discussed in **section 4.3**.

4.3 Climate change

4.3.1. The 2012 study considered climate change allowance for fluvial flows, in accordance with latest (at the time) Environment Agency guidance, that has been since superseded by the Climate Change Allowances guidance published by the Environment Agency in 2016 (Ref 7).

4.3.2. For the purpose of this two village bypass modelling study it was assumed that construction period would be commissioned in 2022 and will last for 2 years, and that the design life of the carriageway would be 100 years. On that basis, two climate change epochs were considered for the key (from flood risk assessment perspective) development phases, i.e. end of construction phase and end of site lifetime, as follows:

- 2034 – End of construction / start of operation (assessed at 2030 as road scheme assumed to be completed by this time to aid construction of the main development site);
- 2134 – End of development's lifetime (assessed at 2140, more conservative, in line with end of decommissioning of interim fuel spent store at the main development site).

4.3.3. In line with the Environment Agency guidance allowances for increase in fluvial flows were considered for the Higher Central and Upper End scenarios respectively for the two key development phases as follows:

- 2030 – 15% and 25%;
- 2140 – 35% and 65%.

4.3.4. In addition to the allowance for increase in fluvial flow, sea level rise has also been considered and applied at the downstream model boundary. For that purpose, the UK Climate Projections (Ref 8) published in 2018 (UKCP18) were used in line with the latest Environment Agency and Office for Nuclear Regulations advice (Ref 9).

4.3.5. The allowances for sea level rise were derived for the flood risk assessment of the main development site, that considered construction phase at 2030 and end of decommissioning phase at 2140. It was considered appropriate to use those derived allowances for the purpose of this two village bypass assessment, thereby applying a conservative approach.

4.3.6. Therefore, the adopted sea level rise allowances are 0.148m and 1.815m for the 2030 and 2140 epochs respectively. These allowances were used for model scenarios considering both the Higher Central and Upper End allowances for increase in fluvial flow for the two key development epochs.

4.3.7. Further details on the derivation of the sea level rise allowances are available in the UKCP18 review report (Ref 10).

5 Model parameters and stability

5.1 Run parameters

5.1.1. All simulations were run using Flood Modeller version 4.3.6 and TUFLOW version 2017-09-AA-iDP-w64. The model was run to simulate 50 hours which allowed suitable time for the hydrograph to pass through the catchment.

5.1.2. A fixed time-step of 1.0 second was applied to the 1D element of the model and a time-step of 2.0 seconds was applied to the 2D element of the model. These time-steps were chosen as they provided model stability and are appropriate given the 4m cell size of the 2D model domain.

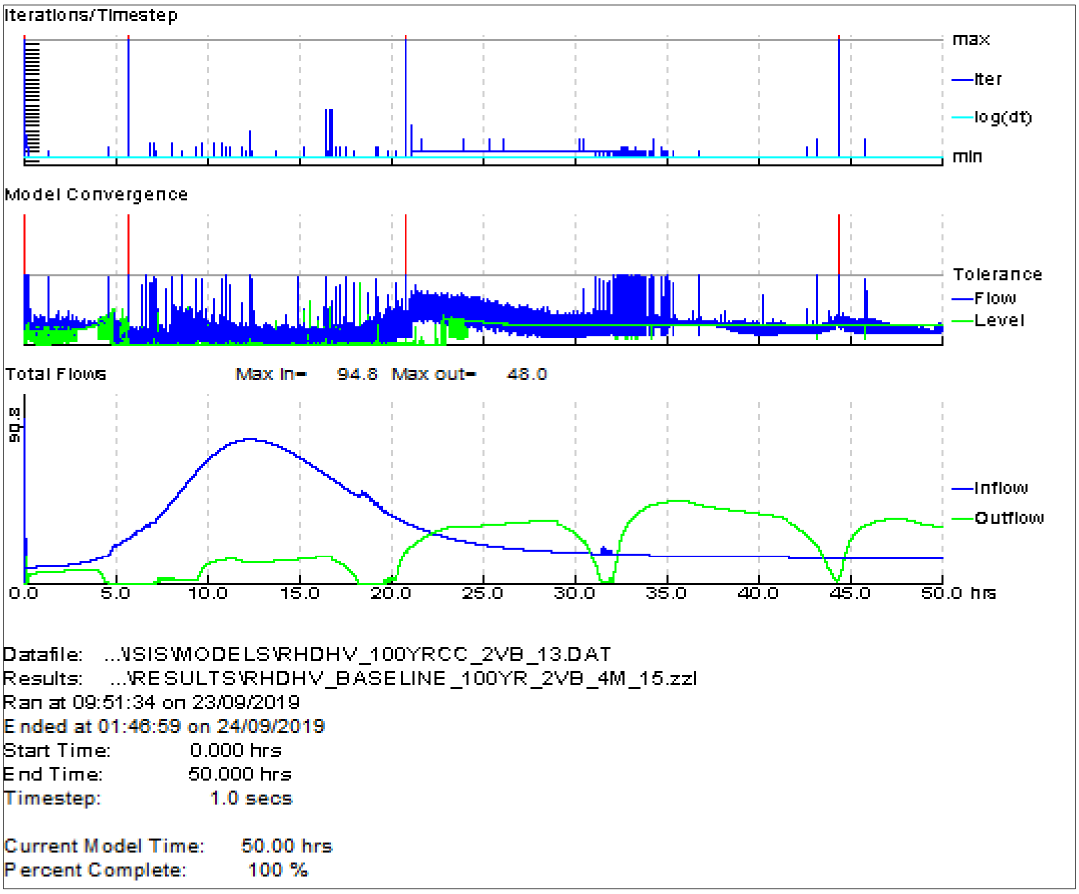
5.1.3. The following parameters were amended in the 1D model to improve overall model stability and confidence in results:

- To prevent model failure due to the channel drying out at low-flows, the automated Preissmann slot option was activated;
- dflood was raised from 3 to 10. this parameter is used to set up the size of the cross-section property arrays within Flood Modeller. By providing a larger dflood the model uses more memory and also allows more chance of converging;
- Theta was increased from 0.7 to 0.95. Increased theta improves model stability and tends to smooth numerical spikes;
- Orifice linearisation head was changed from 0 to 0.05 to prevent oscillations at low head differences in the orifice units;
- Maxitr was raised from 6 to 29. Increasing Maxitr allows for more calculations to be performed. In general, the larger the model the larger Maxitr should be to improve model convergence;
- Top slot height: Specified global value for total depth of conduit top slot, measured from its opening to its top was set to 5m.

5.2 1D Model stability

5.2.1. The 1 in 100-year model simulation satisfactorily completed with limited non-convergence, as illustrated in **Plate 5.1**.

Plate 5.1. 1D model convergence plot for the 1 in 100-year event.



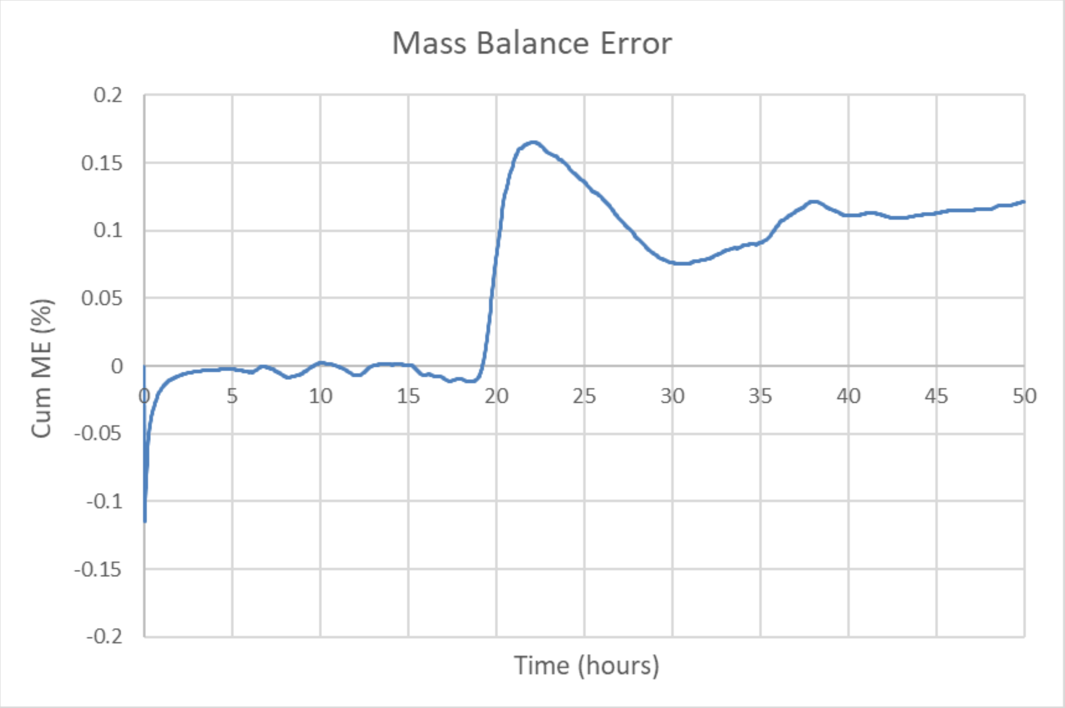
```
Datafile:   ...\ISIS\MODELS\RHDHV_100YRCC_2VB_13.DAT
Results:    ...\RESULTS\RHDHV_BASELINE_100YR_2VB_4M_15.zzl
Ran at 09:51:34 on 23/09/2019
Ended at 01:46:59 on 24/09/2019
Start Time:          0.000 hrs
End Time:           50.000 hrs
Timestep:              1.0 secs

Current Model Time:     50.00 hrs
Percent Complete:        100 %
```

5.3 2D Model stability

5.3.1. Numerical convergence in the 2D model has been checked through examination of the mass balance error time series within the MB2D.csv results. Numerical convergence is considered very good if cumulative mass balance errors are less than 1%.

5.3.2. The mass balance output for the 1 in 100-year event is shown in **Plate 5.2**. The results of the mass balance error show that the model is within the expected tolerance.

Plate 5.2. Cumulative 2D mass balance error for the 1 in 100-year event.



6 Results

6.1 Baseline model

6.1.1. The baseline model was simulated for 1 in 20-year, 1 in 100-year and 1 in 1,000-year return period events for the present day and with allowance for climate change (15%, 25%, 35% and 65%) scenarios.

6.1.2. Results presented in this report are focused on the 1 in 100-year return period event with 35% allowance for climate change for the assessment of off-site impacts and 1 in 100-year event with 65% climate change allowance for on-site flood risk.

6.1.3. Full set of 1D and 2D model results for all modelled scenarios for the baseline and 'with scheme' schematisations are supplied together with this technical note in a digital format.

6.1.4. Complete set of figures illustrating maximum flood depth, velocity and hazard for the baseline modelling for all considered return period events and climate change scenarios are provided in Appendix A: 2VB Fluvial model results – Baseline flood depth, hazard and velocity.

6.1.5. Results illustrating the maximum flood depth, velocity and hazard in the area of interest for the 1 in 100-year return period event with 35% and 65% climate change allowance (as basis of design) and the 1 in 1,000-year event with 65%CC representing a very extreme event are presented in **Plate 6.1** to **Plate 6.9** respectively.

Plate 6.1. Maximum flood depth for the baseline scenario for the 1 in 100-year return period event with 35% climate change allowance.

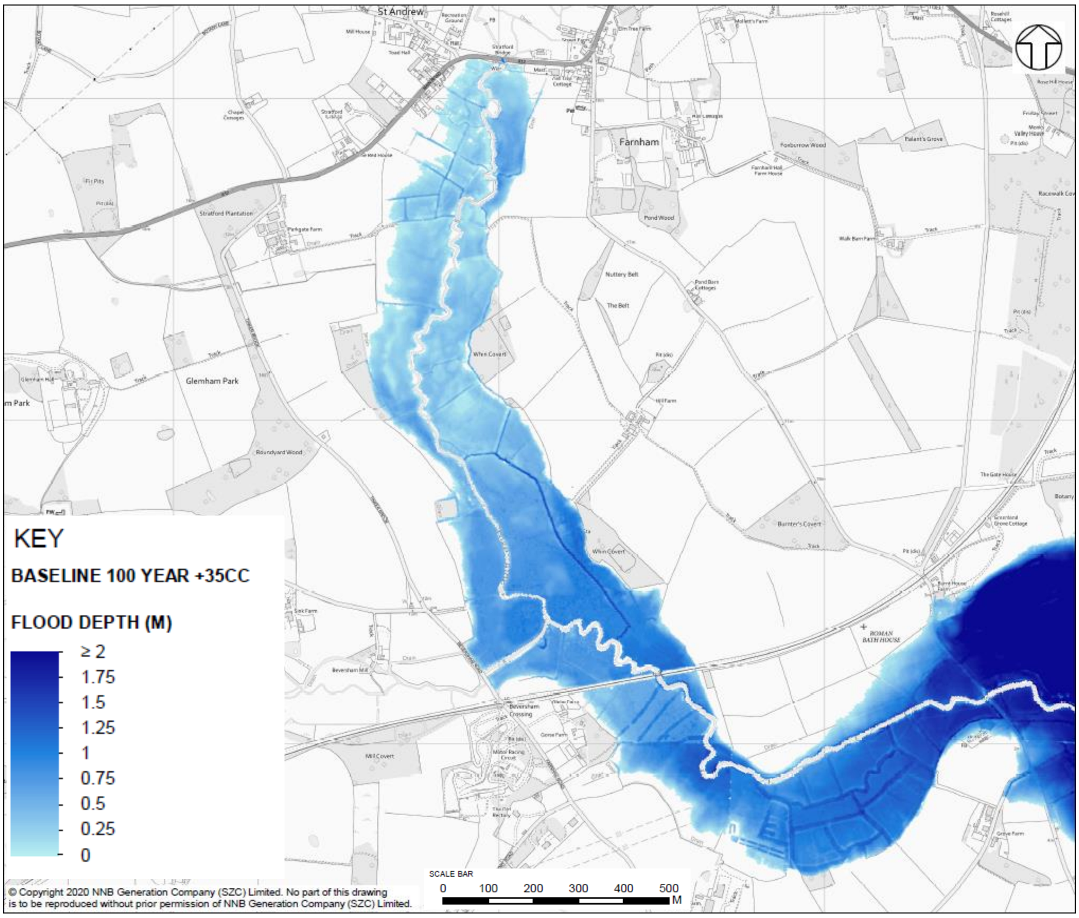


Plate 6.2. Maximum flood depth for the baseline scenario for the 1 in 100-year return period event with 65% climate change allowance.

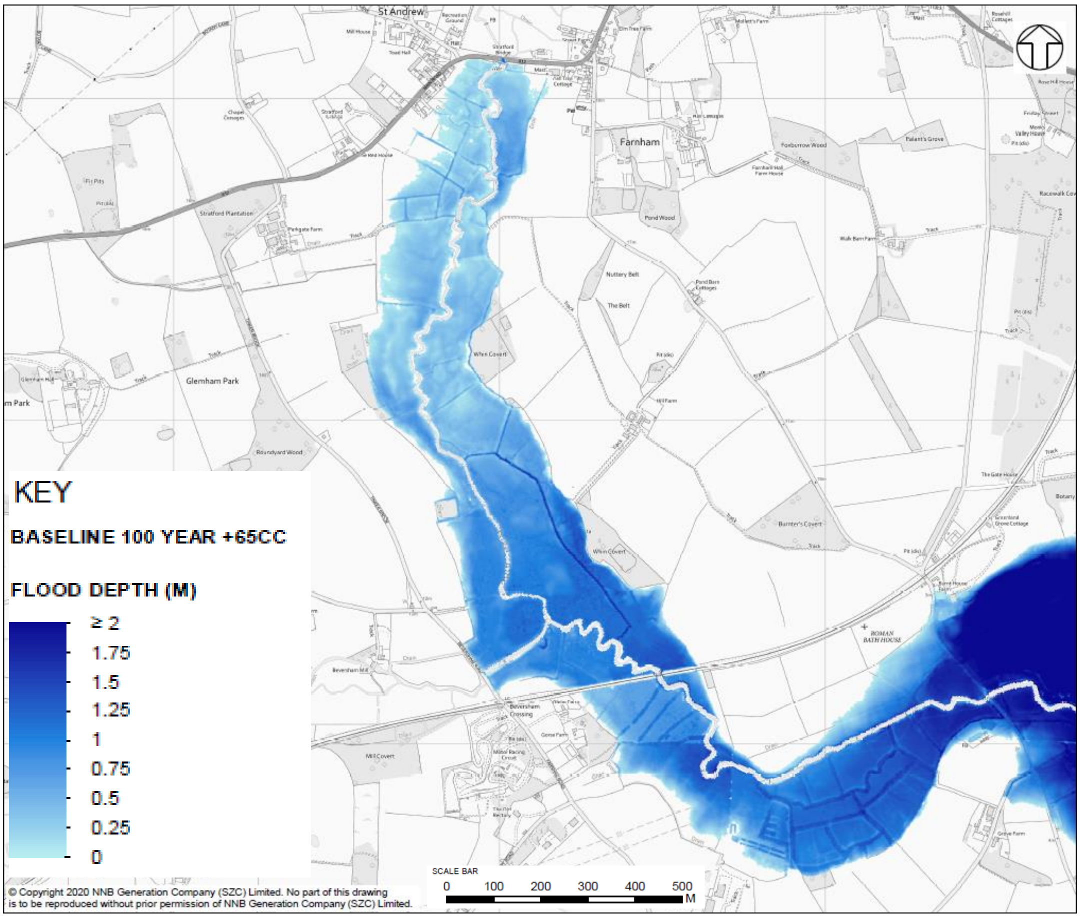
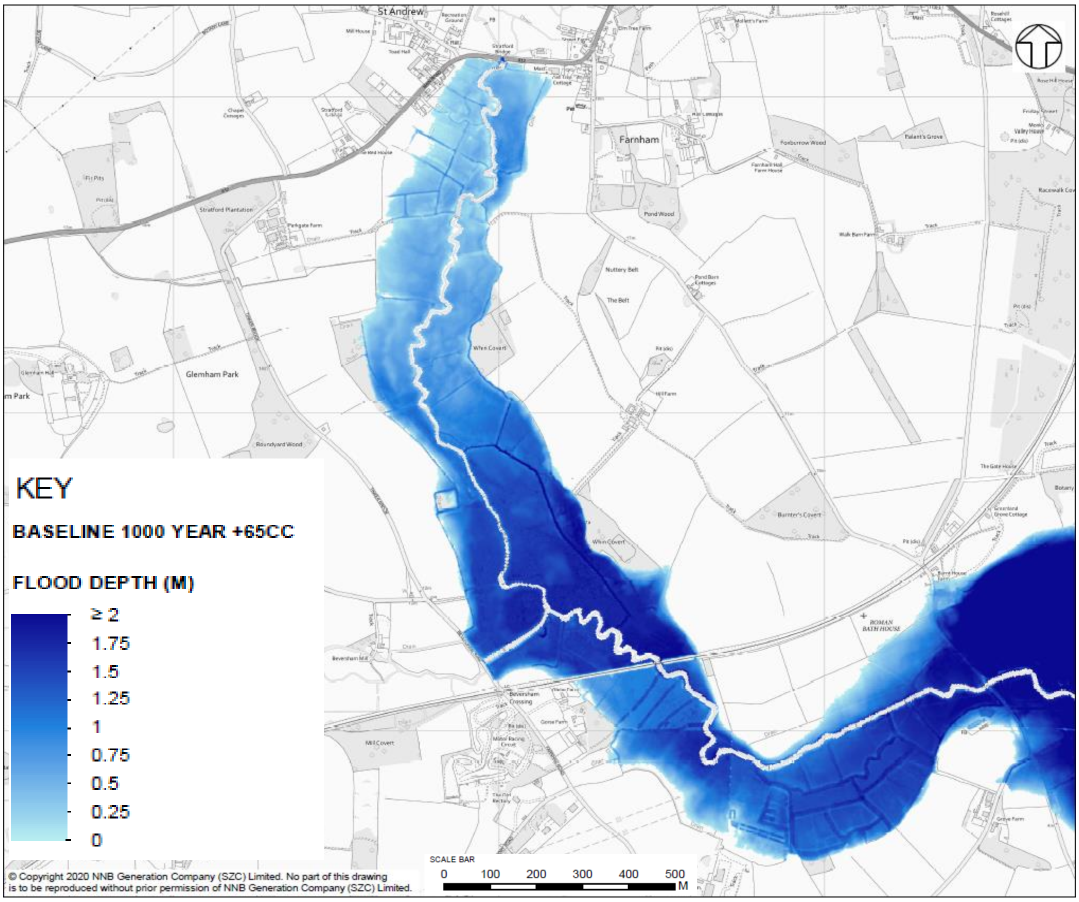


Plate 6.3. Maximum flood depth for the baseline scenario for the 1 in 1,000-year return period event with 65% climate change allowance.



6.1.6. The results presented above (**Plate 6.1** - **Plate 6.3**) show that the River Alde floodplain is relatively wide and fully inundated with the maximum flood depth in the area of interest (between A12 at Stratford St Andrew and the railway line north of Blaxhall/near Gorse Farm). The depths are up to 1.0m, 1.2m and 1.8m within the eastern floodplain near the railway line for the 1 in 100-year event with 35% and 65%CC and the 1 in 1,000-year event with 65%CC allowance respectively. In the area of the proposed development the flood depths are approximately 0.3m, 0.4m and 0.6m for the presented events respectively.

Plate 6.4. Maximum flood velocity for the baseline scenario for the 1 in 100-year return period event with 35% climate change allowance.

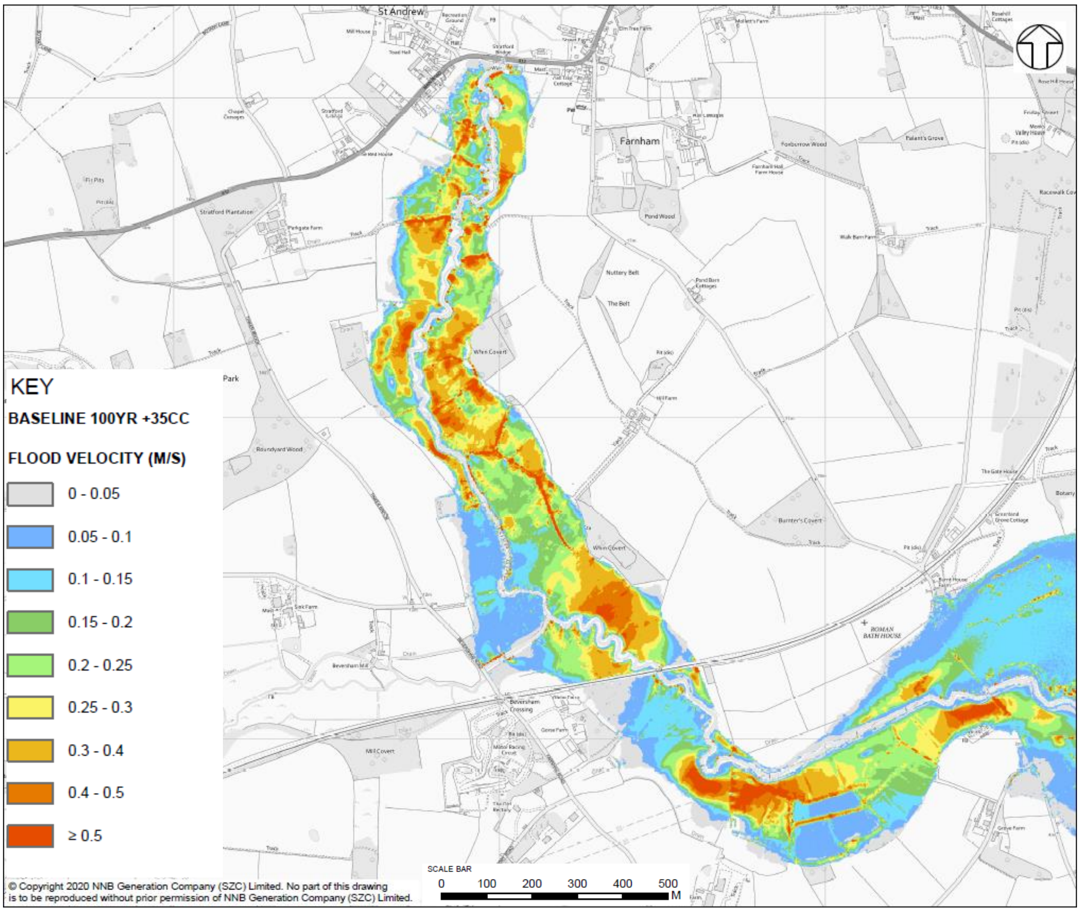


Plate 6.5. Maximum flood velocity for the baseline scenario for the 1 in 100-year return period event with 65% climate change allowance.

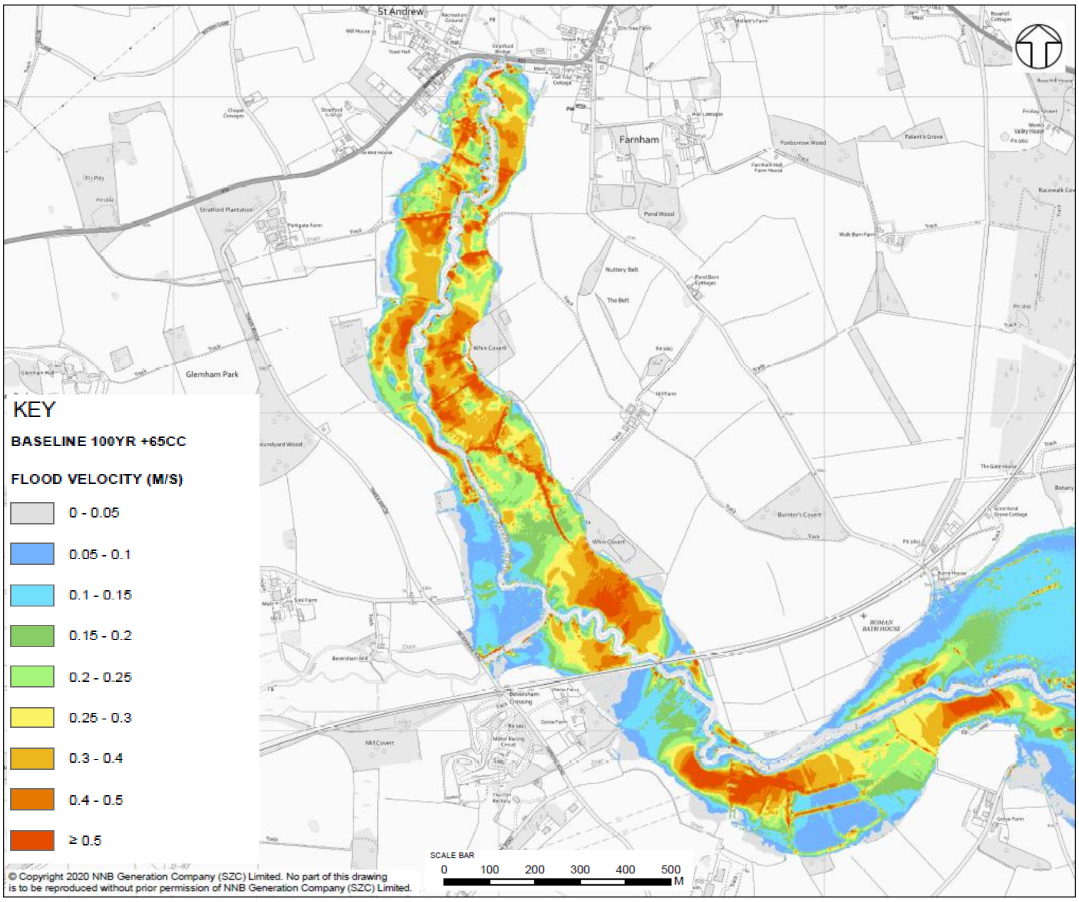
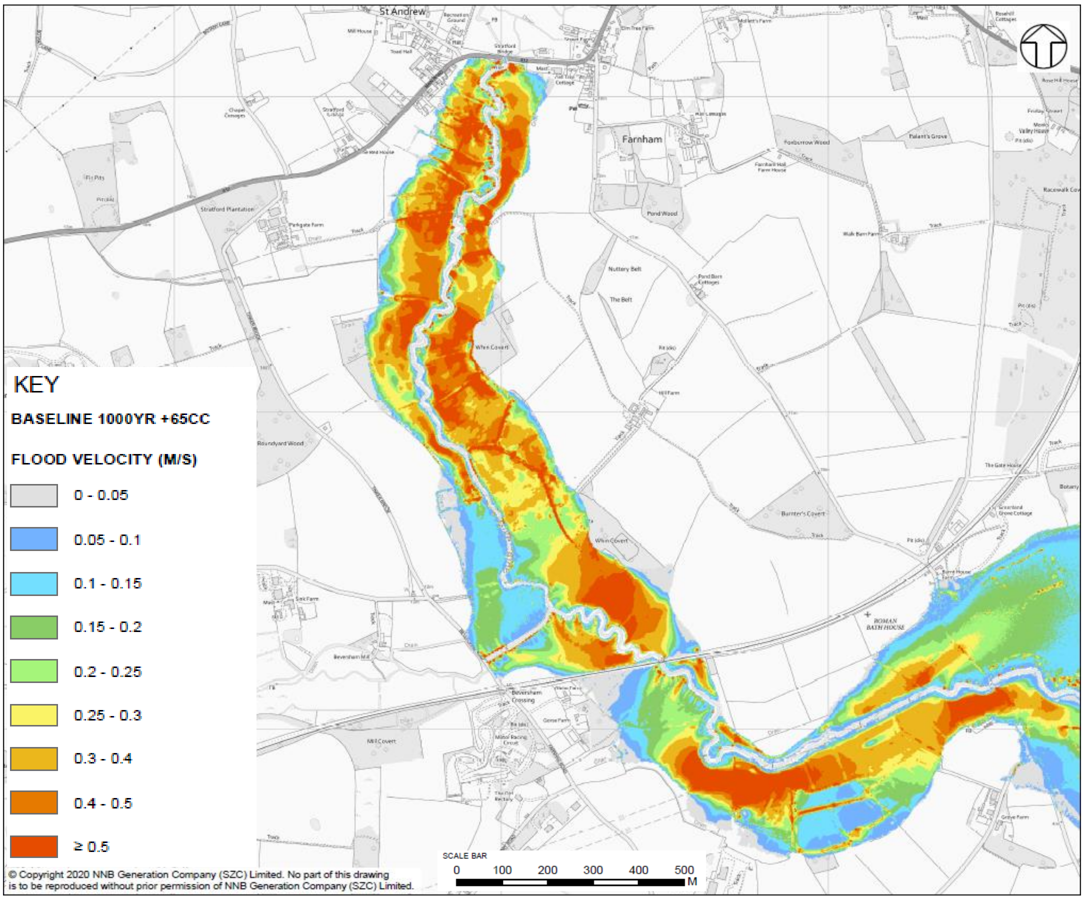


Plate 6.6. Maximum flood velocity for the baseline scenario for the 1 in 1,000-year return period event with 65% climate change allowance.



6.1.7. The velocities through the floodplain in the area of interest (**Plate 6.4** - **Plate 6.6**) are quite variable, ranging from 0.1 m/s to 0.5 m/s with larger areas of higher velocity in the more extreme scenarios. This is mainly due to changes in topography, presence of drains and embankments that impact the distribution of flow.

Plate 6.7. Flood hazard rating for the baseline scenario for the 1 in 100-year return period event with 35% climate change allowance.

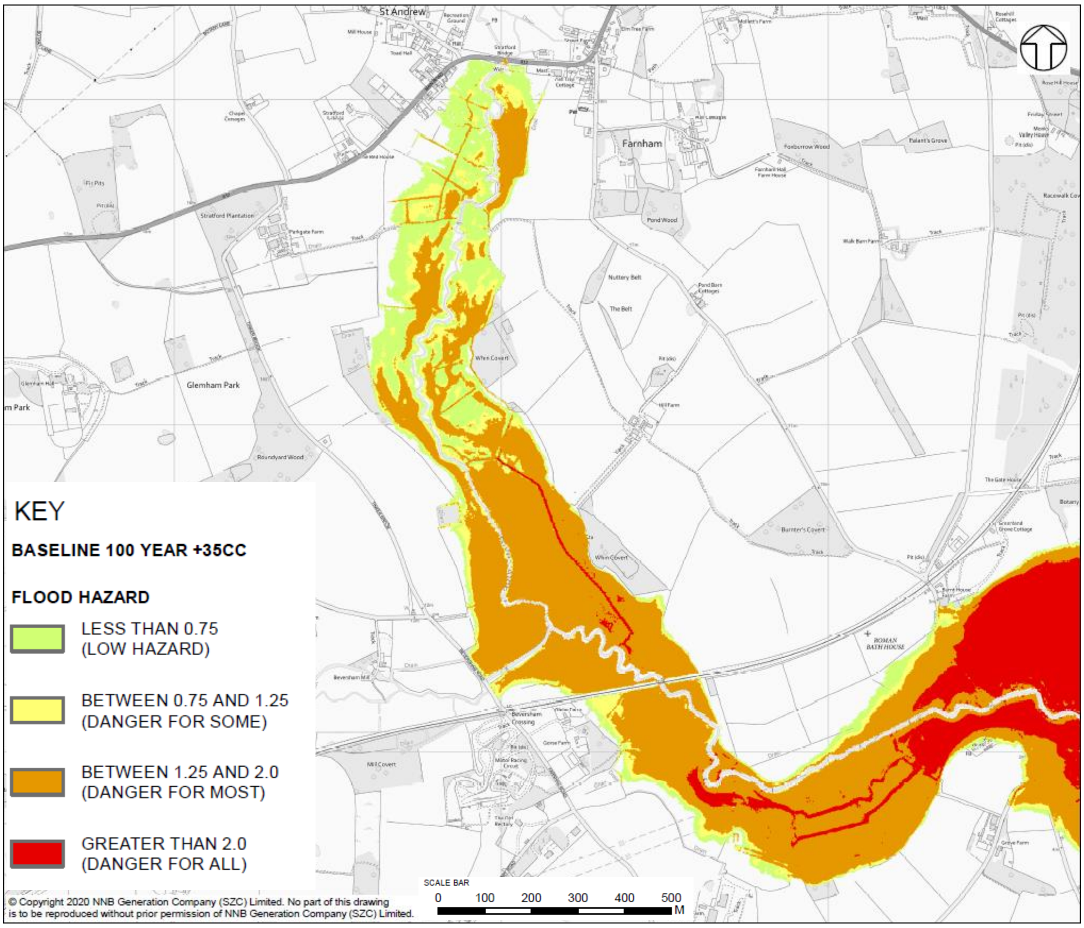


Plate 6.8. Flood hazard rating for the baseline scenario for the 1 in 100-year return period event with 65% climate change allowance.

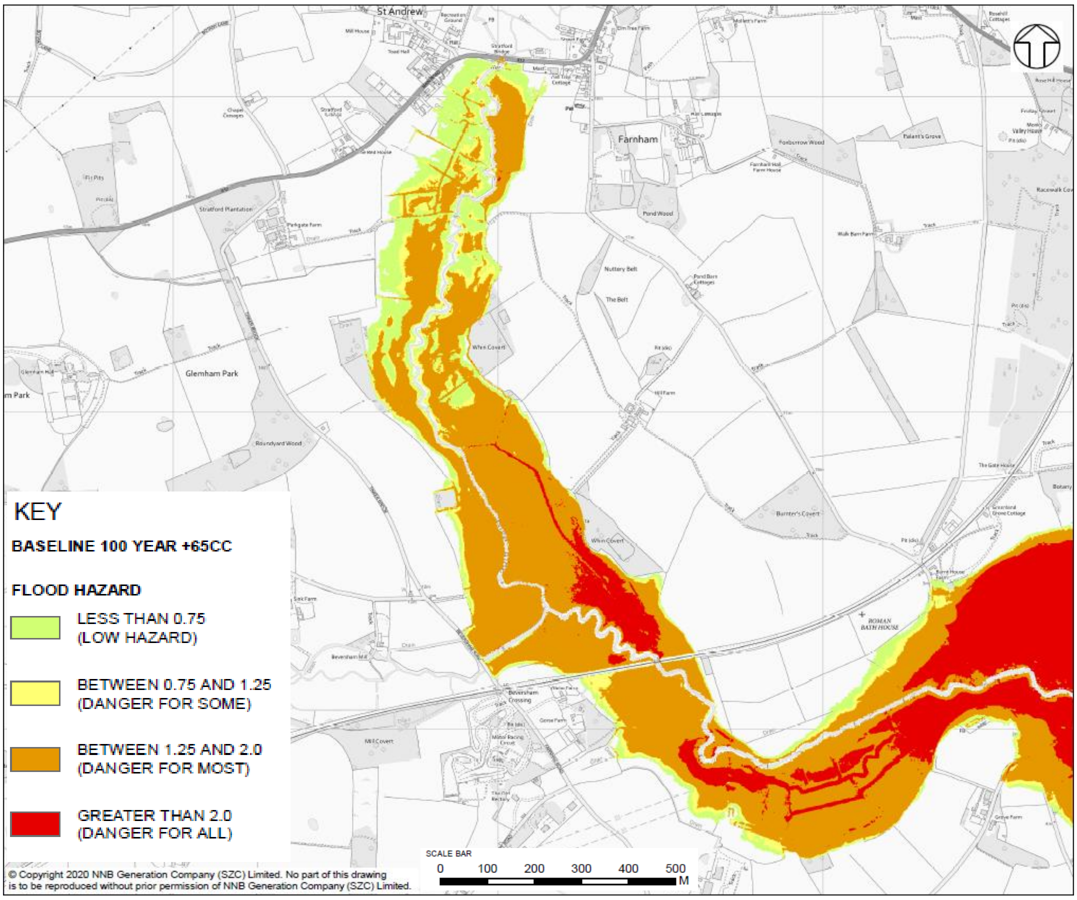


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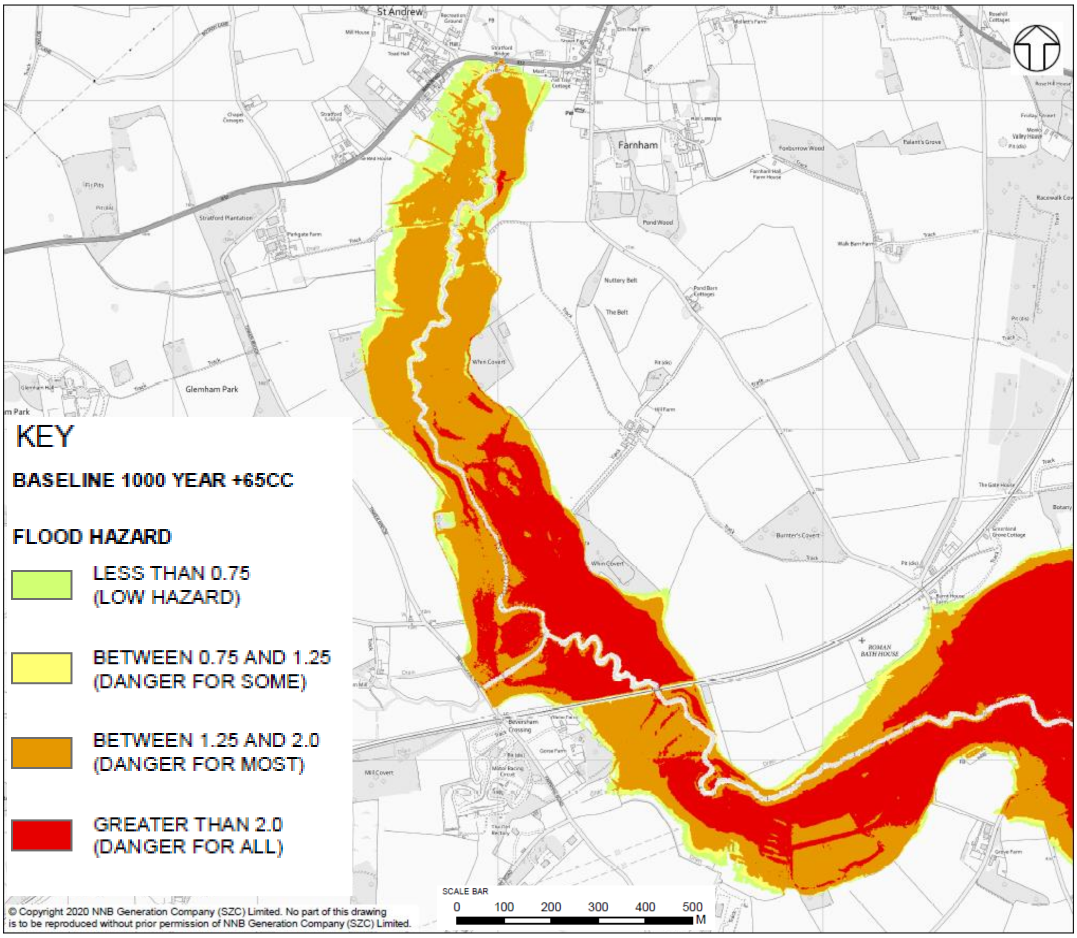
Plate 6.9. Flood hazard rating for the baseline scenario for the 1 in 1,000-year return period event with 65% climate change allowance.



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6.1.8. The flood hazard rating maps (**Plate 6.7** - **Plate 6.9**) show that within the area of interest the hazard rating for the 1 in 100-year event with 35%CC is mostly 'danger for most' near the railway line whereas near proposed development location it is mostly 'low hazard' with areas of 'danger for some' and 'danger for most', and it increased to mostly 'danger for all' and 'danger for most' in the 1 in 1,000-year event with 65%CC in the two areas respectively.

6.1.9. There are no residential or commercial properties within the floodplain between the B12 at Stratford St Andrew and the railway line north of Blaxhall/near Gorse Farm. The main receptors in this area are farmland, flora and fauna.

6.1.10. The maximum stages from baseline model results for selected 1D model nodes within the area of interest (**Plate 6.10**) for all considered return period events and climate change scenarios are presented in **Table 6.1**.

Plate 6.10. Selected 1D model nodes in the area of interest.

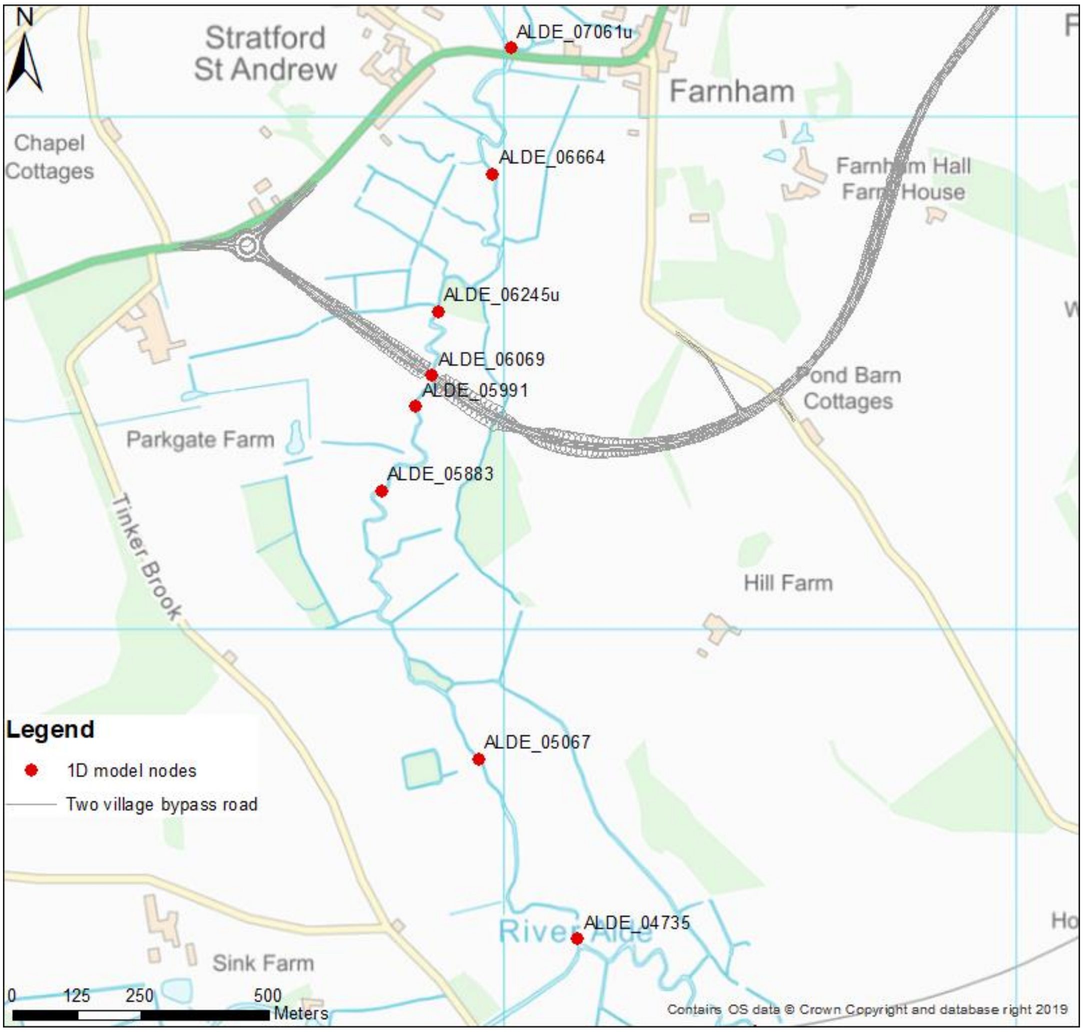


Table 6.1. Maximum stage for selected 1D model nodes – baseline

Return Period (years)	1D model node							
	ALDE 07061u	ALDE 06664	ALDE 06245u	ALDE 06069	ALDE 05991	ALDE 05883	ALDE 05067	ALDE 04735
20	6.23	5.75	5.28	4.93	4.78	4.68	3.75	3.59
20 +15%CC	6.31	5.80	5.32	4.94	4.80	4.70	3.79	3.66
20 +25%CC	6.36	5.82	5.34	4.95	4.82	4.71	3.82	3.70

Return Period (years)	1D model node							
20 +35%CC	6.42	5.85	5.35	4.97	4.84	4.73	3.87	3.76
20 +65%CC	6.58	5.91	5.39	5.00	4.87	4.77	3.96	3.89
100	6.48	5.87	5.37	4.98	4.85	4.74	3.89	3.81
100 +15%CC	6.62	5.92	5.39	5.00	4.88	4.77	3.99	3.94
100 +25%CC	6.68	5.94	5.41	5.01	4.89	4.78	4.04	4.00
100 +35%CC	6.76	5.97	5.43	5.02	4.90	4.80	4.10	4.09
100 +65%CC	7.03	6.03	5.47	5.05	4.94	4.84	4.28	4.28
1,000	7.11	6.05	5.48	5.06	4.95	4.85	4.32	4.32
1,000 +15%CC	7.35	6.09	5.51	5.08	4.98	4.88	4.43	4.43
1,000 +25%CC	7.51	6.12	5.53	5.10	5.00	4.91	4.52	4.52
1,000 +35%CC	7.70	6.14	5.54	5.12	5.03	4.94	4.63	4.64
1,000 +65%CC	8.10	6.20	5.57	5.18	5.11	5.04	4.86	4.86

6.2 ‘With scheme’ model

6.2.1. The ‘with scheme’ model was simulated for the same scenarios as the baseline model, namely: 1 in 20-year, 1 in 100-year and 1 in 1,000-year return period events for the present day and with allowance for climate change (15%, 25%, 35% and 65%).

6.2.2. Similar to **section 6.1**, results presented in this report from the ‘with scheme’ model are focused on the 1 in 100-year return period event with 35% and 65% allowance for climate change and the 1 in 1,000-year event with 65% climate change allowance.

6.2.3. A fuller set of 1D and 2D model results for all modelled scenarios for the baseline and 'with scheme' schematisations are supplied together with this technical note in a digital format.

6.2.4. A complete set of figures illustrating maximum flood depth, velocity and hazard for the baseline modelling for all considered return period events and climate change scenarios is provided in Appendix B: 2VB Fluvial model results – 'With scheme' flood depth, hazard and velocity.

6.2.5. Results illustrating the maximum flood depth, velocity and hazard in the area of interest for the 1 in 100-year return period event with 35% and 65% allowance for climate change and the 1 in 1,000-year event with 65%CC are presented in **Plate 6.11** to **Plate 6.19**.

Plate 6.11. Maximum flood depth for the 'with scheme' scenario for the 1 in 100-year return period event with 35% climate change allowance.

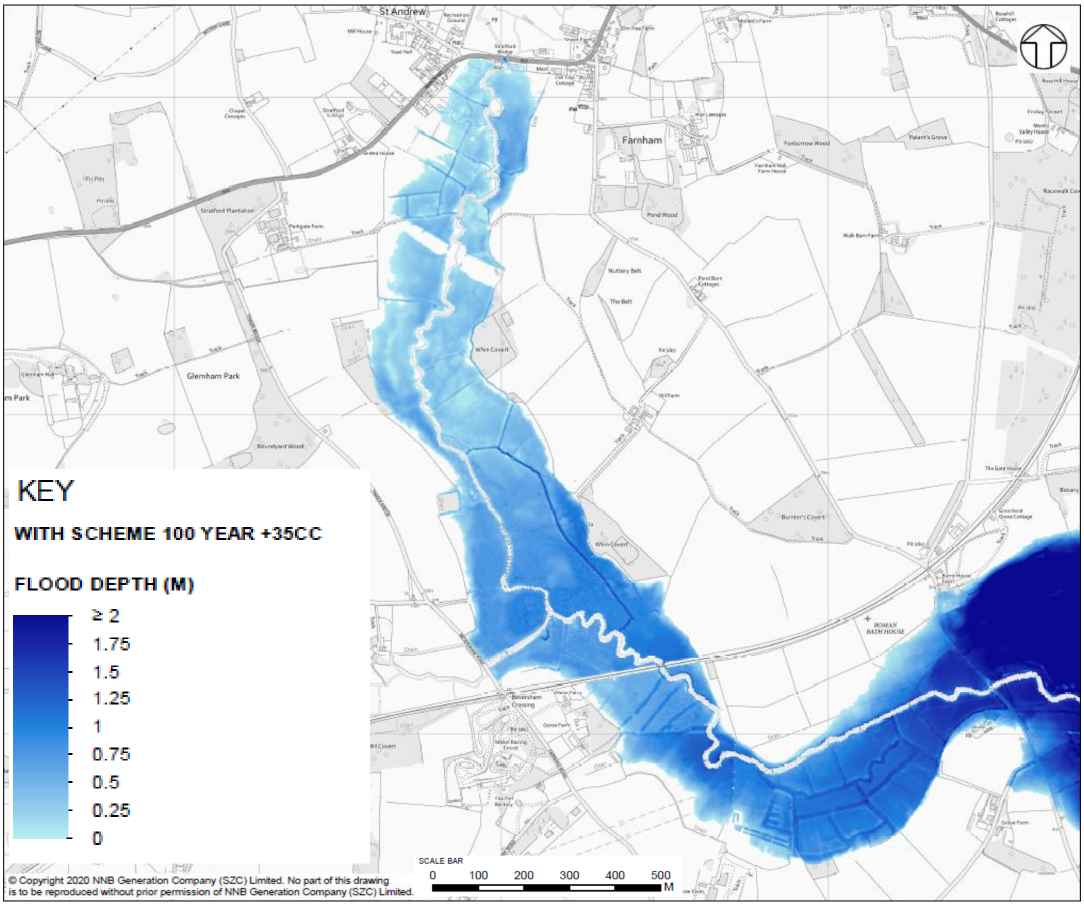


Plate 6.12. Maximum flood depth for the ‘with scheme’ scenario for the 1 in 100-year return period event with 65% climate change allowance.

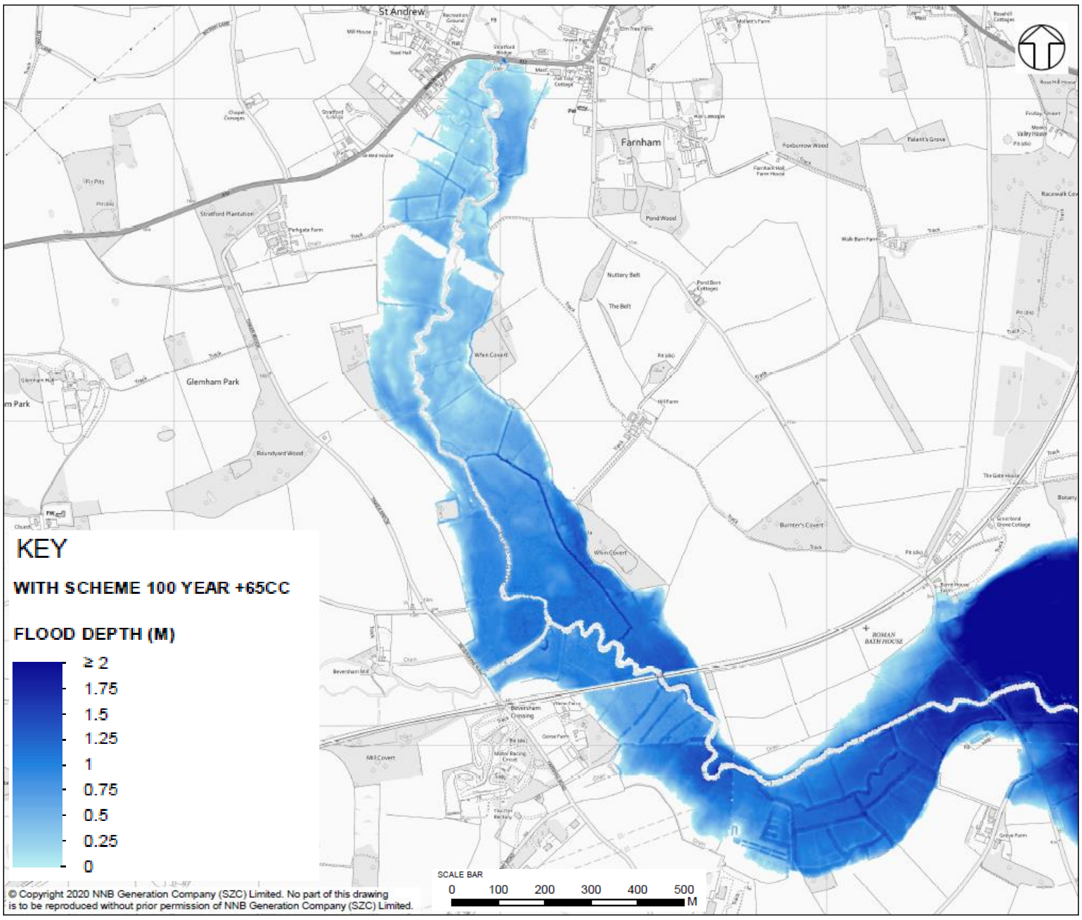
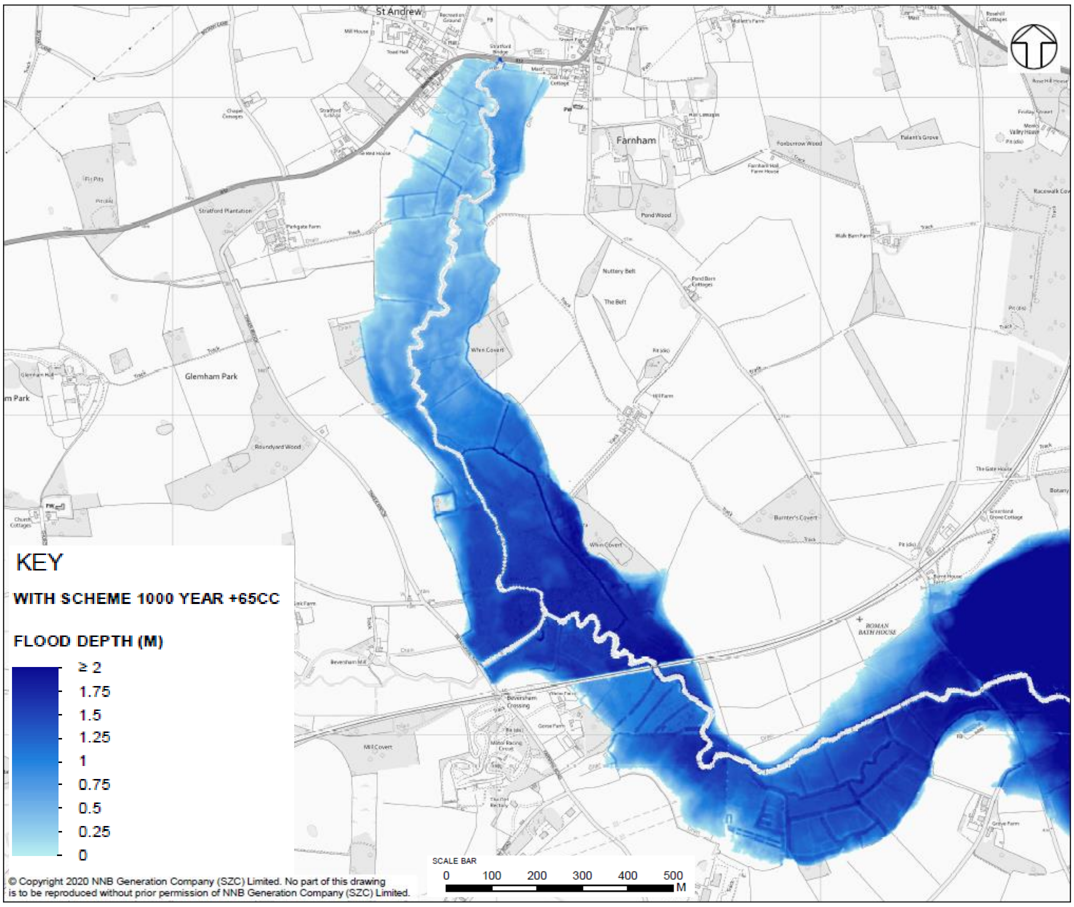


Plate 6.13. Maximum flood depth for the ‘with scheme’ scenario for the 1 in 1,000-year return period event with 65% climate change allowance.



6.2.6. The results presented above (**Plate 6.11** - **Plate 6.13**) show very similar flood extent and flood depth to the baseline scenario. The water depth in the vicinity of the River Alde crossing is predicted up to 0.5m, 0.6m and 0.9m for the 1 in 100-year event with 35% and 65% climate change and the 1 in 1,000-year event with 65%CC respectively.

Plate 6.14. Maximum flood velocity for the ‘with scheme’ scenario for the 1 in 100-year return period event with 35% climate change allowance.

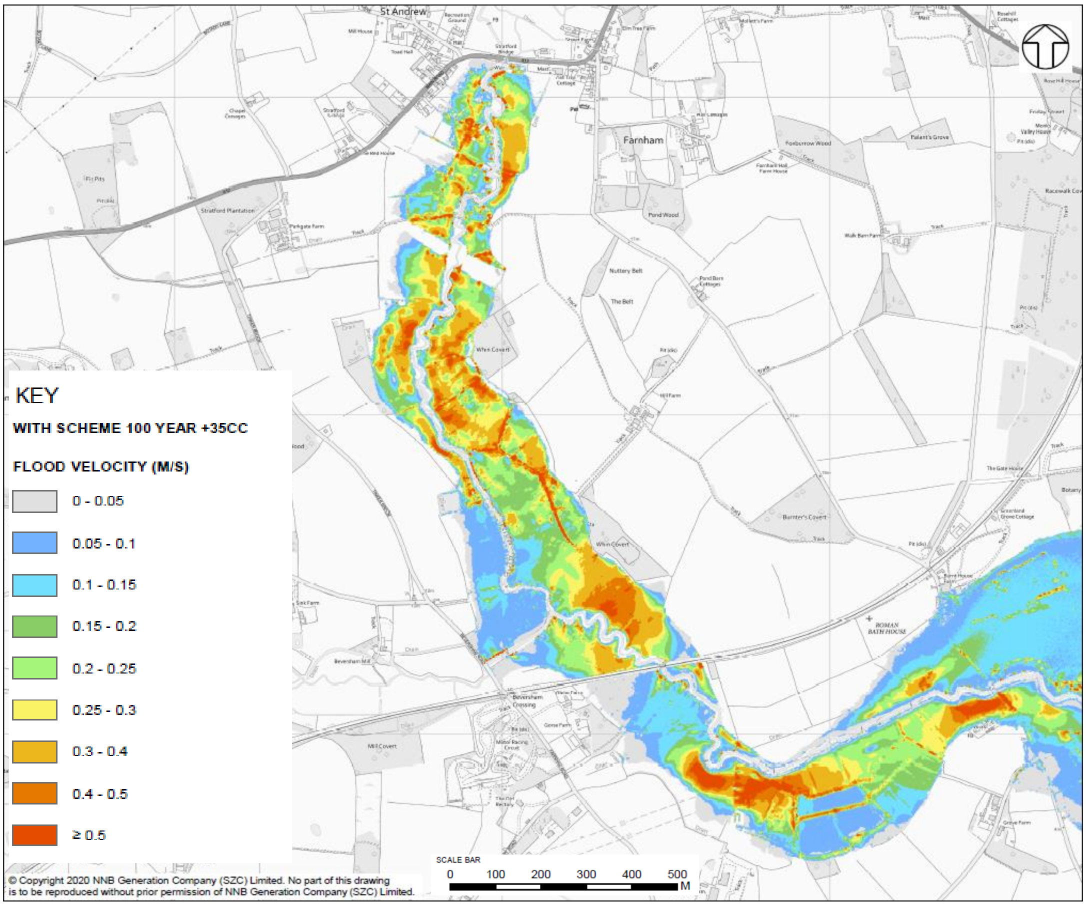


Plate 6.15. Maximum flood velocity for the ‘with scheme’ scenario for the 1 in 100-year return period event with 65% climate change allowance.

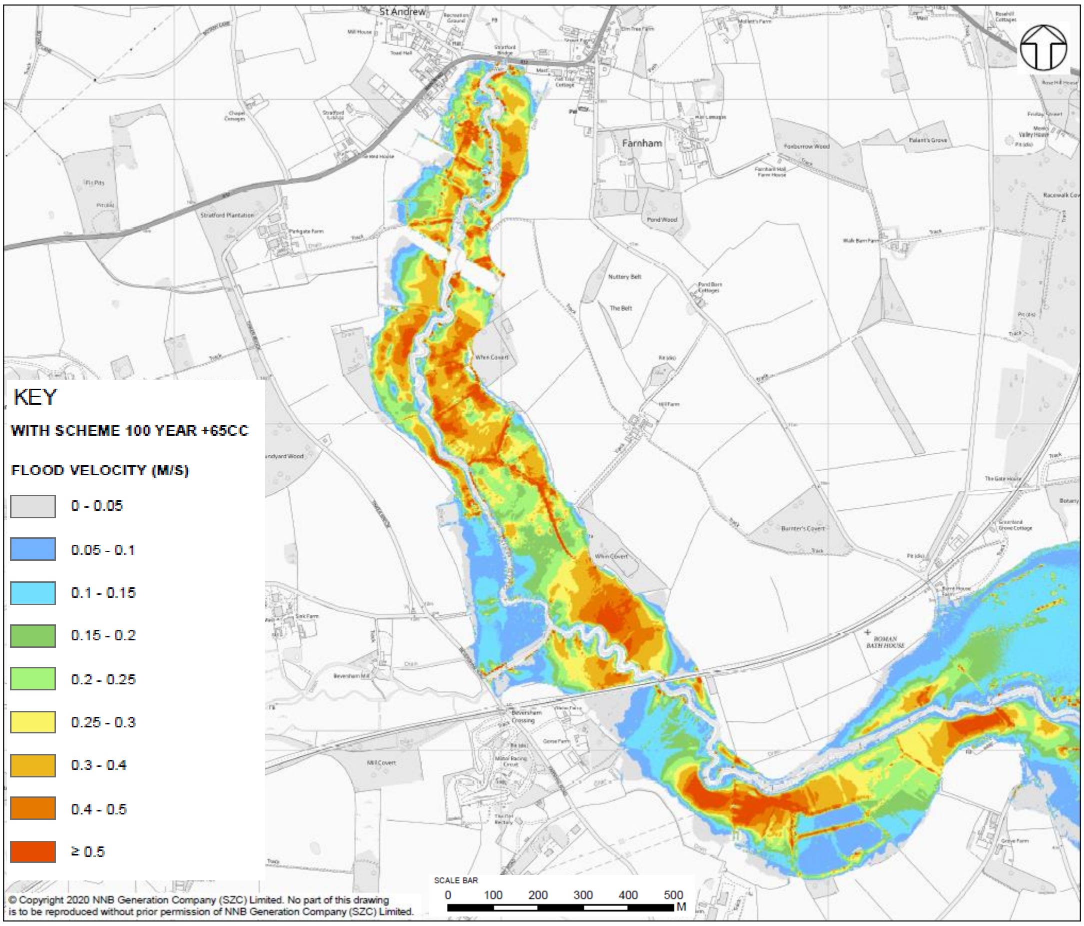
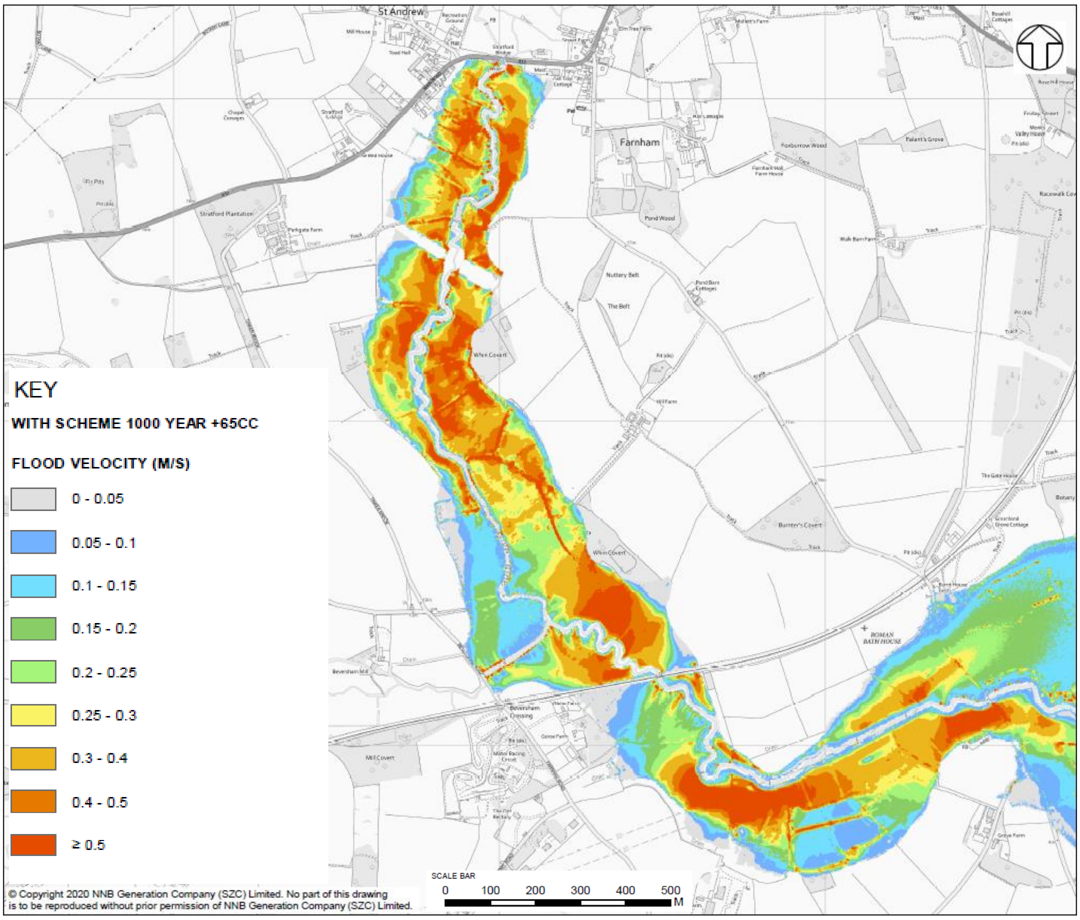


Plate 6.16. Maximum flood velocity for the 'with scheme' scenario for the 1 in 1,000-year return period event with 65% climate change allowance.



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6.2.7. The velocities through the floodplain near the road embankment (**Plate 6.14** - **Plate 6.16**) are low due to impoundment the embankment introduces with local higher velocity areas (above 0.5 m/s) where the water is flowing in and out of the flood relief culverts. Apart from the local differences along the road embankment the velocity in the rest of the model results are very similar to the baseline model results.

Plate 6.17. Flood hazard rating for the ‘with scheme’ scenario for the 1 in 100-year return period event with 35% climate change allowance.

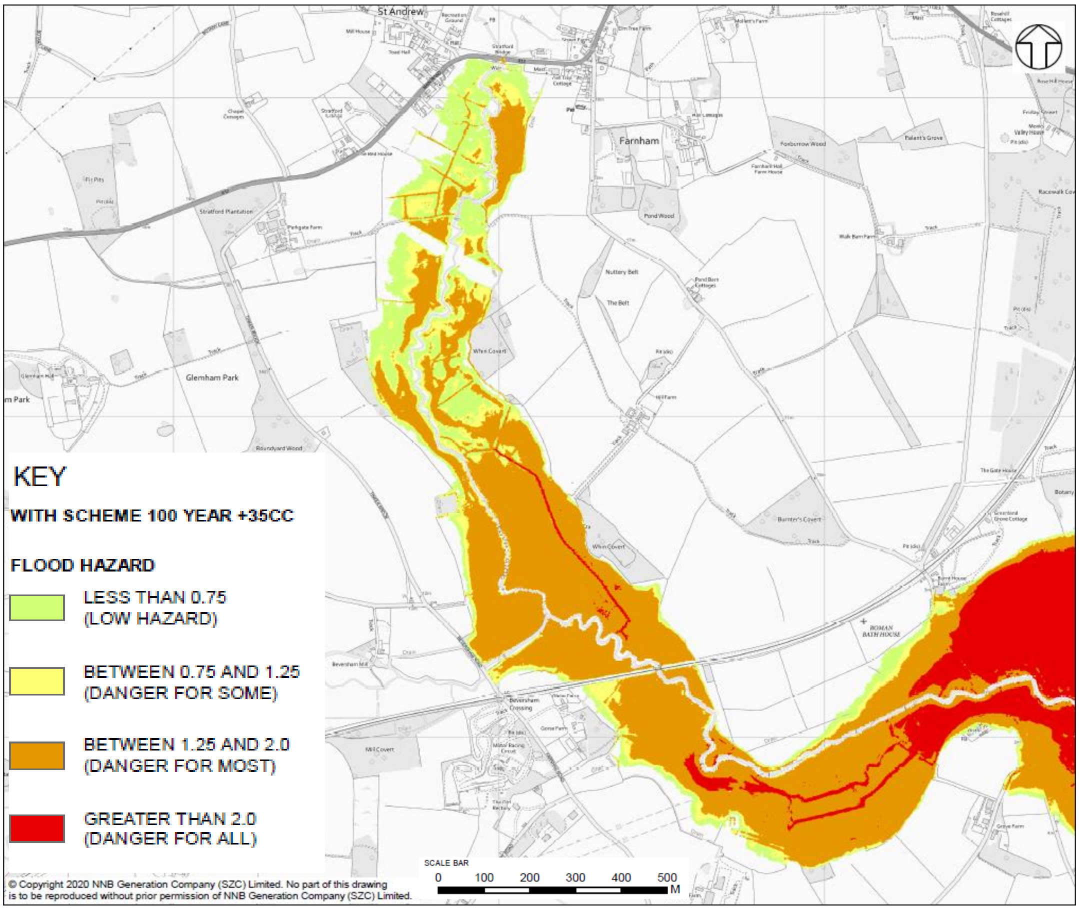


Plate 6.18. Flood hazard rating for the 'with scheme' scenario for the 1 in 100-year return period event with 65% climate change allowance.

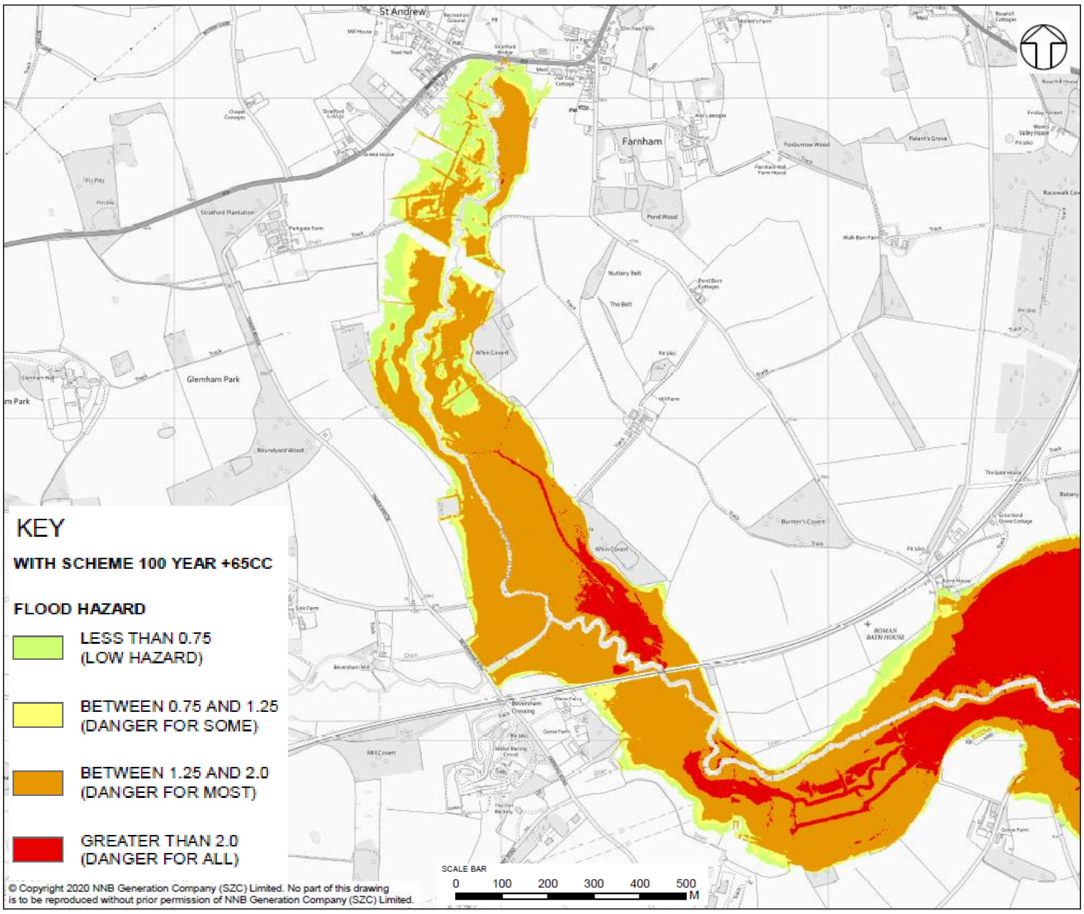
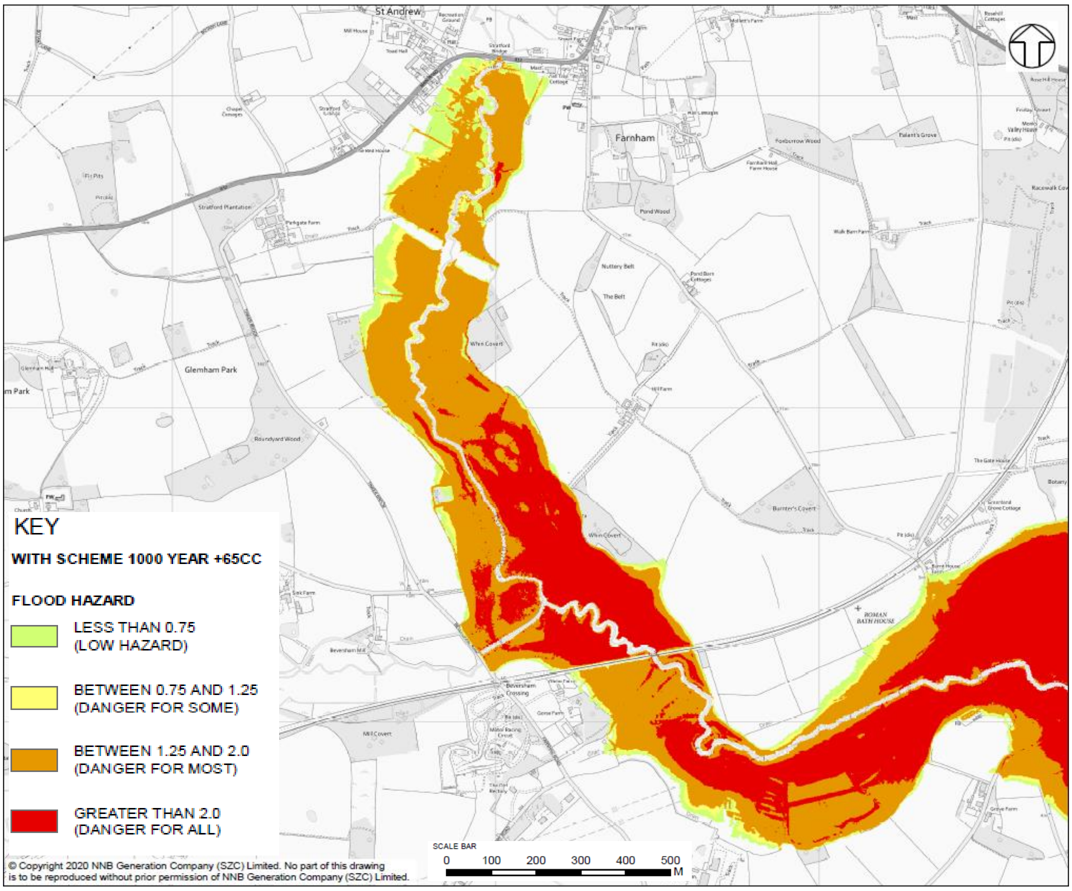


Plate 6.19. Flood hazard rating for the 'with scheme' scenario for the 1 in 1,000-year return period event with 65% climate change allowance.



6.2.8. The flood hazard rating near the proposed development in the 'with scheme' scenarios is very similar to the baseline scenario ranging from 'low hazard' in the 1 in 100-year event with 35%CC to 'danger for most' in the 1 in 1,000-year event with 65%CC. However, there are no properties at risk within the flood extent. Also, the development itself is not inundated in all assessed scenarios and therefore the flood hazard to the site is considered to be low.

6.2.9. The maximum stage results from the 'with scheme' model for selected 1D model nodes within the area of interest (**Plate 6.10**) for all considered return period events and climate change scenarios are presented in **Table 6.2**.

Table 6.2. Maximum stage for selected 1D model nodes – 'with scheme'

Return Period (years)	1D model node							
	ALDE 07061u	ALDE 06664	ALDE 06245u	ALDE 06069	ALDE 05991	ALDE 05883	ALDE 05067	ALDE 04735
20	6.23	5.74	5.16	4.94	4.80	4.69	3.74	3.58
20 +15%CC	6.31	5.80	5.20	4.96	4.82	4.71	3.79	3.66
20 +25%CC	6.36	5.84	5.23	4.97	4.83	4.72	3.82	3.70
20 +35%CC	6.41	5.86	5.26	4.99	4.85	4.74	3.85	3.76
20 +65%CC	6.57	5.93	5.32	5.01	4.89	4.77	3.95	3.88
100	6.47	5.90	5.28	5.00	4.87	4.75	3.89	3.80
100 +15%CC	6.62	5.93	5.33	5.01	4.88	4.77	3.97	3.90
100 +25%CC	6.67	5.96	5.36	5.02	4.90	4.79	4.03	3.99
100 +35%CC	6.76	5.98	5.38	5.03	4.91	4.80	4.09	4.07
100 +65%CC	7.02	6.04	5.44	5.08	4.96	4.85	4.27	4.26
1,000	7.11	6.06	5.46	5.10	4.97	4.86	4.30	4.30
1,000 +15%CC	7.35	6.10	5.51	5.14	5.01	4.89	4.41	4.42
1,000 +25%CC	7.51	6.13	5.54	5.16	5.03	4.91	4.49	4.50
1,000 +35%CC	7.70	6.15	5.57	5.20	5.06	4.94	4.60	4.61
1,000 +65%CC	8.11	6.20	5.64	5.27	5.13	5.04	4.84	4.84

6.2.10. Results in **Table 6.2** show that the maximum water levels around the two village bypass crossing (1D model node ALDE_06069) are less than 5.5m AOD whereas the road level of the carriageway is proposed at approximately 7m AOD. On that basis, the model results show that the carriageway itself would not be at risk of flooding, even at such extreme flood event as 1 in 100-year with 65% climate change allowance or 1 in 1,000-year return period throughout its all design lifetime.

6.3 Comparison between baseline and 'with scheme'

6.3.1. Results from both the baseline and 'with scheme' models have been compared to assess potential impact of the development on the flood risk in the surrounding areas. For that purpose, difference plots of maximum flood depth were prepared. These are presented in **Plate 6.20** – **Plate 6.22** for the 1 in 100 year return period with 35% and 65% allowances for climate change and the 1 in 1,000-year event with 65% climate change scenarios respectively.

6.3.2. For the 1 in 100 year with 35%climate change scenario, the 'with scheme' model results show an average increase in water level within the floodplain by approximately 64mm localised to the area immediately upstream of the road embankment. There is a relatively confined low-lying area immediately upstream of the road embankment on the western floodplain where maximum increase in water level is up to 300mm.

Plate 6.20. Difference in flood depth – 1 in 100-year event with 35%CC

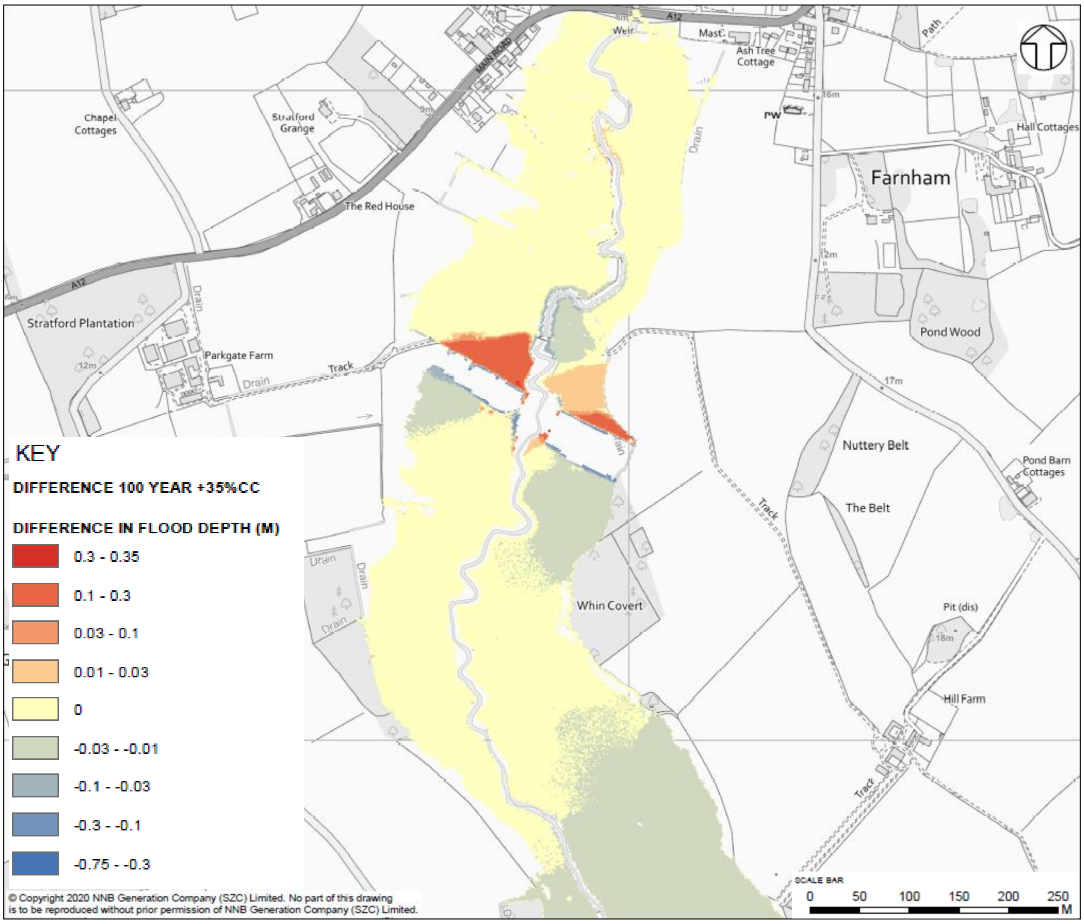


Plate 6.21. Difference in flood depth – 1 in 100-year event with 65%CC

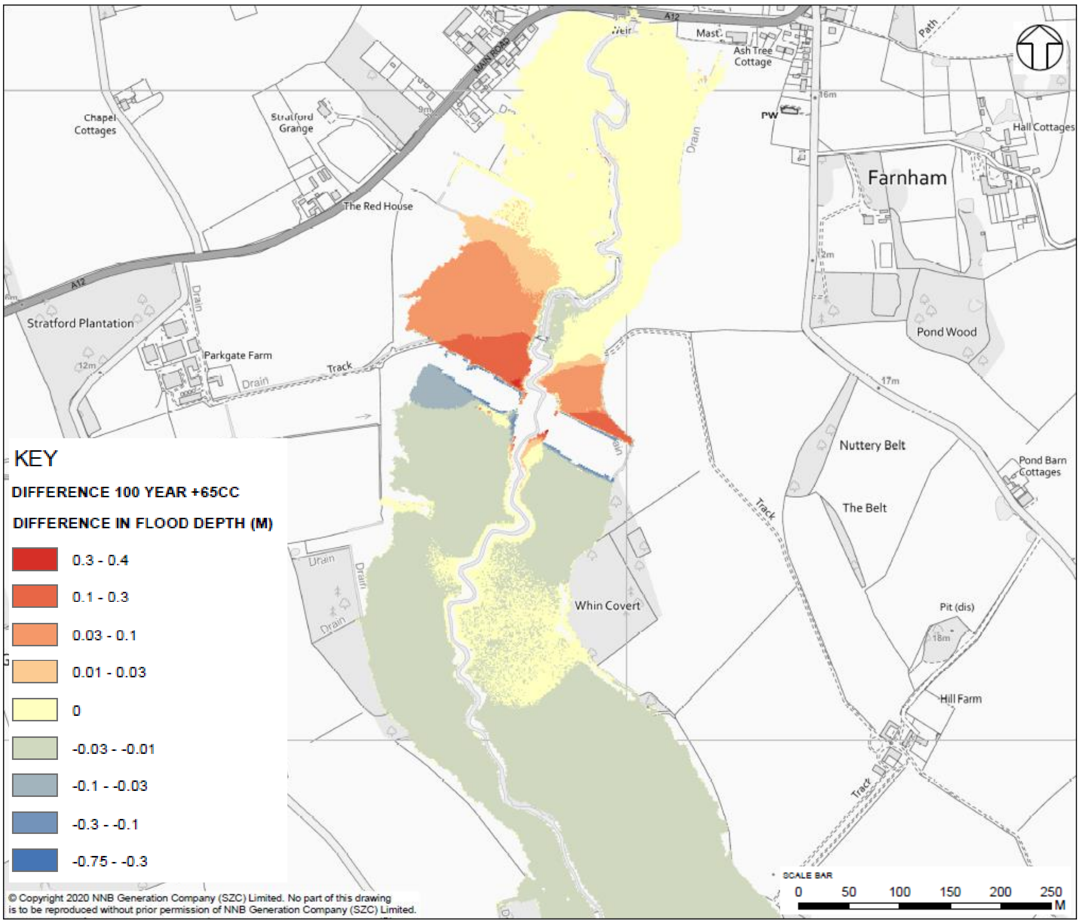
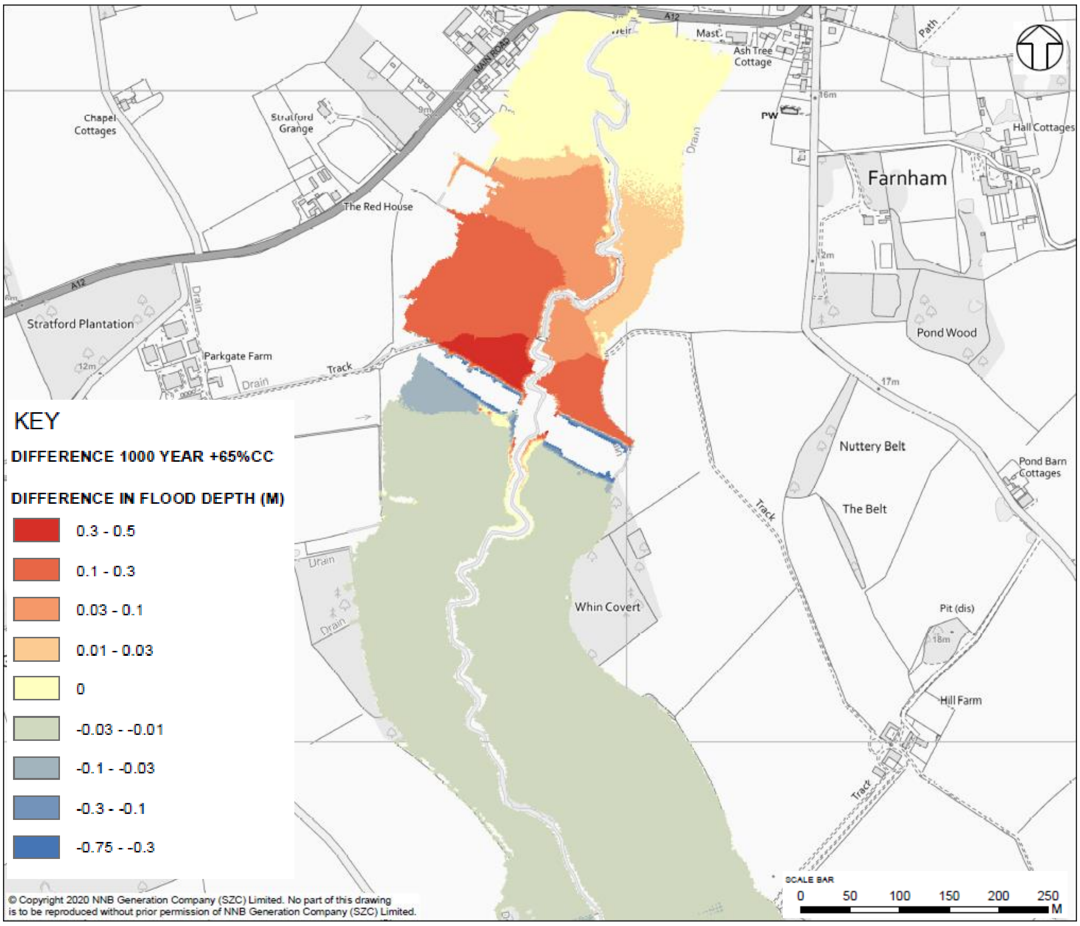


Plate 6.22. Difference in flood depth – 1 in 1,000-year event with 65%CC



6.3.3. **Plate 6.23** - **Plate 6.26** show difference in flood velocity and hazard for the 1 in 100-year and 1 in 1,000-year event with 65% climate change allowances respectively.

6.3.4. These plots show that there is no significant difference in flood velocity or hazard, and the changes are mostly associated with the road embankment and areas of change in flood depth.

6.3.5. There is limited change in flood extent, as illustrated in **Plate 6.27** and **Plate 6.28** for the 1 in 100-year and 1 in 1,000-year event with 65% climate change allowance respectively. The proposed development appears to be flood at the western edge of the floodplain, however that is only due to alignment of the embankment layer in the model limited by grid size and orientation. The flood levels are much lower than the elevation of the proposed crossing.

Plate 6.23. Difference in flood velocity – 1 in 100-year event with 65%CC

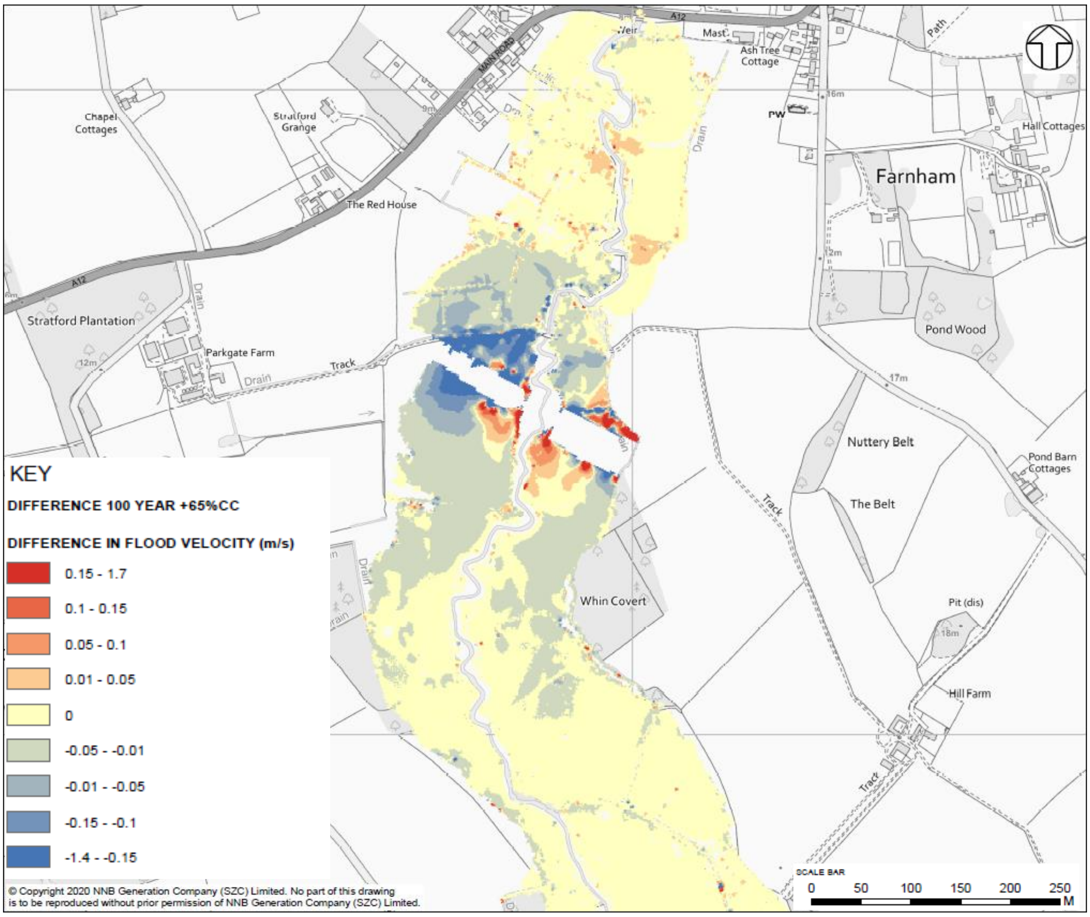


Plate 6.24. Difference in flood velocity – 1 in 1,000-year event with 65%CC

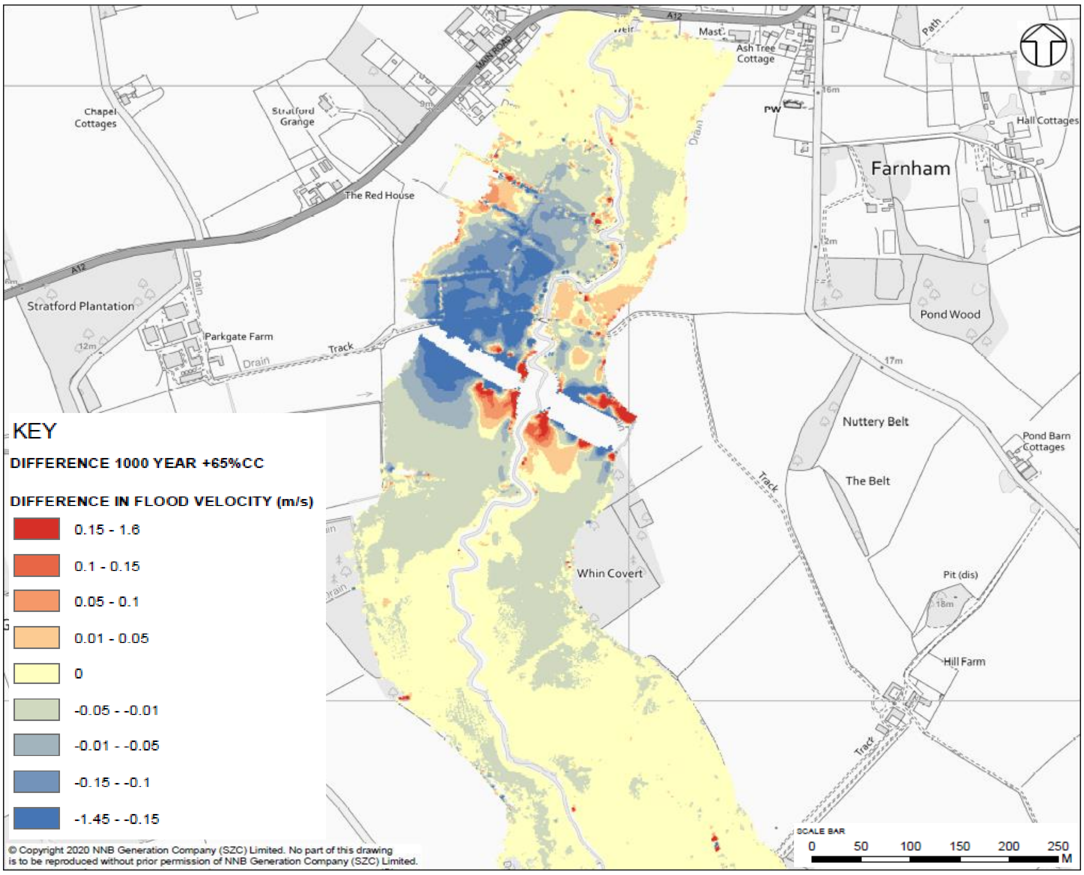


Plate 6.25. Difference in flood hazard – 1 in 100-year event with 65%CC

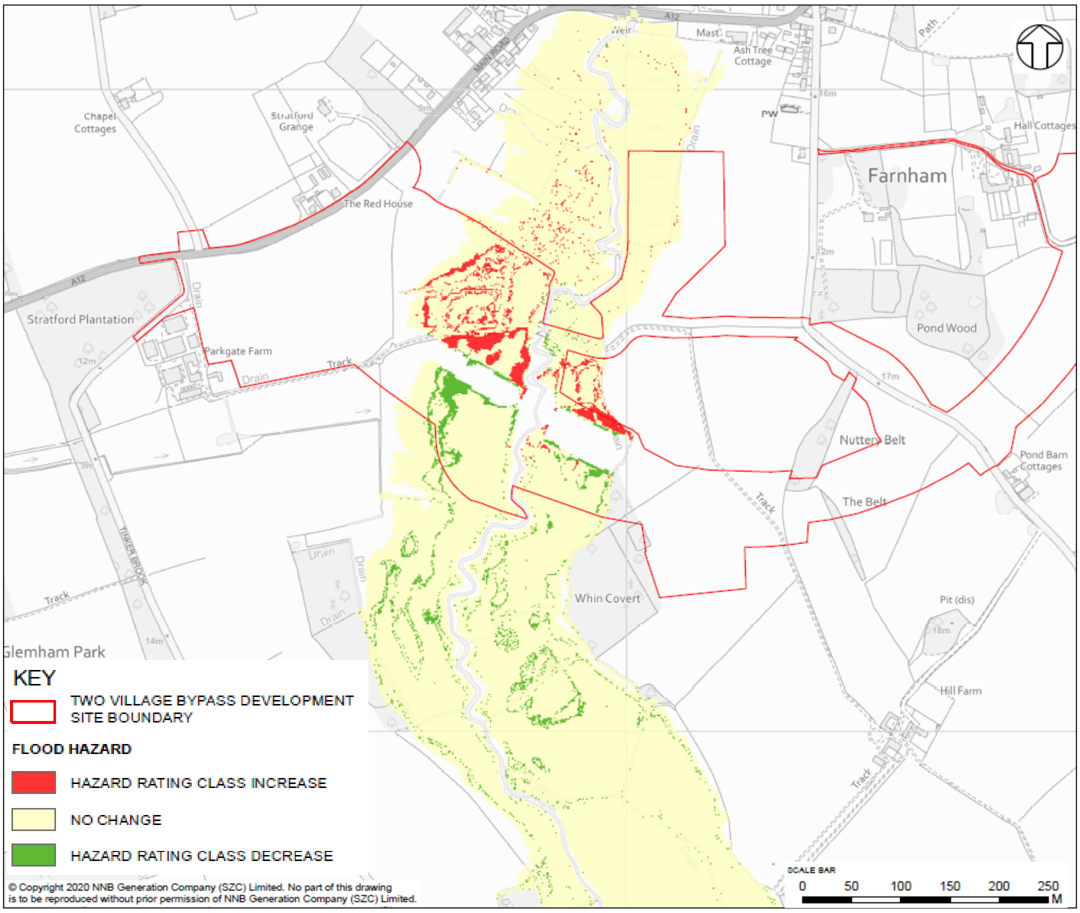


Plate 6.26. Difference in flood hazard – 1 in 1,000-year event with 65%CC

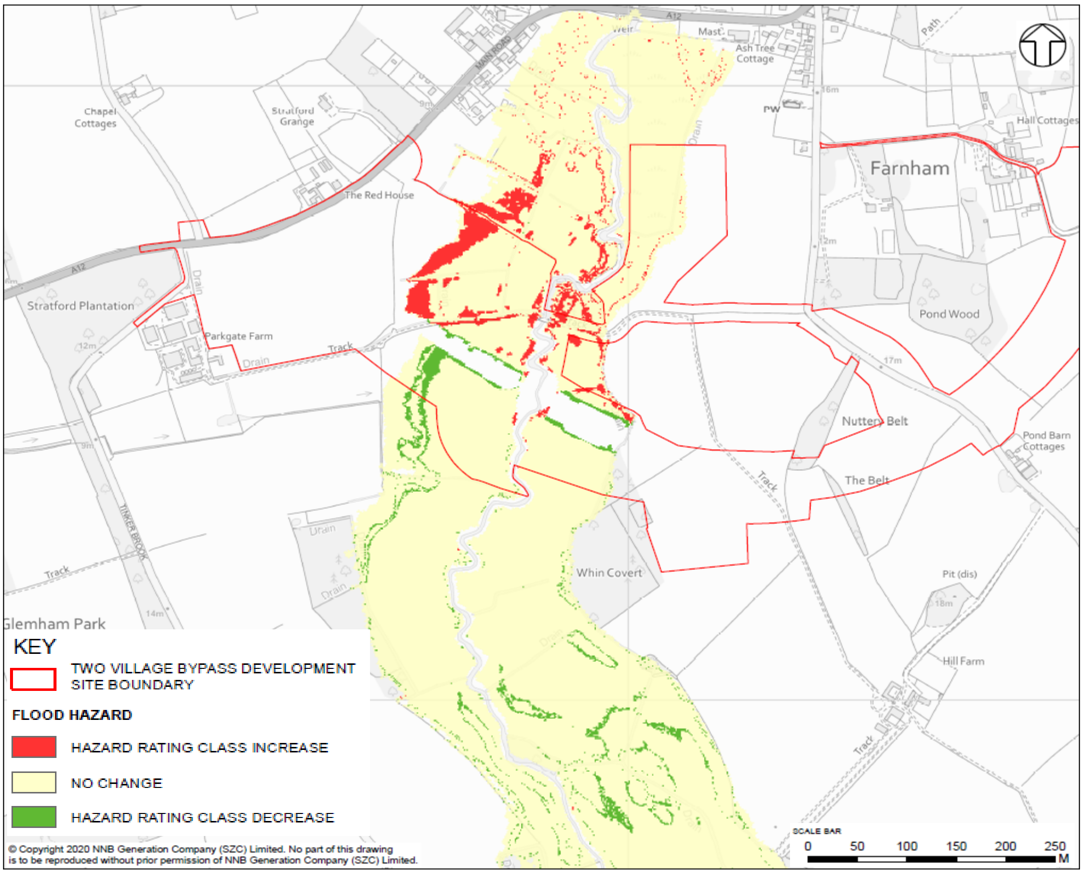


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Plate 6.27. Difference in flood extent – 1 in 100-year event with 65%CC

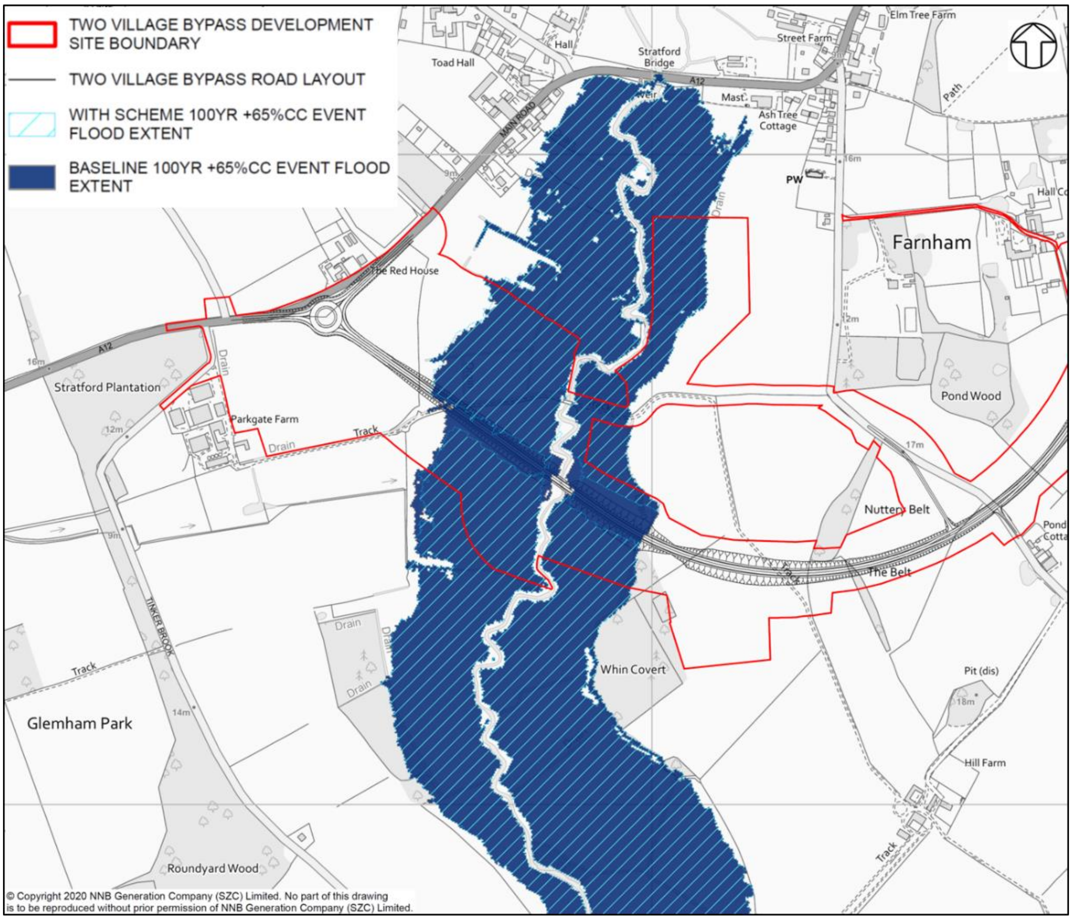

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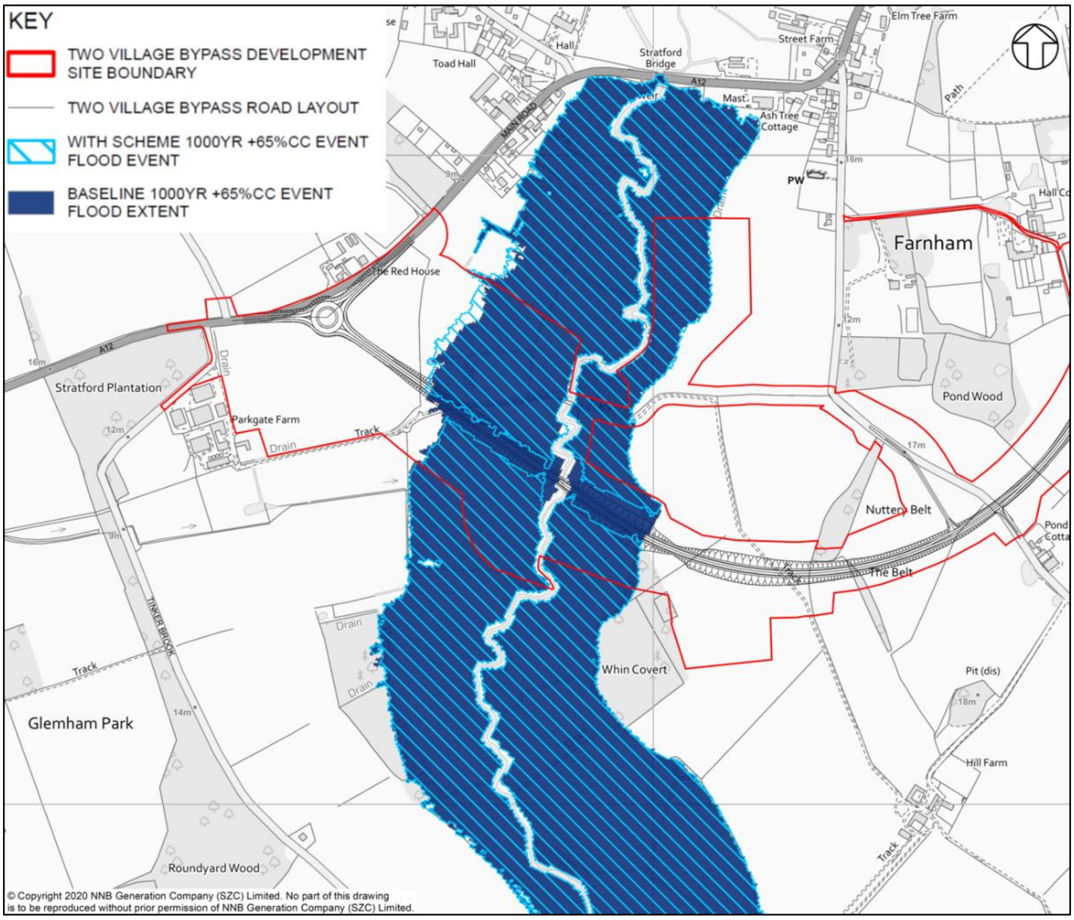
Plate 6.28. Difference in flood extent– 1 in 1,000-year event with 65%CC



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6.3.6. The difference in maximum stage results between the ‘with scheme’ and baseline models for selected 1D model nodes within the area of interest (**Plate 6.10**) for all considered return period events and climate change scenarios are presented in **Table 6.3**.

6.3.7. Results in **Table 6.3** show that the difference in stage at the two village bypass crossing (1D model node ALDE_06069) for the basis of design event (1 in 100-year with 35%CC) is 14mm, and the maximum difference at the bridge is 32mm and 38mm for the more extreme 1 in 100 year with 65% climate change and the 1 in 1000 year events respectively.

6.3.8. Comparison of the results also shows that the two village bypass has only very localised impact on flood levels, and the maximum stage is within a few millimetres of the baseline results, which is considered insignificant and could be partly accounted for by model accuracy.

6.3.9. This is particularly important for the existing gauging station near A12 (closest 1D model node: ALDE_07061u) where the change in peak level for the 1 in 100-year event with 35% and 65%CC is only 4-6mm and considered negligible (within model tolerance). On that basis, the overall impact of the development on flood risk in the area is considered minimal.

Table 6.3. Difference in maximum stage for selected 1D model nodes – 'with scheme' minus baseline

Return Period (years)	1D model node							
	ALDE 07061u	ALDE 06664	ALDE 06245u	ALDE 06069	ALDE 05991	ALDE 05883	ALDE 05067	ALDE 04735
20	0.002	-0.010	-0.119	0.011	0.015	0.008	-0.004	-0.003
20 +15%CC	-0.003	0.002	-0.115	0.015	0.015	0.006	-0.002	-0.002
20 +25%CC	-0.004	0.012	-0.104	0.016	0.015	0.007	-0.002	-0.002
20 +35%CC	-0.005	0.017	-0.097	0.019	0.012	0.011	-0.014	0.004
20 +65%CC	-0.008	0.020	-0.063	0.013	0.014	0.005	-0.008	-0.009
100	-0.007	0.024	-0.084	0.018	0.018	0.009	-0.004	-0.005
100 +15%CC	-0.006	0.013	-0.065	0.010	0.004	-0.003	-0.025	-0.036
100 +25%CC	-0.004	0.018	-0.054	0.010	0.009	0.004	-0.012	-0.015
100 +35%CC	-0.006	0.015	-0.047	0.014	0.009	0.003	-0.013	-0.016
100 +65%CC	-0.004	0.012	-0.027	0.032	0.016	0.005	-0.018	-0.019
1,000	-0.003	0.009	-0.024	0.038	0.017	0.004	-0.020	-0.020
1,000 +15%CC	-0.003	0.012	-0.001	0.055	0.023	0.005	-0.019	-0.018
1,000 +25%CC	-0.002	0.009	0.012	0.066	0.026	0.005	-0.029	-0.029
1,000 +35%CC	-0.002	0.010	0.029	0.076	0.027	0.003	-0.031	-0.030

Return Period (years)	**1D model node**							
1,000 +65%CC	0.014	0.001	0.069	0.089	0.024	-0.003	-0.025	-0.025

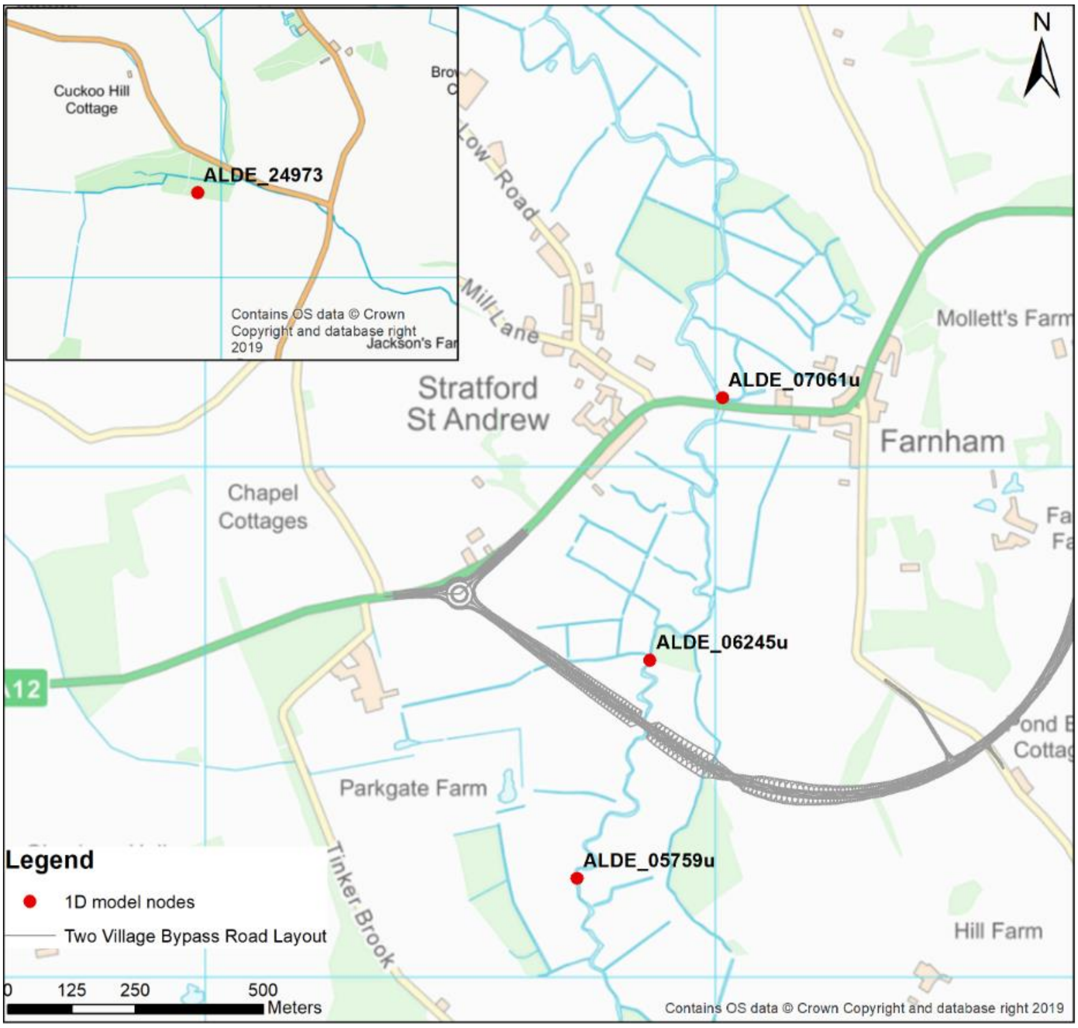
6.3.10. Figures illustrating differences in flood depth, velocity, hazard and extent between the 'with scheme' and baseline models for all modelled scenarios are provided in Appendix C: 2VB Fluvial model results – Difference in flood depth ('with scheme'-baseline).

6.4 Environment Agency (2019) model comparison

6.4.1. As previously mentioned in **section 2.2**, in late 2019 the Environment Agency issued updated flood modelling for the Rivers Alde, Ore and Fromus (Ref 11). The updates included revised hydrological assessment, updated topography and survey information and other improvements to model schematisation, however this model was not available in time for this two village bypass FRA modelling study and therefore the previous (2012) model was used, although some results from the updated 2019 Environment Agency model were provided following completion of this study.

6.4.2. The supplied 2019 model results were analysed against the results obtained from the updated 2012 model in order to determine any potential impacts on overall results and consequently the FRA conclusions with main concern in change in hydrological assessment. For that purpose, flow and stage at four locations presented in **Plate 6.29** were compared. These locations are: main inflow into River Alde – ALDE_24973, node immediately upstream A12 bridge – ALDE_070601u; node upstream of the track bridge (upstream of the proposed crossing) – ALDE_06245u; and node downstream of the proposed crossing – ALDE_05759u.

Plate 6.29. Location of the 1D model nodes selected for comparison



6.4.3. Results were compared for the present-day 1 in 100-year and 1 in 1,000-year return period events (**Plate 6.30 - Plate 6.37**). In addition, comparison of flood extents for those events was made for the present-day and future scenario with 35% climate change allowance for the 1 in 100-year return period event, as illustrated in **Plate 6.1**.

6.4.4. Overall results from the comparison show that at the main inflow into River Alde in the 2012 model is approximately 10% lower than in the 2019 model for the 1 in 100-year event but not different for the 1 in 1,000-year event, whereas the peak water levels are lower by 0.11m and 0.05m respectively.

6.4.5. Upstream of the A12 and upstream of the proposed crossing, the flow in the 2012 model is lower by approximately 15% and 10% for the 1 in 100-year and 1 in 1,000-year events respectively with slightly higher peak water levels when compared to 2019 model. Further downstream, the flows and water levels in the updated 2012 model are slightly higher than in the 2019 model (**Plate 6.37**).

6.4.6. Comparison of flood extents for the present-day 1 in 100-year event and 1 in 100-year with 35% climate change allowance shows very similar flood extents between the two models with slightly wider extents in the 2019 model upstream and downstream (**Plate 6.38**).

6.4.7. However, the grid resolution in the 2019 model is 8m whereas in the updated 2012 model it is 4m and it is likely that most differences in the flood extents could be attributed to the differences in grid resolution and consequently topography representation in the two models.

6.4.8. Even though there are some differences between the two models, the updated 2012 model is deemed appropriate for this FRA study, where focus is to determine the relative impact of the proposed two village bypass development on flood risk.

Plate 6.30. Comparison between updated 2012 and 2019 models – flow at ALDE_24973

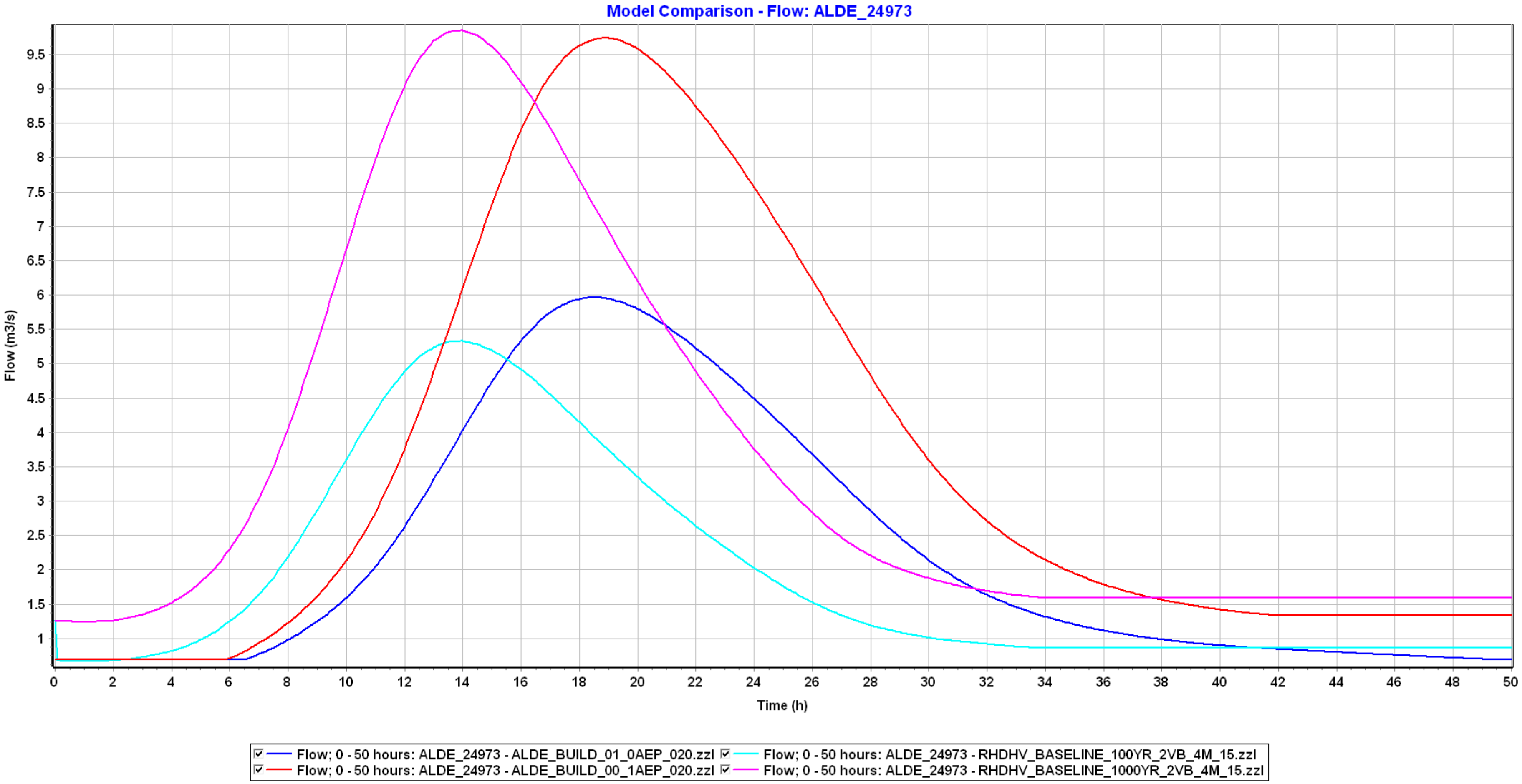


Plate 6.31. Comparison between updated 2012 and 2019 models – stage at ALDE_24973

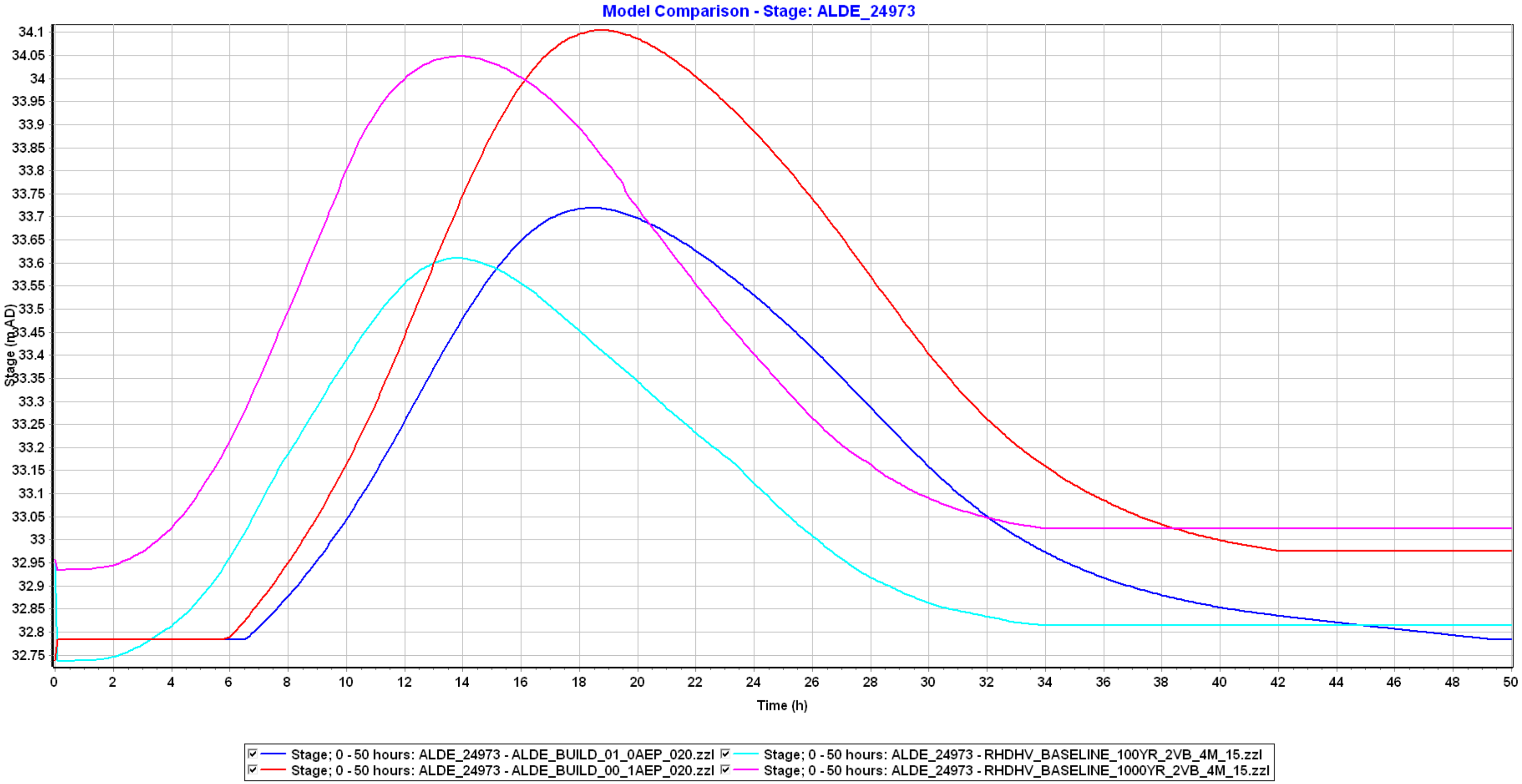


Plate 6.32. Comparison between updated 2012 and 2019 models – flow at ALDE_07061u

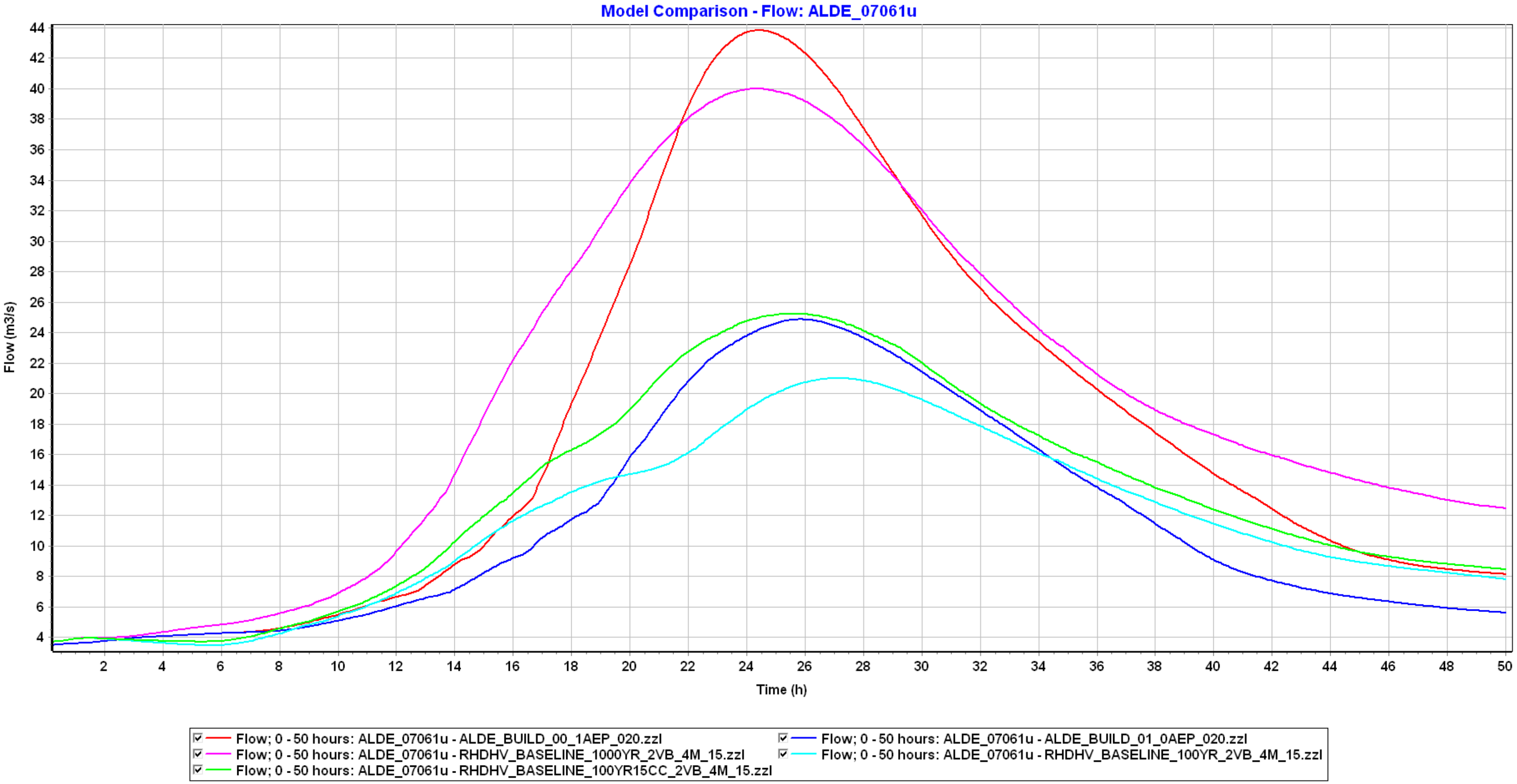


Plate 6.33. Comparison between updated 2012 and 2019 models – stage at ALDE_07061u

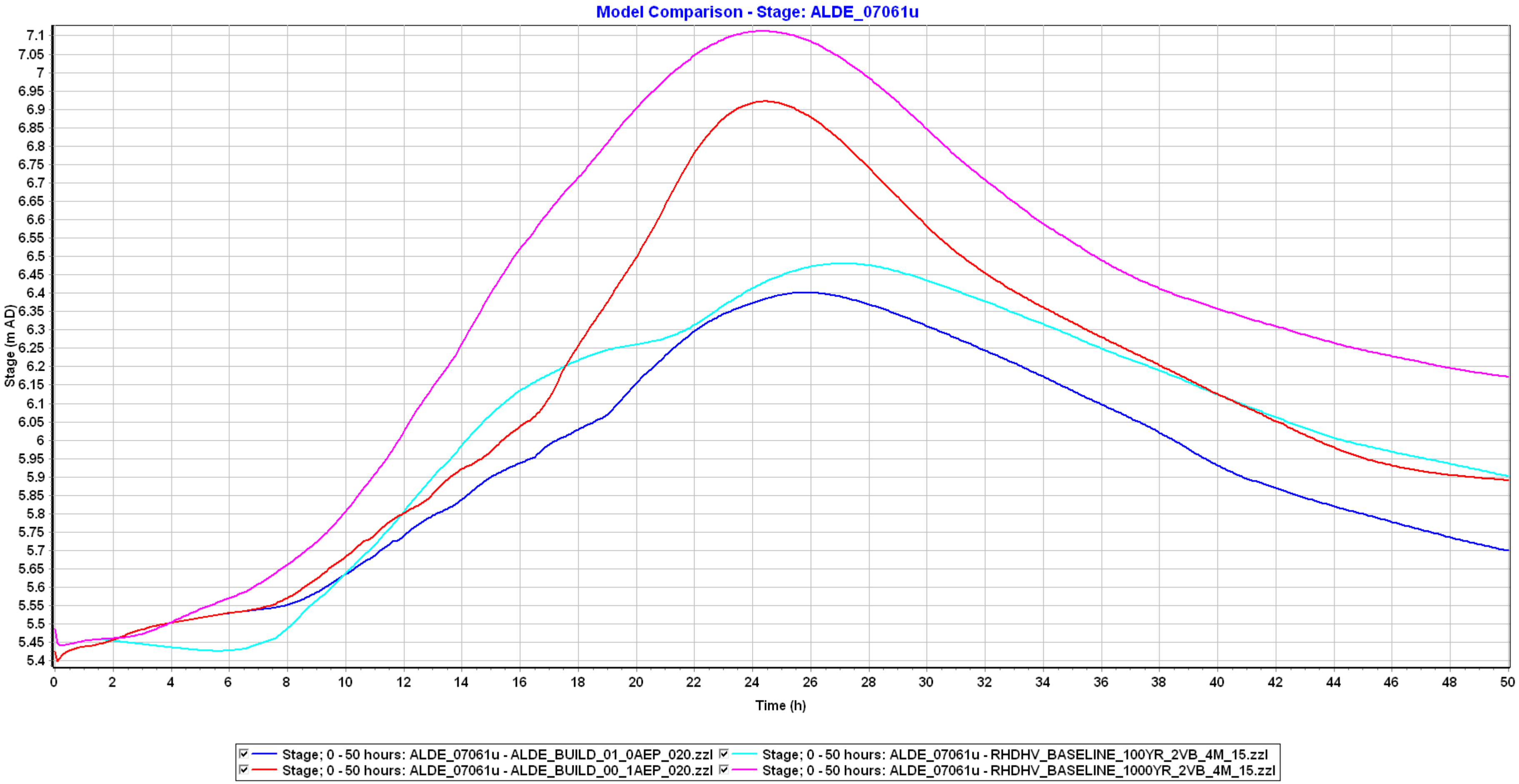


Plate 6.34. Comparison between updated 2012 and 2019 models – flow at ALDE_06245u

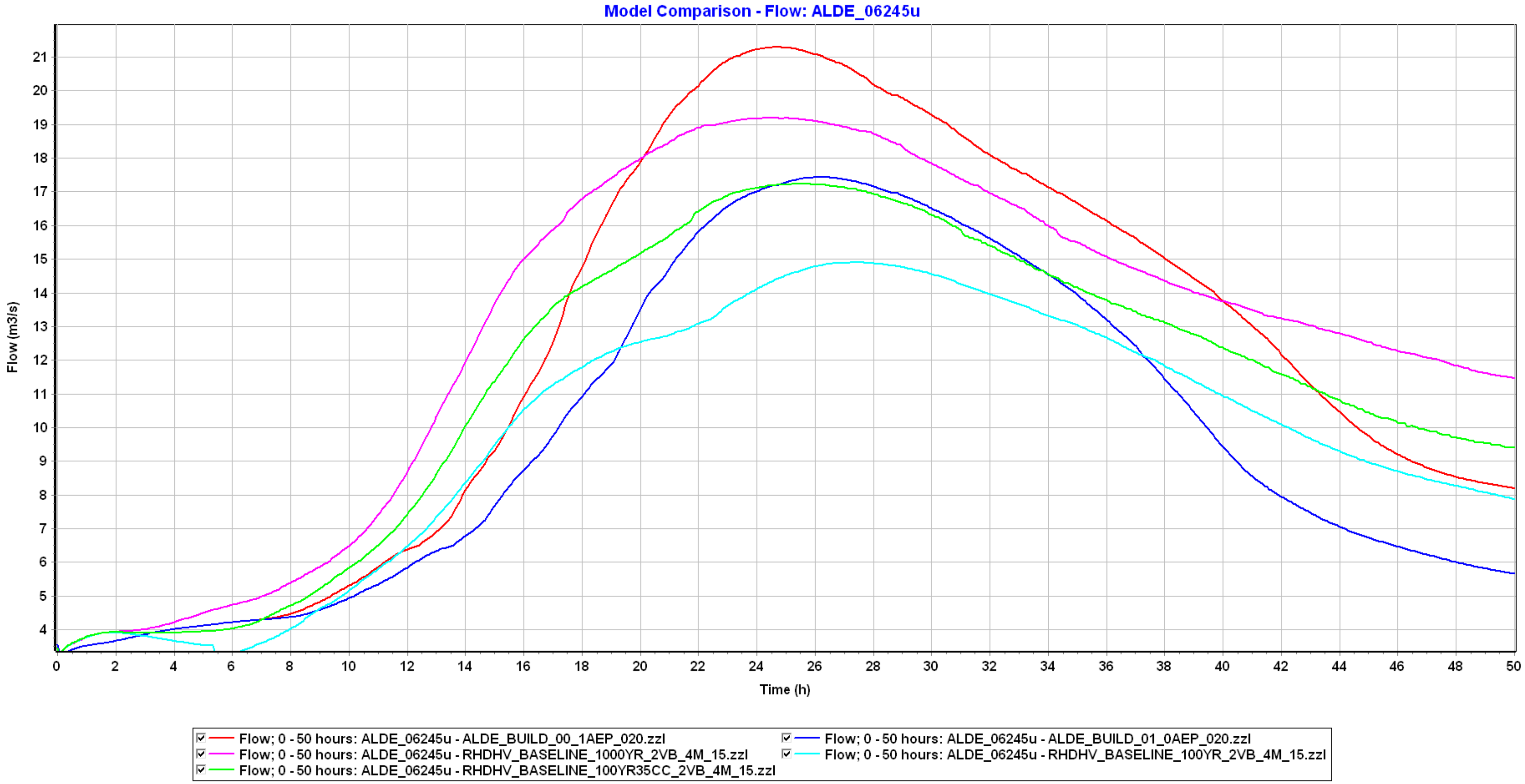


Plate 6.35. Comparison between updated 2012 and 2019 models – stage at ALDE_06245u

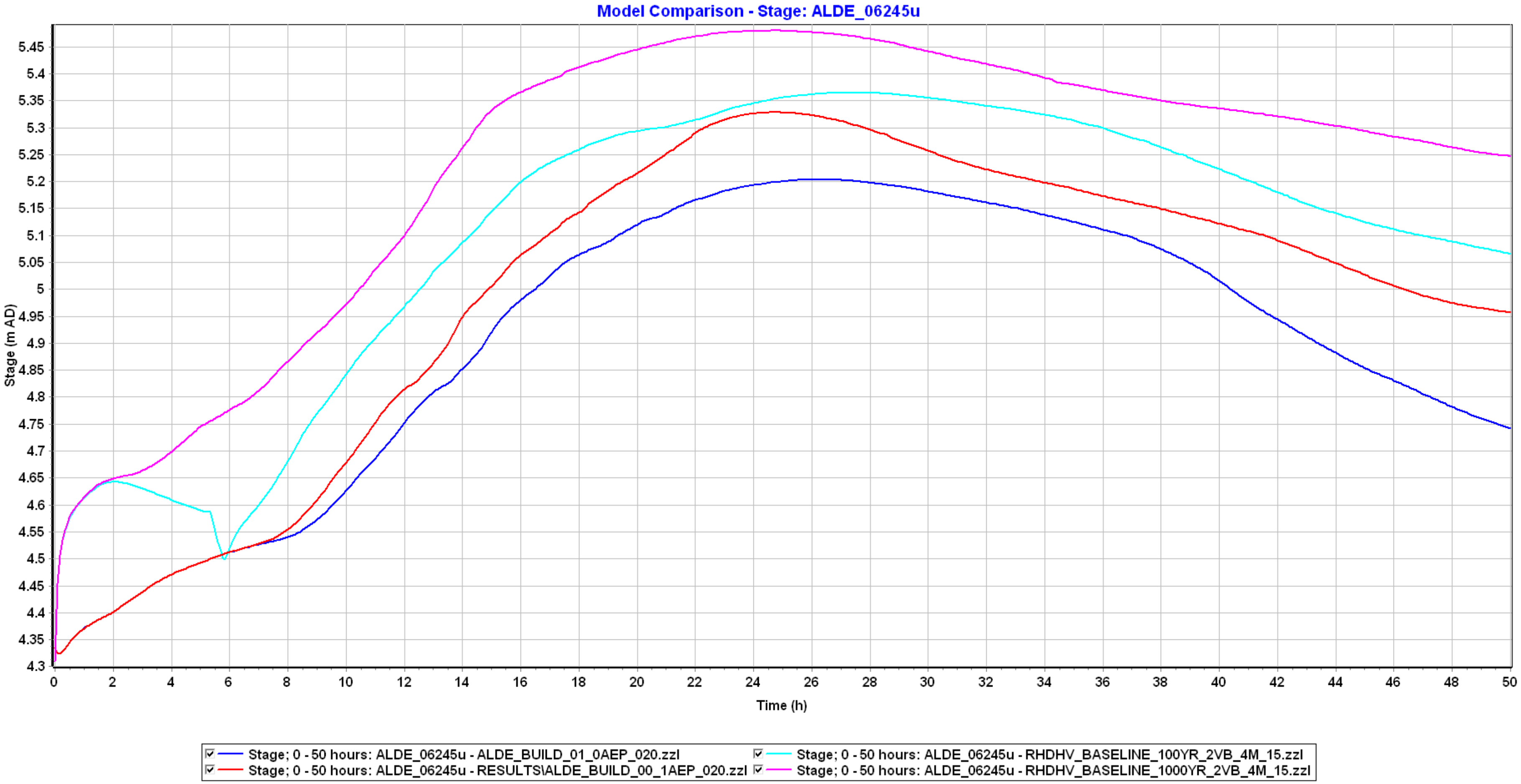


Plate 6.36. Comparison between updated 2012 and 2019 models – flow at ALDE_05759u

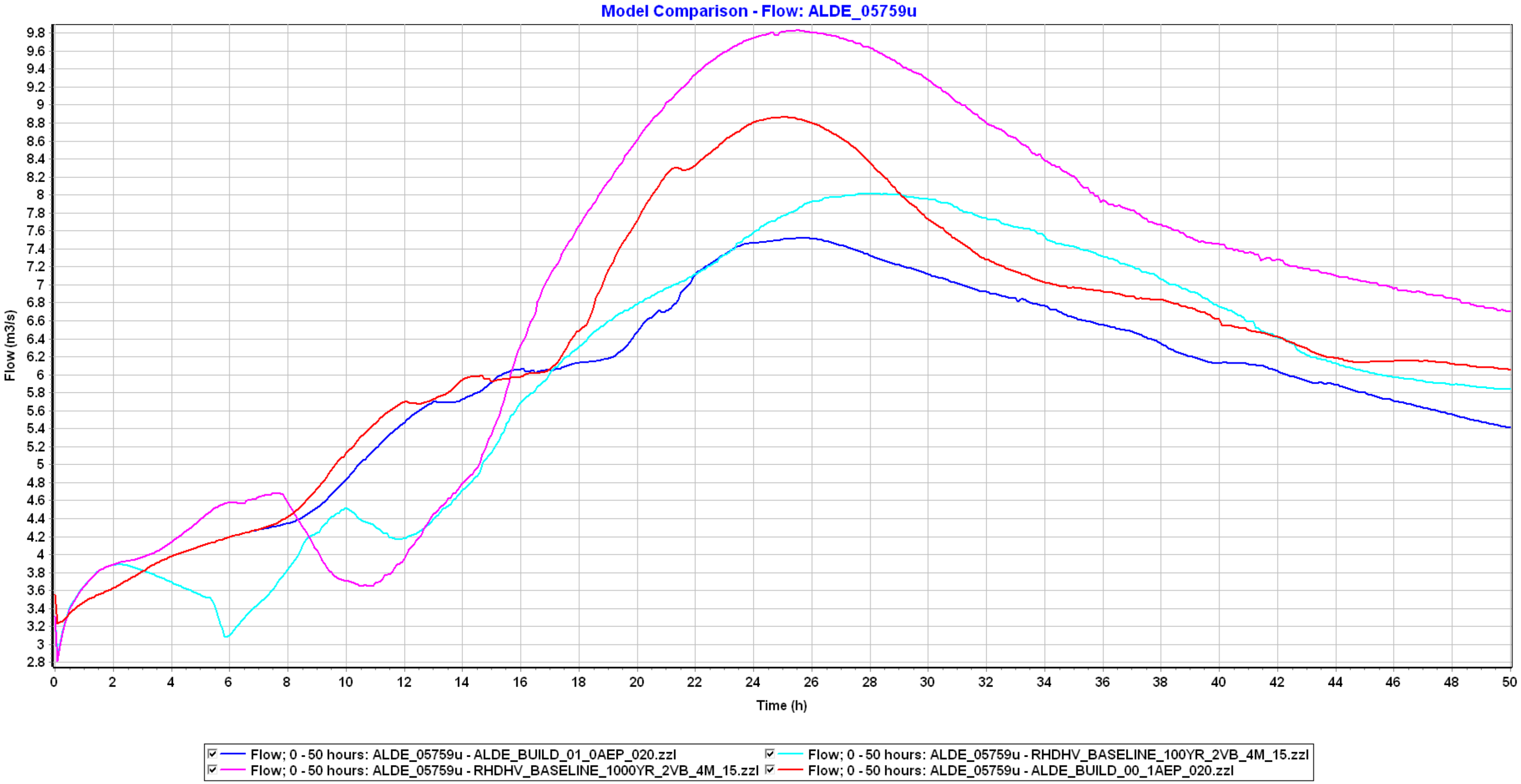


Plate 6.37. Comparison between updated 2012 and 2019 models – stage at ALDE_05759u

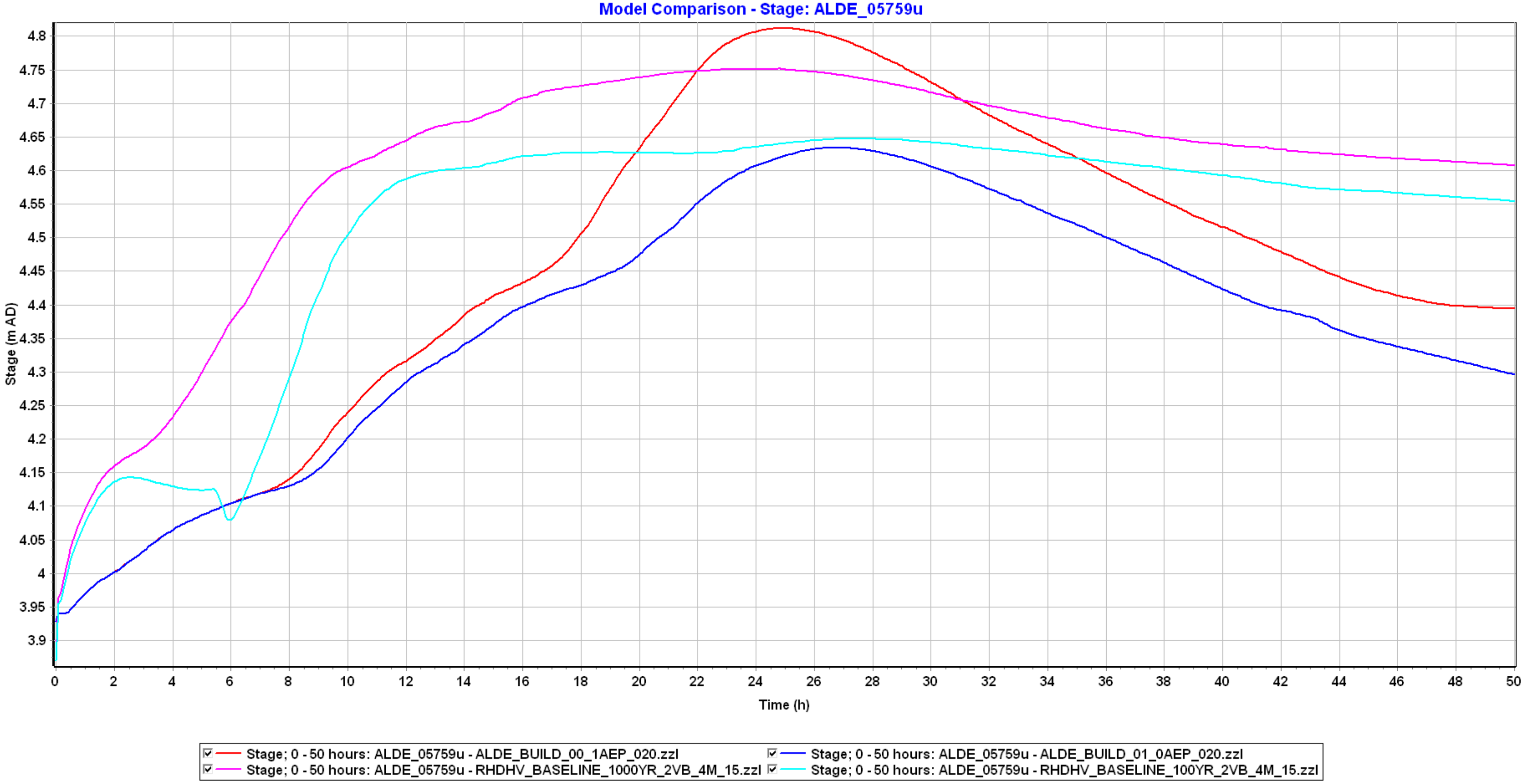
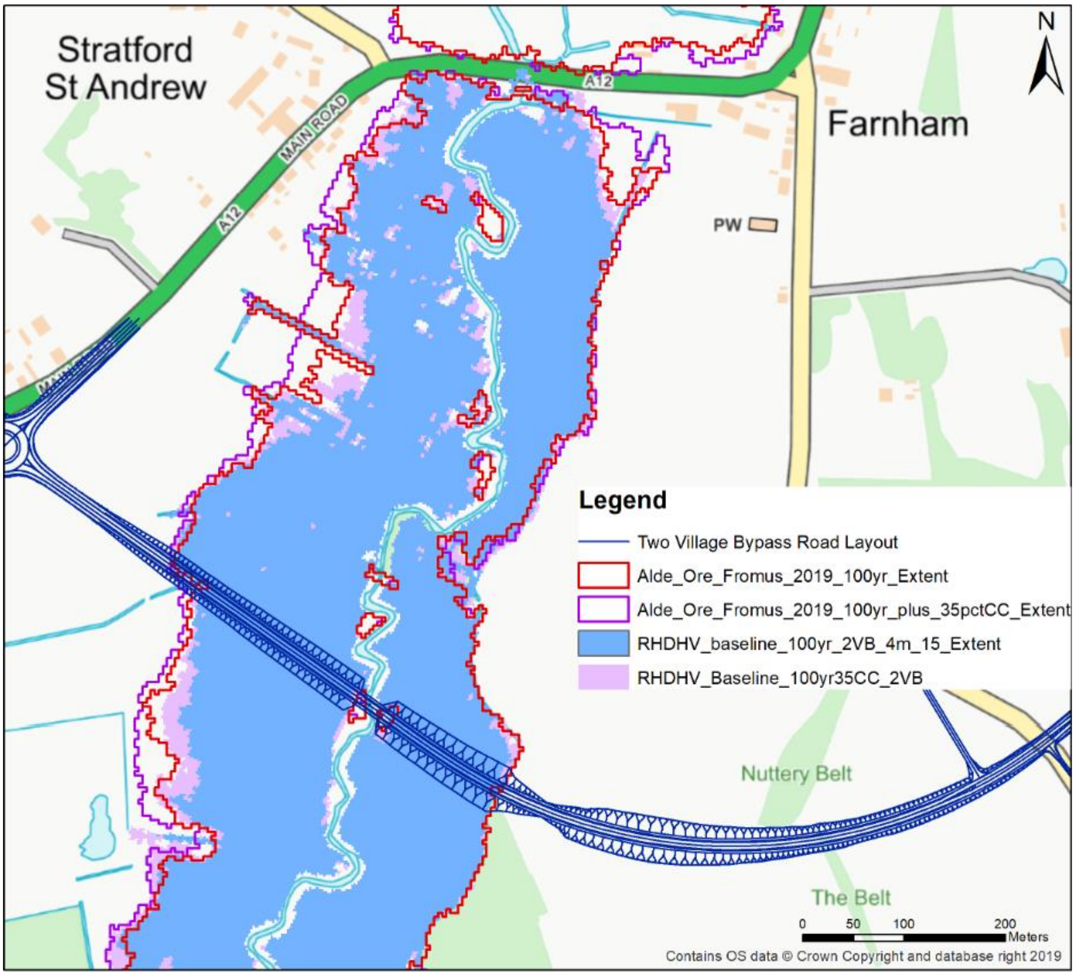


Plate 6.38. Comparison between updated 2012 and 2019 models – flood extent for the 1 in 100-year event (present-day and with 35%CC)



7 Limitations

7.1.1. Hydraulic models and flow estimates are produced in an attempt to represent real world systems. It is inevitable that some stages of the modelling process will be subject to assumptions made by the modeller and limitations imposed by the available data and software ability.

7.1.2. A 1D-2D Flood Modeller-TUFLOW approach has been used utilising the Fluvial Alde, Ore and Fromus model (ISIS-TUFLOW) supplied by the Environment Agency. The largest limitation is that this model was not calibrated due to lack of calibration data. Sensitivity analysis has indicated that the greatest level of uncertainty is associated with flow estimation. The assessment of the impact of the proposed two village bypass to a wide range of return periods gives the confidence that potential flow estimation uncertainties do not affect the validity of the overall project outcomes, particularly regarding changes between baseline and ‘with scheme’ results.

7.1.3. There were also a number of generic assumptions that have been applied to the Alde, Ore and Fromus model. Many of these are general, such as assuming the survey data is sufficient to best represent the topography of the channel, model coefficients values, channel and floodplain roughness values and location of the boundary between the 1D and 2D domains.

7.1.4. Another uncertainty factor relates to the use of tidal boundary which has been derived from the Alde estuary hydraulic model. This model has been calibrated using data from the tidal gauge at Felixstowe and has therefore been extrapolated from the gauged record located a significant distance away rather than gauged directly at site. Changes in the boundary impact results near Snape although the effect does not propagate upstream further than Blaxhall and therefore does not impact the area of interest of this two village bypass study.

7.1.5. The supplied model has not been formally reviewed as a part of this study. The model was found to be numerically unstable for higher return period simulations and therefore minor changes have been done to improve the stability in order to run required scenarios. This is discussed in **section 5**.

7.1.6. Overall the updated Flood Modeller-TUFLOW model achieves satisfactory numerical convergence and results are consequently considered reliable. Some numerical non-convergence has arisen during the model development. This has been addressed by adoption of dflood value of 10, theta value of 0.95 and alpha value 0.5. These model parameter values are within acceptable ranges. Given this modelling is for the purposes of assessing differences between baseline and ‘with scheme’ scenarios, it is considered adequate.

8 Conclusions and recommendations

8.1.1. As a part of the two village bypass study, a 1D–2D River Alde, River Ore and River Fromus hydraulic model has been used, and updated to better represent flood mechanism in the area of the development.

8.1.2. The updated (2012) model was used to assess the current fluvial flood risk posed by River Alde, River Ore and River Fromus watercourses presented as the baseline modelling scenario. The baseline model was then amended to include the proposed two village bypass carriageway to assess flood risk to the development itself and the impact of the scheme on the flood regime in the surrounding areas.

8.1.3. The baseline and 'with scheme' models were simulated for a series of scenarios, namely 1 in 20-year, 1 in 100-year, and 1 in 1,000-year return period events, present day and with climate change allowances (15%, 25%, 35% and 65%).

8.1.4. For the basis of design event, i.e. the 1 in 100 year return period with 35% climate change allowance, the model results show a maximum increase in water levels in the river channel immediately upstream of the bridge by approximately 14mm, whereas average increase in water level in the floodplain is 64mm immediately upstream of the road embankment with very localised afflux of 300mm within a low-lying area in the western floodplain.

8.1.5. Overall change in flood levels as a result of the two village bypass development is very localised. There are no residential or commercial buildings located within the floodplain in the area of interest, between the A12 at Stratford St Andrew and the railway line north of Blaxhall/near Gorse Farm). Therefore, impact of the development on flood risk in the area is considered minimal.

8.1.6. The model used in this two village bypass study was initially developed in 2012. Although it benefits from using gauge data to improve hydrological inflows to the model, no calibration data were available for the river Alde, Ore or Fromus at the time of model development. This model has been recently revised by the Environment Agency and published in late 2019 with updated hydrological assessment and improvements to model schematisation and representation of key structures.

8.1.7. Comparison of peak river inflows and resulted flood levels at key locations was made to determine impact of the recent Environment Agency 2019 model updates on outcomes of this study. Although the updated 2019 hydrological assessment results in inflows increased by approximately 10% when compared to the inflows developed in 2012, the flood levels close to the Farnham gauging station and near the proposed development are slightly higher in the adopted (and updated) 2012 model. Therefore, it is considered that presented results and conclusions based on the adopted 2012 model are slightly more conservative and suitable for this two village bypass flood risk assessment study.

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