Hoveton Great Broad Restoration Project

Environment Agency

Modelling report

Version 1

April 2019

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1. Introduction

Jacobs were commissioned to undertake a modelling investigation of Hoveton Great Broad Restoration Project. The purpose of the study has been to assess the flood risk impact of installing four bio-manipulation barriers. The barriers will be installed to prevent fish from entering the Hoveton Great Broad from the River Bure.

Modelling has been undertaken to assess tidal and fluvial flood risk. A worst-case scenario has been modelled, assuming that the barriers will prevent exchange of flood flows between the River Bure and Hoveton Great Broad. Twelve combinations of fluvial and tidal flood risk have been simulated for the baseline (no barriers) and with barrier scenarios.

The location of the four proposed barriers is shown in Figure 1.

The modelling investigation has been undertaken using the Broadlands Environmental Services Limited (BESL) model. There are several versions of this BESL model which are used for strategic, detailed and flood mapping purposes. For the Hoveton Great Broad investigations the 2012 1D BESL model has been used. Boundary conditions are from the MIU1 Hydrology update (2012) for fluvial inflows and 2012 for tidal time series at Great Yarmouth.

The intellectual property rights (IPR) of the BESL model currently belong to BESL. An agreement has been reached as part of the Modelling and Forecasting 2016-17 Package 1, that ownership will be transferred from BESL to the Environment Agency in 2019.

The aims of the Hoveton Great Broad modelling were to:

- Provide peak water levels for 12 fluvial-tidal and climate change epoch design event combinations for the baseline and with barriers scenarios.
- Provide an analysis and comment on maximum water level differences attributable to the barriers
- Provide updates to flood outlines.

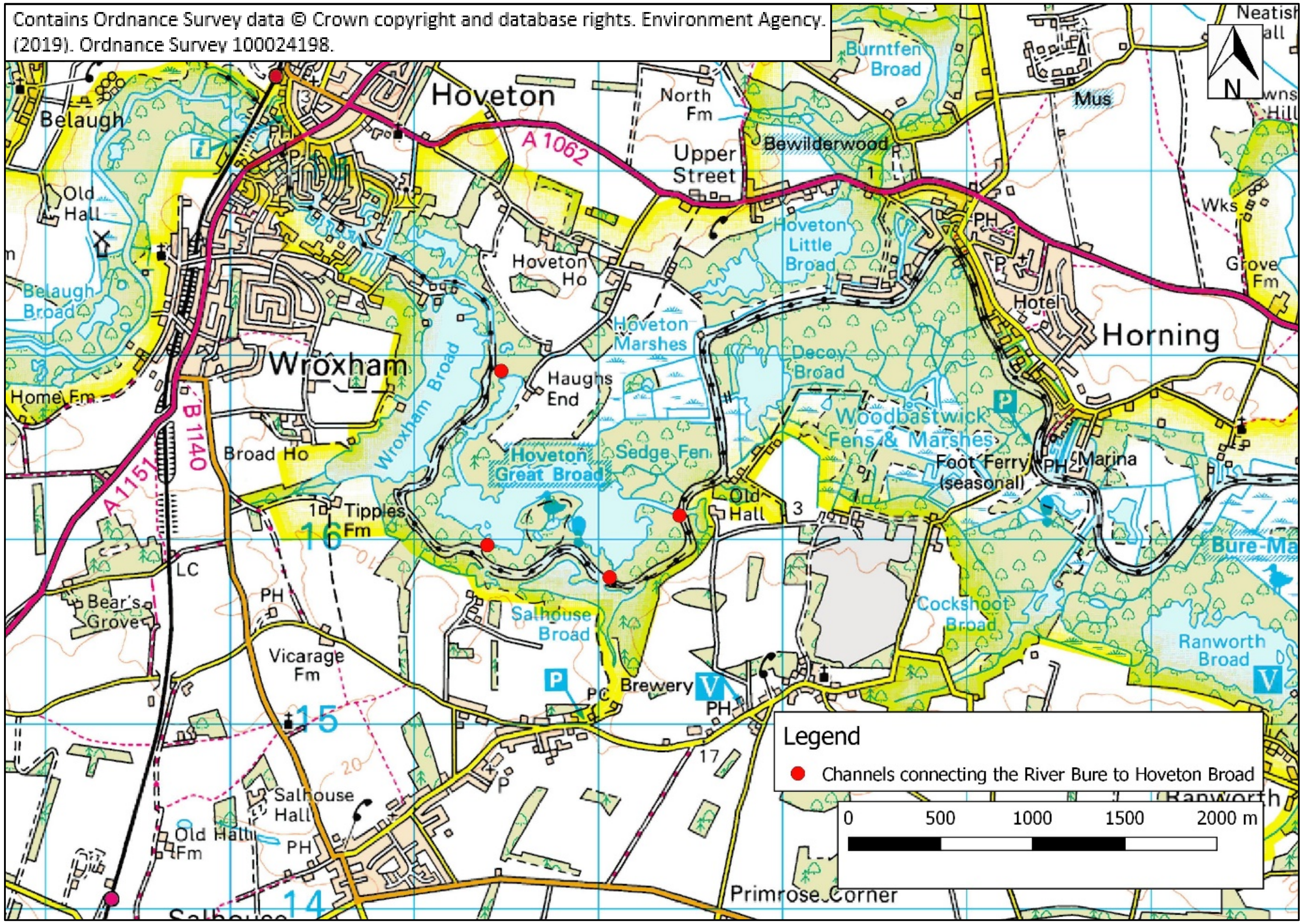

Figure 1: Location of four proposed bio-manipulation barriers

2. Available Data

The following data has been made available for this project:

- 2012 BESL Model
- 2009 1 m LiDAR available from http://www.geostore.com/environment-agency/survey.html#/survey
- 2010 River Bure (Cockshoot Broad to A1151 Bridge) – B.A Existing Hydro Survey.

A key limitation of the data is there are no survey data of the four channels connecting the River Bure to Hoveton Great Broad. Dimensions for these channels have been estimated (see Section 3.2). There are also no survey data of Hoveton Great Broad and the depth-area relationship has been estimated from LiDAR.

3. BESL Model

3.1 Introduction

There is an extensive number of previous reports and iterations of the BESL model. The model was originally constructed for the BESL project and has a 20-year history of use. Regularly updated it is the only current model available of the Broadlands systems. A summary of the BESL model history is provided in Table 1. For the Hoveton Great Broad investigations the 2012 1D model has been used. The 2012 model is currently being updated as part of the Modelling and Forecasting 2016-17 Modelling 1 package. This update does not include any changes to the River Bure at Hoveton Great Broad. The 2012 model therefore remains the best available model for investigation of bio-manipulation barriers at Hoveton Great Broad.

Date	Comment
May 2001	Commencement of the Broadlands Environmental Service Limited (BESL) contract.
2001	Broadlands system surveyed. River channel sections at 200 m intervals with banktop levels every 50 m.
May 2001	Commencement of construction of 1D Broadlands model, comprising of: • Base model (present day 2001), • Proposals (future options) Model constructed using predominantly 2001 survey supplemented with EDI 1995 survey for Bure upstream of Ant confluence. Sections through Great Yarmouth sourced from existing MIKE-11. Floodplain reservoir units/compartments defined by IDB sub-areas. Floodplain reservoir unit geometry determined from 2 m resolution LiDAR (1999 – 2001). Upstream boundary location selected to be coincident with extent of tidal influence.
2002	Completion of first iteration of BESL baseline and proposal hydraulic models.
December 2003	Calibration of baseline model using flood event data from January 2000 (tidal event), December 2000 (fluvial-tidal event) and March 2001 (fluvial-tidal event). Derivation of hydrological design inflow boundaries. Update to compartment 18 in As-built model.
April 2005	Model updates to Base model to form ‘As-built’ model.
June 2007	Update included schemes for compartments 26 and 5 in the as-built model and 1, 10, 14, 22 Ph 3, 23, 24 and 25b in the Proposals model.
Summer 2007	0.1% AEP simulation to provide information Broadlands SFRA.
July 2008	Compartments 27, 21, 28, 1, 2, 10, 14, 22 ph3, 23, 24 and 25b were incorporated into the As-built model. Compartments 11 Bure, 37 and 7 were included in the Proposals model.
2008-9	Development of the separate Forecast Model, including upstream extension to gauging stations and some floodplain re-schematisation.

Date	Comment
April 2010	Environment Agency commission BESL to undertake scoping study with aim of improving the Broadlands model to make outputs suitable for flood mapping purposes. Work commissioned a series of model improvements units (MIU's). The MIU's implemented were: - MIU1: hydrological update to fluvial boundaries (undertaken in 2011) - MIU3 – River Ant/Thurne extension (undertaken in 2012) - MIU4 – River Bure extension (undertaken in 2012). Other MIU's identified were not progressed due to funding constraints.
Oct 2010	Improved naming convention, Oulton Broad Spill Improvements, New Tidal Boundary.
August 2011	Consistency checks, between models and model roughness throughout the model
September 2011	Inclusion of As-Built survey data for compartments 4, 6, 11 Bure, 12&13, 29&30 as well as the proposed design solutions for compartments 3, 6a, 7, 8, 9, 20, 25, 25a Phase 2, 33 and 34.
May 2012	MIU3 and 4 delivery: extension of the 2011 as-built model on the River Ant from Barton Broad Honing Lock and River Bure from Wroxton/Hoveton to Horstead Mill. Thurne from Hickling/Martham Broad. Two versions of the model were generated: - 1D only – retained by BESL - 1D-2D used for flood mapping for the Environment Agency. New survey was commissioned for this extension. Calibration using June 2001 and March 2010 events. MIU1 Hydrology update on the Bure, Waveney and Yare. Separate flood mapping models with 2D elements have been constructed for Norwich and Beccles for the Environment Agency.
June 2013	Separate ISIS-TUFLOW models of Norwich and Beccles developed. Remaining area uses the as-built model.
August 2014	Further model outputs of the June 2013 model

Table 1: Summary of BESL model history

3.2 Model modifications

The lower reaches of the River Bure are included in the BESL model using in-channel river-cross sections. The floodplain is represented through extended cross sections.

For the bio-manipulation barrier investigations, the model has been modified to improve representation of Hoveton Great Broad and the adjacent floodplain. The extended cross-sections were cut back on the left flood plain and Hoveton Great Broad included as a model reservoir unit with the depth/area relationship taken from LiDAR. This approach assumes that the LiDAR provides a reasonable estimate of the water level in the broad.

The following cross-sections were trimmed:

- BA18839
- BA18365
- BA18169
- BA17557
- BA17339
- BA16742
- BA16535
- BA15948
- BA15814
- BA15696
- BA15562

Four channels (represented as spill units) were added into the model to represent the connections from the River Bure to the Hoveton Great Broad. The width of the four channels was approximated from Google aerial view and OS maps. The LiDAR dataset were also interrogated but provided no additional insight on channel dimensions. The depths of the channels (bed inverts) were assumed to be same as the adjacent River Bure in-channel survey.

The widths and depths of the channels are summarized in Table 2.

Easting	Northing	Width (m)	Bed invert (mAOD)
631472	316913	2.29	-2.28
631397	315968	6.83	-2.27
632061	315794	13.04	-2.29
632440	316129	21.74	-2.55

Table 2: Dimension of the four channels added into the model to connect the River Bure and Hoveton Broad.

The updated model schematisation is shown in Figure 2. The spills units representing the channels connecting the Bure and Hoveton Broad are highlighted in yellow. In addition to the four connecting channels, during flood conditions flow may overtop the banktops and spill from the River Bure into Hoveton Broad.

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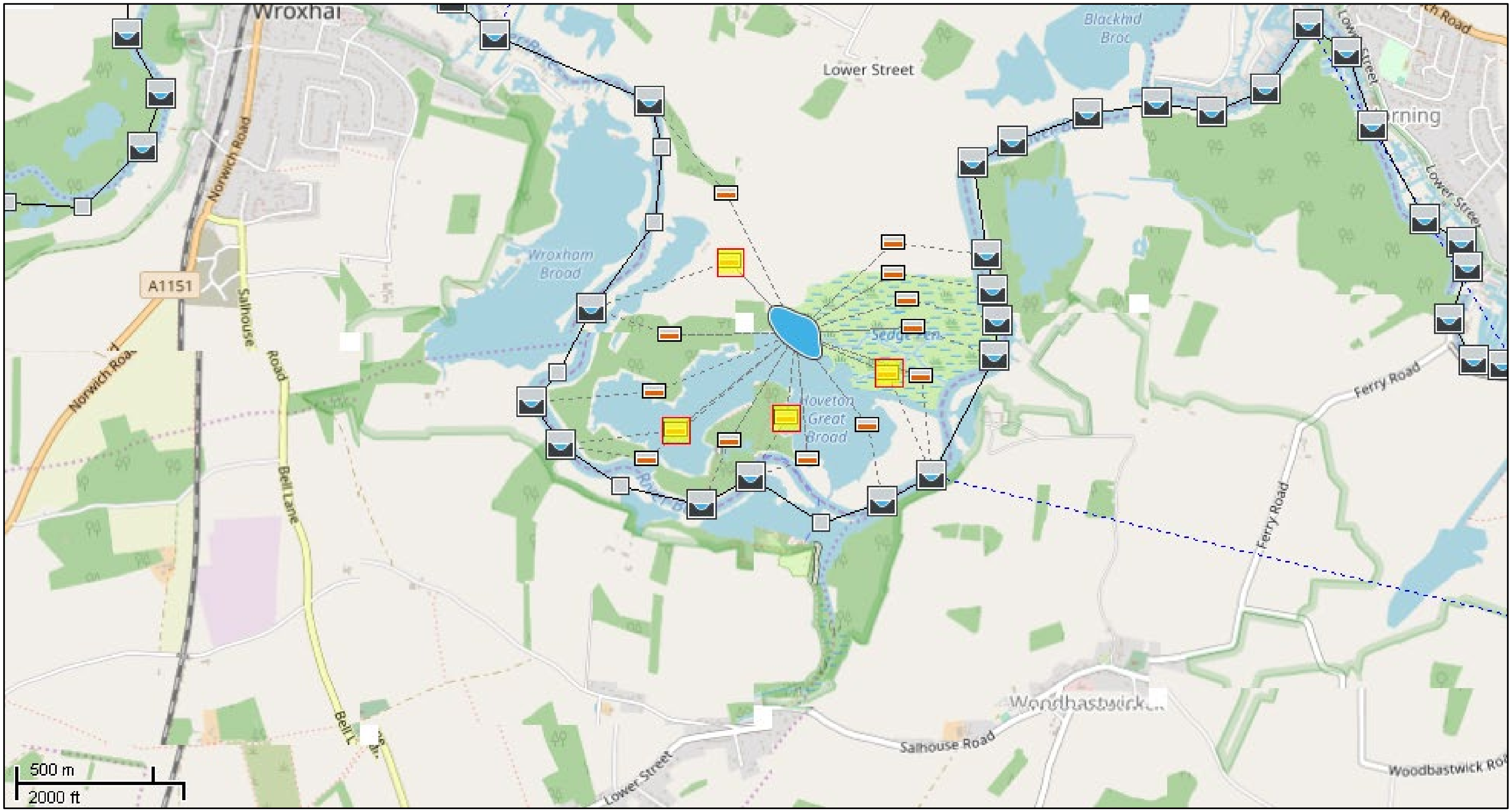

Figure 2: Updated Hoveton Broad schematisation.

4. Fluvial and tidal boundaries

4.1 Tidal events

Model simulations were undertaken using present day and climate change scenarios. For present day the 2012 tidal boundaries were used. For the climate change scenario, the present-day boundaries were uplifted using the latest National Planning Policy Framework (NPPF) guidance for sea level allowance (Table 3). Peak levels were uplifted to 2039, this horizon being likely lifetime of the bio manipulation barriers.

The present day and climate change tidal boundaries applied to the model at Great Yarmouth are shown in Figure 3 and Figure 4 respectively for the tidal events.

Climate Change Epoch	Sea Level Rise per year (mm)
1990 – 2025	4
2026 – 2055	8.5

Table 3: Climate change uplifts applied at Great Yarmouth

Tidal max stage and flow summary for each event can be seen in Table 4 to Table 6.

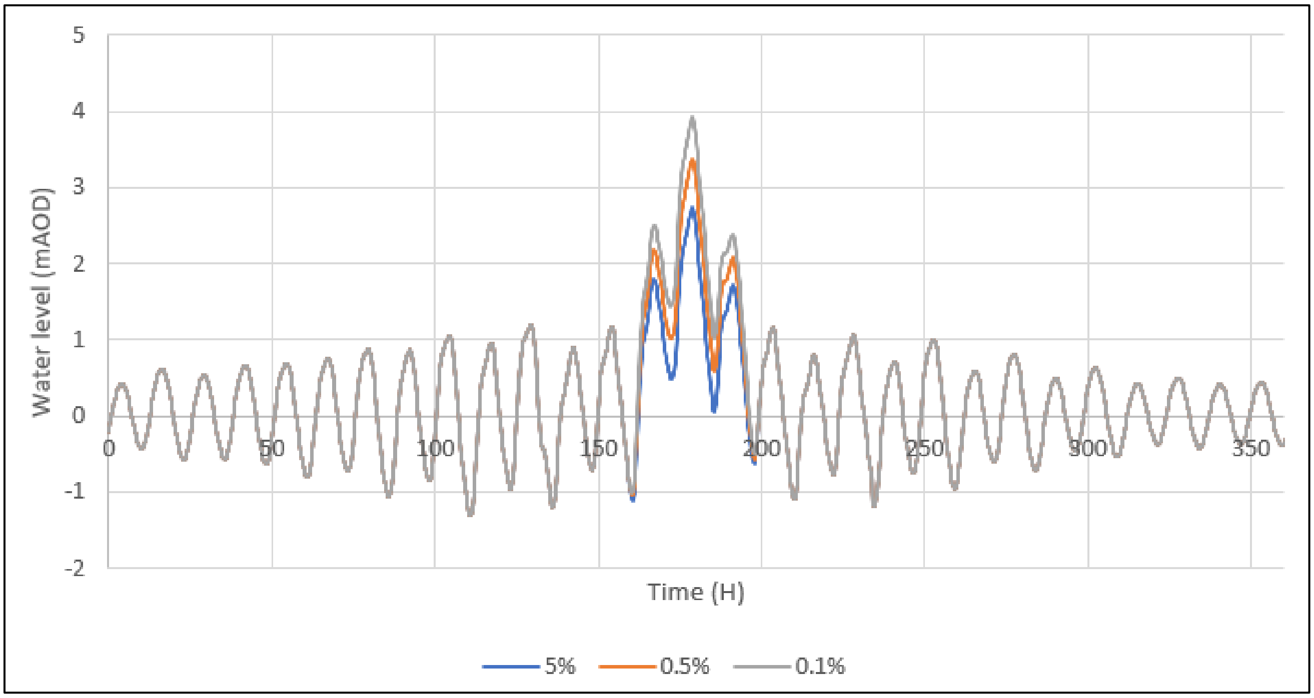

Figure 3: Present day tidal hydrographs for 5%, 0.5% and 0.1% AEP events

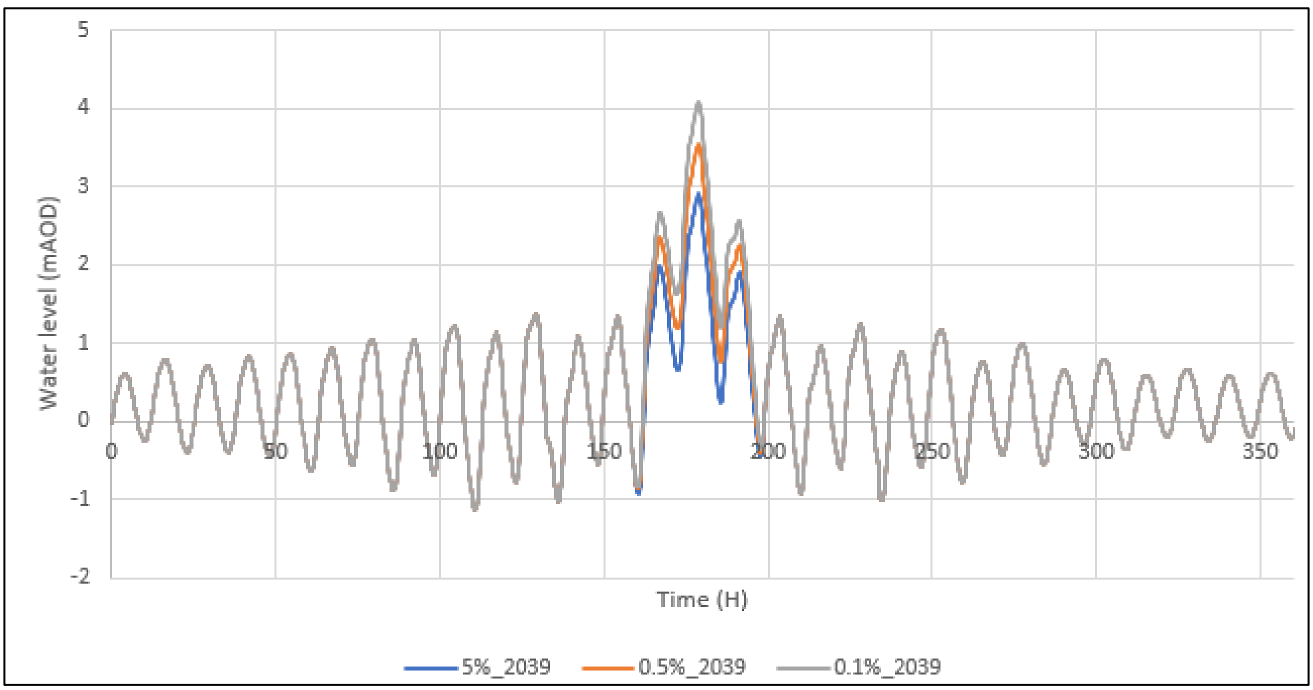

Figure 4: Climate Change (2039) tidal hydrographs for 5%, 0.5% and 0.1% AEP events

Boundary	Max Water Level (mAOD)	Max Water Level Climate Change (mAOD)
Lothing	2.47	2.64
Y0M (Great Yarmouth)	2.74	2.91

Table 4: Boundary 5% baseline and climate change maximum flow (m^3/s) and water level (mAOD) for tidal events

Boundary	Max Water Level (mAOD)	Max Water Level Climate Change (mAOD)
Lothing	3.09	3.26
Y0M (Great Yarmouth)	3.38	3.55

Table 5: Boundary 0.5% baseline and climate change maximum flow (m^3/s) and water level (mAOD) for tidal events

Boundary	Max Water Level (mAOD)	Max Water Level Climate Change (mAOD)
Lothing	3.60	3.77
Y0M (Great Yarmouth)	3.92	4.09

Table 6: Boundary 0.1% baseline and climate change maximum flow (m^3/s) and water level (mAOD) for tidal events

Fluvial inflow into the River Bure for the tidal events, assume a nominal steady baseflow of 2.44 m^3/s. For climate change events, the baseflow has been uplifted by 10%.

4.2 Fluvial events

The present-day fluvial events were taken from the 2012 hydrological update. The central Anglian uplift was applied to uplift the present day flows to the 2039 horizon. A 10% uplift was applied (Figure 5).

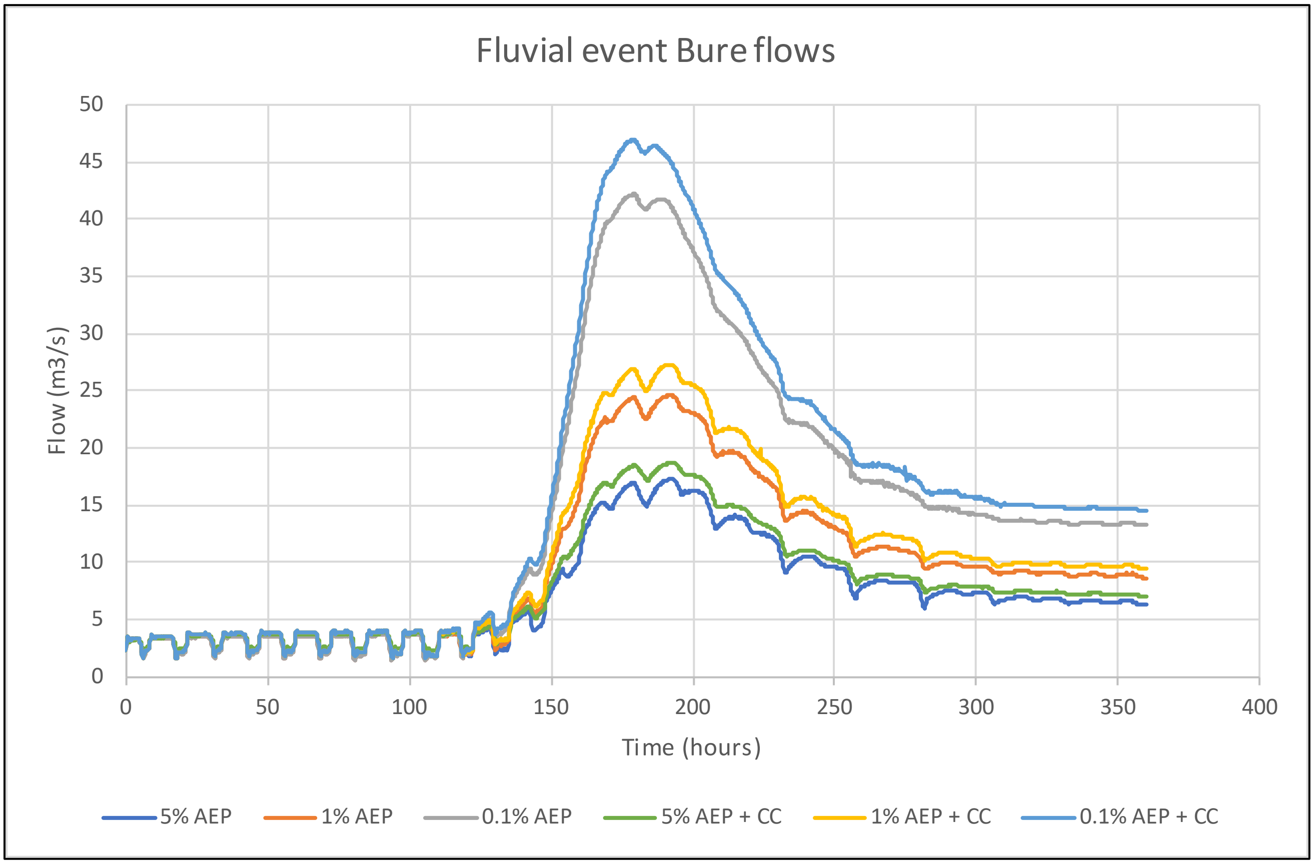

Figure 5: Bure fluvial event design flows

The present day and climate change tidal boundaries applied to the model at Great Yarmouth are shown in Figure 6 for the fluvial events. A Mean High Water Springs (MHWS) event was adopted.

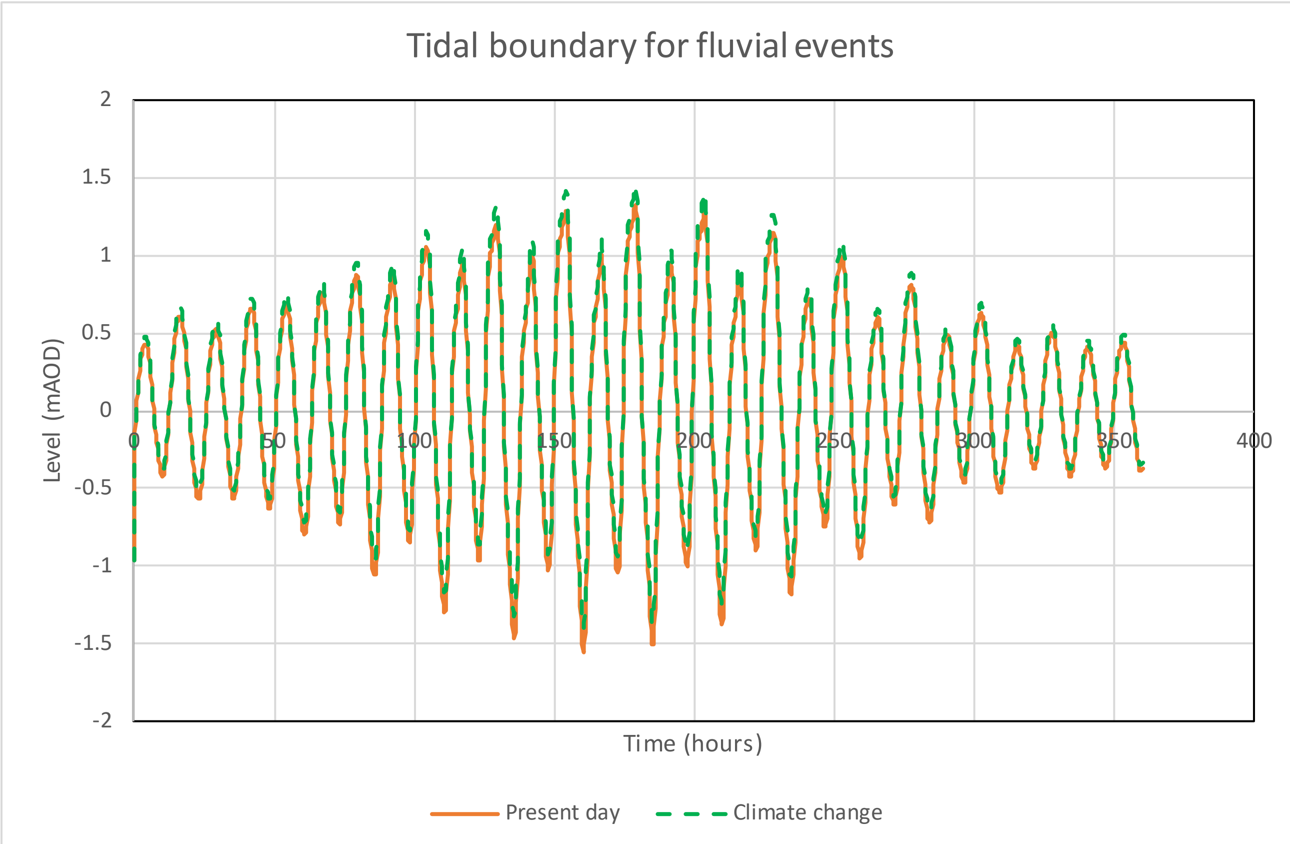

Figure 6: Tidal boundary adopted for present day and climate change simulations

5. Model Simulations

Twelve simulations were undertaken, these simulations are summarized in Table 7. Full blockage of the linking channels between the River Bure and Hoveton Great Broad was considered a worst-case scenario. All 12 simulations completed successfully with limited non-convergence events. Confidence in model results is therefore considered good.

	5% AEP	0.5% AEP	0.1% AEP
Present day, linking channels open	✓	✓	✓
Present day, linking channel blocked	✓	✓	✓
2039, linking channels open	✓	✓	✓
2039, linking channels blocked.	✓	✓	✓

Table 7: Summary of 12 simulations undertaken

6. Model Results

6.1 Introduction

The results from the 12 simulations were compared to determine the impact of blockage of the linking channels. The comparison included assessment of the peak water levels, these peak levels being the primary determinant of flood extents. Results were compared at Hoveton Great Broad, Wroxham and Horning.

The results showed that peak water levels were very similar in the blocked and fully open scenarios and consequently no difference in the flood extents could be determined.

Detailed results are provided in Appendix A, with summary results in Section 6.2 (tidal event) and Section 6.3 (fluvial events).

6.2 Tidal events

6.2.1 Hoveton Broad

The model results for the 5%, 0.5% and 0.1% present day and climate change events showed no difference in the peak levels between open and blocked connecting channels at Hoveton Great Broad (Table 8). The long-section on the River Bure show no difference in peak water levels adjacent to Hoveton Great Broad.

Annual Exceedance Event (AEP)	Baseline	Blockage	Difference (m)
	Tidal Water level (mAOD)	Tidal Water level (mAOD)	
5%	0.69	0.69	0.00
5% +Climate Change	0.76	0.76	0.00
0.5%	0.76	0.76	0.00
0.5% + Climate Change	0.82	0.82	0.00
0.1%	0.80	0.80	0.00
0.1% + Climate Change	0.85	0.85	0.00

Table 8: Tidal event peak water levels for the baseline and proposed (blockage) scenarios, Hoveton Great Broad

Figure 7 shows the water level-time series in Hoveton Great Broad for the 0.5 % fluvial event in both the baseline and proposed scenario. The time series plot shows that water levels are unaffected by blockage of the four linking channels.

Figure 8 to Figure 9 respectively show the total flow through the four linking channels and over the top of the bank for the 20% AEP event. Figure 10 and Figure 11 show the total flow for the 0.5% AEP event. These flow time series show that:

- Prior to the main tidal event, there is positive and negative (reverse) flows through the four linking channels reflecting the rising and falling tide. During the main period of the tidal event, there is negligible flow through the linking channels as levels in the River Bure and Hoveton Great Broad are equalised. When the linking channels are blocked, there is no flow.
- Prior to the main tidal event, there is over-bank flow from the River Bure into Hoveton Great Broad in the 20% and 0.5% AEP events. When the linking channels are blocked, there is greater flow over the banktops. During the main period of the tidal event, flows over the banktop are very similar in the open and blocked simulations.

The model results show that peak tidal levels are unaffected by blockage of the channels as there is negligible flow through the channels. Prior to the main tidal event, blockage of the channel results in increased flows (positive and reverse) over the banktops.

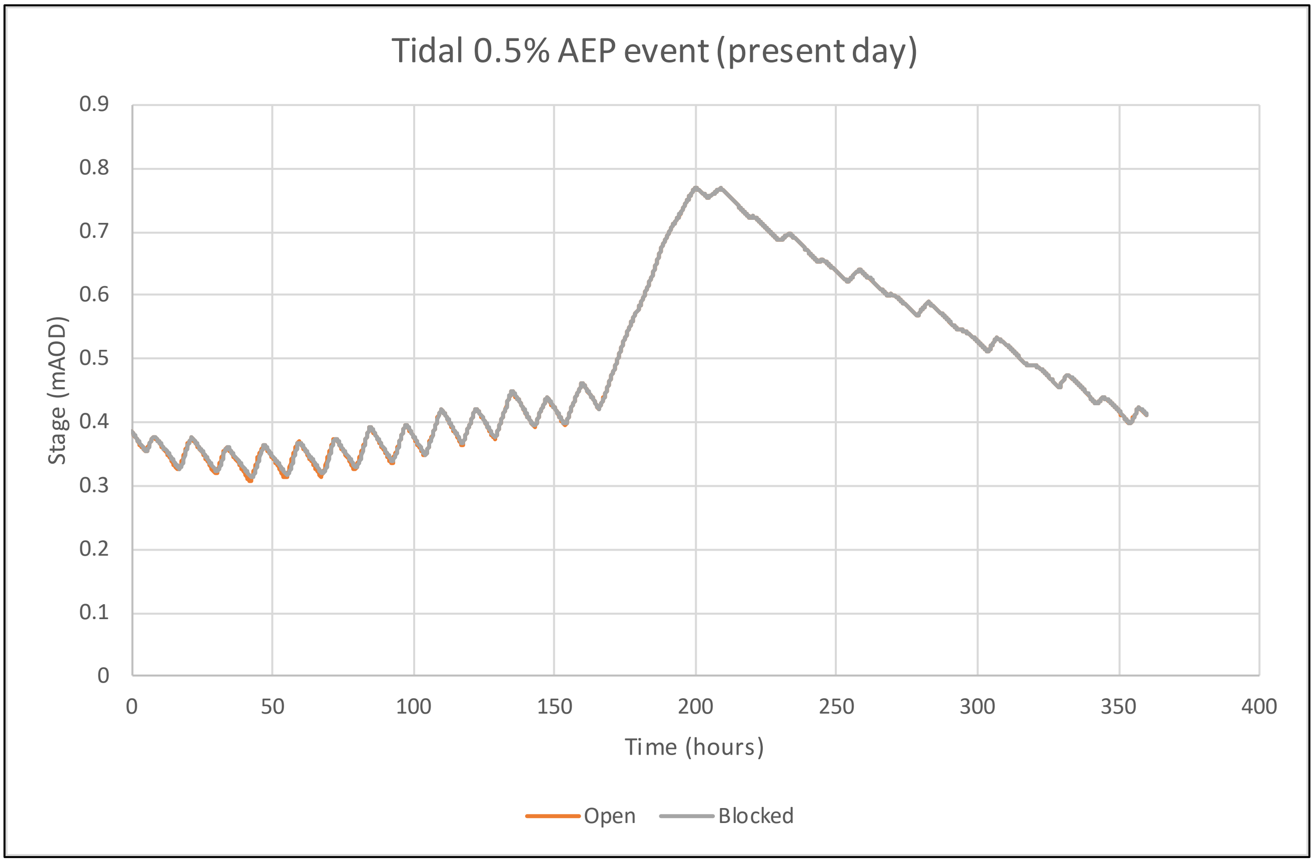

Figure 7: 0.5% AEP tidal event, water levels at Hoveton Great Broad, linking channels open and blocked

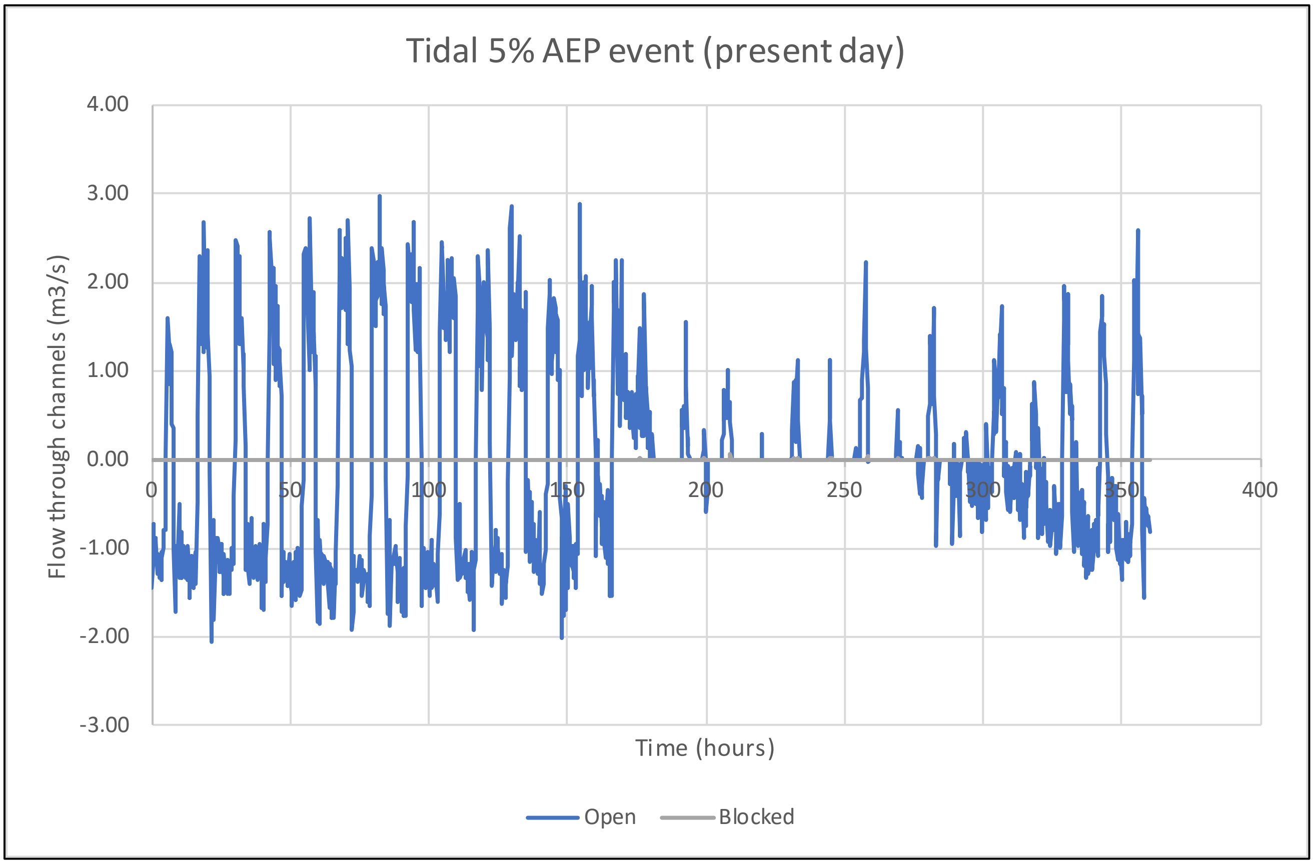

Figure 8: 5% AEP tidal event, total flow through the four channels linking Hoveton Great Broad to the River Bure

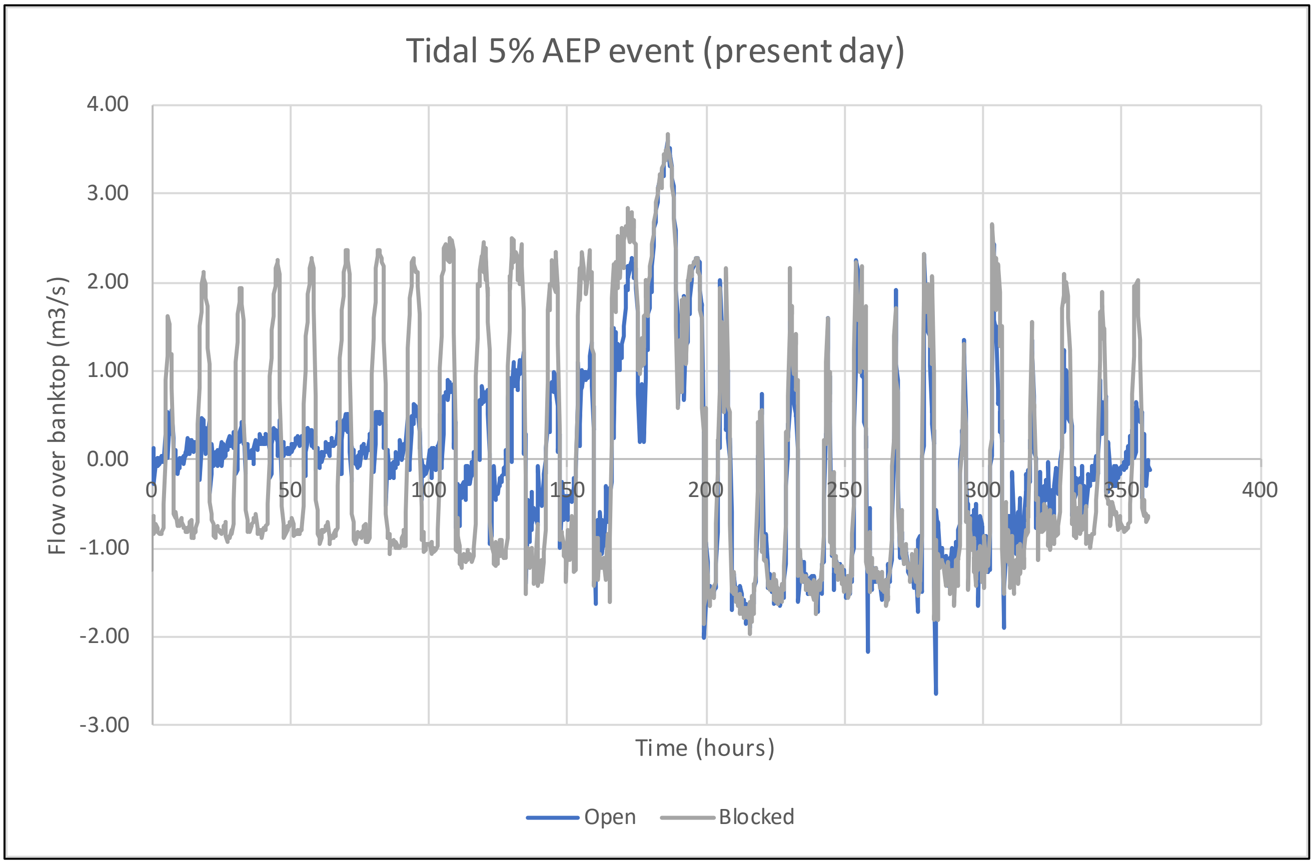

Figure 9: 5% AEP tidal event, total flow over the left bank between the River Bure and Hoveton Great Broad

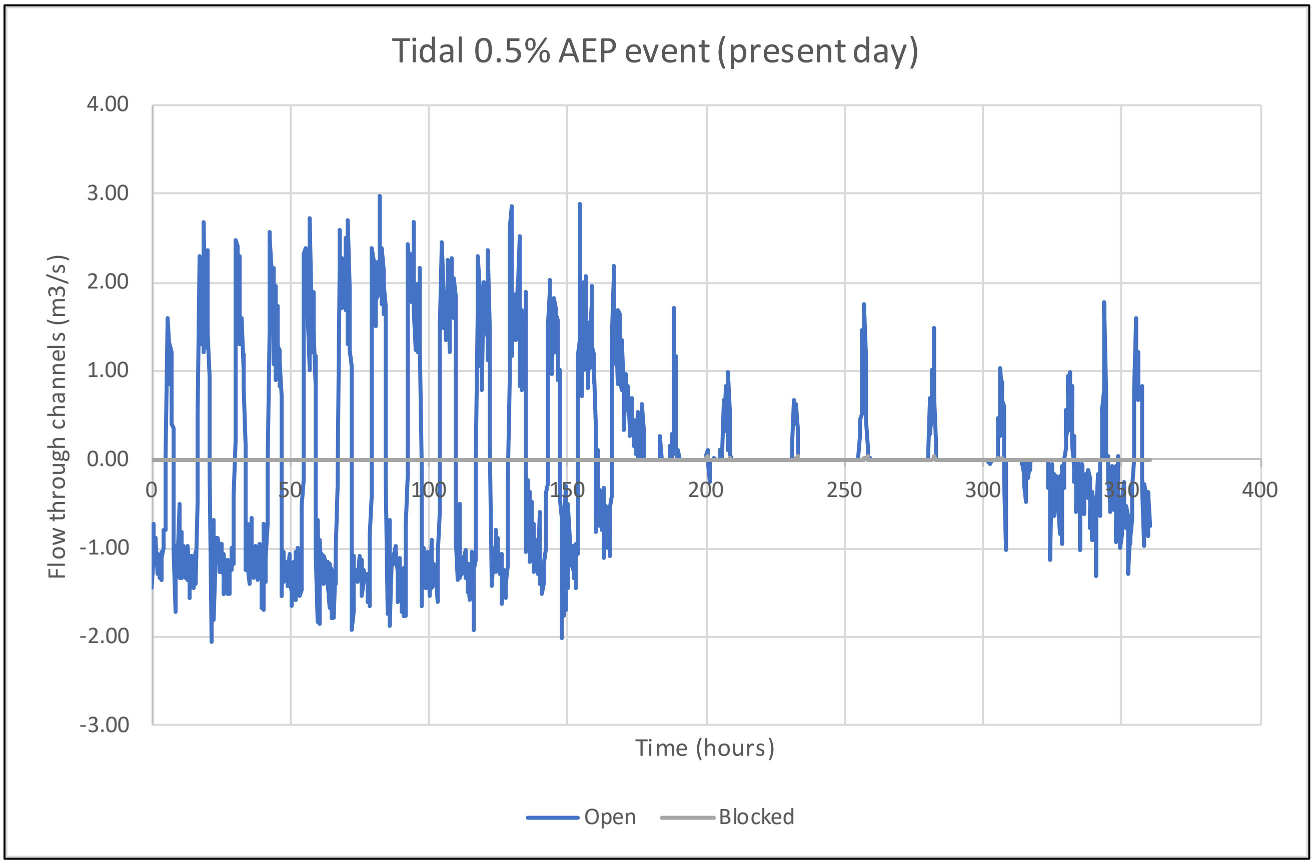

Figure 10: 0.5% AEP tidal event, total flow through the four channels linking Hoveton Great Broad to the River Bure

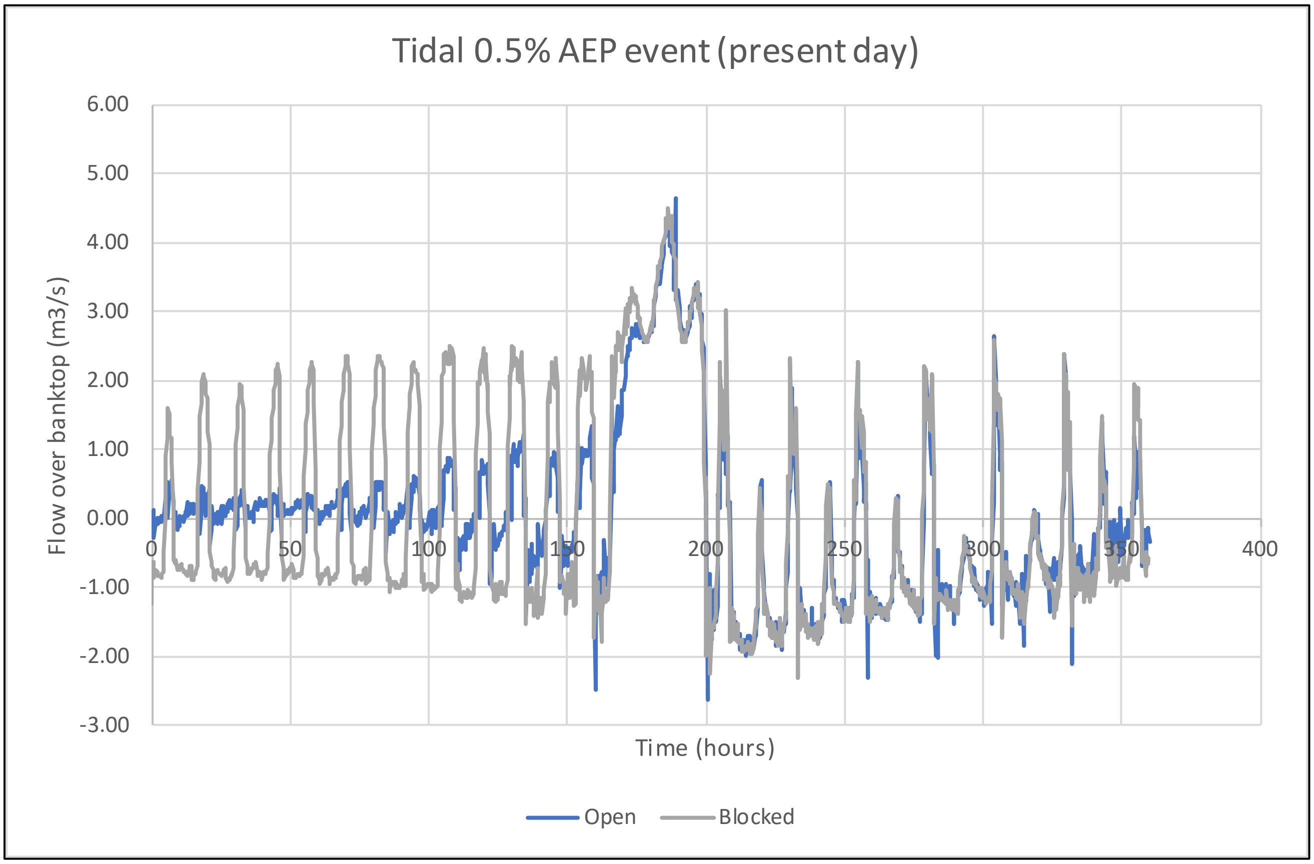

Figure 11: 0.5% AEP tidal event, total flow over the left bank between the River Bure and Hoveton Great Broad

6.2.2 Wroxham

The model results for the 5%, 0.5% and 0.1% present day and climate change events showed no difference in the peak levels between open and blocked connecting channels at Hoveton Great Broad (Table 9). Very minor differences are evident in the time series results prior to the arrival of the main tidal event (Figure 12). These minor differences (< 0.01 m) are considered well within modelling tolerances.

Wroxham Node BA21061			
Annual Exceedance Event (AEP)	Tidal Baseline (mAOD)	Tidal Blockage (mAOD)	Difference (m)
5%	0.69	0.69	0.00
5% + Climate Change	0.76	0.76	0.00
0.5 %	0.77	0.77	0.00
0.5 % + Climate Change	0.82	0.82	0.00
0.1%	0.81	0.81	0.00
0.1% + Climate Change	0.85	0.85	0.00

Table 9: Peak water level (mAOD) for the baseline and proposed (blockage) scenario for the tidal events at Wroxham

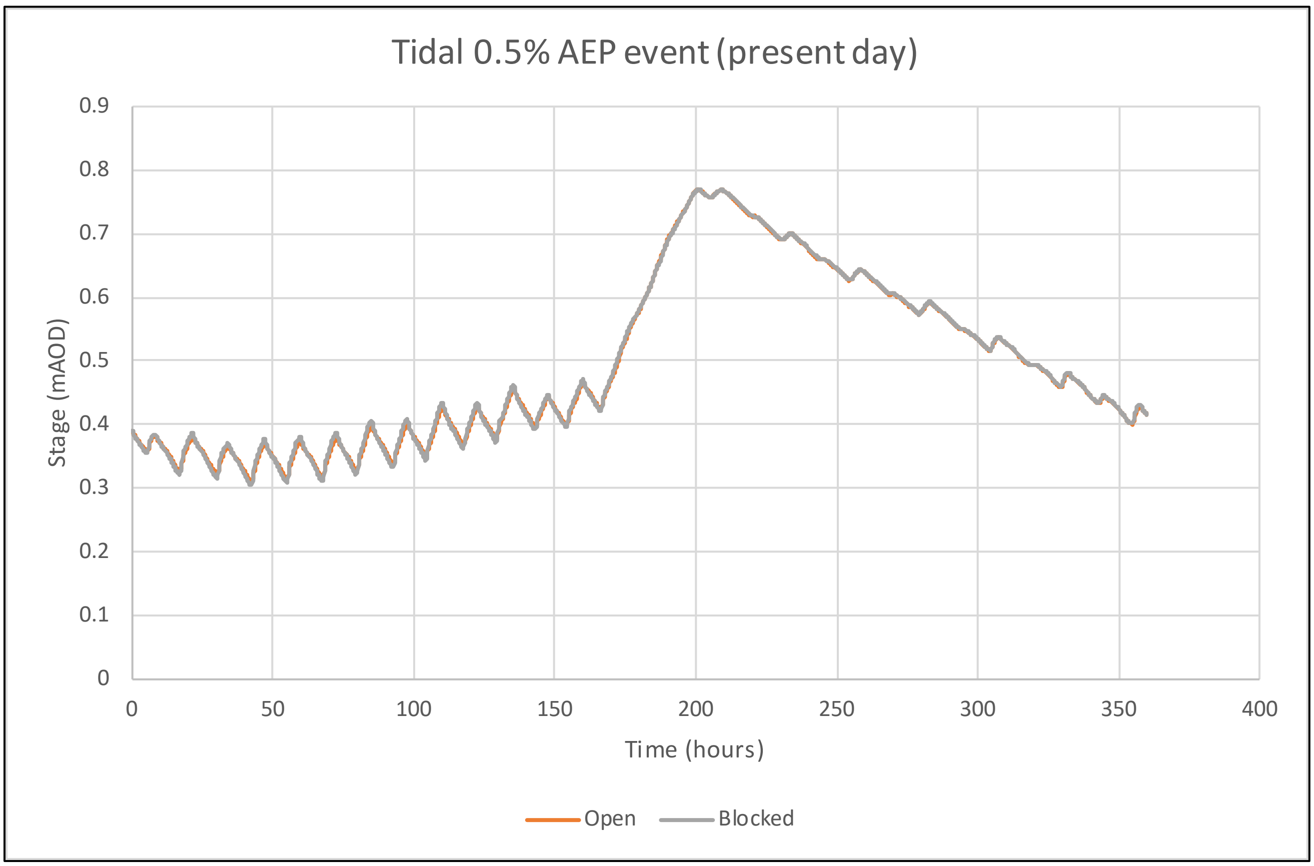

Figure 12: 0.5 % AEP tidal event, stage at Wroxham with open and blocked channels at Hoveton Great Broad

6.2.3 Horning

The model results for the 5%, 0.5% and 0.1% present day and climate change events showed no difference in the peak levels between open and blocked connecting channels at Hoveton Great Broad (Table 10). Very minor differences are evident in the time series results prior to the arrival of the main tidal event (Figure 13). These minor differences (< 0.01 m) are considered well within modelling tolerances.

Horning Node BA13529			
Annual Exceedance Event (AEP)	Tidal Baseline (mAOD)	Tidal Blockage (mAOD)	Difference (m)
5%	0.69	0.69	0.00
5% + Climate Change	0.76	0.76	0.00
0.5%	0.77	0.77	0.00
0.5% + Climate Change	0.82	0.81	0.01
0.1%	0.81	0.80	0.01
0.1% + Climate Change	0.85	0.85	0.00

Table 10: Peak water level (mAOD) for the baseline and proposed (blockage) scenario for the tidal events at Horning

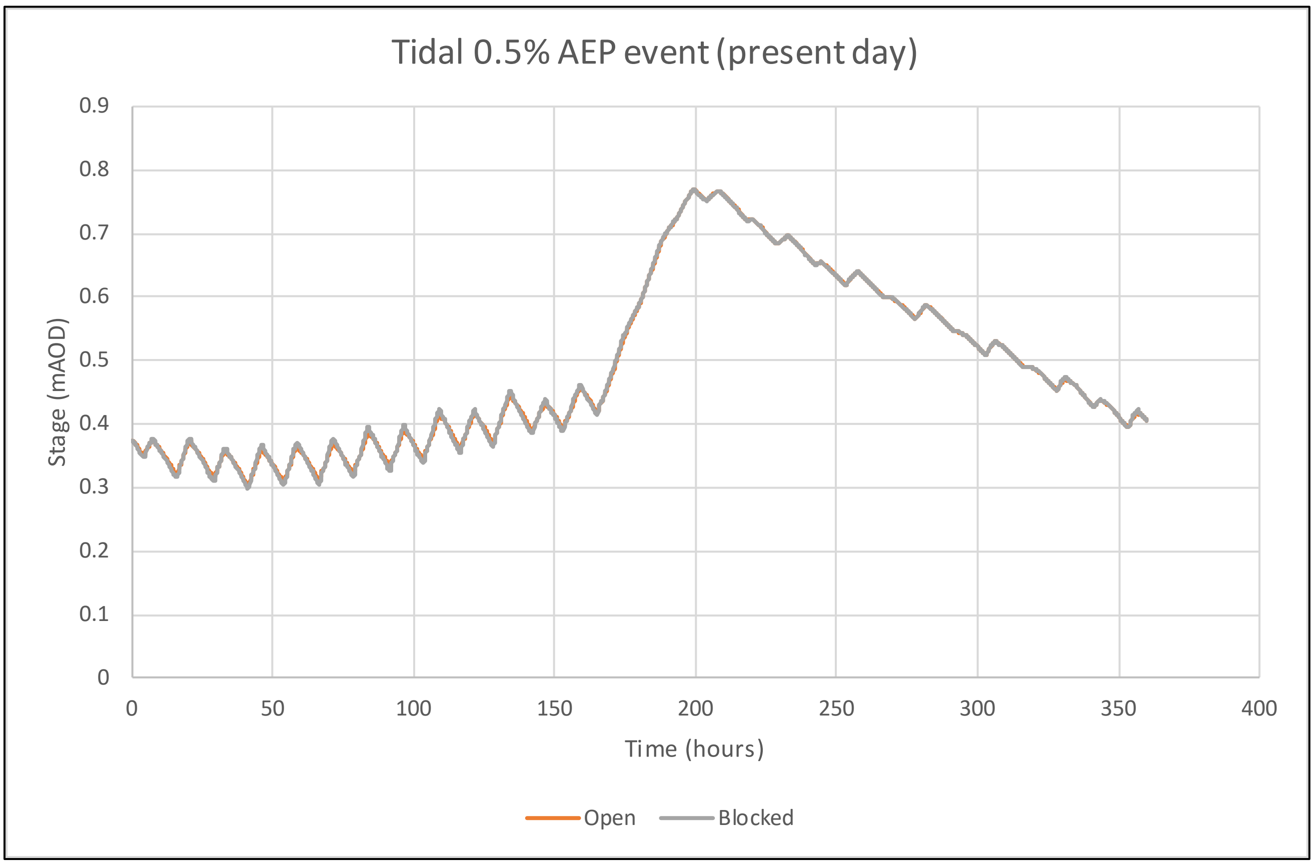

Figure 13: 0.5 % AEP tidal event, stage at Wroxham with open and blocked channels at Hoveton Great Broad

6.3 Fluvial events

6.3.1 Hoveton Broad

Results from the 5%, 1% and 0.1% present day and climate change fluvial simulations showed negligible difference attributable to blockage of the four connecting channels (Table 11). Figure 14 shows the time series results for the 1% AEP + climate change and confirms no differences occur.

Annual Exceedance Event (AEP)	Baseline Fluvial Water level (mAOD)	Blockage Fluvial Water level (mAOD)	Difference (mAOD)
5%	0.81	0.81	0.00
5% +Climate Change	0.86	0.86	0.00
1%	0.92	0.92	0.00
1% + Climate Change	0.96	0.96	0.00
0.1%	1.10	1.10	0.00
0.1% + Climate Change	1.16	1.16	0.00

Table 11: Fluvial event peak water levels for the baseline and proposed (blockage) scenarios, Hoveton Great Broad

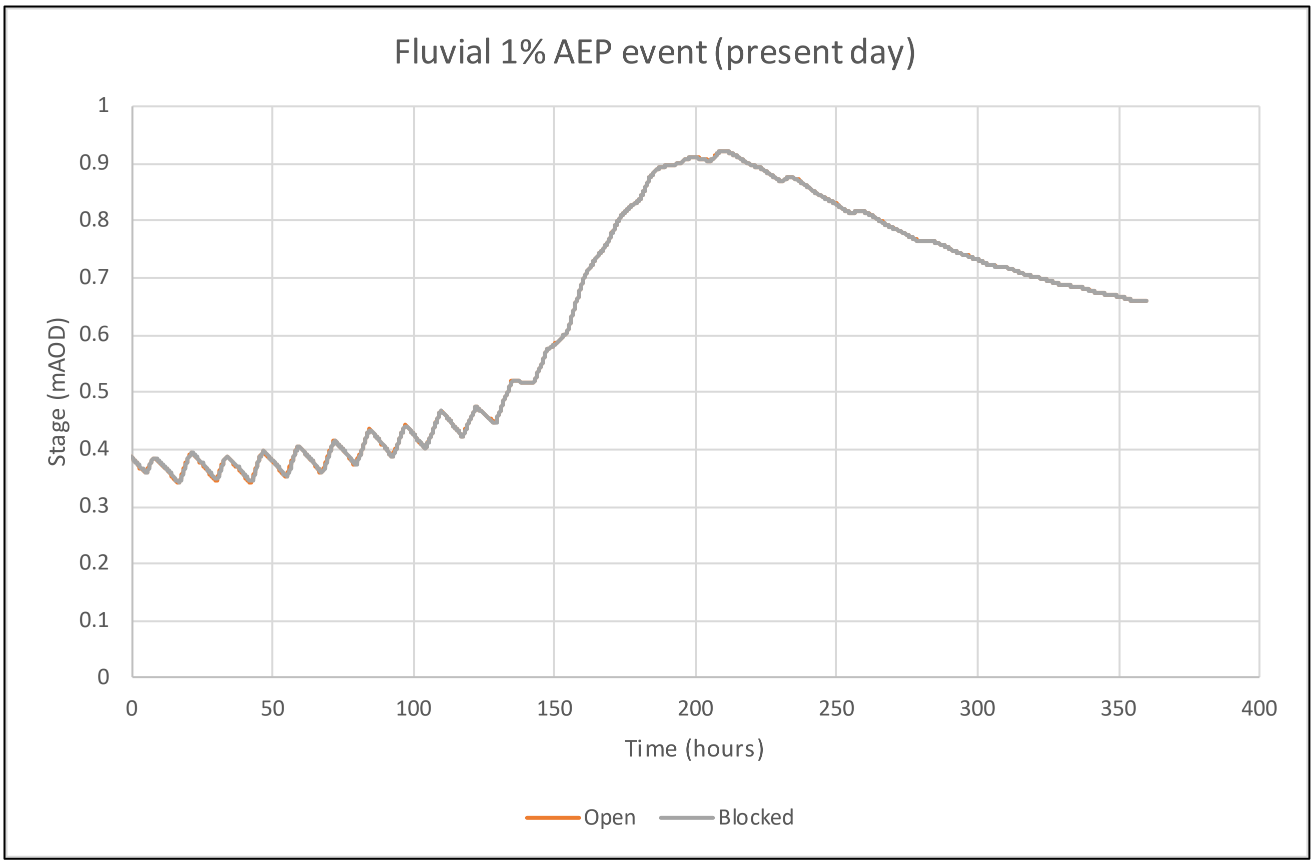

Figure 14: 1% AEP fluvial event, water levels at Hoveton Great Broad, linking channel open and blocked

Figure 15 and Figure 16 respectively show the total flow through the four linking channels and over the top of the bank for the 20% AEP event. Figure 17and Figure 18 show the total flow for the 1 % AEP event. These flow time series show that:

- Prior to the main fluvial event, there is positive and negative (reverse) flows through the four linking channels reflecting the rising and falling tide. During the main period of the fluvial event, there is negligible flow through the linking channels as levels in the River Bure and Hoveton Great Broad are equalised. When the linking channels are blocked, there is no flow. This is the same pattern of flow as that occurring in the tidal events.

- Prior to the main fluvial event, there is over-bank flow from the River Bure into Hoveton Great Broad in the 20% and 0.5% AEP events. When the linking channels are blocked, there is greater flow over the banktops. During the main period of the fluvial event, flows over the banktop are very similar in the open and blocked simulations.

The model results show that peak tidal levels are unaffected by blockage of the channels as there is negligible flow through the channels. Prior to the main tidal event, blockage of the channel results in increased flows (positive and reverse) over the banktops.

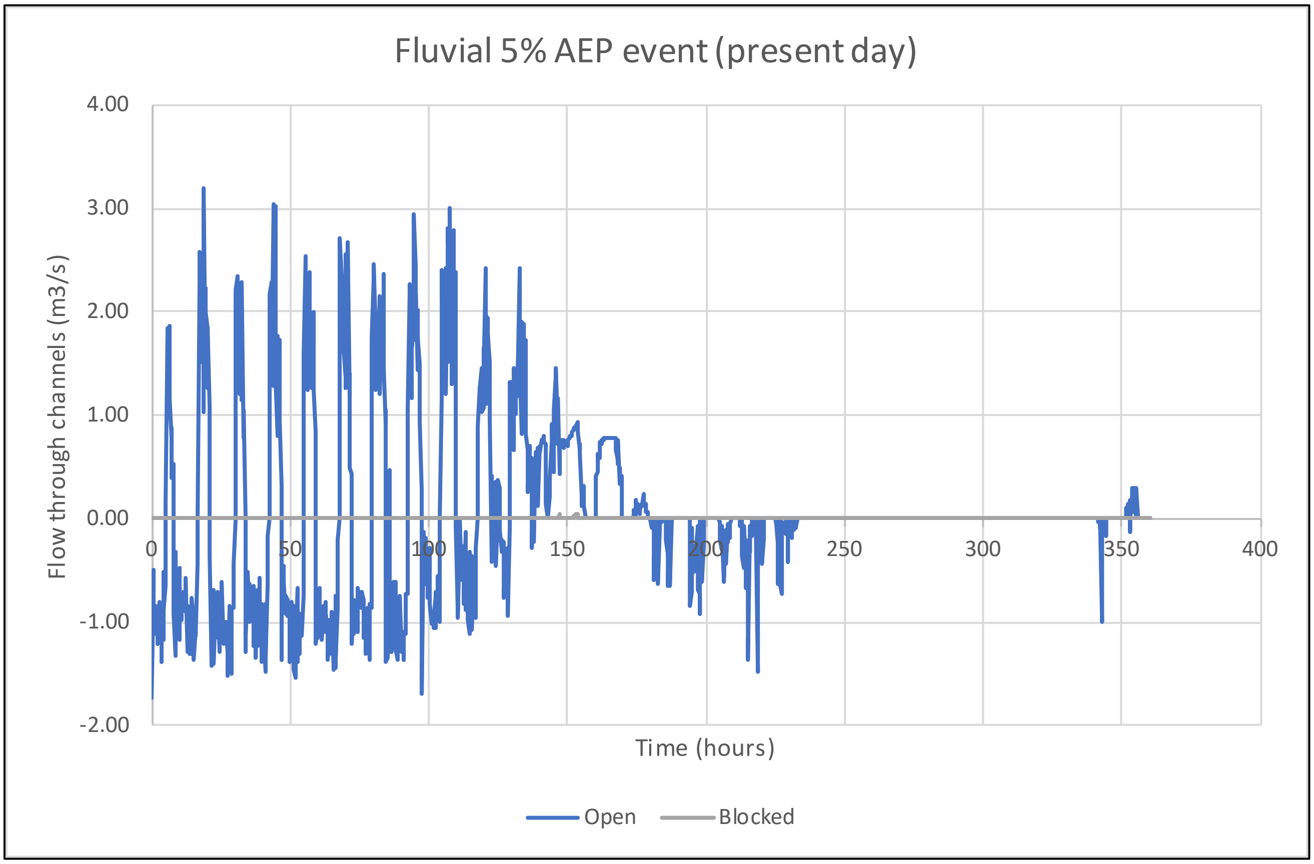

Figure 15: 5% AEP fluvial event, total flow through the four channels linking Hoveton Great Broad to the River Bure

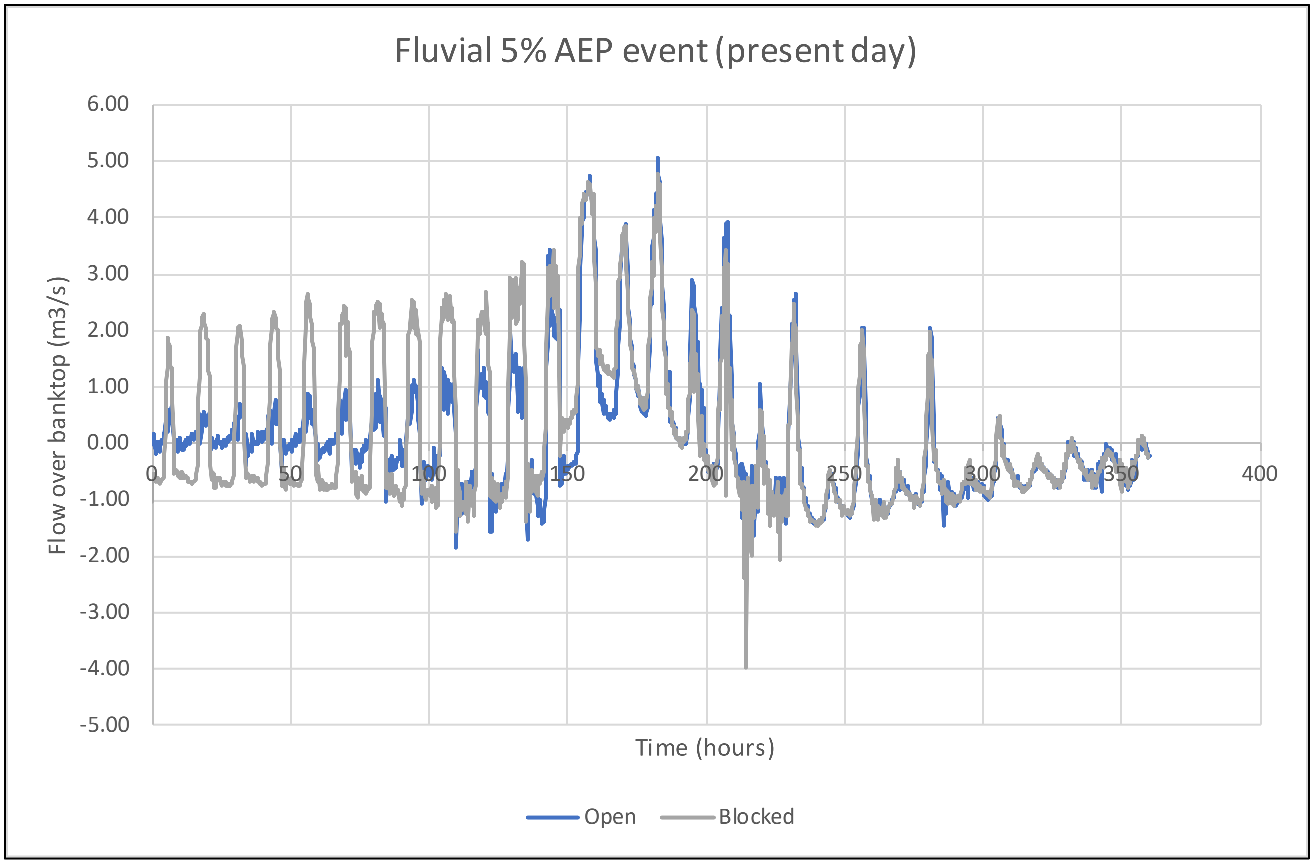

Figure 16: 5% AEP fluvial event, total flow over the left bank between the River Bure and Hoveton Great Broad

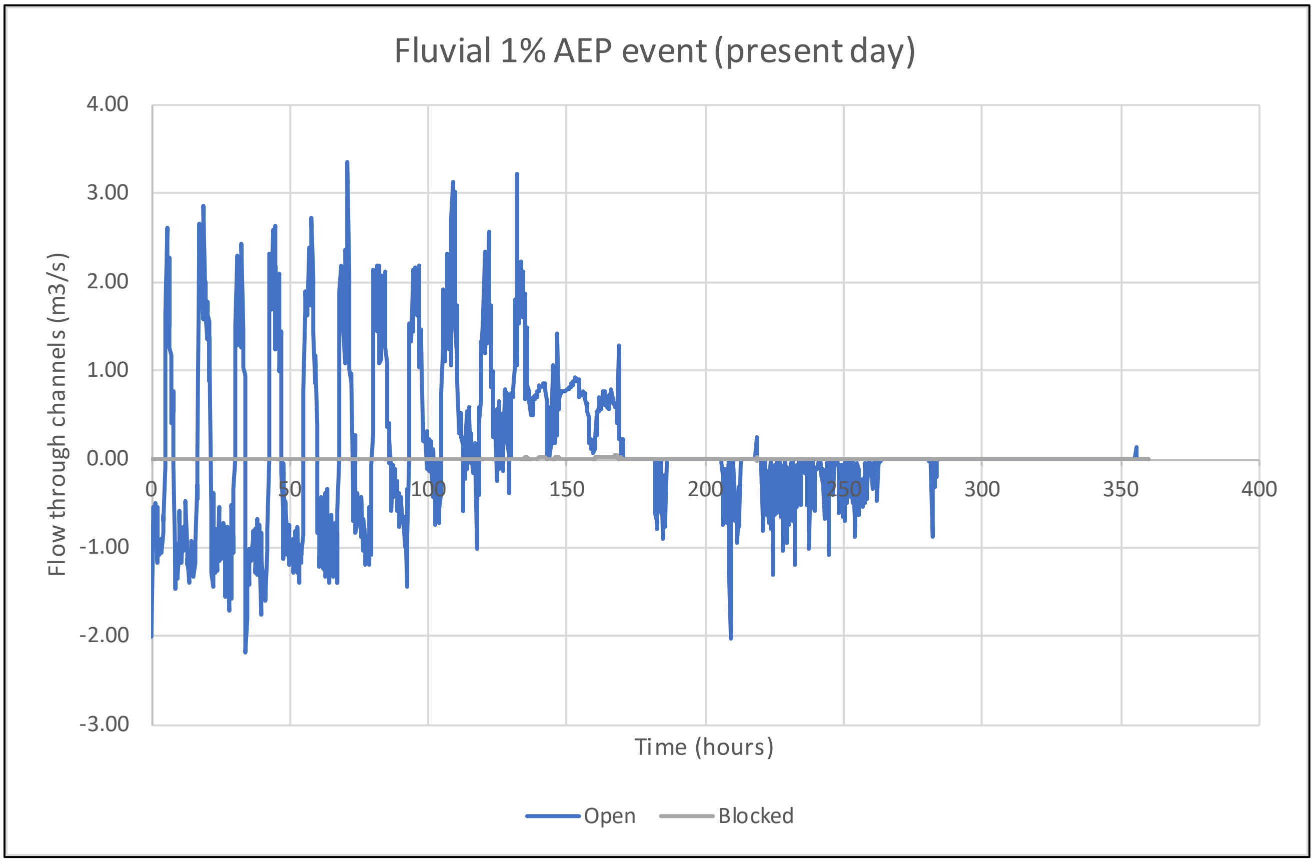

Figure 17: 1% AEP fluvial event, total flow through the four channels linking Hoveton Great Broad to the River Bure

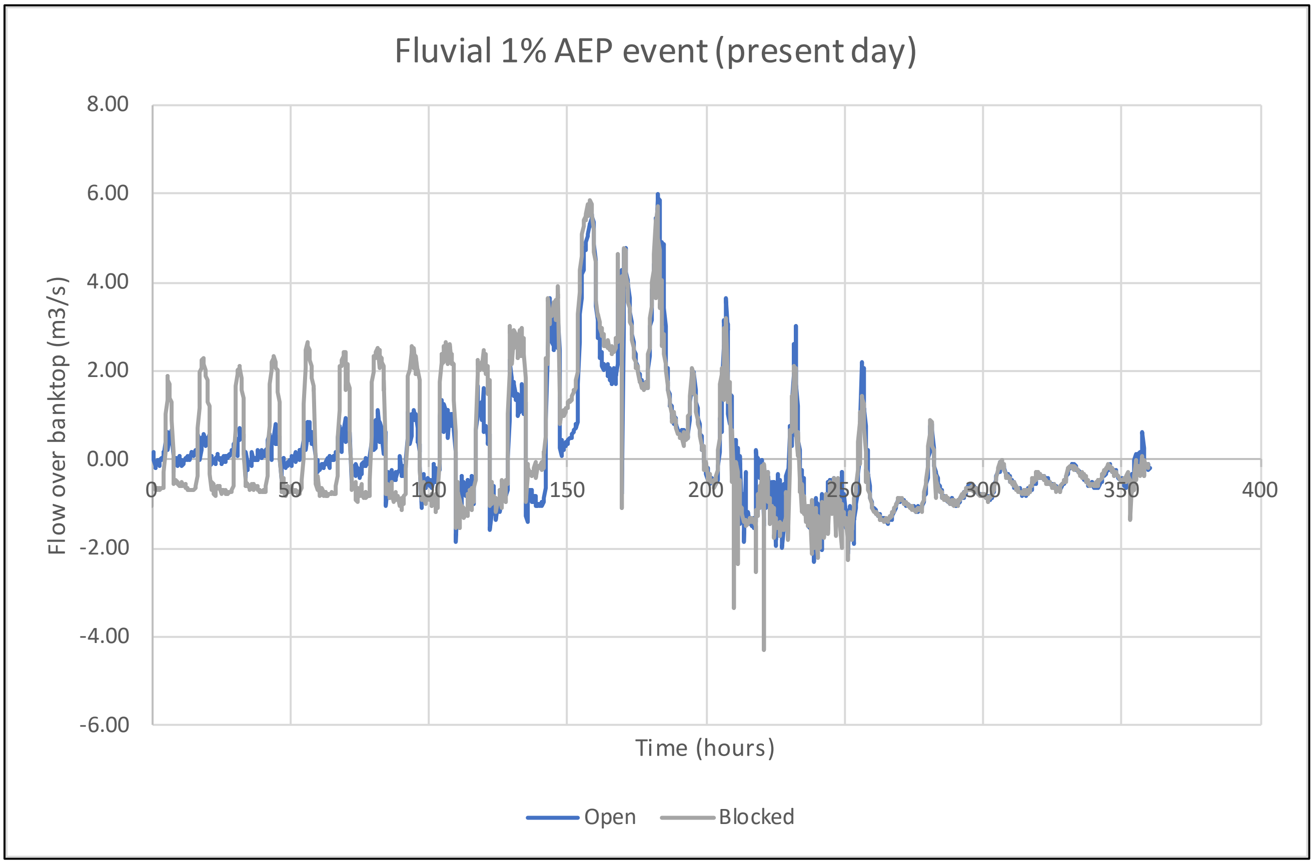

Figure 18: 1% AEP fluvial event, total flow over the left bank between the River Bure and Hoveton Great Broad

6.3.2 Wroxham

The model results for the 5%, 1% and 0.1% present day and climate change events showed no difference in the peak levels between open and blocked connecting channels at Hoveton Great Broad (Table 12). No difference in evident in the time series results (Figure 19).

Wroxham Node BA21061			
Annual Exceedance Event (AEP)	Fluvial Baseline (mAOD)	Fluvial Blockage (mAOD)	Difference (m)
5%	0.83	0.83	0.00
5% + Climate Change	0.88	0.88	0.00
1%	0.95	0.95	0.00
1% + Climate Change	0.99	0.99	0.00
0.1%	1.16	1.66	0.00
0.1% + Climate Change	1.22	1.22	0.00

Table 12: Peak water level (mAOD) for the baseline and proposed (blockage) scenario for the fluvial events at Wroxham

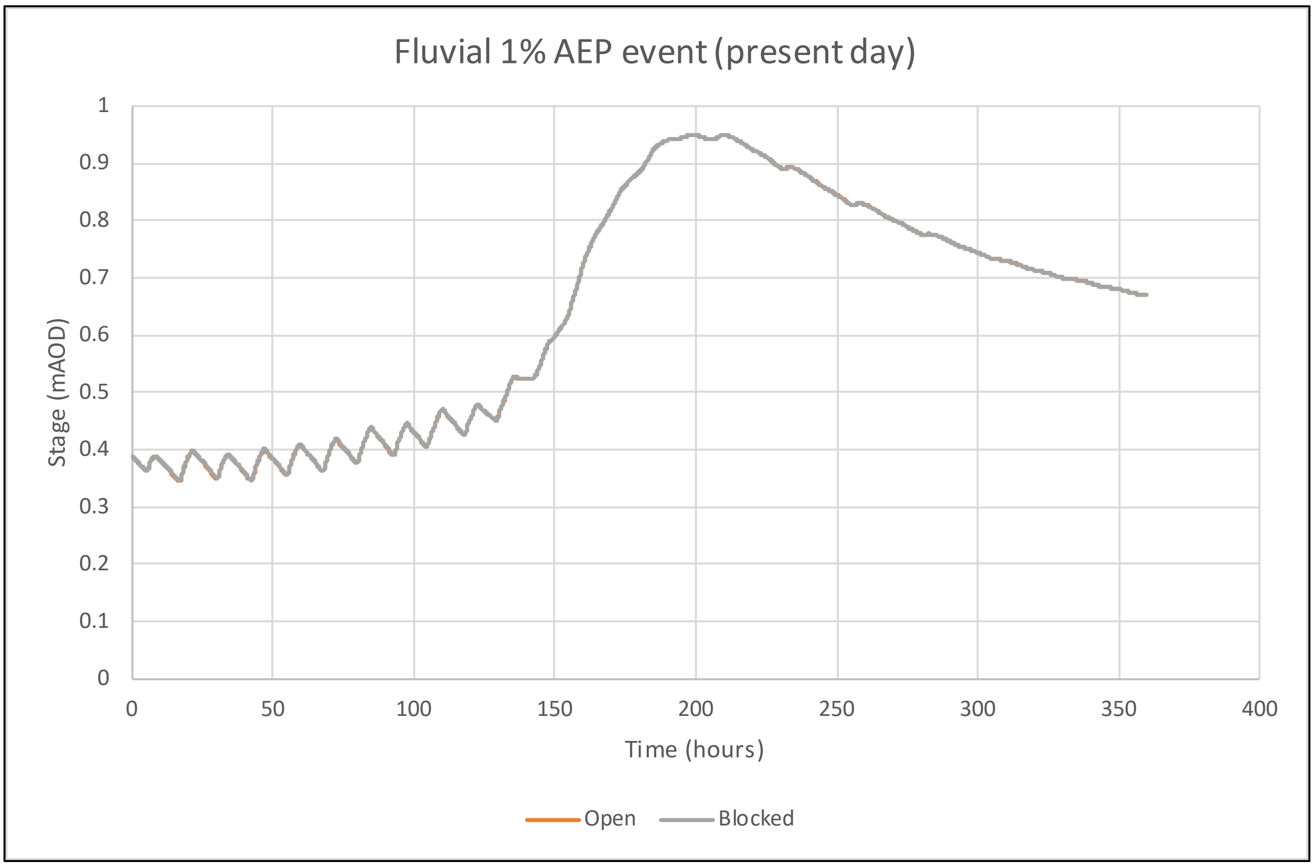

Figure 19: 1 % AEP fluvial event, stage at Wroxham with open and blocked channels at Hoveton Great Broad

6.3.3 Horning

The model results for the 5%, 1% and 0.1% present day and climate change events showed no difference in the peak levels between open and blocked connecting channels at Hoveton Great Broad (Table 13.). No difference in evident in the time series results (Figure 20).

Horning Node BA13529			
Annual Exceedance Event (AEP)	Fluvial Baseline (mAOD)	Fluvial Blockage (mAOD)	Difference (m)
5%	0.81	0.81	0.00
5% + Climate Change	0.85	0.85	0.00
1%	0.91	0.91	0.00
1% + Climate Change	0.95	0.95	0.00
0.1%	1.09	1.09	0.00
0.1% + Climate Change	1.15	1.15	0.00

Table 13: Peak water level (mAOD) for the baseline and proposed (blockage) scenario for the fluvial events at Horning

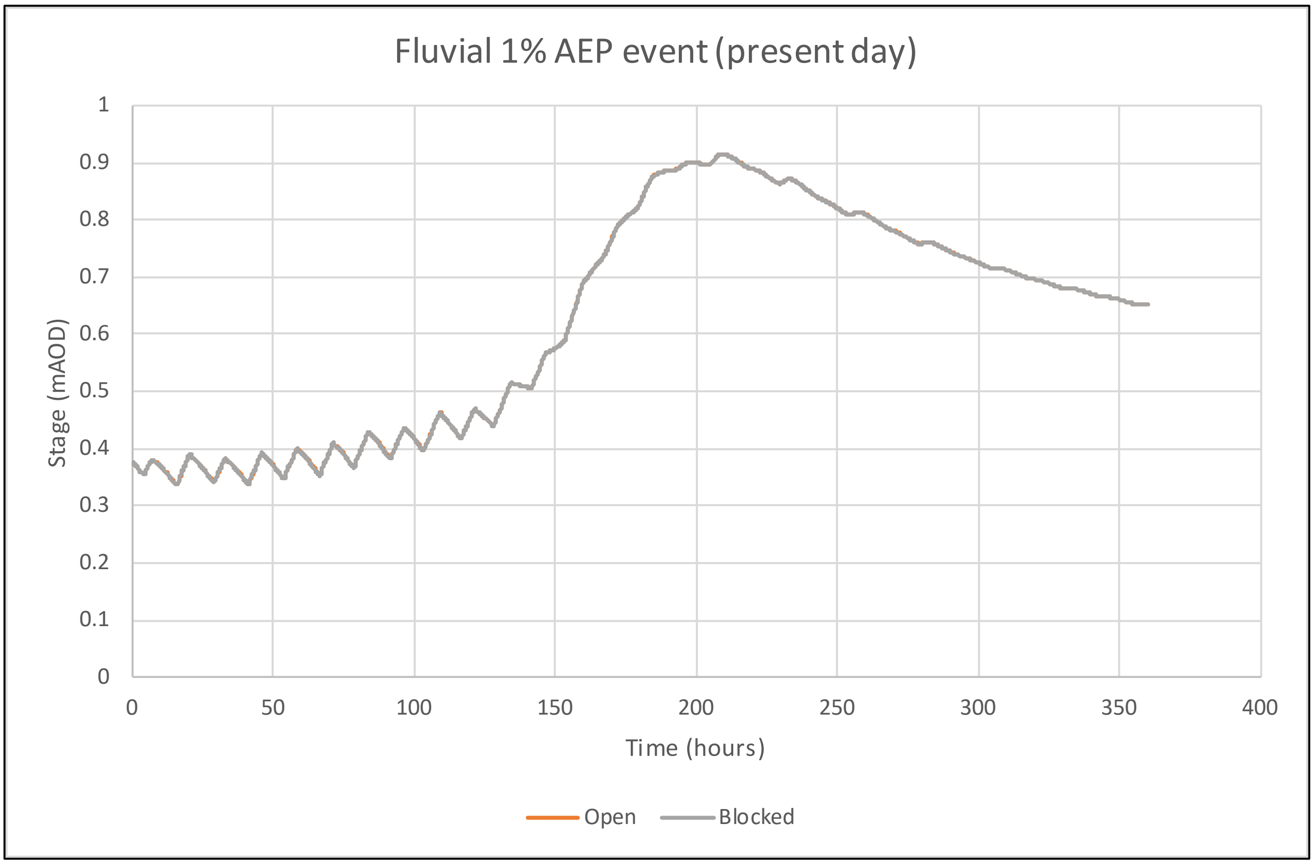

Figure 20: 1 % AEP fluvial event, stage at Wroxham with open and blocked channels at Hoveton Great Broad

7. Limitations

The main limitation of the modelling assessment is absence of topographic survey of Hoveton Great Broad and the four linking channels. Estimated data have been used as follows:

- Hoveton Great Broad depth-area curve has been derived from LiDAR.
- Dimensions for the four linking channels are estimated using:
    - Width: on-line imagery
    - Depth: invert assumed same as the adjacent River Bure.

To test the sensitivity of results to the estimated data the following two tests have been conducted:

1. Double width of linking channels
2. Lower the Horton Great Broad depth-area reservoir curve by 1 m.

Changes to the linking channel depth was not conducted as the approach adopted was considered conservative i.e. invert lower than reality. The 5% AEP fluvial and tidal events were tested, the smallest event being expected to be the most sensitive to the modelling assumptions.

The water levels in Hoveton Great Broad are shown in Figure 21 and Figure 22 for the 2 x channel width and Figure 23 and Figure 24 for the lowering of the reservoir unit. The results show that doubling the linking channel width had no impact in both the fluvial and tidal events. Lowering of the Hoveton Great Broad model reservoir depth-area curve by 1 m had a very small impact of < 0.01 m in the fluvial event and <0.02 m in the tidal event. Such small differences are well within modelling tolerances.

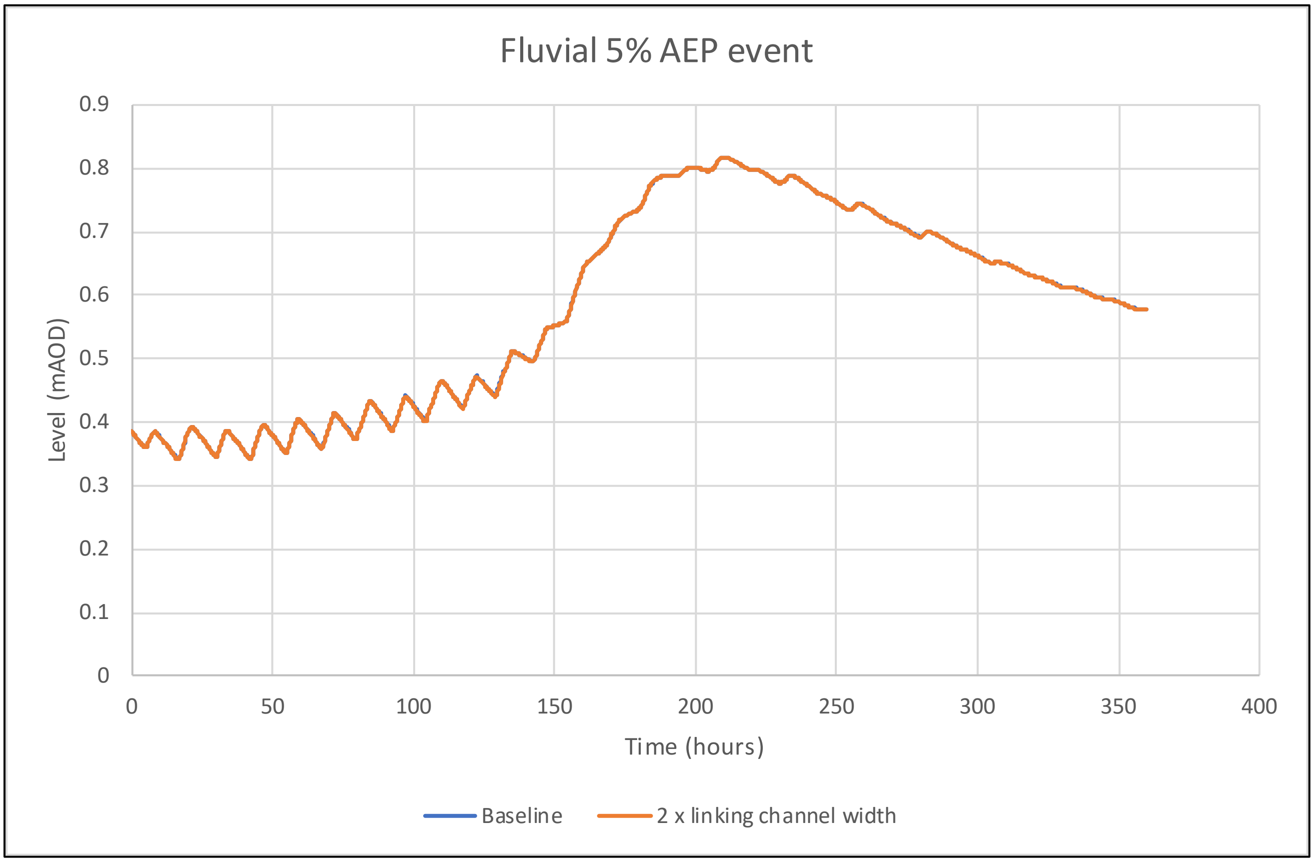

Figure 21: 5% fluvial event, water level in Hoveton Great Broad, baseline and 2 x linking channel width

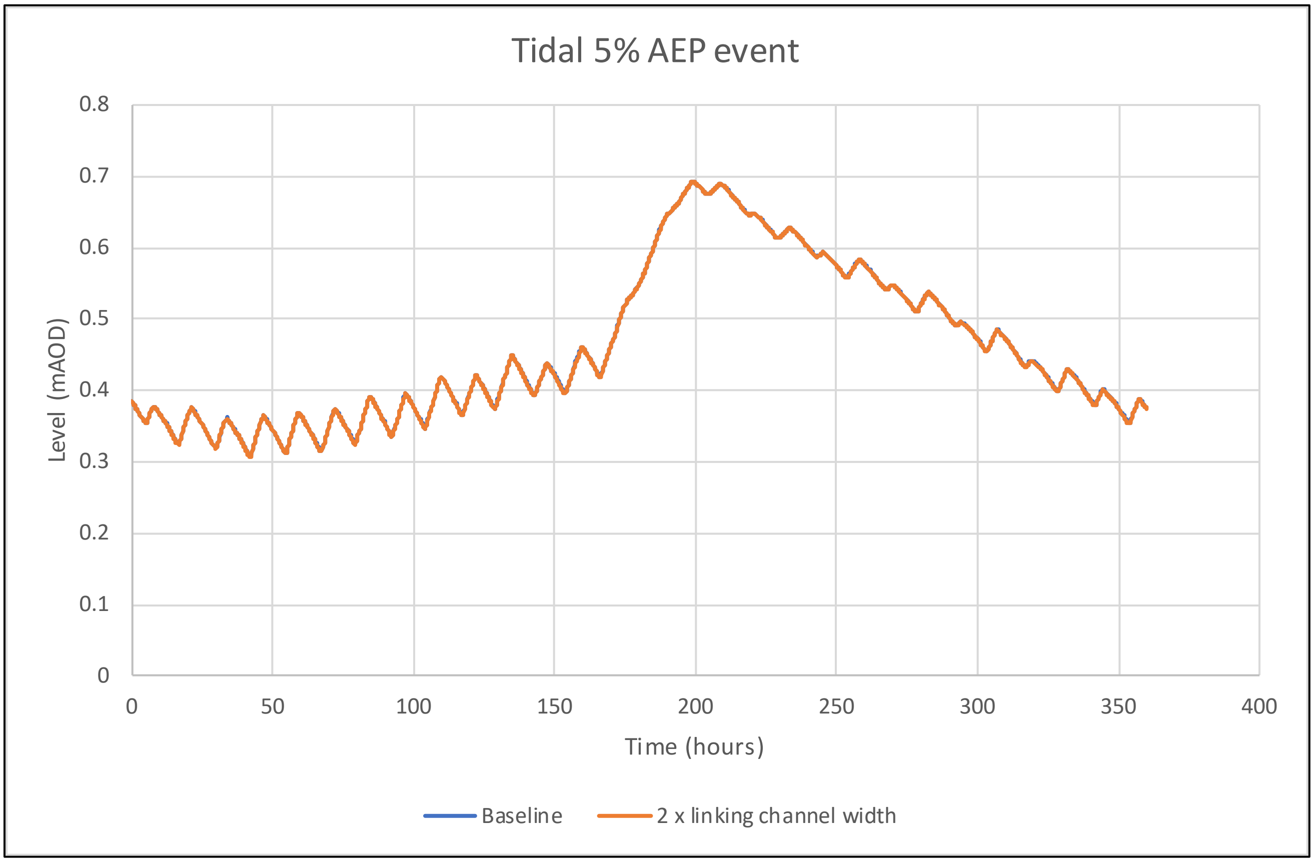

Figure 22: 5% tidal event, water level in Hoveton Great Broad, baseline and 2 x linking channel width

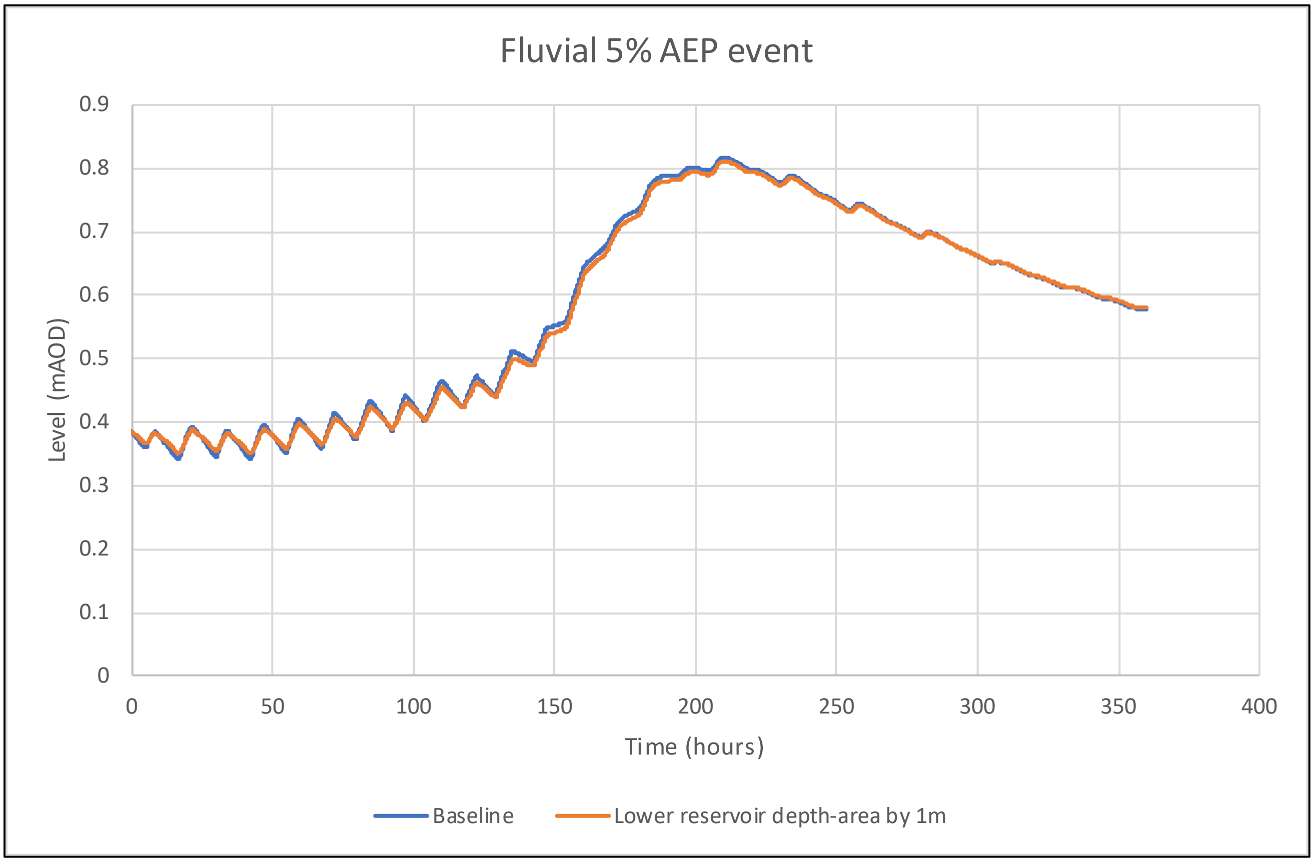

Figure 23: 5% fluvial event, water level in Hoveton Great Broad, baseline and lowered depth-area curve

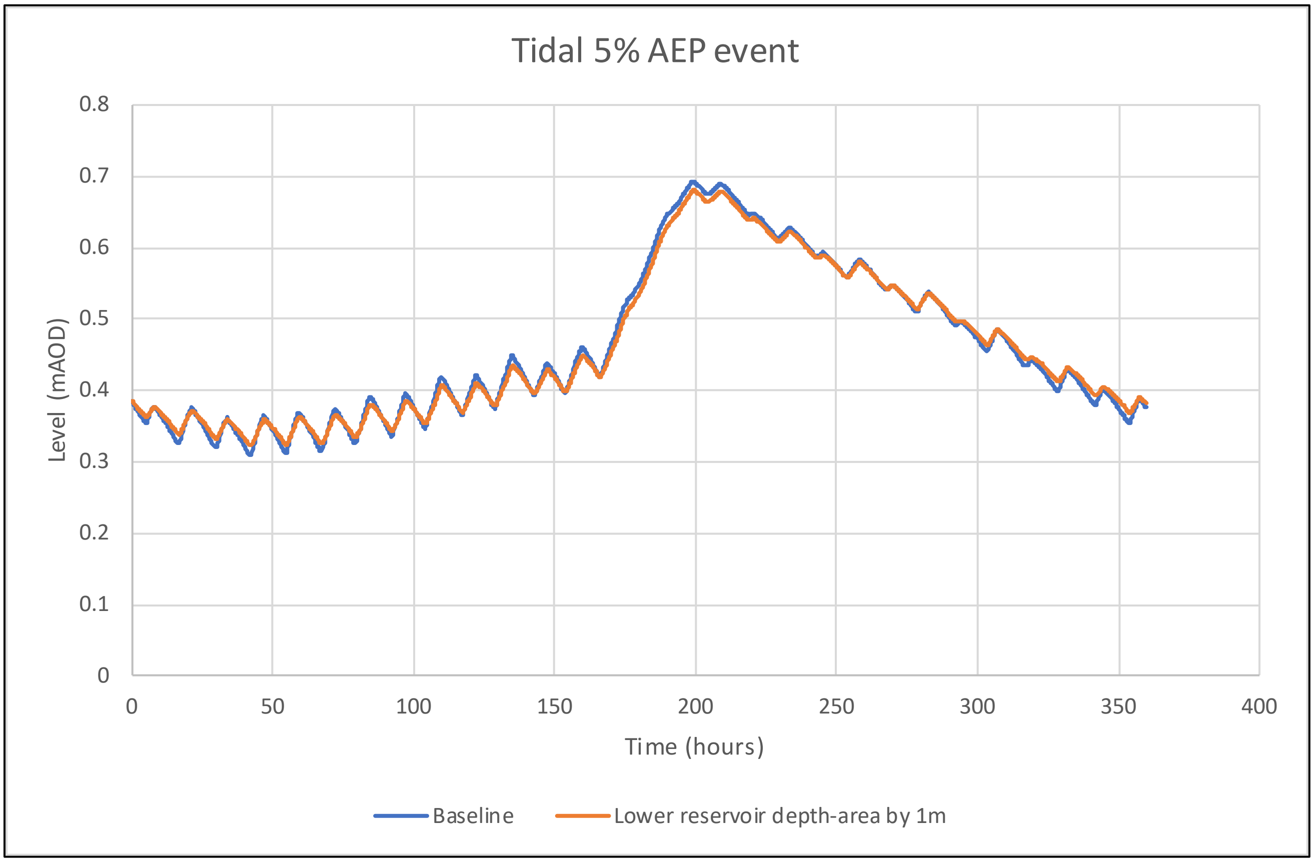

Figure 24: 5% tidal event, water level in Hoveton Great Broad, baseline and lowered depth-area curve

8. Conclusions and recommendations

A modelling investigation has been undertaken to evaluate the impact of installation of four bio-manipulation barriers at Hoveton Great Broad. There are four small channels linking Hoveton Great Broad to the River Bure. Bio-manipulation barriers are proposed on each of the four channels to prevent fish migration. During flood events, flow over-bank flows may also occur enable exchanges between the River Bure and the Broad.

The BESL 1D model has been used, with the model modified to include Hoveton Great Broad as a reservoir unit and the four linking channels added as spills. Overbank flow routes are also represented using spill units. The four channels linking the Bure and Hoveton Great Broad are either assumed fully open or totally blocked. Comparison of the results provides a worst-case of the likely impact of the bio-manipulation barriers.

The modelling analysis has investigated the impact of the barriers for tidal flood events (5%, 0.5% and 0.1% AEP) and fluvial events (5%, 1% and 0.1% AEP). Climate change simulations have also been conducted.

A limitation of the modelling analysis has been absence of topographic survey of the linking channels and of Hoveton Great Broad. A sensitivity analysis has been conducted to address this limitation. The sensitivity analysis showed that results are not sensitive to the assumed channel and broad geometry and hence there is no need for topographic survey.

The results show that installation of the barriers has negligible impact on peak water levels at Hoveton Great Broad and on the River Bure. This result is attributable to overbank flows occurring during all simulated events, these flows equalize levels in the Bure and Hoveton Great Broad. The equalization of levels means there is no head difference to drive flows through the linking channels.

During the early period of the tidal events, blockage of the linking channels results in additional overbank flows. This additional over-topping would potentially increase the risk of erosion of the banktops and potentially allow additional frequency for fish movement between the Bure and Hoveton Great Broad.

The model results show that the bio-manipulation barriers do not affect tidal or fluvial flood levels and consequently will have no impact on flood extents. The results show that the barriers may affect over-topping during normal tidal events (outside of fluvial flood periods) and further investigation of such conditions is recommended.