[redacted]

Written Representation concerning the development application for the East Anglia Two Offshore Wind Farm.

From Mr. R A Brooks. Reference Number: IP20024473

My wife and I are retired and have been permanently resident at the above address in Friston since November 2013.

Having attended all available consultations relating to the SPR proposals since November 2017, I have recognised that affected communities have been informed rather selectively, for example there was no advertised public presentation in Friston itself until after the Grove Wood site had been chosen. Presenters often did not know the answers to questions, and communities were engaged with at the latest possible stage, only out of necessity, and then ignored.

I am concerned that the impact of the onshore installations regarding the following issues have been either disregarded by the applicant, or have been under-estimated:

Landscape: The utilitarian structures proposed are of such vast scale and footprint as to be impossible to screen given realistic tree growth rates. The sites are in close proximity to the village of Friston, would be situated on relatively high ground, and would have a significant visual impact in rural surroundings. The structures would be clearly visible from all four approach routes to the village. No corresponding photomontages were provided by the applicant, which would have demonstrated the extent of the permanent eyesore to passing traffic, as well as a constant reminder to residents on every return home. The structures would even be evident from the Sailor's Path between Snape and Blackheath, part of the Sandlings Walk, and the proposed National Coast Path.

Local Economy: Recent surveys have indicated the probable impact on the local tourist industry and associated businesses, causing business failures and consequent loss of employment. There will be no local benefit, and the adverse impact will therefore be significant.

Local Amenities: The land acquisition proposed would eliminate the historic and well used Footpath 6 (The Pilgrims' Way), and render most other village footpath routes unusable or undesirable. I presently use these routes daily in order to exercise myself and our dog; the alternative would necessitate car journeys to more suitable locations. Cycle routes would also be adversely affected, and the land grab appears to even include the Friston village allotments.

Noise: The present ambient noise levels in Friston are demonstrably low, and are barely measurable on normal scales. Noise from both construction sites and haul road would be significant and intrusive for local residents. During the operational phase, tonal noise from the installations would be both continuous, unavoidable and invasive. SPR appear to have erroneously compared noise impact to that at the site at Bramford, which is close to the A14 trunk road and the London to Norwich main railway line, and on the outskirts of Ipswich.

Health: The construction phase would create dust and pollution. The consequent reduction in air quality will have an impact on those residents with existing respiratory conditions. Such a person [redacted], and in consequence we may be forced to relocate from a house in which we expected to spend the rest of our retirement. The prospect of the reduction of quality of life resulting from this industrial development has caused stress related illnesses in the parish; the mental health impact has already been significant.

Light: The proposed development site is presently a dark sky area. This will be lost following installation of security lighting for both construction and operational phases.

Flooding: This is seriously underestimated by SPR. The entire construction site, and also 1 km of the proposed haul route and cable corridor lie within the water catchment area of the village of Friston. This catchment area to the north of the village is predominantly cultivated permeable sandstone, but flood events in the village are still a regular occurrence. The applicant's proposal would result in a large area of this catchment being covered with impervious materials, during both construction and operational phases. The additional flood risk to the village is therefore extremely serious, and is unlikely to be mitigated by the applicant's proposed water storage facilities. I attach a copy of a local flood report prepared for The Environment Agency in 2016. The vulnerable parts of the village are identified, and there is an indicative map of the whole catchment area of the Friston watercourse on page 12. I understand that a more recent survey, to which I do not have access, has been undertaken by Suffolk County Council.

Heritage: Activities at the landfall site and cable corridor will adversely affect the coastal amenity footpaths and tourist businesses, and are invasive of the AONB. The cable corridor also impacts on ancient woodland and listed buildings.

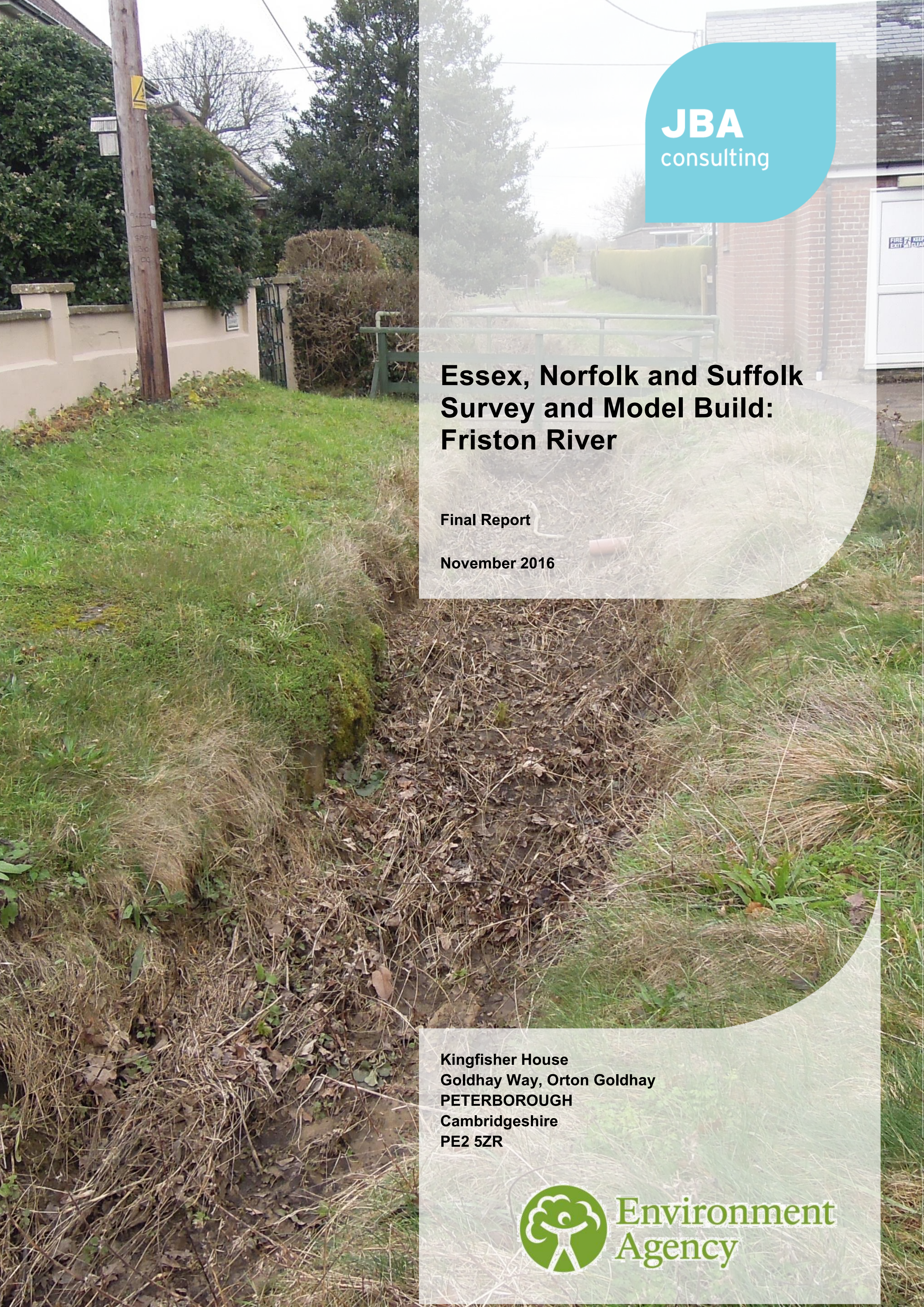
Cumulative Impact: This was deliberately restricted by the applicant to considering only the cumulative impact with the Sizewell C development, when further connections to the National Grid substation of Friston were already known. The promise of a connection by National Grid to the proposed Friston hub for a further six energy projects is now registered and public. This is devastating. The construction phase of the whole development would therefore stretch over a decade, and the "temporary" haul road to the site would effectively become semi-permanent.

To Conclude: There are wider impacts. The viability of a hitherto popular area to visit, and in which to live, containing the resorts of Aldeburgh and Thorpeness, and the associated cultural and commercial centre of The Maltings, is to be permanently sacrificed; the result of a commercial free-for-all consequent on a recognised absence of strategic planning at national level.

This has belatedly been acknowledged by the recent NGESO Offshore Coordination Project consultation. I believe that the SPR proposals should ultimately be included in the forthcoming BEIS Offshore Transmission Network Review.

Finally, I note the extensive reservations and criticisms of this proposal by local councils and public bodies, and would give special mention to the comments of Suffolk Coastal MP Therese Coffey, and to the diligent, intelligent, and expert appraisal of this application by the team from SASES; all of whom have my support.

This is a development application with appalling consequences, and I can only appeal to you to reject it.



Essex, Norfolk and Suffolk Survey and Model Build: Friston River

Final Report

November 2016

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Revision History

Revision Ref / Date Issued	Amendments	Issued to
Draft v1.0/ July 2015		Rebecca Brown & Laura Baird
Draft v2.0/ September 2015	Updates made following Environment Agency review of the draft report	Rebecca Brown & Laura Baird
Draft v3.0/ October 2015	Updates made following an email received from Rebecca Brown containing comments dated 21 October 2015	Rebecca Brown
Final v4.0/ November 2015	Updates made following an email received from Rebecca Brown containing comments dated 28 October 2015	Rebecca Brown
Draft v5.0/ October 2016	Updates made following remodelling of Friston River after incorporating updated survey data within Friston village	Sarah Marseglia
Final v6.0/ November 2016	Updates made following an email received from Sarah Marseglia containing comments dated 24 November 2016	Sarah Marseglia

Contract

This report describes work commissioned by the Environment Agency under the Water and Environmental Management (WEM) Framework, Lot 1; Modelling, Mapping and Data services. The Environment Agency's representatives for the contract were Angela Barber, Rebecca Brown and Sarah Marseglia. Hydrologist Matt Roberts and modellers Ben Gibson and Matt Savill of JBA Consulting carried out this work.

Prepared by .... Matthew Roberts BSc MSc DIC

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Purpose

This document has been prepared as a flood risk mapping report for the Environment Agency. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBA Consulting has no liability regarding the use of this report except to the Environment Agency.

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JBA is aiming to reduce its per capita carbon emissions.

Executive Summary

Overview

JBA Consulting was commissioned by the Environment Agency to undertake Flood Risk Mapping of nine main river watercourses in Essex, Norfolk and Suffolk (ENS), for which currently only broadscale 2D mapping (JFlow) exists. These watercourses comprise the River Hun in North Norfolk; the Friston River, the River Glem, Belstead Brook, and Holbrook Stream in Suffolk; Kirby Brook, Sandon Brook, Jaywick Ditch and Hawkins Road Ditch in Essex.

Individual reports have been produced for each watercourse; this report concerns Friston River, located in Suffolk. Flood Risk Mapping of Friston River was undertaken by constructing a 1D-2D ISIS-TUFLOW model of the watercourse. This study has been commissioned under the Water and Environmental Management (WEM) Framework, Lot 1.

The Friston River catchment is located in Suffolk. Friston River flows from north to south-east and joins the River Alde near the mean high water level (NGR TM 43096 57856). The source is located near Woodside Farm, upstream of Church Road (NGR: TM 41270 60462) and flows through Friston. Friston River flows for approximately 0.8km in a southerly direction before reaching the upstream extent of a flood storage area (FSA) which has an area of approximately 0.03km^2 (0.7% of the catchment area at the downstream extent of the FSA). This online FSA is not included on the FEH CD-ROM as it is dry during normal conditions i.e. it only starts to fill once flow is present in the channel. The elevated crest at the outlet results in the storage of all water until this crest is overtopped. The geology of the Friston River catchment predominantly consists of sandstone deposits (Crag Group). Therefore, the catchment is quite permeable and a slower response is expected which is supported by fairly high BFIHOST values in the range of 0.655 (downstream extent) to 0.900 (smaller unnamed drain catchment). This is overlain by a mixture of superficial deposits including Diamicton (Lowestoft formation), sands, gravels, clays and silts. Other superficial deposits include Tidal Flat deposits and Peat which are comprised of clays and silts but these are mostly confined to the lower tidal reaches.

Hydrological Analysis

A full hydrological analysis was carried out for Friston River. Design flows for the following annual exceedance probability (AEP) events were required; 50%, 20%, 10%, 5%, 3.33%, 2%, 1.33%, 1%, 0.5% and 0.1%. In addition, the effects of climate change on the 1% AEP, 0.5% AEP and 0.1% AEP were considered (this is represented by the flow estimated for the 1%, 0.5% and 0.1% AEPs plus a 20% increase in flow).

Flow estimates derived using the FEH Statistical method were considered the most suitable for Friston River, given that the catchment is highly permeable. The ReFH method was not used to estimate flows as this flow estimation method is not applicable for catchments with BFIHOST values in excess of 0.65. Unfortunately, this catchment is ungauged and there is limited flood history within the catchment and therefore limited calibration / verification could be undertaken for this catchment. For more information on flood history see Section 7.1 of the FEH calculation record.

The FEH Statistical method allows the use of donor transfer from nearby catchments which have similar features along the study reach. The FEH Statistical method is also based on a larger dataset and can be used with more confidence than other methods.

Storm duration testing was carried out for this watercourse and two storm durations were simulated for design events: the 6.75-hour storm duration was found to produce the largest flood extents within Friston village, whilst the 23.35-hour storm duration event produced larger extents at the FSA downstream of Friston and further downstream in the catchment. Each was tested for the 1% AEP event.

The downstream boundary condition applied to the model was derived by scaling a time series extracted from the Alde and Ore hydraulic model close to the Friston outfall using a frequency analysis at Orford gauging station. The peak fluvial flow from upstream is timed to coincide with the peak water level of the tide.

Hydraulic modelling

A hydrodynamic linked 1D-2D ISIS-TUFLOW model has been developed for the purposes of this study. The model has been based on survey of the watercourse which was collected in February 2007 by EDI Surveys Ltd and also survey sections between Church Road and the A1094 (Friston FSA) collected by the Environment Agency between November 2015 and February 2016 when works were carried out on the channel in this location. The 2D TUFLOW domain has a grid resolution of 4m and ground levels have largely been based on 2m filtered LIDAR data available for the full study area, although towards the downstream extent of the study area 1m filtered LIDAR data was available which was used. The FSA located downstream of Friston village is represented in the 2D domain, but elsewhere the model is 1D-2D linked throughout with the channel and floodplain connected by TUFLOW HX links.

Sensitivity tests were carried out on the 1% Annual Exceedance Probability (AEP) base model (6.75-hour storm duration hydrology). Sensitivity to flow (±20%), hydraulic roughness (±20%) and downstream boundary conditions (±1m) were tested globally within the model. Sensitivity testing of storm duration was completed with the 1% AEP event. Storm durations tested were 6.75-hour, 13.25-hour, 23.25-hour and 31.25-hour events.

Additionally, further scenarios were tested to assess model sensitivity and changes in flood risk. These involved a.) increasing hydraulic roughness of the channel between Church Road and Friston FSA (Manning's roughness values of n=0.067 and n=0.077 were each tested representing scenarios of increased vegetation and/or obstructions in the channel) along with b.) increasing bed levels with the same reach by up to 0.3m.

Model results have been presented in this report and supplied to the Environment Agency in digital format. Modelled flood outlines, maximum flood water depths, velocities and hazards grids have been produced.

Summary of flood risk

The hydraulic model indicates the following key flood risk messages for Friston River:

- The mechanism of flooding is dominated by bank exceedance resulting in flood water spilling onto the floodplain.
- The FSA, located downstream of Friston, does not provide protection to the village but is likely to reduce flows passing downstream and therefore reduce the frequency and magnitude of flooding to properties and open land downstream.
- Flooding is first predicted within Friston in the 20% AEP event, where flooding is predicted close to Friston village hall. In the 5% AEP event exceedance of culvert capacity results in relatively isolated flooding at Grove Road and Low Road. Flooding becomes more widespread in the 3.33% AEP event, with the south-west flow route becoming more prevalent across the B1121. Flood extents gradually increase with magnitude of flood event, with widespread flooding along Low Road predicted in the 1% AEP event.
- Flood water is stored in Friston FSA in all events tested, and the crest level of Friston FSA is exceeded in the 0.5% AEP event and above.
- Downstream of the FSA, property flooding is predicted in the 20% AEP event close to Firs Farm due to bank exceedance and overland flow.
- At the downstream of the study extent, flooding initially follows ditches and drainage networks and then becomes more widespread, particularly with larger magnitude events. Tide-locking will contribute to flooding as discharge through the tidal outfall cannot take place during the peak of tidal water levels.
- Compared with existing Flood Zone information, the results from this study are notably smaller at the downstream end of the study extent. This is expected as tidal flooding is not considered as part of this study, but is included within the Flood Zones. Upstream of the tidal influence, flooding from this study is larger than existing Flood Zones. The existing Flood Zones appear offset from the location of the channel, suggesting the ground level information may have been of less good quality. Also these commence at the downstream of Low Road and do not appear to include the

FSA, so modelled outputs from this study are an improvement in both coverage and representing the mechanisms in the catchment.

Conclusions and recommendations

The objectives of the study have been fulfilled and, from the study, a number of recommendations have been highlighted:

- It is recommended that a gauge is to be installed on the watercourse, in order to improve the flow estimates.
- Review model outputs against future periods of raised flow/flooding, verifying the hydraulic model and its inputs, where possible.
- Collect detailed survey of the culvert extending from upstream of Aldeburgh Road to Low Road to better inform the dimensions of the culverts and where these transition into a single culvert.
- Review the blockage scenario outputs and consider reviewing or putting plans in place to manage potential blockages at culverts e.g. through clearance schedules or upgrading structure inlets (e.g. trash screens).
- Investigate the benefits of the FSA to understand whether this should be maintained as a defence asset, or returned to a more natural state.
- Investigate surface water flood risk within the catchment, and particularly Friston. Available outputs from mapping such as the updated Flood Map for Surface Water should be assessed and consideration given to more detailed investigation or planning to manage the flood risk.

The study has highlighted key areas where there is flood risk and hazard to people. The mapped outputs of this study will be useful for the Environment Agency in terms of future planning and development, and potentially for future flood alleviation and flood warning schemes where gauging stations are located.

Contents

List of Figures

List of Tables

Abbreviations

1D	1-dimensional
2D	2-dimensional
AEP	Annual Exceedance Probability
AM	Annual Maximum
AREA	Catchment area (km^2)
BHS	British Hydrological Society
CC	Climate Change
D	Depth
DEM	Digital Elevation Model
DF	Debris Factor
DTM	Digital Terrain Model
EA	Environment Agency
ENS	Essex, Norfolk, Suffolk
FEH	Flood Estimation Handbook
HR	Hazard Rating
ISIS	1D hydraulic modelling software
ISIS-TUFLOW	1D-2D hydraulic modelling software
Km	Kilometres
LIDAR	Light Detection and Ranging
Km^2	Kilometres squared
m	Metres
mm	Millimetres
m^3	Metres cubed
m^3/s	Metres cubed per second
mAOD	Metres above Ordnance Datum
MDSF2	Modelling and Decision Support Framework
QMED	Median Annual Flood (with return period 2 years)
NFCDD	National Flood and Coastal Defence Database
NRFA	National River Flow Archive
ReFH	Revitalised Flood Hydrograph
SFRA	Strategic Flood Risk Assessment
SoP	Standard of Protection
WEM	Water and Environmental management (Framework)
v	Velocity
yr	Year

1 Introduction

1.1 Purpose of Study

JBA Consulting was commissioned by the Environment Agency to undertake Flood Risk Mapping of nine main river watercourses in Essex, Norfolk and Suffolk (ENS), for which currently only broadscale 2D mapping (JFlow) exists. These watercourses comprise the River Hun in North Norfolk; the Friston River, the River Glem, Belstead Brook, and Holbrook Stream in Suffolk; Kirby Brook, Sandon Brook, Jaywick Ditch and Hawkins Road Ditch in Essex. Individual reports have been produced for each watercourse; this report concerns Friston River, located in Suffolk.

The aims and objectives were to undertake a new hydrological analysis of the watercourse, and construct a 1D-2D ISIS TUFLOW model using existing channel survey data and LIDAR. This will be used to identify and understand the nature of flood risk within the Friston River catchment by producing flood risk mapping for a suite of Annual Exceedance Probability events. A variety of sensitivity tests were also completed. This study has been commissioned under the Water and Environmental Management (WEM) Framework, Lot 1.

Figure 1-1 shows the model schematisation for the study watercourse.

1.2 Report Structure

This main project report is intended to provide an overview of the various elements of the study. The technical methodology and calculations are provided as appendices to the main report. The structure and content of this report has been based on the recently revised Model Report Performance Scope (September 2010), which replaces the previous Section 105 specification.

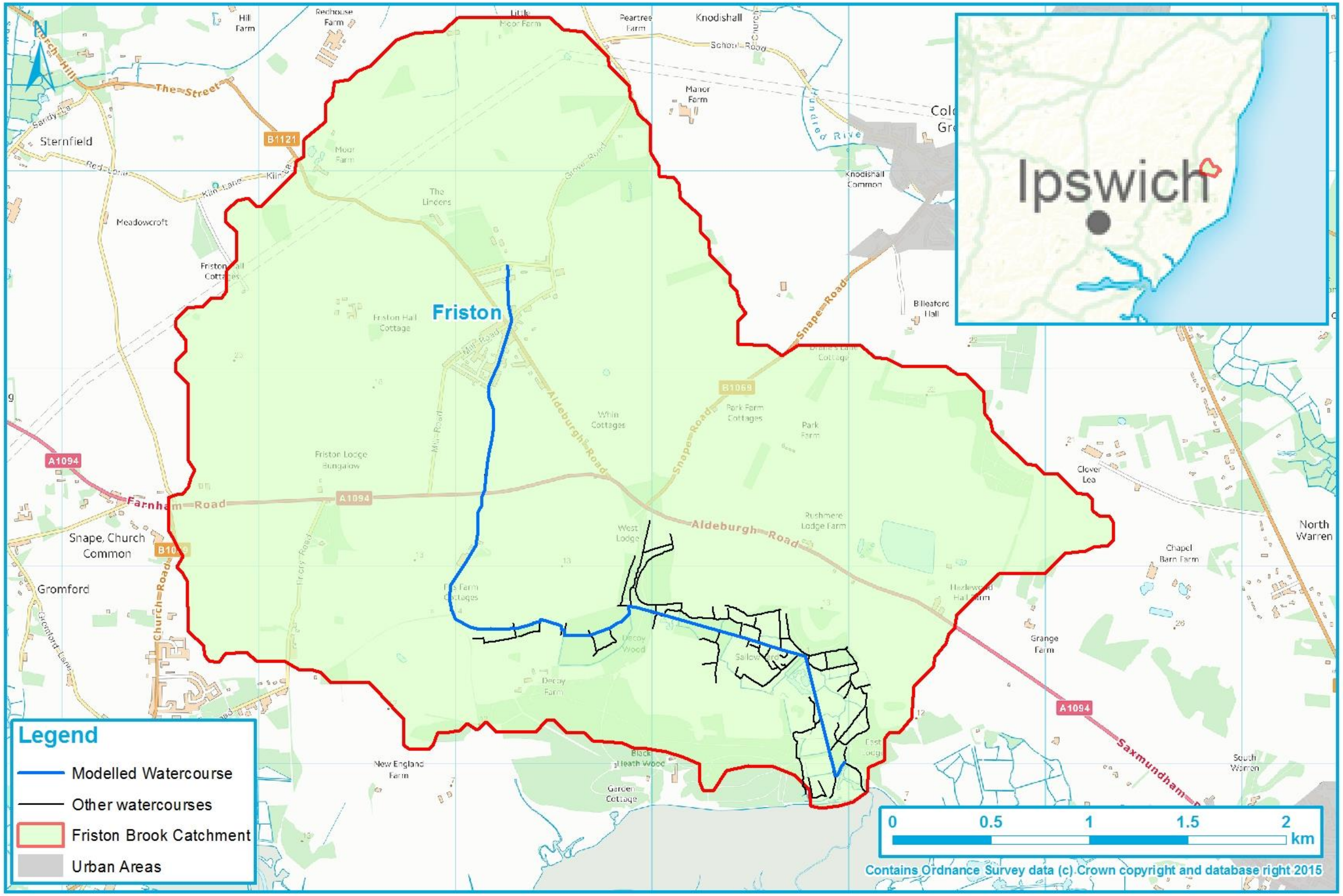
The following project deliverables have been produced in digital format and supplied to the Environment Agency:

- Flood outlines for all the modelled AEP events (ArcGIS and MapInfo format),
- Maximum flood water depth, velocity, and hazard grids (ESRI ASCII format),
- Maximum water levels and flows from the 1D model, including in-channel model nodes in ESRI shapefile format, for each AEP event (excel spreadsheet),
- Raw data and check/diagnostics files for all model runs
- MDSF2 system-ready data.
- All necessary files have been converted to NFCDD format.

1.3 Overview of Catchment

Friston River drains a catchment area of approximately 11.2km^2 to the northeast of Ipswich. The catchment is rural with Friston village the only settlement along the length of the watercourse. Downstream of Friston a flood storage area (FSA) is present, beyond which farm buildings are located adjacent to the channel before the catchment widens, becoming flatter and more expansive. The modelled extent of Friston River extends from Church Road in Friston to river's outfall into the River Alde. This study does not include any assessment of tidal flooding.

Figure 1-1: Study catchment and model extent

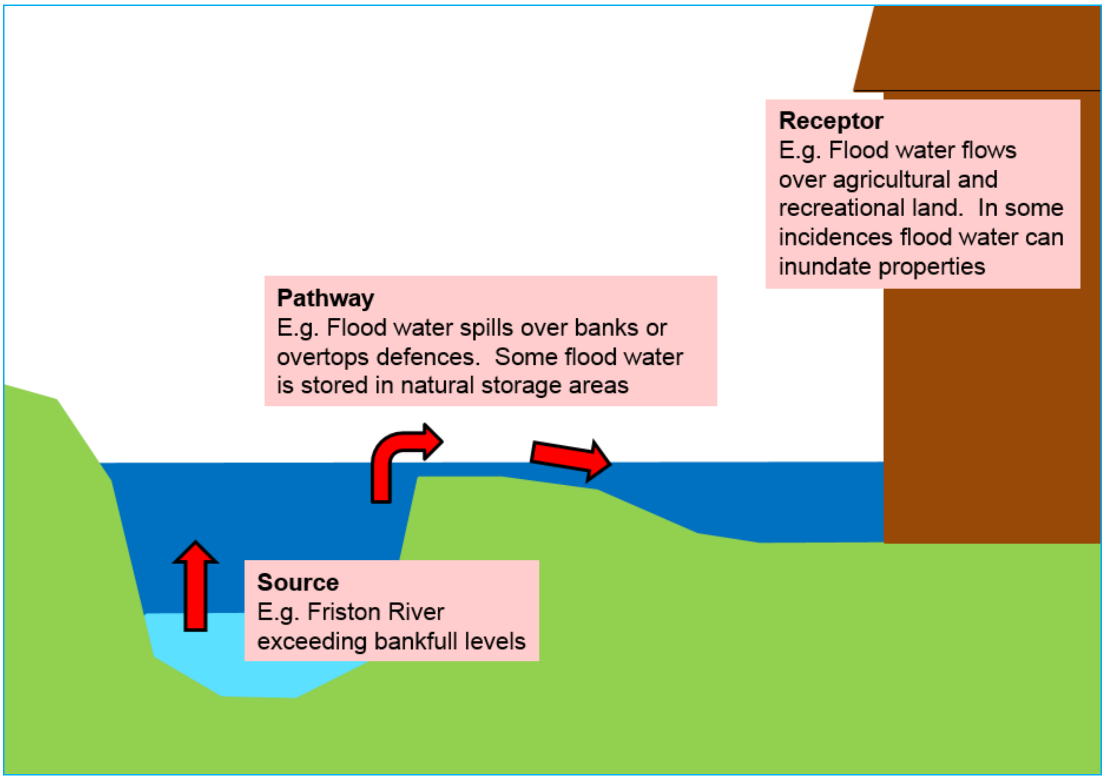


2 Qualitative Description of Flood Response

2.1 Source-Pathway-Receptor

The Source-Pathway-Receptor concept can be used to highlight the processes that influence the flood risk in a given area. A simple schematic is illustrated in Figure 2-1.

Figure 2-1: Source-Pathway-Receptor



2.1.1 Sources

The sources of flood water in the study catchment are summarised below:

The flood water source along the study reach is dominated by the Friston River and the potential for groundwater flooding. There is also some evidence of surface water flooding in the reported flood history within Friston village. This is identified within the updated Flood Map for Surface Water (uFMfSW) flood risk information provided by the Environment Agency which shows predicted flooding within Friston. Overland flow forms north of Church Road and appears to follow the track and other preferential routes north of here.

The study reach is also considered to be at tidal flood risk from the Alde Estuary, as the Friston River outfalls into the tidal reaches of the River Alde. Whilst the outfall of Friston River is flapped, extreme tidal flood events may overtop the sea wall. Although tidal downstream boundaries have been applied to the model, only fluvial flood risk has been considered within this study.

2.1.2 Pathways

The main flood risk along the study reach is a result of Friston River which therefore provides the main pathway for flood water. However, there is potential for some roads to provide pathways for surface water within Friston. The influence of tide locking from the Alde Estuary and Ham Creek also provides a pathway for flood risk.

2.1.3 Receptors

Much of the area at flood risk through the study area is rural. However, Friston village is a key area which is at risk of flooding including some local roads (Church Road, B1121, and A1094), particularly within Friston.

These areas have been represented in the hydraulic model which has been produced for this study. Using the model results the flood risk in these areas for a range of AEP events will be assessed.

3 Model Approach and Justification

3.1 Approach and Appropriateness

This study has been commissioned to improve understanding of fluvial and tidal flood risk within several catchments in Essex, Norfolk and Suffolk. This particular study focuses on fluvial flood risk from Friston River.

The upstream limit of the modelled watercourse is Church Road, Friston where open channel commences downstream of a track which it is understood is a preferential flow route for surface water. From here it flows in a southerly direction through the village of Friston. The open channel terminates at a flood storage area approximately 1km south of the village. A high level spill is present at the downstream of the FSA meaning all flood water is stored until this levels is reached. Once flood water passes over the spill it flows into a culvert under the A1094 road before flowing in open channel again. After a short southerly section of open channel downstream of the FSA outlet the watercourse flows in an easterly direction towards the sea wall/outfall where the floodplain widens. A culvert with a flapped valve is present at the sea wall prevent discharge south of the sea wall when levels in the River Alde are high. The model terminates at the downstream of the tidal wall.

A full hydrological analysis was carried out for the study watercourses, in line with the most up-to-date guidance and datasets. The results of this assessment have been used to provide the inflows to the hydraulic model, and are provided in Appendix B.

A hydrodynamic, linked 1D-2D ISIS-TUFLOW model was developed for Friston River and the model was simulated for a full suite of AEP events. These include 50%, 20%, 10%, 5%, 3.33%, 2%, 1.33%, 1%, 0.5% and 0.1% AEP events. In addition, the effects of climate change on the 1% AEP, 0.5% AEP and 0.1% AEP events were considered (this is represented by the flow estimated for the 1%, 0.5% and 0.1% AEPs plus a 20% increase in flow). Sensitivity analysis was also undertaken; this involved testing the effects of flow, hydraulic roughness and downstream boundary conditions on maximum water levels along Friston River.

Table 3-1: 1D-2D Model Extents

Model	Upstream limit	Downstream Limit
1D-2D ISIS TUFLOW	FB01_5872 TM 412632 60528 Downstream of Church Road	FB01_1195 TM 42985 58004 Culvert outfall into the River Alde estuary

A 1D-2D ISIS-TUFLOW model is the most appropriate type of model for the purposes of the study. They provide accurate information on flood water depths, levels, velocities, timings and hazard ratings, which need to be quantified to provide the Environment Agency with sufficient information to manage the area effectively.

The approach outlined is suitable to fulfil the Environment Agency's study objectives as ISIS defines the channel and provides the best representation of in-channel structures, and TUFLOW allows for a detailed representation of the floodplain once water is out of bank and potential complex overland flow routes, using efficient techniques to manipulate the model grid to define floodplain features which control flood mechanisms. The volume of storage on the floodplain is also likely to be more accurately modelled with a 2D domain compared with a 1D cross-sections for instance.

All calculations and methodologies used in the hydrology and hydraulic modelling stages of this study have been documented and added as appendices to this report.

3.2 Uncertainty and strategy for model proving

3.2.1 Natural uncertainty

The largest source of uncertainty in modelled water levels quoted for a given AEP event is often the inherent uncertainty surrounding design flow estimation. Flood frequency estimates tend to be the largest source of uncertainty, especially for longer AEP events, such as the 1% (equivalent to a return period event of 100 years), as they are derived from growth curves fitted to flood peak series that rarely exceed 40 years.

A formal assessment of the uncertainly of a flood frequency curve is a major undertaking, requiring techniques such as resampling of pooled growth curves to investigate natural uncertainty. However, typical confidence limits for design flows are often quoted at ±30-40% where no data has been used to refine flow estimates.

There are no gauges in the catchment so model calibration through comparison with gauged data is not possible.

Uncertainty is also dependent on several other factors, including the similarity of the study catchment to sites within the pooling group. The default pooling groups derived for this study have been reviewed and amended accordingly to improve their suitability. However, given the highly permeable nature of the Friston River catchment, and the influence of the FSA in altering the hydraulic response of the watercourse, the degree to which the applied pooling groups are able to represent the catchment is limited in accordance with the limited number of permeable gauged sites that are suitable are pooling.

Given the lack of hydrometric data, limited flood history and the uncertainty in typical catchment response within Friston River, there is a relatively high degree of uncertainty in the design flow estimates.

3.2.2 Hydraulic model uncertainty

The equations generally used to model hydraulic systems are approximations of the physical processes involved but after decades of use and of continuous improvement the limitations and the implications of the approximations are well understood. Uncertainty can be introduced by the modeller who decides on the best way to represent the study reach. It is important that all decisions that may introduce model uncertainty are well documented.

Structure types and coefficients can have a significant impact on model results. Best practice guidance has been adopted when modelling structures throughout this study and has been based on the original survey data, where available. This is discussed further in the hydraulic model check files in Appendix C. However, if further detailed studies are undertaken along the watercourse, sensitivity testing regarding structure coefficients is recommended. In particular, the parameterisation of the entrance to the Low Road culvert, the outfall of the FSA downstream of Friston village and the entrance to the Firs Farm culvert are particularly important to the model results. The geometry of the culvert at the B1121 which runs adjacent to Low Road has been informed from surveyed culvert inlet and outlet dimensions. No CCTV information was available for use in the study. It is believed that the right-side culvert which is raised at the upstream face of the culvert joins the lower culvert, as only a single culvert outlet is present where the culvert becomes open channel along Low Road. The location and nature of this join is unclear and therefore a simplified approach to representing the raised culvert has been taken forward, whereby an orifice unit connects to the upstream channel and lower culvert downstream of the B1121. This culvert forms one of the main locations for out of bank flooding within Friston and therefore future work should seek to better understand the connections at this culvert and its impact on flood risk.

Sensitivity analysis has been carried out to provide a semi-quantitative measure of parameter uncertainly. The results of this analysis are detailed in Section 6.3.

4 Input Data Plan

4.1 Summary of project data

Data Type	Source	Ownership	Format	Quality	Uncertainties	Post-processing
Hydrometric data	Environment Agency	Environment Agency	.all (text file)	Flow data from nearby gauge (Hollesley gauge)	The Environment Agency have quality control systems in place when collecting and processing hydrometric data. The data is flagged where data is uncertain or anomalies have been identified.	Data was analysed and used in the hydrological analysis. Any data used has been documented in the FEH Calculation Record in Appendix A.
LIDAR	Environment Agency - Geomatics Group	Environment Agency - Geomatics Group	GIS – Ascii grids	1m and 2m resolution data generally of good quality. 1m resolution data flown October 2014, available for the downstream 800m of the model. 2m data flown February 2008 (note: where finer resolution data is available this will have been re-sampled to 2m), available for the full study extent Filtering issues were identified for raised bank features within the FSA at Friston, including part of the embankment south of properties at Friston not being present. At these	LIDAR ground levels using filtered data usually have an uncertainty of ±150mm depending on land use	Filtered LIDAR was used. Where filtering issues were identified, Z-Lines were used to enforce features within the hydraulic model. These are described in the model check file. Elevations of these features were informed by either interpolation of level from filtered LIDAR data where issues are not present, or from unfiltered LIDAR data where elevations were considered to be representative.

Data Type	Source	Ownership	Format	Quality	Uncertainties	Post-processing
				locations vegetation was identified in the unfiltered dataset which it is assumed resulted in the filtering issues. These gaps in the embankment were filled by enforcing levels recorded either side of the gaps in the filtered LIDAR data.		
Survey	EDI Surveys Ltd Collected in February 2007	Environment Agency	AutoCAD, pdf, ISIS	The survey quality has been checked by comparing it against elevations in the LIDAR. A small number of spot checks were completed comparing LIDAR levels and surveyed levels to ensure no gross differences existed between the datasets. This was found not to be the case.	The survey report notes that the precision of heights on hard surfaces may be taken, to a 90% confidence level, to be within ±10mm relative to the control station height.	Formal QA of the February 2007 survey information was not completed as this was an existing EA dataset and prior QA was assumed to have taken place. The survey information was found to contain sufficient detail to enable the construction of the hydraulic model and representation of the main components of the Friston River system. Note: this survey was used to inform the model representation of the channel and structures downstream of the A1094. However, upstream of here, more recent survey information was available to inform channel dimensions, so the 2007 survey data was only used to inform the dimensions of structures in this area.
Survey	Environment Agency Collected in November 2015 to February 2016 on various	Environment Agency	MS Excel	The survey quality has not been checked in detail. The information supplied had been used by the Environment Agency and was considered to be suitable for use. Sensibility	Confidence/ accuracy information is not available for the survey. The survey was collected by the Environment	Information contained within the raw data file was typically Easting, Northing and Elevation. For cross-sections, the distance between data points was calculated based on the Easting and Northing values to provide a chainage across

Data Type	Source	Ownership	Format	Quality	Uncertainties	Post-processing
	occasions.			checks were conducted when implementing the data, which indicated that the sections recorded were expected to be representative.	Agency using GPS equipment.	the section. Distances were not adjusted so that the section is completely linear, but divergence from a straight line was small when points were visually inspected. These sections then formed the model cross-sections. Where this information was used to inform bank levels, the data points themselves were used with no adjustment.
MasterMap	Ordnance Survey	Environment Agency and Ordnance Survey	GIS	Complete coverage of study area	Low uncertainty	The MasterMap data was used to create the various Manning's n roughness zones throughout the TUFLOW domain.
1:10,000 and 1:50,000 scale mapping	Ordnance Survey	Environment Agency and Ordnance Survey	GIS	Complete coverage of study area	Low uncertainty	The OS data was used to produce report figures and animations of the model results.

5 Technical Method and Implementation

5.1 Hydrological Assessment

This section summarises the hydrological analysis undertaken to derive, where required, flow estimates along the study reach. The results of the hydrological analysis should be considered in the context of the needs of this study, and may not be appropriate for wider use.

A full hydrological analysis was carried out for Friston River and two un-named tributaries, named West and East Drain for this study. Design flows for the following annual exceedance probability (AEP) events were required; 50%, 20%, 10%, 5%, 3.33%, 2%, 1.33%, 1%, 0.5% and 0.1%. In addition, the effects of climate change on the 1%, 0.5% and 0.1% AEP events were to be considered. Additional model runs will be undertaken for these events with flow increased by 20% as stated within the NPPF planning guidance which is based on the FCDPAG3 Economic Appraisal (DEFRA, 2006). This approach was agreed with the Environment Agency at the start-up meeting.

The hydrological analysis is documented in the FEH (Flood Estimation Handbook) Calculation Record in Appendix B. It is recommended that this document is read in conjunction with this section.

5.1.1 Location of required flow estimates

Flow estimation points (FEPs) were chosen based upon the watercourses to be modelled, tributaries that flow into the model watercourses, and any locations where there is a large increase in catchment area (greater than 10%). A number of flow estimates were also included at key points (upstream and downstream of the Flood Storage Area) to allow flow to be distributed appropriately within the hydraulic model.

Catchment descriptors were obtained for each sub-catchment defined by the FEPs from the FEH CD-ROM v3.0[1]. Catchment boundaries were checked against OS 1:10,000 and 1:50,000 scale mapping, as well as against available LIDAR.

Intervening areas were defined for the areas draining the watercourse between flow estimation points.

The location of the model inflows and intervening areas are shown in Figure 5-1. Details of the location of the full suite of FEPs are provided in the FEH calculation record in Appendix B.

5.1.2 FEH Methodologies

There are various methods which can be used to calculate flow estimates along a watercourse. Detailed guidance on the choice of methods for flood frequency estimates and on restrictions in the applicability of the methods can be found in Volumes 1 and 4 of the FEH. The choice of method is based on the nature of the catchment, the type and extent of the data available and the purpose of the study.

Usually, a number of flow estimation methods are tested and the most suitable method, based on the study catchment characteristics is selected. The two principle methods available include the FEH statistical method and the Revitalised Flood Hydrograph (ReFH) method. However, given that the catchment is highly permeable based of FEH CD-ROM descriptors and the ReFH method is not applicable for catchments with BFIHOST values in excess of 0.65, only the FEH Statistical method is appropriate for this catchment. At the most upstream inflow (FB_US) reductions in BFIHOST were taken forward (see section 5.1.4) in light of EA understanding that the catchment is less permeable that indicated by FEH CD-ROM descriptors. However, elsewhere within the catchment FEH CD-ROM catchment descriptors were retained.

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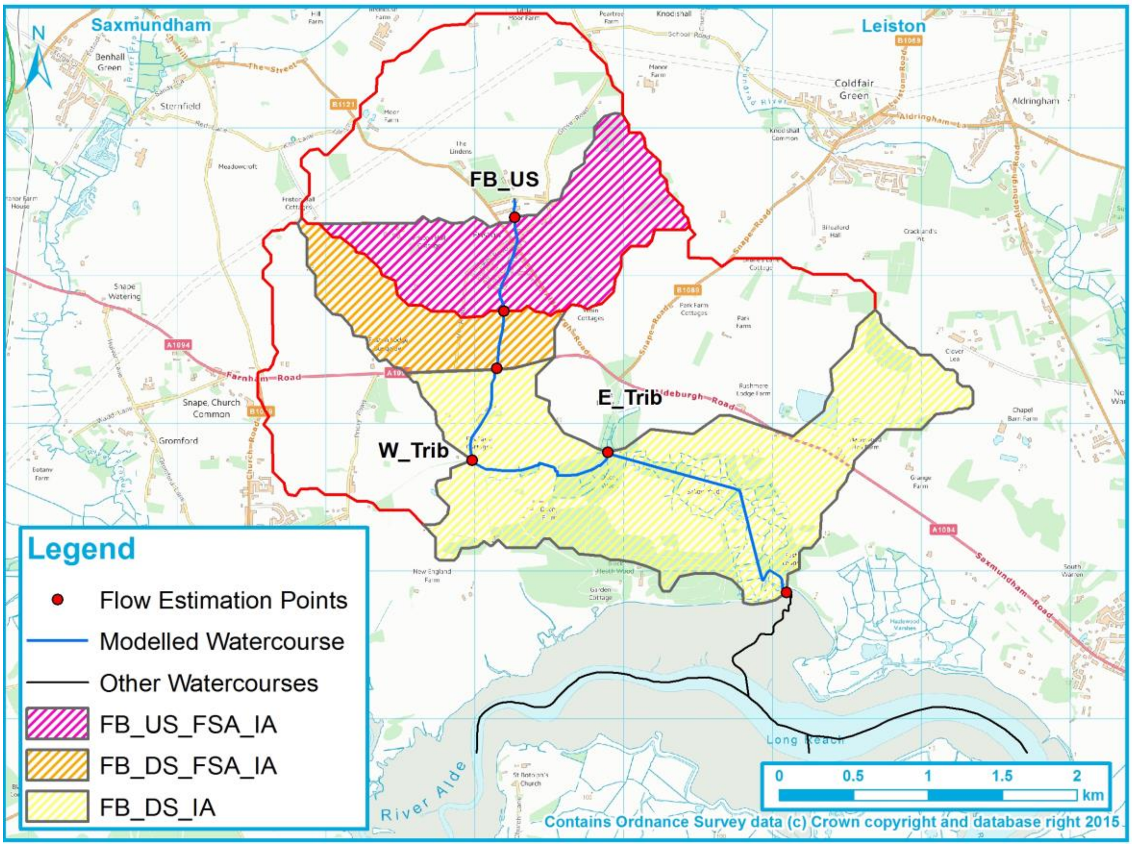
[1] FEH CD-ROM v3.0 © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.

Figure 5-1: Friston River modelled inflows



5.1.3 FEH Statistical Method

The statistical method involves two steps: estimating the index flood, QMED, and estimating a growth curve. QMED can be estimated by using flow data (preferred option), data transfer from a donor catchment or from catchment descriptors.

The statistical method allows for the use of donor transfer from gauges within/ in nearby catchments and benefits from an up-to-date flood peak dataset, sourcing flow estimates on growth curves from hydrologically similar catchments (pooled analysis).

Unfortunately, there are no gauges located within the study catchment. A brief assessment of donor stations was carried out for this study using WINFAP-FEH to assess stations that are suitable for QMED within the HiFlows-UK dataset. No suitable donor stations could be located within 25km as the donor catchments were more than 10 times larger than the subject catchment. However, during the review of the FEH Calculation Record (Appendix A) by the Environment Agency (08/01/2015), it was identified that there is a potential donor station for the study catchment which is not contained within the HiFlows-UK or NRFA datasets. It was confirmed with the Environment Agency Hydrometry & Telemetry (H&T) team that the Hollesley gauging station is suitable for QMED estimation.

Growth curve factors were derived using pooling group data. Growth curves were identified using WINFAP-FEH v3 software based on pooling groups with a target return period of 500 years. The initial pooling groups were accepted unless there was clear reason to change them, details of which are given in Section 3.4 of the FEH Calculation record in Appendix B. The pooled growth curves were fitted using the Generalised Logistic or Generalised Extreme Value distributions. Flood frequency curves were then estimated for each of the flow points based on scaling the relevant (pooled) growth curves by QMED.

5.1.4 Chosen Method and Discussion

The FEH Statistical method was chosen for the study watercourse. As the catchment is highly permeable, the ReFH method is not applicable as the Friston River catchment has BFIHOST values in excess of 0.65.

The FEH Statistical method allows for the use of donor transfer from adjacent catchments and was the preferred method as it is based on a larger dataset and can be used with more confidence than other methods.

Flow estimates produced from the FEH Statistical method were mostly consistent and considered the most appropriate when compared against observed flood extents within the Friston River catchment. The only main inconsistency lies with the upstream inflow resulting in smaller predicted flood extents than the EA were originally expecting (see text below).

Post-review, the EA formally requested that BFIHOST be reduced from 0.655 to 0.400 for the upstream inflow location (FB_US). Typically, such parameters would not be amended within the design hydrology to better replicate observed flood extents. However, the EA's local knowledge suggests that the upper catchment has a higher clay content and may therefore be less permeable than the FEH CD-ROM suggests. This decrease in BFIHOST was determined to be an appropriate way to increase flows. This resulted in more representative flood extents based on observed flooding and increased QMED by 228% at the upstream extent.

5.1.5 ReFH Storm Duration Testing

In a distributed rainfall runoff application, it is vital to apply a consistent design storm in terms of duration, Areal Reduction Factor (ARF) and rainfall profile. The critical storm duration is the duration which produces the highest peak flows or largest flood volumes at the site of interest. A number of storm durations were tested within the hydraulic model to determine how sensitive the model is to storm duration and which duration is critical at the site of interest. The 1% AEP event was selected for this testing process as this is generally considered to be the key design event.

The storm duration based on the standard FEH equation is useful as the starting point for assessing the storm durations for testing. Based on this, two storm durations were initially selected for testing in the hydraulic model (6.75 and 13.25 hours). However, following initial testing, and after adjustments were made to the BFIHOST value of inflow 'FB_US' it become apparent that due to the presence of the FSA and the expansive floodplain close to the tidal outfall, testing of longer duration events would be required. Therefore 23.25 and 31.25-hour storm duration events were also tested. The ReFH model requires the storm duration to be an odd integer multiple of the selected data interval. In this case a data interval of 0.25 hours was adopted for all durations for consistency. These are detailed within the table below:

Scenario	Duration (hrs)	Timestep (hr)	ARF	Reason for selection
1	6.75	0.25	0.975	Shorter storm durations were found to be critical in the upper catchment and therefore critical for Friston village.
2	13.25	0.25	0.981	Recommended duration for the study catchment using the FEH equation within ReFH
3	23.25	0.25	0.972	Longer duration event tested beyond recommendation of FEH equation
4	31.25	0.25	0.972	Longer duration event tested beyond recommendation of FEH equation

5.1.6 Final design flows

The final flow estimates for Friston River and its minor drains, which have been taken forward to the 1D-2D modelling stage, are shown in Table 5-1. The final flow estimates for the climate change events are shown in Table 5-2.

Check flow locations are shown in green.

The flow locations shown in purple do not account for the FSA. However, these areas were used to derive representative intervening areas for the lateral inflow hydrographs.

The BFIHOST values at the check flow location and the other flow locations downstream were not updated as a result of the reduced BFIHOST value upstream. Therefore, the 'check flows' downstream are lower than the upstream inflow. The scaling of the intervening areas was determined based on model runs with the FSA removed, in order to reconcile the modelled flows against the design check flows (shown in purple).

Table 5-1: Final design flow estimates

Site code	Flood peak (m^3/s) for the following annual exceedance probabilities (%)									
	50	**20**	**10**	**5**	**3.33**	**2**	**1.33**	**1**	**0.5**	**0.1**
FB_US	0.55	0.78	0.95	1.14	1.26	1.43	1.58	1.69	1.99	2.89
FB_US_FSA	0.31	0.44	0.54	0.64	0.71	0.81	0.89	0.95	1.12	1.64
FB_DS_FSA	0.32	0.46	0.56	0.67	0.74	0.84	0.93	0.99	1.17	1.70
W_Trib	0.06	0.08	0.09	0.11	0.12	0.13	0.14	0.15	0.17	0.23
E_Trib	0.13	0.19	0.23	0.28	0.31	0.35	0.38	0.41	0.48	0.70
FB_DS	0.52	0.73	0.88	1.02	1.12	1.24	1.34	1.42	1.62	2.16

Table 5-2: Final climate change design flow estimates

Site code	Flood peak (m^3/s) for the following annual exceedance probabilities (%)		
	1% (plus CC)	**0.5% (plus CC)**	**0.1% (plus CC)**
FB_US	2.03	2.39	3.47
FB_US_FSA	1.14	1.35	1.97
FB_DS_FSA	1.19	1.40	2.04
W_Trib	0.18	0.21	0.28
E_Trib	0.49	0.58	0.84
FB_DS	1.70	1.94	2.59

5.2 Hydraulic Modelling

5.2.1 Method and Model Software

A linked 1D-2D ISIS-TUFLOW model was developed for the purposes of this study. Details of the model extents are provided in Table 5-3. The model was based on existing survey information collected in February 2007 by EDI Surveys Ltd, provided by the Environment Agency, and also survey data collected by the Environment Agency upstream of the A1094 (within Friston Village and the FSA) between November 2015 and February 2016. Where this information was available it replaced the data from the EDI Surveys Ltd (2007) data. The November 2015 to February 2016 data was collected following channel clearance and other channel works (e.g. removing obstructions) completed during this time.

The model results are presented in Section 7 and will be used to improve the understanding of the flood dynamics and to assess flood risk for a full suite of AEP events along the study reach.

Standard modelling approaches have been used to build and develop the ISIS-TUFLOW model. These have been discussed in more detail in the hydraulic model check files which can be found in the appendices.

The versions of the modelling software used for this study are ISIS (version 3.7.2) and TUFLOW (2013-12-AE-iSP-w64), which were the most current versions of each at the time the study was undertaken.

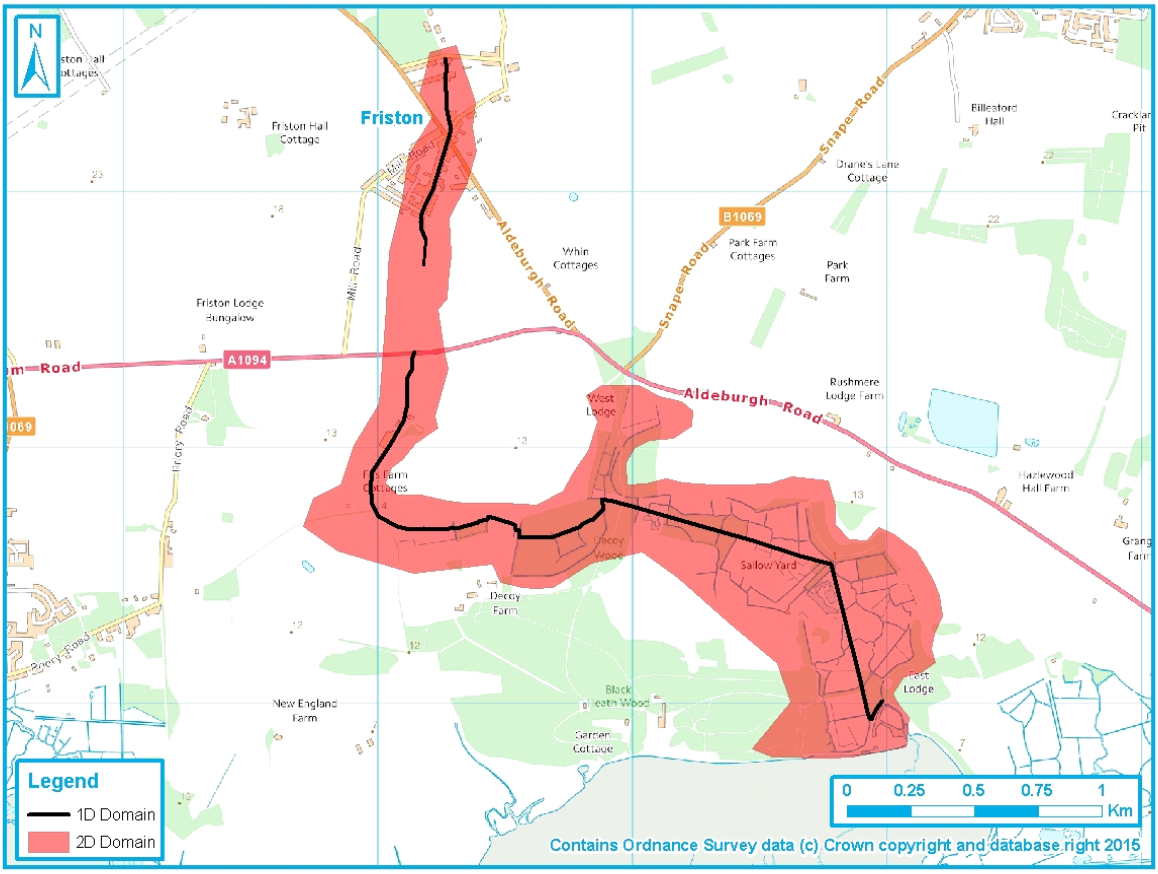
5.2.2 Model Schematic

Figure 5-2 shows the location and boundary of the 1D domain (ISIS) and 2D domain (TUFLOW). The ISIS model comprises two separate reaches, upstream of the FSA and downstream of the FSA, linked to the 2D domain using HT boundaries and SX links.

Table 5-3: 1D-2D Model Extents

Model	Upstream limit	Downstream Limit
Friston River	FB01_5872 TM 412632 60528 Downstream of Church Road	FB01_1195 TM 42985 58004 Culvert outfall into the River Alde estuary

Figure 5-2: Friston River model schematic



Contains Ordnance Survey data (c) Crown copyright and database right 2015

5.2.3 Model Parameters

The modelling coefficients have been checked as part of this study to ensure they are suitable for the intended purpose. The structure coefficients in the ISIS model appear to be suitable for the purposes of this WEM study.

The ISIS run parameters are specified in the event file (.ief).

Current recommendations for grid size - time step relationships (where the 2D time step should be approximately half to a quarter of the grid cell size and the 1D time step should be half of the 2D timestep) have been followed where possible. The model grid size is 4m, with 1D and 2D timesteps of 0.5s and 1s, respectively.

Channel roughness values have been represented in the models by Manning's 'n'. It is appropriate to define values on a reach basis, taking account of the overall features of that reach. In addition, the Environment Agency specification for flood mapping suggests that flood levels should be predicted using a model representing 'typical' condition[2].

Floodplain roughness values within the 2D TUFLOW model domain have been allocated using MasterMap data, supplied by the Environment Agency's Geostore. Codes within the MasterMap dataset are used to allocate a Manning's n value depending on land type (

Table 5-4).

The methodology adopted is deemed appropriate for the purposes of this Flood Risk Mapping study.

Table 5-4: Range of Manning's n values used in the floodplain

Land Use Type	Manning's n value
Building	0.300
General surface – multi surface	0.050
General surface – step	0.050
General surface	0.060
Glasshouse	0.200
Inland water	0.045
Landform	0.060
Landform – slope	0.060
Landform – cliff	0.060
Boulders	0.065
Coniferous trees	0.120
Coniferous trees – scattered / Orchard	0.070
Coppice or osiers	0.090
Marsh Reeds or Saltmarsh	0.060
Non coniferous trees	0.090
Non-coniferous trees – scattered	0.060
Rough grassland	0.060
Scrub	0.070
Path – step	0.050
Path	0.050
Rail	0.040
Road	0.040
Roadside	0.050
Structure	0.300
Structure – upper level of communication	0.300
Structure – pylon	0.060
Tidal water – foreshore	0.055
Tidal water	0.055
Unclassified	0.060
Rock	0.070
Heath	0.090
High roughness for stability	0.300

5.2.4 Hydrological Boundaries

The hydrological inputs into the ISIS models are based on the flow estimates discussed in Section 5.1.

A ReFH boundary unit was applied to the upstream model extent and two locations downstream of the FSA representing the upstream part of the Friston River catchment and two tributary watercourses, respectively. In addition to these model inflows, lateral inflows have been applied

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[2] Specification for Flood Mapping Version 1.0 (Draft), Environment Agency 2003

to the model to represent the inflows from surrounding areas (intervening area catchments). For information on which models nodes the inflows are connected to, please refer to the Model Check File (Appendix C).

5.2.5 Downstream Boundaries

A Head-Time (HT) boundary was applied at FB01_1195d. This boundary was derived by scaling a time series extracted from the Alde and Ore model close to the Friston outfall using a frequency analysis at Orford gauging station. The frequency analysis at Orford, comprised an average of:

- ARI of 1 month computed by fitting best fit line to the extracted POT series, using 6-year data available from the intermittent 11-year record
- MHWS computed from the continuous data period water years 2011-2013 (note December 2013 excluded as outlier).

The peak fluvial flow from upstream is timed to coincide with the peak water level of the tide.

5.2.6 Friston Flood Storage Area

The storage area situated downstream of Friston is represented within the 2D domain. The 1D channel discharges water into the 2D domain via an SX link just downstream of Friston where a channel has been implemented via a Z-Shape which lowers cells to create a continuous flow route to the centre of the FSA (where the channel terminates). The outlet spillway in the FSA is raised, meaning no flow will pass downstream until this level is reached. The spillway is represented by a SPILL unit in ISIS, which is connected to the 2D domain by an SX link. At the SX link 2D grid cells are adjusted to the elevation of the spillway by a Z-Shape.

5.3 Floodplain Mapping

The flood outlines are provided as MapInfo .tab and ESRI shapefiles for all modelled AEP events. Maximum flood water depth, water surface, velocity and hazard grids have also been provided in Ascii and MapInfo format. The model results are discussed in Section 7.

Two storm durations (6.75-hour and 23.25-hour) were simulated through the hydraulic model for each design event, and the maximum flood extents, water levels, flows and velocities were extracted from the simulations to provide maximum outputs. The model location(s) where peak water levels typically transition from one storm duration event to the other were inspected. Based on this, it is suggested that future modelling studies simulate the 6.75-hour storm duration event to produce critical outputs (peak water levels and extents) to node FB01_5175 (the south of Low Road) and the 23.25-hour storm duration event downstream of here (within and downstream of the FSA south of Low Road).

6 Model Proving

6.1 Introduction

This section describes the sensitivity analysis which has been undertaken on the hydraulic model. The results from the sensitivity tests are documented below and digital outputs (flood outlines and tabulated results) are provided in Appendix A.

6.2 Calibration and Sensibility

To calibrate a model it is necessary to know the flow of a watercourse at a specified location (i.e. a gauge) during a past flood event. The predicted water levels and flows from the model can then be compared to observed data. The model can then be adjusted accordingly to ensure correct representation of the flood event.

Calibration has only been possible for four of the nine watercourses, the River Glem, Belstead Brook, River Hun and Sandon Brook, given that the remaining watercourses are un-gauged. Sensibility checks and known flood histories of the remaining five watercourses has been used to assess their suitability.

Initial draft outputs and final draft results were provided to the Environment Agency as this study has progressed. The Environment Agency has collated historical flooding information and has also used local knowledge to identify areas along the study reaches which are known to be at flood risk.

Following Environment Agency review of draft model results, it was considered that flooding within Friston (initially not predicted until the 0.5% AEP event) was not representative and that more frequent flooding should be predicted. This is largely informed by local understanding of the watercourse. However, a report of flooding at the Low Road, Main Road and Donkey Road is recorded from October 1993, although the source of this may have been surface water driven. Consequently, the Environment Agency requested that BFIHOST be revised down from 0.655 to 0.400 for the upstream inflow location (FB_US) in order to better replicate the expected flood extents within Friston village. Please refer to section 5.1.4 for further information.

6.3 Sensitivity Testing

Several sensitivity testing scenarios were completed which are reported in Table 6-1. Certain model proving and sensitivity testing analyses were initially completed with the hydraulic modelling finalised in September 2015. This modelling was completed prior to the inclusion of the updated survey information within Friston Village collected between November 2015 and February 2016 (and therefore the channel system was based entirely on the EDI Surveys Ltd 2007 data), along with hydraulic roughness updates made in the same location. Some of these sensitivity analyses completed at this time was not repeated as it was considered that the findings of the assessment e.g. sensitivity of model reaches to the adjustments tested, would remain relatively consistent following updates made to the model in the upper reaches of Friston River. For example, areas showing higher sensitivity than others to changes in model flows would remain consistent if the exercise has been repeated.

Sensitivity tests were primarily carried out for the 1% AEP flood event, using the 1% AEP base model as a comparison. In most cases the 6.75-hour storm duration design events were used as the basis for this. Table 6-1 documents the sensitivity scenarios completed, the hydraulic model used to inform this and the storm durations simulated as part of the analysis. The trends in model sensitivity with changes to flow, hydraulic roughness or downstream boundary (see below) are expected to be the similar across different storm durations, meaning the 6.75-hour event data is suitable for this purpose.

It is particularly important to test the sensitivity of models to the chosen parameters when there is limited data available for calibration. The following table lists the parameters tested. The results from the sensitivity tests have been supplied in digital format to the Environment Agency.

Table 6-1: Sensitivity model testing overview

Sensitivity test	Description
Storm duration testing	Four durations tested: 6.75 hours, 13.25 hours, 23.25 hours and 31.25 hours. Tested for the 1% AEP event. Tested with the modelling finalised in September 2015.
Channel and floodplain roughness	±20% change in manning's n roughness coefficients applied to 1D and 2D models. These amendments take into account a reasonable cut back or growth in vegetation in the channel and floodplain. Tested for the 6.75-hour storm duration 1% AEP event. Tested with the modelling finalised in September 2015.
Flow	±20% change in all model inflows Tested for the 6.75-hour storm duration 1% AEP event. Tested with the modelling finalised in September 2015.
Downstream boundary condition	±1m change to 1D downstream boundary levels Tested for the 6.75-hour storm duration 1% AEP event. Tested with the modelling finalised in September 2015.
Structure Blockage	The Environment Agency identified key structures along Friston River thought to be at risk of blockage. Three model scenarios were carried out; structures were blocked to 25%, 50% and 75%. The structures were: - Culvert at B1121 (Aldeburgh Road) - Friston FSA outlet Tested for the 1% AEP event. Completed for both the 6.75-hour and 23.25-hour storm duration events. Tested with the modelling finalised in May 2016 (the latest modelling).
Channel roughness between Church Road and Friston FSA	Hydraulic roughness of the channel between Church Road and Friston FSA was increased to n=0.067 and n=0.077 in separate simulations. This increases the hydraulic roughness from the baseline of n=0.052. This was tested to understand the influence on flood risk of vegetation growth in the channel. Tested for both the 5% and 1% AEP events. Completed for both the 6.75-hour and 23.25-hour storm duration events. Tested with the modelling finalised in May 2016 (the latest modelling).
Increase in bed levels between Church Road and Friston FSA by 300mm	Bed levels of the channel between Church Road and Friston FSA were raised by 300mm from the lowest elevation recorded in each section as a sensitivity test on siltation within the channel. Tested for both the 5% and 1% AEP events. Completed for both the 6.75-hour and 23.25-hour storm duration events. Tested with the modelling finalised in May 2016 (the latest modelling).

6.3.1 Storm Duration Testing

Storm duration testing was undertaken to determine the critical durations for the catchment in order to generate representative inflows for the hydraulic model. Depending on the size of the catchment and the variability in response across the catchment, in terms of underlying geology, urban coverage, slope, etc., there may be a large variation in critical storm durations for different parts of the catchment. As a starting point, the ReFH standard equation can be used to determine the likely storm durations for the catchment as a whole. The selection of storm durations tested in the hydraulic model was based upon work undertaken and reported in Section 5.1.5 and reported within the FEH calculation record, usually including a lower and higher storm duration than that originally recommended by ReFH. Based on the results of these analyses, storm duration testing was undertaken for the following four scenarios:

- 6.75-hour duration event;
- 13.25-hour duration event;
- 23.25-hour duration event; and
- 31.25-hour duration event

Each of the storm duration events were tested for the 1% AEP event. The flood extents generated by the model are shown in Figure 6-1, Figure 6-2 and Figure 6-3 and show that the 6.75 hour storm duration event produces the largest flood extents within Friston upstream of Low Road. At Low Road, the 6.75 and 13.25-hour duration events produce similar extents, each event producing slightly larger flood extents in different locations (6.75-hour event at the north of Low Road and 13.25-hour duration event at the south of Low Road). Peak flows passing through Friston are largest in the 6.75-hour duration event. Downstream of Low Road, flood extents are larger under longer storm durations. This results from longer duration events having larger flood volumes, meaning the FSA reaches capacity earlier and greater flood volumes pass downstream. The expansive floodplain downstream therefore fills to a greater extent producing larger flood outlines. The 23.25-hour duration event produces slightly larger extents at the FSA, whilst the 31.25-hour duration event produces slightly larger extents downstream of the channel north of Decoy Farm. Between these locations extents are similar between events.

In light of the differences in predicted flooding with storm duration, two storm durations of 6.75 hours 23.25 hours were taken forward for design runs. The 6.75-hour storm event produces greatest flows and extents within Friston, whilst downstream of here, both at the FSA and in the downstream floodplain the 23.25-hour event is deemed critical, as this results in larger flood extents. Whilst it is noted that the 31.25-hour storm duration produces slightly larger flood extents close to the catchment outlet, differences between this and the 23.25-hour duration are small.

Figure 6-1: Critical storm duration test results (Friston and FSA)

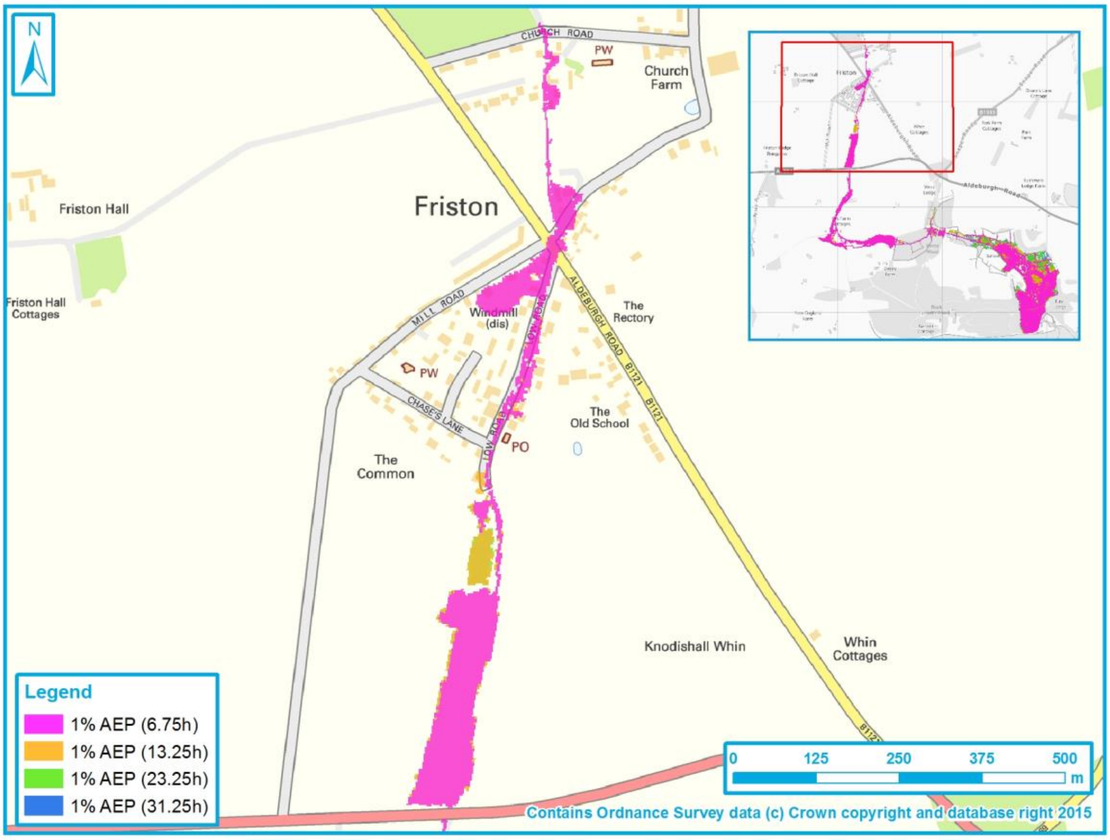


Figure 6-2: Critical storm duration test results (downstream of FSA)

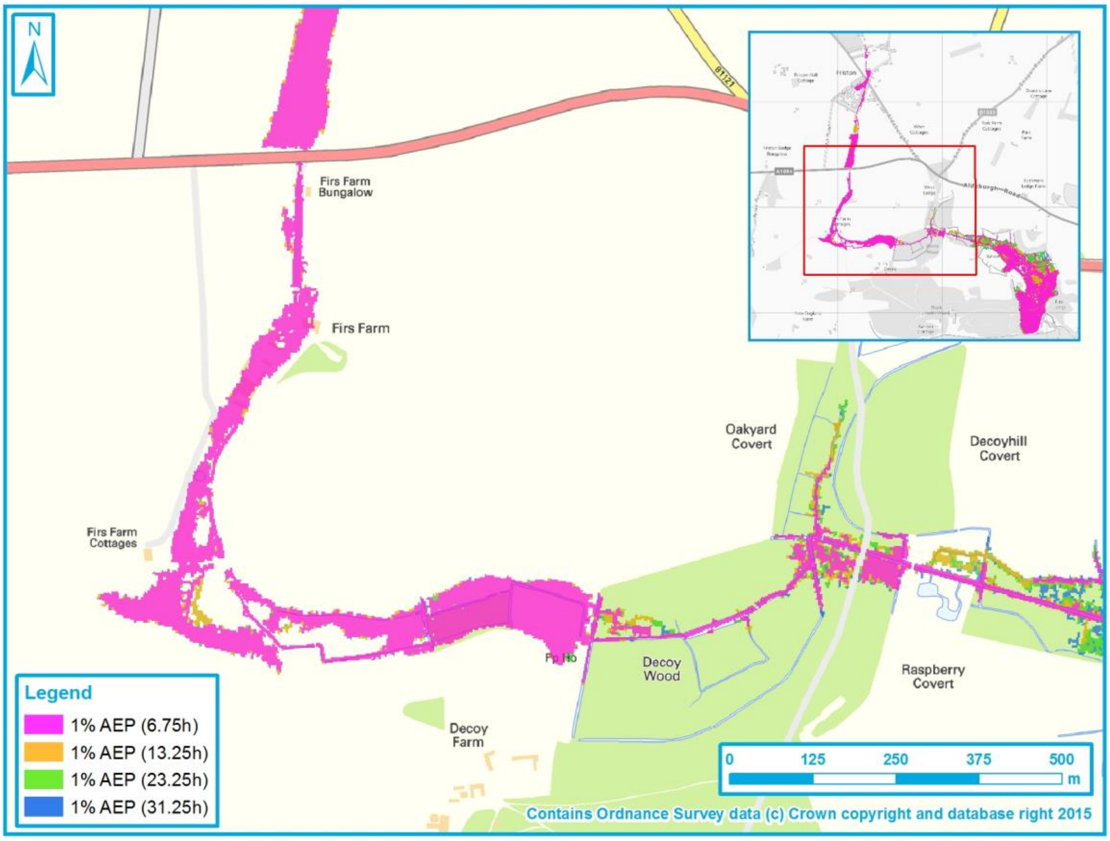
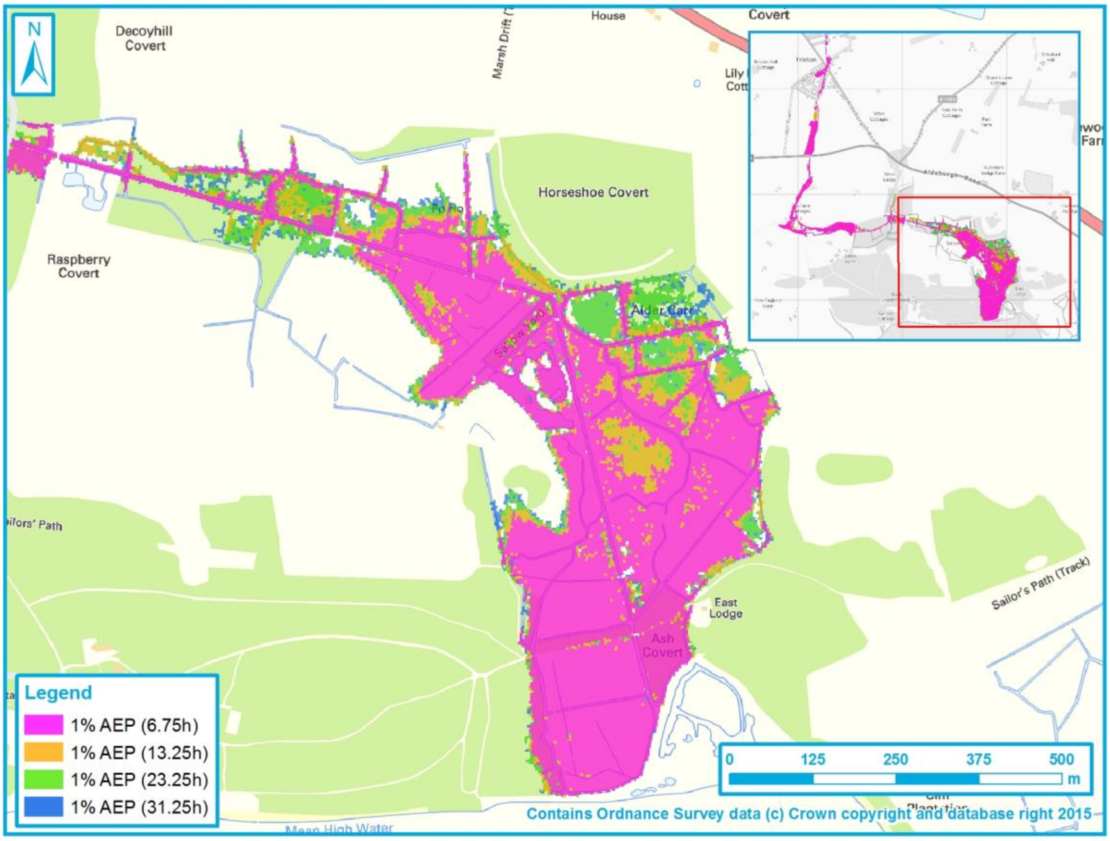


Figure 6-3: Critical storm duration test results (downstream extent)



6.3.2 Sensitivity to roughness (global adjustment ±20% within the model)

Sensitivity to hydraulic roughness was tested by increasing and decreasing in-channel and floodplain roughness by 20%. Typically, an increase in Manning's n roughness should increase levels, and a decrease in Manning's n roughness should decrease levels. This behaviour is observed within the Friston River catchment. Figure 6-4, Figure 6-5 and Figure 6-6 display the changes in predicted flooding with increased/decreased hydraulic roughness at Friston, downstream of the FSA and at the downstream study extent, respectively. Note blue outlines (representing the decreased roughness case) are shown above the green (baseline) and red (increased roughness) outlines and therefore red outlines show increases in flooding as a result of increased roughness.

On average, peak in-channel water levels are increased/decreased by 0.03m under the increased/decreased roughness runs compared with the baseline 1% AEP event. Upstream of the FSA differences are greater at +0.07m/-0.05m, whilst downstream of the FSA differences are less marked at +0.01m/-0.02m, respectively. These differences are likely to reflect the narrower and more contained channel and floodplain upstream compared with the wider and more expansive channel and floodplain downstream.

Within Friston, increasing hydraulic roughness produces similar flood extents compared with the baseline case, although a slight expansion in the flood extent is noted towards the downstream of Low Road. Under the reduced hydraulic roughness scenario, a contraction in flood extent is predicted in Friston, primarily a reduction in overland flooding predicted from the north to south along Low Road. Downstream of Friston, adjustments to hydraulic roughness has limited impact on predicted flooding, which is likely to be a result of the floodplain becoming widespread and the channel and floodplain already being well connected.

Figure 6-4: Manning's n roughness coefficient sensitivity testing (Friston and FSA)

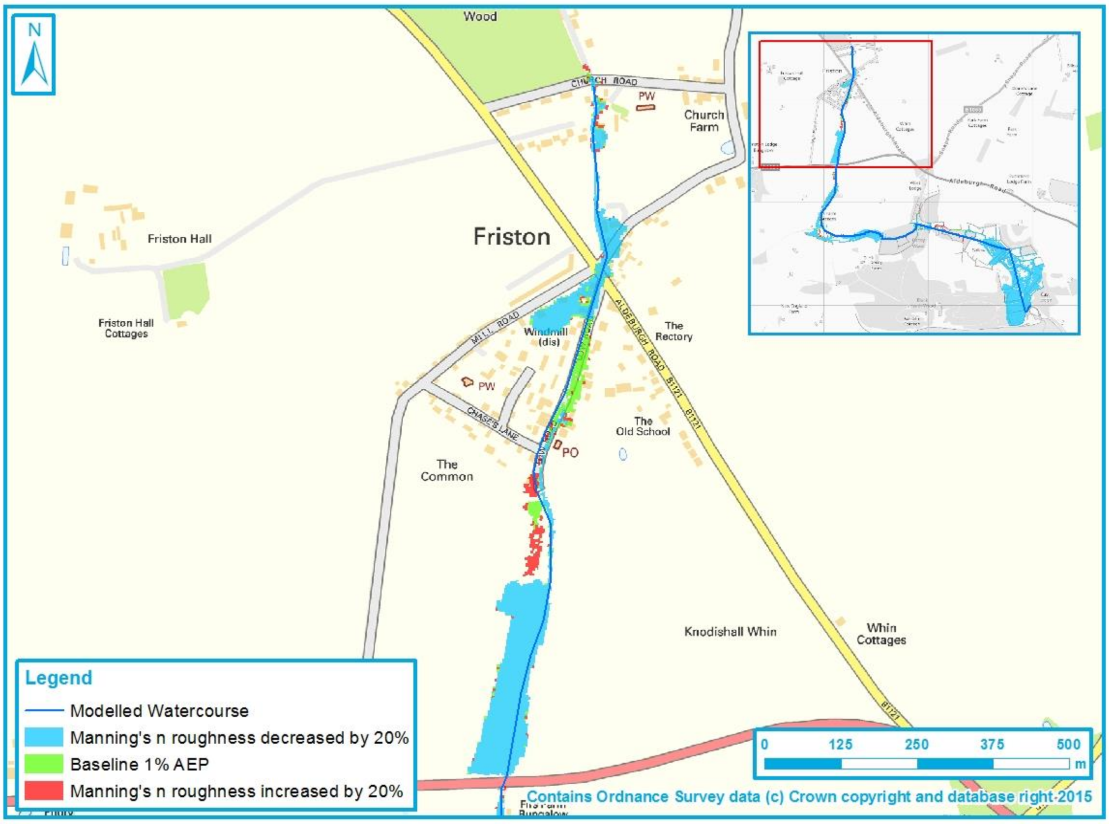


Figure 6-5: Manning's n roughness coefficient sensitivity testing (downstream of FSA)

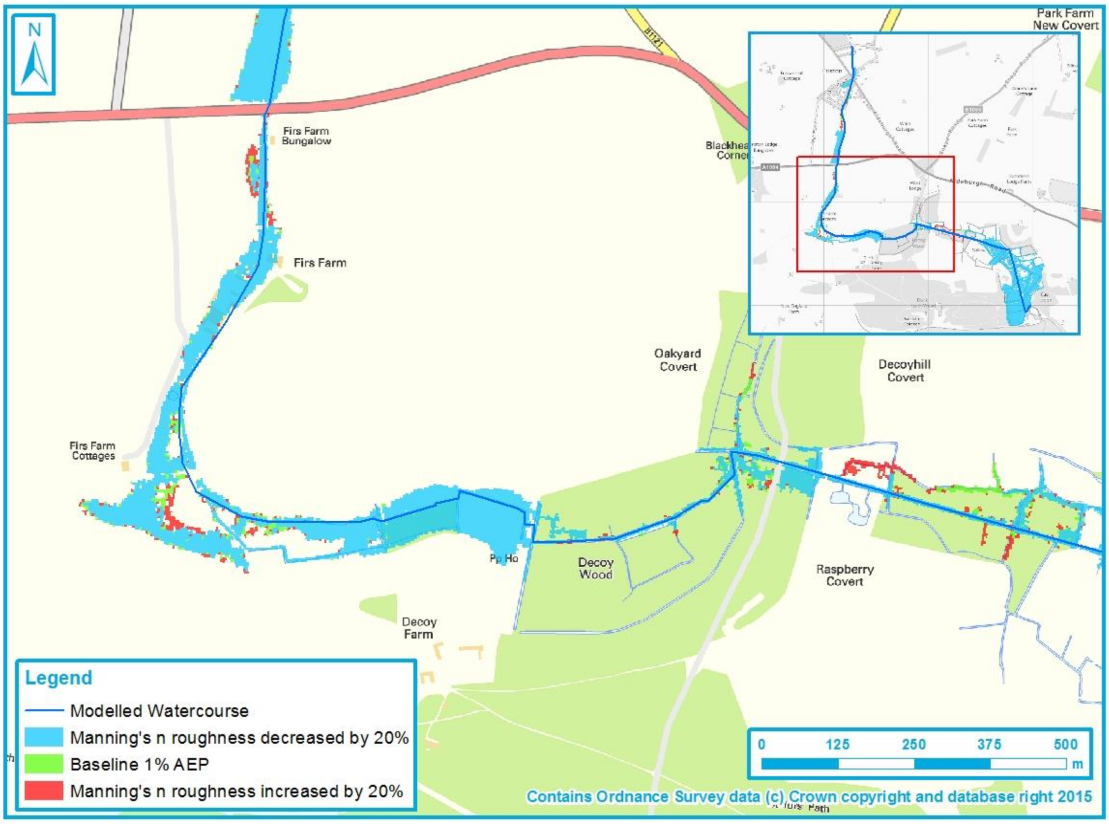
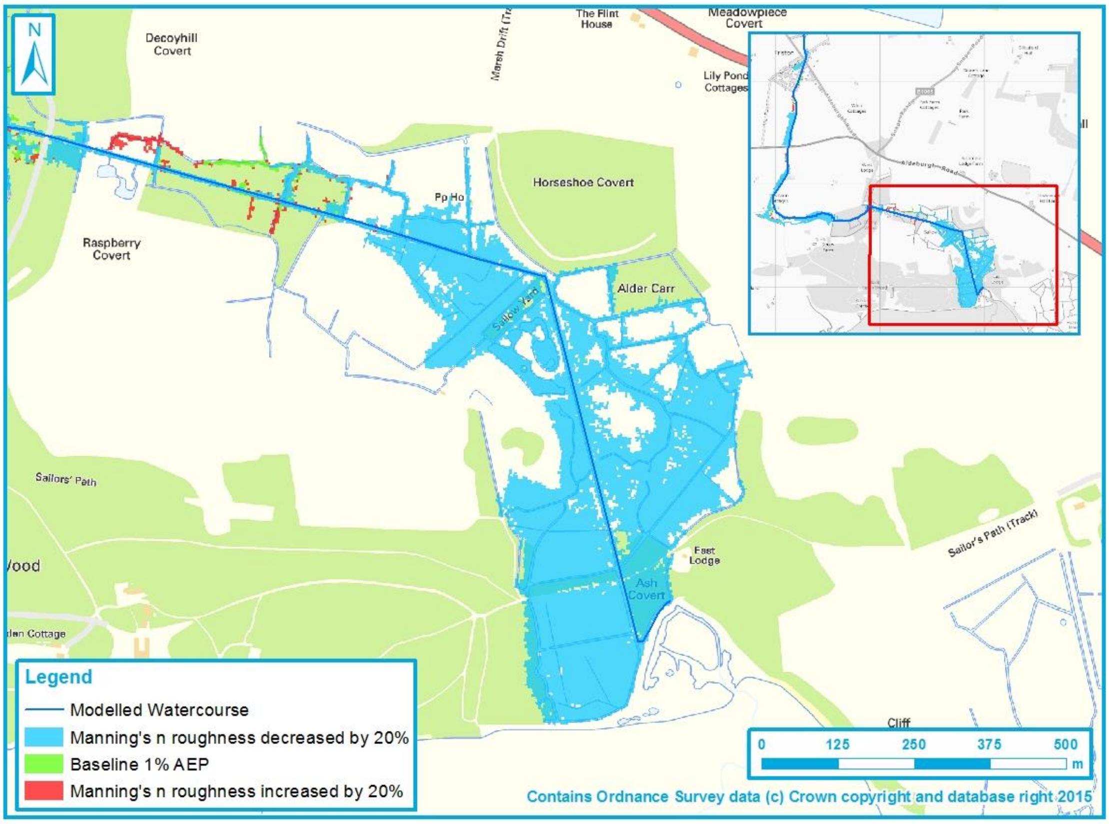


Figure 6-6: Manning's n roughness coefficient sensitivity testing (downstream extent)



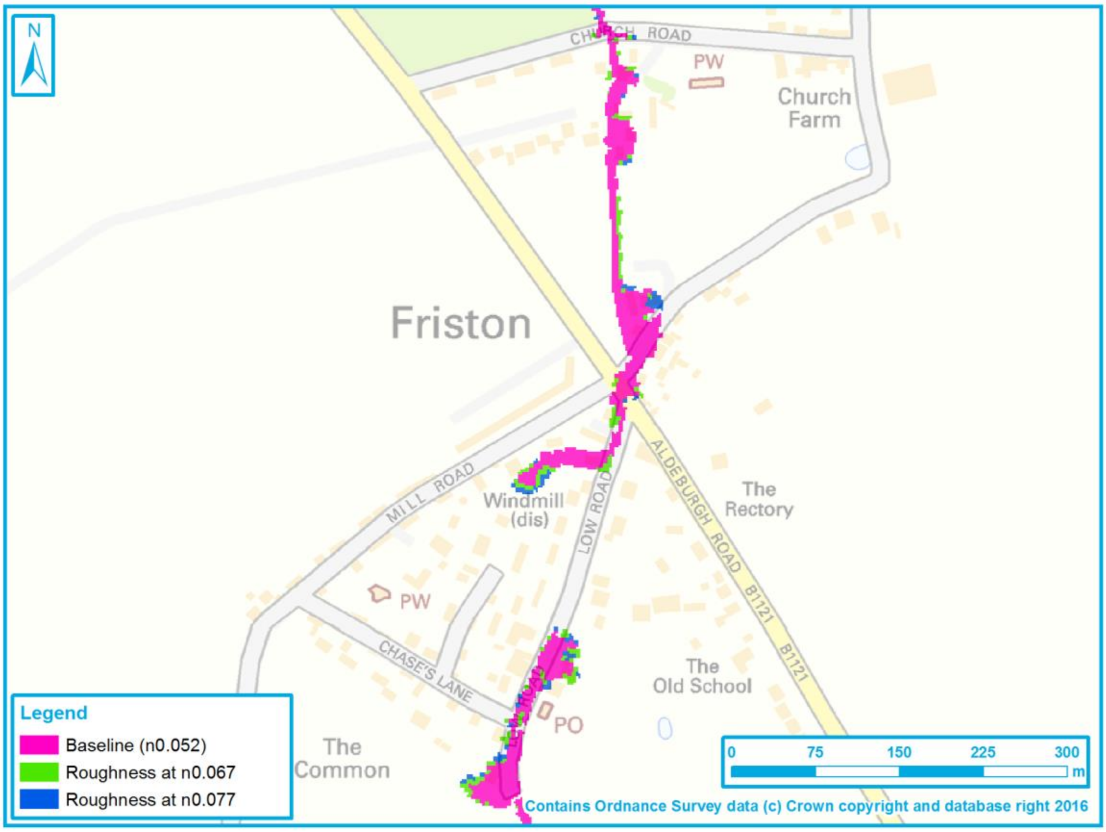
The sensitivity of the predicted flooding to changes in hydraulic roughness should be kept in mind. Whilst hydraulic roughness selected is considered representative, if conditions change (particularly in the channel) e.g. through increased vegetation growth, the outcomes of this assessment may indicate likely changes in predicted flood risk.

6.3.3 Sensitivity to hydraulic roughness within the Friston River channel between Church Road and Friston FSA

Sensitivity to hydraulic roughness within the Friston River channel between Church Road and Friston FSA was tested by increasing in-channel hydraulic roughness (Manning's n) to n=0.067 and n=0.077 in separate simulations from the baseline value of n=0.052. These scenarios were informed from consideration of Cowan's method (1956)[3] and represent a case where the amount of vegetation and/or obstructions within the channel increases. The scenarios were simulated for the 5% AEP and 1% AEP design events. roughness by 20%.

Figure 6-7 and Figure 6-8 display the changes in predicted flooding within increased hydraulic roughness scenarios for the 5% and 1% AEP design events, respectively.

Figure 6-7: Manning's n roughness coefficient sensitivity testing between Church Road and Friston FSA (20% AEP event)



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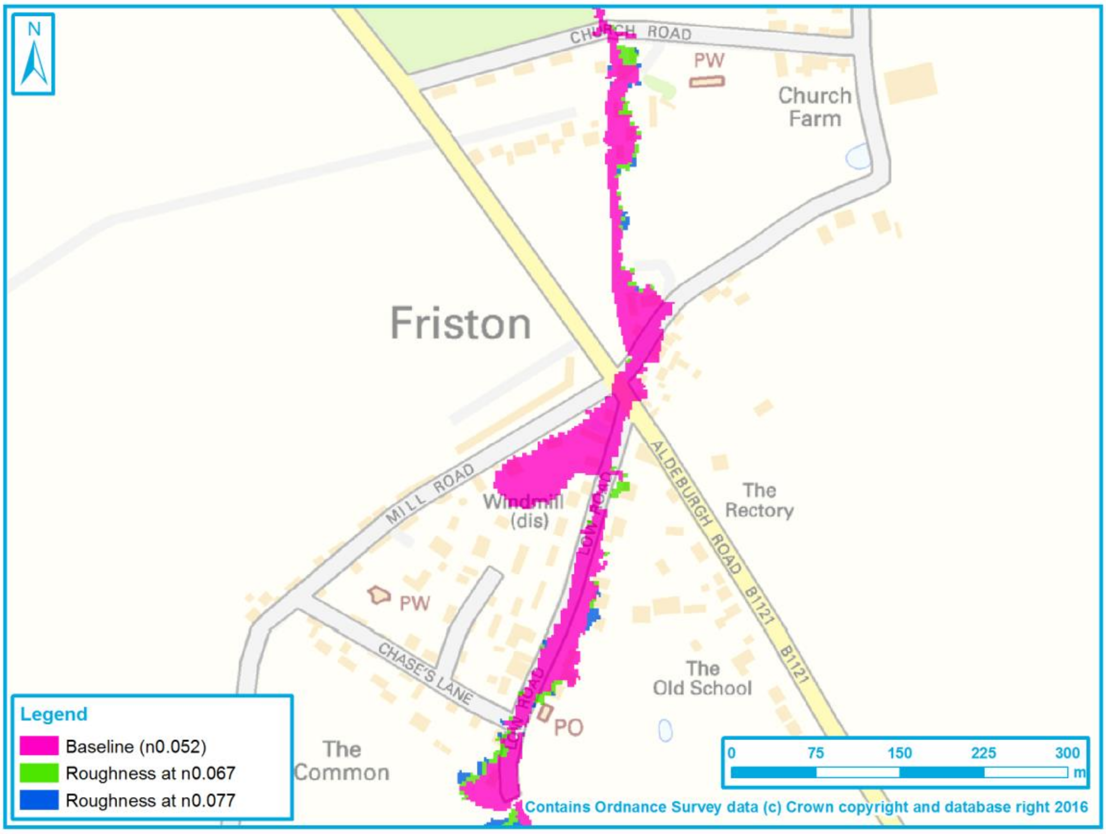
[3] Cowan, W. L. (1956). Estimating hydraulic roughness coefficients: Agricultural Engineering, v. 37, no. 7, p. 473-475.

Figure 6-8: Manning's n roughness coefficient sensitivity testing between Church Road and Friston FSA (1% AEP event)



On average, peak in-channel water levels are increased by 0.01m and 0.03m under the n=0.067 and n=0.077 increased roughness runs for the 5% AEP event, and increased by 0.01m and 0.06m under the n=0.067 and n=0.077 increased roughness runs for the 1% AEP event, compared with the baseline events. Generally, maximum increases in water levels predicted are located at the south of Low Road, where the channel enters the FSA. At this location increases in peak water levels are typically 2-3 times greater than the average values reported above.

Within both the 5% and 1% AEP events tested, flood extents show a general expansion with the increased roughness of the channel, but no new notable areas of flooding are predicted in each design event.

As noted in section 6.3.2, the sensitivity of the predicted flooding to changes in hydraulic roughness should be kept in mind as the analysis demonstrates that flood depths and extents would increase through vegetation growth and obstructions in the channel. Also, increased hydraulic roughness within the channel increases the likelihood that flows would begin flowing across Low Road (as is predicted in the 1% AEP event).

6.3.4 Sensitivity to increased bed levels between Church Road and Friston FSA

Sensitivity to increased bed levels within the Friston River channel between Church Road and Friston FSA was tested by increasing bed levels by up to 300m (0.3m). This scenario test was completed to understand the impact that siltation within the channel could have on predicted flood risk. The schematisation of the scenario involved identifying the lowest point at each river section and bridge structure, raising this level by 0.3m. All other bed level points which were below these elevations were also raised to the same levels. The invert level of culverts was also adjusted to the level to replicate the presence of silt within the culvert.

The scenarios were simulated for the 5% AEP and 1% AEP design events.

Figure 6-9 and Figure 6-10 display the changes in predicted flooding within the increased bed level scenarios for the 5% and 1% AEP design events, respectively.

Figure 6-9: Bed level raising sensitivity testing between Church Road and Friston FSA (20% AEP event)

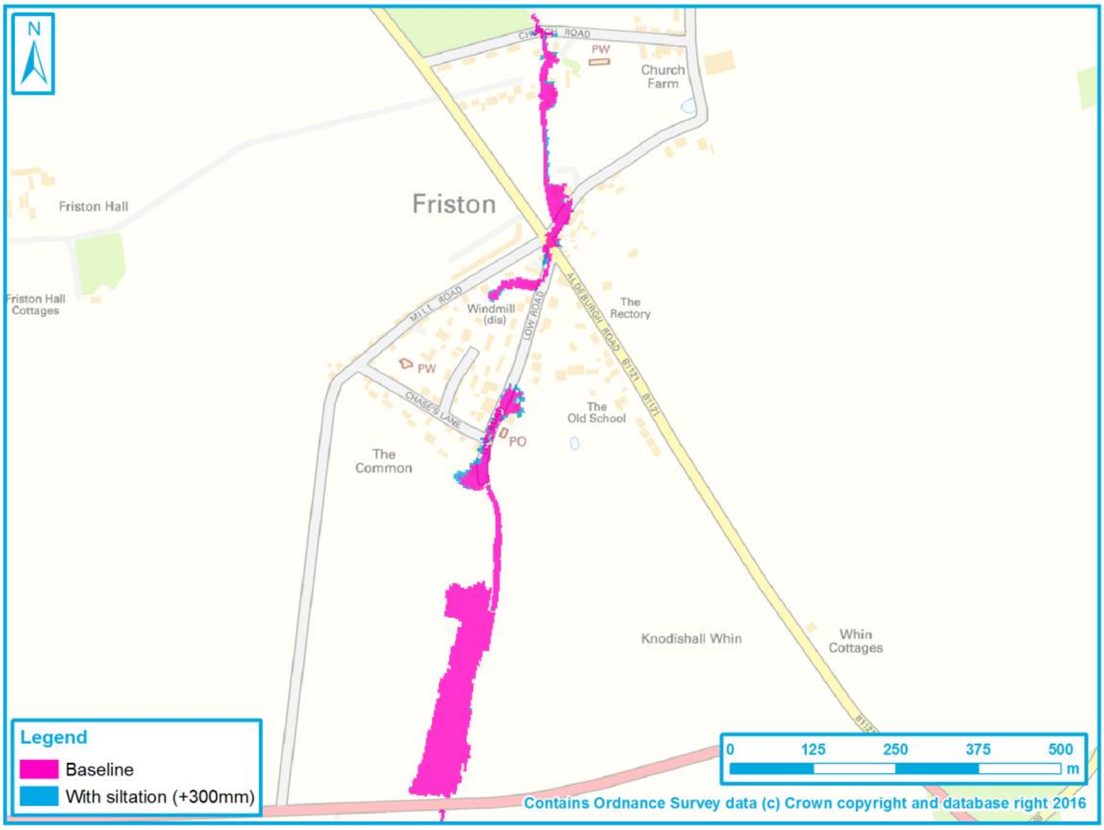
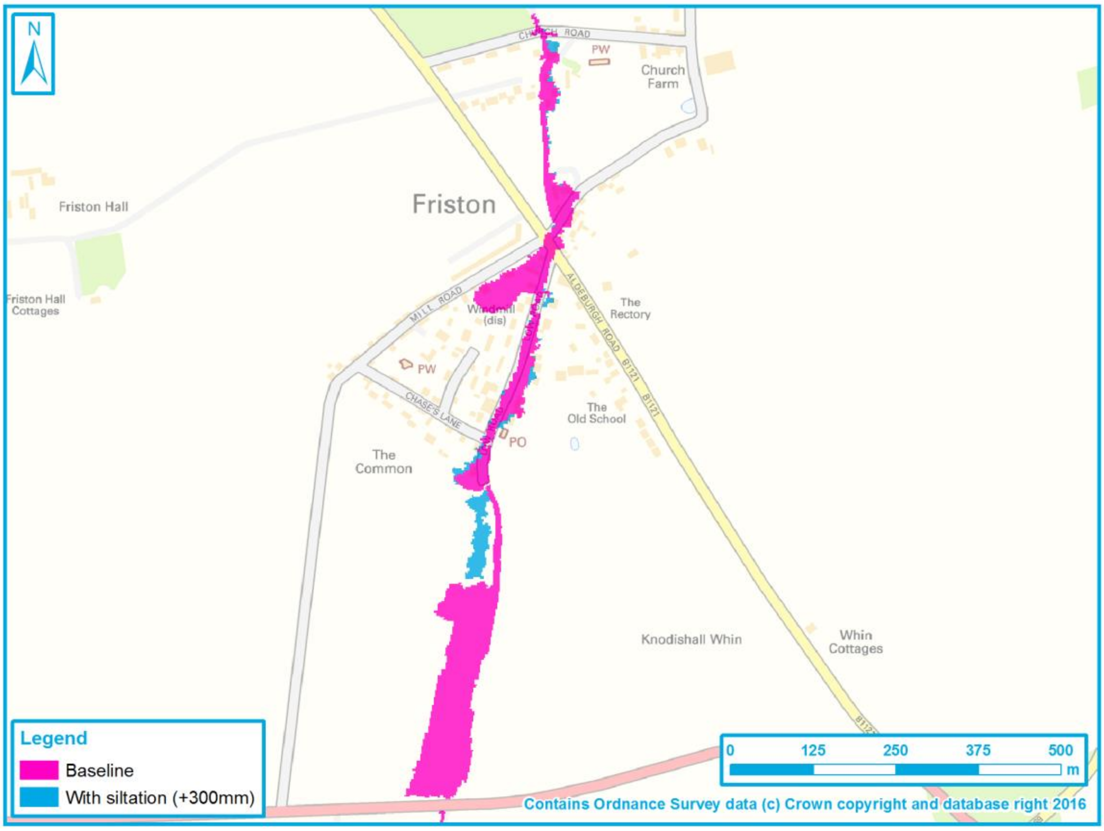


Figure 6-10: Bed level raising sensitivity testing between Church Road and Friston FSA (1% AEP event)



On average, peak in-channel water levels are increased by 0.09m and 0.08m under the 5% AEP and 1% AEP events, respectively. Maximum increases in water levels predicted are located at the south of Low Road, where the channel enters the FSA. At this location increases in peak water levels are typically double the average values reported above. Very minor (less than 0.01m) reductions in water levels are predicted downstream of the FSA, which is likely to result from greater storage of flood water on the floodplain upstream of the FSA given the prevalence of out of bank flow increases.

Within both the 5% and 1% AEP events tested, flood extents show a general expansion with the increased bed level of the channel. The only notable area of new flooding is within the 1% AEP event where the parcel of land south west of Low Road and at the north of the FSA is predicted to flooding.

A lower change in peak water level in the 1% AEP event, compared with the 5% AEP event, is predicted because flooding is more extensive in the 1% AEP event and the channel and floodplain are better connected. Given the more extensive flooding in the larger event, the water displaced by raising the bed by 0.3m is spread over a larger area of floodplain and levels rise less.

The sensitivity indicated to changes in bed level should be kept in mind as the analysis demonstrates that flood depths and extents would increase through siltation of the channel, and increase the prevalence of flooding for a given flow.

6.3.5 Sensitivity to flow

Fluvial model inflows were varied by ±20% to assess the sensitivity of model results to the final hydrological estimates applied to the model. The sensitivity showed that:

- The increase in model inflows results in increased water levels/extents, whilst decreases in inflows results in decreased water levels/extents.
- Under the increased flow scenario there is a mean increase in water levels of 0.08m compared to the baseline model 1% AEP results. Upstream of the FSA the differences are larger (+0.14m on average) compared with downstream of the FSA where smaller differences are predicted (+0.05m on average). These differences are likely to reflect the narrower and more contained channel and floodplain upstream compared with the wider and more expansive channel and floodplain downstream.
- Under the decreased flow scenario there is a mean decrease in water levels of 0.05m compared to the baseline model 1% AEP results. Upstream of the FSA the differences are slightly larger (-0.06m on average) compared with downstream of the FSA where smaller differences are predicted (-0.04m on average). Again, these differences are likely to reflect the narrower and more contained channel and floodplain upstream compared with the wider and more expansive channel and floodplain downstream.
- Increasing / decreasing flow has a notable influence on predicted flooding in Friston. Under the decreased flow scenario, much of the predicted flooding at the south of Low Road is removed. Under the increased flow scenario, flooding at the east of Low Road is more expansive, and so too is flooding at the very north of the FSA.
- Downstream of the FSA, a general expansion/contraction in predicted flooding is predicted with increased/decreased flows.

Changes in predicted flooding as part of flow sensitivity testing is displayed for areas upstream of the FSA, downstream of the FSA and at the downstream model extent in Figure 6-11, Figure 6-12 and Figure 6-13, respectively.

The sensitivity of flooding to flows should be kept in mind particularly given the uncertainty in design flow estimates on this watercourse. A 20% increase and decrease in flows for the 1% AEP event roughly equates to flows for the 0.5% and 3.33/2% AEP events, respectively, indicating that even if uncertainty were limited to 20% in design flows, the range of AEP events this equates to would still be quite large. Note blue outlines (representing the decreased flow case) are shown above the green (baseline) and red (increased flow) outlines and therefore red outlines show increases in flooding as a result of increased flows.

Figure 6-11: Model inflow sensitivity testing (Friston and FSA)

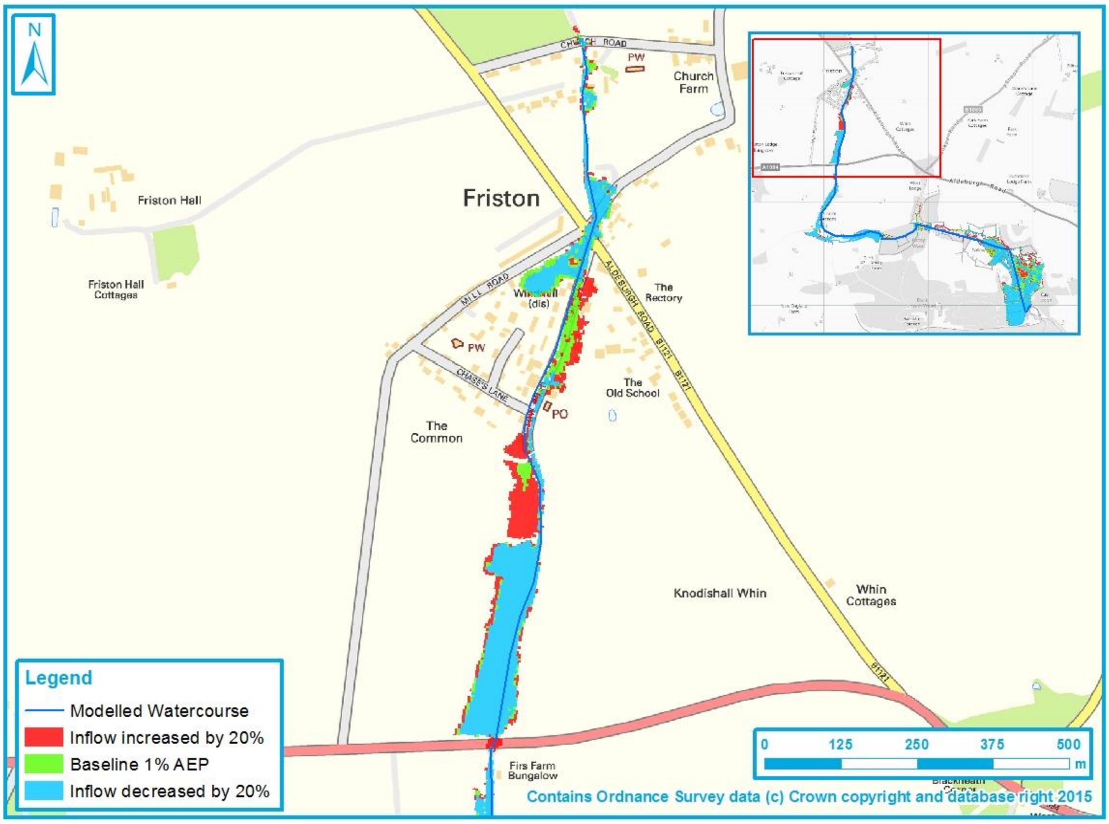


Figure 6-12: Model inflow sensitivity testing (downstream of FSA)

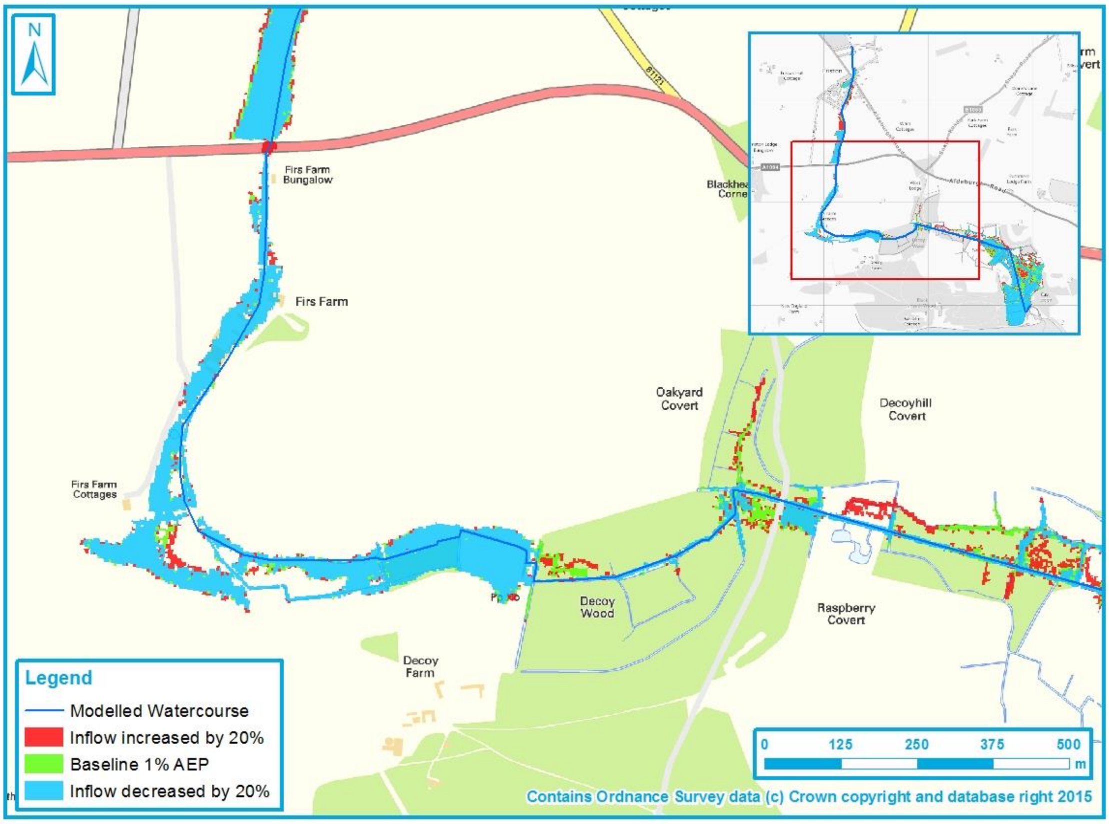
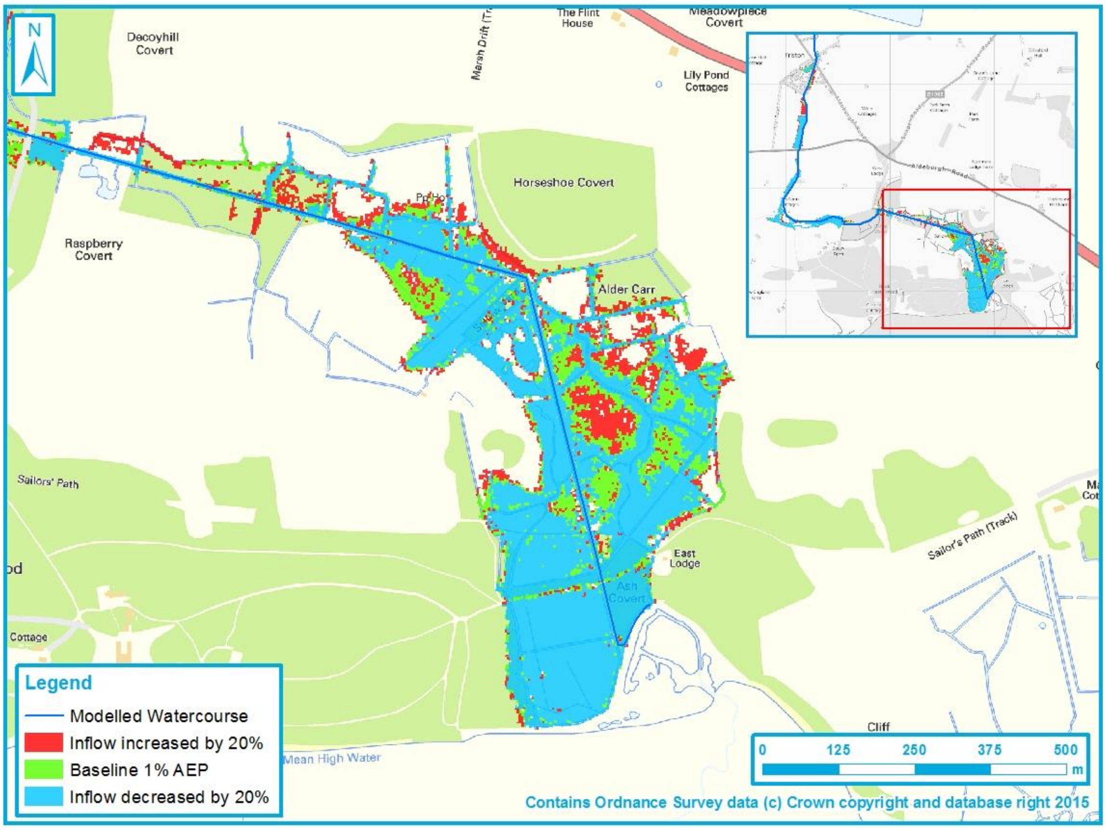


Figure 6-13: Model inflow sensitivity testing (downstream extent)



6.3.6 Sensitivity to downstream boundary

Sensitivity testing on downstream boundary conditions was undertaken by adjusting the level of the downstream boundary by a value of ±1m across the full series. As the baseline downstream boundary condition levelled off at a value of -0.079m AOD, when the downstream boundary was raised by 1m, the lower part of the tidal curve was extended to the same -0.079 value, otherwise a value of +0.921m AOD would be the minimum value which is not representative. The baseline and sensitivity downstream boundary levels are displayed in Figure 6-14.

Changes in predicted flooding as part of downstream boundary sensitivity testing is displayed in Figure 6-15. No differences in flooding are predicted upstream of the track leading to Black Heath Wood (TM 41955 58775). Downstream of this location a general expansion/contraction in flooding is predicted under the increased/decreased boundary scenario, but flooding remains relatively widespread. The change in extents is likely to be driven primarily by flood volume, with events with a greater volume likely to show greater differences in extent (and distance upstream to which are affected) compared with those with smaller volumes. Although not tested here, the phasing of peak flows with the tidal cycle may also influence sensitivity. That being for the same hydrological event, a flood which peaks at the low tide may result in smaller extents as greater outflow can occur into the estuary before tide-locking occurs. Note blue outlines are shown on top of red and green outlines and therefore red outlines show increases in flooding as a result of changes in downstream boundary.