South Norfolk Level 2 Strategic Flood Risk Assessment

Hydraulic Modelling Report

December 2022

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Revision History

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Contract

This report describes work commissioned by South Norfolk District Council by an email dated 14 May 2021. South Norfolk District Council's representative for the contract was Simon Bessey. Christopher Goodwin of JBA Consulting carried out this work.

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Purpose

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Acknowledgements

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Abbreviations

AEP	Annual Exceedance Probability
CFB	Coastal Flood Boundary dataset
DTM	Digital Terrain Model
JBA	Jeremey Benn Associates
LiDAR	Light imaging Detection and Ranging
m	Metres
m AOD	Metres above Ordnance Datum
SFRA	Strategic Flood Risk Assessment
UKCP	UK Climate Projections
VCHAP	Village Clusters Housing Allocations Plan

1 Introduction

1.1 Introduction and context

JBA Consulting (JBA) were commissioned by South Norfolk Council to undertake a Level 2 Strategic Flood Risk Assessment (SFRA) with the purpose of supporting the South Norfolk Village Clusters Housing Allocations Plan (VCHAP). The VCHAP is a document being developed by South Norfolk Council to find suitable housing for a minimum of 1,200 new homes in the smaller villages across South Norfolk. This Level 2 SFRA forms an addendum to the Greater Norwich Level 2 SFRA completed in 2021 and involves the assessment of proposed development sites in the VCHAP area which have been identified by South Norfolk Council.

This document describes the hydraulic modelling undertaken to support the assessment of flood risk in the Level 2 SFRA addendum. The report summarises the model build processes, and the uncertainties and limitations with the model outputs.

1.2 Proposed development sites

Hydraulic modelling has been undertaken to support the assessment of flood risk in relation to six proposed development sites in the villages of Brockdish, Needham, Wortwell and Gillingham, South Norfolk for the Level 2 SFRA addendum. Figure 1-1 shows the locations of the proposed development sites which have been the focus of the flood modelling work.

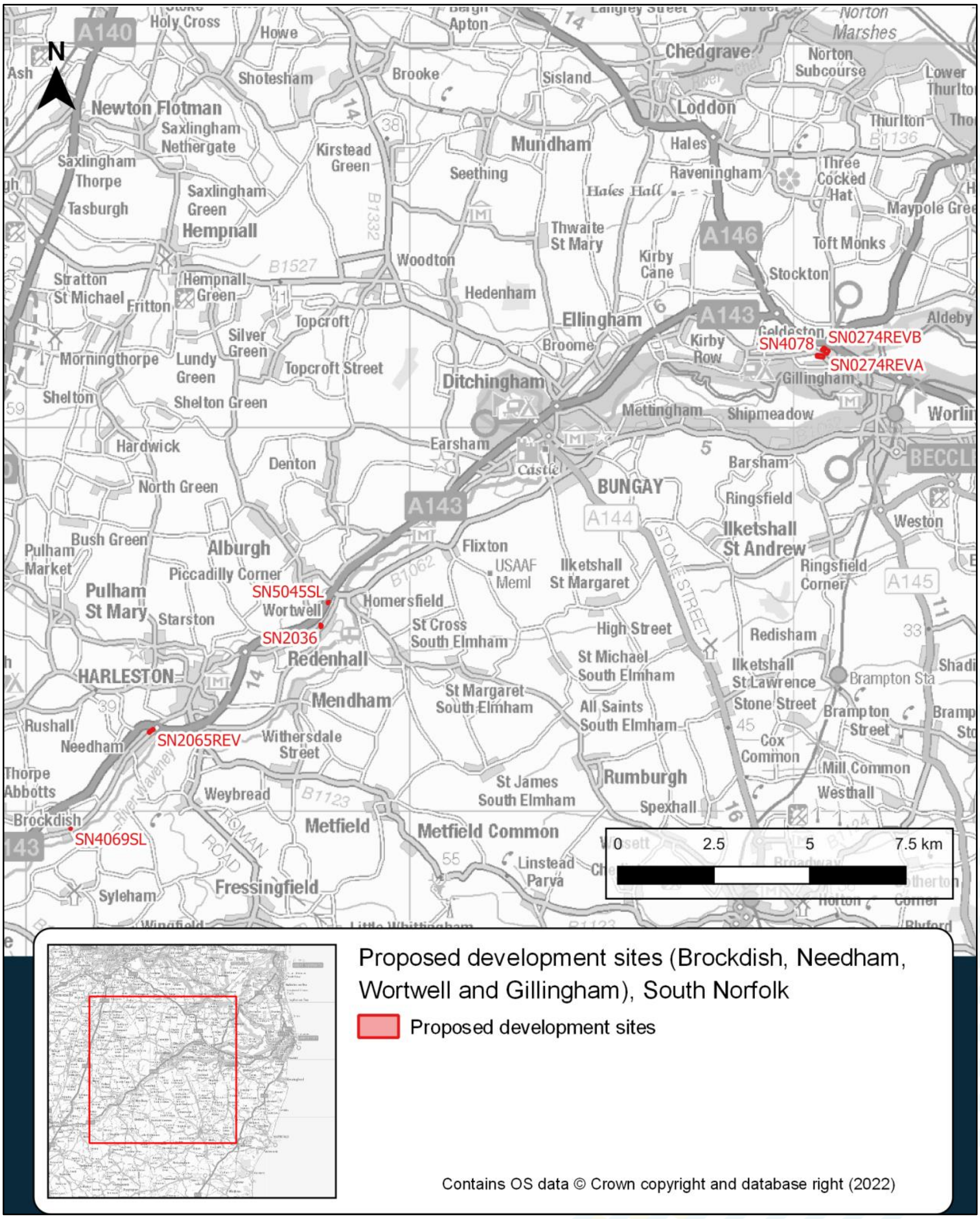

Figure 1-1 Proposed development site locations

2 Hydraulic modelling

2.1 Hydraulic modelling outline

This chapter provides a summary of the hydraulic modelling work undertaken to support the assessment of flood risk in the Level 2 SFRA addendum supporting South Norfolk Council's VCHAP. This chapter is split into two main sub-sections; the first describing the modelling work undertaken in relation to the proposed development sites SN4069SL in Brockdish, SN2065REV in Needham and SN2036 in Wortwell and the second in relation to Sites SN0274REVA, SN0274REVB and SN4078 in Gillingham.

2.2 Sites SN4069SL (Brockdish), SN2065REV (Needham), SN2036 (Wortwell), SN5045SL (Wortwell)

Hydraulic modelling to support the assessment of fluvial flood risk to proposed development sites SN4069SL in Brockdish, SN2065REV in Needham, SN2036 and SN5045SL in Wortwell from the River Waveney has been based on the existing Environment Agency Lower Waveney model, 2013; as rerun in 2017 by JBA Consulting[1] for the Environment Agency to complete climate change allowance runs. The Lower Waveney model is predominantly a 1D model utilising extended sections and reservoir units to represent the floodplain; but includes a small TUFLOW 2D domain covering the Bungay area. The modifications made to the Lower Waveney model as part of the current study are described in Section 2.2.1.

The area of the River Waveney around the proposed development sites contains a complex system of tributaries and other small drainage systems which are not explicitly included in the existing Environment Agency Lower Waveney model. High level 2D TUFLOW modelling has therefore been conducted to provide an improved understanding of the fluvial flood risk from two key tributaries which were considered to have potential impacts on flood risk for proposed development sites SN4069SL in Brockdish and SN2065REV in Needham. The development of these 2D tributary models is described in Section 2.2.2.

The Starston Brook, a larger tributary of the River Waveney, runs northwest to southeast approximately 400m north of proposed development sites SN2036 and SN5045SL in Wortwell. The Startston Brook is separated from proposed development sites by an intervening spur of high ground and has therefore not been represented by a separate tributary model. The existing EA flood maps indicate that this watercourse would have no influence on the flood risk to these sites.

2.2.1 Lower Waveney Model (1D-2D linked Flood Modeller/TUFLOW)

As described in Section 2.2, above, hydraulic modelling to support the assessment of fluvial flood risk to proposed development sites in Brockdish, Needham and Wortwell is based on the existing Environment Agency Lower Waveney model.

Flood Modeller and TUFLOW software was used for the existing Lower Waveney model and was retained for this study. The current study utilised Flood Modeller version 4.5.1 and TUFLOW version 2020-01-AB-iSP-w64.

To improve the understanding of fluvial flood risk from the River Waveney to the proposed development sites, two 2D domains covering relevant portions of the floodplain on the left bank of the River Waveney were added to the model. One 2D domain covered the Brockdish and Needham areas, a second 2D domain covered the Wortwell area. These two new 2D domains were created with separate TUFLOW geometry (.tgc) and boundary condition (.tbc) files to be run alongside the existing TUFLOW domain for the Bungay area, in a multi-domain 1D-2D Flood Modeller-TUFLOW model. This required alterations to the

1 JBA Consulting, 2017, 2016s5155 Final ENS CC Technical Note v3, Technical note for the climate change model reruns

existing Flood Modeller 1D network, the creation of the two 2D domains and 1D-2D linkages along with associated updates to the existing TUFLOW model control files.

The 1D channel, channel roughness, structure representation and downstream boundary conditions used for this study were adopted from the 1000-year version of the existing Lower Waveney model 1D network (2012_WAVE_042_Lower_Wave_010_1000yr.DAT); as used for the climate change allowance re-runs for the 1% and 0.1% Annual Exceedance Probability (AEP) events in 2017. To facilitate the addition of the new 2D domains river and structure cross-sections in the Flood Modeller 1D network (.DAT) file that included left bank flood plain between model nodes WAVE0603988 and WAVE0503926D (Brockdish and Needham area) and between nodes WAVE0500576E and WAVE0304040u (Wortwell area) were deactivated/cut down to the left bank of the river channel. Three reservoir units that represented the flood plain in the Wortwell area, and associated spill units connecting these reservoir units to the River Waveney channel, between model nodes WAVE0401578i and WAVE0306194E were also removed. In addition, panel markers added where necessary to improve model stability, as were embankment markers at bridges at WAVE0306250N (Homersfield Bridge) and WAVE0306194N (B1062 Roadbridge).

Model topography for both 2D domains was based on Environment Agency 1m LiDAR DTM (last flown circa 2017). A normal depth, HQ boundary, with a slope of 0.006 was applied to the Wortwell 2D domain adjacent WAVE0304040, approximately 2.2km downstream of SN2036 in Wortwell. A downstream boundary condition was not applied to the Brockdish-Needham domain as the left bank of the River Waveney abuts an area of high ground at the end of this 2D domain around nodes WAVE0504170i to WAVE0503926D.

2D roughness (.mat) files were created to represent key land uses; buildings, roads, open water and woodland, across both 2D domains, based on Ordnance Survey Zoomstack mapping. These land uses were assigned Manning's *n* values from the existing TUFLOW material file (Wave_001.tmf) from the Lower Waveney model. Areas of land not specifically assigned to one of the key land use classes were represented by assigning the existing Manning's *n* value for grass areas as a default value. The Manning's *n* values assigned to the key land use classes from OS Zoomstack are described in Table 2-1.

Table 2-1 2D roughness values

Code (assigned from existing .tmf file)	2D roughness value (Manning's *n*)	Feature	Comments
1	0.04	Grass	Used as default value for all areas not specifically assigned one of the below classes.
2	0.08	Dense trees	Value used for woodland areas. Created based on OS ZOomstack Woodland (local) polygons.
5	0.025	Footpaths, paved areas, and roads	Value used for roads. Created using buffers applied to the OS Zoomstack Roads Local (4m buffer), Roads Regional (4m buffer) and Roads National (6m buffer), polyline layers.
8	0.3	Buildings	Created based on OS Zoomstack local buildings polygons.
12	0.03	Water surfaces	Value used for surface water (rivers, lakes ect.) Created based on OS Zoomstack surface water (local) polygons.

A 2D domain grid size of 4m was retained from the pre-existing Bungay 2D TUFLOW domain as it was considered to give an appropriate balance between providing sufficient detail of the floodplain /flow routes across the mainly rural catchment and model run times; whilst also limiting the computational size of model outputs. The 2D timestep of 2 seconds and 1D timestep of 1 second were also retained.

To link the updated 1D network and the two 2D domains, a 1D network node layers was created for each domain based on the 1D Flood Modeller cross-section chainage information. TUFLOW HX lines were then digitised to represent the relevant portions of the River Waveney's left bank based on the Environment Agency's 1m LiDAR DTM. TUFLOW CN connection lines were digitised to link the 1D network nodes layer and the HX lines. Note an additional energy loss (A flag=0.5) has been applied to a short section of HX line between nodes WAVE0600068 and WAVE056207u to resolve a localised stability issue around a bridge unit (WAVE0506377N).

The 5% AEP, 1% AEP and 0.1% AEP events (with and without allowances for climate change) were required to inform the Level 2 SFRA addendum. Model inflows were based on the existing hydrology for the Lower Waveney model and event (.ied) files for the 5% AEP, 1% AEP and 0.1% AEP events were retained from the existing modelling. Climate change allowances have, however, been updated by the Environment Agency since the model was last run in 2017. New event files were therefore created based on the existing 5% AEP, 1% AEP and 0.1% AEP event files, with flow multipliers updated to account for climate change allowances of 11% and 20%, for the Central and Higher Central peak river flow allowances in line with Environment Agency Guidance[2] for the Broadland Rivers Management Catchment, 2080s epoch.

Initial conditions for the 1000 year version of the model were adopted for the 1% and 0.1% AEP events (with and without allowance for climate change), as used for climate change allowance runs in the previous 2017 modelling. Separate 5% AEP initial conditions were adopted from the existing Lower Waveney model for this event.

Figure 2-1 shows a model schematic of the 2D domain covering the Brockdish and Needham area added to the Lower Waveney model and Figure 2-2 shows a model schematic of the 2D domain covering the Wortwells area added to the Lower Waveney model.

[2] Environment Agency, Flood risk assessments: climate change allowances, https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances , last updated 6 October 2021

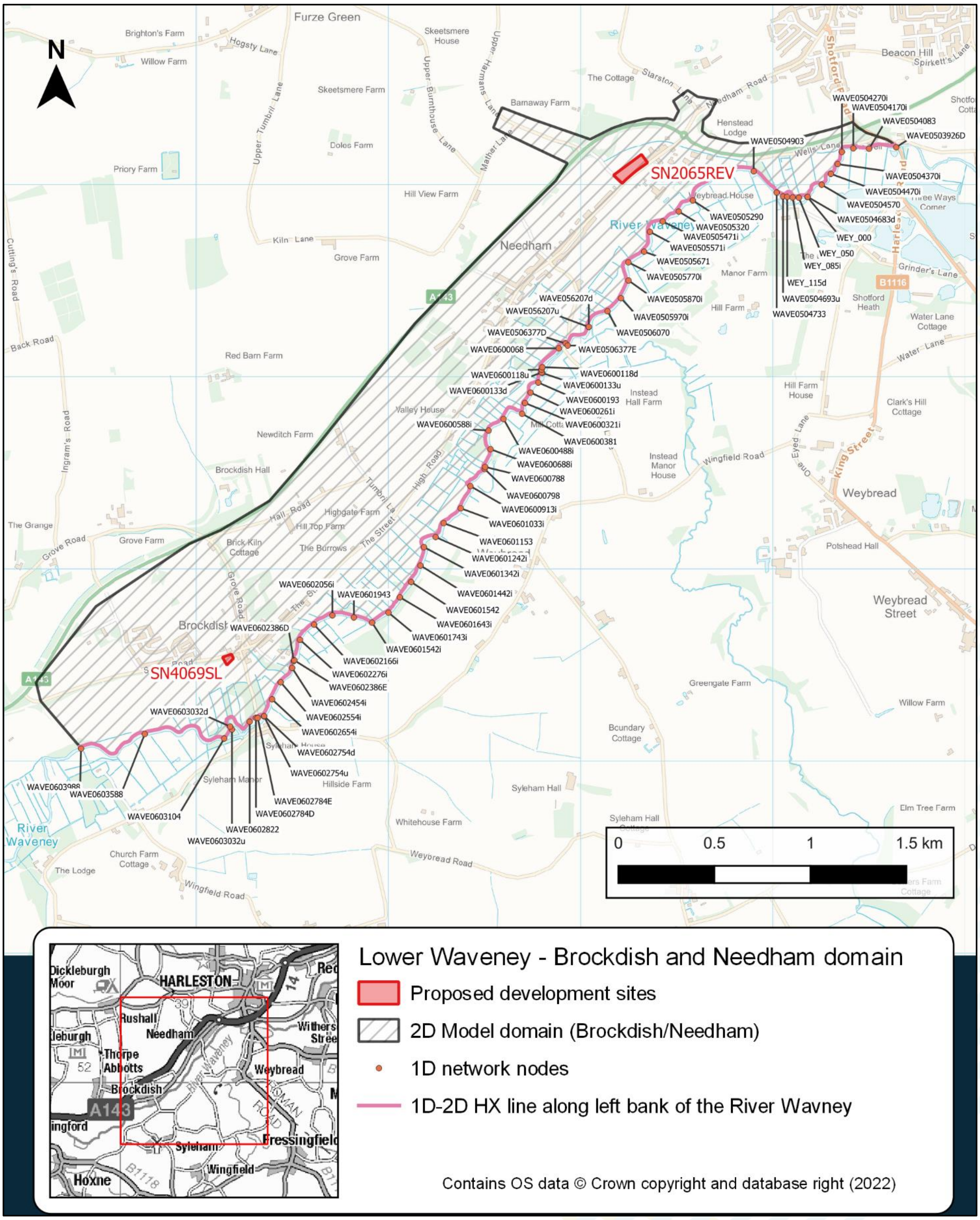

Figure 2-1 Model schematic additional 2D domain added to the Lower Waveney model for the Brockdish and Needham Area.

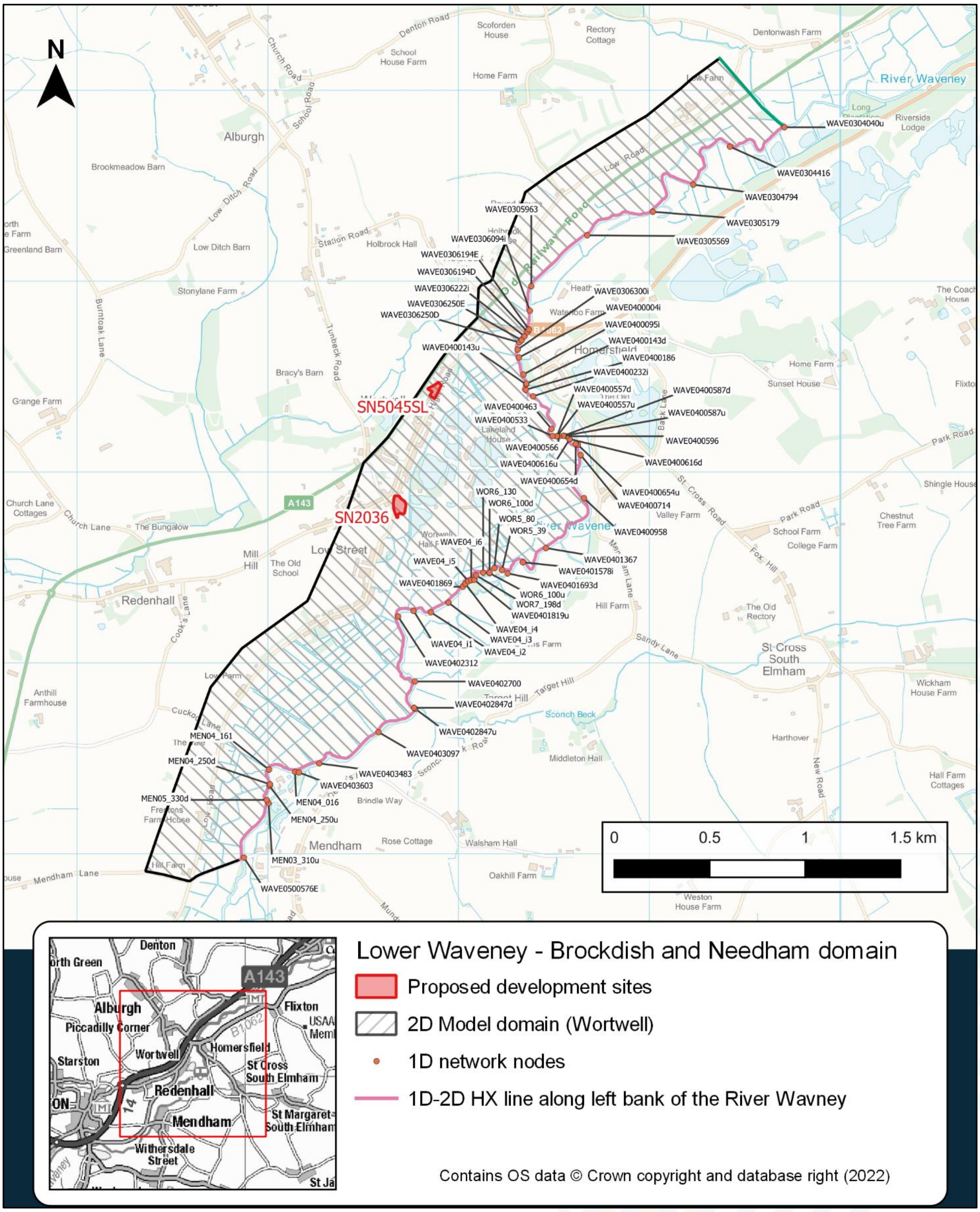

Figure 2-2 Model schematic additional 2D domains added to the Lower Waveney model for the Wortwell area

2.2.2 **Lower Waveney Tributary modelling (TUFLOW)**

The lower River Waveney area contains a complex system of tributaries and other small drainage systems which are not explicitly included in the existing Environment Agency Lower Waveney model. Two key unmodeled tributaries were identified that were likely to have potential impacts on flood risk sites for proposed development sites SN4069SL in Brockdish and SN2065REV in Needham. No channel or structure survey data for these tributaries was available and therefore a simplified 2D TUFLOW modelling approach has been utilised to provide a high-level understanding of the potential fluvial flood risk from these two key tributaries. Separate 2D domains were created for the relevant portions of Brockdish and Needham which were run as a single multi-domain model. TUFLOW version 2020-01-AB-iSP-w64 was utilised for this modelling.

2D domain topography was based on Environment Agency 1m LiDAR DTM data, as used for the Lower Waveney modelling described in Section 2.2.1. Channels were burnt into the 2D domain topography using Z Shape layers based on selected levels in the tributary channels from the 1m LiDAR DTM. These Z Shapes are read into the model using a MIN/GULLY command and have a shape width of 3.5m; greater than 1.5 times the model grid cell size (i.e. a THICK line), to carve a continuous flow route through the underlying model topography.

2D material roughness (.mat) files were created to represent key land uses; buildings, roads, open water and woodland, across both 2D domains based on Ordnance Survey Zoomstack mapping and were assigned Manning's *n* roughness coefficients, as detailed in Section 2.2.1 and Table 2-1 for the Lower River Waveney modelling.

Water Level, Head-Time (HT) boundary conditions were applied along the left bank of the River Waveney to each domain to represent bank full conditions around the confluence of each tributary with the River Waveney. A constant water level of 19.1m AOD was applied to the left bank of the Waveney in the Brockdish 2D domain. A constant water level of 16.67m AOD was applied to the left bank of the Waveney in the Needham 2D domain.

A 2D domain grid size of 2m, with a 2D timestep of 1s, was used to give an appropriate balance between the channel representation, providing sufficient detail of the floodplain flow routes and model run times.

The 5% AEP, 1% AEP and 0.1% AEP fluvial events (with and without allowances for climate change) were required to inform the Level 2 SFRA addendum. Model inflow hydrology for the 5% AEP, 1% AEP and 0.1% AEP events was calculated using the Flood Estimation Handbook (FEH) revitalised flood hydrograph method (ReFH2) method. The ReFH2 Flood Modelling software package, version 3.0.7. was used for these calculations.

Inflow hydrographs for the Brockdish tributary were calculated based on FEH catchment descriptors at British National Grid Easting: 621400, Northing: 279450, close to the confluence of the tributary with the River Waveney. The 7.5 hour storm duration recommended by the ReFH2 software with a winter storm profile was adopted. Inflow hydrographs for the Needham tributary were calculated based on FEH catchment descriptors at British National Grid Easting: 623400, Northing: 281800, close to the confluence of the tributary with the River Waveney. The catchment drainage area was however revised to 5.025km^2 to account for a missing portion the catchment. The mean drainage path length (DPLBAR) descriptor was therefore also updated based on the revised catchment drainage area using the equation DPLBAR=AREA$^{0.548}$, as described in Section 7.2.4 of FEH Book 5[3]. The 11 hour storm duration recommended by the ReFH2 software with a winter storm profile was adopted. Model inflows for both Brockdish and Needham tributaries were applied using Flow-Time (QT) points at the upstream end of the tributaries.

[3] Bayliss, A. C. (1999) Catchment descriptors. Volume 5 of the Flood Estimation Handbook. Centre for Ecology & Hydrology.

For climate change scenarios inflows were increased by 11% and 20% for the Central and Higher Central peak river flow allowances respectively, in line with Environment Agency Guidance[4] for the Broadland Rivers Management Catchment, 2080s epoch.

[4] Environment Agency, Flood risk assessments: climate change allowances, https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances , last updated 6 October 2021

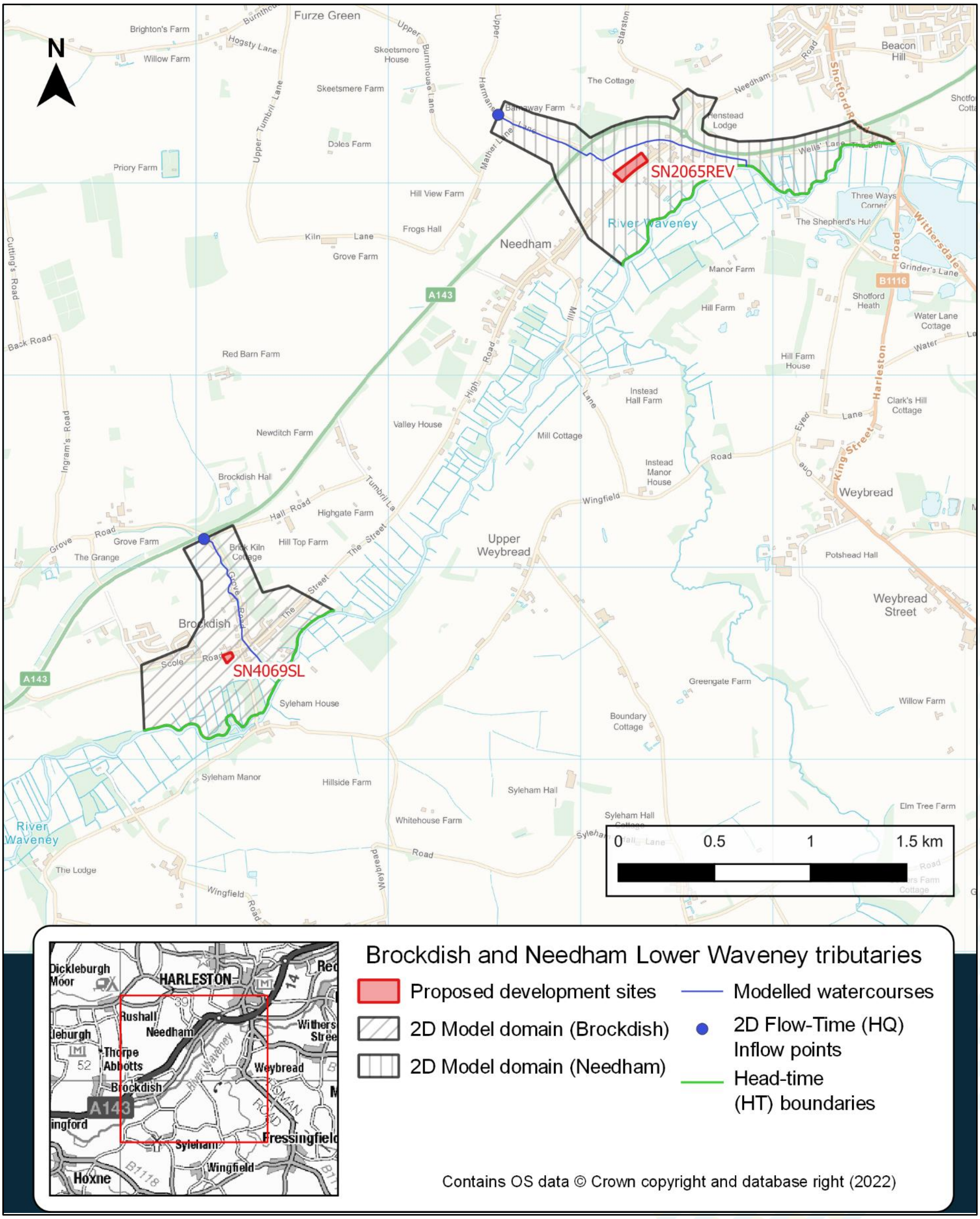

Figure 2-3 shows a model schematic of the tributary models for proposed development sites SN4069SL in Brockdish and SN2065REV in Needham.

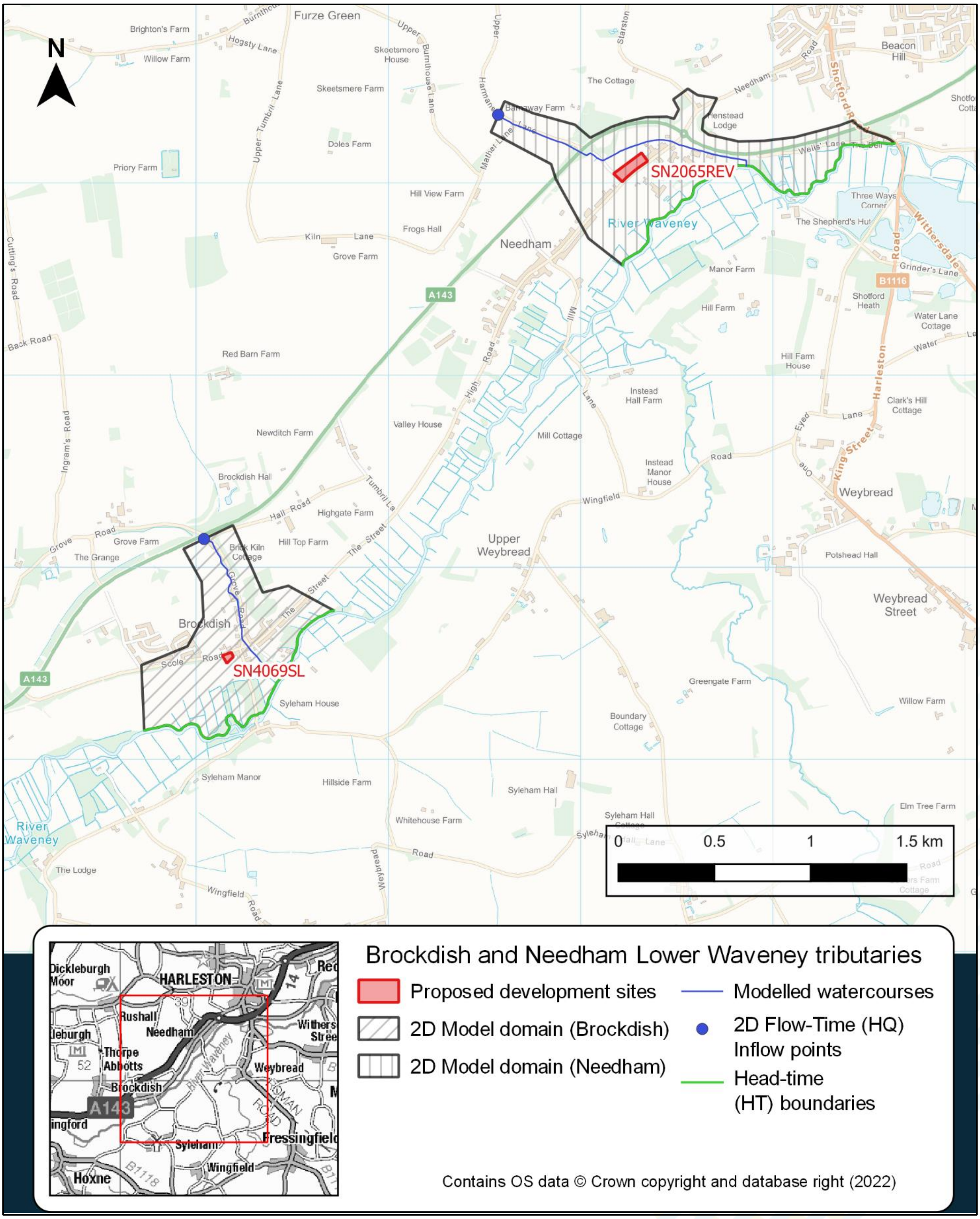

Figure 2-3 Model schematic Lower Waveney Tributary models

2.3 Sites SN0274REVA, SN0274REVB, SN4078 (Gillingham)

Proposed development sites SN0274REVA, SN0274REVB and SN4078 are located in Gillingham, South Norfolk. Given the location of the sites both tidal and fluvial flood risk require consideration. It was beyond the scope of the current works to consider joint probability of fluvial and tidal flooding, and therefore fluvial and tidal risk have been considered separately.

The proposed development sites could potentially be at risk of flooding from the River Waveney however the Lower Waveney model does not extend as far downstream on the River Waveney as Gillingham and it was not possible, within the scope of the current work, to model fluvial flood risk from this source. High level 2D modelling of a key small watercourse identified running close to the proposed development sites has however been undertaken in TUFLOW.

No tidal modelling of the Gillingham area was available for use in this study. Coastal flood modelling was available for Lowesestoft area, where the River Waveney joins the sea after passing through Oulton Broad and Lowestoft Harbour. The Lowestoft coastal model was created by JBA Consulting for the Environment Agency in the period 2014-2019 as part of the East Anglian Coastal Modelling study, a wider assessment of coastal flood risk along the East Anglian coastline[5].

The Lowestoft coastal model does not extend as far upstream as Gillingham and extending the Lowestoft tidal model was not within the scope of the current works. High level tidal modelling has therefore been undertaken based on the application of water levels from Coastal Flood Boundary (CFB) Extreme Sea Levels dataset at chainage site 4162. This tidal modelling represents a very conservative approach and is unlikely to represent a realistic representation of potential risk to the proposed development sites due to the impact on tidal flood levels of Mutford Lock, located at the downstream end of Oulton Broad and the distance of the proposed development sites from the coastline, approximately 13.5km. To better understand the potential tidal risk to the proposed development sites in Gillingham resulting from the presence of Mutford Lock, tidal simulations based on 2D flood level results from the Lowestoft model directly upstream of Mutford Lock, have also been undertaken.

Both fluvial simulations for the key smaller watercourses and tidal modelling has been conducted within a single 2D TUFLOW model for Gillingham. This model, including both fluvial and tidal simulations, is described in Section 2.3.1, below.

2.3.1 Gillingham fluvial and tidal modelling

As described in Section 2.3, above, a 2D TUFLOW model was created to provide an improved understanding of fluvial flood risk from a key small watercourse and of potential Tidal flood risk to proposed development sites SN0274REVA, SN0274REVB, SN4078 in Gillingham, South Norfolk.

2D domain topography was based on Environment Agency 1m LiDAR DTM data, as used for the Lower Waveney modelling described in Section 2.2.1. A small unnamed watercourse was identified that may having bearing on fluvial flood risk to the Gillingham proposed development sites. No channel or structure survey data was available for this reach of watercourse. Analysis of Aerial imagery and OS Mapping implied that this watercourse runs broadly north to south through Gillingham and appears to split into two branches to the north of the proposed development sites around Old Yarmouth Road. One branch of this watercourses appears to run broadly southeast on the northern side of Old Yarnmouth Road, adjacent to the proposed development site SN0274RevB before turning southwards

[5] JBA Consulting, February 2019, East Anglia Coastal Modelling Final Summary Report; JBA Consulting, February 2019, East Anglia Coastal Modelling, Model development report

to run alongside the western side of The Street towards the River Waveney. The other branch appears to run southwards from Old Yarmouth Road before turning eastwards to a confluence with the other branch to the southwest of The Street. This branch runs approximately 30m-60m to the south of proposed development site SN4078. As no channel or structure survey data for these watercourses was available a simplified 2D approach was adopted. Channels were burnt into the 2D domain topography using Z Shape layers based on selected levels in the tributary channels from the 1m LiDAR DTM. These Z Shapes are read into the model using a MIN/GULLY command and have a shape width of 3.5m; greater than 1.5 times the model grid cell size (i.e. a THICK line), to carve a continuous flow route through the underlying model topography. The channels were included in both fluvial and tidal simulations.

2D material roughness (.mat) files were created to represent key land uses; buildings, roads, open water and woodland, across both 2D domains based on Ordnance Survey Zoomstack mapping and were assigned Manning's *n* roughness coefficients, as detailed in Section 2.2.1 and Table 2-1 for the Lower River Waveney modelling.

A 2D domain grid size of 2m, with a 2D timestep of 1s, was used in both fluvial and tidal scenarios to give an appropriate balance between the channel representation, providing sufficient detail of the floodplain flow routes and model run times.

The 5% AEP, 1% AEP and 0.1% AEP fluvial events (with and without allowances for climate change) were required to inform the Level 2 SFRA addendum. Model inflow hydrology for the 5% AEP, 1% AEP and 0.1% AEP events was calculated using the Flood Estimation Handbook (FEH) revitalised flood hydrograph method (ReFH2) method. The ReFH2 Flood Modelling software package, version 3.0.7. was used for these calculations. Inflow hydrographs were calculated based on FEH catchment descriptors at British National Grid Easting: 640850, Northing: 291650 adjacent King's Dam road. The 11 hour storm duration recommended by the ReFH2 software with a winter storm profile was adopted. The fluvial model inflow hydrographs were applied using a Flow-Time (QT) point at the upstream end of the small watercourse. As tidal and fluvial flooding were considered separately this inflow point was applied for fluvial scenarios only. For climate change scenarios inflows were increased by 11% and 20% for the Central and Higher Central peak river flow allowances respectively, in line with Environment Agency Guidance[6] for the Broadland Rivers Management Catchment, 2080s epoch.

In the fluvial events normal depth, HQ boundaries, with slopes of 0.006 were applied along the downstream edge of the Gillingham model domain between two areas of high ground. A small, separate normal depth, HQ, boundary with a slope of 0.0033 was applied across the A146, Norwich Road, which cuts through the eastern area of high ground. Figure 2-4 shows a model schematic for the Gillingham model fluvial events.

[6] Environment Agency, Flood risk assessments: climate change allowances, https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances , last updated 6 October 2021

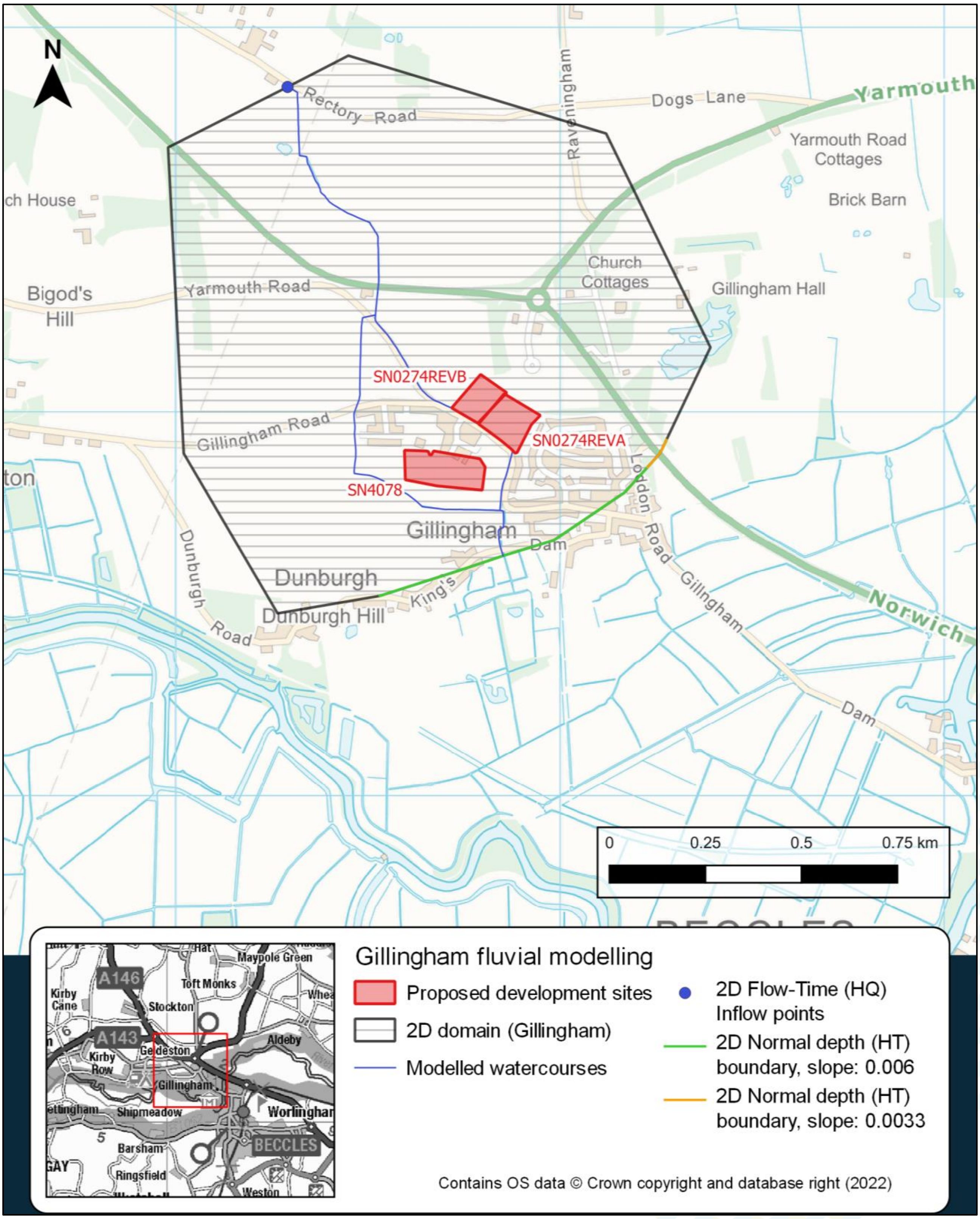

Figure 2-4 Model scehmatic Gillingham fluvial modelling

The 1% AEP, 0.5% AEP and 0.1% AEP tidal events (with and without allowances for climate change) were also required to inform the Level 2 SFRA addendum. As previously discussed in Section 2.3, the Lowestoft tidal model does not extend as far upstream as Gillingham and extending the Lowestoft tidal model was not within the scope of the current works. As a conservative approach, high level tidal modelling has therefore been undertaken based on the water levels from CFB Extreme Sea Levels dataset (2018) applied to an event surge profile at the downstream end of the Gillingham model. Table 2-2 summaries the coastal flood boundary data used.

Table 2-2 Coastal flood boundary data

Highest Astronomical Tide (HAT) Location	Surge Donor Location	CFB dataset point chainage
Lowestoft	Lowestoft	4162

The CFB Extreme Sea Level datasets have a base year of 2017. To represent the present day, 2022, scenario the CFB Extreme Sea Levels for the base year of 2017 were uplifted to the current year, 2022, based on the UKCP18 Mean Sea Level Anomaly to 2125. The Higher central and Upper end climate change allowances were used to inform the Level 2 SFRA Addendum[7] and a development lifetime of 100 years was assumed based on the minimum lifetime for residential development[8] . Sea level allowances for climate change between 2022 and 2122 Higher Central and Upper End were calculated based on the 70th and 90th percentiles for the (UKCP18 8.5 RCP scenario) Mean Sea Level Anomaly to 2125.

Table 2-3 summarises the sea level rise values applied to uplift from the base year 2017 to the current year, 2022 as well as the Higher central and Upper end sea level allowances applied for 2122. The peak tide levels applied for the present day, 2022, and 2122 model scenarios are summarised in Table 2-4.

Table 2-3 Sea level rise uplifts

Scenario	Uplift applied to CFB Extreme Sea Levels dataset (m AOD)
Uplift of CFB base year of 2017 to present day 2022	0.029
2022 present day to 2122 Higher Central climate change allowance (70th percentile)	1.054
2122 Upper End climate change allowance (90th percentile)	1.413

Table 2-4 Peak tide levels based on Coastal Flood Boundary dataset (2018) chainage point 4162

[7] Environment Agency, Flood risk assessments: climate change allowances, https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances , last updated 6 October 2021

8 Department for Levelling Up, Housing and Communities and Ministry of Housing, Communities & Local Government, Flood Risk and Coastal Change, https://www.gov.uk/guidance/flood-risk-and-coastal-change#what-is-lifetime-of-development, last updated 20 August 2021

Scenario	Peak tide level (m AOD)		
	1% AEP event	0.5% AEP event	0.1% AEP event
2022, present day	3.14	3.32	4.55
2122 Higher Central climate change allowance	4.19	4.37	4.73
2122 Upper End climate change allowance	4.55	4.79	5.15

These tidal events were applied to the model using a water level, head-time (HT), boundary at the downstream edge of the model. Figure 2-5 shows a model schematic for the Gillingham model tidal events.

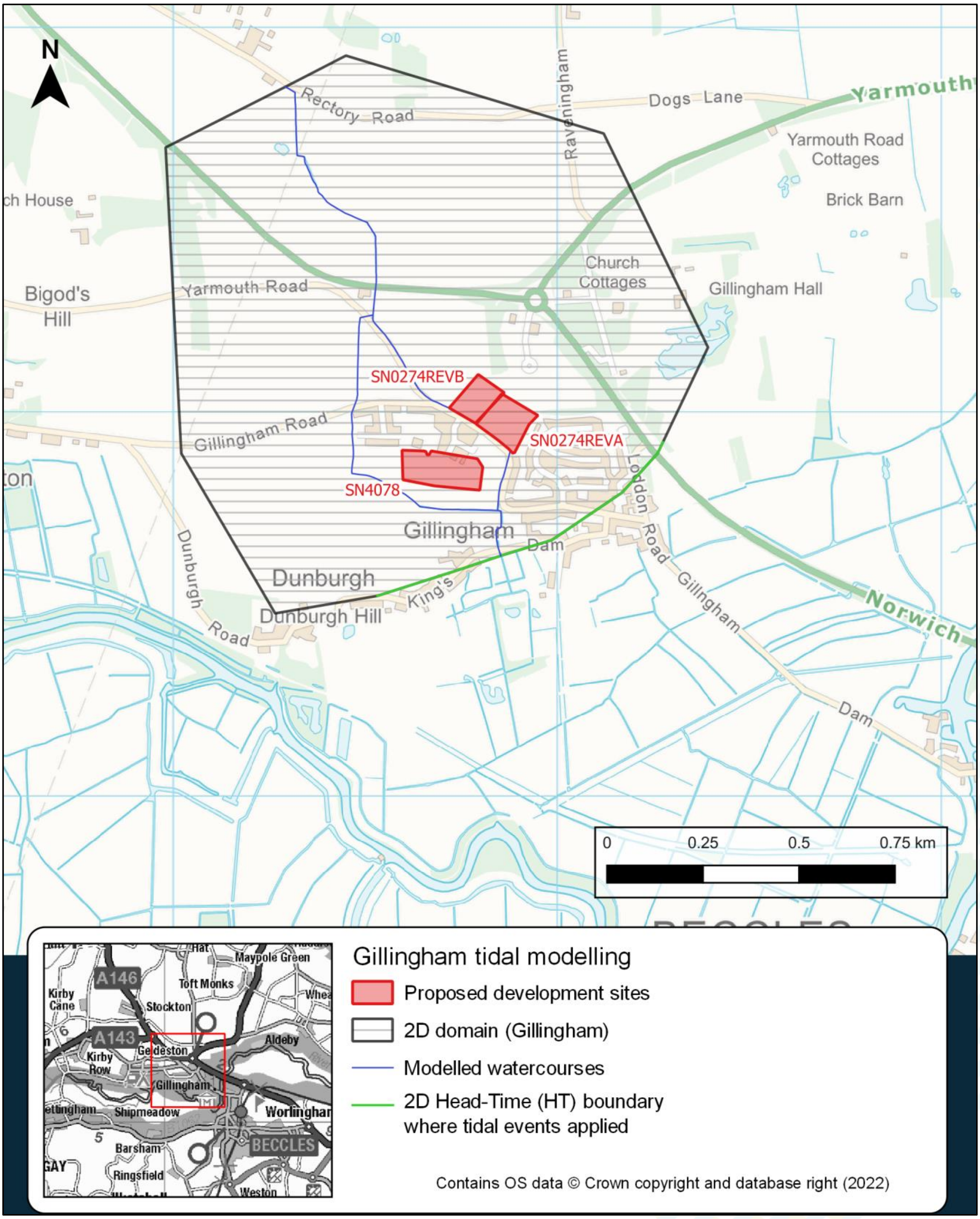

Figure 2-5 Model schematic Gillingham tidal model

As previously outlined in Section 2.3 the application of the Coastal Flood Boundary dataset directly to the Gillingham model area is a very conservative approach which is unlikely to present a realistic representation of the potential tidal risk to the proposed development sites due to the impact on tidal flood levels of Mutford Lock located at the downstream end of Oulton Broad and the distance of the proposed development sites from the coastline; approximately 13.5km. To provide better understanding of the potential tidal risk to the proposed development sites in Gillingham resulting from the presence of Mutford Lock alternate tidal simulations based on 2D flood level results from the Lowestoft coastal model have also been conducted.

The Lowestoft coastal model[9] is a 2D TUFLOW model covering the urban area of Lowestoft from Corton Woods in the north of Lowestoft to Heathland Beach Caravan Park in the south and includes Lake Lothing and Oulton Broad. Mutford Lock is located at the downstream end of Oulton Broad between Oulton Broad and Lake Loathing, approximately at British National Grid Reference Easting: 652098, Northing: 292803. Alternate present day tidal curves to be applied to the downstream edge of the Gillingham model were calculated based on extracting water levels directly from the time-varying (.XMDF) Lowestoft model results, Undefended Scenario, at a point in Oulton Broad; approximately 7m upstream of Mutford Lock; British National Grid Easting: 652065.5, Northing: 292811.5, see Figure 2-6.

[9] JBA Consulting, February 2019, East Anglia Coastal Modelling Final Summary Report; JBA Consulting, February 2019, East Anglia Coastal Modelling, Model development report

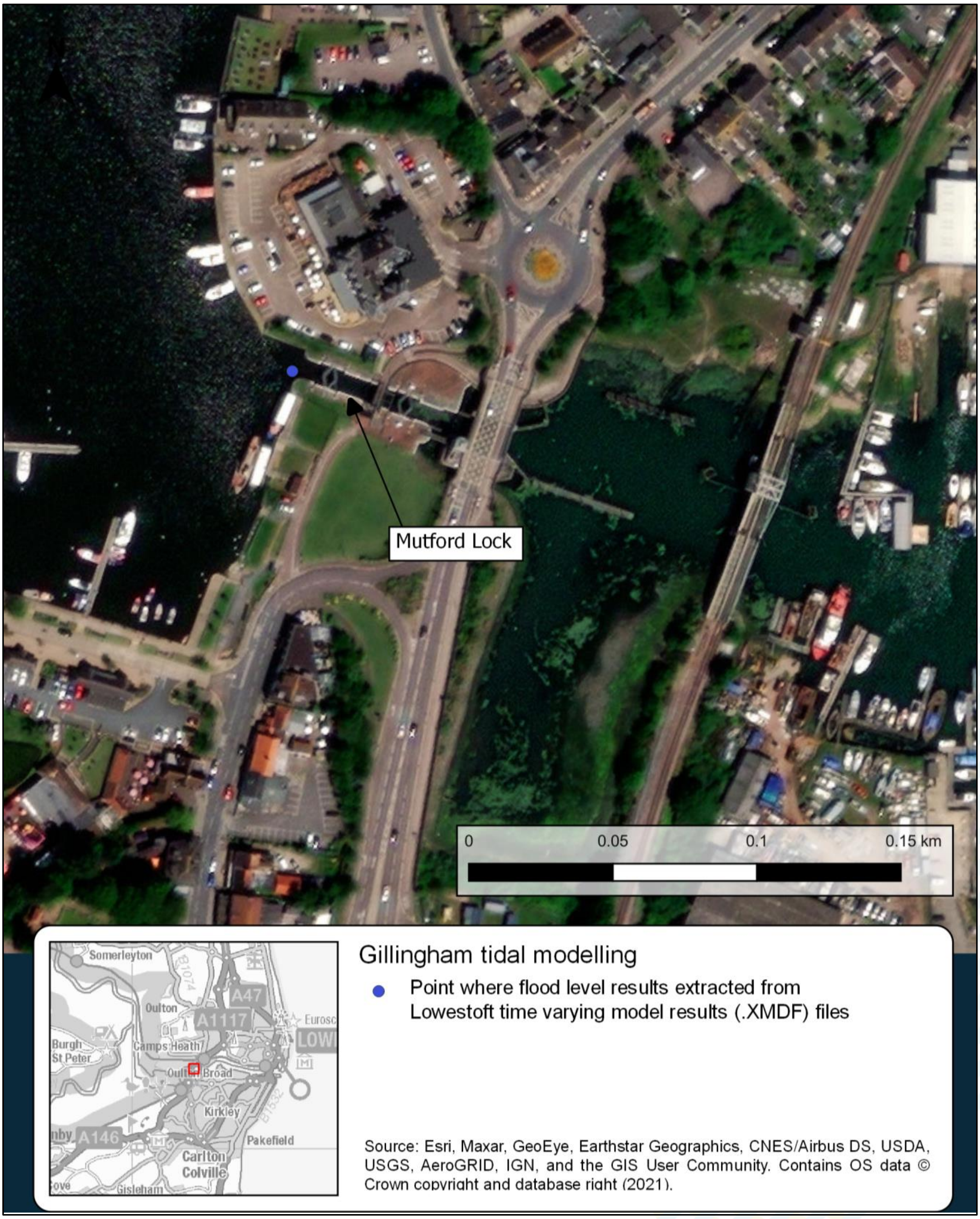

Figure 2-6 Lowestoft model flood level result extraction point

The Lowestoft model tidal inflows are based on an older iteration version of the Coastal Flood Boundary dataset (2011) which was updated as part of the East Anglia Coastal Modelling study to include 5 additional years of tide gauge data from 2009-2014[10]. The maximum tide levels applied to the Lowesoft model in the East Anglia Coastal Modelling study with the Gillingham present day for the relevant events are summarised in Table 2-5

Table 2-5 Comparison of CFB levels for the Lowestoft Model (CFB with 2008 base year, updated with additional 4 years gauge data to 2014) with CFB for Gillingham model (2017 base year, uplifted to 2022)

	Maximum tide level per AEP event (m)		
	1% AEP event	0.5% AEP event	0.1% AEP event
Updated sea levels for 2014 used for Lowestoft model in the East Anglia Coastal Modelling study	3.19	3.4	3.92
2022 present day scenario	3.12	3.30	3.73

As shown in Table 2-5 the extreme sea levels for 2014 applied to the Lowestoft model are higher those for the present-day Lowestoft CFB dataset previously applied to the Gillingham model. Model results for Lowestoft were therefore used unaltered, without any additional uplift accounting for the base year to represent the present day, 2022, scenario. The Higher central and Upper end climate change allowances were applied to extracted water levels for 2122 scenarios using the uplift values shown in Table 2-3.

The extracted water levels based on the Lowestoft model results directly upstream of Mutford Lock, with and without climate change allowances, are applied at the Head-Time (HT) boundary; at the downstream end of the model in place of those based on the CFB dataset. The extracted Lowestoft model results were cut at the start of the event to include only the two tidal peaks to reduce run time. Instabilities at the initial wetting phase of tidal simulations, were identified in initial runs of the present-day events. The tide curves were therefore manually amended to 0.1m AOD for the first 5 to 6.5 hours of the event, to reduce these stability issues and would have no bearing on results at time of peak tide levels. The peak water levels applied to the Gillingham tidal model, based on the Lowesoft model results upstream of Mutford Lock, are shown in Table 2-6.

Table 2-6 Peak tidal levels based on Lowestoft model, undefended scenario, model results

Scenario	Maximum tide level per AEP event (m)		
	1% AEP event	0.5% AEP event	0.1% AEP event
2022, present day	0.809	1.145	1.590
2122 Higher Central climate change allowance	1.863	2.199	2.644
2122 Upper End climate change allowance	2.222	2.558	3.003

[10] JBA Consulting, February 2019, East Anglia Coastal Modelling Final Summary Report, Section 3.2.5.

3 Model performance, limitations, and uncertainties

3.1 Model performance

3.1.1 Lower Waveney model

The performance for the 1D-2D Flood Modeller-TUFLOW model for the Lower Waveney, updated with the new 2D domains for Brockdish and Needham, is summarised below.

Flood modeller convergence plots indicate that the model is fairly stable however all events contain a short period of non-convergence at the start of the simulation likely caused by the initial conditions. Whilst it would be preferable for the initial conditions to be revised, this was not within the scope of the current works.

In the 0.1% AEP events, with and without allowances for climate change, small spikes of non-convergence occur around the bridge at model node WAVE0306250N at the end of the Wortwell domain and around a sluice unit, WA0801010Slu at Billingford Gauging station at the upstream end of the Lower Waveney model. The instabilities around bridge unit WAVE0306250N cover very short periods, of between approximately 1-2 minutes each, and are associated with a small conveyance issue at the bridge unit that occurs around the elevations of the channel banks. As previously discussed in Section 2.2.1, panel markers and embankment lines were added where necessary to improve model stability, but this has not eliminated all stability issues at this location. WA0801010Slu at Billingford Gauging station is located approximately 4.8km upstream of the area of interest around Brockdish, Needham and Wortwell. This portion of the model is represented unaltered from the existing Lower Waveney model. It would be beyond the current scope of works to resolve stability issues with the existing Environment Agency Lower Waveney model so far upstream of the proposed development sites.

Cumulative mass error percentages (Cum ME %) within the 2D TUFLOW domains in all events are initially much greater than the ±1% typical range for a stable flood model, with maximum Cum ME % occurring around the first timesteps in all simulations. This results from some initial wetting of the 2D domain caused by the model initial conditions. Cum ME % drops to ±1% in all scenarios during the first 0.5 hours and remains within this range for the rest of the simulation, in all events. Therefore, the model is considered stable and fit for purpose.

In addition, TUFLOW reported a variety of checks and warnings as well as a large number of 2D negative depths and negative velocities. These checks, warnings, 2D negative depths and negative velocities all relate to the existing Bungay 2D domain only. The Bungay 2D domain is represented unaltered from the existing Lower Waveney model and it would be beyond scope to resolve these issues. In addition, the Bungay domain is located approximately 7.5km downstream of the closest proposed development sites in the Wortwell area and is therefore unlikely to have any impact on model results in the Brockdish, Needham and Wortwell areas relevant to the current study.

3.1.2 Lower Waveney tributary models (Brockdish and Needham)

TUFLOW reports Cum ME % that are initially greater than the ±1% typical range for a stable flood model for the multi-domain tributary model covering the two identified small watercourses in Brockdish and Needham. However, Cum ME % drops to between ±1% in all scenarios after approximately the first minute of the simulation and remains below this value for the rest of the simulations for all events, apart from the 1% plus 11% central allowance for climate change event. Cum ME % in that event rises over the recommended value of ±1% after approximately 26.5 hours. There is no obvious reason for the rise in mass error, however this occurs much later than the peak water level in the model, and is therefore not considered to of concern.

TUFLOW reports two warnings related to the upstream HQ inflow boundary; identical apart from the domain name reported in them. This warning message is noted below:

- WARNING 2400 - Hidden node not allocated as a primary node to a 2D2D link cell in 2D Domain "[domain name]". Review 2D link line shape and check vertex spacing is not too close.

The TUFLOW guidance for Warning 2400[11] notes this warning occasionally occurs at 2d_bc boundaries of type QT, such as used in this modelling, and states that in these cases the warning has been outputted in error and are not of concern.

3.1.3 Gillingham fluvial and tidal modelling

Peak Cum ME % for the Gillingham fluvial model is reported in Table 3-1. As shown in Table 3-1, the peak Cum ME % in the 5% and 1% AEP events (with and without allowances for climate change) is between 1% and 1.5%; slightly above the ±1% typical range. The model is a 2D only model and there is considerable uncertainty surrounding the representation of the channel and other features which interact with the water surface as no survey information was available. Given these limitations, the Cum ME % was considered to be acceptable.

Cum ME % in the 0.1% AEP events (with and without climate change allowances) are below the ±1% typical range for a stable flood model throughout the whole of these simulations.

Table 3-1 Gillingham fluvial model peak cumulative mass balance error (%)

	Event (% AEP)								
	Present day (no climate change allowance)			With 11% (Central) climate change allowance			With 20% (Higher Central) climate change allowance		
	5%	1%	0.1 %	5%	1%	0.1 %	5%	1%	0.1 %
Peak Cum ME (%)	1.1	1.24	0.85	1.25	1.07	0.81	1.47	1.01	0.79

In the Gillingham tidal model, based on water levels from the CFB dataset, the Cum ME % in all events, apart from the present day 0.1% AEP event, is initially above the ±1% typical range. This relates to initial wetting of the model and the Cum ME % drops to the ±1% typical range within the first 2 hours and remains within ±1% for the rest of the simulations, for all events.

In the Gillingham tidal model, based on water levels from the Lowestoft model, Cum ME % are initially above the ±1% typical range in all events where an uplift for climate change has been applied. Cum ME % for the present day, 2022, events are below 1% typical range. The initial mass balance error in the climate change events relates to the portion of the event that has been applied with a static level of 0.1m AOD to reduce instabilities involving initial wetting of the model in the present-day events. This initial high mass balance error has no bearing on results at time of peak tide levels and the mass balance errors reduce to below ±1% within approximately 1 hour and then remains within the ±1% range.

TUFLOW did not record any negative depths in any of the fluvial or tidal simulations of the Gillingham model. There were no TUFLOW Warnings or Checks raised in any of the Gillingham fluvial or tidal scenarios.

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[11] Official TUFLOW wiki, TUFLOW Message 2400, https://wiki.tuflow.com/index.php?title=TUFLOW_Message_2400 , last modified 4 October 2018

3.2 Limitations, assumptions, and uncertainties

Developing a hydraulic model requires the application of simplifications and generalisations. As such, several assumptions were made when building the model. This can lead to model uncertainties and subsequent limitations in the results. The below sections summarise the key limitations, assumptions and uncertainties of the high-level modelling conducted for the South Norfolk SFRA addendum.

3.2.1 Lower Waveney model

The modelling work undertaken to assess fluvial flood risk from the River Waveney is based on the Environment Agency's existing Lower Waveney model. The Lower Waveney model was however built circa 2013, with minor updates to for new climate change runs in 2017. A full review and update of the Lower Waveney was beyond the scope of the current work, and it has been assumed that the existing modelling is fit for purpose, that model cross-sections and structures are appropriately represented and significant changes to the channel and/or associated structures have not occurred. In addition, it has also been assumed that the 1D flood model accurately represents the right bank flood plain in the Brockdish/Needham and Wortwell areas where 2D domains have been added to the left bank.

As per the existing Environment Agency Lower Waveney model it is assumed that there is no tidal influence on the modelled portion of the Lower River Waveney.

Whilst climate change allowances have been updated to account for the latest guidance the modelling utilises the existing hydrology from the Lower Waveney model. Hydrological methods and software have been updated in the intervening period since the model was built and more hydrometric data for the watercourse may be available.

The two 2D domains added to the model are based on Environment Agency LiDAR DTM last flown circa 2017. It has been assumed there have been no significant changes to the topography of the area since this time. The LIDAR bare earth DTM is also a source of model uncertainty as it has been filtered to remove the presence of buildings and vegetation. At these locations, the filtering process can lead to problems with incorrect changes in elevation. The model performance, however, indicates that there are no significant 2D stability issues, which are sometimes experienced with poorly filtered LIDAR.

There are a number of lakes, ponds and small watercourses/drainage ditches within the Lower Waveney area. These features are not explicitly accounted for beyond their impact on the LiDAR terrain.

3.2.2 Lower Waveney Tributary models (Brockdish, Needham, Wortwell)

No survey information for the modelled channels was available. The modelled watercourses were therefore represented in the 2D domain based solely on available mapping and Environment Agency LiDAR 1m DTM data. Due to the lack of channel survey information and the limitations of the 2D modelling approach there is considerable uncertainty in channel representation, connectivity, and capacity/conveyance. In addition, the area of the lower River Waveney contains a complex system of ordinary watercourses/drainage ditches which are not explicitly represented.

No survey information for structures, e.g. bridges, culverts, weirs ect. within the watercourse was available. Structures could therefore not be reasonably accounted for, and considerable uncertainty therefore exists in the results as to the potential flood risk to the proposed development sites.

Conducting detailed hydrology assessments was beyond the scope of the current work and model inflows have therefore been based solely off ReFH2. No statistical estimates have been produced and no hydrometric gauge analysis or assessment of previous flooding events has been completed. In addition, no critical duration testing has been undertaken however the recommended critical duration from ReFH2 has been adopted.

The downstream boundary conditions for both modelled watercourses are based on water levels in the River Waveney at bank full conditions close to their confluence with the River Waveney. The tributary model results therefore are only suitable for assessing potential flood risk for the identified development sites on those tributaries and not for other areas adjacent the Lower Waveney, even where results for these models may be included in the 2D domain.

The same limitations regarding the LiDAR DTM age and filtering that apply to the Lower Waveney modelling, described in Section 3.2.1, also applies to the Lower Waveney tributary modelling.

3.2.3 Tidal and Waveney Tributary model (Gillingham)

Proposed development sites SN0274REVA, SN0274REVB, SN4078 in Gillingham could be subject to fluvial flood risk from the River Waveney. The Lower Waveney model does not however extend as far Gillingham and under the current scope of works flood risk to the Gillingham post development sites from the River Waveney could not be considered. Consideration of joint probability of fluvial and tidal events would also have been beyond the scope of study and therefore fluvial and tidal events have been considered separately and the uncertainty surrounding the propagation of the tide up the Waveney from Lowestoft meant assessment this was not warranted for this scale of study.

It is unclear how far tidal flooding from the coast at Lowestoft would propagate inland either directly or up the River Waveney and whether it would impact on the proposed development sites in Gillingham given the long distance, approximately 13.5km, from the coast at Lowestoft and the presence of Mutford Lock at the downstream end of Oulton Broad. Neither tidal modelling approach currently applied is providing a true reflection of how the tide may propagate up the Reiver Waveney and it’s floodplain or the impact of the gates at Mutford Lock. It has, however, been assumed that utilising a tidal boundary condition based on the Lowestoft model results just upstream of Mutford Lock provides a better representation of the potential tidal risk to the proposed development sites than the CFB dataset.

The downstream boundary conditions in the fluvial modelling use a normal depth approach calculated based on slope and do not account for any interaction with water levels in or flooding from the River Waveney.

No survey information for the modelled channels was available. The modelled watercourses were therefore represented in the 2D domain only based on available mapping and Environment Agency LiDAR 1m DTM data. Due to the lack of channel survey information and the limitations of the 2D modelling approach there is considerable uncertainty in channel representation, connectivity, and capacity/conveyance. In addition, the Gillingham area contains a complex system of ordinary watercourses/drainage ditches which are not explicitly represented.

No survey information for structures, e.g. bridges, culverts, weirs ect. within the watercourse was available. Structures could therefore not be reasonably accounted and considerable uncertainty therefore exists in the results as to the potential flood risk to the proposed development sites.

Conducting detailed hydrology assessments was beyond the scope of the current work and fluvial model inflows have therefore been based solely off ReFH2. No statistical estimates have been produced and no hydrometric gauge analysis or assessment of previous flooding events has been completed. In addition, no critical duration testing has been undertaken however the recommended critical duration from ReFH2 has been adopted.

The same limitations regarding the LiDAR DTM age and filtering that apply to the Lower Waveney modelling, described in Section 3.2.1, also applies to the Gillingham fluvial and tidal modelling.

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