Fens 2100+

Lower Welland

Flood risk baseline

2025

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Glossary of Terms

- **AIMS** – Asset Information System - An Environment Agency hosted database of information on Environment Agency assets, as well as some other key RMA assets.
- **AOD** – Above Ordnance Datum - Referring to an altitude above a localised mean sea level.
- **BRC** - Below Required Condition.
- **Cumecs –** is the SI unit of volumetric flow rate and are equivalent to cubic meters per second (m^3/s).
- **FCERM** – Flood and Coastal Erosion Risk Management.
- **The Fens** – In the context of Fens 2100+, the combined catchments of the Witham, Lower Welland, Lower Nene, Great Ouse and Steeping, including land with an elevation at or below 6m AOD.
- **Flood risk** - A combination of the probability and the potential consequences of flooding. This includes risks from various sources such as rivers, the sea, direct rainfall, rising groundwater, overwhelmed sewers, and reservoirs
- **IDB -** Internal Drainage Board - A public body that manages water levels in an area, known as an internal drainage district.
- **LLFA** – Lead Local Flood Authority, bodies with a statutory responsibility for taking the lead operational role in managing the risk of flooding.
- **MEICA** - Mechanical, Electrical, Instrumentation, Control and Automation assets, in the context of this report relating to flood and coastal risk management (FCRM) assets.
- **NFM** – Natural Flood Management, the practice of using natural processes to reduce the risk of flooding.
- **Resilience**: The capacity of people and places to plan for, protect, respond to, and recover from flooding and coastal change. Resilience has been considered in the context of Fens 2100+ as follows:
  - Anticipate and adapt: Taking action to prepare for and adjust to both the current effects of climate change and the predicted impacts in the future, while responding to local place-based needs and ambitions.
  - Protect: Reducing the risk of flooding and coastal erosion to enhance the safety of communities and places (through investment in physical grey and green infrastructure).
  - Maintain: Co-ordinated activity to realise the whole life value from flood risk infrastructure though inspection, operational management, repair, replacement, renewal and decommissioning.
  - Respond: The ability of places and people to prepare for and react to flooding and coastal erosion in a way that results in minimal impacts to property, the natural environment and health and wellbeing.

  - Recover: The ability of places and people to rebound from flooding and coastal erosion with minimal impacts to property, the natural environment, and health and wellbeing.
  - Transform: To change and improve the way FCERM infrastructure is planned, delivered and operated to be more efficient, sustainable and resilient.
- **RMA** - Risk Management Authority - an organisation responsible by statute for flood and coastal erosion risk management.
- **RNAG** – Reasons for Not Achieving Good.
- **SoP** – Standard of Protection - The severity of flooding that something is designed to withstand, represented by the percentage chance of a certain level of flooding occurring in that year.
- **Telemetry** – is technology that enables an asset to operate without manual interaction.
- **WFD** – Water Framework Directive.
- **WLCS** – Water Level Control Structures.

1. Introduction

1.1 Aim and purpose of this document

This document presents a catchment-scale assessment of current and future flood risk for the Lower Welland catchment. Using the best available data, it presents an overview of current and future flood risk and is intended to support future choices, investments and actions for the Fens 2100+ programme (hereafter referred to as “Fens 2100+”).

1.2 Usage statement

The purpose of the document is to support strategic decision making for the Fens 2100+. This document should be read alongside the Lower Welland baseline evidence report and is intended to provide a strategic current and future flood risk baseline which will inform the development of a future asset management strategy for the Fens 2100+ programme. This document provides a proportionate level of detail required for a strategic catchment-scale baseline. It is anticipated that specific interventions will need to be supported by a more detailed study.

1.3 The Fens 2100+ study area

Fens 2100+ comprises the seven catchments of the Steeping, Lower Welland, East and West Fens, Lower Witham Fens, South Forty Foot Drain, Lower Nene and Great Ouse (see Figure 1).

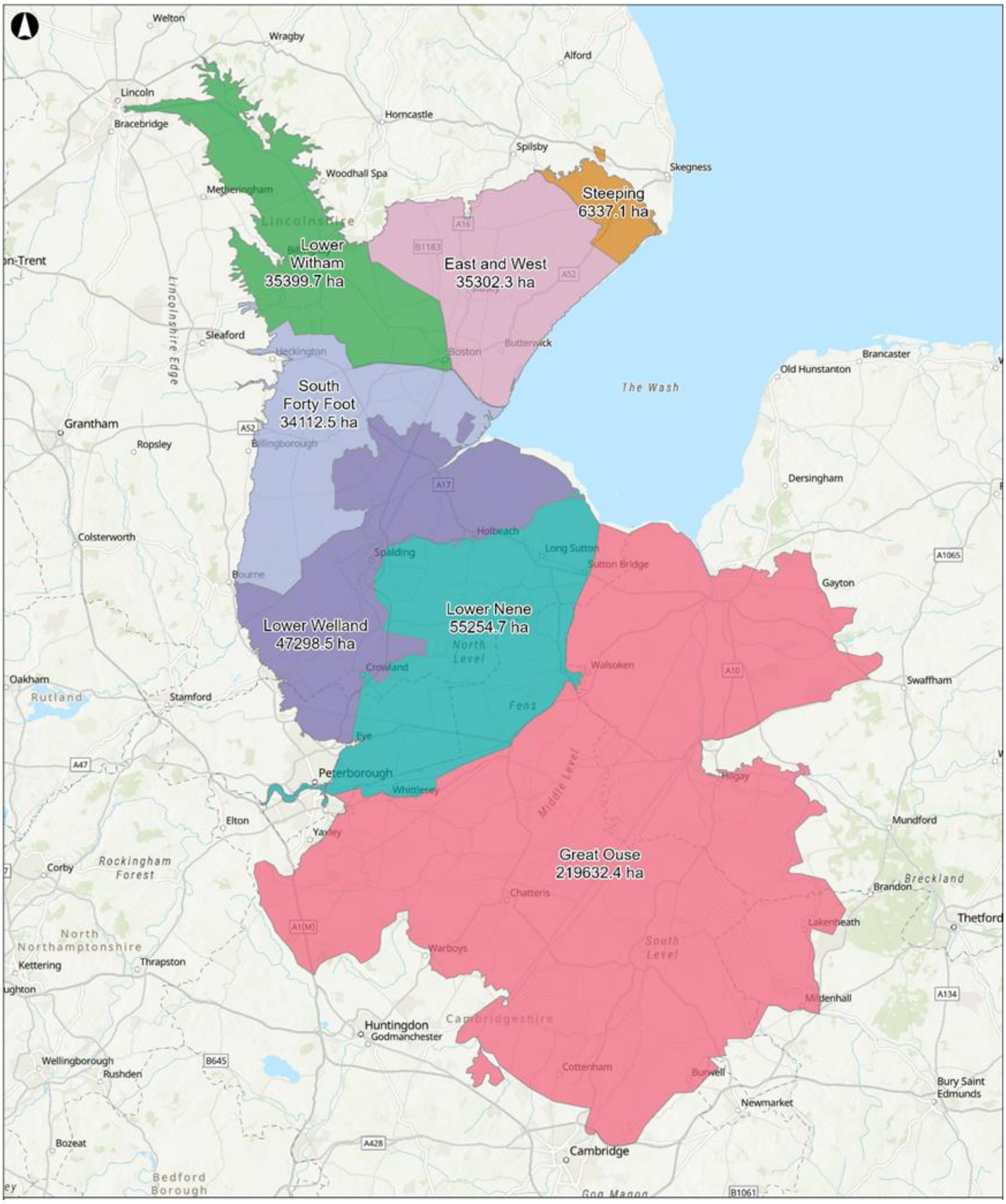


Figure 1: Fens 2100+ study area

1.4 Lower Welland catchment

The Lower Welland catchment (hereafter referred to as "the catchment") covers an area of approximately 473km^2 (47,300 ha) of primarily rural, highly productive agricultural land. The catchment is situated in East Lincolnshire at the centre of the wider Fens 2100+ study area, bordering the Lower Nene and South Forty Foot catchments.

The catchment spans from Market Deeping, around the Deeping Fens in the south-west of the catchment, to the Fosdyke Wash in the east. The reach of the River Welland encompassed by the catchment is approximately 54km long.

The Lower Welland catchment contains a complex network of low-lying drains and rivers draining across the Fens to the North Sea.

The catchment's low-lying terrain is typical of the wider Fens with most of the land lying just above sea level (approximately 3mAOD). Much of the catchment consists of reclaimed wetlands and peatlands dominated by highly productive agricultural land.

Figure 2: Aerial image of Pinchbeck Common © Chris and licenced for reuse under Creative Commons Licence

It is acknowledged that the catchment is not strictly a hydrological catchment, as there are movements of water both into and out of the area defined, that are not being considered in this report. However, the term 'catchment' has been used throughout the dialogue with the Environment Agency during establishment of the study areas and these areas are being defined for water management purposes. Therefore, the term catchment is used to describe the study area.

1.5 Catchment context

The primary watercourse within the catchment is the River Welland, which collects urban run-off from northern Peterborough before flowing north-eastwards to Spalding.

At Spalding, the artificial Coronation Channel diverts some of the flow of the Welland around the town, and the structures of Fulney Lock and Marsh Road Sluice mark the tidal limit on the two channels. The River Welland eventually discharges into The Wash a further 20km downstream of Spalding.

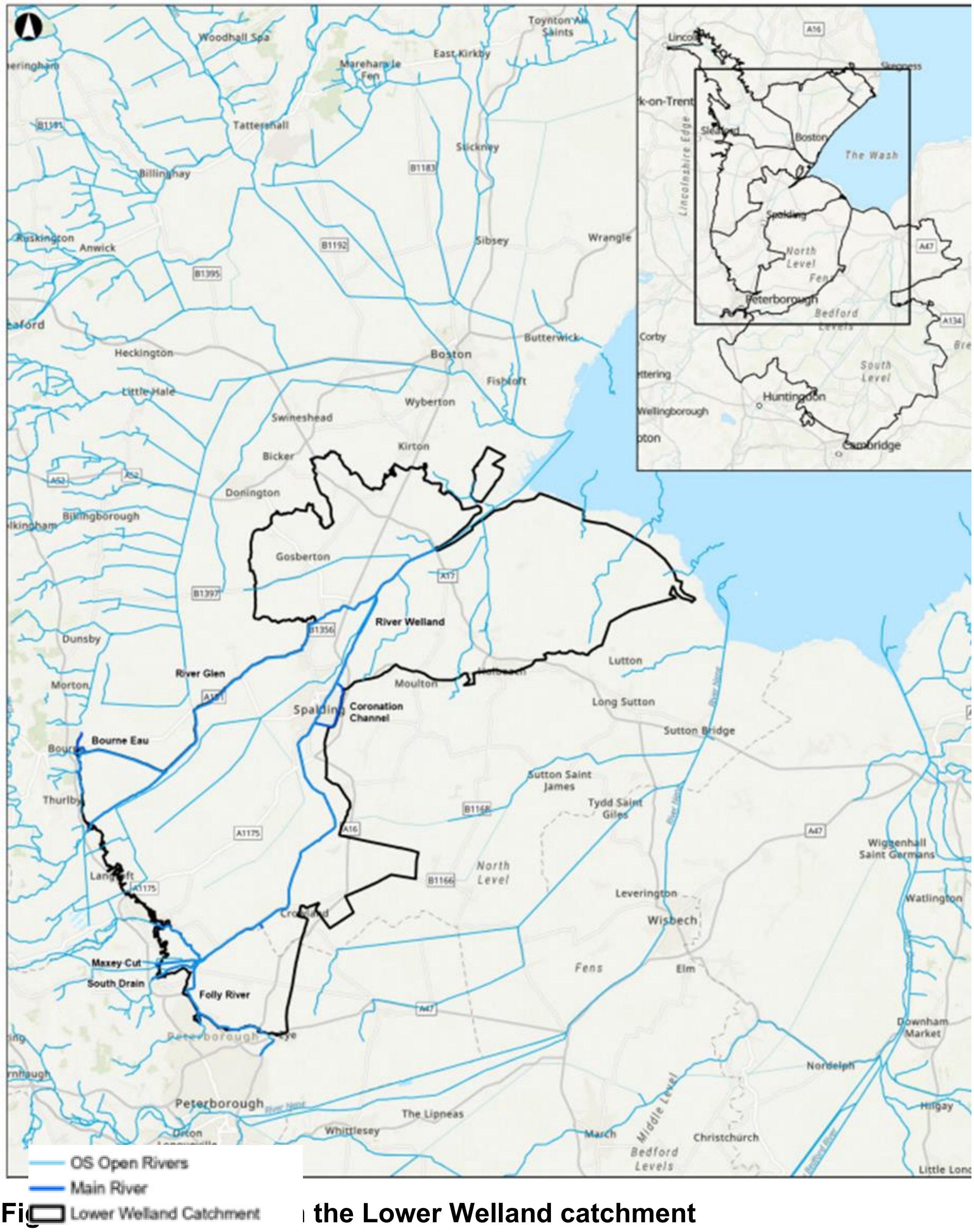
Several significant tributaries connect to the River Welland, including the River Glen and the Holbeach River. These converge with the River Welland in its tidal reach. The catchment is also drained by an extensive network of man-made drains.

These include the Vernatt's Drain, North Drove Drain, and South Drove Drain, which all carry water to the River Welland from the south-west portion of the catchment, known as Deeping Fen. Most of the pumped drainage system is managed by Welland and Deepings Internal Drainage Board, but the South Holland Internal Drainage Board manage pumping to drain land south of the River Welland, between Spalding and the coast, and North Level District IDB pump the area south and east of the Crowland and Cowbit Washes.

Many of the major components of the current catchment system were designed following the severe breach of the Crowland and Cowbit Washes in 1947. The Major Improvements Scheme that followed the flood created a connection between the upper course of the River Glen (the West Glen River) and the Welland, via the Greatford Cut. The diversions of the Welland via the straightened Maxey Cut and the Coronation Channel downstream are also artefacts of this scheme.

The River Welland is navigable 36km inland of The Wash, and the River Glen is navigable up to Tongue End, although the locks in the catchment can only be opened at certain tide levels.

The Main Rivers in the catchment are shown in Figure 3**Error! Reference source not found.**.



Fi the Lower Welland catchment

1.6 Key assets

The Lower Welland catchment contains a network of sluices, pumping stations, embankments and flood defences which work together to drain the catchment and prevent flooding.

Error! Reference source not found. gives an overview of the locations of some of the key assets. For clarity, not all assets have been included.

The proceeding sections give further details of some of these key assets. Refer to the Assets Technical Baseline Appendix for further information.

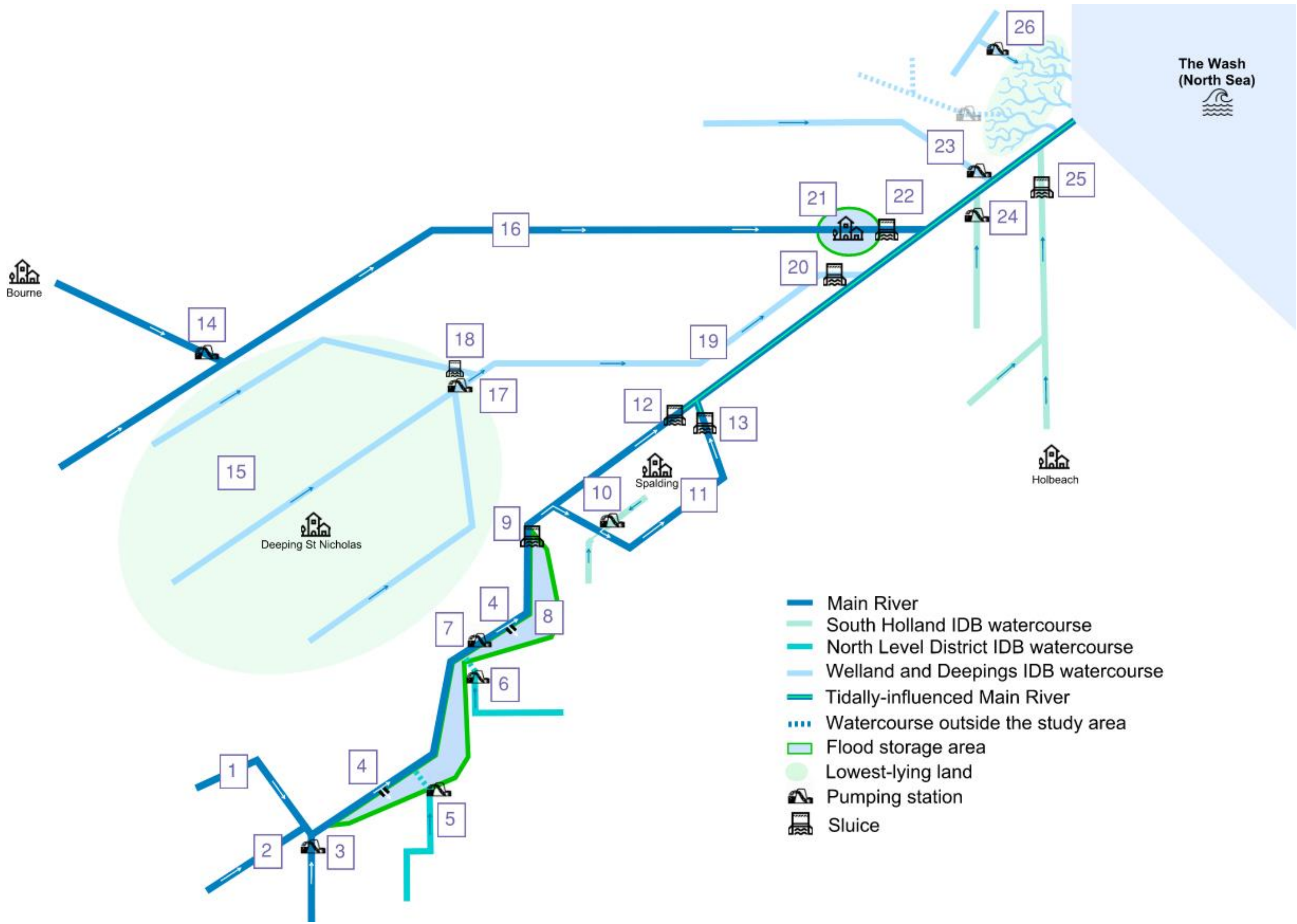


Figure 4: Lower Welland catchment overview

1 **River Welland**
Main River
Tidal as far inland as Marsh Road Sluice.

2 **Maxey Cut**
Main River
Upstream of the study area, it diverts a proportion of the River Welland's Flow, rejoining the River Welland upstream of the Crowland and Cowbit Washes.

3 **Peakirk Pumping Station**
Environment Agency
Controls the flow entering the River Welland from the Folly River, which carries water from Peterborough to the South. It marked the approximate natural tidal limit of the River Welland before Marsh Road Sluice was constructed.

4 **Cradge Bank Syphons**
Environment Agency
Newborough Syphon (upstream) and Four Mile Bar Syphon (downstream) were designed as the main inlets for water from the River Welland into the Crowland and Cowbit Washes.

5 **Newborough Pumping Station**
North Level IDB
Drains land to the south by pumping water 140m across the Washes through discharge pipelines into the River Welland.

6 **Postland Pumping Station**
North Level IDB
Drains Crowland and land to the south by pumping water 90m across the Washes through discharge pipelines into the River Welland.

7 **Crowland and Cowbit Pumping Station**
Welland and Deepings IDB
Lifts water from drainage channels in the Washes back into the River Welland.

8 **Crowland and Cowbit Washes**
Environment Agency & Partners
Registered under the Reservoirs Act 1975, the Washes function as a flood storage area, with the EA acting as Undertaker. If flows in the River Welland are exceptionally high, water can overtop the Cradge Bank and spill into the Washes, which are contained on the outer edge by the Barrier Bank.

9 **Locks Mill Sluice**
Environment Agency
If the Washes are filled with water, this sluice allows water to flow back into the River Welland once river levels have lowered.

10 **Clay Lake Pumping Station**
South Holland IDB
Pumps water from Spalding and an area to the south into the Coronation Channel.

11 **Coronation Channel**
Main River
This bypass channel conveys the majority of the River Welland's flow around the southern edge of Spalding.

12 **Fulney Lock**
Environment Agency
Sets the tidal limit of the River Welland. It also allows navigation but is rarely used for this purpose.

13 **Marsh Road Sluice**
Environment Agency
Sets the tidal limit of the Coronation Channel.

14 **Bourne Eau Pumping Station**
Environment Agency
Lifts water coming from Bourne via the Bourne Eau upwards into the River Glen.

15 **Deeping Fen**
A particularly low-lying area in the south-west of the catchment.

16 **River Glen**
Main River
Between its confluence with the Bourne Eau and the village of Surfleet, it marks the northern boundary of the Welland catchment.

17 **Pode Hole Pumping Stations**
Welland and Deepings IDB
Deeping St Nicholas Pumping Station and Adventurers Pumping Station lift water from from the North Drove Drain and South Drove Drain into the Vernatts Drain.

18 **Pode Hole Pointing Doors**
Welland and Deepings IDB
Prevent water which has been pumped through Pode Hole Pumping Station from flowing back up the Counter Drain towards Market Deeping.

19 **Vernatts Drain**
Welland and Deepings IDB
Carries water from Deeping Fen towards its outfall at Surfleet Sluice.

20 **Vernatts Sluice**
Welland and Deepings IDB
Marks the tidal limit of the Vernatts Drain, and allows water to flow out of the drain into the Welland at low tide.

21 **Surfleet Reservoir**
Environment Agency
The reservoir was originally constructed to store water to flush silt accumulating at Surfleet Sluice. The embankments prevent flooding of surrounding fenland. The reservoir is unusual in that there are now residential properties situated within the storage area.

22 **Surfleet Sluice**
Environment Agency
Marks the tidal limit of the River Glen and allows navigation.

23 **Risegate Eau**
Welland and Deepings IDB
Carries water from Gosberton to the River Welland. It is pumped into the River Welland by Risegate Eau Pumping Station.

24 **Lord's Drain Pumping Station**
South Holland IDB
Pumps water from Lord's Drain into the River Welland.

25 **Holbeach River Sluice**
South Holland IDB
Sets the tidal limit of the Holbeach River and controls the discharge of water into the River Welland.

26 **Kirton and Frampton Marsh Pumping Station**
Welland and Deepings IDB
Pumps water from the isolated section of the catchment into the coastal saltmarsh, where it can drain into The Wash.

1.6.1 Sluices

1.6.1.1 Surfleet Sluice

Surfleet Sluice consists of two sets of gates positioned in parallel and adjacent to one another (Figure 5). One set of gates faces the catchment, called the 'fluvial gates', which control the level of the River Glen upstream. The second set of gates faces the tidal River Glen and controls the flow of water from the tidal river into the catchment, thus marking the tidal limit of the River Glen. It is owned and managed by the Environment Agency. The vertical gates were operated manually until 2016 when the attendant retired. In 2018, the Environment Agency automated it[1].

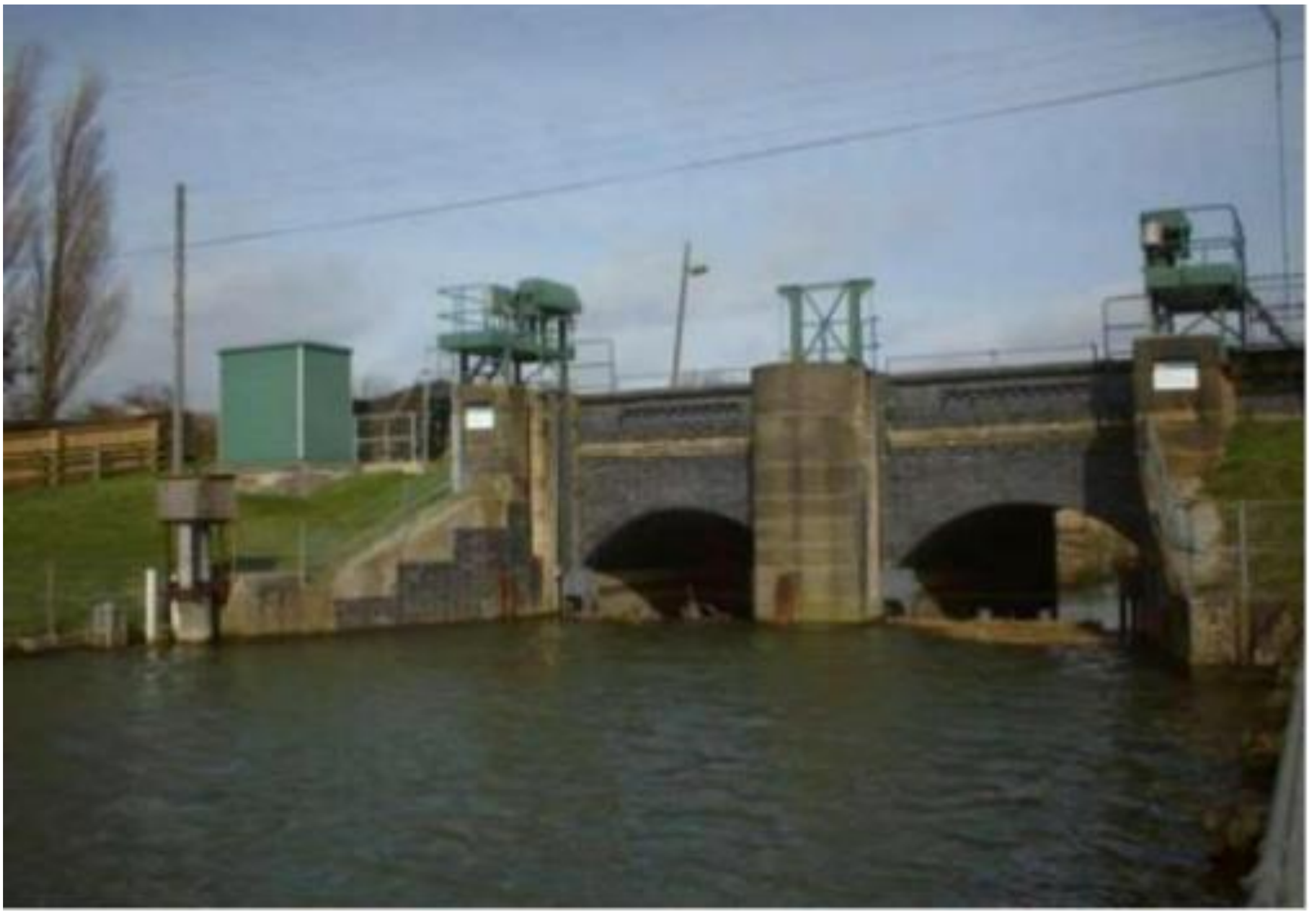


Figure 5: Upstream (reservoir) side of Surfleet Sluice © Environment Agency

1.6.1.2 Vernatt's Sluice

Vernatt's sluice sits at the downstream end of Vernatt's Drain and sets the drains tidal limit. It is therefore the terminal point of the channel which has come from Pode Hole. Vernatt's Sluice consists of three arches, each 5m high and 3m wide. Beneath the waterline is timber decking that sits up to the point where it meets the sheet piling on the bank. The purpose of the timber boards is to reduce scour of the waterway bed. It is noted to be a critical asset in the IDB system. It's owned by Welland and Deepings Internal Drainage Board(WDIDB).

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[1] Environment Agency (2019) Surfleet Reservoir Flood Risk Management Initial Assessment.

1.6.1.3 Fulney Lock

Fulney Lock is a navigation lock which also sets the tidal limit of the River Welland (see Figure 6). The purpose of it is to protect Spalding from coastal flooding due to a high tide or a high tide combined with a storm surge. It consists of a single set of pointing doors that close on incoming pressure from the tide. It was noted that in 2013, there was a significant tidal surge that reached the top of the walls that sit higher than the level of the doors.

Figure 6: Fulney Lock © Arup

1.6.1.4 Marsh Road Sluice

Marsh Road Sluice is owned by the EA and consists of sets of vertical doors that manage the fluvial levels upstream, and a set of tidal doors (on The Wash/ downstream side of the sluice) that control tidal levels. The doors controlling the tidal levels are cycloidal doors that work on the pressure of the tide.

1.6.1.5 Locks Mill Sluice

Locks Mill Sluice comes into operation when the Crowland and Cowbit Washes are filled during a storm event (see Figure 7 and Figure 8). The sluice is used to drain the Washes once the river water levels have receded[2]. This structure has a limit on what can be drained through gravity, as after the sluice was installed ground levels in the Washes have sunk, and when necessary, pumps are brought to boost the flow of water from the Washes into the River Welland. It is owned by the Environment Agency.

Figure 7: New River Drain from the Locks Mill Sluice © Environment Agency

[2] Environment Agency (2024) Crowland and Cowbit Washes Strategic Outline Case Support

Figure 8: Locks Mill Sluice on Welland Side[3]

1.6.1.6 Holbeach River Sluice

Holbeach River Sluice sets the tidal limit of the Holbeach River and controls the discharge of water into the River Welland. It is owned by the South Holland IDB (SHIDB).

1.6.2 Pumping Stations

Peakirk Pumping Station is located to the southeast of the catchment and is managed by the Environment Agency. All the water in the North region of Peterborough converges at the point where Peakirk Pumping Station is located. Water flows to this point from the south through Brook Drain, Folly River and Car Dyke. These then become the River Welland to the east of Peakirk. It was constructed in 1986.

Clay Lake Pumping Station was originally built in 1971 to address drainage issues in Spalding. It pumps water from the Exeter Drain catchment into the Coronation Channel which eventually reaches the River Welland. The Exeter Drain serves catchments to the north and south of the Coronation Channel which are linked by a culvert under the Coronation Channel. It consists of two pumps, with 0.85 cumecs per pump, and was commissioned in 2014 and is owned by SHIDB.

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[3] Environment Agency (2024) Crowland and Cowbit Washes Strategic Outline Case Support

Lords Pumping Station and Drain has a pumping station and sluice operating at the site. During normal operation, 95% of the water goes through the sluice and the pumping station is used in wet periods. This site drains the Lords catchment and discharges into the tidal River Welland. It consists of two pumps, with 1.42 cumecs per pump. It was commissioned in 1963 and refurbished in 2023. It's owned by SHIDB.

Lawyers Pumping Station discharges onto The Wash. It consists of three pumps, with 1.40cumecs per pump. The sluice which was originally here was replaced by a pumping station in 2013. It's owned by SHIDB.

Pode Hole Pumping Station is the largest of WDIDB's pumping stations. Consisting of two pumping stations on one site, they have a total capacity of 21.79 cumecs. It lifts water from North Drove Drain, South Drove Drain, and from the area west of Spalding into Vernatt's Drain. The electrically powered pumping by Pode Hole meets normal levels of demand and is controlled automatically through telemetry. The diesel pumps are generally only required to operate during periods of high flow, which in recent years has been around 21 days per year. Deeping St Nicholas was constructed in 1964, and Pode Hole Adventurers in 1957.

Crowland and Cowbit Pumping Station lifts water from drainage channels in the Washes back into the River Welland.

1.6.3 Reservoirs

The Surfleet Reservoir was constructed in 1739 to store water in tide locking situations, as well as to allow flushing to avoid siltation. Tide locking is becoming more common due to climate change and therefore the reservoir is at increasing risk of flooding. There are around 40 properties within the reservoir area which started as temporary holiday properties but are now lived in year-round (see Figure 9).

Figure 9: Surfleet Reservoir

The Crowland and Cowbit Washes Flood Storage Reservoir (FSR) is an offline storage reservoir extending for around 19km alongside the River Welland between Peakirk and Spalding. If flows in the River Welland are exceptionally high, water can overtop the Cradge Bank and spill into the Washes which are contained on the outer edge by the Barrier Bank (see Figure 10 and Figure 11). These Washes are drained by a network of channels which are pumped into the River Welland by the Welland and Deeping IDB pumping station, located at Four Mile. However, if the Washes are filled by a storm, they can be drained by Locks Mill Sluice downstream.

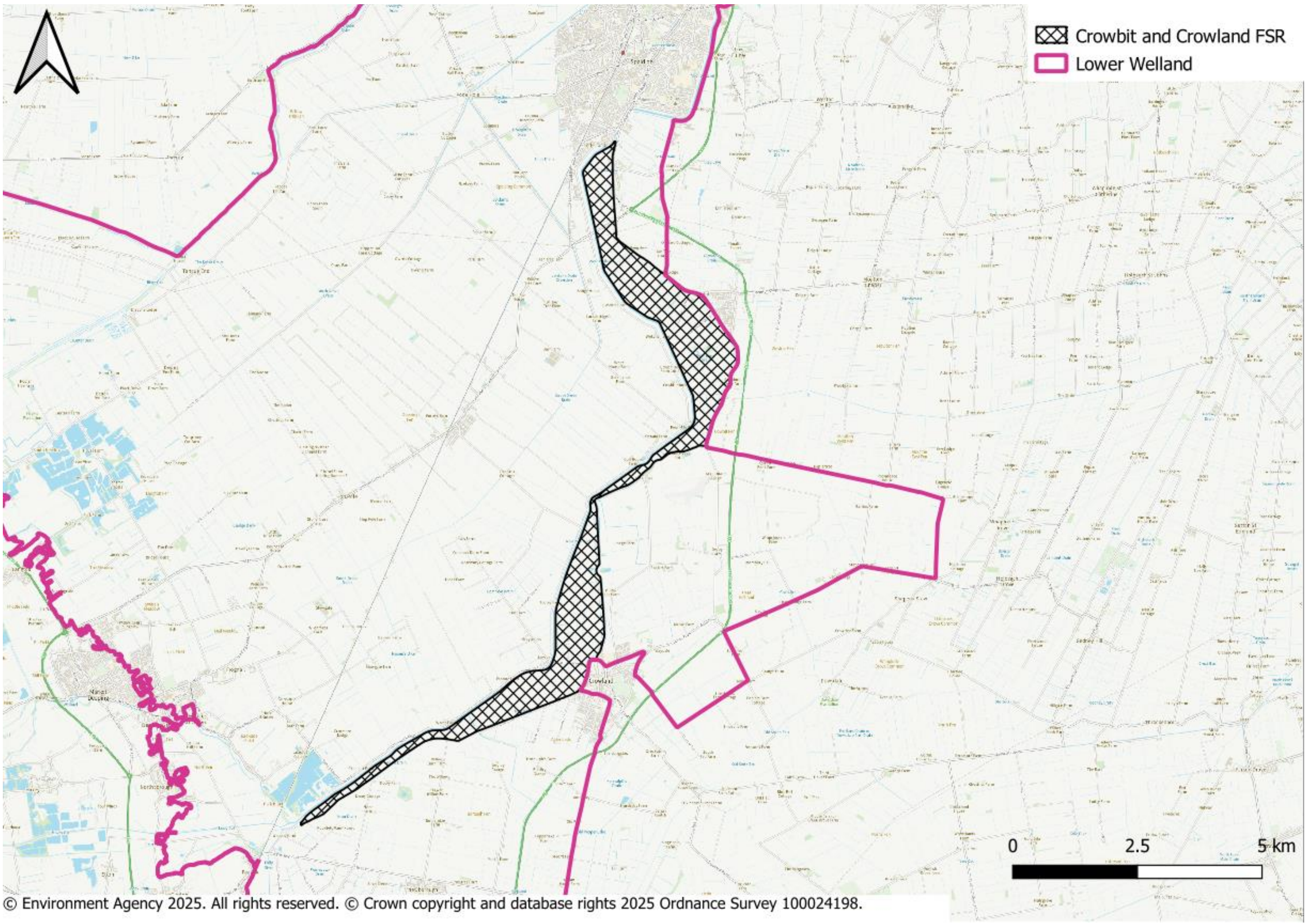

Figure 10: Location of Crowland and Cowbit Washes Flood Storage Reservoir © Environment Agency

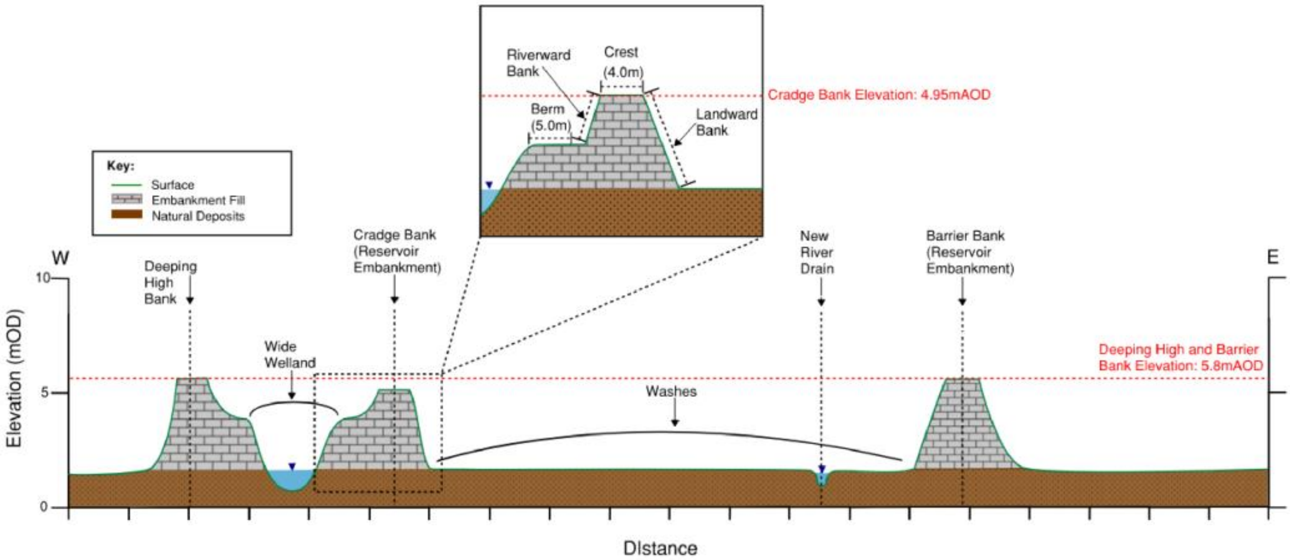

Figure 11: Schematic cross-section of the Crowland and Cowbit Washes Flood Storage Reservoir © Environment Agency

1.6.4 Embankments

Deeping High Bank, Cradge Bank and Barrier Bank are key Environment Agency managed embankments which contain the River Welland. Locations of Environment

Agency owned, operated or maintained embankments in the Lower Welland catchment are shown in **Error! Reference source not found.**.

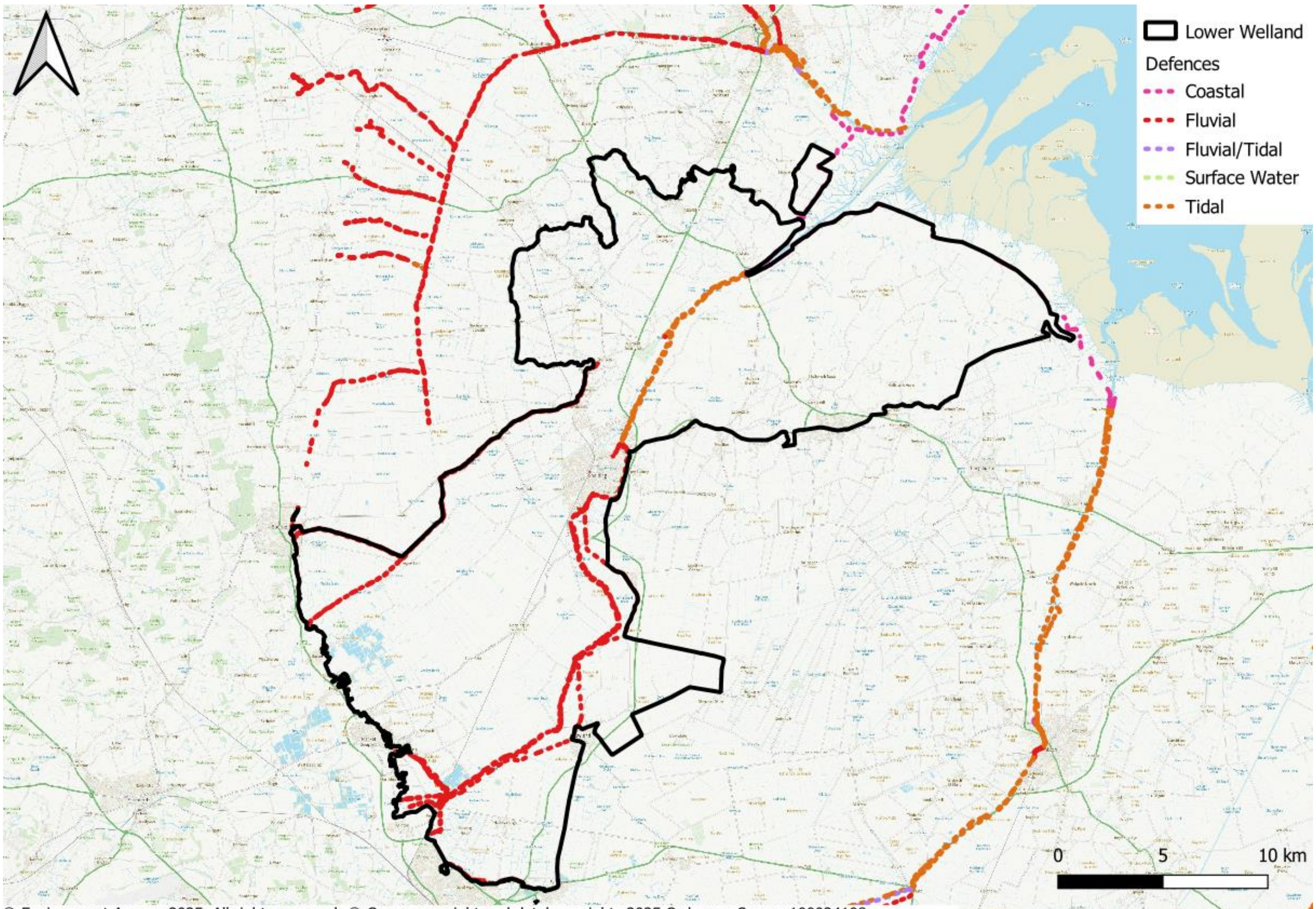

Figure 12: Locations of Environment Agency owned, operated or maintained embankments within the Lower Welland catchment

1.6.5 Siphons

The Crowland and Cowbit Washes are fed by two siphons located along Cradge Bank: The Newborough and Four Mile Bar Siphon. The Newborough Siphon (Figure 13) discharges water into the Crowland Wash and the Four Mile Bar Siphon discharges into the Cowbit Wash. They were constructed in 1974 but have not been used as water overtops Cradge Bank before either of the siphons is fully primed[4].

[4] Environment Agency (2024) Crowland and Cowbit Washes Strategic Outline Case Support

Figure 13: External view of the Newborough Siphon © Environment Agency

2. Notable flood history

A number of flood events have impacted the Lower Welland catchment. These events have been summarised in the proceeding sections. Information on flood history has come from a number of sources, including:

The Environment Agency, in the form of:

- Recorded flood outlines (GIS files) and,
- Reports:
  - Surfleet Reservoir Flood Risk Management Initial Assessment (2019);
  - Crowland and Cowbit Washes Strategic Outline Case Support (2024);
  - River Welland Hydraulic Modelling Report (2016)

A Lincolnshire council report;

- Joint Lincolnshire Flood Risk and Water Management Strategy 2019-2050 (2019).

And information from online archives and news articles;

- South Holland Heritage;
- Peterborough Images Archive;
- Lincolnshire Live;
- Lincs Online.

2.1 January 1947

In 1947 major flooding occurred, triggered by the mass thawing of ice across the catchments combined with a storm event. The combined effect of melting snow and rain amounted to up to 4.5 inches (114.3mm) - the equivalent of a 24 hour long heavy thunderstorm[5].

The first breach occurred on the River Glen near the old Counter Drain station and flooded the Tongue End washes.

Two days later, a 50-yard-wide (45.72m) breach, shown in Figure 16, formed in the North Level Barrier Bank on the side of the Cowbit Wash between Brotherhouse Bar and Crowland, leading to severe and sudden flooding[6]. The subsequent flood water surrounded Crowland, as shown in Figure 14 and Figure 15.

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[5] South Holland Heritage (2023) Floods couldn't defeat South Holland's Spirit – Memories of 1947 Flood. Available at: https://www.heritagesouthholland.co.uk/article/floods-couldnt-defeat-south-hollands-spirit-memories-1947-flood/ Accessed: March 2025

[6] South Holland Heritage. 1947 Floods. Available at: https://www.heritagesouthholland.co.uk/article/1947-floods/. Accessed: March 2025

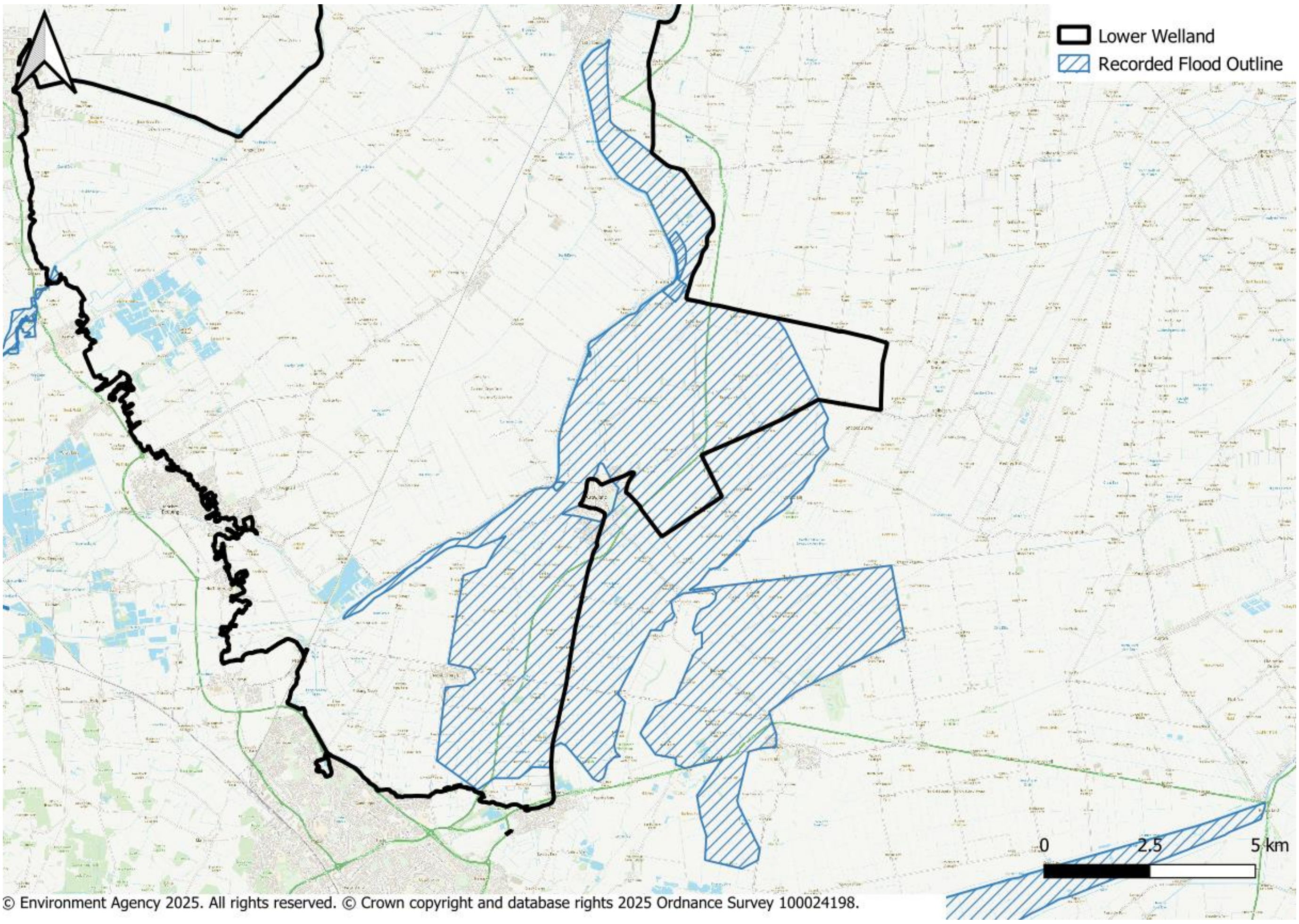

Figure 14: 1947 Recorded flood extent

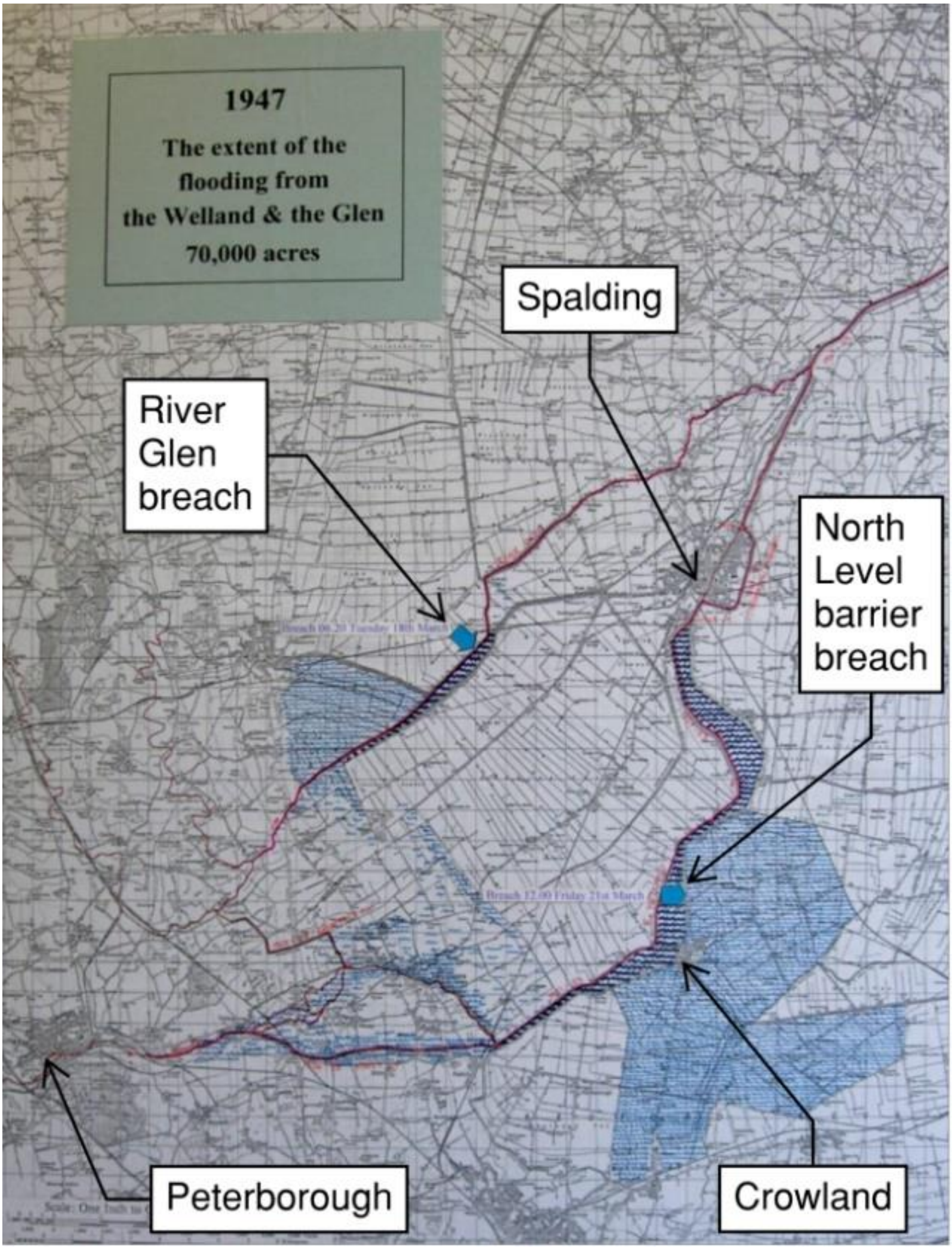

Figure 15: Diagram of 1947 Flooding Extent © South Holland Heritage

Figure 16: **Historical photograph of the Barrier Bank breach following the flooding event of 1947 © Peterborough Images Archive**

2.2 February 1994

In February 1994 there was out-of-bank flooding of the River Glen at Surfleet Reservoir. Images, such as that shown in Figure 17, from the event show properties on the left bank experiencing flooding.

Figure 17: Photo of River Glen out-of-bank at Surfleet Reservoir (1994) © Environment Agency

2.3 Easter 1998

2.3.1 Crowland and Cowbit

Overtopping of the River Welland occurred between Crowland and Cowbit in Easter of 1998 flooding farmland as shown in Figure 18. As mentioned in section 1.6.5 there are two siphons designed to discharge flows from the Wellandinto the Crowland and Cowbit Washes, however in 1998 the water overtopped the embankment before the siphons were fully primed[7] (see Figure 19 & Figure 20).

[7] Environment Agency (2024) Crowland and Cowbit Washes Strategic Outline Case Support

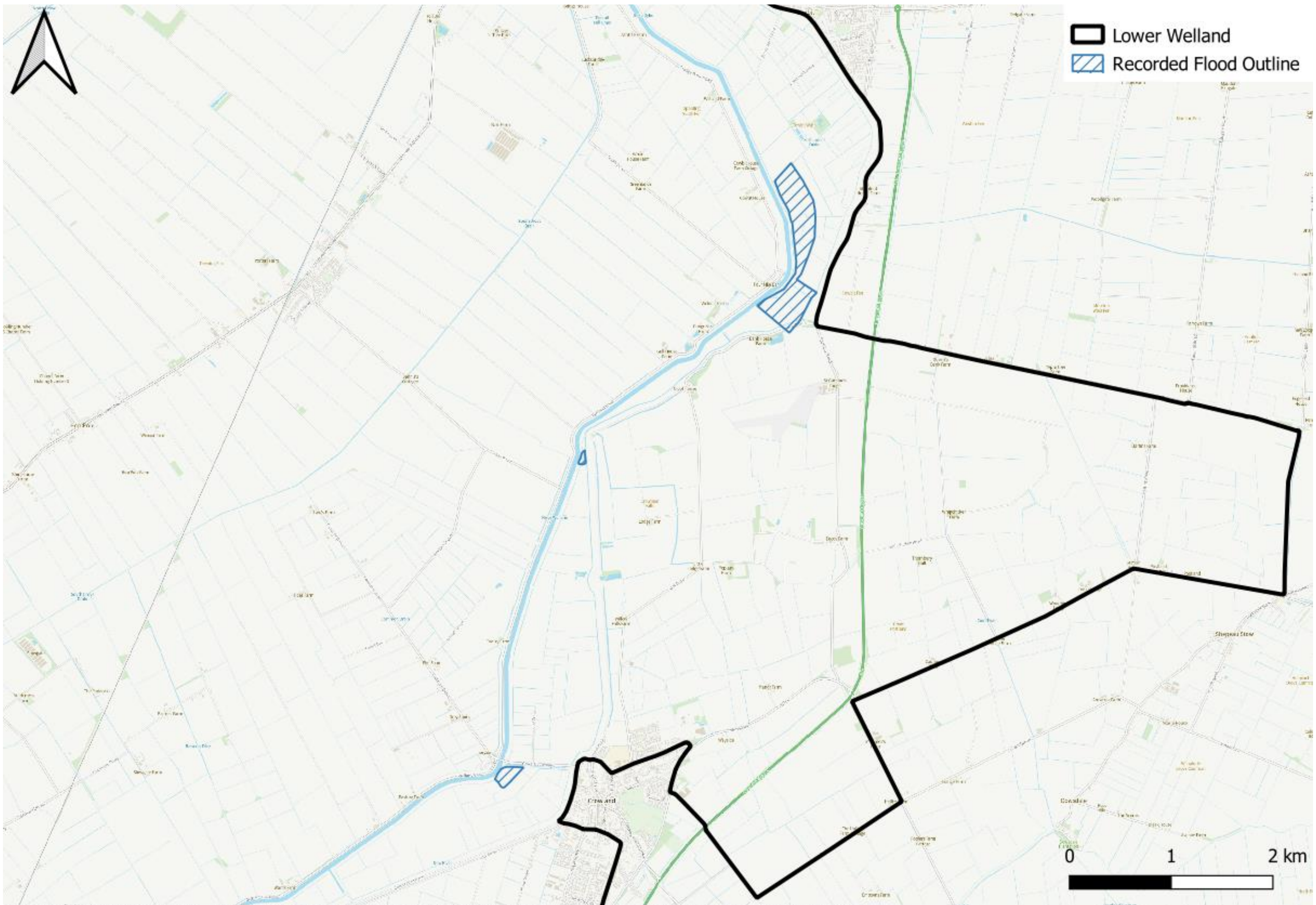

Figure 18:1998 flood extent

Figure 19: Overtopping of Cradge Bank during the 1998 flooding event © Environment Agency

Figure 20: Four Mile Bar Siphon not fully primed during the 1998 flooding event Environment Agency

2.3.2 Surfleet Reservoir

Localised flooding was also recorded at Surfleet Reservoir, impacting a number of properties, as shown in Figure 21.

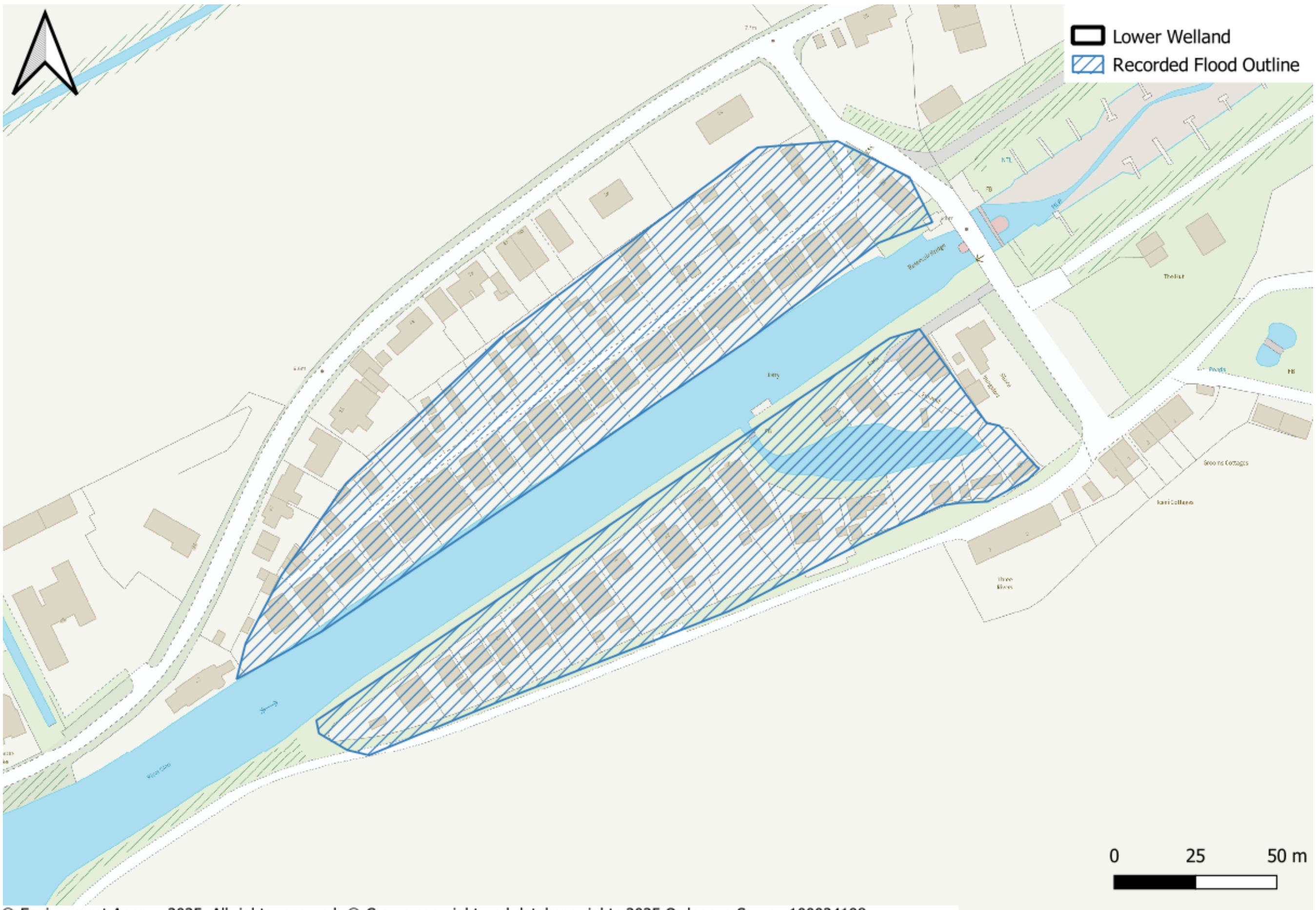

Figure 21: Localised flooding at Surfleet Reservoir 1998 © Environment Agency

2.4 April 2018

Heavy rainfall over the River Glen catchment and high tides led to the flooding of the gardens of some properties at the Surfleet Reservoir (Figure 22).

Figure 22: Flooded gardens at Surfleet Reservoir April 2018 © LincsOnline

2.5 December 2020

A representative of the IDB observed flooding which overtopped and seeped through the Cradge Bank and the Crowland and Cowbit Washes. Some water overtopped the siphons, but they did not fully prime. Agricultural land was flooded, but there was no flooding to property. Flows were the highest recorded since 1998.

2.6 January 2021

In January 2021, a number of properties were flooded at Surfleet Reservoir due to a combination of high tides and pumped water from the Bourne Eau system (Figure 23).

Figure 23: Flooding at Surfleet Reservoir January 2021 © LincsOnline

2.7 January 4th 2024

Storm Henk caused flooding in the catchment, as rain fell on already-saturated ground. The River Welland breached its banks into the Crowland and Cowbit Washes. This resulted in the flooding of agricultural land in the catchment (Figure 24). It was the first time the Crowland and Cowbit Washes had stored a significant volume of water since the scheme was constructed.

Figure 24: River Welland breach near Cowbit and Crowland © Lincolnshire Live

2.8 Other events

The flood events detailed in the preceding sections detail the flood history of the catchment where records have been found. Recorded flood history is likely to be biased towards flooding that impacts properties.

It is expected that there will be more instances of flooding of agricultural land that have not been recorded.

2.9 Discussion

There are no records of tidal flooding in the Lower Welland catchment.

The fluvial flood history suggests that the main high risk flood locations are the Crowland and Cowbit Washes, and Surfleet Reservoir.

2.9.1 Crowland and Cowbit Washes

A number of flood events have occurred on the banks of the River Welland in the vicinity of the Crowland and Cowbit Washes. The first significant recorded event in 1947 resulted in extensive flooding with flood waters surrounding and almost cutting off the town of Crowland. Additional minor flooding events were also recorded in 1998, 2020 & 2024. It is important to note that the Washes are designed to flood, and that this prevents a wider area from flooding. Prior to the construction of Major Improvements Scheme the Crowland and Cowbit Washes used to regularly flood.

2.9.2 Surfleet Reservoir

There are around 40 properties within the reservoir area. These have experienced flooding on a number of occasions including 1994, 1998, 2018 and 2021, due to a combination of high river levels and tidal locking.

3. Methodology and data review

3.1 Methodology

The methodology used in this assessment is to use best available information (i.e. no new modelling work has been undertaken for this study) to document both current and future flood risk and has been agreed with the Environment Agency. This assessment has been informed by a review of the existing hydraulic modelling and engagement with the relevant Environment Agency teams.

The proceeding sections detail the existing datasets used to determine the baseline flood risk in the Lower Welland catchment.

3.2 Detailed hydraulic modelling

A review of all detailed models in the Fens 2100+ was undertaken. The review found that in the Lower Welland catchment, there were three models that could be used to describe flood risk and which a number of metrics could be extracted from:

- 2016 Welland Catchment Strategic Model Study, of which the following models were used:
  - Bourne Eau Fluvial Model; and
  - Welland-Glen Fluvial Model;
- 2010 Northern Area Tidal Modelling.

These models are described in more detail in the proceeding sections.

The 2011 Tidal Welland model was considered, however was discounted for use within this project as it was a tidal breach model only and would not provide a suitable representation of current and future flood risk.

3.2.1 Bourne Eau Fluvial Model

In 2016, Mott MacDonald, on behalf of the Environment Agency developed a 1D-2D MIKE FLOOD model of the Bourne Eau, a tributary of the River Glen as part of the Welland Catchment Strategic Model Review and Update project. The model includes the Bourne Eau and its two tributaries, Car Dyke South and Car Dyke North as well as the surrounding floodplain (Figure 25).

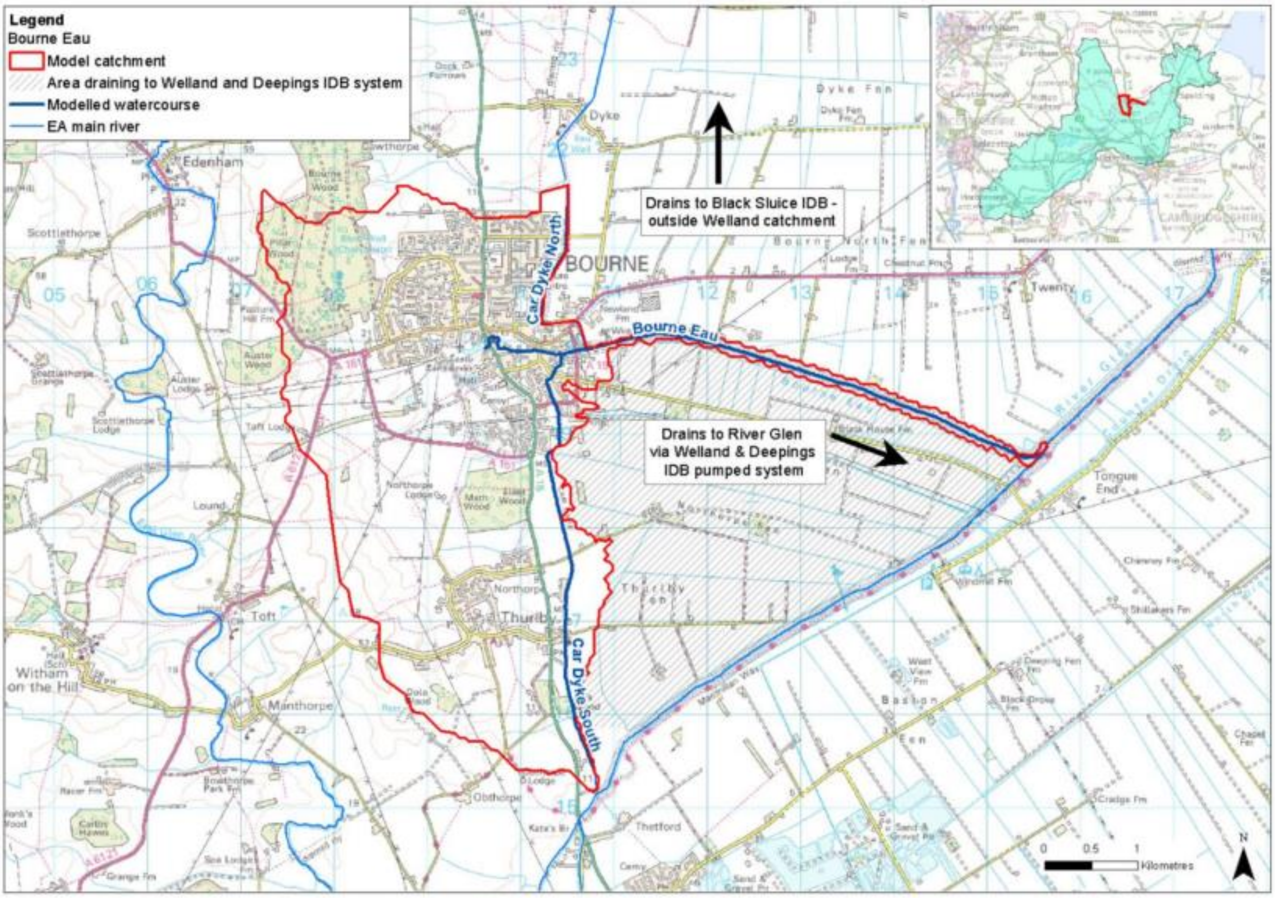

Figure 25: Bourne Eau model study area © Mott Macdonald

The model simulated defended and undefended scenarios for a range of fluvial events (50% AEP, 20% AEP, 10% AEP, 5% AEP, 3.33% AEP, 2% AEP, 1.33% AEP, 1% AEP, 1% AEP + climate change, 0.5% AEP, 0.01% AEP & 0.01% AEP + climate change). For the climate change scenarios, a 20% uplift in peak flow has been applied.

ReFH rainfall-runoff methods were used as there are no flow gauges in the catchment, only level gauges, therefore there is a high degree of uncertainty in the model[8].

3.2.2 Welland-Glen Fluvial Model

In 2016, Mott MacDonald, on behalf of the Environment Agency, updated a 1D defended MIKE FLOOD models of the River Welland-Glen system as part of the Welland Catchment Strategic Model Review and Update project. As shown in Figure 26, the model extends from Market Harborough to The Wash. Though the defended model is 1D only, the undefended model (which includes the undefended Bourne Eau model) is partially 2D in the lower catchment.

[8] Mott MacDonald (2016) Welland Catchment Modelling Update Volume 15, Bourne Eau Hydraulic Modelling Report

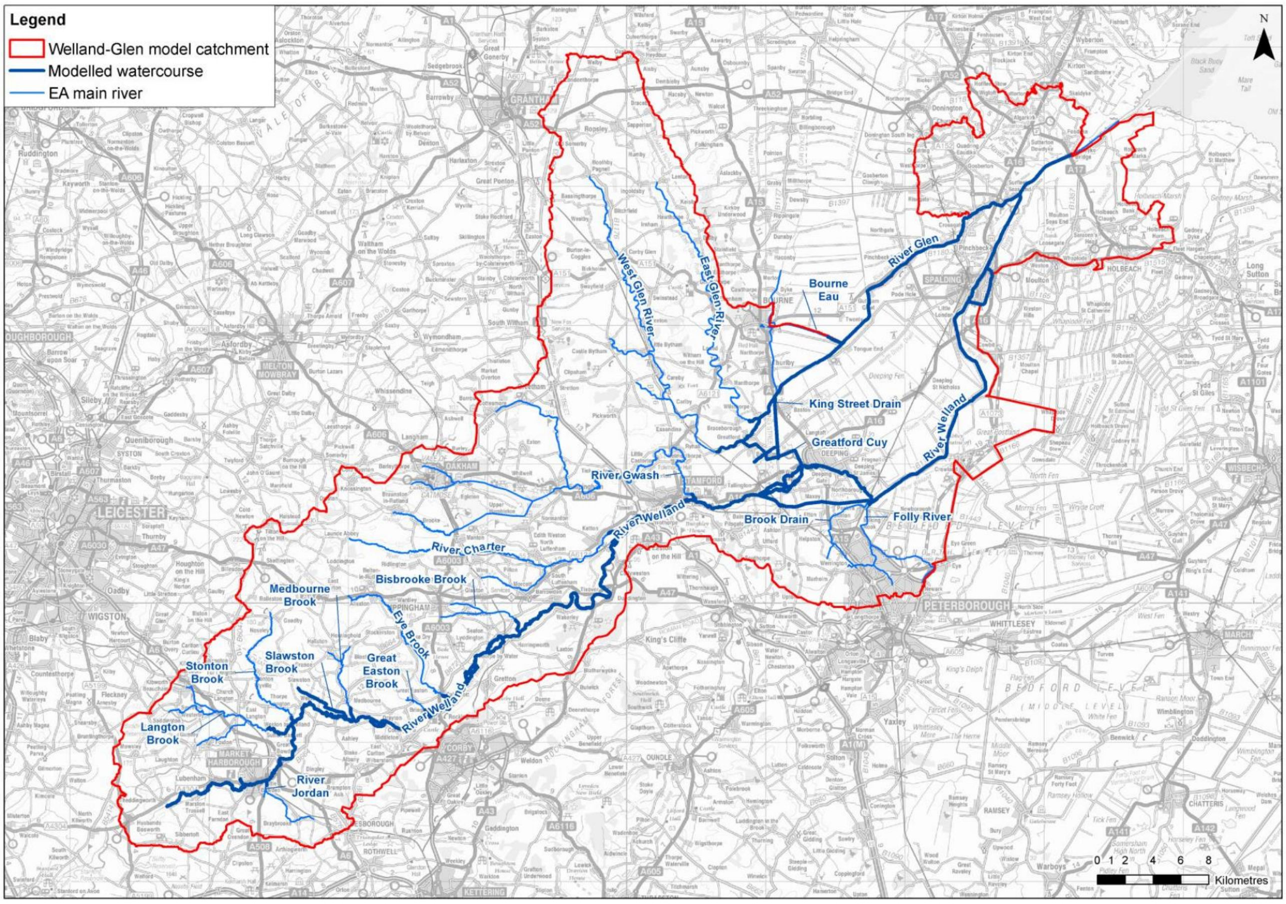

Figure 26: Welland-Glen model study area, extracted from the River Welland Hydraulic Modelling report © Mott Macdonald

The model simulated defended and undefended scenarios for a range of fluvial events (50% AEP, 20% AEP, 10% AEP, 5% AEP, 3.33% AEP, 2% AEP, 1.33% AEP, 1% AEP, 1% AEP + climate change, 0.5% AEP, 0.01% AEP & 0.01% AEP + climate change). For the climate change scenarios, a 20% uplift in peak flow has been applied.

An average spring tidal range has been incorporated within the hydraulic model, but no assessment of flooding from tidal surges has been carried out.

3.2.3 Northen Area Tidal Modelling

In 2010, Mott MacDonald, on behalf of the Environment Agency undertook tide, surge and wave analysis of the coastline from the Humber to The Wash. The results from this analysis were then input into a 2D TUFLOW model of the same area to understand the flood risk. The study area for the modelling is shown in Figure 27.

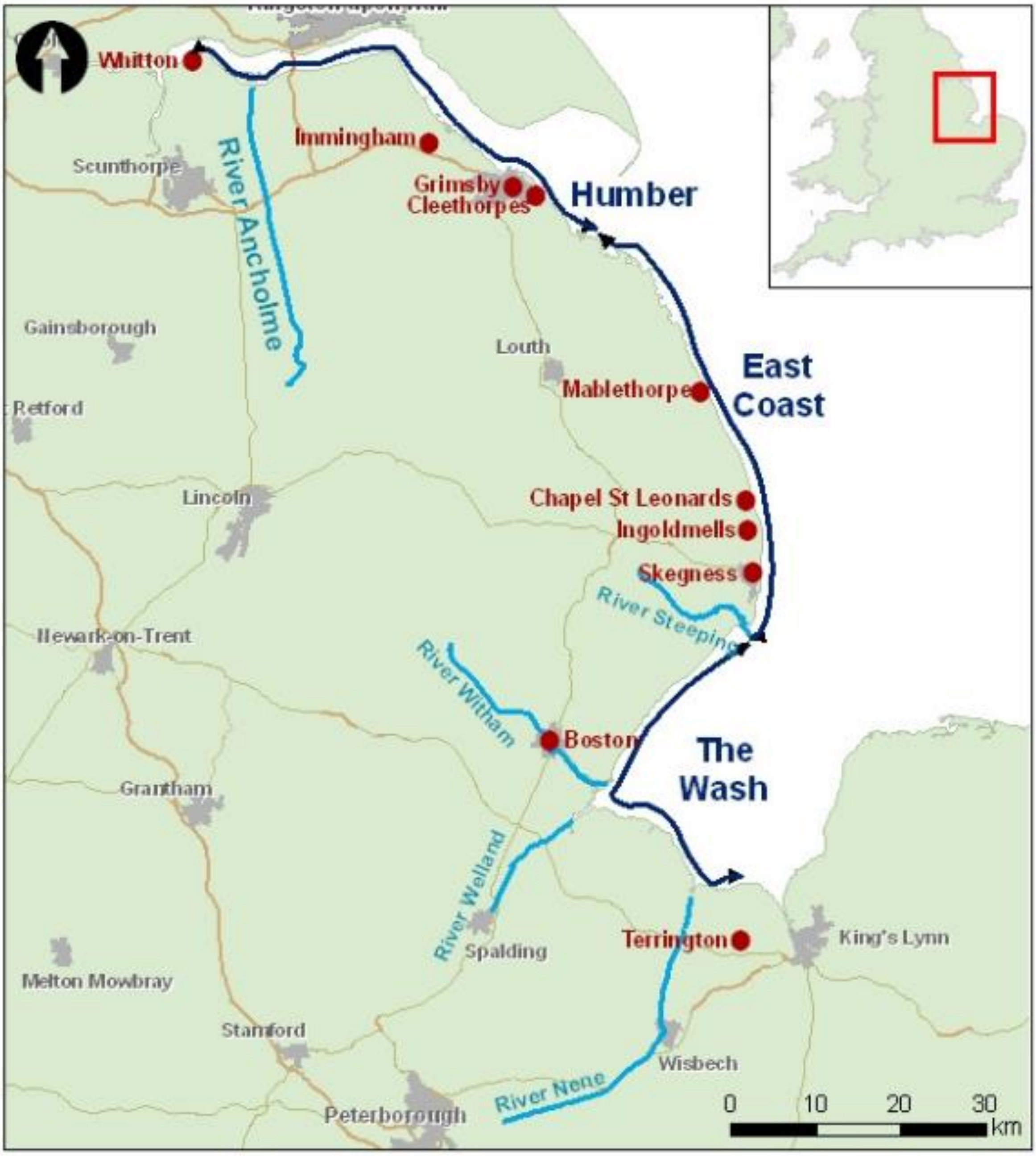

Figure 27: Northen Area Tidal Modelling study area, extracted from the Northern Area Tidal Modelling report.

As part of the inundation modelling, defended and undefended scenarios were undertaken.

The modelling only assessed tidal flood risk - no representation of fluvial flooding has been undertaken as part of this modelling study.

As part of the same study, a detailed analysis of the wind and wave conditions in the study area was undertaken. This established the 1 in 1 year wave conditions (wave overtopping that would be expected every year) and used in the TUFLOW inundation modelling. For the climate change scenarios, a 10% uplift was applied to wave inflows.

Figure 28 details the events undertaken as part of the Northern Area Tidal Modelling study.

Water Level - Event Scenario	Water Level - Annual Exceedance Probability	Wave Condition	Present Day (2006)	Climate Change (2115)
1 in 10	10%	1 in 1 annual chance	Humber and East Coast models and for internal use only.	x
1 in 75	1.3%	1 in 1 annual chance	√	x
1 in 100	1%	1 in 1 annual chance	√	x
1 in 150	0.7%	1 in 1 annual chance	√	x
1 in 200	0.5%	1 in 1 annual chance	√	√
1 in 1000	0.1%	1 in 1 annual chance	√	√

Figure 28: Events modelled as part of the 2010 Northern Area Tidal Modelling © Environment Agency

An update of the coastal modelling is currently in progress and is due to be delivered in March 2026.

3.2.4 Limitations

The following limitations are associated with the data:

- All three models were developed for Environment Agency – therefore are focussed on flooding from tidal and Main River sources, as such the representation of flooding from drainage ditches is likely to be simplistic of not represented at all.

3.2.5 Bourne Eau Fluvial Model

- There was no detailed banktop survey between the surveyed cross sections. Therefore, linear interpolation was required to determine if out of bank flooding occurs. There was no flow gauge in the catchment, and limited level data available for model calibration and verification.
- Limited observed rainfall data was available for model calibration.

3.2.6 Welland-Glen Model

- The Welland-Glen model did not include an assessment of joint probability for fluvial and tidal variables. Water levels in the lower reaches of the River Welland and Glen may be more sensitive to tidal events.
- Detailed bank-top survey to determine out of bank spills, was not available between surveyed cross-sections, instead LiDAR levels are used.
- The gauges within the catchment have a record length of 30 years, therefore there are uncertainties associated with the flow estimation of less frequent flood events.
- There have been several large fluvial events since the hydrology was updated in 2016, including April 2018 and Storm Henk in January 2024, which would likely change the inflow hydrology.
- Since 2016, there has been changes and updates to methods used to develop fluvial flood flows.

3.2.7 Northern Area Tidal Modelling

- The model did not include any fluvial elements.
- Structures, such as the Surfleet Sluice will not have been represented explicitly in the model.
- The model does not extend along the full length of the tidal Welland. The River Welland is only considered as far as Fosdyke, therefore there is a gap in the tidal flooding data upstream of this location and Fulney Lock on the Welland, which marks the tidal limit – this is located at Spalding. The model uses tidal boundary data that is now 15 years old – these levels will certainly have changed.
- It uses LIDAR data which will have been superseded by finer resolution data.

3.3 Other data sources

3.3.1 National Flood Risk Assessment

The National Flood Risk Assessment (NaFRA) consists of a number of different products, including:

Risk of Flooding from Rivers and Sea - A geospatial dataset which divides the floodplain into 50m x 50m cells and each allocated one of four flood risk likelihood categories.

Reduction in Risk of Flooding from Rivers and Sea Due to Defences - Produced using the defended scenario of flood risk in the Risk of Flooding from Rivers and Sea dataset and an undefended scenario of flood risk from rivers and sea.

Risk of Flooding from Surface Water (RoFSW) - A geospatial dataset the floodplain split into 2m x 2m cells and each allocated one of four flood risk likelihood categories.

Risk of Flooding from Multiple Sources (RoFMS) - A geospatial dataset combining data from RoFRS & RoFSW. The RoFMS inherits the appearance of the input datasets. When both RoFRS and RoFSW indicate a risk in the same area, the RoFSW (surface water flood risk) will be the more prominent feature, indicating the potential for flooding from surface water in that specific location (see Figure 29).

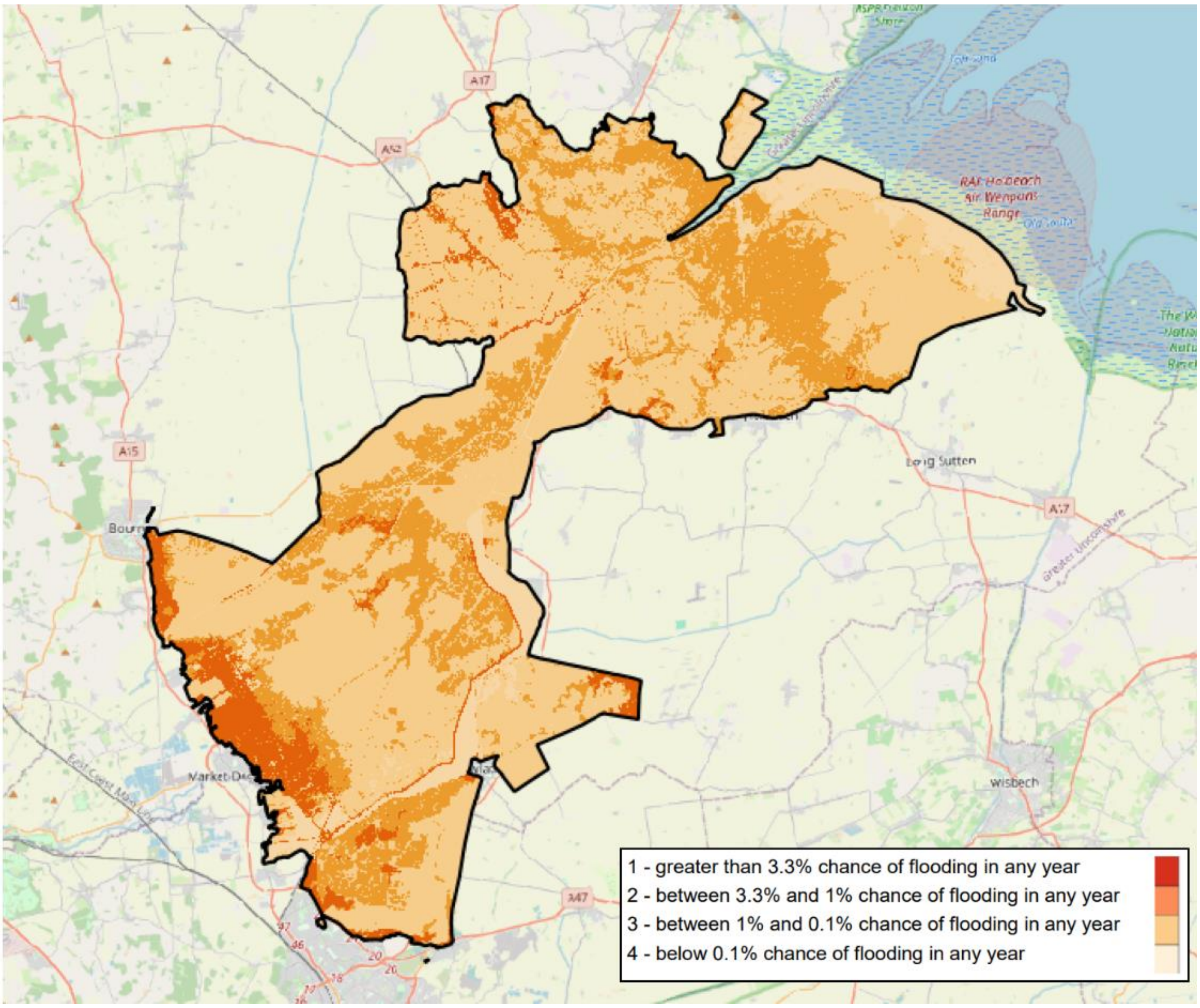

Figure 29: Risk of flooding from multiple sources (Environment Agency, 2025)

Reduction in Risk of Flooding from Rivers and Sea Due to Defences - Produced using the defended scenario of flood risk in the Risk of Flooding from Rivers and Sea dataset and an undefended scenario of flood risk from rivers and sea.

Reduction in Risk of Flooding from Rivers and Sea Due to Defences - Produced using the defended scenario of flood risk in the Risk of Flooding from Rivers and Sea dataset and an undefended scenario of flood risk from rivers and sea.

Flood Zone 2 - It is the best estimate of the areas of land at risk of flooding, when the presence of flood defences is ignored and covers land between Zone 3 and the extent of the flooding from rivers or the sea with a 0.1% AEP chance of flooding each year.

Flood Zone 3 - It is the best estimate of the areas of land at risk of flooding, when the presence of flood defences is ignored and covers land with a 1% AEP or greater chance of flooding each year from Rivers; or with a 0.5% AEP or greater chance of flooding each year from the Sea.

The datasets listed above, have been developed using an ‘undefended’ approach – i.e. the tidal and fluvial flood defences have been removed. . Given the low lying nature of the majority of the catchment and the reliance on flood defence assets, this will inevitably result in an over-prediction of current flood risk. The dataset does not include any allowance for climate change. It will also not represent flood risk accurately in a heavily pumped catchment such as the Lower Welland catchment.

As the Lower Welland catchment has detailed models for tidal flood risk, NaFRA has not been used in the tidal assessment. However, the only 1D-2D defended fluvial model for the catchment is the Bourne Eau (though the downstream extent of the Welland-Glen model has a 2D zone, but this is only for the undefended model), which only covers a small portion of the catchment, as such the use of NaFRA to assess current and future fluvial flood risk has been considered.

Figure 30 shows the yearly chance of flooding from rivers and sea. There are a number of "High chance" areas:

- NaFRA combines both fluvial and tidal flood risk – as such it is impossible to separate the two – particularly towards the coast.
  - Along the tidal defences in the north of the catchment – this generally agrees with the 2010 tidal modelling results.
- In the Cowbit and Crowlands Washes – these areas are intended for water storage in storm situations.
- NaFRA is modelled as undefended – it does not include the embankments and sluices that provide a high degree of protection from fluvial flood events.
  - As such, large majority of the catchment is at current flood risk – this does not correspond to the flood history of the catchment.

The above limitations mean that the current and future flood risk sections of this report will be narrative, only using available historic flood data.

The Welland-Glen model includes 2D climate change scenarios for the 1% and 0.1% AEP events; this is for the undefended only model only.

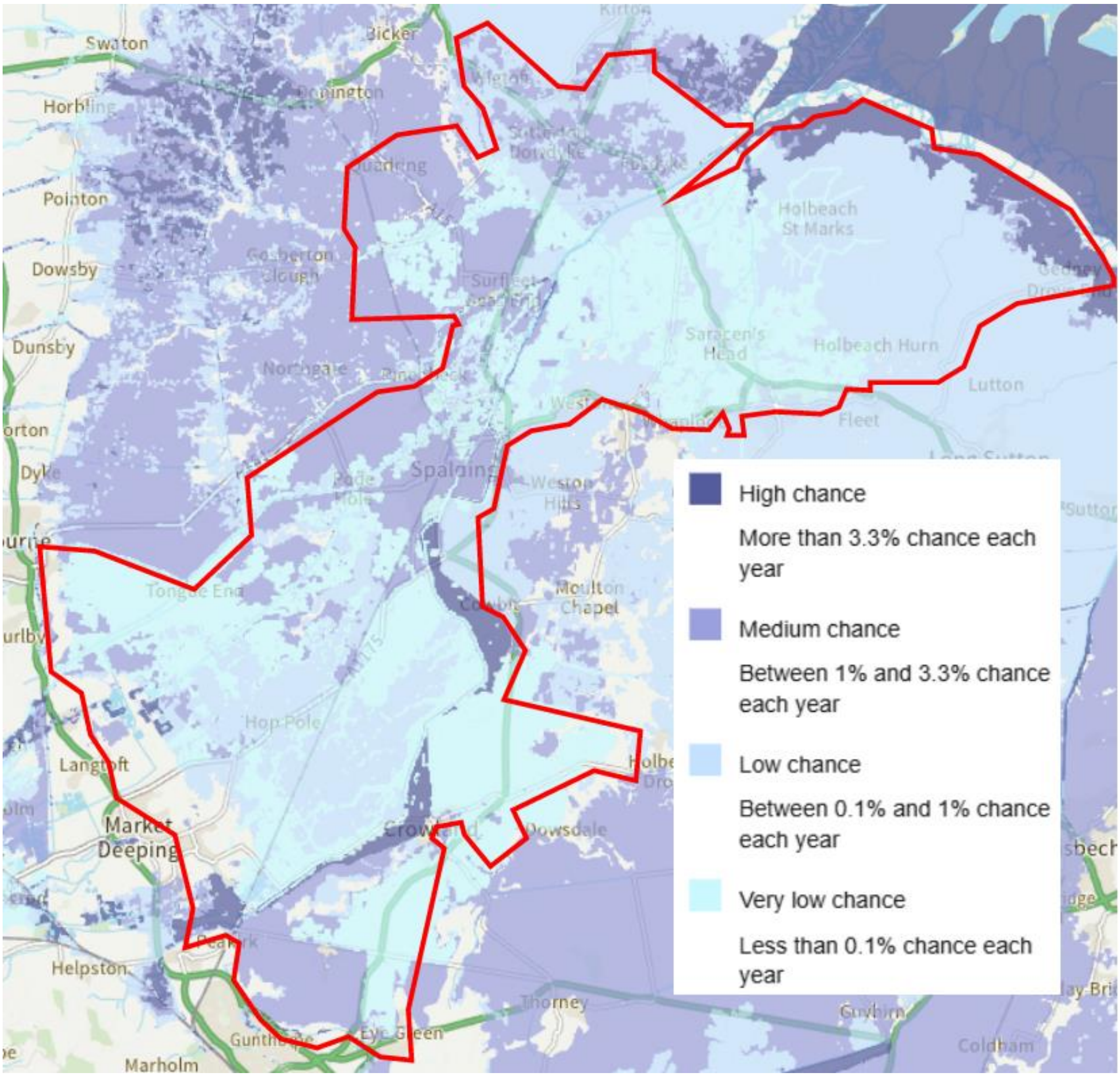

Figure 30: NaFRA Rivers and sea map - Yearly chance of flooding[9]

3.3.2 National Flood Risk Assessment 2

National Flood Risk Assessment 2 (NaFRA2) includes:

- NaFRA2 software system: a web-based IT solution for Environment Agency staff; and
- New National Modelling (NNM): provides hazard outputs for rivers, sea, and surface water for various scenarios.

For NaFRA2, the focus is on using local modelling, though limited detailed local models are available within the catchment. The NNM will be used throughout most of the catchment and features:

[9] NaFRA (2025) Rivers and sea map – Yearly chance of flooding. Available at: https://check-long-term-flood-risk.service.gov.uk/map# Accessed: March 2025

- A 2m model grid based on the Environment Agency's Integrated Height Model 2019 and Defra Marine DEM;
- Outputs including maximum depth, level, etc.; and
- Present day and climate change scenarios.

However, a specific Fens model developed for NaFRA2 is not available for this project, as it is not currently approved for use locally due to Environment Agency.

3.3.3 Internal drainage board models

We have not been made aware of any models produced by the two Internal Drainage Boards whose districts cover the Lower Welland catchment. Although there are Environment Agency models for both fluvial and tidal flood risk as detailed in Section 3.2 these models would be of limited use when trying to understand the wider drainage network.

3.4 Other sources of information

3.4.1 South East Lincolnshire Strategic Flood Risk Assessment (2017)

This outlines how development should consider flood risk at every stage of the development process. It includes a standard advice appendix which describes the assessment and mitigation measures required, based on Flood Zones and vulnerability to flood risk.

3.5 Key receptors

3.5.1 Settlements

There are several small settlements within the catchment including Crowland, Pinchbeck, Surfleet, Deeping Saint Nicholas, Gosberton and Fosdyke. The larger market town of Spalding sits centrally in the catchment. Connectivity within the catchment is supported by key transport routes, such as the A17, A16, A151 and the A1175, and the railway station at Spalding which links it to Peterborough and Sleaford.

3.5.2 Agriculture

The Fens is an area of national agricultural importance due to its rich peaty soils. Farms across the catchment are mainly focused on the production of arable and grassland crops.

The land use within the Lower Welland catchment is primarily agricultural, predominantly arable, and higher value field scale horticulture due to the high quality of farmland throughout the catchment. It's concentration of the highest quality land is directly responsible for this catchment being the intensive crop capital of the UK, with a focus on high value crops and the UK's largest fresh produce processing, marketing and logistics cluster.

A small proportion of the agricultural land is used for the grazing of livestock, with several farms producing beef cattle and/or sheep, on grazed areas. The catchment also has a range of intensive agricultural operations, with glasshouse and controlled environment agriculture enterprises, as well as some housed monogastric livestock units; and a Recirculating Aquaculture System (RAS) shrimp farm at Crowland is under construction.

Across the catchment, around 441km^2 (93%) of land is classified as Agricultural Land Classification (ALC) Grades 1 and 2 land, with the majority of the Grade 1 land located in the northern portion of the catchment. Table 1 and present an overview of ALC classification.

Table 1: Overview of ALC classification within the catchment

	Grade 1	Grade 2	Grade 3	Grade 4	Non-agricultural
Area (km^2)	242.40km^2 (24,240ha)	198.40km^2 (19,840ha)	24.8km^2 (248ha)	0.02km^2 (2ha)	7.09km^2 (709ha)
Percentage of catchment (%)	51.3	42.0	5.2	<0.01	1.5

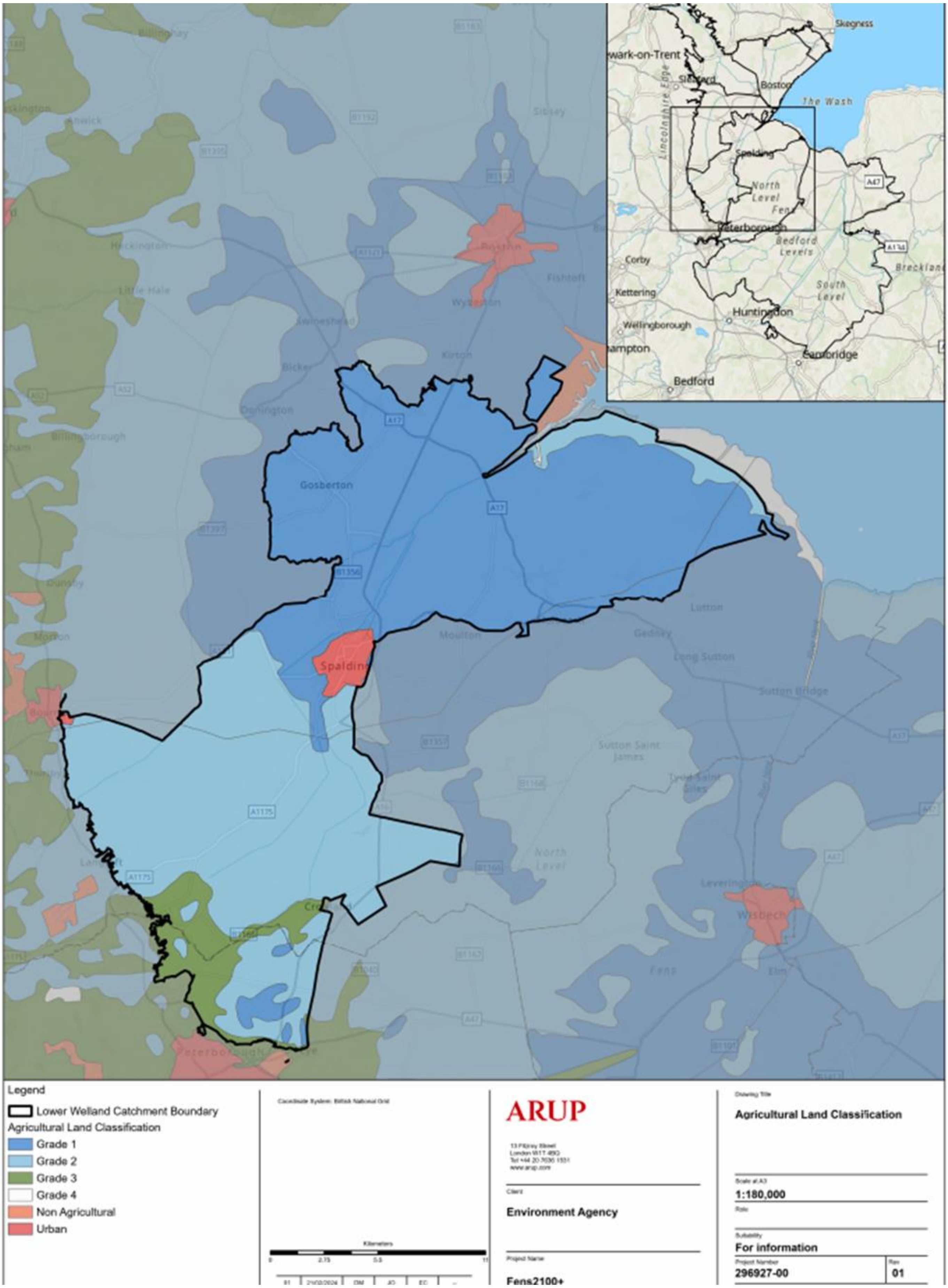

Figure 31: Land classification across the catchment

Approximately 416km^2 (88%) of land across the catchment is currently farmed.

It is estimated that the agricultural value of the crops grown on this land (based on 2023 data) is as follows:

- Cereal production – c. £30.1 million;
- Other arable – c. £25.2 million; and
- Fruit and vegetables – c. £75.1 million.

Grassland does not directly create economic value but instead supports the grazing of sheep and cattle, or the production of livestock feed. The estimated overall economic output of crop and livestock is in the region of £183.6 million, highlighting the importance of the agricultural sector.

4. Climate change

The impact of climate change has been represented in all three models used in this assessment to define tidal and fluvial impacts. The approach to climate change in each of the models is described in the proceeding sections.

4.1 Tidal climate change

Climate change has been assessed as part of the Northern Area Tidal Modelling up to 2115 by an allowance for calculated rates of sea level rise over time. The increases used in this study are shown in Figure 32.

Years	Net Sea Level Rise (mm/yr)	Calculated Sea Level Rise (m)
2006 - 2025	4	0.08
2025 - 2055	8.5	0.26
2055 - 2085	12	0.36
2085 - 2115	15	0.45
Calculated Total Sea Level Rise (2006 – 2115)		**1.14**

Figure 32: Sea level rise used in 2010 Northern Area Tidal Modelling

The sea level rise applied to the design peak water levels generates a level of **7.13mAOD** at Fosdyke Bridge.

Since the study, which was completed in 2010, sea level rise estimates have been revised. Currently, the Environment Agency guidance recommends assessing against two scenarios; Higher Central and Upper End. The allowances for sea level rise are shown in Table 2.

Table 2: Sea level allowances for each epoch

Area of England	Allowance	2000 to 2035 (mm)	2036 to 2065 (mm)	2036 to 2065 (mm)	2066 to 2095 (mm)	Cumulative rise 2000 to 2125 (metres)
2025 Anglian	Higher Central	5.8	8.7	11.6	13	1.20
	Upper End	7	11.3	15.8	18.1	1.60

For Flood Risk Assessments and Strategic Flood Risk Assessments, both the Higher Central and Upper End allowances will need to be assessed.

Flood and Coastal Erosion Risk Management (FCERM) schemes are typically assessed against the Higher Central. Given the long-term nature of the Fens 2100+ project, the 2080’s epoch with the Higher Central allowance is most applicable to this study.

These estimates have been compared to those applied in the 2010 modelling, shown in Figure 33. This shows that the estimates used in the 2010 study lie between the Higher Central and Upper End. Given that FCERM schemes typically assessed against the

Higher Central it is considered that the climate change estimates used in the 2010 modelling are appropriate for use in this study.

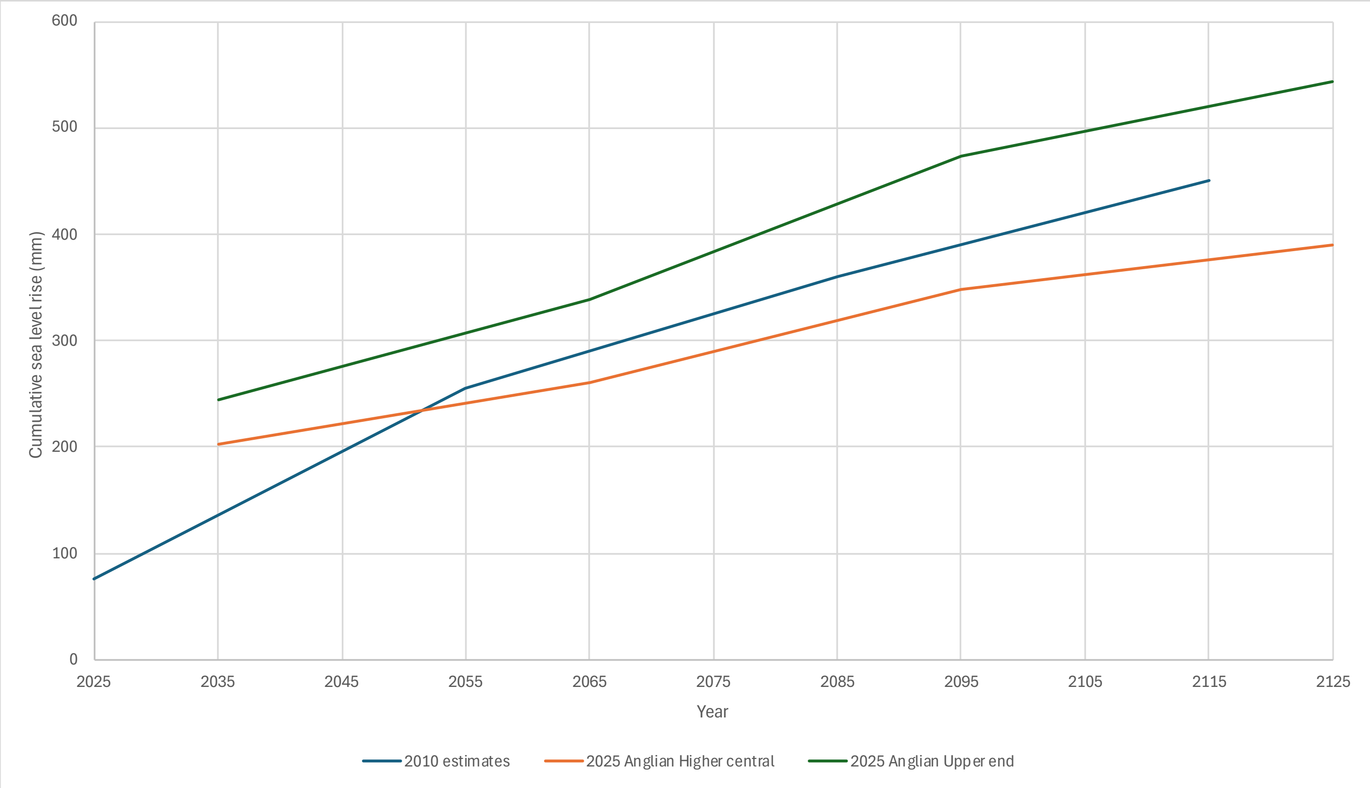

Figure 33: Comparison of sea level rise estimates

4.1 H++ scenario

The Fens 2100+ project is a long term adaptive plan for the landscape as such the H++ is a useful sensitivity test. Current Environment Agency guidance states that a value of 1.9m up to 2100 should be used (There is no H++ value for sea level rise beyond 2100).

None of the available modelling for the Lower Welland catchment includes an assessment of the H++ scenario. The most extreme value for climate change used within the 2010 modelling (as detailed in Table 3) is 1.14m – this is considerably smaller than the value if 1.9m. We can therefore infer that the H++ scenario would show more flooding (depth and extent) than the results presented in the proceeding sections.

4.2 Fluvial climate change

Both the 2016 Bourne Eau model and the 2016 Welland-Glen mode have applied a 20% uplift in peak flow to represent climate change based on DEFRA 2006 guidance. This uplift is applied to the 1% AEP and 0.1% AEP scenarios and is applied by increasing the rainfall values.

Current DEFRA guidance for the Lower Welland Catchment is shown in Table 3.

Table 3: DEFRA climate change allowances[10]

	Central	Higher	Upper
2020's	5%	10%	22%
2050's	4%	10%	26%
2080's	17%	28%	53%

For flood risk assessments and strategic flood risk assessments the following are used:

- flood zones 2 or 3a:
  - essential infrastructure – Higher allowance
  - highly vulnerable – Central allowance (development should not be permitted in flood zone 3a)
  - more vulnerable – the Central allowance
  - less vulnerable – the Central allowance
  - water compatible – the Central allowance
- flood zone 3b:
  - essential infrastructure – use the Higher Central allowance
  - highly vulnerable – development should not be permitted
  - more vulnerable – development should not be permitted
  - less vulnerable – development should not be permitted
  - water compatible – use the central allowance

For FCERM schemes, the following are used:

- Central allowance as the design allowance;
- Higher allowance to test the impacts of higher scenarios of climate change and any extra mitigation;
- Upper allowance to test the option under more extreme climate change and exceedance events; and
- 2080s epoch allowances for changes beyond the 2080's epoch and up to 2115.

4.3 Discussion

The 2010 Northern Area Tidal Model, 2016 Bourne Eau Model and 2016 Welland-Glen models (both 2016 models are part of the same project) all represent climate change.

[10] DEFRA (2025) Climate Change Allowances. Available at: https://environment.data.gov.uk/hydrology/climate-change-allowances/river-flow?mgmtcatid=3112. Accessed: (March 2025)

The 2016 Bourne Eau and 2016 Welland-Glen models use a 20% uplift on peak flows to represent climate change. DEFRA guidance on climate change has been updated since, and as the Fens 2100+ project is looking to provide resilience into the 22nd Century, the Upper 2080's uplift of 53% would be appropriate. These models will therefore underestimate the future fluvial flood risk; however, they still provide a useful indication of the possible impacts of climate change.

The 2010 Northern Area Tidal Modelling study inevitably uses older sea level rise estimates. A review of the data suggests that these estimates will be between the Higher Central and Upper End scenarios in the current guidance, though it will be dependent on the exact nature of any study – for example the H++ scenario may be more appropriate for stress testing and a system wide approach. Whilst not exact, the sea level rise estimates in the 2010 model are broadly comparable to current estimates, as such are considered suitable for assessing future flood risk at a strategy scale.

5. Tidal flood risk

5.1 Current tidal flood risk

The Lower Welland catchment is protected by significant tidal defences as shown in Figure 34. There is no record of the defences being overtopped.

The 2010 Northen Area Tidal Modelling shows that tidal current tidal flood risk in the 0.5% AEP would impact the agricultural areas close to the coastline (see Figure 34).

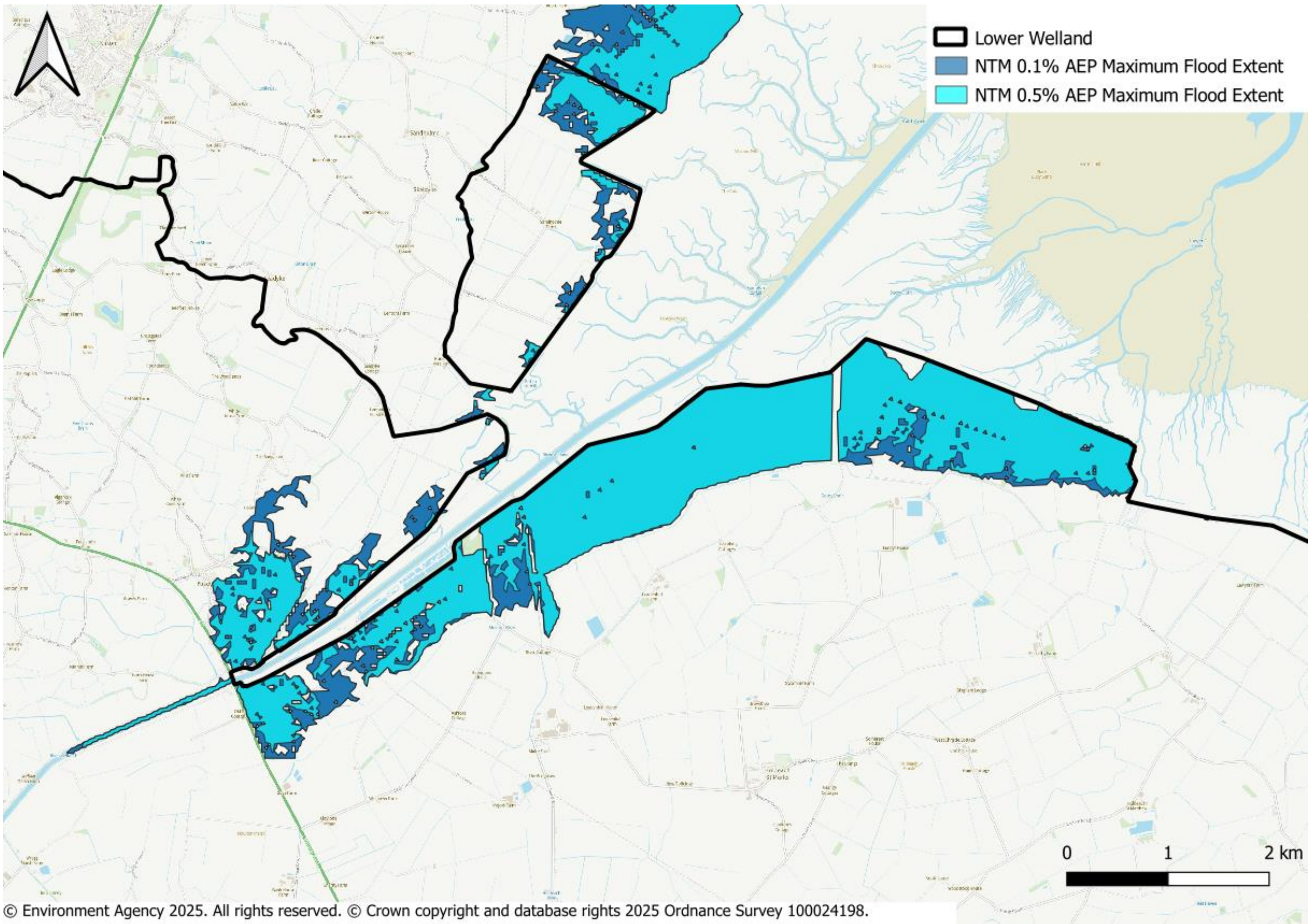

Figure 34: 0.5% AEP (light blue) and 0.1% AEP(dark blue) tidal event maximum flood extents

During the 0.5% AEP event some properties may be impacted in Fosdyke (see Figure 35). Flood depths in this event reach a maximum depth of around 2m in the agricultural fields immediately behind the tidal defences. In Fosdyke, the maximum flood depth would be around 1m.

It should be note that in the Northern Area Tidal Modelling, which informs this assessment The River Welland is only considered as far as Fosdyke, therefore there is a gap in the tidal flooding data upstream of this location and Fulney Lock on the Welland, which marks the tidal limit – this is located at Spalding. Therefore, there may be additional tidal flooding in this location not captured by the modelling.

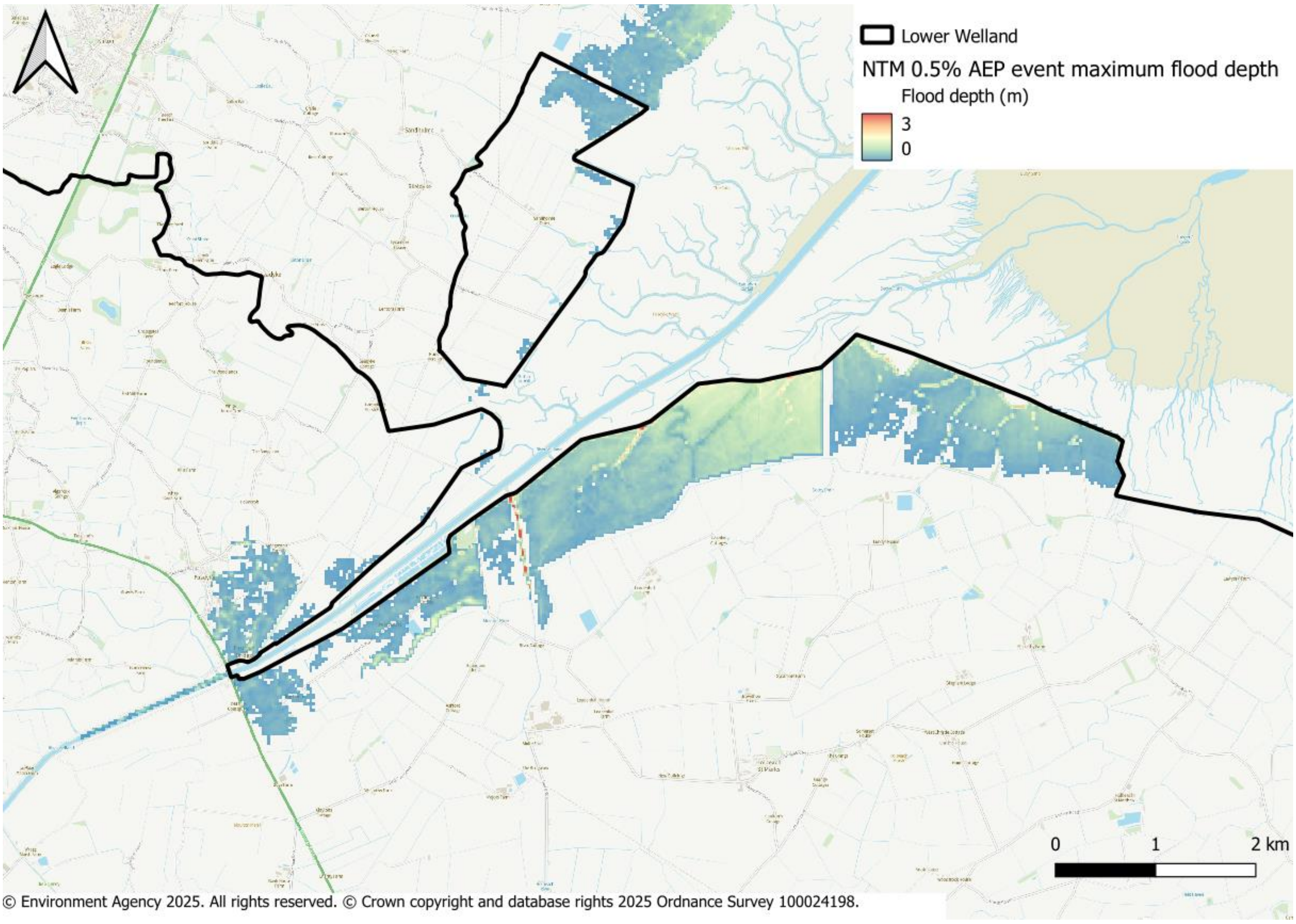

Figure 35: 0.5% AEP event maximum flood depth

Inspection of model results shows that the defences are not overtopped during the 0.5% AEP event, rather the flooding is as a result of wave overtopping.

In the 0.1% AEP event, there is not a significant change in modelled flood extents (see Figure 34), though a few more properties in Fosdyke may be affected. Flood depths are increased in comparison to the 0.5% AEP event, with a maximum depth of around 2.5m in the agricultural fields immediately behind the tidal defences. In Fosdyke, the maximum flood depth would be around 1.2m.

5.2 Future tidal flood risk

Tidal climate change has been assessed using the 2010 Northern Area Tidal modelling for the 0.5% AEP event up to 2115.

Results from the modelling showed a significant increase in flood risk in comparison to present day with large areas of the Lower Welland catchment predicted to inundate, including the settlements of Gedney Drove End and Fosdyke, as well as a business park just outside Holbeach St Marks (Figure 36).

The main mechanism is water overtopping of the existing flood embankments, as the sea level for the 0.5% AEP with climate change is higher than many of the existing embankments, this results in significant flooding across the Lower Welland catchment.

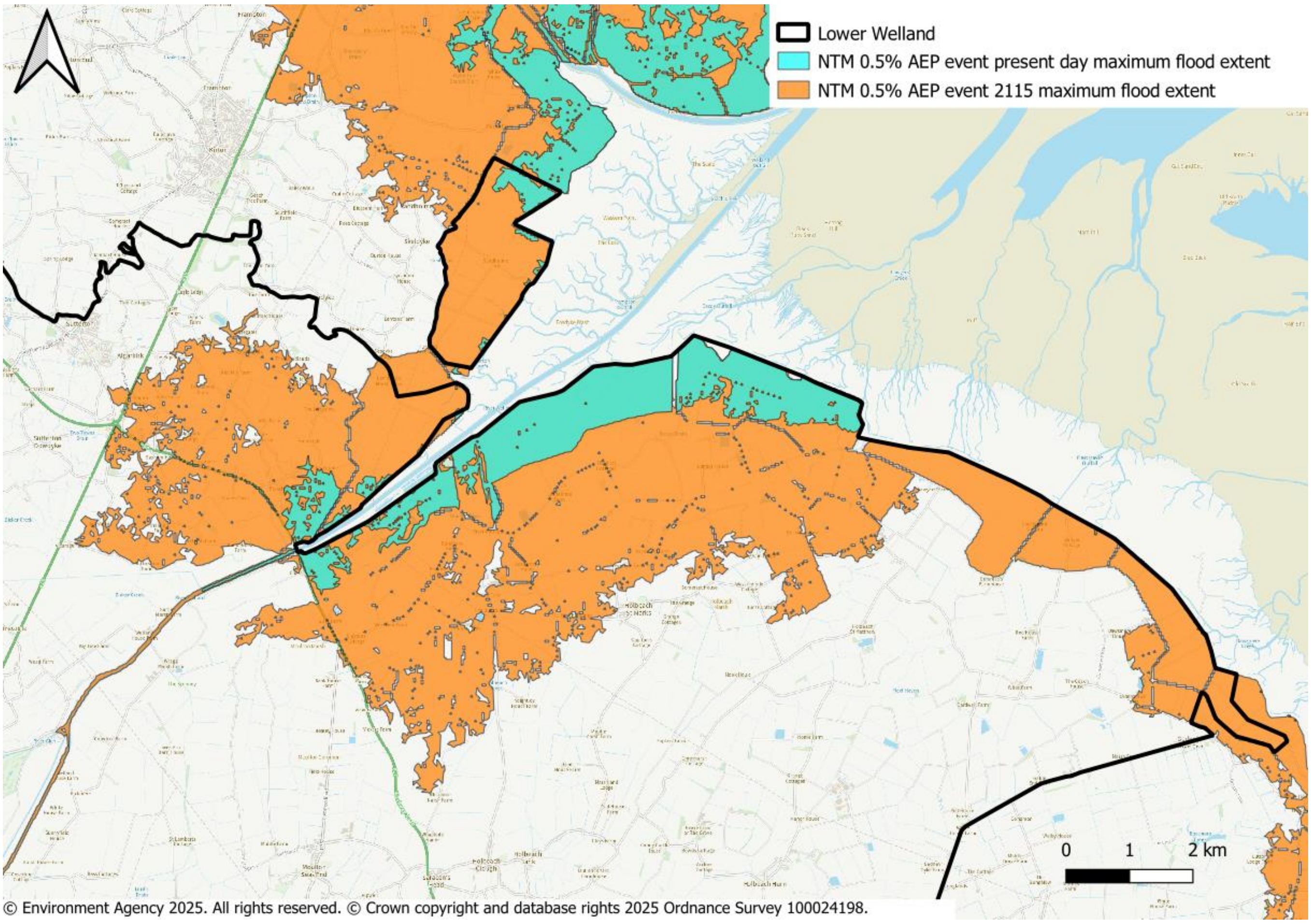

Figure 36: Comparison between 0.5% AEP present day (blue) and 0.5% AEP with climate change applied up to 2115 (orange)

5.3 Key metrics

5.3.1 Total area

The total modelled area which was found to be at risk of tidal flooding within the Lower Welland catchment was:

- 0.5% AEP event – 7.47km^2 (747ha) – **1.6%** of total catchment area.
- 0.5% AEP with sea level rise up to 2115 event – 52.65km^2 (5,265ha) – **11.1%** of the total catchment area.
- 0.1% AEP event – 9.2km^2 (920ha) – **1.9%** of total catchment area.

5.3.2 Grades of agricultural land

The agricultural land within the Lower Welland catchment area is assessed for flood risk based on different grades. This has been summarised in Table 4.

Table 4: Agricultural land grading at risk of current tidal flooding

Agricultural Grade	0.5% AEP (km^2)	0.5% AEP with an allowance for climate change (km^2)	0.1% AEP (km^2)
Grade 1	2.13km^2 (213ha)	41.66km^2 (4,166ha)	3.37km^2 (337ha)
Grade 2	5.25km^2 (525ha)	10.73km^2 (1,073ha)	5.63km^2 (563ha)
Total	**7.38km^2 (738ha)**	**52.38km^2 (5,238ha)**	**8.99km^2 (899ha)**

5.3.3 Percentage area over 30cm flood depth

The area that floods over 30cm for each event is:

- 0.5% AEP event – 3.71km^2 (37ha) – **0.78%** of total catchment area.
- 0.5% AEP with sea level rise up to 2115 event – 39.66km^2 (3,966ha) – **8.4%** of total catchment area.
- 0.1% AEP event – 5.44km^2 (544ha) – **1.15%** of total catchment area.

5.4 Discussion

The significant increase in flood risk for the 0.5% AEP event when climate change is included shows how vulnerable the Lower Welland catchment is to sea level rise. A present day 0.5% AEP event results in minimal flooding, though some flooding to Fosdyke. When climate change is applied to the same event, the flood extent is considerably greater, inundating all of Fosdyke as well as a number of other settlements and large areas of agricultural land.

6. Fluvial flood risk

6.1 Current fluvial flood risk

The flood history suggests that the main source of fluvial flood risk to the Lower Welland catchment is flooding from the River Welland in the vicinity of the Crowland and Cowbit Washes. The first significant recorded event in 1947 resulted in extensive flooding with flood waters breaching the Crowland and Cowbit Washes embankment and surrounding the town of Crowland. Additional minor flooding events were also recorded in 1998, 2020 & 2024.

There have also been a number of flooding events impacting properties at the Surfleet Reservoir in 1994, 1998, 2018 and 2021, due to a combination of high river levels and tidal locking.

6.1.1 Bourne Eau model

This model covers a very small corner of the catchment adjacent to Bourne. There is no flooding in the modelled 1% AEP event, and only minimal flooding in the 0.1% AEP event, due to the presence of flood embankments ,which all occurs outside the catchment boundary as shown in Figure 37 and therefore is not relevant to this study.

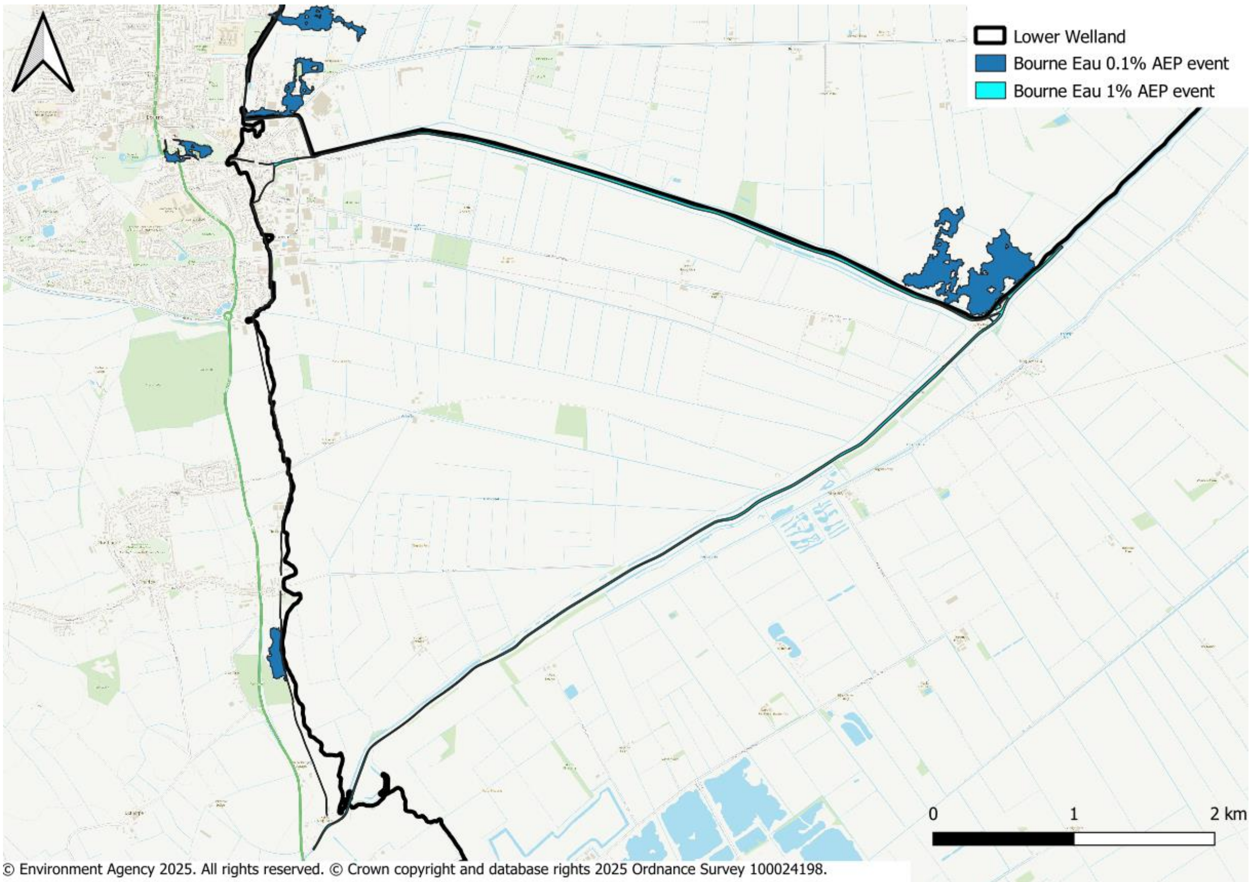

Figure 37: 1% AEP and 0.1% AEP tidal events maximum flood extent

6.1.2 Welland-Glen model

Results from the Welland-Glen model show that the Crowland and Cowbit Washes experience flooding in a 5% AEP event. However, even in a 0.1% AEP event, flood waters are contained within the Crowland and Cowbit Washes embankments and therefore no properties are predicted to flood (Figure 38).

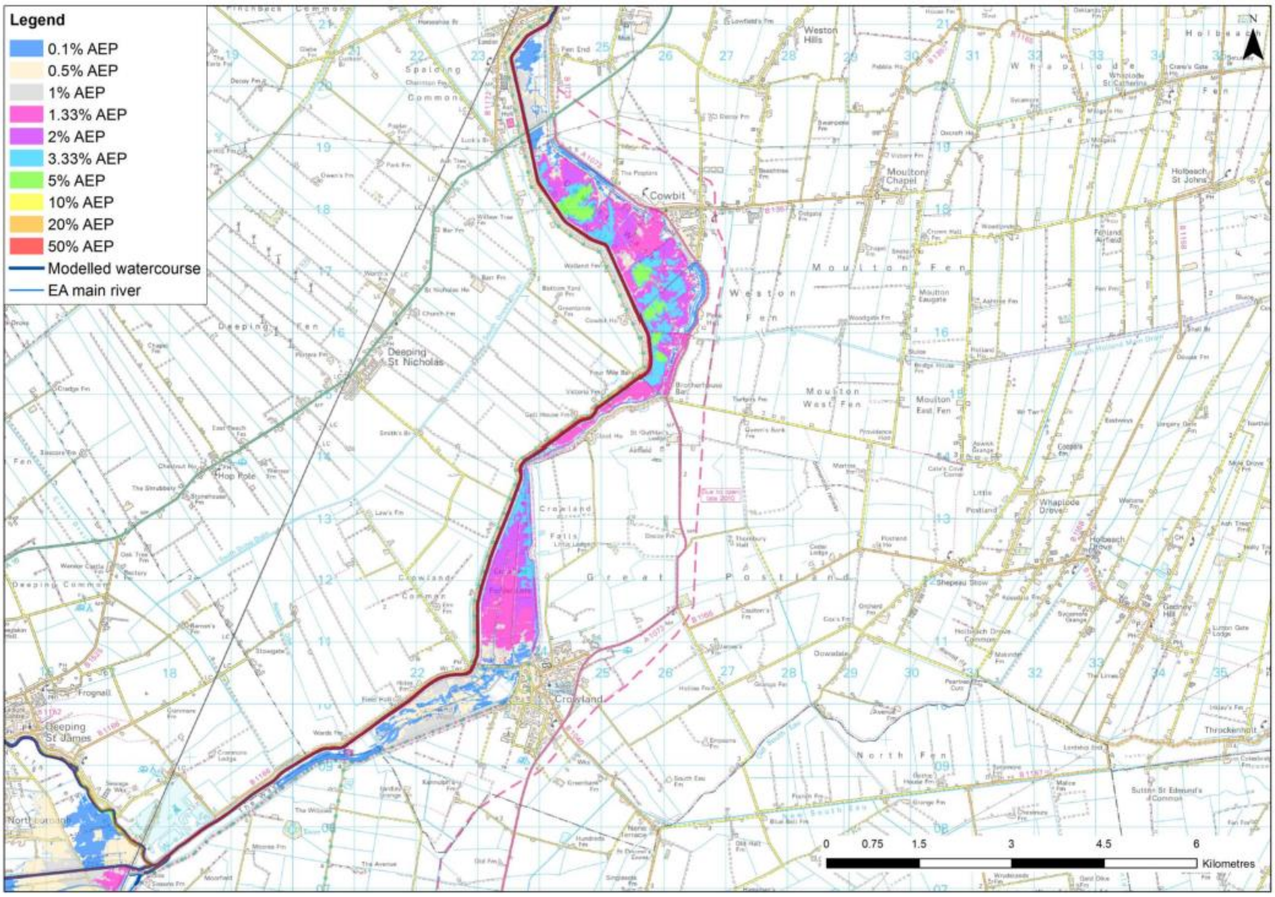

Figure 38: Defended model extents - present day – Crowland and Cowbit Washes, extracted from the River Welland Hydraulic Modelling report © Environment Agency

There is also some flooding to the south of Market Deeping, the extent of which lies partially outside the catchment boundary as shown in Figure 39. Flooding first appears during the 1.33% AEP event and starts to affect a small number of properties in the 0.5% AEP event.

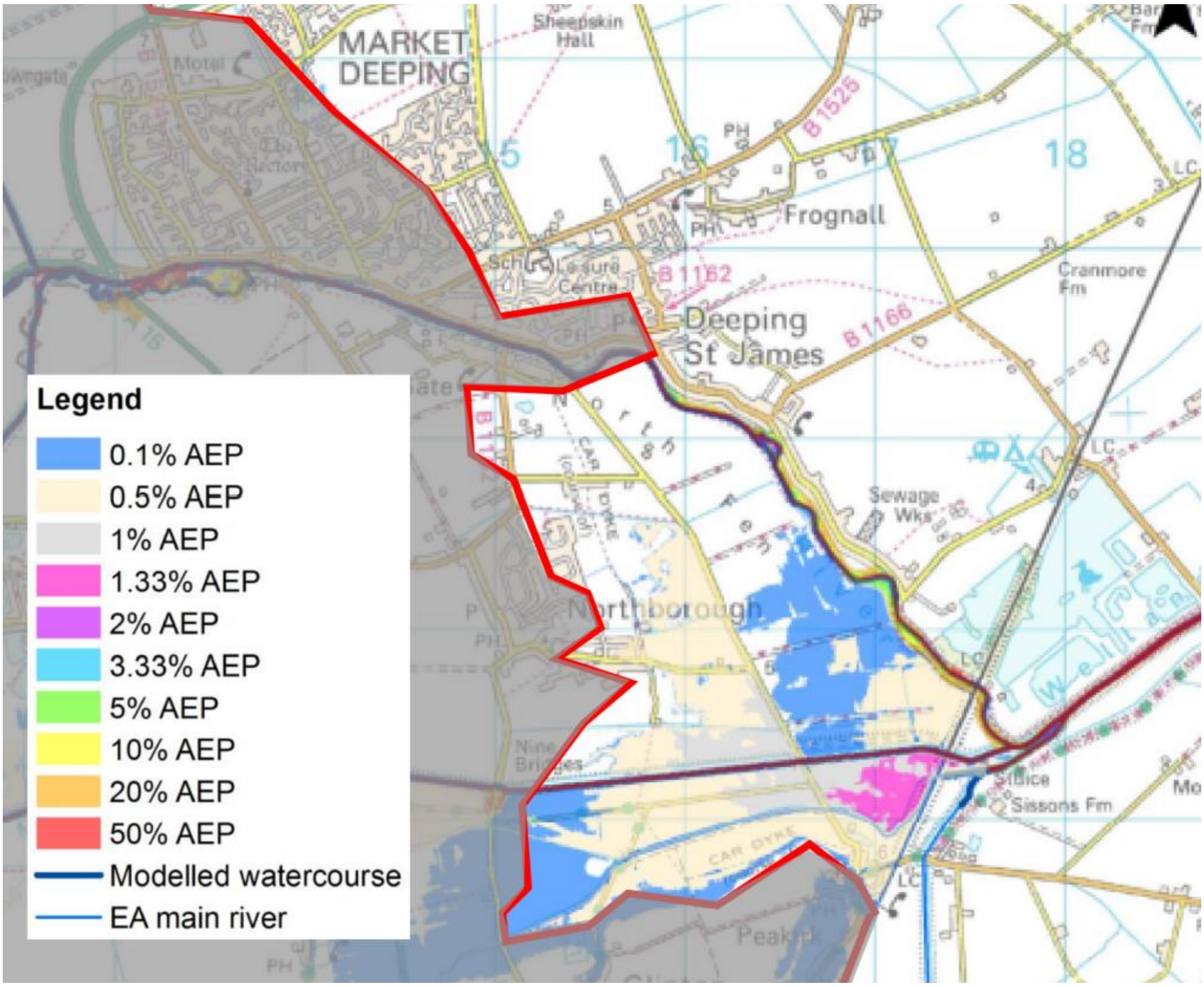

Figure 39: Defended model extents - present day - Market Deeping, extracted from the River Welland Hydraulic Modelling report © Mott Macdonald

6.2 Future fluvial flood risk

Both the 2016 Bourne Eau model and 2016 Welland-Glen mode have applied a 20% uplift in peak flow to represent climate change based on DEFRA 2006 guidance. This uplift is applied to the 1% AEP and 0.1% AEP scenarios and was applied by increasing the rainfall values.

As previously stated, the latest DEFRA guidance on climate change suggests an uplift of 53% would be appropriate for this scenario. Hence the future fluvial flood risk results from the models should be used as an indication only. Future fluvial flood risk is likely to be considerably greater.

6.2.1 Bourne Eau model

As can be seen in Figure 40, there is no significant flooding in the climate change scenario, as the increased flows are still kept in-channel by the existing flood defences.

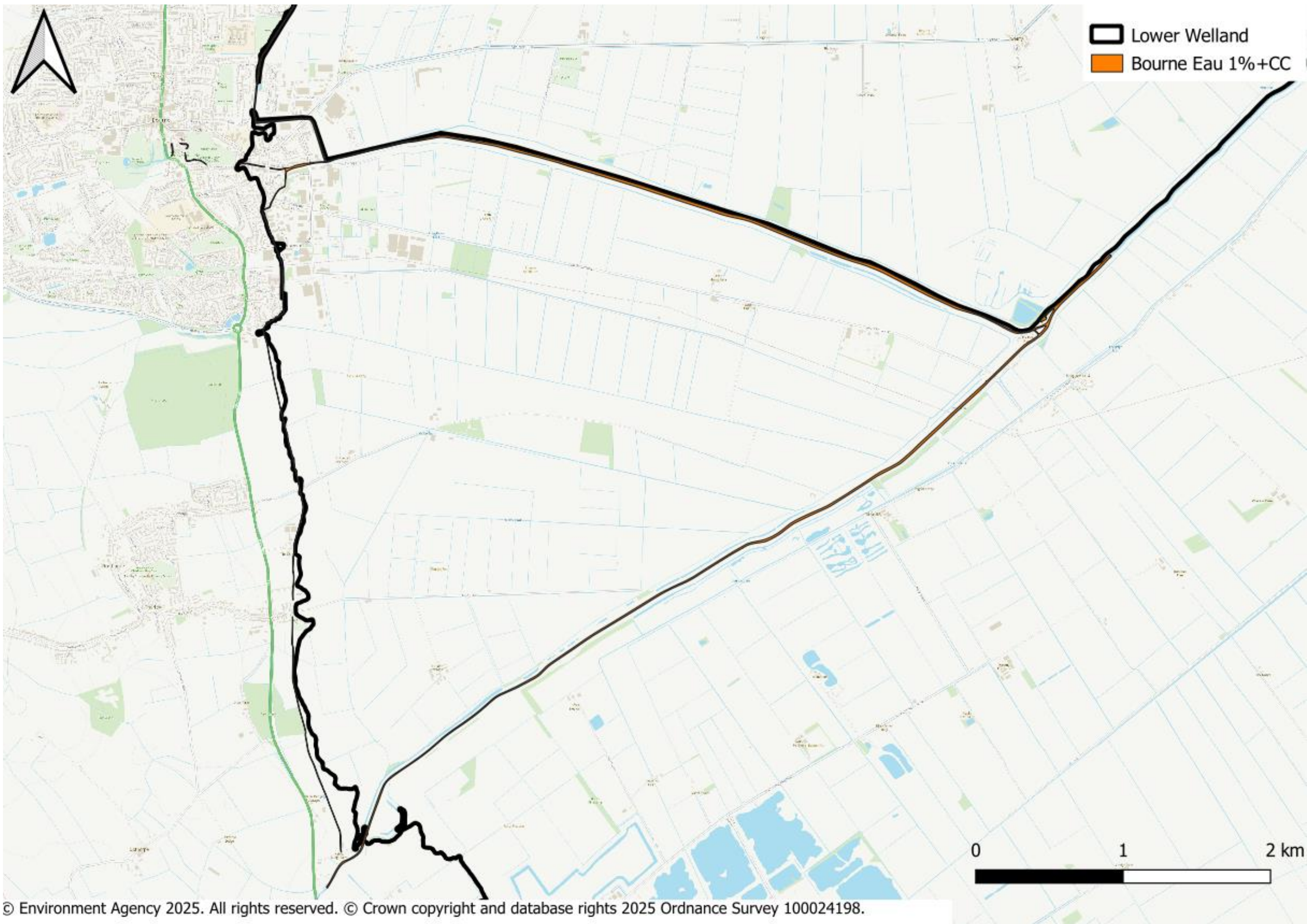

Figure 40: 1% AEP flood event with a 20% uplift for climate change

6.2.2 Welland-Glen model

As expected, the uplift in fluvial inflows results in an increase in flood risk. The flooding in the region of the Crowland and Cowbit Washes is still contained within the embankments and therefore does not pose a risk to properties or wider areas of agricultural land (Figure 41).

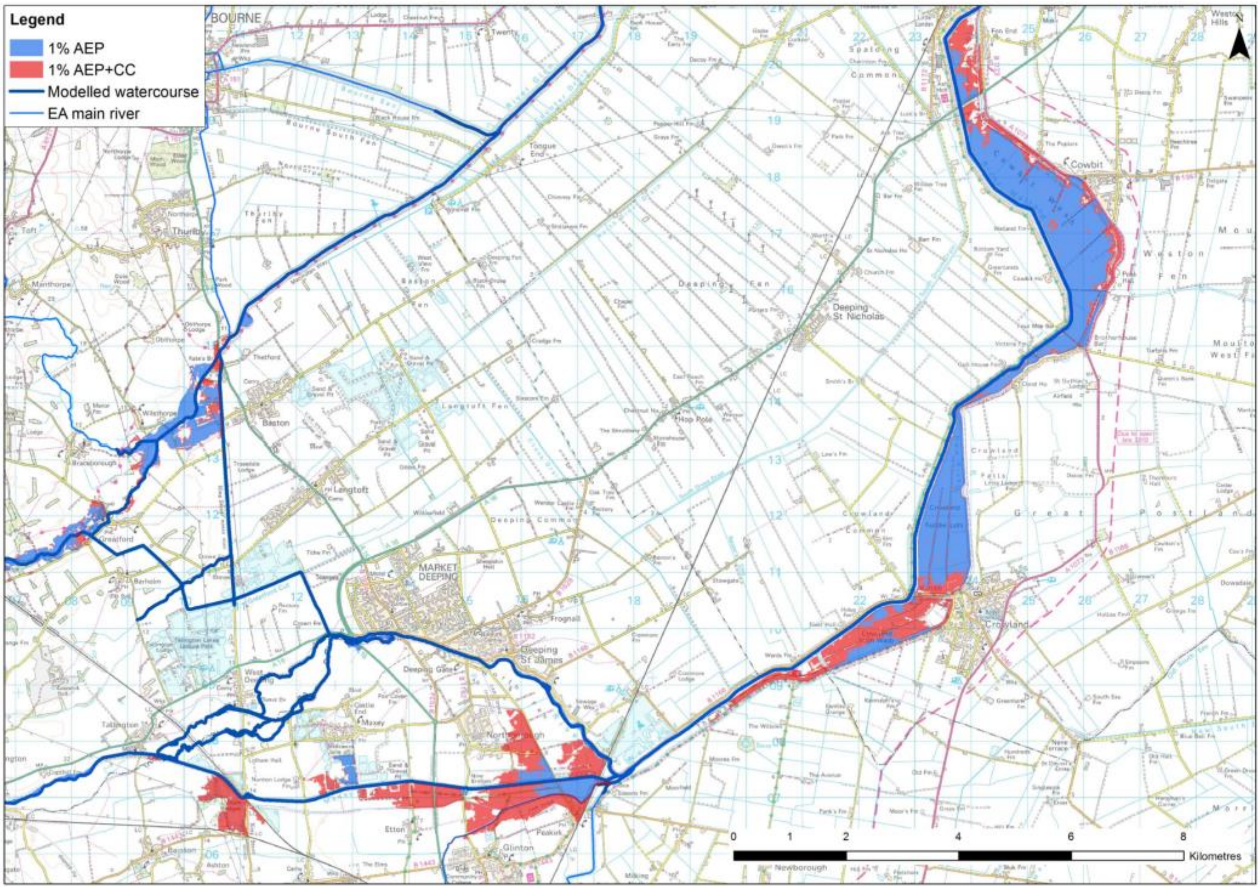

Figure 41: Defended model flood extents with climate change – Crowland and Cowbit Washes, extracted from the River Welland Hydraulic Modelling report © Mott Macdonald

The flooding extent in the region of Market Deeping increases significantly when climate change is taken into account. As can be seen in Figure 42, the majority of the flooding is to agricultural land, although there are some properties in Peakirk and Northborough at risk of flooding.

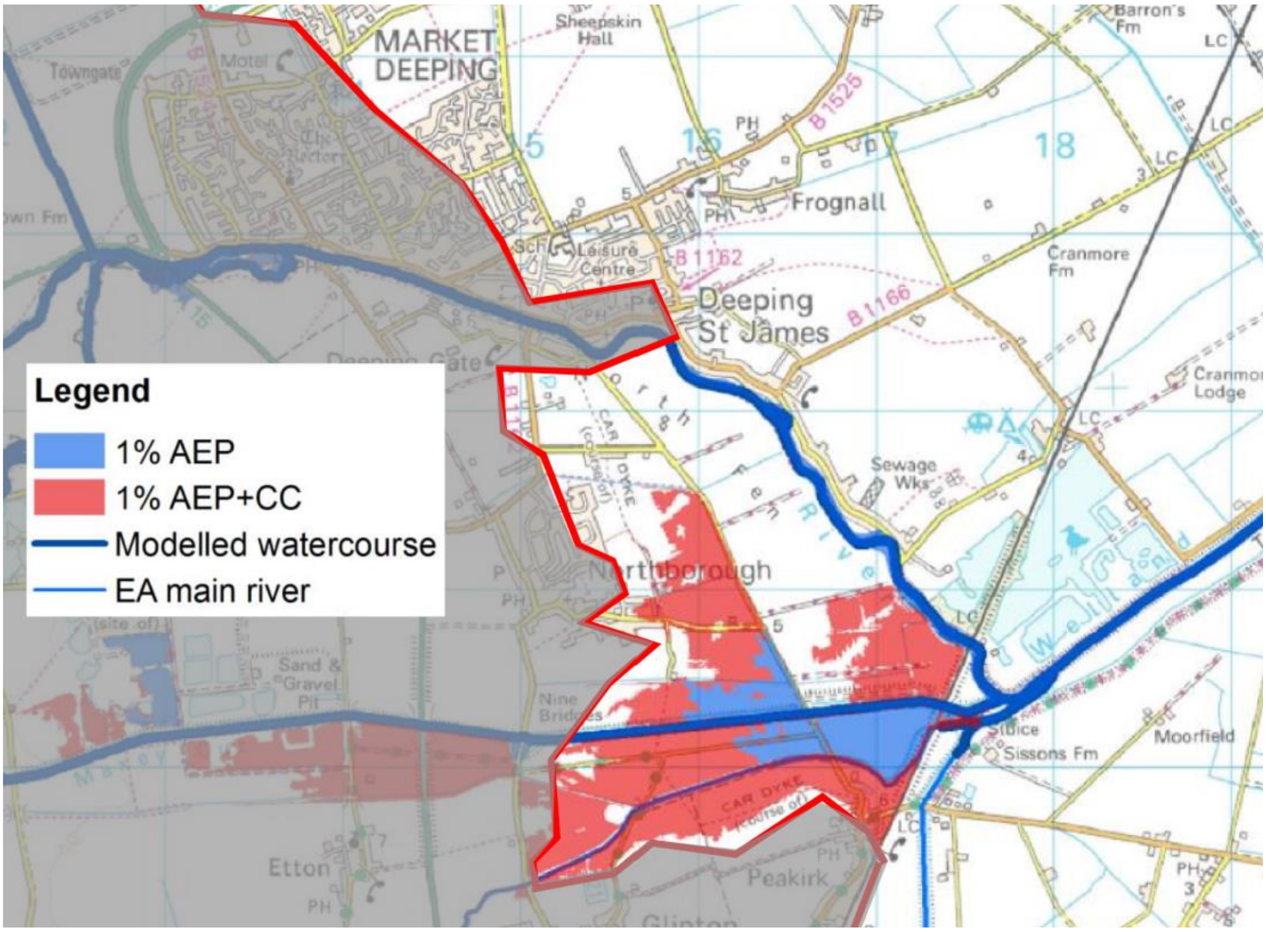

Figure 42: Defended model flood extent with climate change - Market Deeping, extracted from the River Welland Hydraulic Modelling report © Mott Macdonald

6.3 Key metrics

As previously discussed, the 2016 Bourne Eau model only covers a very small portion of the catchment, and the flooded area represents <0.01% of the catchment area, therefore it's not possible to extract any meaningful key metrics.

With regards to the 2016 Welland-Glen model, only the modelling reporting is available, not the model results, hence it is not possible to extract any key metrics for fluvial flood risk.

6.4 Discussion

Based on historic reports and previous modelling, fluvial flood risk across the catchment is relatively low. The only major fluvial flood event was in 1947 when the Crowland and Cowbit Washes embankment breached and the town of Crowland was surrounded. Since then, flooding in the Crowland and Cowbit area has been restricted to the Crowland and Cowbit Washes – two offline storage areas intended for the purpose of storing flood waters. Current and future modelling does not predict any flood waters escaping these storage areas, though breach scenarios have not been modelled.

There is also historic evidence of repeated localised flooding at Surfleet Reservoir impacting a number of properties, partly caused by tidal locking exacerbated by climate change. This flooding has not been captured in the modelling, and therefore it is not known what impact climate change may have – though given that sea levels are expected to rise, and fluvial flows expected to increase it can be inferred that flood will occur more frequently.

The only other area of flooding identified by the modelling is to the south of Market Deeping. This flooding primarily affects agricultural land, though a number of properties are at risk in Northborough and Peakirk in the 0.5% AEP event. In the modelled climate change scenario, there is an increase in the area of agricultural land that is flooded, and some properties in Peakirk and Northborough are at risk of flooding.

Overall, the fluvial flood risk in this catchment is low provided that flood defences are not breached. However, as previously noted, the climate change uplift in both models is significantly lower than current guidance (20% instead of 53%), hence it is likely that the future fluvial flood risk is underestimated by these models.

7. Other sources of flooding

Aside from fluvial and tidal, other sources of flooding include surface water, groundwater, and reservoirs. These sources can be the sole cause of flood events or compound the effects of flooding from fluvial or tidal sources. This section sets out these other sources of flood risk, and potential impacts from these sources. It will also consider historical events in the catchment which highlight these issues. This information is intended to provide a high-level summary of the risk of flooding from these wider sources.

7.1 Surface water

Surface water flooding occurs when intense rainfall generates excessive overland flow before it can reach a watercourse or drainage network. This type of flooding may also occur when rainwater is unable to drain through conventional drainage systems or infiltrate the ground. Contributing factors include insufficient system capacity, saturated ground, or failures in the drainage network due to blockages or culvert collapses. Presence of sandy or gravel soils can mean increased susceptibility to movement of groundwater and flooding from this source.

While surface water flooding is typically caused by high-intensity rainfall, it can also occur during lower-intensity rainfall if the land has low permeability. Factors such as development, frozen ground, or already saturated soil can reduce permeability. Additionally, flooding can occur if the drainage network is already at capacity, preventing efficient water drainage to the intended watercourse or sewer.

The Environment Agency's long term flood risk service[11] provides mapping of surface water flood risk. It shows that flood risk from surface water is generally highly localised, with dense but small and isolated patches where surface water flooding is likely. However, there are larger areas of surface water flood risk concentrated in the far west of the catchment between the Bourne Eau and the River Glen, just east of Bourne.

7.1.1 Quadring surface water flood event 2nd January 2024

Quadring is a village in the South Holland district, which experienced surface water flooding in January 2024. The predominant flood mechanism identified to affect the property was surface water runoff from the surrounding land and water overtopping from an adjacent riparian ditch to the west of the property.

7.2 Groundwater

Groundwater flooding occurs when the water table, the level of water within the land, rises above the ground surface. This type of flooding typically follows extended periods of sustained rainfall and can persist for a prolonged duration, often lasting longer than other types of flooding. Throughout the year, the water table naturally fluctuates in response to seasonal rainfall, with groundwater flooding being most common in the spring following prolonged rainfall during the preceding autumn. The presence of sandy or gravel soils can mean increased susceptibility to movement of groundwater and flooding from this source.

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[11] Environment Agency (2024) Check the long term flood risk for an area in England. Available at: Information for planning - Check your long term flood risk - GOV.UK. Accessed 04/04/2025.

Across the Lower Welland catchment, the land is low-lying, which can contribute to a higher risk of groundwater flooding through the water table being at a shallow depth[12]. There is also a risk that any flooding will not recede for long periods of time due to the flat nature of the catchment and the reliance on pumping for drainage. The SFRA for South East Lincolnshire[13] identifies no recorded incidents of flooding in the Lower Welland catchment, although it is possible that high groundwater levels contributed to flooding in a number of historic flood events caused by other sources.

7.3 Reservoir

Reservoir flooding is very rare but occurs when there is a failure of reservoir impounding structures such as raised embankments. By far the largest reservoir in the study area is the Crowland and Cowbit Washes Flood Storage Area (a Statutory Reservoir), but the Surfleet Reservoir is also located within the catchment.

The likelihood of the catchment flooding from the failure of large, raised reservoirs such as the Crowland and Cowbit Washes is very low. This is due to the high level of protection offered by the Reservoir Act. Nevertheless, the consequence of a failure of the retaining structures could be quick and catastrophic flooding of surrounding land and property. Mapping of reservoir flood risk across the UK[14] shows that it is the southern half of the catchment (south of Spalding) where risk from reservoir flooding is concentrated. This area known as 'The Deepings' has some of the lowest-lying land in the catchment.

Surfleet Reservoir lies immediately upstream of Surfleet on the River Glen and is classified as Flood Zone 3b Functional Floodplain. This zone comprises land where water has to flow or be stored during flood events. The reservoir contains approximately 50 properties, which were originally built as holiday chalets and intended for temporary occupancy only. Over the years as chalets have changes hands, with many properties now occupied year-round as permanent dwellings. Flooding of these properties does occur; however, this is not reservoir flooding as the reservoir is acting as it was intended to. The South East Lincolnshire SFRA[15] recommends that due to the increased likelihood of flood events affecting properties at this location, further development in this area should not be supported and opportunities to relocate existing residents outside the functional floodplain zone be explored.

Maps of Reservoir Flood risk arising from individual reservoirs show that a breach of the Crowland and Cowbit Washes would lead to flooding of land to the east, affecting the western extent of the catchment north and south of Crowland (see Figure 43 **Error! Reference source not found.**).

Figure 43and Figure 44 shows that any reservoir flood risk north of the Crowland and Cowbit Washes arises from the Eyebrook Reservoir, located upstream of the catchment in Leicestershire. Water is shown to flow along the River Welland in its upper course, entering the catchment near Market Deeping and spreading across the flat lowlands of the

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[12] Peterborough City Council (2018) Peterborough Level 1 Strategic Flood Risk Assessment & Outline Water Cycle Study. Available at: Local flood and water documents | Peterborough City Council. Accessed 08/04/2025.

[13]South East Lincolnshire Joint Strategic Planning Committee (2017). South East Lincolnshire Strategic Flood Risk Assessment. Available at: SE-Lincolnshire-SFRA-2017-v6-24th-Jan-2018.pdf. Accessed 08/04/2025.

[14] Environment Agency (2024) Check your long-term flood risk. Available at: Technical map - Check your long-term flood risk - GOV.UK. [Accessed 07/04/2025].

[15] South East Lincolnshire Joint Strategic Planning Committee (2017). South East Lincolnshire Strategic Flood Risk Assessment. Available at: SE-Lincolnshire-SFRA-2017-v6-24th-Jan-2018.pdf. Accessed 08/04/2025.

Deepings. The undertaker for this reservoir is Tata Steel UK Ltd, as set out in Defra's Reservoir Flood Map Search Facility[16].

[16] Reservoirs Flood App

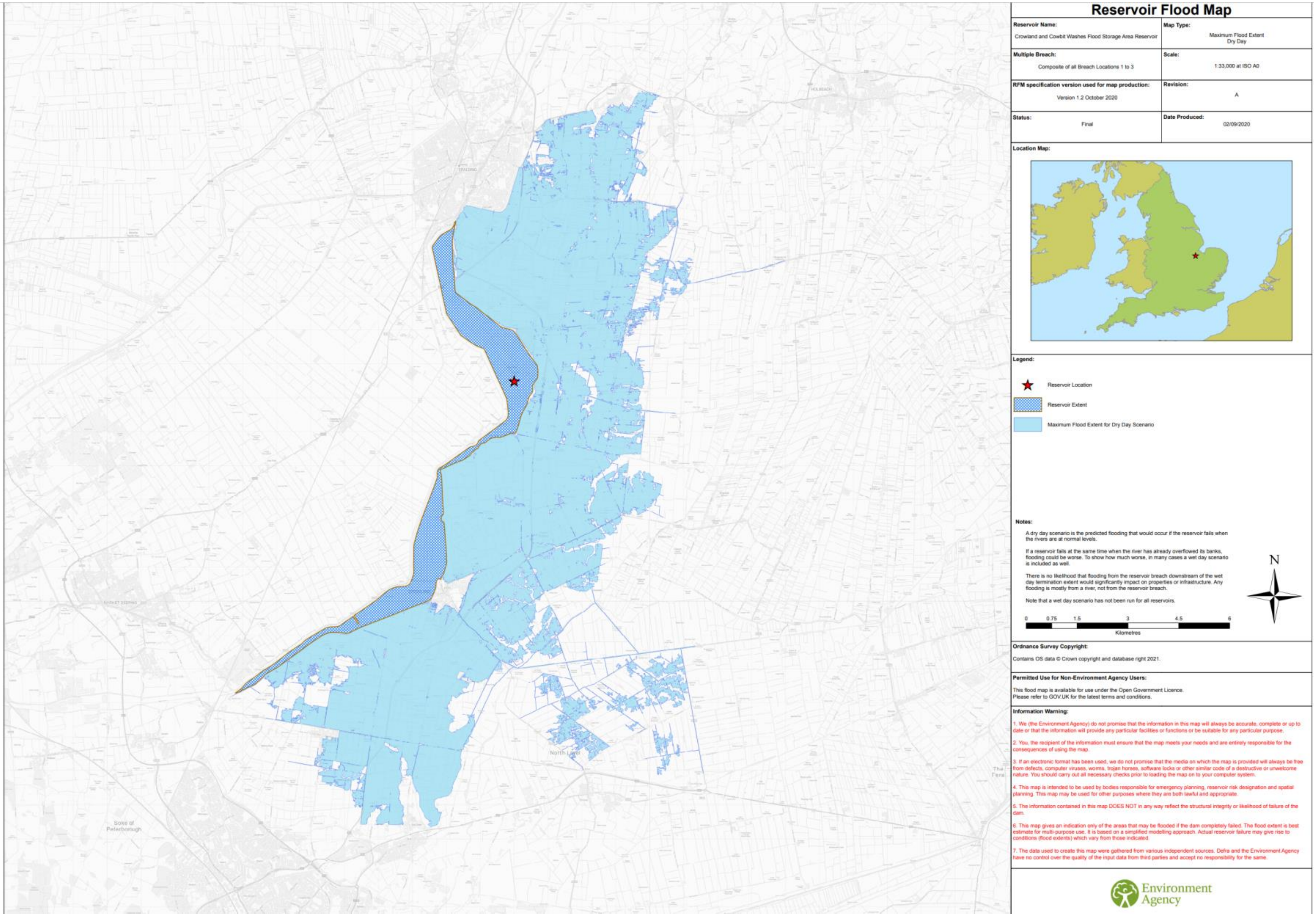

Figure 43 Reservoir Flood Map for the Crowland and Cowbit Washes © Environment Agency

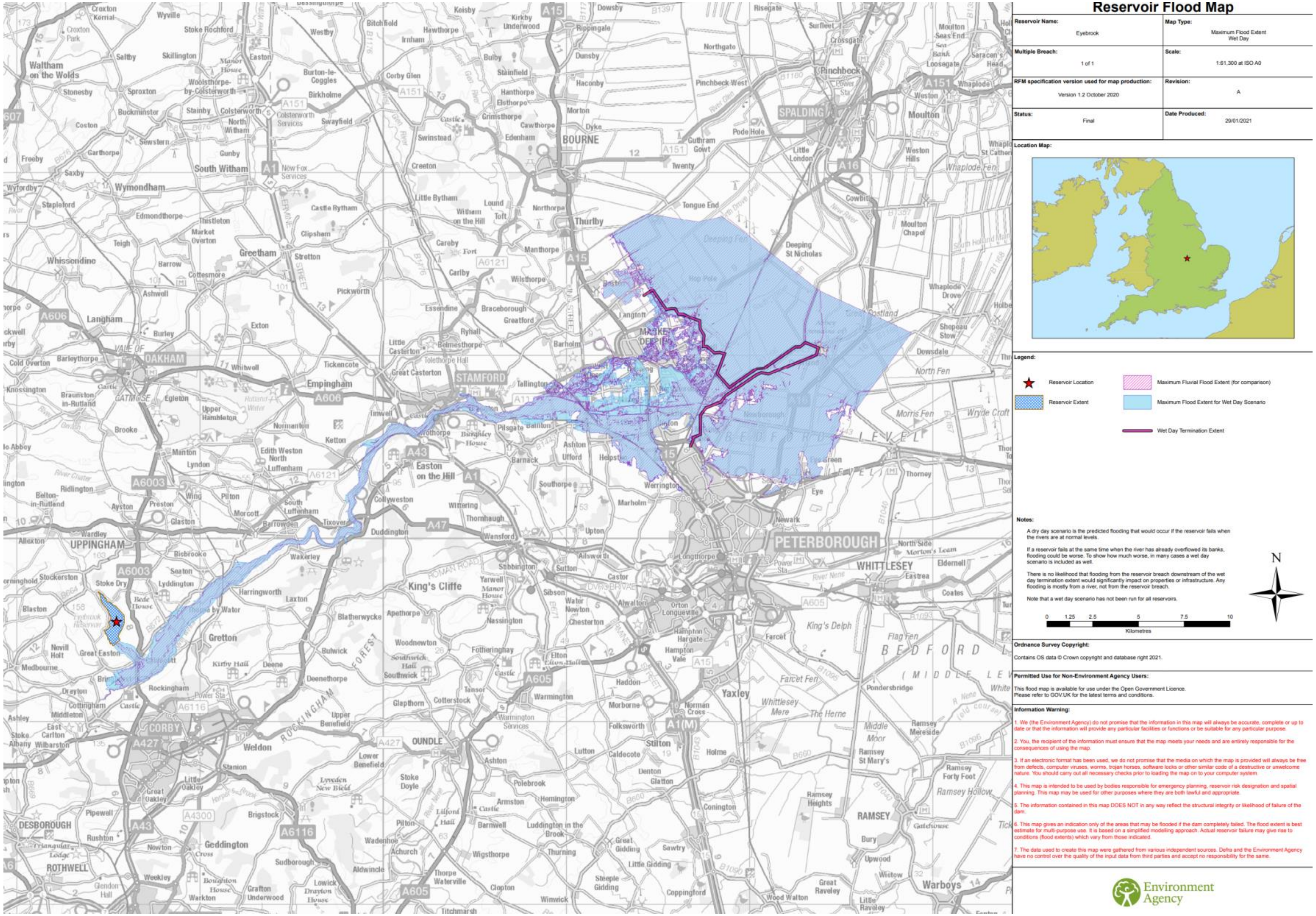

Figure 44: Reservoir Flood Map for the Eyebrook Reservoir © Environment Agency

8. Summary

8.1 Tidal flood risk

Current tidal flood risk is predominantly to Grade 1 and Grade 2 agricultural land near the coast as well as partial flooding of Fosdyke. Overtopping of the existing embankments only occurred in the most extreme event modelled – the 0.1% AEP event. Flooding in the 0.5% AEP event was caused by wave overtopping, rather that the tide level being higher than the existing embankments.

In the future, the modelled flood risk increases significantly once sea level rise up to 2115 has been applied to the existing modelling. Modelling shows that for the 0.5% AEP event when sea level rise has been considered, the total area flooded covers approximately 11% of the Lower Welland catchment (in comparison to 1.6% in the present day). This results in flooding of 41.66km^2 (4,166ha) of Grade 1 agricultural land – in comparison to 2.13km^2 (213ha) in the present day 0.5% AEP event. Future tidal flood risk results in the flooding of a number of settlements withing the Lower Welland catchment, including Gedney Drove End, a business park just outside Holbeach St Marks and all of Fosdyke.

Overall, the current tidal flood risk to the Lower Welland catchment is low due to the presence of significant flood defences, such as tidal embankments, however this increases significantly when climate change is applied, resulting in flooding of a tenth of the catchment during the 0.5% AEP event. Whilst it can be considered that the current flood risk is low, this assumes the existing embankments do not fail during an event. A breach in the tidal defences is likely to result in significant flooding of the Lower Welland catchment – in particular to Grade 1 agricultural land and Fosdyke.

8.2 Fluvial flood risk

The flood history of the Lower Welland catchment shows there have been a number of fluvial flood events that have impacted properties and agricultural land.

The main area at risk appears to be in the region of the Crowland and Cowbit Washes, which has experienced embankment breaches on a number of occasions. The only clear documentation of the flood waters escaping the Wash offline storage area is the 1947 flood event that resulted in the town of Crowland being surrounded by flood waters. Current and future modelling does not predict any flood waters escaping these storage areas. However, the modelling assumes that there are no breaches in the existing embankment.

There is also historic evidence of repeated localised flooding at Surfleet Reservoir impacting a number of properties though this has not been captured in the modelling, therefore it is not known what impact climate change may have however given that sea levels are expected to rise, and fluvial flows expected to increase it can be inferred that flood will occur more frequently.

In addition, modelling suggests there is also a risk of some localised flooding to the south of Market Deeping, mainly affecting agricultural land. Some properties are also at risk in a 0.5% AEP event or when climate change is taken into account.

It is likely that in all these areas, future fluvial flood risk has been considerably underestimated as the guidance on peak flow uplift has changed (20% to 53%) since the models were produced in 2016.

8.3 Conclusions

Modelled present day tidal and fluvial flood risk to the Lower Welland catchment is relatively low. The presence of significant tidal and fluvial embankments, as well as assets such as the Crowland and Cowbit Washes, provide a high degree of protection to the catchment from both fluvial and tidal sources. Where current tidal and fluvial flood risk is predicted; it is usually to high grade agricultural land. It should also be noted that all the modelling assumes no breaches in the flood defences. If a breach were to occur, then flooding could be extreme.

Modelling predicts that the Lower Welland catchment is vulnerable to sea level rise as a result of climate change – for the 0.5% AEP event around 11% of the catchment is predicted to inundate, even allowing for the presence of the tidal embankments.

Whilst the models show a moderate increase in fluvial flood risk as a result of climate change, the percentage peak flow uplift applied is well below current guidance. It is therefore difficult to say how severe the future fluvial flood risk will be, however given that the topography of this area is flat – it is likely to spread – resulting in an increase in flood extent. In comparison, it is clear that the future tidal flood risk is significant, with over 10% of the catchment at risk.