GREAT OUSE TIDAL RIVER BASELINE REPORT

July 2017

Environment Agency

Great Ouse Tidal River Baseline Reporting Project

This report was developed for the Environment Agency and stakeholders in the area. The report is divided into the following sections:

Click on this icon throughout document to view glossary of terms

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South Level Barrier Bank and Ouse Washes near Earith © Richard Humphrey - geograph.org.uk

Aerial view of Great Ouse Rivers at Denver Sluice: kite aerial photograph by Bill Blake Heritage Documentation

1 Introduction

The aim of this report is to develop a common understanding among all stakeholders on the Flood Risk Management (FRM) issues of the Great Ouse Tidal River System and to provide a summary of the Environment Agency's asset management and maintenance regime which is in place for the main river system. This report summarises information from a range of sources, in particular the 2010 Great Ouse Tidal River Strategy, some of which have been specifically updated to reflect current conditions. These updates were carried out as a separate study in 2016-17.

The components of 2010 Strategy that have been updated include the hydraulic modelling and the economics. These updates are primarily due to the new guidance on climate change, partnership funding and recent changes in river bed levels. We have, in light of these updates, reassessed the recommendations of 2010 Strategy. It should be noted however, that the strategy has not been revised.

While the 2010 Great Ouse Tidal River Strategy document is commonly referred to as the 2010 Strategy, the document was not formally adopted as such. The main reason being that it was finalised when two major new guidelines were released (climate change and partnership funding guidance). A decision was made at the time not to spend additional resources to incorporate the new guidance. Instead, following internal review by the Environment Agency, the findings of the 2010 Strategy were agreed in principle and the document was adopted as a Technical Management Framework for the Great Ouse Tidal River System. In this report the document will be referred to as the 2010 Strategy.

This document aims to:

Develop a common understanding on the Flood Risk Management (FRM) system and its operation for the Great Ouse Tidal River System.

Summarise the existing maintenance regime and planned works for the FRM system.

This report provides

- A description, history and operation of the Great Ouse Tidal River System from an FRM point of view.
- A review of the recommendations from the 2010 Strategy and the main findings from the 2016-17 Study.
- A summary of the existing maintenance regime and planned works for the FRM system over the next five year period (to 2021).

2 Great Ouse Tidal River System

2.1 2010 Strategy area

The Great Ouse is one of the longest rivers in the United Kingdom. It flows from Syresham, in Central England, to East Anglia before discharging into The Wash, a North Sea bay. The watercourse is tidally influenced from Brownshill Staunch, near Needingworth, Cambridgeshire. The last reach of the river from Earith to The Wash flows through a number of main rivers. In this document, rivers downstream of Earith are collectively referred to as the Great Ouse Tidal River System, whilst the river upstream of Earith is referred to as the Bedford Ouse. The Environment Agency undertook a strategy study to identify a long term sustainable plan for managing flood risk for the area along the Great Ouse Tidal River System. This study concluded in 2010 and is referred to as the 2010 Strategy.

The 2010 Strategy area covers 408km^2 of Cambridgeshire and Norfolk adjacent to the lower reach of the Great Ouse catchment from Earith to The Wash as illustrated in in Figures 2-1 and 2-2. The strategy area includes around 2,200 residential properties and 30,150 hectares of agricultural land at risk of flooding.

Figure 2-1: Location of the Great Ouse Tidal River System

The 2010 Strategy aims to provide a 100-year flood management plan for the Great Ouse Tidal River System and takes into account navigation and the natural environment. The strategy area has been divided into 14 flood cells along river channels.

The area consists of a complex system of channels forming a branched network, managed by several water level management structures. Watercourses in the study area include: the Hundred Foot River (also known as New Bedford River) from Earith to Denver (excluding the Cradge Bank) and the Great Ouse Tidal River from Denver to King's Lynn. Other watercourses and FRM assets in the area (not formally part of the 2010 Strategy) include: Old Bedford River, Ouse Washes, Ely Ouse and Flood Relief Channel as shown in Figure 2-2.
All these rivers are high level water carriers with embankments up to 6m above the surrounding floodplain.

The Ouse Washes is a 90,000,000m^3 flood storage reservoir between the Old Bedford and the Hundred Foot River. The area is seasonally flooded grassland of internationally recognised environmental value. The area has formal designation as a Site of Special Scientific Interest (SSSI), Special Protection Area (SPA) and Ramsar. The Ouse Washes plays an important role in FRM of the area but is not included in the 2010 Strategy area.

The immediate catchment area of the Great Ouse Tidal River System is predominantly rural with the key urban areas being March, Chatteris, Downham Market, Ely and King's Lynn. The 2010 Strategy area includes only a small portion of Downham Market and King's Lynn. Urban areas and villages are generally built on isolated 'islands' higher than the surrounding floodplain.

The topography is flat and low-lying with 60% of the land lying below 2mAOD (metres above Ordnance Datum). The natural catchment boundary on the south west is formed by the low clay hills of the Huntingdonshire uplands. Higher ground is also found along the coast at The Wash. Since Roman times the low-lying terrain has steadily been shrinking due to heavily managed artificial drainage activities.

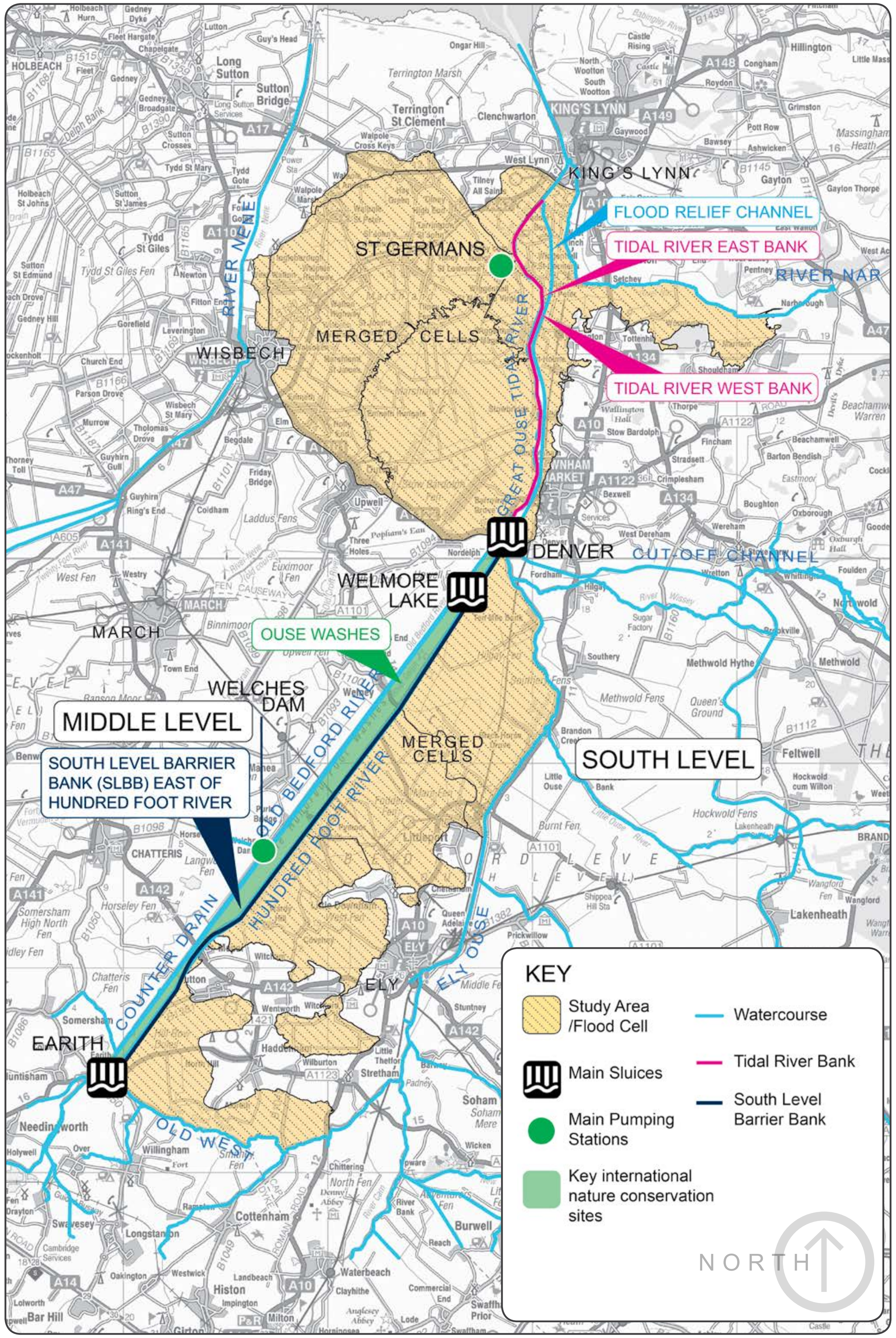

Figure 2-2: Great Ouse Tidal River System

2.2 Historical background[1]

The 2010 Strategy area is part of the Fenland system. The Fenland is a very low-lying area of England which was formed during the Quaternary Ice Age, when Britain and continental Europe were joined together. Despite being predominantly flat and low-lying, the surface of the Fenland already presented some 'high' spots known nowadays as 'islands'.

2.2.1 Roman period and Middle Ages

With the arrival of the Romans, major engineering works, including canals and roads, were constructed. By medieval times, the Fenland territory was fully used and settled. The area was very active from a commercial point of view with main activities being salt-making, fishery, agriculture and pasture. The Fenland was also the base of some important monasteries in the UK, including Ely, Peterborough, Ramsey and Spalding, which were crucial to the commercial success of the area.

Commercial activities were heavily dependent on existing waterways. During early Middle Ages, the Rivers Nene, Ouse and the Cam were discharging into the sea at Wisbech. In the 13th century, Wisbech estuary became severely silted and the Great Ouse began to flow via Wiggenhall into the sea at Lynn. This facilitated international traffic from Cambridge and Ely towards Lynn.

During the Middle Ages, flood management was up to riparian landholders who looked after the assets in their territory. Such divided responsibilities, gave many opportunities for evasion and negligence. It was during this time that the 'commission of the sewers' was introduced to ensure that landholders were fulfilling their duty. However most of the time the commissioners were landholders themselves and therefore unwilling to perform their duties.

2.2.2 Sixteenth century

In 1531, following severe flooding, Henry VII strengthened the administrative system by creating an Act of Parliament to grant further authority to the commissions of sewers. The commissions acquired judicial, executive and legislative character, meaning that they had the right to: punish offenders as appropriate, administer financial arrangements for repairs, and make statutes and provisions as required. Crucially, the commissioners had no right to construct new drains or banks.

Gradually but steadily, the idea of a large-scale drainage project was taking place, replacing individual and local efforts. In 1588, a general commission of the counties of Northampton, Lincoln, Cambridge and Huntingdon asked about the conditions of the Fenland. Sir William Russel, second Earl of Bedford and sewer commissioner for Cambridgeshire, was among those taking an interest in the drainage of the area and brought three Dutch experts to examine the Fenland near Thorney. In the meantime, Humprey Bardley (a Dutch surveyor) urged that the only way to drain the area was to direct the water along the shortest track possible through the biggest outfall (King's Lynn).

Following some severe flooding in the late 1590s, there was more and more pressure on the local and national authorities to coordinate a definitive large-scale drainage solution.

As a result, in 1600 an Act for reclaiming many thousands of acres of marshes within the Isle of Ely and the counties of Cambridge, Huntingdon, Northampton, Lincoln, Suffolk, Norfolk, Essex, Sussex and Kent was approved. Outside financial assistance was required due to lack of capital funds from the state.

To secure external contribution, part of the reclaimed land was offered to the contributors. Not everyone however was favourable to draining the Fenland.

Parties interested in navigation were not keen on any drainage system, fearing this could lower water levels and have a detrimental effect on boat traffic. Among those, the most famous is perhaps Cambridge University, which received provisions through boats coming from King's Lynn.

2.2.3 Seventeenth century

It was not until 1630 with the 'Lynn Law' that the fourth Earl of Bedford appointed Cornelius Vermuyden (a Dutch engineer) to drain the southern part of the Fenland. The main objective of the drainage was to create land free from water in summer and ensure 'reasonable' amount of flooding in winter. The idea of completely eliminating flood risk all year round still appeared unreachable.

At the time, there were two main drainage options namely: deepen and clear existing channels or shorten/straighten the course of existing rivers. Vermuyden was an advocate for straight cuts and began construction of the Old Bedford River from Earith to Salter's Lode to convey water more quickly between Earith and King's Lynn. The cut was designed to relieve the meandering course of the Great Ouse and provide lands for summer grazing (known as 'summer grounds').

[1] *H.C. Darby (1983), "The changing Fenland", Cambridge University Press*

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In 1650, the 'Pretended Act' had the ambitious project to make the summer grounds 'winter grounds' to enable cultivation of colseed and rapeseed in the Fenland. Vermuyden was then instructed to make the Fenland area dry all year round.

In 1653, a second cut (the Hundred Foot River) was then built, running parallel to the Old Bedford. The Counter Drain (parallel to the Old Bedford) and Welches Dam were also built in this period. The Hundred Foot River was made the main channel for flood water of the Great Ouse.

The flood storage area of the Ouse Washes was created at the same time. The Ouse Washes was also intended as a storage for high tides and, for this purpose, a lock was installed near Denver preventing tidal ingress into the Ely Ouse system. For navigation purposes, Denver Sluice was kept closed during summer maintaining high freshwater levels along the Ely Ouse system.

Vermuyden divided the Fenland area into three parts: North Level (between the River Nene and the Welland), Middle Level (between the River Nene and the Old Bedford) and South Level (contained by the Hundred Foot River and the Ely Ouse). This geographical division was also used for administrative purposes by the commissioners. All levels were divided into districts under the regulation of their respective commissions. Early in the 20th century boundaries of the three levels were revisited to include new areas.

Despite drainage improvements, some of lands were still drowned in the South Level.

In 1663 complaints that some lands in the South Level were still drowned were collected in the General Drainage Act. Flooding was attributed to siltation along the Great Ouse Tidal River (due to low gradient and sediment transport during the rising tide) and lack of hydraulic head at Denver Sluice.

In addition, oxidation of peat resulted in surrounding land levels lowering, and caused stability problems to watercourses' banks. Frequent maintenance works on the watercourses' banks were required, together with dredging of bed channels and systematic weeding. The system became very expensive to maintain and increasingly prone to flooding. One main issue was that the Bedford Level Corporation was only responsible for maintaining existing drains, but could not build any additional dykes. Local landowners were forced to supplement the larger drainage scheme by local district enterprise at their own expense.

*Cornelius Vermuyden**

2.2.4 Eighteenth century

The introduction of pump engines in the 18th century was a critical factor in saving the Fenland from permanent re-inundation. The engines were initially powered through horses, wind or water mills.

Some people tried to take a broader view and find a scheme which could solve the Fenland's flooding problem. As in the pre-drainage Fenland, the conflict of interest between navigation and agricultural needs continued.

In the 18th century there were discussions about silt deposition at sluices (especially Denver Sluice), mechanics of siltation and formation of sand-banks in the Great Ouse Tidal River.

2.2.5 Nineteenth century

By the 19th century, it was clear that wind and water mills were not adequate to deal with flooding of the Fenland, which was worsened by lowering of peat. Banks, even where well made, consisted of porous and light material, prone to breaching.

In 1821, a cut near Wiggenhall St. James was built to ease flow through the meandering Great Ouse Tidal River to The Wash. In 1825, Welmore Lake Sluice was built together with widening and deepening of the Hundred Foot River and enlarging of the Cradge Bank. In 1844, the Middle Level Main Drain was excavated to connect the Middle Level Area to the Great Ouse Tidal River at St. Germans. The existing pumps in the catchment were also gradually being replaced with steam driven pumps. These improvements in drainage were paralleled by advances in agricultural techniques. The Fenland was gradually taking on its modern character.

* Source: http://www.bbc.co.uk/arts/yourpaintings/paintings/ sir-cornelius-vermuyden-15951677-133559

2.2.6 Twentieth century

Despite major drainage improvements carried out from the 17th century, the Fenland still experienced flooding in 1936, 1937, 1939 and 1940. The major controversies in the 19th and 20th centuries were about Denver Sluice and the Great Ouse Tidal River between Denver and King's Lynn. From 1900, many shoals and obstructions on the Great Ouse Tidal River caused water to be higher than in previous years. When spring tides coincided with river floods and a North Sea surge, a flood in the Ely Ouse system could occur as Denver Sluice gates could not be kept open long enough.

In the first years of the 20th century, most of the South Level was waterlogged. In August 1912, it was reported that crops at Ramsey could be harvested only via boats. The addition of a new 'eye' (sluice gate) at Denver Sluice did not improve conditions. This was not Vermuyden's fault, as his original design was not completely realised. Vermuyden's design also included a channel to collect flood waters from three rivers, known then as Mildenhall, Brandon and Stoke Ferry Rivers (now Lark, Little Ouse and Wissey) and divert them via a Cut-off Channel to the north of Denver Sluice.

The Great Ouse Catchment Board called in consulting engineers, Sir Murdoch MacDonald and Partners to study a solution and mitigate flooding in the South Level. In July 1940 Sir Murdoch MacDonald's Report of Flood Protection was published. The 1940 MacDonald's report recommended building a Cut-off Channel,

QUATERNARY ICE AGE
Fenland formed; first settlements established

ROMAN PERIOD
Major engineering works constructed (including canals and roads)

MIDDLE AGES
Fenland fully settled and commercially active

1588
Dutch experts examine the Fenland near Thorney

1590s
Severe flooding

1600
Act for reclamation approved

1630s
'Lynn Law' - Cornelius Vermuyden appointed to drain southern part of the Fenland, construction of Old Bedford

1650
'Pretended Act' Vermuyden instructed to make the Fenland dry year round

1653
Hundred Foot River built

18th century
Introduction of pump engines

1844 Middle Level Main Drain excavated to connect Middle Level Area to the Great Ouse at St. Germans

1934 Pumping station at St. Germans opened

1936-40
Continued flooding

1940 Sir Murdoch MacDonald Report of Flood Protection published

1939-45 World War II
(Flood Relief Channel project put on hold)

1947 Major flooding

1949 Great Ouse Flood Protection Act passed

1953 Great Ouse Flood Protection Act agreement reached

1954
Murdoch MacDonald scheme works started

1968
Ely Ouse – Essex Water Act passed, resulting in three new sluices to be built near Denver

1970
Murdoch MacDonald scheme works finished

Figure 2-3: Great Ouse Tidal River System historical overview

collecting water from the Lark, Little Ouse and Wissey (key tributaries of the Ely Ouse) and a Flood Relief Channel from Denver to King's Lynn. The report also included an alternative 'cheaper' option, which included only the Flood Relief Channel. The initial plan of the Board was to go for the most economic option due to lack of funds. The project was however put on hold due to the Second World War.

March 1947 was a particularly bad winter with very heavy rain, accompanying snow melt and heavy winds creating waves against the banks and breaches. Most of the South Level was under water for approximately two weeks. The years following 1947 saw improvements in land drainage of the areas with diesel pumps being installed to cope with decrease in the peat surface, however the MacDonald scheme was still to be implemented. The Great Ouse Board was keen to amplify the scheme in light of the catastrophic effect of the 1947 flood but the main objector was the King's Lynn Conservancy Board and other parties interested in navigation. As a result, in 1949 the Great Ouse Flood Protection Act was passed with a clause for protection of shipping interests. Construction of the Flood Relief Channel was conditional upon protective works in the estuary being agreed among all interested stakeholders. In 1953 an agreement was finally reached. In the same year, a destructive tidal event took place along the North Sea Coast, which prompted the agreement to include heightening the banks of the Great Ouse Tidal River. In 1954 works for the Murdoch MacDonald scheme finally started. The scheme included the construction of the Flood Relief Channel from Denver to the outskirts of King's Lynn with water entering from A.G. Wright Sluice and discharging from Tail Sluice; elimination of the Great Ouse bend at St. Mary Magdalen; deepening and widening of the Ely Ouse channel from Denver to its junction with the Cam; creation of the Cut-off Channel; additional works in The Wash for safeguarding shipping interests. Works lasted until 1970.

Flooding in Ely 1947 © Copyright Ely Standard

In 1970 as a result of the 'Ely Ouse – Essex Water Act' of 1968, three additional sluices were built near Denver (Residual Flow Sluice, Impounding Sluice and Diversion Sluice). The structures were required to 'divert' the course of the flow along the Cut-off Channel and enable transfer of freshwater from the Great Ouse basin to Essex (known as the 'Essex Transfer Scheme').

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2.3 Overall system

The Great Ouse Tidal River System is a heavily modified system with a complex network of structures hydraulically linked with each other. These include:

- A Hundred Foot River
- B Great Ouse Tidal River
- C Old Bedford/River Delph
- D Counter Drain/Old Bedford
- E Ouse Washes
- F Old West
- G Ely Ouse
- H Ten Mile River
- I Cut-off Channel
- J Denver Complex
- K Flood Relief Channel
- Lowland drainage area

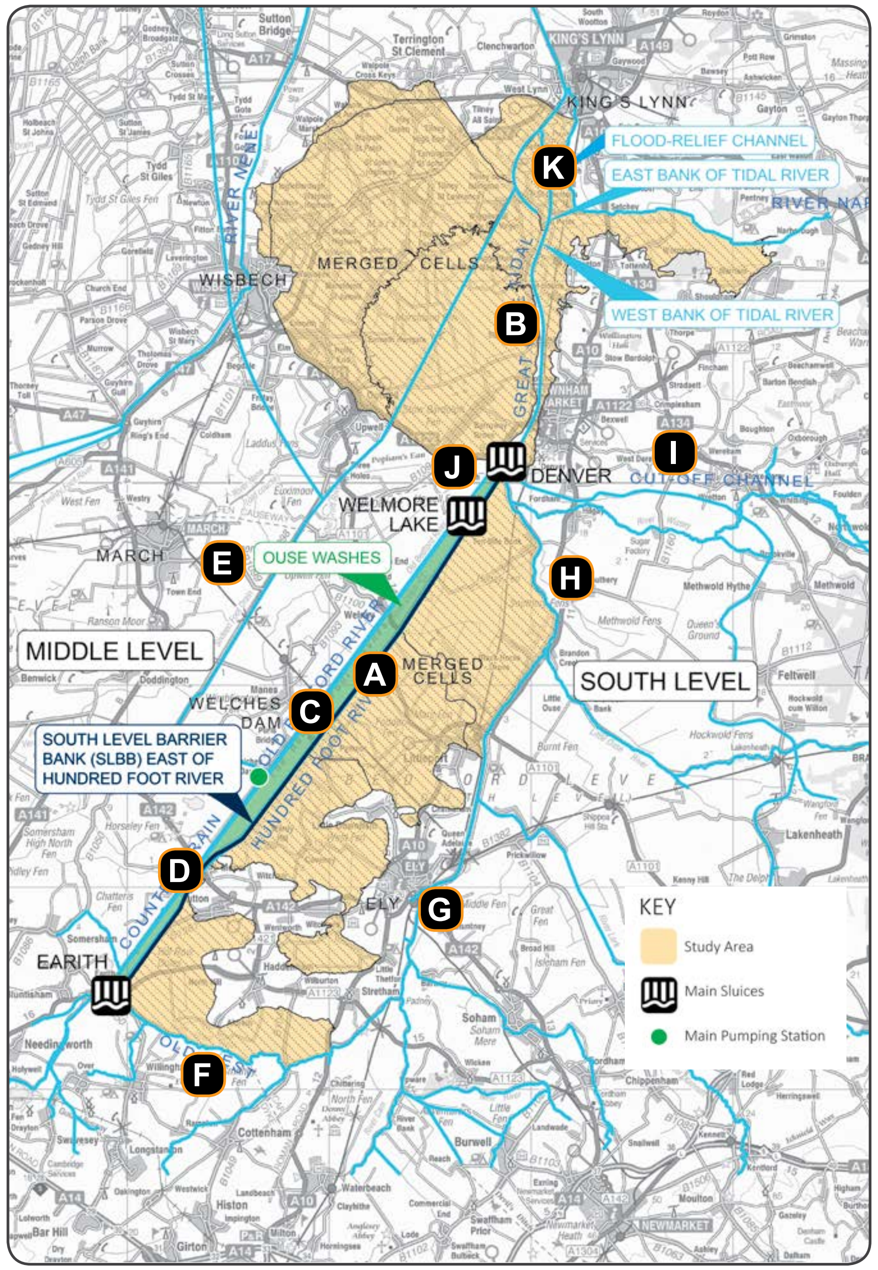

Figure 2-4: Great Ouse Tidal River System structure location map (simplified)

A Hundred Foot River

The Hundred Foot River (also known as the New Bedford River) flows from Earith to Denver Sluice. The South Level Barrier Bank runs along the right-hand side of the Hundred Foot River and protects the South Level from flooding. Its left-hand bank is called Cradge Bank. The watercourse is tidally influenced as it is directly connected to the Great Ouse Tidal River.

B Great Ouse Tidal River

The Great Ouse Tidal River is the length of river from Denver Sluice to The Wash. The river is a high level water carrier with bank heights of up to 6m above the surrounding floodplain. The Great Ouse Tidal River System is connected to the Ely Ouse System (a freshwater environment) through the Denver Sluice. The Ely Ouse system includes the Old West, the Ely Ouse, the Cut-off Channel and the Flood Relief Channel.

C Old Bedford River/River Delph

The Old Bedford River (known as River Delph downstream of Welches Dam) runs parallel to the Hundred Foot River from Earith. The area between the two watercourses serves as a flood storage reservoir called the Ouse Washes. At the northern end of the Ouse Washes, the Old Bedford/ River Delph terminates at Welmore Lake Sluice where it joins with the Hundred Foot River. The Middle Level Barrier Bank runs along the left-hand side of the Old Bedford/ River Delph and protects the Middle Level from flooding.

D Counter Drain/Old Bedford River

The Counter Drain (known as Old Bedford downstream of Welches Dam) is further to the west of Middle Level Barrier Bank and runs parallel to the Old Bedford/ River Delph. The Low Bank forms the outer bank of the Counter Drain/Old Bedford. The Counter Drain/ Old Bedford normally discharges through the Old Bedford Sluice at Salters Lode

under gravity, however when this is not possible, water is pumped into the Old Bedford/ Ouse Washes from Welches Dam Pumping Station. Welney Gate, a vertical sluice downstream of Welches Dam, is closed to manage water levels in the river at the time of pump operation at Welches Dam.

E Ouse Washes

The Ouse Washes is maintained by the Environment Agency (river and embankments), private landowners and Hundred Foot Washes IDB (riparian habitat). The Ouse Washes is one of the largest remaining areas of lowland wet grassland in the UK and holds notable environmental value as a Site of Special Scientific Interest (SSSI), Special Protection Area (SPA) and Ramsar site. Earith Sluice regulates flow entering the Old Bedford River and the Ouse Washes. Welmore Lake Sluice and pumping station maintain a defined water level in the Washes. The Ouse Washes is bounded by the Middle Level Barrier Bank (Old Bedford) and the Cradge Bank (Hundred Foot River).

F Old West

The Old West was the former course of Great Ouse River before the construction of Old Bedford in 1630. The channel links the Hundred Foot River, near Earith, to the Ely Ouse. The channel is mainly used for navigation purposes and the access to its downstream length is regulated through Hermitage Lock. The Old West boundaries are defined by Earith (upstream) and its confluence with the River Cam (downstream).

G H Ely Ouse/Ten Mile River

Downstream of the Old West, the previous course of Great Ouse River (prior to 1630) is called Ely Ouse. It runs from the confluence with the River Cam to Littleport Bridge, where it is known as the Ten Mile River. The flow from this river to the Great Ouse Tidal River is regulated by Denver Sluice at its downstream end.

I Cut-off Channel

The Cut-off Channel diverts flood water from the Lark, Little Ouse and Wissey, before it reaches the Ely Ouse. Excess water is then discharged into the Flood Relief Channel and eventually in the Great Ouse Tidal River at Tail Sluice. The Cut-off Channel flow can be reversed during low-flow conditions to transfer water from the Ely Ouse catchment as part of the Ely Ouse-Essex Water Transfer scheme for public water supply.

J Denver Complex

In addition to discharging water from the Ely Ouse into the Great Ouse Tidal River, Denver Sluice also prevents tidal ingress into the Ely Ouse and allows boats to navigate between the two systems.

Denver Sluice is part of the Denver Complex which includes the following structures:

- A.G. Wright Sluice (or Head Sluice): regulating flow into the Flood Relief Channel from the Ely Ouse/Ten Mile River.
- Impounding Sluice: used to reverse flow along the Cut-off Channel as part of the Ely Ouse-Essex Water Transfer scheme. In high-flow period, the sluice allows excess water from the Cut-off Channel to flow into the Flood Relief Channel.
- Diversion Sluice: operated in conjunction with Impounding Sluice to transfer water from the Ely Ouse/Ten Mile River to Essex as part of the Ely Ouse-Essex Water Transfer scheme.
- Residual Flow Sluice: low-flow structure connecting the Flood Relief Channel with the Ely Ouse/Ten Mile River. The structure diverts residual flow to the Flood Relief Channel when required.
- Denver Relief Channel Lock: lock connecting the Ely Ouse/Ten Mile River to Flood Relief Channel for navigation.

K Flood Relief Channel

The Flood Relief Channel runs close to the Great Ouse Tidal River from Denver to the outskirts of King's Lynn, 1.5km north of Saddlebow. The Flood Relief Channel functions as a flood storage for the Ely Ouse/Ten Mile River and the Cut-off Channel. Flow in the Flood Relief Channel is regulated by A.G. Wright Sluice and Impounding Sluice at Denver Complex at its entry and by Tail Sluice at the downstream end. Tail Sluice is a gravity sluice discharging in the Great Ouse Tidal River during low tide conditions.

Lowland drainage area

The surrounding floodplain comprises of a network of land drains and pumped catchments. Internal Drainage Boards (IDBs) manage this area of land in terms of flood risk and without their infrastructure of drains and pumping stations the area would be liable to flooding. The following IDB districts fall within the strategy area:

- Haddenham Level (managed by the Middle Level Commissioners)
- Littleport and Downham IDB district (part of the Ely Group of Internal Drainage Boards)
- Downham and Stow Bardolph IDB, Stokeferry IDB and East of Ouse Polver and Nar IDB (part of the Dowham Market Group of IDBs)
- Kings Lynn Drainage Board (part of the Water Level Management Alliance)
- Middle Level Commissioners.

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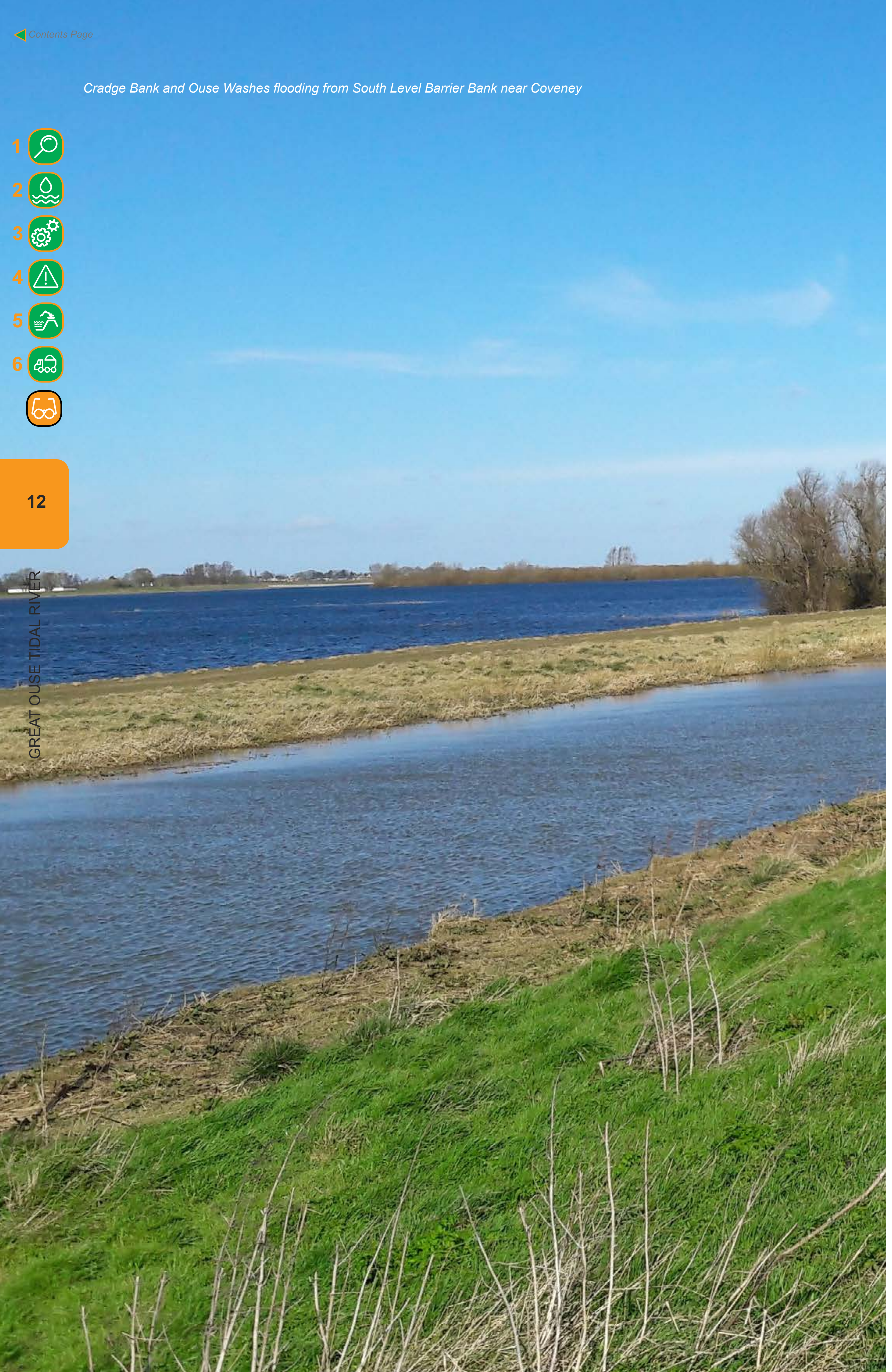

Cradge Bank and Ouse Washes flooding from South Level Barrier Bank near Coveney

DATA SHEET 1

Hundred Foot River

Description

The Hundred Foot River (also known as New Bedford River) is an engineered channel flowing between Earith and Denver for approximately 33.5km. The river is a high level water carrier which is tidally influenced. In normal flow conditions, the majority of the water from the Bedford Ouse flows through this. The Cradge Bank forms its left bank while the South Level Barrier Bank serves as its right bank.

The Hundred Foot River lies adjacent to the Ouse Washes with the Cradge Bank between. During high-flow events, water can spill from the Hundred Foot River into the Ouse Washes or in the opposite direction from the Ouse Washes into the Hundred Foot River.

The Hundred Foot River is hydraulically connected with the Old Bedford system through Welmore Lake Sluice.

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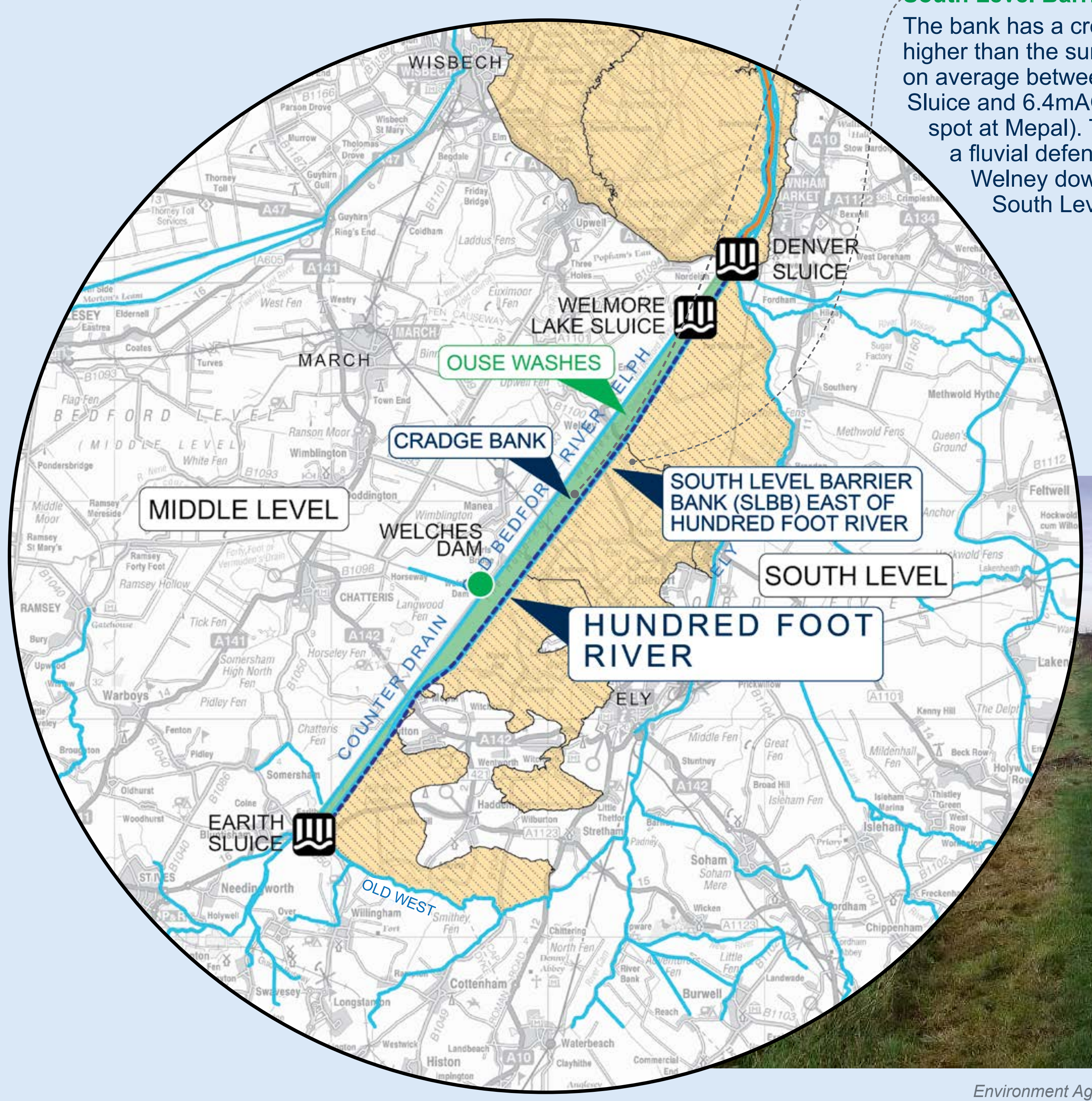
Cradge Bank

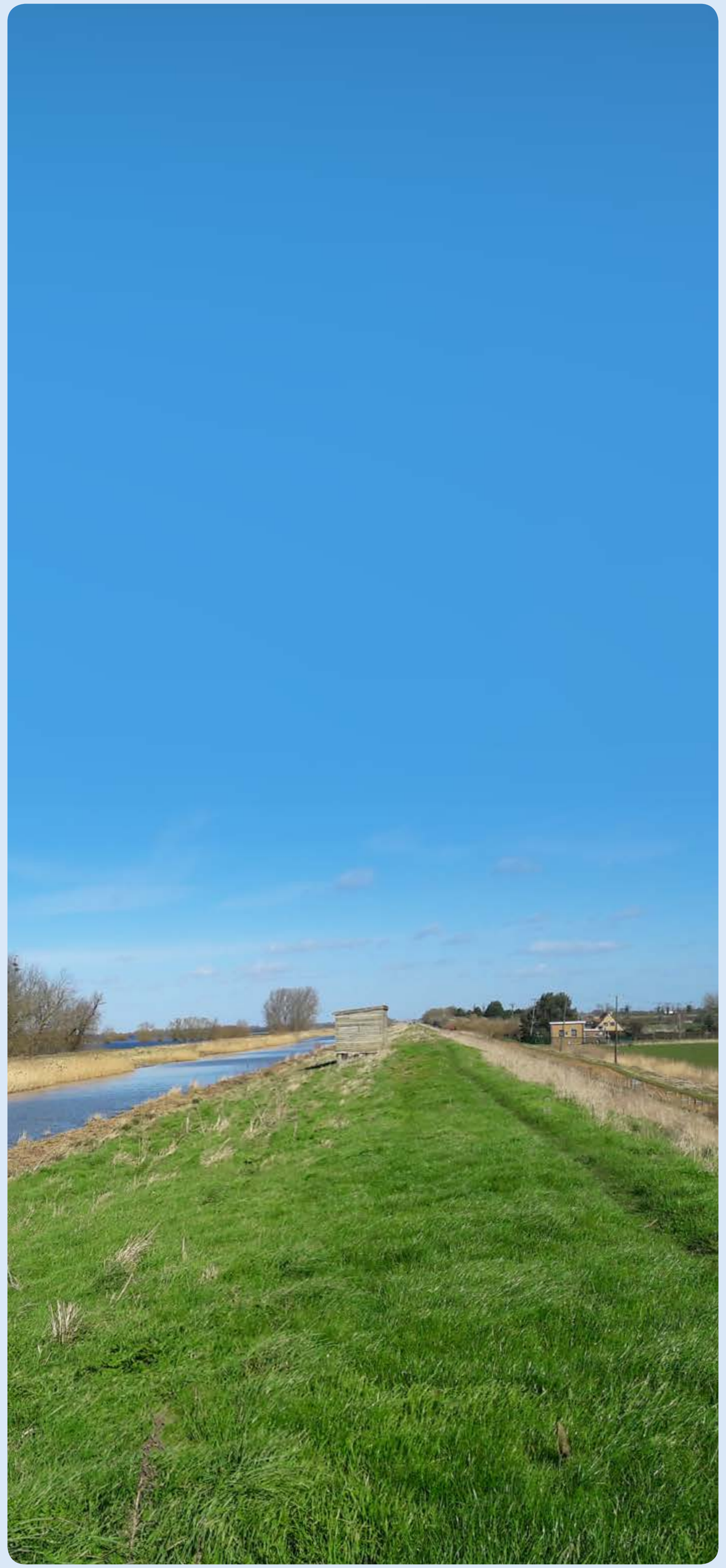
The bank is part of the reservoir designation for the Ouse Washes. However, during extreme flood events, the bank is submerged and water is contained between the Middle Level Barrier Bank (left bank of the Old Bedford River) and the South Level Barrier Bank.

South Level Barrier Bank

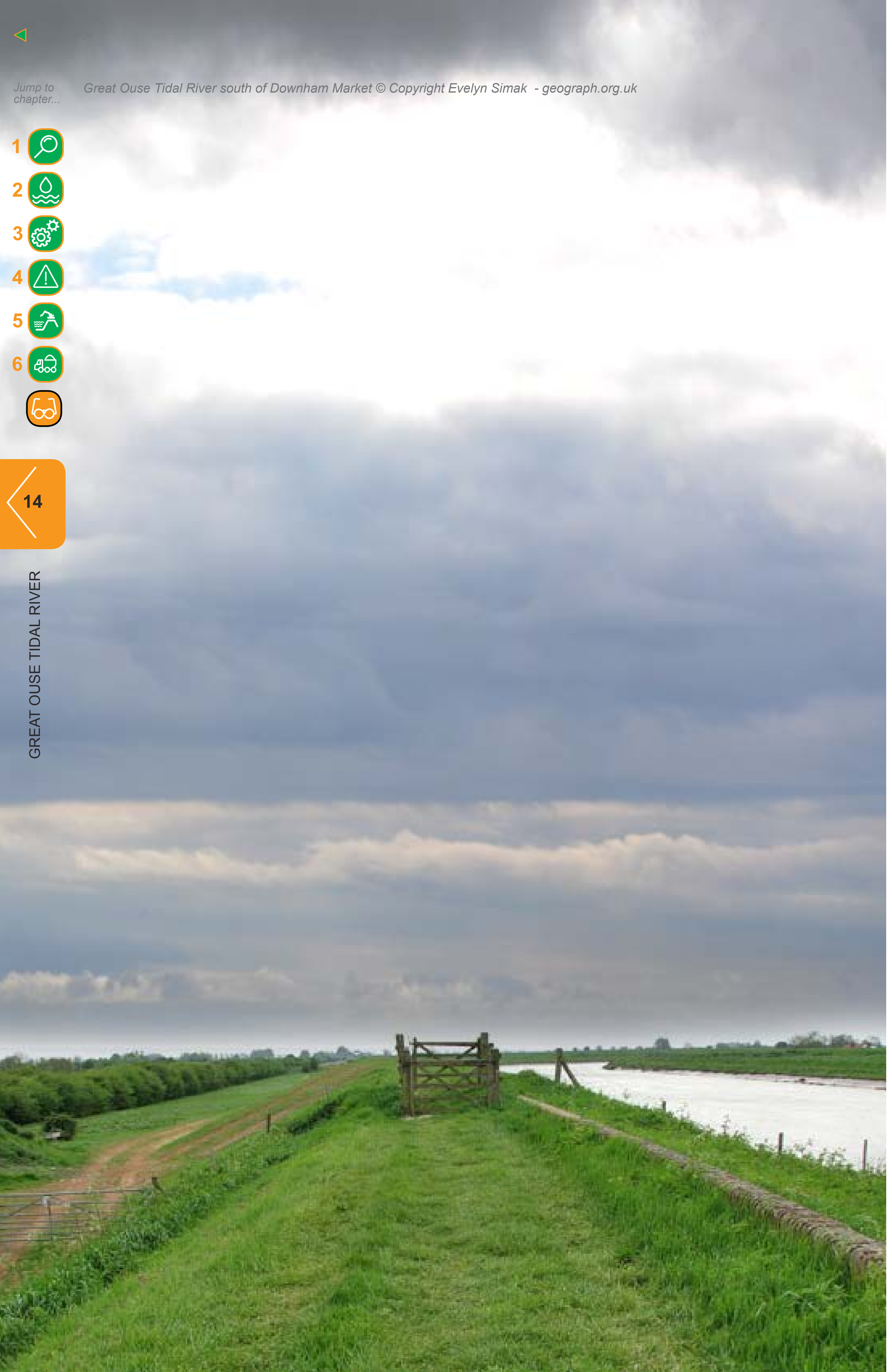
The bank has a crest level approximately 6m higher than the surrounding floodplain (5.7mAOD on average between Mepal and Welmore Lake Sluice and 6.4mAOD upstream, excluding low spot at Mepal). The South Level Barrier Bank is a fluvial defence from Earith to Welney. From Welney downstream the bank protects the South Level against surge tides.



Environment Agency cutting grass along the South Level Barrier Bank



Cradge Bank and Ouse Washes in flood from the South Level Barrier Bank near Coveney


Great Ouse Tidal River south of Downham Market © Copyright Evelyn Simak - geograph.org.uk

DATA SHEET 2

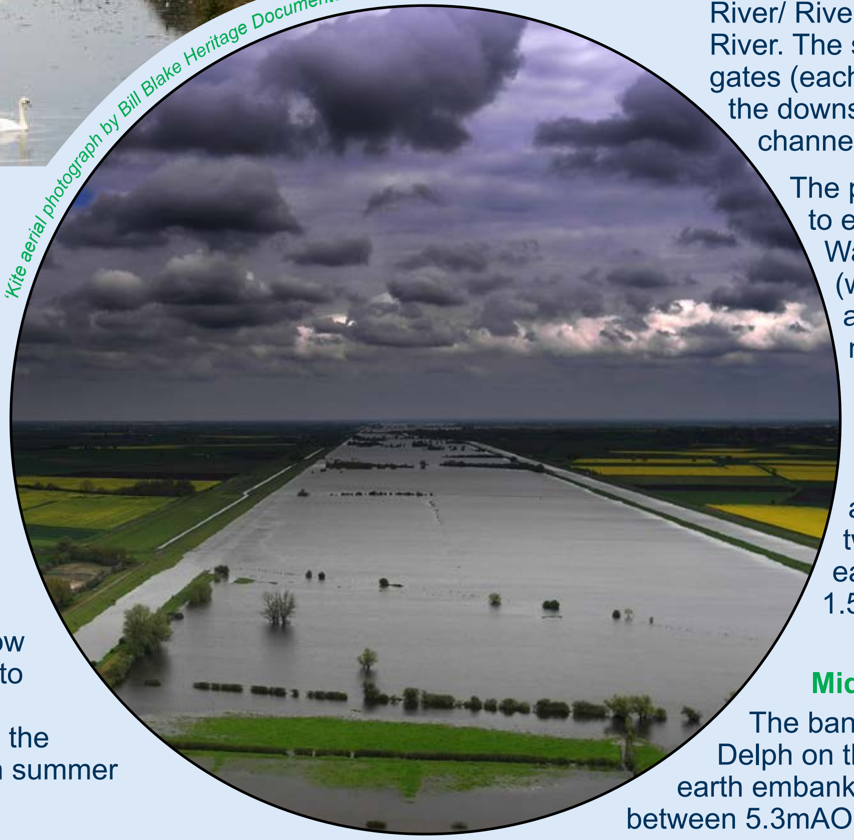
Old Bedford River/River Delph and Counter Drain/Old Bedford

Description

The Old Bedford/ River Delph is an engineered channel diverting flood flow from the Bedford Ouse through Earith Sluice. The channel runs from Earith to Welmore Lake Sluice, where it joins the Hundred Foot River. The area of land between the Old Bedford River/ River Delph and the Hundred Foot River is known as the Ouse Washes. During high-flow conditions, water spills from the right-hand bank of the Old Bedford into the Washes, providing flood storage. The left bank of the Old Bedford is called Middle Level Barrier Bank. The watercourse is known as the River Delph downstream of Welches Dam. The Counter Drain/ Old Bedford lies immediately west of the Middle Level Barrier Bank. The Low Bank forms the outer bank of the Counter Drain. The Counter Drain/ Old Bedford normally gravity discharges through Welney Gate and the Old Bedford Sluice into the Great Ouse Tidal River but when this is not possible it is pumped into the Old Bedford/ Ouse Washes at Welches Dam Pumping Station.

The Old Bedford is predominantly a freshwater system.


Ouse Washes © Richard Humphreys - Geograph.org.uk


Kite aerial photograph by Bill Blake Heritage Documentation

Earith Sluice

The structure is located at the upstream end of the Old Bedford River. The sluice is integrated into a road bridge structure on the A1123 east of Earith, Cambridgeshire. The structure consists of three radial sluice gates each 6.7m wide. The gates allow excessive flow from Bedford Ouse into the Old Bedford River during flood conditions for storage in the Ouse Washes until levels recede. The sluice is generally closed in normal flow conditions, but opens in high-flow periods to allow floodwater into the Old Bedford and the Ouse Washes. The sluice opens when the upstream water levels reach 3.77mAOD in summer and 3.17mAOD in winter.

Welmore Lake Sluice and pumping station

The structure, also known as John Martin Sluice, is set at the downstream end of the Old Bedford River/ River Delph where it joins the Hundred Foot River. The structure consists of three guillotine gates (each 7.3m wide) with timber 'V' doors on the downstream face protecting the upstream channel against tidal infiltration.

The primary functions of the structure are to evacuate flood water from the Ouse Washes into the Hundred Foot River (when water levels in the river are low) and to maintain water levels during normal flow conditions. A pumping station at the side of the structure can be used for draining water from the Ouse Washes at low levels. The pumping station has a capacity of approximately 6m^3/s and comprises of two land drainage pumps of 0.75m^3/s each and three transfer pumps of 1.5m^3/s each.

Middle Level Barrier Bank

The bank runs parallel to the Old Bedford/River Delph on the west side. The bank comprises earth embankments with existing crest levels lying between 5.3mAOD and 6.4mAOD.

Ouse Washes

The Ouse Washes is a flood storage reservoir lying between the Hundred Foot River and the Old Bedford/ River Delph for the length of watercourses between Earith and Welmore Lake Sluice. Water can enter the Ouse Washes from Earith Sluice in the Old Bedford or by overspilling the Earith Causeway road (A1123) when river levels are extremely high. The Ouse Washes covers an area of approximately 23km^2 (approximately 33km long and up to 1.7km wide) and offers a storage volume of 90,000,000m^3. The Washes is defined between the Middle Level Barrier Bank along the Old Bedford (left bank) and the Cradge Bank along the Hundred Foot River (left bank). The Ouse Washes is also a site of internationally recognised environmental value hosting overwintering and breeding birds, and the spined loach (a fish) in the watercourses.

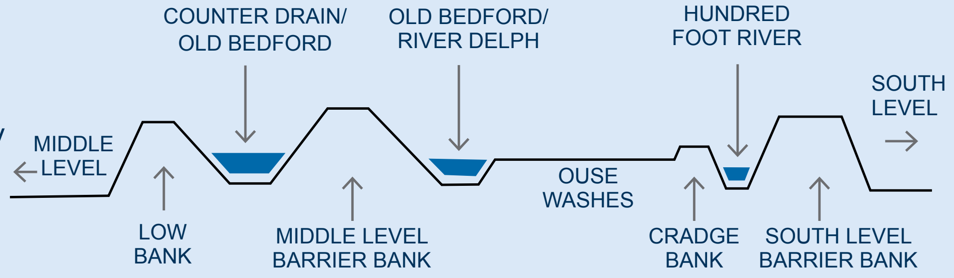


Figure 2-5: Ouse Washes section (indicative/not to scale)


Welmore Lake Sluice with desilting in progress


Earith Sluice


Welmore Lake Sluice and pumping station

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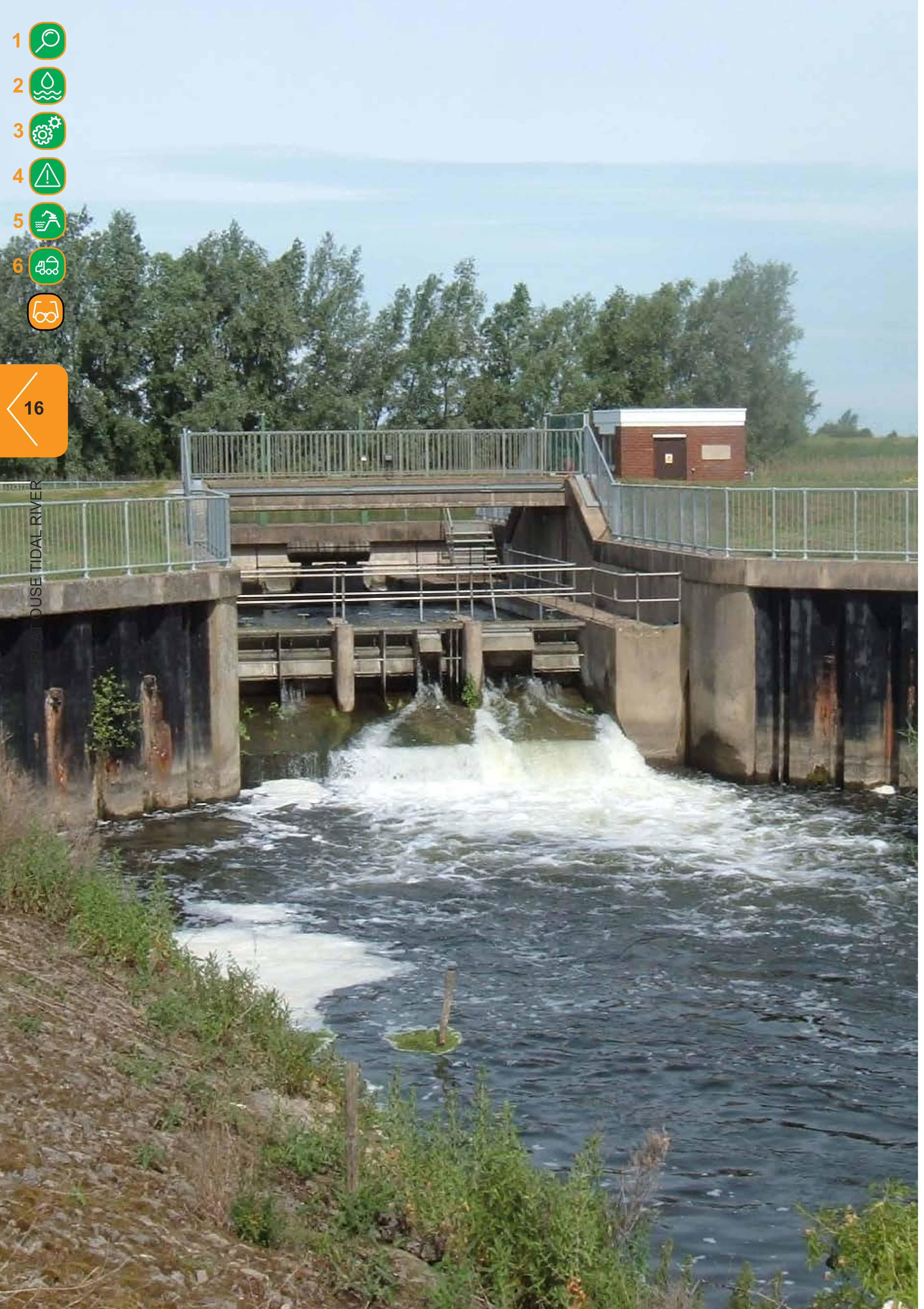
Residual Flow Sluice at Denver Complex



DATA SHEET 3

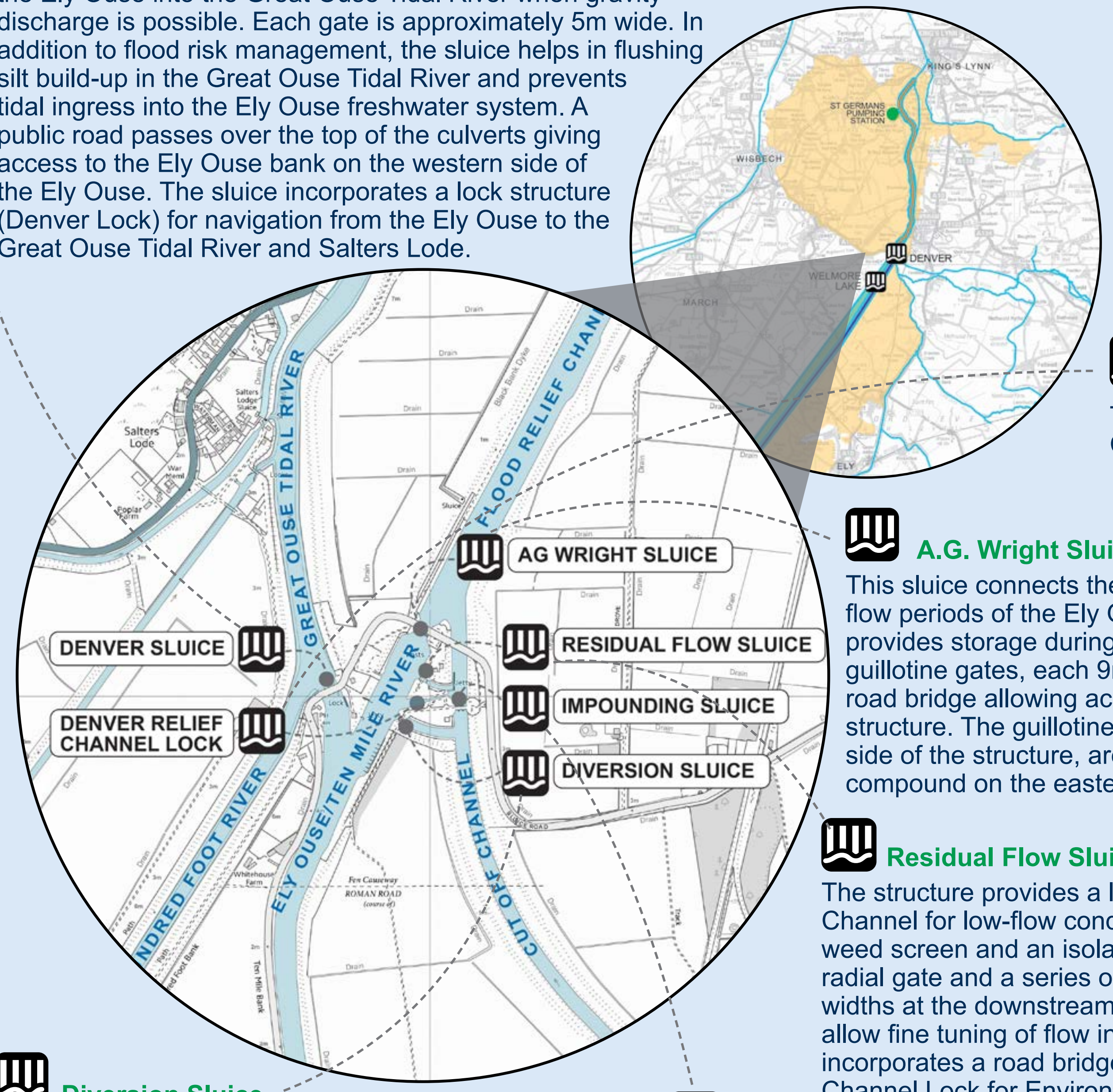
Denver Complex

Description

Denver Complex is a combination of structures at the confluence of five watercourses. The complex is a key hydraulic control for the flood risk management system with all assets being manually operated.

Denver Sluice

Three separate vertical lift gates (on the fluvial side) and three mitre-gate sluices (on the tidal side) discharge water from the Ely Ouse into the Great Ouse Tidal River when gravity discharge is possible. Each gate is approximately 5m wide. In addition to flood risk management, the sluice helps in flushing silt build-up in the Great Ouse Tidal River and prevents tidal ingress into the Ely Ouse freshwater system. A public road passes over the top of the culverts giving access to the Ely Ouse bank on the western side of the Ely Ouse. The sluice incorporates a lock structure (Denver Lock) for navigation from the Ely Ouse to the Great Ouse Tidal River and Salters Lode.



Denver Relief Channel Lock

This lock connects the Ely Ouse to the Flood Relief Channel for navigation.

A.G. Wright Sluice

This sluice connects the Ely Ouse to the Flood Relief Channel in high-flow periods of the Ely Ouse catchment. The Flood Relief Channel provides storage during high tides. A.G. Wright Sluice consists of three guillotine gates, each 9m wide. The structure incorporates a public road bridge allowing access to land and properties to the west of the structure. The guillotine gates and access way, located on the upstream side of the structure, are enclosed within an Environment Agency compound on the eastern side of the structure.

Residual Flow Sluice

The structure provides a link between the Ely Ouse and Flood Relief Channel for low-flow conditions. It acts as a flow gauge and incorporates a weed screen and an isolation penstock at the upstream end, a float control radial gate and a series of individually isolated flow control gates of various widths at the downstream end of the structure. The flow control gates allow fine tuning of flow into the Flood Relief Channel. The structure also incorporates a road bridge allowing access to the north side of Denver Relief Channel Lock for Environment Agency vehicles.

Diversion Sluice

This is a water level management structure that allows water from the Ely Ouse to the Cut-off Channel. The structure consists of a bottom hinged variable height weir and is used to transfer flow into the Cut-off Channel to meet the supply demands of the Ely Ouse Transfer Scheme to the Essex Water Company. The structure also incorporates a road bridge allowing vehicular access to boat moorings immediately upstream of the site. Access to the operating mechanism for the gate is enclosed in a locked compound fenced off from the public.

Impounding Sluice

The structure helps to manage water levels in the Cut-off Channel. The sluice consists of three guillotine gates and incorporates a road bridge on extended piers at the downstream end allowing access to the south side of the Denver Relief Channel Lock and to boat moorings on the right-hand side of the Ely Ouse. The sluice gates and access way, are enclosed behind locked gates. Closing the sluice helps to build-up water level in the Cut-off Channel (up to 0.6mAOD) and allows flow in the reverse direction. Water is then transferred from Ely Ouse (through Diversion Sluice) to Essex as part of the Ely Ouse- Essex Water Transfer scheme.

Impounding Sluice

A.G. Wright Sluice

Residual Flow Sluice

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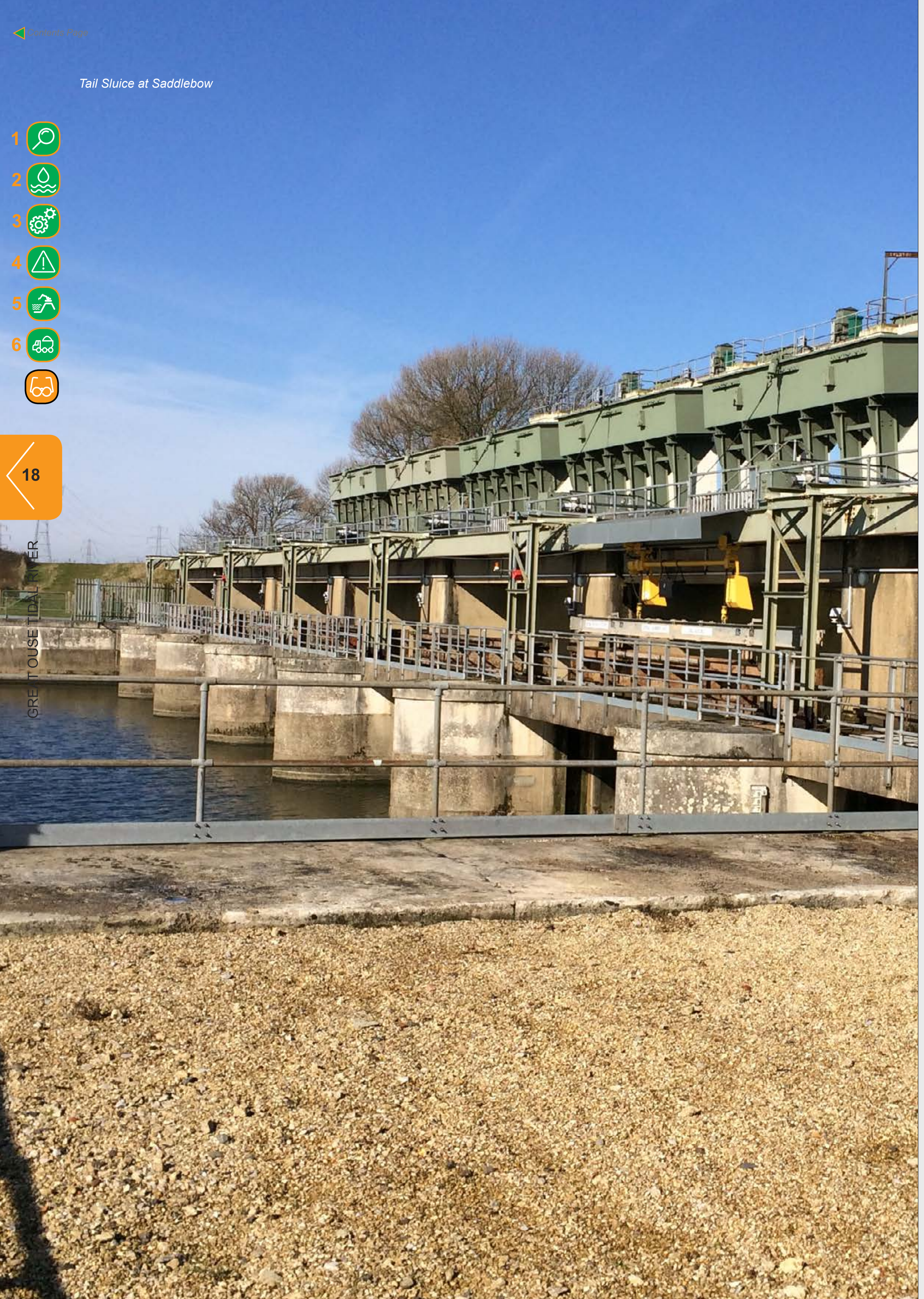


Tail Sluice at Saddlebow

Great Ouse Tidal River

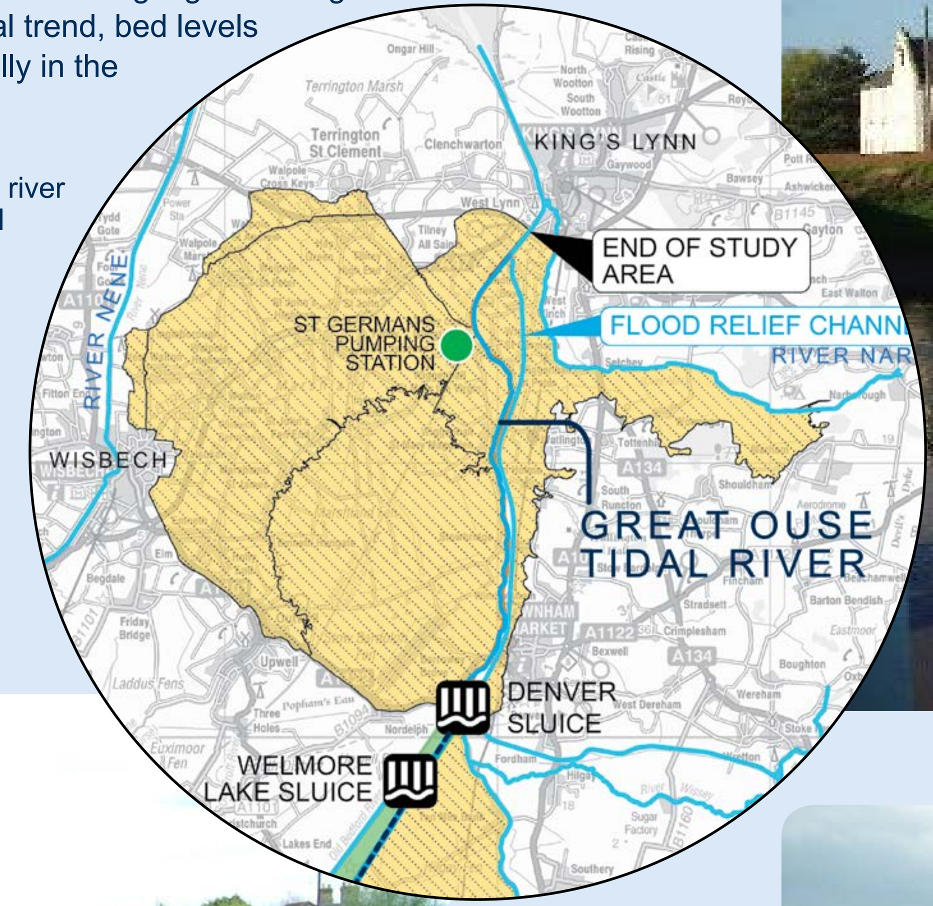
Description

The Great Ouse Tidal River is approximately 26km long and flows from Denver Sluice to The Wash. The 2010 Strategy area considers the stretch of the watercourse between Denver Sluice to the A47 bridge (approximately 17km in length). The width of the river varies considerably within the study area (50m at Denver and 140m at Freebridge, King's Lynn). The watercourse is tidally influenced with tidal range being 6m at King's Lynn and 4m at Denver. It is known that bed levels in this stretch are subject to considerable changes. Silt material comes from The Wash with incoming tides and settles on the river bed. The material accumulates until there is enough river flow to flush it back towards the sea. Sediment patterns follow a broadly seasonal cycle with levels being higher during summer season and lower in winter. Despite the seasonal trend, bed levels have been gradually increasing since the 1930s, especially in the proximity of Denver Sluice.

The Great Ouse Tidal River is bounded by east and west tidal river banks. The banks protect the surrounding floodplain from tidal flooding.

A number of low-land catchments discharge into the Great Ouse Tidal River either via gravity drains or through pumping stations along its length. The biggest one being the Middle Level Main Drain (managed by the Middle Level Commissioners), discharges into the Great Ouse Tidal River through St. Germans pumping station (max. capacity of 100m^3/s) near Wiggenhall St. Germans.

To the east of the Great Ouse Tidal River, the Flood Relief Channel runs in a south-north direction starting from Denver Complex and terminating at Tail Sluice near Saddlebow industrial estate south of King's Lynn.

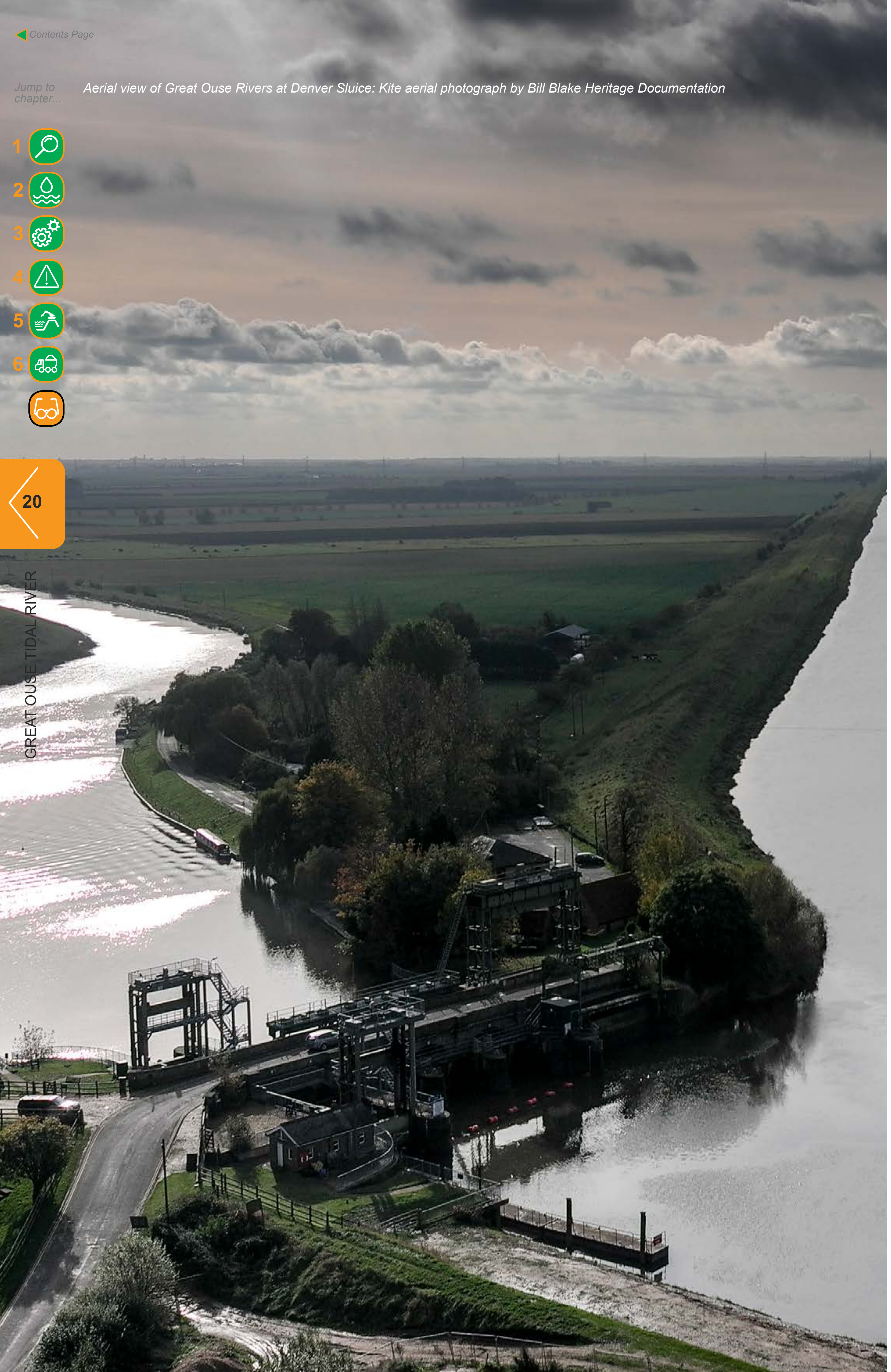


Great Ouse Tidal River at Stowbridge looking west © Copyright Dr Charles Nelson - geograph.org.uk - geograph.org.uk

Crest walls on east bank of the Great Ouse Tidal River

Crest walls on west bank of the Great Ouse Tidal River

Aerial view of Great Ouse Rivers at Denver Sluice: Kite aerial photograph by Bill Blake Heritage Documentation



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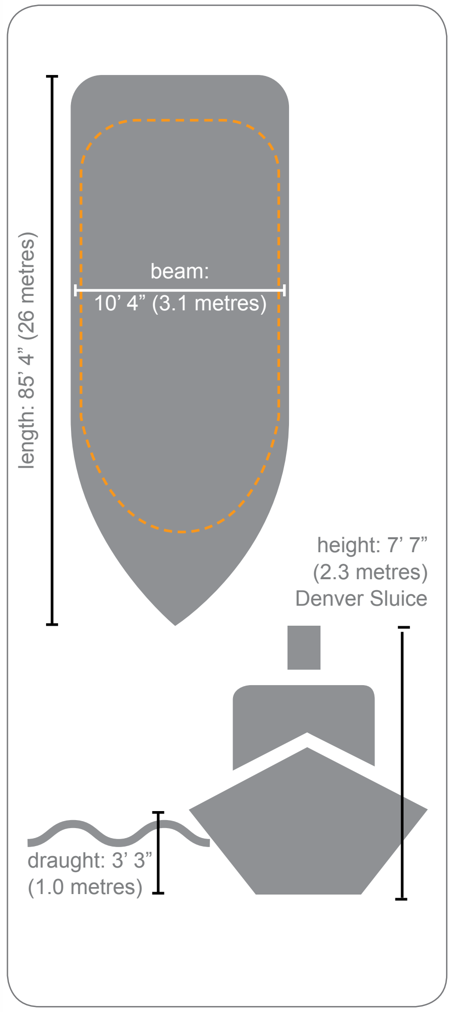


Figure 2-6: Maximum size of boat that can navigate throughout the Great Ouse

2.4 Navigation infrastructure and operation

The River Great Ouse is navigable from Bedford to The Wash at King's Lynn. The system is connected to the River Nene (via the Middle Level) and the Rivers Cam, Lark, Wissey and Little Ouse.

There are a total of 18 locks along 120km of the main navigable rivers. The Ely Ouse, Hundred Foot River, and Flood Relief Channel from Denver Sluice to near King's Lynn are all navigable. The Great Ouse Tidal River downstream of Denver Sluice is suitable only for sea-going boats.

The Environment Agency is responsible for maintaining the navigation infrastructure and undertakes silt management in the Great Ouse Tidal River, particularly near Denver Sluice. Investigation on means to improve connection between the Great Ouse Tidal River System at King's Lynn and the inland waterway network is ongoing (e.g. installation of tidal lock at the Tail Sluice).

Watercourses within the Ouse Washes are non-navigable, except for the Old Bedford River, which has statutory navigation between the Forty Foot Lock (near Welches Dam) and the Old Bedford Sluice. However, this is not normally navigable due to conditions of the levels and channels. Users are keen to re-establish regular navigation along this length (project 'Hereward').

The Great Ouse Tidal River between Denver Sluice and Salters Lode Lock is actively maintained for navigational purposes. Whilst the Hundred Foot and Old Bedford are maintained by dredging and vegetation control, the work is primarily for FRM purposes.

Hermitage Lock

3 Main river system operation

3.1 Normal operation

The operation of the Great Ouse Tidal River System varies depending on fluvial and tidal conditions and seasonal requirements.

Under normal conditions, water from the Bedford Ouse flows into the Hundred Foot River near Earith with Earith Sluice being generally closed. Earith Sluice opens when upstream water levels exceed 3.17mAOD, between November and March, and 3.77mAOD, between April and October. Operation of the sluice is automated. The Hundred Foot River carries river flow to the Great Ouse Tidal River before discharging into The Wash.

Welmore Lake Sluice and pumps (at the end of the Old Bedford River/ River Delph) are used to meet the requirements of the water level management plan for the Ouse Washes. The sluice and pumps are operated to achieve a retention level of 0.50mAOD in the Old Bedford in summer (May to October) and 1.5mAOD in winter (November to April).

Hermitage Lock is operated only for navigation purposes, meaning that the Old West is not normally hydraulically connected with the upstream Bedford Ouse.

Water from the Ely Ouse flows to the Great Ouse Tidal River through Denver Sluice, which is generally left open to maximise discharge into the Great Ouse Tidal River and clear silt. When Denver Sluice cannot discharge flows into the Great Ouse Tidal River (due to either tide or flood conditions), A.G. Wright Sluice is operated to control the upstream water levels and direct water to the Flood Relief Channel. All structures at Denver Complex are manually operated. Further details of Denver Complex operations are given in Section 3.5.

In the Great Ouse Tidal River, in normal conditions, the tidal range is approximately 4m at Denver and 6m at King's Lynn. At King's Lynn port, mean high water spring level is 3.8mAOD, whilst mean low water spring is -2.0mAOD.

Operating levels (water levels in upstream rivers)

Summer Winter

Earith Sluice

Summer: 3.77mAOD

Winter: 3.17mAOD

Welmore Lake Sluice

Summer: 0.5mAOD

Winter: 1.5mAOD

3.2 Flood warning and incident response system

Flood alert areas and flood warning areas within the 2010 Strategy are shown in Figure 3-1 and Figure 3-2 respectively.

Flood alerts are issued when flooding is possible and the recipients should be ‘prepared’ for flooding and to take action. Flood alert areas are less focused than the flood warning areas, extending wider than the 2010 Strategy area. Flood alerts are issued based on observed water levels at Freebridge (King’s Lynn, West Lynn and The Wash frontage), Bodney Bridge and Castle Rising (North West Norfolk rivers), and Ely (Ely Ouse).

Flood warnings are issued when flooding is expected and an immediate action is required. This could happen in case of a breach in existing defences, expected fluvial or tidal surge events. Flood warnings are issued based on observed water levels at Freebridge (King’s Lynn river frontage, South Lynn and Wiggenhalls). Breach warnings are based on breach mapping and are issued depending on where the correspondent breach is predicted to be.

The flood alert and flood warning system is regularly updated with results from the up-to-date hydraulic models. Reviews also take place following real events in the catchment.

Welmore Lake Sluice

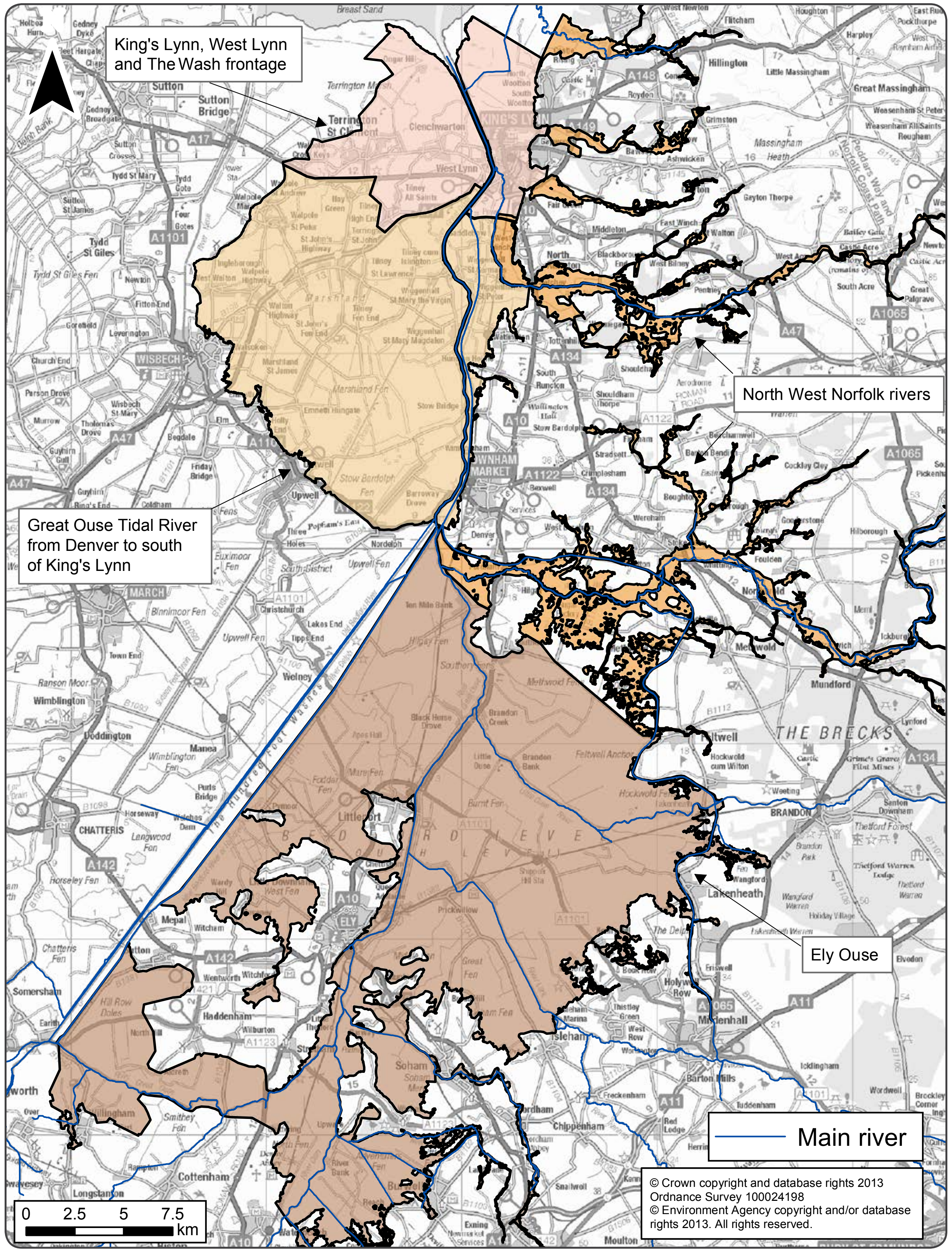


Figure 3-1: Flood alert areas within the Great Ouse Tidal River Strategy

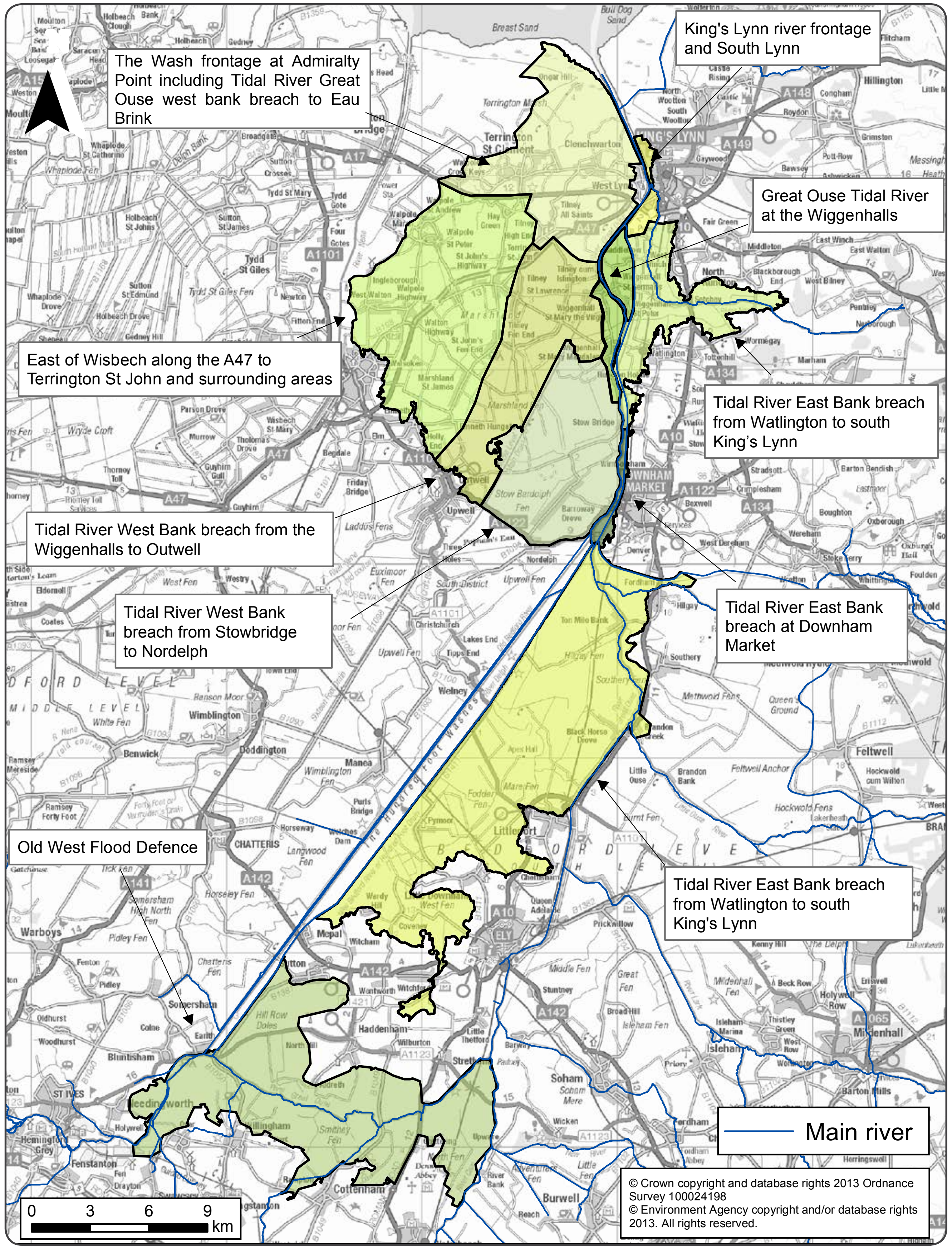


Figure 3-2: Flood warning areas within the Great Ouse Tidal River Strategy

3.3 Operation - fluvial event

Higher than normal fluvial events (from rainfall in the catchment) and overflowing/ breaching of the South Level Barrier Bank are the primary causes of (potential) flooding along the Great Ouse Tidal River System from Earith to Welmore Lake Sluice.

During high-flow periods in the Bedford Ouse:

- When Earith upstream water level is exceeded (3.77mAOD in summer, 3.17mAOD in winter), the sluice opens and water is diverted into the Old Bedford River and into the Ouse Washes. The centre gate opens first and if this is not sufficient then the other gates are opened. When river levels are extremely high, water can enter the Ouse Washes by overspilling the Earith Causeway road (A1123). The flood flows travel along the Ouse Washes and Old Bedford/ River Delph towards Welmore Lake Sluice. All gates at Welmore Lake Sluice open simultaneously when upstream water levels exceed 0.5mAOD.
- Part of the fluvial flow from the Bedford Ouse also goes directly through the Hundred Foot River, the Great Ouse Tidal River and eventually into The Wash. If water levels continue to rise in the Hundred Foot River, it can spill over the Cradge Bank and into the Ouse Washes.
- Flooding of the South Level is prevented by the South Level Barrier Bank running from Earith to Denver.
- Discharge from the Ely Ouse system through Denver Sluice and Tail Sluice is not possible until the tide level is low enough to allow gravity discharge.
- Generally, periods of high flows in the Bedford Ouse do not coincide with periods of high flows in the Ely Ouse and high tide level at King's Lynn. Operation of pumping stations and minor inflows during high-flow period in the upstream catchment have little effect on water levels.

3.4 Operation - tidal event

High sea levels and consequent overflowing/ breaching of the banks are the predominant flooding mechanism in the downstream part of the system (from Welmore Lake Sluice to King's Lynn). During surge events, water travels from The Wash along the Great Ouse Tidal River. Flooding of the surrounding floodplain is prevented by the Great Ouse Tidal River banks. Denver Sluice remains closed and tidal flows enter the Hundred Foot River.

Welmore Lake Sluice, as mentioned earlier, only operates to evacuate flood water from the Ouse Washes and to maintain target water levels during normal conditions (i.e. closed). The sluice is therefore closed in high-tide conditions.

In the case of higher tide levels, flood water can spill over the Cradge Bank and flood the Ouse Washes. Due to overspilling of the Cradge Bank, peak tidal flood levels are significantly reduced beyond this location.

3.5 Denver Complex operation

The Denver Complex plays a critical role in FRM and water management operation of the Great Ouse Tidal River System. During fluvial events in the Ely Ouse catchment, it allows flood water into the Great Ouse Tidal River or into the Flood Relief Channel to provide flood relief for the catchment. During tidal events, it prevents tidal inundation from the Great Ouse Tidal River into the Ely Ouse. Additional operation of Denver Complex includes water transfer from Ely Ouse to Essex as part of the Ely Ouse-Essex Water Transfer scheme and operation of Denver Sluice in silt clearance and managing bed levels in the Great Ouse Tidal River.

Whilst maximising discharge into the Great Ouse Tidal River, it is also necessary to maintain a level of 1.5mAOD at Ely in winter (1 November and 31 March). Operational levels immediately upstream of Denver can range between a maximum of 2.1mAOD and a minimum of 1.2mAOD.

For anticipated flood events, Denver Sluice is used to lower water levels in South Level system in advance of the event to maximise the available storage in the system.

In summer (1 April to 31 October), the operation of Denver Sluice varies depending on flooding in the Ouse Washes. If the Ouse Washes is not flooded, Denver Sluice is used for all discharges, trying to maintain an upstream water level of 1.6mAOD at Ely. The Cut-off Channel is held at -0.2mAOD by using Impounding Sluice if necessary.

If the Ouse Washes is underwater (Welmore Lake Sluice upstream level 0.9mAOD or Offord discharge greater than 25m³/s), Denver Sluice is completely closed to optimise gravity discharge through Welmore Lake Sluice.

Under the Ely Ouse-Essex Water Transfer scheme, surplus water from the Great Ouse catchment can be transferred to the Cut-off Channel at Denver and by raising the level of this channel to 0.6mAOD at Impounding Sluice water flow is reversed in the channel. Diversion Sluice and Impounding Sluice are used as necessary to achieve the above mentioned level on the Cut-off Channel to reverse flow direction.

Denver Relief Channel Lock, within the Denver Complex, provides continuity of navigation route connecting the Flood Relief Channel with the Ely Ouse, Great Ouse Tidal River and Salters Lode. Denver Relief Channel Lock is managed by a permanent lock keeper.

All the structures at Denver Complex are manually operated.

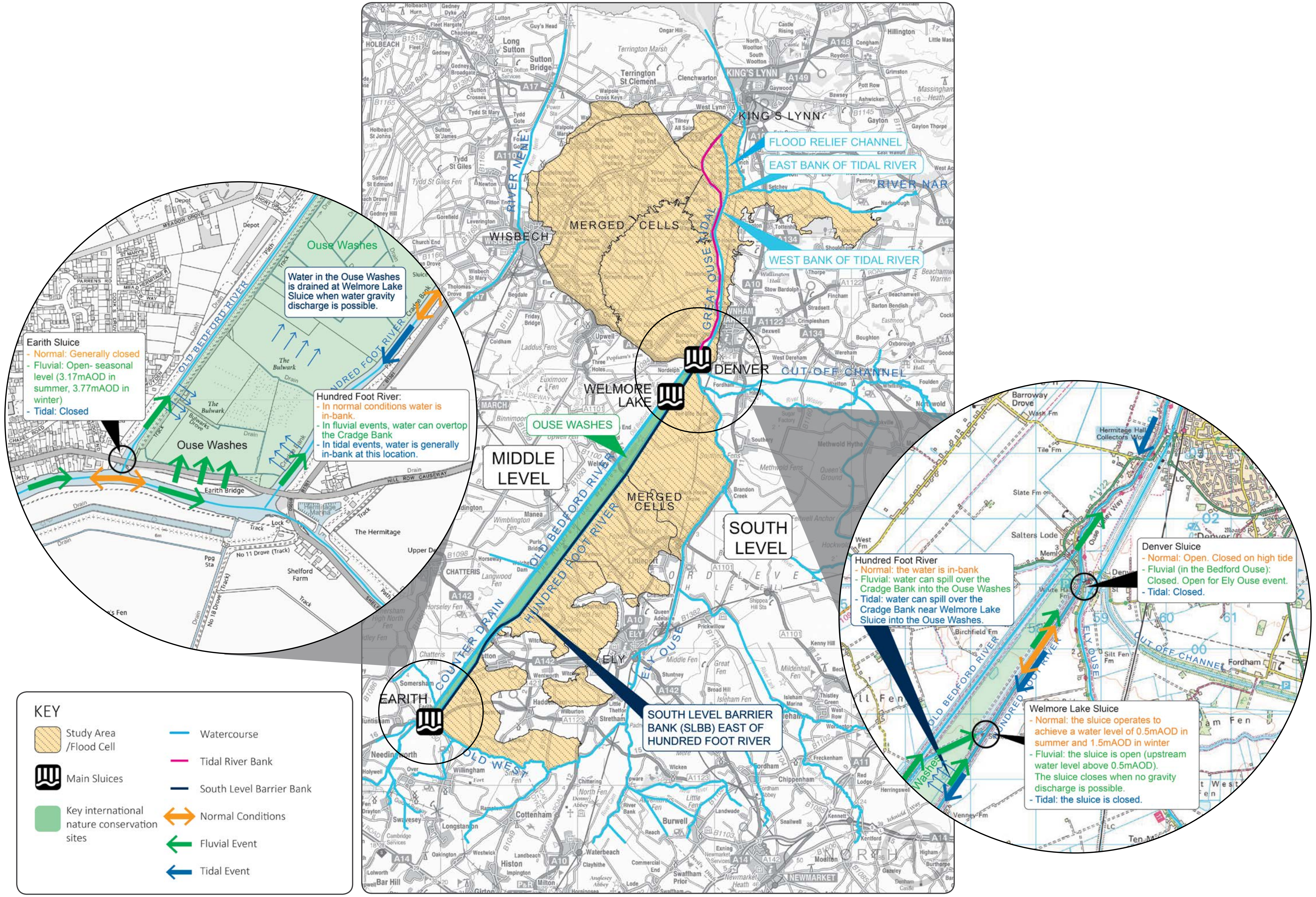


Figure 3-3: Great Ouse Tidal River System operation

Welmore Lake Sluice

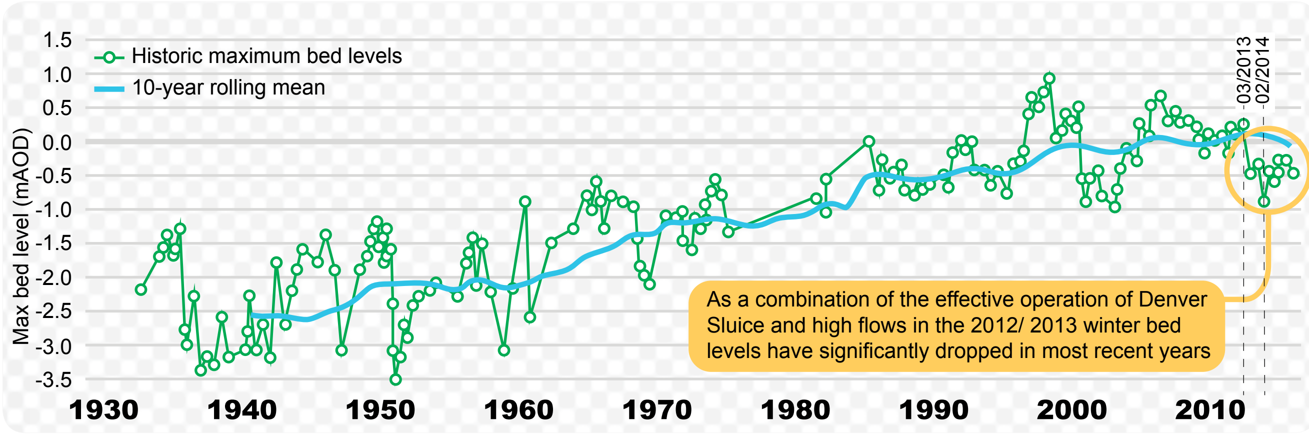


Figure 3-4: Max bed levels from Environment Agency quarterly surveys along the Great Ouse Tidal River (from Denver to King's Lynn) and 10-year rolling mean. Surveys are carried out by measuring an average bed level in each kilometre along the deepest part of the cross section

3.6 Recent bed level changes

Bed levels throughout the Great Ouse Tidal River are dynamic with significant oscillations from year to year and season to season. Despite this seasonal trend, bed levels have been increasing since 1930s, particularly around Denver Sluice.

The 2010 Strategy analysed the long term trend in maximum bed levels in the Great Ouse Tidal River using observed data from 1932 to 2006. Analysis of the bed levels show a clear upward trend since the 1930s. This analysis has now been updated using latest data up to June 2016. Results from updated analysis confirm the upward long term trend.

Previous studies, including the 2010 Strategy, determined that most silt material comes from The Wash with incoming tides. The material then settles on the river bed, where it accumulates until there is enough flow (i.e. the water is 'fast enough') to flush it towards the sea again. Generally, silt will tend to accumulate during low-flow periods (and this is exacerbated by periods of prolonged dry weather), whilst during high-flow periods silt will be flushed towards the estuary.

The Great Ouse catchment is a heavily managed catchment whose flow regime is influenced by human activities. The construction of the Flood Relief Channel in the 1960s significantly reduced flood flow from the Ely Ouse into the Great Ouse Tidal River through Denver Sluice.

Increased water abstraction from the system has also influenced flow regime. These activities reduced flood flows ("flushing") in the Great Ouse Tidal River and resulted in higher bed levels. This is confirmed through analysis of bed level time series. Bed levels significantly increased in 1960 and in the first half of the 1980s, which coincided with the opening of the Flood Relief Channel and refurbishment of Denver Sluice respectively.

Sea level rise is also a possible cause for increased bed levels. The effect of sea level rise on siltation process was also analysed in the 2010 Strategy by looking at observed water levels at Denver. Analysis showed a maximum increase rate of 4.5mm per year in water levels between 1949 and 2007: this would equate to a sea level rise of 0.26m. Analysis of low water levels (i.e. water levels during low tide conditions) at Denver however showed an increase of over 1m in the same period. In normal to low flow conditions, low water levels at Denver Sluice will be close to bed levels. It was therefore concluded that sea level rise was contributing to only a small proportion of the increase in low water levels.

High bed levels in the Great Ouse Tidal River decrease gravity discharge from the Hundred Foot River and from the Ely Ouse and have a detrimental effect on flood risk by:

- Increasing the risk of flooding of the Ouse Washes and the A1101 road at Welney.
- Preventing outflow thereby reducing the capacity of the Ouse Washes as a flood storage reservoir.
- Increasing risk of flooding along the South Level Barrier Bank.

Silt accretion also has a detrimental effect on navigation, reducing the available travel time between Denver and The Wash. It also affects, the environment, increasing frequency of flooding of the Ouse Washes in the spring-summer season, adversely affecting the breeding success of the nesting birds.

One approach to managing siltation is to undertake significant dredging of the Great Ouse Tidal River and of the Hundred Foot River, with the objective of reducing bed levels

Despite the variations, there is an underlying upward trend in bed levels (Figure 3-4). Given the anticipated climate change, gravity flows through Denver Sluice and silt management will become increasingly challenging due to sea level rise. This will be closely monitored by the Environment Agency. Until sea level rise becomes a constraint, gravity discharge through Denver Sluice will be maximised as an effective way of managing silt accretion in the system.

and improving river capacity. An Environment Agency study carried out in 2015 indicates that capital dredging is unlikely to give significant benefits for two main reasons:

- For dredging to achieve a noticeable and sustained reduction in bed levels, the volume of silt removed would need to be far larger than in the routine maintenance de-silting activities. It was found that de-silting would be necessary over a long length of river (approximately 10km) downstream of Denver and involve the removal of 185,000m^3 of silt, which equates to covering an area of ten football pitches to a depth greater than the height of the goal posts. The silt could also return within four to six months if a period of low flows followed.
- Conveyance capacity of the Hundred Foot River has remained almost constant over the last 25 years, despite considerable variation in bed levels during that period.

The 2010 Strategy determined that flow discharged from the Ely Ouse to the Great Ouse Tidal River through Denver Sluice helps to flush out the silt and lower bed levels. This was proven by analysis of observed bed levels in the Great Ouse Tidal River and by using hydraulic and sediment models. Costs associated with this approach are also significantly lower than costs for other options (e.g. dredging). Optimal operation of Denver Sluice (i.e. 85% of theoretical maximum flow discharged through the sluice) is now considered the most effective way for managing bed levels in the river, apart from natural high flows in the Bedford Ouse.

Reflecting this understanding, the Environment Agency has a proactive approach in managing the siltation:

- Routine maintenance activities and capital interventions in recent years include major refurbishment of Denver Sluice in 2014/ 2015 and change in the operation of Denver Sluice, as recommended in the 2010 Strategy. A full list of the routine maintenance activities and capital interventions is reported in Section 6.
- Bed levels in the Great Ouse Tidal River and the Hundred Foot River are surveyed every three months. The surveys help to measure an average bed level every kilometre along the deepest part of the river cross sections. These surveys, known as the 'mean kilometre surveys', have been undertaken since the 1930s.

Such management and operation of the system has been shown to improve conditions.

As a combination of the effective operation of Denver Sluice and high flows in the 2012/ 2013 winter, bed levels have significantly dropped in most recent years. As shown in Figure 3-4, the measured maximum bed levels from 2012 to February 2014 dropped by over 1m and were the lowest in 30 years. Modelling of the river system confirms that decrease in bed level improves gravity discharge from the Hundred Foot River leading to flood risk benefit for the area further upstream (see Section 4.3.2 for further details).

4 Existing and predicted flood risk

4.1 Introduction

Rainfall in catchments or surge in sea levels lead to flooding from rivers and sea. Although it is hard to precisely determine the level of flooding, scientists use historic data, statistical analysis and computer models to assess existing and future flood risk by using rainfall or surge level data and climate change predictions.

Flood risk is expressed as annual chance of occurrence of a particular rainfall or surge event and this is technically referred to as Annual Exceedance Probability (AEP). Statistically and as per historic data, low level events have comparatively higher chance of occurrence in comparison to bigger events. The flood risk from rivers is referred to as fluvial flood risk while flooding from sea is called tidal flooding.

With a given chance of occurrence of a rainfall or surge event, the computer models estimate water depth in river or a floodplain as per its physical characteristics (width, depth, shape, surface smoothness, slope etc). The calculations are repeated to derive water depths for multiple events to assess which event can be accommodated within a river or floodplain. For obvious reasons, each river or floodplain has a finite capacity to pass flood water safely without overtopping of its banks, embankments or walls (called flood defences). This safe capacity varies with the changing characteristics of a river or floodplain along its length. The maximum safe capacity of flood defences of a river or a floodplain is technically called the Standard of Protection (SoP). For convenience, SoPs of flood defences are expressed as the annual chance of occurrence of a flood event corresponding to the top level of the defences. This helps to link the SoP to risk of flooding. SoPs are calculated for current and future events, where calculations for future events include allowance for changes in rainfall and surge events due to expected climate change.

SoPs also signify robustness of flood defences beyond which significant damages to properties and infrastructure could occur as a result of flooding. The damages and loss avoided by flood defences up to their safe level therefore represent the economic benefits of providing and maintaining robust flood defences. Generally, higher level defences offer higher SoPs but cost more to build and maintain.

To maximise value for public money spent on flood defences, government through the Department for Environment, Food and Rural Affairs (Defra), has set out national level guidances for appraising options for sustainable economic SoPs for FRM projects. These guidances are updated with evolving knowledge on flood damages and climate change. Since 2011, government has also embarked upon maximising the outreach of government funding for flood defences by encouraging funding from other partners through partnership funding mechanisms.

A flood with a 1% annual exceedance probability has a chance of occurring

1:100

in any given year

The 2010 Strategy appraised existing and future SoPs for flood defences in the strategy area using the above principles, appraisal guidance and climate change considerations recognised at the time of the strategy study.

Since the completion of the 2010 Strategy, the Environment Agency released new guidance on climate change (Adapting to Climate Change: Advice to Flood & Coastal Risk Management Authorities, 2016) and Defra's policy statement on Partnership Funding (PF) (Flood and Coastal Resilience Partnership Funding, 2011).

Release of the new climate guidance together with the changes in river bed levels over time, required an update of the SoP and economics of the 2010 Strategy.

A high-level assessment of the expected partnership funding was also required. As the 2010 Strategy only assessed fluvial and tidal flood risks for the strategy area, an overview of other sources of flooding was also required. Both assessments were part of the 2016-17 Study.

This section briefly comments on the results from the 2016-17 Study, provides an overview of the strategy area, recognises other sources of flooding, gives an overview of the 2010 Strategy proposed work and provides a comparison of how the findings of the two studies compare.

4.2 Flood cells

To estimate SoPs, the 2010 Strategy divided the study area into 14 flood cells along the length of the rivers. The flood cell boundaries were decided on the basis of the river channels, topography and the boundaries of other studies (see Figure 2-2). Interlinked cells were combined for options appraisal. This is a standard practice when carrying out appraisal studies. The flood cells (individual or combined) with their key infrastructure are summarised in Figure 4-1.

Aerial view of the Ouse Washes © Copyright Mike Pennington - Geograph.org.uk

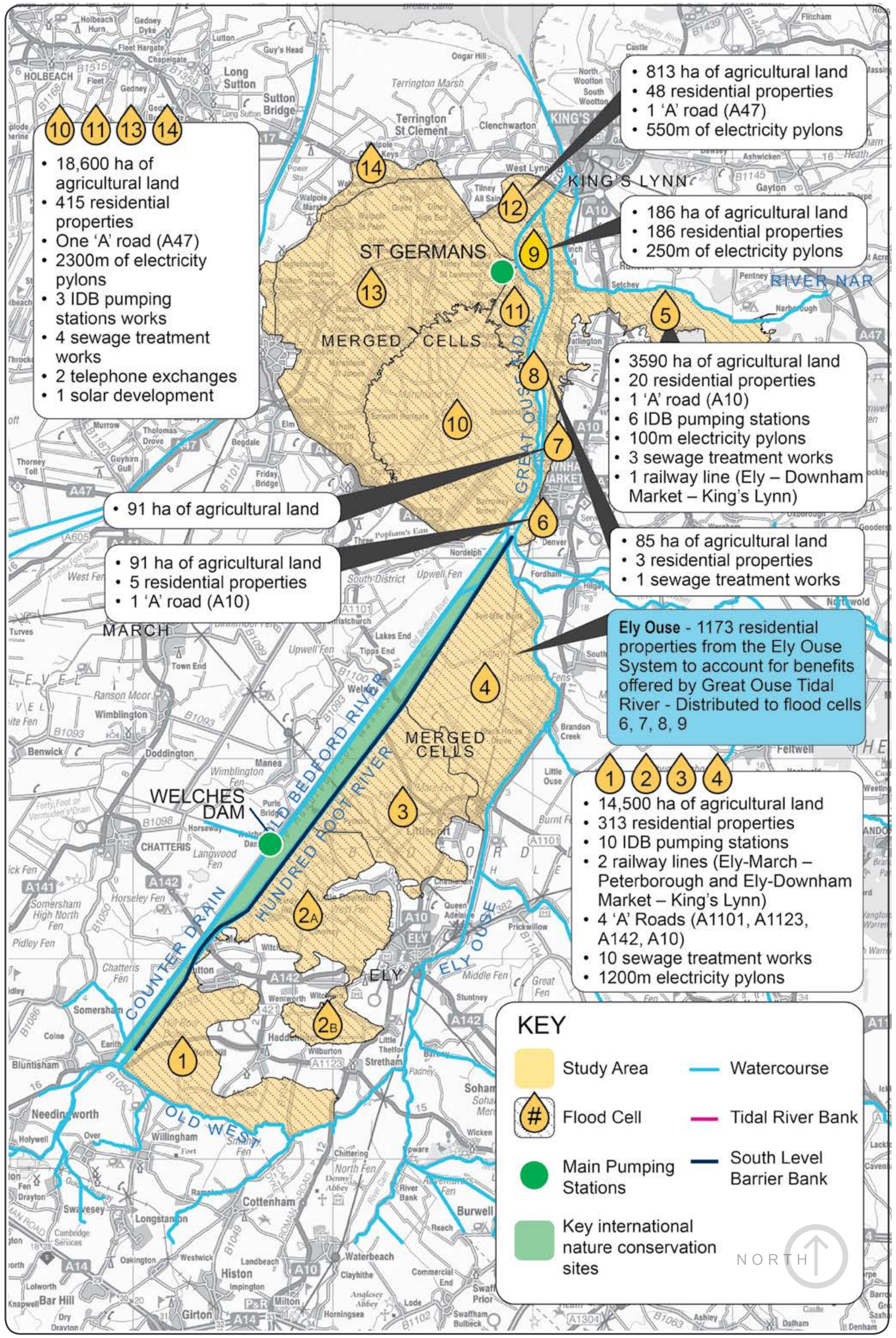


Figure 4-1: Summary of flood cells characteristics

4.3 Standard of protection

4.3.1 2010 Strategy

The main aim of the 2010 Strategy was to identify sustainable economic options for managing flood risk for the study area. The strategy appraised a number of SoP options for the 14 flood cells in the study area against tidal and fluvial flood risk. SoPs were estimated for the present-day scenario and for three future epochs over the next 100-year period (namely 2055, 2085 and 2109).

The study found that SoPs along existing defences will decrease with time due to the combined effect of sea level rise, bank settlement, increased fluvial flows and rising bed levels along the Great Ouse Tidal River.

The 2010 Strategy preferred option based on standard appraisal guidance for current and future SoPs for each flood cell is reported in Table 4-1 (see Section 6 of the 2010 Strategy for further details).

The 2010 Strategy found that without significant capital intervention on bank raising, SoPs along the South Level Barrier Bank would fall below 5% AEP beyond 2085. In addition, the strategy found that bank raising will be required for tidal flood cells 9, 10, 11, 13 and 14 beyond 2085 to maintain economic SoPs for the flood cells.

The 2010 Strategy included a sensitivity assessment of providing a higher SoP of 2% AEP for flood cells 1, 2, 3 and 4. The test was based on the assumption that increased flood risk beyond 2% AEP would discourage investment in higher value agriculture in the area, leading to abandonment of high value growing regime and economic loss to the Fenland. The risk of such an economic loss to local and national economy would encourage the local landowners to provide higher contributions towards an improved SoP of 2% AEP. It was therefore argued that the most beneficial and acceptable SoP for flood cells 1,2,3 and 4 would be 2% AEP. This was therefore included as one of the recommended options in the 2010 Strategy.

However, since the viability of this option is dependent on availability of higher partnership funding contributions from local landowners, this option needs further consultation at detailed appraisal stage. This report therefore only includes the 2010 Strategy preferred option as per standard appraisal guidance. The sensitivity option of providing the higher SoP to flood cells 1,2,3 and 4 has not been considered at this stage.

Table 4-1: Summary of 2010 Strategy preferred option, based on standard appraisal guidance

Defence	Flood Cell	Current		2055		2085		2109	
		1 in X	AEP %	1 in X	AEP %	1 in X	AEP %	1 in X	AEP %
South Level Barrier Bank	1	250	0.4	70	1.4	45	2.2	22	5.0
	2, 3, 4	120	0.8	35	2.8	20	5.0	20*	5.0*
Tidal River East Bank	5	>1000	<0.1	>1000	<0.1	290	0.3	80	1.3
	6	>1000	<0.1	500	0.2	140	0.7	70	1.4
	7	>500	<0.2	270	0.4	90	1.1	35	2.8
	8	>500	<0.2	270	0.4	90	1.1	35	2.8
	9	>1000	<0.1	>500	<0.2	190	0.5	75*	1.3*
Tidal River West Bank	10, 11, 13, 14	>500	<0.2	280	0.4	100	1.0	100*	1.0*
	12	>1000	<0.1	>1000	<0.1	290	0.3	80	1.3

** Economic SoP after investing in bank raising. The SoPs would otherwise deteriorate.*

Cattle at Chain Corner, Ouse Washes © Copyright Hugh Venables - Geograph.org.uk

4.3.2 2016-17 Study

The 2016-17 Study reviewed current and predicted SoPs for the 14 flood cells in view of recent changes in bed level and climate change guidance. Results from the 2016-17 Study showed a slight improvement in SoPs compared to the 2010 Strategy (see Figure 4-2 and Table 4-2). Changes in SoP can be attributed to a combined effect of recent reductions in bed levels and latest climate change allowances. The study found that:

- On the overall study area level, the present day SoPs of defences in the Great Ouse Tidal River System are high (ranging from 0.1% to 0.5% AEP).
- Present day SoPs along the South Level Barrier Bank increased from 0.8% AEP (in the 2010 Strategy) to 0.5% AEP. This improvement is attributed to changes in river bed levels, especially around Denver Sluice. The study showed that beyond 2085, SoPs would fall below the economic option of 5% AEP for flood cells 2 to 4 if banks are not raised to cater for expected climate change. This confirms the 2010 Strategy findings.
- Present and future SoPs along the Great Ouse Tidal River (flood cells 5 to 12) have improved from the 2010 Strategy especially for cell 9. This improvement is attributed to new climate change allowances on sea level rises as per new guidance. Sea level rise projections in 2108 using the latest guidance are approximately 0.3m lower than projections used in the 2010 Strategy. Beyond approximately 2085, bank raising will be required along flood cells 10, 11, 13 and 14 to maintain economic SoPs for the flood cells. This is consistent with the 2010 Strategy findings.

For further details on SoP calculation and modelling, please consult Great Ouse Baseline Reporting- Hydraulic Modelling Report.

Notable flood events

1937
Widespread event across the catchment. Over 2,300 acres of farmland flooded by fluvial and surface water.

1947
Widespread river flooding caused by a combination of rapid snowmelt and heavy rainfall.

1953
Extreme meteorological event conditions resulted in a North Sea tidal surge causing breaching of the banks between King's Lynn and Denver. Significant coastal flooding occurred.

1978
Tide event of 5.97mAOD in January. Highest tide on record to that date at King's Lynn. The effect was widespread damage with many properties flooded. This subsequently led to major improvements in the King's Lynn defences, which were completed in 1991.

1993
Following a wet September, heavy rain fell on the 11th, 12th and 13th of October. Estimated return period of 12.5% AEP at Earith on the Great Ouse and 5.9% AEP for the Great Ouse at Denver. Reported flooding took place mainly on eastern/southern tributaries of the Great Ouse.

1998
Heavy rainfall across central England during the 9th and the 10th of April. The effect was widespread with many properties being affected.

Flooding of several locations in the upper and mid Great Ouse catchment, including the Alconburys, Bedford, Buckingham, Clapham, the Hemingfords villages, Newport Pagnell, St. Ives, St. Neots, Stony Stratford and Towcester.

The estimated severity across the catchment was 0.8% AEP, even though this varied according to the location considered.

2013
Extreme tidal event along the East Coast. The recorded peak level at King's Lynn was 6.17mAOD. The estimated severity at King's Lynn was over 0.5% AEP. No flooding of the study area was observed.

Figure 4-2: 2016-17 Study updated standard of protection

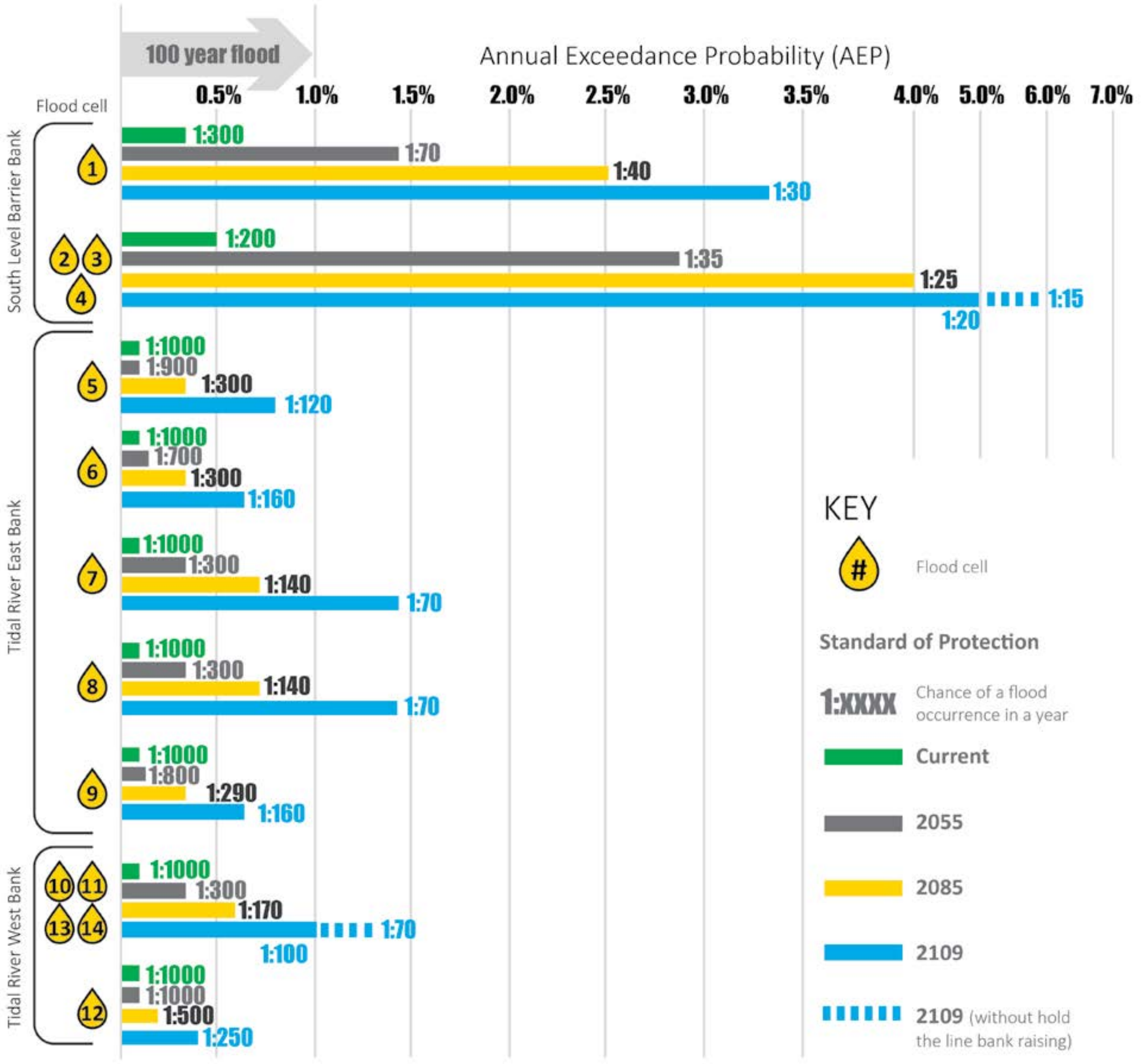


Table 4-2: 2016-17 Study updated standard of protection

Defence	Flood Cell	Current		2055		2085		2109	
		1 in X	AEP %	1 in X	AEP %	1 in X	AEP %	1 in X	AEP %
South Level Barrier Bank	1	300	0.3	70	1.4	40	2.5	30	3.3
	2, 3, 4	200	0.5	35	2.9	25	4.0	20*	5.0*
Tidal River East Bank	5	1000	0.1	900	0.1	300	0.3	120	0.8
	6	1000	0.1	700	0.1	300	0.3	160	0.6
	7	1000	0.1	300	0.3	140	0.7	70	1.4
	8	1000	0.1	300	0.3	140	0.7	70	1.4
	9	1000	0.1	800	0.1	290	0.3	160	0.6
Tidal River West Bank	10, 11, 13, 14	1000	0.1	300	0.3	170	0.6	100*	1.0*
	12	1000	0.1	1000	0.1	500	0.2	250	0.4

** Bank raising required to meet most cost-beneficial SoP as set in 2010 Strategy preferred option*

Sugar beet crop at Stowbridge on the left bank of the Great Ouse Tidal River © Copyright Dr Charles Nelson - geograph.org.uk

4.4 Updated economics

The methodology for calculating benefits for FRM projects is described in the "Flood and Coastal Erosion Risk Management appraisal guidance" (Environment Agency, 2010). As part of the 2016-17 Study, the economic model from the 2010 Strategy has been updated bringing prices and methodology up-to-date and in line with current guidance. The update was centred on the benefits estimation while project costs were updated by indexing the values from 2010 Strategy.

Total of £1.2billion of economic assets at flood risk:

- **30,150ha to 35,610ha of agriculture land**
- **2,200 to 4,820 residential properties**
- **Road network: A1101, A10, A47, A1122 and A1123**
- **Rail network: Ely-March-Peterborough and Ely-Downham Market-King's Lynn**
- **17 IDB pumping stations**
- **2 telephone exchanges**
- **18 sewage treatment works**
- **18.5km of electricity supply line and a solar farm**

For details of economic update consult Technical Note on Economic Update for Great Ouse Tidal River Baseline Report.

In summary, there have been no significant changes in land use or economic receptors (contributing to benefits) since the 2010 Strategy. The total value of assets at risk from flooding is approximately £1.2 billion.

Economic receptors as per 2010 Strategy include:

1. Agricultural land: Agricultural land is the main receptor to flood risk. A total of 30,150ha of agricultural land is at risk due to a 0.5% AEP event following a breach. This increases to 35,610ha in 100 years due to climate change.

2. Properties: 2,200 residential properties are at risk due to a 0.5% AEP event without defences. This increases to 4,820 in 100 years. This is due to flow increase, sea level rise and increase in bed levels created by expected climate change.

3. Road network: A number of national and local roads are at risk of flooding. Roads at risk of flooding include A1101, A10, A47, A1122 and A1123.

4. Rail network: Two railway lines would potentially be affected by flooding in the strategy area: Ely - March - Peterborough railway line and Ely - Downham Market - King's Lynn railway line.

Table 4-3: Costs and benefits for the 2010 preferred option based on standard appraisal guidance (Table 6-18, 2010 Strategy)

Defence	Flood Cell	Benefit-Cost Ratio (BCR)	
		2010 Strategy	2016-17 Update
South Level Barrier Bank	1	5.3	7.0
	2, 3, 4	7.7	9.6
Tidal River East Bank	5	2.9	3.9
	6	12.3	12.4
	7	15.6	15.8
	8	12.5	12.7
	9	11.9	12
Tidal River West Bank	10, 11, 13, 14	6.6	7.8
	12	5.0	5.8

5. Other infrastructure, utilities: Other key infrastructure and utilities at risk of flooding in the strategy area include 17 IDB pumping stations, approximately 18.5km of electricity pylon line, 18 sewage treatment works, two telephone exchanges and one renewable energy site.

The cost benefit assessment at each flood cell for the 2010 Strategy preferred option (based on standard appraisal guidance) is summarised in Table 4-3. Benefit Cost Ratio (BCR) is a simple ratio between benefits offered by defences and the cost of building and maintaining them over their entire life. If the project has a BCR of less than 1, the project is considered an uneconomical investment as costs exceed benefits, whilst projects with a BCR score of over 3 are considered a healthy investment.

Table 4-3 shows the updated BCR from the 2016-17 Study. It shows that the BCR has increased for all flood cells individually and, at overall area level, it increased from 8.0 to 8.3. This is because benefits have, on average, increased more than costs. This increase in BCR is not uniformly distributed across flood cells.

4.5 Partnership Funding

Flood and Coastal Erosion Resilience Partnership Funding (PF) is the mechanism used by government (since 2011) for allocating government funding for Flood and Coastal Erosion Risk Management (FCERM) projects. Government funding, called the Flood and Coastal Risk Management Grant in Aid (FCRM GiA), allocated by the PF mechanism is based on the outcome of a project in terms of number of households protected and other benefits achieved. The following outcomes of a proposed FCERM project attract FCRM GiA:

- **Outcome Measure 1 –** all economic benefits arising from the project investment, less those accounted for under other outcome measures below
- **Outcome Measure 2 –** households moved to a lower flood risk category
- **Outcome Measure 3 –** households better protected against coastal erosion
- **Outcome Measure 4 –** statutory environmental obligations met through FCERM

The amount of FCRM GiA funding is calculated by multiplying each of the measures above by a fixed rate per unit of outcome (or benefit). Dividing the calculated funding by the total cost of the project gives FCRM GiA as a percentage of the project investment available from government. This is commonly referred to as ‘Partnership Funding score’ (PF score). Based on this algorithm, projects can either be fully or partially funded by government. For partially funded projects, the algorithm provides the additional amount required as PF contribution from other sources. This means that projects can still go ahead if additional amounts required are available. This encourages relevant risk authorities, sectors and communities to work closer together to deliver more FCERM projects.

Frozen washland - The Ouse Washes near Welney © Copyright Hugh Venables - geograph.org.uk

For Great Ouse Tidal River System, a high level assessment of the PF score has been undertaken using the updated economics. The calculations show that significant PF contributions will be required, and partners will need to be identified to implement the FRM scheme recommended in the 2010 Strategy.

Results of this assessment are given in Table 4-4 and Figure 4-3. These show the contribution that would come from government as FCRM GiA plus the remaining amount required from others in the form of PF. Table 4-4 gives these both as a percentage and as a monetary figure, this latter figure being the proportion of total expenditure on FRM required over the next 100 years (discounted to present values). It should be noted that this scenario takes the conservative view that some flood defence benefits must be shared with other risk management authorities as a consequence of their own FRM projects. Finally, a ‘low’ and ’high’ estimate is provided in Table 4-4 (the difference between these represented by the hatched portion of the pie charts in Figure 4-3), reflecting whether the minimum PF is being sought, or a larger amount that may ensure a greater likelihood of government funding.

From both the table and figure, it is shown to be the case for all flood cells that government funding through FCRM GiA will only meet, at best, 40% and, more generally, a third or less of the cost of implementing future FRM projects. This proportion may increase if there is less requirement to share benefits with other risk management authorities. Similarly, given the complex nature of the Fenland, more detailed investigation may conclude that greater benefits can be accrued from outside the strategy area, such as from the Ely Ouse system. However, even with such changes there is still likely to remain a large gap in funding that will need to be met through PF.

Table 4-4: Proportion of future FRM costs provided from FCRM GiA and partnership funding

Flood Cell	Total PV*** cost of implementing the 2010 Strategy	FCRM GiA		Parternship Funding	
		Low Estimate*	High Estimate**	Low Estimate**	High Estimate*
1	£9,560k	15% £1,400k	18% £1,680k	82% £7,880k	85% £8,160k
2, 3, 4	£33,800k	20% £6,800k	24% £8,080k	76% £25,600k	80% £27,000k
5	£5,840k	8% £480k	10% £573k	90% £5,270k	92% £5,360k
6	£4,890k	26% £1,270k	31% £1,520k	69% £3,370k	74% £3,620k
7	£4,390k	33% £1,450k	40% £1,740k	60% £2,650k	67% £2,940k
8	£6,810k	26% £1,800k	32% £2,160k	68% £4,650k	74% £5,010
9	£5,310k	25% £1,330k	30% £1,600k	70% £3,710k	75% £3,980k
10, 11, 13, 14	£51,100k	16% £8,300k	19% £9,950k	81% £41,200k	84% £42,800k
12	£4,410k	12% £530k	15% £640k	85% £3,770k	88% £3,880k

** Based on 120% adjusted partnership funding score*

*** Based on 100% adjusted partnership funding score*

**** PV = 'present value' and represents the value today of future sums of money discounted using the HM Treasury social preference discount rate*

Bridleway south of Denver Sluice © Copyright Hugh Venables - geograph.org.uk

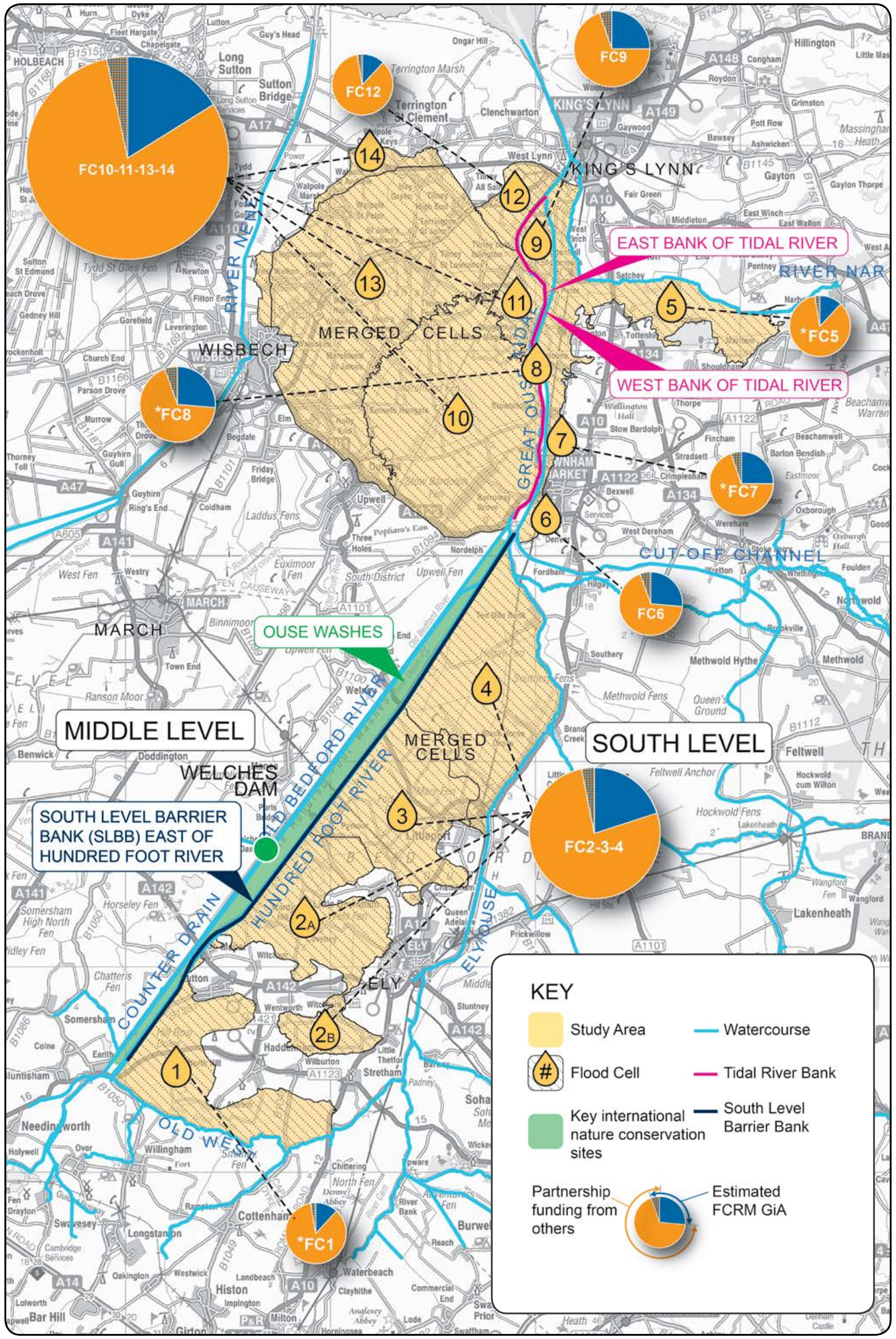


*Figure 4-3: FCRM GiA Partnership funding (pie sizes are proportional to the capital investment, *sizes are not to scale)*

4.6 Other sources of flooding

The 2016-17 Study includes a brief review of other sources of flooding within the 2010 Strategy area. This was conducted using published reports and web based information available from relevant risk management authorities. The review shows that in addition to fluvial and tidal flood risks (which are being managed by the Environment Agency), the area is at risk of flooding from land drainage, surface water (pluvial flood risk), reservoirs and ground water sources. The risk of flooding however varies according to areas considered.

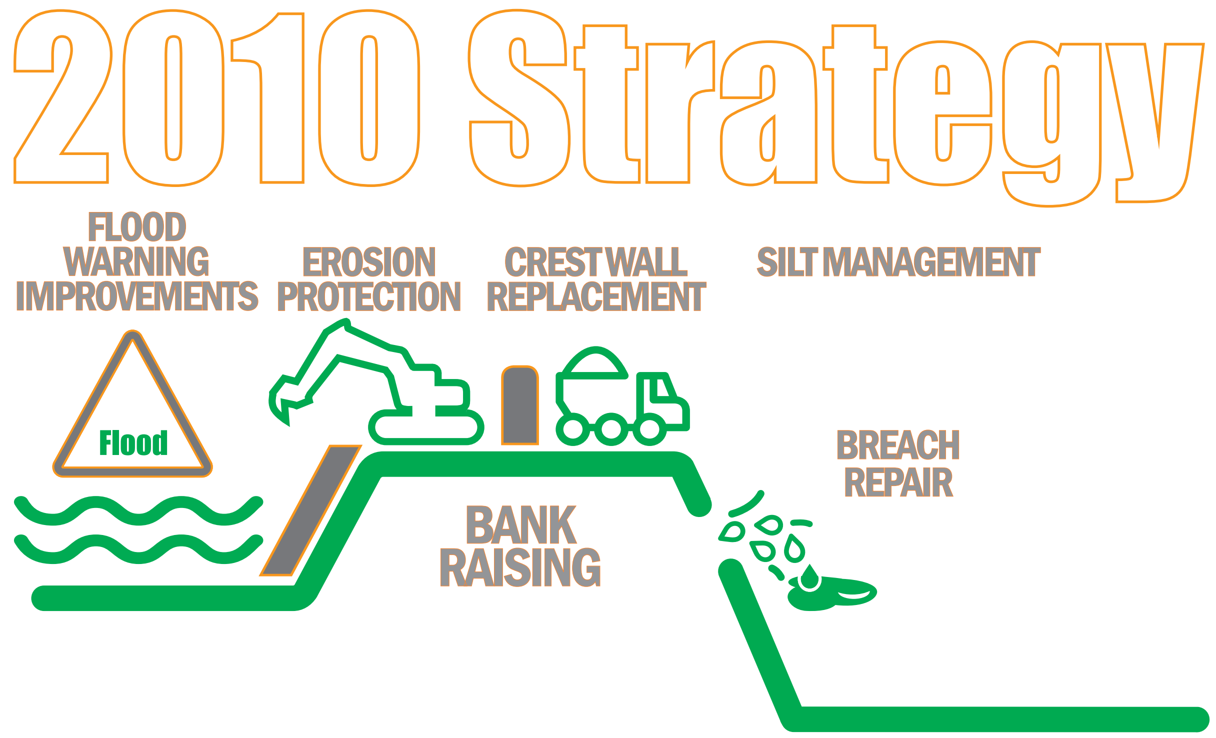
Figure 4-4 summarises potential sources of flooding within the study area, responsible authorities and mitigation measures in place.

In the current 6-year programme of relevant flood risk management authorities, 18 projects are planned to manage these risks. The projects are going to be led by IDBs and other risk management authorities.

Further details of possible sources of flooding within the study area are available as a separate technical note titled “A Review of other sources of flood risk management technical note”.

Sewer Flooding	Location	None identified
	Mitigation	Mitigation measures will be identified as part of the AMP5 programme
	Lead Management Authority	Anglian Water
Surface Water	Location	South Lynn, Downham Market, Littleport, Little Downham
	Mitigation	Implementation of Sustainable Drainage Systems (SuDS)
	Lead Management Authority	Norfolk County Council, Cambridgeshire County Council
Reservoirs	Location	North West Norfolk Catchment, Ely Ouse Catchment
	Mitigation	Compliance with reservoir safety legislation
	Lead Management Authority	All Risk Management Authorities (RMAs)
Ground water	Location	Saddlebow, Warmegay
	Mitigation	None identified
	Lead Management Authority	Norfolk County Council
Land Drainage	Location	Areas within pumped catchment not served by surface water infrastructure
	Mitigation	Various projects within the Environment Agency 6-year programme
	Lead Management Authority	Haddenham Level, Littleport & Downham IDB, Downham & Stow Bardolph IDB, East of Ouse IDB, Polver & Nar IDB, Middle Level Commissioners, King's Lynn IDB

Figure 4-4: Summary of possible sources of flooding in the Great Ouse Tidal River Strategy area



5 2010 Strategy recommendations

5.1 The strategy options

The 2010 Strategy was developed just before the adoption of guidance on partnership funding. At that time, it was decided not to spend further resources on incorporating new guidance requirements and, following a review and assurance process, the Environment Agency adopted the document in principle as a Technical Management Framework for the Great Ouse Tidal River System.

The fluvial and tidal flood defences within the strategy area mainly comprise river channels, flood embankments (with some sections with crest walls and additional erosion protection measures) and sluice structures (some with locks). The 2010 Strategy appraised a number of options for the management of flood risk for the strategy area. The preferred option based on standard appraisal guidance included a combination of erosion protection, crest wall replacement, bank raising (where economically justified) and breach repair (should it happen). The options for each flood cells and target SoPs from 2010 Strategy are summarised in Table 5-1. In addition, the strategy recommended a proactive approach to maintaining existing embankments in all flood cells, optimal operation of Denver Sluice and improvements to the existing flood warning/ alert system.

Denver Sluice

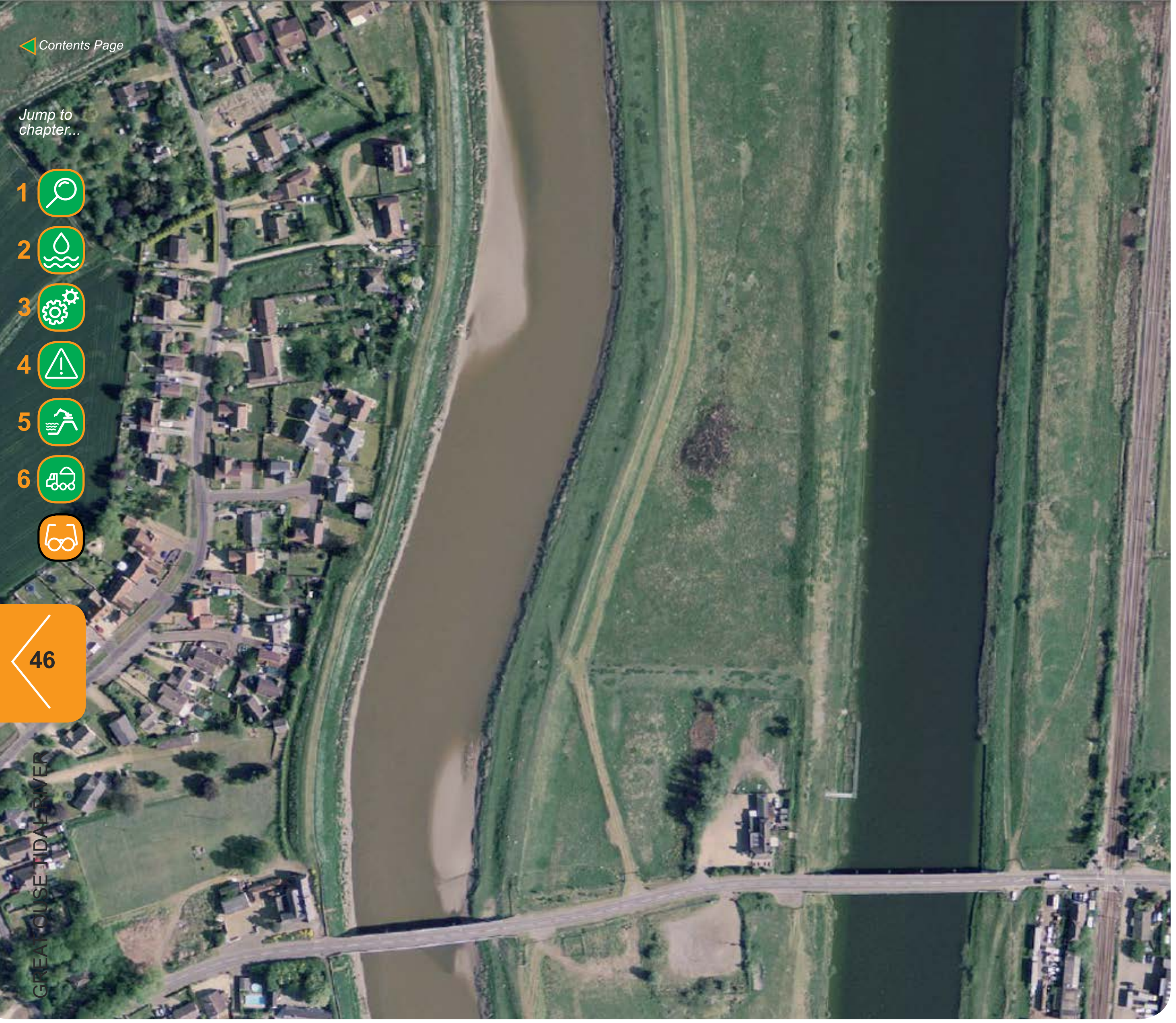
Table 5-1: 2010 Strategy preferred option based on standard appraisal guidance for each flood cell

Defence	Flood Cell	2010 Strategy preferred option based on standard appraisal guidance- physical works
South Level Barrier Bank	1	Erosion protection (year 5 to 15)
	2, 3, 4	Erosion protection (year 5 to 15) + Crest wall replacement (2035) + Bank raising (2080) for Hold the Line to 5% AEP (1 in 20) SoP
Tidal River East Bank	5	Erosion protection (2050- 2060)
	6	Erosion protection (year 5 to 15) + Crest wall replacement (2035)
	7	Erosion protection (year 0 to 5) + Crest wall replacement (2035)
	8	Erosion protection (year 0 to 5) + Crest wall replacement (2035)
	9	Erosion protection (year 5 to 15) + Crest wall replacement (2035) + Bank raising (2085) for Hold the Line to 1.33% AEP (1 in 75 years) SoP
Tidal River West Bank	10, 11, 13, 14	Erosion protection (year 0 to 15) + Crest wall replacement (2035) + Bank raising (2085) for Hold the Line to SoP 1% AEP (1 in 100 years)
	12	Erosion protection with silt management (2040 - 2050)

The 2010 Strategy also included ongoing maintenance and operations monitoring activities. These recommendations are summarised below in Table 5-2.

Table 5-2: Other recommendations of the 2010 Strategy

Maintenance/ continuation of services	1. Proactive maintenance of existing embankments and channels (e.g. desilting at sluice locations, vegetation control, repairs). 2. Optimal operation of Denver Sluice (85% of theoretical flow) to manage bed level increases along the Great Ouse Tidal River. Denver Sluice is used to discharge freshwater from the Ely Ouse into the Great Ouse Tidal River as the lowest risk and most cost-effective way of managing siltation. 3. Ongoing operation and maintenance of Denver Sluice and Earith Sluice. Maintenance and repair/ replacement works to be carried out as necessary. Refurbishment of Denver Sluice is included within the 2010 Strategy and was completed in 2014/2015. 4. Bed level survey along the Hundred Foot River and the Great Ouse Tidal River to be continued with a frequency of four months. 5. Annual monitoring of water levels in the Ouse Washes and discharge through Denver Sluice and Welmore Lake Sluice. 6. Influence planning and development proposals. 7. Continuation of the flood warning service.
Review of system operation	1. A review of the winter operational levels of Earith Sluice to delay ingress of water into the Ouse Washes and therefore direct more flow in the Hundred Foot River for siltation management. 2. A review of the operational levels within the Ely Ouse system with the potential of increasing discharge through Denver Sluice. 3. Review of flood warning/ alert system together with review of incident response procedure as the effects of climate change and bed level rise becomes more evident.
Strategy Review	1. Should maximum bed levels along the Great Ouse Tidal River exceed 0.9mAOD, a review of the 2010 Strategy should be undertaken. 2. Future strategy reviews to investigate siltation management, using bed level data collected in the intervening period and reassess higher cost options which could not be justified on the base of the cost-benefit analysis undertaken in 2010. 3. The Ouse Washes Habitat Creation Project was assumed to be completed by 2020, which should coincide with the 10-year strategy review. The progress of the Habitat Creation Project should be incorporated in the 2010 Strategy and assessed in a Full Habitat Regulation Assessment. 4. A botanical survey of the Ouse Washes is recommended as part of the 10-year strategy review and an ongoing monitoring programme. Activities within the monitoring programme entail: review of bed levels in the Hundred Foot River and Great Ouse Tidal River; the effectiveness of the gravity discharge at Welmore Lake Sluice and the impact of bed levels on this discharge; comparison of observed bed levels at Denver against modelled predictions; pumping activities and discharge at Welmore Lake Sluice during the summer period.



Silt bars in the Great Ouse Tidal River downstream of Denver Sluice

5.2 Review of the proposed 2010 Strategy works

The proposed FRM improvement works from the 2010 Strategy (as detailed in Table 5-1 and 5-2) include erosion protection works, crest wall replacement and bank raising to maintain an economic SoP for the study area. In summary the preferred option identified the need for:

- Erosion protection for all 14 flood cells
- Crest wall replacement for all except flood cell 12
- Varying degree of bank raising for flood embankments along flood cells 2, 3, 4, 9, 10, 11, 13 and 14 in future (2050 and onward)

As detailed in preceding Sections, the 2016-17 Study has reassessed the proposed FRM options of the 2010 Strategy. Based on updated hydraulic modelling and economic analysis, the 2016-17 Study has largely corroborated the recommended preferred option and proposed works of the 2010 Strategy. For cell 9 however, the 2016-17 Study findings differ from the 2010 Strategy. Revised hydraulic modelling shows that bank raising for flood cell 9 will not be required for the study period to 2109 because the SoP should not reduce as quickly as previously assumed.

Since completion of the 2010 Strategy, the Environment Agency has undertaken operation and maintenance activities and improvement works to existing embankments and other structures in line with the objectives of the 2010 Strategy. The Environment Agency has undertaken annual inspections of erosion protections along the length of flood defences and where required, maintenance and repair works have been identified and completed. Intermittent repairs have been undertaken at Denver Sluice and a refurbishment project for the sluice is in progress. These works embrace the spirit of the recommendations of the 2010 Strategy.

Shimering sun - The Ouse © Richard Humphrey - geograph.org.uk

6 Existing asset management regime

6.1 System asset management plans

Works on FRM assets in the area are carried out by the Environment Agency using a risk-based approach that prioritises investments to match available funds. The Environment Agency's System Asset Management Plans (SAMPs) are long-term plans covering all assets protecting a discrete area of a catchment. SAMPs help the Environment Agency in identifying where investments are required and their overall priority. Information available in SAMPs include:

- In year and whole life costs for each asset.
- Evidence to show when asset replacement is best value.
- A forward investment profile.
- Assessment of all failing assets prioritising actions needed to resolve them.
- Prioritised plan of management actions and study work.

Data feeding into SAMPs is extracted daily from the Asset Information Management System (AIMS).

AIMS is a database storing asset information such as crest levels, target conditions, current conditions and consequence of failure for every asset in England. The information on level and target conditions are set in the system from design operational or functional requirements of each asset, while data on current condition is updated through asset inspection regime.

Consequence of failure is categorised as HIGH/ MEDIUM/ LOW followed by a number (e.g. HIGH08) according to asset criticality for the FRM system. Failure of assets with a 'HIGH' code would cause extensive flooding of land and properties with potential risk to life. In addition to the consequence of failure categorisation (e.g. HIGH08), assets are classified in condition grades varying between 1 (very good) to 5 (very poor).

Schedules of inspections, routine maintenance and more intermittent maintenance (e.g. five years) are based on current conditions and consequence of asset failure. The scale of work arising from asset inspections can vary hugely from small health and safety works to extensive works. The total value for these works can exceed thousands of pounds. Works over £50k are generally defined as capital works. Funding for capital works is sought through an appraisal/ business case process.

Funding awarded to the project follows partnership funding calculations described earlier. The scale of appraisal for business cases is proportional to the level of investments and risks involved.

6.2 Recent improvement works for flood risk management

Recent improvements to the FRM infrastructure in the system include:

- Installation of pumps at Welmore Lake Sluice in 2010: the pumps maintain levels in the Old Bedford/ River Delph once gravity discharge has ceased from the Ouse Washes.
- Change in operation at Denver Sluice to maximise flow from the Ely Ouse into the Great Ouse Tidal River in normal flow conditions. This helps to maximise the effect of flushing of silt from the tidal river bed into the estuary at King's Lynn and is therefore a natural way of managing silt. Flow volumes through Denver Sluice in the last six years have returned to what was achieved in the late-1970s, late-1980s and 1990s. If the same effective Denver Sluice operation is continued, it will significantly enhance chances of maintaining river bed levels at an acceptable level. If the operation of Denver Sluice becomes less effective, the likelihood of another period of very high bed levels increases.
- The 2014 Earith Drawmark project concluded that there is no significant environmental or FRM benefit for amending current rules. Scenarios tested as part of the project showed that there is only a minor change in frequency of inundation of the Ouse Washes. As such there is no compelling case for changing the current Statutory Instrument that determines operation of the sluice.
- Major refurbishment of Denver Sluice in 2014/2015; works included emergency repairs of 'v-doors' damaged during the 2013 flood event.
- Major refurbishment of Earith Sluice, between 2010 and 2012. Works included: stabilisation of piled walls and refurbishment of sluice gates.
- Improvement to the flood warning service using up-to-date modelling data and data collected during real flood events (e.g. 2013 surge event). Recent improvements include update of flood warning areas in Hunstanton, Heacham, West Lynn, Snettisham and the Wiggenhalls

Regular maintenance of assets is also carried out. Without the necessary maintenance, current standards of service for the system could not be sustained. Routine maintenance activities from SAMPs are summarised in Section 6.4. Additional activities include:

- Annual vegetation control
- Measurements of water levels on the Ouse Washes using telemetry sites and daily flow data at Denver Complex structures
- 10-year monitoring of habitat conditions in the Ouse Washes through botanical surveys

Since completion of the 2010 Strategy, the Environment Agency has invested more than £1m in maintaining the system and removed 150,000m^3 of silt.

The Environment Agency will shortly (2017) be undertaking work raising the crest level of the South Level Barrier Bank for a distance of approximately 2.6km upstream of Sutton Gault. This is being done in order to not increase the risk of future embankment breaching potentially caused by planned future raising of the Middle Level Barrier Bank that is required to comply with reservoir legislation. These works will have negligible impact on the current and predicted future SoP for flood cell 1.

The Environment Agency is also delivering, in partnership with IDBs, a project to trial a 'water injection agitation' technique as a potential method of managing and/or lowering bed levels in the Great Ouse Tidal River. The site is approximately 5km downstream of Denver Sluice known locally as the 'Stowbridge Hump'. The project has potential to carry on for five years. Work is planned to commence in October/ November 2017.

Close collaboration with Local Planning Authorities is ongoing to ensure that any development within flood risk areas has appropriate flood risk mitigation measures in place. The East Cambridgeshire District Council Local Plan specifically refers to the 2010 Strategy.

6.3 Capital works and investigations

A summary of capital works in the study area included in the Environment Agency 6-year programme is provided in Table 6-1. The Environment Agency 6-year programme is a government investment plan between 2015 and 2021. The Environment Agency regularly carries out reviews to ensure it can respond appropriately to changes such as serious flooding, local partnership funding contributions and new flood risk information.

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Table 6-1: Proposed capital works from the Environment Agency 6-year programme. Works listed are managed by the Environment Agency as the 'Lead Risk Management Authority'

Project name	*Description*
Denver Sluice refurbishment	Replacement/repairs of sluice gates. This work is in line with recommendations of the 2010 Strategy.
Denver Sluice emergency repair	Urgent work to return asset to full operational capacity.
Welmore Lake Sluice works	New silt jetting system and seals to gates replaces.
Coastal model and forecast data review	This project is to collate data collected from Heacham Gauges and to re-run and review the coastal model used to create the forecast point. Potentially providing new flood warning area triggers for this stretch. This work is in line with recommendations of the 2010 Strategy.
Combined river model at Denver review and update	Review models which cover the Ouse Washes, Cut-off Channel and Ely Ouse systems which converge at Denver and combine them into one simplified model. This combined model will improve understanding of the whole system and potentially feed into improvements for flood warning purposes and communications with local communities. It will also be used to provide evidence required to consider future capital investment, structure operations and the consequences of any breaches in the area.
Great Ouse Sediment Strategy	Sediment build-up in main river channels increases flood risk, increases the need for maintenance and degrades habitat. This project will identify and correlate main sediment sources in the Great Ouse Catchment, with depositional areas. This will allow improved targeting of measures to reduce flood risk and improve habitat for less money. This study will help in developing silt management measures is in line with the recommendations of the 2010 Strategy.
East Anglian Fenland futures	Unaffordable defences in rural areas below sea level, undertake assessment of partnership funding and future sustainability of FRM to develop a partnership approach to FRM.
Scenario planning model runs	Re-running existing models to provide evidence to inform a more efficient and sustainable regime for delivering future maintenance. This project will consider what the consequences for flood risk would be if a structure failed or was operated differently.
Topographic surveys	The project will collect topographic survey to feed into new modelling work including real time models. This will enhance incident management capability, improve flood warning areas and provide better information that the Environment Agency can share with partners and provide to communities and the general public.

6.4 Routine maintenance work

Routine maintenance works for the FRM assets are listed in Table 6-2. All assets listed in Section 2.3 of this report are FRM assets with the exception of Residual Flow Sluice, Impounding and Diversion Sluice at Denver Complex which are water level management structures. Inspections planned for the next five years are summarised in Table 6-3.

Table 6-2: Maintenance activities for FRM assets in the study area

Annual maintenance	Intermittent maintenance
• Vermin inspection of all embanked sections. • Grass cutting or grazing. • Minor repairs to earth embankments and crest walls (if present). Where required proposed works will include sealant repairs, replacing missing/ damaged sections of bricks. • Management and control of badger activity along the South Level Barrier Bank, Middle Level Barrier Bank and part of the Great Ouse Tidal River banks. • Minor repairs to haul roads. • Mechanical Electrical Instrumentation Control and Automation (MEICA) maintenance at all major assets including Earith Sluice, Welches Dam, Welmore Lake Sluice and pumping station, Denver Complex (excl. Residual Flow, Impounding and Diversion Sluice) and Tail Sluice. MEICA maintenance at these structures generally includes mechanical and electrical maintenance together with electrical testing.	• Detailed asset inspection every six years. • Any bridge owned by the Environment Agency in the area will also be subject to the same assessment.

Table 6-3: Inspections planned in the next five years

Works planned timeline for the next five years

2017/18

Welmore Lake Sluice – inspection of pumps (one per year)

2018/19

- **Welches Dam** – inspection of pumps (one per year)
- **Welches Dam** – weedscreen cleaner refurbishment (replacement of drive components)
- **Welmore Lake Sluice** – inspection of pumps (one per year)
- **Welmore Lake Sluice** – change chains
- **Denver Lock** – replace gate motors and gearboxes

2019/20

- **Welches Dam** – inspection of pumps (one per year)
- **Old Bedford Sluice** – replacement of control kiosk.
- **Welmore Lake Sluice** – inspection of pumps (one per year)

2020/21

- **Welches Dam** – inspection of pumps (one per year)
- **Welmore Lake Sluice** – inspection of pumps (one per year)

2021/22

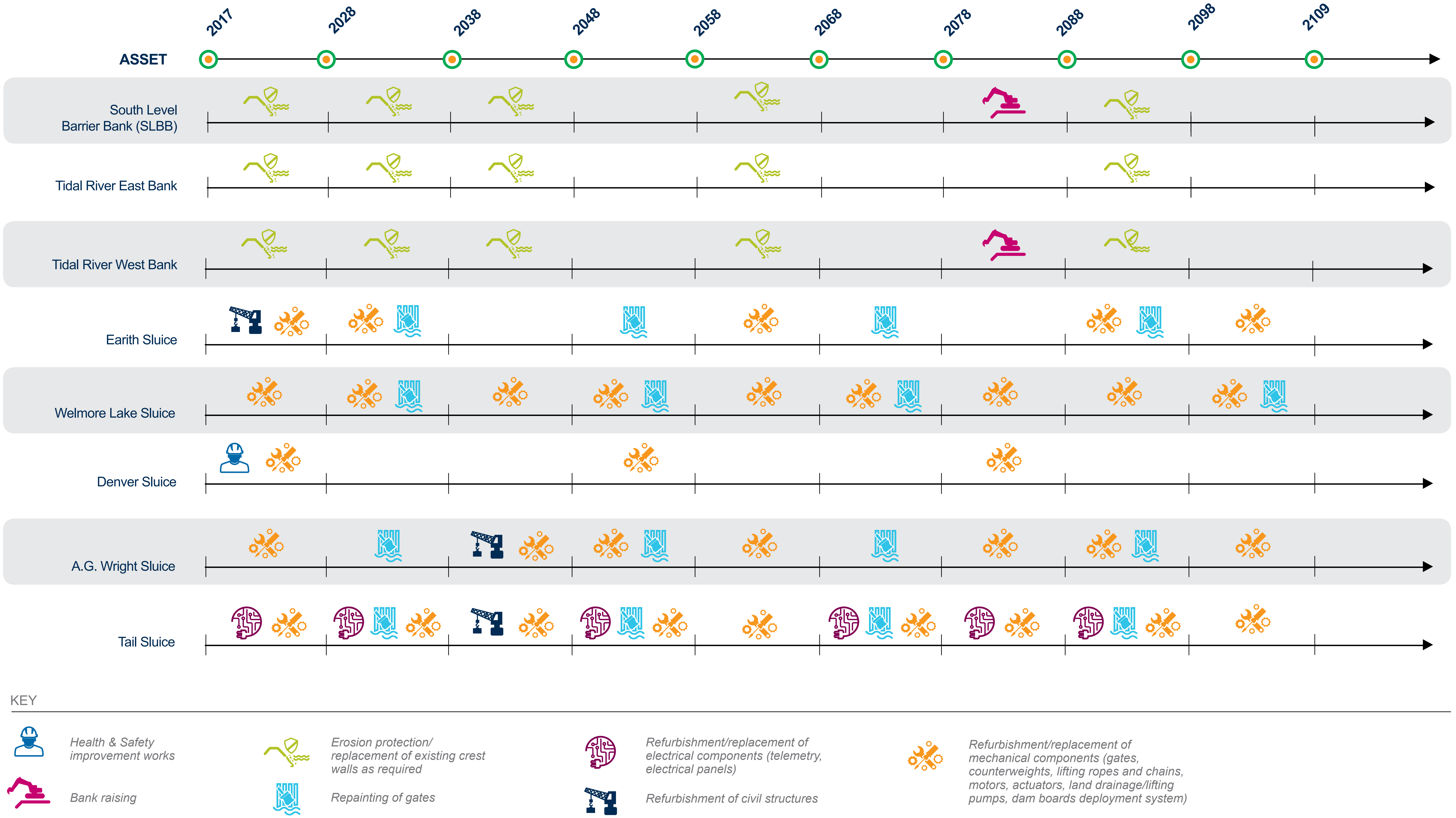
- **Welches Dam** – inspection of pumps (one per year)
- **Welmore Lake Sluice** – inspection of pumps (one per year)

6.5 Future pipeline of works

In addition to the current 6-year programme for capital improvement works, long term asset improvements and refurbishment works will be required to maintain the FRM assets over the 100-year life of the 2010 Strategy. These works will be a combination of recommendations from 2010 Strategy and other works required to maintain the existing assets which were not covered in 2010 Strategy.

These works, summarised in Figure 6-1, give an indication of the overall effort and investment that will be required in future to sustain the current Great Ouse Tidal River System.

Figure 6-1: Future pipeline of works



Glossary/acronyms

Accretion: Process by which particles carried by the flow of water or by the wind are deposited and accumulate (opposite is erosion).

Annual Exceedance Probability (AEP): The probability associated with a return period (T), e.g. event of return period 100 years has an AEP of 1/T or 0.01 or 1%.

Asset: In flood defence, any man-made or natural feature – such as a raised defence, retaining structure, channel, pumping station or culvert – that performs a flood defence or land drainage function. Includes components owned by the Environment Agency or another body, whether or not flood defence is the primary function or is incidental to some other purpose, and components which may be detrimental to flood defence objectives.

Asset Management: Systematic and coordinated activities through which an organisation manages its assets and asset systems for the purpose of achieving its strategic aims. This includes the performance of the assets and the associated risks and expenditures throughout their lifecycles, and carries an implication that the management is undertaken in an optimal and sustainable manner.

Benefit Cost Ratio (BCR): BCRs are used to identify the relative worth of one approach over another. It is the ratio of the PV benefits to the PV costs for each option.

Conveyance: For a channel, function of the flow area, shape and roughness of a channel, which can be used as a constant in a formula relating discharge capacity to channel gradient.

Crest: Top surface of a weir or other control structure over which water passes, highest part of floodbank.

Desilting: Removal of accumulated sediment from the bed of a channel, generally as a maintenance activity. Also referred to as dredging, although this term is more commonly reserved for major works rather than routine maintenance.

Discharge: The volume of water that passes through a channel cross section in unit time, normally expressed at cubic metres per second (m^3/s) in fluvial design (often more simply referred to as ‘flow’).

Embankment: An artificial, usually earthen, structure, constructed to prevent or control flooding, or for various other purposes including carrying roads and railways.

Erosion: Process by which particles are removed by the action of wind, flowing water or waves (opposite is accretion).

Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG): Defra guidance to Risk Management Authorities on the process for appraising flood and coastal defence projects to ensure best use of public money.

Flood and Coastal Risk Management Grant in Aid (FCRM-GiA): Government money allocated to Risk Management Authorities (Environment Agency, Local Authorities, Internal Drainage Boards) for capital works which manage and reduce flood and coastal erosion risk.

Flood Bank: Flood embankment.

Flood Defence Asset: Any structure with the prime purpose to provide flood defence, e.g. culvert.

Fluvial: Relating to the flow in the river that originates from the upstream catchment and not the sea.

Flood Risk Management (FRM): Flood risk management aims to reduce the likelihood and/or the impact of floods. Experience has shown that the most effective approach is through the development of flood risk management programmes incorporating the following elements:

- **Prevention:** preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas; by adapting future developments to the risk of flooding; and by promoting appropriate land-use, agricultural and forestry practices;
- **Protection:** taking measures, both structural and non-structural, to reduce the likelihood of floods and/or the impact of floods in a specific location;
- **Preparedness:** informing the population about flood risks and what to do in the event of a flood;
- **Emergency response:** developing emergency response plans in the case of a flood;
- **Recovery and lessons learned:** returning to normal conditions as soon as possible and mitigating both the social and economic impacts on the affected population.

Floodplain: Area of land bordering a river which is partly or wholly covered with water during floods.

Floodwall: Wall, of any form of construction, built to prevent or control the extent of flooding.

High Level Water Carrier: a river/ watercourse whose bed level lies above the level of the surrounding floodplain.

Incremental Benefit Cost Ratio (IBCR): Ratio of the additional benefit/cost for two options.

Property Level Protection – Measures installed at individual properties to provide resilience against flooding. Includes flood board, air brick covers and flood gates.

Lead Local Flood Authority: After flooding in 2007 the government commissioned a review, which recommended that "Local authorities should lead on the management of local flood risk, with the support of the relevant organisations (The Pitt Review, 2008). This led to the Flood and Water Management Act (2010) and the set-up of Lead Local Flood Authorities (LLFA) who have new powers and duties for managing flooding from local sources, namely Ordinary Watercourses, surface water (overland runoff) and groundwater.

Main river: Main rivers are usually larger rivers and streams. Other rivers are called ‘ordinary watercourses’. The Environment Agency carries out maintenance, improvement or construction work on main rivers to manage flood risk. Environment Agency powers to carry out flood defence work apply to main rivers only. Lead local flood authorities, district councils and internal drainage boards carry out flood risk management work on Ordinary Watercourses. The Environment Agency decides which watercourses are main rivers. It consults with other risk management authorities and the public before making these decisions.

Maintain: Active intervention to keep defences at their current level of protection.

Multi-coloured Manual (MCM): Provides techniques and data that can be used in benefit assessments.

Outfall: Structure through which water is discharged into a channel or other body of water.

Overtopping: The passage of water over a component such as a floodbank or seawall, due to high water levels or wave action Overtopping does not necessarily represent ‘failure’ of a flood defence to perform its function.

Present Value (PV): Monetary value of ongoing or future costs, discounted to provide equivalent present day costs.

Ramsar: The Convention on Wetlands of International Importance, called the Ramsar Convention, is the intergovernmental treaty that provides the framework for the conservation and wise use of wetlands and their resources.

Resilience: In asset management, the ability of an asset or asset system to resist the damaging effect of extreme loading Resilience measures can, for example, help to achieve design standards beyond the standard of protection.

Risk: Risk is a combination of the probability that an event will occur and the consequence to receptors associated with that event.

Scour: Erosion of the bed or banks of a watercourse by the action of moving water, typically associated with the presence of a feature such as bridge pier or abutment that constricts the flow.

Sediment: Material ranging from clay to gravel (or even larger) that is transported in flowing water and that settles or tends to settle in areas where the flow slows down.

Sluice/sluice gate: Rectangular gate that moves vertically between guides.

Stakeholder: An individual or group with an interest in, or having an influence over, the success of a proposed project or other course of action.

Standard of Protection (SoP): The design event standard, measured by Annual Event Probability (AEP), that an existing asset or proposed scheme provides.

Standard of Service (SoS): The performance of an asset at a specific point in time.

Strategy Plan: A documented strategy which is developed from a strategic study into a problem and describes the course of action which has been determined to implement the preferred option.

Sustainability: The concept of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

System Asset Management Plan (SAMP): Long-term investment plan for a flood defence system that identifies the investment needed and the benefits provided.

Uncertainty: Lack of precision that is due to (i) natural variability and (ii) knowledge uncertainty arises principally from lack of knowledge or of our ability to measure or to calculate, which give rise to potential differences between the assessment of some factor and its ‘true’ value.

Washland: Low land adjacent to a river or other channel used for the temporary storage of flood water, often developed for that use by the erection of bunds and control structures.

Watercourse: Defined natural or man-made channel for the conveyance of drainage flows and floods by gravity.

Weir: Structure over which water may flow, used to control the upstream water level in a channel or other body of water, and/or to measure the discharge.

Wetland: Transitional habitat between dry land and deep water Wetlands include marshes, swamps, peatlands (including bogs and fens), flood meadows, river and stream margins.

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