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1 Qualifications and Experience

1.1 My name is Sun Yan Evans. I am a Technical Director for Storm and Flood Risk Management with Mott MacDonald, an international multidisciplinary consultancy. I was also the Storm and Flood Management Practice Leader in Mott MacDonald from 2012 to 2016.

1.2 I am a chartered civil Engineer with a MSc in Hydraulic and River Engineering, a member of the Institution of Civil Engineers and a Member of the Chartered Institution of Water and Environmental Management. I am also a member of the Environment Agency & Defra R&D Theme Advisor Group on Incident Modelling and Management (**IMM**).

1.3 I was a Committee Member of International Association for Hydraulic Research – British Branch from 1995 to 1998.

1.4 I was a Committee Member of the Chartered Institution of Water and Environmental Management – East Anglian Branch from 2007 to 2015.

1.5 I am the main author or co-author of four technical books on hydrology, water quality, water quality standards and pollution control.

1.6 I have published and/or presented about 30 technical papers in technical journals, national and international conferences, on topics covering flood modelling, flood forecasting, flood risk management, climate change adaptation, building flood resilience, water quality and pollution control.

1.7 I have over 30 years of experience of hydraulic and water engineering both in the UK and overseas. I specialise in hydrodynamic modelling of rivers, estuaries and coasts; flood risk assessments and flood risk mapping. I have prepared and also presented evidence on flood risk related matters in public inquiries.

1.8 I have been responsible for numerous projects involving modelling and flood risk assessment of a wide range of existing and new developments throughout the UK and abroad.

1.9 I was a technical specialist responsible for the technical supervision of the flood risk assessment and scour assessment of the potential impact of the construction of the Cable Car on the tidal reach of the River Thames.

1.10 I have worked on many projects involving sluice gates, flood Barriers and barrages over the last thirty years. For example, I was a technical specialist responsible for undertaking and supervising the flood risk and sedimentation assessment works associated with the operation of Guddu Barrage on the River Indus in Pakistan; responsible for providing technical supervision on sediment transport study associated with the operation of barrages of the Tarbela Dam in Pakistan; I led the field testing of the performance of many sluice gates (vertical and radial gates) on the Medway in Kent, including the sluices at Town lock, Porters' Lock, Anchor Sluices, East Teston, East Farleigh, and Allington Lock; I was also responsible for undertaking and supervision of the testing and analysis of the performance of the operation of Leigh Barrier on the Medway near Tonbridge using numerical models.

1.11 I carried out a book review on Hydraulic Gate and Valves on behalf of the Institution of Civil Engineers in the mid-1990s and published a short article of this review in the New Civil Engineer magazine.

1.12 I am currently working on National Grid's Flood Resilience Programme to protect over 100 major electricity substations from flooding across the country. On this project I am the technical manager responsible for modelling, flood risk assessment, developing asset flood resilience solutions.

1.13 Mott MacDonald undertook the Flood Risk Assessment, modelling and preparation of the Environmental Statement.

1.14 The evidence provided in this proof is based on my assessment of the flood risk assessment (FRA) (**A/16/2C**) and modelling work undertaken and the findings of that work, my over 30 years' experience in flood risk management and modelling, and my professional judgement.

2 Scope of Evidence

2.1 I am presenting evidence on behalf of the Environment Agency.

2.2 So far as it is within my knowledge, experience and capability, I comment upon matters where I have relevant experience to the extent that it can and may inform the inquiry.

2.3 Where possible, I respond to the objections raised that are within the scope of my knowledge, practical ability, experience and professional capacity.

2.4 My evidence provides my opinion on flood risk and modelling related to the pre and post construction of the Boston Barrier Scheme.

2.5 My evidence covers the following aspects:

2.5.1 History and effects of flooding in Boston;

2.5.2 The benefits of the scheme;

2.5.3 The robustness of flood risk assessment and modelling;

2.5.4 Impact on flood risk downstream of the Barrier along the Haven;

2.5.5 Impact on flood risk upstream;

2.5.6 Effect of the Barrier on the velocity of water in the channel; and

2.5.7 The location of the Barrier.

2.6 In my evidence, I also:

2.6.1 respond to objections raised related to the scope of my evidence; and

2.6.2 summarise my evidence in respect of aspects of Statement of Matters that I address.

2.7 Of the matters about which the Secretary of State particularly wishes to be informed, my evidence will address the following:

Matter 1 The aims of, and the need for, the proposed Boston Barrier and related works;

Matter 2 The main alternative options considered by the Environment Agency and the reasons for choosing the proposals comprised within the Scheme;

Matter 3 The justification for the particular proposals in the draft Transport and Works Act Order (**TWAO**), including the anticipated flood risk, environmental and socio-economic benefits of the Scheme;

Matter 5(b) The justification for the location, design and operation of the Scheme including questions overs the reinforcement and maintenance of 'earth banks' running from the site of the barrier downstream;

Matter 7 The compatibility of the scheme with future climate change scenarios;

Matter 12 Whether alternative modelling of the tidal and fluvial flows around construction and operation of the barrier would mitigate against concerns of:

(i) perceived increased risk of low-lying inland and fluvial flooding;

(iii) flow velocity concerns in relation to the fishing fleet's ability to use the river;

Matter 14(a) The likely impacts of constructing and operating the scheme on the operation of businesses in the area, including issues around perceived increased flow velocities creating difficulty for the fishing and pleasure craft industry to operate safely.

2.8 My evidence should be read in conjunction with all other experts' evidence presented on behalf of the Environment Agency for the proposed Boston Barrier Scheme.

3 Introduction

3.1 This section briefly describes the history of flooding in Boston, the need for the Boston Barrier Scheme, the key components of the Boston Barrier works and the standard of protection that the scheme will offer.

Background

3.2 Boston town in Lincolnshire is within the River Witham catchment on the tidal reach of The Haven. It is located on the edge of The Wash in the low lying fens, much of which is below mean high water spring tide levels, and is entirely located within the floodplain.

3.3 Boston has a history of tidal flooding from the tidal river known as 'the Haven'. The major flood risk in the town of Boston is from the tidal surges propagating up the tidal river from the Wash.

3.4 In 1953, Boston was badly flooded by a big tidal surge event. In December 2013, an even greater tidal surge event hit east coast, sea water propagated up the Haven, overtopped the river banks, inundated the streets, flooded people's houses, shops, schools and business premises, also caused significant damages to critical infrastructure, such as road and substations. The floods significantly affected Boston and led to severe disruptions and economical losses.

The need for a Barrier

3.5 Boston Borough Council completed a Strategic Flood Risk Assessment (**SFRA**) in October 2010 (**C/3/3**). The majority of Boston is identified in Flood Zone 3 and dominated by tidal flood risk from the Haven. The level of flood risk for the majority of Boston is classified 'medium' or 'high' based on national flood risk classification – Risk to People.

3.6 The SFRA also identified that if a breach in the defences occurred, the surrounding land would be in the 'Danger to All' or 'Danger to Most' category due to deep water and fast flowing water.

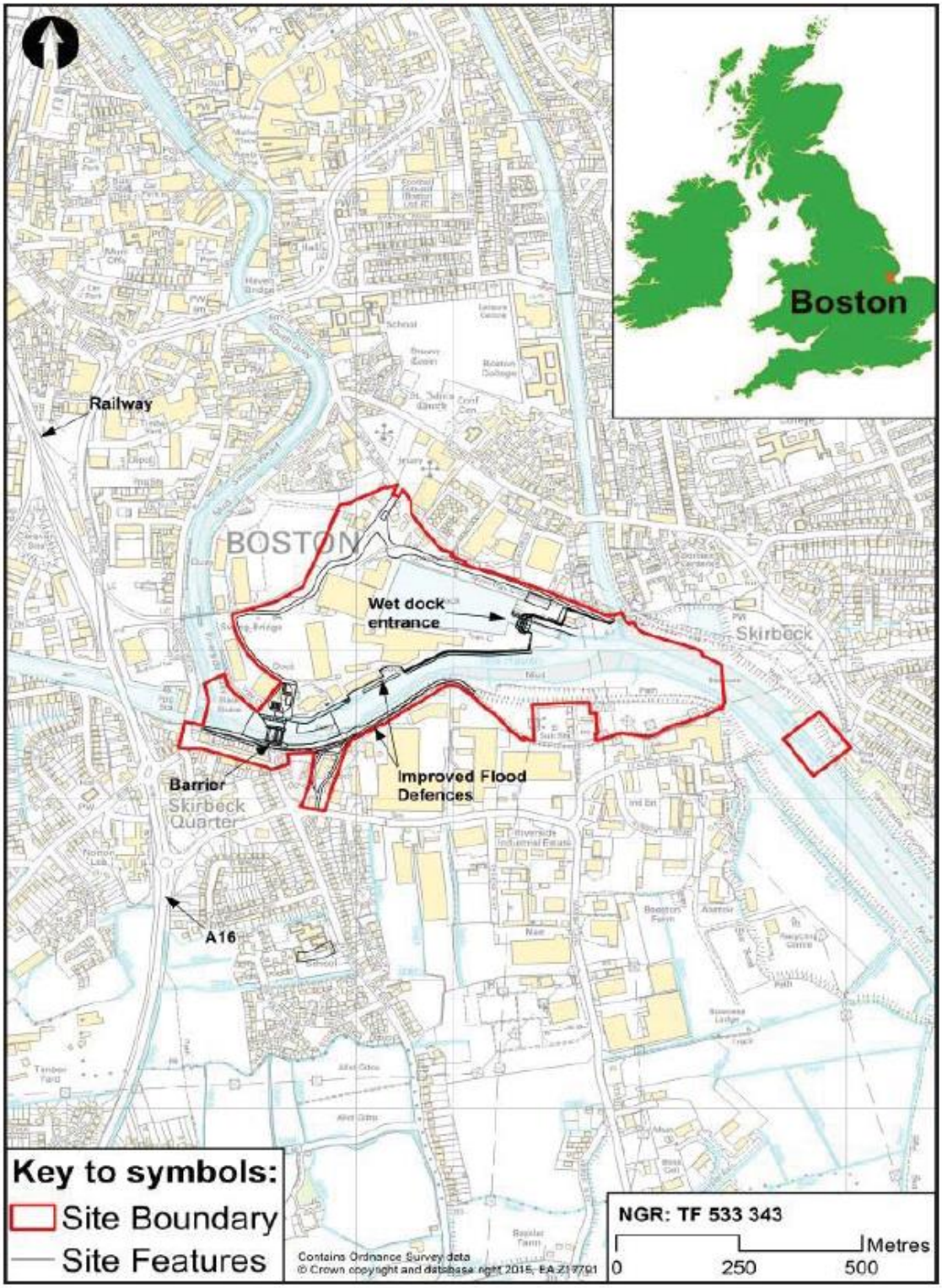
3.7 With the predicted sea level rise due to climate change, the potential flood risk to the Boston community, and the built and natural environment, is increasing. Therefore, improved resilience is absolutely needed.

3.8 The Environment Agency intends to manage the risk of flooding from the tidal River Witham in Boston, Lincolnshire. To achieve this, the Environment Agency proposes to build a tidal Barrier and raise the downstream embankments on the Haven as required to reduce the flood risk and mitigate the effects of climate change.

The context of the Barrier

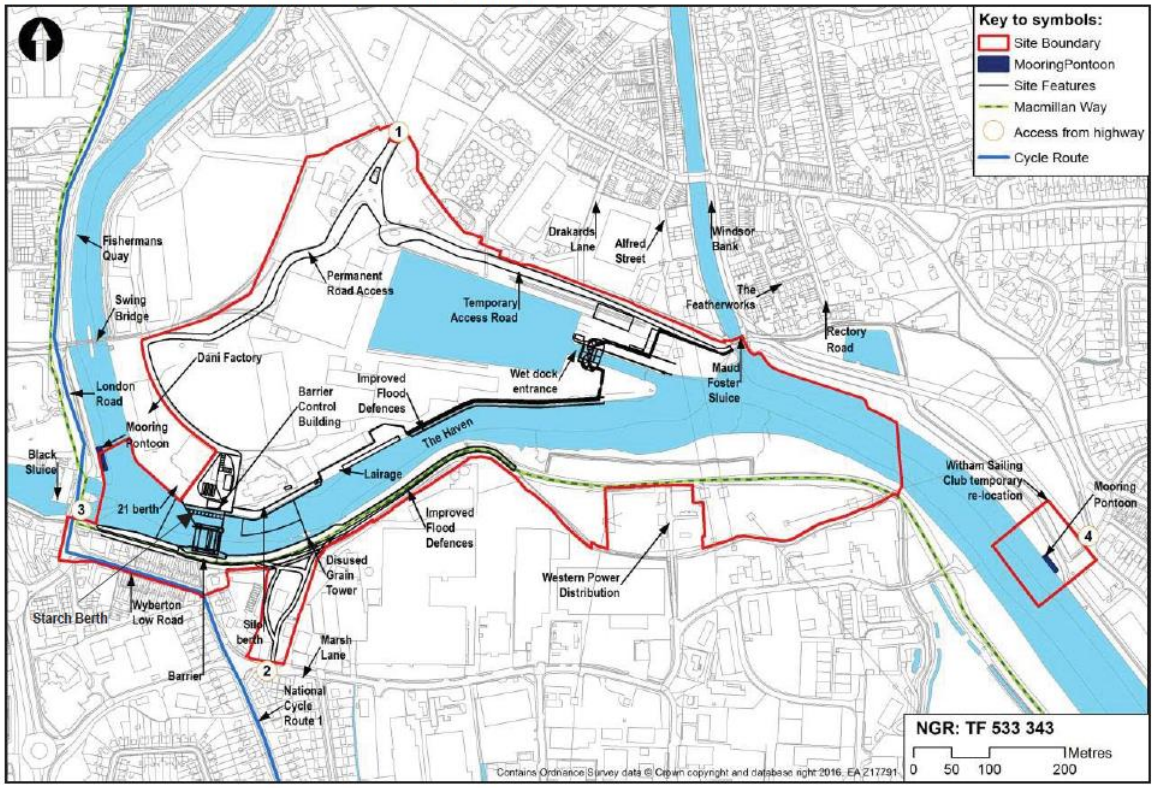
3.9 A 25 metre (m) wide, steel, rising Barrier (the **Barrier**) is proposed to be located downstream of Black Sluice lock within the tidal River Witham - the Haven. The reasons why this location is the preferred location and why alternative locations were not chosen are discussed in Section 6.6 (The Location of the Barrier) of my evidence. The proposed location is shown in Plates 1 and 2 of the Environmental Statement: Volume 1: Main Report (**A17/1**, 12 August 2016). They are inserted here for ease of understanding.

Plate 1: Location of Project



Source: Mott MacDonald 2016

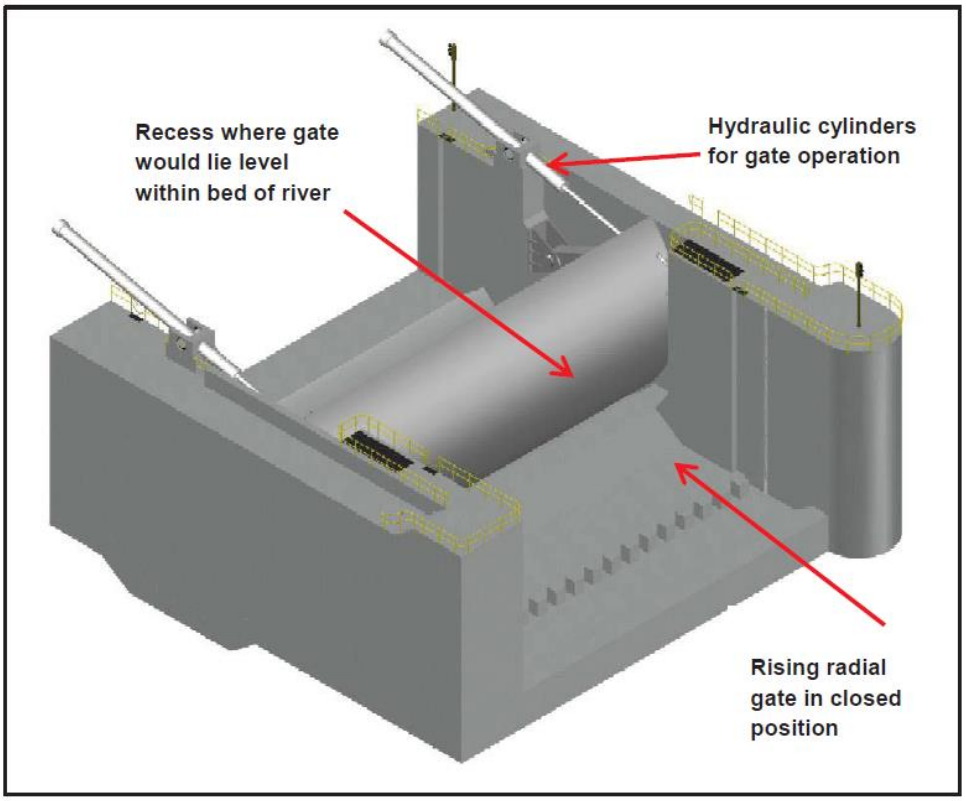
Plate 2: Project elements and nearby features



Source: Mott MacDonald 2016

3.10 The proposed Barrier comprises a U-shaped structure which provides a 25m navigable channel. It is 35m in length, with a gate approximately 10.5m high when raised, when measured from the river bed (see Plate 3 of the Environmental Statement: Volume 1: Main Report (**A17/1**, 12 August 2016)). The top of the gate structure in its raised position would be 7.55mAOD, approximately 2.73m above mean high water. The Boston Barrier works also include raising the height of flood protections along both banks downstream of the proposed Barrier to ensure a consistent level of protection is achieved.

Plate 3: Tidal barrier structure



Source: Mott MacDonald 2016

3.11 The scheme also comprises new flood defence walls on both banks of the Haven, see Plates 7 and 8 of the Environmental Statement: Volume 1: Main Report (**A17/1**, 12 August 2016).

Plate 7: Visualisation showing the proposed left bank (flood wall and retaining wall) downstream of the tidal barrier

Source: Mott MacDonald 2016

Plate 8: Visualisation of the left bank (flood wall and retaining wall) viewed from downstream of the proposed tidal barrier location from the right bank

Source: Mott MacDonald 2016

The flood wall ranges in height from 1.5 to 2.4m above ground level (see Plate 8). Access gates would be provided within the flood wall to allow access to the PoB quayside.

3.12 The maximum height that the Barrier can hold water in the Haven is governed by the height of the Haven banks. The Environment Agency are aware that there are some low spots on the Haven banks and have a scheme programmed to raise these to the required level. When the Barrier and improvements to the downstream Haven embankments are completed, Boston will have a 1 in 300 standard of protection (**SoP**)[1] from tidal flooding – one of the best standards of tidal flood defence outside London.

3.13 On 23 August 2016 the Environment Agency (the **Agency**) applied to the Secretary of State for the Environment Food and Rural Affairs to make the Boston Barrier Order (the **Order**) under the Transport and Works Act 1992.

3.14 The application (the **TWAO Application**) was made in accordance with the procedure prescribed in the Transport and Works (Applications and Objections Procedure) (England and Wales) Rules 2006 (the **Application Rules**) (**B/11**).

3.15 A number of representations on the proposed Order have been submitted to the Secretary of State. Some of the issues arising from these representations relating to Flood Risk and Modelling are discussed in Chapter 6 of this Proof of Evidence.

4 History and Impacts of Flooding in Boston

4.1 This section illustrates the history of flooding in Boston and associated impacts on people's lives, the economy and the environment.

4.2 Boston is located on the edge of The Wash in the low lying fens and is entirely located within the floodplain. It has long suffered from flooding caused by North Sea storm surges over the past 200 years, described in the following sections.

4.3 The information given below has been gathered from various sources including newspaper articles, Environment Agency records and published texts. Please refer to **Appendix 1** for the original source of the text and descriptions of flood events.

4.4 Storm Surges in Late 18th Century

4.4.1 One of the earliest records of flooding in Boston due to storm surges was in 1779 when the tide flooded the lower part of Boston town.

4.4.2 Storm surges struck again in 1807 to flood much of Boston town to one foot deep.

4.4.3 Less than three years after this, severe storm conditions on 10th November 1810 led to the highest flood level in Boston. For nearly an hour the flood-tide appeared to be stationary as the waters surged up the river and over the sea walls. The old banks at Boston East, Skirbeck, Wyberton, Frampton and Fosdyke all had reported breaches caused by erosion as the raised tide flowed over them.

4.4.4 The area flooded stretched from Wainfleet to Spalding as a result of the overtopping and breaching of the Haven sea banks and wider Wash sea banks.

[1] 1 in 300 Standard of Protection: means it can protect against event with a 1 in 300 (0.33%) chance of happening in any given year over a 100 year time period.

4.4.5 In Boston, the flooding in 1810 was estimated to be deep. According to the Boston Gazette, the reported height of the water against the western end of St Boltoph's steeple reached 2 foot and 8.5 inches.

4.4.6 The severity of the 1810 flooding was such that many of the residents were forced to shelter in the roof spaces of their homes. 10 people are thought to have lost their lives in and around Boston because of this flood.

4.4.7 Many of the roads to Fosdyke and land-based communications were cut-off, isolating the town of Boston in the middle of the Fens.

4.4.8 Vessels capsized near the Skirbeck Quarter and many more were lost at sea, contributing the economic loss of the fishing fleet.

4.4.9 Farmland used for sheep grazing was inundated as evidenced by the large number of dead livestock reported in the local newspaper.

4.5 Storm Surges in Mid-20th Century

4.5.1 On 27th February 1949, a storm surge caused severe coastal flooding from Whitstable to London, including Boston. Various sea banks were shown being overtopped or breached by this storm.

4.5.2 The 1949 flood was reported as the worst in 65 years at the time but served as a precursor to the tragedy of the larger 1953 flood, less than four years later.

4.5.3 On the night of 31st January 1953, a storm surge known as 'the Great Flood' came rushing down the East Coast to flood much of East Anglia and the Thames Estuary. The extreme coastal conditions coupled with the condition of the sea banks and the lack of communication meant that 307 people died in the worst national peacetime disaster in the UK.

4.5.4 The timing of the flooding, which occurred in the middle of the night, and single-storey dwellings in other parts of Lincolnshire, greatly increased the risk to life because:

(a) there was little to no warning of the flooding, especially in locations with breaches;

(b) the elderly and the young were less able to escape the rapidly rising waters to avoid drowning; and

(c) for those who could escape, exposure to the cold waters was the main secondary cause of death.

4.5.5 Boston was severely flooded. The Boston Borough Council summarised the impacts of the flood as follows:

(a) there were 1,200 different breaches of sea defences along the east coast, 32,000 people had to be evacuated, 24,000 homes were flooded and 100 miles of roads were impassable. A total of 160,000 acres of agricultural land

was inundated and not usable for several years and 46,000 livestock were lost; and

(b) damage at 1953 prices was £50 million - more than £1.2 billion at today's prices.

4.5.6 Sewer systems were overwhelmed, contaminating the flood waters. This presented a real risk of food contamination and encouraged the spread of disease. Sewerage systems were out of action for 17 days afterwards in places along the east coast, prolonging the misery of those trying to return to their homes.

4.5.7 As a result of the 1953 flood, a national Storm Tides Warning Service was also introduced to forewarn the east coast population.

4.5.8 Additionally, the old sea banks were replaced by coastal defences along the Lincolnshire coast and the Haven to lessen likelihood of overtopping and condition improved to reduce the risk of breaches.

4.5.9 In March 1961, less than 10 years later, another storm surge led to many houses being flooded in Skirbeck Quarter by water flowing through displaced brickwork at the Black Sluice.

4.5.10 Further houses were flooded in the vicinity of London Road by water flowing through access gaps in the Corporation's wharf wall. Additional flooding of roads and cellars occurred due to a combination of defective brick walls and leaking sewers in the town.

4.6 Storm Surges in Late 20th Century

4.6.1 Storm surges in 1976 and 1978 continued to test the new coastal defences despite the wide-scale improvements since 1953.

4.6.2 On 3rd January 1976, water levels at Boston Docks were recorded as high as the 1953 record. Some seepage through the walls was observed opposite the new police station. At St Anne's Lane, a sewer valve failed to seal and approximately 7 houses were flooded in Oxford Street. However, the flood walls were not overtopped or breached.

4.6.3 Two years later, on 11th January 1978, a storm surge occurred with an estimated 1 in 27 chance of occurring in any given year. Flood defences were overtopped and breached during the event. Flooding was extensive with around 250 properties flooded and in some instances streets were flooded to a metre deep.

4.6.4 Conditions were worse in the Wash than in 1953 as the wind and surge are believed to have been funnelled into the wide bay and up into the Haven. This resulted in a level up to 0.25m higher than the 1953 and 1976 storm surge.

4.6.5 Boston flooded despite the flood walls and raised embankments owing to the collapse of a brick wall under the pressure of the rising water. This resulted in St Boltolph's church flooding along with an estimated 180 houses.

4.7 Recent Storm Surges in 21st Century

4.7.1 In more recent years there have been various smaller storm surges in 1993, 1999 and 2011. However, none of these have been reported to cause flooding in Boston or along the Haven.

4.7.2 Unfortunately, the largest storm surge on record hit the East Coast and Boston on 5th/6th December 2013.

4.7.3 Many of the local gauges were overwhelmed and failed to record the peak. However, it is known that the high tide combined the tidal surge to produce the highest water levels in memory.

4.7.4 The high water level overtopped the low quayside and Dock areas initially, then overwhelmed the flood walls and demountable defences in the town. Boston Borough Council CCTV footage shows the extent of this overtopping stretching all the way along the Fisherman's Quay onto London Road, South Terrace and upstream on both banks.

4.7.5 Overtopping of the embankments downstream of Maud Foster is thought to have started erosion down the backslope of the bank at Slippery Gowt. This added to any seepage to exploit the weakness and lead to the sudden failure or breach of the bank at the peak of the event.

4.7.6 The resultant flooding affected the landfill site and commercial properties on the Riverside Industrial Estate. An estimated 220 million litres of water were pumped out by the Black Sluice Internal Drainage Board (IDB) in a successful attempt to avoid flooding at Wyberton and Frampton.

4.7.7 A further breach of the flood wall was reported at the junction of South Terrace and Bath Gardens, flooding the properties and businesses beyond along Skirbeck Road.

4.7.8 The Black Sluice pumping station was heavily flooded, with all five pumps out of action due to flood waters damaging gearboxes, cooling pumps and electronics. This limited Black Sluice's capacity to manage water levels in the South Forty Foot Drain after the flood until two out of the five pumps were restored.

4.7.9 At the peak of the event, water spilled over the top of the Grand Sluice gates into the River Witham. This allowed the flood waters to flow up the River Witham as far as the gauge at Langrick Bridge, although this is reported to have remained in the river channel.

4.7.10 The tidal surge on 5th December 2013 was caused by extreme weather conditions, when high spring tides combined with strong winds and low pressure caused the sea to rise and large waves damaged and over topped flood defences. Overall water levels were about 1 metre higher than what would normally be expected. The tidal surge was the most serious in 60 years and severe flood warnings were issued. Severe warning means 'Danger to Life'.

4.7.11 During the December 2013 tidal surge event, the defences were overtopped, damaged or breached. There was extensive flooding to 668 properties across 55 streets in Boston, including 115 businesses close to the Haven.

4.7.12 The following quotes were reported by BBC News[2] describing the devastating situation faced by the local residents due to the 2013 flooding in Boston:

(a) '**Tidal Wave**' - Resident Neil McCafferty said water was "***literally pouring down the streets***"; "It is like a tidal wave coming down...".

(b) '**Devastating situation**' - Mayor of Boston Paul Kenny said: "***It's an experience that I hope we don't ever see in Boston again***".

(c) The town's St Botolph's church, also known as the Boston Stump, was severely damaged. Fundraising manager Peter Coleman said the church, which had recently undergone a major renovation project, had about 2ft (0.6m) of water inside and 4ft (1.2m) outside the building. "***It's a rather devastating situation***" he said.

4.7.13 In addition to the stark numbers of devastated homes and businesses and the tragic impacts which resulted from the tidal surge, there were also incalculable costs and personal turmoil faced by residents and business owners in returning to normality, particularly those who were uninsured.

4.7.14 A far greater number of people were affected by the flood as roads, railways and other infrastructure were flooded. Hundreds of people were evacuated from their homes to temporary refuge centres and some were still living in temporary accommodation a year later. Furthermore, there were also huge financial impacts to the public sector.

4.7.15 In the aftermath of flooding, the physical and psychological health and wellbeing of affected individuals and communities can become severely diminished, with symptoms of stress, mental illness and risk of chronic disease being exacerbated for many years after flooding occurs (see the pictures in **Appendix 2** and some of the quotes from some of the flood victims given in paragraph 4.7.18 below). Other properties affected by flooding included Boston College, Boston Grammar School, Leisure Centre, Bus Station and Black Sluice Pumping Station. Roughly £1m of damage was caused to St Botolph's church, with extensive repairs needed to the heating system, electrics and pews, as well as its cafe and shop. Below is some of the information taken from the website:

(a) The picture shown in **Appendix 2** indicates the severity of the flooding at Boston College ground;

[2] BBC News (2013, December 7). Boston flooding: Two hundred residents in temporary accommodation. Retrieved from BBC News Lincolnshire: http://www.bbc.co.uk/news/uk-england-lincolnshire-25254770?_sm_au_=iJV2Zf1qRVPNPS32

(b) Boston Grammar school was badly flooded. Students study hours were affected. The Boston Standard[3] reported that the school library only reopened six months after the floods caused significant damages;

(c) A Newsflare video[4] shows how badly the Bus Station was flooded;

(d) Some of the flood scenes in Boston included **Appendix 2** show the level of damages.

4.7.16 The cost of flood damage in the UK was estimated to exceed £5billion per annum with many homes and businesses being underinsured, as reported in the Telegraph by Rebecca Burn-Callander[5].

4.7.17 Financial expenditure incurred from coping with the negative aftermaths of flooding in the UK is also substantial, with current estimates suggesting this figure is around £1billion per annum, as reported by The Guardian[6] .

4.7.18 In some cases local residents' mental and physical health was put at risk. Below are two examples abstracted from an article by Dave Wade and the BBC News[7] :

(a) Mike and Pat Leighton's home was flooded in 2013, the ground floor of their Tower Street house was 18 inches (46cm) underwater. Mrs Leighton says that for five months afterwards they were "**upside down**".

"***We didn't have a Christmas last year.***

"About a foot to 18 inches all the way round the house - carpet, furniture, we lost everything."

A year on, the couple are almost back to normal now but they are still feeling the effects. Mrs Leighton is being treated for an infection in her nose, which her doctor told her is a result of the dirty floodwater.

"***It was obviously a germ in the water, in the muck, that got into my system because I was very poorly afterwards,"*** she says.

"***We both got poorly because of whatever the water brought into the house***."

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[3] Boston Standard. (2014, June 26). Historic grammar school library restored after flood damage. Retrieved from Boston Standard: http://www.bostonstandard.co.uk/news/education/historic-grammar-school-library-restored-after-flood-damage-1-6141872?_sm_au_=iJVSRH4Qs6r6H7D5

[4] Mark1. (2013, December 5). Boston bus station after storm surge. Retrieved from Newsflare: https://www.newsflare.com/video/8742/weather-nature/boston-bus-station-after-storm-surge?_sm_au_=iJVSRH4Qs6r6H7D5

[5] Burn-Callander, R. (2015, December 28). UK flooding: cost of damage to top £5bn but many homes and businesses underinsured . Retrieved from The Telegraph: http://www.telegraph.co.uk/finance/economics/12071604/UK-flooding-cost-of-damage-to-top-5bn-but-many-homes-and-businesses-underinsured.html?_sm_au_=iJVSRH4Qs6r6H7D5

[6] Osbourne, H. (2014, February 10). UK flood clean-up costs could hit £1bn, insurance expert warns. Retrieved from The Guardian: https://www.theguardian.com/business/2014/feb/10/flooding-costs-one-billion-pounds-insurance-expert-warns-rising-premiums?_sm_au_=iJVSRH4Qs6r6H7D5

[7] Wade, D. (2014, December 5). Boston floods: A year on from the tidal surge. Retrieved from BBC News: http://www.bbc.co.uk/news/uk-england-lincolnshire-30225852

(b) Mr Drake's farm land was flooded over a metre deep. The severity of the flooding 12 months ago can still be seen a year later.

Mr Drake says "***I can only say that it was the worst day of my life. I don't think I've ever known such a feeling of shock and apprehension and fear***."

"***Everything that I have tried to do over the years was just gone. It was a very depressing moment***."

4.7.19 All emergency services were involved during the event and the recovery after (see emergency rescue pictures in **Appendix 2**). Millions of pounds worth of damage was caused as a result of the December 2013 event (see pictures in **Appendix 2**).

4.7.20 Receptors vulnerable to future flooding in Boston include electricity sub stations, pumping stations, filling stations, sewage pumping stations, water distribution station, primary schools, secondary schools, ambulance stations, hospitals, nurseries, nursing homes, and telecom masts. A flood event can give rise to need for a mass evacuation or, depending on the time available, a focused evacuation of the most vulnerable members of the community.

4.7.21 The 1953 east coast floods resulted in 307 people dying in England - 42 in Lincolnshire (see **Appendix 1**). Any death of a member of the community resulting from flooding event can have far-reaching influences in terms of the contributions of that person to the community; both in a practical sense through work and community groups, and on an emotional level by the loss of social and family support. These influences can increase significantly as the number of fatalities increases with an increasing risk in tidal flooding. Particularly in smaller communities, when multiple lives are lost, the ability of the community to cope and adapt to the loss is limited.

4.7.22 Whilst historical events are often recorded in terms of the number of deaths, this is not the only measure of the impacts of flooding. Being witness to severe flooding and injuries to loved ones is traumatic and can be formative experiences in the lives of people.

4.7.23 The toll on people psychologically from witnessing events like flooding is unquantifiable. The loss of homes is a major influence on individuals in terms of emotional trauma in addition to financial loss.

4.7.24 Items of particular significance to people can have a value much greater than their objective financial value, for example; photographs, souvenirs, heirlooms etc. Losing these items can cause individuals emotional stress due to the high importance or value placed on these possessions.

4.7.25 Through increased financial stress because of the flood damages, there are a number of follow on effects to the lives of people involved. Immediate consequences from financial hardship have a detrimental effect on the wellbeing of members of the community subject to higher levels of stress. There is also a reduction in social mobility associated with an increase in financial stress, and an increased risk in homelessness which stem from difficulties in affording appropriate housing. These

issues increase the burden on social support networks and stretch the resources to assist.

4.7.26 During flood events, there is also a considerable amount of sediment and debris movement involved with the flow of flood waters. After the receding of flood waters the clean-up of all the debris and sediments can be costly and time consuming. With the greater frequency of flooding, there is an associated increase in clean-up efforts. With increasing tidal levels due to the rise in sea levels caused by climate change, the frequency of flooding will increase. This in turn increases the cost of clean-up efforts.

4.7.27 Maintenance of infrastructure, equipment and machinery is also a considerable cost which is generally included in estimates of flood damages. These maintenance efforts can be inconvenient and lost time during flood events can be significant, particularly in areas where regional transport routes are closed down. Roads and railways are sensitive to flooding in that vehicles cannot safely traverse floodwaters. Where transportation links are cut and there is no alternate route which provides a practical secondary option, people become stranded and lose the ability to perform normal duties.

4.7.28 With flood inundation of commercial properties and homes, a large amount of personal and business property will be damaged and destroyed. Whilst insurance policies in some cases do cover aspects of losses, there are unquantified costs which are not generally considered. For some properties, it is not possible to secure insurance.

4.8 Recent 'Near-Miss' Storm Surge Events in 2011 and 2017

4.8.1 A near miss occurred on 27th November 2011 where a 2m surge occurred during the ebb tide,1 ½ hours after high tide. Although lower than it could have been, the high water level still resulted in seepage through flood walls and flooding of road gullies. However, no property flooding or damage reported.

4.8.2 Most recently, there was a near miss on 13th January 2017. Fortunately, the large storm surge did not coincide with high tide as initially forecast. Thus the high water levels and associated flooding was avoided in Boston.

4.8.3 Despite the relatively lower risk, the flood warnings prompted great concern from residents. Very significant effort went into the preparation for the east coast incident in January 2017. The Boston town's population was "on edge" after their experiences of the 2013 flood. The facts and numbers provided below demonstrate the level of effort went into this preparation for the east coast incident including Boston:

(a) Nature and Duration of Incident:

(i) Environment Agency became aware of potential risk of an East Coast Surge incident on Monday 9 January 2017;

(ii) Duty staff managed the incident from Monday 9 January through to Monday 16 January 2017;

(iii) The Lincolnshire and Northamptonshire Incident Room was opened from 06.00 hours on Thursday 12 January to 22.00 hours on Saturday 14 January 2017;

(iv) The period of highest risk was approximately 15.00 hours to 18.00 hours on Friday 13 January 2017.

(b) Cost of responding to the incident:

(i) Approximately £70,000 was spent in Lincolnshire and Northamptonshire Area including Boston.

(c) Staff resources deployed:

(i) Duty staff based in Lincolnshire and Northamptonshire were involved throughout the incident;

(ii) Staff based in Lincolnshire and Northamptonshire who undertake incident activated roles were involved from Tuesday 10 January through to Monday 16 January 2017;

(iii) In total, approximately 100 Lincolnshire and Northamptonshire staff were involved each day (Wednesday to Saturday) and approximately 30 staff were involved on each of the other days (Monday 9th, Tuesday 10th, Sunday 15th and Monday 16th January);

(iv) Staff from other Areas within the Environment Agency were brought in to assist the Environment Agency's response under the Environment Agency's Mutual Aid arrangements; 55 people came to Lincolnshire and Northamptonshire on mutual aid and a further 36 staff were requested and on standby to travel to Lincolnshire and Northamptonshire but were stood down once the period of highest risk had passed. Staff came from as far as London and Manchester to assist;

(v) Incident response work continued throughout the weekend of 14 to 15 January 2017; and

(vi) Recovery work continued through the period from 16 to 31 January 2017.

(d) Equipment and Resources utilised:

(i) Significant amounts of plant and equipment based in Lincolnshire and Northamptonshire were used;

(ii) Approximately 2km of temporary barrier was deployed to Lincolnshire and Northamptonshire from the Environment Agency's national stockpiles;

(iii) Approximately 15 pumps of various sizes were deployed to Lincolnshire and Northamptonshire from the Environment Agency's national stockpiles as well as from other Environment Agency Depots across the country; and

(iv) Support from Lincolnshire Fire and Rescue and Lyndsey Marsh Drainage Board was provided.

4.9 Summary of Consequences of Flooding

4.9.1 Historical flooding in Boston has shown far reaching consequences, such as:

(a) **The risk to life, stemming from**:

(i) the depth and speed of the water rushing down the streets and into homes;

(ii) suspension of safe vehicular access for both those escaping and emergency responders; and

(iii) increased likelihood of infection and disease from contact with contaminants in flood waters;

(b) **The disruption and temporary loss of local amenities including**:

(i) educational institutions;

(ii) transportation facilities; and

(iii) utilities such as power and gas.

(c) **The immediate financial loss from**:

(i) the flooding of residential and commercial property regarding the buildings, personal effects and merchandise damaged by the flood waters; and

(ii) the loss of livestock and reduced harvest potential for primary producers;

(d) **The short-term economic loss from**:

(i) driving away businesses, lack of investment due to risk of flooding; and

(ii) additional funds being required for the repair, cleaning and further maintenance of public infrastructure;

(e) **The longer-term economic loss through**:

(i) damaged crops and reduced quality of soils affecting future yields;

(ii) slowing of the agricultural economy which provides goods and employment; and

(iii) adverse effects on commercial and agricultural businesses in the long term;

(f) **The cultural loss from**:

(i) flood damages to local landmarks and architecture;

(g) **Environmental loss from**:

(i) loss of life and habitats for native fauna; and

(ii) environmental damage and contamination of habitats from the spread of contaminants in flood waters;

(h) **The longer-term secondary health risks, including**:

(i) extended financial stress and decrease in quality of life suffered through flood damages to homes; and

(ii) damage to mental health, where flood victims suffer symptoms of post-traumatic stress disorder (**PTSD**), depression and anxiety as a result of traumatic events.

4.10 Conclusions

4.10.1 In summary, the town of Boston is entirely located within the floodplain and it has a history of tidal flooding. Just within over 200 years' span, Boston experienced nine instances of flooding, namely in 1779, 1807, 1810, 1949, 1953, 1961, 1976, 1978 and 2013. The 1953 tidal surge event (called the Great Flood) claimed 307 lives in England and 42 in Lincolnshire. The most recent tidal surge event in December 2013 led to significant economic, social and environmental damages in Boston. With climate change and predicted sea level rise in the future, the threat of tidal flooding to the public's health and safety, and to the high grade agricultural land, which is so important to this country's food security and sustainability, is on the increase.

4.10.2 It is my opinion that not building a Barrier would have major negative impacts upon the people in Boston due to the potential flood damage and risk to life along with the stress and health related impacts of living at risk of flooding, as well as the financial and economic impacts. The misery experienced by the people of Boston in the past, e.g. in 1953, 1978 and 2013, simply should not be allowed to be repeated.

4.10.3 The increasing fear of tidal flooding by the communities in Boston every time a high surge event is forecasted should be removed. Building a Barrier on the Haven will not only help to significantly reduce the actual risk of tidal flooding, but also help to remove the secondary effects of living at constant risk of being flooded upon those people and businesses. It is my opinion that building a Barrier is an absolute necessity to protect Boston and remove the fear of people and flood victims in Boston.

5 Benefits of the Barrier

5.1 This section describes the current level of flood protection in Boston, what benefits will be brought by the proposed Scheme, including the number of properties and businesses which would be protected, and the protection of critical infrastructure, as well as the wider benefits.

5.2 The current level of flood protection for Boston is 'low'. Based on the analysis of previous flood events, flooding in Boston will occur, with a likelihood of 2% in any one year. This frequency of flooding is based on the current day sea level and climate conditions. However, climate change induced sea level rise and increased storminess will result in the current Standard of Protection (**SoP**) for Boston of 1 in 50[8] , becoming diminished. The frequency of flooding will increase over time.

5.3 The Boston Barrier Scheme will improve the standard of protection in Boston from tidal flooding. The Scheme would offer protection against an 'extreme' tidal flood event – considered to be an event with a 1 in 300 (0.33%) chance of happening in any one year over a 100 year time period including allowance for climate change.

5.4 Without intervention the existing tidal flood defences have a high probability of overtopping and breaching in the next ten years. A breach would be followed by a rapid inundation of the low lying land behind. By 2110 the consequences of failure in a 'do nothing' scenario are predicted to result in:

(a) permanent loss of 17,269 residential and commercial properties within Boston due to regular tidal flooding;

(b) increased risk of loss of life from remaining properties at significant flood risk;

(c) permanent loss and damage to cultural heritage assets including the Conservation Areas and Listed Buildings in Boston town centre;

(d) inundation and damage of the A16 main trunk road, which is a vital emergency evacuation route;

(e) permanent change to or impacts on freshwater ecological features due to regular sea water intrusion; and

(f) permanent closure (or temporary closure during surge events) of the railway line from Boston to Skegness.

5.5 The benefits of the Scheme therefore include:

(a) a reduction in flood risk from 'significant' to 'low' to 17,269 residential properties;

(b) a reduction in flood risk to nearly 582 commercial properties; and

(c) present value benefits of £1,116m (October 2015 cost base).

[8] Standard of Protection of 1 in 50: means it can protect against event with a 1 in 50 (2%) chance of happening in one year over a 100 year time period

5.6 Additionally, benefits to Boston as a result of the improved flood defence will also be realised in financial terms. With reduced risk of flooding, insurance premiums for residential and commercial buildings will become lower. This will contribute to an increased buying power and quality of life for residents and increased profitability for businesses. A reduction in lost time will also benefit the bottom line of businesses. The reduced frequency of flooding will result in fewer instances of clean-up efforts expended by the local authorities, as well as fewer instances of preparing for near miss flood events.

5.7 Had the Barrier and the associated raising of defences been in place in December 2013, every one of those properties affected in Boston would have remained safe and protected.

5.8 It is widely recognised that not building a Barrier is not an option. I also hold the opinion that the Boston Barrier is urgently needed. The provision of a tidal defence Barrier and raising the downstream embankments on the Haven as required to mitigate the effects of climate change will help to reduce flooding risk to over 17,000 homes and businesses in Boston. It will help to fulfil a long standing ambition for the borough of Boston.

5.9 The proposed Barrier will improve the present day standard of protection from as low as 1 in 50 (2%) to as high as 1 in 300 (0.33%) chance of flooding each year.

5.10 Building a Barrier on the Haven will help to reduce the collective anxiety in the local community every time a storm surge is forecasted, known that their homes are less likely to flood.

5.11 It will help to provide the opportunity for greater regeneration and economic development in Boston in the most social-economically deprived areas.

5.12 In conclusion, considering the history of flooding, the damage and misery caused by flooding in the past, the fear of flooding arising from the risk hanging over Boston, and the increasing flood risk faced by Boston communities as outlined in **Section 4** (History of Flooding) of my evidence, considering the wider benefits that will be offered by the proposed Barrier scheme, it is my opinion that this scheme is urgently needed. Not building the Barrier or improving the downstream Haven embankments is not an option. The Scheme will not only help to reduce the flood risk for Boston town, it may also help some of the property owners or occupiers to insure their properties and possessions, and help the house owners to reduce their insurance premiums. Furthermore, it may help to provide confidence; enabling people to invest in Boston, allow for future economic growth and prosperity. The Barrier and improvements to the Haven embankments downstream of the Barrier will provide security and peace of mind to the people of this borough, investors, visitors and business.

6 Flood Risk and Modelling

6.1 Some concerns have been raised by third parties regarding the flood risk impacts of the proposed Scheme. Some of these concerns are related to the same topics and so in this section I address these concerns on a topic-by-topic basis. Those concerns are categorised into the following aspects:

6.1.1 robustness of the flood risk assessment and modelling, including climate change;

6.1.2 impact of flood risk downstream of the Barrier along the Haven;

6.1.3 impact of food risk upstream of the Grand Sluice;

6.1.4 the location of the Barrier; and

6.1.5 effect of the Barrier on the velocity of water in the channel.

6.2 My response to those concerns is provided on a topic-by-topic basis in Sections 6.3 to 6.8 below.

6.3 The Robustness of the Flood Risk Assessment and Modelling

6.3.1 A Flood Risk Assessment (**FRA**) (**A/17/2C**) was undertaken by Mott MacDonald in 2016 on behalf of the Environment Agency.

6.3.2 Specific concerns have been raised that the model might under-estimate the velocity in the Haven. There have also been some concerns raised about the robustness of the FRA and modelling.

6.3.3 To allow me to address issues related to the robustness of the flood risk assessment and modelling, I have carefully reviewed the following five elements and set out below my analysis for each element:

(a) the background to the FRA and modelling;

(b) what was done in terms of flood risk assessment to inform the scheme, including the modelling work that has been undertaken, software used, and the competency of the team carrying out the FRA;

(c) whether the models used for the FRA are capable of reproducing flood levels and velocity of real events, including the worst recorded tidal surge event in December 2013;

(d) the hydrological conditions considered for the FRA, in particular whether the worst credible-case combination for fluvial dominant and tidal dominant scenarios were taken into account during modelling and FRA; and

(e) the work been quality assured.

6.3.4 Finally, at the end of this section I give my summarised opinions on the robustness of the FRA and modelling.

Background

6.3.5 The hydraulic model used for the FRA extends from the mouth of the Haven at the Wash up the River Witham to Tattershall Bridge. It incorporates the lower reaches of the Kyme Eau, River Bain and adjacent floodplain areas to ensure the upstream limit of impacts from the Scheme are fully understood. The model extent is presented in the Flood Risk Assessment report (**FRA**) (**A/17/2dC**) and is also shown in **Appendix 3** for easy referencing.

6.3.6 The FRA was based on hydraulic modelling of the Barrier in the preferred location B using the preferred single opening configuration on the right bank (see section 6.6

for details regarding the advantages and disadvantages of alternative locations and why location B is the preferred location in my opinion).

6.3.7 The South Forty Foot Drain has been modelled separately for the Black Sluice Catchment Works study. This was a separate study carried out by Mott MacDonald on behalf of the Environment Agency. The findings of that study are stated in the Black Sluice Catchment Works Consultation Response Document a copy of which can be found at **Appendix 4** to my proof of evidence. They have been checked and approved by the Environment Agency. This model considers the latest river flow and Internal Drainage Board information as well as the pumping operation at Black Sluice after December 2013. The modelled outflow at Black Sluice represents the latest conditions and features for this catchment. Therefore, flows derived from this other model have been used to inform the impact assessment of the Barrier on the operation of the Black Sluice. A 1D/2D modelling approach was chosen to assess flood risk from the River Witham and Haven. The river system was represented in 1D which allows for detailed modelling of flow through the river system and hydraulic structures. The floodplain was represented in 2D which allows for realistic simulation of the flood propagation on the floodplain. The 1D river system is hydrodynamically linked with the 2D floodplain model. It enables the prediction of overtopping, overland flow paths, flood extents, depths, velocity and flood hazard within Boston and downstream.

Modelling and FRA

6.3.8 The FRA has been conducted following the Government's Flood Risk Assessment Guidance[9] , and the procedures for practical application of hydraulic modelling in the Environment Agency's Fluvial Design Guide (**Appendix 5**). The software used to build the hydraulic models is ISIS and TUFLOW. The software is capable of simulating flood water levels, velocity and flood water propagating along the river and on the floodplain.

6.3.9 Both ISIS and TUFLOW have been independently benchmarked and successfully used worldwide for flood risk assessment purposes for over 20 years and 10 years respectively. They have been used widely in the UK on major flood risk management schemes, such as HS2 flood risk assessment, Network Rail Flood Resilience Schemes in south west, and the River Thames Flood Alleviation Schemes.

6.3.10 The latest benchmarking process was undertaken by an independent organisation, Heriot Watt University in Edinburgh, in 2013. It assessed the robustness of particular 1D/2D hydraulic software in numerically solving the conditions of a given flow, geometry and downstream condition. Both ISIS and TUFLOW software and the 1D/2D ISIS-TUFLOW link have been benchmarked.

6.3.11 The SC120002 DEFRA report "Benchmarking the latest generation of 2D hydraulic modelling packages" concluded that ISIS/TUFLOW linked model is comparable to the physical model data and other model software predictions (**Appendix 6**).

[9] Department for Environment, Food & Rural Affairs and Environment Agency. (2017, February 27). Flood risk assessment for planning applications. Retrieved from UK Government: https://www.gov.uk/guidance/flood-risk-assessment-for-planning-applications

6.3.12 The benchmarking report points out that the calculation is sensitive to the representation of river bank levels in the calculation of volume exchange. Therefore, I have checked that careful representation of river bank elevation based on the latest topographic crest survey had been undertaken by the modelling team to define the banks. I can confirm that it was.

6.3.13 Having personally used ISIS (including ONDA, an early version of ISIS) for 26 years, TUFLOW for 15 years for a wide range of flood risk assessment, and having managed the first round of benchmarking of hydraulic models including ISIS in mid-1990 on behalf of the National Rivers Authority (the predecessor of the Environment Agency), it is my professional opinion that the choice of the software of ISIS and TUFLOW on this project for FRA is appropriate.

Experience of the team undertaking the modelling and FRA

6.3.14 The key staff responsible for the FRA and modelling of the Boston Barrier Scheme are:

(a) Marianne Piggott - who has a BSc in geography, with nine years' experience in FRA and modelling;

(b) Dr Xiaolin Wang - who has a BSc degree in hydraulic Structure Engineering in 2003, MSc in hydraulic and river dynamics in 2003, PhD in hydo-environmental engineering in 2011, with five years' experience in FRA and modelling; and

(c) Mr Christian Hetmank - a chartered water and environmental manager, with 20 years' experience water sector, and has extensive FRA and modelling experience;

6.3.15 They are all on the Environment Agency's Water and Environment Management Framework approved list for carrying out flood risk modelling and mapping projects.

6.3.16 All three staff have the relevant knowledge and experience in carrying out FRA and modelling. They have extensive experience in using both the ISIS and TUFLOW software that has been applied in the Boston FRA. They have been involved in many similar flood risk assessment for the Environment Agency, Network Rail and National Grid using the same techniques and software as have been employed in relation to the Boston Barrier Scheme.

Model calibration

6.3.17 The 1D/2D hydraulic model for the Boston Barrier was based on the Lower Witham hydraulic model developed by AECOM (formerly Faber Maunsell) under the Witham Catchment Strategic Model (WiCSM) commission. The purpose of the original model was to improve flood mapping for the catchment, documented in the Lower Witham Volume 1 - Modelling and Flood Mapping Report (**Appendix 7**).

6.3.18 In order to ensure that the models developed and used for assessing the flood risk assessment are capable of realistically predicting the reality for the current and future scenarios, it is important that models are calibrated against historical events

including to the most recent highest/worst recorded tidal surge event in December 2013.

6.3.19 The Lower Witham model has been used previously to simulate observed high flow events. Model calibration was undertaken previously to achieve the best match to the gauged water levels in the river system. The model was calibrated by AECOM in 2007 to recorded data from the November 2000 and February 2001 events. The calibration to observations was based on a consistent topographic survey of banks along the Lower Witham and the design operation of the washlands in the Upper Witham and IDB pumps within the Lower Witham catchment. That model had been previously checked and approved by the Environment Agency at that time.

6.3.20 Through development of the Boston Barrier modelling work by Mott MacDonald, all possible calibration has been completed, informed by recorded data. Additionally, the model has been further verified against the largest fluvial event on record, occurring on the Witham in January 2008. The results are presented and discussed in **Appendix 8**. This additional testing was to further verify the robustness of the model and its ability to reproduce the reality of the worst historical fluvial events on record.

6.3.21 The criteria for the selection of model calibration and verification events was to include high fluvial flow scenarios, high tide scenarios, and scenarios representing high fluvial and tidal combinations if there was observed data available in the area of interest. This was to ensure that the full range of river conditions has been tested by the model and the model is capable of replicating the realities for the full range of river conditions.

6.3.22 As a result, all the model calibration and verification events have been selected based on past real events where observed data was available in the area of interest. They cover:

(a) the largest/worst fluvial event;

(b) moderate fluvial event;

(c) the largest tidal event; and

(d) moderate fluvial event combined with moderate tidal event.

6.3.23 No event has been identified that has happened in the past where extreme tidal conditions coincide with extreme fluvial conditions. Statistic analysis has shown that the probability for extreme fluvial and extreme tidal conditions to occur at the same time is extremely low.

6.3.24 The results of the calibration efforts indicate that the model is a valid representation of the catchment response and is the best available tool for assessment, given the analysis of data from all recorded historical events. It cannot be reasonably expected that further calibration efforts could be carried out.

6.3.25 My checking has shown that great effort was made to calibrate the updated 1D/2D model against the December 2013 event. This event is the highest/worst tidal surge

event recorded along the east coast in the last 60 years. The focus of the model calibration was to match the model predicted results with the recorded water levels and flooding extent experienced in the December 2013 storm surge.

6.3.26 Apart from the December 2013 event, great effort was also made to simulate other combinations of fluvial and tidal magnitudes discussed in 6.3.22. Collaboratively with the Environment Agency, five more events were identified with tidal magnitudes less than the December 2013 event in conjunction with different magnitudes of fluvial flows to reflect the spectrum of the combined events. They are listed below:

6.3.27 Apart from the December 2013 event, great effort was also made to simulate other combinations of fluvial and tidal magnitudes discussed in 6.3.22. Five more events were identified with tidal magnitudes less than the December 2013 event in conjunction with different magnitudes of fluvial flows to reflect the spectrum of the combined events, and events with specially collected data. They are listed below:

(a) **December 2013 event** – the largest/worst tidal surge event on record in the last 60 years, the gauges were overwhelmed so the exact water level is subject to some uncertainty;

(b) **September 2013 event** - a large tidal event (0.2m below the annual maximum tide) with fluvial flow greater than normal base flow;

(c) **January 2016 event** – a moderate tide (0.7m below the annual maximum tide) with a large fluvial discharge;

(d) **March 2016 event** - a moderate tide (0,.25m below to the annual maximum tide) with a fluvial flow close to approximately 1 in 2 (50%) chance of happening in one year over a 100 year time frame, larger than the 1/2016 event;

(e) **October 2011 event** - velocity data was purposely acquired by CH2M for model calibration purposes with a moderate to high tide (0.17m below the annual maximum tide); and

(f) **January 2008 event** – the largest recorded fluvial event with a moderate tide (0.63m below the annual maximum tide).

6.3.28 Those six events cover the historical events experienced in the Haven which have available observed data, including the annual high tide conditions in conjunction with typical river flow conditions and ‘difficult’ river flow conditions. They include the largest fluvial event occurred in January 2008 on record and the December 2013 event - the largest tidal surge event in the last 60 years.

6.3.29 The results of the calibration efforts indicate that the model is a valid representation of the catchment response and is the best available tool for flood risk assessment. Considering the analysis of data from all recorded historical events and the model calibration results, it cannot be reasonably expected that further calibration efforts could be carried out. Any further calibration will not lead to any different outcome.

6.3.30 After the model had been calibrated against the worst tidal event and a mixture of tidal and fluvial events listed in paragraph 6.3.27, the model was then further verified against the largest fluvial event recorded. Additionally, a full range of design tidal and fluvial events have been tested to assess the flood risk for future scenarios as part of the FRA. The design events range from:

(a) regular high tide (mean high water spring tide), annual tide, 1in 200 annual chance and up to 1 in 1000 annual chance of tides; and

(b) river baseflow, 1 in 20 annual chance, 1 in 100 annual chance and up to 1 in 1000 annual chance of river flows.

6.3.31 Climate change conditions have also been taken into accounting during scenario testing using the recommended values sea level rise given in Table 3, fluvial flow increase in Table 1 of the Government's Flood Risk Assessments Climate Change Allowances (**Appendix 9**). Paragraphs 6.3..60 to 6.3.72 of this evidence, under the heading of 'Climate change considerations in the FRA (**A/17/2C)**, specifically address how the climate change conditions have been considered in accordance with the latest Government Climate Change Allowances Guidance.

6.3.32 During the December 2013 tidal surge event, several gauges in the Haven and nearby areas failed to record the entire event, for example some of the peak levels were not recorded. There was also a breach in the flood defence at Slippery Gowt during this worst tidal surge event on record over the last 60 year. However, the breach dimensions and how the breach was developed throughout the event were not known. Nevertheless, the available water level records did provide very valuable information about the magnitude of the tidal levels at different locations in the areas of interest along the Haven. The information was sufficient for the purposes of the modelling.

6.3.33 A reasonable and appropriate match in levels and flooding mechanisms was achieved for most of the tidal curve at the gauge downstream of Grand Sluice despite the uncertainty in the breach data at Slippery Gowt and the reliability of the gauging equipment when overwhelmed by the flood waters. Also, the model replicated the overtopping at Grand Sluice and reproduced the reverse flow and water level rise at Langrick Bridge gauge to within ±0.1 m (see section 4.1.3 of **Appendix 10**).

6.3.34 The channel width and channel sectional areas vary from location to location downstream of Grand Sluice. Some structures on the river system have smaller cross sectional areas. At those locations, higher velocities are generally observed by the river users.

6.3.35 In order to determine the flow pattern and the magnitude of the velocity in the Haven, on 28 October 2011 Halcrow (predecessor of CH2M) undertook a standard velocity test using an orange on the peak velocity path at the Swing Bridge on the Haven during an ebb tide when the highest velocity would occur during a typical tide cycle. The observed velocity was recorded between 0.1m/s-1.16m/s(0.2 - 2.3 knots). The one-dimensional and two-dimensional models developed for flood modelling and flood risk assessment were used to simulate this event. The model predicted velocity

was subsequently compared against the observed values and presented in **Appendix 11**.

Additional model calibration

6.3.36 The model has been calibrated against the December 2013 tide surge event and achieved a reasonable and appropriate match as described in paragraph 6.3.25. Under such severe tidal conditions, of course, the boat users would be advised not to navigate in the Haven. In the preparation of this evidence, and in order to give me the confidence that the model is capable of replicating the velocities in the Haven under normal high tide range conditions when boat users are likely to use the Haven for navigation, I made a suggestion to the Environment Agency in November 2016 to carry out flow measurements at faster flowing sections on the Haven during a high tide event. This suggestion was willingly accepted and supported by the Environment Agency.

6.3.37 I examined the forecasted tide table along the Haven and in The Wash and identified two high tides forecasted on 13 and 14 December 2016 and suggested that the Environment Agency take velocity measurements at the following five locations on the Haven:

- Immediately downstream of Grand Sluice
- A52/John Adams Way
- Swing Bridge
- Proposed Boston Barrier Location
- Geest Point

6.3.38 The reason for choosing these locations was because the velocities at those locations are reported by river users to be higher than at other locations in the Haven.

6.3.39 Subsequently, a plan was developed to measure the velocities at those locations on 13 and 14 December 2016 when high tides were forecasted during these two days.

6.3.40 The reason for choosing two days to measure the velocity was to ensure that if, on 13 December 2016, velocities could not be measured as planned due to any unforeseen circumstances, then the velocity still could be captured when the tide remained high on 14 December 2016. The two-day window was chosen to provide a safety factor in getting the velocity data under high tide conditions that I was looking for.

6.3.41 The observed velocities at these five locations are presented in **Appendix 12**, no velocity measurement was taken immediately downstream of Grand Sluice except one reading as the water remained more or less static during the time of the survey. The reason that the water was static downstream of Grand Sluice at the time of survey was that because of high tide no water discharged through Grand Sluice as the sluice was automatically closed to prevent tidal water propagating upstream.

6.3.42 The following observations can be made from the analysis of the observed velocity:

(a) Higher velocity was recorded at the deeper part of the channel, and lower velocity was recorded at the shallow part of the channel towards the banks;

(b) The typical range of velocities experienced was from 0.0m/s to approximately 1.1m/s at each of the river sections during the periods of maximum velocities during a tidal cycle; and

(c) The highest velocity was observed at the Swing Bridge, then at John Adams Way, Geest Point and the proposed Barrier location in a decreasing order.

6.3.43 The model was used to simulate the 13 and 14 December 2016 high tide event. The model also predicted the highest velocity at Swing Bridge, then at John Adams Way, Geest Point and the proposed Barrier location in a decreasing order.

6.3.44 The model-predicted velocities have been compared against the observed velocities. The comparison shows a good match of the velocity pattern and magnitude predicted by the model with those surveyed (see **Appendix 13**).

6.3.45 Following the review of the additional testing, I can draw the following conclusions:

(a) the model calibration results are reasonable;

(b) no more testing could be reasonably done; and

(c) the concerns expressed by objectors over the capability of the model to realistically predict the water levels and velocities are misplaced.

Fluvial and tidal combinations considered in the FRA

6.3.46 The FRA (MM 2016) (**A/17/2C**) has considered the hydrological conditions described below which represent the credible worst-case combination for fluvial dominant and tidal dominant scenarios.

6.3.47 The severity of flooding is influenced by the magnitude of the flood (i.e. the peak flow) and the duration and volume of the flood hydrographs. The severity of flooding in the Lower Witham catchment is more affected by flood volume, rather than the peak flow, because of the flat nature of the floodplain. The bigger the flood volume, the bigger the flood extent.

6.3.48 Therefore, using a longer storm duration to derive the flow hydrographs is more desirable as it will yield a larger flood volume than short duration event and the estimated flows will be more conservative.

6.3.49 Hence longer but reasonable storm duration of 48.5 hours was derived based on historical data for the lower reaches of the Witham catchment. This will lead to a conservative estimation of the flood volume.

6.3.50 Similarly, for South Forty Foot Drain (**SFFD**) a conservative storm duration of 40 hours was derived and used for the same reason to produce a conservative flood volume.

6.3.51 The downstream boundary conditions for the modelling work were abstracted from Northern Tidal Modelling - Tidal Analysis Report. This was produced by Mott McDonald in 2006 on behalf the Environment Agency to establish the tide levels along the east coast from the Humber to the Wash. The analysis and findings have been independently reviewed by Atkins. They have also been reviewed and approved by the Environment Agency.

6.3.52 This analysis provides the best available estimate of the annual probability exceedance of a given level at Boston resulting from a tidal surge event. The study utilised data from the Hobhole gauge downstream of the Hobhole Sluice and used regression analysis to produce levels at the Maud Foster gauge, the approximate location of the proposed Barrier.

6.3.53 Spatial trending of gauges along the coast of the Wash was used to generate a consistent set of water levels. As a precautionary estimate of extreme tidal events, the design water levels were subsequently increased by 70mm so that the along shore trend for the 1 in 200 annual chance (0.5% AEP[10]) peak water levels corresponded with the trend for the 1 in 1 annual chance water levels.

6.3.54 The phasing of the River Witham and SFFD catchments has been based on the calibrated fluvial models

6.3.55 This results in SFFD flood peaks reaching the outfall slightly before the River Witham reaches the Haven. This again reflects the real situation.

6.3.56 This phasing corresponds with the gauge records at the Grand Sluice and the Black Sluice, particularly for the real events in January and March 2016.

6.3.57 The river floods are phased to arrive at high tide in the Haven, creating the maximum potential for tide-locking as a credible worst-case.

6.3.58 The design events tested range from a frequent, i.e. a less than annual chance event, to a very rare - a 1 in 1000 (0.1%) annual chance event.

6.3.59 In conclusion, I am satisfied that the credible worst fluvial and tidal combinations have been taken into account in the FRA on a conservative basis. I am confident with the modelling and the FRA. There is no need for any different or more conservative modelling.

Climate change consideration in the FRA

6.3.60 The FRA (**A/17/2C**) has considered the climate change conditions following the National Planning Policy Framework (NPPF, March 2012) (**C/1/1**) and has

[10] AEP means annual exceedance probability

considered the implications of the latest climate allowances set out in Flood risk assessments: climate change allowances (DEFRA, February 2016).

6.3.61 During the course of the FRA being undertaken for the Boston Barrier Scheme, the climate change guidance for developments was updated in flood risk assessments: climate change allowances (UK Government 19th February 2016)[11] . However, the previous estimate of net sea level rise in The Wash over the next 100 years remains the same as set down within the National Planning Policy Framework guidelines (**C/1/1**). Therefore the new guidance on climate change allowance for sea level rise does not change the values adopted in the FRA (**A/17/2C**).

6.3.62 The proposed Barrier is classified as water-compatible development. Therefore, river flows were assumed to increase by 25% over 100 years according to the central emissions estimate of climate change for the Anglian River Basin District of Table 1 'Peak river flow allowances by river basin district'.

6.3.63 The original modelling applied a 20% increase in river flows in accordance with the National Planning Policy Framework (2012) (**C/1/1**) to model a range of events including the 1%AEP with 20% river flow increase and 0.1%AEP with 20% river flow increase fluvial floods.

6.3.64 The model has already simulated the flow conditions that are on either sides of the government recommended climate change allowance of 25% increase in river flows. Therefore, the peak water levels upstream of Grand Sluice were interpolated from the available model results to derive the water levels corresponding to the river flow conditions with a 25% increase in river flows.

6.3.65 For the 1%AEP event, i.e. for the event with 0.1% annual chance of occurring, the peak water levels were extrapolated from the model results to derive the water levels corresponding to the river flow conditions with a 25% increase in river flows.

6.3.66 The result from the interpolation shows that using the latest climate change allowances, i.e. a 25% increase in river flows, the change in flood levels upstream is less than 0.04m. That is because of the presence of large flat floodplain upstream, an extra 5% increase in flow (increasing the low from 20% to 25%) makes very little difference in flood levels as the water is already out of banks upstream under such conditions. There is little change in the amount of water contained in the river flowing downstream. Therefore, it makes negligible difference in the water level in the Haven further downstream of the Witham catchment.

6.3.67 Without the Barrier in place, the increase in peak fluvial flood levels attributed to a 20% increase in river flow have been found to be less than 0.1m above the baseline in a 0.1% AEP event in 2115 in the Haven.

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[11] Environment Agency. (2017, February 3). Flood risk assessments: climate change allowances. Retrieved from UK Government: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

6.3.68 When a 1.14m sea level rise is considered at the downstream boundary the level in combination with a 20% increase in river flows, the water levels in the Haven increase by over 1m accordingly (See FRA report, Figure 2.6 (**A/17/2C**)).

6.3.69 Upstream of Grand Sluice, the increase in peak fluvial flood levels attributed to a 20% increase in river flow is limited to less than 0.01m change in water level increase above the existing scenario (See FRA report, Figure 2.6 (**A/17/2C**)).

6.3.70 Extrapolating these results at Grand Sluice for the latest climate change allowances, a 25% increase in river flows shows that the change in flood levels upstream would still be less than 0.04m (see FRA report, Figure 2.7(**A/17/2C**)).

6.3.71 It is evident that when considering the latest climate change allowance, a 25% increase in river flows in the catchment would result in additional flooding on the floodplain upstream, as in the upper reaches of the Witham river system, the channel has much smaller capacity compared to the downstream reach near Grand Sluice. However, by the time the water reaches the Haven, the water levels would still remain below the flood defence/bank levels. That is because the majority of the flow in the catchment is stored on the vast flat floodplain further upstream.

6.3.72 Therefore, the operation of the Barrier during fluvial floods does not change fluvial flood risk to Boston even with the consideration of increasing river flows due to climate change. The main flood risk in Boston is tidal flooding, i.e. the risk from the sea.

Quality assurance of FRA and modelling

6.3.73 The calibrated model was then used to assess the flood risk for 'with' and 'without' the proposed Barrier scenarios as well as the 'during construction' scenario, for both present day and future climate change conditions.

6.3.74 The models, modelling results, FRA (**A/17/2C**) and modelling reports have been independently checked, reviewed and approved by the Environment Agency technical specialists and representatives with catchment knowledge and experience in the area team who are not part of the project team.

Conclusions

6.3.75 After examining the software used for the FRA (**A/17/2C**), the events used for the model calibration, the model calibration results, the design range of conditions tested, the FRA and the hydraulic modelling reports, I am satisfied that:

(a) the software used is appropriate for the FRA;

(b) the model development and calibration have been based on best available data;

(c) the modelling and calibration process have followed industry best practice;

(d) the models have been calibrated against real events including the worst tidal surge event in the last 60 years;

(e) it has demonstrated that the hydrodynamic models are capable of reproducing the real events and are capable of predicting the reality in terms of water levels and velocity;

(f) the combination of the fluvial and tidal events tested ranges from frequent (less than annual occurrence event) to very rare event up to the 1 in 1000 annual chance (0.1% AEP) event;

(g) the FRA has considered the climate change conditions following the National Planning Policy Framework (NPPF, March 2012 (**C/1/1**)) and took into account the climate change allowances recommended in the latest Government's Flood Risk Assessments Climate Change Allowances document[12];

(h) the model results show a very substantial reduction in flood extent with the implementation and operation of the proposed Barrier compared with the existing, i.e. 'without Barrier' situation; and

(i) additionally, the models also represent the 'best available' information to assess the impact of the Barrier and to inform the evidence.

6.3.76 The results of the calibration efforts indicate that the model is a valid representation of the catchment response and is the best available tool for assessment, given the analysis of data from all recorded historical events. It cannot be reasonably expected that further calibration efforts could be carried out.

6.3.77 In conclusion, the FRA (**FRA**) (**A/17/2C**) has been carried out in accordance with all relevant guidance and best practice. The FRA and modelling has been carried out using the best available data, using the most advanced and well-tested techniques and software, following industry best practice and represents the best available information. The models were properly calibrated against previous known events, including the worst fluvial and worst tidal events recorded. The model tests and assessment were thorough and comprehensive. It is my opinion that any further or different modelling would not have led anyone to being any better informed and would not have produced any different or additional data. All the modelling and testing that can reasonably be done has been done. The modelling is compatible with future climate change scenarios. Therefore, it is my considered opinion that the FRA and modelling is robust and complete.

6.4 Impacts on Flood Risk Downstream along the Haven

6.4.1 Specific concerns have been raised by some third parties that the implementation and operation of the proposed Barrier will cause increased flood risk to the downstream reach of the Haven[13] . This concern is ill-founded and is based on a misunderstanding of the location of the Barrier. My opinion is provided below by reference to the following key aspects:

[12] Environment Agency. (2017, February 3). Flood risk assessments: climate change allowances. Retrieved from UK Government: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

[13] Wyberton Parish Council; Boston and District Fishermen's Association.

(a) what factors influence the water level in the Haven now;

(b) what factors will influence the water level in the haven after the implementation of the Barrier; and

(c) what the impact of flood risk downstream will be following the implementation and operation of the Barrier.

Under the current situation (without the Barrier)

6.4.2 Both Grand Sluice and Black Sluice are connected with the Haven, and in turn the Haven is connected to The Wash.

6.4.3 When the water level in the Haven exceeds the water level upstream of Grand Sluice, Grand Sluice will be automatically closed to stop tide water travelling beyond Grand Sluice. The same will happen at Black Sluice.

6.4.4 When the water level upstream of Grand Sluice is higher than that in the Haven, the sluice gate will open. Black Sluice functions in a similar way to Grand Sluice under gravitational discharge. Black Sluice also has pumping ability.

6.4.5 The water level in the Haven downstream of the Grand Sluice is primarily influenced by the water level in the Wash.

6.4.6 The water level in the Haven goes up with the flood (rising) tide and falls with the ebb (falling) tide.

Under the future situation with Barrier and forecast tide is below 5.3m AOD

6.4.7 The Barrier is connected with the Haven, and the Haven is connected to The Wash. When the tide goes up in the Wash, the tide propagates up the Haven towards the Barrier. If the forecast tide is less than 5.3mAOD in the Wash, the Barrier will lie on the river bed, so the tide will continue to propagate towards Black Sluice and Grand Sluice.

6.4.8 Grand Sluice and Black Sluice will operate in exactly the same way as the current situation under gravitational discharge, and the water level in the Haven will remain the same as prior to the Barrier's construction.

6.4.9 There is no increase in flood risk from the Haven under this condition as the Barrier does not interfere with the tide propagating upstream or travelling downstream.

Under the future situation with Barrier and forecast tide exceeds 5.3m AOD

6.4.10 Similar to the situation above, the Barrier is connected with the Haven, and the Haven is connected to The Wash. When the tide goes up in the Wash, the tide propagates up the Haven towards the Barrier and towards Grand Sluice. If the forecast tide exceeds 5.3m AOD in the Wash, the Barrier will be raised to stop the tide propagating upstream once the water level reaches 5.1m AOD. This will help to reduce the risk of tidal flooding in Boston.

6.4.11 This also means the channel capacity between the Barrier and Grand Sluice above 5.1m AOD will not be occupied by tidal water as compared to the 'without Barrier' situation. As the distance between the Barrier and Grand Sluice is about 2km, the typical channel width is 50m wide. Therefore the available channel surface area and channel capacity between Grand Sluice and the Barrier above the 5.1m AOD threshold are going to be negligible compared to the vast surface area and volume of the Wash and the sea. Hence, the 'removal' of the storage space in the Haven between the Barrier and the Grand Sluice above the 5.1m AOD threshold will not have any material change in the water levels in the Wash.

6.4.12 As the water level in the Haven is connected to and dictated by the water level in the Wash, if the water level in the Wash is not going to have any material change downstream of the Barrier as compared to the 'no Barrier scenario', then the water level in the Haven would not have any material change either.

6.4.13 Hence the flood risk to the communities at Fishtoft, Skirbeck and Wyberton which are downstream of the Barrier will not be increased as the result of the operation of the Barrier.

Conclusions

6.4.14 For forecast tide below 5.3m AOD, the water level in the Haven will remain the same as the current, without Barrier situation.

6.4.15 For forecast tide exceeds 5.3m AOD, the tide will continue to propagate towards Grand Sluice before the tide reaches 5.1m AOD. Once the tide exceeds 5.1m AOD, the Barrier will be raised up to stop the high tide propagating beyond the Barrier. This will help to reduce the risk of flooding in Boston.

6.4.16 When the Barrier is raised, the channel capacity between the Barrier and Grand Sluice above 5.1m AOD will not be occupied by tidal water as compared to the 'without Barrier' situation. As the distance between the Barrier and Grand Sluice is relatively short, (only about 2km), the typical channel width is also small (50m wide) in comparison of the size of the Wash and the sea. Therefore the available channel surface area and channel capacity between Grand Sluice and the Barrier above the 5.1m AOD threshold are going to be negligible compared to the vast surface area and volume of the Wash and the sea. Hence, the 'removal' of the storage space in the Haven between the Barrier and the Grand Sluice above the 5.1m AOD threshold will not have any material change in the water levels in the Wash.

6.4.17 As the water level in the Haven is connected to the water level in the Wash and dictated by the water level in the Wash, if the water level in the Wash is not going to have any material change compared to the 'no Barrier scenario', then the water level in the Haven downstream of the Barrier would not have any material change either.

6.4.18 Hence the flood risk to the communities at Fishtoft, Skirbeck and Wyberton which are downstream of the Barrier will not be increased as the result of the operation of the Barrier compared to the no-Barrier scenario.

6.5 Impact on Flood Risk Upstream

6.5.1 Concerns have been raised by some objectors that that the implementation and operation of the proposed Barrier will cause increased flood risk upstream. My proof of evidence provides my assessment of the impact of the flood risk upstream from the Barrier following the implementation and operation of the Barrier.

Under the current situation (i.e. without the Barrier)

6.5.2 Grand Sluice is a tidal lock structure. When the water level in the Haven is higher than the water level upstream Grand Sluice, the sluice gate will be shut. This stops tide propagating beyond Grand Sluice. When the water level in the Haven is lower than the water level upstream of Grand Sluice, the gate will be open, discharging water from the Witham into the Haven.

6.5.3 During a high tidal surge event, Grand Sluice will be in a shut position to stop the tide propagating upstream of Grand Sluice.

6.5.4 The water level upstream of Grand Sluice is influenced by the rainfall run off from the Witham catchment and the tide level in the Haven (and the resultant tide lock of Grand Sluice).

Under the future situation with Barrier and with different magnitudes of tide

6.5.5 When no tidal event is forecasted, the tidal gate of the Barrier would lie level with the river bed of the Haven at -3.0m AOD.

6.5.6 The tidal gate would be raised during very high tidal conditions when tidal level forecast is expected to exceed a level of 5.30m above ordinance datum (AOD) in the Wash – the High Astronomical Tide is 4.73m AOD.

6.5.7 The operational level for the Barrier is +5.30m AOD. The forecast trigger level for the Barrier to close will be +5.10m AOD.

6.5.8 Following the implementation of the Barrier, the Barrier will only be raised during elevated tidal conditions, or for training, maintenance and testing.

6.5.9 When the forecast tide is below 5.3m AOD, the Barrier will lie level with the river bed. Under such tidal conditions, the Grand Sluice will operate the same way as it is now. There is no change to the flood risk upstream.

6.5.10 When the forecast tide is expected to exceed 5.3m AOD, the tidal gate will be raised at the threshold of 5.1m AOD. The water level upstream of Grand Sluice can be one of the following two scenarios:

(a) *Scenario 1* – water level upstream of Grand sluice is greater than the water level downstream of Grand Sluice

Under Scenario 1 the water will continue to discharge from the Witham to downstream of Grand Sluice until the water level on each side of the gate reaches the same level. There will be no increase in flood risk upstream

compared to the current without Barrier situation. For some situations when the tide level in the Haven downstream of the Barrier is much higher than the water level upstream of the Barrier, this could potentially help to reduce the fluvial flood risk upstream of Grand Sluice compared to the no-barrier scenario.

(b) *Scenario 2* – water level upstream of Grand sluice is equal or lower than the water level downstream of Grand Sluice

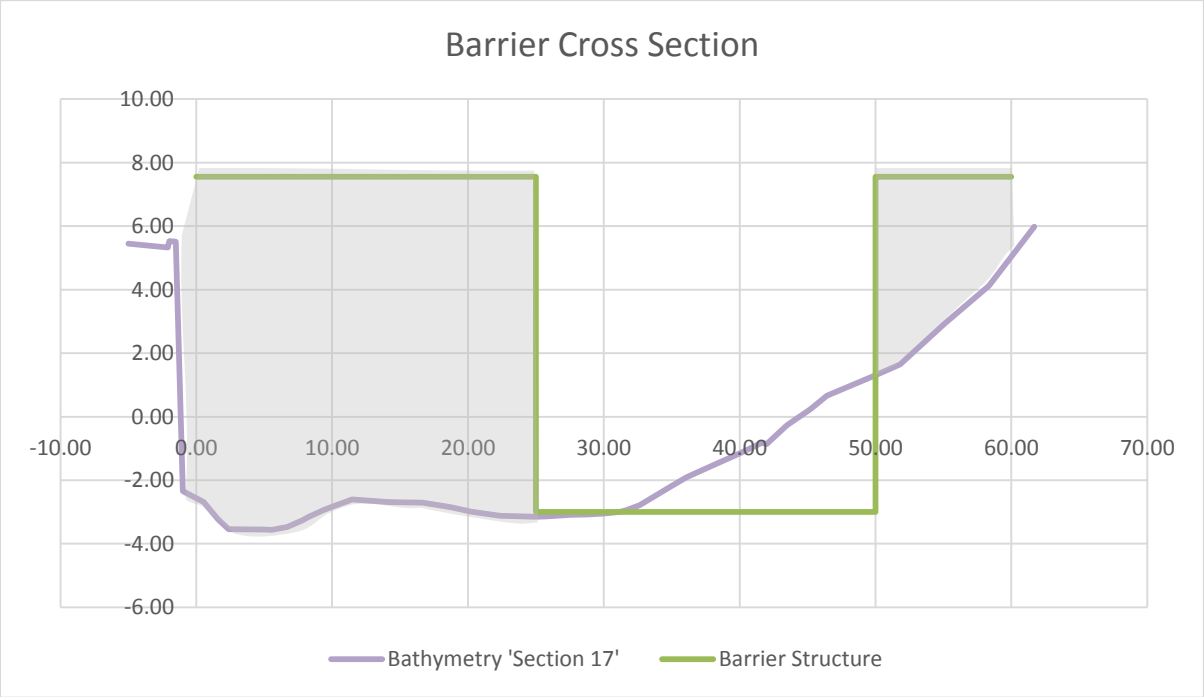
Under scenario 2, Grand Sluice will be closed, the same as the existing without Barrier situation. Therefore, there will be no increase in flood risk upstream compared to the current without Barrier situation.

Under future situation: with Barrier and under river flood conditions

6.5.11 Under fluvial, i.e. river, flood conditions and with the forecast tide level below 5.3m AOD, the Barrier would lie on the river bed and would not obstruct the flow in the vertical direction.

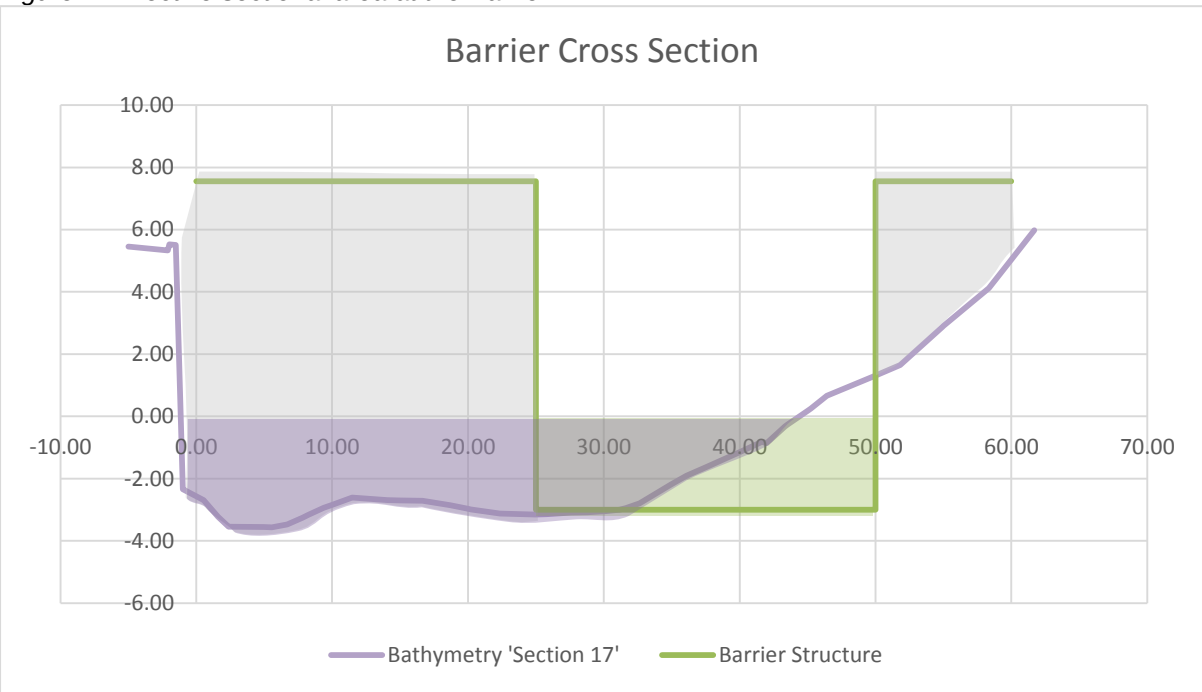
6.5.12 With the construction of the proposed Barrier, the profile of The Haven will change, as observed in **Figure 1**. A cross-section is shown with two profiles, representing the existing channel and the proposed structure profile. The current profile is shown by the magenta line, with the uneven channel bed profile. The proposed profile with the structure will be different, shown as the green line on the cross section. The two areas shaded grey, either side of the open Barrier section represent the Barrier walls. The area between the purple and green profiles not shaded indicates dredging of the river bed to suit the new Barrier profile, shown green.

Figure 1 The Haven channel profile



6.5.13 The effective area of the cross section is the area available for water to flow through, see **Figure 2**. The portion of the cross sectional area shown magenta against the left quay wall will become ineffective. The portion of cross-sectional area shaded both green and magenta will remain. The portion of the cross-sectional area shown green will become effective.

Figure 2 Effective sectional area at the Barrier



Note. Purple and green shaded areas represent effective area, water level shown at 0.00mAOD

Table 1 Changes in effective sectional area at the Barrier

Location Name	**Effective Sectional Area (m2)**		
	Below 0.00mAOD	*Below 0.50mAOD*	*Below 1.00mAOD*
Barrier (constructed profile)	75.0	87.5	100.0
Barrier (existing profile)	115.5	136.0	156.5

6.5.14 The table above indicates the loss of effective area through construction of the Barrier. For reference, other sections in The Haven/Witham are indicated in the table below. The sections are ranked in order of smallest effective area through to largest effective area.

Table 2 Changes in effective sectional area

Location Name	**Effective Sectional Area (m2)**			
(upstream to downstream)	*Below 0.00mAOD*	*Below 0.50mAOD*	*Below 1.00mAOD*	*Rank*
Town Bridge	39.0	52.1	65.9	1
John Adams Way (A52)	49.9	64.3	78.8	2
Swing Bridge	77.0	97.5	120.4	4
(Swing Bridge, left opening only)	(41.7)	(53.7)	(65.6)	
Barrier	75.0	87.5	100.0	3
Geest Point	101.2	122.4	144.4	5

6.5.15 Table 2 indicates that there are two locations of smaller effective area at Town Bridge and John Adams Way compared to the Barrier section after it is built. This means that the reduction in area at the Barrier section does not result in a cross-section smaller than at Town Bridge and John Adams Way. This suggests that in the Haven, after the construction of the Barrier, the effective sectional area at the Barrier location will be reduced, nevertheless it does not form the same level of 'restriction' or 'bottle neck' effect to flows as Town Bridge and John Adam's Way. Therefore, it would have less effect on the water levels upstream compared to Town Bridge and John Adam's Way.

6.5.16 The Barrier structure would reduce the existing channel width to approximately 25m. The existing channel width varies from approximately 55m wide at mean high water to approximately 34m at low water.

6.5.17 Whilst the width at the Barrier would be reduced to 25m, the river bed along the right bank of the river channel will be lowered by 2-4 metres typically in the vicinity of the proposed Barrier location. This will not only help to increase the channel capacity, but also to ensure that the whole 25m would be at a depth that is navigable.

6.5.18 As the position of the Barrier would be slightly offset to the right from the centre of the channel, and the bed level will be dredged to increase the depth and capacity of the channel in the vicinity of the Barrier location, this would help to offset the narrowing effect of the channel width at the Barrier to a certain degree.

6.5.19 The modelling results have shown that the operation of the Boston Barrier will not significantly change the water levels in the River Witham upstream of the Grand Sluice during fluvial floods. (See **Appendix 14** for further details).

6.5.20 The impact on flood levels in the River Witham system for a 1 in 100 (1%) annual chance fluvial incident has been considered. Modelling by Mott MacDonald documented in the Hydraulic Modelling Report (2016)[14] has demonstrated that increases in flood levels are minor and less than 0.1 metres along the River Witham

[14] Mott MacDonald. (2016). Boston Barrier TWAO - Hydraulic Modelling Report. Cambridge: Mott MacDonald.

(typically between 0.01m to 0.07m) (see **Appendix 14**). Increased flood levels are all contained within existing flood defences, with the exception of Anton's Gowt lock. Following construction of the Barrier the increase in flood levels on the River Witham could potentially result in overtopping immediately adjacent to the lock structure. Local land levels mean this water would then be channelled back into the lock pen, where it could overtop into the extensive lowland drainage system beyond but not place properties at risk of flooding.

6.5.21 Currently, the pumping station at Black Sluice sometimes pumps water from South Forty Foot Drain into the Haven when Black Sluice is tidally locked. The Environment Agency owns the pumping station and is responsible for the operation of the pumps. The Environment Agency has confirmed that upstream and downstream levels are monitored at Black Sluice Pump Station. If the Barrier is closed and there is a need to pump the South Forty Foot Drain and there is capacity downstream of the pumping station (upstream of the barrier) pumping will continue. If there is no capacity downstream of the pump station, pumping would cease. The Environment Agency has operational procedures that duty teams follow during an incident. If there are any changes / updates / new procedures required due to the Barrier then this will be put in place by the Environment Agency.

6.5.22 The analysis has also demonstrated minor increases (0.01m to 0.05m) in upstream levels in the South Forty Foot Drain, when water is not pumped into the Haven during tidal lock conditions, and when the Barrier is raised, though properties would not be flooded as the relevant thresholds are above the peak flood levels.

Conclusions

6.5.23 In summary, the implementation and the operation of the Barrier will not increase the flood risk upstream of Grand Sluice and upstream of Black Sluice for tidally dominant events when the Barrier is raised during high tide.

6.5.24 Under fluvial flood conditions, the Barrier would lie on the river bed and would not obstruct the flow in the vertical direction.

6.5.25 Although the channel width is going to be reduced at the Barrier location to 25m wide, the bed level is going to be lowered to -3m AOD.

6.5.26 The effective area at the Barrier is 75m2 when the water level reaches 0.00m AOD. The effective areas at Town Bridge, John Adams Way and Swing Bridge are 39m2, 50m2 and 77 m2 respectively at this water level (see **Appendix 15**).

6.5.27 The effective section area at the Barrier, allowing the water to pass below the 0.00m AOD threshold, is 92% greater than that at Town Bridge, 50% greater that at John Adams Way (A52), about the same as that at Swing Bridge.

6.5.28 Therefore, due to the lowering of the river bed at the Barrier, the reduction in the channel width at the Barrier will have negligible impact on the flood risk upstream as its effective areas is still much greater than at Town Bridge and John Adams Way.

6.5.29 The modelling results have shown that the operation of the Boston Barrier will not significantly change the water levels in the River Witham upstream of Grand Sluice

during fluvial floods. The increases are minor and less than 0.1 metres along the River Witham (typically between 0.01m to 0.07m). Increased flood levels are all contained within existing flood defences, with the exception of Anton's Gowt lock, where it could overtop into the extensive lowland drainage system beyond and not therefore place properties at risk of flooding.

6.5.30 The analysis has also demonstrated minor increases (0.01m to 0.05m) in upstream levels in the South Forty Foot Drain, when water is not pumped into the Haven during tidal lock conditions, and when the Barrier is raised, though properties would not be flooded as the relevant thresholds are above the peak flood levels.

6.6 Effect of the Barrier on the Velocity of Water in the Channel

6.6.1 Comments made by third parties suggest that the velocity through the Barrier will increase, and could be as high as 2.5 times the velocity in the current situation due to the narrowing of the channel section at the Barrier to less than half of its current width. Concerns were raised over the potential impact on navigation as a result of this concern. These concerns are misplaced.

6.6.2 The location of the increased velocity at the Barrier has limited effects on river users based on the proximity of the Barrier to other constricted river sections. The increased velocity has impacts on the users passing through the Barrier section, which is close to the Swing Bridge location. River users travelling the Lower Witham will also pass the Swing Bridge location, a section which is further constricted than the proposed Barrier. These river users will already be subject to higher velocities at this further constricted section. Please refer to **Appendix 15** for discussion of the constricted locations.

6.6.3 This constriction at Swing Bridge already limits the number and type of vessels travelling further up the Lower Witham. This is due to the constricted section and reduced depth of channel allowing for the draft of larger vessels. At present, larger vessels tend to terminate their navigation downstream of Swing Bridge. These larger vessels will not be impacted by a constricted section at the proposed Barrier location.

6.6.4 To address the concerns raised by third parties in relation to this issue, I will explain the following aspects of flow in the channel:

(a) when the high and low velocities occur in the Haven;

(b) where high velocities occur in the Haven under the existing – i.e. 'without' Barrier conditions:

(i) with typical river flows through Grand Sluice and Black Sluice; and

(ii) with 'difficult' flow conditions, i.e. high flows through Grand Sluice and Black Sluice;

(c) changes to the velocity at the Barrier location between 'with' and 'without' the Barrier scenarios:

(i) with typical river flows through Grand Sluice and Black Sluice; and

(ii) with 'difficult' flow conditions, i.e. high flows through Grand Sluice and Black Sluice; and

(d) how the velocity at the Barrier location compared to the velocities currently experienced at other fast flowing sections:

(i) with typical river flows through Grand Sluice and Black Sluice; and

(ii) with 'difficult' flow conditions, i.e. high flows through Grand Sluice and Black Sluice.

6.6.5 Afterwards, I will draw my conclusion on the velocity through the Barrier, including that it will not be the highest in the Haven. The potential impact of velocity changes at the Barrier on navigation is covered in the evidence of Gillian Watson (**EA/4/1**) and Captain Peter McArthur (**EA/5/1**).

When the high and low velocities occur and how velocity in the Haven works

6.6.6 The following paragraphs describe how velocity in the Haven works, including when high velocity and low velocity occur.

6.6.7 The speed at which water flows in the channel is known as the water's velocity.

6.6.8 The velocity and direction of the water is usually down a river. However, coastal rivers that directly connect with the sea, such as the Haven, can flow in both directions. How far up a river the tides will have an effect depends on the slope and size of the river. Man-made structures can alter how far inland the tide reaches, such as the tidal sluices, sea doors and locks at Grand Sluice and Black Sluice.

6.6.9 In the Haven, water can travel both up the Haven towards Grand Sluice on the flood tide; and down the Haven towards the Wash on the ebb tide. The tidal sluice gates at Grand Sluice, Black Sluice, Maud Foster and Hobhole determine the tidal limit of the Haven up their river systems.

6.6.10 On the flood tide, the velocity is highest between low and mid tide as the water flows back into the now empty Haven. This is associated with the fastest rise in water levels. This is supported by both the field survey data (**Appendix 12**), the model results and common sense.

6.6.11 **Figure 4** shows the variation of the maximum depth average velocity through the tidal cycle at John Adams Way, Swing Bridge, Barrier location and Geest point under tidal influenced conditions only, i.e. no significant fluvial flow from the Witham or South Forty Foot Drain. A positive velocity indicates water flowing downstream (out to sea) and a negative velocity indicates water flowing upstream. Maximum velocity occurs during the flood tide. The locations referred to in **Figure 4** are shown in Figure 5. As the model is calibrated against observed velocities measured in the river system at multiple locations (see **Appendix 12**), the results shown in these figures are reliable.

Figure 4: Velocity vs tide at key locations in the Haven – without significant river flows

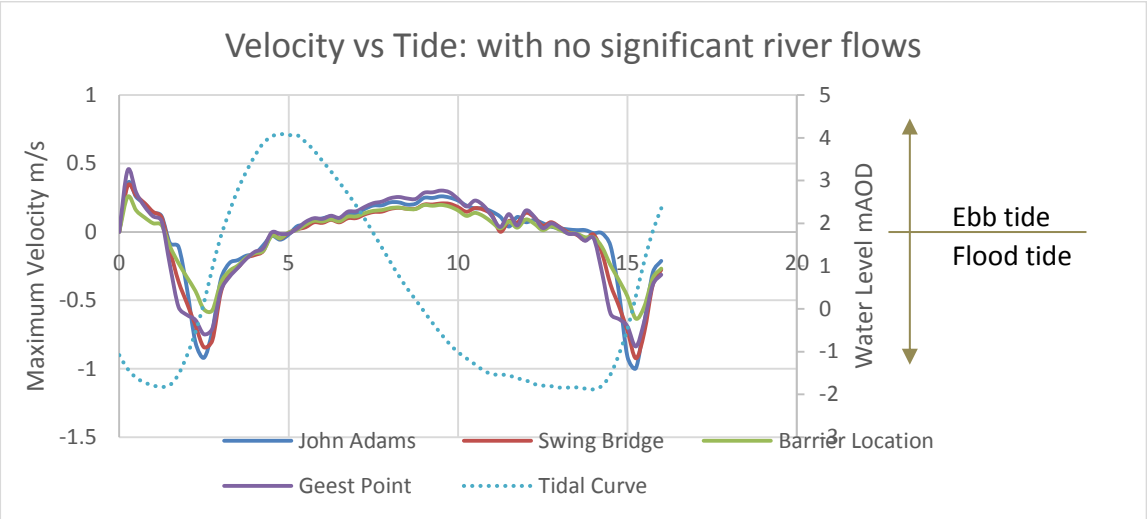
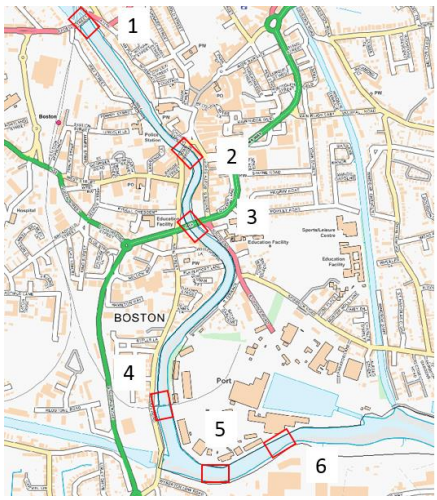


Figure 5 Map of locations



Location	Name
1	Downstream of Grand Sluice
2	Town Bridge
3	John Adams
4	Swing Bridge
5	Barrier
6	Geest Point

6.6.12 From **Figure 4** it can be seen that:

(a) the velocity in the Haven is slowest at the turning of the tide at high water, also known as slack water. The water in the Haven is not moving very much because the water levels are not changing very much due to the tidal curve tailing off at high and low water;

(b) on the ebb/falling tide, the velocity increases again with the highest velocities at mid to low tide as the Haven empties and flows back out to sea. This is associated with the fastest fall in water levels;

(c) when the water falls below a certain depth, although it is fast flowing, it no longer affects navigation in practice as the boats cannot navigate below a certain depth (typically 2-3m deep depending on the type and size of the

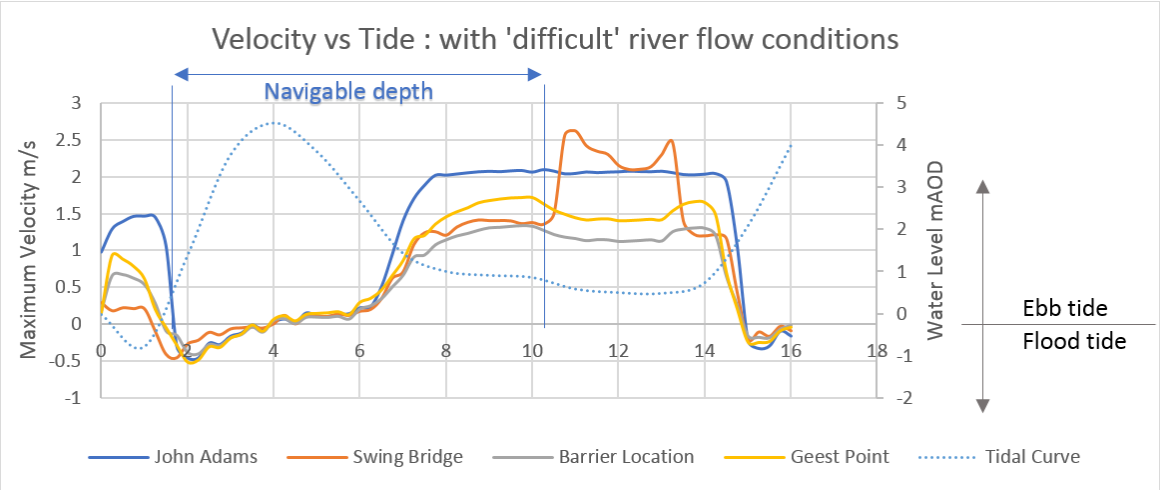
boat). It is deemed unsafe to sail when water drops below a certain threshold depth when the tide continuous to recede/fall; and

(d) water levels rise more rapidly on the flood/rising tide than fall with the ebb tide. Therefore, velocities can be expected to be faster on the flood tide when there is little to no water being released from the sluices.

6.6.13 The main tidal sluices at Grand Sluice and Black Sluice are designed to release the river water when the tidal levels downstream of the sluice gates/sea doors drop below those on the upstream of the sluice gates/sea doors.

6.6.14 Therefore, water is released on the ebb tide in periods of high river flows after heavy rainfall in the River Witham and South Forty Foot Drain river systems. The extra water from Grand and Black Sluice like the fluvial event on 10 March 2016 (101 m3/s through Grand Sluice, 65 m3/s through Black Sluice) adds to the already outgoing tidal waters, therefore creating faster flowing water during periods of high river flows as shown in **Figure 6**.

Figure 6: Velocity vs tide at key locations in the Haven – with 'difficult' (high) river flows



6.6.15 Figure 6 shows the velocity variation through the tidal cycle at John Adams Way, Swing Bridge, the proposed Barrier location, and Geest Point, based on the river flow conditions on 10 March 2016. This event was selected based on consultation with local fishermen as it was regarded as 'difficult' flow conditions by the fishermen.

6.6.16 Among these four locations shown, Swing Bridge exhibits the highest velocity, then John Adams Way, Geest Point, and the Barrier location, in a decreasing order.

6.6.17 Velocity is usually measured in metres per second for scientific applications or knots for nautical applications. Both units of measurement have been quoted in the documentation for reference.

6.6.18 In summary the following conclusions can be drawn regarding how velocity works in the Haven in general:

(a) on the flood tide, the velocity is highest between low and mid tide as the water flows into the now empty Haven;

(b) on the ebb tide, the velocity is highest between mid and low tide (but close to low tide) as water flows back to The Wash.

(c) at the highest tide, the velocity tends to be at its lowest as the water is changing direction from travelling up the Haven to travelling down the Haven;

(d) the navigation window is limited to mid to high tide when the velocity is lower than low tide;

(e) when water is released through Grand Sluice on the ebb tide in periods of high river flows after heavy rainfall in the River Witham, this can create faster flowing water compared to normal flow conditions; and

(f) highest velocity occurs normally at Swing Bridge under the existing (i.e. without Barrier) conditions.

Changes of velocity at Barrier location under typical and high river flow conditions

6.6.19 The following paragraphs describe the following aspects of this topic:

(a) changes in effective sectional area (i.e. the area which allows the water to pass through) at the Barrier location;

(b) how the velocity changes at the Barrier location for with and without Barrier scenarios, under typical river flow conditions;

(c) how the velocity changes at the Barrier location for with and without Barrier scenarios under 'difficult' (i.e. high) river flow conditions; and

(d) then conclusions are drawn and summarised at the end.

Changes in effective sectional area at the Barrier location

6.6.20 **Figure 2** (which appears after paragraph 6.5.13 above) shows the changes in effective sections areas at the Barrier location between with and without Barrier scenarios

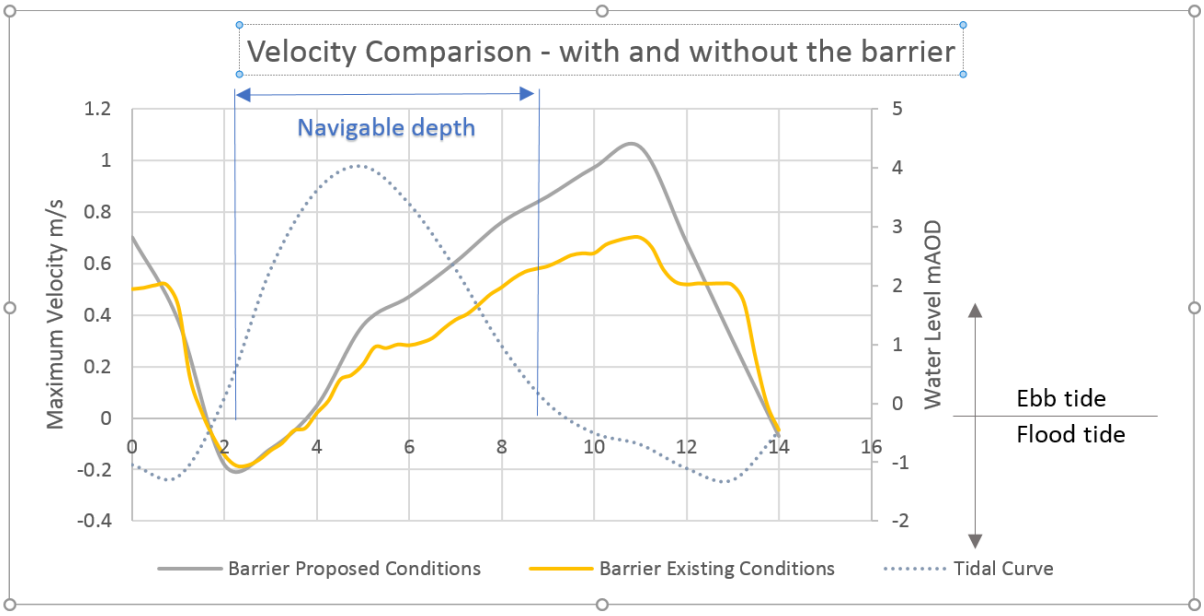
6.6.21 Table 1 tabulates the changes of effective sections areas. With the proposed Barrier width and depth as indicated in Figure 2, the effective area will be reduced by roughly 35% at the threshold of navigation depth (assume 3m deep), see Table 1 in section 6.5.

6.6.22 As the effective sectional area is reduced at the Barrier location, the question of how much effect this has on velocity at the Barrier location is considered in the following paragraphs.

(a) Changes of velocity at Barrier location – under typical winter river flow conditions

6.6.23 **Figure 7** shows the comparison of velocity at the Barrier location for 'with' and 'without' the Barrier scenarios and under typical winter river flow conditions, with the peak flows through Grand Sluice and Black Sluice at 55 m3/s and 19 m3/s respectively in conjunction with mean spring tide in The Wash. As the model is a calibrated against observed velocities measured in the river system at multiple locations (see **Appendix 12**), therefore the results shown in this figure are reliable.

Figure 7: Velocity Comparison at the Barrier location - with and without the Barrier under typical winter river flow conditions



6.6.24 The following observations can be made from the data represented in Figure 7:

(a) the velocity through the Barrier will increase by varied amounts through the tidal cycle for post Barrier conditions compared to the existing situation due to the reduction in effective cross sectional area;

(b) the maximum velocity increase with the presence of the Barrier occurs at low water depth during the falling tide, but it is within safe navigation speed limit (please refer to Captain Peter McArthur's proof of evidence (**EA/5/1**) on safe speed limit for navigation, Section 9.6). Moreover, under such low water depth, the Haven would be normally unnavigable; and

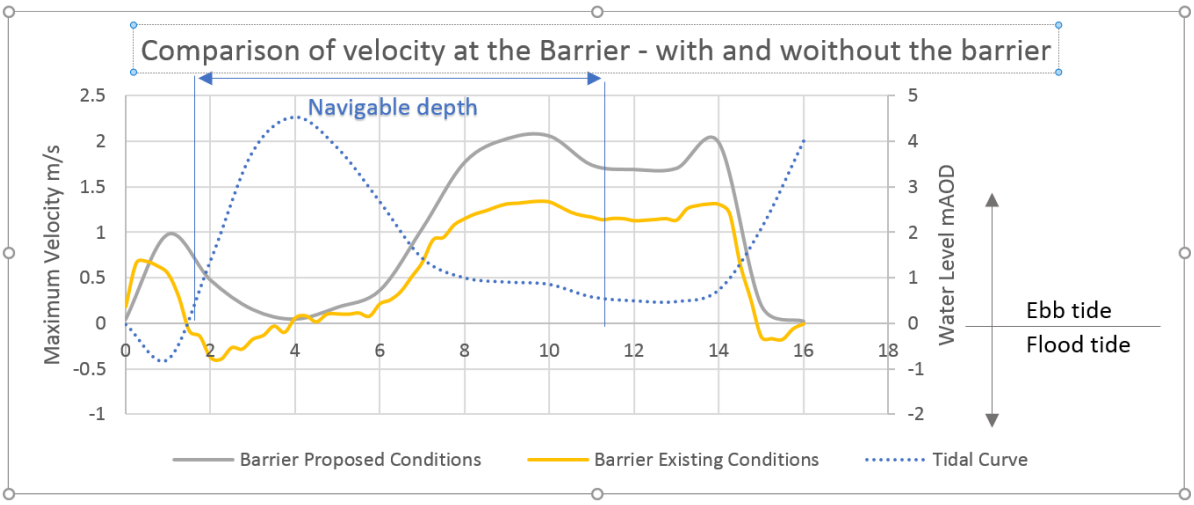
(c) during rising/flood tide, the velocity increase is not significant. The maximum velocity is again well within the navigable velocity range (Please refer to Captain Peter McArthur's proof of evidence (**EA/5/1**) on velocity range for navigation).

(b) Changes of velocity at Barrier location – under 'difficult' winter river flow conditions

6.6.25 **Figure 8** shows the comparison of velocity at the Barrier location for scenarios 'with' and 'without' the Barrier and under 'difficult' winter river flow conditions, with the peak flows through Grand Sluice and Black Sluice at 101 m3/s and 65 m3/s respectively

in conjunction with mean spring tide in The Wash. These 'difficult' winter flow conditions were based the river flow conditions observed on 10 March 2016. This event was selected through consultation with local fishermen as it was considered by the fishermen as 'difficult' river flow conditions. The results presented in this figure is based on a calibrated model, therefore are reliable.

Figure 8: Velocity comparison at the Barrier location - with and without the Barrier under 'difficult' winter river flow conditions



6.6.26 The following observations can be made from the data represented in **Figure 8**:

(a) the velocity through the Barrier will increase by varied amounts through the tidal cycle for post Barrier conditions compared to the existing situation due to the reduction in effective cross sectional area;

(b) the maximum velocity increase with the presence of the Barrier occurs at low water depth;

(c) under such low water depth, the Haven is normally not navigable from safety consideration. Despite that, the maximum velocity is still within the safe velocity limit for navigation, therefore it would not give rise to problems of navigation (please refer to Captain Peter McArthur's proof of evidence (**EA/5/1**) on safe velocity for navigation, Section 9.6); and

(d) during high tide/high depth period, despite the velocity increase, the maximum velocity is nevertheless well within the navigable velocity range (Please refer to Captain Peter McArthur's proof of evidence (**EA/5/1**) on velocity range for navigation, Section 9.6).).

The Haven locations where higher velocities result from constricted cross-sectional area

6.6.27 The velocity in the Haven is greatly influenced by the effective channel sectional area, i.e. the area allowing the water to pass. To pass the same amount of water, the smaller the sectional area the higher the water velocity is likely to be. Therefore, in order to identify where high velocity locations are, it is important to identify where the small effective section areas are. The following paragraphs compare the effective sectional areas for the key narrow river sections on the Haven, identify which section has the smallest effective sectional area and consider how the Barrier effective sectional area compares to other narrow sections.

6.6.28 Downstream of Grand Sluice, currently, there are a number of locations that have smaller effective channel section areas, namely:

(a) Town Bridge – It is situated about 590m downstream of Grand Sluice. It is a single span arch bridge with vertical wall on either bank (see **Appendix 15**). The effective channel width at Town Bridge crossing is 27m, its effective sectional area is 39 m2 below the water level of 0.00mAOD. It forms the smallest effective channel section downstream of Grand Sluice.

(b) John Adams Way (A52) – It is situated about 880m downstream of Grand Sluice. It is a single span arch bridge with vertical wall on either bank (**Appendix 15**). Its effective sectional area is about 50m2 below the water level of 0.00mAOD. It forms the second smallest effective channel section downstream of Grand Sluice.

(c) Swing Bridge – It is situated about 1,700m downstream of Grand Sluice and 320m upstream of the proposed Barrier location. It has two openings, only the opening on the right is navigable, the one on the left is not navigable due to high level of siltation. The total effective sectional area at Swing Bridge is 77m2 below the water level of 0.00mAOD.

(d) Proposed Barrier – The width of the proposed Barrier is 25m wide, but the depth is going to be increased through dredging as part of the overall scheme. The effective channel sectional area is 75m2 below the water level of 0.00mAOD. It is very similar to that at Swing Bridge at this water level.

(e) Haven Bridge (A16 Crossing) – it is situated approximately 900m downstream of the Grand Sluice and 800m upstream of the Swing Bridge. The channel is about 35m wide at this location. But about one third of the river section was heavily silted up to about 2.5m to 3.5m and the effective width of the channel at the Haven Bridge is currently about 22m.

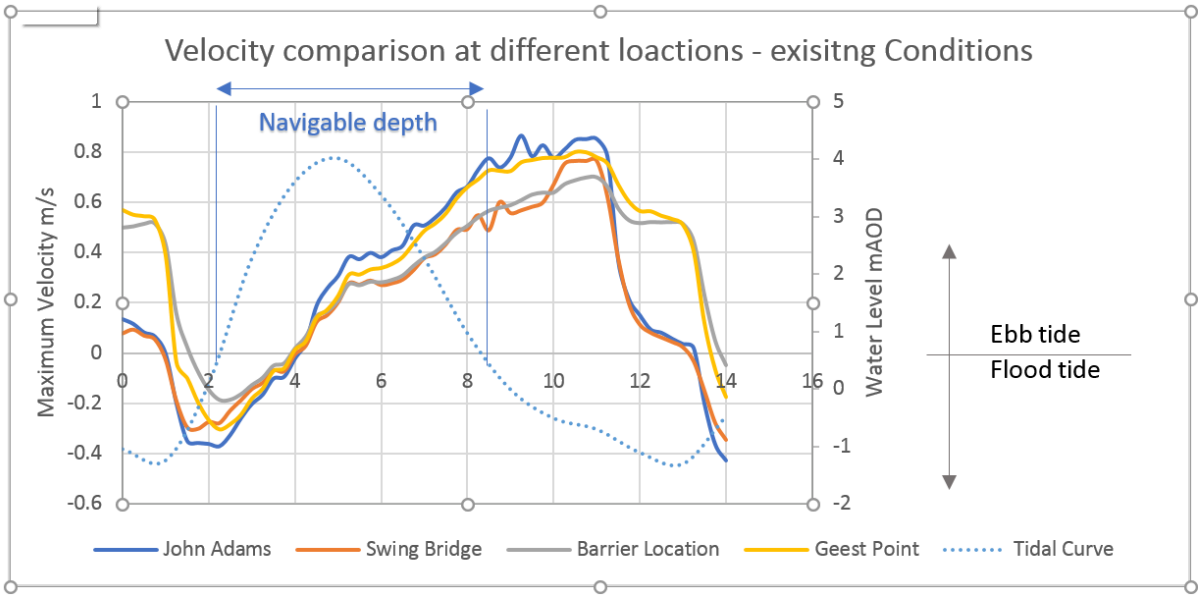
6.6.29 The order of effective sectional area from the smallest to the largest is: Town Bridge, John Adams Way, proposed Barrier, Swing Bridge, Haven Bridge (A16 Crossing). The area with the Barrier therefore lies in the middle of the range.

(a) The Haven locations with higher velocity – for existing conditions with typical winter river flow conditions

6.6.30 As described in Section 6.3.41 c), based on the velocity measurements taken on 13 and 14 December 2016 during high tides, the highest velocity was observed at Swing Bridge, then at John Adams Way, Geest Point and the proposed Barrier location in a decreasing order with the existing geometry. The model predicted the same results as observed as described in Sections 6.3.43 and 6.3.44.

6.6.31 **Figure 9** shows the comparison of velocity at the key locations in the Haven associated with the existing without Barrier scenario and with typical winter river flow conditions: the peak flows through Grand Sluice and Black Sluice were 55 m3/s and 19 m3/s respectively in conjunction with mean spring tide in The Wash. These flows were derived based on the actual water levels recorded upstream and downstream of Grand Sluice and Black Sluice for real winter fluvial events using standard equations for hydraulic structures. The model used for simulating this event is based on a calibrated model, therefore the results are reliable.

Figure 9: Velocity comparison at key locations in the Haven – existing conditions with typical winter river flow conditions



6.6.32 The following observations can be drawn from the data represented in **Figure 9:**

(a) the maximum velocities at John Adams Way, Swing Bridge, Geest Point and the Barrier location are not significantly different, with velocity at John Adams Way and Geest Point being slightly higher than at Swing Bridge and the Barrier location;

(b) the highest velocity at each location corresponds to low water depth during the falling tide;

(c) under such low water depth, it is not suitable for navigation based on safety considerations even though the maximum velocity remains within the safe

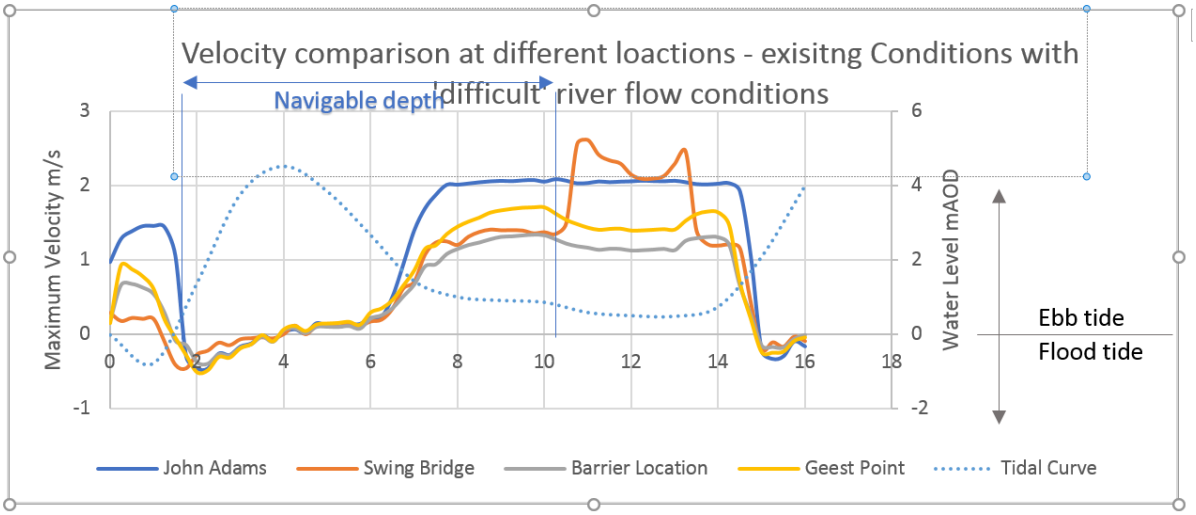
navigable velocity limit (please refer to Captain Peter McArthur's proof of evidence (**EA/5/1**) on safe navigation depth, Section 9.6); and

(d) during high tide/high depth period, the maximum depth average velocity at each location is much lower than at low tide, again falls well within the navigable velocity range and would not give rise to problems of navigation either.

(b) The Haven locations with higher velocities – for existing conditions with 'difficult' winter river flow conditions

6.6.33 **Figure 10** shows the comparison of velocity at the key locations in the Haven associated with the existing 'without' Barrier scenario and with 'difficult' winter river flow conditions: the peak flows through Grand Sluice and Black Sluice at 101 m3/s and 65 m3/s respectively in conjunction with small spring tide in The Wash. These flows were derived based on the actual water levels recorded upstream and downstream of Grand Sluice and Black Sluice for real winter fluvial events using standard equations for hydraulic structures. The model used for simulating this event is based on a calibrated model, therefore the results are reliable.

Figure 10: Velocity comparison at key locations in the Haven – existing conditions with 'difficult' winter river flow conditions



6.6.34 The following observations can be drawn from the data represented in Figure 10:

(a) the highest velocity at each location corresponds to low water depth during the falling tide;

(b) the highest velocity is at Swing bridge, then John Adam's Way, Geest Point and the proposed Barrier location;

(c) the highest depth average velocity at the Barrier is about 2m/s, at Swing Bridge is about 2.5m/s, i.e. at the Barrier, the maximum velocity is lower than at Swing Bridge. It happens at the time corresponding to low tide when, under such low water depth, the Haven is normally unnavigable. Even with

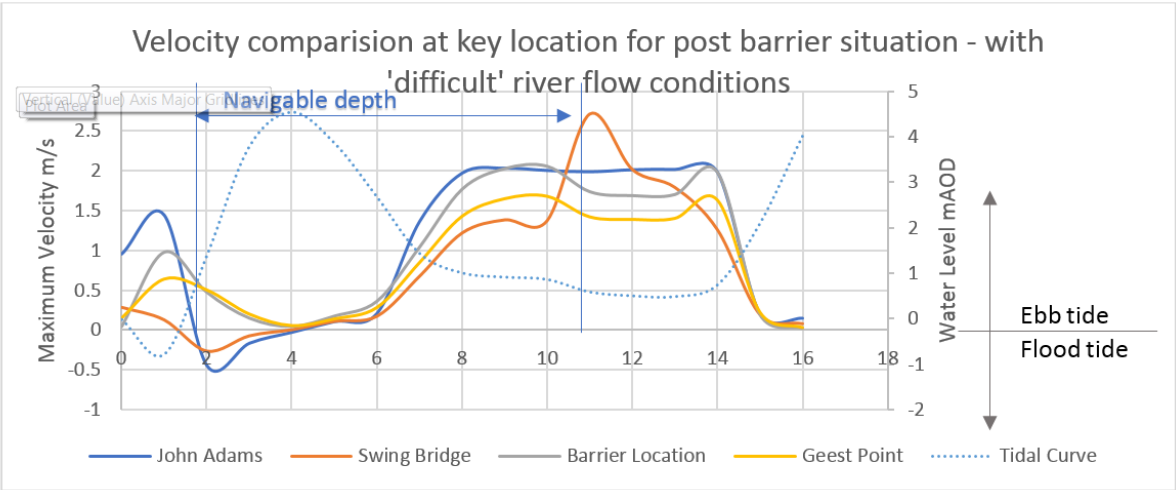
the highest velocity, it would not give rise to problems of navigation (please refer to Captain Peter McArthur's proof of evidence (**EA/5/1**) on safe velocity range for navigation, Section 9.6); and

(d) during high tide/high depth period, the maximum depth average velocity at each location is much lower than at low tide, again falls well within the navigable velocity range and would not cause rise to problems of navigation either.

(c) The Haven locations with higher velocity – for post Barrier with 'difficult' river flow conditions

6.6.35 **Figure 11** shows the comparison of velocity at the key locations in the Haven associated under the post Barrier situation with typical winter river flow conditions: the peak flows through Grand Sluice and Black Sluice at 55 m3/s and 19 m3/s respectively in conjunction with mean spring tide in The Wash. These flows were derived based on the actual water levels recorded upstream and downstream of Grand Sluice and Black Sluice for real winter fluvial events using standard equations for hydraulic structures. The model used for simulating this event is based on a calibrated model, therefore the results are reliable.

Figure 11: Velocity comparison at key locations in the Haven – post Barrier situation with 'difficult' river flow conditions



6.6.36 The following observation can be drawn from the data represented in **Figure 11**:

(a) the maximum velocity is predicted at Swing Bridge and the maximum depth average velocity at the proposed Barrier location is lower than at Swing Bridge, and is comparable to that at John Adams Way bridge.

Summary of modelling results

6.6.37 As described in Section 6.3.43 to 6.3.44 earlier, the model is capable of reliably reproducing measured velocities for real events at all key locations in the Haven that exhibit low and high velocities. Therefore, the model results reflect reality and should be accepted as accurate and reliable.

6.6.38 The modelling results have shown that:

(a) the maximum velocities in the proposed Barrier area are predicted to be higher than velocities in the existing channel;

(b) the maximum velocities occur between mid to low tide, which normally falls outside of the navigable period due to reduced water depth;

(c) the velocities at the Barrier location are similar to those at the Swing Bridge and John Adams Way; and

(d) these findings correspond with the field velocity measurement data and tests undertaken and are in line with what would be expected given the relative depths of the channel.

Logical reasoning

6.6.39 Although the effective channel sectional area will be reduced by 35% at the Barrier, its effective sectional area is still greater than those at Town Bridge and John Adams Way, and similar to that at the Swing Bridge (**Appendix 15**).

6.6.40 Therefore, there is no reason to suggest that, under the same tide and flow conditions, the velocity at the Barrier location would be higher than those already experienced at Town Bridge, John Adams Way, and the Swing Bridge when the Barrier is lying flat on the river bed.

6.6.41 It is worthy of note that the proposed Barrier is at 25m wide with full navigable depth, compared with the A16/Haven Bridge at 22m (variable navigable depths) and Swing Bridge 16m (variable navigable depths) (See **Appendix 15**).

Conclusions

6.6.42 Logical reasoning, field measuring data and modelling results all support the following conclusions:

(a) under the tidal dominant situation, i.e. with small river discharges, the velocity at the Barrier will increase by different amounts varying with the changes in tide level. However, the maximum velocity increase through the Barrier section will happen between the mid and low tide during the ebb tide. During such period, the channel is not navigable due to insufficient depth. During the navigation period, the velocity is well within the navigable speed limit;

(b) under high river flow conditions, even with the increased velocity at the Barrier, the magnitude of the velocity at the Barrier will not be higher than those currently experienced at the Swing Bridge or the Haven Bridge during navigation periods;

(c) therefore, the proposed Barrier does not cause the highest velocity in the Haven and will not give rise to problems as a result of the velocity of the water in terms of magnitude; and

(d) it is recognised that the Barrier is located at a bend on the Haven. However, it is concluded in Captain Peter McArthur's proof that the velocity experienced through the Barrier will not give rise to problems to navigation despite it the Barrier is located on a river bend. Please refer to Captain Peter McArthur's proof of evidence (**EA/5/1**) for further detail on this point.

6.7 The Location of the Barrier

6.7.1 Comments made by third parties suggest that the proposed Barrier should be located towards the mouth of the Haven, or as close as possible to it. Concerns have been raised that the current location only protects the centre of Boston from flooding whereas it is said that a Barrier located at the end of the Haven with a lock would provide protection for a larger area. In the following sections I have detailed:

(a) my review of the Boston Sea Lock Preliminary Feasibility Study Report produced in 1994;

(b) the current preferred Barrier location as well as the other rejected locations during previous consultation;

(c) the advantages and disadvantages of the Barrier location at the mouth of the Haven and other shortlisted locations; and

(d) my conclusions on the Barrier location.

1994 Sea Lock PFS report

6.7.2 In 1994 a Boston Sea Lock Preliminary Feasibility Study (**PFS**) report was produced by Balfour Maunsell on behalf the NRA (the predecessor of the Environment Agency). The study presented the assessment of the feasibility of building a lock with a barrage at the mouth of Haven, so as to raise the water level in the Haven, make the Haven navigable at both high tide and low tide, and to reduce flood risk to Boston.

6.7.3 It is stated in the 1994 report that permanently raising the water level in the Haven would preclude normal gravity discharge from South Forty Foot Drain, Maud Foster Drain and Hobhole Drain. This would require pumping to maintain the water levels in the drains. It was not considered sufficiently attractive to pursue in 1994. It would remain unattractive today also.

6.7.4 It is also stated in the 1994 report that four alternative locations were compared. The option nearest to the mouth of Haven was considered to be the least preferred option from a sewage effluent disposal aspect. The locations downstream require progressively more difficult and expensive solutions to this problem. This continues to be the case today.

6.7.5 It is also said in the 1994 report that the final river alignment is extremely important from navigation and flood discharge considerations as well as erosion and accretion along the banks. Building a sea lock and a barrage at the mouth of the Haven was not considered to be able to provide a better final alignment than the location further upstream. This conclusion remains true today.

6.7.6 In the 1994 report, it was concluded that the barrage location further downstream of the Haven was less preferable from an environmental point of view. The downstream area is protected by international and EU environmental legislation. Emma Lunt's proof (**EA/8/1**) provides evidence on why building a Barrier at the downstream location is effectively prohibited today on environmental grounds.

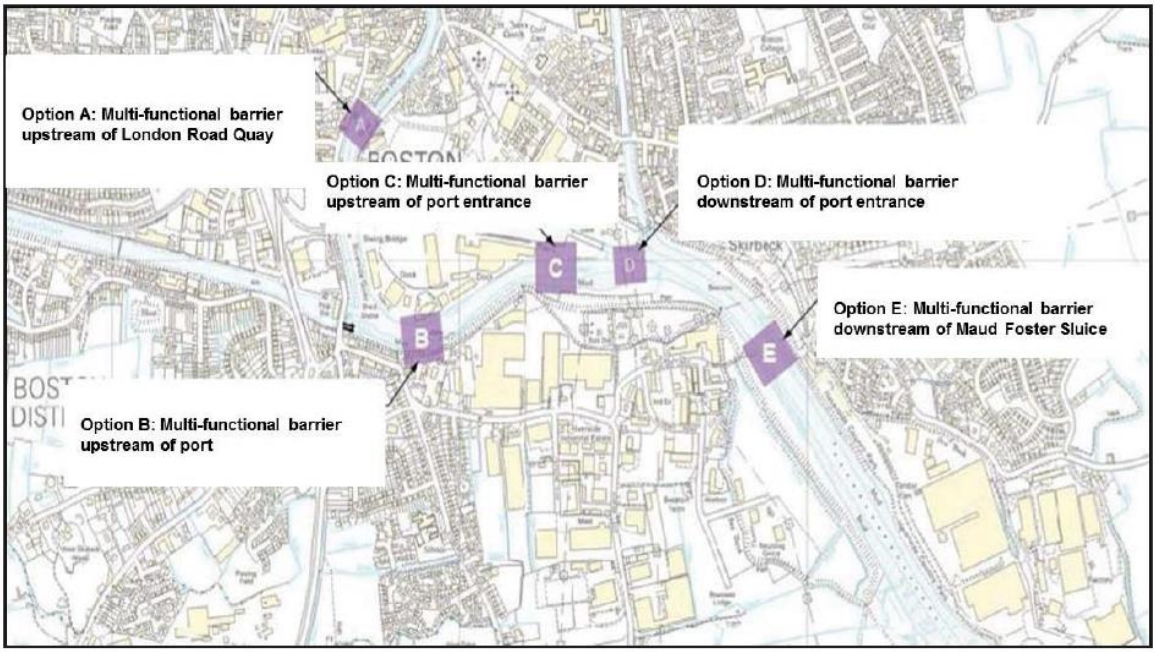
6.7.7 In the 1994 report, multiple factors were taken into account when assessing the advantages and disadvantages of the sea lock and barrage locations. It was concluded that when considering navigation, engineering, environmental and cost aspects, building a sea lock and a barrage at the mouth of the Haven was less preferable than at a further upstream location. This conclusion remains true today.

Locations investigated and preferred Barrier location

6.7.8 As set out in chapter 2 of the Environmental Statement: Main Report (**A/17/1**) in determining the location of the proposed Barrier the Environment Agency has undertaken a detailed and thorough site selection assessment.

6.7.9 Five locations (A, B, C, D and E) were shortlisted and assessed. Plate 10 in the ES shows the five shortlisted locations. This plate is proved below (**Figure 3**) for easy reference.

Figure 3: Five shortlisted Barrier locations



6.7.10 Mr. James Anderson has provided evidence in his proof (**EA/1/1**) explaining why location 'B' was the preferred location from the technical, environmental and economic points of view. Peter Mallin has provided evidence in his proof (**EA/3/1**) explaining why the location proposed by the Environment Agency is preferable from a design and engineering perspective. Emma Lunt has provided evidence in her proof (**EA/8/1**) explaining why location 'B' was the preferred location from an environmental and ecological point of view.

6.7.11 From a flood risk point of view, building the Barrier at the mouth of the Haven and making the Haven navigable at both high tide and low tide would present the biggest risk to sewage effluent disposal as sewerage outfalls would not be able to discharge through gravity outfalls, leading to sewer flooding. This was the concern identified in the 1994 report. This concern remains unchanged today.

6.7.12 Although a Barrier at location 'A' would affect fewer sewer outfalls than at location 'B', location 'A' would limit the opportunity of implementing the water level management (**WLM**) aspirations in the future.

6.7.13 Considering the limited distance between locations 'A' and 'B', the number of sewer outfalls which could be affected is also limited.

6.7.14 From a combined, foul and surface water flooding risk point of view, building the Barrier at location 'B' is preferable than at downstream locations 'C', 'D', 'E' or at the mouth of the Haven. The further downstream the Barrier location is proposed, the more sewer outfalls will be affected and would cause more sewer flooding due to prolonged tidal locking compared to the no-barrier scenario.

6.7.15 Furthermore, and in any event, a Barrier located at the mouth of the Haven or downstream of Boston Port would mean that all PoB sizes of commercial shipping traffic would need to go through the barrier. If the barrier was to accommodate the maximum cargo vessel identified in the Navigation Impact Assessment, a navigable opening in the order of 50m would be required, twice the width of the current scheme. It would be more costly and take a longer time to build than what is currently proposed. This is explained in Peter Mallin's evidence (**EA/3/1**).

6.7.16 The level of protection offered by a proposed scheme is determined by the standard used for the design of the scheme. If a barrier at the mouth of the Haven is designed to protect Boston from tidal flooding for a 1 in 300 annual chance of tidal event occurring, i.e. the same design standard as the Barrier currently proposed, then the level of protection offered by a scheme at the mouth of the Haven would be the same as the proposed Barrier scheme, i.e. 'no greater level' of protection would be provided.

6.7.17 In fact, as the Barrier at the mouth of Haven would need to be a far bigger and more complex structure to cater for a far greater number and larger sizes of vessels to go through. This could increase the chance of collision and damage arising to the structure, hence could potentially increase flood risk due to damages to the defence structure. Moreover, the Barrier at the mouth of the Haven would also be exposed to much stronger current and especially much stronger wave actions as it is in a more exposed location compared to the proposed location 'B'. This again could increase the risk of flooding. All of these factors could potentially increase flood risk due to potential damage to the structure. The current proposed Barrier location is at location 'B', which is downstream of the Black Sluice. The location has been determined following extensive public consultation and review of the technical, economic and environmental benefits and the future aspirations.

6.7.18 A Barrier built downstream of the Port of Boston would cause significant disruption to the Port and to commercial river users navigating out to the Wash. At a location downstream of the Port, the barrier would need to be a far larger and a more complex structure to cater for the larger commercial vessels destined for the Port. The construction of the Barrier would also be much more complex as the Port would need to be kept open for business during construction.

6.7.19 A Barrier downstream of the Port of Boston has many disadvantages, including:

(a) to maintain navigation we would need to create a new bypass channel in the Haven large enough to let vessels safely pass during construction;

(b) it would be more difficult and costly to get mains electricity supply, construction plant and machinery the further downstream the barrier is located on the Haven;

(c) we would need to build a larger and more complex Barrier to reduce the risk of collision damage and allow larger vessels heading for the Port to navigate through; and

(d) it could cause disruption to the Witham 4th IDB operating procedures.

6.7.20 The proposed location upstream of the Port also:

(a) enables better access for construction plant and machinery;

(b) serves its purpose to reduce tidal flood risk;

(c) minimises environmental damage to The Wash - an internationally designated site; and

(d) does not preclude the strategic aim to deliver water level management to the town centre at a later date.

6.7.21 Please refer to the proofs of evidence of James Anderson (**EA/1/1**), Emma Lunt (**EA/8/1**), and Peter Mallin (**EA/3/1**) for their views as to why it is still not feasible and practical to build the Barrier close to the mouth of the Haven or other locations along the Haven when considering technical, environmental and cost factors.

Conclusions

6.7.22 It was concluded in the 1994 Sea Lock PFS report that flood protection was needed to protect Boston. Since then, Boston was flooded badly in December 2013 (see Section 6. 3 about the misery of suffered by the people in Boston). Considering the increasing risk faced by Boston due to climate change, the need for a Barrier is even more urgent than before.

6.7.23 It was also concluded in the 1994 report when considering navigation, engineering, environmental and cost aspects, building a sea lock and a barrage at the mouth of the Haven was less preferable than at a location further upstream. This assessment is supported even more so today, considering the special protected ecological status

assigned to the Wash and the downstream reach of the Haven by international environmental law (see Emma Lunt's proof of evidence (**EA/8/1**)).

6.7.24 A multi-functional Barrier holding water to the mouth of The Wash would affect land drainage and gravity discharge of rivers – increasing flooding risk to the people of Boston and surrounding area.

6.7.25 The current proposed Barrier location offers a range of the benefits and has attracted the support of key stakeholders, as outlined in the ES.

6.7.26 In the current preferred location it will not only serve its purpose to reduce the risk from tidal flooding but will also provide the most practical, social, economic and environmental benefits overall.

6.7.27 The level of protection offered by a proposed scheme is determined by the standard used for the design of the scheme. A Barrier at the mouth of the Haven or other alternative locations would provide no greater level of protection from flood risk and would protect no greater an area than the proposals comprised within the Scheme, if the same design standard were to be employed in the scheme design, whilst suffering a range of disadvantages outlined above, including increasing the risks of sewer flooding due to prolonged tidal locking. The further downstream the Barrier location is, the higher the sewer flooding risk wold be. There could be a potential increase in flood risk due to:

(a) the increased number and size of vessels needing to go through the barrier, resulting in increased chances of collision and/or damages to the barrier and

(b) the increased exposure of the flood defence infrastructure to much stronger current and wave action especially at the mouth of the Haven.

6.7.28 A Barrier built downstream of the Port of Boston would cause significant disruption to the Port and to commercial river users navigating out to the Wash. At a location downstream of the Port, the barrier would need to be a far larger and a more complex structure to cater for the larger commercial vessels destined for the Port. The construction of the Barrier would also be much more complex as the Port would need to be kept open for business during construction.

6.7.29 Looking at the water environment as a whole, including drainage and sewerage, to locate the barrier downstream of the Port is not a preferred location either in my view. Proposed location B remains as the preferred location in my opinion.

7 Issues Raised in Objections

7.1 Introduction

7.1.1 Following the submission of the Agency's application for the Order on 23 August 2016, a 42 day period ran from 24 August until 5 October 2016 during which representations were invited in response to the TWAO Application.

7.1.2 I have considered all comments raised within the objections and representations related to flood risk and modelling matters. They primarily fall within the following areas:

(a) Efficacy of the proposed Barrier;

(b) Location of the Barrier at the mouth of the Haven or other locations;

(c) Increased fluvial risk;

(d) Increased tidal flooding at Wyberton, Fishtoft and Frampton;

(e) Increase velocity in the channel.

7.2 Efficacy of the Proposed Barrier

7.2.1 Mr David Mathews (**OBJ/2**) has suggested that the proposed Barrier will not work, or that it will be ineffective in providing improved flood risk management.

7.2.2 The evidence related to this matter is provided in Section 6.3 of my proof of evidence. In summary I have assessed the robustness of the FRA and modelling undertaken and reached the conclusion that:

(a) the FRA (**FRA**) (**A/17/2C**) has been carried out in accordance with relevant guidance and best practice;

(b) the FRA and modelling have been carried out using the best available data, the most advanced and well-tested techniques and software, following industry best practice and represents the best available information;

(c) the models were properly calibrated against previous known events;

(d) the model tests and assessment were thorough and comprehensive; and

(e) the FRA and modelling is correct, appropriate and robust.

7.2.3 The FRA has demonstrated the provision of the Barrier (and improvements to the embankments downstream of the Barrier) will improve the standard of protection to Boston from the current 1 in 50 (2%) annual chance event to a 1 in 300 (0.33%) annual chance event. There is absolutely no reason to doubt that the Barrier will be effective.

7.2.4 The Scheme will bring multiple benefits as listed in Section 5 of my proof of evidence.

7.3 Location of the Barrier at the Mouth of the Heaven or Other Locations

7.3.1 Comments made by Mr Ron Careless, Boston District Fishman Association (**OBJ/23**), Witham Fourth IDB (**REP/2**), Wyberton Parish Council (**OBJ/20**) and David Mathews (**OBJ/2**) suggest that the proposed Barrier should be located towards the mouth of the Haven or as close as possible to it. Concerns have been raised that the current location only protects the centre of Boston from flooding

whereas a Barrier located at the end of the Haven would provide protection for a larger area.

7.3.2 The evidence related to this matter is provided in Section 6.6 of my proof of evidence. In Section 6.6 I have set out:

(a) my review of the Boston Sea Lock Preliminary Feasibility Study Report produced in 1994;

(b) the current preferred Barrier location as well as other rejected locations during previous consultation;

(c) the advantages and disadvantages of the Barrier location at the mouth of the Haven and other locations; and

(d) my conclusions on the Barrier location.

7.3.3 Following my assessment of the 1994 Sea Lock report, the FRA and the shortlisted Barrier locations, and based on my professional experience and judgement, I consider that:

(a) the proposed Barrier at location 'B' will not only help to reduce the tidal flood flooding risk to Boston, but will also help to provide the most practical, social, economic and environmental benefits compared to other shortlisted locations 'A', 'C','D', 'E' and locations at or towards the mouth of the Haven;

(b) the 1994 report concluded that when considering navigation, engineering, environmental and cost aspects, building a sea lock and a barrage at the mouth of the Haven was less preferable than at a location further upstream. This assessment is supported even more so today, especially considering the special protected ecological status assigned to the Wash and the downstream reach of the Haven by international legislation (see Emma Lunt's proof of evidence (**EA/8/1**));

(c) a multi-functional Barrier holding water to the mouth of The Wash would affect land drainage and gravity discharge of rivers – increasing flooding risk to the people of Boston and surrounding area;

(d) from a flood risk point of view, building the Barrier at the mouth of the Haven would present the biggest risk to sewage effluent disposal as sewerage outfalls would not be able to discharge through gravity outfalls, leading to sewer flooding. This was the concern identified in the 1994 report and this concern remains unchanged today;

(e) a Barrier further downstream would mean that more sewer outfalls would be affected due to prolonged tidal locking, this would lead to more sewer flooding;

(f) the level of protection offered by a proposed scheme is determined by the standard used for the design of the scheme. A Barrier at the mouth of the Haven or other alternative locations would provide no greater level of

protection from flood risk and would protect no greater an area than the proposals comprised within the Scheme, if the same design standard is the scheme design, whilst suffering a range of disadvantages outlined above, including increasing the risks of sewer flooding due to prolonged tidal locking. The further downstream the Barrier location is, the higher the sewer(combined, foul and surface water system) flooding risk would be.

(g) a Barrier at the mouth of Haven would need to be a far bigger and more complex structure to cater for a far greater number and larger sizes of vessels to go through. This could increase the chance of collision and damage arising to the structure, hence could potentially increase flood risk due to damages to the defence structure. Moreover, the Barrier at the mouth of the Haven would also be exposed to much stronger current and especially much stronger wave actions as it is in a more exposed location compared to the proposed location 'B'. This again could increase the risk of flooding;

(h) a Barrier built downstream of the Port of Boston would cause significant disruption to the Port and to commercial river users navigating out to the Wash. At a location downstream of the Port, the barrier would need to be a far larger and a more complex structure to cater for the larger commercial vessels destined for the Port. The construction of the Barrier would also be much more complex as the Port would need to be kept open for business during construction; and

(i) looking at the water environment as a whole, including drainage and sewerage, locating the barrier downstream of the Port is not a preferred location in my view. Proposed location 'B' remains as the preferred location in my opinion.

7.3.4 In the current preferred location the Barrier will not only serve its purpose to reduce the risk from tidal flooding but will also provide the most practical, social, economic and environmental benefits overall.

7.4 Increased Fluvial Risk

7.4.1 Rodney Bowles (**OBJ/14**), Mr David Mathews (**OBJ/2**), , Terry Despicht (**OBJ/15**), Councillor David Brown (**OBJ/7**) and Councillor. Yvonne Stevens (**OBJ/3**) have expressed concerns that the proposed Barrier will cause increased fluvial flood risk during operation. Both 1D and 2D hydraulic modelling was undertaken to assess flood risk from the River Witham, South Forty Foot Drain and Haven. The modelling results are presented in the FRA (**A/17/2C**).

7.4.2 The evidence related to this matter is provided in Section 6.5 of my proof of evidence. In summary, the FRA and modelling demonstrate that:

(a) the implementation and the operation of the Barrier will not increase the flood risk upstream of Grand Sluice and upstream of Black Sluice for tidally dominant events when the Barrier is erected during high tide;

(b) due to the lowering of the river bed at the Barrier, the reduction in the channel width at the Barrier will have negligible impact on the flood risk

upstream as its effective area is still much greater than at Town Bridge and John Adams Way;

(c) the modelling results have shown that the operation of the Barrier will not significantly change the water levels in the River Witham upstream of Grand Sluice during fluvial floods. The increases are minor and less than 0.1 metres along the River Witham (typically between 0.01m to 0.07m). Increased flood levels are all contained within existing flood defences, with the exception of Anton's Gowt lock, where it could overtop into the extensive lowland drainage system beyond but not place properties at risk of flooding; and

(d) there may be minor increases (0.01m to 0.05m) in upstream level in the South Forty Foot Drain when water is not pumped into the Haven during tidal lock conditions and when the Barrier is raised, though properties would not be flooded as their thresholds are above the peak flood levels.

7.5 Increased Tidal Flooding at Wyberton, Fishtoft and Frampton

7.5.1 Specific concerns have been raised by Wyberton Parish Council (**OBJ/20**) and the Boston and District Fisherman's Association (Obj/22) that a Barrier at the proposed location would cause increased flood risk to the Parishes of Wyberton, Fishtoft and Frampton. As explained above, a FRA has been undertaken for the Scheme (**A/17/2C**).

7.5.2 The evidence related to this matter is provided in Section 6.4 of my proof of evidence. In summary, the FRA and modelling demonstrate that:

(a) for tides less than 5.3m AOD high, the water level in the Haven will remain the same as the current 'without' Barrier situation, therefore no change to flood risk will arise;

(b) for tides exceeding 5.30m AOD, the tide will continue to propagate towards Grand Sluice before the tide reaches 5.1m AOD. Once the tide exceeds 5.1m AOD, the Barrier will be raised up to stop high tide propagating beyond the Barrier, this would reduce the risk of tidal flooding in Boston

7.5.3 My analysis has shown that when the Barrier is raised, the channel capacity between the Barrier and Grand Sluice above 5.1m AOD will not be occupied by tidal water as compared to the 'without Barrier' situation. As the distance between the Barrier and Grand Sluice is relatively short, (only about 2km), the typical channel width is also small (50m wide) in comparison of the size of the Wash and the sea. Therefore the available channel surface area and channel capacity between Grand Sluice and the Barrier above the 5.1m AOD threshold are negligible compared to the vast surface area and volume of the Wash and the sea.

7.5.4 Hence, the 'removal' of the storage space in the Haven between the Barrier and the Grand Sluice above the 5.1m AOD threshold will not have any material change in the water levels in the Wash. As the water level in the Haven is connected to and dictated by the water level in the Wash, if the water level in the Wash is not going to

have any material change compared to the 'no Barrier scenario', then the water level in the Haven downstream of the Barrier would not have any material change either.

7.5.5 Hence the flood risk to the communities at Fishtoft, Skirbeck and Wyberton which are downstream of the Barrier will not be increased as the result of the operation of the Barrier compared to the no-Barrier scenario.

7.6 Increase in the Velocity in the Channel

7.6.1 Concerns have been raised by Mr David Mathews (**OBJ/2**) who thinks that the speed will be 2.5 times faster at the Barrier and who appears to have the perception that the design has grossly under estimated the flow. Captain BDC Franklin (**OBJ/8**) has raised concerns over stronger water flows whilst the Inland Waterways Association (**OBJ/9**) has raised concerns over flow velocities. In summary, it has been perceived that reducing the channel width at the Barrier will cause increased velocity that could hinder navigation.

7.6.2 As explained above, velocity survey and modelling have been undertaken for the Scheme (**A/17/2C**).

7.6.3 The evidence related to this matter is provided in Section 6.7 of my proof of evidence. In summary, the field velocity survey, modelling and logical reasoning all demonstrate that:

(a) although the channel width is going to be reduced from over 60m to 25m at the Barrier location, the effective channel sectional area at the Barrier will only be reduced by about 35%. Despite this reduction, the effective sectional area at the Barrier location will still be greater than the effective sectional areas at Town Bridge and John Adams Way and be comparable to Swing Bridge;

(b) under tidally dominant conditions, i.e. with small river discharges, the velocity at the Barrier will increase by different amounts with the changes in tide level. However, the maximum velocity increase through the Barrier section will happen between the mid and low tide during the ebb tide. During such period, the channel is not navigable due to insufficient depth. During the navigation period, the velocity is well within the navigable speed limit;

(c) under high river flow conditions, even with the increased velocity at the Barrier, the magnitude of the velocity at the Barrier will not be higher than that currently experienced at the Swing Bridge or the Haven Bridge during navigation periods;

(d) the proposed Barrier does not cause the highest velocity in the Haven and would not therefore cause a problem to navigation in terms of magnitude; and

(e) Captain Peter McArthur has provided evidence in his proof (**EA/5/1**) explaining why the resulting magnitude of the velocity at the Barrier and the resulting velocity at a bend would not cause a problem to navigation either.

8 Response to Statement of Matters

8.1 The Secretary of State has set out the matters about which she particularly wishes to be informed. My evidence addresses the following matters (or aspects of them).

Matter 1 The aims of, and the need for, the proposed Boston Barrier and related works

8.2 This matter is covered in Sections 4 (History of Flooding) and 5 (Benefits of the Scheme) of this proof of evidence and within pages 12 – 15 of the Statement of Case of Environment Agency (December 2016) (**I/1**). The aims and the needs for the Scheme are also explained in James Anderson's evidence (**EA/1/1**) which I have read and am in agreement with.

Matter 2 The main alternative options considered by the Environment Agency and the reasons for choosing the proposals comprised within the Scheme

8.3 This matter is covered in Section 6.7 (Barrier Locations) of this proof of evidence and in within pages 39 -43 of the Statement of Case of Environment Agency (December 2016) (**I/1**).

Matter 3 The justification for the particular proposals in the draft TWA Order, including the anticipated flood risk, environmental and socio-economic benefits of the Scheme

8.4 This matter is partially covered in Sections 4 (History of Flooding) and 5 (Benefits of the Scheme) of this proof of evidence and within pages 12 – 15 and pages 48 – 56 of the Statement of Case of Environment Agency (December 2016) (**I/1**). It is also covered in James Anderson's proof of evidence (**EA/1/1**).

Matter 5(b) The justification for the location, design and operation of the Scheme including questions overs the reinforcement and maintenance of 'earth banks' running from the site of the barrier downstream

8.5 Aspects of this matter are covered in Section 6.7 (Barrier Location) of this proof of evidence and within pages 39 – 43 of the Statement of Case of Environment Agency (December 2016) (I/1) in relation to the location. Regarding the design and operation of the scheme, the reinforcement and maintenance of 'earth banks' running from the site of the Barrier downstream are covered in James Anderson's proof of evidence (**EA/1/1**) and partly covered in Peter Mallin's proof of evidence (**EA/3/1**) too.

Matter 7 The compatibility of the scheme with future climate change scenarios

8.6 This matter is covered in Section 6.3, paragraph 6.3.60 to 6.3.72 (under the heading of 'Climate Change Considerations') of this proof of evidence.

Matter 12 Whether alternative modelling of the tidal and fluvial flows around construction and operation of the barrier would mitigate against concerns of:

i **perceived increased risk of low-lying inland and fluvial flooding;**

8.7 This matter is covered in Section 6.3, paragraphs 6.3.75 to 6.3.77 and Section 6.5, paragraph 6.5.20 to 6.5.22 of this proof of evidence.

ii **flow velocity concerns in relation to the fishing fleet's ability to use the river**

8.8 This matter is covered in Section 6.6, paragraphs 6.6.42 of this proof of evidence. Based on the analysis presented in Sections 6.3 (Robustness of the FRA and Modelling) and my professional judgement, I consider that the modelling work and the FRA undertaken were thorough, comprehensive and robust. The results are reliable. No further modelling work could be reasonably expected. No further modelling work could lead to a different outcome either.

8.9 Based on the analysis presented in Section 6.5 – Effect of Flood Risk Upstream, I consider that the operation of the Boston Barrier would not significantly change the water levels in the River Witham upstream of Grand Sluice nor upstream of Black Sluice during fluvial floods. The increases are minor and less than 0.1 metres along the River Witham (typically between 0.01m to 0.07m). Increased flood levels are all contained within existing flood defences, with the exception of Anton's Gowt lock, where it could overtop into the extensive lowland drainage system beyond and would not therefore place properties at risk of flooding. Equally, the increases in water levels upstream in the South Forty Foot Drain would be very small too (0.01m to 0.05m), when water is not pumped into the Haven during tidal lock conditions, and when the Barrier is raised. No properties would not be flooded as their thresholds are above the peak flood levels.

8.10 Based on the analysis presented in Section 6.6 (Effect of the Barrier on the velocity of water in the channel) of my evidence, I reached the conclusions that although the velocity at the Barrier location would increase compared to the existing situation after the Barrier is built, the magnitude of the velocity at the Barrier location would not be higher than those currently experienced at Town Bridge, John Adam's Way, both of them have much smaller effective sectional areas than at the Barrier location. Therefore, the increase in velocity should not present a problem to navigation.

Matter 14(a) The likely impacts of constructing and operating the scheme on the operation of businesses in the area, including issues around perceived increased flow velocities creating difficulty for the fishing and pleasure craft industry to operate safely.

8.11 This matter is covered in Section 6.6, paragraph 6.6.42 of this proof of evidence in relation the changes to velocity due to the construction and operation of the Barrier. Regarding the issues around perceived increased flow velocities creating difficulty for fishing and pleasure craft operating safely, this matter is covered in Gillian Watson (**EA/4/1**) and Captain Peter McArthur's proof of evidence (**EA/5/1**).

9 Conclusions

9.1 The town of Boston is entirely located within the floodplain and it has a history of tidal flooding. Just within over 200 years span, Boston experienced nine instances of flooding, namely in 1779, 1807, 1810, 1949, 1953, 1961, 1976, 1978 and 2013. The famous 1953 tidal surge event (called the Great Flood) claimed 307 lives in England and 42 in Lincolnshire. The most recent tidal surge event in December 2013 led to significant economic, social and environmental

damage in Boston. With climate change and predicted sea level rise in the future, the threat of tidal flooding to the public's health and safety, and to the high grade agricultural land, which is so important to this country's food security and sustainability, is on the increase.

9.2 It is my opinion that not building a Barrier would have major negative impacts upon the people in Boston due to the potential flood damage and risk to life along with the stress and health related impacts of living at risk of flooding, as well as the economic impacts. The misery experienced by the people in Boston in the past, e.g. in 1953, 1978 and 2013, simply should not be allowed to be repeat. The increasing fear of tidal flooding by the communities in Boston every time when a high surge event is forecasted should be removed. It is my opinion that building a Barrier is an absolute necessity to protect Boston.

9.3 The proposed Barrier is the solution which will provide the best flood protection to Boston and will deliver considerable wider benefits to the local area. It is widely recognised that not building a Barrier is not an option. I also hold the opinion that Boston Barrier is urgently needed. The provision of a tidal defence Barrier will help to reduce flooding risk to over 17,000 homes and businesses in Boston. It will help to fulfil a long standing ambition for the borough of Boston.

9.4 The proposed Barrier (and improvements to the downstream Haven embankments) will improve the present day standard of protection from as low as 1 in 50 (2%) to as much as 1 in 300 (0.33%) chance of flooding each year.

9.5 Building a Barrier on the Haven in this location (and improvements to the downstream Haven embankments) will help to reduce the collective anxiety in the local community every time a storm surge is forecasted, as people will know that their homes are at a greatly reduced risk of flooding.

9.6 It will help to provide the opportunity for greater regeneration and economic development in Boston, including in the most social-economically deprived areas.

9.7 Considering the history of flooding, the damage and misery caused by flooding in the past and the increasing flood risk faced by Boston communities as outlined in Section 4 (History of Flooding), and considering the wider benefits that will be offered by the proposed Barrier scheme (and improvements to the downstream Haven embankments) (Section 5), it is my opinion that this Scheme is urgently needed. Not building the Barrier is not an option.

9.8 The Scheme will not only help to reduce the flood risk for Boston town, it will also help some of the property owners to insure their properties, and occupiers to insure their possessions, and to help people reduce their insurance premiums. Furthermore, it will help to provide the confidence enabling people to invest in Boston, and allow for future economic growth and prosperity. The Barrier (and improvements to the downstream Haven embankments) will provide security and peace of mind to the people of this borough, investors, visitors and businesses.

9.9 Extensive modelling of the flood effects has been undertaken, with appropriate validation and testing. The results have shown that the proposed Barrier (and improvements to the downstream Haven embankments) will work and will offer the protection needed to Boston.

9.10 The FRA and modelling have been carried out using the best available data, the most advanced and well-tested techniques and software, following the best practice. The models were calibrated and verified against past real events. The assessment was thorough and

comprehensive. The FRA and modelling is robust and represents the best information to inform decisions.

9.11 For tides less than 5.3m AOD high, the water level in the Haven will remain the same as the current situation without Barrier situation.

9.12 For tides exceeding 5.3m AOD, the tide will continue to propagate towards Grand Sluice before the tide reaches 5.1m AOD. Once the tide exceeds 5.1m AOD, the Barrier will be raised up to stop high tide propagating beyond the Barrier.

9.13 The operation of the proposed Barrier will not have any material change in water levels in the Haven downstream of the Barrier, nor in the tide level in the Wash. Hence the flood risk to the communities at Fishtoft, Skirbeck and Wyberton which are downstream of the Barrier will not be increased as the result of the operation of the Barrier.

9.14 The implementation and the operation of the Barrier will not increase the flood risk upstream of Grand Sluice or upstream of Black Sluice for tidally dominant events when the Barrier is erected during high tide.

9.15 Under fluvial flood conditions, the Barrier would lie on the river bed and would not obstruct the flow in the vertical direction.

9.16 Due to the lowering of the river bed at the Barrier, the reduction in the channel width at the Barrier will have negligible impact on the flood risk upstream, not least as its effective area is still much greater than at Town Bridge and John Adams Way.

9.17 The modelling results have shown that the operation of the Boston Barrier will not significantly change the water levels in the River Witham upstream of Grand Sluice during fluvial floods. The increases are minor and less than 0.1 metres along the River Witham (typically between 0.01m to 0.07m). Increased flood levels are all contained within existing flood defences, with the exception of Antons Gowt lock, where it could overtop into the extensive lowland drainage system beyond but not place properties at risk of flooding.

9.18 The analysis has also demonstrated minor increases (0.01m to 0.05m) in upstream levels in the South Forty Foot Drain, when water is not pumped into the Haven during tidal lock conditions, and when the Barrier is raised, though properties would not be flooded as the relevant thresholds are above the peak flood levels.

9.19 Regarding the Barrier location, the proposed Barrier at Location B will not only reduce the tidal flood flooding risk to Boston, but will also help to provide the most practical, social, economic and environmental benefits compared to other shortlisted locations A, C, D, E and locations at or towards the mouth of the Haven.

9.20 The 1994 report concluded that when considering navigation, engineering, environmental and cost aspects, building a sea lock and a barrage at the mouth of the Haven was less preferable than at a location further upstream. This assessment is supported even more so today, especially considering the special protected ecological status assigned to the Wash and the downstream reach of the Haven by international legislation (please see Emma Lunt's proof of evidence (**EA/8/1**)).

9.21 Furthermore, a Barrier at the mouth of the Haven or other alternative locations would provide no greater level of protection from flood risk and would protect no greater an area than the proposals comprised within the Scheme whilst suffering a range of disadvantages outlined Section 6.6.

9.22 The effective channel sectional area at the Barrier will be reduced by about 35%, but it will still be greater than the effective sectional areas at Town Bridge and John Adams Way and be comparable to that at the Swing Bridge.

9.23 Under tidally dominant conditions, i.e. with small river discharges, the velocity at the Barrier will increase by different amounts with the changes in tide level. However, the maximum velocity increase through the Barrier section will happen between the mid and low tide during the ebb tide. During this period, the channel is normally not navigable due to insufficient depth. Nevertheless, throughout the tidal cycle, the velocity is within the safe speed limit for navigation.

9.24 Under high river flow conditions, even with the increased velocity at the Barrier, the magnitude of the velocity at the Barrier will not be higher than those currently experienced at the Swing Bridge or the Haven Bridge during navigation periods.

9.25 The proposed Barrier does not cause the highest velocity in the Haven.

9.26 Considering the flood risk faced by Boston town now and the increasing flood risk in the future, considering the wider benefits could be brought by the proposed Barrier, in my opinion, permission should be granted to implement the Boston Barrier scheme.

10 Statement of Truth

10.1 I confirm that insofar as the facts stated in my proof of evidence are within own knowledge I have made clear which are and I believe them to be true, and that the opinions I have expressed represent my true and complete professional opinion.

10.2 I confirm that my proof of evidence included all facts which I regard as being relevant to the opinions which I have expressed and that attention has been drawn to any matter which would affect the validity of those opinions.

10.3 I confirm that my duty to the Inquiry as an expert witness overrides any duty to those instructing or paying me, that I have understood this duty and compiled with it in giving my evidence impartially and objectively, and that I will continue to comply with that duty as required.

Signed: ……
Sun Yan Evans

Date: ……

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