REPORT

Southwold Harbour Study

Project Report

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Executive Summary

Project Overview

East Suffolk Council (ESC) is responsible for the structures at the entrance to Southwold Harbour. The South Pier is in a poor condition and at risk of collapse, and replacing it is expected to require substantial investment. The North Wall within the harbour is not well used for mooring, which may be due to wave disturbance, possibly linked to the poor condition of the South Pier. The Southwold Harbour Management Committee (HMC) aims to increase use of the harbour, which would benefit from improved conditions at the North Wall.

In 2009 the Blyth Estuary Flood Risk Management Strategy (the EA Strategy) concluded that investment to sustain or improve the condition of the present estuary flood defences could not be justified on economic grounds. The preferred option identified by the EA Strategy was the eventual withdrawal of maintenance combined with local works to mitigate flood risk to properties in Southwold and Walberswick. The Strategy was approved by the Environment Agency (EA) in June 2009. The EA are responsible for the management of the Blyth estuary flood defences and East Suffolk Council is not able to take over this responsibility. Landowners are entitled to protect their land from flooding and erosion, at their own cost.

If the flood banks are no longer maintained, it is expected that they will gradually fail over their full length. This will lead to regular flooding of the marshes, which form a series of large flood cells[1] in the estuary. The tidal prism[2] of the estuary will increase if the flood defences fail, as a larger area of the marshes will be able to flood. Sea level rise due to climate change is also expected to increase the tidal prism because there is likely to be a greater depth of flooding, depending on the rate at which the ground level of the marshes rises due to sediment deposition. A larger tidal prism will cause higher flow rates through the harbour entrance, which could increase erosion of the channel bed and the risk of failure of the harbour entrance structures. Changes to tidal flows will also affect conditions for navigation and mooring in the harbour.

The harbour entrance and the estuary defences are mutually dependent, so the future management of the estuary defences and potential changes in the tidal prism need to be taken into account when considering what needs to be done to improve or replace the South Pier and other harbour structures.

As well as providing a defined entrance to the harbour, the North and South Piers are control structures for the adjacent coast. If the South Pier was to collapse and not be replaced or repaired, this would increase the exposure of the North Pier, which would then also fail. With the loss of both structures, erosion of the coastline would accelerate, and the form and location of the estuary mouth would be expected to change.

A further issue is flood risk to properties and businesses within the harbour. Access to the harbour is already restricted on high tides, with the condition of the Harbour Road deteriorating, and the frequency of flooding will increase with climate change. Investment in the harbour entrance structures will have less benefit if the viability of the harbour is affected by the frequency of flooding.

The local economy is strongly linked to coastal tourism, with Southwold Harbour being a key component in this, so the potential benefits of works to the Harbour entrance structures (and the consequences of inaction) extend beyond flood and coastal erosion risk.

A realistic investment plan is required to inform future funding needs for the Southwold Harbour entrance structures and management of the estuary defences. This plan needs to be based on an improved understanding of the interrelation of physical processes within the estuary and the condition, performance and useability of the harbour entrance structures.

The coastal management team at Coastal Partnership East (CPE) is supporting ESC with the delivery of this project, with Royal HaskoningDHV appointed in September 2019 to develop the Southwold Harbour Investment Plan and to undertake the associated technical investigations. This report presents the findings of the Southwold Harbour Study and Investment Plan, advising on options to address the future function, operation, and survivability of the entrance to Southwold Harbour in the broader context of estuary management and the economic future of the harbour.

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[1] *A flood cell is defined as an area which can flood independently of other areas located upstream or downstream.*

[2] *The tidal prism is the volume of water held in the estuary between high tide and low tide.*

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What is the problem?

Figure 1 illustrates the sequence of events that would be expected to occur if nothing was done to improve the condition of the harbour entrance structures.

SP1 If nothing was done to improve the condition of the South Pier, it is expected to collapse during a severe storm within the next 5 years. If the South Pier does not fail due to wave impact then failure from undermining (following erosion of the channel bed) might occur within 10 years.

SP1.1 Collapse of sections of the South Pier could block the entrance channel, restricting access to the Harbour and potentially causing a safety hazard.

SP1.1.1 With gaps in the South Pier, wave disturbance in the entrance channel and harbour would increase, affecting navigation and moorings at the North Wall and further upstream.

SP1.1.2 Sediment would move into the outer harbour from the south, further restricting access.

SP1.1.3 Loss of the South Pier would enable increased sediment movement from south to north, accelerating erosion of the dunes and increasing the risk of tidal flooding to Walberswick.

SP1.2 Increased wave impact on the North Pier.

SP1.2.1 The condition of the North Pier would deteriorate quite rapidly as this structure is not designed for direct wave impact, with failure expected within 10 years of failure of the South Pier. The adjacent structures would then be affected.

SP1.2.2 Wave penetration into the inner harbour would increase further and the North Pier would no longer retain the southern end of the Denes. The north beach would collapse into the harbour channel. This could result in increased sediment movement from north to south, which could offset erosion impacts associated with the loss of the South Pier.

SP1.2.3 Erosion of the Denes to the north would increase flooding and erosion risk for Southwold.

Figure 1: Illustration of the impacts of the Do Nothing scenario for the harbour entrance structures

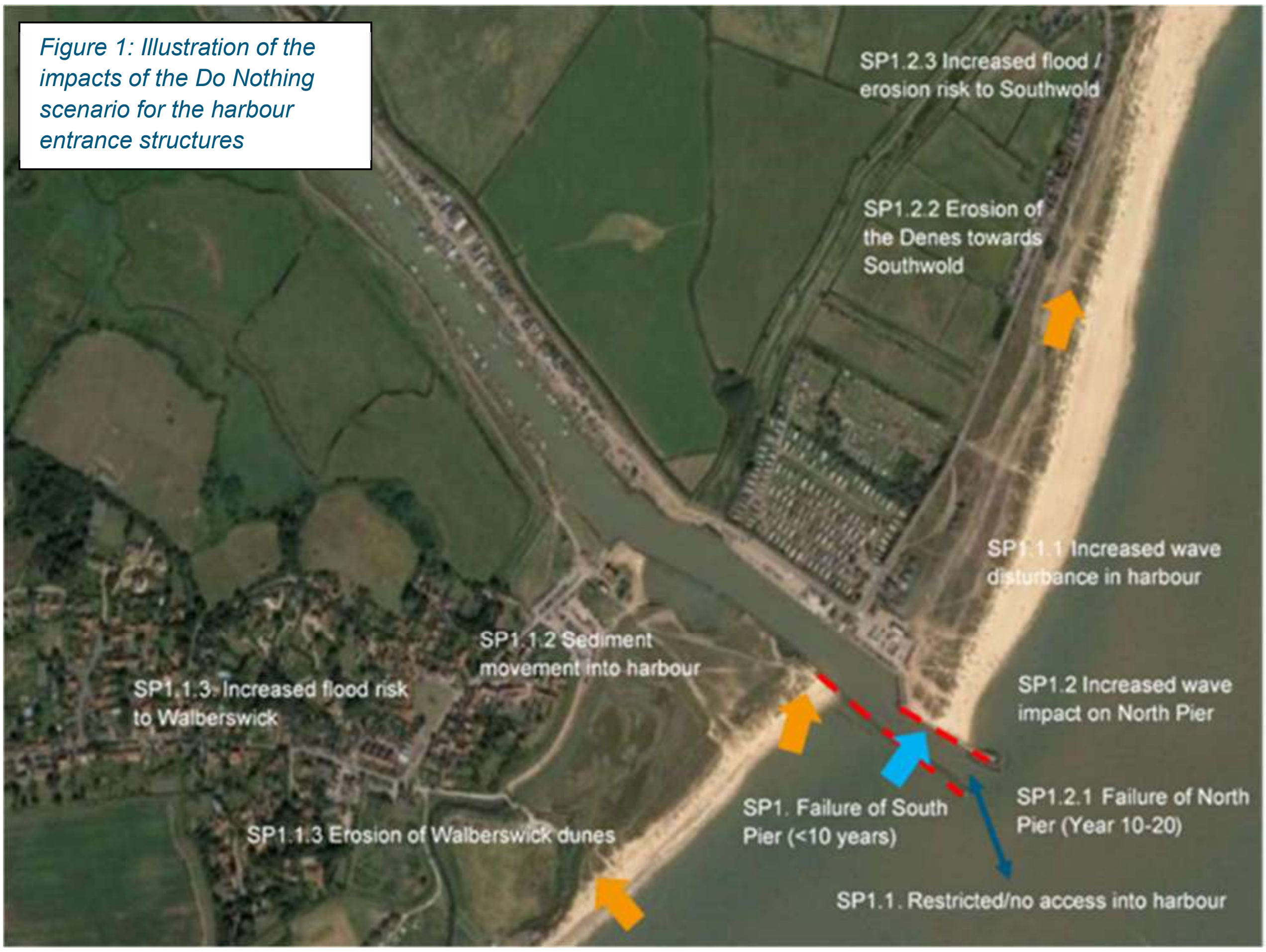

Figure 2 illustrates the sequence of events if nothing was done to improve the estuary flood embankments.

E1 Gradual failure of the estuary flood defences would occur over the next 20 years, with overtopping of the embankments to Tinkers' and Robinsons' marshes expected at least every 5 years on average, with a high risk of embankment failure if overtopping occurs.

E1.1 Following failure of the embankments, the marshes will be inundated on high tides, increasing the risk of flooding to properties in Walberswick and Southwold.

E1.1.1 Flooding of the marshes is expected to reduce the peak flood levels in the river, reducing the risk of flooding to Blackshore properties and harbour businesses.

E1.1.2 The tidal prism of the estuary will increase significantly, resulting in an increase in the peak flow rate in the river channel, particularly at the constrained harbour entrance.

E1.1.2.1 An increased flow rate is expected to increase the rate of erosion of the channel bed and therefore the risk of failure of the harbour entrance structures. Erosion of the channel bed at the narrowest point of the estuary would reduce resistance to tidal inflow and thereby increase the tidal prism.

E1.1.2.2 The increased flow rate would also impact on navigation in the Harbour.

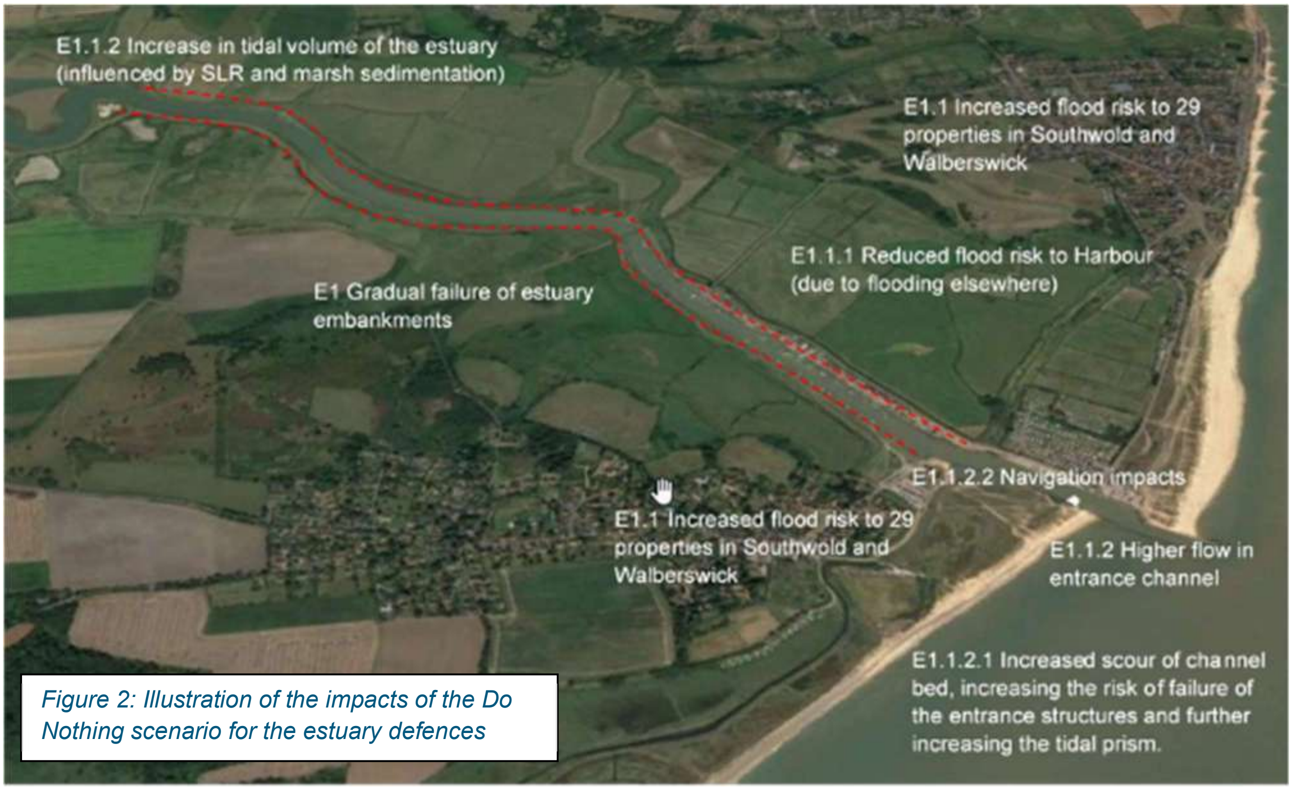

Figure 2: Illustration of the impacts of the Do Nothing scenario for the estuary defences

Options Considered

In developing the Investment Plan, a range of options were considered for: 1) the improvement or replacement of the harbour entrance structures; 2) improvement of the estuary defences; and 3) to reduce flood risk to the harbour. There are inter-relationships between some of these options.

Harbour entrance structures

The following options to improve the condition and sustain the performance of the harbour entrance structures were developed, considering the various possible structural options:

- **H1 - Do Nothing**
- **H2 - Do Minimum (Maintain South Pier)**
- **H3 - Do Minimum (Repair South Pier)**
- **H4 - Repair then replace South Pier**
- **H5 - Replace South Pier with a similar structure**
- **H6 - Replace South Pier with a breakwater**

Estuary defences
The potential strategic management scenarios for the estuary defences are as follows:

- **E0 – Maintain Integrity of Present-Day Defences:** This option aims to keep the existing estuary defences in place for as long as possible, but without major capital investment, assuming that the embankments can be maintained and repaired until about 2040. After this time a decision would be taken as to whether to (a) discontinue maintenance (Do Nothing) or (b) improve the estuary defences.
- **E1 – Do Nothing:** This scenario assumes no further works are undertaken to the estuary defences. The flood embankments and harbour structures would be allowed to deteriorate and fail.
- **E2 – Improve Estuary Defences:** This option assumes that the estuary defences are improved to provide protection against a 1 in 100 (1% AEP) surge event, allowing for sea level rise to 2070. The harbour structures would also be maintained or improved as required. Variations on this option that provide a lower standard of protection (SOP) would also be possible.
- **E3 – SMP Policy:** The defences on the north side of the estuary are improved to keep pace with sea level rise. Banks on the south side of the estuary would be realigned or their crest levels reduced allowing for flooding of Robinson's Marsh and Tinker's Marsh. The harbour entrance structures would be maintained or improved as needed.
- **E4 – EA Strategy Position:** Management of the estuary defences and harbour structures would be withdrawn gradually until 2030, with defences abandoned thereafter. Secondary defences would be built to reduce the risk of flooding to Walberswick and Southwold, plus a terminal groyne at Gun Hill.
- **E5 – Tidal Barrier:** A tidal barrier would be constructed across the harbour entrance, which could be raised or lowered on surge events to prevent flooding.
- **E6 – Spillway:** The flood embankments to Robinson's, Tinker's, Town, and Reydon Marshes would be improved to keep pace with sea level rise, and the harbour entrance structures maintained or improved as necessary. A 250m long spillway would be constructed within the embankment to Tinker's Marsh which would be overtopped on surge tides to flood Tinker's Marsh.
- **E7 – Narrow Channel:** The river channel could be narrowed opposite the North Wall to constrain the volume of water entering the estuary and reduce water levels upstream. This option could be combined with any of the other management options for the estuary defences and harbour structures.

Flood risk to the harbour
The following options to reduce flood risk to the harbour were assessed:

- **B1: Do Nothing**
- **B2: Raise Harbour Road (1 in 5 year Standard of Protection (SOP))**
- **B3: Raise Harbour Road (1 in 100 year SOP)**
- **B4a: Raise Harbour Road plus concrete flood walls (1 in 100 year SOP)**
- **B4b: Raise Harbour Road plus glass and concrete flood walls (1 in 100 year SOP)**
- **B5: Raise Harbour Road (1:5 SOP) + concrete flood walls to Blackshore (1 in 100 year SOP)**
- **B6: Do Minimum (limited improvements to road condition)**

Summary of Findings

A summary of the assessment of the options is provided in **Table 2** at the end of this Executive Summary. The preferred solutions for managing Southwold Harbour and the inter-related estuary defences, subject to securing the necessary funding, are described below. Selection of these preferred options has considered various factors, including performance against the objectives (based on the modelling results), cost estimates and stakeholder feedback (refer to **Appendix G**). It should be noted that whilst cost was considered in the assessment, affordability has not been fully assessed because a comprehensive business case (including benefits assessment) has not yet been developed.

Replacement of the South Pier
The preferred option for works to the South Pier is **Option H6 – Replace South Pier with a breakwater**. The total initial capital cost of these works is **£13.9 million**[3]. A breakwater constructed of rock armour or

[3] *All cost estimates quoted in the Executive Summary include 75% Optimism Bias.*

concrete units would significantly improve wave conditions within the entrance channel and the inner harbour, reducing wave heights at the North Wall to about 0.5m during conditions expected to occur once every year on average. A rock armour and concrete unit breakwater is the option with the greatest benefits for wave conditions and is a more cost-effective solution than other long-term options.

The review of options to replace the South Pier has included various additional assessments to optimise the proposed solution. Issues considered have included:

- *Requirement for timber fenders to the inner face of the proposed breakwater.* Timber fenders may be necessary to mitigate safety risks to vessels if the breakwater was constructed from rock armour. Cost estimates currently indicate that a hybrid rock armour and concrete unit structure without fenders may be slightly less expensive than a rock armour breakwater with timber fenders, and without the future maintenance costs associated with fenders. However, the difference in costs is less than £150k (1%).

  Due to the ongoing volatility in construction costs, the most cost effective design for the South Pier should be reviewed as part of design development, with input from a construction contractor, and considering buildability issues as well as the costs for materials and future maintenance.

- *Options for maintaining tidal flows and wave penetration into the entrance channel,* with the aim of replicating the effects of the existing 'windows' through the South Pier. A range of options incorporating box culverts were assessed using the tidal model (see **Appendix H**), which concluded that incorporating culverts in the breakwater would be of limited benefit to improving navigation conditions.

  It is therefore recommended that the proposed breakwater does not include culverts, and that the design of the mouth of the harbour entrance channel should optimise conditions for navigation into and out of the channel, with additional wave and sediment transport modelling and consultation undertaken as part of the design development.

- *Dredging of the sediment bank located opposite the North Wall*, to increase the navigable width of the outer harbour, improve access to the inner harbour and create space at the North Wall for vessel mooring. The potential impact of dredging the shoal bank on wave conditions, flow velocities and directions and peak water levels in the harbour was assessed (**Appendix I**), including additional tidal modelling. This assessment determined that dredging would not change conditions in the entrance channel, flow velocities in the outer harbour would be reduced, and the impact on upstream flow velocities would be limited, but there would be negative impacts on peak water levels further upstream. The impact of dredging on peak water levels could be mitigated with the construction of a rock groyne to narrow the channel, with a location upstream of Dunwich Creek preferred if this option was taken forward. A marine licence would be required to enable the shoal bank to be removed, and the application process for this could take 6 to 12 months.

  Discussions with the HMC concluded that dredging should not be undertaken at this time. The potential opportunities for increasing mooring at the North Wall are to be reviewed, and sediment samples taken from the shoal bank in case dredging is required in future.

- *A rock groyne to narrow the channel opposite the North Wall*, which could have benefits for upstream conditions with and without dredging of the inner harbour. Assessment of this option showed that it would slightly reduce wave heights in the inner harbour and reduce peak water levels at the Blackshore during extreme surge tide conditions. However, this option would not fully address the risk of flooding to the Blackshore and would introduce restrictions for navigation and limit mooring at the North Wall.

  Therefore, this option is not currently recommended, but could be progressed in the future if dredging proposals were to be taken forward.

- Other works within the harbour area and at Dunwich Creek have been reviewed but are not proposed as they would have limited additional benefit for wave conditions and use of the harbour. Improvements could be made to the North Wall to improve mooring conditions if required, such as the addition of fenders and mooring bollards.

It is also recommended that minor works to repair the North Pier should be undertaken at the same time as the replacement of the South Pier. The SHED concrete units which form the inner face of the North Pier are broken over a length of about 25m at the seaward end of pier. These repairs have an estimated cost of about £1 million.

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Estuary management

The preferred option for the future management of the estuary defences is **Option E6 – Improve Estuary Defences with Spillway**. With this option, the flood embankments to Robinson's, Tinker's, Town and Reydon Marshes would be improved to provide a 1 in 100 (1% AEP) SOP, allowing for climate change. A 250m long reinforced spillway would be constructed in the embankment to Tinker's Marsh, which would be overtopped on surge tide events. The total initial capital cost of these works is **£17.8 million**. This option achieves the following in terms of the project objectives:

- The tidal prism would be comparable to the present day conditions. In 2070, peak flow rates in the entrance channel would be about 3.0 knots on the ebb of a spring tide, an increase of approx. 8% from the present-day peak flow rate of 2.8 knots. Peak flow on extreme events could be higher than if all banks were raised, as the flooded marshes drain. If the estuary embankments were to fail (Do Nothing), the peak flow rate would be about 4.8 knots.
- This option provides a 1 in 100 (1% AEP) SOP against future flooding to properties in Southwold and Walberswick. Apart from the expensive tidal barrier, or raising the defences without the spillway, other options would require additional flood protection to Southwold and Walberswick.
- This option maintains the present-day risk of flooding to the Blackshore. For a surge event equivalent to December 2013, peak water level at the Blackshore would be comparable to the 2013 flood level.
- This option could be delivered through a phased approach, initially focusing on the sections of defence at greatest risk of failure or with the lowest standard of protection.

Variations on this option that provide a lower standard of protection would be possible, at a lower cost but with a reduction in the economic benefits achieved. Costs for a 1 in 5 (20% AEP) SOP would be £12.1m, but this would deliver only limited improvements to the protection provided compared to the present day defences. The potential to attract funding may also be reduced with a lower SOP. A full range of standards of protection was not fully assessed as part of this project. Development of a business case for estuary management works should consider sensitivity to the standard of protection provided, and the potential for phasing the construction works (undertaking improvements in stages as funding becomes available).

Works to the estuary defences cannot be undertaken by the HMC, so a suitable delivery approach would need to be identified, as well as securing funding to enable Option E6 to be undertaken. Recognising that it may be difficult to obtain funding for the proposed works, a viable alternative would be **Option E0 – Maintain Integrity of Present-Day Defences**. There is no initial capital cost for this option, but a plan and budget would be needed for ongoing maintenance, so that breaches of the estuary embankments could be repaired if they occur. This option achieves the following:

- For water levels which do not exceed the crest level of the embankments, peak flow rates will be similar to those experienced at present, limiting the risk of erosion of the entrance channel. Peak flow rates in the entrance channel would be about 3.0 knots on the ebb of a spring tide in 2070 (8% increase from the present-day peak flow rate).
- This option has less impact on peak water level at the Blackshore, as overtopping of the estuary defences would occur on an extreme surge event, so peak water levels in the harbour would be less than if the height of the embankments was increased.
- There would continue to be a risk of flooding to properties in Southwold and Walberswick unless secondary defences were constructed (not currently included in this option).
- This option would enable works to the embankments in the future if funding is secured at a later date.

The main risk with this option is that multiple failures of the estuary flood embankments could occur during an extreme surge event, with the risk and frequency of failure increasing with time. Repair of a breach in the embankments can be difficult and expensive, due to access constraints during flood events. Repair works could become more technically challenging following multiple breaches, increasing costs. The cost of repairs would be an operational cost rather than a capital investment, so grant funding is unlikely to be available. Therefore, this option is not currently the preferred approach to future management of the estuary defences.

Flood risk to the Harbour

Following discussions with harbour users and other stakeholders, the preferred option to manage flood risk to the harbour in the short term is **Option B6 – Do Minimum** (limited improvements to road condition). This option would involve infilling the low spots in the road (to be confirmed by topographic survey), and installation of edge protection to reduce the rate of wash-out of the road surface. It is expected that these works would be undertaken by the harbour users themselves, potentially using donated materials and other resources. As such a cost estimate has not been prepared for this option.

This option would not preclude future works to raise the level of the road or to install flood walls, which are technically viable options but with much higher costs of between £4 million and £9 million, as well as complexities relating to the requirements for accessing properties, boat sheds and the harbour pontoons.

Investment Plan

The proposed 50-year Investment Plan for the preferred options described above is set out in Table 1, including the two alternative approaches for future management of the estuary flood banks. The total initial capital cost (Year 0 to Year 5) for **Option E6** (Improve Estuary Defences and a Spillway), **Option H6** (Replace South Pier with a Breakwater), and minor repairs to the North Pier is estimated at £32.6 million, with a total discounted present-value cost for all works to 2070 of £42.2 million.

The alternative **Option E0** (Maintain Integrity of Present-day Defences) combined with **Option H6** (Replace South Pier with a Breakwater), is estimated to have an initial capital cost of £14.9 million and a total present-value cost for all works to 2070 of £31.7 million, allowing for repeated repairs to the embankments.

The timescales for the initial works recognise the time needed to secure funding and develop the design. Works to the South Pier are more time-critical than the proposed improvements to the estuary defences, although it should be recognised that failure of the embankments could occur during a severe storm event.

Table 1: Recommended Investment Plan

Financial Year	Proposed works	Option E6 – Improve estuary defences + spillway		Option E0 – Maintain integrity of present-day defences	
		Cost (£)	Discounted Present-Value Cost (£)	Cost (£)	Discounted Present-Value Cost (£)
2024-25	Replace South Pier	13,851,234	12,930,275	13,851,234	12,930,275
2024-25	Repairs to North Pier	1,017,347	949,705	1,017,347	949,705
2026-27	Raise estuary defences + spillway	17,759,880	15,476,709	-	-
2027-28	Replace N Pier fenders[4]	1,157,000	974,000	1,157,000	974,000
2022-32	Maintenance & Monitoring	1,339,234	1,153,092	2,678,469	2,305,863
2032-42	Maintenance & Monitoring	1,339,234	817,221	2,678,469	1,634,442
2042-43	Replace North Pier[5]	11,823,436	5,942,056	11,823,436	5,942,056
2042-52	Maintenance & Monitoring	1,339,234	579,000	3,883,780	1,670,725
2053-54	Toe piling to South Pier[6]	7,758,131	2,683,548	7,758,131	2,683,548
2052-62	Maintenance & Monitoring	1,339,234	419,221	4,553,397	1,410,652
2062-72	Maintenance & Monitoring	1,339,234	311,940	5,356,938	1,247,758
	TOTAL	**60,063,200**	**42,236,766**	**54,758,200**	**31,749,024**

Recommendations

Funding for the works proposed for the South Pier should be sought as soon as possible, so that the required consents processes (including environmental assessment) and design can be progressed. The scope of work for this project did not include the assessment of affordability or funding availability, and additional economic appraisal is expected to be required to secure funding. Alongside these activities, plans should be progressed to improve the resilience of properties and businesses against more severe flood events.

Subject to securing the necessary funding, it is recommended that replacement of the existing South Pier structure with a rock armour and concrete unit breakwater is undertaken as soon as possible.

[4] Planned replacement of fenders to North Pier (channel section), not included in annual maintenance budget. These works are expected to be required in approx. 5 years.

[5] Costs for replacing the North Pier and the Knuckle are (conservatively) included in Year 20. With the replacement of the South Pier, and with improvements to the estuary embankments, the residual life of the North Pier could be more than 20 years.

[6] Costs for installing additional toe piling to the South Pier are included in approx. Year 30 as a conservative estimate. May not be required before Year 50 as the breakwater would be designed to adapt to falling bed levels, and the breakwater will dissipate wave energy and reduce scour.

It is recommended that the following works are undertaken to the Blyth Estuary flood embankments, subject to identifying a suitable delivery process as well as obtaining funding, as these works cannot be undertaken by the HMC. These works are a lower priority than replacing the South Pier:

- The estuary flood embankments to the Town Marshes, Robinson's Marsh, Tinker's Marsh and Reydon Marsh are raised to provide a 1 in 100 year (1% AEP) SOP, allowing for climate change (assuming a medium emissions scenario). The existing flood embankments would be retained, with works undertaken to raise the crest level and increase the embankment width on the landward side.
- A 250m long reinforced spillway should be constructed within the embankment to Tinker's Marsh, with a crest level of about 2.0mODN. The location of this spillway and its crest level would be confirmed during the design phase, considering the local topography.

Development of the design for the proposed works to the harbour and the estuary defences will need to consider the following issues:

- An economic benefits assessment is expected to be required to support any funding applications and would need to be undertaken before detailed design can progress. Due to ongoing volatility in construction costs, it is recommended that the economic appraisal includes updated cost estimates, with input from a construction contractor.
- Constraints on funding for works to the estuary defences could require further consideration of alternative lower-cost solutions, such as phased implementation of the proposed works.
- The alignment of the breakwater, particularly at the mouth of the harbour entrance channel, should be optimised during detailed design in terms of the wave conditions within the entrance channel, the requirements for navigation (e.g. transition from open sea to entrance channel), future tidal flow rates and minimising the risk of sedimentation. Performance of the breakwater under all potential wind and wave directions should be considered.
- Design of the breakwater should include a review of the most cost effective design, within input from a construction contractor, considering potential combinations of rock armour and concrete units, and the associated requirement for fenders. Buildability issues should be considered, as well as the cost of materials and future maintenance.
- Options to retain the South Pier in place and maintain navigation as far as possible during construction of the breakwater should be considered as part of the design of the works.
- An Environmental Impact Assessment (EIA) will be required to assess the environmental impacts of the proposed works and identify appropriate mitigation measures.

Next Steps

The following tasks will be required to progress the delivery of the proposed works to the South Pier:

- Initiation of relevant Council processes for the proposed capital works;
- Assessment of funding options and affordability;
- Cost / Benefit assessment, recognising the requirements of the funding applications;
- Environmental assessments, and preparation of information required for planning and other consents applications; and
- Detailed design of all proposed works.

The following activities are recommended in relation to the wider Investment Plan, including the recommended works to the estuary defences:

- Identification of potential mechanisms for delivery, funding options and review of affordability of the proposed improvements to the estuary defences;
- Planning for the risk of future breaches in the estuary embankments, as improvements to the estuary defences may not be undertaken for some time; and
- Planning for future maintenance and investigations in the harbour, e.g. repeat bathymetric surveys.

Table 2: Summary of assessment of options for the future management of Southwold Harbour and the estuary defences

Scenario / Issue	**Do Nothing**	Maintain Integrity of Present-day defences	EA Strategy	Raise all banks (1:100+CC SOP)	Raise N banks only (SMP policy)	Raise downstream banks + spillway (1:100+CC SOP)	Tidal barrier
Harbour structures	S Pier fails (<5 years), restricts harbour access.	Breakwater to replace South Pier (Option H6). Limited repairs to North Pier (approx. £1.0M). **Total Cost: £14.9M** Replacement of North Pier may be needed Year 30 – 50.					
Flood risk (Southwold/ Walberswick)	Increased flood risk to 29 properties	Flood risk on extreme events when banks are overtopped. Secondary defences could be provided.	Secondary defences provided.	Addresses future flood risks.	Tinkers / Robinsons Marsh banks allowed to fail. Secondary defence needed at Walberswick (£0.7M[7]).	Requires bank/wall to Walberswick (£0.7M).	Addresses future flood risks.
Flood risk to Harbour (peak flood levels)	240mm lower than 2013 event due to estuary flooding. South Pier failure affects access.	Increasing flood risk to harbour with sea level rise.	240mm lower than 2013 event.	190mm higher than 2013 event. Higher than all other options.	Comparable to present-day. Increasing flood risk with sea level rise.	Comparable to present-day scenario. 220mm lower than bank raising alone.	Addresses all future flood risks.
		Improvements to condition of Harbour Road, to be undertaken by harbour users. Costs TBC. Additional property resilience measures are likely to be needed in future.					No works required
Tidal flow in entrance (erosion & navigation risks)	Increase to 4.7 knots by 2070 (larger tidal prism).	3.0 knots by 2070. Peak flow on extreme events higher than with all banks raised.	Increase to 4.7 knots by 2070 (larger tidal prism).	3.0 knots by 2070. Best case as tidal prism is minimised.	3.0 knots by 2070. Peak flow on extreme events higher than with all banks raised.	3.0 knots by 2070, as for present-day defences. Peak flow on extreme events would be higher than if all banks are raised.	Increase to 4.7 knots by 2070 - no works to flood banks
Cost of works to estuary defences	N/A	Emergency repair cost ~£500,000 for each 10m breach.	**£3.1M[8]**	**£18.3M**	**£7.8M**	**£17.6M**	**~£90M**
Other issues	Long-term realignment of coast.	Regular maintenance and repair of breaches. Cost will increase with time.	Flooding of marshes, secondary defences.	-	Flooding of marshes, secondary defences.	Secondary defences, operational risks.	-
Total Initial Capital Cost	**N/A**	**£14.9M**	**£18.0M**	**£33.2M**	**£23.4M**	**£33.2M**	**~£105M**

[7] *Cost estimate for secondary defences to Walberswick based on cost estimate for EA Strategy option.*

[8] *Initial capital cost relates to construction of secondary defences only. Does not include for compensatory habitat (already acquired). Cost estimate given in StAR is £2.2m at 2007 prices. Increased by 41% to £3.1m to reflect inflation to December 2022.*

1 Introduction

Southwold Harbour is located on the Suffolk coast at the mouth of the River Blyth estuary, as shown in **Figure 1-1**.

East Suffolk Council (ESC) is currently responsible for the assets at the entrance to Southwold Harbour (**Figure 1-2**). Lack of investment has resulted in a severe deterioration in the condition of the South Pier, which means that it is at risk of collapse. The poor condition of the South Pier may be affecting wave and tidal conditions at the North Wall, which is under-utilised for mooring. Replacement of the South Pier is expected to require substantial investment. The local economy is strongly linked to coastal tourism, with Southwold Harbour being a key component in this. Therefore, the potential benefits of works to the Harbour entrance structures (and the consequences of inaction) extend beyond flood risk.

The Blyth Estuary Flood Risk Management Strategy ('the EA Strategy', Ref. 4) concluded that investment by the Environment Agency (EA) to sustain the present estuary flood defences was not justified. The preferred option identified by the EA Strategy was for the eventual withdrawal of maintenance combined with local works to mitigate flood risk. Failure of the estuary flood embankments would be expected if maintenance is not continued, resulting in regular flooding of the large estuary flood cells (**Figure 1-3**).

The inundation of these flood cells will increase the tidal prism[9] of the estuary, which is expected to result in an increase in tidal flow rates. Higher tidal flows may cause an increase in erosion of the channel bed at the mouth of the estuary, which will increase pressure on the structures at the Harbour Entrance and a greater risk of failure. Changes to tidal flows will affect conditions for navigation and mooring within the harbour. Future sea level rise will also affect the tidal prism of the estuary. The Harbour entrance and the estuary defences are mutually dependent, so the future management of the estuary defences and potential changes in the tidal prism need to be allowed for when planning any future works at the estuary mouth. In addition, it is likely that ESC will need to play a role in the future management of the Blyth Estuary.

A realistic investment plan is required to inform future funding needs for the Southwold Harbour entrance structures and management of the estuary defences. Technical investigations are required to improve the understanding of the interrelation of processes, to inform the development of the Investment Plan and support decisions relating to the prioritisation of works.

The coastal management team at Coastal Partnership East (CPE) is supporting ESC with the delivery of this project, with Royal HaskoningDHV appointed in September 2019 to develop the Southwold Harbour Investment Plan. This Investment Plan will advise on options to address the future function, operation and survivability of the Southwold Harbour Entrance in the broader context of estuary management and the economic future of Southwold Harbour.

[9] *The tidal prism of an estuary is the volume of water held in the estuary between mean high tide and mean low tide, or the volume of water leaving an estuary over an ebb tide.*

Figure 1-1: Location of Southwold Harbour

Figure 1-2: Southwold Harbour Structures

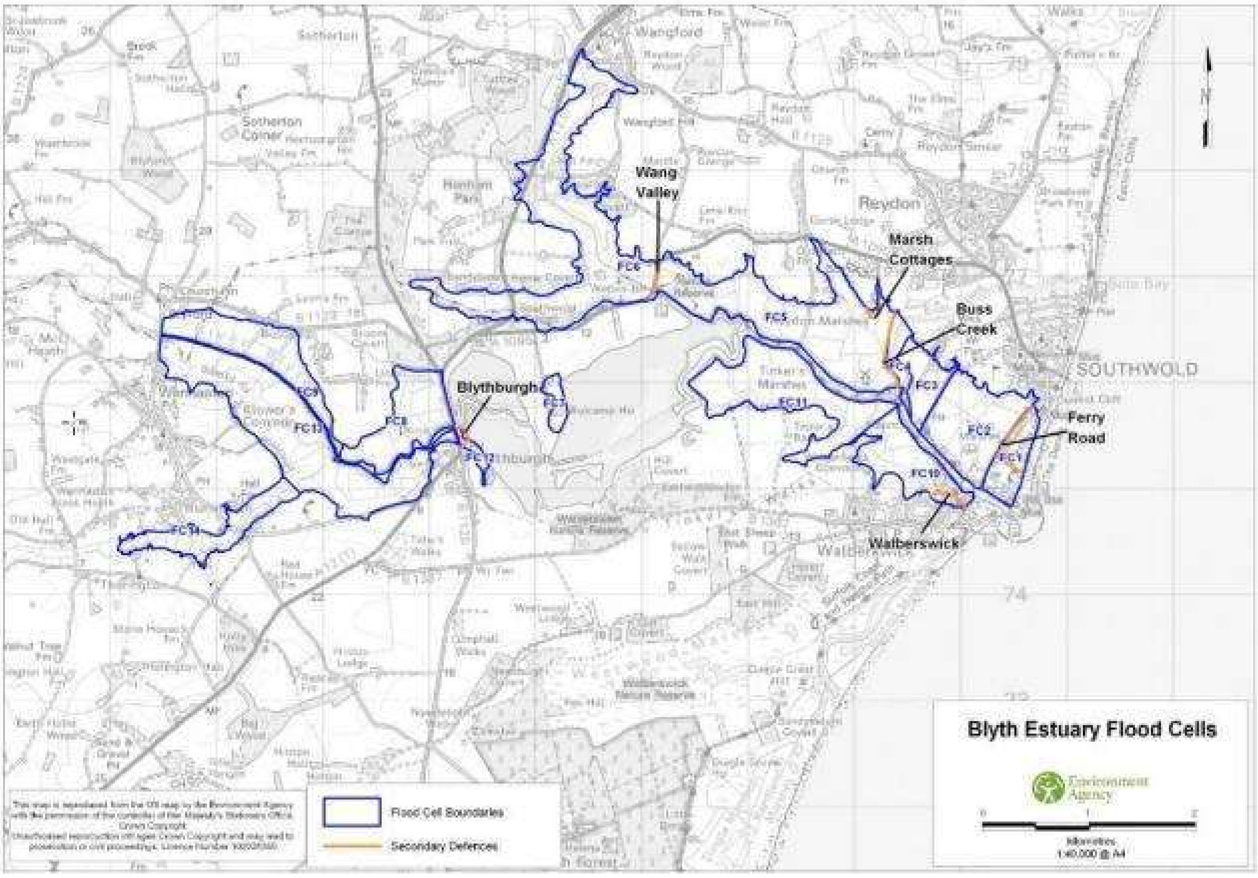

Figure 1-3: Blyth Estuary Flood Cells (figure extracted from Blyth Estuary Strategy)

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2 Background to the Project

2.1 Description of the Project Area

2.1.1 Southwold Harbour

Southwold Harbour is located at the mouth of the River Blyth and extends nearly a mile upstream from the river mouth. There are approximately 100 moorings within the harbour, on both sides of the channel. The harbour previously supported the local fishing industry, but this commercial activity has declined and made way for recreational use by yachts and small pleasure boats. Despite the decline in commercial fishing the area still supports a small but active fishing industry and associated shore-based activities. The harbour is also a base for a RNLI Lifeboat. Southwold Sailing Club and The Harbour Inn are located on the north side of the harbour, about 1.5km upstream, in the area known as the Blackshore. The river can be crossed by a public footbridge (the Bailey Bridge) upstream of The Harbour Inn. Towards the mouth of the Blyth, a rowed ferry service runs between the Walberswick and Southwold banks.

Figure 2-1: Southwold Lifeboat Station

The market town of Southwold is located to the north of Southwold Harbour. The village of Walberswick is located to the south of the River Blyth. Walberswick Beach attracts summer visitors and is a 'walkers' beach throughout the year.

2.1.2 Blyth Estuary

The Blyth Estuary is 11km long and is located within the Suffolk Coasts and Heaths Area of Outstanding Natural Beauty (AONB), as shown in
Figure 2-2, which is reproduced from the SMP (Ref. 5). The intertidal areas, plus Tinker's Marsh and Hen Reedbeds, are part of the Minsmere to Walberswick Special Protection Area (SPA) and Ramsar sites.

There are about 17km of flood defences to the Blyth estuary, which are primarily earth embankments, some with toe protection. The flood defence embankments have a typical standard of protection (SOP) of between 1 in 50 year (5% AEP[10]) and 1 in 5 year (20% AEP) and protect 670 ha of mostly grazing land. There are 86 residential and commercial properties in Southwold, Blythborough and Walberswick which are within the 1 in 300 year (0.33% AEP) floodplain. Of these properties at risk, only 29 are located below the level of the flood defences.

On the northern side of the estuary is the low lying valley of the river Wang, which joins the main estuary at Wolsey Bridge, upstream of Reydon Marsh. On the south side of the estuary, opposite Reydon Marsh, is Tinker's Marsh. These two defended areas lie upstream of the Bailey footbridge at the upstream end of the relatively straight Harbour Reach. To the north of the Harbour Reach are the reclaimed Woodsend, Town and Havenbeach Marshes, with Robinson's Marsh located to the south of the Harbour Reach.

[10] *Annual Exceedance Probability (AEP) is the probability of a flood event occurring in any year. More severe flood events occur less often and so have a lower annual probability.*

Figure 2-2: Southwold Harbour, the Blyth Estuary and the adjacent coast, reproduced from the Suffolk Coast SMP (Ref. 5)

The present Blyth Estuary flood defences developed following navigational improvements, reclamations, and localised bank failures. In the early 20th century, the River Blyth was mainly canalised downstream of Blyford. Some of the defences to the east of Blythburgh were abandoned between 1940 and 1970 after they breached during storm events. This resulted in the development of about 250 ha of intertidal mudflats with fringing saltmarsh (Angel and Bulcamp Marshes). The defences west of Blythburgh failed in 2006 and those at Tinker's Marsh failed in 2007. A 3.1km long canalised section of the river now connects the middle part of the estuary to the sea at Southwold Harbour.

The Buss Creek watercourse runs to the north of Southwold, entering the Blyth estuary upstream of the Town Marshes. The main Sewage Works to the area is located within the low-lying valley of Buss Creek.

The A12, the main road between Great Yarmouth and London, crosses the floodplain on a bridge and embankment at Blythburgh. This road floods during surge tides with a return period of about 1 in 10 years (10% AEP), causing disruption and diversions which increase the length of a journey by about 5 miles. The A1095 is the main road into Southwold and crosses the floodplain to the north of Reydon Marshes. The A1095 also has a level of protection of about 1 in 10 years (10% AEP).

The tidal estuary channel continues inland within a narrowing valley through to Blyford, 3km upstream of Blythburgh.

2.1.3 Adjacent coast

The 2010 SMP describes the coastline adjacent to Southwold Harbour, which is part of the SMP Policy Development Zone 3 – Easton Broad to Dunwich Cliffs (
Figure 2-2). This description is summarised below.

A ridge of high land runs from the village of Reydon to the coast at Easton Bavents, and this ridge is closely associated with the headland of Southwold. To the south of the Southwold headland is the main entrance to the Blyth estuary, which is a potentially wide mouthed inlet. The estuary mouth has been controlled by the harbour entrance structures, reclamation of the flood plain to the north and south of the estuary and 3km of constrained narrow channel between the harbour entrance and the Bailey Bridge river crossing. The Southwold Headland and the harbour entrance act as a downdrift control point for the coast to the north.

The estuary mouth projects out beyond the Southwold headland forming a small ebb tide delta. To the north of the estuary, held by the harbour structures, is a wide area of sand beach and low dunes. This beach connects to the Southwold seafront, which has a narrow beach with many groynes. A promenade at the back of Southwold beach provides protection to the toe of the coastal slope. To the north of the pier, land levels drop to the Buss Creek or Easton Marshes valley. The defences to the Southwold frontage were upgraded between 2005 and 2007, with new rock and timber groynes, improvements to the promenade wall and beach recharge. As part of this scheme, a cross bank was also built upstream of the Blyth Estuary defences to protect parts of Southwold and Reydon from estuary flooding.

Since the first Harbour Piers were installed, sand and shingle has accumulated against these, predominantly on the updrift (north) side of the North Pier. This has also occurred to a lesser degree to the south of the South Pier. The Piers were progressively extended due to this accumulation of sediment, resulting in a wide beach at the south end of the Southwold frontage.

To the south of the harbour entrance, the village of Walberswick is set back some 250m from the dune foreshore, with the channel of the Dunwich River located between the dunes and the village. Flood defences landward of this channel protect the village of Walberswick. The village is bordered to the north by Robinson's and Tinker's Marshes. The main part of the village is on higher ground, with a small number of properties at the quay on the River Blyth.

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The Dunwich River flows north from Dunwich across low lying land behind the natural sea defence. The nature of the foreshore changes from dunes to a narrow shingle bank within 1km south of the Blyth estuary. Extensive marsh lands are located behind this shingle bank. Dunwich Village is located at the southern end of this coastal marsh land, built on rising land behind the Dunwich Cliffs. The harbour entrance structures act as an updrift control point to Dunwich Bay.

Following breach of the Walberswick to Dunwich shingle ridge during storms in 2006 and 2007, the Environment Agency withdrew maintenance from this section of the coast, in accordance with the policy of the 1998 SMP. The shingle ridge now behaves naturally, with breaches occurring during winter storms.

2.2 Historical Background

The following historical background to Southwold Harbour is based on information provided in the scope of work for this project (Ref. 8). The early history of the harbour is largely drawn from the two references, Winter and Bumstead (Ref. 6) and Simper (Ref. 1).

In medieval times the River Blyth ran to the south of its present entrance, separated from the sea by a shingle bank and meeting the coast near to Dunwich. A more direct route to the sea was created by dredging a new entrance channel around 1329. There were further unsuccessful attempts to create an open channel in the late 1300s. In 1590, another attempt was made to create a stable entrance, and the present entrance channel remains in this location, although it has required continued intervention to maintain this.

The first seawards projecting Pier was built in 1750, possibly with the aim of reducing shingle infill. Further developments included the Blyth Navigation canal, opened in 1761, which linked Halesworth (inland) to the Southwold Harbour Entrance, with about 3km of the river upstream of the entrance being 'canalised'.

The river mouth continued to fill in, with records from between 1805 and 1818 showing the Harbour mouth was dredged 13 times. An early chart (1840) of the Harbour Entrance shows two straight Piers, with little difference between the shore alignment to the north and south. Channel deposition in the early 19th century may have been aggravated by the reclamation of about 12km^2 of saltmarsh, which reduced the tidal prism of the estuary.

Subsequent maps of the Harbour suggest that the general layout of structures remained much the same through the 19th century, with a new quay installed on the south side of the inner Harbour between 1840 and 1884. **Figure 2-3** includes a map of the harbour in 1904, clearly showing the two Piers (which have been extended further seawards), a quay and mooring along the south bank, and a build-up of sand/shingle against the North and South Piers.

The North bank had a natural form in 1904, apart from the quay and mooring, but a concrete wall was constructed in 1908, which is shown on the 1927 map (**Figure 2-4**). The build-up of shingle against the North and South Piers means that they now have a secondary coast protection role, providing essential protection to land and infrastructure.

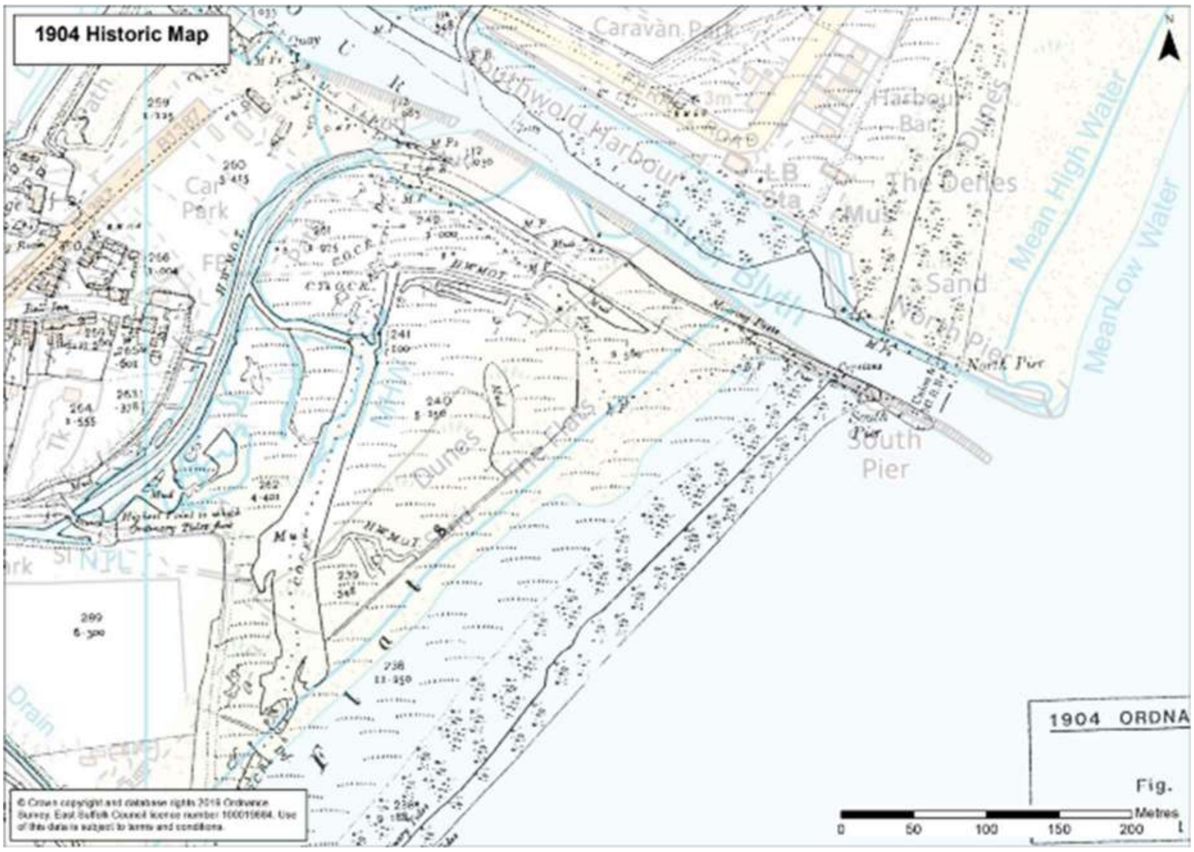

Figure 2-3: Southwold Harbour in 1904, overlayed on present-day map

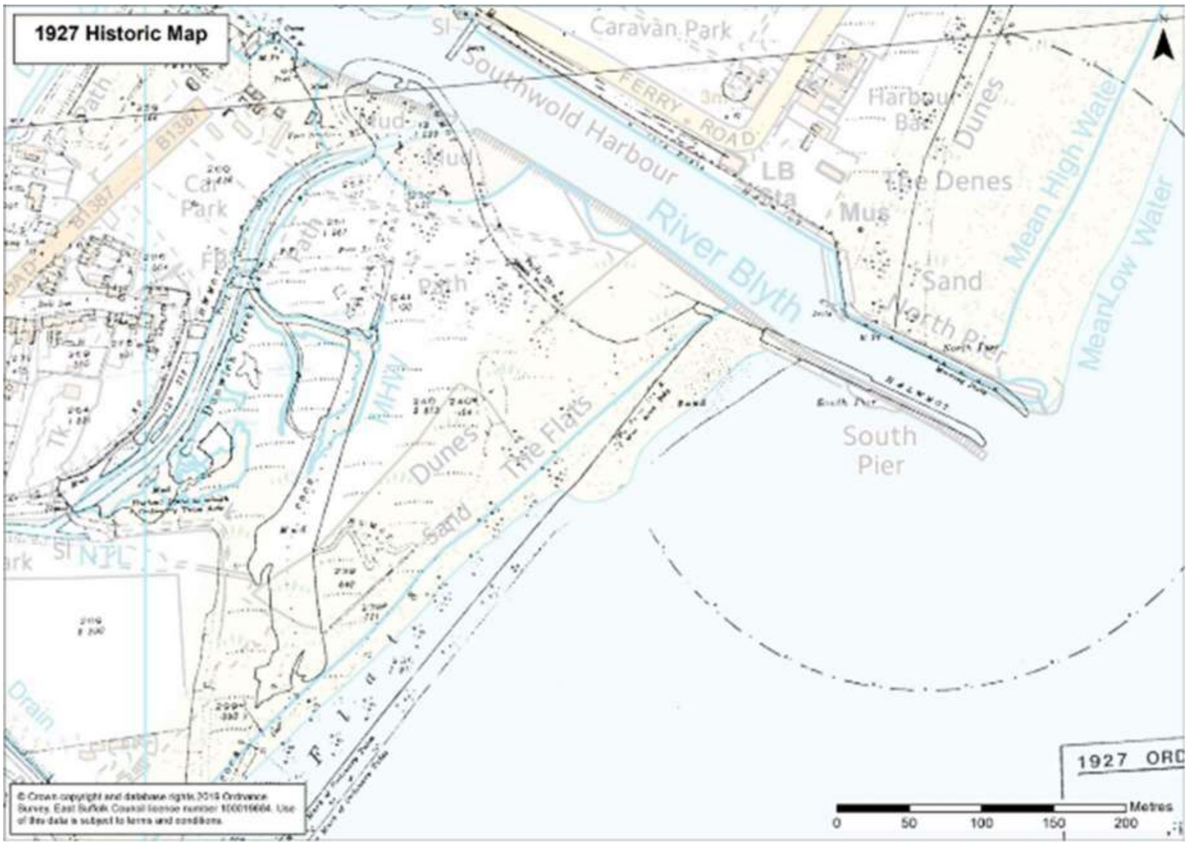

Figure 2-4: Southwold Harbour in 1927, overlayed on present-day map

Harbour developments since the 1920's are summarised below. This list is based on records of detailed designs that were prepared, but which may not have been completed. On the other hand, the list probably underestimates the full catalogue of maintenance and restoration campaigns that were actually undertaken:

- 1930's Reconstruction of the Harbour Entrance forming a funnel shape. This was found to encourage wave activity within the Harbour and was altered;
- 1934 Sheet piling repairs proposed for the 'southern Harbour';
- 1934 Possible reconstruction of North Pier;
- 1936/39 North Pier replaced due to sheet piling being worn away;
- 1952 Repairs to North Pier;
- 1962-63 Inner end of South Pier opened up in to alleviate waves in the Harbour;
- 1962 Detailed Harbour improvement works (South Pier);
- 1963 Southwold Harbour Work 2 (North Pier and Knuckle);
- 1990 Southwold Harbour Entrance, coast protection improvement works to North Pier, Knuckle, South Pier (**Figure 2-5**), including use of rock armour to seal breaches in the South Pier (further details in **Section 4.1**.);
- 2009-12 Feasibility study of the North Wall, to address the rotation of the structure. Construction of a new wall on the channel side of the previous structure (further details in **Section 4.6**).

This brief historic review shows that Southwold Harbour, and in particular the entrance, has required significant ongoing maintenance and major capital works throughout its history.

2.3 Present Situation

2.3.1 Harbour entrance structures

The layout of the structures at the entrance to Southwold Harbour is as shown in **Figure 1-2**. The present condition of the harbour entrance structures is set out in **Section 4** and **Appendix A**.

After the works that were undertaken in the 1930s to build the South training arm, there has not been significant change to the overall form of the outer part of Southwold Harbour. Recent changes to the coast protection structures are the improvement works that were undertaken to the North Pier, the South Pier and the Knuckle in 1990, which are shown in **Figure 2-5**. The form of construction of these structures has not changed since 1990.

The most recent work to the harbour entrance structures was the construction of a new North Wall in 2012-2013. An anchored sheet piled wall was constructed approximately 2m in front of the existing concrete wall, as shown in **Figure 2-6**.

2.3.2 Navigation and use of the Harbour

Southwold Harbour previously supported a major local fishing industry, but this commercial activity has declined and made way for an increase in recreational use of the harbour. Southwold Harbour now attracts many yachting visitors, particularly day yachtsmen. Walberswick Beach attracts summer visitors and is a 'walkers' beach throughout the year. Despite the decline in commercial fishing the area does still support a small but active fishing industry with associated shore-based activities. The harbour is also a base for a RNLI Lifeboat.

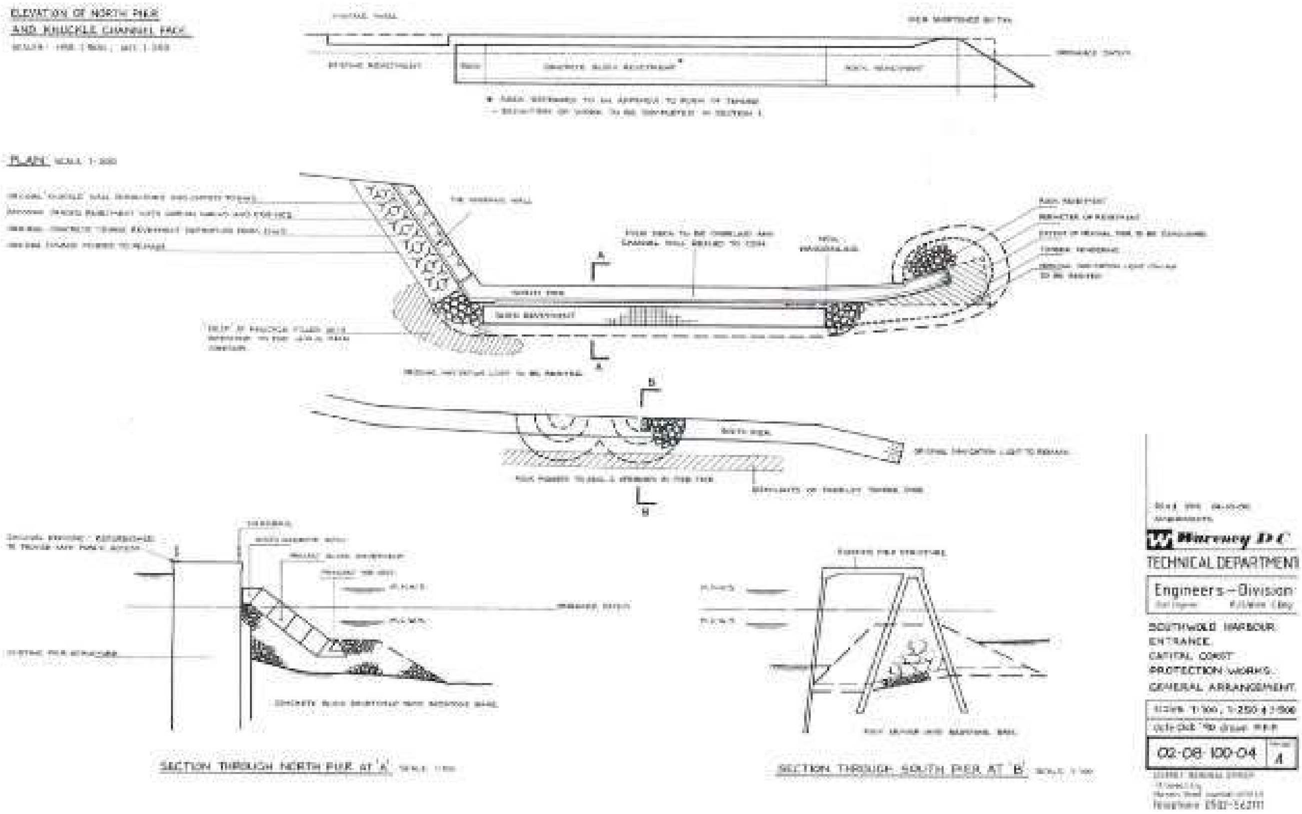

Figure 2-5: Coast Protection Works undertaken in 1990

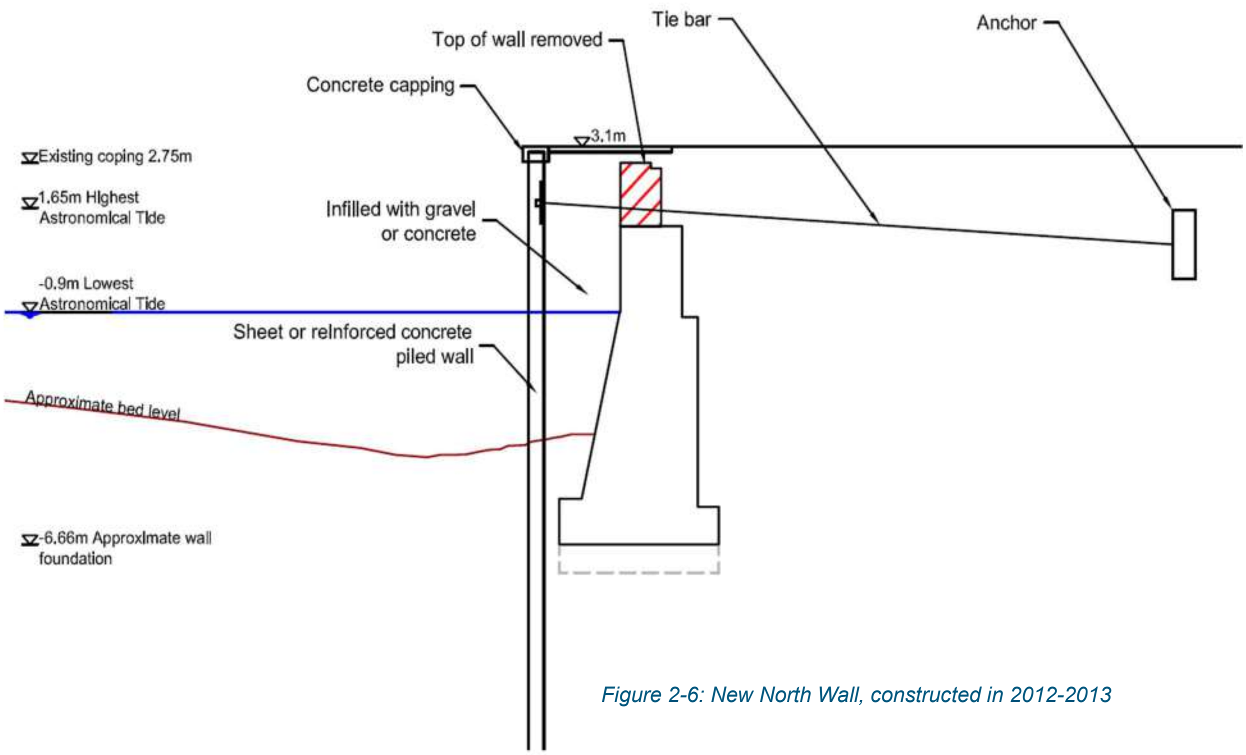

Figure 2-6: New North Wall, constructed in 2012-2013

The narrow entrance to Southwold Harbour limits the penetration of surge tides, but constrains the ebb flow, increasing flow rates. Navigation of the harbour entrance requires a suitable depth of water, which depends on the channel bed level and sea level as well as vessel size. Navigation is also affected by the rate of flow of water through the entrance channel flow rate, with vessels having to work with or against the flow to enter or leave the harbour. Vessels using the harbour are up to 70ft long, with a 3m draught. The maximum tidal flow for safe navigation is 5 knots, or 2.5m/s.

Harbour users have commented that low powered vessels often struggle to enter the harbour on a strong ebb tide, and that it can be easier to navigate the entrance on a low tide. The gaps in the South Pier help with navigation, by introducing a cross-flow which interrupts the standing waves that can form in the entrance channel during onshore winds. Regarding the planned withdrawal of maintenance of river defences, there is concern that flow speeds in the entrance channel will regularly exceed 5 knots if the estuary tidal prism increases in response to the inundation of new land areas.

Historically, the form of the entrance channel and the associated structures has influenced sediment deposition in the entrance channel. The trial-and-error relocation of the river mouth to several locations on the Dunwich-Southwold coastline aimed to achieve an entrance which didn't get blocked with sediment. The construction of the Piers to the north and south of the entrance reduced sedimentation to some extent, as the Piers move the entrance into deeper water, so less sediment is able to move into the entrance channel. In addition, the narrowed entrance means that the ebb flow from the estuary is more rapid than it would be for a wider natural river mouth, which acts to flush some sediment from the entrance.

Occasional sediment accumulations have occurred in the Harbour Entrance, e.g. in 1987 (**Figure 2-7** and **Figure 2-8**), but similar issues have not occurred within the last 20 years (as reported by the stakeholder group).

There is an accumulation of sediment (referred to as the 'shoal bank') located immediately upstream of the Knuckle, opposite the North Wall, which is shown in **Figure 2-8**. Whilst the shoal bank is not currently as large as in this photo, it is still present, and is reported by harbour users to affect the local hydrodynamic behaviour, with swells building over this shallow area, although it can also act as a 'baffle' which breaks incoming waves. Anecdotal evidence suggests that the shoal bank may have formed due to the deposition of sediment carried by flows from Dunwich Creek. The presence of this bank of sediment means that the navigation channel is forced to the north, close to the North Wall.

Figure 2-7: Sediment accumulation, north side of harbour, 1987

Figure 2-8: Sediment accumulation, south side of harbour, 1987

The moorings along the North Wall are currently not well used. The poor condition and performance of the South Pier may be a factor in this, with wave penetration through the harbour entrance causing disturbance at the moorings. Relatively shallow water in the harbour entrance means that it is inaccessible to vessels more than 40ft long, and the width available for turning is limited.

The form of construction of the new North Wall (built in 2008) is reported by harbour users as restricting its use for mooring, due to poor fendering and boat fenders being 'lost' between piles, and a risk of the overhanging concrete abutment causing damage to vessels. The alignment of the wall has reduced the channel width by 2m, with the navigation channel already being located close to the North Wall due to the bank of sediment opposite the wall. Due to the location of the navigation channel, when vessels are moored against the North Wall, access into the harbour can be restricted.

2.3.3 Strategic context

<u>The Blyth Estuary Flood Risk Management Strategy (the EA Strategy)</u>
The EA Strategy (Ref. 4) concluded that investment by the Environment Agency (EA) to sustain the present estuary flood defences is not justified. The key points from the EA Strategy were as follows:

- The Blyth Estuary defences had breached multiple times between 2006 and 2009. They are often disproportionately expensive to repair and can require helicopters to import materials and equipment.
- The SOP of the defences (in terms of the crest level compared to extreme water level predictions) was stated as ranging from 1 in 5 years (20% AEP) to 1 in 20 years (5% AEP) across the estuary.
- The proposed strategy was for managed withdrawal of maintenance of the estuary defences over a twenty-year period beginning in 2009.
- The withdrawal of maintenance would adversely affect 29 properties, with secondary defences proposed to provide protection to 16 properties with a SOP at least as high as at present for 100 years, allowing for climate change.
- Withdrawal of maintenance from some areas will result in the loss of SPA and Ramsar sites designated for their freshwater habitats. Compensatory habitat is required to mitigate this loss.
- All assets within the flood risk area will have a greater risk of inundation, with the water supply borehole and electrical apparatus needing to be relocated in the future.

A significant impact of withdrawing maintenance from the flood defences is that the tidal volume of the estuary will increase because additional land below the high tide level will be able to flood. This will result in a greater volume of water being discharged through the estuary mouth, resulting in higher flow speeds because of the constrained width of the harbour entrance channel. The EA Strategy noted that the loss of Reydon Marsh would increase the tidal volume by 52% (a location plan for the features referred to in the

EA Strategy is reproduced as **Figure 2-9**). However, the EA Strategy proposed to withdraw maintenance from Reydon Marsh in 2019, as set out in **Table 2-1** and **Table 2-2**. The EA are no longer maintaining any of the Blyth estuary flood embankments.

The EA Strategy noted that the harbour entrance structures are principally navigation structures and the responsibility of Waveney District Council (now East Suffolk Council). Whilst the EA Strategy recognised the role of the Harbour structures in controlling tidal flow into and out of the estuary, and in holding the coastline to the north, no costs for maintaining these structures were included in the Strategy as it was assumed that such costs would be borne by the Council as Harbour Authority. Instead, a sum of £540,000 was included for construction of a short rock groyne and revetment just south of Gunhill to act as to terminal groyne in order to retain the shoreline over the Southwold Town frontage following failure of the North Pier, or a breach in the defences to the north of the pier.

The proposed EA Strategy resulted in a negative reaction from the local community and local businesses. A campaign was initiated by the Blyth Estuary Group (BEG) to challenge the outcomes of the EA Strategy. This consortium comprised local government agencies, charitable organisations, conservation bodies and landowners. Further details of this group and other stakeholder interests are included in **Section 2.3.4**.

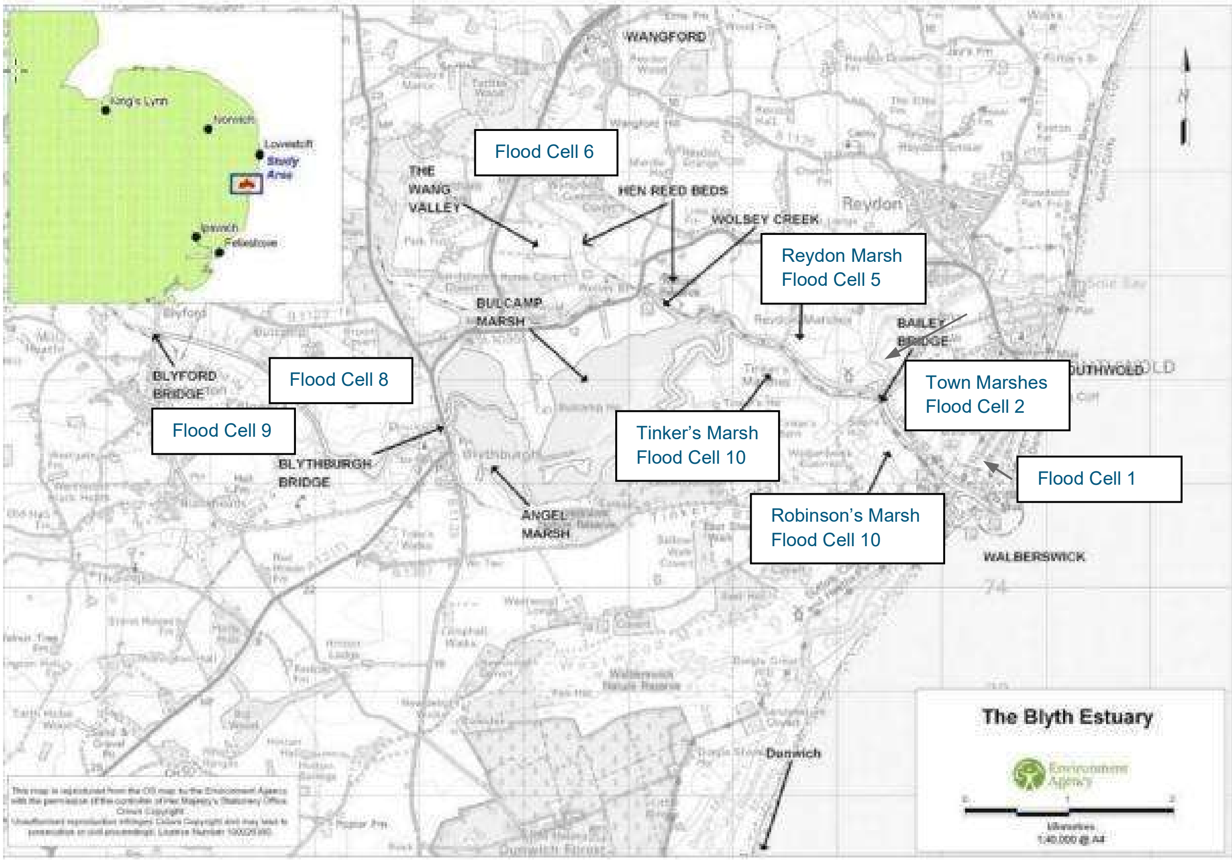

Figure 2-9: Key Locations, reproduced from EA Strategy

The preferred option identified by the EA Strategy was for eventual withdrawal of maintenance combined with local works to mitigate flood risk. It is understood that the Strategy was adopted by the Environment Agency in 2009. The actions set out in **Table 2-2** mean that maintenance may be withdrawn to most of the estuary defences by 2029 onwards. Failure of the flood embankments in multiple locations would then be expected in the medium term, which would lead to regular flooding of the large flood cells within the estuary (**Figure 1-3**).

The inundation of these flood cells will increase the tidal prism[11] of the estuary, which is expected to result in an increase in tidal flow rates. Higher tidal flows may cause an increase in erosion of the channel bed at the mouth of the estuary, which will increase pressure on the structures at the Harbour Entrance and a greater risk of failure. Changes to tidal flows will affect conditions for navigation and mooring within the harbour. Future sea level rise will also affect the tidal prism of the estuary. The Harbour entrance and the estuary defences are mutually dependent, so the future management of the estuary defences and potential changes in the tidal prism need to be allowed for when planning any future works at the estuary mouth. In addition, it is likely that ESC will need to play a role in the future management of the Blyth Estuary.

Table 2-1: Summary of EA Strategy preferred option

Flood Cell (see Figure 2-9)	Strategic Management Approach	Description of Strategy and Options
FC1 - Harbour Entrance and Ferry Road	Hold the Line	Management withdrawn from Harbour Entrance, and from mid and upper estuary defences by 2030. Maintain integrity of beach and dune defence for a minimum 30 years, allowing natural response. Construct rock groynes at Gun Hill, to the south of Southwold. Construct secondary defences with 50-year life and raise as required
FC2, 3, 4, 7 - Town Marsh, Buss Creek, Bulcamp House	Do Nothing	Do Nothing
FC5 - Reydon Marsh	Hold the Line	Withdraw maintenance by year 20. Construct secondary defence embankments with a crest level of +2.8mODN.
FC6 - Wang Valley	Managed Realignment	Withdraw Maintenance within 20 years.
FC10 - Robinson's Marsh	Managed Realignment	Withdraw maintenance of embankments by year 20. Construct secondary defence embankments with a crest level of +2.7mODN. Allow retreat of north end of Walberswick Dunes, with regular maintenance of beach and dunes for minimum 30 years, then "Do Nothing". Consider maintaining SOP of dunes for 100 years by raising according to rise in sea level.
FC11 - Tinker's Marsh	Managed Realignment	Withdraw Maintenance within 20 years, with some realignment needed.
FC 8, 9, 12, 13, 14 - Upstream of A12	Managed Realignment	Withdraw maintenance by year 20. Construct secondary defence embankments.
River channel	N/A	Increased tidal volume expected by 2100, significant changes expected by 2040.

Table 2-2: Timeline for EA Strategy preferred option

Date	Action
2009	Issue notice to withdraw maintenance from flood cells 7 in 2011. Issue notice to withdraw maintenance from flood cells 5, 6 and 12 in 2019. Issue preliminary notice to withdraw maintenance from all other flood cells in 2029. Sourcing of replacement habitat via Anglian RHCP[12].
2011	Withdraw maintenance from flood cell 7.
2019	Construct secondary defences in flood cells 1-4 (Buss Creek), 5-6 and 12. Withdraw maintenance from flood cells 5, 6 and 12.
2019-2024	Review Strategy with respect to updated guidance and historical maintenance costs.
2029	If confirmed in Strategic Review, withdraw maintenance on all remaining flood cells (1-4 and 10). Construct secondary defence in flood cell 1 (Ferry Road) and 10.
2030-2109	Continue maintenance of approved secondary defences to flood cells 1, 5, 6, 10, 12 and raise when required.

[11] The tidal prism of an estuary is the volume of water held in the estuary between mean high tide and mean low tide, or the volume of water leaving an estuary over an ebb tide.
[12] Compensatory habitat has now been obtained by the EA.

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Suffolk Shoreline Management Plan (SMP2)

The SMP2 recognised that if the North Pier was to collapse and not be repaired or replaced, then sand and shingle would begin to be lost from the Denes and Southwold Beach, with the material migrating south.
In terms of the future management of the estuary defences, considering a 'no active intervention' approach, the SMP2 says:

"The most significant failure … would be to the Reydon Marshes (within 5 years). This would significantly increase the tidal prism, increasing pressure along the tidal reach and undermining the Harbour structures (the North Pier within 20 years, possibly the South Pier and Walberswick Quay earlier) … The initial changes would occur rapidly once the influence of the North Pier was lost … The overall effect would be the loss of the Harbour and flooding throughout the estuary as well as the loss of the seaward end of Walberswick".

The Suffolk SMP2 was adopted in 2010. The principal intent of the SMP for this area is to maintain the high economic and socio-economic value associated with the harbour and Walberswick in a sustainable manner. As such, the SMP2 took a more holistic view of the estuary defences and Harbour structures and challenged the findings of the EA Strategy. It was recommended that the Harbour Entrance structures should be maintained in order to sustain a viable Harbour and provide coast protection, and that some of the estuary flood defences should be sustained, to minimise the impact of a future increase in tidal prism on flow rates and therefore on the harbour entrance structures. However, the plan is dependent on availability of funding in addition to that provided nationally for flood and coastal risk management. The specific SMP2 policies for the Harbour and estuary defences are reproduced below in **Table 2-3** and **Table 2-4** respectively.

Table 2-3: Summary of SMP Policies for the Denes to Walberswick (source: Suffolk SMP2)

Policy Unit		Policy Plan			Comments
		2025	2055	2105	
BLY 9.1	The Denes	Hold the Line	Hold the Line	Hold the Line	Maintain integrity of beach and dune defence, allowing the dunes to respond naturally.
BLY 9.2	Harbour Entrance (north and south)	Hold the Line	Hold the Line	Hold the Line	Maintain and improve harbour structures in line with use and development of the harbour.
BLY 9.3	Harbour Reach – north side	Hold the Line	Hold the Line	Hold the Line	Improve defence and raise in 50 years in line with harbour use. Policy will have to be reviewed if not technically feasible and/or economically justifiable using private funding.
BLY 9.4	Harbour Reach – south side	Hold the Line	Managed Realignment	Managed Realignment	Redevelop defences in line with harbour use but maintain defence to Walberswick.
BLY 9.5	Walberswick Dunes	Managed Realignment	Managed Realignment	Managed Realignment	Retain beach and dunes as a defence.

Table 2-4: Summary of SMP Policies for the Blyth inner estuary (source: Suffolk SMP2)

Policy Unit		Policy Plan			Comments
		2025	2055	2105	
BLY 10.1	Lower inner estuary	Managed Realignment	Managed Realignment	Managed Realignment	Maintaining the northern defences, subject to confirmation of funding.
BLY 10.2	A12	Hold the Line	Hold the Line	Hold the Line	Improve defence.
BLY 10.3	Upper estuary	No Active Intervention	No Active Intervention	No Active Intervention	-

Local Flood Risk Management Strategy

The Suffolk Local Flood Risk Management Strategy was published by the Suffolk Flood Risk Management Partnership in March 2016. This Strategy provides an update to the 2013 strategy report, accounting for changes to legislation, improved knowledge, and further development of local policy. The primary focus of the strategy is on local flooding from surface water, groundwater, or ordinary watercourses, although the

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Strategy does provide information on all forms of flooding and the organisations involved in all aspects of flood risk management. The Strategy notes that Suffolk is ranked number three in the national list of critical tidal flooding locations but it does not make any specific reference to the River Blyth or to Southwold.

2.3.4 Stakeholders

East Suffolk Council

East Suffolk Council (ESC) is currently responsible for the assets at the entrance to Southwold Harbour, and is leading the delivery of this project, supported by Coastal Partnership East.

Southwold Harbour Management Committee (HMC)

The HMC was established on 2nd March 2021 and comprises five members appointed by the Cabinet of East Suffolk Council and four non-elected members (appointed based on relevant skills and expertise). The HMC will be responsible for taking forward any recommendations from this Harbour Study, to deliver the Investment Plan.

Blyth Estuary Partnership (BEP)

The Blyth Estuary Group (BEG) was formed in February 2006 to address local concerns regarding the Blyth Estuary Strategy, including the potential impact of the proposed managed realignment of the southern flood embankments on the future of Southwold Harbour. The BEG includes a broad range of people and organisations with commercial, community and regulatory interests, with representatives from:

- East Suffolk Council
- Suffolk Coastal District Council,
- Southwold Town Council
- Blythburgh, Reydon, Walberswick and Wenhaston Parish Councils
- Southwold RNLI
- Southwold Sailing Club
- Walberswick Sea Defence Group
- Southwold Harbour & River Blyth Users Association
- Local landowners

In 2017 the BEG became the Blyth Estuary Partnership (BEP), to align with Defra's Partnership Funding approach and with other local coastal partnerships with similar aims. The stated aims of the BEP are:

1. To protect and preserve the Blyth Estuary, it's Harbour and infrastructure for the next generation.
2. To investigate the science behind the EA's strategy and challenge those elements the group considers flawed.
3. To develop an affordable 'contingency plan' for the reinstatement and future maintenance of the clay walls.
4. To undertake repairs identified by the 'contingency plan' and develop a program for ongoing maintenance.
5. To seek cooperation through continued dialogue with the Government Agencies to facilitate advancement of these aims.
6. To campaign for a change in the 1991 'Water Resources Act' to give the EA a statutory duty to maintain the estuary defences to an agreed and acceptable standard.

A key issue highlighted by the BEP in the challenge to the EA Strategy was sedimentation within the estuary, with the BEP maintaining that the mudflats (Bulcamp and Angel Marshes, see **Figure 2-9**) are accreting at a rate exceeding the present rate of sea level rise. This accretion would therefore mitigate any impact of sea level rise on the tidal prism.

In 2009, the BEG obtained planning permission for a programme of river bank improvement works using private funds. This planning permission was to raise the flood embankments to a level of 2.8mODN downstream of the Bailey Bridge and to 2.7mODN upstream of the Bailey Bridge. However, residents and businesses with properties located in front of the defence at the Blackshore have objected to these plans on the basis that raising the embankments would increase their flood risk. The BEP undertook consultation in 2018-19 with the aim of reaching consensus on this issue. It is understood that no works have been undertaken by the BEP since 2018, on the basis that this study was to be undertaken. The planning permission expired in 2012.

Environment Agency (EA)
The EA continues to be responsible for the flood embankments to the Blyth Estuary. For this project, the EA has been consulted in order to obtain relevant data and information about the estuary and from the Blyth Estuary Strategy. The EA has not yet been consulted regarding the project outcomes and recommendations. Engagement with the EA would be needed if an application was to be made for Flood Defence Grant in Aid funding to contribute to the costs of delivering any flood defence and/or coast protection improvement works.

Natural England
For this project, Natural England have been contacted for information about the designated sites within the estuary, and their current status. The scope of this project has not included the assessment of the environmental impacts of the potential options, and Natural England have not yet been consulted regarding the project outcomes and recommendations. Consultation with Natural England would be required, in accordance with relevant legislation, to gain the necessary consents to deliver any capital works as part of the Investment Plan.

Project Stakeholder Group
A Project Stakeholder Group was formed at the start of this project, including representatives from the BEP, harbour users (including fishermen, vessel owners and operators and the Harbour Master), harbour businesses and Blackshore residents.

Initial engagement was undertaken with this group before the project commenced, to understand what the stakeholders would like to be delivered by the project. Details of this engagement is included in **Appendix G.** Consultation meetings were subsequently held throughout the project, providing updates on progress and interim findings. Records from these consultation meetings are also included in **Appendix G.**

2.4 Key Risks and Issues

The primary risks for the future use and function of Southwold Harbour can be summarised as follows:

- The condition of the harbour entrance structures and the potential for these structures to fail; and
- The risk of failure of the Blyth estuary flood defences, under the various future scenarios for the management of these structures, and considering potential sea level rise.

Of secondary concern is the performance and usability of the harbour structures, and the potential to improve conditions for navigation and mooring within the harbour.

These risks need to be considered in the context of their potential impacts on the following:

- Navigation through the harbour entrance channel and within the harbour;
- The ability for vessels to moor within the harbour;
- Flood risk to properties and businesses within the harbour;

- Flood risk to properties in Walberswick and Southwold[13]; and
- Coastal erosion to the north and south of Southwold Harbour.

These risks and issues are inter-dependent. The impact of the future estuary management scenarios on the tidal prism of the estuary and tidal flow rates may directly affect the likelihood of failure of the harbour entrance structures, as well as affecting conditions for navigation and mooring and flood risk. The tidal prism of the estuary is also dependent on the rate of sea level rise due to climate change, and the rate of sediment deposition in the marshes.

2.5 Objectives for this Project

The main objective for this project is to develop a realistic Investment Plan for capital investments that may be required for Southwold Harbour over the next 50 years. The Investment Plan is required to provide information about future funding needs, in the context of a strategic financial review.

The development of the Investment Plan needs to be based on an improved understanding of the hydrodynamic regime and performance of the harbour entrance, considering:

- Condition, performance and usability of the harbour structures;
- Options for the harbour entrance structures that achieve a satisfactory wave climate for mooring;
- Hydrodynamic regime of the harbour and estuary, including the influence of the South Pier on wave conditions within the Harbour Entrance and at the North Pier and North Wall;
- Sedimentation behaviour of the harbour, including its response to wave and tidal climate and events;
- Impacts of the estuary flood risk management strategy on the harbour, including the influence of sedimentation of the marshes;
- Inter-relationships between coastal and harbour processes;
- Experience of local harbour users of the harbour entrance behaviour and their future aspirations for the harbour;
- Prioritisation of potential works; and
- Requirements for future monitoring of parameters relating to sensitivities identified by the studies.

The Investment Plan needs to include the cost of future capital and maintenance works associated with the Harbour in the short term (next 20 years) and medium term (20-50 years), for all of the estuary management options, allowing for:

- Maintaining safe navigation to and from and within Blyth Harbour;
- Maintaining safe mooring within the Harbour;
- Sustaining coast protection (inhibiting retreat of Southwold beach);
- Management of flood risks in the Blyth estuary area and within the Harbour, including enabling drainage from the Blyth catchment area and protecting against tidal inundation;
- Risk and uncertainty.

The following aspirations for the future conditions within the harbour have been proposed by stakeholders, during the development of the scope of work for this project and the initial stakeholder meetings (see **Appendix G**):

[13] *Whilst this issue is recognised in the assessment of the options, it is not a key driver for the decisions to be made regarding the future management of Southwold Harbour.*

- Accommodate vessels of up to 70m length and 3m draft;
- Reduce wave height at the North Wall by 50%;
- Ebb current to be less than 3.5 knots;
- Flood current to be less than 2.5 knots;
- No increase in sedimentation of the entrance channel and outer harbour;
- Future navigation conditions to be comparable with present-day conditions if possible;
- Improve general conditions for mooring at the North Wall (safety, risk of damage to vessels, easier mooring for leisure craft); and
- Improve visitor awareness on how to navigate the Harbour Entrance and access the moorings.

2.6 Approach to Delivery of this Project

The approach taken to delivering this project is primarily based on the brief prepared by ENBE in 2018-19 (Ref. 8). The overarching approach was to combine the results of technical analysis with local knowledge provided by the stakeholder group. Engagement with the stakeholder group also enabled an understanding to be gained of the range and nuance of the stakeholder's ambitions for Southwold Harbour and the surround area. There have also been a number of changes to the scope of work over the course of the project, based on feedback from stakeholders. The project delivery programme was affected by these changes and also by restrictions due to the Covid-19 pandemic during 2020 and 2021. The overall methodology is summarised below.

- Review of existing data: Relevant available data was collected and reviewed, including the previous hydraulic modelling (Ref. 2), EA Strategy (Ref. 4), Shoreline Management Plan (SMP2, Ref. 5), and associated studies as scheduled in the scope of work for this project (Ref. 8). The data review was discussed with the stakeholder group in the first workshop.
- Hydrographic survey: A hydrographic survey, including water levels, current and sediment measurements, was undertaken in February 2020 to inform the overall understanding of the baseline behaviour of the estuary and provide data for development and calibration of the hydraulic models.
- Stakeholder engagement: It was recognised in developing the approach to this project that effective stakeholder engagement would be critical to the project's success. For example, it was necessary to demonstrate that the hydraulic modelling had considered information provided by stakeholders, and to address any concerns the stakeholder group might have with the modelling results. The following stakeholder workshops were held (further details are provided in **Appendix G**):
  - *Consultation 1 (Workshop 1, December 2019)* – Introduction to project, discussion of key issues, sourcing any additional data.
  - *Consultation 2 (May 2020)* – Due to COVID-19 restrictions, it was not possible to hold a workshop at this time. Briefing information was provided to the stakeholder group, including a progress update, the draft condition assessment report, a summary of the approach to the hydraulic modelling, and a link to the online GIS which presented the baseline understanding of the estuary processes. Comments were invited on this information, and responses provided to the comments that were received.
  - *Consultation 3 (Workshop 2, July 2020)* – Due to COVID-19 restrictions, an online meeting was held using Microsoft Teams. During this workshop, the findings of the baseline hydraulic modelling were presented and discussions held to confirm the issues to be addressed by the project and the potential options for the harbour entrance structures.

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- *Consultation 4 (Workshop 3, October 2020)* – This workshop was held online, via Microsoft Teams. The findings of the wave and tidal modelling were presented and discussed.
- *Consultation 5 (Workshop 4, February 2021)* – This online workshop addressed issues raised during the previous meeting, including sensitivity of the modelling results to the marsh levels, to the width of the entrance channel and to transmission through the South Pier. Potential tidal barrier solutions were also discussed.
- *Consultation 6 (Workshop 5, April 2021)* – This online workshop included further discussion of the sensitivity of the modelling results to the level of the marshes. A potential option for the management of the estuary defences, involving a spillway or sluice gate was explored.
- *Consultation 7 (Workshop 6, June 2021)* – This online workshop presented the project findings so far, including the results of modelling undertaken for the additional options of a spillway and a narrowed entrance channel.
- *HMC Meeting (September 2021)* – This meeting was held in person in Southwold with the newly formed HMC. A project progress update was provided, and the initial conclusions, recommendations and proposed next steps were presented and discussed.
- *Consultation 8 (Workshop 7, March 2022)* – This workshop was held in person in Lowestoft, following the issue of the draft report. The conclusions, recommendations and proposed next steps were presented and the feedback from the group was discussed.
- *HMC meeting (March 2022)* – At this meeting of the HMC's Investment Plan Working Group the project conclusions, recommendations and proposed next steps were presented and discussed in person.
- *Consultation 9 (September 2022)* – This meeting with the project stakeholder group was held on online, to refresh the group on the project findings and an provide update on the additional work that had been undertaken on the passive spillway option.
- *HMC meeting (September 2022)* – This HMC working group meeting discussed the next steps for progressing the project recommendations. Details of the initial findings from the modelling of the passive spillway option were also presented.

- GIS visualisation of data: A data-driven approach was taken to stakeholder engagement. Project data was collated into a GIS database to enable visualisations to be presented during stakeholder workshops, including the baseline understanding of the estuary's hydro-geomorphological behaviour and the potential management options. Diagrams and animations from the hydraulic models were used to inform discussion of modelling results during workshops. The GIS database will be updated with the project conclusions and recommendations and will be transferred to Coastal Partnership East and East Suffolk Council for use during the implementation phase of this project.

- Baseline understanding of estuary hydrodynamics: Following the collation and review of all existing information, plus Workshop 1, a conceptual description of the hydrodynamic regime of the estuary as a whole was developed, including waves, tidal flows and sediment transport. This qualitative assessment established the overarching baseline understanding of the present-day behaviour of the estuary. Initial validation of this baseline understanding was undertaken with the stakeholder group via the information presented in Consultation 2, so that the accepted conceptual model could be used to validate the hydraulic model outputs.

- Develop and calibrate wave transformation models: Relevant input data for the wave and tidal models was collated, including data purchased from the UK Met Office, and information obtained from previous studies and the hydrographic survey.

  A two-dimensional wave transformation model was set up using the MIKE21 Spectral Wave (SW) model to derive wave conditions outside the harbour entrance. The MIKE21 Boussinesq Wave (BW) model was then used to assess wave conditions within Southwold Harbour, for the present day, the Do Nothing scenario (assuming failure of the South Pier), and various options for possible changes to the South Pier and the harbour layout.

The model results for the present-day wave conditions within the harbour were discussed with the stakeholder group during Workshops 2 and 3, to validate the results against observed wave conditions.

Further details of the approach taken to the wave modelling are provided in **Appendix C**.

- Develop and calibrate a hydrodynamic flow model: Royal HaskoningDHV's existing two-dimensional regional tidal model of the English Channel and the North Sea uses DHI's MIKE21 Flow Model FM software. This model was extended into the Blyth Estuary, with the bathymetry improved using the survey results. The regional model is calibrated and validated using astronomic and measured tidal data and was re-calibrated and validated using current measurement data from the hydrographic survey and stakeholder observations.

  The tidal model was used to derive present-day tidal flow conditions (tide levels, speeds and directions) in the navigable parts of the Harbour and upstream waterway. The model was also used to assess the changes to the flow conditions due to the various options for the future management of the estuary. Sensitivity to climate change (Sea level rise) and sedimentation of the marshes was considered.

  Further details of the approach taken to the tidal modelling are provided in **Appendix D**.

- Assess sedimentation behaviour: Results from the wave and tidal modelling, as well as the conceptual understanding of the estuary behaviour, was used to assess the potential for sedimentation and/or scour throughout the estuary. Data from the metocean survey regarding current speed and sediment size provided an initial indication of siltation within the estuary.

- Define present form, condition and performance of the Harbour Entrance structures: An inspection was undertaken of the harbour structures following the review of relevant data from previous studies. The residual life of the structures was assessed based on this inspection, considering the effects of decay, climate change, and sediment regime, informed by the agreed hydro-geomorphological baseline and the initial modelling results.

  The calming influence of the South Pier on wave activity was assessed following completion of the baseline wave modelling, considering wave interactions in the entrance channel and wave energy transmission through the South Pier.

  The present use of the North Wall for mooring was considered based on the modelling results, assessment of the condition of the harbour structures, and discussion with stakeholders.

- Assess potential improvements to Harbour structures and residual functional life of the harbour: The findings of the structural condition assessment, and the comments from stakeholders, were used to inform an assessment of the potential works required for the management strategies, including modifications and improvements to the South Pier. Cost estimates were developed for each component of the potential management strategies.

- Develop Investment Plan: The Investment Plan was prepared, taking account of the findings of all previous activities, to provide an economic comparison of the strategic options. The Plan sets out the investment needed for capital works, future maintenance and ongoing monitoring in the short and medium term, allowing for risk and uncertainty and considering funding requirements.

- Reporting: The project processes and findings, including the Investment Plan and conclusions from the comparison of the management options, are presented in this project report. A Non-Technical Summary of the report will be prepared in a visual format, based on the project's GIS database.

3 Physical Conditions

3.1 Hydrographic Survey

A hydrographic survey was commissioned as part of this project to provide baseline information to inform the set-up of the wave and tidal models, and to calibrate the baseline results. The area of interest for the hydrographic survey was from approximately 100m offshore of Southwold Harbour up to the A12 bridge at Blythburgh. This survey was undertaken by SHORE Monitoring and Research B.V. of the Netherlands in February 2020. A full report setting out the findings of the survey is included as **Appendix A**.

The scope of work for the survey included the following:

1. Create a local benchmark for clear vertical referencing of all measurements
2. Maintain tide gauge or obtain tide gauge readings within the harbour throughout all survey work. This was achieved by installing 3 water level loggers for the duration of the measurements.
3. Bathymetric survey from 50m seawards of the harbour piers up to the Bailey Bridge.
4. Topographic LiDAR survey of channel banks
5. Over a spring tide and a neap tide, measure tidal current profiles at 6 locations within the harbour entrance and the Blackshore area.
6. Obtain sediment grab samples from the sea bed within the harbour entrance, and from the channel upstream to the Bailey Bridge.
7. Suspended sediment turbidity measurements and samples taken from two locations.

The following sections provide a summary of the physical conditions within the harbour, including bathymetry, water levels, wave climate, tidal flows and suspended sediments, based on the findings of the hydrographic survey and other relevant information.

3.2 Bathymetry

Figure 3-1 shows the sea bed bathymetry for the east coast of England, which was obtained from the CMAP web-based resource. Sea bed levels are shown in metres below Chart Datum. This data has been used in the wave and tidal models (see **Section 6, Appendix C** and **Appendix D**).

The local bathymetry within the harbour, as recorded by the February 2020 hydrographic survey, is shown in **Figure 3-2**. This survey was compared with a previous survey undertaken by the EA in 2013, as shown in **Figure 3-3**.

At Southwold, Ordnance Datum (ODN) is 1.75m above the local Admiralty Chart Datum (CD), i.e. 0.0mODN is equivalent to 1.75mCD.

The comparison of the 2013 and 2020 bathymetric surveys shows that there has been relatively little change in the channel bed overall during this 7-year period. The areas where the bed level is relatively lower or higher have not moved. This supports the anecdotal evidence from harbour users, and also demonstrates good confidence in both survey datasets. A brief discussion is provided below of the comparison of the two surveys, for locations i. to x. as indicated on **Figure 3-3.**

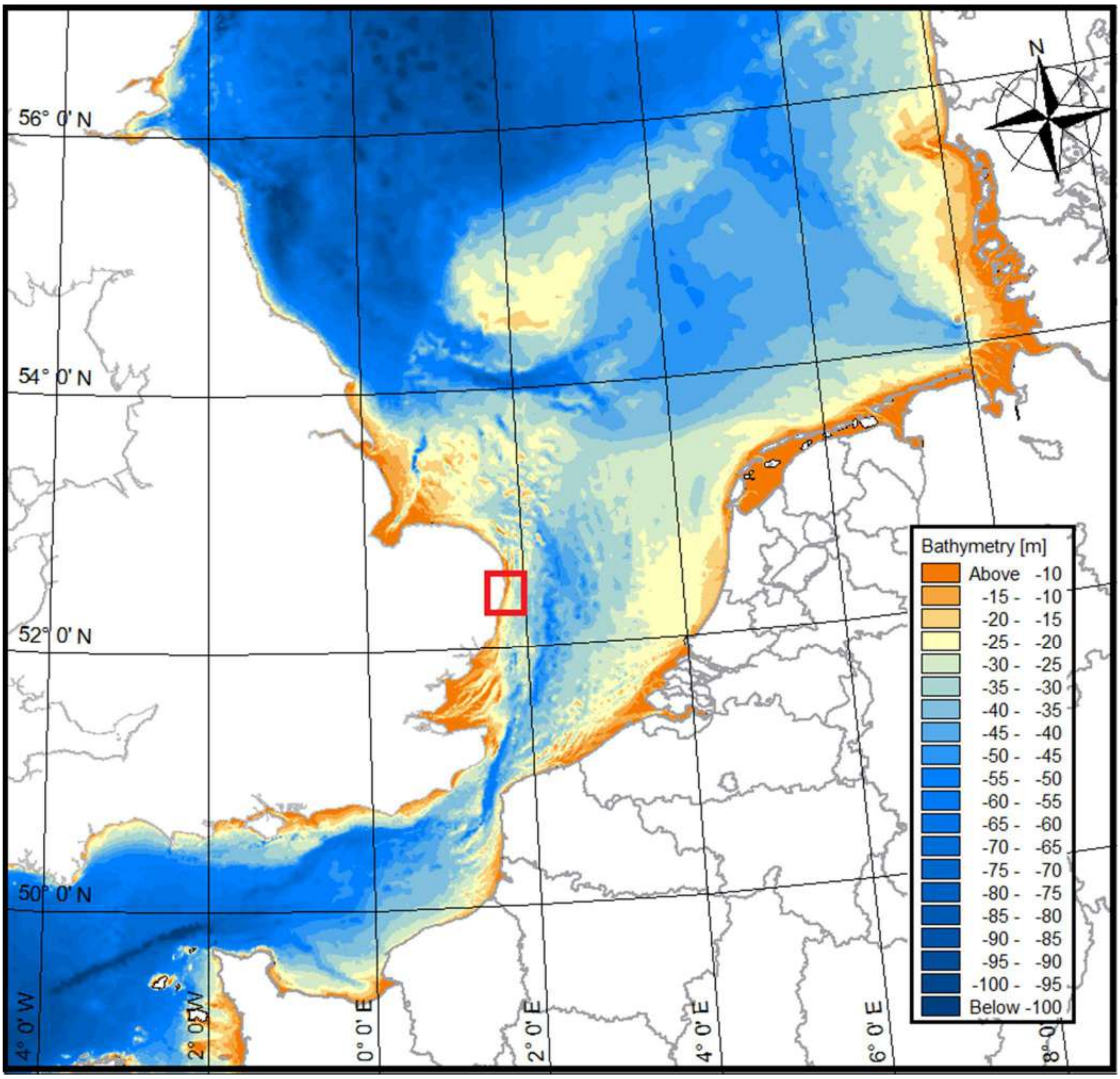

Figure 3-1: Sea bed bathymetry for the East coast of England (CMAP, 2020)

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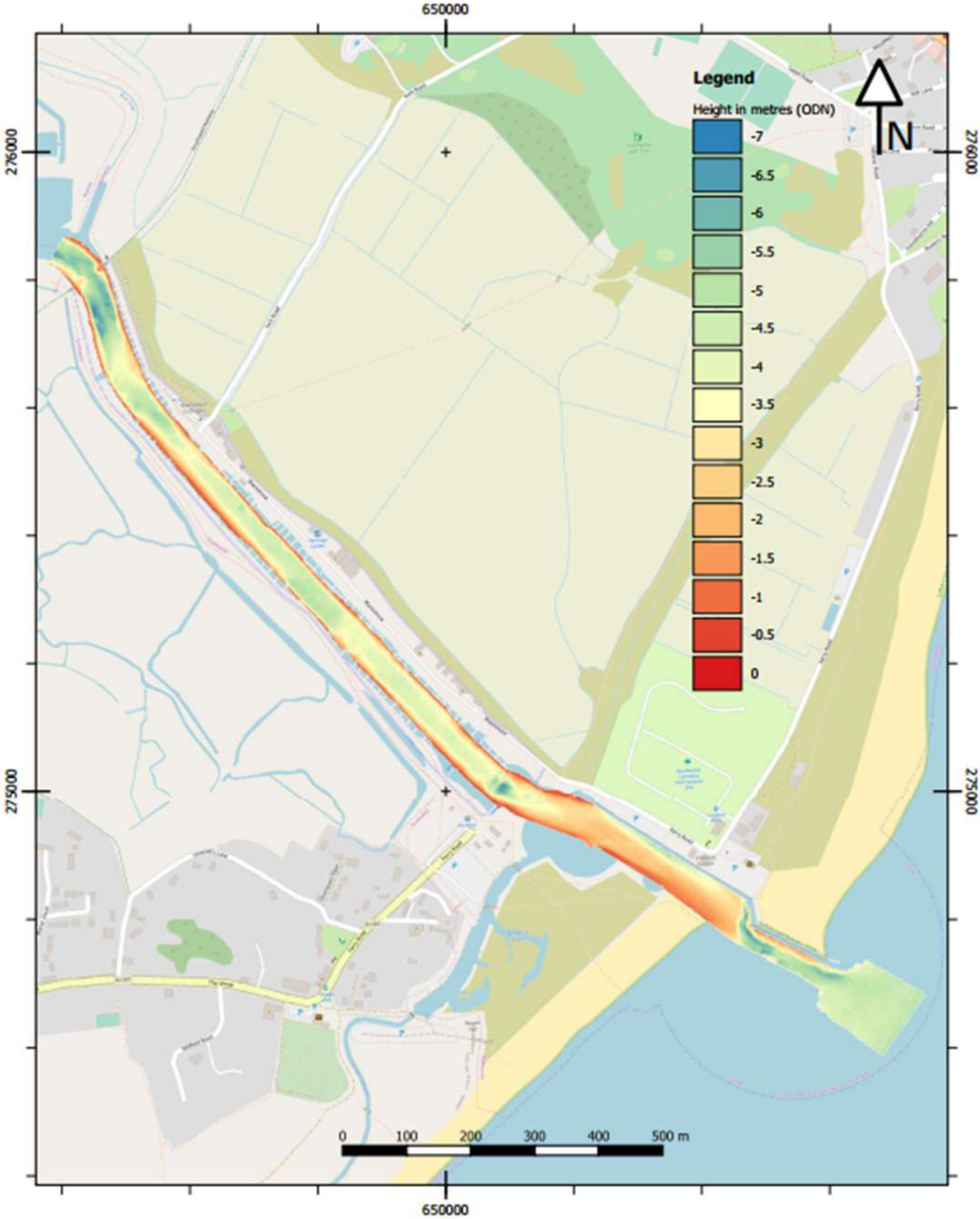

Figure 3-2: Bathymetric survey of Southwold harbour, February 2020

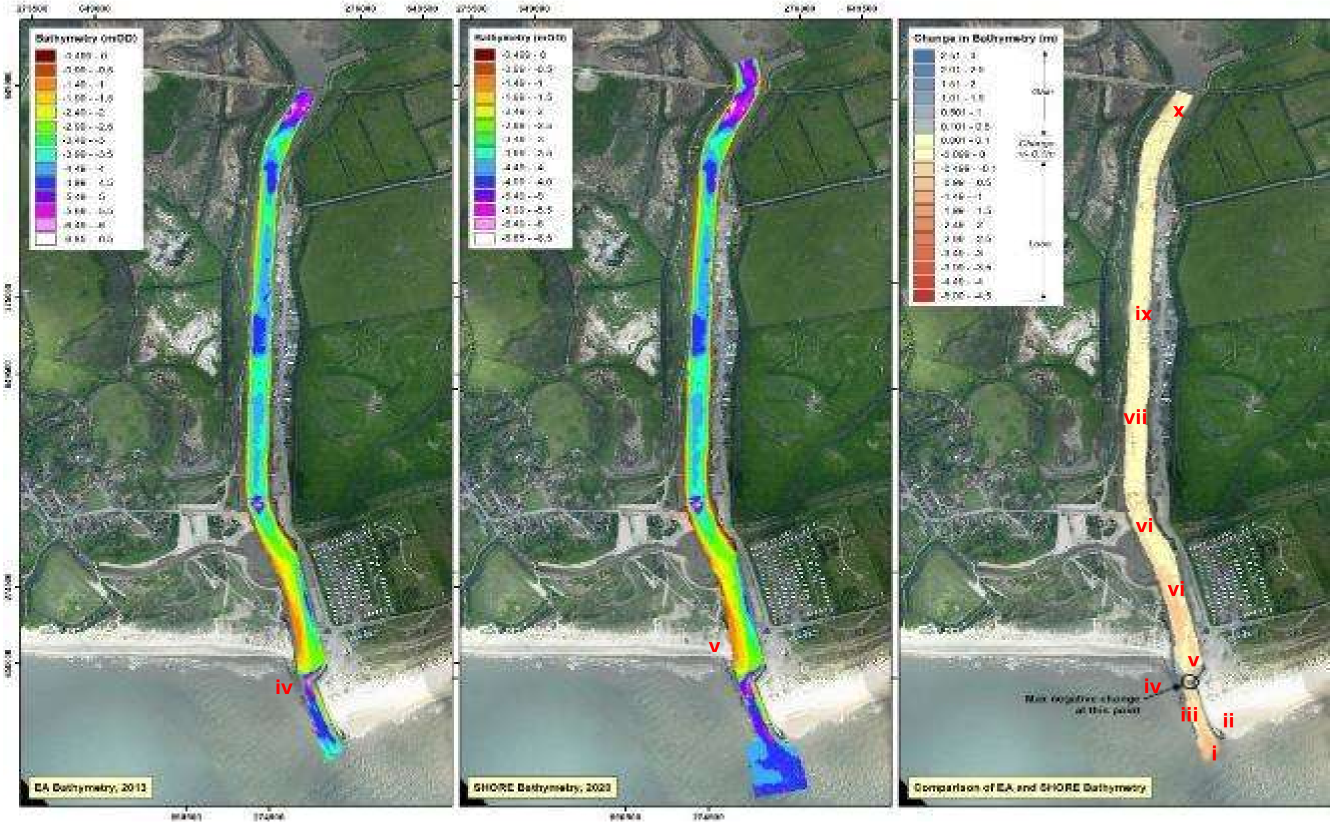

Figure 3-3: Comparison between the 2013 and 2020 bathymetric survey

i. The North Pier is currently long enough to retain beach material and sediment moving alongshore from north to south. Without the pier, sediment would move into the channel, as is known to have happened when the North Pier was shorter. In terms of future scenarios, we need to consider what would happen in terms of sediment transport and deposition if the North Pier wasn't there.

ii. At the mouth of the harbour, erosion of up to 1.5m has occurred.

iii. There has been up to 0.5m of erosion along the centre of the channel over the full length of the entrance.

The channel bed level immediately adjacent to the seaward section of the South Pier (170m length) is 5.5m ODN.

iv. In the centre of the channel where the North Pier meets the Knuckle, a small area of erosion of >2m is indicated. However, review of both surveys suggests that this is more likely to be due to errors in the 2013 survey, which did not record data over the full channel width in this area.

The channel bed level immediately adjacent to the landward section of the South Pier (100m length) is -2.0m ODN.

v. Sediment deposition of up to 0.5m is shown upstream of the Knuckle on both sides of the channel. Tidal flows around the Knuckle, combined with interference from flows out of the Dunwich Creek, mean that sediment is deposited in the areas where the flow rate is less.

This has resulted in the development of a sand bank on the southern side of the channel extending north from opposite the Knuckle towards the Dunwich Creek entrance. Once a build-up of sediment has begun it supports its own growth as wave heights and flow velocities decrease in the reduced water depths. Comparison of the bathymetric surveys indicates that this sand bank could be extending to the south, towards the entrance channel, although with a slow rate of growth.

vi. Erosion of up to 1m is shown over the full channel width adjacent to the North Wall. This may indicate an ongoing trend of erosion of 0.1-0.2m/year, but further monitoring would be needed to confirm this.

vii. Seaward of the Walberswick Ferry, there may be ongoing erosion of up to 0.5m.

viii. Limited erosion of both channel sides (<-0.5m) may be occurring over a length of about 250m to the north of the Walberswick Ferry. However, this change could relate to interference in the data from e.g. moored vessels.

ix. The channel to the Blackshore area shows little change in bed levels, with small pockets of erosion and accretion less than +/- 0.5m, suggesting the movement of ripples on the channel bed. An area of slight accretion of the northern edge of the channel is apparent over about a 100m length in the vicinity of the Harbour Marine buildings, with erosion of the southern bank in the same area.

x. Immediately to the south of the Bailey Bridge, the channel bed is generally lower than elsewhere in the harbour. Deposition has occurred on either side of the river between 2013 and 2020. These issues may be due to accelerating flows around the channel meander at this location, and differences in channel bed roughness between the bank and the centre of the channel.

   An area of erosion of up to 1m between 2013 and 2020 is apparent along the south bank immediately to the south of the Bailey Bridge. This may be the result of a bank slip (unconfirmed). Otherwise, there has been limited change in the bed levels here, with pockets of erosion and accretion generally less than +/- 0.5m.

In reviewing the survey data, we have considered the significance of any changes. In general, only change of the order of +/-0.5m or greater is likely to indicate an ongoing trend in the sedimentation within the harbour area. Therefore, the main area of change is from the harbour entrance to the north end of the North Wall. For this area, an ongoing trend of erosion of 0.1-0.2m per year is indicated, but this would need to be confirmed by future monitoring.

A further review of the bathymetric survey data was undertaken as part of the dredging assessment that is included as **Appendix I.** This assessment confirmed a 0.5m reduction in the crest level of the shoal bank since 2013 but did not indicate a noticeable southerly movement of the shoal bank.

3.3 Water Levels

Water levels at Southwold, including extreme water levels, have been extracted from the United Kingdom Climate Predictions 2018 (UKCP 2018) from Lowestoft (20km to the north of Southwold) and Felixstowe (45km to the south of Southwold) and are set out in **Table 3-1** below. Water levels observed at Southwold are typically comparable to those at Lowestoft. Present-day extreme water levels are based on the RCP4.5 (50%) scenario. **Section 5.2.1** provides further information about the UKCP climate change scenarios, and predictions of future water levels.

Table 3-1: Water Levels

Return Period (years) (AEP %)	Water Level (mODN)	
	Lowestoft	Felixstowe
MLWS	-0.86	-1.49
MHWS	1.08	1.91
1 (100%)	2.03	2.70
5 (20%)	2.40	2.99
10 (10%)	2.56	3.12
50 (2%)	2.94	3.44
100 (1%)[14]	3.11	3.60

[14] *The 1 in 100 year (1% AEP) water level is approximately equivalent to the tide level which occurred at Southwold in December 2013.*

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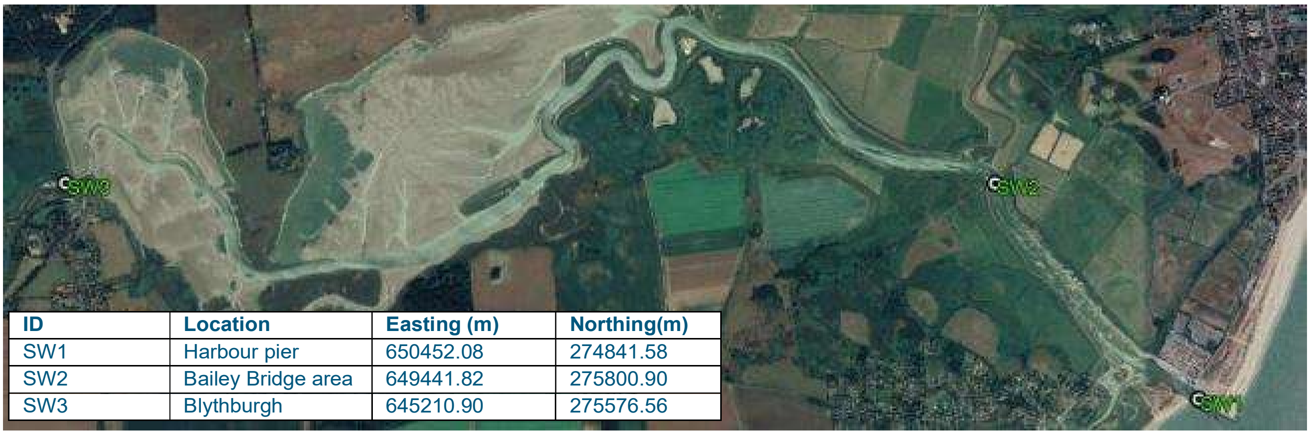
The hydrographic survey recorded water levels at three locations along the River Blyth, as shown in **Figure 3-4**. Measured water levels between 19th and 25th February 2020 are shown in **Figure 3-5**. Note that 0.0m ODN is approximately Mean Sea Level. **Figure 3-6** shows how water levels varied at these locations over a neap tide (a) and a spring tide (b).

It can be seen from a comparison of **Figure 3-6** and **Table 3-1** that surge tides occurred during the period of the hydrographic survey, with water levels exceeding typical MHWS levels at Southwold.



ID	Location	Easting (m)	Northing(m)
SW1	Harbour pier	650452.08	274841.58
SW2	Bailey Bridge area	649441.82	275800.90
SW3	Blythburgh	645210.90	275576.56

Figure 3-4: Water level measurement locations

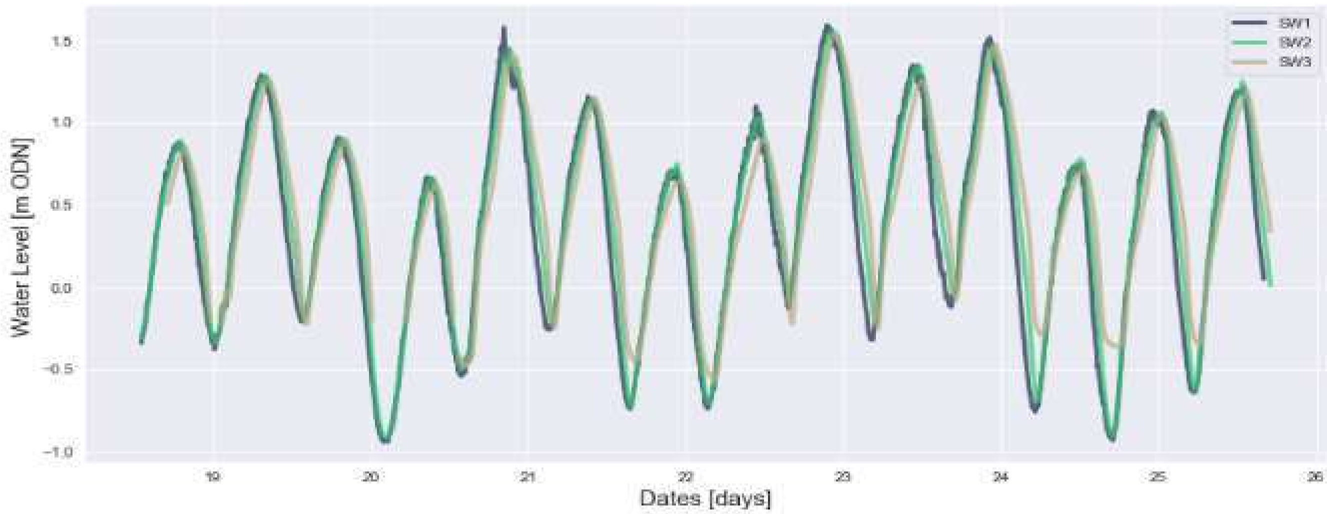


Figure 3-5: Water levels at the Harbour Pier (SW1), Bailey Bridge (SW2) and Blythburgh (SW3), 19th to 25th February 2020

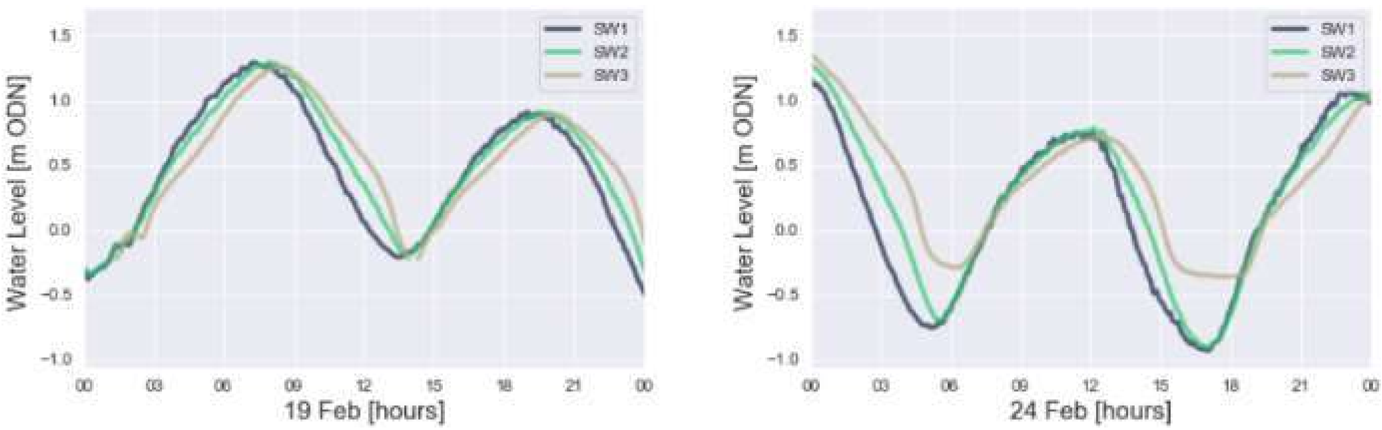


Figure 3-6: Single day time series of water level elevation (a – Neap tide; b-Spring tide)

3.4 Wave Conditions

Offshore wave data has been purchased from the UK Met Office WWIII model, at location 52.265°N, 1.996°E. The offshore wave rose for this location is provided as **Figure 3-7** and shows that the predominant wave directions are split between the north to north-easterly and south to south-westerly sectors, with very limited wave activity from the north-east to south-east sectors.

Wave heights offshore of Southwold can exceed 3m, although such extreme waves have a very low frequency of occurrence (approximately 1% of all waves).

Southwold Harbour is generally protected against waves from the north and north-east by the North Pier. Offshore waves from the south to southwest have the most influence on the conditions in the harbour. Waves from the north

After refraction from onshore to inshore, nearshore waves approach the harbour entrance from directions between 70° and 170° (refer to **Appendix A** for results from wave transformation modelling).

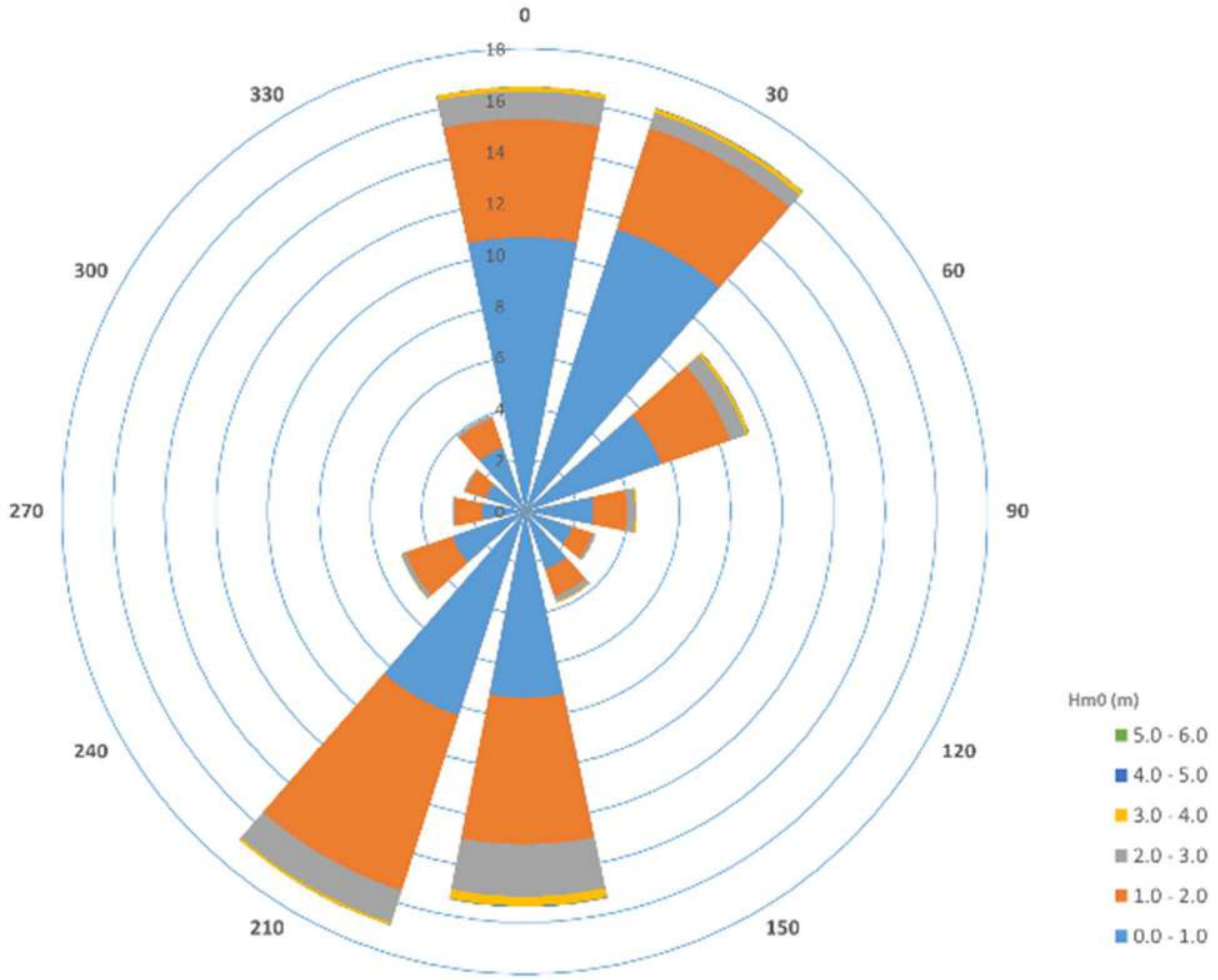


Figure 3-7: Annual wave rose offshore of Southwold (1980 – 2019)

3.5 Flow Rate

The flow velocities and discharge in the river were measured for a neap and spring tide during the hydrographic survey in February 2020. The locations where the measurements were taken are shown in **Figure 3-8.** Current measurements were recorded over the full cross section of the river channel at each location. Further details of the survey process are provided in the report included as **Appendix A**.

Figure 3-8: Location of current measurements

The neap and spring tide discharge measurements recorded peak seaward discharge (on the ebb tide) of 150-180m^3/s and peak inland discharge (on the flood tide) of 100-120m^3/s, as shown in **Figure 3-9** and **Figure 3-10** respectively. Both the neap and spring tides had a net volumetric outflow. The recorded maximum discharges were lower on the spring tide, however, the survey results will have been affected by the surge tide which occurred at the time of the survey.

The measured flow rates show consistent discharge volumes at each measurement location, as would be expected. **Figure 3-9** and **Figure 3-10** show positive values for ebb tide flow (out to sea), with negative flows being the flood tide (flow into the estuary). The graphs demonstrate that the estuary is ‘ebb dominant’, with flow rates being higher when water levels are falling and flowing out to sea compared to the flood (rising) tide. The figures also show the time lag between the ebb tide and the flood tide in the estuary. On a spring tide the flood tide takes about 4.5 hours (low tide to high tide). The ebb tide takes about 6 hours (high tide to low tide).

Figure 3-11 to **Figure 3-16** show the peak flow rates during the Spring tide of 24th February 2020. These figures show that in the channel downstream of the Bailey Bridge, typical Spring tide peak flows on the flood (incoming) tide are about 0.9 m/s (1.7 knots). Typical peak flows on the ebb (outgoing) tide are about 1.5 m/s (2.9 knots). The tidal flow behaviour at each location is discussed below.

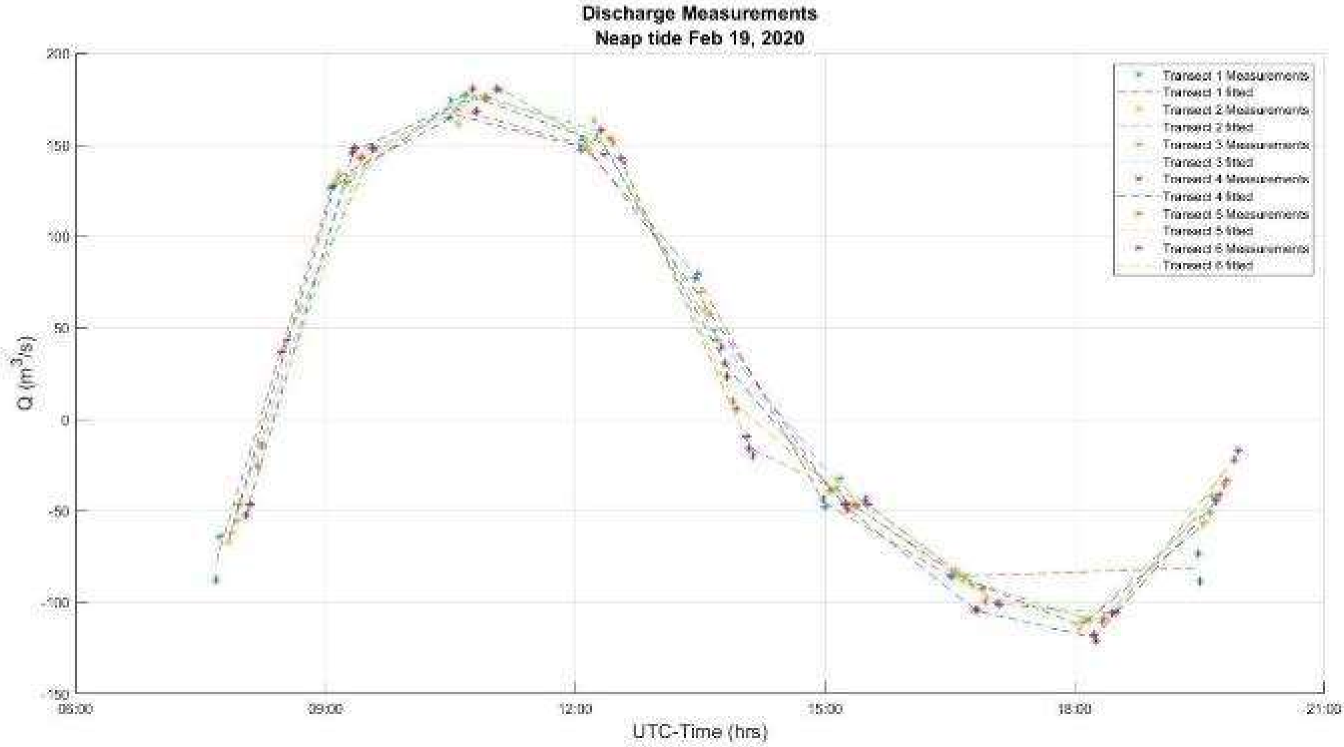


Figure 3-9: Neap tide discharge measurements (19th February 2020)

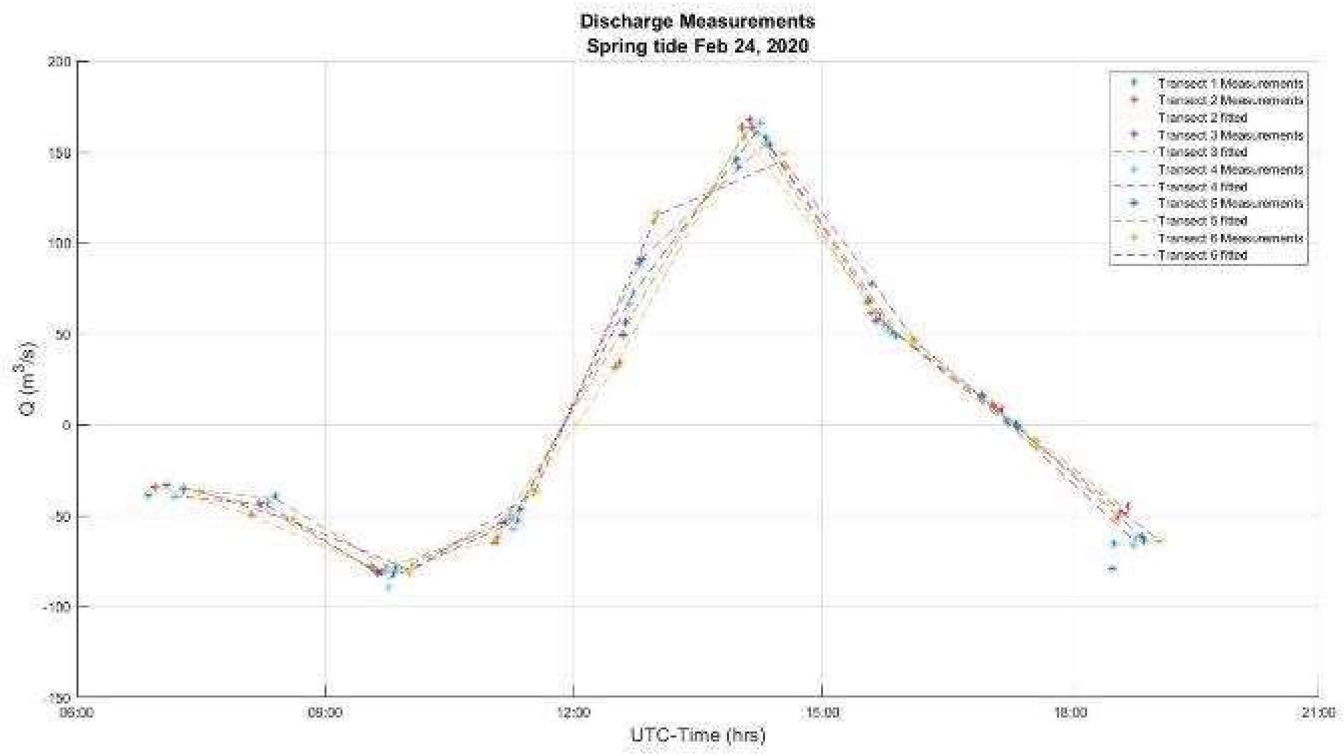
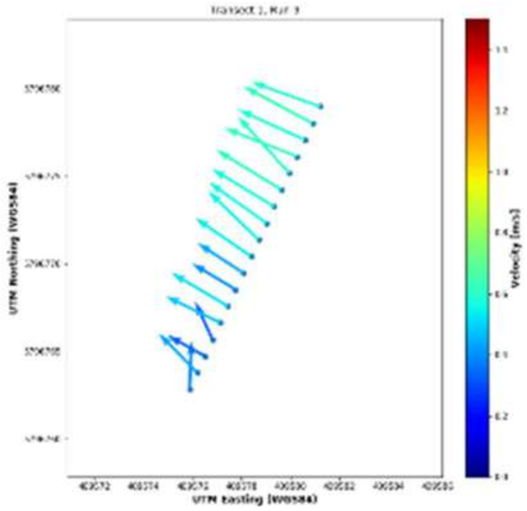


Figure 3-10: Spring tide discharge measurements (24th February 2020)

Royal HaskoningDHV

Peak flow on flood tide



Peak flow on ebb tide

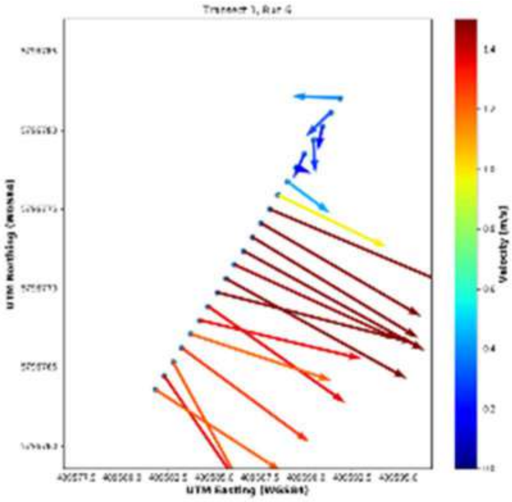
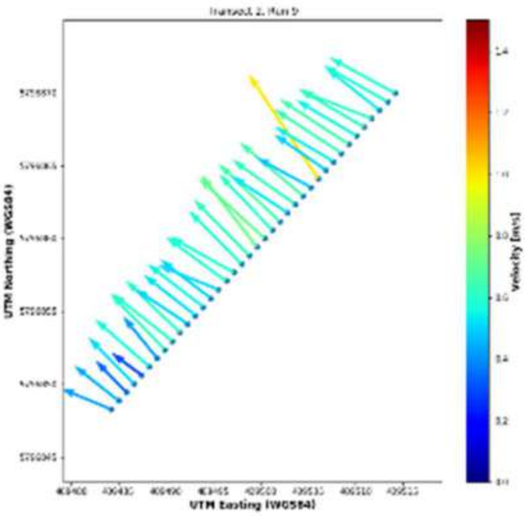


Figure 3-11: Peak flow rates (Spring tide) – Transect 1

Peak flow on flood tide



Peak flow on ebb tide

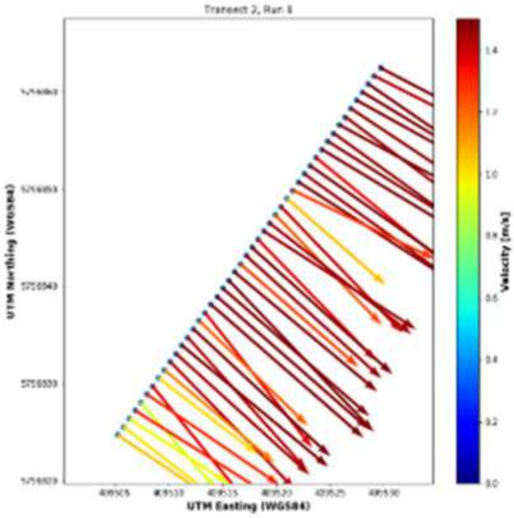
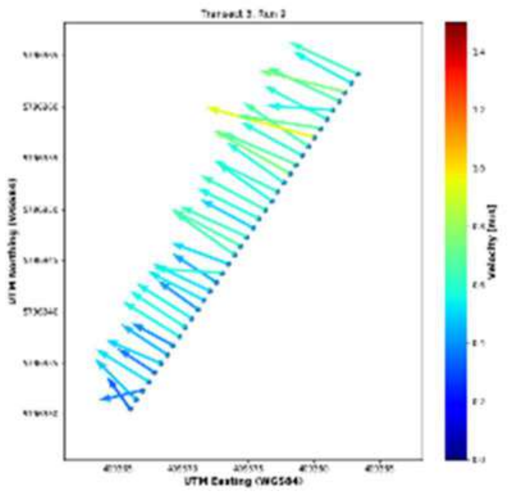


Figure 3-12: Peak flow rates (Spring tide) – Transect 2

Peak flow on flood tide



Peak flow on ebb tide

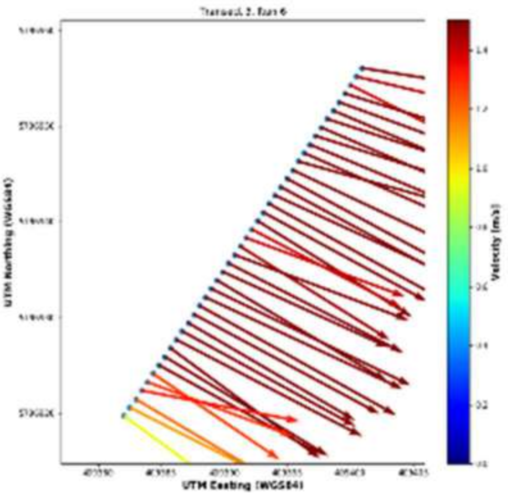


Figure 3-13: Peak flow rates (Spring tide) – Transect 3

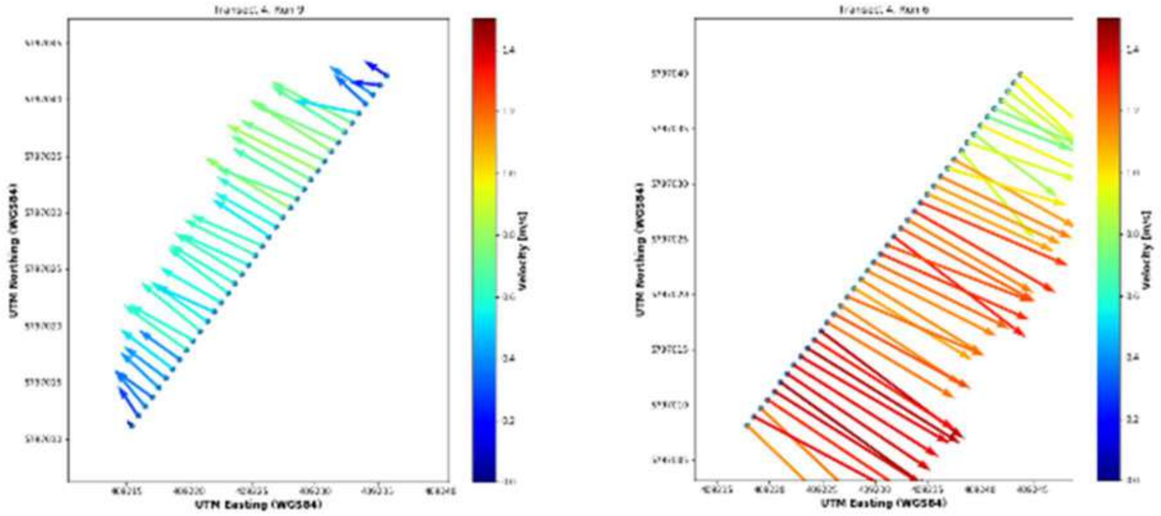


Figure 3-14: Peak flow rates (Spring tide) – Transect 4

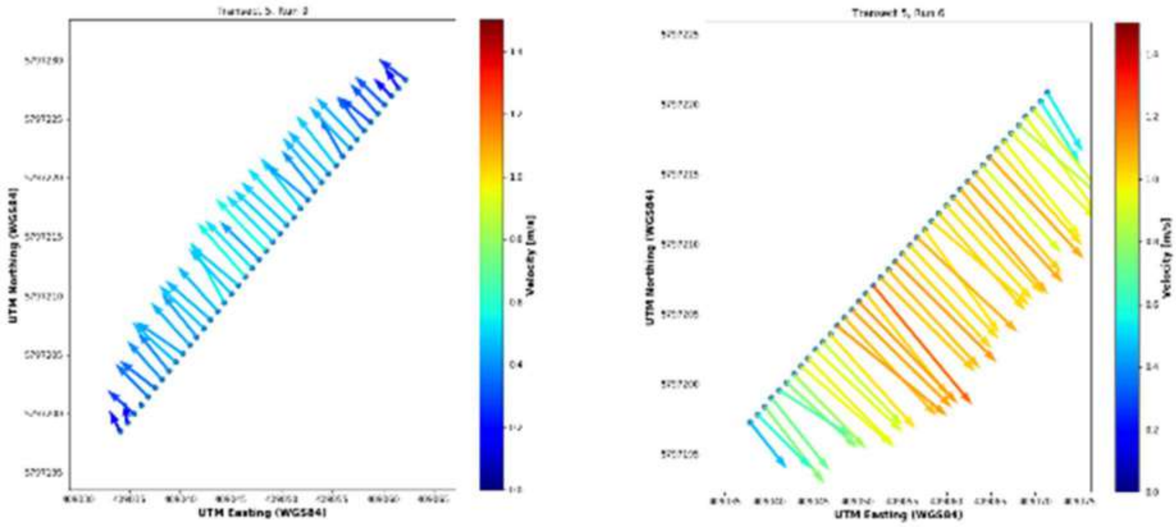


Figure 3-15: Peak flow rates (Spring tide) – Transect 5

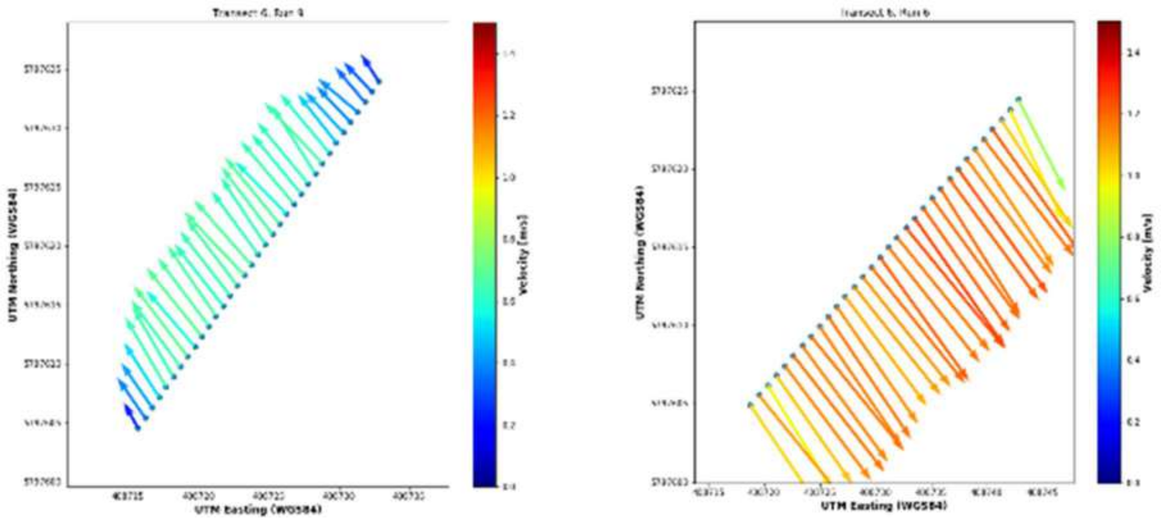


Figure 3-16: Peak flow rates (Spring tide) – Transect 6

- At Transect 1, **Figure 3-11** for the ebb tide shows the confused conditions in the harbour entrance just after the high spring tide, where the tidal currents are affected by wave action and flow through the South Pier.
- For Transect 2 (North Wall), **Figure 3-12** demonstrates how the tidal flow is influenced by and contributes to the building of the bank of sediment along the southern side of the channel, opposite the North Wall. On the flood tide (water flowing into the estuary), the tidal flow bends to be more easterly as it moves around the sand bank, with stronger flows over the northern half of the channel. At the peak of the ebb tide (water flowing out to sea) the tidal flow is more aligned to the channel direction, with flow rates quite consistent over the channel width (1.5m/s), due to the greater water depth.
- At Transect 3, to the north of the sand bank, tidal flows are generally more aligned with the channel direction on both the flood and the ebb tide (**Figure 3-13**). Flow rates remain slightly stronger over the northern half of the channel (1.5m/s).
- At Transect 4, near the Walbersick Ferry, **Figure 3-14** shows the flow direction to be turning to become aligned with the more northerly channel direction. Ebb tide flows are stronger in the northern half of the channel and flood tide flows stronger over the southern part (1.5m/s). In this location we are starting to see stronger flows in the centre of the channel, although this is not as clear as for Transect 5.
- At Transect 5 (Blackshore) flows are more aligned with the channel direction (**Figure 3-15**), with the highest flow rates in the centre of the channel (1.2m/s).
- At Transect 6, near to the Bailey Bridge, **Figure 3-16** shows that flood tide flows are starting to turn towards the north, and ebb tide flows towards the south, as the channel realigns again. The highest flow rates are in the centre of the channel (1.3m/s).

The measured tidal flow data supports the comparison of bathymetric data. The higher flow rates on the ebb tide suggest that erosion of the channel would be expected, which is observed to be occurring to a limited extent in the outer part of the harbour.

The tidal flow conditions in the harbour are currently manageable in terms of vessel navigation, with harbour users observing conditions to be better than in the past. Therefore, any plans for the future management of the harbour should aim to maintain the present-day tidal flow conditions as far as possible.

3.6 Sediment

3.6.1 Shoal Bank opposite the North Wall

As discussed in **Section 3.2**, there is sediment deposition in the outer harbour. A sand bank has developed on the southern side of the channel opposite the North Wall, extending from opposite the Knuckle towards the Dunwich Creek entrance. Anecdotal evidence suggests that this shoal bank may have formed due to the deposition of sediment carried by flows from Dunwich Creek. Its development may have been initiated during an extended period of high sediment deposition (see **Figure 2-8**) or due to a one-off release of sediment, e.g. during works in the Dunwich Creek area to install the timber piles.

Tidal flows around the Knuckle, combined with interference from flows out of the Dunwich Creek, mean that the flow rate reduces in the area of the sand bank when compared to flows in the entrance channel. This is shown by the tidal flow measurements for Transect 2 (**Figure 3-12**). With the channel bed higher in this area, wave heights and flow velocities decrease in the reduced water depths, which may encourage further sediment deposition. The sand bank may be extending towards the entrance channel, although the rate of growth is slow.

Further discussion of the historic evolution of the shoal bank is included in **Appendix I**.

3.6.2 Sediment samples

As part of the hydrographic survey, grab samples were taken from the channel bed at 17 locations between the harbour entrance and the Bailey Bridge (Error! Reference source not found.). A further 4 samples were taken from outside the harbour entrance and from the adjacent beaches to the north and south of the entrance. These samples were analysed by the SGS laboratory in Lowestoft, and the results are included in **Appendix A.**

The particle size data for the grab samples shows that most of the samples from the channel consisted of large particles, reported by the surveyor to be shingle, shells and other large objects. A possible explanation for this is that the finer sediments were washed out of the sample vessel as it was hoisted up, but it is also very likely that the strong currents in the channel wash away all fine sediment from the bed, leaving only the coarser material (stones, shells) and the underlying cohesive clay fractions as bed material. This interpretation was confirmed by harbour users. The particle size analysis of the additional sediment samples taken from outside the harbour and on the adjacent beaches show that finer sediments are present locally.

Sediment sample 2a may be the most appropriate example of the sediments present in the outer harbour, as this shows a much greater proportion of sand particles and fewer large particles, and compares best with the samples taken from outside the harbour. This sample was taken in the vicinity of the sand bank opposite the North Wall. Most of the samples taken to the north of the Bailey Bridge are considered to be representative of those locations, and were sampled in locations where the flow rate was lower, so are more likely to have retained all of the sample.

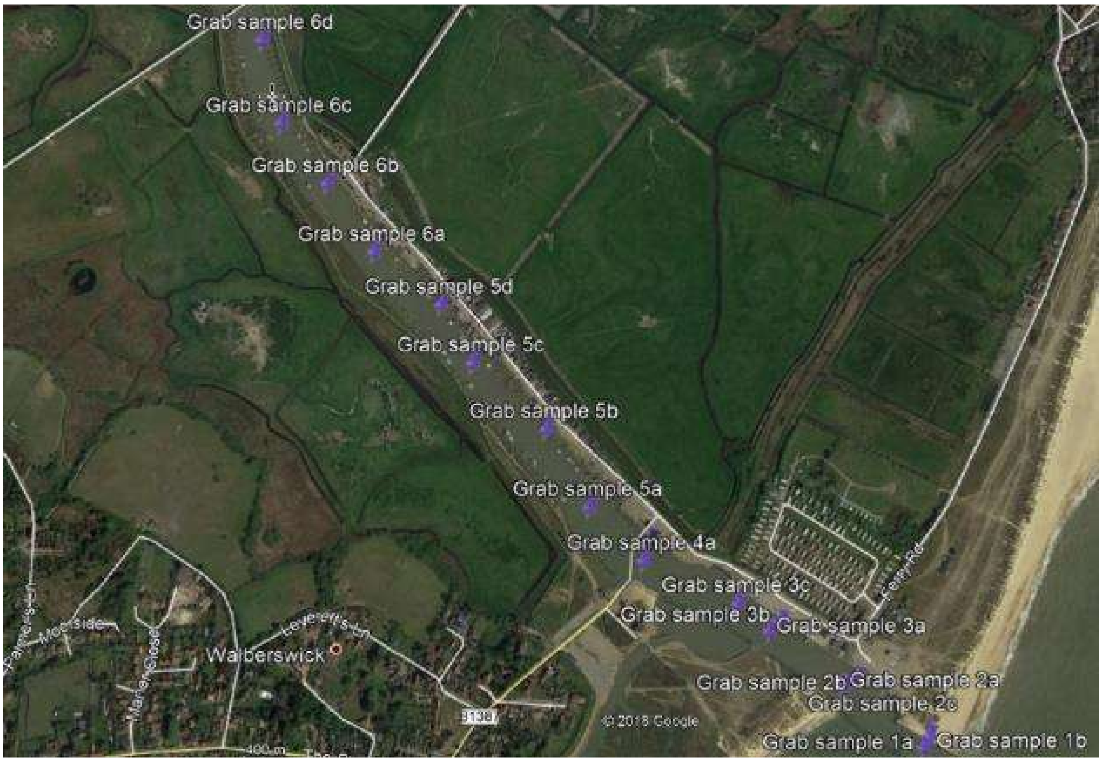


Figure 3-17: Locations of sediment grab samples

3.6.3 Suspended sediment

The hydrographic survey also included turbidity measurements and sampling of suspended sediments. Turbidity is a measurement of the cloudiness of water due to the presence of sediment particles. This information was used to inform the tidal model and the assessment of present-day and potential future sediment transport.

Turbidity measurements were recorded between 20th and 25th February 2020 at two fixed locations in the river channel, above the bed level:

- A: On the stepladder attached to the North Wall, close to the Harbour Entrance.
- B: On a pillar of a fixed berth in a deep part of the channel, seaward of the Harbour Master's Office.

The variation in suspended sediment concentrations over time is shown in **Figure 3-18**. The timeseries shows an asymmetrical pattern over the tidal period, with a peak in turbidity on each flood tide, and slow decay during the ebb tide.

Sediment samples were also obtained at each location over the tidal cycle on 24th February 2020 and the samples analysed to determine the total quantity of suspended particle matter, as shown in Error! Reference source not found..

The largest quantity of suspended sediment was recorded at Location B at 14:00 on 24th February 2020, which was approximately 2 hours after high tide. Location B is closer to the Dunwich Creek entrance, which may be the reason for the larger quantity of suspended sediment being recorded here than at Location A.

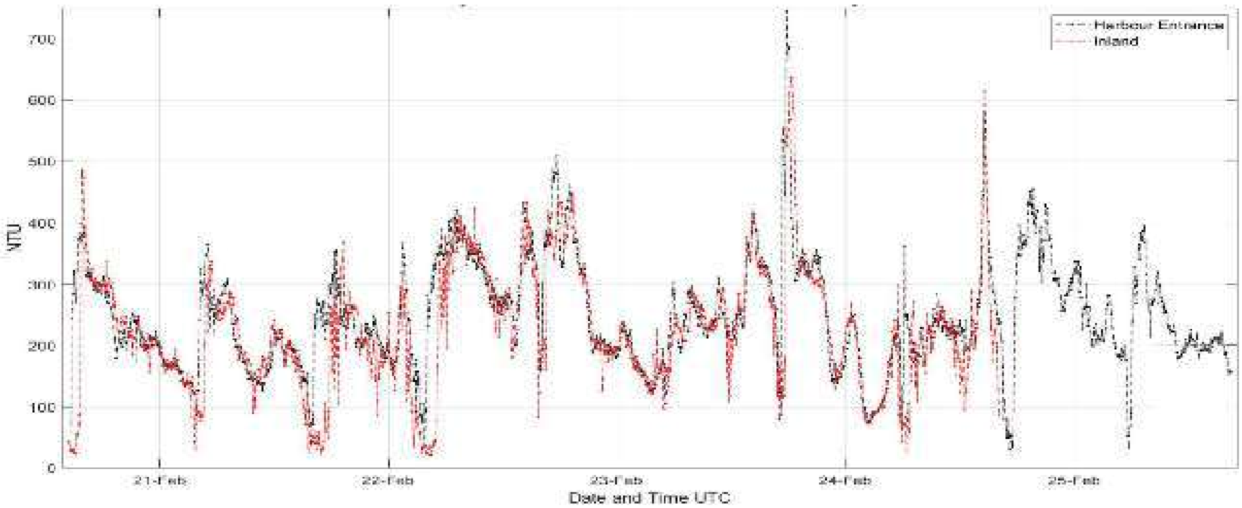


Figure 3-18: Turbidity Measurements in Southwold Harbour, February 2020

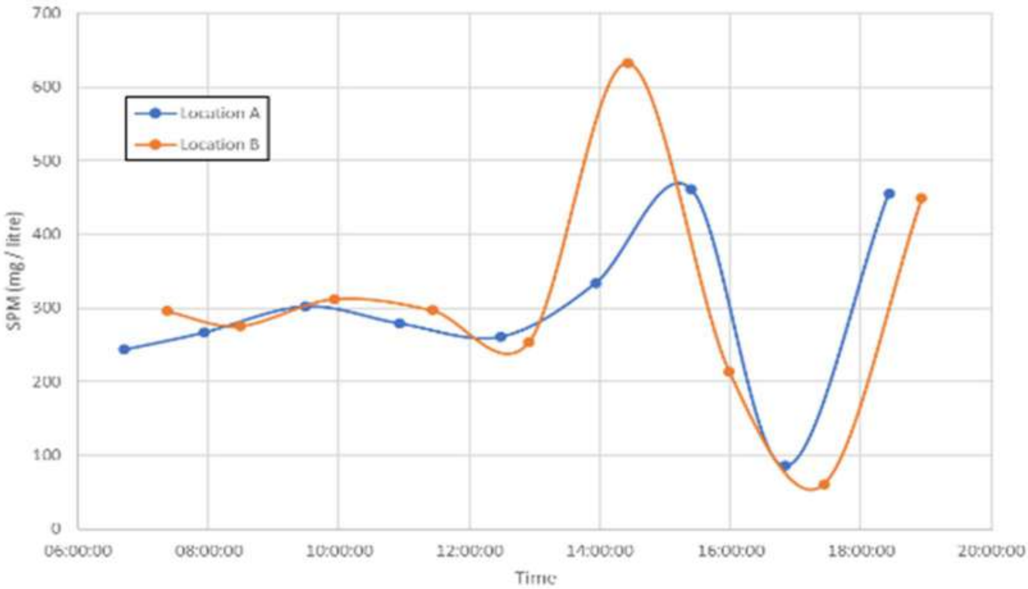


Figure 3-19: Sediment Particle Concentrations, Southwold, February 2020

3.7 Coastal Processes

3.7.1 Present-day coastal processes

The 2010 Shoreline Management Plan (Ref. 5) includes a description of the coastal processes operating along the coast adjacent to Southwold Harbour (Policy Development Zone 3, Easton Broad to Dunwich Cliffs,
Figure 2-2), which is summarised below.

The main physical control features of the zone are the Southwold Headland, which acts as a downdrift control point for the coast to the north, and the entrance to the estuary. From the north of PDZ3, there is a southerly net drift, with modelled rates varying between 20,000m 3 /yr to 100,000m 3 /yr. There is expected to continue to be erosion of the coastline to the north of PDZ3 in the medium to longer term, which will supply a significant volume of material to the Southwold shoreline. Sediment supply from the Easton Bavents Cliffs is relatively smaller, and erosion of these cliffs is limited by the Southwold Headland.

Sediment drift rates across the Southwold frontage tend to be to the south, but are only in the order of 3,000m3/yr net volume. There can be significant north and south drift under specific wave conditions. To the south of Southwold, the net drift rate tends to increase but then reduces towards the estuary mouth as the coast has built out to the north of the North Pier. Therefore, Southwold acts as a partial barrier to sediment drift from the north and has an area of net loss to the south. The coast then realigns to a stable shape to the south of this.

When sediment drift across the frontage is to the north (driven by waves from the south), Southwold acts as an updrift headland to the coast to the north. This potentially results in material being moved away from the coast. Under these conditions, the Southwold Headland acts to provide some shelter to the Easton Bavents Cliffs, although this does not prevent erosion of the cliffs.

The defences in front of the town are always under some pressure due to its position as a headland, which is currently managed using groynes to restrict sediment movement away from the frontage, as well as sand recharge to the beach. Management of the coast to the north of Southwold is important in maintaining both a supply of sediment and in ensuring that a sediment pathway is maintained along the shore. With sea level rise, coast to the north of the pier will become more difficult to manage with increased potential for erosion. Management of the coast to the south of the town is important in that maintaining a healthy width of beach retains sediment that can occasionally move north to supplement the beach in front of the town.

The cliffs at Dunwich anchor the sweeping curve of the bay to the south of the estuary mouth. The harbour mouth structures have a strong influence on the northern end of Dunwich Bay, acting as an updrift headland. The shape of Dunwich Bay is considered to be quite stable in terms of net wave energy and there is only a limited net drift along the shore. However, this means that there is little sediment supply of shingle to the shingle bank which forms the backshore to Dunwich Bay. Increasing overtopping of the shingle bank is expected with sea level rise in the future, leading to roll back of the bank and regular flooding and eventual inundation of the marshland behind.

Overall, the coastal system to the south of Southwold is strongly controlled by the position of the estuary mouth. The North Pier acts to retain the beach south of Southwold, with the South Pier controlling the shape of the coast to the south, particularly over the section between Walberswick and Dingle Great Hill. The tidal flows into and from the estuary have a limited direct influence on the coast due to the control imposed by the harbour entrance structures. The more indirect impact of the tidal flows is on how the management of the wider estuary could influence the management of the harbour entrance structures, with the integrity of these structures being strongly influenced by the tidal prism of the estuary. Management of the estuary is therefore very important in relation to the management of the coast.

3.7.2 Influence of the Blyth Estuary on coastal processes

Within the Blyth Estuary, management upstream of the A12 has little overall influence on estuary behaviour, and the flood defences to this area are no longer maintained. The historic retreat of the defence line between Blythburgh and the Reydon and Tinkers Marshes significantly increased flows through the lower reaches of the estuary and resulted in the estuary becoming slightly ebb dominant. This imposed increased stress on the confined channel between Tinkers and Reydon Marshes and through the harbour.

Abandoning the flood defences to the marshes within the estuary would result in a large increase in tidal volume, which could impose considerable pressure on the structures at the mouth of the estuary. The SMP assessed that the flooding of the Reydon Marshes would increase tidal flow rates by about 50% within the harbour reach. Abandoning the defences to Tinkers' and Robinson's Marshes would have a similar but smaller effect.

The direct impact on coastal processes of the loss of defences to the marshes would be relatively low, potentially increasing the size of the ebb tidal delta. This would result in some adjustment to the coast but this is relatively minor in comparison with the control imposed by the harbour entrance structures. The main impact on the coast would arise from abandonment or failure of the harbour control structures. The ability to manage the harbour entrance structures depends on the impact of the increase in tidal volume.

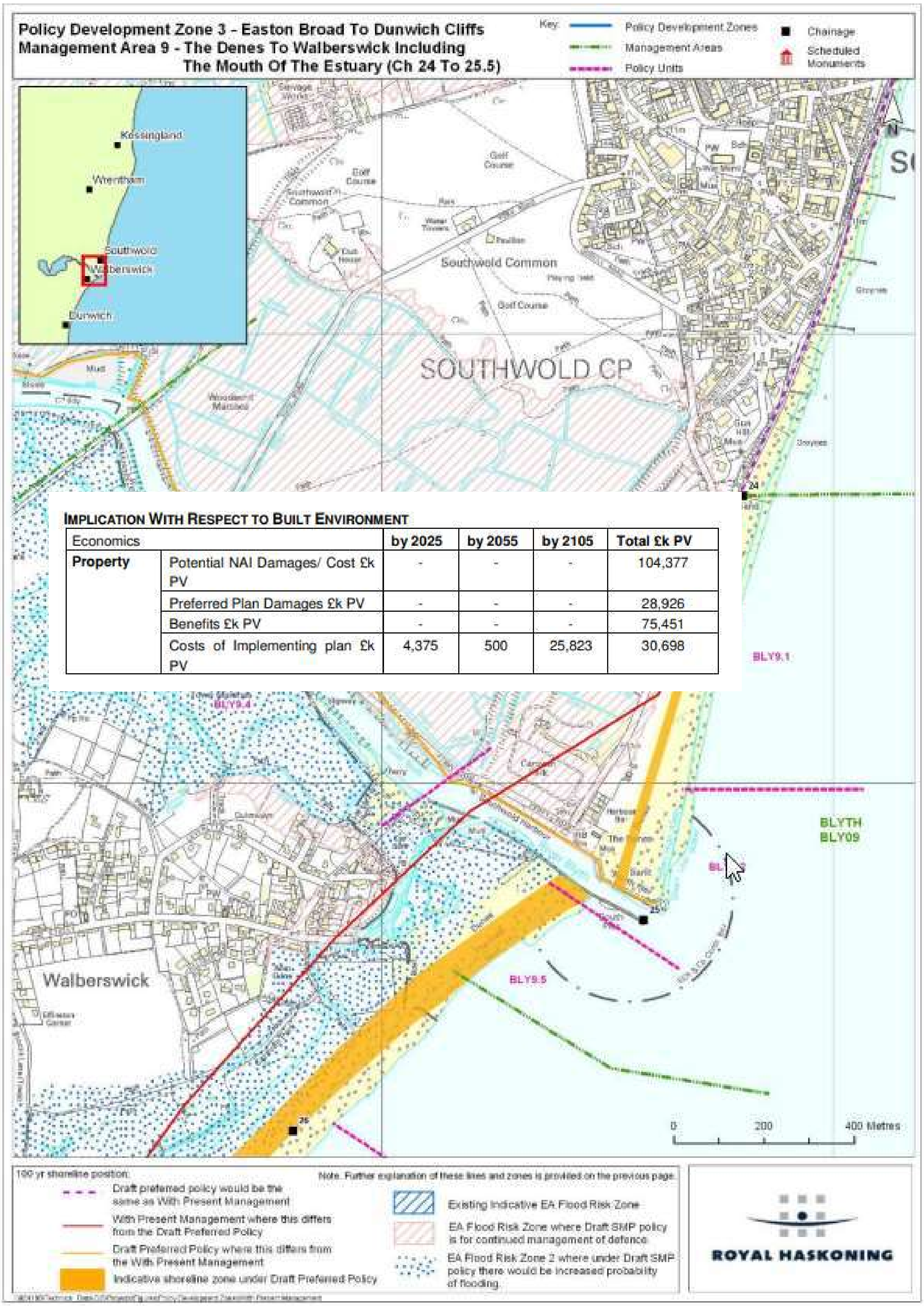
3.7.3 Unconstrained management scenario

The SMP assess the impact of the 'Unconstrained Scenario' on coastal processes at Southwold. This scenario assumes that all defences, including the harbour entrance structures, are removed. Although unrealistic the scenario highlights the natural pressures on the coast and could become the default management scenario if funding for replacement of defence structures cannot be obtained.

With no defences to the Southwold Headland there is likely to be increased erosion along Easton Bavents and exposure of the cliff to Southwold behind the pier. As the headland erodes, its influence on the shoreline would decrease and the whole coast would effectively retreat.

At the mouth of the Blyth Estuary, there would be an immediate response in the coast to the removal of the control imposed by the entrance structures. The sediment held to the north (within the beach and the Denes) would rapidly erode. It is probable that the estuary mouth would infill such that there would be an area of low-lying marsh covering the whole inlet mouth, with the potential for a southerly spit to develop. The baseline of the coast would retreat significantly, although held forward to some degree by the ebb tide delta. The underlying shoreline shape could ultimately retreat as far back as the village of Walberswick, with the coast to the south retreating over its full extent down to Great Dingle Hill. Although this retreat could increase the resilience of the shingle bank, there would be regular inundation of the marshes behind. Dunwich would still control the southerly point on the coast.

The SMP Policy for the coast between The Denes and Walberswick is set out in **Section 2.3.3**, with **Figure 3-20** showing the expected change to the coastline to the north and south of the estuary mouth with the preferred SMP policy.



IMPLICATION WITH RESPECT TO BUILT ENVIRONMENT

Economics		by 2025	by 2055	by 2105	Total £k PV
Property	Potential NAI Damages/ Cost £k PV	-	-	-	104,377
	Preferred Plan Damages £k PV	-	-	-	28,926
	Benefits £k PV	-	-	-	75,451
	Costs of Implementing plan £k PV	4,375	500	25,823	30,698

Figure 3-20: Predicted shoreline mapping with the preferred SMP policy

3.8 Marsh levels and sedimentation

3.8.1 Sedimentation studies

Previous studies have shown that the level of the breached marshes located downstream of Blythborough directly influences the tidal prism of the estuary and therefore tidal flow rates through the harbour entrance. The level of the marshes can change due to sedimentation and erosion, so the potential future levels of the marshes needs to be taken into account when considering the future hydrodynamic behaviour of the estuary and solutions for the harbour entrance. Therefore, alongside this project, Kenneth Pye Associates Ltd (KPAL) was commissioned to produce an update to the Blyth Estuary Sedimentation Study undertaken in 2008-09 (Pye & Blott, 2009, Ref. 3).

The 2009 study investigated the thickness of accumulated sediment on reactivated tidal flats within the areas known as Bulcamp Old Marshes, Bulcamp New Marshes, Sandpit Covert Marshes and Angel Marshes. Sediment has accumulated on these marshes when they have flooded, which has occurred periodically since the marshes were breached (1920s to 1950s). The study assessed data from a new survey using RTK GPS equipment, as well as available ground survey and LIDAR data. Estimates of average sedimentation rates across the four marshes were compared with observed sea level rise and with future sea level rise allowances.

For the 2019 update (Ref. 10), EDI Surveys undertook a new RTK GPS survey of the marshes and provided updated estimates of average sedimentation rates and volumes over a period of 76 years, again considered against climate change and sea level rise projections. The findings of this study were reviewed to inform the tidal modelling and the assessment of future options for the harbour.

3.8.2 Summary of 2019 Sedimentation Study

The 2019 topographic survey determined the tidal flat elevations at 170 points on Sandpit Covert Marshes, Angel Marshes, Bulcamp Old Marshes and Bulcamp New Marshes, at the same locations as the 2008 survey. Sediment samples were also collected from each survey location and analysed to compare the particle size characteristics with the previous results. The survey findings can be summarised as follows:

- Surface lowering has occurred across the central parts of the tidal flats of Sandpit Covert Marshes, with accretion around the margins, giving a median reduction in level of -2 cm between 2008 and 2019.
- Areas of surface accretion and lowering are evident for Angel Marshes between 2008 and 2019, with a median change in level of +1 cm overall.
- The median average annual sedimentation rates on Sandpit and Angel Marshes between 2008 and 2019 are significantly lower than those between 1943 and 2019.
- Average accretion of 7 cm and 10 cm was recorded on Bulcamp Old Marshes and Bulcamp New Marshes respectively between 2008 and 2019.
- Average annual sedimentation rates on Bulcamp Old Marshes and Bulcamp New Marshes between 2008 and 2019 were similar to that recorded between 1943 and 2019.
- Average accretion for the whole study area between 2008 and 2019 was +3 cm.
- The tidal prism of the marshes below MHWS level is estimated to have decreased from 1,836,189 m3 in 1943 to 1,298,197 m3 in 2008 and to 1,240,787 m3 in 2019, despite sea level rise. Between 2008 and 2019 MHWS is estimated to have risen by approximately 3 cm, but due to sediment accretion the tidal prism decreased by 57,410 m3 (4.4%).

3.8.3 Review of 2019 study findings

The median sedimentation rate observed between 2008 and 2019 for all four marshes is equivalent to average annual sea level rise between 1964 and 2018, at 3 mm/year. This indicates that sediment supply into the Blyth estuary continues, the rate of tidal flat accretion could increase sufficiently to keep pace with rising sea level, if the rate of sea level rise does not accelerate.

Figure 8 of the 2019 Sedimentation Study update shows how water levels at Lowestoft have changed since 1964. The figures include linear trendlines for the average annual increase in water level (+3.08 mm/yr for MSL). However, the figures for MSL and MHWS (reproduced as **Figure 3-21** below) demonstrate that the rate of sea level rise may have accelerated over the past decade, although with a relatively low average level recorded in 2018. This potential acceleration is not reflected in the linear trendline. If sea level rise is accelerating, as is also projected by UKCP, then the rate of accretion of the marshes may not keep pace with sea level rise, and the tidal prism will increase.

Figure 9 of the 2019 Sedimentation Study update is reproduced as **Figure 3-22** below and compares the projected future elevation of the marshes against projections for future mean sea level. The figure predicts that the elevations of the marshes will increase at a faster rate than mean sea level, based on the average rate of increase in marsh levels from 1943 to 2019, and the linear trend in Mean Sea Level at Lowestoft.

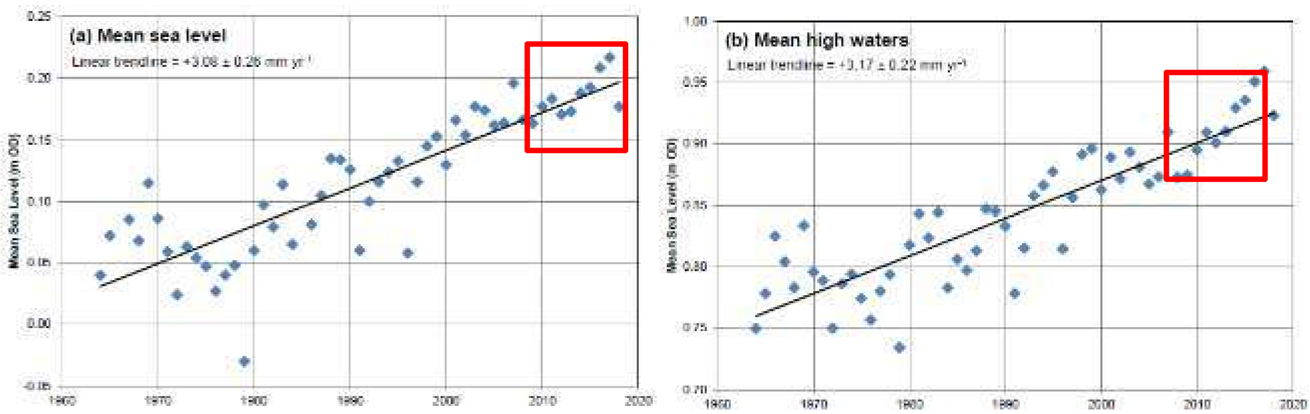


Figure 3-21: Change in water levels at Lowestoft since 1964
(Source: Figure 8 of 2019 Sedimentation Study)

However, apart from for Bulcamp New Marsh, the extrapolated future marsh levels assume an increase in the rate of sedimentation from that which has occurred between 2008 and 2019 if the average rate from 1943 to 2019 is to be maintained. With only two recent surveys (2008 and 2019), there is not yet strong evidence that the accretion trend will continue. If the present trends for erosion or slow accretion continue for Angel and Sandpit Covert Marshes, the rate of sea level rise will exceed the rate of accretion, even for the lower bound sea level rise projections, and the tidal prism will start to increase.

The 2019 sedimentation study update concluded that the levels of the marshes forming the flood plain to the Blyth Estuary could continue to rise due to sediment deposition, at the rate assessed to have occurred between the 1940s and the present day. However, the results also show that erosion as well as accretion can occur to the marshes. When potential sea level rise is considered, the rate of accretion of the marshes may not keep pace with this, so the tidal prism of the estuary could begin to increase, resulting in an increase in flow rates at the mouth of the harbour.

3.8.4 Conclusions of review of 2019 Sedimentation Study Update

Based on the above assessment it was concluded that the present-day levels of the marshes should be used for the tidal model. This approach means that the worst-case conditions are assessed, in terms of the future tidal prism for the estuary and the associated flow rates at the harbour entrance. With a lower marsh level, the tidal prism will be larger and therefore discharge rates higher. This provides a precautionary assessment of the harbour conditions, to determine the risk of failure of the existing structures and the potential design requirements for any new structures.

It is recognised that if marsh levels build at the higher rates predicted by the sedimentation study, then the assessed flow rates and potential for erosion of the entrance channel may be higher than occurs in practice. Therefore, sensitivity tests were completed on relevant model runs to assess the impact of an increase in marsh levels on tidal flows in the harbour, and what this could mean in terms of the Southwold Harbour Investment Plan proposals.

The Investment Plan includes recommendations (and associated costs) for carrying out further similar monitoring studies for the marshes in the future, which should be repeated at regular intervals (e.g. every 5 years). Ongoing monitoring will enable any trend in ongoing sediment deposition to be confirmed, and the impact of this on the tidal prism of the estuary and flow rates at the harbour entrance to be reviewed. Monitoring of tidal currents should also be undertaken, for comparison with the assessment of changes to the tidal prism. If a reduction in the tidal prism was to continue then we would expect to observe a reduction in tidal currents in the entrance channel.

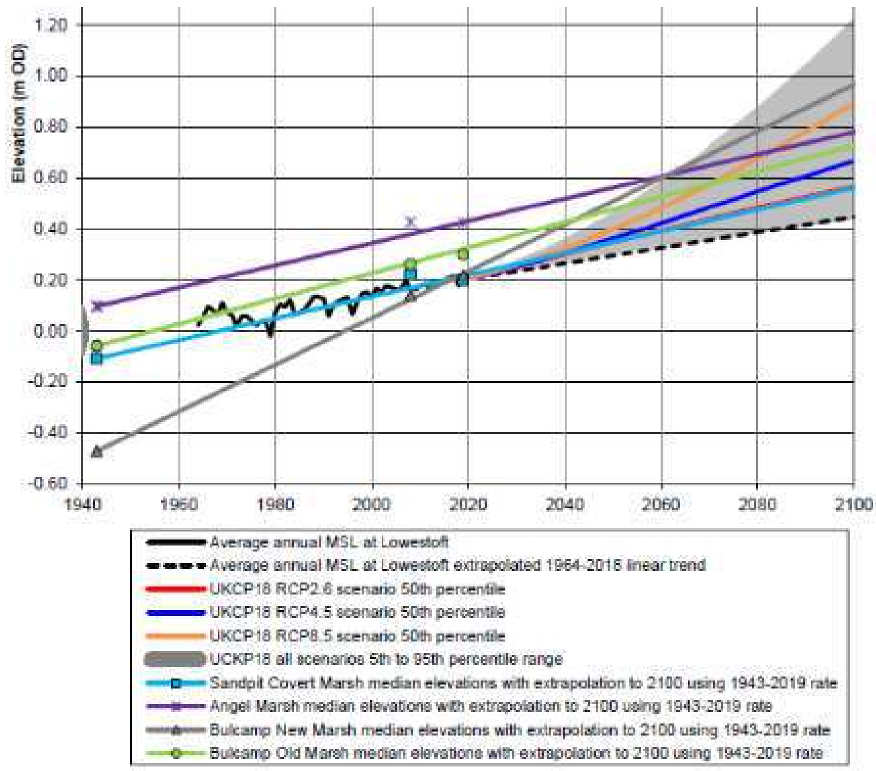


Figure 9. Mean sea level recorded at Lowestoft 1964-2018, and extrapolated to the inner Blyth (0.20 m AOD in 2018), and projected to 2100 under the UKCP18 RCP2.6, 4.5 and 8.5 scenarios for the mouth of the Blyth. Also shown are the median mudflat elevations on Sandpit, Angel, and Bulcamp Marshes in 1943, 2008 and 2019, and linearly extrapolated elevations based on the observed average sedimentation rate between 1943 and 2019

Figure 3-22: Mean sea level at Lowestoft compared to marsh elevations
(Source: Figure 9 of 2019 Sedimentation Study)

4 Existing Harbour Structures and Estuary Defences

Figure 4-1 shows the locations of the various structures within Southwold Harbour. A condition assessment was completed for each of these structures based on a site visit undertaken in February 2020. The site visit and condition assessment report is provided as **Appendix B** to this report and summarised below. **Appendix B** includes a summary of historical information about the harbour structures.

Figure 4-1: Structures within Southwold Harbour

4.1 South Pier

4.1.1 Form of defence

The South Pier is comprised of three or four different types of structure having undergone various repairs over the last 90 years (**Figure 4-2**). In summary it consists of a 417m long continuous reinforced concrete structure faced on its north side with either reinforced concrete planks or steel sheet piling, supported by pairs of raking piles connected with concrete longitudinal and cross members. In places, the raking piles are surrounded by rock armour, intended to reduce scour.

The outermost section of the pier, Length A (**Figure 4-3**), comprises box piles at each crossmember interlocked with sheet piles driven in front of the original concrete planks. The box piles are understood to be filled with concrete above the seabed level. The concrete planks have been cut off at -1.0mODN, forming 'windows' in the structure, which were created to dissipate wave energy and allow tidal flow into the entrance channel from the south, to improve conditions for navigation. The rear concrete beams have been replaced at some point, and the joints between the box piles and the crossmembers have been repaired in the past.

Length B1 appears to retain the original form of construction of the pier (without the added box piles and steel sheet piles) is still in relatively good condition.

Length C comprises steel sheet piles driven in front of the concrete planks which are again cut off at -1.0mODN (**Figure 4-4**). Newer raking piles, beams and crossmembers have been added to this part of the structure, which differs slightly from the original design in that the rear beams are below the cross members rather than in line with the cross beams.

Length B2 is the remainder of the structure inshore of Length C, which continues up to the entrance to Dunwich Creek. This section is similar in construction to Length B1.

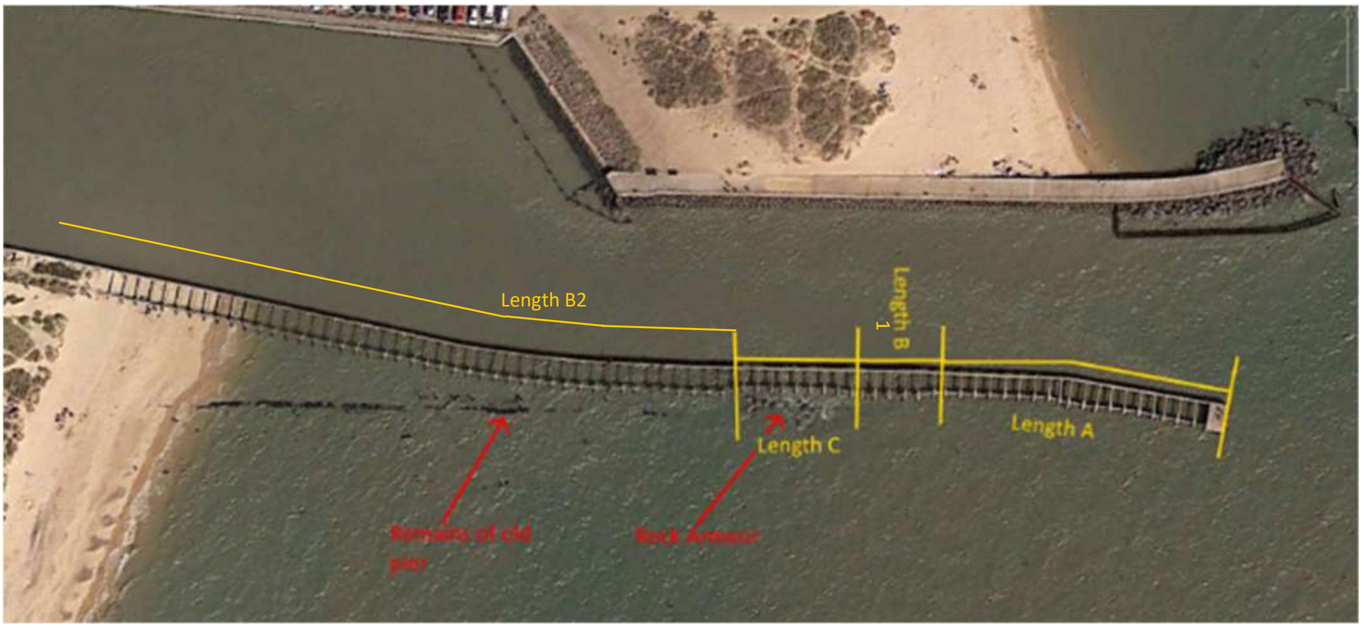


Figure 4-2: Map of South Pier with marked Lengths A-C

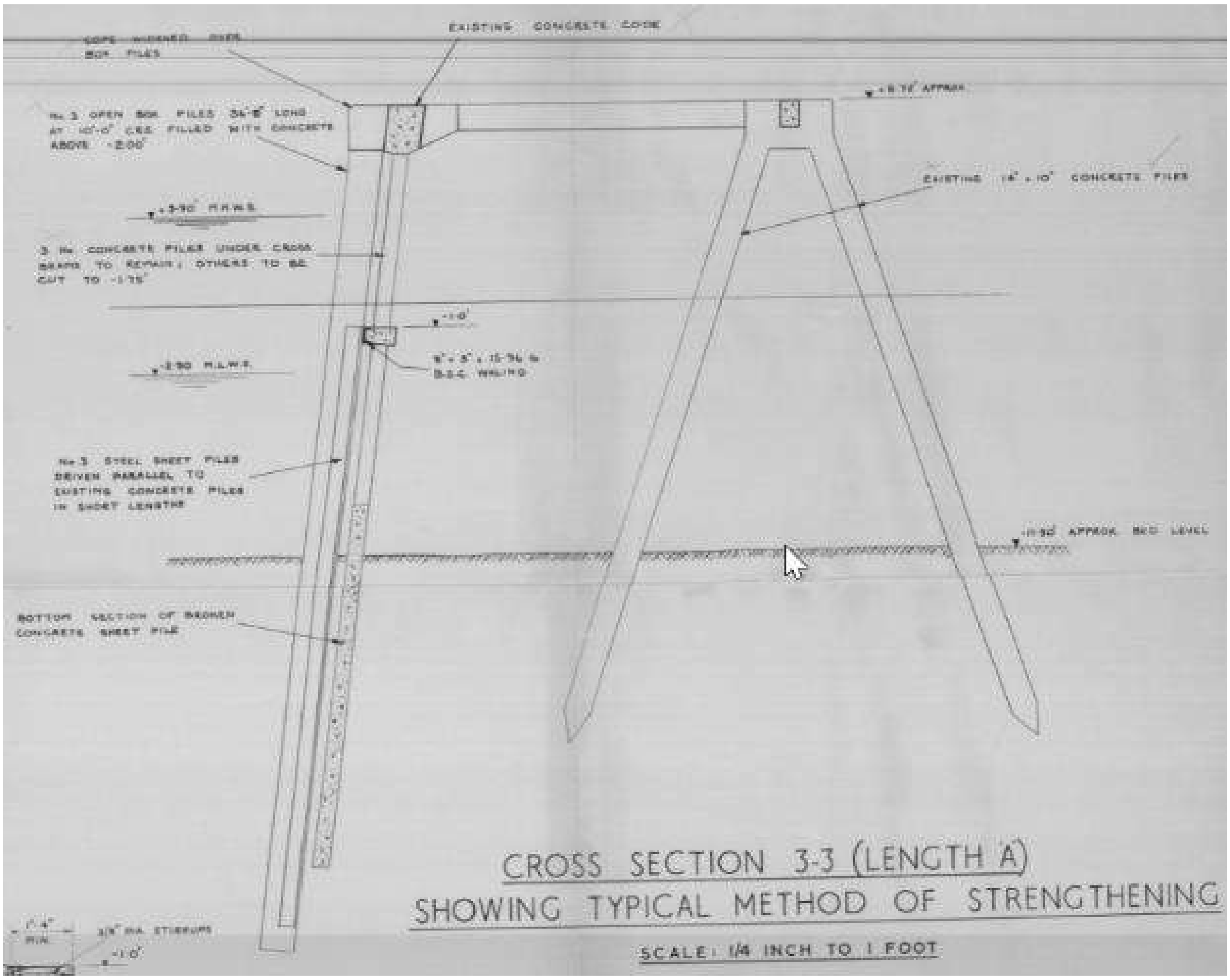


Figure 4-3: South Pier Length A, Section 3-3

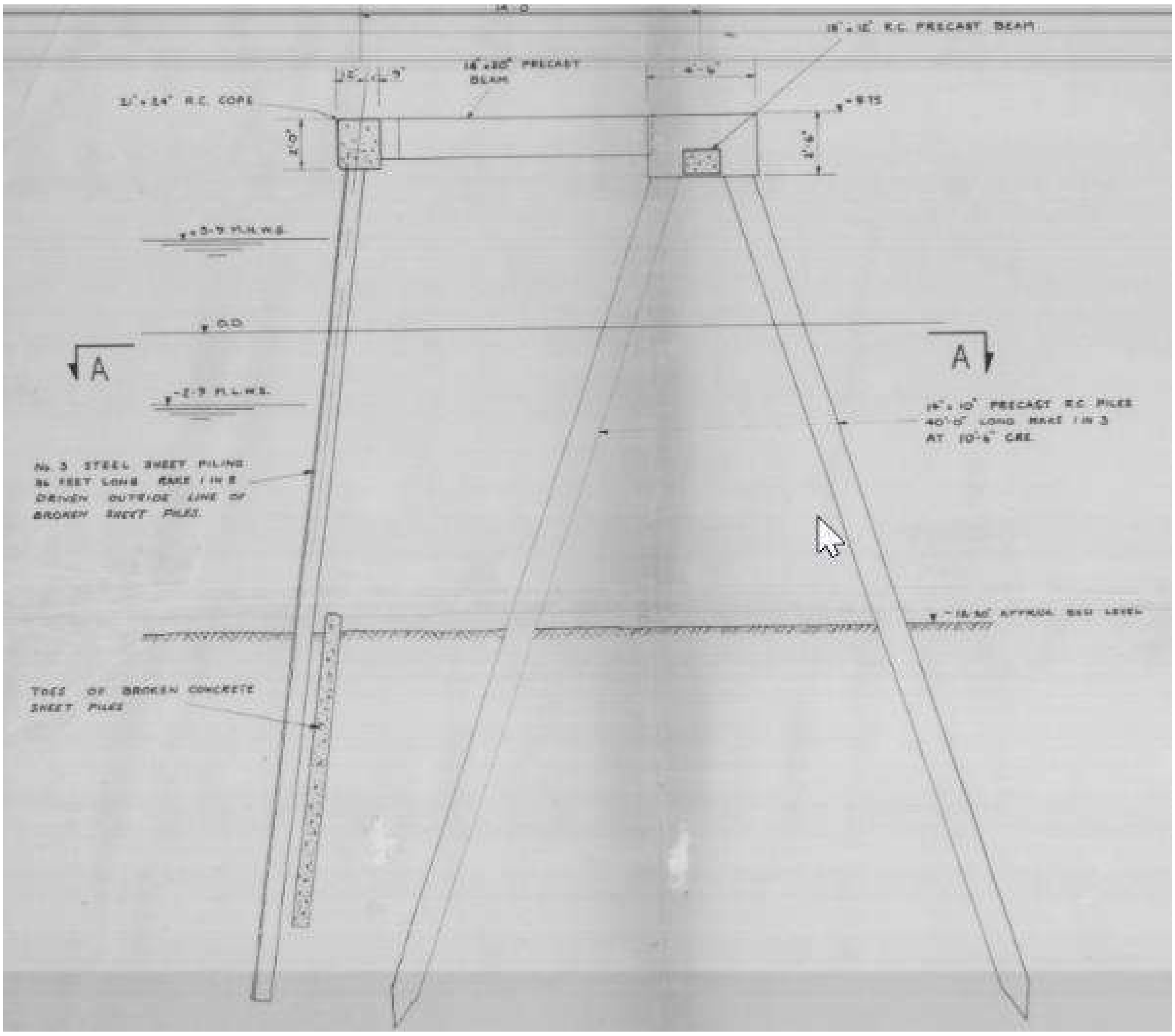


Figure 4-4: Example cross-section of South Pier (Length C)

4.1.2 Summary of condition assessment

The 2010 Suffolk Shoreline Management Plan (Ref. 5) described the South Pier as being in poor condition with a residual life of 5 years. Considering this previous assessment, the condition assessment completed for this project determined that the majority of the structure was in a better condition than might have been expected, as summarised below:

- The concrete part of the structure does not appear to be at the end of its life. Whilst a few areas have failed, and reinforcement exposed in localised areas, there are no signs of imminent failure. The cracking in the concrete appears to be due to failure of previous poor-quality patch repairs.
- Most raking piles are in good condition.
- The narrow crossmembers are typically the part of the structure in worst condition, with exposed reinforcement and signs of corrosion to about 20% of these.
- The sheet steel piles in Length C extend into the splash zone and have suffered from significant corrosion, providing limited support to the front beam, which is cantilevered off the piles behind and as such is the most 'at risk' part of the structure (**Figure 4-5**). During a storm surge event this beam is liable to be driven upwards, which could lead to the crossmembers or rear piles failing and a length of this front beam collapsing into the harbour.

Figure 4-5: Length C corroded steel sheet piles and unsupported front beam.

- The deterioration in Length C appears to have been slowed by the placement of rock armour to block openings in the pier face **(Figure A02).**
- Length A is generally less vulnerable than Length C, due to the installation of more substantial box piles around the original concrete structure. The additional lower-level steel sheet piles are typically located below low water level so visibility was limited during the inspection. However, the section continues to be well aligned and the upper edge of the sheet piles has not corroded in the same way as those to Length C.
- One of the box piles near to the harbour mouth (**Figure 4-6**) is not supporting the beam above it. This pile is likely to have been struck by a vessel resulting in a dent at the low tide waterline and causing the top beam to be cantilevered off the rear piles.
- The western end of the pier, adjacent to the Walberswick dunes, has developed some holes between the planks resulting in scour on the southern side.

Figure 4-6: Box Pile 8 failure

4.1.3 Life expectancy and recommendations

Whilst the South Pier is the harbour structure at greatest risk of failure, the condition of the structure and the predicted failure mechanisms are essentially unchanged from the 1990s. It is therefore considered likely to last another 15-20 years if the unsupported and cantilevered sections are repaired, and assuming no further erosion of the channel bed. Specific issues and recommendations include:

- Length C has essentially failed and could collapse within the next 5 years. Failure could risk damage to adjacent parts of the structure. This section should be repaired as soon as possible.
- The steel sheet piles to Length A are not considered to be at high risk of failure at present based on the above water inspection, and therefore the residual life of 15-20 years for the overall structure is applicable in this area. The condition of this part of the structure should be monitored, and a diving inspection undertaken if any change is observed.
- Reinforced concrete could be patched or replaced at the locations where the rebar is exposed, but this would not improve structural stability.
- If necessary considering the aims of the scheme, scour holes could be filled after the gaps in the planks and piles have been repaired.

The above assessment is based only on the inspection of the present condition of the structure, and does not consider additional risks due to scour of the bed of the entrance channel. As described in **Section 3.2**, an ongoing trend of erosion of 0.1-0.2m year is indicated from review of recent bathymetric surveys. In places, the toe piles to the inner face of the South Pier are buried by only 3m, so if this erosion rate was to continue the toe piles could be undermined within 15 years, with increasing risk of failure before that time.

4.2 South Training Wall

This is the same structure as the original South Pier, with most concrete planks cut down to -1.0mODN. The structure is separated from the South Pier by a narrow entrance that allows access to Walberswick Quay from the Harbour (**Figure 4-7**).

As with the South Pier this structure is not at the end of its life. Most of the concrete is still intact with only a few localised patches of exposed rebar. The cut concrete planks appear to still have a toe in place, supporting the bed material on the Walberswick Quay side and preventing it from collapsing into the harbour.

The condition of the South Training Wall has not changed significantly since the 1996 study, and it is therefore reasonable to assume that this structure will have at least another 15-20 years of life.

Exposed rebar and areas of damage to the reinforced concrete could be patched and replaced but this will not increase structural stability.

It is recommended that the lower sections of the cut concrete planks are left in situ to support the build-up of sediment inside Walberswick Quay and prevent it from collapsing out into the harbour channel.

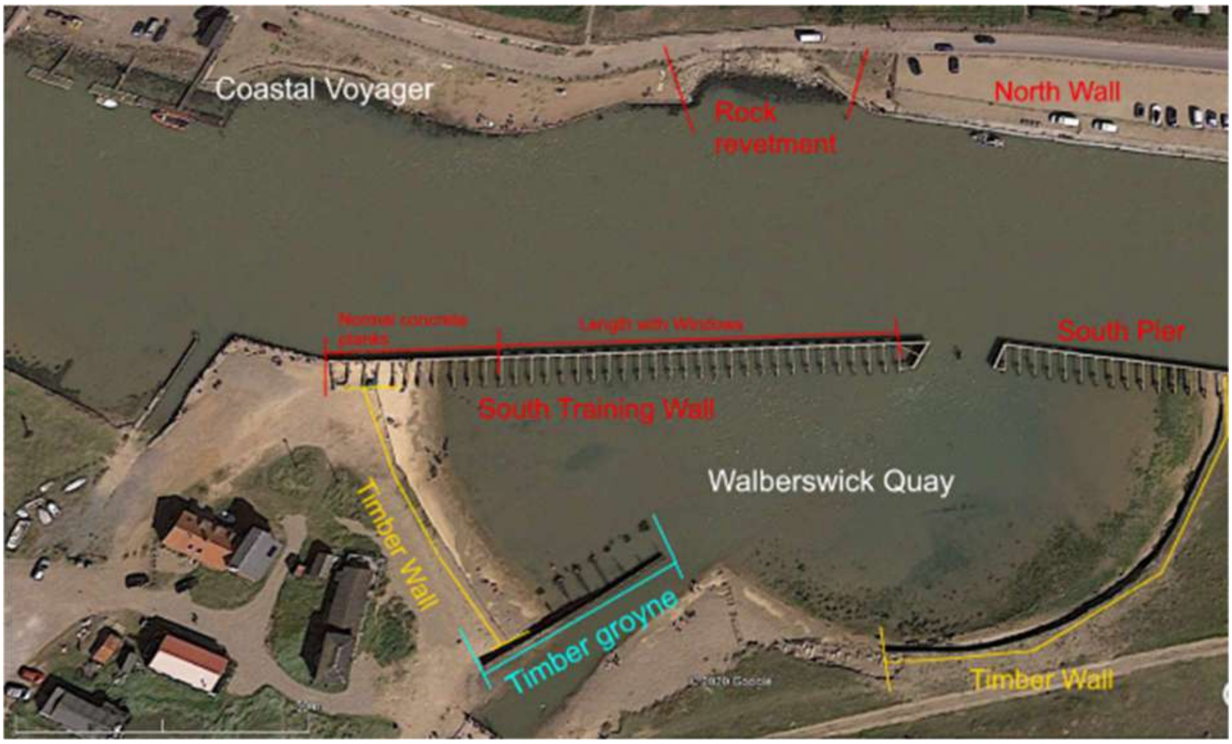


Figure 4-7: South Training Wall, Walberswick Quay

4.3 Walberswick Quay

The north beach to Walberswick Quay is protected by a timber groyne at the mouth of Dunwich Creek, with a timber wall at the top of the beach (**Figure 4-7**, **Figure 4-8**). The aim of the timber groyne is to maintain the beach so that this contributes to the dissipation of wave energy within the harbour. The timber groyne and wall are in a relatively good condition and are expected to have at least another 20 years of life.

The timber piled wall may influence wave reflection in the harbour, potentially limiting accretion of the spending beach, and the beneficial effects of this beach on wave energy dissipation.

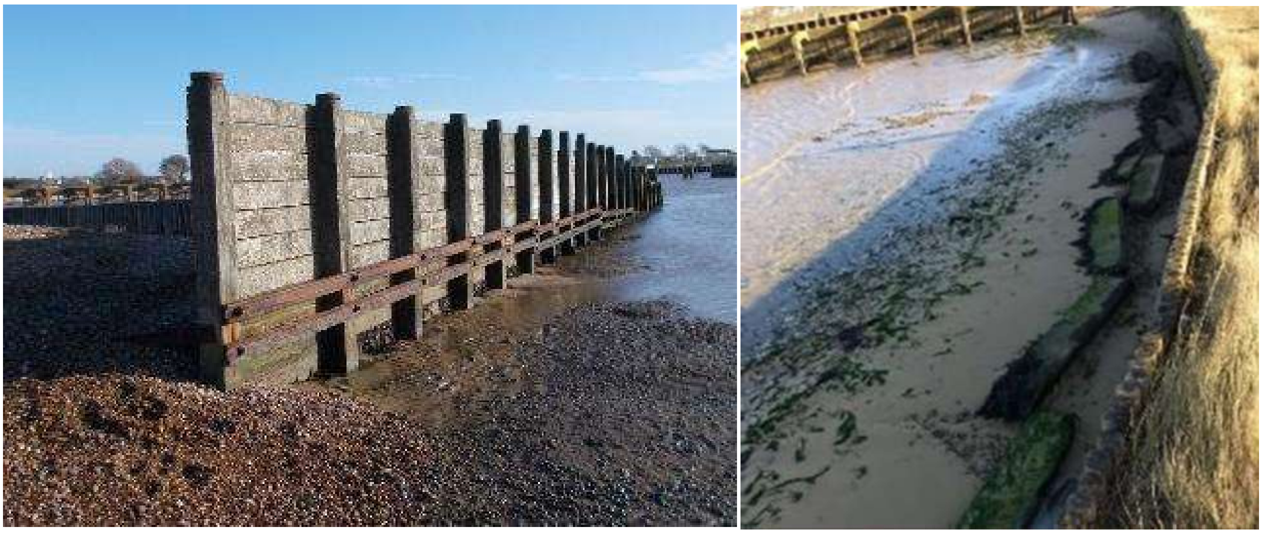


Figure 4-8: Timber groyne and wall at Dunwich Creek

4.4 North Pier

4.4.1 Form of defence

The North Pier forms the northern side of the harbour entrance. This is comprised of a continuous concrete structure protected by a SHED concrete block revetment (**Figure 4-12**) along most of the length plus rock armour which forms a roundhead at the outer end of the pier. Timber fendering is installed around the seaward end of the pier, which is currently being replaced.

The pier structure itself is comprised of steel sheet or concrete piles supporting a concrete deck. The area beneath the deck is typically infilled with concrete and beach materials, although there are voids recorded beneath the deck.

Works to the North Pier were undertaken in 1992 (**Figure 4-10**:), which reduced the length of the structure by 11m with the aim of increasing flow through the entrance channel to prevent sedimentation restricting navigation, and to reduce wave energy in the harbour to improve mooring conditions. The rock armour revetment and timber fendering were added around the pier head at this time, as well as the SHED concrete block revetment along the inner face of the pier (**Figure 4-11**:).

Figure 4-9: Map of North Wall and Knuckle

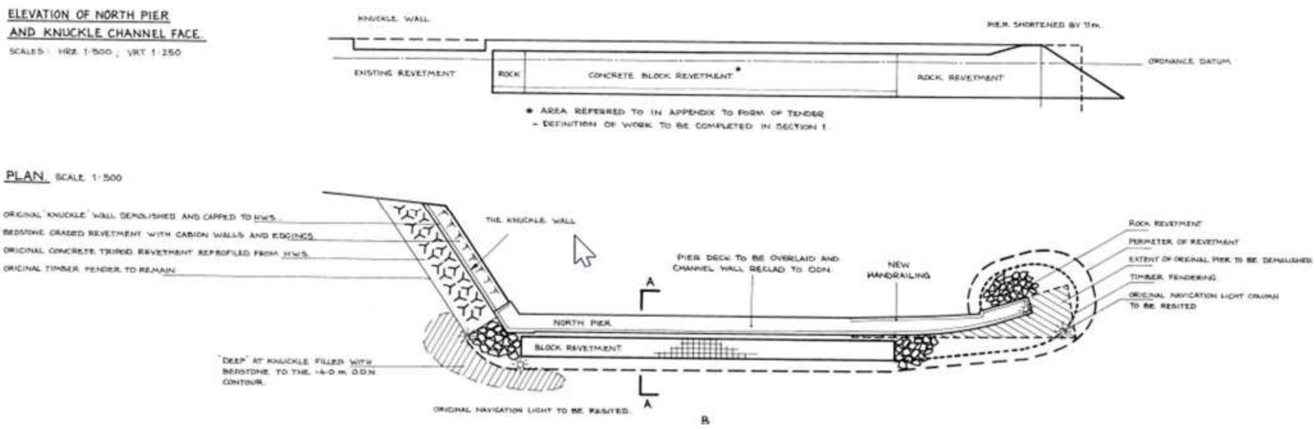


Figure 4-10: 1992 North Pier works plan

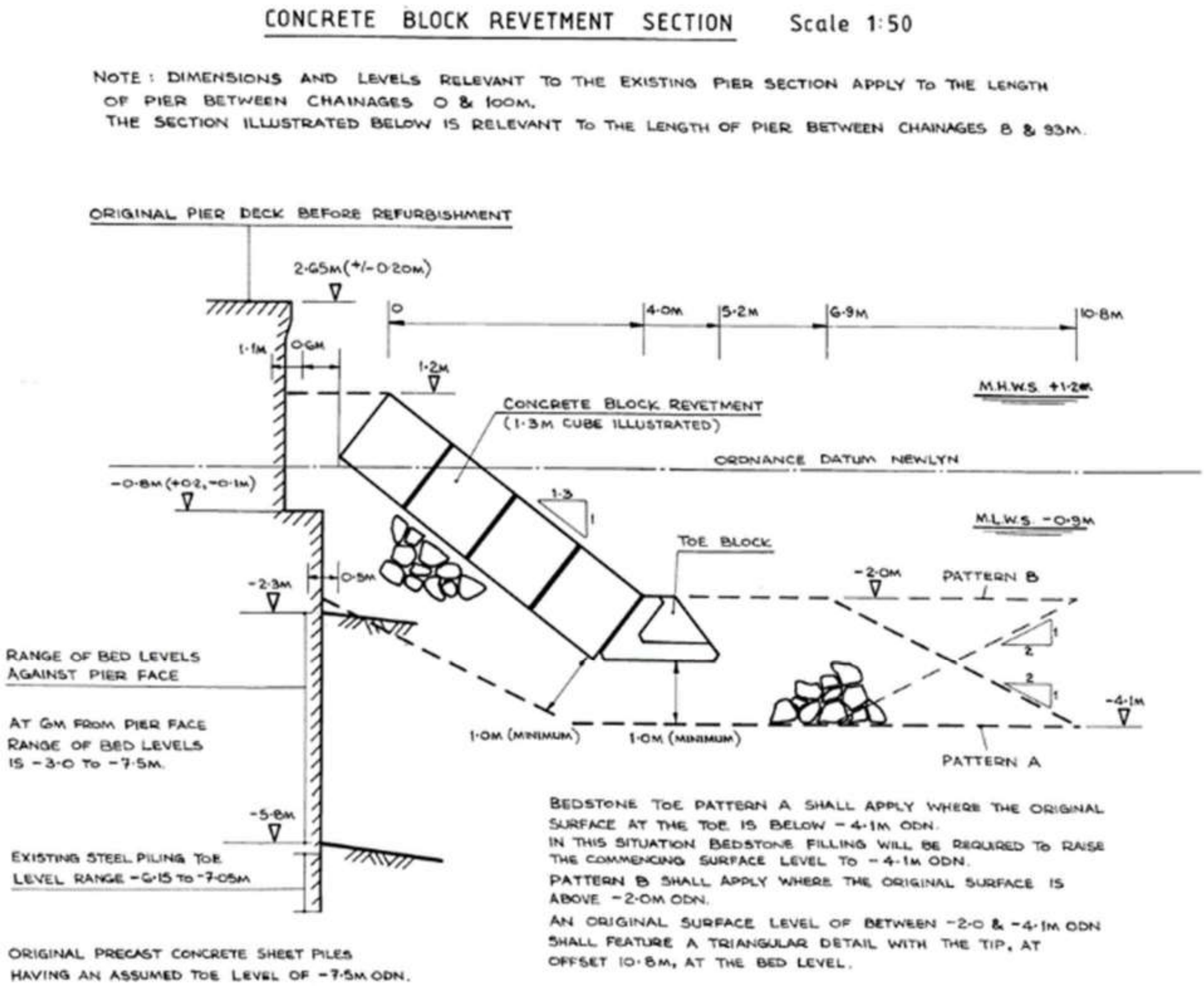


Figure 4-11: 1992 SHED concrete block revetment section

4.4.2 Condition assessment and life expectancy

Overall, the North Pier shows no obvious signs of being at end of its life, although some of the blocks have cracked and failed, particularly at the eastern end of the SHED concrete block revetment (**Figure 4-13**:), over a length of about 25m. The rock armour forming the roundhead is in good condition.

The timber fendering at the seaward end of the pier was replaced in 2022, and replacement of the fendering to the channel section is due within 5 years. The fendering is typically replaced every 20-25 years.

Overall the North Pier is considered to have a remaining life of at least 20 years, assuming no further erosion of the channel bed, and if the South Pier remains in place. Improvements to the South Pier could extend the life of the North Pier, particularly if the failed concrete blocks at the eastern end of the North Pier SHED revetment were also replaced.

The above assessment is based only on the inspection of the present condition of the structure and does not consider additional risks due to scour of the bed of the entrance channel. Based on the bathymetric surveys (**Section 3.2**), the channel bed to the north of the entrance channel is more stable than on the southern side, with some evidence of accretion rather than erosion. If the erosion trend of 0.1-0.2m year was to extend to this part of the channel, then the toe of the North Pier could be undermined within 20 years, although the rock toe is designed to have some flexibility to accommodate a reduction in the bed level.

Figure 4-12: SHED concrete blocks with rock fill

Figure 4-13: Failed blocks near east end of concrete block revetment

Figure 4-14: Rock armour, navigational light and damaged timber fendering

4.5 Knuckle

The Knuckle is located on the northern shore of the Harbour, between the western end of the North Pier and the North Wall (**Figure 4-17**). The structure is a rock revetment with gabion walls and edgings and a concrete toe beam (**Figure 4-16**:). The structure is surrounded on the landward sides by a guard rail. Two mooring posts are cast into the toe.

The revetment and its concrete toe beam are both in a good condition. Although the gabion cages are failing the wall has bedded into the surrounding ground and seems to be very solid. The Knuckle is expected to have at least another 20 years of life.

4.6 North Wall

The northern side of the harbour, to the west of the North Pier and Knuckle (**Figure 4-17**), is protected by an anchored piled wall consisting of sheet piling with a concrete capping beam. Type 1 stone infills between the sheet piles and the original concrete harbour wall. The structure is approximately 14.5m high, with the tops of piles at +3.1mODN (**Figure 4-20**), although it is noted that the capping beam has recently been surveyed at +2.8mODN. Mooring posts are spaced at regular intervals, cast into the capping beams. A setback safety barrier has been installed along the length of the wall with access ladders at regular intervals.

This structure was built less than 10 years ago. It is still very good condition (**Figure 4-18**) and would be expected to have another 50 years of life or more.

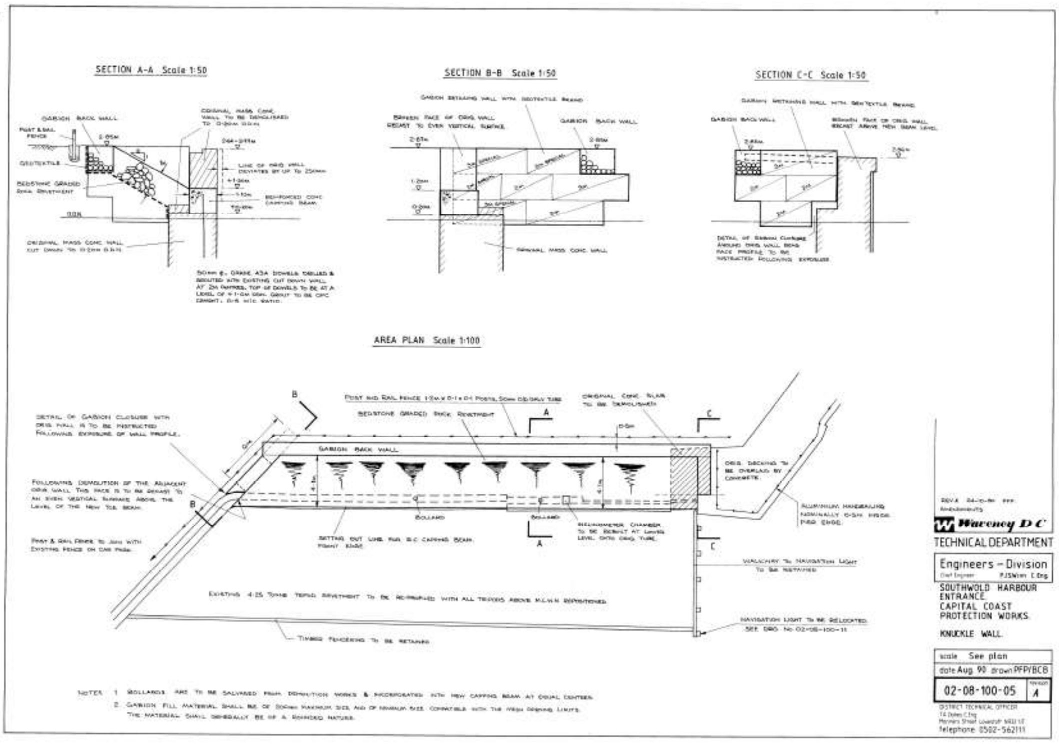


Figure 4-15: 1990 works to the Knuckle

Figure 4-16: Current condition of Knuckle

It is noted that harbour users have raised concerns regarding the form of construction of the new North Wall, which restricts mooring by smaller vessels due to the overhanging crest and lack of fendering. Mooring by larger vessels is restricted by the navigation channel which runs close to the wall due to the channel bathymetry.

At the west end of the new piled wall there is a short length of the old sheet piled wall, with a 20m length of rock revetment to the west of this (**Figure 4-19**). These are in moderate condition, but are not considered to be at risk of failure within the next 20 years.

Figure 4-17: Plan of North Wall and Knuckle, showing rock revetment and old sheet piles

Figure 4-18: Current condition of North Wall

Figure 4-19: Rock revetment West of North Wall

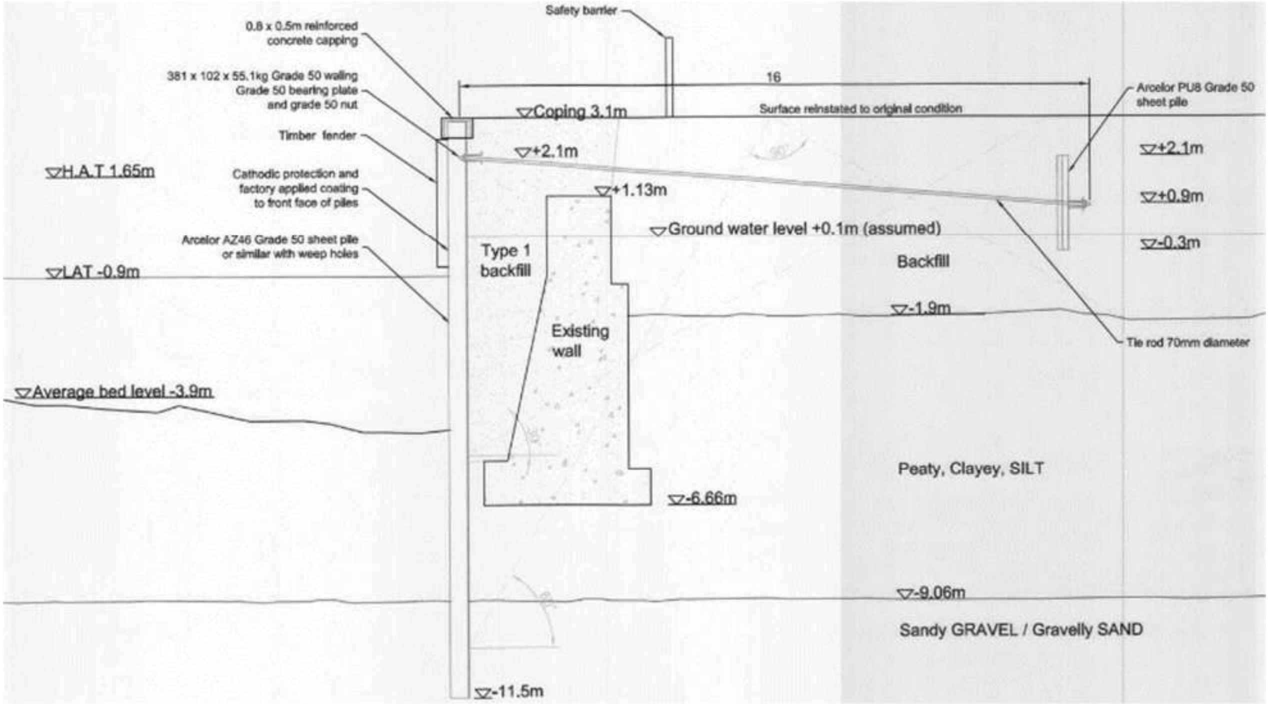


Figure 4-20: North wall work drawings - 2012-13

4.7 Estuary defences

The scope of work for this project did not include for undertaking an inspection and condition assessment of the estuary flood embankments. Information from the EA Strategy and observations from site visits have informed this section. It is recommended that a detailed inspection and condition assessment is undertaken as part of future stages of this project, to inform the design of the proposed solutions and the development of maintenance plans.

The estuary flood embankments are very narrow, with a crest width that is typically less than 2m and side slopes of between 1.0 and 2.0. The photograph in **Figure 4-21** gives an example of the condition of the embankments to Tinker's Marsh.

Figure 4-21: Embankment to Tinker's Marsh

The tidal model (**Appendix D**) includes embankment crest levels, based on the LiDAR data for the area. Survey data has also been provided by the Blyth Estuary Partnership. Extracts from this data are included in **Figure 4-22**, which also shows the locations of the embankment breaches that occurred during the 2013 surge event.

The tidal model results and embankment crest levels have been used to assess the present SOP provided by the flood embankments. **Figure 4-23** shows the water levels at which the existing embankments would be overtopped, at various points along the river channel, for present-day conditions. **Figure 4-24** shows the water levels at which the existing embankments would be overtopped in 2070, assuming the RCP4.5, 50% climate change scenario (mid-range). The locations of the flood cells referred to in these figures are shown in **Figure 2-9**.

Table 4-1 below shows the SOP currently provided by the estuary flood embankments, demonstrating the very low SOP in some places, particularly Robinson's, Tinker's and Reydon Marshes. The table also shows how much the SOP will be reduced by 2070. **Table 4-2** sets out the embankment levels that would be required to achieve a range of standards of protection, both now and in 2070. The numbers in red show the water levels for which the 'typical' defence level in the flood cell would be exceeded.

Table 4-1: Standard of protection (SOP) provided by existing estuary flood defences

Location	Defence level, mODN		SOP (return period, years)					
			Present day		2070 (RCP4.5, 50%)		2070 (RCP8.5, 95%)	
	Minimum	Typical	Minimum	Typical	Minimum	Typical	Minimum	Typical
FC1 Ferry Rd	2.76	2.9	100	220	31	85	7.5	24
FC2 Town Marsh	2.56	2.6	45	50	12.5	15	3	3.5
FC3 Woodsend Marsh	2.41	2.5	30	45	9	13.5	1.5	2.5
FC4 Buss Creek	2.42	2.6	30	50	9	21	1.5	3.5
FC5 Reydon Marsh	2.24	2.4	15	35	4	10	1	2
FC6 Wang Valley	2.23	2.4	15	35	4	10	1	2
FC7 Bulcamp House	2.7	2.9	150	400	55	170	15	55
FC10 Robinson's Marsh	2.18	2.3	5	10	1.5	2.5	0.7	1
FC11 Tinker's Marsh	1.85	2.2	0.8	10	0.3	3.3	0.25	0.95

Table 4-2: Defence levels required to achieve return period standards of protection (SOP)

Location	Required defence level to achieve SOP (return period, years)																
	Present day						2070 (RCP4.5, 50%)						2070 (RCP8.5, 95%)				
	5	10	20	50	100	200	5	10	20	50	100	200	5	10	20	50	100
FC1 Ferry Rd	2.15	2.30	2.45	2.60	2.75	2.90	2.45	2.55	2.70	2.85	2.95	3.15	2.70	2.80	2.90	3.10	3.35
FC2 Town Marsh	2.15	2.25	2.40	2.60	2.80	2.90	2.40	2.50	2.70	2.85	2.95	3.15	2.70	2.80	2.90	3.05	3.30
FC3 Woodsend Marsh	2.10	2.20	2.35	2.55	2.70	2.85	2.35	2.45	2.60	2.75	2.85	3.10	2.60	2.70	2.80	3.00	3.25
FC4 Buss Creek	2.10	2.20	2.35	2.55	2.70	2.85	2.35	2.45	2.60	2.75	2.85	3.10	2.60	2.70	2.80	3.00	3.25
FC5 Reydon Marsh	2.10	2.20	2.30	2.50	2.70	2.80	2.30	2.40	2.60	2.75	2.85	3.05	2.60	2.70	2.80	2.95	3.20
FC6 Wang Valley	2.10	2.20	2.30	2.50	2.70	2.80	2.30	2.40	2.60	2.75	2.85	3.05	2.60	2.70	2.80	2.95	3.20
FC7 Bulcamp House	2.10	2.20	2.30	2.50	2.65	2.80	2.30	2.40	2.55	2.70	2.80	2.95	2.60	2.70	2.75	2.90	3.15
FC10 Robinson's Marsh	2.15	2.25	2.40	2.60	2.70	2.90	2.40	2.50	2.70	2.85	2.95	3.15	2.70	2.80	2.90	3.05	3.30
FC11 Tinker's Marsh	2.10	2.20	2.35	2.50	2.70	2.80	2.30	2.40	2.60	2.75	2.85	3.05	2.60	2.70	2.80	2.95	3.20

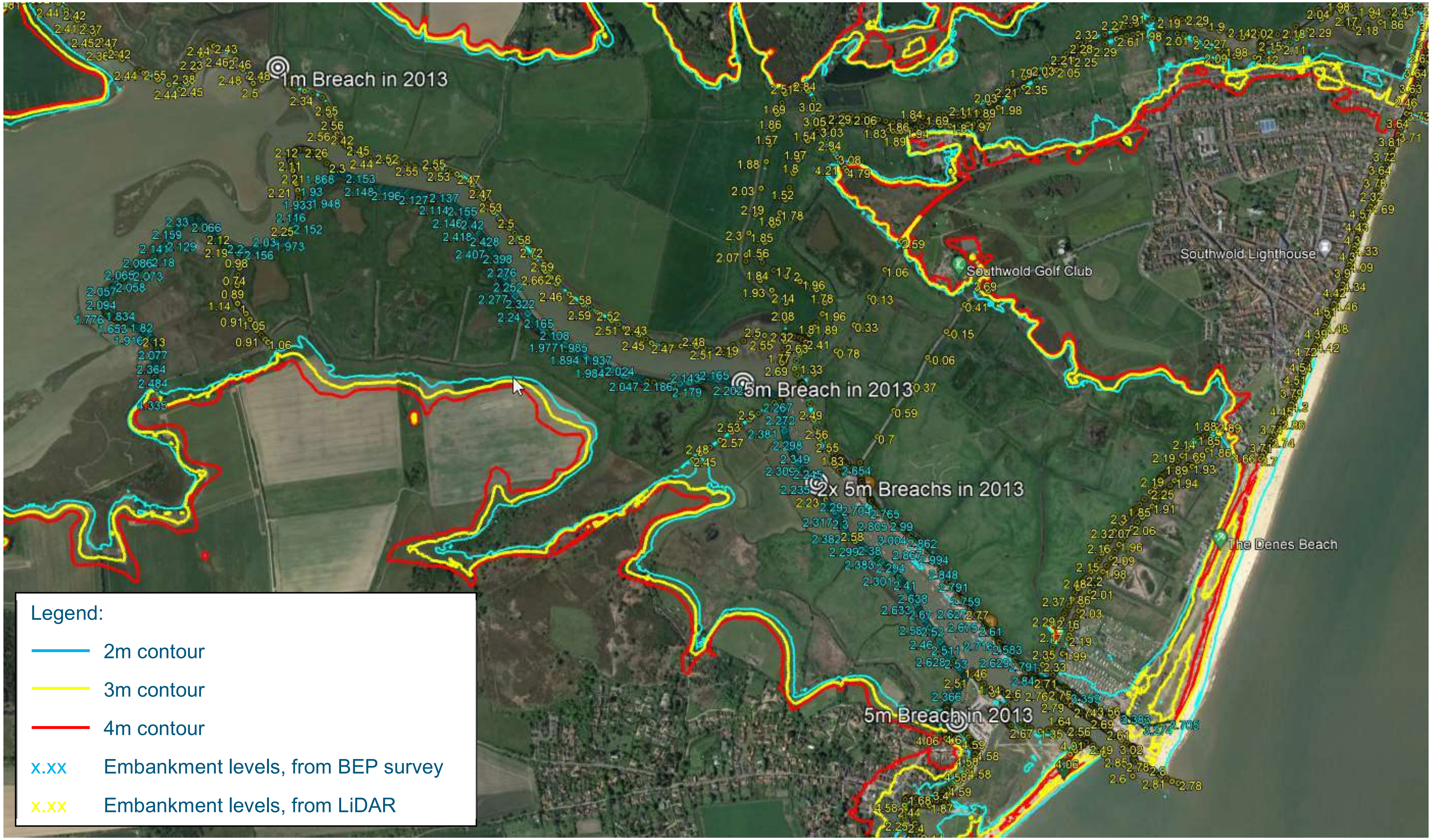


Figure 4-22: Ground levels, embankment levels and 2013 breach locations

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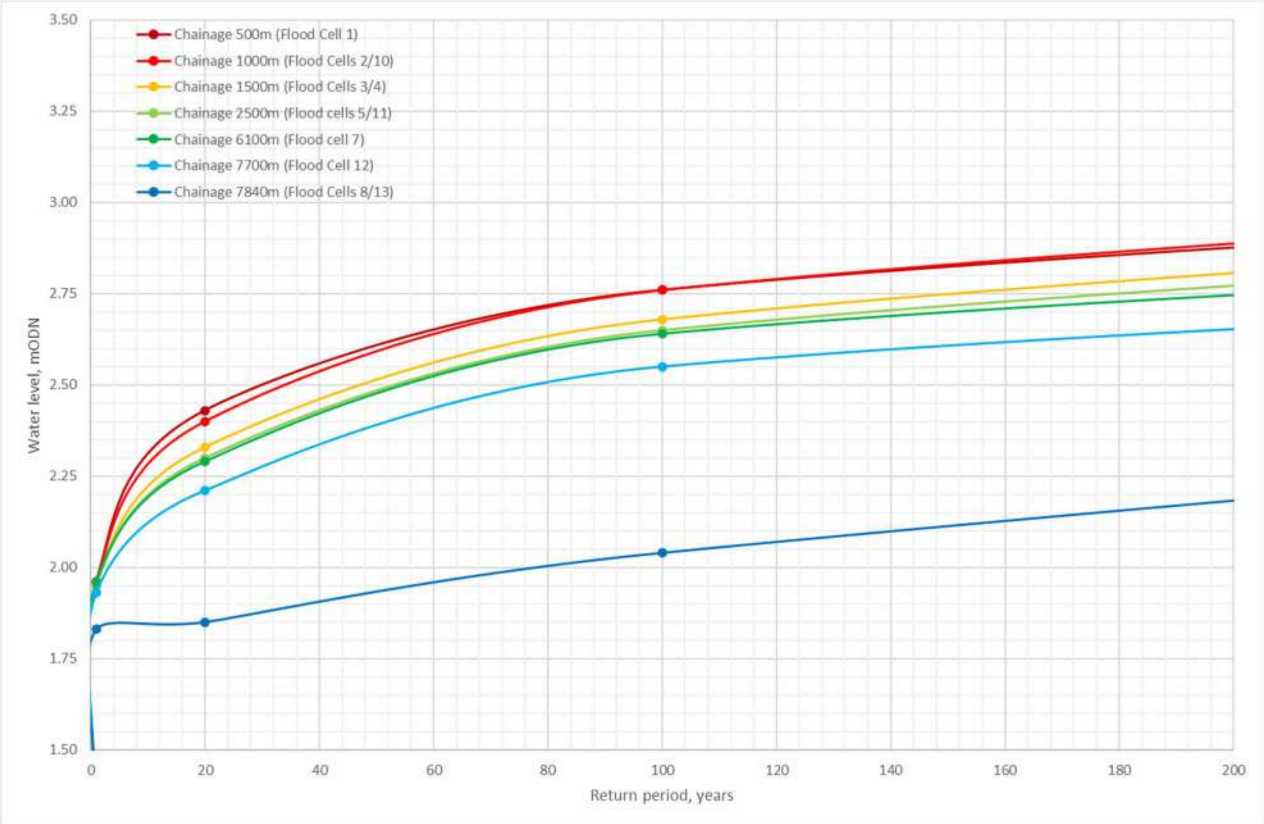


Figure 4-23: Change in peak water level with return period for raised defences, present day

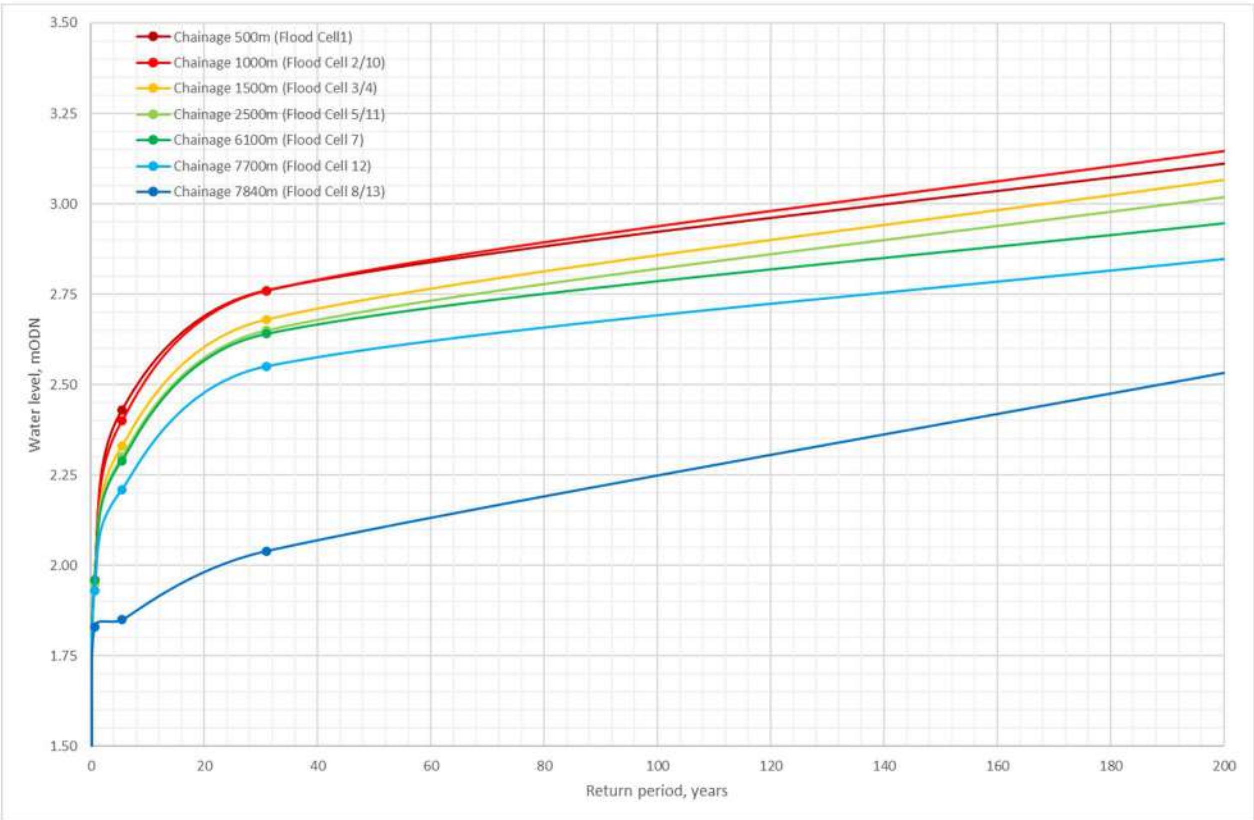


Figure 4-24: Change in peak water level with return period for raised defences, 2070

5 Wave and Tidal Conditions – Existing Layout

The wave modelling results are presented in full in **Appendix C.** The tidal modelling results are included in **Appendix D.** These appendices describe the modelling methodology and the relevant input conditions. This Section discusses the findings from the modelling for the existing layout of the harbour entrance structures and estuary defences, in both present day and future conditions. **Section 6** discusses the modelling results for the Do Nothing scenario, to inform the definition of the problem. The modelling results for the options for future management of the harbour and estuary are presented in **Section 8**.

5.1 Present-Day Conditions

5.1.1 Wave conditions

Wave transformation modelling was undertaken to assess how offshore waves move inshore towards Southwold Harbour. After refraction inshore, waves approach the harbour entrance from directions between 70° and 170°.

The nearshore waves diffract around the ends of the harbour entrance structures. The modelling results show that waves from the north to north-east sectors can cause disturbed seas at the mouth of the harbour, but don't have a significant impact on conditions within in the entrance channel as they can't fully diffract around the North Pier, as shown in .

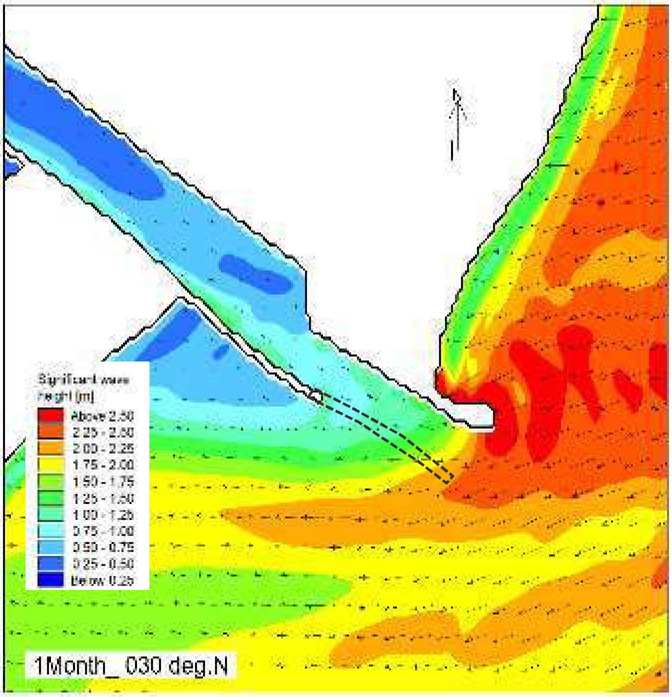
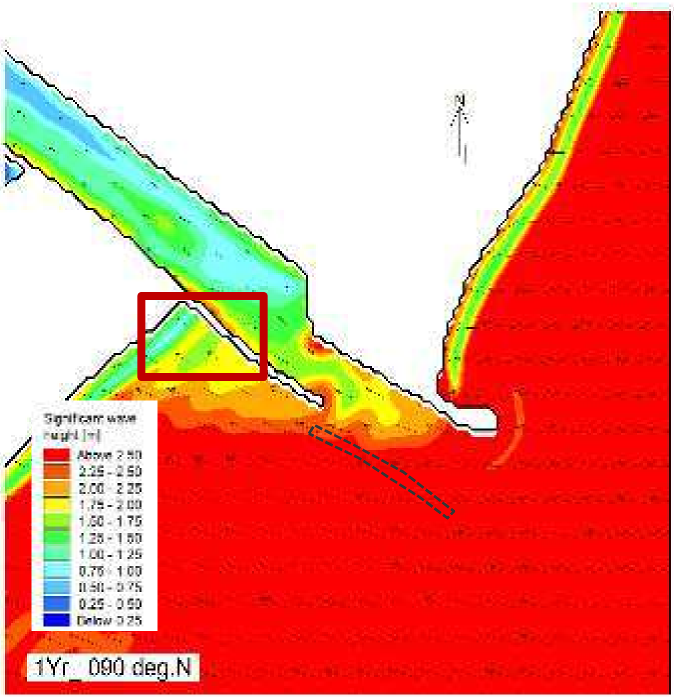


Figure 5-1: Wave disturbance modelling, 1-month wave from 30 degrees offshore

Waves from the east to south-east sectors are able to run directly through the entrance channel, with wave heights reported to build over the shoal bank opposite the North Wall, in the area shown by the red box in **Figure 5-2.**



Aerial photos clearly show how much calmer it is within Southwold Harbour compared to outside (**Figure 5-3**). Waves which enter the harbour at an angle to the pier structures will reflect from the North and South Piers. This reflection results in a disturbed wave pattern within the harbour entrance (**Point A, Figure 5-3**). Wave fronts curve as they spread out through the harbour (**Point B, Figure 5-3**). Wave heights are amplified along the south side of the channel due to reflection, and wave breaking over the sandbank along the inner section of the South Pier is clearly visible (**Point C, Figure 5-3**).

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Figure 5-2: Wave disturbance modelling, 1-year wave from 90 degrees offshore

Figure 5-3: Wave behaviour at Southwold Harbour

Wave reflection is greatest from smooth vertical surfaces and is reduced by rock armour and concrete units, which dissipate wave energy. This reflection results in a disturbed wave pattern within the harbour entrance, as shown in **Figure 5-3** and **Figure 5-4**.

The holes in the South Pier were created to reduce wave reflection. The holes themselves act to dissipate wave energy, and there is less of a hard surface to cause reflection. Waves can also travel directly into the channel through the South Pier, as shown in **Figure 5-4**.

Although the waves that travel through the South Pier cause more disturbance in the entrance channel, these waves interfere with the reflected waves in the channel, so there is less amplification of wave heights, which can make the channel easier to navigate.

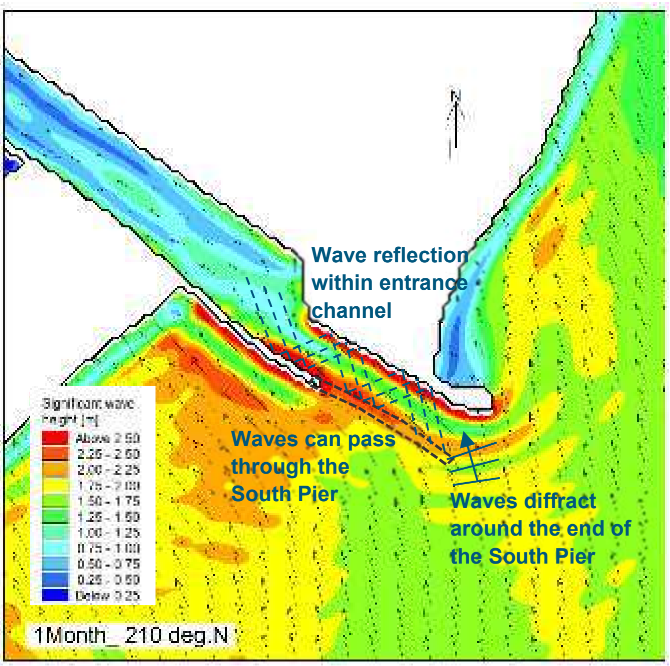


Figure 5-4: Wave disturbance modelling, 1-month wave from 210 degrees offshore

Waves are reflected from the smooth, vertical face of the North Wall (**Point D, Figure 5-3**). This may be causing erosion behind the inner section of the South Pier (**Point E, Figure 5-3**) (through the holes in the concrete planking). Waves are also reflected by the timber piles around the western half of the Dunwich Creek entrance (**Point F, Figure 5-3**). Wave reflection may be concentrated by the curved shape of this bay. Combined with the loss of the spending beach from this area, wave reflection may be causing erosion on the opposite bank (**Point G, Figure 5-3**) and increasing wave disturbance at the outer vessel berths. The spending beach on the eastern side of the Dunwich Creek entrance acts to dissipate wave energy (**Point H, Figure 5-3**). Upstream of Walberwick Ferry, waves are no longer reflected by the shallow slopes of the channel sides, and because of the interference caused by flows out of the Dunwich Creek and the vessels and mooring pontoons along Blackshore.

1-month return period conditions (approx. MHWS) ***1-year return period conditions***

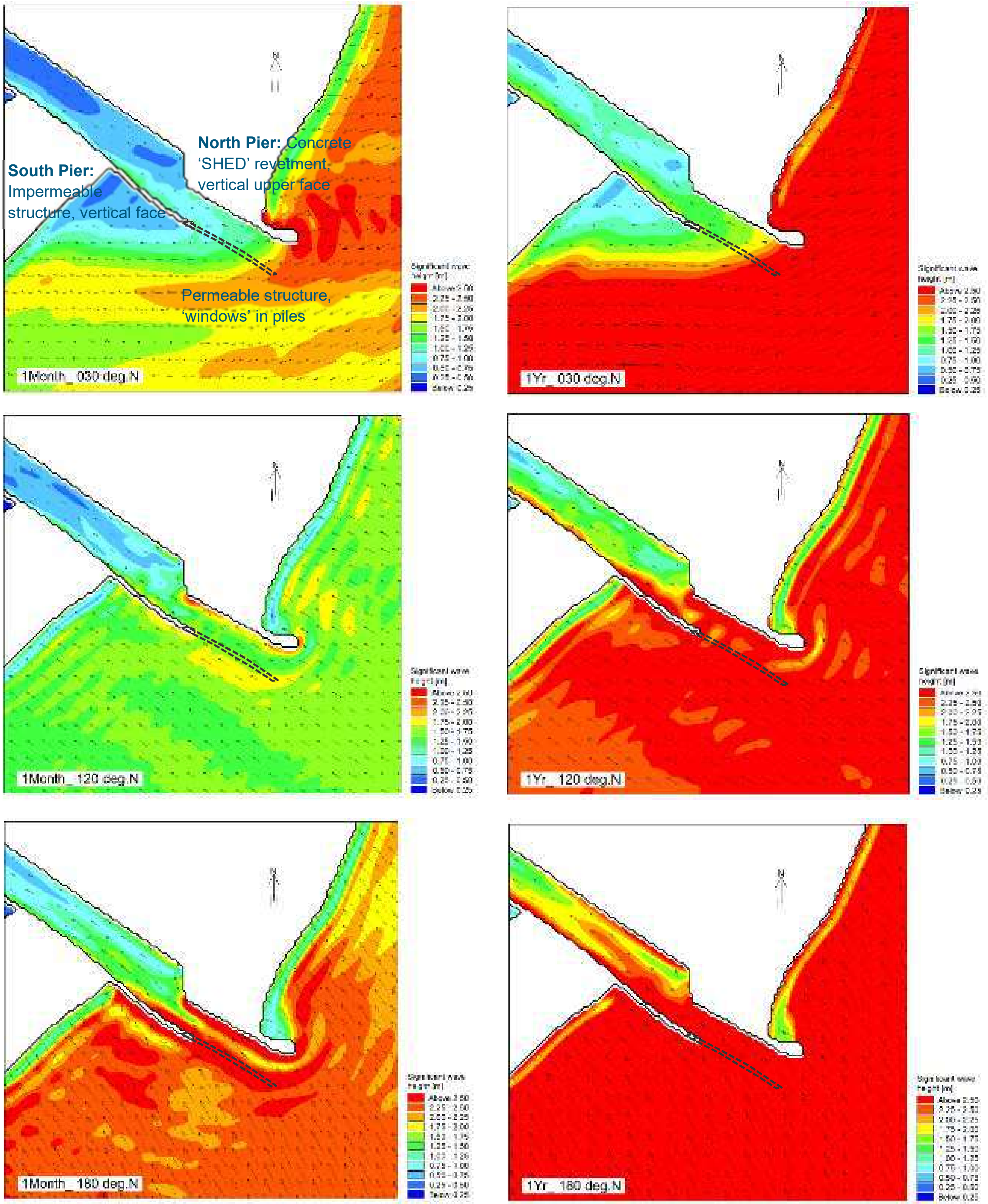


Figure 5-5: Wave disturbance modelling results

The wave disturbance modelling results for waves from 30 degrees, 120 degrees and 180 degrees offshore are provided **in Figure 5-5**. The wave conditions at the North Wall are set out in **Table 5-1** for all wave directions, which shows that waves can exceed 0.5m from all directions during 1-month wave conditions. The input conditions for these model runs are provided in **Appendix C**.

The guidelines for the maximum acceptable wave heights in harbours[15] state that for vessels less than 20m long, a wave height of 0.15-0.30m can be accepted, depending on wave direction and period. Larger vessels, such as tugs and barges, can be moored in waves of 0.5-0.8m, depending on wave direction. This confirms the anecdotal evidence that wave conditions at the North Wall are generally unsuitable for mooring at present.

Table 5-1: Wave conditions in front of the North Wall

Offshore wave direction sector (deg.N)	Range of Hm0 (m) in front of harbour	
	1 month	1 Year
0	0.4-0.7	0.7 - 1.0
30	0.5-0.8	0.8 - 1.2
60	0.4-0.8	0.6 – 1.0
90	0.5-1.2	0.6 – 1.4
120	0.6-2.0	1.0 – 2.2
150	0.7-2.0	1.0 – 2.6
180	1.0-2.4	1.5 -3.5
210	1.0-2.0	1.3 – 3.3

5.1.2 Flood extents and peak water levels

The tidal model has been used to assess flood extents and water depths and peak water levels at Southwold for the present-day conditions of the harbour entrance structures and estuary defences. The models included the existing harbour entrance structures and flood embankments, with the embankment levels based on the most recent Environment Agency survey. The February 2020 and December 2013 conditions were modelled, with the results shown in **Figure 5-6** to **Figure 5-9**.

The model results for the February 2020 conditions show that there is no overtopping of the defences for a maximum water level of 1.4m ODN. This water level is higher than MHWS, as there was a 0.3m surge during the hydrographic survey on 24th February 2020. The February 2020 conditions are approximately equivalent to MHWS in 2070, assuming the RCP4.5, 50 percentile climate change scenario.

On 5th December 2013, the water level during the storm surge reached 3.0mODN at the harbour entrance. This resulted in overtopping of the estuary embankments and Walberswick dunes, and extensive flooding, as shown in **Figure 5-8**. The estuary embankments breached in two locations, which was observed to reduce water levels at Blackshore by about 0.3m. This is represented in the modelling, with **Figure 5-9** showing the peak water level to be 0.28m lower at the Bailey Bridge compared to the level at the North Wall.

The modelled flood extents for the 2013 event can be compared to the EA Strategy modelling results for the 1% AEP conditions (1 in 100 year return period), which are included as **Figure 5-10**. The East Anglian Coastal Modelling (Ref. 9) results for the present day, defended scenario are also included as **Figure 5-11**, with the 1% AEP flood outline shown in light green. It is noted that the EA Strategy modelling doesn't include for overtopping of the Walberswick dunes, which is included in the tidal modelling for this project and in the

[15] *PIANC 1995 Workgroup 24 Criteria for Movements of Moored Ships in Harbours*

East Anglian Coastal Modelling results. The EA Strategy and East Anglian Coastal Modelling show a greater extent of flooding upstream of Wolsey Creek (see **Figure 2-9**), which may be due to assumptions regarding the level of the A1095 road and/or potential breach of the road embankment.

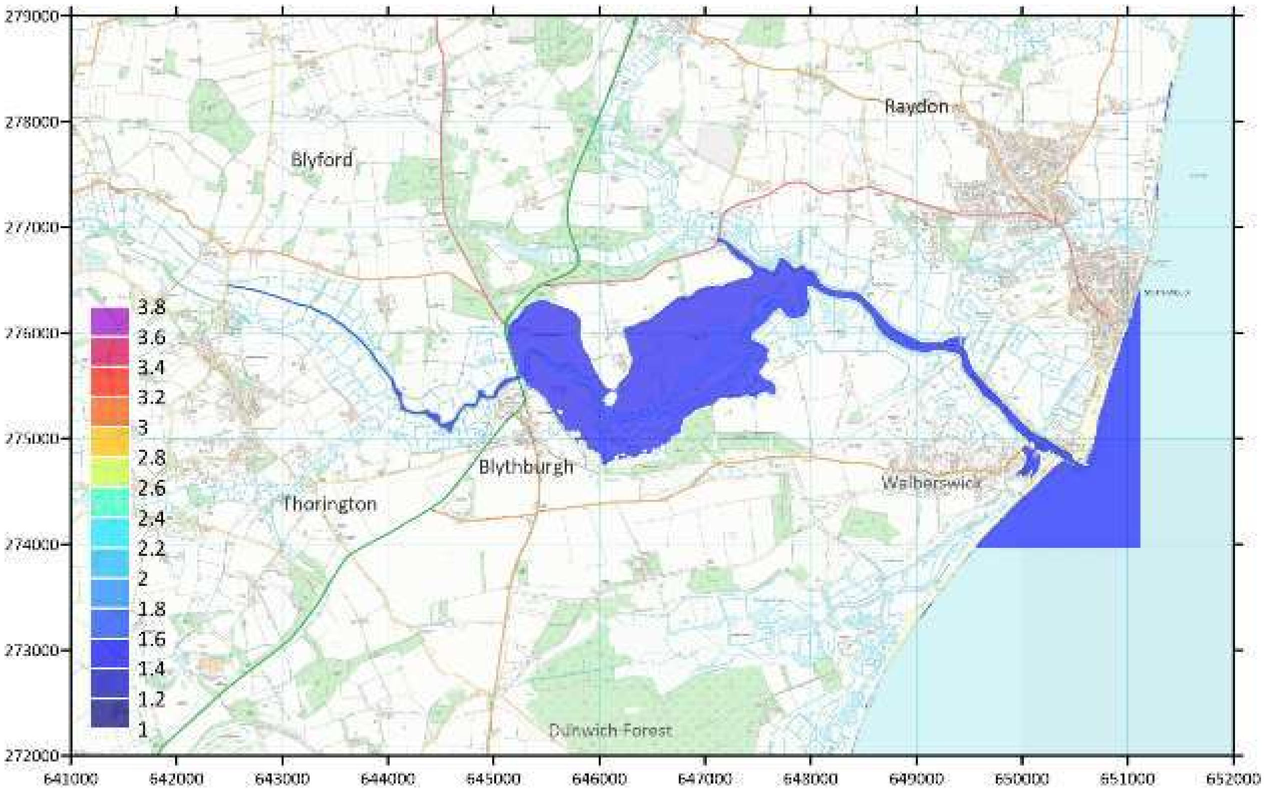
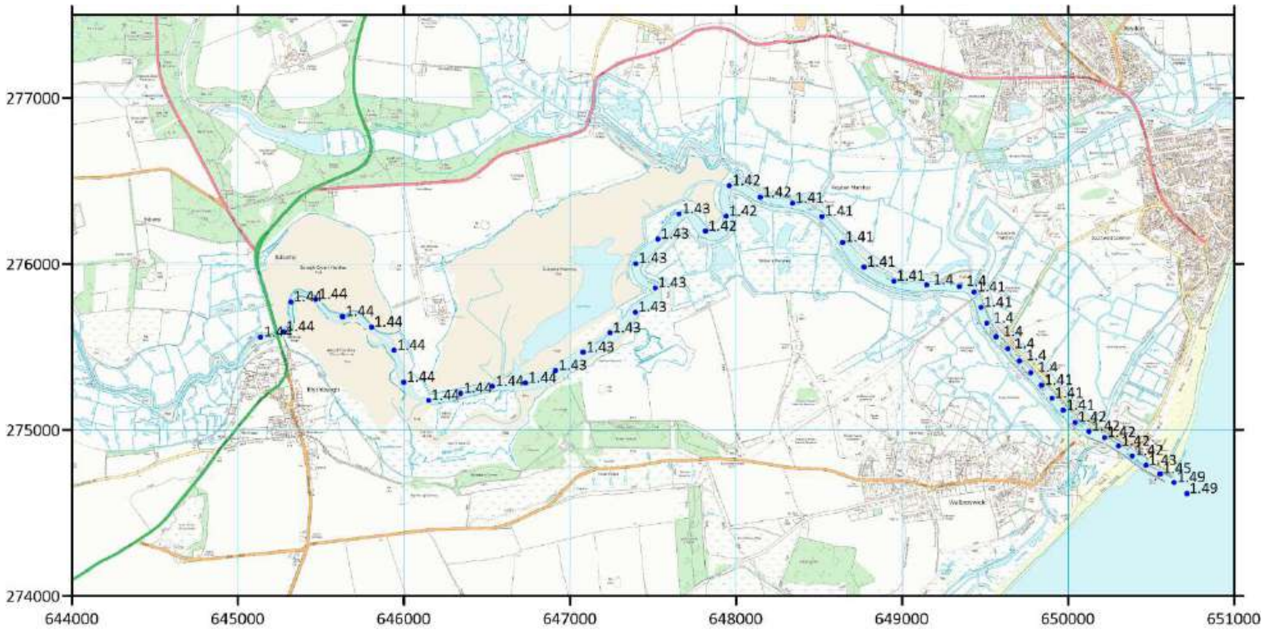


Figure 5-6: Flood extent and depth (present-day defences, February 2020 conditions)

Figure 5-7: Peak flood levels (present-day defences, February 2020 conditions)



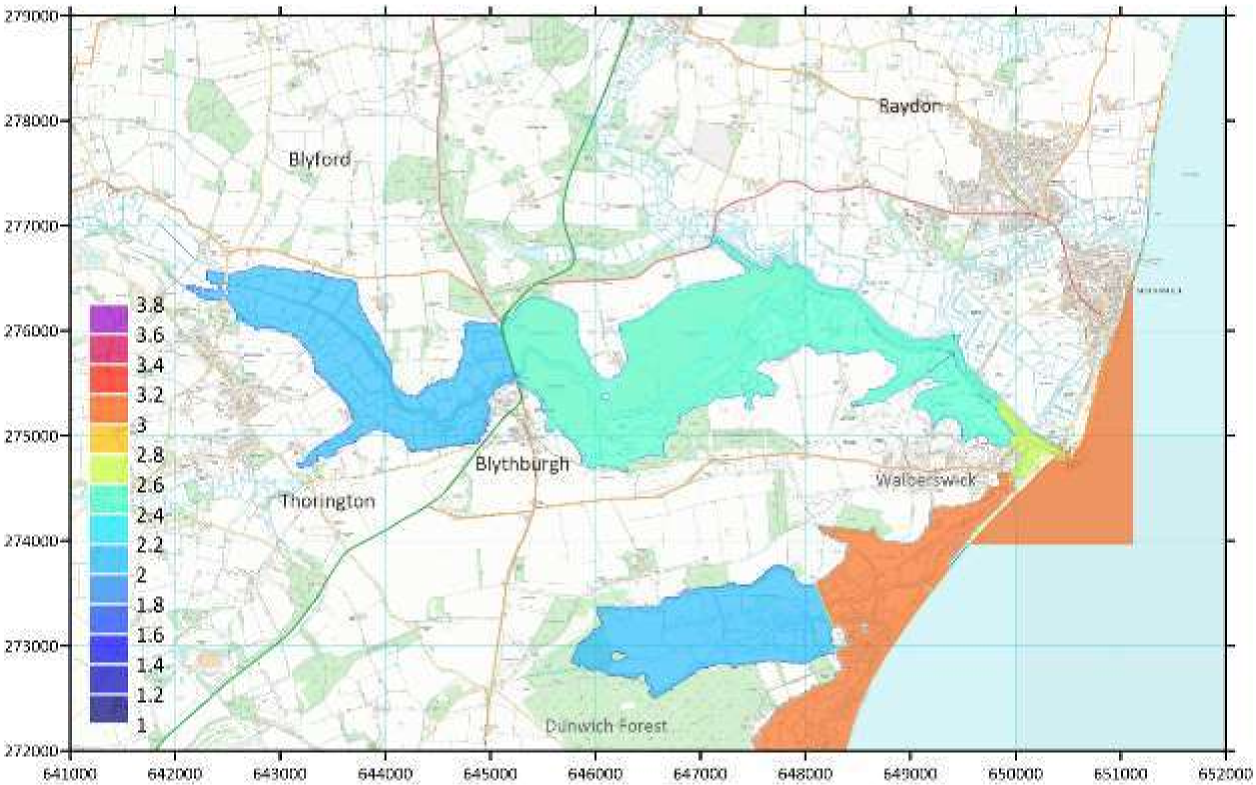


Figure 5-8: Flood extent and depth (present-day defences, December 2013 conditions)

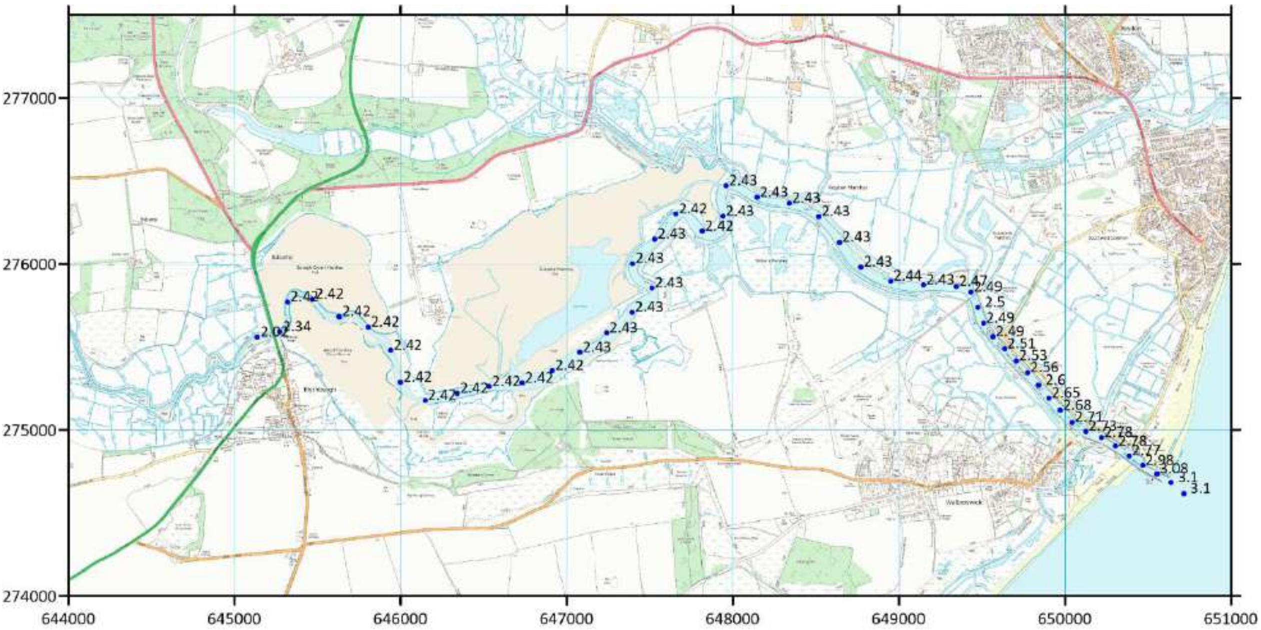


Figure 5-9: Peak flood levels (present-day defences, December 2013 conditions)

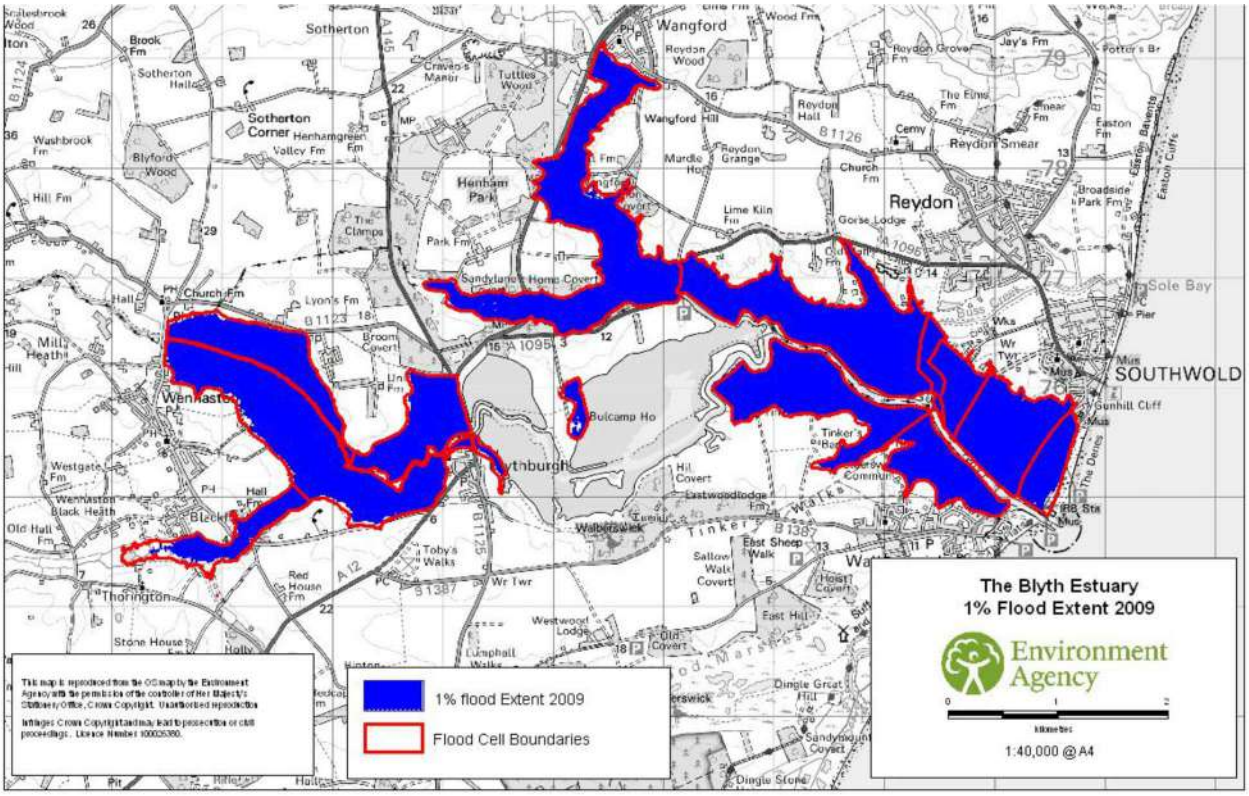


Figure 5-10: Blyth Estuary Strategy modelled 1% AEP flood extent

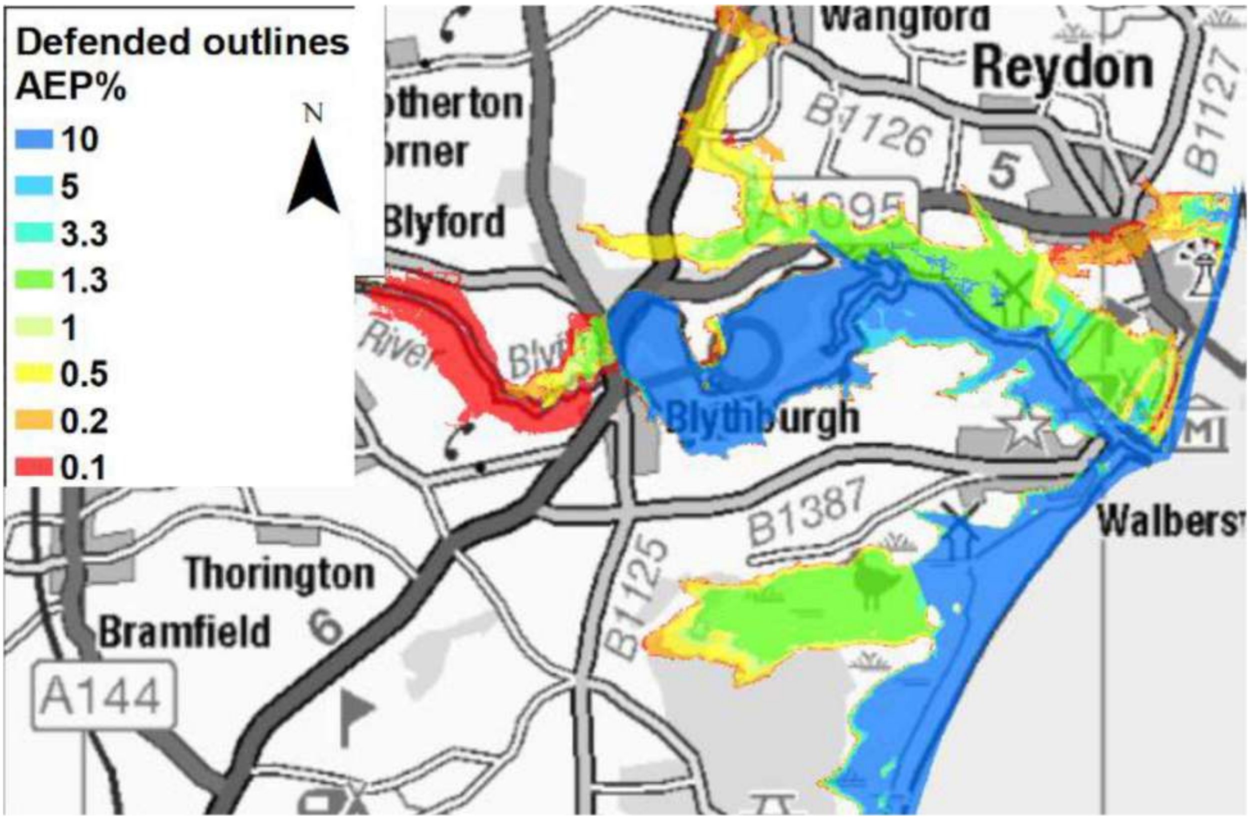


Figure 5-11: East Anglian Coastal Modelling, defended scenario, present day

5.1.3 Peak flow rate

The tidal model was also used to assess peak flow rates in the river channel and the wider Blyth estuary for the present-day harbour entrance structures and estuary defences. Flow rates are the maximum depth-average velocity at that point in the channel over the modelled tidal cycle. The February 2020 and December 2013 conditions were modelled, with the results shown in **Figure 5-12** and **Figure 5-13**.

For safe navigation of the entrance channel, the peak flow rate on the ebb tide needs to be less than 3.5 knots. The model results show that peak flow rates within the entrance channel are expected to be less than 1.5m/s (3 knots) for MHWS conditions, noting that the water level was higher than MHWS for the modelled February 2020 conditions. During the December 2013 event, peak flow rates reached 2.0m/s in the entrance channel (4 knots).

Figure 5-12: Peak flow rates (present-day defences, February 2020 conditions)

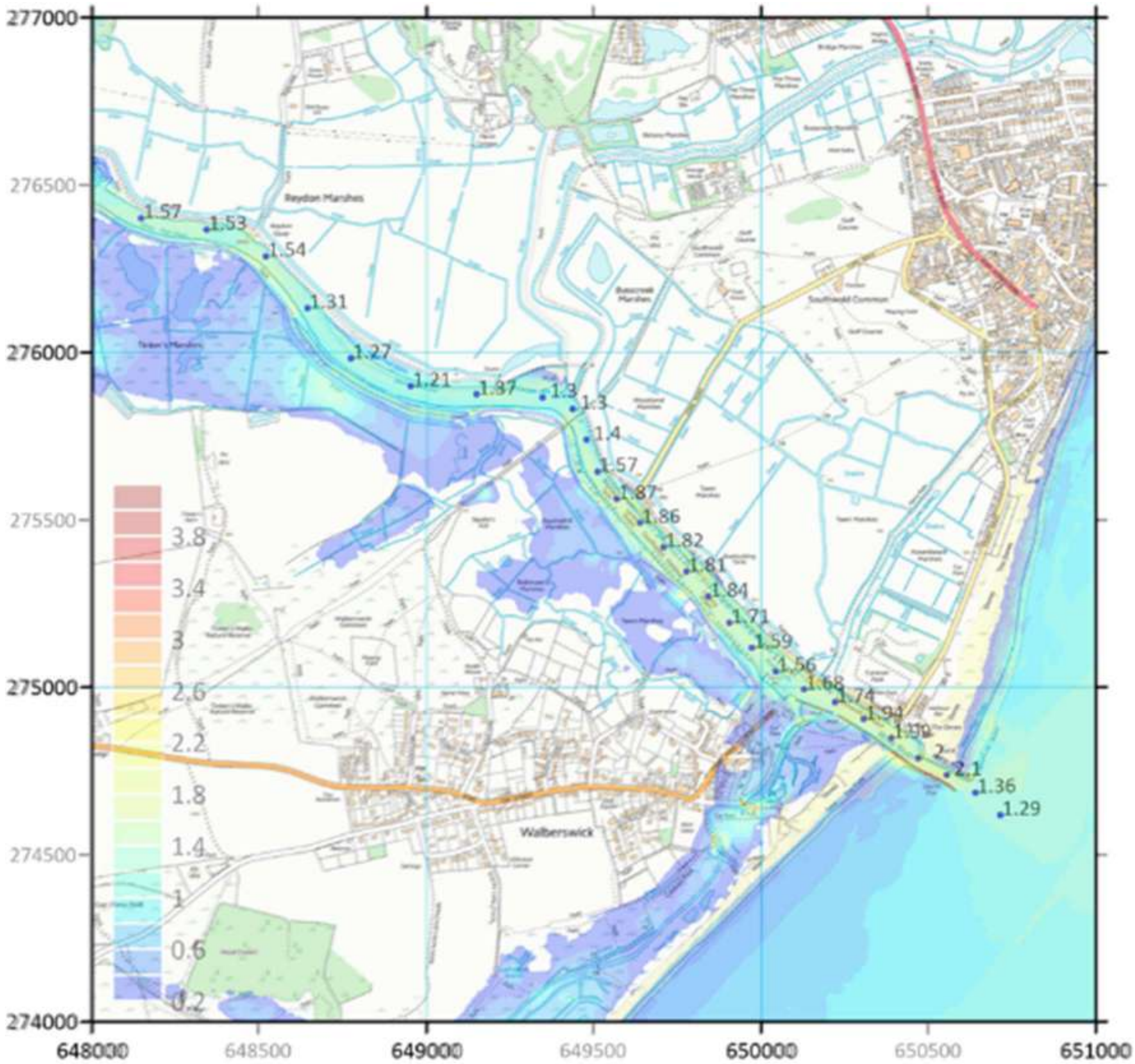


Figure 5-13: Peak flow rates (present-day defences, December 2013 conditions)

5.2 Future Conditions

5.2.1 Sea level rise

The assessment of future conditions at Southwold Harbour has considered the potential impact of climate change on sea levels. The UK Climate Projections 2018 (UKCP18)[16] include projections for sea level rise and future extreme water levels. These projections have been considered to determine the range of potential future sea levels at Southwold.

UKCP18 uses emissions scenarios, called Representative Concentration Pathways (RCPs), which are the emissions scenarios used in the Intergovernmental Panel on Climate Change's 5th assessment report. RCPs specify the concentrations of greenhouse gases that would result in target amounts of radiative forcing at the top of the atmosphere by 2100, relative to pre-industrial levels. Four forcing levels have been set: 2.6, 4.5, 6.0 and 8.5 W/m^2, which create the four RCPs used in UKCP18; RCP 2.6, RCP 4.5, RCP 6.0 and RCP

[16] https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index

8.5. The global mean temperature increase associated with each RCP is shown in **Table 5-2**. For sea level rise, RCP 2.6, RCP 4.5 and RCP 8.5 are typically used. For each RCP, data is presented for a range of percentiles (5% to 95%) which reflect the likelihood of occurrence of the climate impacts.

Table 5-2: UKCP18 emissions scenarios

RCP	Increase in global mean surface temperature (°C) by 2081-2100	Most similar SRES[17] (UKCP09) scenario (in terms of temperature)
RCP 2.6	1.6 (0.9 – 2.3)	None
RCP 4.5	2.4 (1.7 – 3.2)	SRES B1 (low emissions scenarios in UKCP09)
RCP 6.0	2.8 (2.0 – 3.7)	SRES B2 (between the low and medium emissions scenarios in UKCP09)
RCP 8.5	4.3 (3.2 – 5.4)	SRES A1F1 (high emissions scenarios in UKCP09)

Further information on RCPs is provided in UKCP18 Guidance on Representative Concentration Pathways and in the Science Overview Report. A guidance document is also available which compares UKCP18 to the previous UKCP09: ukcp18-guidance-ukcp18-for-ukcp09-users.pdf (metoffice.gov.uk).

Figure 5-14 shows the projected extreme water levels at Lowestoft in 2070, for the full range of RCP climate change scenarios. **Table 5-3** compares water levels at Lowestoft for 2020, 2040 and 2070.

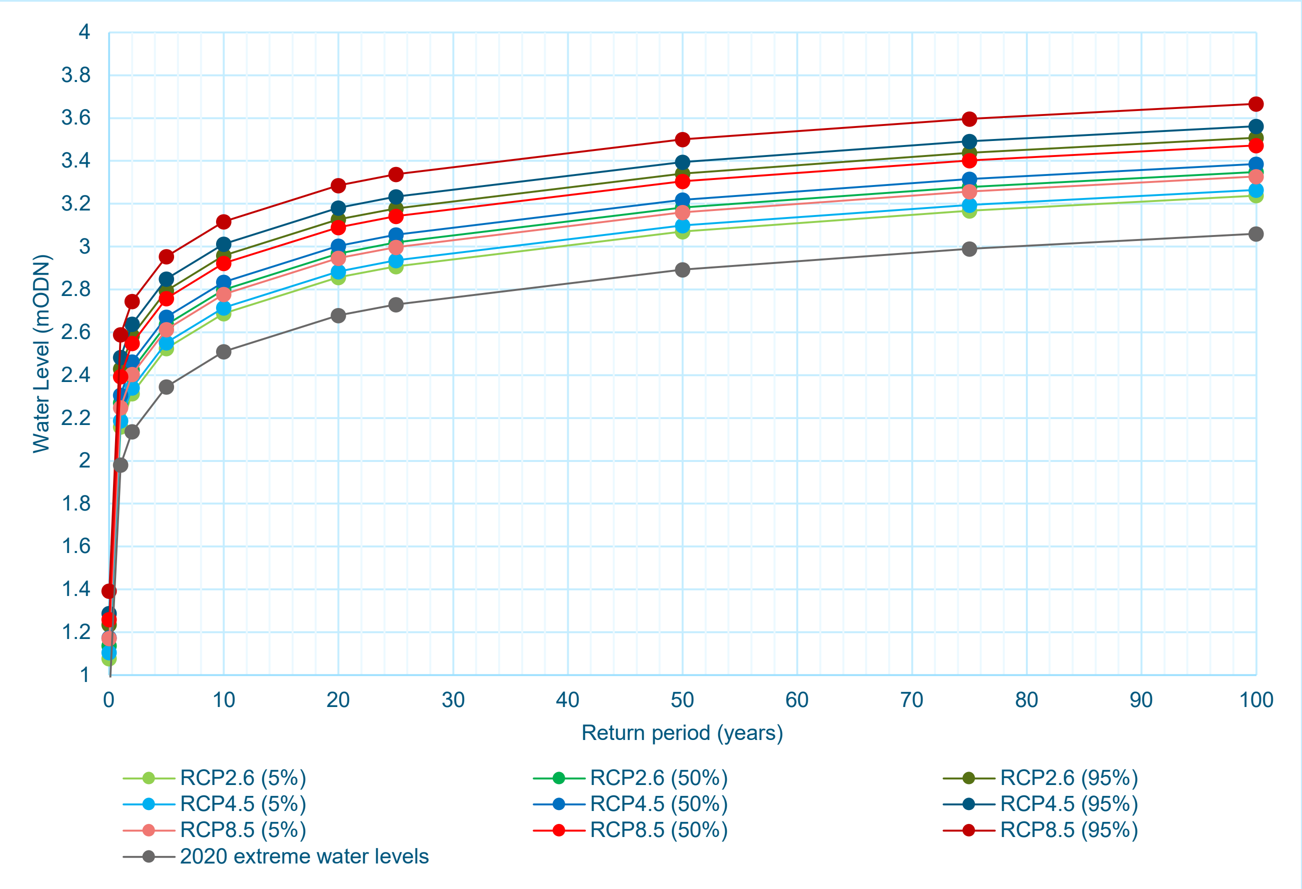


Figure 5-14:: Extreme water levels at Lowestoft, 2070

[17] *UKCP09 used the SRES (Special Report on Emissions Scenarios) emissions scenarios which were reported on in the IPCC's 4th assessment report.*

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Table 5-3: Future water levels at Lowestoft

Return Period, years (AEP %)	Water Level at Lowestoft, m ODN									
	2020			2040			2070			
	RCP2.6 (50%)	RCP4.5 (50%)	RCP8.5 (95%)	RCP2.6 (50%)	RCP4.5 (50%)	RCP8.5 (95%)	RCP4.5 (5%)	RCP2.6 (50%)	RCP4.5 (50%)	RCP8.5 (95%)
MLWS	-0.86	-0.86	-0.86	-0.76	-0.76	-0.71	-0.65	-0.62	-0.59	-0.37
MHWS	1.08	1.08	1.08	1.18	1.18	1.23	1.29	1.32	1.35	1.57
1 (100%)	2.03	2.03	2.09	2.13	2.13	2.25	2.18	2.27	2.31	2.59
5 (20%)	2.39	2.40	2.46	2.49	2.50	2.61	2.55	2.64	2.67	2.95
10 (10%)	2.56	2.56	2.62	2.66	2.66	2.78	2.72	2.80	2.84	3.12
50 (2%)	2.94	2.94	3.01	3.04	3.04	3.16	3.10	3.18	3.22	3.50
100 (1%)	3.11	3.11	3.17	3.20	3.21	3.33	3.27	3.35	3.39	3.67

During the December 2013 storm surge event, the water level at the mouth of Southwold harbour reached about 3.1m ODN. **Figure 5-14** shows that this event had a return period of about 100 years (1% AEP) based on the 2020 extreme water levels. The frequency of occurrence of a 3.1m ODN water level would be expected to increase in the future with climate change. For the least severe climate change scenario (RCP2.6, 5th percentile), the return period of a 3.1m ODN water level would be about 50 years (2% AEP). For the most severe climate change scenario (RCP8.5, 95th percentile, the return period of the 2013 event would be about 10 years (10% AEP).

Some members of the stakeholder group have requested that the assessment of future conditions focuses on a sea level rise scenario whereby there is no acceleration in the rate of sea level rise, so that the assessment of potential future scenarios for Southwold Harbour is not overly conservative. It has been suggested that the RCP4.5, 5th percentile projections best represent the increase in sea level at Southwold in recent years. Under this scenario, the water level at the harbour entrance would be about 3.3m ODN for a 100 year return period event (1% AEP). However, it is also recognised by the wider stakeholder group that the rate of sea level rise is uncertain and could now be accelerating.

The tidal modelling of the future estuary management options (**Appendix D** and **Section 8**) has considered a range of sea level rise scenarios, to enable assessment of the potential impact of increases in tidal prism on the harbour entrance structures. The following water level conditions were selected as input conditions for the tidal model, covering return periods ranging from less than 1 year (100% AEP) in the present day to 100 years (1% AEP) in 2070):

- 1.49m ODN at harbour mouth (February 2020 conditions)
- 2.04m ODN at harbour mouth (2070 RCP2.6 50th percentile, applied to February 2020 conditions);
- 2.7m ODN at harbour mouth[18];
- 3.1m ODN at harbour mouth (December 2013 conditions); and
- 3.57m ODN at harbour mouth (2070 RCP8.5 95th percentile, applied to December 2013 conditions).

The tidal modelling results for this range of water level conditions also enables an assessment to be made of the expected conditions for other water levels, by interpolation. For example, the water level and tidal current conditions for a water level of 3.3m at the harbour entrance would be expected to be approximately equivalent to the average of the results for the 3.1m and 3.57m tide levels.

5.2.2 Wave conditions

As the water depth in Southwold Harbour is of the order of 5m, waves 2m high would not be expected to break. Therefore, depth induced wave breaking does not influence operational wave conditions within the

[18] *To model this water level, a 0.4m reduction was applied to the December 2013 conditions.*

outer harbour. Consequently, the modelled wave heights within the harbour will be unchanged for higher water levels (e.g. due to sea level rise).

In terms of future wave conditions in the context of the design of any structures to replace the North and South Piers, a 1 in 100 year (1% AEP) wave condition allowing for 50 years of sea level rise is assumed. Waves from the 180 degree sector give the worst-case 1 in 100 year conditions at the North and South Piers (and **Figure 5-15**).

Table 5-4: Breakwater Design Conditions

Breakwater Design Conditions (100 year)	
Significant Wave Height, Hs	4.5m
Peak Wave Period, Tp	10 s
Wave Direction	180 degrees

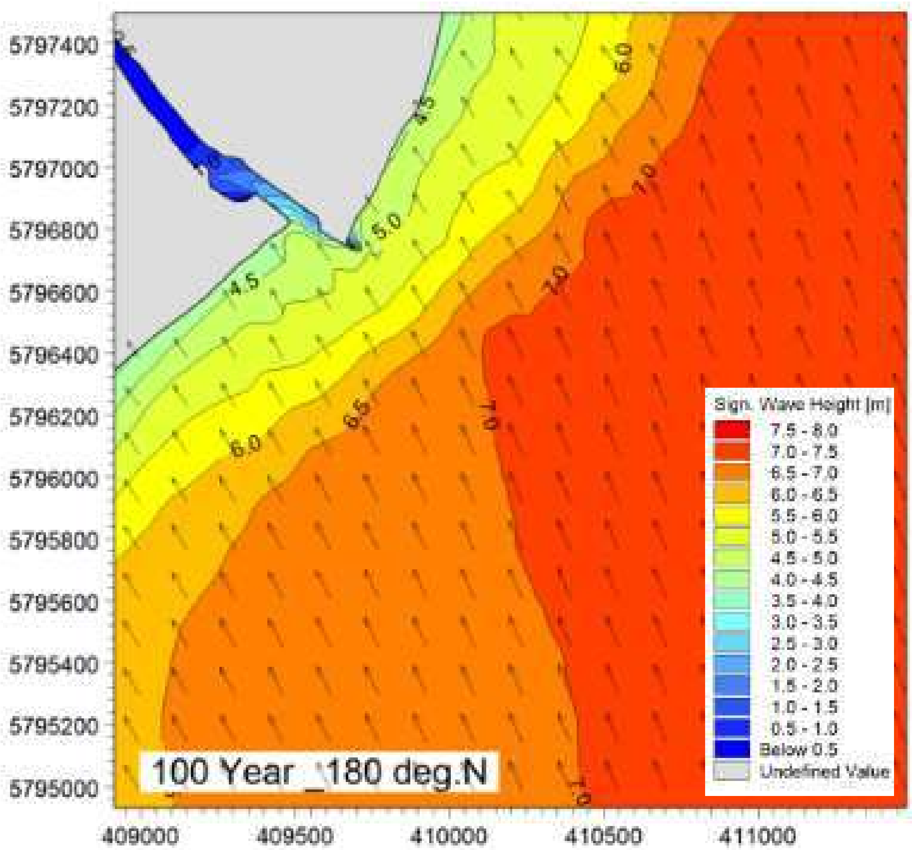

Figure 5-15: MIKE 21 Wave Transformation Model, 1 in 100 year wave from 180 degrees

5.2.3 Flood extents and peak water levels

Figure 5-16 shows that when 0.55m of sea level rise is applied to the February 2020 conditions (RCP 2.6, 50th percentile), flooding would be expected upstream of the A12, but the present-day estuary defences would not be overtopped. Peak water levels in the river channel increase in line with the increase in sea level at the harbour entrance (**Figure 5-18).**

Figure 5-17 shows that with the RCP8.5 95th percentile scenario applied to the December 2013 event conditions, the extent and depth of flooding increases significantly compared to the December 2013 event itself (**Figure 5-8**). The Walberswick dunes would be heavily overtopped and the Walberswick sluice overwhelmed. Peak water levels drop by 0.66m between the harbour mouth and the Bailey Bridge, where the peak water level is 2.81m ODN (**Figure 5-18)**.

With sea level rise, the Blackshore area will be at increasing risk of flooding. Many parts of the Harbour Road are already 0.2m below the Highest Astronomical Tide (1.6m ODN). **Figure 5-18** compares the peak water level in the channel for the baseline scenario (present day defences to harbour entrance and estuary), for all modelled water level conditions. This shows the effect that the narrow harbour entrance has in reducing water levels upstream, with water levels reducing by about 0.5m over the harbour entrance (Chainage 0 to 400m) for the higher water levels.

5.2.4 Peak flow rate

Figure 5-19 compares the peak flow rate in the channel for the baseline scenario (present day defences to harbour entrance and estuary), for all modelled water level conditions. This shows that for all water level conditions, there is a comparable variation in the peak flow rates with distance along the channel (the shape of the graph is the same).

The peak flow rate in the entrance channel exceeds 1.75m/s (3.5 knots) for the three highest water levels that were modelled. **Figure 5-20** compares the sensitivity of peak flow rates to water level at the harbour mouth, for various locations up to the Bailey Bridge. This shows that the peak flow rate in the entrance channel would be expected to exceed 1.75m/s (3.5 knots) when the water level at the harbour mouth was 2.4m ODN or higher. This is approximately equivalent to a present-day 1 in 5 year (20% AEP) event, or a 1 in 1 year (100% AEP) event with sea level rise to 2070. Therefore, if the integrity of the present day estuary defences was sustained, it is expected that the harbour entrance would continue to be navigable on a typical ebb tide. Higher flow rates would be experienced under more extreme water level conditions, but it is less likely that vessels would be leaving the harbour during such conditions.

Figure 5-16: Flood extent and depth (present-day defences, Feb 2020 conditions + SLR to 2070)

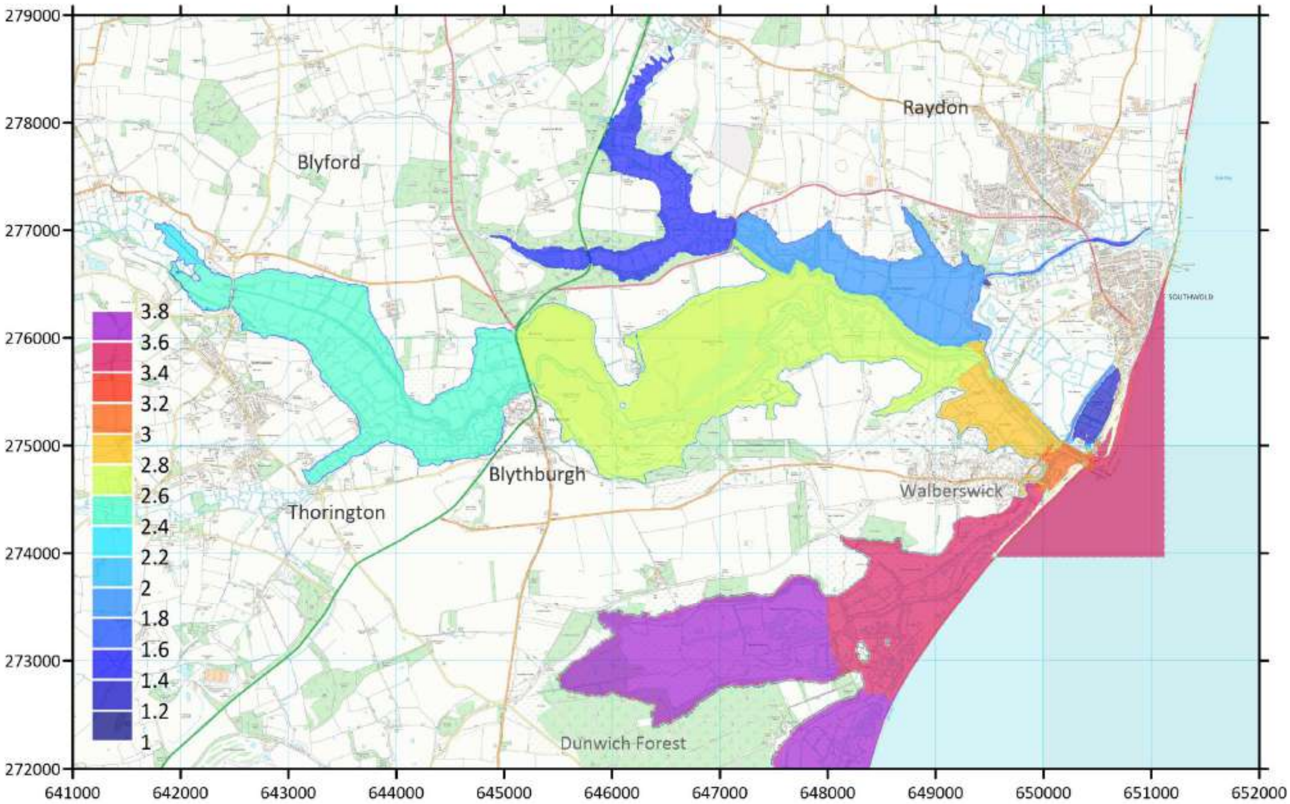

Figure 5-17: Flood extent and depth (present-day defences, Dec 2013 conditions + SLR to 2070)

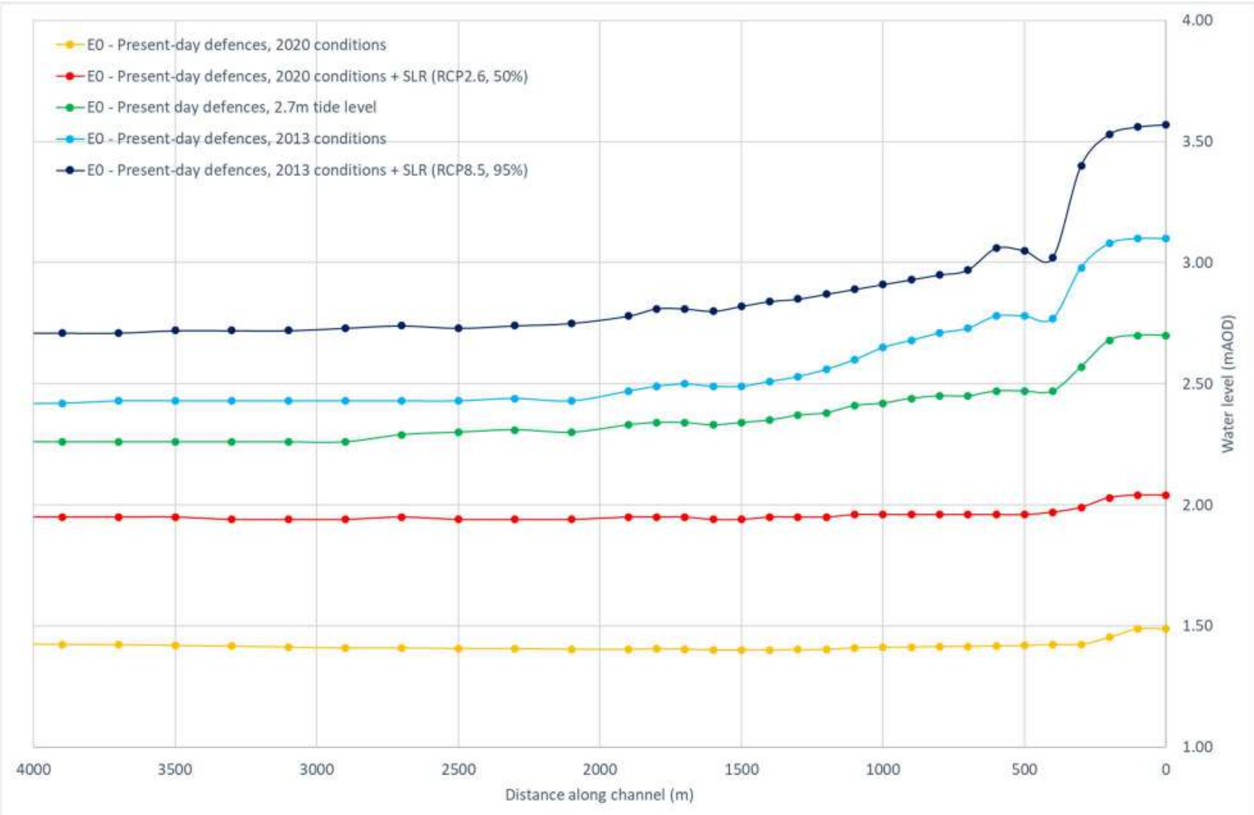

Figure 5-18: Change in peak water level along river channel, present day defences only

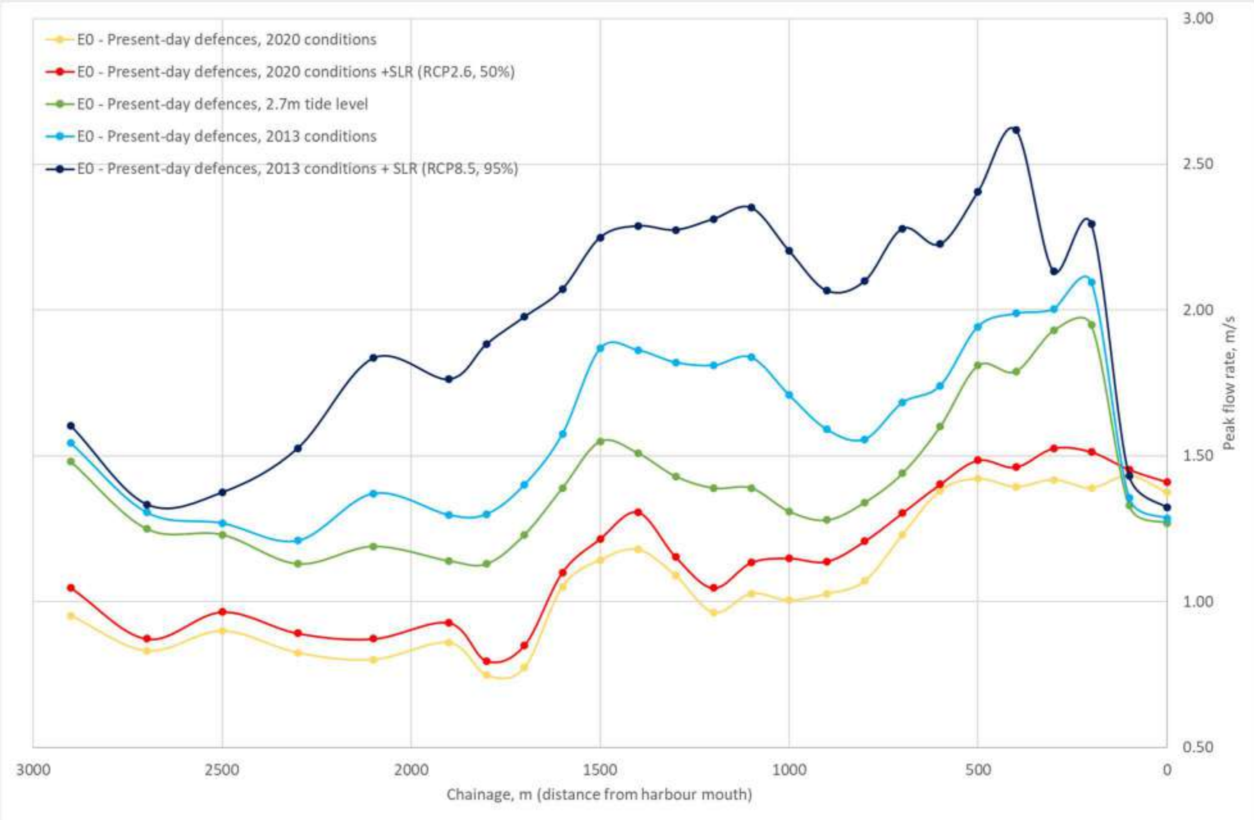

Figure 5-19: Change in peak flow rate along river channel, present day defences only

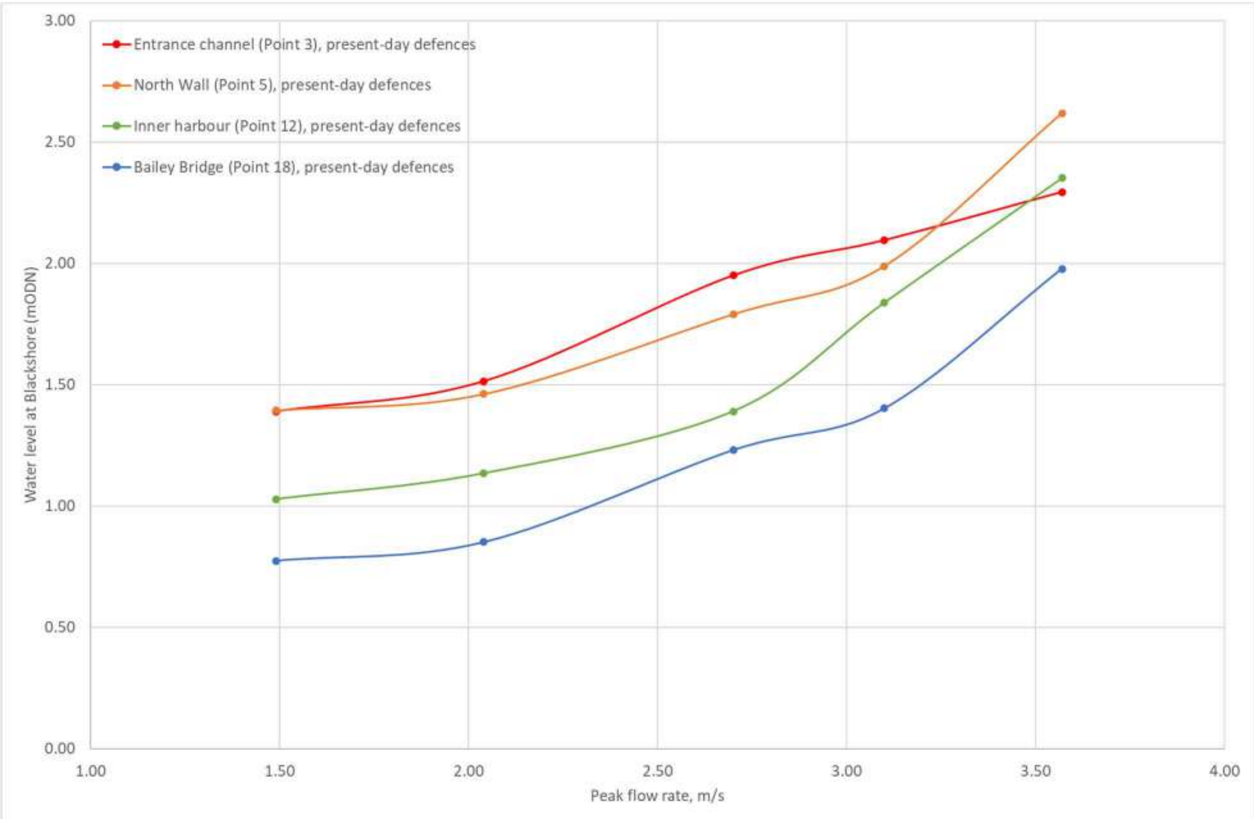

Figure 5-20: Sensitivity of flow rate to water level at harbour mouth, present day defences

6 Definition of the Problem

Section 6.1.1 describes the sequence of events that would be expected if nothing was done to improve the condition of the harbour entrance structures. **Section 6.1.2** describes the sequence of events if maintenance was to be withdrawn from the estuary embankments.

Section 6.2 summarises the future hydraulic conditions that would be expected within the harbour under a 'Do Nothing' scenario, in terms of waves, water levels and tidal flow rates, based on modelling carried out in the project.

Section 6.3 summarises the expected impacts of the Do Nothing scenario, considered against the project objectives for navigation and moorings, flood risk to properties and the Harbour, and long-term coastal management.

6.1 What would happen if nothing was done?

6.1.1 Harbour entrance structures

Figure 6-1 illustrates the sequence of events that would be expected to occur if nothing was done to improve the condition of the harbour entrance structures.

SP1. If nothing was done to improve the condition of the South Pier, it is expected to collapse within the next 5 years, with a high risk of failure during any severe storm, as it can no longer sustain its design loading. Failure would be dependent on wave conditions impacting on the pier, and it is noted that the residual life of the South Pier has been defined as <10 years since 1984, so it is possible that the South Pier could remain in place for more than 5 years.

Section C of the South Pier is at greatest risk of failure (**Section 4.1**). Otherwise, the seaward end of the pier is likely to fail more quickly than the inner sections, due to greater wave exposure. The remainder of the pier would then progressively collapse. Failure would be slower for the section of the South Pier from the shoreline to the Dunwich Creek channel, as the beach and dune system provides some protection.

The North and South Piers are also at risk of failure from undermining due to erosion of the bed of the harbour entrance channel (**Section 3.2**). If the South Pier does not fail due to wave impact, then failure from undermining might occur within 10 years.

SP1.1 Collapse of sections of the South Pier could cause blockage of the entrance channel, restricting or preventing access to the Harbour and potentially causing a safety hazard. Collapse of any section of the South Pier would increase the risk of collapse of adjacent sections.

SP1.1.1 With gaps in the South Pier, wave disturbance in the entrance channel and harbour will increase, affecting navigation and moorings at the North Wall and further upstream.

SP1.1.2 Sediment would move into the outer harbour from the south, which might further restrict access.

SP1.1.3 Increased sediment movement from south to north could accelerate the rate of erosion of the Walberswick dunes.

SP1.1.4 The risk of tidal flooding to Walberswick would also increase.

SP1.2 The loss of the South Pier would increase wave impact on the North Pier, which is not designed for direct wave impact.

SP1.2.1 The condition of the North Pier would be expected to deteriorate quite rapidly, with scour at the toe increasing the risk of failure. Failure of the North Pier would be expected within 10 years of failure of the South Pier (year 10 – 20).

SP1.2.2 Following the failure of the South and North Piers, the adjacent structures would begin to be affected, leading to collapse of the defence structures at the Knuckle and the South Training Arm, and eventually erosion around the seaward end of the North Wall. Failure of the structures in the vicinity of the Dunwich Creek channel might have safety impacts and could affect tidal flows and sedimentation. Failure of these structures would have only limited impact on the behaviour of the harbour in terms of waves and tidal flows.

SP1.2.3 Following failure of the North Pier, wave penetration into the inner harbour would increase further. The North Pier would no longer retain the southern end of the Denes, with the North beach expected to collapse into the present harbour channel and the coast eroding northwards to Southwold. The south beach would also erode more rapidly than at present.

SP1.2.4 With no intervention, erosion of the Denes will eventually lead to an increased risk of flooding to Southwold, and erosion of the Southwold town frontage

Erosion of the coastline will lead to the river channel gradually moving southwards due to sedimentation of the north side of the harbour. The longer-term realignment of the coast is described in the Suffolk SMP (Ref. 5) and shown in **Figure 6-2** below, which is reproduced from the SMP.

Table 6-1 summarises the expected residual life of the harbour structures under a Do Nothing scenario.

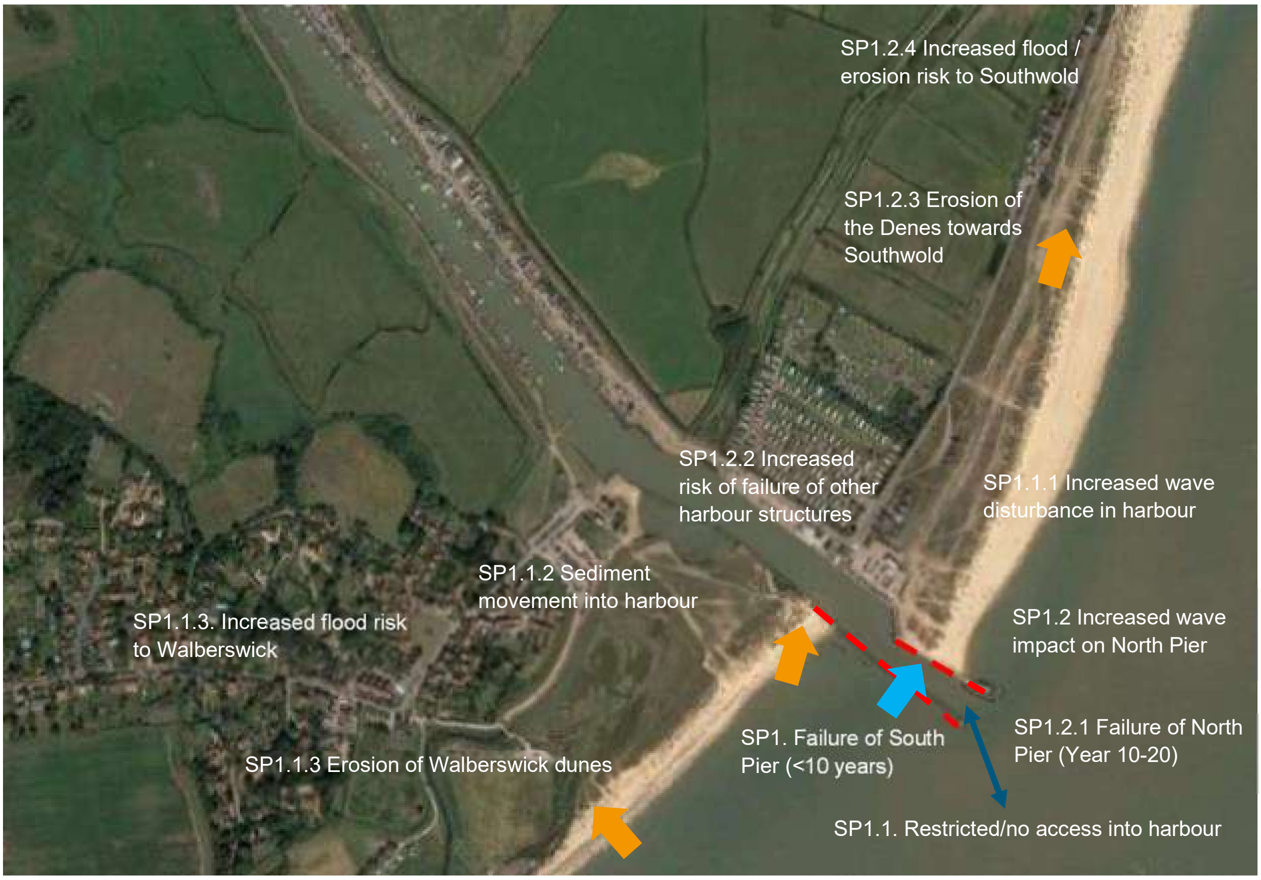

Figure 6-1: Illustration of impacts of Do Nothing scenario for the harbour entrance structures

Table 6-1: Residual life of harbour entrance structures in Do Nothing scenario

Structure	Residual Life with 'Do Nothing'
South Pier	<5 years
North Pier	10-20 years
South Training Wall	10-20 years
Dunwich Creek Timber Groyne	10-20 years
Knuckle	10-20 years
North Wall	20-30 years

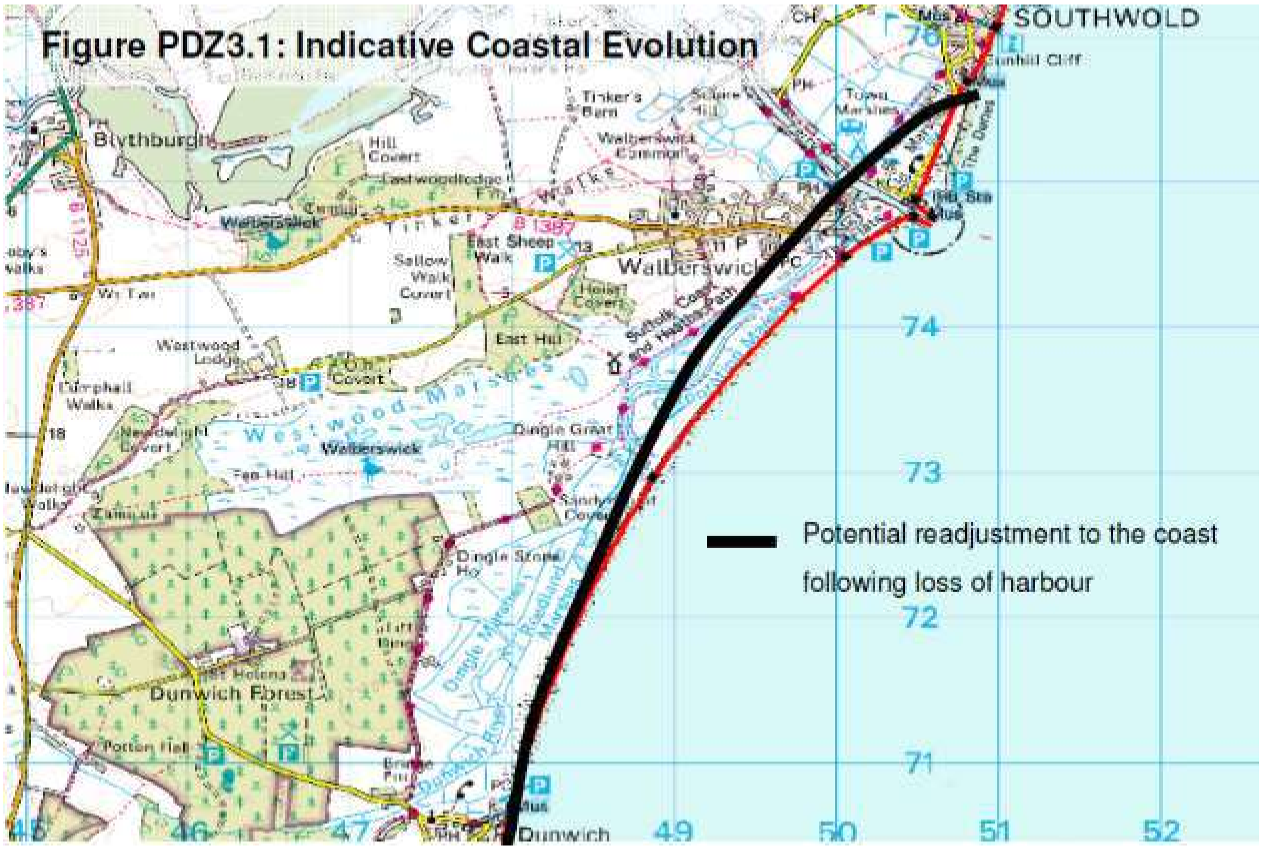

Figure 6-2: Expected future evolution of the coastline, from Suffolk SMP (Ref. 5)

6.1.2 Estuary defences

Figure 6-3 illustrates the sequence of events that would be expected to occur if nothing was done to improve the condition or standard of protection provided by the estuary flood defences.

E1. If nothing was done to improve the condition or defence level of the flood embankments to the Blyth estuary, gradual failure of these defences would be expected over the next 20 years.

Based on the existing crest level of the defences, overtopping of the embankments to Tinkers' and Robinsons' marshes would be expected during storm events with return periods of 1 in 5 years or more (>20% AEP). When embankments are overtopped, there is a high risk that a breach will occur. Therefore at least one breach in the estuary embankments would be expected within 5 years, with the number and extent of the breaches increasing with time if they are not repaired.

E1.1 With the failure of the embankments, the marshes will be inundated on high tides, increasing the risk of flooding to properties in Walberswick and Southwold.

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E1.1.1 Flooding of the marshes is expected to result in reduced peak flood levels in the river channel, reducing the risk of flooding to Blackshore properties and harbour businesses.

E1.1.2 With the marshes available to flood, the tidal prism of the estuary is expected to increase significantly, although this may depend on the rate of sedimentation of the marshes (**Section 3.8**). The rate of flow of water in and out of the estuary is directly related to the volume of water that can be held in the estuary, so the peak flow rate in the river channel will increase. This increase in flow rate will be greatest at the harbour entrance, where the channel width is constrained by the North and South Piers.

E1.1.2.1 An increase in the flow rate in the harbour entrance channel would be expected to increase the rate of erosion of the channel bed. If the harbour entrance structures were still in place, the risk of failure would be increased.

E1.1.2.2 The increased flow rate would also impact on navigation in the Harbour.

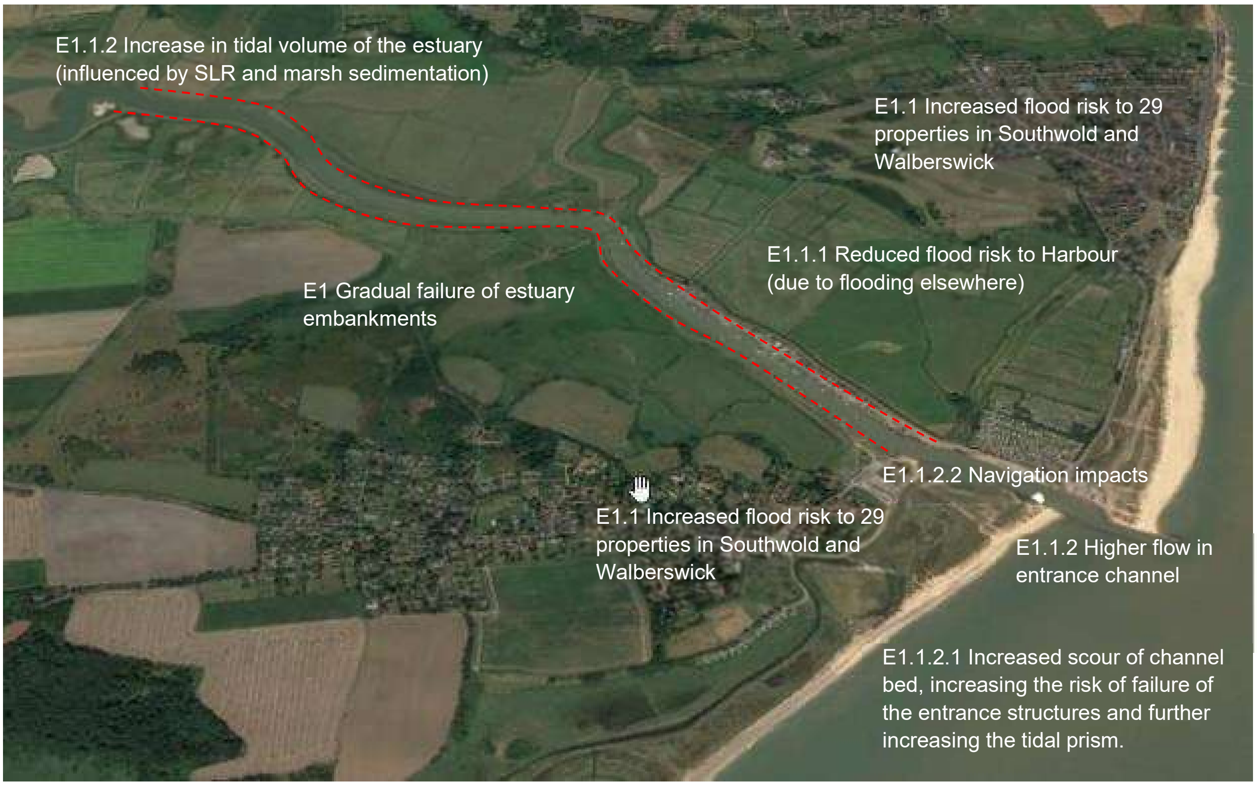

Figure 6-3: Illustration of the impacts of the Do Nothing scenario for the estuary defences

6.2 Hydraulic Regime in the Harbour

6.2.1 Wave conditions

Figure 6-4 and **Table 6-2** compare the 1-year return period wave conditions in the harbour with the present-day entrance structures against the conditions if the outer part of the South Pier was allowed to fail. These results show that the loss of the outer part of the South Pier has relatively limited impact on wave conditions in the outer harbour, because at present waves are able to penetrate through the windows in the South Pier, with the model showing quite high levels of wave transmission through the pier. As discussed in **Section 5.2.2**, the modelled wave heights are unchanged if water levels increase due to sea level rise.

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1-year return period conditions (present day) *1-year return period conditions (Do Nothing)*

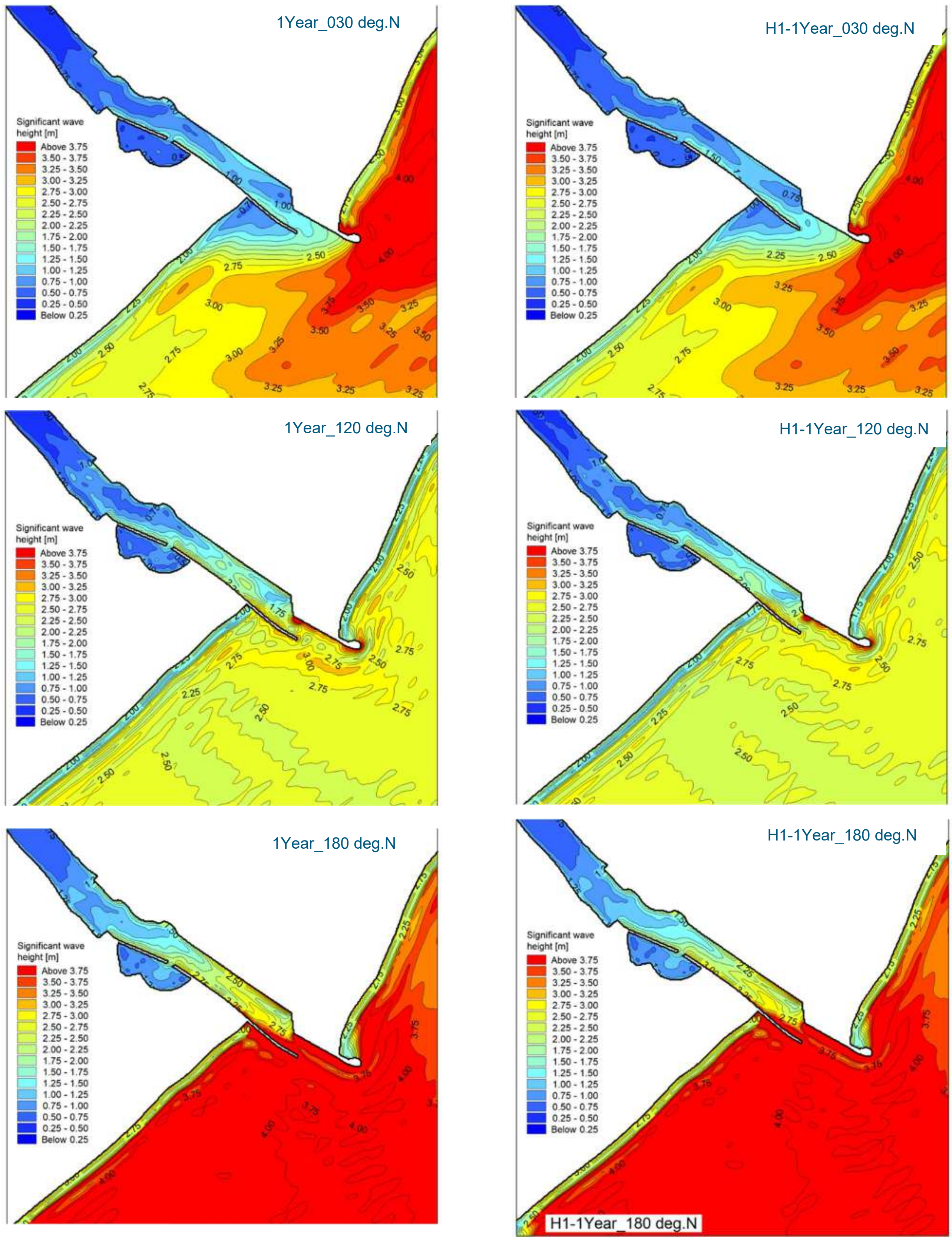

Figure 6-4: Wave modelling results comparing Present-day harbour entrance with Do Nothing scenario

Table 6-2: Wave conditions in the Harbour, comparing present-day and Do Nothing

Location	Scenario	Hm0 (m) due to waves from Offshore Direction (deg.N)							
		0	**30**	**60**	**90**	**120**	**150**	**180**	**210**
Harbour front	H0 - Present-day Baseline	0.7-1.0	0.8-1.2	0.6-1.0	0.6-1.4	1.0-2.2	1.0-2.6	1.5 -3.5	1.3-3.3
	H1 - Do Nothing	0.7-1.0	0.8-1.2	0.6-1.0	0.6-1.5	1.0-2.4	1.0-3.0	1.5-3.7	1.3-3.5
Dunwick - Walberswick	H0 - Present-day Baseline	0.5-1.5	0.6-1.8	0.5-1.4	0.5-1.3	0.7-1.8	0.7-2.0	1.0-2.3	0.7-2.1
	H1 - Do Nothing	0.5-1.5	0.7-1.8	0.5-1.4	0.5-1.5	0.7-2.0	0.8-2.3	1.0-3.0	0.7-2.3
Upstream Moorings	H0 - Present-day Baseline	0.3-0.5	0.3-0.6	0.3-0.7	0.3-0.6	0.3-0.7	0.3-0.7	0.6-0.9	0.4-0.7
	H1 - Do Nothing	0.3-0.5	0.4-0.6	0.3-0.7	0.4-0.6	0.4-0.7	0.5-0.7	0.7-1.0	0.5-0.7

6.2.2 Flood extents and peak water levels

The tidal model was used to assess the flood extents, water depths and peak water levels for the Do Nothing scenario, for both the present-day and future water level conditions. The results are presented in **Figure 6-5** to **Figure 6-8**.

Figure 6-5 shows that with failure of the estuary defences there would be flooding of Tinkers, Robinsons' and Reydon Marshes for the February 2020 conditions. With sea level rise applied to the February 2020 conditions, Town Marshes and a small area upstream of the A12 would also flood.

Comparing **Figure 6-7** to **Figure 5-8** (present-day defences) shows that for the December 2013 conditions under the Do Nothing scenario there would be a much larger flood extent to the north of the river, as well as a greater depth of flooding. For the most extreme conditions of the December 2013 event with sea level rise to 2070 (RCP8.5, 95%), flooding extends to the Town Marshes, and via Buss Creek into Southwold.

The modelled flood extents for the Do Nothing scenario can be compared with the East Anglian Coastal Modelling results (present day undefended scenario), which are included as **Figure 6-9** (1% AEP flood outline shown in light green). The model results are similar, providing validation of the tidal model results.

Figure 6-10 compares the peak water levels in the river channel for the Do Nothing scenario with the baseline scenario (present-day defences), for all water level conditions. This shows that without flood embankments the peak water level in the channel through the harbour reach (chainage 500m to 1800m) is reduced by about 200mm for the lower water level conditions. On extreme surge events such as the December 2013 conditions, the removal of the defences has a greater impact on peak water levels in the harbour, reducing these by up to 400mm.

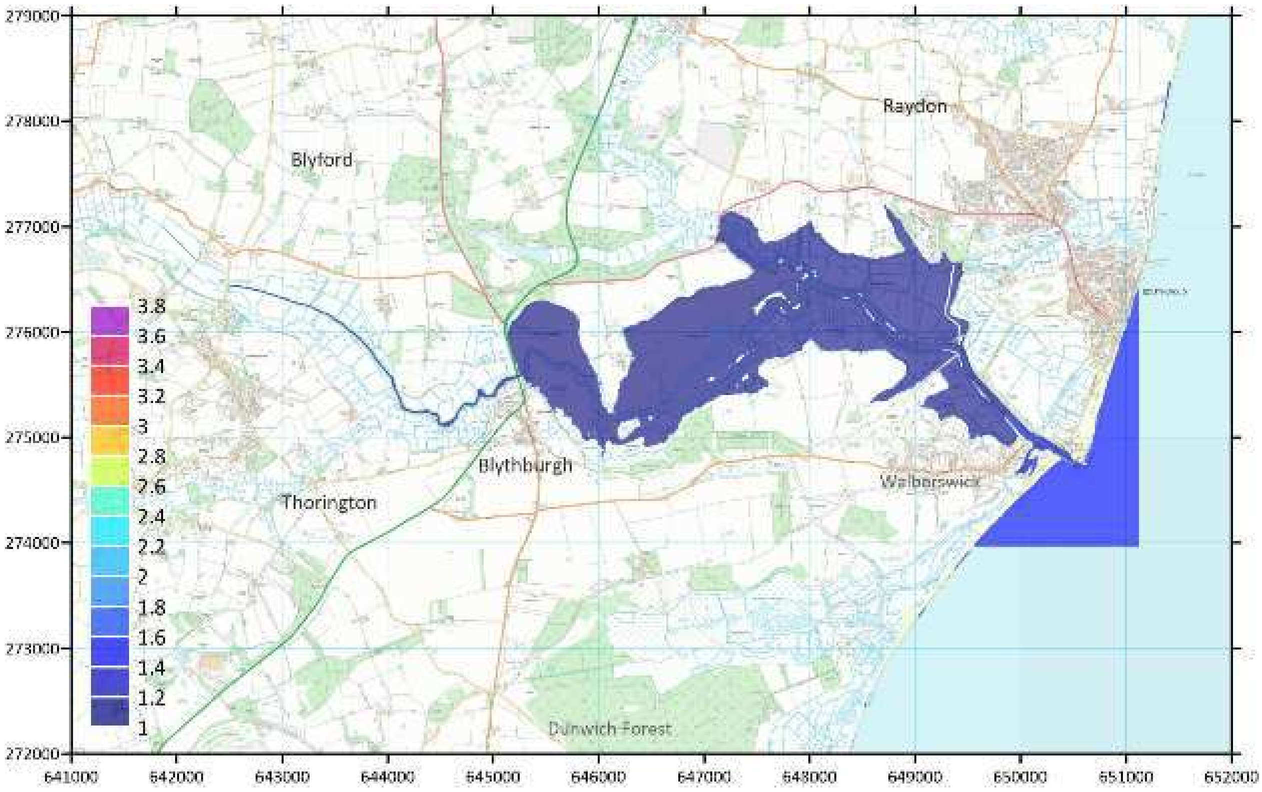

Figure 6-5: Flood extent and depth (Do Nothing, February 2020 conditions)

Figure 6-6: Flood extent and depth (Do Nothing, February 2020 conditions with SLR to 2070)

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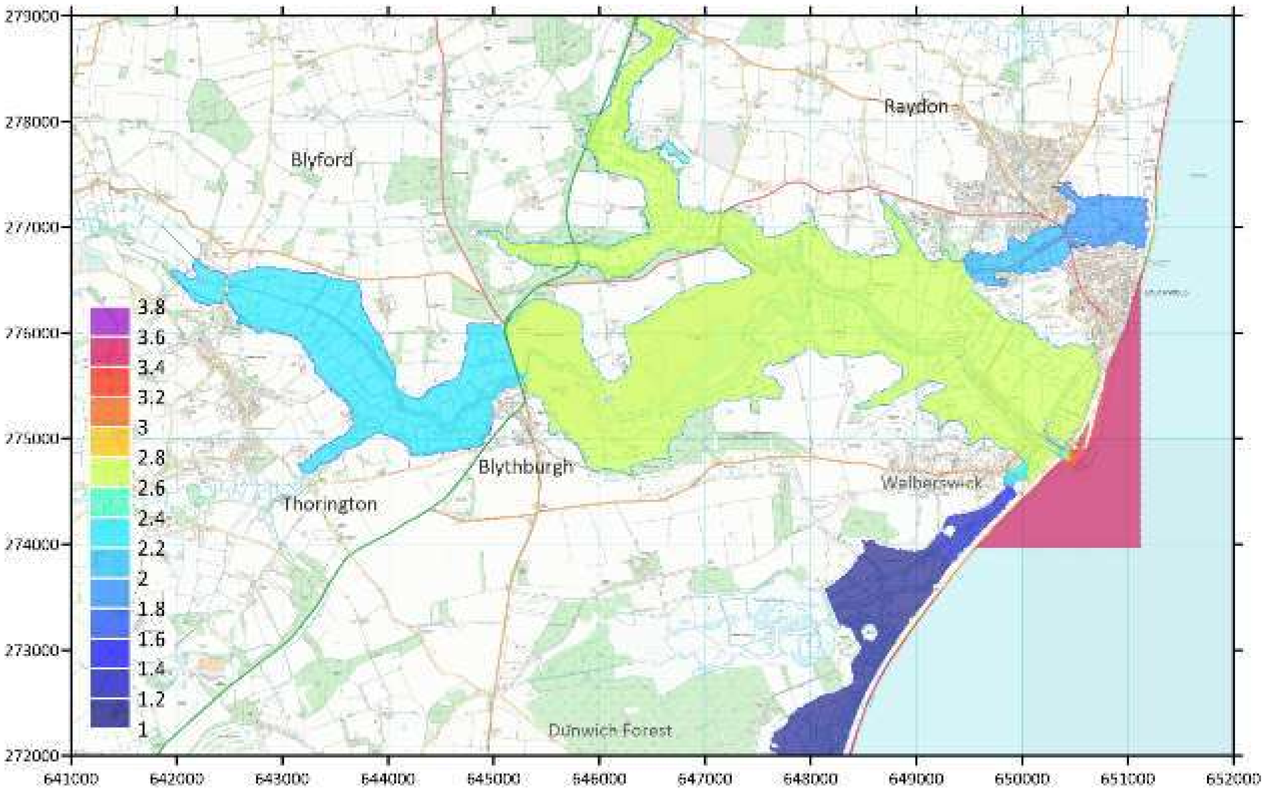

Figure 6-7: Flood extent and depth (Do Nothing, December 2013 conditions)

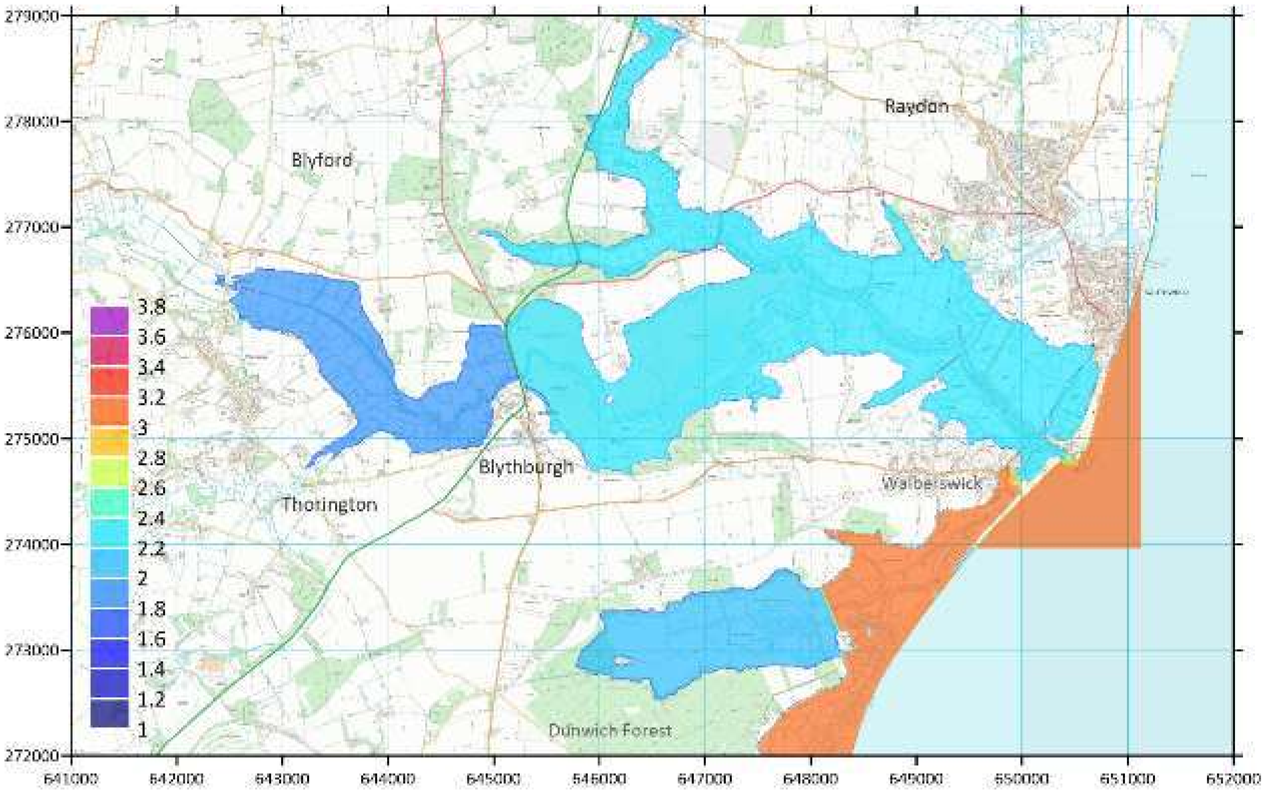

Figure 6-8: Flood extent and depth (present-day defences, Dec 2013 conditions with SLR to 2070)

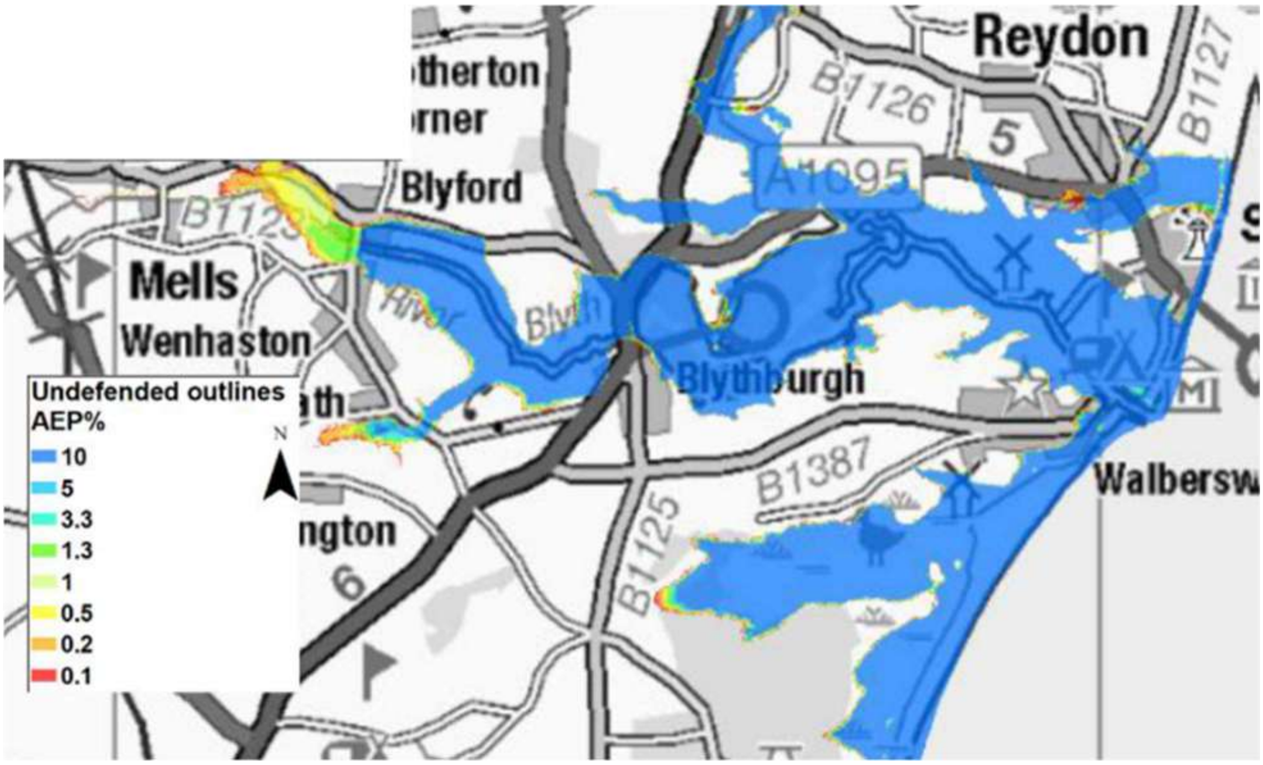

Figure 6-9: East Anglian Coastal Modelling, undefended scenario, present day

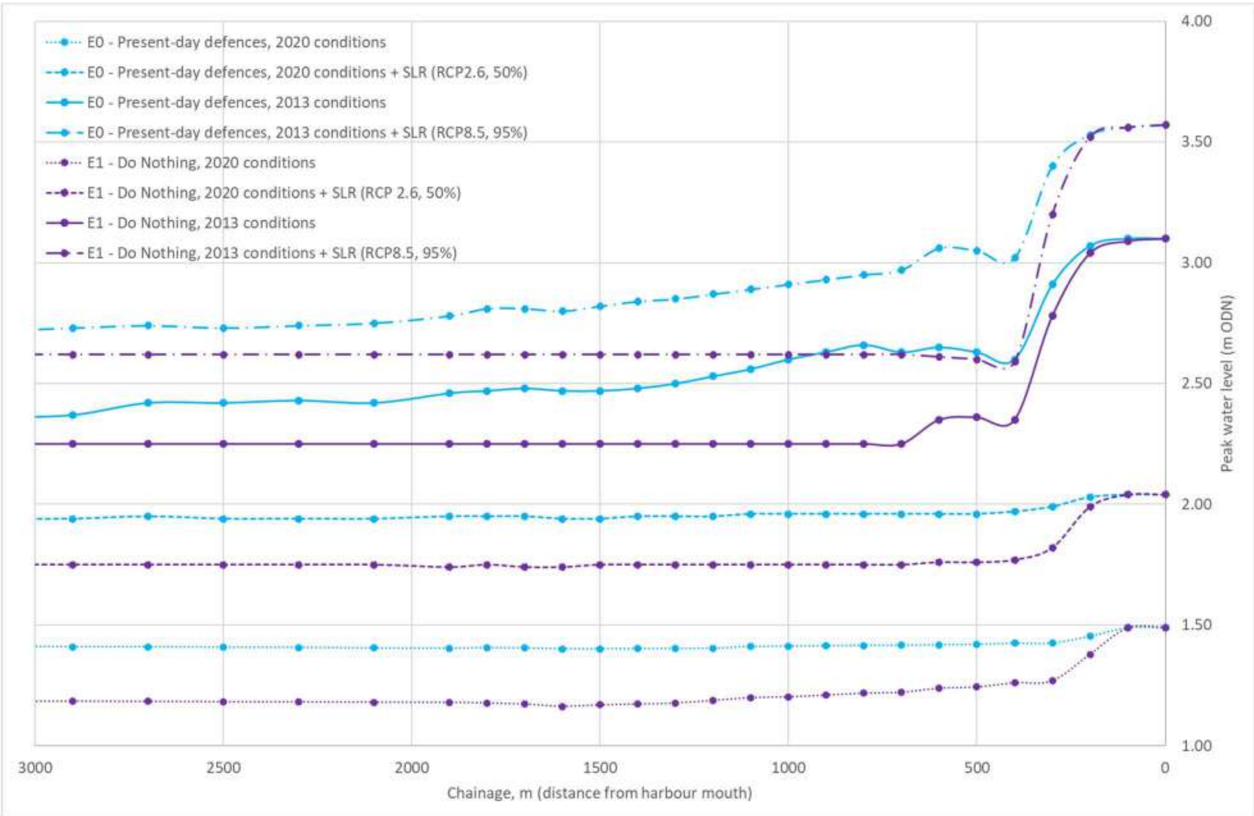

Figure 6-10: Change in peak water level along channel (Present Day Defences / Do Nothing)

6.2.3 Peak flow rate

Peak flow rates were modelled for the Do Nothing scenario, and the results are shown in **Figure 6-12**: and **Figure 6-13**: for the February 2020 and December 2013 conditions respectively. **Figure 6-11** compares the peak flow rate in the river channel for the Do Nothing scenario with the baseline scenario (present-day defences), for all water level conditions, as follows:

- Peak flow rates in the entrance channel exceed 1.75m/s (3.5 knots) for all water level conditions.
- For the February 2020 conditions, peak flow rates in the entrance channel are 36% higher (1.9m/s) for the Do Nothing scenario compared to peak flow rates with the present-day defences (1.4m/s).
- For the 2013 event conditions, peak flow rates in the entrance channel are 49% higher (3.1m/s) for the Do Nothing scenario compared to with the present-day defences (2.1m/s).
- For all water level conditions, peak flow rates in the outer harbour are higher for the Do Nothing scenario. Without the estuary flood defences the tidal prism is increased; more water is held within the estuary so a greater volume of water flows in and out on each tide. In the outer harbour water continues to be mainly held within the river channel, so flow rates increase.
- Further upstream, for the higher water levels, the flood water can spread out over the marshes and therefore peak flow rates can be less than with the present-day defences.

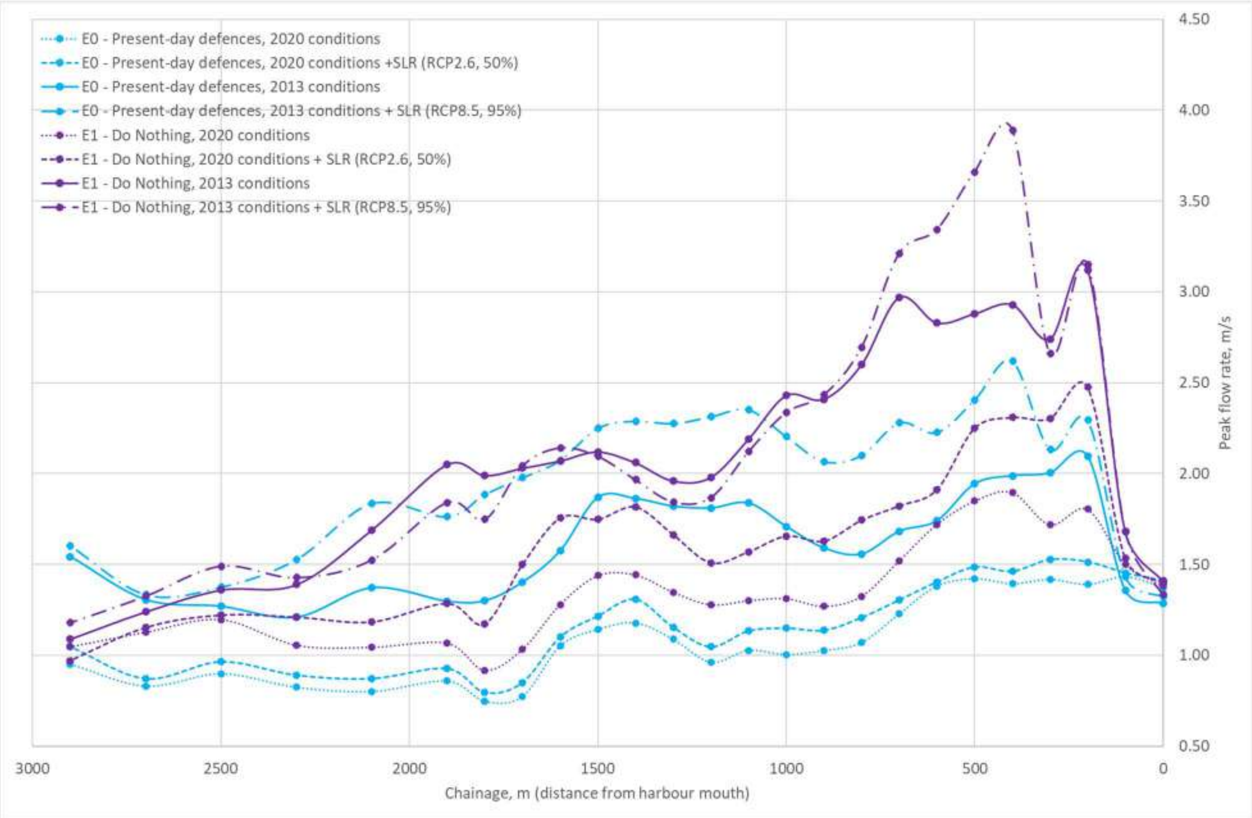

Figure 6-11: Change in peak flow rate along channel (Present Day Defences / Do Nothing)

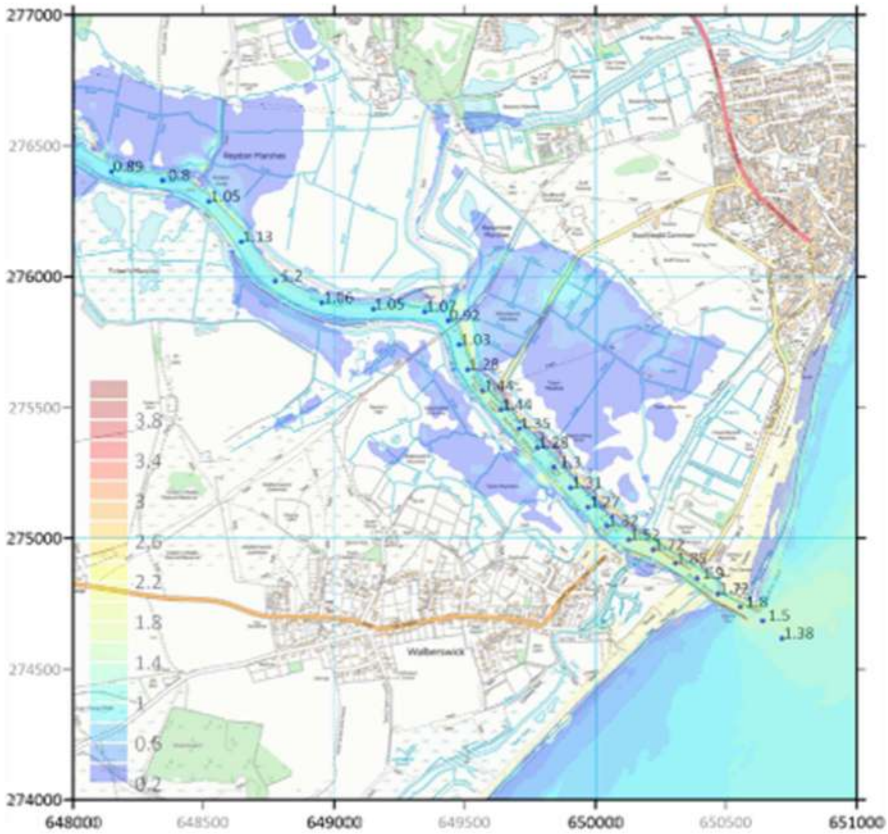

Figure 6-12: Peak flow rates (Do Nothing, February 2020 conditions)

Figure 6-13: Peak flow rates (Do Nothing, December 2013 conditions)

6.3 Summary of Impacts of Do Nothing scenario

The following statements are made in the SMP regarding the impact of the 'Do Nothing' scenario on the harbour and adjacent coastline:

- *"if the defences within the inner estuary are abandoned, the most significant influence on the tidal prism would be the flooding of the Reydon Marshes. This would increase flow rates by some 50% within the harbour reach…Abandoning Tinkers Marsh would have a similar but smaller effect. Similarly, inclusion of Robinson's Marsh would have less impact but would still increase flow at the harbour mouth."*
- *"The integrity [of the harbour entrance structures] is strongly influenced by the tidal prism of the estuary…in the absence of control at the mouth, there would be an immediate response in the coast."*

These statements are supported by the modelling results, which show a 36% increase in flow rates in the for the February 2020 water level conditions, and a 49% increase for the December 2013 conditions. These results show the significant impact that failure of the estuary defences would have on flow rates in the entrance channel, and the associated risk to navigation and for of increased scour of the channel bed.

In terms of peak flood levels in the harbour, failure of the defences would be beneficial, as the peak water level is reduced by about 200mm for the lower water level conditions and by up to 400mm for surge conditions such as the December 2013 event.

Loss of the South Pier would have a slight negative impact on wave conditions in the outer harbour. Present day conditions in the outer harbour are currently severe enough to restrict mooring at the North Wall, with wave transmission through the South Pier affecting this.

7 Option Development

7.1 Approach to Development of Options

The solutions for the future management of the harbour entrance structures have been developed separately from the possible approaches to management of the estuary defences and flood risk to the harbour.

Options for the replacement or refurbishment of the harbour structures were developed considering the full range of strategic solutions and methods available. This assessment is set out in **Appendix E**, with the conclusions summarised below.

The scenarios and associated assumptions for future management of the estuary defences are described in **Section 7.3.** The assessment of the performance of the options, based on the findings of the technical analysis, is presented in **Section 8**.

The approach taken to the management of the estuary defences could influence the future performance of the harbour entrance structures, and therefore any decisions taken for these structures. These interactions and dependencies are addressed in **Section 9**.

7.2 Options for the Harbour Entrance Structures

7.2.1 Strategic options for the harbour entrance

Do Nothing

This option assumes no future intervention of any kind. No further maintenance, repair work, emergency response or warning would be undertaken. The condition of the harbour entrance structures would be allowed to deteriorate over time, eventually leading to failure. Following failure of the structures, they would only be removed if they present a safety risk. The impacts of this strategic option have been assessed and are described in **Section 6.1.1**.

Hold the Line

This option involves either sustaining or improving the integrity and/or standard of protection provided by the existing defences so that the defence line is held at its current position. This option would provide coast protection and maintain access to the harbour. Environmentally this option could maintain the current natural processes operating along the frontage and within the estuary. Various approaches could be taken to achieve the strategic 'Hold the Line' option, ranging from 'Do Minimum' options, such as maintaining or repairing the existing structures for as long as possible, to full replacement of the harbour entrance structures.

Advance the Line

Advancing the line would involve the reconstruction of the harbour structures to extend the mouth of the harbour further seaward, or the addition of a new structure offshore of the harbour entrance, with the aim of improving conditions within the harbour. This is not a stand-alone option; works would still be required to address the poor condition of the South Pier. Whilst this strategic option could improve wave conditions in the harbour, there is a risk that changes to the alignment of harbour mouth could have negative impact on wave reflection, tidal flows and conditions for navigation and moorings.

Replacement of the North and/or South Piers could include a change in alignment to optimise conditions, but it is not expected that an increase in length of either piers would be necessary. A breakwater located offshore of the harbour entrance would restrict navigation and would not fully address wave penetration issues. Therefore, this strategic option is rejected.

Retreat the Line
Retreating the line would involve a reduction in length of the North and/or South Piers, or the reconstruction of new harbour structures some distance landward. There is limited scope for full realignment of the harbour, but the reduction in length of the South Pier could have benefits in terms of tidal flow rates in the entrance channel, so this option has been assessed using the wave and tidal models.

7.2.2 Structural solutions for the harbour entrance

The following solutions, described in **Appendix E,** could be used to improve the condition of the harbour structures, or to replace them:

- Patch repairs to concrete
- Toe reinforcement and/or scour protection
- Local repairs to sections of the South Pier
- Replace North and/or South Piers with a similar structure
- Replace North and/or South Piers with a rock and/or concrete armour breakwater
- Replace North and/or South Piers with a vertical walled structure

All of these measures have been considered further in the development of options for the harbour entrance structures, including an assessment of costs (**Appendix F** and **Section 9**).

7.2.3 Additional measures to improve conditions

The following additional structural measures, described in **Appendix E**, could be implemented in the harbour in combination with the main structural solutions in order to improve conditions and use of the harbour:

- Concrete baffles attached to harbour structures;
- Rock structure to narrow the channel;
- Maintain flow through South Pier;
- Reduce length of South Training Wall;
- Remove Dunwich Creek timber piles;
- Wave energy dissipation measures at Dunwich Creek;
- Dredging; and
- Infilling areas of scour.

The options of concrete baffles and a larger rock structure to act as both a wave baffle and to narrow the channel opposite the North Wall were considered further in the wave and tidal modelling of options.

Development of the proposed breakwater option considered how flow through the South Pier could be maintained. An additional assessment was undertaken to consider this solution further, which is provided as **Appendix H** and discussed in **Section 8.8.1.**

Solutions to improve the conditions around Dunwich Creek are viable and could be considered further in the future. However, if a solution is to be implemented which improves wave conditions as well as improving the structural condition of the South Pier, then works to the structures at Dunwich Creek are unlikely to be required. These options have not been considered further in this assessment.

Some dredging may be required as part of any works to the South Pier. The shoal bank opposite the North Wall could also be removed to provide more space for navigation and mooring. Dredged material could be used to infill areas of scour or placed against the toe of the North or South Piers to reduce erosion risk. An additional assessment was undertaken to review the impact of dredging of the outer harbour on wave conditions and tidal flows, which is provided as **Appendix I** and discussed in **Section 8.8.2.**

7.2.4 Non-structural measures to improve use of the Harbour

Non-structural measures which could improve the use of the harbour and/or future understanding of harbour conditions are described in more detail in **Appendix E**. All of these measures could be undertaken alongside any of the structural solutions.

The following measures are recommended and will be included as part of the Investment Plan:

- Structural condition inspection (e.g. annually)
- Bathymetric survey and tidal flow monitoring (e.g. every 3 years)
- Flood forecasting and warning (ongoing)
- Lead-in mark (as part of any works to replaced the South Pier)

The following measures are not included in the Investment Plan, but could be taken forward by the Council or by Harbour users in the future:

- Fendering and mooring bollards on the North Wall
- Floating pontoons
- Replacement of the Bailey Bridge
- Information / training to harbour users

7.2.5 Options for the Harbour entrance structures

The strategic options and the initial assessment of potential structural solutions described in **Appendix E** have been used to develop a suite of proposed options for the future management of Southwold Harbour, which are set out in **Table 7-1**. These options focus on works to the South Pier, as the condition of this structure is of greatest concern, but the options also refer to potential works to the North Pier and the Knuckle if this is needed in the future. The options do not include the potential non-structural measures, which can be undertaken in combination with any of the options.

The performance of each of these options has been assessed using the wave and tidal models, considering the future impacts of the potential management scenarios for the estuary defences. This assessment is presented in **Section 8**. Cost estimates for each option are presented in **Section 9**.

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Table 7-1: Options for future management of the harbour entrance structures

Option	Description	Impacts	Advantages	Disadvantages
H1 - Do Nothing	This option assumes no future intervention of any kind. No further maintenance or repair work is undertaken, other than to address immediate safety issues. The condition of the harbour entrance structures is allowed to deteriorate over time, eventually leading to failure. The structures would only be removed if they present a safety risk.	The impacts of this option are described in detail in Section 6.1.1.	No cost, other than to address safety issues. No change to navigation and mooring conditions in the short term. No local disruption from construction works. Included in Investment Plan as baseline scenario, and in recognition of the risk of short-term failure of the harbour structures.	High risk of failure of South Pier in the near future, and of other structures within 20 years. Impacts for safety, navigation, and ultimately the viability of the Harbour. Does not address predicted climate change impacts. Doesn’t improve harbour conditions for navigation and mooring. Does not achieve objectives for the future management of the harbour.
H2 - Do Minimum (Maintain)	Maintain present condition of existing defences by undertaking patch repairs as required, until total failure of the structure occurs, e.g. collapse of the South Pier. Undertake emergency response and warning. Repair works would be the lowest cost option, e.g. patch repair to concrete, rock armour placed at sections at immediate risk of undermining or collapse. Following failure of structures, they would only be removed if they present a safety risk.	This option accepts a reducing SOP and an increasing failure risk, with this risk potentially accelerating due to climate change. Structures are allowed to fail when maintenance is no longer possible, after which point the impacts set out for the Do Nothing option would be realised, although delayed. Potential safety risk if structures collapse, with closure of harbour until made safe.	Low Cost compared to replacement options. May reduce risk of structural failure in the short term. Unlikely to make harbour conditions worse.	Risk of failure of South Pier within 10 years, and other structures at later dates. Does not improve harbour conditions for navigation and mooring.
H3 - Do Minimum (Repair)	Upgrade condition of existing defences by undertaking repairs to localised areas of failure / high failure risk. This might include replacing Section C of the South Pier (refer to Section 4), reinforcing the toe of the structures (to address immediate undermining risk) and patch repairs.	This option accepts an ongoing reduction in SOP and an increasing risk of failure, with this risk potentially accelerating in the future with climate change.	Less initial capital investment compared to replacement options, potentially higher whole life cost with repeated repair works.	Risk that repairs cannot be continued beyond the relatively short term. Risk of failure of South Pier within 20 years, and of other structures at later dates.

Option	Description	Impacts	Advantages	Disadvantages
	Short-term repair works to Section C of the South Pier could include infilling this section with rock armour, or replacing the structure with sheet piles. This approach could potentially be taken to repair of other sections of the South Pier to delay the requirement for full replacement. Repair works would be continued whilst they remain viable but are not expected to be able to extend the life expectancy of the harbour structures to 2070. With this option the structures would not be replaced at the end of their life if ongoing repairs cannot be continued.	Structures are allowed to fail when repair is no longer possible, after which point the impacts set out for the Do Nothing option would be realised, although delayed. Potential safety risk if structures collapse, with closure of harbour until it is made safe.	May reduce risk of structural failure in the short term, potentially for longer than the 'Maintain' option. Unlikely to make harbour conditions worse.	Does not improve harbour conditions for navigation and mooring.
H4 - Repair then replace	As discussed above for Option 2: Do Minimum (Repair), the condition of the existing defences would initially be improved by undertaking repairs to localised areas of failure / high failure risk. Repair works would be continued whilst they remain viable. The structures would be replaced, by the lowest-cost option that enables the harbour to continue to function (currently assumed to be replacement of the North and South Piers with a rock or concrete armour breakwater).	Repairs undertaken with the aim of reducing the risk of failure and extending the life of the structure. Replacement works planned as required, undertaking this before failure of the structure occurs. Some failure risk remains until the piers are replaced, although this is reduced compared to the 'Do Minimum' options.	Repair works could delay the need for major capital investment in replacement of the South and North Piers. Allows the economic benefits of replacing the structures to be re-assessed ahead of works being undertaken. Maintains the present conditions for navigation, depending on climate change impacts.	May not be possible to continue repair works beyond the relatively short term. Requirement for capital works to the South Pier within 20 years, and to other structures at later dates. Does not improve SoP / risk of failure / harbour conditions with predicted climate change
H5 – Replace South Pier with a similar structure	Complete replacement of South Pier and training wall with new structure, similar to the existing design. This would include retaining the 'windows' in the structural walls with the aim of maintaining the wave climate within the harbour (subject to future changes). Works assumed to be undertaken within the next 5 years. Structures designed to address risk of failure by undermining (e.g. foundation depth / toe design), and other climate change impacts, e.g. increased overtopping. A new alignment of the South Pier may need to be considered to address the impacts of a future increase in tidal prism.	The South Pier would be removed and replaced within the next 5 years. The design of the structure would address any future risks e.g. expected changes in channel bed level and tidal flow conditions and be optimised in terms of harbour conditions. No further negative impacts on the harbour area would be expected, apart from constraints on use of the	New structure can be designed to reduce failure risks e.g. deeper toe. Maintains existing conditions in the harbour in the short term. Design could be optimised to mitigate climate change impacts, e.g. adjusted alignment, bigger windows,	High cost to remove existing structure and replace. Expect to be higher cost than rock breakwater. Hydraulic performance of harbour is very sensitive to minor changes, so conditions in the harbour could be made worse. Unlikely to improve harbour conditions.

Option	Description	Impacts	Advantages	Disadvantages
	Replacement of the North Pier and Knuckle may be required in the longer term in combination with this option, with the timing dependant on future channel erosion rates. Additional structural measures could be undertaken in the harbour in combination with this option, and the potential advantages of these will be considered further.	harbour during construction of the new pier. There would continue to be a risk that the existing South Pier structure could collapse before the new structure is built.	baffles or rock toe to reduce wave energy. Long-term solution, design life ~100 years.	May not be possible to mitigate future climate change impacts through design.
H6 - Replace South Pier with a breakwater	Construction of a sloping defence structure to replace the South Pier, using rock armour and/or concrete armour units. Works assumed to be undertaken within the next 5 years. Full or partial removal of existing structures before replacement, or by placing rock and/or concrete armour units over / around the existing structures. Structures designed to address risk of failure by undermining (e.g. toe piles). Box culverts could be incorporated into the breakwater to allow flow into the entrance channel from the south, with the aim of maintaining present conditions in the channel. A new alignment of the South Pier could be considered to address the impacts of a future increase in tidal prism. Replacement of the North Pier and Knuckle may be required in the longer term in combination with this option, with the timing dependant on future channel erosion rates. Additional structural measures could be undertaken in the harbour in combination with this option (concrete baffles, structure to narrow the channel), and the potential advantages of these will be considered further.	The South Pier would be removed replaced within the next 5 years. The design of the structure would address any future risks e.g. expected changes in channel bed level and tidal flow conditions and be optimised in terms of harbour conditions. No further negative impacts on the harbour area would be expected, apart from constraints on use of the harbour during construction of the new pier. There would continue to be a risk that the existing South Pier structure could collapse before the new structure is built.	Rock and/or concrete breakwaters dissipate wave energy better than vertical structures and so would improve the wave climate within the entrance channel and harbour. Failure risks reduced through appropriate toe design. Design could be optimised to maintain entrance channel conditions (using box culverts) and to mitigate climate change impacts, e.g. adjusted alignment. Rock armour structures are typically lower cost than vertical walled structures. Long-term solution, design life ~100 years.	High cost for long-term solution. Risk that changes to defence alignment in sensitive wave climate has a negative impact on conditions in entrance channel. Need to include fendering in design to reduce risk of vessels being driven into the rock structure. Larger footprint than Option 2.

7.3 Options for Flood Risk Management of the Blyth Estuary

7.3.1 Strategic management scenarios

The potential strategic management scenarios for the estuary defences were defined in the scope of work for this project (Ref. 8), recognising the conclusions of the Blyth Estuary Strategy and the Suffolk SMP, as well as recommendations from the stakeholder group during initial consultation. All of the following scenarios have been considered in the development of the Investment Plan.

- **E0 – Maintain Integrity of Present-day Defences**

  This option aims to keep the existing estuary defences in place for as long as possible, but without major capital investment, assuming that the embankments can be maintained and repaired until about 2040. After this time a decision would be taken as to whether to (a) discontinue maintenance (Do Nothing) or (b) improve the estuary defences.

- **E1 - Do Nothing**

  This scenario assumes no further works will be undertaken to the estuary flood defences or to the harbour structures. No further maintenance, repair work, emergency response or warning would be undertaken. The condition of the flood embankments and associated structures would be allowed to deteriorate over time, eventually leading to failure. Following failure of the structures, they would only be removed if they present a safety risk. The impacts of this strategic option are described in **Section 6.1.2**, including relevant figures.

- **E2 - Improve Estuary Defences**

  This 'Hold the Line' option assumes that the estuary defences are fully maintained and improved to provide protection against a 1 in 100 year (1% AEP) surge event, allowing for sea level rise to 2070 but assuming that the rate of sea level rise would not accelerate and that sedimentation of the marshes means that tidal flow volumes are decreasing. The harbour structures are maintained or improved as necessary. This scenario reflects the community and landowner aspirations that were presented by the BEP during development of the scope of work for this project. It is comparable with 'Option 2 – Hold the Line' from the Blyth Estuary Strategy. In the assessment of this option, the full range of potential climate change scenarios has been considered.

- **E3 - SMP Policy**

  This 'Managed Realignment' option assumes that the Harbour entrance structures and defences on the north side of the estuary are maintained and improved to keep pace with sea level rise and tidal flow volumes. Banks on the south side of the estuary are realigned allowing for flooding of Robinsons' and Tinkers' marshes. This management scenario is also comparable with 'Option 8 – Hold North Banks' from the Blyth Estuary Strategy.

- **E4 - EA Strategy Position**

  This 'Managed Realignment' option assumes that management of the Harbour entrance structures, and of the estuary defences is withdrawn gradually until 2030, with defences abandoned thereafter. Secondary defences would be built to reduce the risk of flooding to Walberswick and Southwold. A terminal groyne would be built at Gun Hill to the south of Southwold to limit the extent of coastal erosion following loss of the North Pier. This is 'Option 9A – Adaptation + Secondary Defences' from the EA Strategy. This scenario assumes that there is no sedimentation of the marshes, and that the tidal prism will increase significantly due to sea level rise.

7.3.2 Additional estuary management options

Over the course of this project, the following potential modifications to the above listed scenarios have been identified by the project team and the stakeholder group. These options have been included in the assessment of option performance (**Section 8**) and cost estimates (**Section 9**):

- **E5 - Tidal barrier**

  A tidal barrier could be constructed across the harbour entrance, landward of the Lifeboat station, and would be raised or lowered on surge events to prevent flooding. This would be an 'Advance the Line' option in the context of the flood protection of the estuary. Various options for tidal barriers have been reviewed, and are included in **Table E3** within **Appendix E**. Although the capital cost would be very high, a radial tidal barrier (similar to the Thames barrage) is a viable management solution to address flood risk to the Harbour and the wider estuary.

- **E6 – Spillway**

  This option would be a 'managed alternative' to Option E3, the SMP Policy scenario. Instead of removing or realigning the southern estuary defences, the embankments to Robinsons' and Tinkers' marshes would be raised to keep pace with sea level rise.

  With the aim of reducing peak water levels in the Harbour, particularly at the Blackshore, a spillway would be constructed in the embankment to Robinsons' Marsh, Tinkers Marsh or Reydon Marsh. The spillway could take the form of either:

  - An automatically controlled sluice gate which could be opened on surge tides to flood the adjacent marsh (**Option E6a**).
  - A 'passive' spillway, whereby a section of the embankment would be is lowered and reinforced, enabling overtopping into the adjacent marsh when the water level in the river channel is higher than the spillway level (**Option E6b**).

  The development of the potential spillway options is set out in **Appendix E.**

- **E7 - Narrow channel:** The river channel could be narrowed opposite the North Wall to constrain the volume of water entering the estuary and reduce water levels upstream. This option could be combined with any of the other management options for the estuary defences and harbour structures. The narrow channel option is discussed further in **Appendix E and Appendix I**.

- **Reduced Standard of Protection (SOP)**

  For Option E2 (Improve Estuary Defences), a 1 in 100 year (1% AEP) SOP is proposed. The Blyth Estuary Strategy identified the limited economic benefits associated with 'Hold the Line' options for the Blyth Estuary, therefore it was recognised that lower SOPs may need to be considered in case a higher SOP was not affordable. Therefore, improvements to the estuary defences which achieve a 1 in 5 year (20% AEP) SOP (allowing for sea level rise) have also been assessed, for Option E2 (Improve Estuary Defences), Option E3 (SMP Policy), and Option E6b (Passive Spillway). A 1 in 5 year (20% AEP) SOP reflects the optimised SOP identified by the Blyth Estuary Strategy.

- **Maintain defence integrity then Improve (E0b)**

  This option aims to delay the need for major capital investment in the estuary defences for as long as possible. In order to delay the capital investment, an increased level of investment in maintenance of the estuary embankments would be needed in the short term. This would include making provision for repairs to any breaches in the embankments that might occur on an extreme surge tide.

  The estuary embankments currently have a typical SOP of at least 1 in 5 years (25% AEP), not including for future sea level rise. By 2040 it would be expected that the embankments to Robinsons' and Tinkers' marshes would be overtopped most years. Therefore, this option assumes that the estuary defences can be maintained and repaired until 2040, after which time the SOP of the defences would be improved to either a 1 in 5 year (20% AEP) or 1 in 100 year (1% AEP) SOP.

7.4 Options to Reduce Flood Risk to the Harbour

For all of the scenarios for management of the estuary defences, with the exception of the tidal barrier, there remains a risk of flooding to the Harbour. Possible solutions for reducing the risk of flooding to the Blackshore properties and to the Harbour Road are set out in Appendix E, which includes an initial assessment of the viability of these options. Options include:

- A flood wall or embankment in front of the Blackshore cottages;
- Flood walls immediately in front of the Harbour Inn, Sailing Club and adjacent properties, incorporating flood gates as necessary;
- Flood wall along the river edge in front of the Harbour Inn area, incorporating flood gates for access to the pontoons;
- Flood walls along the full length of the Harbour Road;
- Raising the level of the Harbour Road;
- Property level protection measures to the Blackshore properties e.g. stop boards and flood doors; and
- Limited maintenance to infill low spots and reduce channel bank erosion risk.

Flood walls could be constructed using a combination of concrete and masonry. Glass panels could be included in the walls to maintain the visual amenity, although at higher cost.

As for the options for management of the estuary defences, both a 1 in 5 year (20% AEP) and a 1 in 100 year (1% AEP) SOP are considered for the potential works to protect the Harbour in the cost estimates (**Section 9.4**) and assessment of options (**Section 10.4**).

7.5 Summary of Options for the Future Management of Southwold Harbour

All of the options for the harbour entrance structures can potentially be undertaken in combination with any of the management scenarios for the estuary defences, and with any of the options to reduce flood risk to the Harbour. The full list of options assessed in **Section 9** and **Section 10** are listed below.

Options for the Harbour Entrance

- H1: Do Nothing
- H2: Do Minimum (Maintain)
- H3: Do Minimum (Repair)
- H4: Repair then replace
- H5: Replace South Pier with a similar structure
- H6: Replace South Pier with a breakwater

Estuary Management Scenarios

- E0a: Maintain integrity of present-day defences
- E0b: Maintain defence integrity then improve
- E1: Do Nothing
- E2a: Improve Estuary Defences (1:100 SOP)
- E2b: Improve Estuary Defences (1:5 SOP)

- E3a: SMP Policy (1:100 SOP)
- E3b: SMP Policy (1:5 SOP)
- E4: EA Strategy
- E5: Tidal Barrier
- E6: Spillway
- E7: Narrow channel

Options to reduce flood risk to the Harbour

- B1: Do Nothing
- B2: Raise Harbour Road (1:5 SOP)
- B3: Raise Harbour Road (1:100 SOP)
- B4a: Raise Harbour Road plus concrete flood walls (1:100 SOP)
- B4b: Raise Harbour Road plus glass and concrete flood walls (1:100 SOP)
- B5: Raise Harbour Road (1:5 SOP) + concrete flood walls to Blackshore (1:100 SOP)
- B6: Do Minimum (limited improvements to road condition)

8 Technical Performance of Options

8.1 Assessment of Performance against Scheme Objectives

Table 8-1 sets out the criteria considered to assess the performance of the options against the project objectives. The evidence used for the performance assessment is based on the results from the wave and tidal modelling, which are set out in **Appendix C** and **Appendix D** respectively.

The various assessment criteria are relevant for more than one of the project objectives. For clarity, the subsequent sections discuss each of the following performance criteria:

- Wave conditions
- Peak water levels
- Peak flow rates
- Erosion and sedimentation

Table 8-1: Criteria for assessment of performance of options

Objective	Criteria
Sustainable solution for harbour entrance structures (50 years)	Design wave conditions
	Erosion rate in the entrance channel
Sustain or improve navigation conditions in the entrance channel and throughout the Harbour.	Tidal flow rate in the entrance channel
	Tidal flow rte throughout the harbour
	Wave conditions in the entrance channel
	Wave conditions at the North Wall
	Sedimentation in the entrance channel
	Sedimentation in the outer harbour (North Wall)
Sustain or reduce flood risk to the harbour	Peak water levels throughout the harbour
No increase in flood risk to Walberswick	Flood extent and/or peak water levels at Walberswick

8.2 Wave Conditions

The wave modelling results for the various options for the harbour entrance structures are presented in full in **Appendix C.** The 1-year return period wave conditions inside the Blyth estuary are summarised in **Table 6-2** below.

The modelling results show that the replacement of the South Pier with a breakwater (Option H6) significantly improves the wave conditions, with the height of waves from between 120 and 210 degrees offshore being reduced compared to the present day situation by more than 50%, and to less than 0.8m. Wave heights at the North Wall are typically about 0.5m with a rock breakwater, as shown in **Figure 8-1**.

The options with additional improvements such as concrete baffles added to the harbour structures give a slight further reduction in wave height for some wave directions, although this is not significant. Wave heights are typically very low in the vicinity of Dunwich Creek, so works in that area would be of limited benefit in terms of wave conditions.

It the South Pier was to be replaced with a vertical-walled sheet pile or caisson structure, wave disturbance within the entrance channel and at the North Wall would increase, due to the increased wave reflection.

Construction of a rock groyne to narrow the channel near to the Lifeboat Station would improve wave conditions in the inner harbour and is also shown to slightly reduce wave heights between the groyne structure and the harbour entrance.

Table 8-2: Wave conditions inside the Blyth estuary (1-year wave conditions)

Layout	Location	Hm0 (m) due to waves from Offshore Direction (deg.N)							
		0	30	60	90	120	150	180	210
H0 Present-day Baseline	Harbour front	0.7-1.0	0.8-1.2	0.6-1.0	0.6-1.4	1.0-2.2	1.0-2.6	1.5 -3.5	1.3-3.3
	Dunwick - Walberswick	0.5-1.5	0.6-1.8	0.5-1.4	0.5-1.3	0.7-1.8	0.7-2.0	1.0-2.3	0.7-2.1
	Upstream Moorings	0.3-0.5	0.3-0.6	0.3-0.7	0.3-0.6	0.3-0.7	0.3-0.7	0.6-0.9	0.4-0.7
H1 Do Nothing	Harbour front	0.7-1.0	0.8-1.2	0.6-1.0	0.6-1.5	1.0-2.4	1.0-3.0	1.5-3.7	1.3-3.5
	Dunwick - Walberswick	0.5-1.5	0.7-1.8	0.5-1.4	0.5-1.5	0.7-2.0	0.8-2.3	1.0-3.0	0.7-2.3
	Upstream Moorings	0.3-0.5	0.4-0.6	0.3-0.7	0.4-0.6	0.4-0.7	0.5-0.7	0.7-1.0	0.5-0.7
H6 Rock Breakwater	Harbour front	0.5-0.6	0.6-0.8	0.4-0.6	0.4-0.7	0.4-0.7	0.4-0.8	0.6-0.8	0.4-0.6
	Dunwick - Walberswick	0.4-0.9	0.4-0.9	0.3-0.7	0.4-0.7	0.4-0.7	0.4-0.8	0.4-0.8	0.4-0.6
	Upstream Moorings	0.3-0.4	0.3-0.4	0.2-0.3	0.2-0.3	0.2-0.3	0.2-0.3	0.3-0.4	0.2-0.3
H6a Rock Breakwater + Concrete Baffles	Harbour front	0.4-0.6	0.4-0.7	0.3-0.4	0.3-0.4	0.3-0.4	0.3-0.4	0.4-0.6	0.3-0.4
	Dunwick - Walberswick	0.3-0.6	0.4-0.6	0.2-0.4	0.2-0.4	0.2-0.3	0.2-0.3	0.4-0.6	0.2-0.3
	Upstream Moorings	0.3-0.4	0.3-0.4	0.2-0.3	0.2-0.3	0.1-0.2	0.1-0.2	0.2-0.3	0.1-0.2
H6b Rock breakwater + rock to South training arm	Harbour front	0.4-0.6	0.4-0.7	0.3-0.5	0.3-0.5	0.4-0.6	0.4-0.7	0.4-0.8	0.3-0.6
	Dunwick – Walberswick	0.3-0.6	0.3-0.6	0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.5	0.3-0.7	0.2-0.4
	Upstream Moorings	0.3-0.4	0.2-0.3	0.2-0.3	0.2-0.3	0.1-0.2	0.2-0.3	0.2-0.3	0.1-0.2
H6c Breakwater with vertical walls	Harbour front	1.0-1.5	1.0-1.8	1.0-2.0	1.0-2.0	0.7-1.8	1.0-2.0	1.4-2.8	1.0-2.7
	Dunwick – Walberswick	0.7-1.7	0.8-2.0	0.6-1.8	0.6-1.5	0.6-1.5	0.7-1.8	0.8-2.0	0.6-1.5
	Upstream Moorings	0.5-0.7	0.5-0.8	0.4-0.7	0.4-0.6	0.4-0.6	0.4-0.6	0.6-0.8	0.4-0.6
H6d Rock breakwater + narrow channel	Harbour front	0.4-0.6	0.5-0.8	0.3-0.5	0.3-0.6	0.3-0.6	0.4-0.7	0.5-0.8	0.3-0.6
	Dunwick – Walberswick	0.3-0.5	0.3-0.6	0.3-0.5	0.2-0.5	0.2-0.5	0.3-0.6	0.4-0.6	0.3-0.5
	Upstream Moorings	0.2-0.3	0.2-0.3	0.2-0.3	0.2-0.3	0.2-0.3	0.2-0.3	0.2-0.3	<0.25

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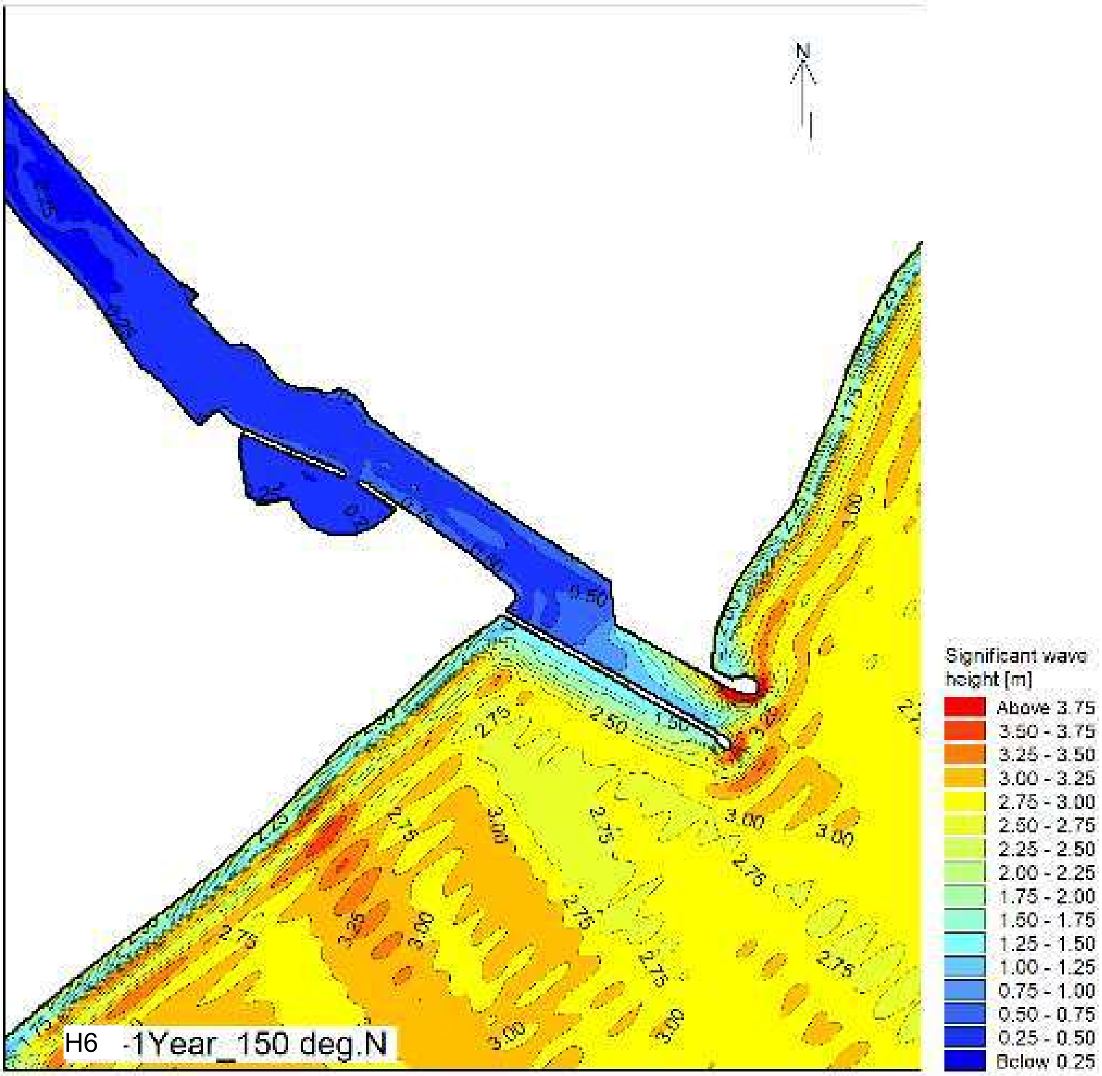

Figure 8-1: Wave conditions with a rock breakwater, for a 1-year return period offshore wave from 150 degrees

8.3 Peak Water Levels

8.3.1 Comparison of options

The tidal model was used to assess flood extents and water depths and peak water levels at Southwold for various options described in **Section 7**, for present day and future water levels, and the results are included in **Appendix D**. **Figure 8-2** compares the peak water levels in the channel for the options with the February 2020 and December 2013 conditions. The spillway options are shown in **Figure 8-3** and the narrowed channel options included as **Figure 8-4**.

The findings of the option modelling for peak water level can be summarised as follows:

- For the February 2020 conditions, the performance of the estuary management options (apart from Do Nothing) is comparable with the present-day defences (refer to **Figure 6-10)**.
- Removing the defences to allow flooding of the marshes (Do Nothing) reduces peak water levels at the Blackshore (approx. chainage 1500m) by about 240mm for the December 2013 conditions.

- For the 2013 event, water levels at the Blackshore (chainage 1500m) would have been 190mm higher if defences were raised to prevent overtopping.
- Allowing overtopping of the southern banks (SMP scenario) does not change the peak water levels in the harbour when compared to the peak water levels for the present day defence levels.
- Including a sluice gate spillway in the raised banks (**S2**) would give a reduction in peak flood levels of up to 80mm at the Blackshore (chainage 1500m) during an event equivalent to December 2013 compared to raising the banks without the sluice gate. Peak water levels for the 2013 event would be 130mm higher at the Blackshore compared to conditions with the present day defences.
- Review of the modelling results for the various passive spillway options shows that a 250m long spillway combined with raising the downstream banks (Robinson's Marsh and part of Tinker's Marsh) would be the most effective arrangement.

  With this option, peak water levels at the Blackshore (chainage 1500m) would be equivalent to the 2013 event conditions with the present day defences, and 220mm lower than they would be if all flood banks were raised. This is the most effective option overall in terms of peak water levels.
- If the channel was narrowed opposite the North Wall, combined with raising the estuary defences, peak flood levels at the Blackshore (chainage 1500m) for the December 2013 conditions are reduced by 110mm compared to raising the defences alone. If the existing defences are unchanged (**E0**), narrowing the channel would reduce peak flood levels by only 10mm.

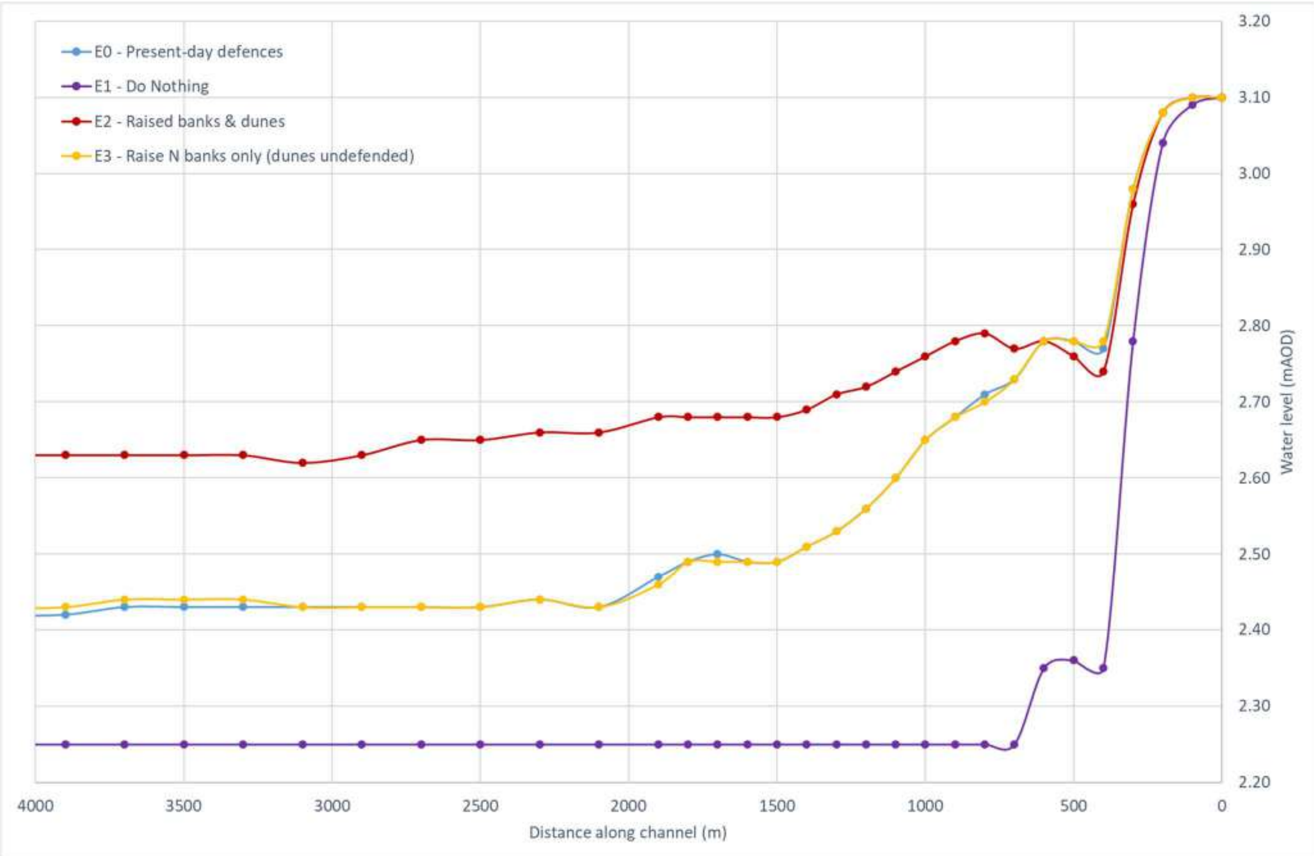

Figure 8-2: Change in peak water level along channel (Dec 2013 conditions)

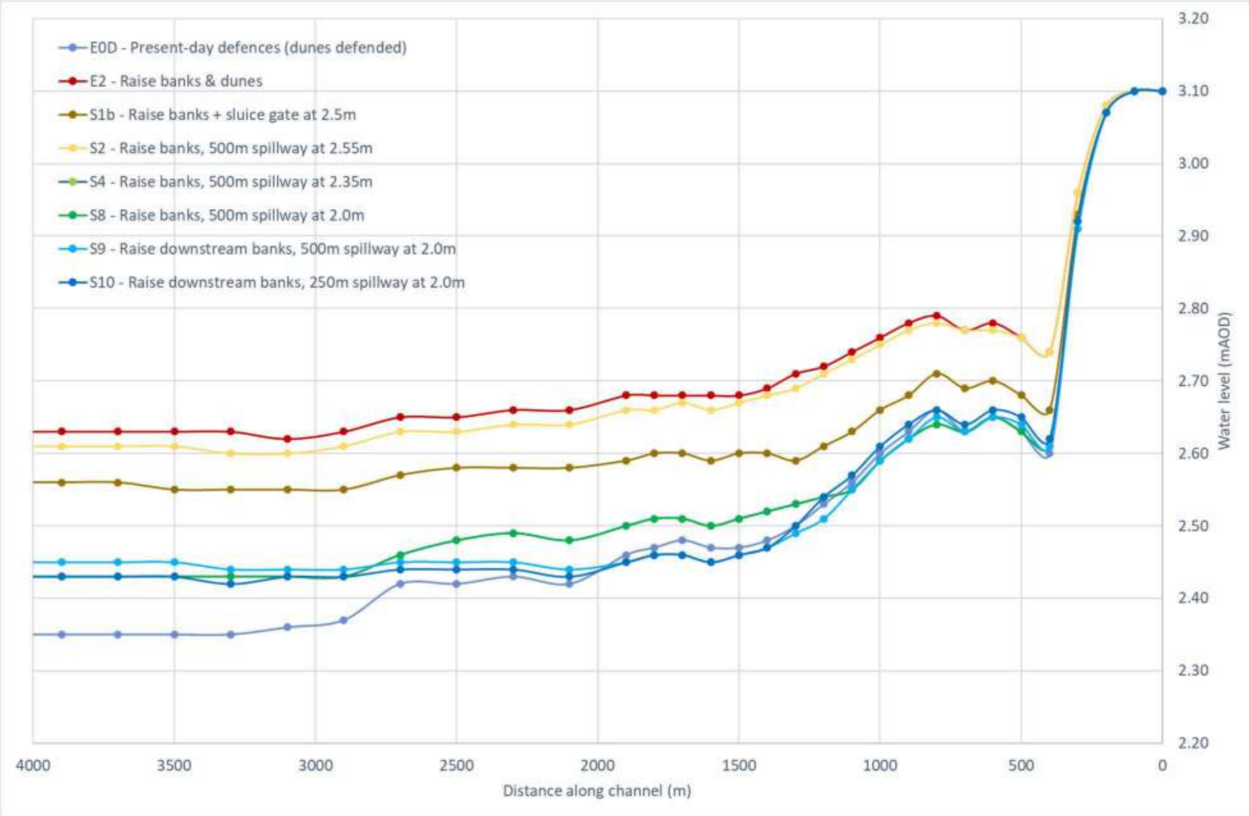

Figure 8-3: Change in peak water level along channel (spillway options, Dec 2013 conditions)

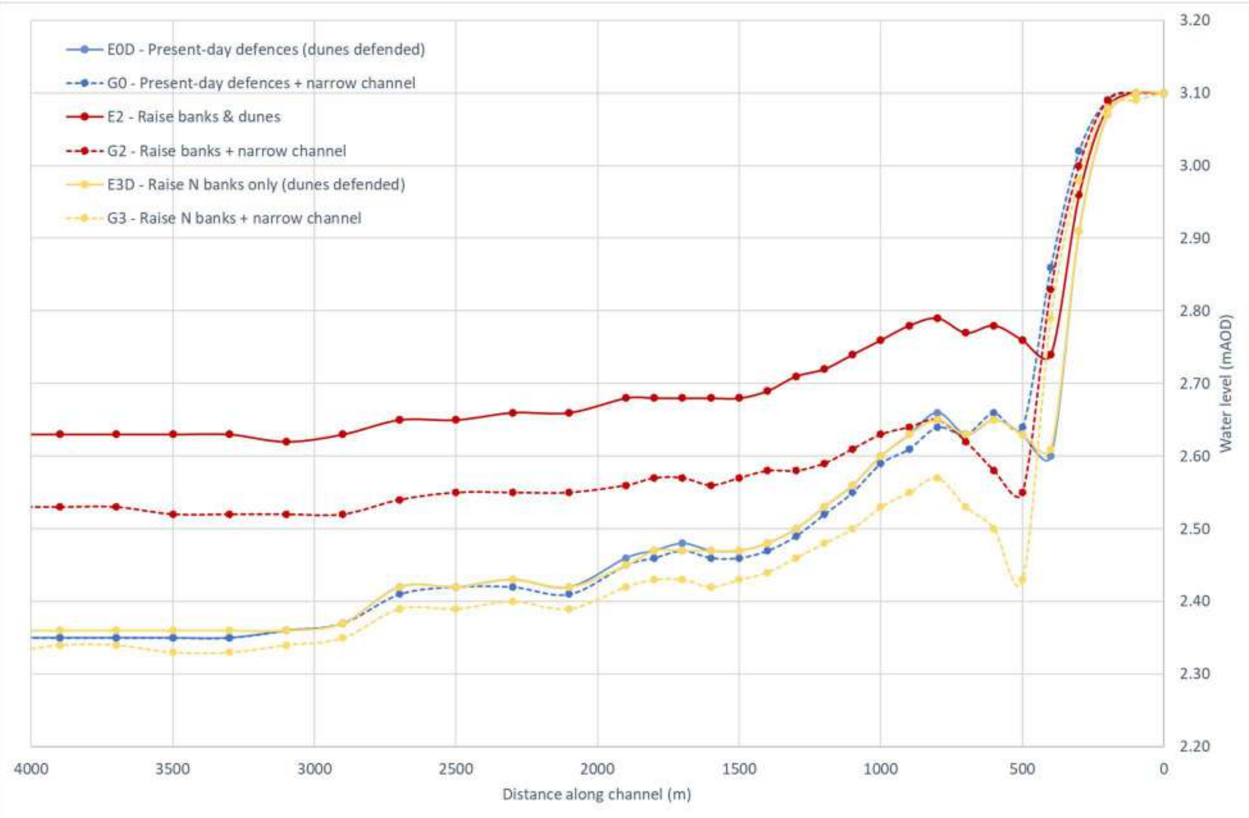

Figure 8-4: Change in peak water level along channel (narrow channel, Dec 2013 conditions)

8.3.2 Impact of sea level rise

The impact of sea level rise was considered in terms of the performance of the options. The tidal modelling assumed that for Option E2 (raised estuary defences) and Option E3 (SMP Policy, raise north banks only), and for most of the spillway options, the crest level of any defences will be high enough that overtopping will not occur.

As shown by the figures and tables in **Section 4.7**, overtopping can occur to parts of the Tinker's Marsh embankment during a 1 year return period event. More extensive overtopping into Tinker's and Robinson's Marshes would be expected on a 1 in 10 (10% AEP) year return period event, or when the water level at the harbour mouth reaches about 2.50m ODN. Tidal modelling was undertaken for a water level of 2.7m ODN at the harbour entrance, and comparison of the peak water levels for the present-day defences and the raised embankment option demonstrates that a limited amount of overtopping of the existing defences would occur for this water level at the harbour mouth (**Figure 8-5**). Below this water level, performance of all options in terms of peak water level is similar to the present-day scenario.

Figure 8-5 compares the options for the most extreme water level scenario that was modelled (2013 conditions with sea level rise to 2070, RCP8.5 95th percentile), i.e. a water level 470mm higher at the harbour mouth than the 2013 event. This shows that with raised embankments the peak water level at the Blackshore (chainage 1500m) would be about 430mm higher than for the December 2013 conditions. With the present-day defences, flooding will occur upstream, so the water level in the harbour would be up to 330mm higher than for the December 2013 conditions.

This comparison demonstrates that sea level rise will have a greater impact on peak water levels in the harbour if the estuary defences are raised. However, as the level of the Harbour Road is currently below the present HAT level, flooding more than once a year, a solution to the flood risk issues for the harbour is needed alongside all of the estuary management options.

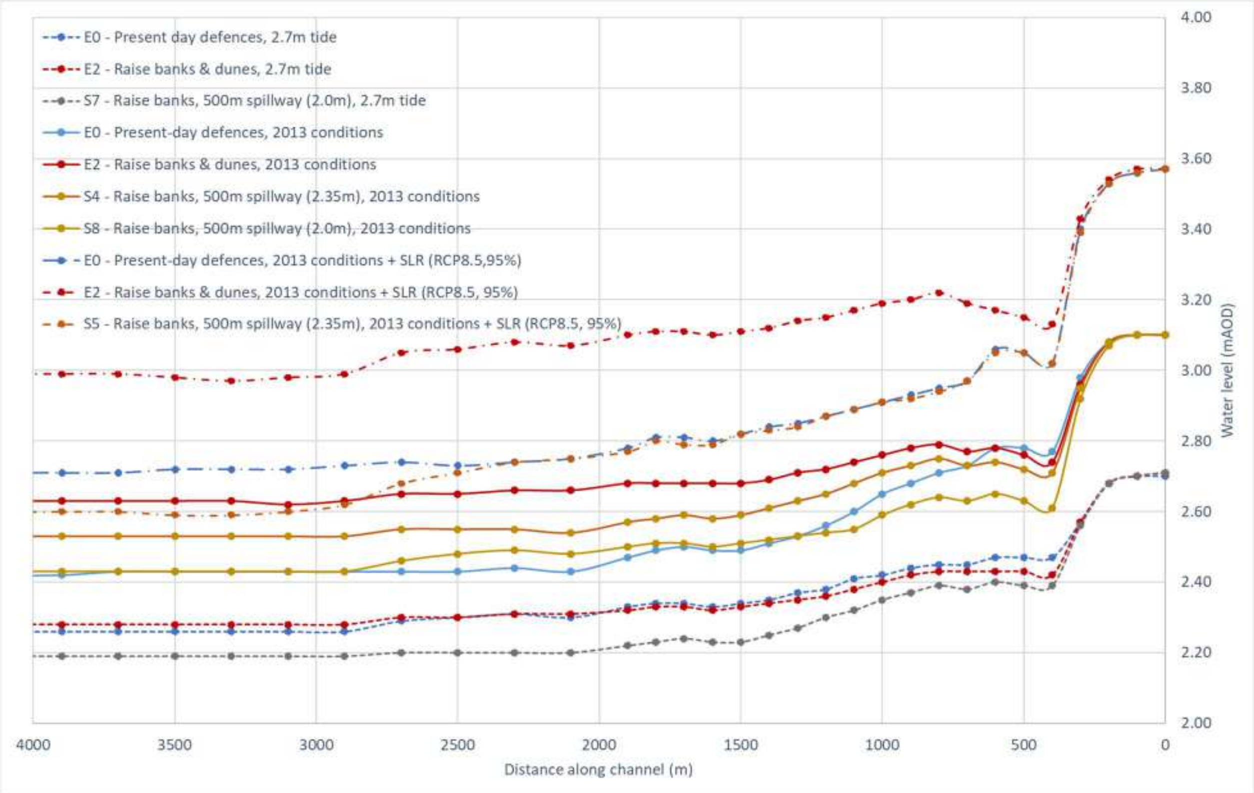

Figure 8-5: Change in peak water level along channel (with sea level rise)

8.4 Peak Flow Rate

The tidal model was also used to assess peak flow rates for the options, with the full results included in **Appendix D**. **Figure 8-6** compares the peak flow rates in the channel for each option with the February 2020 and December 2013 conditions. The narrowed channel options are shown in **Figure 8-8**. The findings of the option modelling for peak flow rate can be summarised as follows:

- For the February 2020 conditions, the peak flow rates for the estuary management options (apart from Do Nothing) are comparable with the present day defences (refer to **Figure 6-11)**.
- The Do Nothing scenario (discussed in **Section 6.2.3**) has significantly higher peak flow rates in the entrance channel than all other options due to the larger tidal prism, but upstream flow rates are lower due to overtopping of the embankments.
- Raising all embankments (**E2**) would reduce the peak flow rates in the entrance channel and further upstream, as the tidal prism is reduced, with an associated reduction in flow rates.
- Raising only the north banks (**E3**) results in a slight reduction in flow rates in the entrance channel compared to the present-day scenario, but otherwise this option does not change the flow rates compared to the present day.
- The spillway options with higher spill levels (**S2** (2.35m), **S4** (2.55m)) have a comparable impact on peak flow rates in the entrance channel and upstream as raising the embankments. For lower spillway levels (options **S8, S9 and S10**), the peak flow rates in the outer harbour (up to chainage 1000m) are similar to the present day scenario. Further upstream, where there is flow into the marshes over the spillway, and an increase in the tidal prism, peak flow rates are higher than present day.
- If the embankments were raised and the channel narrowed opposite the North Wall, peak flow rates in the entrance channel are reduced by about 0.1m/s, compared to embankment raising alone, although flow rates do increase at the point where the channel is narrowed. Peak flow rates further upstream are also reduced.

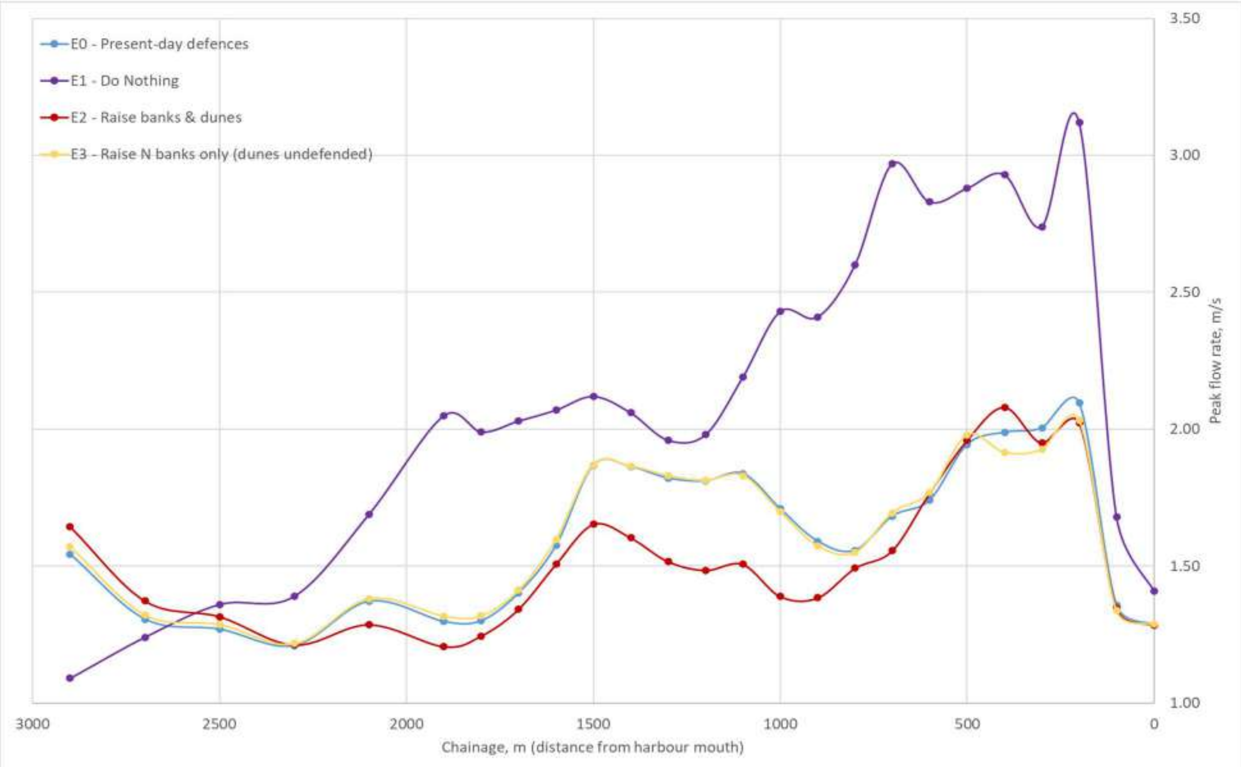

Figure 8-6: Change in peak flow rate along channel (Dec 2013 conditions)

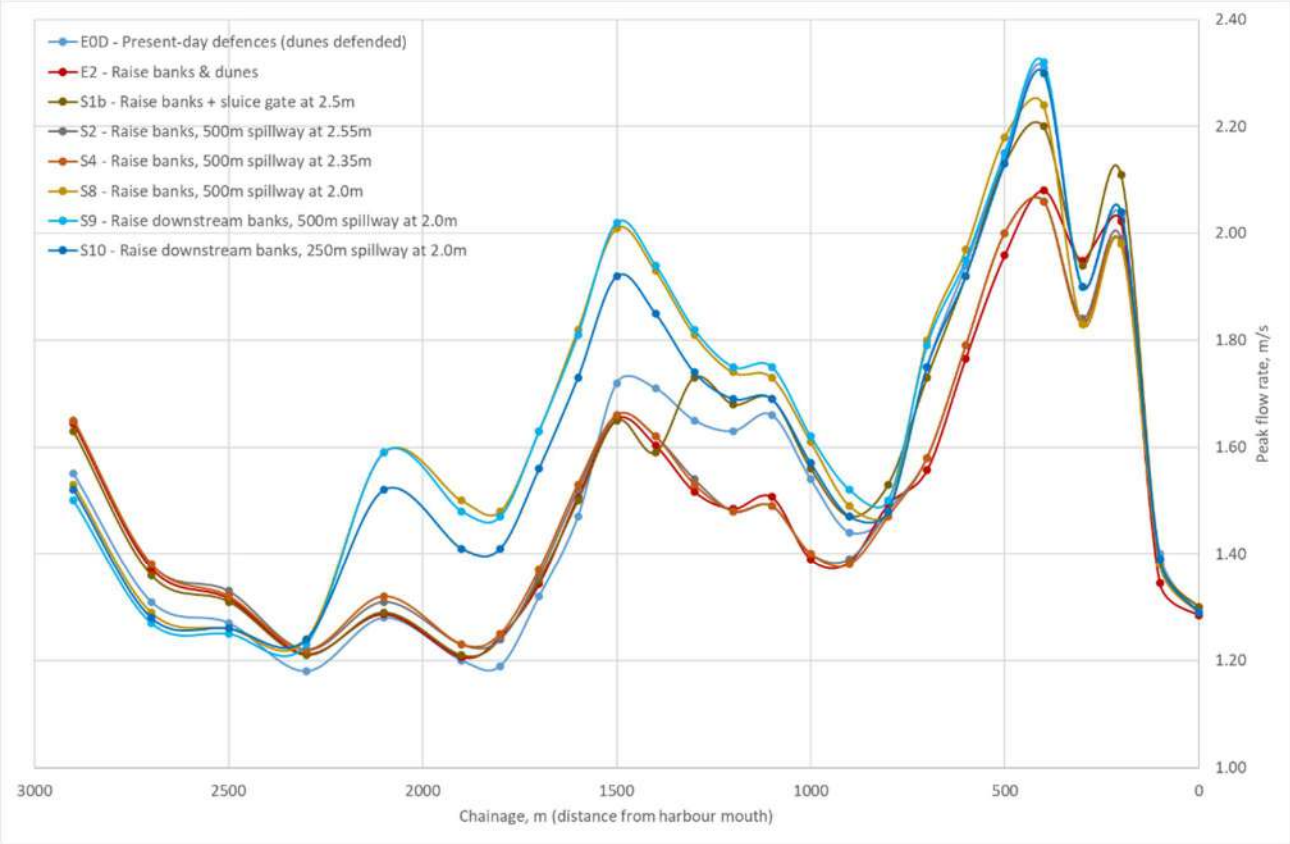

Figure 8-7: *Change in peak flow rate along channel (spillway options, Dec 2013 conditions)*

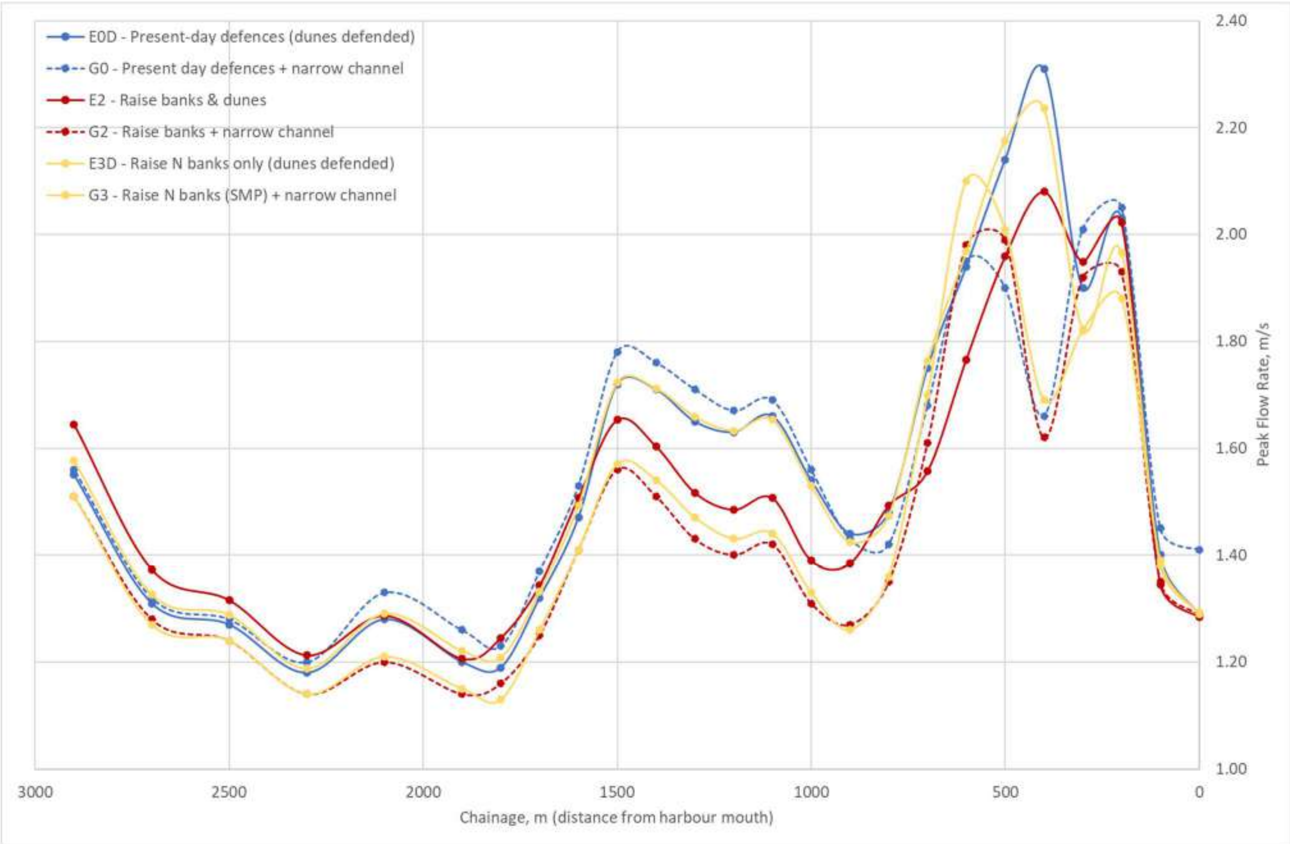

Figure 8-8: Change in peak flow rate along channel (narrow channel, Dec 2013 conditions)

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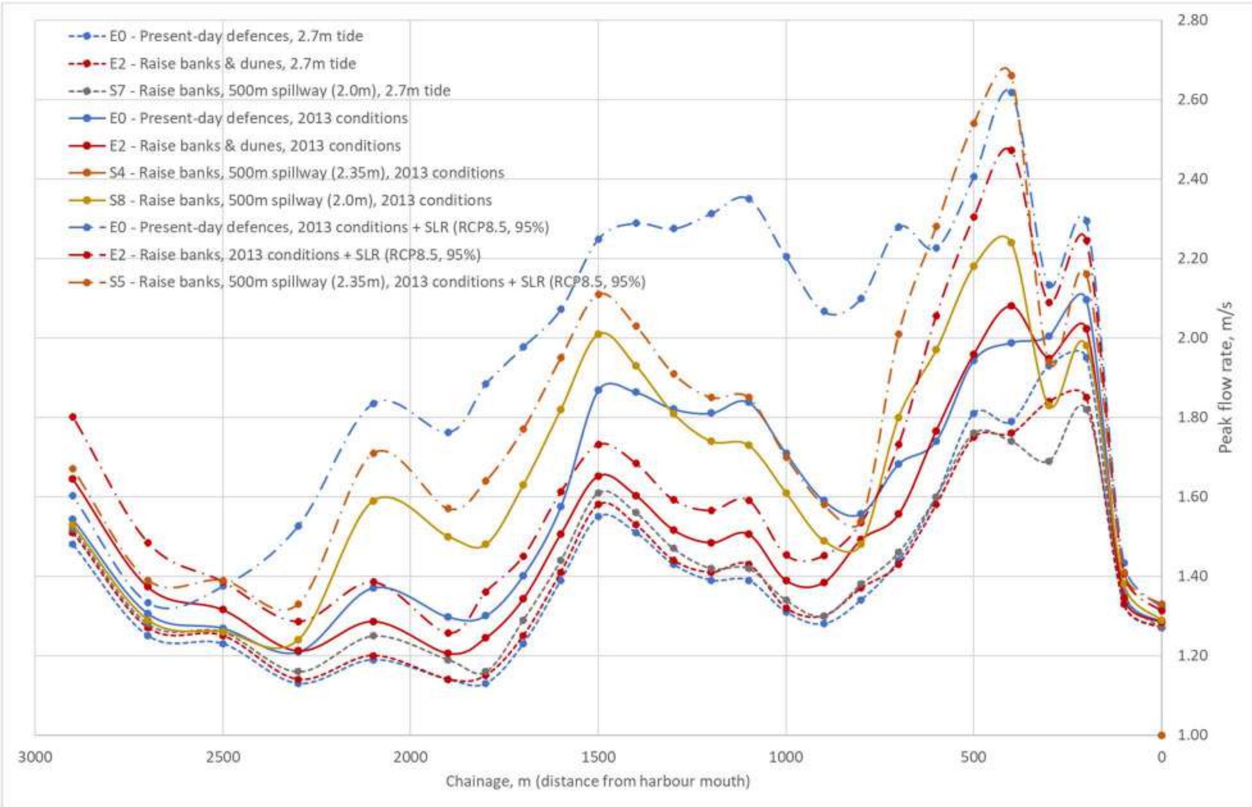

Figure *8-9*: *Change in peak flow rate along channel (with sea level rise)*

8.5 Sensitivity to Marsh Sedimentation

The impact of future sedimentation of the marshes on peak water levels and peak flow rates has been assessed. The net impact of an increase in marsh levels in the marshes on peak flood levels is not simple to predict because the hydrodynamic behaviour of the estuary is a complex, 4-dimensional problem. The impact of marsh levels on peak water level depends on various factors including the dimensions of the estuary, the ratio between depth, width and length of channels and floodplains, tide and surge levels and the influence of the dynamics and inertia of the water. These processes are represented in the tidal model, which considers the whole system, including the shape and volume of the estuary as well as how the hydraulic processes change with time. The modelling results showing the impact of marsh sedimentation for Southwold.

As discussed in **Section 3.8**, average sedimentation since 1943 was 6mm/year, but this has decreased to 3mm/year on average over the past decade. Historic sea level rise is 3mm / year on average, so in comparison with the historic sedimentation rate the tidal prism of the estuary has been reducing with time. However, water level data suggests that the rate of sea level rise has increased over the past decade, and the climate change projections give a range of future sea level rise from 3mm/yr to 10mm/yr. Therefore, we need to consider the potential future range of both sedimentation and sea level.

8.5.1 Impact of sea level rise

When sea level rise (RCP2.6, 50%) is applied to the February 2020 conditions, flooding only occurs for the Do Nothing scenario, so the increase in flow rates is limited by the small increase in tidal prism (increase in water depth in the river channel). The peak flow rate only exceeds 3.5 knots with the Do Nothing scenario. Therefore, day-to-day conditions for navigation are expected to continue to be manageable in the future without any change to the present-day defences.

For water levels below 2.70m ODN, the tidal prism is limited because overtopping does not occur, so the peak flow rates for all options are similar to the present-day scenario (**Figure 8-9**).

Figure 8-9 also shows the impact of extreme surge events on flow rates, with sea level rise applied to the December 2013 conditions (RCP8.5, 95^{th} percentile). This shows that with raised embankments, the peak flow rates in the entrance channel would be 19% higher than for the December 2013 conditions. However, for SMP scenario (north banks raised), peak flow rates would be 39% higher, because of the larger tidal prism due to the flooding of the southern marshes.

High flow rates during extreme events would be further increased due to sea level rise, which could increase scour of the entrance channel and risk of failure of the harbour entrance structures. Because this increased scour would occur relatively infrequently, it is difficult to predict the actual impact on the harbour entrance structures. Change in the channel bed level would need to be monitored.

This comparison emphasises the point that raising the estuary defences is the best-case scenario in terms of minimising future flow rates in the entrance channel.

8.5.2 Impact on peak water levels

Assuming the historic average sedimentation rate of 6mm/year, the breached marshes would be 300mm higher by 2070. In this scenario, the peak water levels in the harbour are increased by about 3cm for the February 2020 conditions (**Figure 8-11** and **Figure 8-10**). For the December 2013 conditions, assuming the embankments are raised to prevent overtopping or breach, the peak water levels increase by about 4cm (**Figure 8-13** and **Figure 8-12**). For an increased sedimentation rate of 12mm/year (marshes 600mm higher by 2070), the peak water levels in the harbour are increased by about 5cm for the February 2020 conditions (**Figure 8-11**) and by about 7cm for the December 2013 conditions with raised embankments (**Figure 8-13**).

The modelling results show that marsh sedimentation has only a limited impact on peak water levels. An increase in marsh levels does not push up the water levels by the same amount. The change in the peak water level is an order of magnitude less than the increase in marsh level.

The impact of marsh sedimentation combined with sea level rise on peak water levels has also been assessed. This is shown in **Figure 8-14** for the present-day defences and in **Figure 8-15** for the raised embankment option. Both of these figures show that marsh sedimentation has very little influence on peak water level in comparison to increases in water level at the harbour mouth.

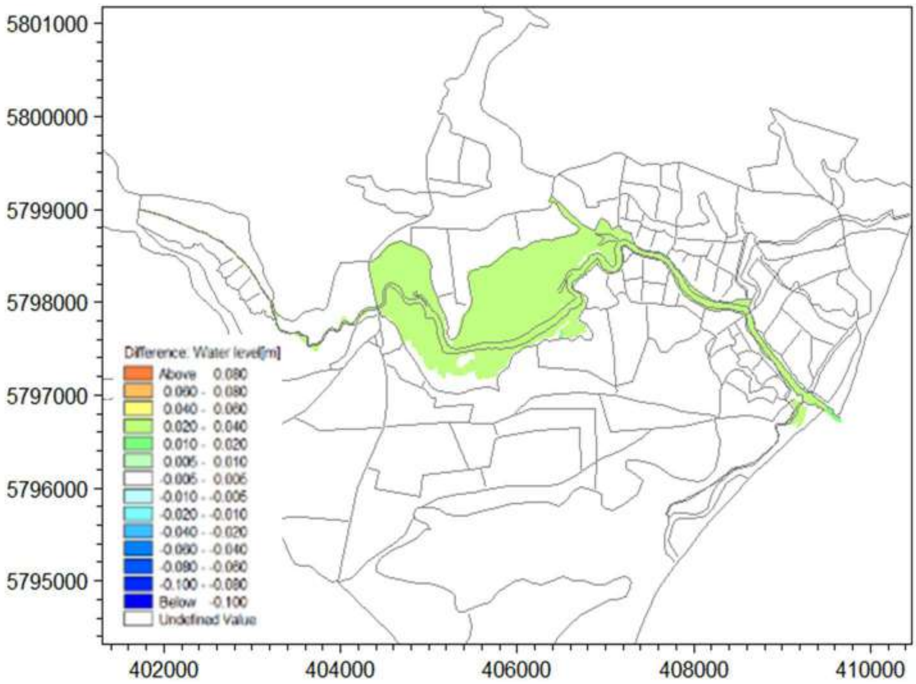

Figure 8-10: Difference in peak water level for marsh levels +300mm (present-day defences, February 2020 conditions)

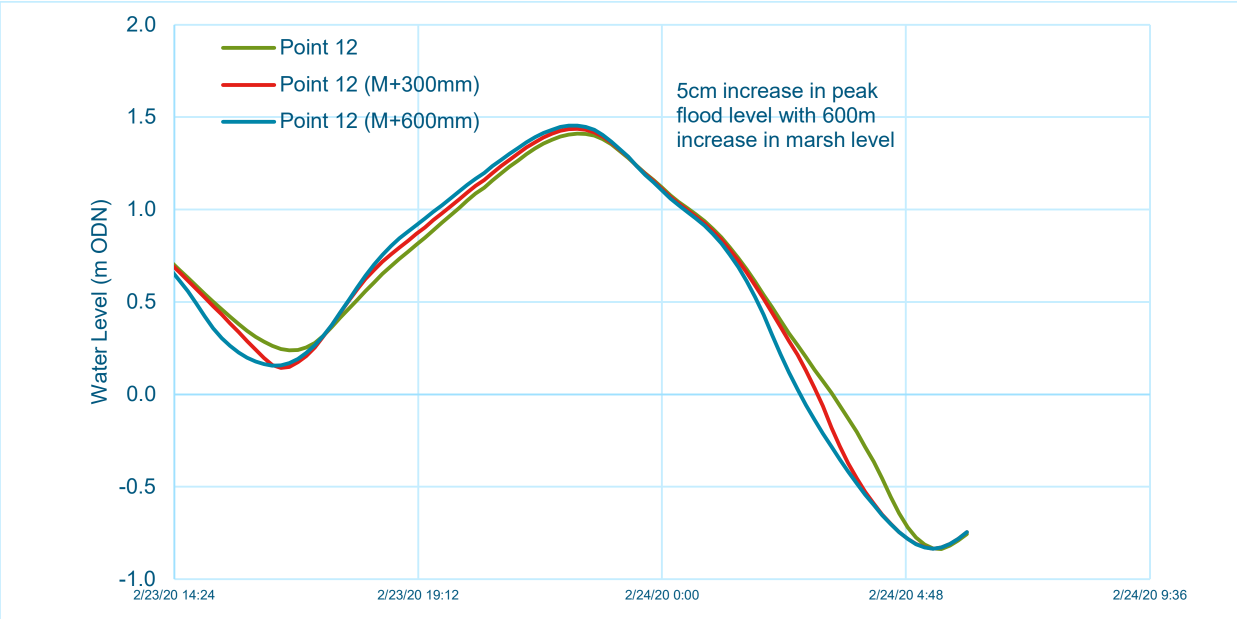

Figure 8-11: Difference in peak water level within the Harbour for increased marsh levels (present-day defences, February 2020 conditions)

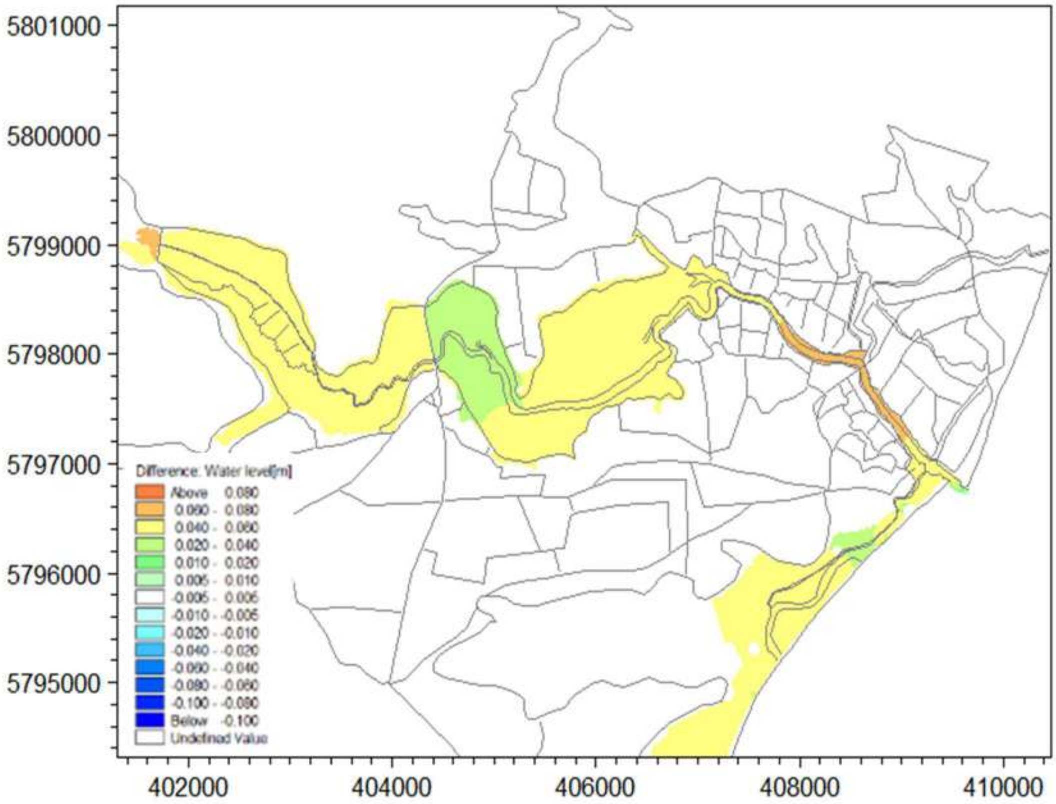

Figure 8-12: Difference in peak water level for marsh levels +300mm (raised defences, December 2013 conditions)

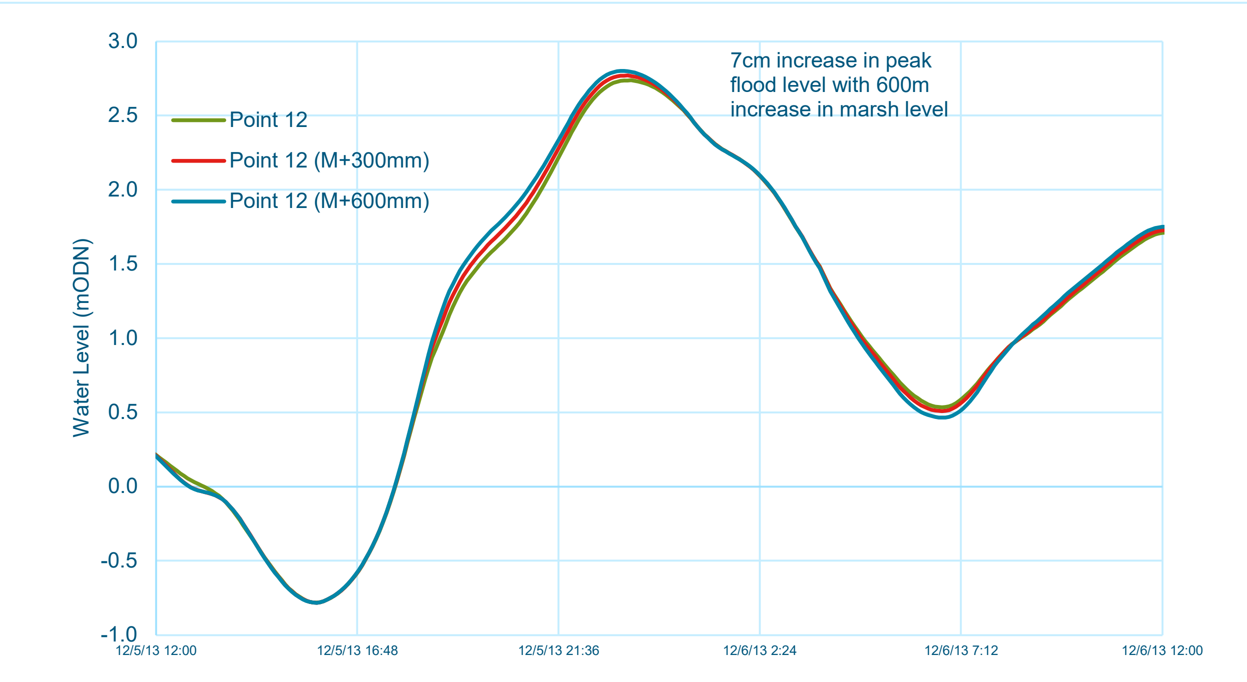

Figure 8-13: Difference in peak water level for increased marsh levels (raised defences, December 2013 conditions)

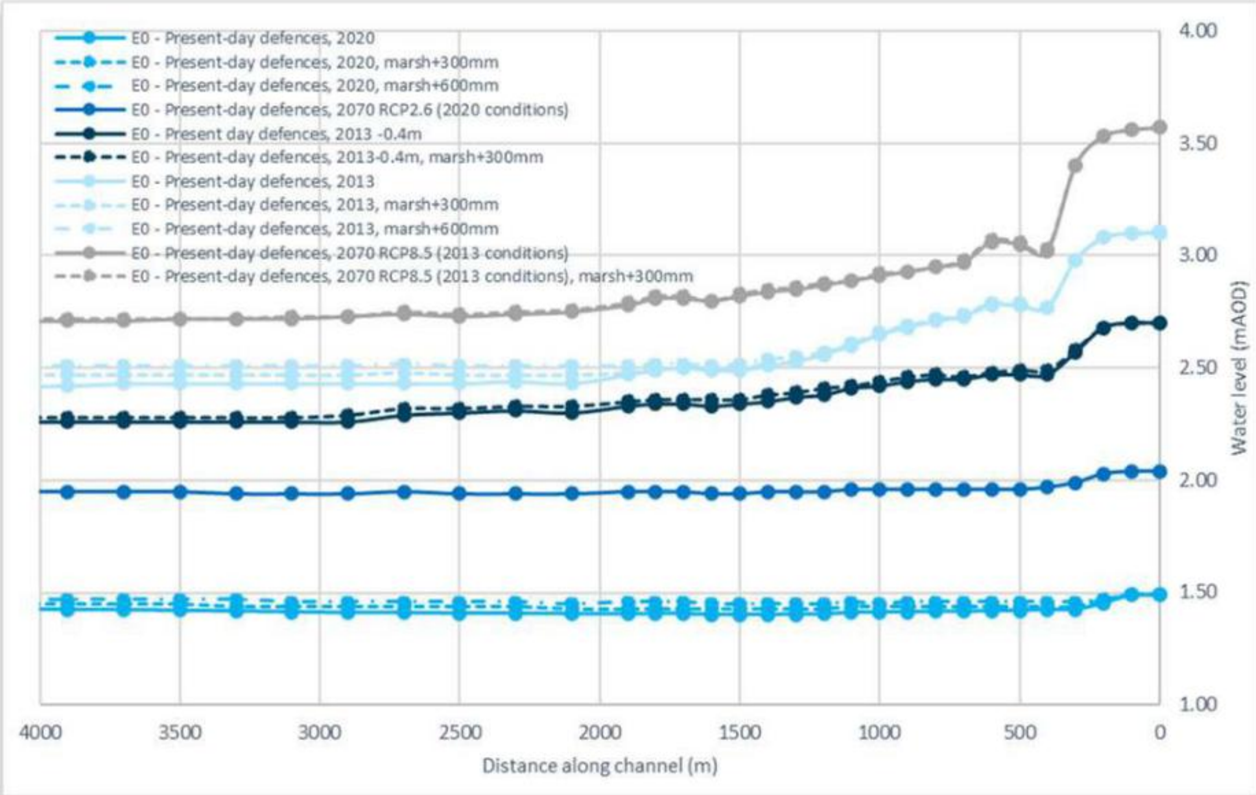

Figure 8-14: Change in peak water level with marsh sedimentation and SLR, present-day defences

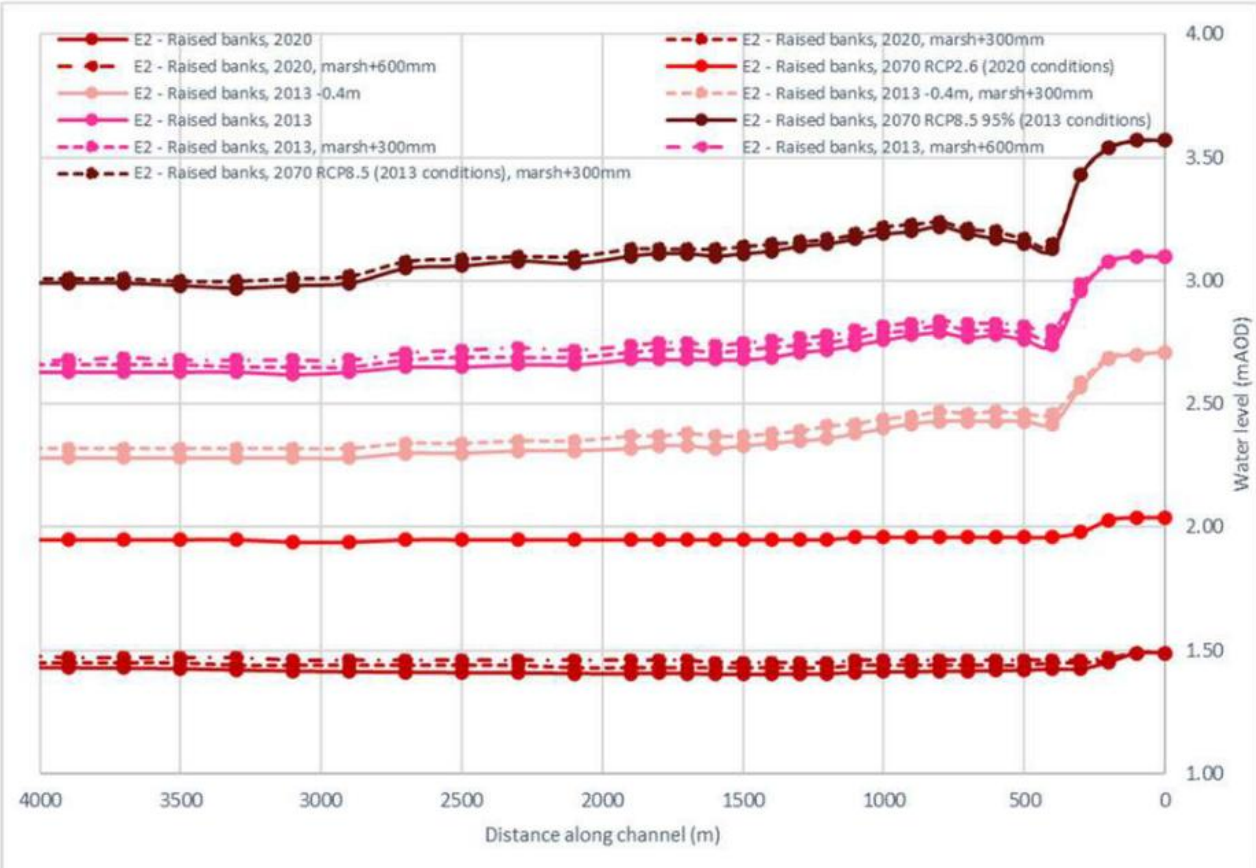

Figure 8-15: Change in peak water level with marsh sedimentation and SLR, raised defences

8.5.3 Impact on peak flow rates

In terms of peak flow rates, a higher marsh level reduces the flow rate, because the tidal prism is reduced. For a higher marsh level, less water fills the estuary in a tidal cycle, so the volume of water flowing in and out of the harbour entrance is reduced, also reducing the peak flow rates.

For the historic average sedimentation rate of 6mm/year (marshes 300mm higher by 2070), Error! Reference source not found. shows that the peak flow rates in the harbour entrance are reduced by 14% for the February 2020 conditions. For the December 2013 conditions, assuming the embankments are raised to prevent overtopping or breach, the peak flow rates are reduced by 3%. For an increased sedimentation rate of 12mm/year (marshes 600mm higher by 2070), the peak flow rates in the harbour entrance are reduced by 35% for the February 2020 conditions and by 6% for the December 2013 conditions with raised embankments. The change in flow rate is less for the December 2013 conditions than it is for lower water levels because we are comparing a smaller percentage difference in the tidal prism.

Sedimentation of the marshes has a positive impact on flow rates, with the potential for erosion of the channel bed reduced.

The impact on peak flow rates of marsh sedimentation combined with sea level rise has also been assessed. This is shown in **Figure 8-17** for the present-day defences and in **Figure 8-18** for the raised embankment option. These figures show that marsh sedimentation has a greater influence on peak flow rates for the lower water levels. For the more extreme surge conditions with higher water levels, the relative influence of the marsh level on the tidal prism is much less. This shows that marsh sedimentation would not offset increases in flow rates for the very high flow events, although it would improve flow rates in the entrance channel for the day-to-day conditions.

8.5.4 Summary of impact of marsh sedimentation

If the level of the marshes does not increase in the future, then the tidal prism of the estuary will increase with sea level rise. This will lead to higher flow rates within the entrance channel, particularly for extreme surge events, which would keep the channel clear but could increase scour. This scenario is the worst-case for the design of any replacement harbour entrance structures.

If the level of the marshes does increase, this would be expected to result in a slight increase in the peak water levels within the harbour, and a reduction in flow rates within the entrance channel. The reduction in flow rate would not be sufficient to offset the impact of sea level rise for the extreme water level events, but in terms of the day-to-day flow conditions it would reduce the risk of scour of the entrance channel and the associated impact on the harbour entrance structures.

February 2020 conditions

December 2013 conditions

Present-day defences, present day marsh levels

Embankments raised, present day marsh levels

Present-day defences, marsh levels +300mm

Embankments raised, marsh levels +300mm

Present-day defences, marsh levels +600mm

Embankments raised, marsh levels +600mm

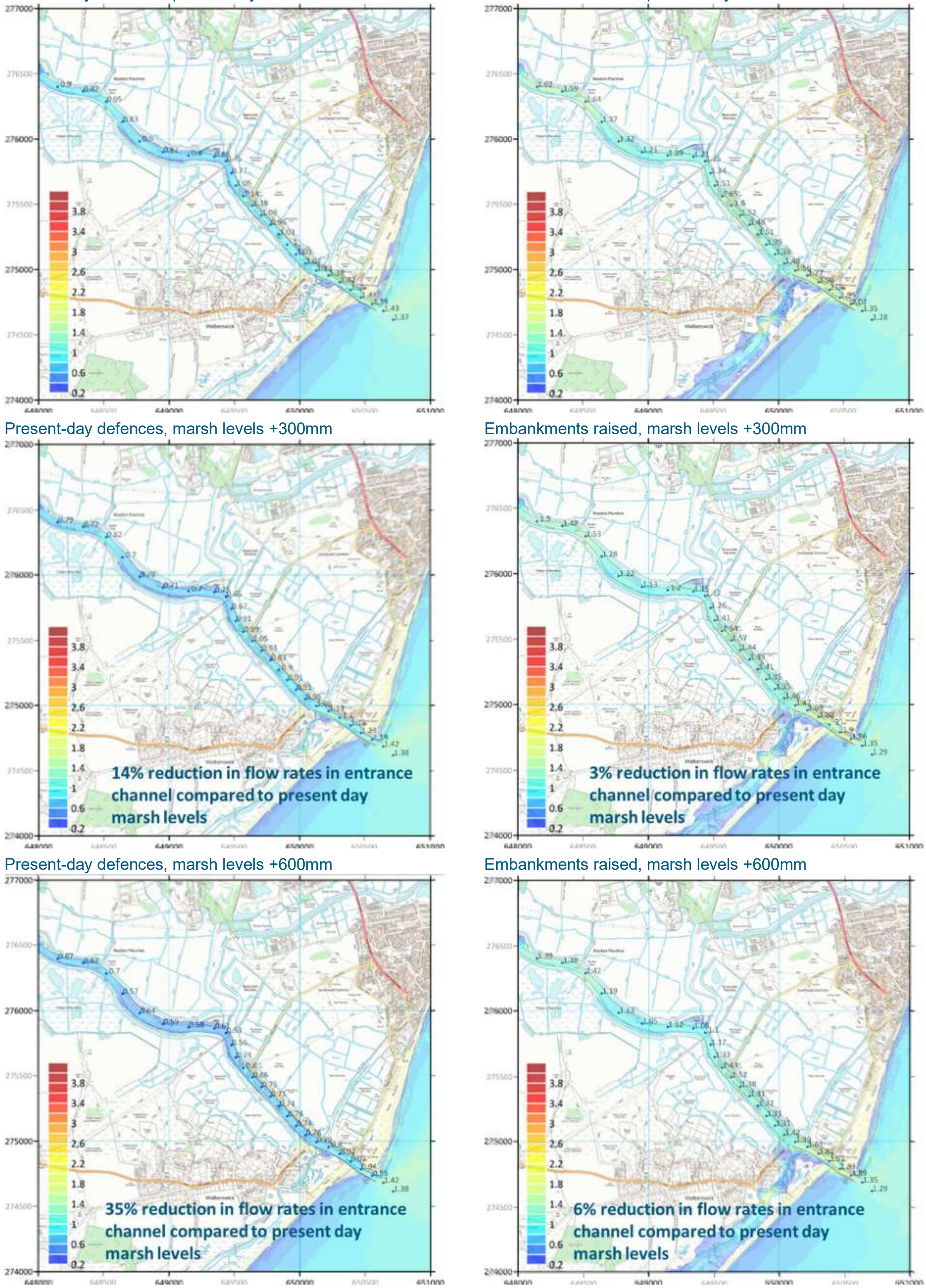

Figure 8-16: Comparison of flow rate with marsh sedimentation, December 2013 conditions

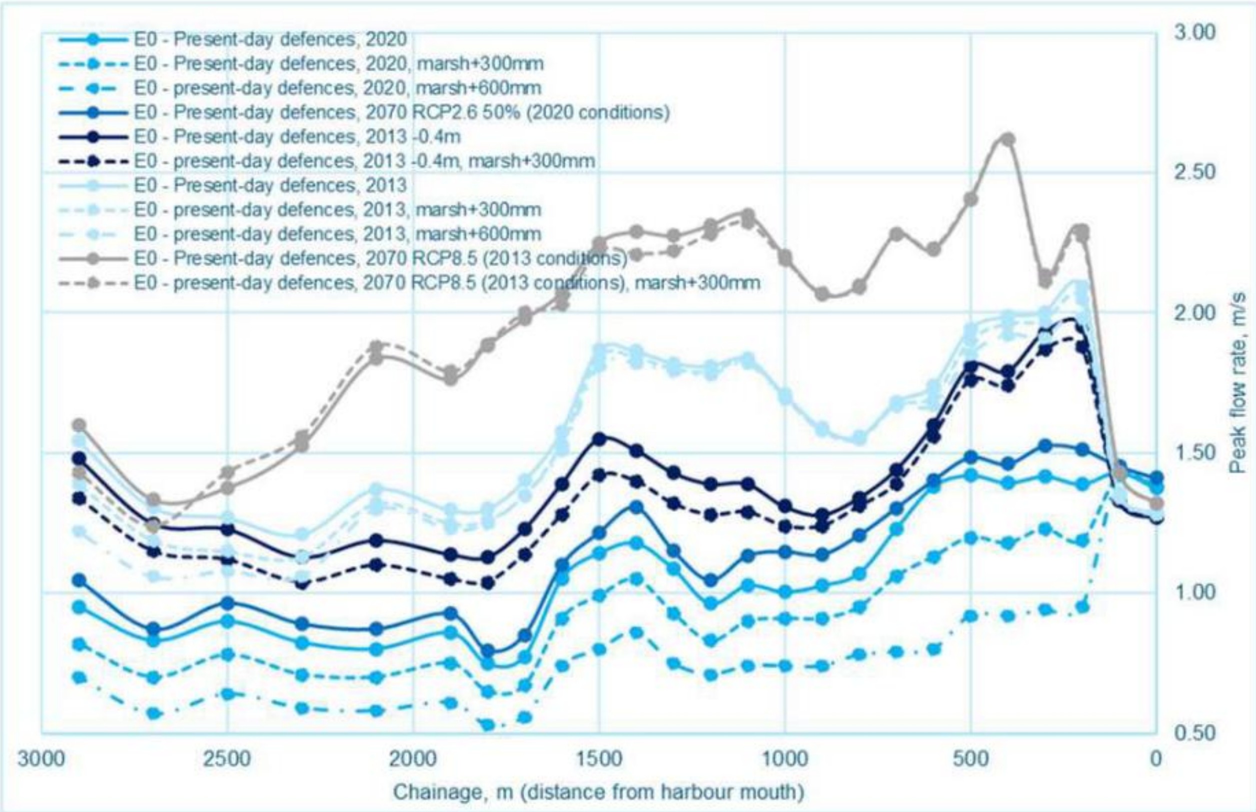

Figure 8-17: Change in flow rate with marsh sedimentation and SLR, present-day defences

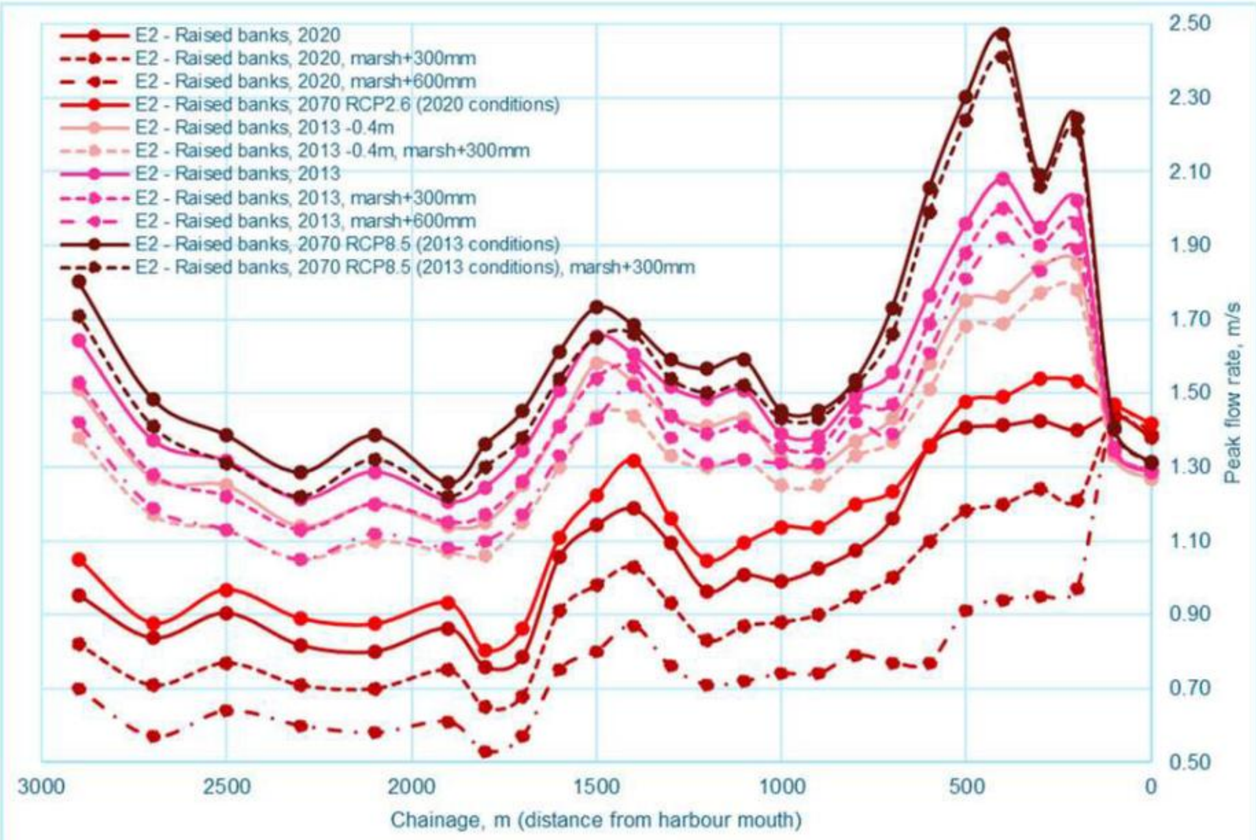

Figure 8-18: Change in flow rate with marsh sedimentation and SLR, present-day defences

8.6 Walberswick Dunes

Following breach of the Walberswick to Dunwich shingle ridge during storms in 2006 and 2007, the Environment Agency withdrew maintenance from this section of the coast, and the shingle ridge now behaves naturally, with breaches occurring during winter storms. Tidal model runs have demonstrated that overtopping of the Walberswick dunes influences peak water levels and flow rates in the river channel, as shown by **Figure 8-19** to **Figure 8-22.**

- Comparing **Figure 8-19** and **Figure 8-20** shows the greater extent and depth of flooding behind the dunes, and greater water depth in the harbour if the Walberswick dunes are not raised to prevent overtopping.
- **Figure 8-21** shows that raising the dunes to prevent overtopping reduces the peak water levels at the Blackshore (chainage 1500m) by about 60mm.
- Raising the dunes would also have an impact on peak flow rates. **Figure 8-22** shows that peak flow rates in the entrance channel would increase if the dunes were raised, but upstream flow rates are reduced.

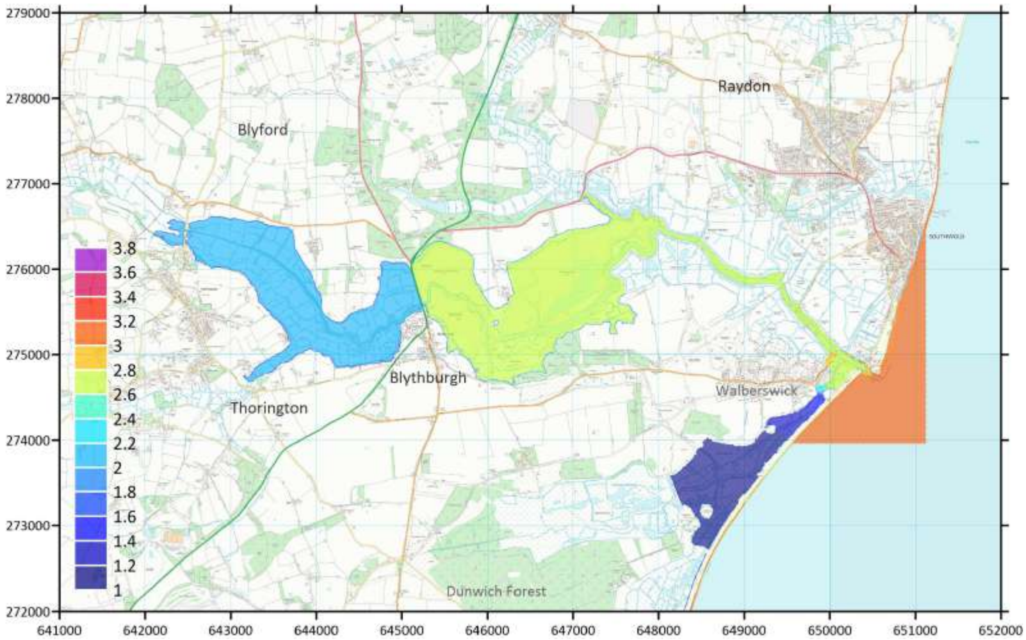

Figure 8-19: Flood extent and depth, raised embankments and dunes, 2013 conditions

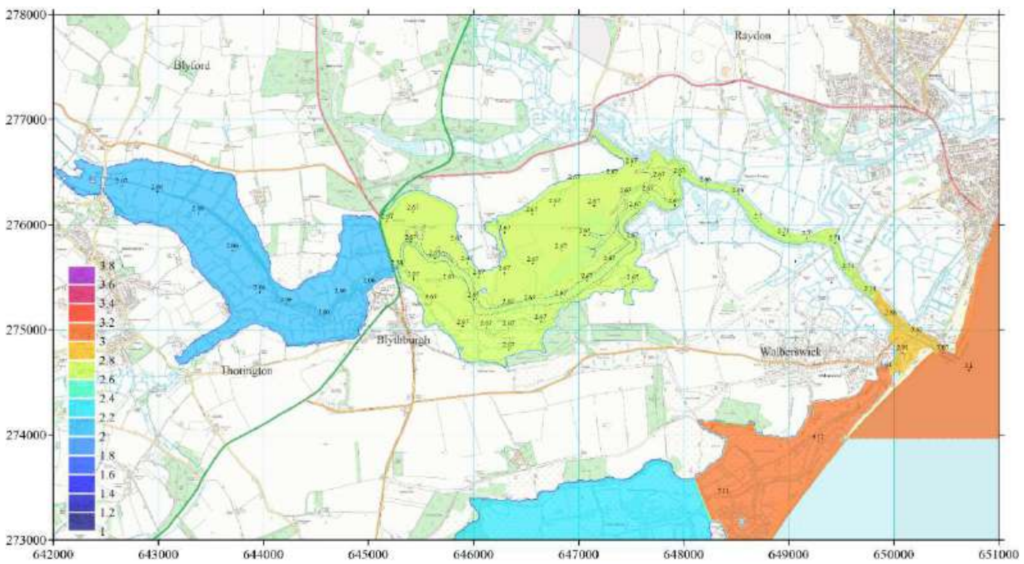

Figure 8-20: Flood extent and depth, raised embankments, dunes <u>not</u> raised, 2013 conditions

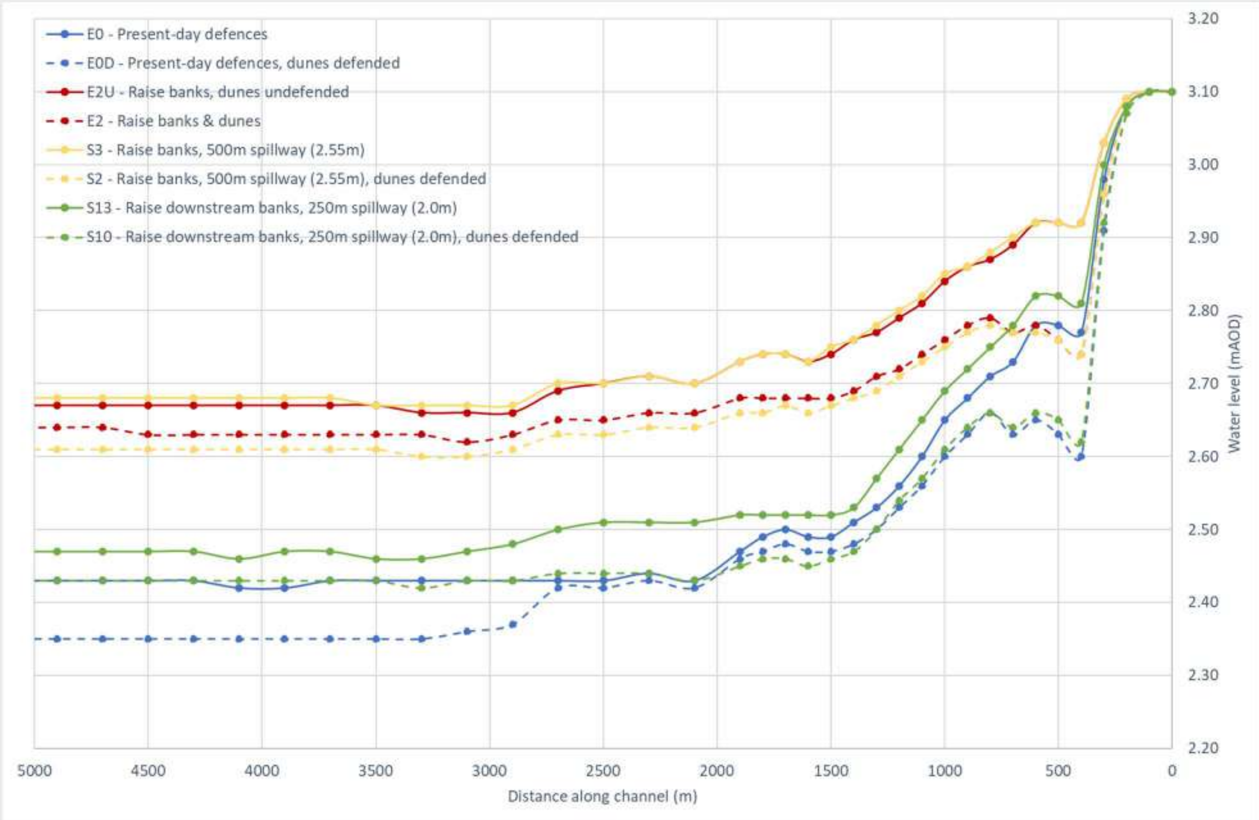

Figure 8-21: Influence of Walberswick dunes on peak water level, 2013 conditions

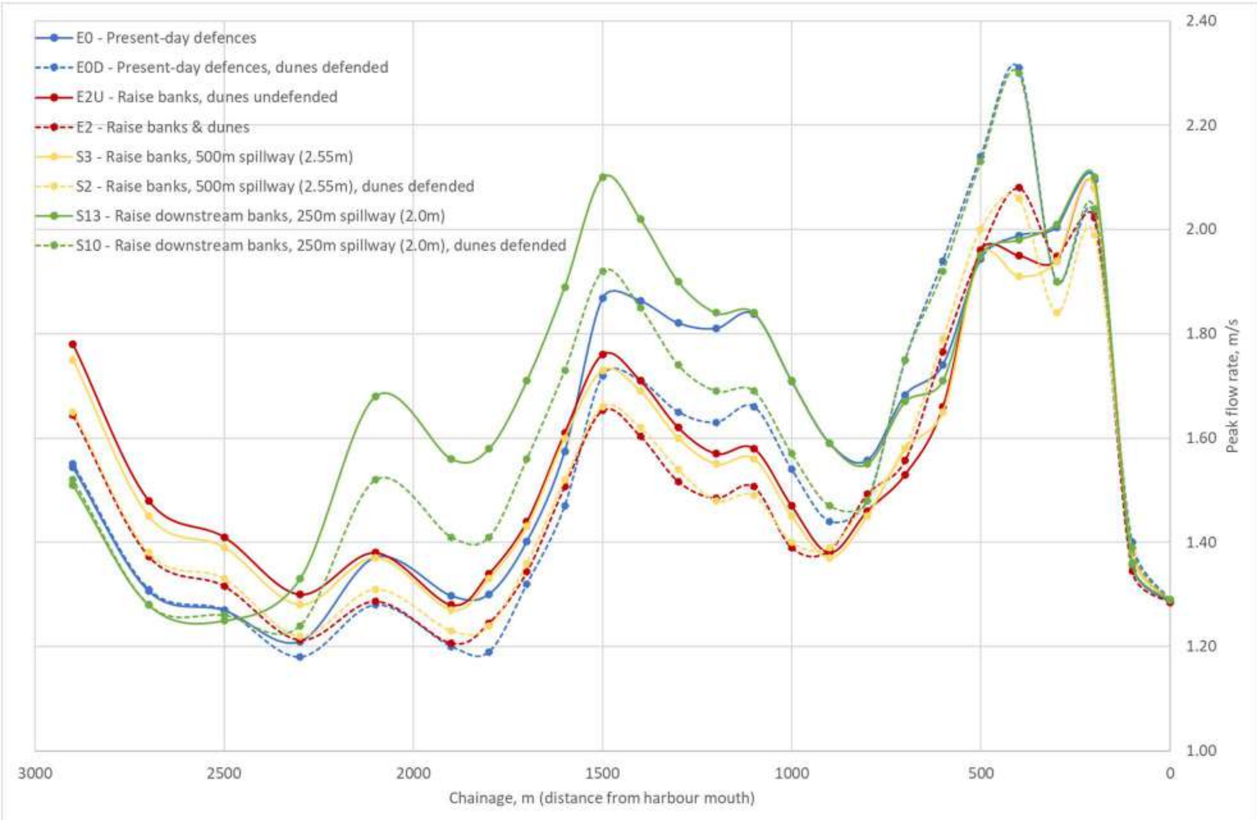

Figure 8-22: Influence of Walberswick dunes on peak flow rate, 2013 conditions

8.7 Erosion and Sedimentation

8.7.1 Entrance channel

The risk of erosion or sedimentation in the entrance channel and further upstream is directly related to the flow rate. The assessment of the performance of the options in terms of peak flow rate determined that for conditions on a typical high tide, or more frequent surge event such as the February 2020 conditions, the peak flow rates for each of the estuary management options are comparable with the present-day flow conditions. Therefore, the present rate of erosion of the channel (discussed in **Section 3.2**) is not expected to change significantly. If the estuary defences were allowed to fail (Do Nothing scenario), then peak flow rates and erosion of the entrance channel would be expected to increase (discussed in **Section 6.2.3**).

The assessment of the impact of sea level rise and marsh sedimentation on flow rates shows that if the marsh levels increase in the future, then the day-to-day flow rates would reduce, potentially reducing the rate of erosion of the entrance channel. Whilst there is a risk that sediment deposition could begin to occur in the entrance channel and further upstream with any reduction in flow rates, this would offset any scour that might occur when flow rates are higher during extreme water level events.

It is difficult to quantify the expected rate of erosion in the entrance channel for the day-to-day conditions or for extreme events, as erosion and deposition can be strongly dependent on specific event conditions. This is something that will need to be monitored, via a programme of regular and post-event monitoring.

8.7.2 Shoal bank opposite the North Wall

The predicted increase in flow rate for the Do Nothing scenario would be expected to increase the rate of erosion of the bank of sediment located opposite the North Wall. If the estuary defences were raised, peak flow rates would reduce during extreme conditions, which could result in growth of the shoal bank. The options which include construction of a rock groyne to narrow the channel would most likely require the removal of the sediment bank, with the rock groyne structure diverting flows and dissipating wave energy, so sediment would be expected to accumulate on both sides of the rock groyne.

If the level of the marshes continues to increase, with an associated reduction in peak flow rates during lower water level conditions, then more sediment could be deposited on the shoal bank. This could be balanced by an increase in erosion during extreme events.

The presence of shoal bank means that the navigation channel runs close to the North Wall, which restricts the space available for mooring of vessels. With an improvement in the wave conditions at the North Wall following construction of a rock breakwater, there may be the desire to increase mooring at the North Wall. This could require removal of the shoal bank to provide sufficient space for both mooring and navigation.

Following discussion with the HMC regarding the potential benefits of dredging the shoal bank, an additional assessment was undertaken to review the impact of removal of this sediment on wave conditions and tidal flows. The dredging assessment is provided as **Appendix I** and discussed in **Section 8.8.2.**

8.8 Additional Assessments

8.8.1 Breakwater Culverts Assessment

An objective of the Investment Plan is to sustain navigation conditions in the harbour entrance as much as possible. The existing South Pier incorporates ‘windows’ in the sheet piles which enable a flow of water into the entrance channel from the south, which has benefits for navigation of the entrance channel. To enable flow through the breakwater, it was proposed that large box culverts could be incorporated into the structure to enable flow through the breakwater in a similar way to the existing windows.

To assess the performance of the proposed culverts, additional tidal modelling was undertaken. The culvert assessment report is provided as **Appendix H**, and considers:

- Wave penetration through the box culverts;
- Wave energy dissipation in the harbour entrance channel due to the proposed rock armour breakwater; and
- Tidal flow through the box culverts.

In summary, the culvert assessment determined that:

- Whilst the proposed box culverts would dissipate wave energy, currents could be generated by waves moving through the culverts, potentially resulting in intermittent jets of water from the culverts into the channel.
- Based on the additional tidal modelling, both the existing 'windows' in the South Pier and the proposed culverts create crossflows into the entrance channel. Although higher current speeds are shown to occur close to the South Pier structure, these flows appear to have only a limited influence on the overall flow conditions in the channel.
- Replacing the South Pier with a breakwater would significantly improve the wave conditions within the entrance channel, as the rock or concrete armour units will dissipate wave energy and reduce wave reflection. The reduction in wave reflection achieved with the breakwater means that maintaining the existing crossflow would not be necessary to reduce wave reflection.
- A review of the wave modelling comparing the conditions for the existing South Pier to those that would occur for a vertical-walled structure without any windows demonstrated the benefits of the windows for limiting wave reflection and potential build-up of swell waves running directly along the vertical wall.
- If the South Pier was replaced with a rock or concrete armour unit breakwater, there could be a risk to navigation due to the rapid reduction in wave heights that would occur between the mouth of the harbour entrance channel and the channel itself. It could be difficult to move from the disturbed wave conditions at the entrance into the much calmer conditions within the channel. This issue would need to be addressed in the design of the breakwater.

The overall conclusions are that:

- The proposed culverts would be of limited benefit to improving navigation conditions in the channel.
- A breakwater continues to be the preferred option to replace the South Pier. The inclusion of box culverts is not recommended.
- The design of the mouth of the harbour entrance channel should optimise conditions for navigation into and out of the channel. Additional wave modelling should be undertaken for less extreme wave conditions, to fully understand any risks to navigation from the transition from disturbed conditions at the harbour entrance to calmer conditions within the channel. Any residual risk should be addressed in the design, informed by consultation with harbour users.

8.8.2 Dredging Assessment

A high bank of sediment has built up close to the Southwold Harbour entrance channel, which restricts navigation and mooring at the North Wall, as identified by the bathymetric survey (**Figure 3-2**). Following discussions with the HMC regarding the potential benefits of dredging this shoal bank, an additional assessment was undertaken to review the impact of the removal of this sediment on wave conditions and tidal flows.

The dredging assessment report is provided as **Appendix I**, and considers:

i. The impact of removing the sediment on tidal flows in the outer harbour and the entrance channel;
ii. The impact on wave conditions at the North Wall and further upstream;

iii. Whether the proposed dredging could be undertaken as maintenance operations or would considered to be capital works;
iv. Whether ongoing maintenance dredging is likely to be needed;
v. Potential beneficial uses of any dredged material;
vi. Any licence requirements for the proposed dredging; and
vii. Any impacts on or from the dredging proposals in relation to other options proposed for the Southwold Harbour entrance, e.g. the proposed ‘narrow channel’ option.

In summary, the dredging assessment concluded that:

- Removing the shoal bank located opposite the North Wall would improve conditions for navigation in the outer harbour and increase space for mooring at the North Wall.
- Dredging would not change conditions in the entrance channel.
- With dredging, flow velocities in the outer harbour would be reduced, and the impact on upstream flow velocities would be limited.
- If the shoal bank was removed, peak water levels in the outer harbour would be approx. 20cm higher than an extreme event similar to 2013. At the Blackshore, peak water levels would be less than 10cm higher.
- If dredging was to be undertaken, construction of a rock groyne to narrow the channel would mitigate the impacts on peak water levels. A location upstream of Dunwich Creek would be preferred if the channel was to be narrowed.
- A marine licence application, supported by an environmental assessment and sediment sample analysis, would need to be completed to enable the shoal bank to be removed. The application and associated consents process for this could take 6 to 12 months.
- Regular bathymetric surveys would be needed to monitor future channel depths and any requirement for maintenance dredging.

Following discussions with the HMC regarding the dredging proposals and the constraints associated with the construction of a rock groyne to narrow the channel, it was concluded that the proposals to dredge the shoal bank should not be included in the Investment Plan.

8.9 Summary of Option Performance

Table 8-3 below summarises the performance of each of the options for the harbour entrance structures against the assessment criteria set out in **Section 8.1.** **Table 8-4** summarises the performance of the options for management of the estuary defences.

Table 8-3: Performance of options for harbour entrance structures against objectives

Objective	Criteria	H1 – Do Nothing	H2 – Do Minimum (Maintain)	H3 – Do Minimum (Repair)	H4 – Repair then Replace	H5 – Replace South Pier with a similar structure	H6 – Replace South Pier with a breakwater
Sustainable solution for harbour entrance structures (50 years)	**Access to harbour maintained**	Harbour entrance not sustained, associated loss of use of harbour and economic impact.	Harbour entrance remains in the short term, loss of use of harbour in the longer term.		Harbour entrance structures remain in place, although with risk of failure and short-term loss of use.	Harbour entrance structures replaced with new structures with >50 year design life.	
	Erosion rate in the entrance channel	Erosion rate depends on estuary management option, sea level rise and marsh sedimentation.					
		Continued erosion of entrance channel until failure of structures. Following failure of South Pier, sediment from Walberswick beach moves into entrance channel.			Continued erosion of entrance channel in short term. Scour reduced after replacement of South Pier with breakwater.	Continued erosion of entrance channel.	Reduced scour due to reduction in wave disturbance in channel.
Sustain / improve navigation conditions in the entrance channel and throughout the Harbour.	**Tidal flow rate in the entrance channel**	Peak flow rate depends on estuary management option, sea level rise and marsh sedimentation.					
		Increased width of harbour mouth following failure of South Pier would reduce flow rate at entrance.			Design of replacement structure could be optimised to reduce tidal flow rate (e.g. alignment, width of entrance).		
	Tidal flow rate in the harbour	Harbour entrance structures have limited influence on peak flow rate in harbour, which depends on the estuary management option, sea level rise and marsh sedimentation.					
	Wave conditions in entrance channel **Wave conditions at the North Wall**	Increased wave disturbance in entrance channel and at North Wall following failure of South Pier	Present wave conditions continue until failure of South Pier,when wave disturbance would increase.		Present conditions continue until South Pier replaced. Rock breakwater would improve wave conditions.	Present conditions continue, potential for increase in height due to climate change.	Rock or concrete breakwater would improve wave conditions.
	Sedimentation in the entrance channel **Sedimentation in the outer harbour (North Wall)**	Low risk of deposition due to increased flow rate. Sediment from Walberswick beach moves into channel and upstream after South Pier fails.	Present conditions continue until failure of South Pier, after which time sediment from Walberswick beach moves into channel and further upstream.		Present conditions continue until South Pier replaced. Rock breakwater could encourage sediment deposition in channel, depending on estuary management option.	Present conditions continue, depending on estuary management option.	Breakwater could encourage deposition in entrance channel, depending on option for estuary management.
Sustain or reduce flood risk to harbour	**Peak water levels in the harbour**	Estuary management options have a greater influence on peak water levels in the harbour than the form of the harbour entrance structures.					
		Peak water levels in harbour could increase slightly following failure of South Pier, with increased width of harbour mouth.			Design of replacement structure could be optimised to reduce peak water level in harbour (e.g. width of entrance).		
No increase in flood risk to Walberswick	**Flood extent and peak water levels at Walberswick**	Increased risk of flooding in long term with change in coastal alignment south of harbour following failure of South Pier.			If harbour entrance structures remain in place, flood risk to Walberswick depends on the estuary management option.		

Table 8-4: Summary of performance of options for estuary management against objectives

Objective	Criteria	E0 – Maintain integrity of Present-day Defences	E1 – Do Nothing	E2 – Improve estuary defences	E3 – SMP Policy	E4 – EA Strategy Position	E5 – Tidal Barrier	E6 – Spillway	E7 - Narrow channel
Sustainable solution for harbour entrance structures (50 years)	**Access to harbour maintained**	Harbour structures remain in place, access maintained.	Maintenance of structures withdrawn, South Pier fails after <10 years, harbour access restricted	Preferred option for harbour structures undertaken. Harbour access maintained.	Preferred option for harbour structures undertaken. Harbour access maintained.	Maintenance of structures withdrawn, South Pier fails <10 years, harbour access restricted	Preferred option for harbour structures undertaken. Harbour access maintained.	Preferred option for harbour structures undertaken. Harbour access maintained.	Harbour structures remain in place, access maintained.
	Erosion rate in the entrance channel	Day-to day erosion rate may increase with climate change. Marsh sedimentation could reduce flow and erosion rates. Increased erosion on extreme events.	Following failure of estuary defences, significant increase in tidal prism and flow rate for all conditions. Worst case in terms of impact on erosion of entrance channel.	Tidal prism and flow rate minimised. This option has the least negative impact on erosion rate.	Increase in tidal prism on extreme events, resulting in higher flow rates and potential increase in erosion compared to maintained or raised defences.	As for Do Nothing, increased tidal prism, flow rate and entrance channel erosion for all conditions.	Tidal barrier closed on surge tide, therefore no erosion occurs during extreme conditions.	Tidal prism and flow rate minimised for day-to-day conditions. May be an increase in flow and erosion rate during drainage of flooded areas after extreme events.	When combined with raised defences, tidal prism and flow rate are minimised. Option has limited negative impact on erosion rate. Further assessment needed for spillway option.
Sustain / improve navigation conditions in the entrance channel and throughout the Harbour.	**Tidal flow rate in the entrance channel**	3.0 knots by 2070 (Feb 2020 conditions + sea level rise (SLR)).	Increase to 4.7 knots by 2070 (Feb 2020 conditions + SLR).	3.0 knots by 2070 (February 2020 conditions + SLR).		Increase to 4.7 knots by 2070 (Feb 2020 conditions + SLR). Larger tidal prism for all water level conditions.	3.0 knots by 2070 (February 2020 conditions + SLR).		3.0 knots by 2070 (Feb 2020 conditions + SLR), when combined with raised banks. Higher peak flows when combined with other options.
		Limited increase in tidal prism for day-to-day conditions, unless breach or overtopping of embankments occurs.	Larger tidal prism for all water level conditions.	Best case as tidal prism is minimised for day-to-day and extreme conditions.	Peak flow on extreme events higher than with all banks raised, due to increase in tidal prism from flooding of southern marshes.		No embankment works, but they are unlikely to fail as barrier is closed during extreme events.	As for raised banks. Tidal prism minimised for day-to-day conditions. Flow rate may increase when flooded area drains.	
	Tidal flow rate in the harbour	Limited increase in peak flow rate throughout harbour for day-to-day conditions.	Significant increase in peak flow rate in harbour from increase in tidal prism	Best case as tidal prism is minimised for day-to-day and extreme conditions.	Limited increase for day-to-day conditions. Flooding of marshes on extreme events would increase flow rates.	Significant increase in peak flow rate in harbour due to increase in tidal prism	Limited increase in peak flow rate throughout harbour for day-to-day conditions.	Peak flow rate minimised for day-to-day conditions. May increase when flooded area drains.	Change in tidal flow patterns around rock groyne.
	Wave conditions in harbour	Wave conditions depend on option selected for management of harbour entrance structures.							
	Sedimentation in the entrance channel and at North Wall	Low risk of sediment accumulation affecting navigation. Higher peak flows during extreme events expected to offset any reduced flow rate from marsh sedimentation.	Increased rate of erosion of entrance channel expected due to larger tidal prism.	Compared to other options, higher risk of sediment accumulation if marsh accretion reduces tidal prism and peak flow rates.	Low risk of deposition affecting navigation. Higher peak flow rates during extreme events expected to offset any reduction in flow rate from marsh sedimentation.	Increased rate of erosion of entrance channel expected due to larger tidal prism.	Potential for deposition in entrance channel (barrier closed during surge events). Marsh sedimentation could reduce tidal prism and peak flow rates.	As for raised embankments (E2), higher risk of sediment accumulation if marsh accretion reduces tidal prism and peak flow rates.	Sediment could be trapped to either side of rock structure. Otherwise, similar to Option E2.
Sustain or reduce flood risk to harbour	**Peak water levels in the harbour**	Increasing flood risk to harbour with sea level rise. Additional works required to reduce harbour flood risk.	240mm lower than 2013 event due to estuary flooding.	190mm higher than 2013 event with present-day defences. Higher than all other options.	As for present-day scenario (E0), increasing flood risk with SLR.	As for Do Nothing (E1), 240mm lower than 2013 event due to estuary flooding.	Addresses all future flood risks.	120mm higher than 2013 event with present-day defences (E0). 80mm lower than bank raising alone (E2).	When combined with bank raising, 110mm lower than bank raising alone (E2).
				Additional works required to reduce harbour flood risk				Additional works required to reduce harbour flood risk	
No increase in flood risk to Walberswick	**Flood extent and peak water levels at Walberswick**	Risk of flooding to Walberswick if defences overtopped.	Increased flood risk to 29 properties in Walberswick and Southwold with failure of estuary defences.	Addresses future flood risks.	Requires secondary defence to Walberswick.	Requires secondary defence to Walberswick.	Tidal barrier addresses future flood risks.	Requires secondary defence to Walberswick.	Addresses future flood risk, depending on main option undertaken.

9 Option Costs

9.1 Approach to Assessment of Option Costs

The basis of the option cost estimates is set out in detail in **Appendix F** and summarised below.

Costs estimates for potential options for works to the South Pier were provided by Mackley Ltd (part of the Van Oord group) in 2020 based on their experience of undertaking similar works on the east coast of the UK. Briefing information was provided to the contractor, which introduced the project, conditions at the site, the form of construction of the South Pier and its present condition, and the options for which cost estimates were required. Cost estimates for potential future works to the North Pier and the Knuckle were developed by RHDHV based on the cost estimates provided by Mackley for the South Pier.

Cost estimates for works to the estuary defences are based on the estimates previously developed by Black and Veatch as part of the Blyth Estuary Strategy in 2008. The assumptions made in these cost estimates have been reviewed and changes made, considering previous feedback on the Strategy cost estimates (Ref. 4). These reviewed assumptions are set out in **Appendix F**. Costs have been updated to present day values (2022) using the Output Price Index, and component costs for materials reviewed against present-day values from SPON'S (Ref. 11).

Optimism bias of 60% has been applied to all cost estimates, in accordance with best practice for a strategic-stage study. Optimism bias is typically reduced as a project progresses, as the risks are better understood.

The cost estimates consider sensitivity to areas of uncertainty (e.g. climate change). Where costs are dependent on other decisions that may be made in relation to management of the estuary, this is discussed in **Section 11.2**.

9.2 Cost Estimates for Works to Harbour Structures

The cost estimates for all options for works to the South Pier are summarised in **Table 9-1** below. Cost estimates for the replacement of the North Pier and the Knuckle are set out **Table 9-2**. Further details of the build-up of the cost estimates are provided in **Appendix F.** These costs are considered in the assessment of the options in **Section 10**, and where appropriate they are carried forward to the proposed Investment Plan in **Section 11**.

Tidal Barrier
An estimated cost of £90m is assumed for a tidal barrier to Southwold harbour. This is based on the cost estimate for the Boston Barrier, with further details of this estimate provided in **Appendix F**.

Sensitivity
The cost estimates for works to the harbour structures are sensitive to the rate of erosion of the harbour entrance channel, and the foundation depth which is required to address this. It is currently expected that the breakwater would be designed using the piles from the existing structure to provide additional support to the toe, with the breakwater designed to be structurally stable without these piles in place, enabling adaptation to channel erosion. Eventually, with continuing channel erosion, replacement toe piling might be required.

At present, the existing piles have a minimum cover of 3m. The current rate of erosion of the channel bed is about 100mm/year so if this was to continue the existing piles could be undermined within 30 years. It is expected that a rock or concrete breakwater would reduce wave disturbance in the entrance channel and any associated scour of the channel bed as wave energy will be dissipated by the structure, so it is assumed that the rate of erosion will not increase, and deeper toe piling will not be required as part of the initial breakwater design. Taking a conservative approach to the cost estimate, an allowance has been included in the Investment Plan for installing replacement toe piling in Year 30, with the actual timing and depth of this piling dependent on the future rate of erosion.

For the like-for-like replacement and sheet piled pier options, there is greater potential for the rate of erosion of the channel bed to increase in the future, so the piled foundations would need to be designed to account for this. The cost estimates provided by Van Oord for piling have been increased by 20% to allow for a greater foundation depth.

For the 'repair' option, an increase in erosion rate would be expected to change the time of failure. Sensitivity to timing of works or failure of structures is considered in **Section 11.2** of this report.

Table 9-1: Cost estimates for options for works to the South Pier

Option	Materials	Labour & Plant	Mobilisation, demolition & disposal	Prelims & Contractor's Risk (25%)	Sub-total (2020)	Sub-total + inflation 2020 to 2023 (15%)	Optimism Bias (75%)	TOTAL
Repairs to existing structure	£301,576	£1,055,700	£254,150	£418,971	£2,030,397	£2,334,956	£1,751,217	£4,086,173
Like-for-like replacement	£1,885,034	£3,229,200	£673,900	£1,504,915	£7,293,049	£8,387,006	£6,290,255	£14,677,261
Sheet piled wall + rock armour[19]	£2,940,550	£1,514,838	£673,900	£1,333,615	£6,462,902	£7,432,338	£5,574,253	£13,006,591
Rock armour breakwater[20]	£3,589,484	£1,262,183	£673,900	£1,436,647	£6,962,213	£8,006,545	£6,004,909	£14,011,454
Concrete unit breakwater[21]	£6,987,297	£1,259,400	£673,900	£2,319,355	£11,239,951	£12,925,944	£9,694,458	£22,620,401
Rock armour + concrete unit breakwater[22]	£3,783,993	£1,004,488	£673,900	£1,420,219	£6,882,601	£7,914,991	£5,936,243	£13,851,234
Rock groyne (narrow channel)	£358,948	£126,218	£67,390	£143,665	£696,221	£800,655	£600,491	£1,401,145
Toe piling[23]	£1,010,201	£1,876,800	£172,500	£795,470	£3,854,972	£4,433,218	£3,324,913	£7,758,131

[19] Sheet piled pier with rock armour to southern face, incorporating gaps in the structure or culverts to maintain flow through the pier.

[20] Rock armour breakwater option includes timber fenders.

[21] For the concrete unit and rock armour plus concrete unit breakwaters it is assumed that timber fenders will not be required.

[22] The cost estimate for the rock armour and concrete unit option assumes that concrete units would be used for approximately 35% of total length of the breakwater.

[23] Toe piling may be required in future to address channel bed erosion.

Table 9-2: Cost estimates for alternative options for works to the North Pier and the Knuckle[24]

Option	Materials	Labour & Plant	Mobilisation, demolition & disposal	Prelims & Contractor's Risk (25%)	Sub-total (2020)	Sub-total + inflation 2020 to 2023 (15%)	Optimism Bias (75%)	TOTAL
Concrete units (similar to existing)	£3,493,648	£646,950	£522,100	£1,212,301	£5,874,999	£6,756,249	£5,067,187	**£11,823,436**
Rock revetment	£2,082,242	£648,341	£522,100	£845,698	£4,098,381	£4,713,138	£3,534,853	**£8,247,991**

9.3 Cost Estimates for Works to Estuary Defences

The cost estimates for all options for works to the estuary defences are summarised in **Table 9-3** below. Further details of the build-up of the cost estimates are provided in **Appendix F.** These costs are considered in the assessment of the options in **Section 10**, and where appropriate they are carried forward to the proposed Investment Plan in **Section 11**.

Table 9-3: Cost estimates for works to the estuary defences

Option	Materials	Contractor's Costs[25]	Engineering & Client Costs[26]	Optimism Bias (75%)	TOTAL (2023)
E2a. Raise all estuary defences (20% AEP)	£4,397,992	£1,698,037	£653,744	£5,062,330	**£11,812,102**
E3a. Raise north banks only (20% AEP)	£1,960,797	£723,159	£278,416	£2,221,779	**£5,184,151**
E6a. Raise downstream defences + passive spillway (20% AEP)	£4,515,087	£1,744,875	£671,777	£5,198,804	**£12,130,542**
E2b. Raise all estuary defences (1% AEP)	£6,784,760	£2,652,744	£1,021,306	£7,844,108	**£18,302,918**
E7. Raise all estuary defences + narrow channel[27] (1% AEP)	£6,389,999	£2,494,840	£960,513	£7,384,014	**£17,229,367**
E3b. Raise north banks only (1% AEP)	£2,911,357	£1,103,383	£424,802	£3,329,657	**£7,769,199**
E6b. Raise downstream defences + passive spillway (1% AEP)	£6,512,629	£2,543,892	£979,398	£7,526,940	**£17,562,859**

Sensitivity

The cost estimates for works to the embankment defences to the Blyth estuary are sensitive to the design water levels, and therefore to the rate of sea level rise. The cost estimates provided in **Table 9-3** assume a 1 in 100 year (1% AEP) water level at the harbour mouth of 3.35m ODN in 2070, based on the mid-range UKCP18 scenario RCP4.5 (50 percentile).

9.4 Flood Protection to the Harbour

The cost estimates for the options for works to reduce flood risk to the harbour are summarised in **Table 9-4** below. Further details of the build-up of the cost estimates are provided in **Appendix F.** These costs

[24] Cost estimates assume replacement of the existing concrete armour units over the full length of the North Pier and Knuckle, using either concrete armour units or rock armour. Costs do not include for any reconstruction of the core piled structures.

[25] Contractor's costs include labour & plant, mobilisation/demobilisation, preliminary items & overheads, and contractor's risk & profit.

[26] Engineering and Client costs include site investigations, engineering design, consent process incl. associated studies, construction management and supervision and other associated costs to East Suffolk Council.

[27] Costs do not include for works to construct the rock groyne to narrow the channel. With the narrow channel, the upstream defence crest level is slightly less, so the embankment costs are lower than without the rock structure to narrow the channel.

are considered in the assessment of the options in **Section 10**, and where appropriate they are carried forward to the proposed Investment Plan in **Section 11**.

If property-level protection is required to Blackshore properties in the future, then this could cost £50,000 per property on average. Costs are dependent on property size and the extent of internal works required, e.g. replacement flooring and flood resistant kitchens. These costs are not included above as they are not proposed as an initial capital investment.

Table 9-4: Cost estimates for works to reduce flood risk to the harbour

Option	Embankments	Flood walls and gates	Sub-total (2020)	Sub-total + inflation 2020 to 2023 (15%)	Optimism Bias (75%)	TOTAL
B2: Raise Harbour Road (1:5 SOP)	£ 2,060,863	-	£ 2,060,863	£ 2,369,992	£ 1,777,494	**£ 3,838,357**
B3: Raise Harbour Road (1:100 SOP)	£ 2,552,215	-	£ 2,552,215	£ 2,935,047	£ 2,201,285	**£ 4,753,500**
B4a: Raise Harbour Road plus concrete flood walls (1:100 SOP)	£ 1,069,296	£ 2,130,569	£ 3,199,865	£ 3,679,845	£ 2,759,883	**£ 5,959,748**
B4b: Raise Harbour Road plus glass and concrete flood walls (1:100 SOP)	£ 1,069,296	£ 3,944,417	£ 5,013,713	£ 5,765,770	£ 4,324,328	**£ 9,338,041**
B5: Raise Harbour Road (1:5 SOP) + Blackshore Flood Walls (1:100 SOP)	£ 2,060,863	£ 638,544	£ 2,699,406	£ 3,104,317	£ 2,328,238	**£ 5,027,644**
B6: Do Minimum	Costs not assessed, limited works to improve road condition would be undertaken on an ad-hoc basis by harbour users					

9.5 Associated Costs

9.5.1 Design and associated studies

The cost estimates for the proposed works to replace the harbour entrance structures and to improve the estuary defences include allowances for design, consents and licences (including associated environmental studies) and construction management and supervision. Internal costs to East Suffolk Council have also been estimated.

9.5.2 Coast protection

The cost estimates do not include any works to improve cost protection to the north or south of the harbour, e.g. the rock groyne at Gun Hill which was proposed as part of the EA Strategy preferred option, or works to raise the crest level of the Walberswick Dunes. Costs for additional works to the adjacent coast may need to be included as part of any future detailed economic appraisal that compares economic damages and benefits as well as costs.

9.5.3 Maintenance and monitoring

Monitoring and maintenance costs for the estuary defences are based on the maintenance costs assumed by the EA Strategy, adjusted for inflation to 2021. This gives an annual average monitoring and maintenance cost of about £100k, which is considered to be conservatively high. It is therefore assumed that this maintenance cost would also cover maintenance of the harbour entrance structures. Maintenance cost estimates could be refined based on data held by the local drainage board, but it has not yet been possible to obtain this information.

The maintenance cost estimate does not include for:

- Maintenance dredging, as a programme of maintenance dredging is not currently recommended.
- Replacement of the channel section of timber fendering to the North Pier in year 5. The approximate cost of these works is assumed to be about £1 million (present-day value), based on the cost of the recent fender replacement works. This cost is included in the Investment Plan as a capital cost.

A programme of regular bathymetric surveys is recommended, with surveys undertaken at least every 3 years, as well as following significant surge events, at a cost of about £10,000 per survey. A more comprehensive hydrographic survey should be completed every 5 or 6 years, at a cost of about £20,000 (excluding the associated bathymetric survey). The marsh sedimentation survey should also be repeated at least every 10 years, at a cost of about £15,000. Based on these cost estimates, an annual average monitoring cost of £10,000 is assumed to be included in the total annual monitoring and maintenance allowance of £100,000.

For some of the estuary management options, an allowance should be included for the risk of a breach of the flood embankments. The cost of repairing a defence breach is known to be very expensive in this location, due to access restrictions and other construction constraints following a flood. Previous breach repairs have required helicopters to deliver materials. Therefore, it would be reasonable to expect that emergency repair works could be at least three times as expensive as planned works. Based on the cost estimate for improvement works to the estuary flood embankments, the cost to repair a 10m breach could be £500,000. This cost estimate could be refined if relevant data could be obtained from the Environment Agency and/or the local drainage board.

The frequency of occurrence of breaches to the estuary embankments will depend on the estuary management option, with breaches occurring more frequently if no works were undertaken to improve the condition of the estuary defences. If the estuary defences were raised, and appropriate maintenance undertaken following those works, then it would be reasonable to assume that the defences would not breach.

10 Assessment of Options

This section completes the assessment of the proposed options for the future management of the Southwold Harbour entrance structures and the estuary defences based on the performance of the options against the objectives and the estimated costs. This assessment is discussed below and is summarised in **Table 10-1**.

10.1 Improvements to the South Pier

The assessment of the options for repair or replacement of the South Pier are summarised below:

- The South Pier is in poor condition and is expected to fail within five years.
- Options to repair the South Pier are not expected to extend its life to 2070, and there would continue to be a risk of the structure collapsing into the entrance channel.
- The wave modelling results show that replacement of the South Pier with a breakwater (**Option H6**) would improve the wave conditions in the outer harbour and the entrance channel. Wave heights at the North Wall, during a 1-year return period storm, would be reduced by more than 50% compared to the current situation, to less than 0.8m.
- A vertical-walled pier would significantly increase wave disturbance in the entrance channel and at the North Wall and would also be more expensive than a rock armour breakwater.
- For a breakwater constructed from rock armour alone, timber fenders may be required to reduce the risk of vessel impact on the rock. Therefore, a combination of rock armour and concrete units is currently preferred, for which fenders are not expected to be required, which would reduce ongoing maintenance costs. The section of the breakwater constructed from concrete units would have a smaller footprint than a structure constructed fully from rock armour. The design of the structure could be optimised in terms of the combination of rock armour and concrete units, and the associated costs.
- The cost estimate for a breakwater constructed from a combination of rock armour and concrete units is £13.9 million, which is more cost effective than other long-term options for the replacement of the South Pier.
- A rock armour and concrete unit breakwater could be designed to address the risk of scour at the toe, and toe piling could be added in future if necessary.
- The landward end of the breakwater could be designed to minimise impact on the adjacent dunes.
- The alignment of the breakwater and the width of the harbour entrance could be optimised during design to improve flow conditions.

Therefore, it is concluded that replacement of the South Pier with a rock armour and concrete unit breakwater (Option H6) is the preferred solution to improve the conditions of the harbour entrance in the short term and towards 2070.

10.2 Other Works to the Harbour Structures

The requirement for other works to the harbour structures is assessed as follows:

- The North Pier is assessed to have an overall residual life of more than 20 years if the South Pier was to be replaced and repairs undertaken to the seaward end of the SHED concrete revetment. Conservatively, replacement of the North Pier should be planned for in 20 years' time, but the condition of the structure should be monitored to determine whether these works could be delayed.

- Works to replace the timber fendering to the outer part of the North Pier is expected to be required in about 5 years. Subsequent works to renew the North Pier timber fenders have been allowed for in the Investment Plan,
- The HMC would like an increase in the use of the North Wall moorings, as this would increase the harbour revenue, with associated benefits for the economic viability of the harbour. To facilitate this, the North Wall could be improved through the addition of fenders and mooring bollards. The HMC is planning to undertake further investigations into the condition of the North Wall. Removal of the shoal bank opposite the North Wall would provide additional space for mooring. Further assessment of this option showed that removal of the shoal bank would improve conditions for navigation in the outer harbour but would increase peak water levels upstream. Construction of a rock groyne to narrow the channel would mitigate the impacts on peak water levels, with a location upstream of Dunwich Creek currently preferred if the channel was to be narrowed.
- A marine licence application, supported by an environmental assessment and sediment sample analysis, would need to be completed to enable the shoal bank to be removed. The option was reviewed by the HMC and it was concluded that the proposals to dredge the shoal bank should not be included in the Investment Plan.
- Other works to the harbour structures, such the addition of baffles to the South Training Arm, or changes to the structures at Dunwich Creek, would have limited benefit in terms of the wave conditions in the outer harbour and are therefore not recommended.

The Investment Plan should include for undertaking limited repairs to the outer part of the North Pier alongside the proposed replacement of the South Pier. It should also allow for replacement of the North Pier with a rock breakwater in 2043. The condition of the structure should be monitored to determine whether these works could be delayed.

10.3 Future Management of the Estuary Defences

The advantages and disadvantages of the options for the future management of the estuary defences are compared below:

- If the flood defences along the Blyth estuary were allowed to fail, the tidal prism of the estuary will increase significantly, resulting in increased peak flow rates in the harbour entrance channel. This would accelerate scour of channel bed, risking failure of the harbour entrance structures and impacting on navigation. If these issues are not addressed, investment in works to improve the South Pier may not be justified due to the future risk of failure.
- None of the options for the future management of the estuary defences provides an ideal solution to all of the issues for Southwold Harbour.
- Improving the condition of the estuary defences and increasing the standard of protection provided would be the best option in terms of minimising the future tidal prism and associated flow rates through the channel. This option (**Option E2**) would also reduce the risk of flooding to the wider area. However, raising the embankments would increase peak flood levels within the harbour during extreme surge events, e.g. similar to the conditions experienced in December 2013.
- The option recommended by the Suffolk SMP2 (**Option E3**), whereby only the northern estuary flood embankments would be raised, with the southern banks allowed to overtop and ultimately to retreat, has limited additional benefits compared to maintaining the present-day defence levels. In addition, secondary defences would be needed to address the continued flood risk to Walberswick.
- A range of spillway options have been assessed (**Option E6**), which could be considered to be a 'managed alternative' to the SMP policy scenario. The most effective spillway option would raise the defences to Robinson's, Tinker's, Reydon and Town Marshes to provide a 1 in 100 year SOP. A 250m long reinforced spillway would be constructed, with a lower crest level than the

embankments. When peak flood levels need to be reduced on a surge tide, the spillway into Tinker's Marsh would be overtopped and the marsh would flood.

This option would increase peak water levels in the harbour by less than if all the defences were raised without the spillway in place. If the river channel was to be narrowed by constructing a rock groyne opposite the North Wall, peak water levels would be reduced compared to conditions without the structure in place. However, this option would not fully address the risk of flooding to the Blackshore and there would be a risk of sediment accumulation on either side of the rock groyne, reduced space for mooring at the North Wall, and higher flow rates around the structure with the potential for scour and navigation constraints. Therefore, this option is not currently recommended, but could be progressed in the future if dredging proposals were to be taken forward.

- If the present-day defence levels were to be maintained, the future peak flow rates in the entrance channel would be manageable in terms of navigation. Flood risk to the harbour would be less than if the height of the flood embankments was increased, as the defences would be overtopped during extreme surge events.
- If the condition of the estuary embankments is not improved, there would continue to be a risk of failure (breach) during an extreme event. If the embankments are not repaired following a breach, progressive failure could occur. Therefore, if maintaining the present-day defence levels was to be the preferred option, there would need to be an effective management plan in place to ensure appropriate maintenance is undertaken as well as emergency repairs when necessary.

Option E6 - improving the downstream estuary defences (Robinson's, Tinker's Reydon and Town Marshes) to provide a 1 in 100 year (1% AEP) SOP, with a spillway into Tinker's Marsh is the preferred solution for the future management of the estuary. However, this option has a high cost of £15.7 million.

Whilst this option could be implemented with a lower standard of protection, this is not recommended. Providing a 1 in 5 year (20% AEP) SOP would cost £10.8m but would not greatly increase the protection beyond that currently provided by the existing defences.

Maintaining the present-day defence levels would be an alternative solution if an effective management plan could be implemented. This option would enable phased improvements to be made to the estuary defences when funding becomes available.

10.4 Flood Risk to the Harbour

The risk of flooding to the residential properties and businesses located in the Harbour area is of both immediate and long-term concern. The frequency of flooding of the Harbour Road will increase with sea level rise, and the condition of the road will continue to deteriorate, resulting in access restrictions and economic impacts. These issues reduce the benefits of undertaking works to improve the South Pier.

Options to reduce flood risk to the harbour include raising the level of the Harbour Road to 2.65mODN (approx. 1.65m increase, **Option B2**), which would provide a 1 in 5 year (20% AEP) SOP, at a relatively high cost of £3.4m. For this design standard, additional measures would be required in the future to improve the flood resilience of residential properties and businesses. Raising the road to this level would be difficult to achieve due to the increased footprint that would be needed for a raised road considering the current location of harbour businesses and boat sheds and the requirement to maintain access to the pontoons.

Alternatively, flood walls could be constructed along the full length of the Harbour Road (**Options B4a, B4b, B5**). This could have other benefits to the harbour, e.g. enabling segregation of pedestrians and vehicles. These options could be considered further, but have a much higher cost of between £5.4m and £8.4m.

Due to the high costs and constraints relating to the options to provide flood protection to the Harbour, a Do Minimum option has also been considered (**Option B6**). With this option, limited maintenance works to infill low spots in the road and stabilise the channel banks would be undertaken on an ad-hoc basis by harbour users.

The high costs and other constraints associated with the options to reduce the risk of flooding to the Harbour Road mean that they are unlikely to be viable. Therefore, the preferred option is to undertake limited works to improve the road condition (Option B6 – Do Minimum).

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Table 10-1: Summary of assessment of options for the future management of Southwold Harbour and the estuary defences

Scenario / **Issue**	**Do Nothing**	Maintain Integrity of Present-day defences	EA Strategy	Raise all banks (1:100+CC SOP)	Raise N banks only (SMP policy)	Raise downstream banks + spillway (1:100+CC SOP)	Tidal barrier
Harbour structures	S Pier fails (<5 years), restricts harbour access.	Breakwater to replace South Pier (Option H6). Limited repairs to North Pier (approx. £1.0M). **Total Cost: £14.9M** Replacement of North Pier may be needed Year 30 – 50.					
Flood risk (Southwold/ Walberswick)	Increased flood risk to 29 properties	Flood risk on extreme events when banks are overtopped. Secondary defences could be provided.	Secondary defences provided.	Addresses future flood risks.	Tinkers / Robinsons Marsh banks allowed to fail. Secondary defence needed at Walberswick (£0.7M[28]).	Requires bank/wall to Walberswick (£0.7M).	Addresses future flood risks.
Flood risk to Harbour (peak flood levels)	240mm lower than 2013 event due to estuary flooding. South Pier failure affects access.	Increasing flood risk to harbour with sea level rise.	240mm lower than 2013 event.	190mm higher than 2013 event. Higher than all other options.	Comparable to present-day. Increasing flood risk with sea level rise.	Comparable to present-day scenario. 220mm lower than bank raising alone.	Addresses all future flood risks.
		Improvements to condition of Harbour Road, to be undertaken by harbour users. Costs TBC. Additional property resilience measures are likely to be needed in future.					No works required
Tidal flow in entrance (erosion & navigation risks)	Increase to 4.7 knots by 2070 (larger tidal prism).	3.0 knots by 2070. Peak flow on extreme events higher than with all banks raised.	Increase to 4.7 knots by 2070 (larger tidal prism).	3.0 knots by 2070. Best case as tidal prism is minimised.	3.0 knots by 2070. Peak flow on extreme events higher than with all banks raised.	3.0 knots by 2070, as for present-day defences. Peak flow on extreme events would be higher than if all banks are raised.	Increase to 4.7 knots by 2070 - no works to flood banks
Cost of works to estuary defences	N/A	Emergency repair cost ~£500,000 for each 10m breach.	**£3.1M[29]**	**£18.3M**	**£7.8M**	**£17.6M**	**~£90M**
Other issues	Long-term realignment of coast.	Regular maintenance and repair of breaches. Cost will increase with time.	Flooding of marshes, secondary defences.	-	Flooding of marshes, secondary defences.	Secondary defences, operational risks.	-
Total Initial Capital Cost	**N/A**	**£14.9M**	**£18.0M**	**£33.2M**	**£23.4M**	**£33.2M**	**~£105M**

[28] Cost estimate for secondary defences to Walberswick based on cost estimate for EA Strategy option.

[29] Initial capital cost relates to construction of secondary defences only. Does not include for compensatory habitat (already acquired). Cost estimate given in StAR is £2.2m at 2007 prices. Increased by 41% to £3.1m to reflect inflation to December 2022.

11 Investment Plan

11.1 Recommended Investment Plan

As reflected by the scope of work for this project, the discussion of the ‘Do Nothing’ scenario in **Section 6**, and the Assessment of Options in **Section 10**, the highest priority for the Investment Plan is to undertake works to replace the South Pier, which is at high risk of collapse during a severe storm. Funding for these works should be sought as soon as possible, so that design of the scheme and the associated consents processes can be progressed.

The condition of the harbour road is also of immediate concern. Minor works to improve the condition of the road should be planned as soon as possible. The Investment Plan does not include costs for undertaking these works, as they would be carried out on an ad-hoc basis by harbour users, e.g. when suitable fill material can be sourced. Plans should also be progressed for improving the resilience of harbour businesses to flood events, considering the expected increased risk with sea level rise.

In terms of the Blyth Estuary defences, the preferred solution based on technical grounds is to undertake works as soon as possible to raise the level of the embankments to Robinson’s, Tinker’s, Reydon and Town Marshes to provide a 1 in 100 year (1% AEP) SOP, allowing for climate change up to 2070, plus the construction of a reinforced spillway into Tinker’s Marsh (**Option E6**).

Recognising funding constraints, the investment required for the alternative **Option E0** – Maintain Integrity of Present-day Defences, is also presented below. This option requires less up-front capital investment but would require a management plan to ensure the required maintenance would be undertaken, and to deal with any emergency response that would be needed if failure of the estuary embankments was to occur during an extreme flood event. The Investment Plan assumes that on average one breach repair would be required every 5 years until 2040, increasing to two repairs every five years from 2040 to 2055, and three repairs every five years between 2055 and 2070.

Conservatively, the Investment Plan includes for the replacement of the North Pier in Year 20, and for the installation of toe piling at the South Pier in Year 30. The need for these works depends on the future rate of erosion of the channel bed, which cannot be assessed accurately at this stage and will require future monitoring. The construction of a rock breakwater to replace the South Pier (**Option H6)** is expected to reduce the rate of deterioration in the condition of the North Pier and to reduce scour of the channel. Raising the estuary defences would also minimise future increases in flow rates in the channel and associated erosion. As such, the North Pier may have more than 20 years’ residual life and toe piling at the North Pier may not in fact be required during the 50-year timeline of the Investment Plan.

The proposed 50-year Investment Plan for the preferred options described in **Section 10** is set out in **Table 11-1,** assuming that the required funding can be obtained. **The total initial capital cost (Year 0 to Year 5) for Option E6 (Improve Estuary Defences with Spillway), Option H6 (Replace South Pier with a Breakwater), and minor repairs to the North Pier is estimated at £32.6 million, with a total discounted present-value cost for all works up to 2070 of £42.2 million.**

The alternative **Option E0** (Maintain Integrity of Present-day Defences), combined with the same preferred option for replacing the South Pier, is estimated to have an initial capital cost of £14.9 million, with a total present-value cost for all works to 2070 of £31.7 million, allowing for repeated repairs to the embankments.

The timescales for the initial works recognise the time needed to secure funding and develop the design. Works to the South Pier are more time-critical than the proposed improvements to the estuary defences, although the short-term risk of failure of the embankments should be recognised.

Table 11-1: Recommended Investment Plan

Financial Year	Proposed works	Option E6 – Improve estuary defences + spillway		Option E0 – Maintain integrity of present-day defences	
		Cost (£)	Discounted Present-Value Cost (£)	Cost (£)	Discounted Present-Value Cost (£)
2024-25	Replace South Pier	13,851,234	12,930,275	13,851,234	12,930,275
2024-25	Repairs to North Pier	1,017,347	949,705	1,017,347	949,705
2026-27	Raise estuary defences + spillway	17,759,880	15,476,709	-	-
2027-28	Replace N Pier fenders[30]	1,157,000	974,000	1,157,000	974,000
2022-32	Maintenance & Monitoring	1,339,234	1,153,092	2,678,469	2,305,863
2032-42	Maintenance & Monitoring	1,339,234	817,221	2,678,469	1,634,442
2042-43	Replace North Pier[31]	11,823,436	5,942,056	11,823,436	5,942,056
2042-52	Maintenance & Monitoring	1,339,234	579,000	3,883,780	1,670,725
2053-54	Toe piling to South Pier[32]	7,758,131	2,683,548	7,758,131	2,683,548
2052-62	Maintenance & Monitoring	1,339,234	419,221	4,553,397	1,410,652
2062-72	Maintenance & Monitoring	1,339,234	311,940	5,356,938	1,247,758
	TOTAL	**60,063,200**	**42,236,766**	**54,758,200**	**31,749,024**

11.2 Risk and Uncertainty

Due to the uncertainties relating to securing funding for works to the harbour structures and the estuary defences, there are various risks that need to be recognised, which primarily relate to the timing of works:

- Failure of the South Pier before works are undertaken – costs associated with emergency repairs and addressing any safety risks;
- Failure of part of the North Pier in advance of works being undertaken / planned – costs associated with emergency repairs and addressing any safety risks, increase in present-value costs if works required before Year 20;
- Increased rate of erosion of entrance channel, with toe piling required sooner – increase in present value costs of toe piling works
- Breach of the estuary defences before improvement works are completed - costs associated with emergency repairs and addressing any safety risks;

The decision-process for works to Southwold Harbour and the flood defences to the Blyth Estuary is relatively independent of uncertainties relating to climate change (sea level rise) or sedimentation of the marshes. Climate change is accounted for in the cost estimates for works to the estuary defences. Sedimentation of the marshes has been considered in the assessment of the options but is not relevant to the preferred option of raising the estuary defences.

[30] Planned replacement of fenders to North Pier (channel section), not included in annual maintenance budget. These works are expected to be required in approx. 5 years.

[31] Costs for replacing the North Pier and the Knuckle are (conservatively) included in Year 20. With the replacement of the South Pier, and with improvements to the estuary embankments, the residual life of the North Pier could be more than 20 years.

[32] Costs for installing additional toe piling to the South Pier are included in approx. Year 30 as a conservative estimate. May not be required before Year 50 as the breakwater would be designed to adapt to falling bed levels, and the breakwater would dissipate wave energy and reduce scour.

In addition to the above risks, there is also a significant risk that it will not be possible to justify and secure funding for the preferred option for the Blyth Estuary defences. Potential funding sources are discussed in **Section 11.3**. Until funding is secured, there remains a real risk that these works will have to be delayed or cannot be completed. If sufficient funding cannot be secured to improve the downstream estuary defences to a 1 in 100 year (1% AEP) SOP and to construct a spillway, then there are a number of alternatives, depending on the amount of funding that is available:

i. **Option E0 – Maintain Integrity of Present-day Defences:** Maintain the existing embankments to both the north and south of the estuary for as long as possible, undertaking works to improve the defences when funding becomes available. This option would require annual maintenance of the embankments to reduce the risk of failure, and provision made for repairs to be undertaken if an extreme surge event resulted in embankment failure at one or more locations. The Investment Plan for this alternative option is included in **Table 11-1**.

ii. Downstream estuary defences raised and spillway constructed within the next 5 years, but to a lower SOP, e.g. 1 in 5 years (20% AEP). Works could be undertaken at a later date to increase the SOP if funding was to become available.

iii. No works undertaken to the estuary defences, accepting the Do Nothing scenario whereby the embankments will eventually breach in multiple locations, resulting in regular flooding of the marshes.

All of these options increase the risk of flooding to properties in Walberswick. The construction of a secondary defence embankment could be undertaken alongside any initial phase works.

Options which take a staged approach to works to the estuary defences would incur additional costs relating to contractor mobilisation and site clearance.

If the approach to management of the estuary defences were to revert to a 'Do Nothing' approach (Scenario iv), this would result in a significant increase in the tidal prism of the estuary, with an associated increase in tidal flow rates through the harbour entrance channel, as summarised in **Section 6.** Under this scenario, provision would need to be made in the design of the foundations to the harbour entrance structures for an increased rate of erosion of the channel bed or works undertaken to reinforce the foundations at a later date.

In terms of the long-term risks for the sustainability of Southwold Harbour, estuary management scenarios which minimise the future tidal prism of the estuary are preferred. If funding cannot be justified to maintain or improve the SOP provided by the defences throughout the estuary (north and south banks), then the 'SMP scenario' (Option E3) of maintaining or improving the only the north bank defences may provide an appropriate compromise.

If a relatively low SOP is provided, then the risk of failure of the defences will be greater. If a breach was to occur, then this could result in a change in the management approach from Hold the Line to Managed Realignment or Do Nothing.

11.3 Potential Funding Sources

Potential funding sources for delivery of the proposed works are summarised below:

- Although the EA Strategy determined that works to provide a 1 in 100 year (1% AEP) SOP to the Blyth Estuary could not be economically justified, economic benefits would be delivered by this project through the reduction in flood risk. The funding from central government for managing flood risk in England is known as 'Flood Defence Grant in Aid' (FDGiA). The amount of FDGiA available for a particular scheme is based on a formula that takes into account the number of households protected; the estimated value of damages being prevented; and the other benefits a particular project would deliver, such as environmental improvements. The 'Flood and Coastal Resilience Partnership Funding' system typically pays a share of the costs of a scheme, with the remaining funding needing to be obtained from other sources.

- The Regional Flood and Coastal Committee may be able to provide funding for the project from the Local Levy fund. Local councils raise Local Levy to fund local priority projects that do not qualify for full central government funding.
- The New Anglia Local Enterprise Partnership (LEP) aims to generate economic growth in Norfolk and Suffolk. The LEP works to secure funds from government to support businesses and deliver the infrastructure needed for growth. As such, the LEP could be a source of funding for the work proposed for Southwold Harbour.
- In recent years, government funding has been made available to support projects that will achieve regeneration and economic growth in coastal communities via the Coastal Communities Fund. Whilst this fund is currently closed to new applications, similar funding might be made available in future and could be relevant for this project.
- Funding contributions may need to be sought from property and business owners who would benefit from the project. 'Crowd funding' methods have been used successfully for similar projects in recent years.

In order to obtain either FDGiA or other funding, it is expected to be necessary to undertake a more detailed economic appraisal, in accordance with relevant guidance, of the costs and benefits of the proposed works. The economic appraisal will need to recognise the context of this project, which is wider than flood and coastal protection, with recognised economic growth objectives for Southwold Harbour.

12 Conclusions and Recommendations

12.1 Key Findings

12.1.1 Replacement of the South Pier

The preferred option for works to the South Pier is **Option H6 – Replace South Pier with a breakwater**. The total initial capital cost of these works is **£13.9 million**[33]. A breakwater constructed of rock armour or concrete units is the option with the greatest benefits for wave conditions, as it would significantly improve wave conditions within the entrance channel and the inner harbour, reducing wave heights at the North Wall to about 0.5m during conditions expected to occur once every year on average. A rock armour and concrete unit breakwater is a more cost-effective solution than other long-term options.

The review of options to replace the South Pier included various additional assessments to optimise the proposed solution. Issues considered included:

- *Requirement for timber fenders to the inner face of the proposed breakwater.* Timber fenders may be necessary to mitigate safety risks to vessels if the breakwater was constructed from rock armour. Cost estimates currently indicate that a hybrid concrete unit and rock armour structure without fenders may be slightly less expensive than a rock armour breakwater with timber fenders, and without the future maintenance costs associated with fenders. However, the difference in costs is less than £150k (1%) for a breakwater assumed to comprise 35% concrete units and 65% rock armour.

  Due to the ongoing volatility in construction costs, the most cost effective design for the South Pier should be reviewed as part of design development, with input from a construction contractor, considering potential construction constraints as well as the costs for materials and future maintenance.

- *Options for maintaining tidal flows and wave penetration into the entrance channel,* with the aim of replicating the effects of the existing 'windows' through the South Pier. A range of options incorporating box culverts were assessed using the tidal model (see **Appendix H**), which concluded that incorporating culverts in the breakwater would be of limited benefit to improving navigation conditions.

  It is therefore recommended that the proposed breakwater does not include culverts, and that the design of the mouth of the harbour entrance channel should optimise conditions for navigation into and out of the channel, with additional wave and sediment transport modelling and consultation to be undertaken as part of the design development.

- *Dredging of the sediment bank located opposite the North Wall*, to increase the navigable width of the outer harbour, improve access to the inner harbour and create space at the North Wall for vessel mooring. The potential impact of dredging the shoal bank on wave conditions, flow velocities and directions and peak water levels in the harbour was assessed (**Appendix I**), including additional tidal modelling.

  This assessment determined that dredging would not change conditions in the entrance channel, that flow velocities in the outer harbour would be reduced, and that the impact on upstream flow velocities would be limited. There would be negative impacts on peak water levels further upstream. The impact of dredging on peak water levels could be mitigated with the construction

[33] *All cost estimates include 75% Optimism Bias.*

of a rock groyne to narrow the channel, with a location upstream of Dunwich Creek preferred if this option was taken forward.

A marine licence would be required to enable the shoal bank to be removed, and the application process for this could take 6 to 12 months.

Discussions with the HMC concluded that dredging should not be undertaken at this time. The potential opportunities for increasing mooring at the North Wall are to be reviewed, and sediment samples are to be taken from the shoal bank in case dredging is required in future.

- *A rock groyne to narrow the channel opposite the North Wall*, which could have benefits for upstream conditions with and without dredging of the inner harbour. Assessment of this option showed that it would slightly reduce wave heights in the inner harbour and reduce peak water levels at the Blackshore during extreme surge tide conditions. However, this option would not fully address the risk of flooding to the Blackshore and would introduce restrictions for navigation and limit mooring at the North Wall.

  Therefore, this option is not currently recommended, but could be progressed in the future if dredging proposals were to be taken forward.

- Other works within the harbour area and at Dunwich Creek have been reviewed but are not proposed as they would have limited additional benefit to wave conditions and use of the harbour. Improvements could be made to the North Wall to improve mooring conditions if required, such as the addition of fenders and mooring bollards.

It is also recommended that minor works to repair the North Pier should be undertaken at the same time as the replacement of the South Pier. These works would involve replacement of the broken SHED concrete armour units over a length of about 25m at the seaward end of the North Pier, at a cost of about £1 million.

12.1.2 Estuary management scenarios

The preferred option for the future management of the estuary defences is **Option E6 – Improve Estuary Defences with Spillway**. With this option, it is proposed that the flood embankments to Robinson's, Tinker's, Town and Reydon Marshes would be improved to provide a 1 in 100 (1% AEP) SOP, allowing for climate change. A 250m long reinforced spillway would be constructed in the embankment to Tinker's Marsh, with a lower crest level than the embankments, which would be overtopped on surge tide events. The total initial capital cost of these works is **£17.8 million**. This option achieves the following in terms of the project objectives:

- The tidal prism would be comparable to the present day conditions. In 2070, peak flow rates in the entrance channel would be about 3.0 knots on the ebb of a spring tide, which is an increase of approximately 8% from the present-day peak flow rate of 2.8 knots. Peak flow on extreme events could be higher than if all banks were raised, as the flooded marshes drain. If the estuary embankments were to fail (Do Nothing scenario), the peak flow rate would be about 4.8 knots.
- This option provides a 1 in 100 year return period (1% AEP) SOP against future flooding to properties in Southwold and Walberswick. Apart from the expensive tidal barrier option, or raising the defences without the spillway, other options would require additional flood protection to Southwold and Walberswick.
- This option maintains the present-day risk of flooding to the Blackshore. For a surge event equivalent to December 2013, the peak water level at the Blackshore would be comparable to what was experienced during the 2013 flood event.

- This option could be delivered through a phased approach, initially focusing on the sections of defence at greatest risk of failure or with the lowest SOP.

Variations on this option that provide a lower SOP would be possible, at a lower cost although with a reduction in the economic benefits achieved. Costs for a 1 in 5 year (20% AEP) SOP would be £12.1m, but this would deliver only limited improvements to the protection provided compared to the present day defences. The potential to attract funding may also be reduced with a lower SOP. A full range of standards of protection was not assessed as part of this project. Development of a business case for estuary management works should consider sensitivity to the SOP provided, and the potential for phasing the construction works (undertaking improvements in stages as funding becomes available).

Works to the estuary defences cannot be undertaken by the HMC, so a suitable delivery approach would need to be identified, as well as securing funding to enable Option E6 to be undertaken. Recognising that it may be difficult to obtain funding for the proposed works, a viable alternative would be **Option E0 – Maintain Integrity of Present-Day Defences**. There is no initial capital cost for this option, but a plan and budget would be needed for ongoing maintenance, so that breaches of the estuary embankments could be repaired if they occur. This option achieves the following: in terms of the project objectives:

- For water levels which do not exceed the crest level of the embankments, peak flow rates will be similar to those experienced at present, limiting the risk of erosion of the entrance channel. As for the raised defences, peak flow rates in the entrance channel would be about 3.0 knots on the ebb of a spring tide in 2070 (8% increase from the present-day peak flow rate).
- This option has less impact on peak water levels at the Blackshore: overtopping of the estuary defences would occur on an extreme surge event. therefore peak water levels in the harbour would be less than if the height of the embankments was increased.
- There would continue to be a risk of flooding to properties in Southwold and Walberswick unless secondary defences were constructed (not currently included in this option).
- This option would enable works to the embankments to be undertaken in the future if funding is secured at a later date.
- The main risk with this option is that multiple failures of the estuary flood embankments could occur during an extreme surge event, with the risk and frequency of failure increasing with time. Repair of a breach in the embankments can be difficult and expensive due to access constraints during flood events. Repair works could become more technically challenging following multiple breaches, increasing costs. The cost of repairs would be an operational cost rather than a capital investment, and as such grant funding is unlikely to be available. For these reasons, this option is not currently the preferred approach to future management of the estuary defences.

12.1.3 Flood risk to the Harbour

Following discussions with harbour users and other stakeholders, capital investment in works to raise the harbour road or construct flood walls is not currently recommended, due to the high cost (e.g. £3.8m for a 1 in 5 year (20% AEP) SOP), and constraints relating to existing businesses and boat sheds. Therefore, the preferred option to manage flood risk to the harbour in the short term is **Option B6 – Do Minimum** (limited improvements to road condition). This option would involve infilling the low spots in the road (to be confirmed by topographic survey), and installation of edge protection to reduce the rate of wash-out of the road surface. It is expected that these works would be undertaken by the harbour users themselves, potentially using donated materials and other resources. As such a cost estimate has not been prepared for this option.

This option would not preclude future works to raise the level of the road or to install flood walls, which are technically viable options but with much higher costs of between £4 million and £9 million, as well as complexities relating to the requirements for accessing properties, boat sheds and the harbour pontoons. The requirements for future resilience of harbour businesses should also be considered further.

12.2 Preferred way forward

Funding for the works proposed for the South Pier should be sought as soon as possible, so that the required consents processes (including environmental assessment) and design works can be progressed.

The scope of work for this project did not include the assessment of affordability or funding availability, and additional economic appraisal is expected to be required to secure funding. Alongside these activities, plans should be progressed to improve the resilience of properties and businesses against more severe flood events.

Subject to securing the necessary funding, it is recommended that removal of the existing South Pier structure is undertaken as soon as possible, followed directly by replacement of the structure with a rock armour and concrete unit breakwater.

It is recommended that the following works are undertaken to the Blyth Estuary flood embankments, subject to identifying a suitable delivery process as well as obtaining funding, as these works cannot be undertaken by the HMC. These works are a lower priority than replacing the South Pier:

- The estuary flood embankments to the Town Marshes, Robinson's Marsh, Tinker's Marsh and Reydon Marsh are raised to provide a 1 in 100 year (1% AEP) SOP, allowing for climate change (assuming a medium emissions scenario). The existing flood embankments would be retained, with works undertaken to raise the crest level and increase the embankment width on the landward side.
- A 250m long reinforced spillway should be constructed within the embankment to Tinker's Marsh, with a crest level of about 2.0mODN. The location of this spillway and its crest level would be confirmed during the design phase, considering the local topography.

Development of the design for the proposed works to the harbour and the estuary defences will need to consider the following issues:

- An economic benefits assessment is expected to be required to support any funding applications and would need to be undertaken before detailed design can progress. Due to ongoing volatility in construction costs, it is recommended that the economic appraisal includes updated cost estimates, with input from a construction contractor.
- Constraints on funding for works to the estuary defences could require further consideration of alternative lower-cost solutions, such as phased implementation of the proposed works.
- A detailed condition assessment and topographic survey of the estuary defences would inform the design of the proposed embankment improvements and enable a more accurate cost estimate for the economic appraisal.
- The alignment of the rock armour and concrete unit breakwater, particularly at the mouth of the harbour entrance channel, should be optimised during detailed design in terms of the wave conditions within the entrance channel, the requirements for navigation (e.g. transition from open sea to entrance channel), future tidal flow rates and minimising the risk of sedimentation.

Performance of the breakwater under all potential wind and wave directions should be considered.

- Design of the breakwater should include a review of the most cost effective design, with input from a construction contractor, considering potential combinations of rock armour and concrete units, and the associated requirement for fenders. Buildability issues should be considered, as well as the cost of materials and future maintenance.
- Options to retain the South Pier in place and maintain navigation as much as possible during construction of the breakwater should be considered as part of the design of the works.
- An Environmental Impact Assessment (EIA) will be required to assess the environmental impacts of the proposed works and identify appropriate mitigation measures.

12.3 Next steps

The following tasks will be required to progress the delivery of the proposed Investment Plan:

- Initiation of relevant Council processes for the proposed capital works;
- Assessment of funding options and affordability;
- Cost / Benefit assessment, recognising the requirements of the funding applications;
- Environmental assessments, and preparation of information required for planning and other consents applications; and
- Detailed design of all proposed works, considering the various issues set out in **Section 12.2.**

The following activities are recommended in relation to the wider Investment Plan, including the recommended works to the estuary defences:

- Identification of potential mechanisms for delivery, funding options and review of affordability of the proposed improvements to the estuary defences;
- Planning for the risk of future breaches in the estuary embankments, as improvements to the estuary defences may not be undertaken for some time; and
- Planning for future maintenance and investigations in the harbour, e.g. repeat bathymetric surveys.

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13 References

Additional information that was used to inform this study but which is not directly referenced in this report, is scheduled in the Scope of Work for this project (Ref. 8).

1. The Southwold Saga, Robert Simper, January 1971

2. Suffolk Estuarine Strategies – Blyth Estuary Model, Black & Veatch for Environment Agency, August 2005

3. Blyth Estuary Sedimentation Study, Pye & Blott, January 2009

4. Suffolk Estuarine Strategies – Blyth, Environment Agency, September 2009

5. Suffolk Shoreline Management Plan 2, Environment Agency, January 2010

6. The history of Southwold, John Winter & George Bumstead, October 2014

7. Multibeam bathymetric survey of Southwold Harbour, Aspect Land + Hydrographic Surveys for Blyth Estuary Group, October 2015

8. Southwold Harbour Investment Plan Scope of Work, ENBE for Waveney District Council, October 2015

9. East Anglian Coastal Modelling, JBA for Environment Agency, February 2019

10. Blyth Estuary, Suffolk: Sedimentation Study Update, Pye & Blott, October 2019

11. Civil Engineering and Highway Works Price Book, Spons, 2021

12. Long Term costing Tool for Flood and Coastal Risk Management, Environment Agency, 2021

13. Construction output price indices - Office for National Statistics, https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/datasets/interimconstructionoutputpriceindices/current, 2022

Appendix A

Hydrographic Survey

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Appendix B

Condition Assessment

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Appendix C

Wave Modelling

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Appendix D

Tidal Modelling

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Appendix E

Development of Options

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E1 Structural solutions for the harbour entrance

For the harbour structures, option development initially considered a long list of potential structural solutions for the North and South Piers, recognising the findings of the condition assessment (**Appendix B**). The long list of structural solutions considered is provided in **Table E1** below, which an initial assessment of the suitability of each method.

Additional structural measures, which could be implemented in the harbour in combination with the main structural solutions, are set out in **Table E2**. These additional structural measures could be undertaken in combination with any of the solutions which sustain or improve the condition of the harbour structures and will be considered further based on the modelling results and in the development of the Investment Plan.

The initial assessment of the potential structural solutions has been used to develop a suite of proposed options for the future management of Southwold Harbour, which are described in **Section 7.2.5**. The performance of each option was then assessed using the wave and tidal models, considering the future impacts of the potential management scenarios for the estuary defences. This assessment is presented in **Section** □.

E2 Structural solutions to reduce flood risk to the Harbour

Table E4 outlines potential measures to improve flood protection to the Harbour. This includes large-scale options, such as a tidal barrier or barrage, and more local measures to improve the standard of protection to the Blackshore properties and the Harbour Road.

All options to improve flood protection to the Blackshore properties and the Harbour Road have been carried forward to further assessment. Any decisions on works to the Harbour will depend on further consultation with property owners / residents and Harbour users. The timing of any works to improve protection to the Blackshore properties should be optimised considering the existing level of protection against future peak water levels.

E3 Non-structural measures to improve use of the Harbour

Table E5 sets out potential non-structural measures which could improve the use of Southwold Harbour or reduce the risk of structural failure or flooding. Any combination of these measures could be used alongside the options set out in **Table E3** and **Table E4**.

E4 Development of Spillway Option

<u>Introduction to Spillway Option</u>

Based on the initial results from the tidal modelling, and considering feedback from stakeholders, an additional option was considered for management of the estuary defences. During the December 2013 flood event, the water level in the harbour was observed to drop when the Robinsons' marsh embankment breached opposite the Blackshore. This indicated that a spillway could be a viable option for reducing peak water levels in the harbour, without full realignment of the southern estuary defences.

The aim of a spillway would be to reduce peak water levels in the Harbour during a surge tide, by allowing water to spill into one or more of the marshes. The spillway option would result in less frequent flooding of the marshes compared to the SMP or Do Nothing scenario. Therefore the tidal prism would be smaller, reducing the average flow rates in the river channel and the associated risk of erosion in the harbour entrance channel. Potential constraints include high cost, particularly for a controlled sluice spillway, and the risk that a spillway would not achieve a reduction in peak water levels.

Alternative options for the design of a spillway

Spillways can be incorporated into the design of flood embankments to address the residual risk of a flood event that exceeds the crest level of the embankments, so that overflow occurs at a known location which is reinforced. This reduces the risk that the embankments will breach where they are overtopped.

For a 'passive' spillway, a section of an embankment is constructed with a lower crest level than the adjacent sections, enabling overtopping when the water level in the river channel is higher than the spillway level. Passive spillways are always open, so the spill level needs to be designed so that they do not overflow too often. To either side of the spillway, the embankments need to be raised so that flow is directed through the lower section. The lowered section would need to be reinforced so that overflowing water does not damage the embankment, and the back slope of the spillway may need to be designed with a shallower slope for the same reason. Passive spillways have limited operational requirements and low visual impact.

Alternatively, automatic controlled sluice gates can be incorporated within an embankment. The sluice gates would be opened when peak flood levels need to be reduced on surge tides, reducing peak water levels and the risk of embankment failure further upstream. The crest level of the embankments adjacent to the sluice gate might need to be raised. Automatic sluice gates have significant operational requirements and can be perceived as visually unattractive.

For Southwold, an automatic controlled sluice gate was initially considered to be more likely to be effective than a passive overflow spillway. A wide sluice with a low sill level would be most effective, although it would have a high cost. Based on experience from the assessment of spillway options for similar projects, it was considered unlikely that a passive spillway would be effective, if a controlled spillway option was shown to achieve a limited reduction in peak water levels. Therefore, an initial assessment of this option was made based on a controlled sluice spillway.

Initial assessment of a controlled sluice gate allowing spill into Robinson's Marsh

The most suitable location for a controlled sluice spillway was reviewed , recognising that spillways are less effective near to the mouth of a river, where water can easily flow in from the open sea, topping up the water level in the channel that has been reduced from the flow over the spillway. At Southwold, the narrow entrance channel helps with this issue, by constraining the volume of water that can enter the estuary. If the spillway was to be located upstream of the Bailey Bridge it was expected to have less impact on peak water levels in the Harbour compared to a spillway immediately downstream of the Blackshore properties.

An initial assessment was undertaken for a range of spillway dimensions using the simple 2D hydraulic model TidalB, which was developed in-house by Royal HaskoningDHV. This demonstrated that that a spillway should be viable in terms of the resulting water depth in the marshes and the associated risk of flooding to Walberswick properties. The results of the Tidal B analysis are included in **Table E1.**

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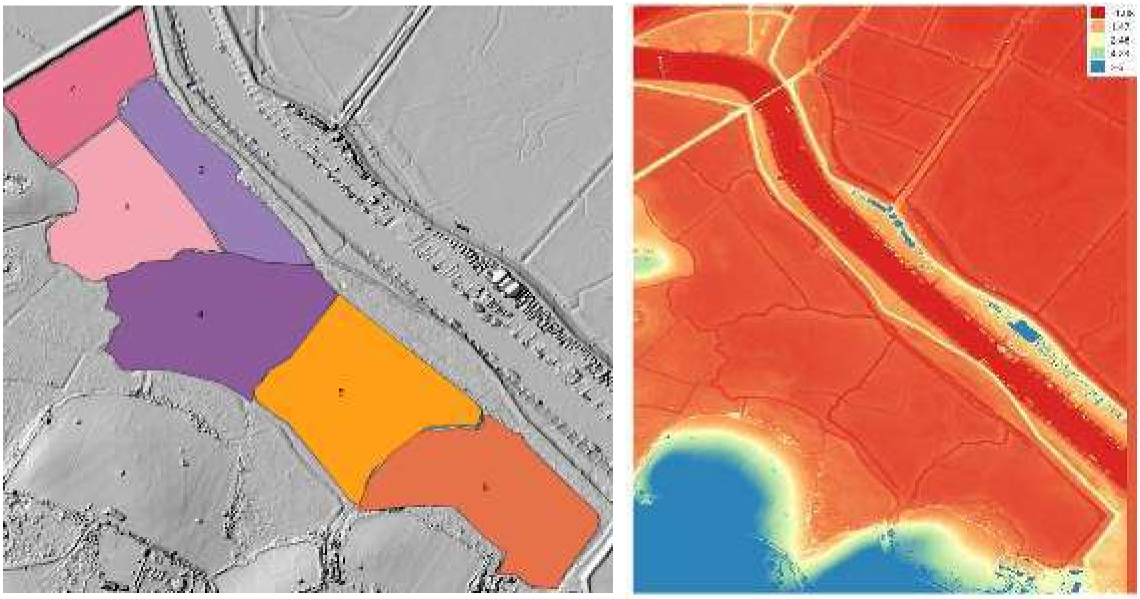
Table E1 – TidalB results for spillway opposite the Blackshore

Water level in channel (mODN)	Flood volume and level vs spillway level					
	Spillway at 2.6m ODN		Spillway at 2.4m ODN		Spillway at 2.6mODN	
	Volume (m^3)	Water level (mODN)	Volume (m^3)	Water level (mODN)	Volume (m^3)	Water level (mODN)
2.35	16,145	-0.13		-	-	-
2.55	35,479	0.12	3,632	-0.17	-	-
2.75	72,878	0.34	19,824	0.02	3,507	-0.17
2.95	128,657	0.64	49,685	0.21	19,480	0.01
3.15	285,301	1.47	179,862	0.91	130,755	0.65

Figure E1 – Sub-compartments and ground levels used in TidalB model



A recent project undertaken by Royal HaskoningDHV for Wells-next-the-Sea assessed the potential benefits of introducing a 'pressure valve' into the tidal embankments with the aim of reducing peak water levels in Wells Harbour. The results of tidal modelling for the December 2013 event showed that a very large sluice gate would only reduce peak water levels by about 150mm. Therefore it was recognised that the impact of a spillway at Southwold could also be quite limited. Tidal modelling was needed to determine whether and how well a spillway could work at Southwold.

Tidal modelling of controlled sluice spillway

The controlled sluice spillway option was assessed using the tidal model to determine peak water levels and flow rates in the Harbour, for comparison with the other estuary management options (**Section □**). The modelling assumed the most effective arrangement of a spillway, with a 30m wide controlled sluice gate with its sill at ground level, and with the structure located immediately downstream of the Blackshore properties. The input conditions for the model represented a scenario where the spillway was most likely to be effective, with the sluice opened ahead of the peak of a 'steep' surge tide. Various timings for opening the sluice gate were assessed to identify the timing that achieved the greatest reduction in peak flood levels. A range of water level conditions were also assessed, for comparison with the other options. Further details of the tidal modelling of the controlled sluice spillway option are included in **Appendix D**.

Tidal modelling of passive spillway

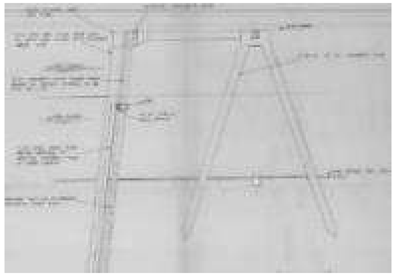
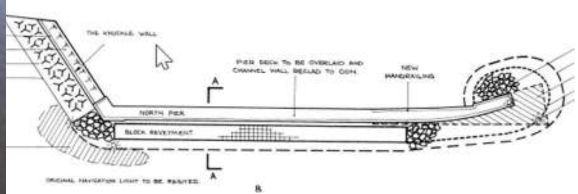
Following review of the draft project report, and meetings with the stakeholder group and HMC, additional modelling was requested by the stakeholders to assess the impact of a passive spillway option on peak water levels and flow rates in the Harbour.

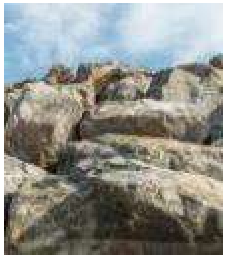
The tidal modelling of the passive spillway initially assumed that a 500m long spillway would be constructed in the embankment to Tinkers Marsh, a short distance upstream of the Bailey Bridge, with the embankment crest levels raised on either side of the slipway. Various spillway levels were considered in order to optimise this against the reduction in peak flood levels that would be achieved. A range of water level conditions were assessed, for comparison with the other options. Sensitivity to spillway length was reviewed, and the impact of allowing flow through the culverts between Tinker's and Robinson's Marshes was also considered.

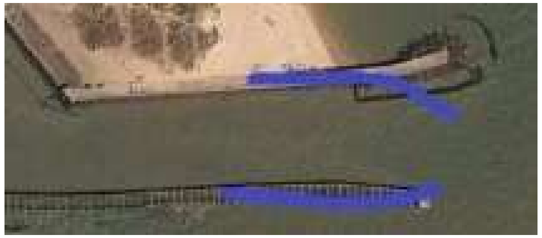
Further details of the tidal modelling of the passive spillway option are included in **Appendix D**.

Table E1- Long-list of potential structural solutions for the North and South Piers

Solution	Benefits	Constraints	Initial assessment
Patch repairs to concrete  Localised repairs to sections of the existing concrete structure. This might include encasement of areas where reinforcement is exposed, or replacement of failed cross-beams.	Low cost in the short term. May extend life of existing structure and delay requirement for major capital investment.	Very short-term solution which does not improve structural stability or reduce the ongoing risk of failure due to wave impact or undermining, or future risks due to climate change.	**Considered further** as part of 'Do Minimum' options, and as potential short-term solution to delay major capital investment.
Toe reinforcement and/or scour protection  Install either sheet piles or rock armour along the toe of the existing North and/or South Piers to reduce the risk of scour and undermining. This solution would need to be undertaken in combination with other repair measures.	Reduced risk of failure from undermining. May delay the requirement for major capital investment to fully replace North or South Pier.	Does not address poor condition of concrete structure and associated failure risk. High mobilisation costs (particularly for piling). Does not improve harbour conditions, or future risks due to climate change.	**Considered further** as part of 'Do Minimum' options, and as potential short-term solution to delay major capital investment.
Local repairs to Section C of South Pier  Sheet piles cut down to MLWS and new sheet piles installed in front of them to the same level. Demolish front beam, crossbeams and rear concrete piles and fill space with rock armour. Alternatively, demolish sheet piles, crossbeams and rear concrete piles and fill gap with rock armour.	Section of South Pier at greatest risk of failure is strengthened prior to failure occurring. May delay the requirement for major capital investment to fully replace South Pier.	Continued risk of failure to adjacent parts of the South Pier, e.g. due to undermining. High mobilisation costs (particularly for piling) for repairs to only part of the structure. Does not improve harbour conditions or address future risks due to climate change.	**Considered further** as part of 'Do Minimum' options, and as potential short-term solution to delay major capital investment.

Solution	Benefits	Constraints	Initial assessment
Replace South Pier with similar structure  Complete replacement of South Pier and training wall with new structure, similar to existing design, including retaining the 'windows' in the structural walls with the aim of maintaining the wave climate within the harbour (subject to future changes). Structures designed to address risk of failure by undermining (e.g. foundation depth / toe design), and other climate change impacts, e.g. increased overtopping. Replacement planned for before failure (e.g. within 5 years) or undertaken after failure has occurred.	Able to design new structure to reduce future failure risks e.g. deeper toe. Maintains existing conditions in the harbour in the short term. Design could be optimised to mitigate climate change impacts, e.g. adjusted alignment, bigger windows, baffles or rock toe to reduce wave energy. Long-term solution, design life ~100 years.	High cost to remove existing structure and replace. Expect to be higher cost than rock breakwater. Hydraulic performance of harbour is very sensitive to minor changes, so conditions in the harbour could be made worse. Unlikely to improve harbour conditions. May not be possible to mitigate future climate change impacts through design without realignment of harbour mouth.	**Considered further**, although expected to be higher cost than rock breakwater, with less beneficial impacts for harbour conditions.
Replace North Pier & Knuckle with similar structure Complete replacement of North Pier and Knuckle with new structure, similar to the existing design. Structures designed to address risk of failure by undermining (e.g. foundation depth / toe design), and other climate change impacts, e.g. increased overtopping. Replacement planned for before failure (e.g. within 20 years, depending on future channel erosion rate), or undertaken after failure has occurred.  	Able to design new structure to reduce future failure risks e.g. deeper toe. Maintains existing conditions in the harbour in the short term. Design could be optimised to mitigate climate change impacts, e.g. adjusted alignment, bigger windows, baffles or rock toe to reduce wave energy. Long-term solution, design life ~100 years.	High cost to remove existing structure and replace, when it is currently expected that the existing structures could be sustained for ~50years, subject to future erosion rates. Hydraulic performance of harbour is sensitive to minor changes, so could make harbour conditions worse. May not be possible to mitigate future climate change impacts through design, without realignment of harbour mouth.	**Considered further** as potential long-term solution for the North Pier and the Knuckle.
Replace with sloping breakwater Construction of a generally sloped defence to replace the South Pier, North Pier and/or Knuckle, using rock armour or concrete armour units. This option could involve full or partial removal of the existing structures before replacement (either on the existing or a new alignment), or by placing rock or concrete armour units over / around the existing structures.	Sloping structures are better at absorbing wave energy than vertical, so this solution would be expected to improve the wave climate in entrance channel and harbour.	High cost for long-term solution. Concrete units more expensive than rock armour. If defence alignment is changed, risk of negative impacts on navigation conditions.	**Considered further.** Concrete units would have a higher cost than rock, but would not require fendering. Concrete units can be built to a steeper profile, giving

Solution	Benefits	Constraints	Initial assessment
Structures designed to address risk of failure by undermining (e.g. toe piles). Breakwater could include culvert ‘windows’ to allow flow into the entrance channel, similar to existing ‘windows’ in the South Pier.   	Design could be optimised to mitigate climate change impacts, e.g. through changes to the alignment. Rock armour structures typically lower cost than vertical walled structures. Long-term solution, design life 50-100 years (dependant on toe design).	Rock armour has a larger footprint than a vertical or concrete frame structure. Sloping concrete block structures can have a smaller footprint than rock armour. Timber fendering may be required for rock structures to reduce the risk of vessel impact.	a smaller cross-section. Concrete units could be used on the inner face, with rock on the outer face. This could be optimised at detailed design stage. Design of culvert ‘windows’ would be optimised at detailed design stage.
Replace with vertical walled structure  Construction of new vertical walled structure using concrete caissons or sheet piles to replace the North and/or South Piers. This option could involve removal of the existing structures before replacement, or encasement of the existing defences. Design to address failure risk from undermining (e.g. foundation depth).	Design could be optimised to mitigate climate change impacts, e.g. adjusted alignment, baffles to reduce wave energy. Long-term solution, design life ~100 years.	High cost. Concrete caissons more expensive than sheet piles. Vertical walled structure more expensive than rock breakwater. Vertical structures are more reflective than the existing structure, so wave conditions in the entrance channel and harbour are likely to become worse. Mitigation could be possible with baffles or rock toe, at additional cost.	**Considered further,** however, initial cost estimates indicate significantly higher costs for this solution than for a rock breakwater, combined with negative impacts for harbour conditions.
Replace North and/or South Piers with breakwaters on new alignment  The North and/or South Piers would be replaced with a vertical walled pier or sloping breakwater (as discussed above), along new alignments which are optimised to improve conditions for navigation in the entrance channel, and conditions for mooring in the harbour. The harbour mouth could be widened or narrowed.	Benefits of vertical wall and sloping breakwater structures are discussed above. A wider harbour entrance channel would improve wave and tidal flow conditions, with associated benefits for navigation and vessel mooring.	Constraints of vertical wall and sloping breakwater structures are discussed above. A wider harbour mouth could increase wave penetration and disturbance within the harbour (depending on design of structures). The volume of water entering the estuary would increase, resulting in higher peak water levels.	**Considered further –** wave modelling results reviewed to assess potential benefits of change in alignment. Would require additional wave and tidal modelling as part of the design of new structures.

Solution	Benefits	Constraints	Initial assessment
 	A narrower harbour mouth would reduce wave penetration, improving conditions for navigation and mooring. The volume of water able to enter the estuary would also be reduced, with benefits for peak water levels.	A narrower harbour mouth could affect navigation/ access and increase tidal flows with associated risks for erosion and navigation. Wave conditions in the harbour are sensitive to any changes to structures. Altering the alignment could increase reflection, making conditions worse. Realigning the South Pier to the South could remove a section of the Walberswick beach/ dunes. High costs associated with full demolition of existing structures, as well as construction of new pier. For the North Pier, a new structure is not expected to be required for 30-50 years.	
Advance the Line - Extend the North and/or South Piers  Extend one or both of the piers seaward, aiming to improve conditions within the harbour. Could be combined with widening/ narrowing the harbour mouth. The form of the extended or realigned structure could include breakwaters, vertical impermeable structures or like-for-like replacement (as above).	Extension to one or both piers would be designed to improve harbour and/or navigation conditions. May have some benefits in terms of addressing increase in tidal currents with climate change. Reduced wave heights will make mooring at the North Wall easier and make the channel more easily navigable.	Risk that changes to alignment of harbour mouth could have negative impact on conditions for navigation and moorings. If only one pier is extended, could increase sediment deposition in the harbour. Not a stand-alone option - works will still be required to address the risk of failure of the South Pier (within 5 years).	**Not considered further.** If the South Pier was to be replaced on a new alignment, the alignment would be optimised, but it is not expected that an increase in length of the pier would be necessary.
Advance the Line - Additional rock structure to reduce wave exposure of harbour entrance A rock armour breakwater could be constructed approx. 100m from the harbour entrance, aligned to reduce wave penetration from the south into the harbour.	Reduced wave penetration into the harbour from south east to south westerly directions, improving conditions for navigation of the entrance channel and mooring within the harbour.	Any structure that reduces wave penetration into the harbour entrance would have additional constraints for navigation, although it could be	**Not considered further.** This solution does not address the condition of the South Pier, and would have a very high additional

Solution	Benefits	Constraints	Initial assessment
		positioned/ designed to minimise such constraints. Does not reduce wave penetration from north to west directions. Does not address poor structural condition of South Pier, which would still be required at additional cost. High cost of construction of offshore breakwater structure in deep water.	cost, whilst introducing additional navigation constraints and without improving conditions for waves from the north east.
Retreat the Line - Full or partial removal of South Pier Removal of full length or outer part of South Pier, e.g. following failure, or as a planned management approach. 	This option would effectively increase the width of the harbour mouth, which could mitigate the impact of increasing tidal flow rates with climate change / increases in tidal prism. This could have benefits for future navigation into the harbour. Could be combined with repair works to improve the condition / extend the residual life of the remaining section of the pier, e.g. toe protection or piling. No cost for replacement of South Pier. Reduced cost for ongoing maintenance.	Increased wave penetration into harbour from the South. Increases the risk of sediment deposition in the harbour channel from sediment moving past the harbour mouth (from south to north). Increased wave impact on the North Pier, increasing failure risk and wave overtopping (flood risk to car park) Costs associated with removal of South Pier structure.	**Wave modelling undertaken to consider this option further.** This solution is expected to have a negative impact on wave conditions, but may be beneficial for future tidal flows and would be a lower cost option than replacing the South Pier. Modelling of this option with modelling also allows assessment of the potential for replacing the South Pier with a shorter structure. Potential impacts on wave conditions could be mitigated with additional structural measures within the harbour.

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Table E2 - Additional structural measures to improve conditions in Southwold Harbour

Option	Benefits	Constraints	Initial Assessment
Concrete baffles  Addition of small concrete block baffles to the upper wall of the North Pier, and/or the inner part of the South Pier. Larger baffle structures could be installed extending out from the inner part of the South Pier (opposite the Knuckle). Baffles act to break up reflected waves, reducing wave height within the harbour.	Potential to improve harbour conditions. Relatively low-cost solution with benefits for wave conditions in the harbour, which could be undertaken in combination with other measures.	Risk that minor changes to harbour layout could make conditions worse. Limited benefit in terms of tidal flows. Reduced width of navigable channel, and potential risk of impact of vessels on baffles, depending on design.	**Considered further**, included as an option in the wave model.
Structure to narrow the channel  A rock structure could be constructed at the inner end of the South Pier, opposite the North Wall. This would reduce both wave penetration into the harbour and the volume of water able to enter the estuary. Pipes / culverts through the structure with flap vales on the seaward end might improve outflow through the structure. A rock structure is proposed as it would act to dissipate wave energy, compared to a vertical walled structure that would reflect waves. A rock structure would also be of lower cost than sheet piled walls. The initial proposal for the location of this structure is slightly downstream of the Lifeboat Station. The location would need to be optimised to minimise negative impacts on navigation and mooring at the North Wall. Wave and tidal conditions modelled for various water levels and estuary management scenarios.	Potential to improve harbour conditions (wave heights and peak water levels). Could be located where the channel is already narrowed by the bank of sediment immediately upstream of the harbour entrance channel.	Potential impacts on navigation through the narrowed section and from increased flow rates. Scour risk due to high flows around the structure. Scour could increase the channel depth, reducing the benefits for peak water levels. With culverts through the structure, there is a risk of blockage and failure of the flap valves. Risk of sediment build up to either side of the structure. Relatively high cost for large engineered structure.	**Considered further,** with wave and tidal modelling undertaken to assess impact on wave penetration, water levels and tidal flows.

Option	Benefits	Constraints	Initial Assessment
Maintain flow through South Pier Options considered for maintaining the flow through the South Pier, as currently experienced due to the 'windows' in the existing structure. The following methods are possible: • concrete frame structure (like-for like replacement) • piled channels to create gaps through the breakwater • lower crest level to sections of breakwater, allowing overtopping • Box culverts through breakwater  Box culverts are the preferred option based on initial assessments of cost, risk and expected performance. The position, level, and alignment of the culverts would need to be optimised during design, to minimise wave penetration.	Maintains flow through South Pier into entrance channel, which has benefits for navigation. Culverts would act to dissipate wave energy. Culverts located at the inner end of the South Pier could help to drain a surge tide.	Risk of scour at either end of the culverts would need to be assessed and addressed through design. Further detailed 3D modelling would be needed during design of the structure to assess changes hydraulic behaviour of the entrance channel at a detailed scale.	**Considered further.** Detailed modelling has not been undertaken at this stage, but costs of this option will be included in costs for replacement of the South Pier.
Reduce length of South Training Wall  Increasing the gap between the South Pier and South Training Wall by removing a section of this wall.	This option would reduce the number of vertical surfaces within the Harbour, with the potential to reduce wave reflection and improve mooring conditions at the North Wall and outer Blackshore moorings. If paired with the removal of the timber piles, the resulting spending beach would further dissipate wave energy.	Could result in collapse of retained sediment, increasing sediment deposition in the harbour.	**Not considered further.** Replacement of the South Pier with a rock breakwater will reduce wave energy and reflection within the harbour, reducing erosion of the Dunwich Creek area.
Remove Dunwich Creek timber piles Removal of timber retaining wall at top of Walberswick quay beach. This would allow a spending beach to re-establish, which would dissipate wave energy. 	This option would reduce the number of vertical surfaces within the Harbour, with the resulting spending beach reducing wave reflection and improve mooring conditions at the North Wall and outer Blackshore moorings.	Risk of erosion to retained ground at Walberswick quay	**Not considered further.** Replacement of the South Pier with a rock breakwater will reduce wave energy and reflection within the harbour, reducing erosion of the Dunwich Creek area.

Option		Benefits	Constraints	Initial Assessment
Wave energy dissipation measures at Dunwich Creek Installation of a gabion mattress or placement of a shingle / crushed rock 'beach' in front of the timber piles, with the aim of dissipating wave energy and improving mooring conditions in the harbour.		This option would provide a means of wave energy dissipation in the Dunwich Creek area, reducing wave reflection and improve mooring conditions at the North Wall and outer Blackshore moorings.	Shingle or crushed rock may not be retained in place and could be washed away into the harbour. Relatively high cost of gabion mattress compared to benefit provided.	**Not considered further.** Replacement of the South Pier with a rock breakwater will reduce wave energy and reflection within the harbour, reducing erosion of the Dunwich Creek area.
Dredging Dredging could be undertaken to the area of sediment build-up (shoal bank) on the inner part of the South Pier, opposite the Knuckle.		Potential reduction in wave heights within the harbour during swell wave conditions. Moving the navigation channel / tidal flows further to the south could provide additional space for mooring at the North Wall, and possibly reduce scour of the channel bed adjacent to the South Pier.	Removal of the sediment bank would increase water depths, so could reduce wave breaking in the harbour and allow larger locally generated waves to penetrate further up the channel. The hydraulic performance of the harbour area is sensitive to minor changes, so there is a risk that dredging the shoal bank would have a negative impact on wave conditions. Maintenance dredging could be required to the realigned channel.	Option to be considered further based on stakeholder feedback, including modelling of tidal flows and assessment of requirements for ongoing maintenance dredging.
Infilling areas of scour 	The areas of scour along the inner part of the South Pier could be infilled with sand. To reduce the risk of further scour the South Pier structure would need to be repaired.	Infilling the scour areas and repairing the adjacent part of the South Pier will reduce the risk of ongoing (and potentially accelerating) scour of the Denes area, which could increase the risk of failure of the inner part of the South Pier. Sediment removed as part of other construction works (e.g. replacement of South Pier) could be used to infill these holes.	If the scour area was to be infilled without repairing the adjacent part of the pier, scour could continue. This solution has no benefit for conditions within the harbour.	**Considered further,** could be included in design of works to replace the South Pier, using any sediment that is removed to infill areas of scour or erosion, or placing it against the toe of the North or South Piers.

Table E3 - Non-structural measures to improve use of Southwold Harbour or reduce risk of structural failure and flooding

Option	Benefits	Constraints	Initial Assessment
Fendering and mooring bollards on the North Wall  Replace fendering on the North Wall with a more suitable type, to address the issues associated with the overhanging wall crest and the shape of the sheet piles. Addition of mooring bollards / sub level cleats at appropriate levels on the North Wall to allow vessels to tie up more easily.	Easier for vessels to moor at the North Wall, and reduced risk of damage to vessels and safety risks for harbour users. This could increase the use of the North Wall for mooring, increasing revenue for the harbour.	May be a relatively costly investment if it does not result in increased use of the North Wall for mooring.	**Not included in Investment Plan,** could be taken forward by harbour users in future.
Floating pontoons  Installation of floating pontoons along the North Wall to improve mooring facilities.	Improved facilities for vessels mooring at North Wall, increasing use of the harbour.	High cost, only justified by significant increase in demand for use of the North Wall (e.g. due to other measures as outlined above). Requires wider channel, likely to need ongoing maintenance dredging.	**Not considered further** by this project, could be taken forward by harbour users in future.
Lead-in mark Installation of a lead-in mark located approx. ¾ nautical mile (1.4 km from the entrance to help with achieving the correct entry and exit angles. 	Reduced risk to harbour users trying to navigate into the harbour.	Installation and maintenance costs. Clarity over responsibility for maintenance.	**Recommended** that installation of a lead in mark is undertaken alongside any works to the South Pier.
Replacement of the Bailey Bridge Removal of the Bailey Bridge and replacement with a swing bridge. 	Blyth estuary opened up to inland navigation, potentially increasing the number of harbour users and associated revenue.	Whilst this option has benefits for navigation upstream, it will not improve the conditions in the harbour.	**Not considered further** by this project, could be taken forward by ESC or Harbour users in future.

Option	Benefits	Constraints	Initial Assessment
Information / training to harbour users This may become more important in the future as conditions could change with sea level rise. Provide information online or via local meetings.	Improving the understanding of harbour users of the constraints on navigation into Southwold Harbour, reducing the risks to vessels and users.	Need to carefully consider how to reach all relevant harbour users. Unclear responsibility re. providing this information.	**Not included in Investment Plan,** could be taken forward by ESC or harbour users in future, following review of responsibilities and method of delivery.
Structural condition inspection Undertake regular inspections of the condition of the harbour structures, particularly the North and South Piers. Inspections should be undertaken at least annually, and after sever storm events. 	Regular monitoring will maintain an understanding of the condition of the harbour structures, whether damage has occurred and if urgent repairs are required. Whilst monitoring does not reduce the risk of failure, it can potentially enable intervention measures to be delayed, if structures	Costs associated with ongoing monitoring and associated analysis / reporting.	**Recommended**, to be included in Investment Plan.
Bathymetric survey Continue to monitor harbour bathymetry, with a focus on the entrance channel, considering the risk of undermining of the North and South Piers (potential increasing risk due to accelerating scour with sea level rise / increasing tidal prism). 	Regular monitoring will maintain understanding of the channel bed levels and therefore whether there is an increasing risk of failure of the North and South Piers.	Costs associated with ongoing monitoring and associated analysis / reporting.	**Recommended**, to be included in Investment Plan.
Tidal flow monitoring Continue to monitor the tidal currents in the harbour, recognising the risk of increasing flow rates due to sea level rise (increase in tidal prism). 	Regular monitoring will maintain understanding of tidal currents in the harbour, how these may be changing with time and any risks for navigation and sedimentation / erosion.	Costs associated with ongoing monitoring and associated analysis / reporting.	**Recommended**, to be included in Investment Plan.
Flood forecasting and warning Continue to provide flood forecasting and warning for properties in Southwold, including the Blackshore. Ensure properties at risk from flooding are signed up to flood warnings.	Flood forecasting and warning is already in place for Southwold, no additional cost.	All properties at risk may not yet be signed up to flood warning.	**Recommended**, to be included in Investment Plan.

Table E4 - Options for reducing flood risk to the Harbour

Option	Benefits	Constraints	Initial Assessment
Radial Barrier  Construction of a radial barrier (similar to the Thames Barrier) across the harbour entrance. The barrier would rotate upwards from the channel bed into the closed position to hold back a tidal surge.	A barrier solution would reduce flood risk to the estuary and the Blackshore (depending on operating conditions). This would reduce the extent of works required to raise the SOP of the estuary defences (embankments) upstream of the harbour.	High cost. Based on similar schemes (Colne, Lowestoft), the likely cost of a radial barrier solution is between £40-70 million. Works would still be required to sustain the harbour entrance structures, and possibly to the Blackshore, depending on proposed operational conditions. Significant operational and maintenance requirements, with associated costs. The requirements for management of the seaward defences (dunes, embankments, Ferry Road) would need to be assessed and included as part of the solution to prevent tidal flooding due to water flowing around the barrier. Risk of flooding upstream due to high fluvial flows as water is retained.	**May be considered further** as a solution to manage estuary flood risk, in combination with replacement of the South Pier, and possibly works to the Blackshore. Economic benefit assessment likely to be required for a full comparison of the range of solutions for management of the estuary and harbour.
Floating Barrier  Construction of a floating barrier, with associated moorings and plant required for operation. A floating barrier for Southwold would take the form of a barge capable of turning through 90 degrees into position and sinking to prevent tidal flow into the harbour. The floating structure needs to be quite large to deal with the hydraulic forces. When not in use, the barrier would be moored against one side of the channel, most likely on the Walberswick side, opposite the North Wall.	As for radial barrier.	Constraints as for radial barrier. Additional constraints include: • Can be difficult to implement. River and tidal currents can make deployment difficult. The barrier structure itself can generate disruptive flows that interfere with the operation of the barrier, how it handles and where it sinks. • Takes up space in the channel when not in use. • Not intended to operate in both directions. Risk that fluvial flows / water pressure from upstream will unseat the barge. • Cannot be opened and closed on a rising tide, increasing the risk of upstream fluvial flooding.	**Not considered further.** Unsuitable for Southwold harbour due to the identified constraints.

Option	Benefits	Constraints	Initial Assessment
Vertical lifting gate  Construction of a vertical lifting gate across the harbour entrance. The barrier would be lowered into place, from between vertical towers.	As for radial barrier. Potentially lower cost than a radial barrier, as works are not required across full width of channel bed.	Constraints as for radial barrier. Additional constraints include: • Greater visual impact due to higher vertical structure. • Operational constraints and associated safety concerns. • Not current best practice in barrier design for above reasons.	**Not considered further** due to identified constraints.
Rising Barrier  Construction of a rising barrier across the harbour entrance. The barrier would rise vertically into place, from a trench in the channel bed.	As for radial barrier.	Constraints as for radial barrier. Additional constraints include: • Slow to operate, increasing risk of fluvial flooding upstream.	**Not considered further.** Higher costs than for a radial barrier and increased risk of fluvial flooding.
West Path embankment or wall and property-side walls  The footpath west of the Harbour Inn would be raised to form an embankment that ties into the existing defence. Alternatively, a flood wall would be constructed along the path. The existing walls and gates to the east of the new embankment would be replaced with floodwalls and floodgates. An additional wall would be built around the eastern cottage, Harbour Inn and sailing club, tying into the existing defences to the rear. Gates and/or ramps would be added for access. The patio to the Inn could also be raised.	No reduction in carpark area. No change in access to pontoons. Flood wall would have smaller footprint compared to embankment. Costs comparable for flood wall and embankment.	Works required very close to properties, with visual impact and potentially limiting access. Flood gates must be closed manually, risk to cottages to the west if gate is left open. Materials cost ~£600,000 (excluding labour/plant, fees, optimism bias, maintenance). Additional works required to protect the Harbour Road and properties / businesses downstream of the Blackshore.	**Considered further.**

Option	Benefits	Constraints	Initial Assessment
West Path embankment or wall with wide carpark wall  The footpath west of the Harbour Inn would be raised to form an embankment that ties into the existing defence. Alternatively, a flood wall would be constructed along the path. A wide wall would also be constructed along the riverside edge of the carpark, with ramp access to the pontoon boardwalks, which would need to be replaced. A floodwall would close the eastern extent of this area with floodgates providing access.	No change in access to properties Opportunity to improve pontoons and boardwalks Fewer floodgates required compared to walls around properties. Flood wall would have smaller footprint compared to embankment	Flood gates must be closed manually, risk to all properties if any gate is left open. Can be expensive to maintain. Changes to pontoon access. Loss of area within car park Cost excluding labour and maintenance >£600,000. Additional works required to protect the Harbour Road and properties / businesses downstream of the Blackshore.	**Considered further.**
Perimeter floodwall with floodgates  Concrete floodwalls constructed around the site, tying into existing defence on the landward side. Floodgates provided for access to the harbour, York Rd and the pontoons.	Smaller footprint of defences compared to embankment	Flood gates must be closed manually, risk to all properties if any gate is left open. Can be expensive to maintain. Changes to pontoon access. Cost excluding labour and maintenance ~£650,000. Additional works required to protect Harbour Road and properties	**Considered further.**

Option	Benefits	Constraints	Initial Assessment
		downstream of the Blackshore.	
Floodglass Walls  Alternative to conventional concrete floodwalls using glass panels mounted on top of a smaller concrete upstand wall. To minimise costs, could be used in specific locations where glass is most suitable, in combination with standard walls. Could potentially be used along the full length of the Harbour Road.	Less visually intrusive than standard walls.	Expensive to maintain. Require regular cleaning if self-cleaning glass not used (uncertain effectiveness). Vandalism can be an issue. Fixings and frames will need replacing within the lifetime of the defence. Expensive material cost for panels and fittings, >£700,000 for front perimeter wall arranged as above excluding labour and maintenance.	**Considered further.**
Property Level Protection Property level flood protection measures include barriers to openings, non-return valves to drains and pumps. These could be installed to the Blackshore properties to reduce the risk of flood damage. 	Reduces risk of flood damage flood risk to all properties and businesses.	Performance of property level protection solutions can depend on effective operation and maintenance by residents. Does not improve access to the Harbour.	**Considered further.**

Option	Benefits	Constraints	Initial Assessment
Harbour Road Embankment  Fill material placed to raise the level of the full length of the Harbour Road. Could be combined with other flood protection measures for the Blackshore properties.	Reduces flood risk to all properties and businesses in the Harbour. Improves access to the Harbour.	Cost depends on SOP provided. Limited economic justification to raise the Harbour Road to a 1:100 SOP. 1:5 year SOP proposed, plus resilience measures to boat huts / businesses. Cost excluding labour and maintenance ~£1,275,000. Design and implementation of this option would be complex due to the requirements to maintain access to boat huts and businesses.	**Considered further.** Requirements for maintaining access to businesses, and associated resilience measures would need further development with Harbour users.
Flood walls to Harbour Road Flood walls could be constructed on along the river bank along the full length of the Harbour Road, incorporating galss panels to maintain visual amenity.	Reduces flood risk to all properties and businesses in the Harbour. Could be combined with creation of pedestrian footpath to improve safety.	Limited economic justification to provide a 1:100 year return period SOP to the Harbour Road.	To be **considered further** by the HMC, based on the potential to combine with pedestrian footpath for safety reasons.
Minor works to Harbour Road Based on discussions with stakeholders, minor improvements could be made to the condition of the harbour road, to increase the level of the road at low spots and gradually over its whole length. Gabion protection could also be installed along the channel edge to reduce the risk of erosion.	Reduced flood risk if road level is raised at low spots. Improved road surface condition. Reduced risk of erosion of channel edge.	Likely to require regular, ongoing work to top-up road level and repair road surface. Gabions can have a short life due to corrosion in saline water conditions.	To be **considered further** by HMC. A cost estimate has not been developed for this option, as these works

Option		Benefits		Constraints	Initial Assessment
			would be undertaken locally on an ad-hoc basis.		
Resilience measures for Harbour businesses The semi-permenant structures (boat sheds etc.) located downstream of the Blackshore will remain at risk from flooding if flood protection is not provided to the Harbour Road. There will be a residual risk of flooding if a low SOP is provided to the Harbour Road. The existing sheds could be replaced with structures that have a built-up floor level, or which are raised on stilts. These measures could be implemented in combination with works to raise the Harbour Road, and could reduce the width over which the Harbour Road would need to be raised.		Protection provided to properties and businesses within the Harbour.			**Considered further.** Requirements for associated resilience measures need further development with Harbour users.

Appendix F

Cost Estimates

F1 Contractor estimates for harbour entrance structures

The potential works to the South Pier at Southwold Harbour would need to be undertaken by a specialist marine contractor. To obtain appropriate cost estimates for the various options, a quote was requested from the marine contractor Mackley Ltd (part of the Van Oord group), who are experienced in undertaking similar works on the east coast of the UK.

Briefing information was provided, which introduced the project, conditions at the site, the existing South Pier form of construction and condition, and the options for which cost estimates were required.

Cost estimates were provided by Mackley in November 2020 for the following options and are included in the tables below. The cost estimates are inclusive of mobilisation / demobilisation costs, preliminary items, risk allowance, contractor's fee and 75% Optimism Bias[34]. The cost estimates have been increased by 15% to allow for inflation between September 2020 and December 2022 (ref. **Table F3.1**).

- **Table F1.1:** Repairs to existing structure
- **Table F1.2:** Like-for-like replacement (concrete frame structure)
- **Table F1.3:** Sheet-piled pier with rock armour on southern face
- **Table F1.4:** Rock armour breakwater
- **Table F1.5:** Concrete unit breakwater

Using the cost estimates prepared for the South Pier, estimates were also prepared for potential future works to the North Pier and the Knuckle. It was assumed that these structures would be replaced with a revetment comprised of either concrete units (similar to existing) or rock armour. These cost estimates are included in **Table F1.6** and **Table F1.7**.

The cost estimates for the replacement of the North and South Piers depend on the foundation depth required, which relates to the future rate of erosion of the channel. The original cost estimates provided by Van Oord assumed that the present rate of erosion of the channel would continue but would not increase. If the rate of erosion of the channel was to accelerate in the future, due to an increase in the tidal prism of the estuary and associated tidal flow rates, then the foundation depth of the harbour entrance structures may need to be increased to account for this.

For the rock armour and concrete unit breakwater options, these would be designed with the piles from the existing structure providing support the toe. The breakwater would be designed to be structurally stable without these toe piles in place, enabling adaptation to channel erosion. Eventually, with continuing channel erosion, additional toe piling might be required.

The proposed design of the rock breakwater would use the piles from the existing structure to support the toe, although the breakwater would be designed to be structurally stable without the toe piles in place. At present, the existing piles have a minimum cover of 3m. The current rate of erosion of the channel bed is about 100mm/year so if this was to continue the existing piles could be undermined within 30 years.

However, the breakwater would reduce wave disturbance within the entrance channel and would be expected to reduce scour of the channel bed as wave energy will be dissipated by the structure. Any seabed sediment excavated during construction of the breakwater could be placed against the toe piles to provide additional cover. Therefore, for the outline design of these structures it is appropriate to assume that the rate of erosion will not increase, and it will not be necessary to include new, deeper toe piling as part of the

[34] Optimism bias is an uplift applied to infrastructure cost estimates to account for the recognised tendency for early cost estimates to be overly optimistic. Optimism bias of 30% is the accepted factor for detailed design-stage cost estimates. Optimism bias of 60% is the accepted factor for concept-stage cost estimates. Current guidance recommends an additional 7% is applied for each year between completion of the project appraisal and estimated construction start date. Therefore Optimism Bias of 75% is applied to the cost estimates for this project.

breakwater design. Taking a conservative approach, an allowance will be included in the Investment Plan for installing toe piling in Year 30. The actual timing and depth of this piling would be dependent on the future rate of erosion.

For the like-for-like replacement and sheet piled pier options, there is greater potential for the rate of erosion of the channel bed to increase in the future, so the piled foundations would need to be designed to account for this. Therefore, the cost estimates provided by Van Oord for piling were increased by 20% to allow for a greater foundation depth.

For the 'repair' option, an increase in erosion rate would be expected to change the time of failure. Sensitivity to timing of works or failure of structures is considered in **Section 11.2** of this report.

Table F1.1 – Cost estimate for repairs to existing structure

Description	Qty	Unit	Rate			Amount (2020)
Materials						
AZ28 - 700 @ 11m long	152	Tonne	£ 770.00		£	117,040.00
Concrete Pre-Cast Pile	22	nr	£ 800.00		£	17,600.00
Pre-Cast Beam	7	m3	£ 800.00		£	5,600.00
Insitu Concrete Capping	30	m	£ 700.00		£	21,000.00
Pre-Cast Capping	7	m3	£ 800.00		£	5,600.00
Insitu Concrete Connections Pile to Beams	22	nr	£ 700.00		£	15,400.00
Concrete Repairs	80	m3	£ 1,000.00		£	80,000.00
			Sub Total		**£**	**262,240.00**
			Fee	15%	£	39,336.00
			Total Materials		**£**	**301,576.00**
Labour & Plant (Access Road)						
Install By Jack Up Barge (as Demolition rate)	3	wks	£ 66,000.00		£	198,000.00
Install Concrete works	3	wks	£ 54,000.00		£	162,000.00
Barge to Access Concrete Repairs	8	wks	£ 66,000.00		£	528,000.00
Gang to Set Up Welfare	4	wks	£7,500.00		£	30,000.00
			Sub Total		**£**	**918,000.00**
			Fee	15%	£	137,700.00
			Total Labour & Plant		**£**	**1,055,700.00**
Mob / Demobilisation & Demolition						
Jack Up Barge, 90t Long Reach Excavator, Cutting jaws, Work boat, Safety boat, Flat top barge, 50t Excavator + Grab and Crew	1	Wks	£ 66,000.00		£	66,000.00
Mob / Demobilisation	2	each way	£ 75,000.00		£	150,000.00
Disposal	1	Sum	£ 5,000.00		£	5,000.00
			Sub Total		**£**	**221,000.00**
			Fee	15%	£	33,150.00
			Total Mob/Demob & Demolition		**£**	**254,150.00**
			Sub Total		**£**	**1,611,426.00**
			Prelims	20%	£	322,285.20
			Contractors Risk	5%	£	96,685.56
			Total		**£**	**2,030,396.76**
			Inflation 2020 to 2022	15%	£	243,647.61

			Total +75% OB (December 2022)	75%	**£ 3,638,470.99**

Table F1.2 – Cost estimate for replacement with similar concrete frame structure

Description	Qty	Unit	Rate		Amount (2020)
Materials					
AZ28 - 700 @ 11m long	1,378	Tonne	£ 770.00		£ 1,061,060.00
Concrete Pre-Cast Pile	189	nr	£ 800.00		£ 151,200.00
Pre-Cast Beam	66	m3	£ 800.00		£ 52,800.00
Insitu Concrete Capping	270	m	£ 700.00		£ 189,000.00
Pre-Cast Capping	66	m3	£ 800.00		£ 52,800.00
Insitu Concrete Connections Pile to Beams	189	nr	£ 700.00		£ 132,300.00
			Sub Total		**£ 1,639,160.00**
			Fee	15%	£ 245,874.00
			Total Materials		**£ 1,885,034.00**
Labour & Plant (Access Road)					
Install By Jack Up Barge (as Demolition rate)	20	wks	£ 66,000.00		£ 1,320,000.00
Install Concrete works	27	wks	£ 54,000.00		£ 1,458,000.00
Gang to Set Up Welfare	4	wks	£ 7,500.00		£ 30,000.00
			Sub Total		**£ 2,808,000.00**
			Fee	15%	£ 421,200.00
			Total Labour & Plant		**£ 3,229,200.00**
Mob / Demobilisation & Demolition					
Jack Up Barge, 90t Long Reach Excavator, Cutting jaws, Work boat, Safety boat, Flat top barge, 50t Excavator + Grab and Crew	6	Wks	£ 66,000.00		£ 396,000.00
Mob / Demobilisation	2	each way	£ 75,000.00		£ 150,000.00
Disposal	1	Sum	£ 40,000.00		£ 40,000.00
			Sub Total		**£ 586,000.00**
			Fee	15%	£ 87,900.00
			Total Mob/Demob & Demolition		**£ 673,900.00**
			Sub Total		**£ 5,788,134.00**
			Prelims	20%	£ 1,157,626.80
			Contractors Risk	5%	£ 347,288.04
			Total		**£ 7,293,048.84**
			Inflation 2020 to 2022	15%	£ 1,093,957.33
			Total +75% OB (December 2022)	75%	**£ 13,419,209.87**

Table F1.3 – Cost estimate for sheet piled walls plus rock armour to south face

Description	Qty	Unit	Rate		Amount (2020)
Materials					
6t to 10t Rock Armour	13,650	Tonne	£ 60.00		£ 819,000.00
1t to 3t Rock Armour	3,600	Tonne	£ 60.00		£ 216,000.00
Quarry Run Material	5,000	Tonne	£ 45.00		£ 225,000.00
Aggregate Tax	22,250	tonne	£ 2.00		£ 44,500.00
HZ King Piles 1080 MB @ 20m long	900	Tonne	£ 910.00		£ 819,000.00
AZ42-700 Intermediate Piles @ 14m Long	578	Tonne	£ 750.00		£ 433,500.00
			Sub Total		**£ 2,557,000.00**
			Fee	15%	£ 383,550.00
			Total Materials		**£ 2,940,550.00**
Labour & Plant (Access Road)					
Place Rock Armour	17,250	tonnes	£ 25.00		£ 431,250.00
Place Quarry Run Material	5,000	tonnes	£ 20.00		£ 100,000.00
Install Combi Piles	14	wks	£ 54,000.00		£ 756,000.00
Gang to Set Up Welfare	4	wks	£7,500.00		£ 30,000.00
			Sub Total		**£ 1,317,250.00**
			Fee	15%	£ 197,587.50
			Total Labour & Plant		**£ 1,514,837.50**
Mob / Demobilisation & Demolition					
Jack Up Barge, 90t Long Reach Excavator, Cutting jaws, Work boat, Safety boat, Flat top barge, 50t Excavator + Grab and Crew	6	Wks	£ 66,000.00		£ 396,000.00
Mob / Demobilisation	2	each way	£ 75,000.00		£ 150,000.00
Disposal	1	Sum	£ 40,000.00		£ 40,000.00
			Sub Total		**£ 586,000.00**
			Fee	15%	£ 87,900.00
			Total Mob/Demob & Demolition		**£ 673,900.00**
			Sub Total		**£ 5,129,287.50**
			Prelims	20%	£ 1,025,857.50
			Contractors Risk	5%	£ 307,757.25
			Total		**£ 6,462,902.25**
			Inflation 2020-2022	15%	£ 969,435.34
			Total +75% OB (December 2022)	75%	**£ 11,891,740.14**

Table F1.4 – Cost estimate for rock armour breakwater

Description	Qty	Unit	Rate			Amount (2020)
Materials						
6t to 10t Rock Armour	27,380	Tonne	£ 60.00		£	1,642,800.00
1t to 3t Rock Armour	7,250	Tonne	£ 60.00		£	435,000.00
Quarry Run Material	10,090	Tonne	£ 45.00		£	454,050.00
Aggregate Tax	44,750	tonne	£ 2.00		£	89,500.00
Timber fenders - supply and place	100	m	£ 5,000.00		£	500,000.00
			Sub Total		**£**	**3,121,290.00**
			Fee	15%	£	468,193.50
			Total Materials		**£**	**3,589,483.50**
Labour & Plant (Access Road)						
Place Rock Armour	34,630	tonnes	£ 25.00		£	865,750.00
Place Quarry Run Material	10,090	tonnes	£ 20.00		£	201,800.00
Gang to Set Up Welfare	4	wks	£7,500.00		£	30,000.00
			Sub Total		**£**	**1,097,550.00**
			Fee	15%	£	164,632.50
			Total Labour & Plant		**£**	**1,279,432.50**
Mob / Demobilisation & Demolition						
Jack Up Barge, 90t Long Reach Excavator, Cutting jaws, Work boat, Safety boat, Flat top barge, 50t Excavator + Grab and Crew	6	Wks	£ 66,000.00		£	396,000.00
Mob / Demobilisation	2	each way	£ 75,000.00		£	150,000.00
Disposal	1	Sum	£ 40,000.00		£	40,000.00
			Sub Total		**£**	**586,000.00**
			Fee	15%	£	87,900.00
			Total Mob/Demob & Demolition		**£**	**673,900.00**
			Sub Total		**£**	**5,525,566.00**
			Prelims	20%	£	1,105,113.20
			Contractors Risk	5%	£	331,533.96
			Total		**£**	**6,962,213.16**
			Inflation 2020 to 2022	15%	£	1,044,331.97
			Total +75% OB (December 2022)	75%	**£**	**12,810,472.21**

Table F1.5 – Cost estimate for concrete armour unit breakwater

Description	Qty	Unit	Rate			Amount (2020)	
Materials							
Concrete Units	4,929	nr	£	1,000.00		£	4,929,000.00
3t to 6t Rock Armour	5,400	Tonne	£	60.00		£	324,000.00
0.3t to 1t Rock Armour	5,010	Tonne	£	60.00		£	300,600.00
Quarry Run Material	10,670	nr	£	45.00		£	480,150.00
Aggregate Tax	21,080	tonne	£	2.00		£	42,160.00
				Sub Total		**£**	**6,075,910.00**
Fee				Fee	15%	£	911,386.50
				Total Materials		**£**	**6,987,296.50**
Labour & Plant (Access Road)							
Place Rock Armour	10,410	tonnes	£	25.00		£	260,250.00
Place Quarry Run Material	10,670	Days	£	20.00		£	213,400.00
Place Concrete Units	4,929	nr		£120.00		£	591,480.00
Gang to Set Up Welfare	4	wks		£7,500.00		£	30,000.00
				Sub Total		**£**	**1,095,130.00**
				Fee	15%	£	164,269.50
				Total Labour & Plant		**£**	**1,276,649.50**
Mob / Demobilisation & Demolition							
Jack Up Barge, 90t Long Reach Excavator, Cutting jaws, Work boat, Safety boat, Flat top barge, 50t Excavator + Grab and Crew	6	Wks	£	66,000.00		£	396,000.00
Mob / Demobilisation	2	each way	£	75,000.00		£	150,000.00
Disposal	1	Sum	£	40,000.00		£	40,000.00
				Sub Total		**£**	**586,000.00**
				Fee	15%	£	87,900.00
				Total Mob/Demob & Demolition		**£**	**673,900.00**
				Sub Total		**£**	**8,920,596.00**
				Prelims	20%	£	1,784,119.20
				Contractors Risk	5%	£	535,235.76
				Total		**£**	**11,239,950.96**
				Inflation 2020 to 2022	15%	£	1,685,992.64
				Total +75% OB (December 2022)	75%	**£**	**20,681,509.77**

Table F1.6 – Cost estimate for rock armour and concrete unit breakwater

Description	Qty	Unit	Rate			Amount (2020)	
Materials							
SHED Concrete Units	1,725	nr	£	1,000.00		£	1,725,150.00
6t to 10t Rock Armour	17,797	Tonne	£	60.00		£	1,067,820.00
1t to 3t Rock Armour	3,625	Tonne	£	60.00		£	217,500.00
Quarry Run Material	5,045	nr	£	45.00		£	227,025.00
Aggregate Tax	26,467	tonne	£	2.00		£	52,934.00
				Sub Total		**£**	**3,290,429.00**
Fee				Fee	15%	£	493,564.35
				Total Materials		**£**	**3,783,993.35**
Labour & Plant (Access Road)							
Place SHED Concrete Units	1,725	tonnes	£	120.00		£	207,018.00
Place Rock Armour	21,422	Days	£	25.00		£	535,550.00
Place Quarry Run Material	5,045	nr	£	20.00		£	100,900.00
Gang to Set Up Welfare	4	wks	£	7,500.00		£	30,000.00
				Sub Total		**£**	**873,468.00**
				Fee	15%	£	131,020.20
				Total Labour & Plant		**£**	**1,004,488.20**
Mob / Demobilisation & Demolition							
Jack Up Barge, 90t Long Reach Excavator, Cutting jaws, Work boat, Safety boat, Flat top barge, 50t Excavator + Grab and Crew	6	Wks	£	66,000.00		£	396,000.00
Mob / Demobilisation	2	each way	£	75,000.00		£	150,000.00
Disposal	1	Sum	£	40,000.00		£	40,000.00
				Sub Total		**£**	**586,000.00**
				Fee	15%	£	87,900.00
				Total Mob/Demob & Demolition		**£**	**673,900.00**
				Sub Total		**£**	**5,462,381.55**
				Prelims	20%	£	1,092,476.31
				Contractors Risk	5%	£	327,742.89
				Total		**£**	**6,882,600.75**
				Inflation 2020 to 2022	15%	£	1,032,390.11
				Total +75% OB (December 2022)	75%	**£**	**12,663,985.39**

Table F1.7 – Cost estimate for replacement of North Pier with concrete armour units

Description	Qty	Unit	Rate			Amount (2020)
Materials						
Concrete Units	2,460	nr	£ 1,000.00		£	2,460,000.00
3t to 6t Rock Armour	2,700	Tonne	£ 60.00		£	162,000.00
0.3t to 1t Rock Armour	2,505	Tonne	£ 60.00		£	150,300.00
Quarry Run Material	5,335	nr	£ 45.00		£	240,075.00
Aggregate Tax	5,270	tonne	£ 2.00		£	10,540.00
			Sub Total		**£**	**3,022,915.00**
			Fee	15%	£	453,437.25
			Total Materials		**£**	**3,476,352.25**
Labour & Plant (Access Road)						
Place Rock Armour	5,205	tonnes	£ 25.00		£	130,125.00
Place Quarry Run Material	5,335	Days	£ 20.00		£	106,700.00
Place Concrete Units	2,460	nr	£ 120.00		£	295,200.00
Gang to Set Up Welfare	4	wks	£7,500.00		£	30,000.00
			Sub Total		**£**	**562,025.00**
			Fee	15%	£	84,303.75
			Total Labour & Plant		**£**	**646,328.75**
Mob / Demobilisation & Demolition						
Jack Up Barge, 90t Long Reach Excavator, Cutting jaws, Work boat, Safety boat, Flat top barge, 50t Excavator + Grab and Crew	4	Wks	£ 66,000.00		£	264,000.00
Mob / Demobilisation	2	each way	£ 75,000.00		£	150,000.00
Disposal	1	Sum	£ 40,000.00		£	40,000.00
			Sub Total		**£**	**454,000.00**
			Fee	15%	£	68,100.00
			Total Mob/Demob & Demolition		**£**	**522,100.00**
			Sub Total		**£**	**4,644,781.00**
			Prelims	20%	£	928,956.20
			Contractors Risk	5%	£	278,686.86
			Total		**£**	**5,852,424.06**
			Inflation 2020 to 2022	15%	£	702,290.89
			Total +75% OB (December 2022)	75%	**£**	**10,487,543.92**

Table F1.7 – Cost estimate for replacement of North Pier with rock revetment

Description	Qty	Unit	Rate			Amount
Materials						
6t to 10t Rock Armour	13,690	Tonne	£ 60.00		£	821,400.00
1t to 3t Rock Armour	3,625	Tonne	£ 60.00		£	217,500.00
Quarry Run Material	5,000	Tonne	£ 45.00		£	227,025.00
Aggregate Tax	11,158	tonne	£ 2.00		£	44,720.00
			Sub Total		**£**	**1,310,645.00**
			Fee	15%	£	196,596.75
			Total Materials		**£**	**1,507,241.75**
Labour & Plant (Access Road)						
Place Rock Armour	17,315	tonnes	£ 25.00		£	432,875.00
Place Quarry Run Material	5,000	tonnes	£ 20.00		£	100,900.00
Gang to Set Up Welfare	4	wks	£7,500.00		£	30,000.00
			Sub Total		**£**	**563,775.00**
			Fee	15%	£	84,566.25
			Total Labour & Plant		**£**	**648,341.25**
Mob / Demobilisation & Demolition						
Jack Up Barge, 90t Long Reach Excavator, Cutting jaws, Work boat, Safety boat, Flat top barge, 50t Excavator + Grab and Crew	4	Wks	£ 66,000.00		£	264,000.00
Mob / Demobilisation	2	each way	£ 75,000.00		£	150,000.00
Disposal	1	Sum	£ 40,000.00		£	40,000.00
			Sub Total		**£**	**454,000.00**
			Fee	15%	£	68,100.00
			Total Mob/Demob & Demolition		**£**	**522,100.00**
			Sub Total		**£**	**2,677,683.00**
			Prelims	20%	£	535,536.60
			Contractors Risk	5%	£	160,660.98
			Total		**£**	**3,373,880.58**
			Inflation 2020 to 2022	15%	£	506,082.09
			Total +75% OB (December 2022)	75%	**£**	**6,207,940.27**

F2 Cost estimate for tidal barrier

The potential costs for a tidal barrier or barrage at Southwold have been assessed based on the cost of previous tidal barrier schemes, summarised in **Table F2.1** below.

Table F2.1– Summary of costs for example tidal barrier schemes

Example	Approx. dimensions	Contract value or estimate? (Year)	Scheme cost, 2018 (£m)	Approx. Barrier Cost, 2018 (£m)
Ipswich tidal barrier	20m navigable width	Contract value (2018)	58	28
Boston barrier	Estimated 60m wide, 25m navigable width	Estimate (2017)	103	69
Bridgwater tidal barrier	50m wide, 15m navigable	Estimate (2017)	73	37 (estimate, 50% of scheme cost)
Colne barrier	130m wide, 30m navigable	Contract value (1993)	29	29
Yare barrier	Assumed approx. 100m wide, 30m navigable width.	Estimate (1995)	136	42
River Hull tidal surge barrier	30m wide	Contract value (1980)	11	11
Barking Creek tidal barrier	92m wide, 39m wide gate	Contract value (1979)	33	Not available

The Boston Barrier is a recently completed scheme in the east of England with dimensions comparable to what would be required at Southwold. The Boston scheme includes lock structures and was constructed in a spatially constrained location in Boston Town Centre, whereas there are less constraints at Southwold.

Based on the Boston Barrier cost estimate and allowing 30% for inflation from 2018 to 2022, an estimated cost of £90m is assumed for a tidal barrier for Southwold.

F3 Cost estimates for works to estuary defences

Cost estimates for works to the estuary defences are based on the estimates previously developed by Black and Veatch as part of the Blyth Estuary Strategy in 2008.

The assumptions made in these cost estimates have been reviewed and revised as follows, considering previous feedback on the Strategy cost estimates (Ref. 4):

- Embankments would be raised by increasing the crest level and widening the landward side as necessary. To maintain flood protection during construction works, the existing embankments would not be removed.
- Existing defence crest levels used for the EA strategy cost estimates were reviewed against more recent survey data. There were limited differences between these levels, so the data from the EA strategy has been used for consistency and ease of comparison.
- New defence crest levels based on water levels from tidal modelling results for each option. Consistent defence level applied to each flood compartment.
- No freeboard allowance included in new defence crest levels, based on stakeholder preference.
- Defence crest level increased to allow for settlement of 75mm over 50 years.
- Landward slope of embankments assumed to be 1:3, based on current design guidance and expected geotechnical design requirements.

- Landward slope for spillways assumed to be 1:5, based on current design guidance and expected geotechnical design requirements.
- Crest width of embankment minimised, reduced to 2m.
- Geotextile assumed to be required, as we are constructing on top of the existing bank structures.
- Spillways to be reinforced using GreenArmour[35] or similar.
- Assume grass seeding rather than turfing, cost rate reduced by 50%.
- Assume rock armour used for toe protection rather than sheet piling, cost rate reduced to reflect this.
- No works will be required to the North Wall within 50 years.
- Habitat compensation costs not included, as compensatory habitat has already been secured by the Environment Agency.
- No change to assumed allowances for Access and Mobilisation (15%), Labour and Plant (15%), Contingencies (0%), Contractors' overheads (20%), Contractor's profit (5%).
- Engineering costs reduced to 8% of construction costs, based on expected design costs for straightforward embankment design.
- Client costs reduced to 3% of construction costs, as local authority costs for project management would be less than Environment Agency costs.

All cost estimates have been updated to present day values using the Output Price Index for Public Works (OPI) (Ref. 13), as set out in **Table F3.1**.

Table F3.1: Multipliers applied to account for inflation

	Date	Output Index	Index multiplier
Base date for original EA Strategy cost estimates	Q2, 2004	136	-
Date used for EA Strategy cost estimates	Q2, 2007	153	1.13
Date used for Southwold Harbour Investment Plan (draft)	Nov 2020	186.9	1.37
Date used for Southwold Harbour Investment Plan (final)	Dec 2022	215.4	1.58

The item rates used in the EA Strategy cost estimates were based on rates taken from the 2004 edition of the SPON'S Civil Engineering and Highway Works Price Book. The updated rates with OPI inflation applied have been compared against the present-day values from SPON'S (Ref. 11), as set out in **Table F3.2**. This shows some rates to be higher than the inflated rates, but with the cost of imported fill material being less than the inflated rate. When the 2020 SPON'S rates are used to calculate the total option costs rather than the inflated 2004 rates, the resulting estimate for the initial capital cost is about 2% higher. Therefore, the cost estimates based on the previous 2004 rates are used, for ease of comparison with the EA Strategy cost estimates.

Table F3.2: Comparison of item costs

[35] GreenArmor (geosolutionsinc.com)

	Item description	Unit	2004 Rate (£)	2004 Rate + inflation to 2020 (£)	2020 Rate	Notes
1	Excavation – foundations / topsoil; not exceeding 0.25m	m^3	1.25	1.71	3.54	
2	Filling - imported; embankments	m^3	10.74	14.71	12.82	
3	Geotextile - slope 10-45 deg.	m^2	2.70	3.70	5.39	
4	Turfing - slope 10-45 deg.	m^2	4.00	5.48	-	Rate reduced by 50%, assuming seeding rather than turfing.
5	Site clearance; general site vegetation	Hectare	795.70	1090.11	1358.17	
7	Land Purchase Costs	m	0.653	0.89	-	
8	Mini Piles (erosion protection)	m	320.97	439.73		Mini-pile rate used for specific sections of exiting piled defence.
9	Rock Toe	m	90.25	123.62		Rock toe assumed for erosion protection (lower cost than piles).

Table F3.3 summarises the costs for the various estuary management scenarios. Costs were assessed for a 1 in 5-year return period SOP (20% AEP) and for a 1 in 100-year return period SOP (1% AEP), allowing for climate change based on a medium emissions scenario (UKCP18 scenario RCP4.5, 50 percentile). Sensitivity to a wider range of climate change scenarios was reviewed for the 'Raise Estuary Defences' option.

Table F3.3: Summary of cost estimates for estuary management options

Option	Materials	Contractor's Costs[36]	Engineering & Client Costs[37]	Optimism Bias (75%)	TOTAL (2022)
Raise all estuary defences (20% AEP)	£4,397,992	£1,698,037	£653,744	£5,062,330	**£11,812,102**
Raise north banks only (20% AEP)	£1,960,797	£723,159	£278,416	£2,221,779	**£5,184,151**
Raise downstream defences + passive spillway (20% AEP)	£4,515,087	£1,744,875	£671,777	£5,198,804	**£12,130,542**
Raise all estuary defences (1% AEP)	£6,784,760	£2,652,744	£1,021,306	£7,844,108	**£18,302,918**
Raise all estuary defences + narrow channel[38] (1% AEP)	£6,389,999	£2,494,840	£960,513	£7,384,014	**£17,229,367**
Raise north banks only (1% AEP)	£2,911,357	£1,103,383	£424,802	£3,329,657	**£7,769,199**
Raise downstream defences + passive spillway (1% AEP)	£6,512,629	£2,543,892	£979,398	£7,526,940	**£17,562,859**

[36] Contractor's costs include labour & plant, mobilisation/demobilisation, preliminary items & overheads, and contractor's risk & profit.

[37] Engineering and Client costs include site investigations, engineering design, consent process incl. associated studies, construction management and supervision and other associated costs to East Suffolk Council.

[38] Costs do not include for works to construct the rock groyne to narrow the channel. With the narrow channel, the upstream defence crest level is slightly less, so the embankment costs are lower than without the rock structure to narrow the channel.

F6 Cost estimate for works to reduce flood risk to the Harbour

Cost estimates for works to reduce flood risk to the harbour are set out in Table F5.1, based on the following assumptions:

- Works to raise the level of the harbour road would be undertaken over approximately a 20m width of the road.
- The present level of the Harbour Road is conservatively assumed to be +1.0m ODN on average along its 1060m length.
- A road level of 3.10m ODN would be required for a 1:100 year (1% AEP) SOP, allowing for climate change to 2070.
- A road level of 2.65m ODN would be required for a 1:5 year (20% AEP) SOP, allowing for climate change to 2070.
- Unit costs for flood walls and embankments are based on the current Environment Agency Cost Database (Ref. 12).
- Costs do not include for relocation or flood resilience measures to the various boat sheds and other structures located along the harbour road, or to replace or adapt the existing pontoons. Further consideration is needed of how best to undertake works to raise the road to minimise the need to relocate these buildings.
- Additional resilience measures may be needed to businesses and properties in the harbour in the future. Property level flood protection measures to the properties in the Blackshore could cost £50,000 on average, depending on the extent of internal works that are required. These costs are not included in the table below.
- Costs for minor works (Option B6) have not been assessed, as these would be undertaken on an ad-hoc basis by harbour users.

Table F5.1: Cost estimates for works to reduce flood risk to the harbour

Option	Embankments	Flood walls and flood gates	Sub-total (2020)	Sub-total (Dec 2022)	Optimism Bias (75%)	TOTAL
B2: Raise Harbour Road (1:5 SOP)	£2,060,863		£ 2,060,863	£ 2,369,992	£ 1,777,494	**£ 3,838,357**
B3: Raise Harbour Road (1:100 SOP)	£2,552,215		£ 2,552,215	£ 2,935,047	£ 2,201,285	**£ 4,753,500**
B4a: Raise Harbour Road plus concrete flood walls (1:100 SOP)	£1,069,296	£2,130,569	£ 3,199,865	£ 3,679,845	£ 2,759,883	**£ 5,959,748**
B4b: Raise Harbour Road plus glass and concrete flood walls (1:100 SOP)	£1,069,296	£3,944,417	£ 5,013,713	£ 5,765,770	£ 4,324,328	**£ 9,338,041**
B5: Raise Harbour Road (1:5 SOP) + Blackshore Flood Walls (1:100 SOP)	£2,060,863	£638,544	£ 2,699,406	£ 3,104,317	£ 2,328,238	**£ 5,027,644**
B6: Do Minimum	Costs not assessed, limited works to improve road condition would be undertaken on an ad-hoc basis by harbour users					

Annex F1 – Contractor Briefing Information

Appendix G

Stakeholder Meetings

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Appendix H

Breakwater Culverts Assessment

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Appendix I

Dredging Assessment

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