Appendix E

Option Development

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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

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 control when flooding of the marshes happens, when peak water levels in the Harbour need to be reduced on a surge tide. Other potential benefits would be less frequent flooding of the marshes compared to the SMP scenario, and a smaller tidal prism, reducing average flow rates and associated channel erosion risk. Potential constraints include a high cost for a controlled sluice spillway, and the risk that a spillway would not achieve a reduction in peak water levels.

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, reducing the risk that the embankments will breach. Passive spillways such as the one shown are always open, so the spill level needs to be designed so that they do not overflow too often. The embankments adjacent to the spillway will need to be raised so that flow is directed through the lower section. Passive spillways have limited operational requirements and low visual impact.

Alternatively, automatic controlled sluice gates can be incorporated within an embankment, which are opened when peak flood levels need to be reduced on surge tides. Opening the sluice gate would reduce peak water levels and risk of embankment failure upstream. The crest level of the embankments might need to be raised in combination with the sluice gate. Automatic sluice gates have significant operational requirements and could be visually unattractive.

For Southwold, an automatic controlled sluice gate was assessed as more likely to be effective than a passive overflow spillway. A very wide sluice with a low sill level would be most effective, although it would have a high cost. If a controlled sluice option is not effective then it is unlikely that passive spillway would achieve a reduction in peak water levels.

The most suitable location for a spillway was also considered, 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 would 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.**

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

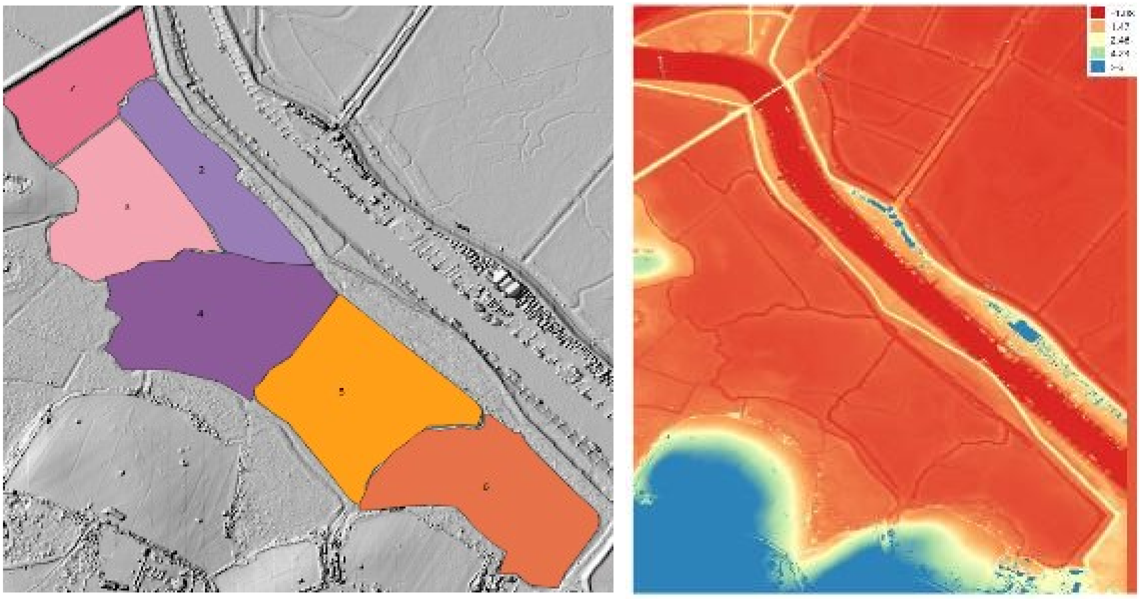

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Table E1 – TidalB results for spillway opposite the Blackshore

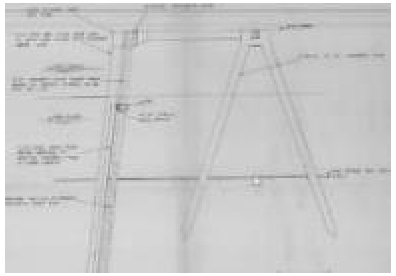
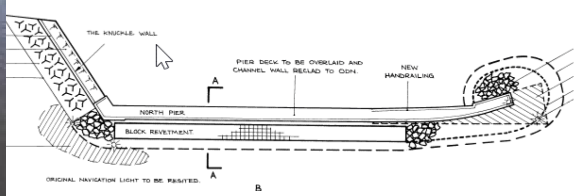
Water level in channel (mAOD)	Flood volume and level vs spillway level					
	Spillway at 2.6m AOD		Spillway at 2.4m AOD		Spillway at 2.6m AOD	
	Volume (m^3)	Water level (mAOD)	Volume (m^3)	Water level (mAOD)	Volume (m^3)	Water level (mAOD)
2.35	16,145	-0.13		-	-	-
2.55	35,479	0.12	3,632	-0.17	-	-
2.75	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

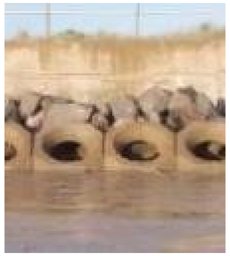
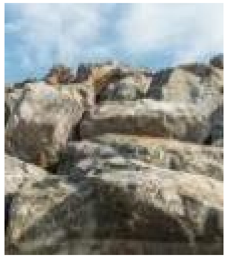
A recent project undertaken by Royal HaskoningDHV for Wells-next-the-Sea assessed the potential benefits of introducing a 'pressure valve' into the tidal embankments with the aim of reducing peak water levels in Wells Harbour. The results of tidal modelling for the December 2013 event showed that a very 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.

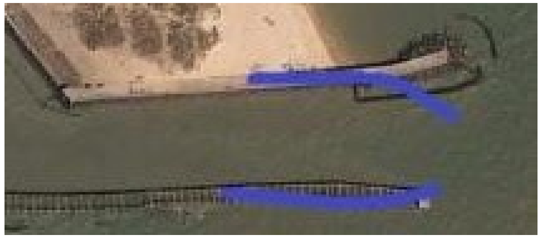
The spillway option was assessed using the tidal model to determine peak water levels and flow rates in the Harbour, for comparison with the other estuary management options (**Section □**). The modelling assumed the most effective arrangement of a spillway, with a 30m wide controlled sluice gate with 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 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.

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 could improve outflow. 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. This 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.

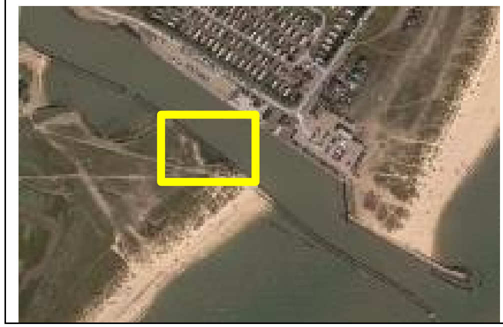
Option	Benefits	Constraints	Initial Assessment
Wave energy dissipation measures at Dunwich Creek  Installation of a gabion mattress or placement of a shingle / crushed rock ‘beach’ in front of the timber piles, with the aim of dissipating wave energy and improving mooring conditions in the harbour.	This 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. This could reduce the build-up of swell waves and therefore improve wave conditions in the harbour. Removal of this sediment bank could also allow the navigation channel and tidal flows to shift further to the south.	Potential reduction in wave heights within the harbour, particularly for swell waves. 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 could reduce wave breaking in the harbour and allow larger 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. Dredging could be required to maintain a realigned channel.	An ongoing dredging programme is **not currently considered to be necessary.** Where limited sediment removal is undertaken as part of other harbour works, this could be used to infill areas of scour or erosion, or placed against the toe of the North or South Piers.
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,** include as part of design of works to replace the South Pier.

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.

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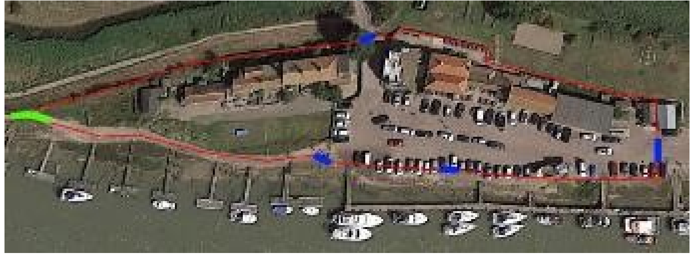
Table E4 - Options for reducing flood risk to the Harbour

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 standard of protection 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, some 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 the Harbour Road and properties / businesses downstream of the Blackshore.	**Considered further.**
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.**

Option	Benefits	Constraints	Initial Assessment
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.**
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 standard of protection 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. Required width of ground raising depends on any associated resilience measures for boat huts / businesses and access to these (see below).	**Considered further.** Requirements for associated resilience measures 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.	**Considered further,** based on potential to combine with pedestrian footpath for safety reasons.
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 standard of protection 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.