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Appendix J3 - Model Narrative Report



Modelling Narrative Report

Langstone Flood & Coastal Erosion Risk Management Scheme

Eastern Solent Coastal Partnership

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1. Introduction

1.1 Background

AECOM was commissioned by the Eastern Solent Coastal Partnership (ESCP) to undertake an option appraisal study and develop an outline design and business case for a tidal flood risk management scheme at Langstone. The 1km Langstone frontage is within the jurisdiction of Havant Borough Council (HBC) and located immediately to the north of Hayling Island. At the site a number of residential properties as well as two public houses are located within a few metres of the water's edge. The study location forms part of a wider flood cell which also covers the adjacent Southmoor frontage to the west.

To support the option appraisal and outline design, AECOM used the East Solent Hayling Island 2D Hydrodynamic model produced by consultants JBA in 2018. This report summarises the modelling approach taken during the project, collating information from various other documents and providing more details where required to support the upcoming detailed design and assurance stages of the project.

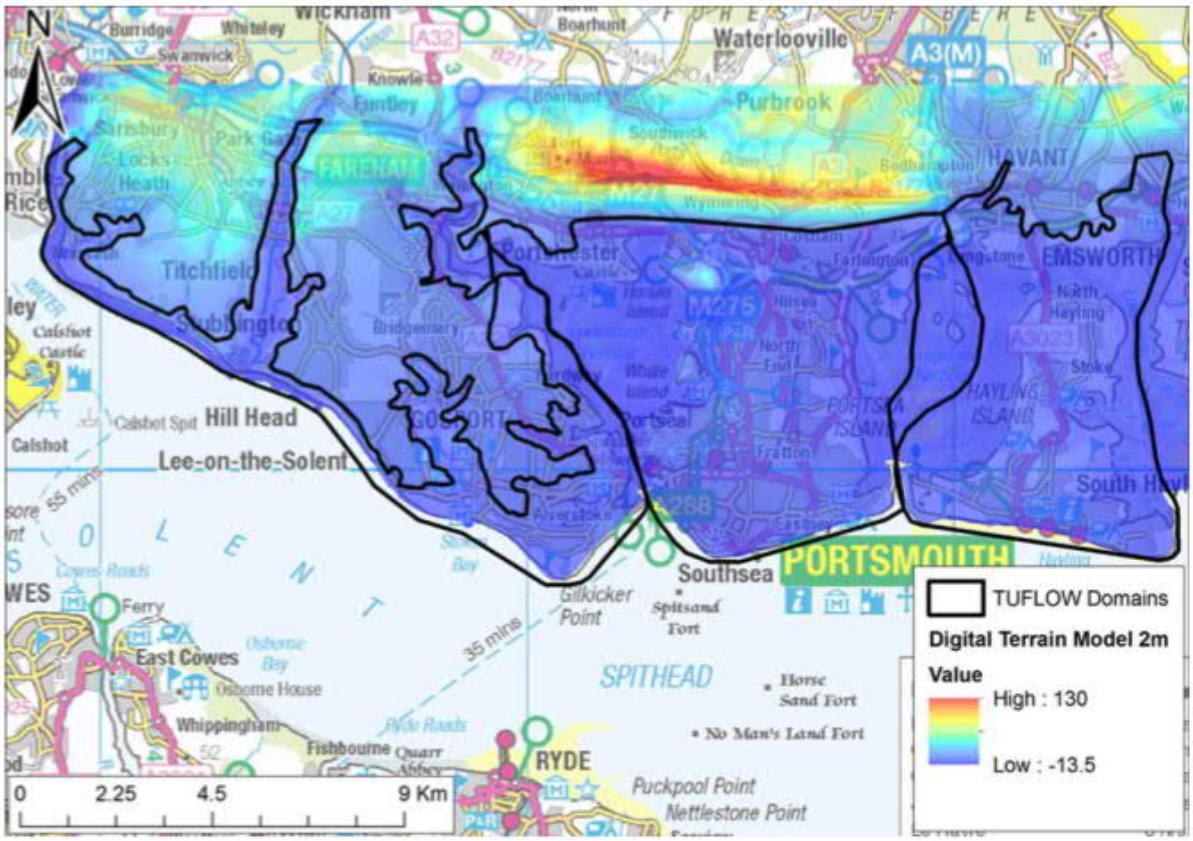
1.2 Model review

Upon receipt of the model, AECOM undertook a technical review of the model to check for completeness and the appropriateness of its application in the project. It was concluded that the model was suitable to simulate tidal flood risk, test options, support economic appraisal and for overall OBC development although the simulation time was longer than anticipated (approximately 75hrs to run one model simulation).

2. East Solent Modelling

2.1 Background

Consultants JBA were commissioned by the Environment Agency to assess tidal flood risk along the Hampshire coastline from Warsash to Emsworth, including Portsea Island and Hayling Island. There were existing tidal models available for this area, but for the study undertaken by JBA, three new tidal inundation models were constructed (Gosport, Hayling and Portsea). The results from the new tidal inundation models were used to provide a greater understanding of the flood risk to the Hampshire coastline. Figure 2-1 shows the model domain areas of the three inundation models constructed by JBA. The model domain on the right, covering Hayling Island, has been used as part of the Langstone Project by AECOM.



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Figure 2-1: JBA model domains along the Hampshire Coastline. From left to right, Gosport domain, Portsea Island domain, Hayling Island domain. Figure obtained from JBA Model Summary Report (2018).

2.2 East Solent modelling approach

The East Solent modelling followed a multi-staged approach to determine the flood risk in the model domains. For a full description of the approach refer to the East Solent Summary Report and East Solent Model Development Report (JBA, 2018). All the information presented in this section on the modelling approach has been obtained from these reports or reports referenced in these documents. No check of the offshore wave transformation or wave overtopping calculations has been undertaken.

In summary, the approach considered the two main sources of tidal flood risk; still water level flooding and overtopping of defences from wave action. In order to simulate both processes, multiple modelling tools were used:

1. Offshore water level and wave data was transformed into the nearshore using a wave transformation model.

2. Wave overtopping discharges at each defence were calculated using the EurOtop Neural Network model and data from the State of the Nation (SoN) National Flood Risk Assessment project.
3. Flood inundation modelling was applied to simulate the flood inundation of the land from both extreme still water level flooding and wave overtopping volumes.

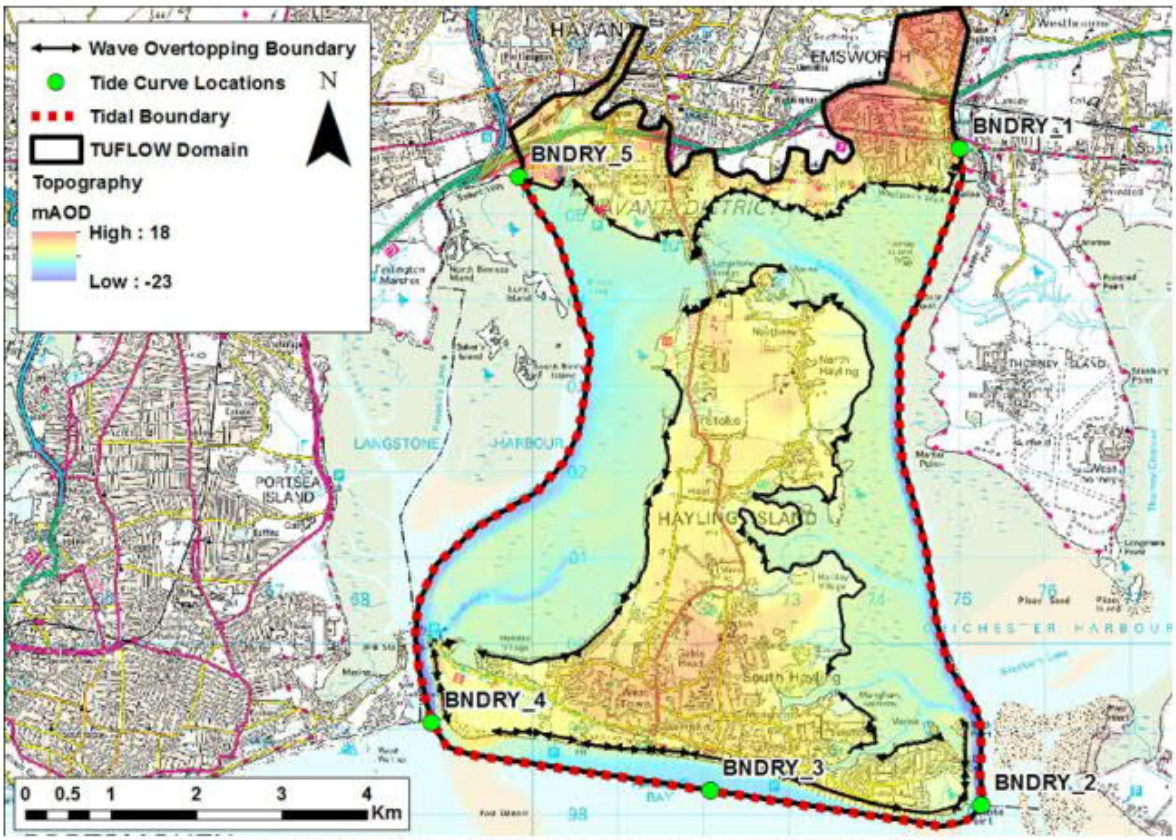
The third stage of the process (flood inundation modelling) is of most interest to the Langstone project as the outputs have been used to assess the flood risk and support the economic appraisal of options. The following section outlines the flood inundation modelling approach in more detail. For more information on the earlier stages of the process (wave transformation modelling and wave overtopping calculations), refer to the East Solent Summary Report and East Solent Model Development Report (JBA, 2018).

2.3 Hayling Island flood inundation modelling

The flood inundation modelling was undertaken using TUFLOW software which is an industry leading hydraulic modelling software for flood, urban drainage, estuarine and coastal assessments.

2.3.1 Extreme still water levels and surge

The Hayling Island 2D TUFLOW model comprises five still water level boundaries. The boundaries were created offshore and in different corners of the model domain to allow the tide and surge component to propagate into the model domain. The position of these boundaries is shown in Figure 2-2 below. In Chichester and Langstone Harbours, either side of Hayling Island, there is a gradient in the extreme water level between the entrance and the top of the harbour (i.e. water level is higher at the top of the harbour than at the entrance). In Chichester Harbour the gradient in water level was identified from the Southern Estuaries and Harbours dataset (JBA, 2015), with the water level at Boundary 1 being +0.16m higher than at Boundary 2. This dataset did not cover Langstone Harbour so the water level change for Langstone was identified from the Littlehampton to Emsworth flood inundation model (JBA, 2016), with the water level at Boundary 5 being +0.14m higher than at Boundary 4.



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Figure 2-2: Hayling Island model domain and water level boundary locations (figure obtained from JBA Model Summary Report (2018).

The still water level boundaries are based on a design tidal curve which simulates the expected change through time during an extreme event. The design tidal curve time series is made of different components:

- Extreme still water level estimate. Based on joint probability analysis of predicted high tides and the skew surge component.
- Design surge shape. This shows how the surge develops over time, for example its duration, speed on onset and timing of the peak.
- Design astronomical tide.

The information used to derive each of these components is provided below:

Extreme still water level estimate

The extreme still water level estimates were taken from the Coastal Flood Boundary (CFB) Dataset for the UK published in 2011 (Environment Agency, 2011). Full details of the how the data within the Coastal Flood Boundary Conditions guidance was derived can be found in the Environment Agency report *SC060064/TR2: Design Sea Levels (2011)*.

The CFB Dataset (2011) provides extreme still water levels around the UK coastline at approximately 2km intervals. The extreme still water levels were developed by statistical analysis which was undertaken on long term tide data recorded at 40 Class A gauge sites around the coastline. The statistical analysis generated probabilities of predicted high tide and of skew surge. Combining these two elements gave the overall design sea level probabilities at the 40 sites, expressed by their respective average return period. In order to provide complete coverage around the UK coastline, an interpolation method was used to determine the return period sea levels between the primary sites. At the time of the East Solent modelling project, the analysis and results from the CFB dataset (2011) provided the best available data of extreme sea levels around the UK coastline. However, it should be noted that the dataset has since been superseded by an update in 2018. This update was released mid-way through the Langstone project and it was agreed with the ESCP to continue using the previous CFB dataset (2011) for the remainder of the project and to sensitivity test the impact of the guidance changes rather than revisiting and redoing the analysis. For more information on how the guidance update has impacted the project, refer to section 4.3.

A key component of the extreme still water levels derived in the CFB (2011) dataset was the skew surge. Surge arises when atmospheric pressure changes, affecting the level of the water surface. Low sea surface pressure acts to raise the level, high surface pressure depresses it. Surface winds drive currents that also determine sea levels. For example, an offshore wind blowing towards land will drive water towards the coastline, leading to a rise in local sea level. The impact on sea level caused by these processes is referred to as surge and can increase or decrease sea levels. Skew surge is the difference between the predicted astronomical tide and the nearest experienced high water (as illustrated in Figure 2-3 below). The approach to derive the extreme still water levels in the CFB (2011) is known as the skew surge joint probability method (SSJPM).

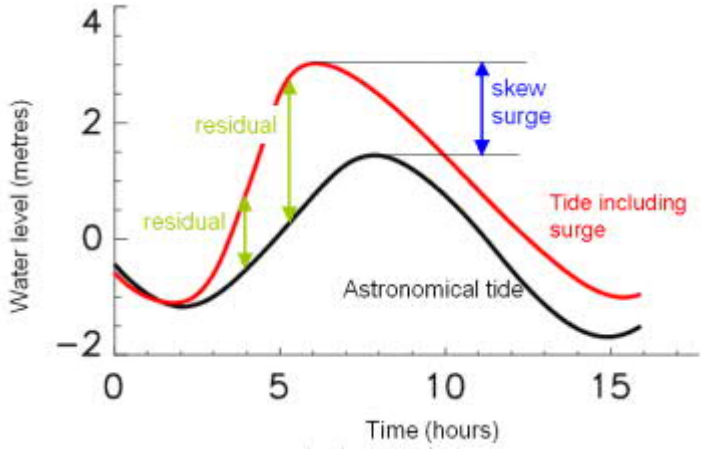


Figure 2-3: Illustration showing skew surge component of an extreme water level (figure obtained from the Environment Agency Report SC060064/TR2)

Statistical analysis was undertaken using the SSJPM to derive the skew surge component for each of the primary tidal gauge sites. All data was de-trended, using a historic sea level rise rate of 2mm per year at each gauge, to a base year of 2008 (JBA, 2018). The rate used was the net combination of land movement and changes in water level. The peak high water levels for each observed tidal event where then identified and the nearest predicted high tide selected.

The difference in water level between the two is the skew surge. This process was repeated for all high water events for each year of data (leading to approximately 705 values of skew surge with corresponding peak predicted tide for each year of recorded data). Histograms of the frequency of the data were calculated and a joint probability analysis was undertaken to form a probability distribution of all possible total sea levels from the skew surge distribution. The probability distribution was then expressed in terms of extreme still water levels for different return period events.

Table 2-1 and Table 2-2 below present the extreme still water levels for the year 2015 for the five still water level boundary locations in the Hayling Island model. The water levels are presented for a range of return period events alongside the CFB (2011) chainage point from which the still water levels were derived in the East Solent modelling exercise. Table 2-1 shows the water levels for model boundaries 2,3 and 4. These were derived directly from the CFB dataset.

Table 2-2 shows the water levels for model boundaries 1 and 5. These were derived by applying an adjustment factor to the CDB dataset to account for the gradient in water level within the harbours (see the start of section 2.3.1 for more details).

Table 2-1: Extreme sea level data used in the derivation of the design tidal graphs for the East Solent modelling project. Boundaries 2,3,4

Boundary	CFB chainage location (2011)	Extreme still water level for the year 2015 (mAOD)							
		10% AEP	4% AEP	3.3% AEP	1.33% AEP	1% AEP	0.5% AEP	0.2% AEP	0.1% AEP
Boundary 2	Chainage 4604	3.03	3.13	3.14	3.25	3.28	3.35	3.45	3.52
Boundary 3	Chainage 4606	2.97	3.07	3.08	3.18	3.21	3.29	3.38	3.45
Boundary 4	Chainage 4610	2.94	3.04	3.05	3.15	3.18	3.25	3.35	3.42

Table 2-2: Extreme sea level data used in the derivation of the design tidal graphs for the East Solent modelling project. Boundaries 1,5

Boundary	CFB chainage location (2011) and adjustment	Extreme still water level for the year 2015 (mAOD)							
		10% AEP	4% AEP	3.3% AEP	1.33% AEP	1% AEP	0.5% AEP	0.2% AEP	0.1% AEP
Boundary 1	*Chainage 4604 + 0.16m	3.19	3.29	3.30	3.41	3.44	3.51	3.61	3.68
Boundary 5	*Chainage 4610 + 0.14m	3.08	3.18	3.19	3.29	3.32	3.39	3.49	3.56

Design surge shape

The design surge shape was also derived from the CFB Dataset (Environment Agency, 2011) which provides surge shapes for the Class A tide gauges sites. The surge shapes were determined by identifying the 15 largest skew events for each site and plotting the variation in surge over time to a standardised unit height. Of the 15 surge events for each location, the maximum duration at each level in the surge was determined and then arranged to form the design surge shape. For the Hayling Island model, the surge shape from the Portsmouth Class A gauge was adopted. The surge shape can be seen by the red line in Figure 2-4.

Astronomical tide

The Chichester Harbour MHWS astronomical tide was obtained and used in the production of the design tidal curve. Figure 2-4 below shows the different components of the design tidal curve (the total sea level coincides with the extreme still water level between 70-85hrs).

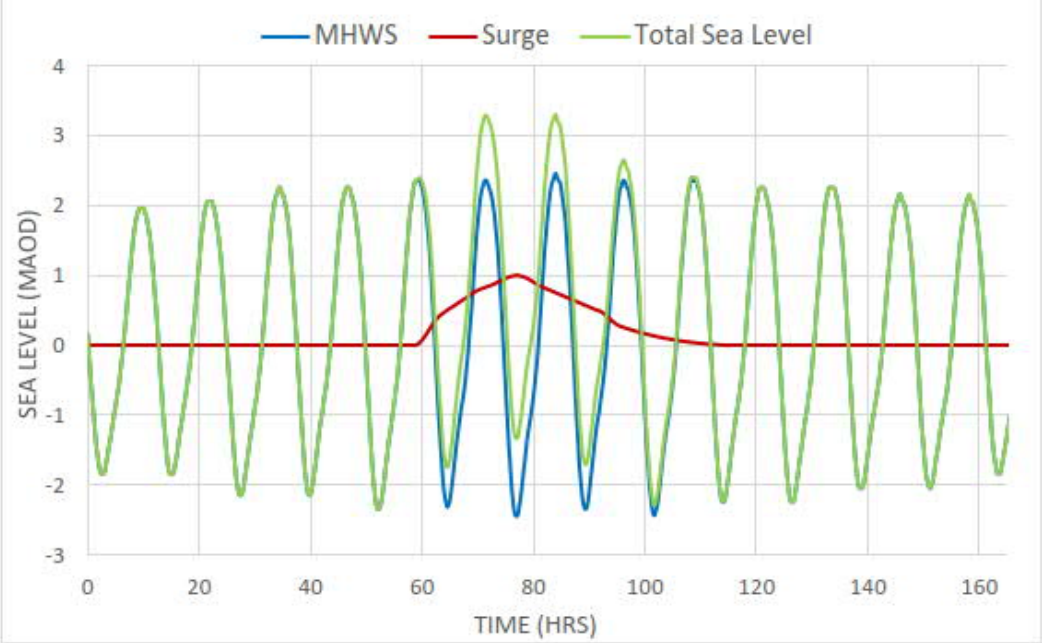


Figure 2-4: Figure showing the components of the design tidal curve for a 200 year event at Boundary location 2. Figure obtained from JBA Model Summary Report (2018).

2.3.2 Wave overtopping volumes

Model simulations were performed by JBA with and without wave overtopping included. For the simulations including wave overtopping, separate wave overtopping boundaries were located along the coastal frontages, slightly landward of the shoreline. These boundaries inject wave overtopping water into the land behind at the location of the flood defences. The wave overtopping values were calculated using EurOtop methods and were based on defence schematisations for both defended and undefended situations. The wave overtopping discharges were applied at the peak of the tide. The model had five wave overtopping boundaries at the study site and these are shown in Figure 2-5 below.

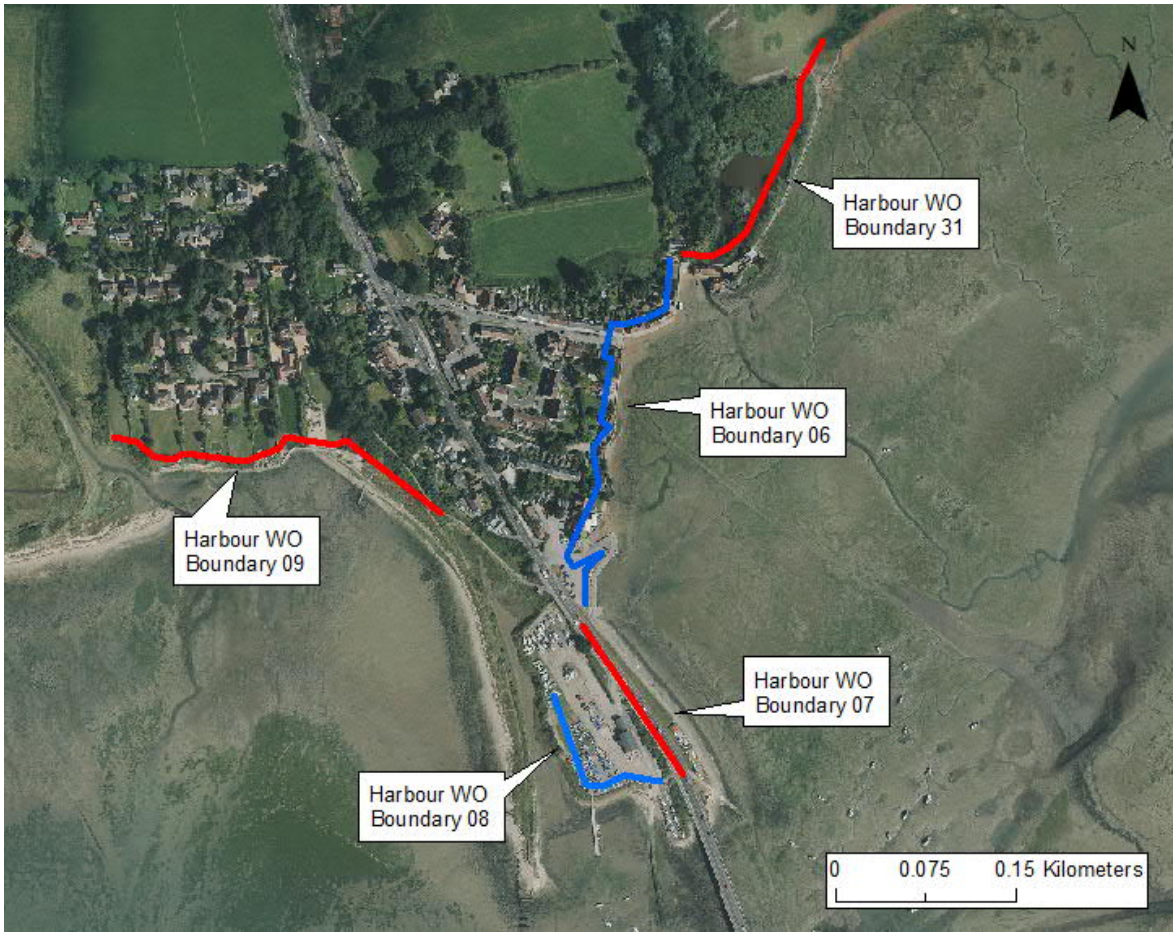


Figure 2-5: Wave overtopping boundaries in the East Solent Model at the study site

Table 2-3 and Table 2-4 present the peak overtopping volumes for a range of return period events at each of the wave overtopping boundaries in the East Solent Model. The volumes presented in Table 2-3 are for the defended scenario, whilst the volumes in Table 2-4 are for the undefended scenario. The defended and undefended wave overtopping volumes are equal at wave overtopping boundary 06, between the Ship Inn and the Royal Oak, because there are no formal raised defences in this location.

Table 2-3: Peak wave overtopping volumes. Defended scenario. 2015 simulations.

Boundary	Peak wave overtopping volume ($m^3/s/m$)						
	50% AEP (1:2yr)	10% AEP (1:10yr)	5% AEP (1:20yr)	2% AEP (1:50yr)	1.33% AEP (1:75yr)	0.5% AEP (1:200yr)	0.1% AEP (1:1000yr)
Harbour_WO_Boundary 31	<0.001	0.004	0.017	0.001	<0.001	<0.001	<0.001
Harbour_WO_Boundary 06	<0.001	0.009	0.022	0.042	0.046	0.023	0.065
Harbour_WO_Boundary 07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Harbour_WO_Boundary 08	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
Harbour_WO_Boundary 09	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001

Table 2-4: Peak wave overtopping volumes. Undefended scenario. 2015 simulations.

Boundary	Peak wave overtopping volume ($m^3/s/m$)						
	50% AEP (1:2yr)	10% AEP (1:10yr)	5% AEP (1:20yr)	2% AEP (1:50yr)	1.33% AEP (1:75yr)	0.5% AEP (1:200yr)	0.1% AEP (1:1000yr)
Harbour_WO_Boundary 31	<0.001	0.004	0.017	0.001	<0.001	<0.001	<0.001
Harbour_WO_Boundary 06	<0.001	0.009	0.022	0.042	0.046	0.023	0.065
Harbour_WO_Boundary 07	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Harbour_WO_Boundary 08	<0.001	<0.001	<0.001	0.001	0.002	0.006	0.035
Harbour_WO_Boundary 09	0.002	0.020	0.025	0.036	0.019	0.008	0.046

For more information on how the wave overtopping discharges were calculated and applied in the model, refer to the JBA East Solent Summary Report and East Solent Model Development Report (JBA, 2018).

2.3.3 Fluvial boundaries

No fluvial boundaries were included in the Hayling Island model. This leads to some uncertainty in the modelled flood risk along the western flank of the Langstone study site where the Langbrook Stream enters Langstone Harbour. This uncertainty is discussed in more detail in section 5.1.3.

2.3.4 Climate change

In addition to present day extreme water level events, the East Solent Modelling also simulated 0.5% Annual Exceedance Probability (AEP) (1:200 year) and 0.1% AEP (1:1000 year) events for 2031, 2065 and 2115 including climate change. As per the guidance at the time of undertaking the modelling exercise, the sea level rise estimates were based on the UKCP09 sea level change guidance using the 95th percentile scenario. The increases in extreme water levels due to sea level rise relative to a 2015 base date are shown in Table 2-5 below.

Table 2-5: Sea level rise estimates applied, relative to 2015 base date

UKCP09 2031	UKCP09 2065	UKCP09 2115
+0.090m	+0.320m	+0.744m

In addition to increases in sea levels, as per the UKCP09 guidance, the East Solent Modelling included a 5% increase in both offshore wind speed and wave height for the 2031 scenarios and a 10% increase in offshore wind speed and wave height for the 2065 and 2115 scenarios. These increases would be expected to increase the wave overtopping rates for the climate change scenarios. Note that since the East Solent Modelling was undertaken, the UKCP09 guidance has been superseded by the UKCP18 guidance. For more information on how this change impacts the project, refer to section 4.3.

2.4 Modelling scenarios provided

To fulfil the scope for the East Solent Modelling Project with the Environment Agency, JBA undertook a range of model simulations of the Hayling Island flood inundation model. The simulations included different return periods for the defended / undefended scenarios, with and without wave overtopping included. Defended scenarios incorporated the existing defence crest levels into the modelling simulations whereas the undefended scenarios did not include defences and established the flood risk from the land elevations obtained from the underlying digital terrain model. For the defended scenario, the defence crest in the model was incorporated as a long section profile obtained from the EA Hayling Island Model, developed by Halcrow in 2010. Two additional simulation were also undertaken for the 0.5% AEP event for two different wind scenarios; fixed winds from the south-west and fixed winds from the south-east, to test the impact on flood risk should a storm experience sustained winds from these directions. Table 2-6 presents the full suite of model simulations which were undertaken.

Table 2-6: Hayling Island flood inundation model simulations undertaken by JBA

Return period	Defended, no wave overtopping	Defended, with wave overtopping	Undefended, no wave overtopping	Undefended, with wave overtopping	Defended, with fixed wind direction
2015 10% AEP	✓	✓			
2015 4% AEP	✓	✓			
2015 3.3% AEP	✓	✓			
2015 1.33% AEP	✓	✓			
2015 1% AEP	✓	✓			
2015 0.5% AEP	✓	✓	✓	✓	✓
2015 0.2% AEP	✓	✓			
2015 0.1% AEP	✓	✓	✓	✓	
2031 0.5% AEP	✓	✓	✓	✓	
2031 0.1% AEP	✓	✓	✓	✓	
2065 0.5% AEP	✓	✓	✓	✓	
2065 0.1% AEP	✓	✓	✓	✓	
2115 0.5% AEP	✓	✓	✓	✓	
2115 0.1% AEP	✓	✓	✓	✓	

3. Langstone Modelling

3.1 Baseline modelling

3.1.1 Model simulations

A range of model simulations were undertaken in the East Solent Modelling project (see Table 2-6). However, it was necessary to undertake additional simulations to support the Langstone baseline damage assessment, economic appraisal and option testing tasks. A list of the additional return periods which were simulated by AECOM to support these tasks is provided below:

- 2015 50% AEP
- 2015 20% AEP
- 2019 1% AEP
- 2031 0.1% AEP
- 2039 1.33% AEP
- 2069 1% AEP
- 2119 20% AEP
- 2119 5% AEP
- 2119 2% AEP
- 2119 1.33% AEP
- 2119 0.5% AEP

3.1.2 Equivalencies and substitution approach

Due to the long model simulation time (approximately 75hrs per simulation), the project team rationalised in a proportionate manner the number of additional model simulations which were required, considering the project program and budget. To do this an equivalencies and substitution approach was adopted, whereby certain model simulations were used to represent different return periods across the various time epochs.

Table 3-1 below provides a summary of the equivalencies approach. The first three columns show the return periods for which flood mapping was needed. The next three columns to the right show which model simulations were used to produce the flood mapping for each return period. For each return period, the difference between the still water level in the model equivalency and the calculated level based on the original model boundaries, adjusted for sea level rise is ±0.05m. This is a suitable level of accuracy to inform the optioneering, economic appraisal and outline design.

Table 3-1: Summary of equivalency approach. Still water levels presented are found Boundary 1 location.

Required flood mapping for project			Model simulation used as equivalency			Difference in water level (m)	Simulation origin
Year	Return period	Still water level (m ODN)	Year	Return period	Still water level (m ODN)		
2019	50% AEP	3.04	2015	50% AEP	3.02	-0.02	AECOM
	20% AEP	3.14	2015	20% AEP	3.12	-0.02	AECOM
	5% AEP	3.29	2015	4% AEP	3.29	0	AECOM / ESM*
	2% AEP	3.38	2015	1.33% AEP	3.41	+0.03	AECOM / ESM
	1.33% AEP	3.43	2015	1% AEP	3.44	+0.01	ESM
	1% AEP	3.46	2019	1% AEP	3.46	0	AECOM
	0.5% AEP	3.53	2015	0.5% AEP	3.51	-0.02	ESM
	0.2% AEP	3.63	2015	0.2% AEP	3.61	-0.02	ESM
2039	50% AEP	3.16	2015	10% AEP	3.19	+0.03	AECOM / ESM
	20% AEP	3.26	2015	4% AEP	3.29	+0.03	AECOM / ESM
	5% AEP	3.41	2015	1.33% AEP	3.41	0	AECOM / ESM
	2% AEP	3.50	2015	0.5% AEP	3.51	+0.01	ESN
	1.33% AEP	3.55	2039	1.33% AEP	3.55	0	AECOM
	1% AEP	3.58	2031	0.5% AEP	3.60	+0.02	ESM
	0.5% AEP	3.65	2015	0.1% AEP	3.68	+0.03	ESM
	0.2% AEP	3.75	2031	0.1% AEP	3.77	+0.02	AECOM

Required flood mapping for project			Model simulation used as equivalency			Difference in water level (m)	Simulation origin
Year	Return period	Still water level (m ODN)	Year	Return period	Still water level (m ODN)		
2069	50% AEP	3.37	2015	1.33% AEP	3.41	+0.04	AECOM / ESM
	20% AEP	3.47	2015	0.5% AEP	3.51	+0.04	ESM
	5% AEP	3.62	2015	0.2% AEP	3.61	-0.01	ESM
	2% AEP	3.71	2015	0.1% AEP	3.68	-0.03	ESM
	1.33% AEP	3.76	2031	0.1% AEP	3.77	+0.01	AECOM
	1% AEP	3.79	2069	1% AEP	3.79	0	AECOM
	0.5% AEP	3.86	2065	0.5% AEP	3.83	-0.03	ESM
	0.2% AEP	3.96	2065	0.1% AEP	4.00	+0.04	ESM
2119	50% AEP	3.80	2065	0.5% AEP	3.83	+0.03	ESM
	20% AEP	3.90	2119	20% AEP	3.90	0	AECOM
	5% AEP	4.05	2119	5% AEP	4.05	0	AECOM
	2% AEP	4.14	2119	2% AEP	4.14	0	AECOM
	1.33% AEP	4.19	2119	1.33% AEP	4.19	0	AECOM
	1% AEP	4.22	2115	0.5% AEP	4.25	+0.03	ESM
	0.5% AEP	4.29	2119	0.5% AEP	4.29	0	AECOM
	0.2% AEP	4.39	2115	0.1% AEP	4.42	+0.03	ESM

**ESM – East Solent Modelling*

3.1.3 Defended and undefended scenarios

As outlined in section 2.4, the model includes both defended and undefended scenarios. For the optioneering and economic appraisal the outputs from the defended model simulations were used to establish the baseline flood risk because this scenario more accurately portrays the existing situation.

The defended model simulations include raised defences on the west side of the study frontage, around the Mill Lane area, Langstone Spit and Langstone Sailing Club. For the east side of the frontage (east of the A3023 main road) there are no raised defences in the model and the flood risk is based upon the land elevations obtained from the underlying digital terrain model.

To support the model review, a topography survey was undertaken by the ESCP in August 2018. The results of the survey were crossed checked by AECOM against the defence crest levels in the defended model simulations. Generally, there was good agreement, within the expected data accuracy tolerance (mean difference between point elevation in topography survey and defence crest data approximately 0.15m, based on representative sample). However, a discrepancy was noted in the defence crest level to the west of Mill Lane. The location is shown in Figure 3-1.

In the location outlined in Figure 3-1, for the defended model simulations the minimum defence crest level in this area was approximately 3.3m ODN. This differed to the topography survey which showed the minimum defence crest to be approximately 2.8m ODN. As a result of this discrepancy, it is likely that the defended model simulations provide an underestimate of the flood risk in this location for certain return periods.

To provide a more accurate representation of flood risk in the area where the topography survey showed a lower defence crest, the flood mapping outputs from the model were modified in GIS. This involved using the undefended model simulation results for the Mill Lane area to the west of the National Cycle Route 2 path. For the remainder of the study area the defended model simulation results were used. The flood depths and extents from the two different areas were merged to create a new flood map.

This approach was only followed for less extreme return period flood events where the lower defence crest identified in the topography survey had the potential to significantly impact the flood risk in the vicinity. The approach was applied to the present day 50% AEP (1:2 year), 20% AEP (1:5 year), 5% AEP (1:20 year) and 2% AEP (1:50 year) events, the 2039 50% AEP (1:2 year), 20% AEP (1:5 year) and 5% AEP (1:20 year) events and the 2069 50% AEP (1:2 year) event. These events were selected because the still water level was lower than the defence crest height in the defended model simulations, but higher than the crest level identified in the

topography survey. For all other return periods no modifications to the model simulations were undertaken in GIS and the defended model scenario results were used.



Figure 3-1: Map showing location of discrepancy between model Z line and topography survey

3.2 Option modelling

During the economic and option appraisal stage of the project, further model simulations were undertaken to establish the effectiveness and residual risk of flooding associated with the leading options. Table 3-2 presents the option model runs which were undertaken.

Table 3-2: Summary of option modelling simulations

Year	Return period	Defence SoP* / option modelled	Purpose of simulation
2019	1.33% AEP	Leading option alignment ODUs 1-3: 2019 1.33% AEP SoP	Test effectiveness of alignment for design event
2019	0.5% AEP	Leading option alignment ODUs 1-3: 2019 1.33% AEP SoP	Establish residual risk of flooding from above design event
2019	1.33% AEP	Leading option alignment ODUs 1-3: 2019 1.33% AEP SoP. Langstone High Street gate open	Establish residual risk of flooding with flood gate across Langstone Highstreet left open. See section 5.1 for rationale for using 1.33% SoP in this simulation.
2019	0.5% AEP	Leading option alignment ODUs 1-3: 2019 0.5% AEP SoP	Test effectiveness of alignment for design event
2019	0.2% AEP	Leading option alignment ODUs 1-3: 2019 0.5% AEP SoP	Establish residual risk of flooding from above design event
2069	1.33% AEP	Leading option alignment ODUs 1-3: 2069 1.33% AEP SoP	Test effectiveness of alignment for design event
2069	0.5% AEP	Leading option alignment ODUs 1-3: 2069 1.33% AEP SoP	Establish residual risk of flooding from above design event
2069	0.5% AEP	Leading option alignment ODUs 1-3: 2069 0.5% AEP SoP	Test effectiveness of alignment for design event

Year	Return period	Defence SoP* / option modelled	Purpose of simulation
2069	0.2% AEP	Leading option alignment ODUs 1-3: 2069 0.5% AEP SoP	Establish residual risk of flooding from above design event
2019	0.5% AEP	Leading option alignment ODUs 2-3: 2019 0.5% AEP SoP	Test effectiveness of ODU 2-3 alignment for design event. Simulation to check that alternative tie-in locations with this alignment worked.

**note: SoP is based on still water level flood risk*

The option model simulations were used in the economic assessment to establish the flood damages for above design event return periods. Figures showing the flood depth and extent from the above design events, and the model simulation with the Langstone High Street flood gate open are presented in Appendix A. Section 5 provides a detailed discussion of the residual risk associated with the scheme.

3.3 Wave overtopping

The baseline and option model simulations do not include wave overtopping and are based on still water level flooding only (i.e. all the simulations listed in Table 3-1 and Table 3-2). The decision to not include wave overtopping inputs was made collaboratively with the ESCP during a monthly progress meeting. The primary reasons for not including wave overtopping inputs in the simulations were:

1. For the majority of the site the dominant source of flood risk is from tidal inundation. Given the sheltered nature of the site and depth limiting factors, wave overtopping plays a lesser, secondary role to the flood risk (for more information, refer to section 3.4).
2. As discussed in section 3.1.1, to establish the baseline, further model simulations were required in addition to those provided by JBA. If simulations including wave overtopping were to be undertaken, a significant amount of additional work to establish wave overtopping volumes for the new simulations would have been required. This work was beyond the scope of the project.
3. If simulations including wave overtopping were to be undertaken, it would have been difficult to ensure a consistent approach with the East Solent Modelling Project was followed. The East Solent Modelling project overtopping calculations were undertaken across a wider geographical area based on a Neural Network approach. Since the calculations were undertaken, new data has become available (e.g. cross sectional information and new locations collected in this study) and different calculation assumptions may be required to estimate overtopping rates at the local level.
4. For the appraisal and design of the scheme it was agreed to deal with modelling uncertainties through a design freeboard or uncertainty allowance.

3.4 Coastal processes and flooding mechanisms

As mentioned in the previous section, the dominant source of flood risk at the site is from still water level flooding from tidal inundation (ESCP, Langstone Coastal Processes Report, 2018[1]). This section describes the flood risk mechanisms in more detail and explains why the role of waves is less significant.

3.4.1 Previous wave modelling

Prior to this project, wave modelling studies for Langstone / Chichester Harbours have been undertaken. The results of these studies are outlined in detail in the Coastal Processes Report (ESCP, 2018). In summary:

- Modelling undertaken as part of the East Solent SMP (1997) provides significant wave height (H_s) estimates for a location immediately to the west of the study site (directly to the south of the Southmoor site). It indicates that the 100% AEP (1:1 year) return period H_s at this location is 0.97m, the 10% AEP (1:10 year) H_s is 1.13m and the 2% AEP (1:50 year) H_s is 1.24m.
- Modelling undertaken as part of the North Portsea FCERM scheme (2014) included modelling to establish 0.5% AEP (1:200 year) return period wave conditions in Langstone Harbour. The results indicate that the worst case waves in Langstone Harbour for this return period occur with a southerly wind direction with maximum H_s values in the range of 0.5-0.75m at the study site.

[1] Langstone Coastal Processes Study Report. ESCP, 2018

It is noted in the Coastal Processes Report that the modelling results do not agree well on estimates of Hs, with the latter modelling study estimating considerably smaller H_s values for the site. However, based on the evidence available, it is concluded that wave heights and wave energy at the study site are typically low due to the sheltered nature of the site and that the main threat of flooding in this area is from still water level flooding rather than wave overtopping. This is due to the narrow harbour entrances which restrict waves from the English Channel and waves are therefore controlled by fetch limited conditions within the harbours.

3.4.2 Historic flooding evidence

Anecdotal evidence from historic flood events suggests that the western side of the frontage (i.e. the side to the west of Langstone Spit) experiences larger waves during flood events than the eastern side (the side to the east of Langstone Spit). This can be explained by the wind and wave climate at the site. Generally, the peak of a storm surge occurs as the lowest atmospheric pressure is overhead or close by. During historic flood events, to produce larger waves on the western side of the frontage the peak of the surge would have coincided with a wind direction from the south-west / west. As outlined in the Coastal Processes Report (ESCP, 2018), this is the predominant wind direction for the study area and therefore would be expected. Figure 3-2 shows a photograph of a historical flood event in which tidal inundation on the east side of the frontage is accompanied by limited wave action.

For the leading defence alignment(s), the proposed defences on the western side of the frontage are setback, located at the top of the beach and along the public footpath. Being setback, these defences would be more sheltered than a frontline solution and depth limiting factors, and wave breaking over the foreshore would be expected to reduce the incoming wave height impacting on these structures. With winds coming from the south-west / west, the defences on the eastern side of the frontage would be sheltered by Langstone Spit.

Whilst the predominant wind direction at the site is from the south-west / west, there remains a possibility that a more modest surge event could coincide with winds from the south east. This could expose the defences on the eastern side of the frontage to more significant wave action. However, given the south-west / west predominant wind direction, this situation is likely to occur less frequently. Furthermore, due to the coastline position of Hayling Island to the south of the study site, there is less fetch distance available in Chichester Harbour to the east of the study site for waves to be generated.

Although strong winds from the south-east could lead to some visible wave overtopping, it is the flooding arising from tidal inundation which has the potential to impact a greater number of properties and bring deeper flooding to a wider area in Langstone. Therefore, it is this risk from tidal inundation which underpins the case for investment in new flood defences in the study area.



Figure 3-2: December 2018 flooding at Langstone. Photograph showing tidal inundation of the east side of the frontage

4. Standard of Protection

4.1 Modelling and the design process

The numerical modelling provided the basis for understanding the length and height requirements of the scheme. A step by step approach was followed to determine the defence alignment details, which is outlined below:

1. The flood mapping outputs from the flood modelling were loaded into GIS. The flood mapping 'layers' were overlain onto LiDAR, background mapping, aerial photography and topography survey data. This step was undertaken during the appraisal of options so therefore flood mapping from a range of return period events was considered.
2. Preliminary start and finish locations (end points) of the alignments were identified at the edge of the flood cell, often where the ground level rises. Start and finish locations were identified for the different intended scheme benefit areas (i.e. scheme to protect ODUs 2-3, scheme to protect ODUs 1-3 etc.).
3. The design water level of the scheme was determined using the extreme still water levels at model boundaries 1 and 5 which the Langstone study site is located between (see Figure 2-2 for the boundary locations). Boundary location 1 has a slightly higher still water level for the extreme events, typically 0.11-0.12m higher than boundary 5. A value between the boundary 1 and 5 water levels was identified for the design water level. To be conservative, a value towards the higher end of the water level range between the boundaries was used, rather than the mean value.

   To inform the economic appraisal, design water levels for four different still water level standards of protection were considered; for the 2019 1.33% AEP (1:75 year) still water level a value of 3.40m ODN was selected, for the 2019 0.5% AEP (1:200 year) still water level a value of 3.50m ODN was selected, for the 2069 1.33% AEP (1:75 year) still water level a value of 3.73m ODN was selected and for the 2069 0.5% AEP (1:200 year) still water level a value of 3.83m ODN was selected.
4. The economic appraisal was undertaken, comparing the relative costs and benefits of the different still water level standards of protection. The preferred standard of protection was identified as the present day 0.5% AEP (1:200 year) still water level.
5. The preliminary start and finish locations of the alignment were revised, ensuring that the end points tied into ground which equalled the design water level of the scheme. For the 0.5% AEP (1:200 year) still water level, the end point of the defences was moved slightly to ensure it tied into ground at 3.50m ODN (previously the end points were based on the model outputs - see step 2).
6. A freeboard (or uncertainty allowance) was added to the design water level to determine the design crest level of the defences. For frontline defences, a freeboard of 0.3m was applied, whereas for setback defences a freeboard of 0.1m was applied. The freeboard was applied to help mitigate uncertainty in still water levels and to a limited extent the potential wave action that may occur in extreme events.

The sections below provide more detail and the rationale for the approach taken to determine the design crest height.

In the time since the East Solent Modelling was undertaken there has been an updated Coastal Flood Boundary (CFB) dataset released (2018 version). As discussed in step 3 listed above, the design crest level for the scheme is based on the East Solent Modelling information adopting the 2011 CFB version. The differences between the two versions of the datasets are comparatively small and are within the degree of uncertainty associated with the datasets and the modelling work. If further modelling is undertaken to support the next phase of the project, it is recommended that use of the latest 2018 CFB dataset is considered.

4.2 Design crest level

As outlined above, the design crest level of the scheme was determined from the extreme still water level and includes a freeboard allowance. For the frontline sections of defence, the crest level is at 3.8m ODN, and for setback sections of the defence, the crest level is at 3.6m ODN, with the defence tie-ins at ground elevations of +3.5m ODN. The defence constructed to these elevations provides a present day 0.5% AEP (1:200 year) SoP against still water level flood risk from Langstone and Chichester Harbours.

No wave overtopping calculations were undertaken to establish the standard of protection for the scheme, should wave overtopping risk be considered. The flood risk at the site is tidally dominated due to its sheltered harbour location, but in localised areas along the frontage which are more exposed, such as in ODU 1b and ODU 3k, there is potential for wave action and overtopping of the defence. Wave overtopping would reduce the effectiveness of the defence in these locations, however, the flood risk would still remain significantly less than the current situation (without a scheme).

Recognising the potential risk from wave overtopping, in addition to uncertainties in the still water level, a freeboard allowance was incorporated into the design. The height of the freeboard was based on a pragmatic decision considering the level of uncertainty / risk and the potential visual impact of the defences on the landscape:

- For the frontline defences, a freeboard of 0.3m was selected to provide a compromise between these competing interests of the scheme; aiming to maximise the benefits delivered, but accepting that the local community and stakeholders have reservations about a high defence due to the impact it would have on the landscape, heritage and conservation features of the site. During the outline design process, the project team agreed that it was unlikely that a frontline defence with a crest level any higher than 3.8m ODN would be supported by the community. Lack of community support would significantly impact the delivery of the scheme.
- For the setback defences, a freeboard of 0.1m was selected. A smaller freeboard was included for the setback defences (relative to the frontline) because there is less uncertainty in the setback locations with regards to wave action. The setback defences are positioned inland in more sheltered locations where wave action would be significantly depth limited. The defences in these areas are therefore effectively just required to mitigate against still water level flood risk.

Within the context of the option appraisal and outline design process, undertaking wave overtopping calculations and defining the SoP of the scheme against wave overtopping was not considered essential for the following reasons:

- The dominant source of flood risk at the site is from still water level flooding from tidal inundation. There are localised exceptions, but most of the frontage is sheltered from significant wave activity.
- As outlined in section 3.3, the economic appraisal and funding case for the next phases of the project is built upon still water level flood modelling results.
- If wave overtopping calculations were to be undertaken, due to landscape impacts it is unlikely that the design crest level of the scheme could be increased to prevent potential wave overtopping. Based on feedback from the public consultation process, it is unlikely that the local community and stakeholders would support further raising of the proposed defences. Alternative defence designs, such as including a bullnose or recurve in areas prone to overtopping, are also not likely to be acceptable to stakeholders due to the landscape and visual impacts.
- Part of the potential wave overtopping risk would be mitigated by the 0.3m freeboard included within the design crest level.

Should clarity on the standard of protection considering wave overtopping be required, it is recommended that a joint probability and wave overtopping assessment is undertaken during subsequent phases of the project once the structure types, alignment and defence geometries have been confirmed. The joint probability assessment should consider the combined occurrence of extreme waves and water levels at the site.

4.3 Scheme Standard of Protection – change over time

4.3.1 Sea level rise

As discussed previously, the design water level for the scheme is +3.5m ODN. This provides a 0.5% AEP (1:200 year) SoP against still water level flooding in the present day. However, over time, with an expected rise in sea levels, the SoP provided by the defence against still water level flooding is set to reduce.

The rate at which the SoP of the scheme will reduce is uncertain given the uncertainty in future sea level rise projections. Figure 4-1 below illustrates the reduction in SoP over time against two sea level rise projections based on different greenhouse gas emission scenarios:

1. UK Climate Projections 2009 (UKCP09) medium emissions projection, 95th percentile. At the time of undertaking the option and economic appraisal, the guidance recommended that this projection was used in FCERM projects.
2. UK Climate Projections 2018 (UKCP18) representative concentration pathway (RCP) 8.5, 70th percentile (higher central). The guidance has recently been updated and specifies this projection for use as the design allowance in FCERM projects, schemes and strategies moving forward.

As can be seen, the two sea level rise projections have little difference on the SoP of the scheme for the first 20 years, with the estimated SoP expected to reduce to a 2% AEP (1:50 year) SoP by year 20. Over time the two sea level rise projections diverge and the resultant SoP of the scheme begins to change. By year 50, based on the UKCP09 sea level rise projection the SoP of the scheme is expected to be a 20% AEP (1:5 year) SoP. However, adopting the UKCP18 sea level rise projection indicates that the SoP would be 50% AEP (1:2 year) in year 50 (approximately the same SoP experienced now (present day) without a scheme in place). The difference in water level in year 50 between the two sea level rise projections is approximately 7mm and therefore is a relatively small difference within the context of the assessment.

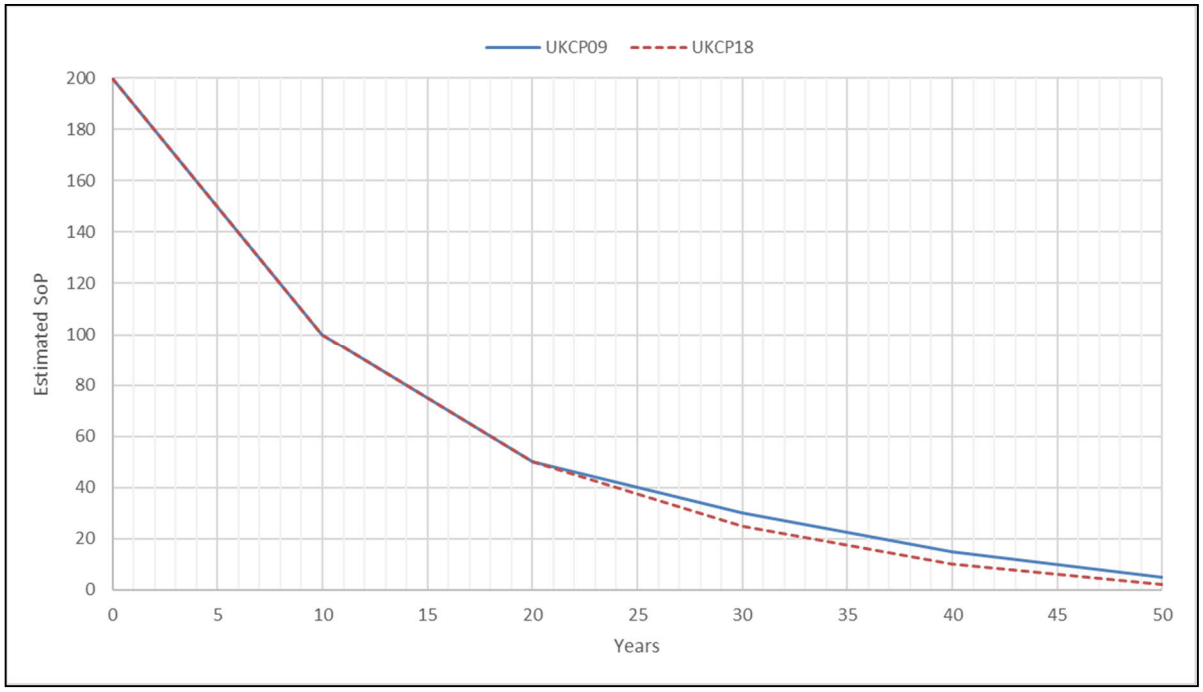


Figure 4-1: Estimated SoP (1:X Years) of the scheme over time (SoP based on still water level flood risk only)

4.3.2 Freeboard considerations

In the sections above, the discussion on the initial standard of protection for still water level flooding and how it changes over time are based on the premise that the freeboard does not contribute to the standard of protection provided by the scheme. From a flood risk management perspective, particularly for the economic appraisal, this is the correct approach given that the freeboard is in place to account for the residual uncertainty in the appraisal, in the modelling and the design process.

As a sensitivity test, should freeboard be included in the assessment of SoP against still water levels, Figure 4-2 and Figure 4-3 show how the standard of protection would change over time.. As the scheme has two freeboard levels; 0.3m for the frontline defences and 0.1m for the setback defences, two figures have been provided.

Figure 4-2 shows the change in SoP over time for the frontline defences with a 0.3m freeboard included in the calculations. For these defences, the still water level SoP for the first 20 years is expected to be greater than 0.1% AEP (1:1000yr event). By year 50, the still water level SoP is expected to be between 1% (1:100yr event) and 1.33% (1:75yr event) depending on which sea level rise scenario is adopted.

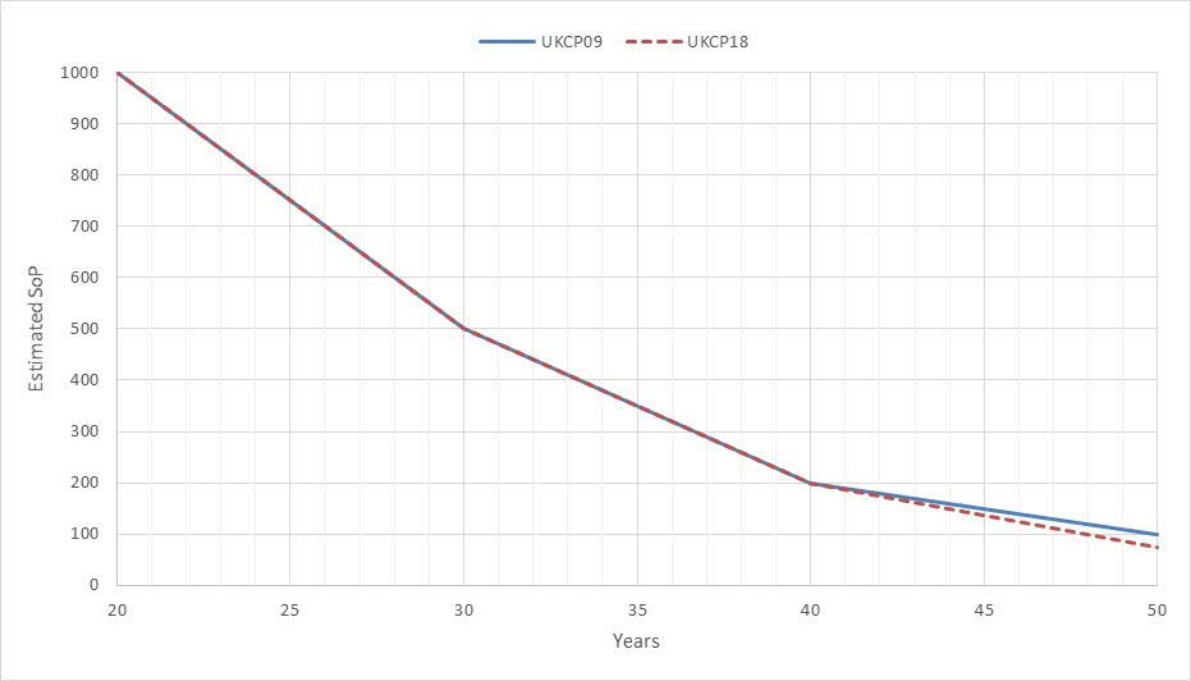


Figure 4-2: Estimated SoP (1:X Years) of the scheme over time (SoP based on still water level flood risk only), with 3.8m defence crest height including freeboard.

Figure 4-3 shows the change in SoP over time for the setback defences with a 0.1m freeboard included in the calculations. For these defences, the still water level SoP starts as 0.2% AEP (1:500yr event) and by year 10 has reduced to 0.5% AEP (1:200yr event). By year 50, if the UKCP09 sea level rise projections are adopted, the SoP is expected to be approximately 5% AEP (1:20yr event). If the UKCP19 sea level rise projections are adopted the SoP is expected to be approximately 10% AEP (1:10yr event).

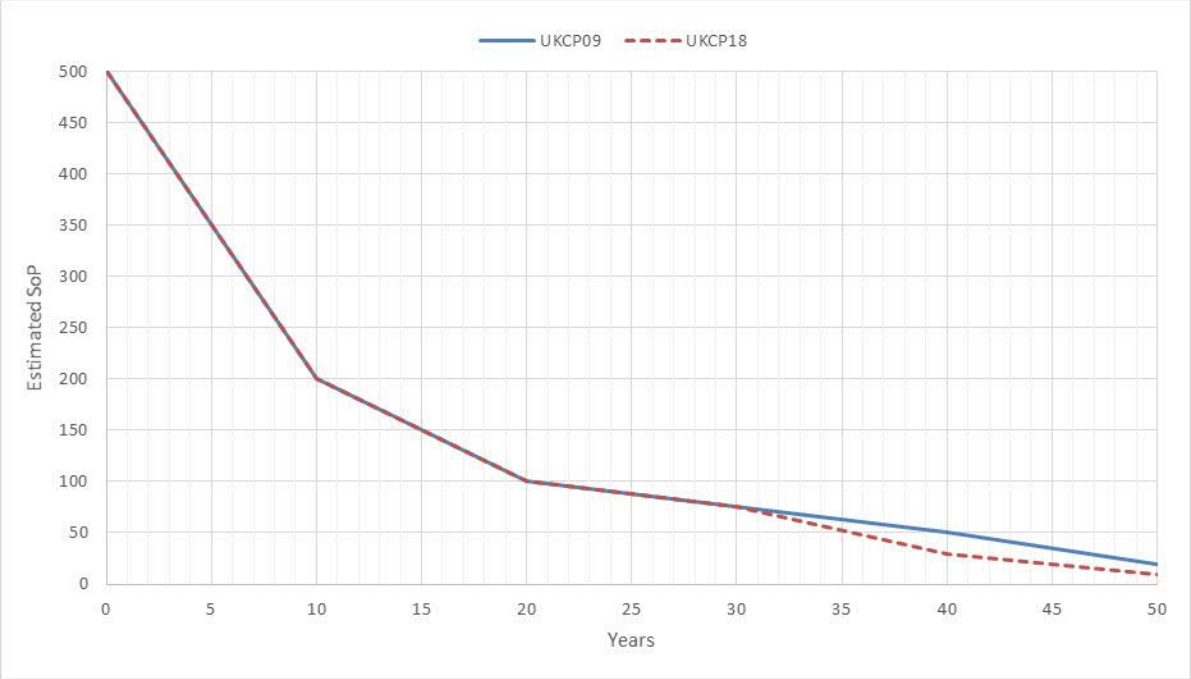


Figure 4-3: Estimated SoP (1:X Years) of the scheme over time (SoP based on still water level flood risk only), with 3.6m defence crest height including freeboard.

For the scheme as a whole with the freeboard included, the still water level SoP is best described using the 3.6m freeboard (i.e. between 5% AEP and 10% AEP). Whilst the frontline defences have a larger freeboard (crest level 3.8m), there is potential for flood water to enter the areas behind the frontline defences if it overflows the setback defences prior. Further modelling would be required to resolve the complexities of determining how flood water may propagate inland behind the defences after overflowing the setback defences.

4.3.3 Effective benefit of scheme

Despite the reduction in SoP over time as described in the preceding sections, there would still be an effective benefit of the scheme during above design standard events. In the description of the SoP in the preceding sections, the SoP is defined as the minimum return period event in which the still water level would begin to overflow the defences. However, the overflowing of the defences for above design return period events that are close to the defined SoP of the scheme would be duration limited, and therefore may not lead to large amounts of flooding to properties in the scheme benefit area. Further modelling would be required to provide a more thorough understanding of which above design events would lead to significant property flooding and the effective benefit of the scheme during above design events.

In addition, it should also be recognised that with the scheme in place, even for above design return period events the scheme would still provide an effective benefit compared to the baseline situation without a scheme. This is because for a given above design flood event, the defence would limit the amount of water flowing over the defence compared to a situation where the defence has not been constructed (i.e. the current situation). For example, in year 50 a 5% AEP (1:20 year) return period above design event would be much less severe with the proposed flood defence in place, than without it (in terms of flood depth and extent in the scheme benefit area).

4.4 A3023 main road

4.4.1 Existing flood risk

A key benefit of the scheme is the reduction in tidal flood risk provided to the A3023 main road at Langstone. The A3023 runs through the centre of Langstone and forms the only transport link between Havant and Hayling Island. Should the road not be protected, the one and only transport link to Hayling Island would be disrupted during periods of flooding and the island would be 'cut-off' from the mainland for a period of time. This has implications for the health and safety of residents on Hayling Island as emergency service access to the island would be restricted or severed.

Without a scheme in place, the A3023 begins to flood from a present day 50% AEP (1:2 year) event, although the extent and depth of flooding for this event on the road is very small. GIS analysis has been undertaken to determine the extent, average and maximum depth of flooding on the A3023 at Langstone (see AECOM A3023 Technical Note, 2019). This has been undertaken for a range of return period flood events for the baseline scenario (i.e. without the scheme in place) using the results of the tidal inundation model. The area and depth of flooding have been obtained for the A3023 in the vicinity of Langstone and do not consider the surrounding area where the road may also be at risk (i.e. no consideration in Havant or on Hayling Island).

The duration of flooding has also been estimated based on the maximum depth of flooding and the typical time taken for the tide to fall from its peak level. The disruption caused by flooding is likely to exceed this duration as debris may need to be cleared off the road and safety checks on the road condition may need to be completed. The extent, depth and estimated duration of flooding is provided in Table 4-1 below. The AA recommends that vehicles should not attempt to drive through flood depths of more than 100mm (0.1m)[2]. Based on this recommendation, an assessment of whether vehicles could still use the road during a flood event has been made, or whether the road is likely to be impassable.

The depth and extent of flooding to the A3023 during future return flood events is estimated from the inundation modelling which adopts the UKCP09 medium emissions scenario for sea level rise. As discussed in section 4.3, more recent guidance has been released (UKCP18). This estimates an additional 7mm of sea level rise by 2070. The flood risk to the road would be expected to increase with the updated guidance, although not substantially as 7mm is a relatively small difference within the context of the assessment.

The analysis indicates that the A3023 is expected to flood and will not be useable for a period of time during the return periods considered. The exception to this is the present day 50% AEP (1:2 year) event, where the flooding only affects the pavement and not the carriageway itself.

[2] Driving in Heavy Rains and Floods (AA). Available at https://www.theaa.com/driving-advice/seasonal/driving-through-flood-water

Table 4-1: Tidal flood risk to A3023 under the baseline scenario (no scheme in place, wave overtopping risk not included).

Time period	Flood event	Area of flooding (m2)	Average depth of flooding (mm)	Maximum depth of flooding (mm)	Estimated duration of flooding (minutes)	Number of lanes affected	Road useable?
2020	50% AEP	25	10	10	0	Pavement	Yes, but potentially not safe
	20% AEP	150	70	140	25	1 (northbound)	Northbound – no Southbound – yes, but potentially not safe
	5% AEP	3,250	80	310	50	2	No
	1.33% AEP	5,825	200	440	70	2	No
	0.5% AEP	6,475	250	520	85	2	No
2040	50% AEP	600	70	210	30	1 (northbound)	Northbound – no Southbound – yes, but potentially not safe
	20% AEP	3,250	80	310	45	2	No
	5% AEP	5,650	180	410	60	2	No
	1.33% AEP	6,575	290	560	80	2	No
	0.5% AEP	7,275	380	680	95	2	No
2070	50% AEP	5,675	180	420	55	2	No
	20% AEP	6,475	250	520	70	2	No
	5% AEP	6,950	340	620	85	2	No
	1.33% AEP	7,700	450	780	105	2	No
	0.5% AEP	7,975	500	830	110	2	No

4.4.2 Flood risk with scheme

With the scheme in place the risk to the A3023 main road will be reduced. Initially the road will be protected to a present day 0.5% AEP (1:200 year) SoP (based on still water level flood risk). Over time, as sea levels rise, the level of protection provided will decrease. Table 4-2 presents how the level of risk is expected to change in the future. The change in risk over time to the road is based on the inundation modelling undertaken, and assuming that the defence freeboard does not contribute to the SoP provided. The risk profile is based on the UKCP09 medium emissions scenario for sea level rise as this was used in the numerical flood modelling for this project. For events where residual risk model simulations have been undertaken, the maximum and average depths of flooding are presented. As can be seen, the residual depth of flooding for above design events is significantly reduced compared to the baseline with no scheme in place; for the 2040 0.5% AEP (1:200 year) event, the average depth of flooding on the A3023 reduces from 380mm to 70mm.

Table 4-2: A3023 risk over time with scheme in place

Time period	Flood event	Risk to the A3023 from still water level flooding	Notes
2020	50% AEP	No	-
	20% AEP	No	-
	5% AEP	No	-
	1.33% AEP	No	-
	0.5% AEP	No	-

Time period	Flood event	Risk to the A3023 from still water level flooding	Notes
2040	50% AEP	No	-
	20% AEP	No	-
	5% AEP	No	-
	1.33% AEP	Yes	-
	0.5% AEP	Yes	Maximum flood depth of 250mm. Average depth of flooding of 70mm.
2070	50% AEP	No	-
	20% AEP	No	-
	5% AEP	Yes	Maximum flood depth of 250mm. Average depth of flooding of 70mm.
	1.33% AEP	Yes	-
	0.5% AEP	Yes	-

5. Residual Risk

There are four key sources of residual risk associated with the scheme at Langstone; operation risk of the deployable defences, risk from above design standard events, risk from wave activity, and the risk of combined tidal / fluvial flooding from the Langbrook Stream to the west of the study area. These sources of residual risk are discussed in more detail below.

5.1 Sources of residual risk

5.1.1 Operation risk of deployable defences

The leading defence option(s) include several deployable defences, such as flood gates and flip-up flood barriers (Flip-up barriers in ODU 3b and Flood gate ODU 3j). The deployment of these defences requires either manual or mechanical work to be undertaken which introduces a residual risk of a problem occurring during the deployment. For example, the deployment team may get stuck in heavy traffic when travelling to the site, or a member of the team could be unavailable. Unforeseen situations such as this may delay the deployment of the defences and potentially lead to flooding.

During the option appraisal process, to improve the understanding of the residual risk associated with defences not being deployed an additional model simulation was undertaken. This involved simulating the leading defence alignment for ODUs 1-3 with the flood gate across Langstone Highstreet left open. Flood defences providing a 1.33% SoP were used in the simulation; at this point in the project the preferred SoP of the scheme (0.5% SoP) had not been agreed and therefore it was decided to use the recommended SoP from the preceding Portchester to Emsworth Strategy (1.33%) for this simulation. The simulation was of a 1.33% AEP flood event (a design standard event) so that there would be no flood risk arising from elsewhere along the frontage. The simulation results suggest that in the scheme benefits area the maximum flood depths on Langstone Highstreet would be between 0.65-0.95m. The flood cell extends through most of Langstone village, floods the A3023 main road and also the area to the west of the road.

It is recommended that during the detailed design process a deployment plan for the defences is produced. This should include a series of steps to be followed to minimise the risk of deployment failure. For example, keeping deployment tools on site, developing contingency plans should the primary access route to site be blocked and establishing the time periods for deployment (i.e. defences should be deployed x hours before the peak water level). Above design standard events

The scheme will be constructed to a present day 0.5% AEP (1:200 year) SoP against still water level flooding. There is a residual risk that a flood event larger than the design standard of the scheme could occur. For example, if a 0.2% AEP (1:500 year) event occurred during the lifetime of the scheme there is a chance that this could lead to flooding.

Due to expected sea level rise in the future, the SoP of the scheme will fall over time. This will mean that the probability of an above design event occurring will increase in the future. Further information on the reduction in SoP over time is provided in section 4.3.

5.1.2 Wave activity

As discussed in previous sections, the dominant source of tidal flood risk at the site is from tidal inundation. However, localised parts of the frontage may potentially be exposed to wave action in some conditions. In these locations the risk of wave overtopping is a residual risk to the scheme. Part of this residual risk will be dealt with by the 300mm freeboard / uncertainty allowance incorporated into the frontline defence design crest level.

The residual risk from wave overtopping has not been quantified in this project because it is the risk from tidal inundation which has the potential to impact a greater number of properties and which underpins the case for investment in new flood defences in the study area. Should the project team wish to quantify the residual risk from wave overtopping (in terms of scheme standard of protection), then joint probability and wave overtopping assessment could be undertaken during subsequent phases of the project.

5.1.3 Fluvial flood risk

The Langbrook stream (otherwise know as the Lavant stream) is located to the west of the study site (see Figure 5-1). The flood inundation modelling used to inform the option appraisal and design is focussed on coastal flood risk and therefore does not include a fluvial input from the stream. This introduces a degree of uncertainty into the assessment of flood risk as a potential flooding mechanism exists whereby a tidal surge leads to fluvial water backing-up the stream. This could exacerbate the flood risk along the western flank of the scheme in ODU 1a and 1b.

The flood risk from the Langbrook Stream was recognised as a limitation in the East Solent Modelling Reports (JBA, 2018). This is discussed in the Model Development Report (JBA, 2018) in section 4.5.2 within the context of model calibration and validation. In the model development report a photograph is provided of the stream breaching the right bank and inundating the adjacent rural land during the February 14th 2014 flood event. However, the model calibration simulations for this event show the water staying within the channel, with the embankment being roughly 0.5m higher than the peak simulated water level. This suggests that, in reality, during the February 14th 2014 flood event fluvial flow being backed up due the surge event may have elevated the water levels in this area and caused inundation not shown in the model.

Given the uncertainty arising from the potential flood risk from the Langbrook Stream it is recommended that additional work is undertaken during the detailed design stage to better understand the local risk in this area and inform the design process. It is recommended that the inundation model is modified to include a fluvial input from the stream; in TUFLOW this can be done by specifying a point inflow at a location along the stream. Model tests could be undertaken to simulate the flood risk including a non-extreme fluvial input, and if justified a joint probability analysis of combined extreme fluvial-tidal surge conditions could be undertaken. The effectiveness of the design (specifically the length and height of the alignment in ODUs 1a and 1b) could be tested for a range of joint probability return period events.



Figure 5-1: Map showing location of the Langbrook Stream

5.2 Residual risk in the economic appraisal

The residual risk associated with above design events and deployable defence operation was incorporated into the economic assessment. The residual risk from fluvial flooding was not included as a more detailed understanding of this risk was needed to help quantify this in the economics and it was beyond the scope of the project to investigate this source of risk in more detail. The sections below outline how the risk from above design events and from deployable defences was incorporated into the assessment.

5.2.1 Operation risk of deployable defences

The residual risk of deployable defence operational failure was quantified by following the guidance presented in FCERM-AG. This involved estimating the probability of successfully deploying the defences and accounting for this probability in the economic assessment of options.

Table 5-1 presents the calculation to determine the probability of a successful deployment. This calculation was informed by examples provided in the FCERM-AG and is based on estimated probabilities of success for each individual action required to deploy the defences. The calculated probability of a successful deployment is 0.84 which results in a 0.16 probability that the defences are not deployed correctly. To account for this the economic benefits of the scheme were decreased by 16%.

The 16% chance of the failing or incorrectly deploying the defences was determined within the context of aiming to conservatively incorporate residual damages within the economic assessment (i.e. an upper end estimate of residual damages to ensure a conservative scheme benefits were produced). In reality, a number of fail-safe measures or mitigation actions could be incorporated into the defence deployment plan to ensure that the risk of failure is substantially reduced.

Table 5-1: Calculation to determine the probability of success for deployable defences

Action	Probability of success	Notes
Flood forecast detected	0.99	
Command given to deploy defences	0.99	
Command received by deployment team	0.99	
Deployment team sent to deploy defences	0.99	
Deployment team finds keys and get access to a suitable transport vehicle	0.99	Assumed this is very likely. ESCP have a large team with a number of vehicles on site which could be used in the event keys are not found for primary vehicle.
Deployment team successfully navigate traffic / other potential disruptions and arrive on site	0.95	
Deployment team able to access defence locations, in potentially difficult weather conditions	0.95	
Team able to successfully deploy defences	0.98	Assumed defences are kept in good condition with minimal rust and obstructions; frequent maintenance included in scheme costs to account for this
Total probability	0.84	(Probability of each action multipled together – e.g. 0.99*0.99*0.99 etc.)

5.2.2 Above design standard events

Above design standard events were simulated in the inundation model and the outputs were used to calculate flood depths for the properties in the scheme benefit area. The flood depths were then incorporated into the economic assessment to produce a more accurate estimation of scheme residual damages and benefits. To support the appraisal of options, above design standard events were simulated for two scheme alignments (ODUs 1-3 and ODUs 2-3) and for different standards of protection.

The following above design standard events were simulated:

- 2019 0.5% AEP (1:200 year) return period event, with ODU 1-3 defence alignment providing a 1.33% AEP (1:75 year) SoP. This simulation suggests that in the scheme benefit area there is generally shallow flooding (<0.25m) in Langstone village to the east of the A3023. However, there are local areas with flood depths between 0.5-0.75m such as at the end of Langstone Highstreet, adjacent to the Mill.
- 2019 0.2% AEP (1:500 year) return period event, with ODU 1-3 defence alignment providing a 0.5% AEP (1:200 year) SoP. This simulation suggests that in the scheme benefits area there is typically flooding upto 0.5m in depth, however, there are local areas where flooding is deeper, such as at the end of Langstone Highstreet. In this simulation, the flooding extends on to the A3023 main road, although the depth of flooding is shallow (<0.25m) in this area.
- 2069 0.5% AEP (1:200 year) return period event, with ODU 1-3 defence alignment providing a 2069 1.33% AEP (1:75 year) SoP. This simulation suggests that in the scheme benefit area there is generally shallow flooding (<0.25m) in Langstone village to the east of the A3023. However, there are local areas with flooding is deeper, such as the Highstreet slipway area and the end of the Highstreet opposite the Mill.
- 2069 0.2% AEP (1:500 year) return period event, with ODU 1-3 defence alignment providing a 2069 0.5% AEP (1:200 year) SoP. This simulation suggests that in the scheme benefit area there would be extensive and deep flooding. However, a high level inspection of the results indicates that compared to the baseline simulation for this return period event (with no scheme in place), the scheme reduces flood depths by approximately 0.3m in the scheme benefit area.

Flood maps showing the flooding extent and depth of the above design event simulations are provided in Appendix A. Ascii files of the flood maps have also been provided to the ESCP.

6. Summary and Recommendations

This report provides an overview of the numerical flood inundation modelling undertaken to support the Langstone scheme and business case development. The key points of the report are listed below:

- The Hayling Island 2D TUFLOW flood inundation model developed by JBA as part of the East Solent Modelling project has been used to simulate tidal flood risk at Langstone.
- The TUFLOW model used the Coastal Flood Boundary Dataset (Environment Agency, 2011) for the extreme still water level estimates at the model boundaries.
- AECOM undertook additional model simulations to support the option and economic appraisal tasks. After collaboratively agreeing the approach with the ESCP, the baseline and option model simulations were based on still water level flood risk and did not include wave overtopping risk. Within the context of the option and economic appraisal, including wave overtopping inputs in the model simulations was not considered essential for the following reasons; the dominant source of flood risk, and main driver of the economic case at the site is from tidal inundation and additional wave overtopping calculations were beyond project scope. In the outline design process, it was agreed to describe the SoP within the context of still water level flood risk only and to address residual uncertainty with a design freeboard / uncertainty allowance.
- The economic appraisal identified the preferred standard of protection for the scheme as the present day 0.5% AEP (1:200 year) still water level. A freeboard provision has been included in the outline design to account for uncertainties (0.3m for the frontline defences and 0.1m for the setback defences). Due to the landscape concerns associated with the scheme, it is unlikely that the scheme would be supported by stakeholders and the public if defence heights greater than the design were suggested.
- With a rise in sea levels anticipated in the future, the standard of protection provided by the scheme is expected to reduce over time. Based on future projections of sea level rise (which are uncertain), by year 20 the scheme is expected to provide a 1% AEP (1:100 year) SoP (still water level flooding only). By year 50 the SoP is expected to be between 50% AEP (1:2 year) and 20% AEP (1:5 year). It should be noted that the SoP is described here without consideration of the freeboard, which is in place to deal with residual uncertainty. However, if the freeboard is included in the calculations, the initial and future SoP would be greater.
- Despite the reduction in SoP over time, there would still be an effective benefit of the scheme even with above design standard events. This is because, for a given above design flood event, the defence would limit the amount of water flowing over the defence compared to a situation where the defence has not been constructed (i.e. the current situation).
- The scheme will significantly reduce the risk of flooding to the A3023 main road in the study site. Currently, without a scheme in place, the road is likely to be impassable for a 5% AEP (1:20 year) flood event. With the scheme in place the road would be protected from still water level flooding in the present day up to a 0.5% AEP (1:200 year) SoP. As sea levels rise the standard of protection will fall over time.
- After the scheme is constructed there will be a residual risk of flooding from above design events and from the operational requirements of the deployable defences. The economic appraisal has incorporated these sources of risk into the valuation of scheme benefits. An additional source of residual risk is from potential fluvial flooding from the Langbrook Stream to the west of the defences. It is recommended that this source of risk is investigated in more detail during the detailed design process.

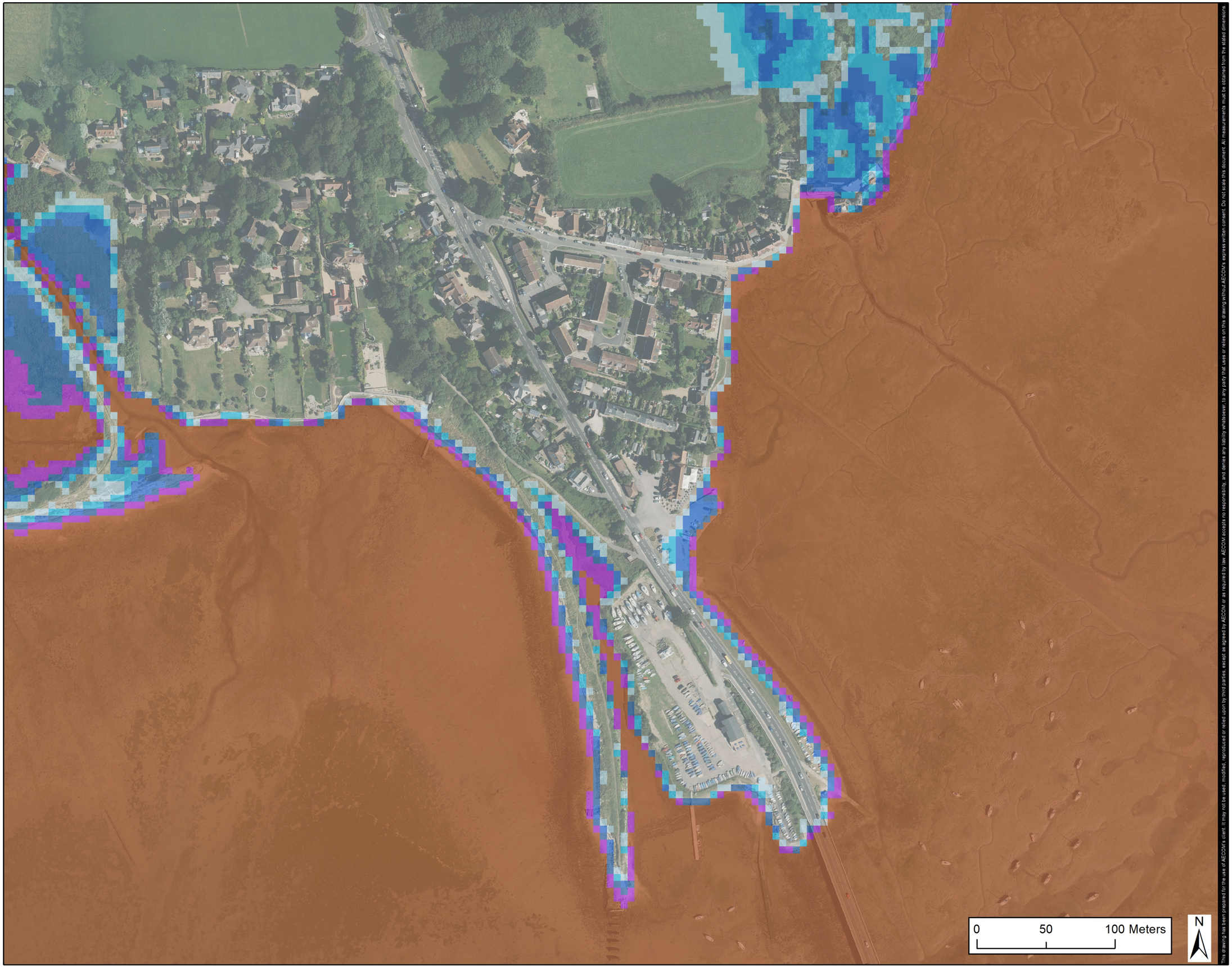
The following recommendations are made in this report:

- Given the uncertainty arising from the potential fluvial flood risk from the Langbrook Stream it is recommended that additional work is undertaken during the detailed design stage to better understand the local risk in this area and inform the design process.
- The residual risk from wave overtopping has not been quantified in this project because it is the risk from tidal inundation which has the potential to impact a greater number of properties and which underpins the case for investment in new flood defences in the study area. Should further clarity on the standard of protection considering wave overtopping be required, it is recommended that a joint probability and wave overtopping assessment is undertaken during subsequent phases of the project once the structure types, alignment and defence geometries have been confirmed.

- In the event that the model is updated during the next phase of the project, to take into account the flood risk from the Langbrook Stream, it is recommended that the model update also incorporates the latest topography survey information and updated extreme sea levels based on the UKCP18 guidance. In the case of the UKCP18 guidance, this is unlikely to make a significant difference to the design given the relatively small change in sea level rise by the end of the appraisal period (7mm) but would ensure the modelling is based on the most up to date information.

7. Appendices

7.1 Appendix A; Flood Mapping



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Legend

2019 1.33% AEP event, 1.33% SoP scheme

Depth (m)

- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1.0
- 1.0 - 1.5
- 1.5 - 2.5

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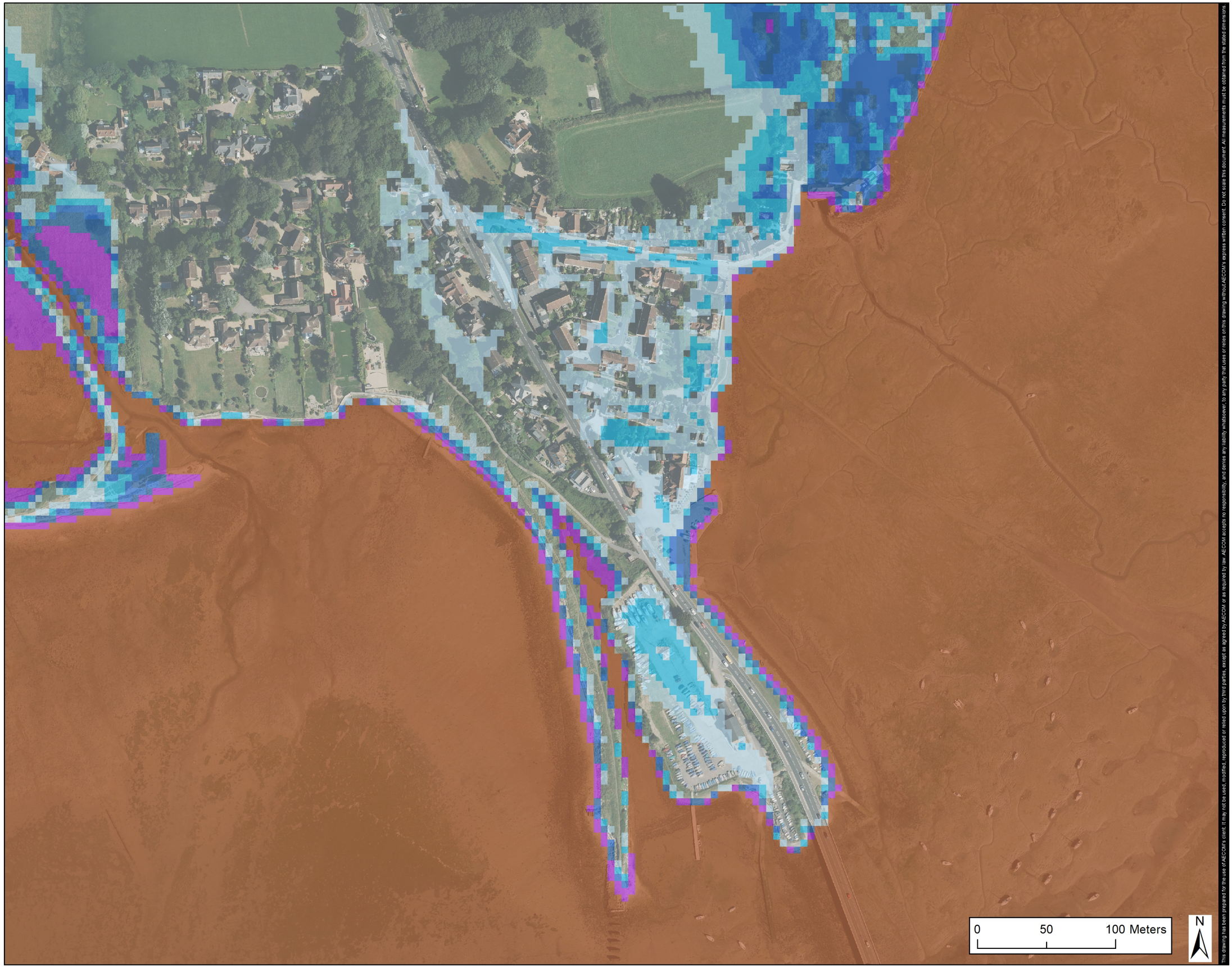
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Depth (m)

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Depth (m)

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- 0.75 - 1.0
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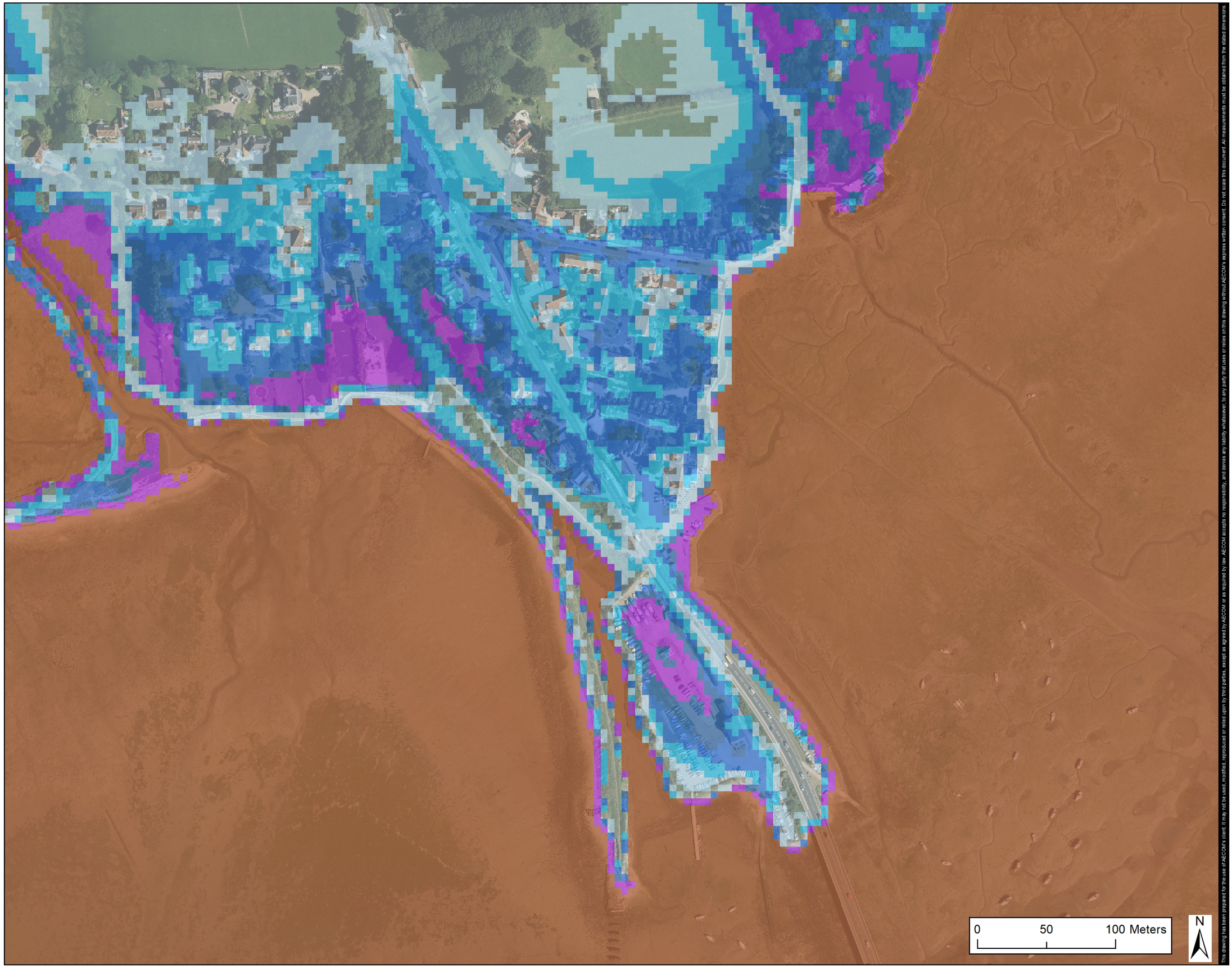
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2069 0.2% event, 0.5% SoP scheme

Depth (m)

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- 0.5 - 0.75
- 0.75 - 1.0
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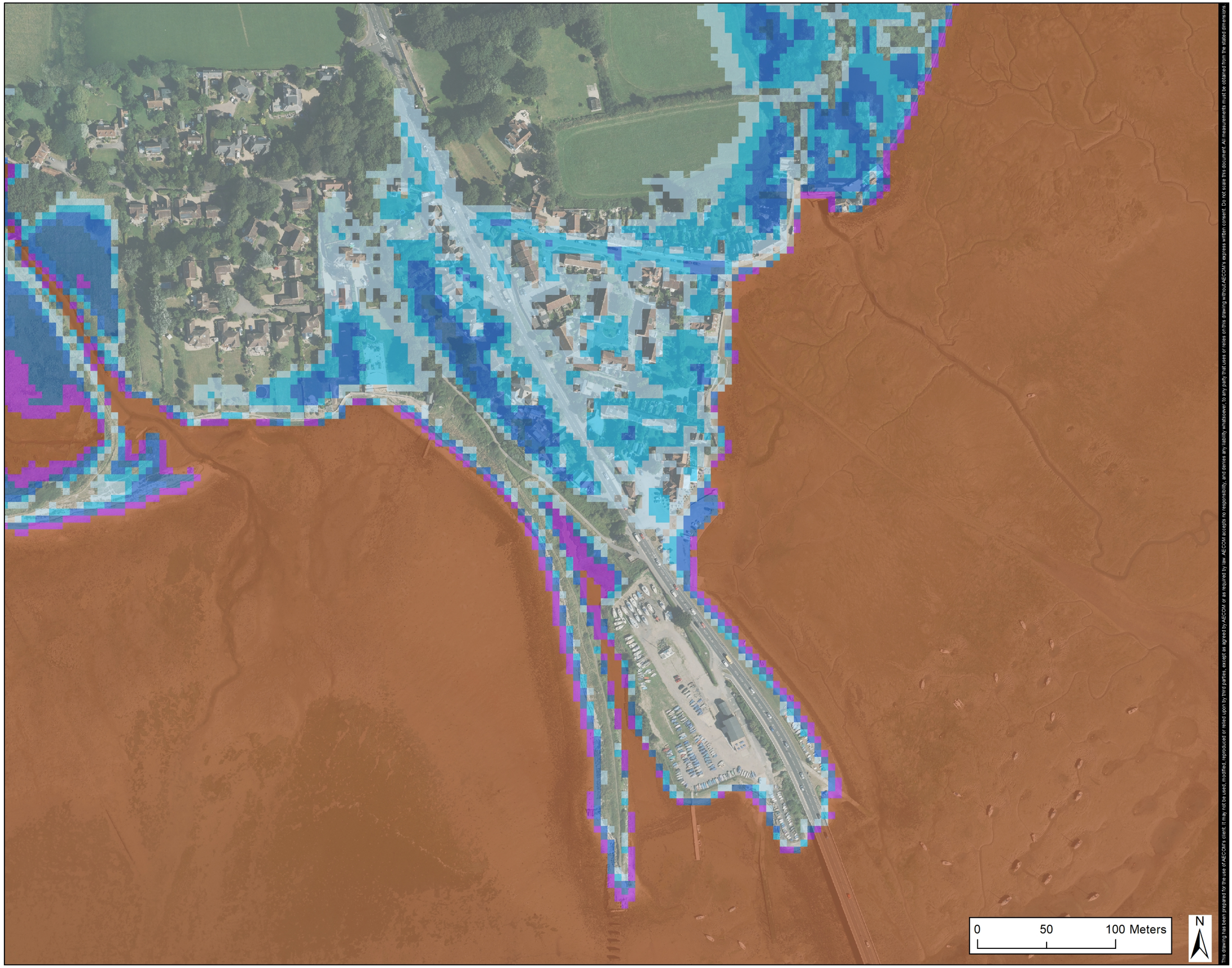
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Legend

2019 1.33% event, 1.33% SoP scheme, gate open

Depth (m)

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- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1.0
- 1.0 - 1.5
- 1.5 - 2.5

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2019 1.33% SCHEME SOP
GATE OPEN

Scale at A3: 1:2,500

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