Chichester SFRA Modelling Report

Final Report

Ocotber 2022

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Abbreviations

SoN	State of the Nation
UKHO	United Kingdom Hydrographic Office
WWIII	WAVEWATCH III
MDA	Maximum distance algorithm
TUFLOW	Two-Dimensional Unsteady Flow
LIDAR	Light Detection and Ranging
AEP	Annual Exceedance Probability

1 Wave Transformation Updates

1.1 Model domain

The SWAN wave transformation model used in this study was developed as part of the previous 2014s0753 - Emsworth to Littlehampton West Bank Coastal Modelling project. The original model domain extends from Portsmouth in the west to Peacehaven in the east. It covers an area from the high-water line along the mainland and extends offshore to WAVEWATCH III (WWIII) points 307 and 301. For the purpose of this study the model mesh was extended in the west to the estuary of the Beaulieu River to include the part of The Solent covered by the State of the Nation (SoN) Joint Probability (JP) region 12 SWAN model (see Figure 1-1). This was done to improve the wave results at the output points located at West Wittering and Emsworth.

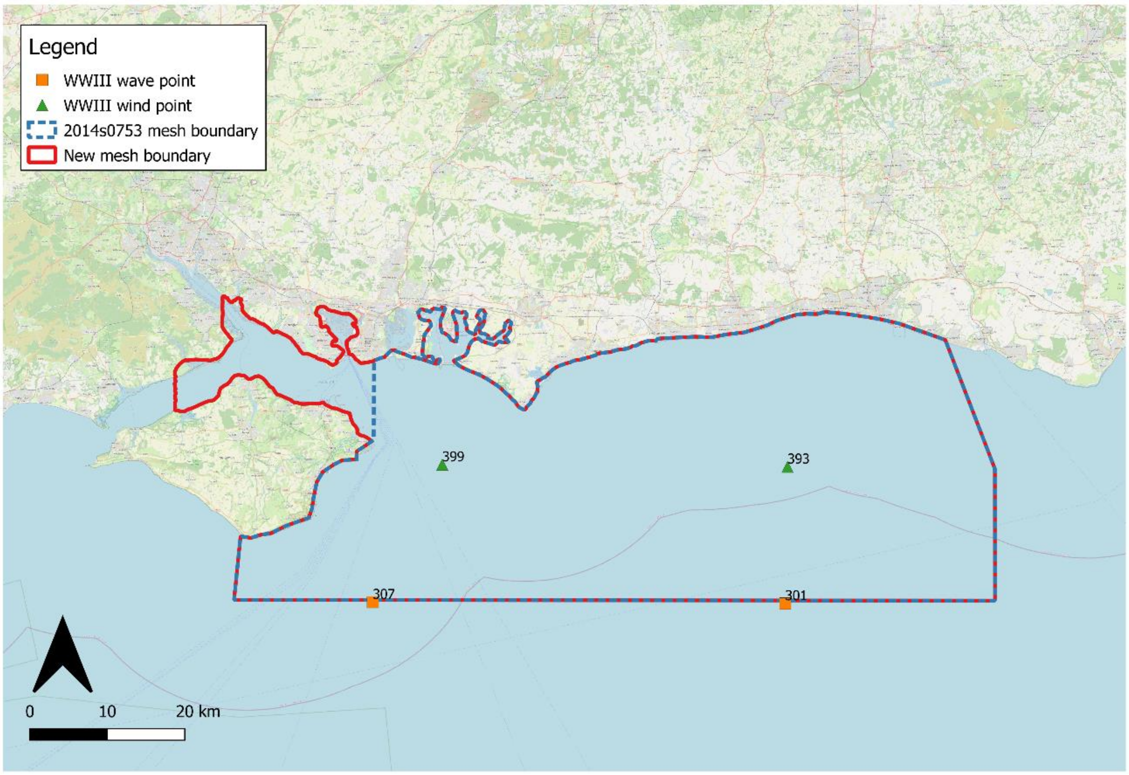

Figure 1-1: SWAN mesh from the previous modelling project is shown in blue and the final model mesh with the extension into the Solent is shown in red.

1.2 Model mesh

This mesh (Figure 1-2) has a spatial resolution of 20m at the coastline and in the swash zone, whereas at the offshore boundary the spatial resolution was 2,000m. The mesh is resolved around key areas of interest such as the toe of the defences, coastal structures and very shallow areas such as sand bars. This increase in resolution provides more detail to the model mesh and enables the model to better resolve shallow wave processes. This mesh covers all the areas of interest from Emsworth to Littlehampton.

To extend the mesh, an additional mesh was used from the 2020s1737 – Farlington Marsh Flood and Coastal Erosion Risk Management (FCERM) Scheme. The resolution of this mesh varies between 10m in the nearshore to 2400m at the offshore boundary. Mesh spacing has been constrained to 10m at the defence toes for this project; 60m around Hayling Island, Portsea and Gosport and less than 350m behind the Isle of Wight. This mesh was used to cover the area within the Solent from Portsmouth to the western edge of the SoN JP12 model mesh at the Beaulieu River.

To create the new model mesh that sufficiently covered the area of interest the following steps were taken:

- The 2020s1737 – Farlington Marsh model mesh was clipped to cover only the area needed within the Solent. This was from the estuary of the Beaulieu River in the west, matching the western boundary of the SoN JP12 model, to the boundary of the 2014s0753 model mesh at Portsmouth in the east.
- The two meshes were appended and the mesh resolution of the 2014s0753 model was refined where necessary along the boundary to better match the resolution of the mesh in the Solent (see Figure 1-3).
- The final model mesh bathymetry was remapped along the join using the 2020s1737 – Farlington Marsh model mesh

The final SWAN model mesh contains 76,934 nodes and has varying spatial resolution as shown in Figure 1-2. Varying the spatial resolution allows for larger mesh spacing between grid points in the offshore region where a detailed representation of bathymetry is unnecessary, and more detailed representation in the nearshore region.

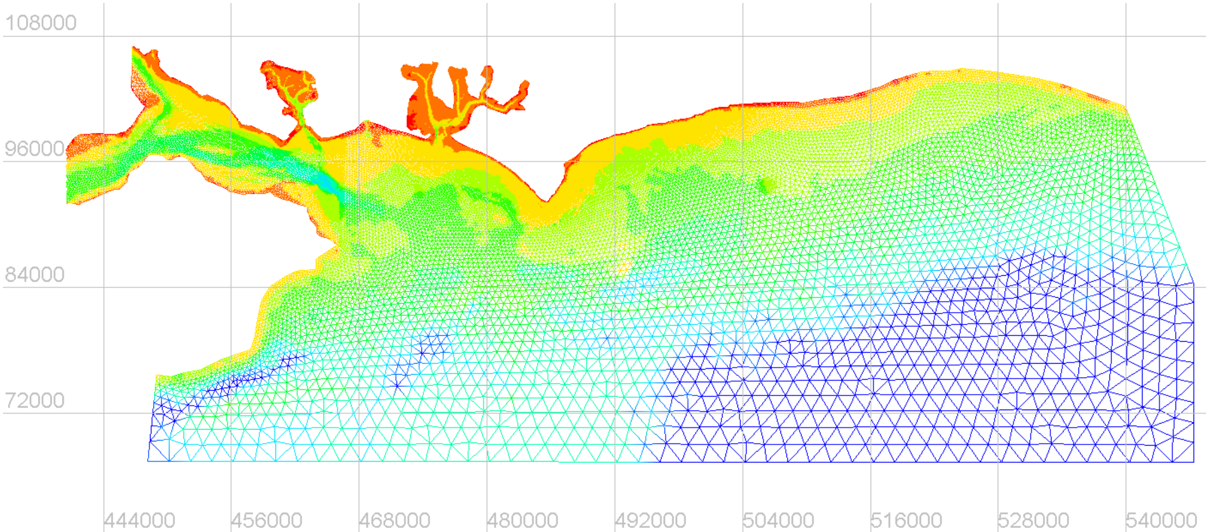

Figure 1-2: Final model mesh

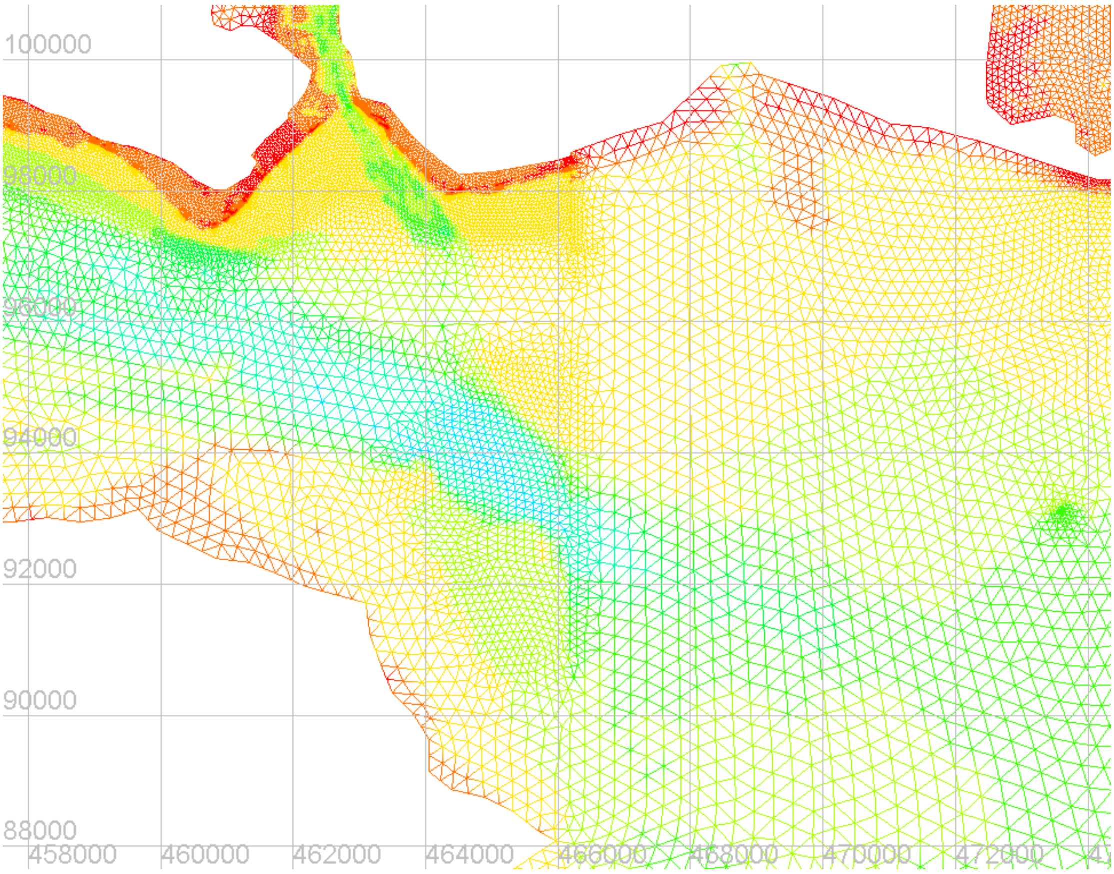

Figure 1-3: Close up of the area where the two meshes were merged

1.3 Mesh bathymetry

The bathymetry data constitute the largest dataset required for the wave model and are used to represent the surface over which waves propagate and interact. The bathymetric information has not been updated in the SWAN model mesh for this project. The wider model mesh taken from the 2014s0753 model is based on the following bathymetric data sources:

- Channel Coastal Observatory LIDAR at 1m and 2m resolution. This was used to represent elevation throughout the foreshore areas and intertidal zone to approximately -1mAOD
- UK Hydrographic Office swath bathymetry has been used for areas further offshore

The extension to the model mesh from the 2020s1737 – Farlington Marsh project uses the following bathymetric data sources:

- NICAS 2019 Drone survey (DSM)
- Channel Coastal Observatory (CCO) bathymetry for Langstone Harbour
- Geomatics 2013 composite data taken from the previous East Solent project
- 1m LIDAR 2019 DTM (downloaded 2019 flight)
- 2m LIDAR 2019 DTM Composite

1.4 Boundary conditions

The model boundary was driven with the SoN JP12 and JP13 offshore extreme multivariate dataset. The transformation model was run with both sets of data, the first time using the offshore dataset from JP12 and the second time using the offshore dataset from JP13. The JP12 dataset comprises of the following three variables:

- Wave data from the WWIII point 307
- Wind data from the WWIII point 399
- Water levels from the Class A Portsmouth tide gauge

This was used to obtain the nearshore wave conditions for the model toes that are located within the area covered by the SoN JP12 model. For the toes that fall within the area of JP13, the model was forced with boundary conditions from the SoN JP13 model. The JP13 dataset comprises of the following three variables:

- Wave data from the WWIII point 301
- Wind data from the WWIII point 393
- Water levels from the Class A Newhaven tide gauge

The location of the WWIII points are shown in Figure 1-1. The SoN offshore base dataset for this study is Multivariate data (MV-data). The MV-data is based on observed gauge records and hindcast wind and wave data, and used statistical modelling and Monte Carlo sampling to provide synthetic datasets that represent 10,000-years of storm event data.

1.5 Water levels

For this study the SWAN transformation model was run using unstructured variable water level grids. These were calculated using the water level boundary conditions provided in the SoN extremes dataset and the equations provided by the SoN report.

1.5.1 JP12

The water level grids used in the wave transformation model when it is forced with the JP12 offshore dataset were generated by interpolating the water levels at the Portsmouth tide gauge. The same method was employed in the SoN study. These grids were generated using the SoN equation for JP12, for extreme conditions (greater than the 1-year water level) the following equation was applied:

$$X = \left(\frac{Easting - 462519}{1000}\right) \qquad V = max\left(-17.193,\ \left(\frac{Easting - 466782}{1000}\right)\right)$$

$$Y = max\left(0.45V - 17.0621,\ \left(\frac{Northing - 98239}{1000}\right)\right)$$

<u>X>3.9</u> $\qquad y = 0.00019036X^2 + 0.01306686X$

<u>X<3.9</u>

$$y = (A_2V^3 + B_2V^2 + C_2V + D_2)Y^2 + (A_1V^3 + B_1V^2 + C_1V + D_1)Y + (A_0V^3 + B_0V^2 + C_0V + D_0)$$

$$A_2 = -0.00000064,\ A_1 = -0.00003557,\ A_0 = 0.000159$$

$$B_2 = -0.00001982,\ B_1 = -0.00096486,\ B_0 = 0.003876$$

$$C_2 = -0.00032034,\ C_1 = -0.01069245,\ C_0 = 0.036143$$

$$D_2 = -0.00360607,\ D_1 = -0.05483715,\ D_0 = 0.085304$$

For non-extreme water levels, a correction factor was applied using the following equation:

$$\left(\frac{wl}{1\ year\ water\ level}\right) y_{1\ year\ water\ level}$$

Note that the SoN water level equations did not give a valid result when the water level at the gauge was negative. As such when this occurred a fixed water level was applied across the model domain to equal the water level at the Portsmouth tide gauge.

An example water level grid, for a water level of 4.935m at the Portsmouth tide gauge (black square) is shown below in Figure 1-4 .

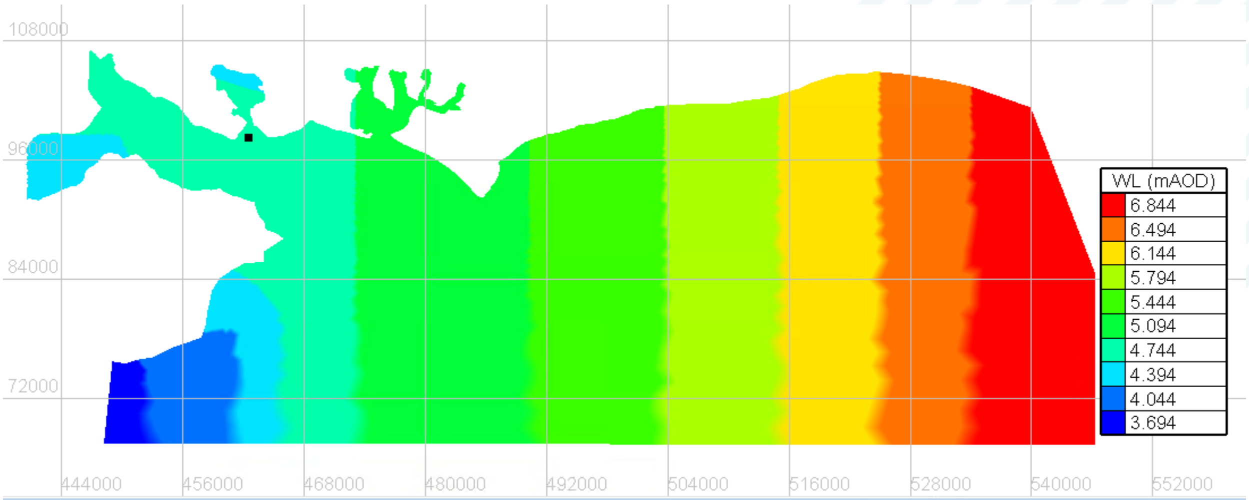

Figure 1-4: Water level grid for the SWAN model calculated using the SoN water level equations for JP12

1.5.2 JP13

The water level grids used in the wave transformation model when it is forced with the JP13 offshore dataset were generated by interpolating the water levels at the Newhaven tide gauge. The same method was employed in the SoN study. These grids were generated using the SoN equation for JP13, for extreme conditions (greater than the 1-year water level) the following equation was applied:

d>-23 $y = 0.0187d + 0.2676$

d>-23 $y = 0.000058d^2 + 0.0082d$

For non-extreme water levels, a correction factor was applied using the following equation:

$$\left(\frac{wl}{1\ year\ water\ level}\right) y_{1\ year\ water\ level}$$

Note that the SoN water level equations did not give a valid result when the water level at the gauge was negative. As such when this occurred a fixed water level was applied across the model domain to equal the water level at the Newhaven tide gauge.

An example water level grid, for a water level of 6.535m at the Newhaven tide gauge (black square) is shown in Figure 1-5 below.

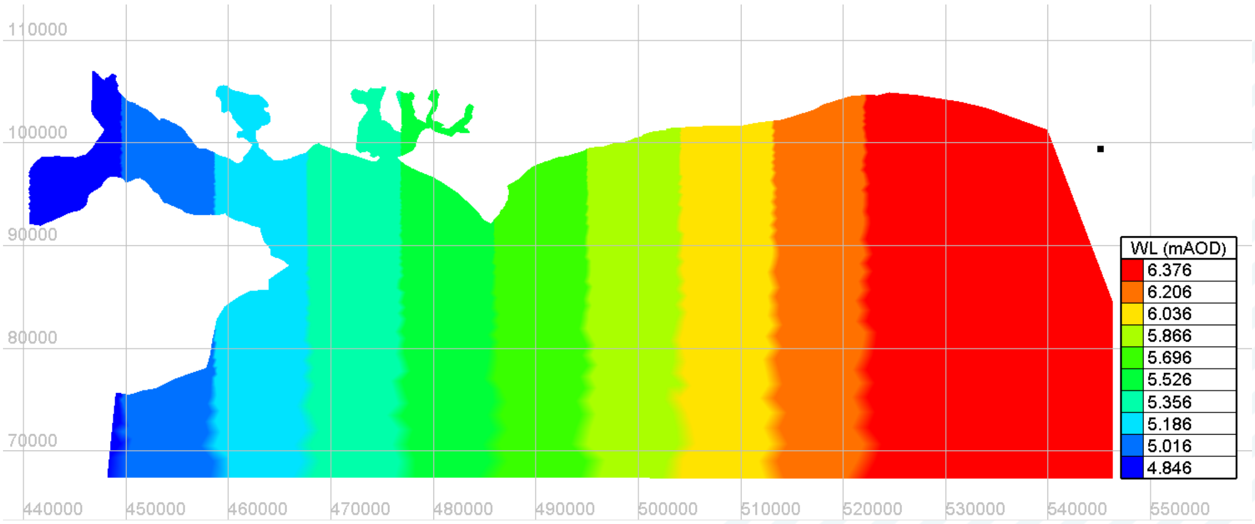

Figure 1-5: Water level grid for the SWAN model calculated using the SoN water level equations for JP13

1.6 Validation

The updated mesh has not been recalibrated, instead the model setup used for the SoN JP12 and JP13 models, has been used and the new model mesh has been validated. Validation has been performed against a number of the largest storm events. The data used to drive the model for the validation is the same sources used to derive the statistical boundary conditions The Solent (JP12) and the Sussex Coast (JP13). Namely the Met Office WaveWatch III (WWIII) wave point 307 and 301 and Met Office WWIII wind point 399 and 393, for JP12 and JP13 respectively.

The wind and wave conditions from the WWIII points are applied along the seaward boundaries (East, South and West). SWAN then transforms the waves across the model domain. This technique provides good results far from the model boundary. However, as a constant wave field based on one location is being applied, the results near the boundary will not be correct.

Observed data from two Channel Coastal Observatory (CCO) wave buoys which are situated within the boundary of the wave transformation grid (see Figure 1-6) were available to validate the model. These buoys were:

- The Rustington Waverider (covering the period 01/01/2010 to 31/12/2019)
- The Bracklesham Bay Waverider (covering the period 01/01/2010 to 31/12/2019)

The Rustington wave buoy was used to validate the model when driven with the SoN JP13 offshore wind and wave conditions and the Bracklesham Bay wave buoy was used to validate the model when driven with the SoN JP12 offshore wind and wave conditions.

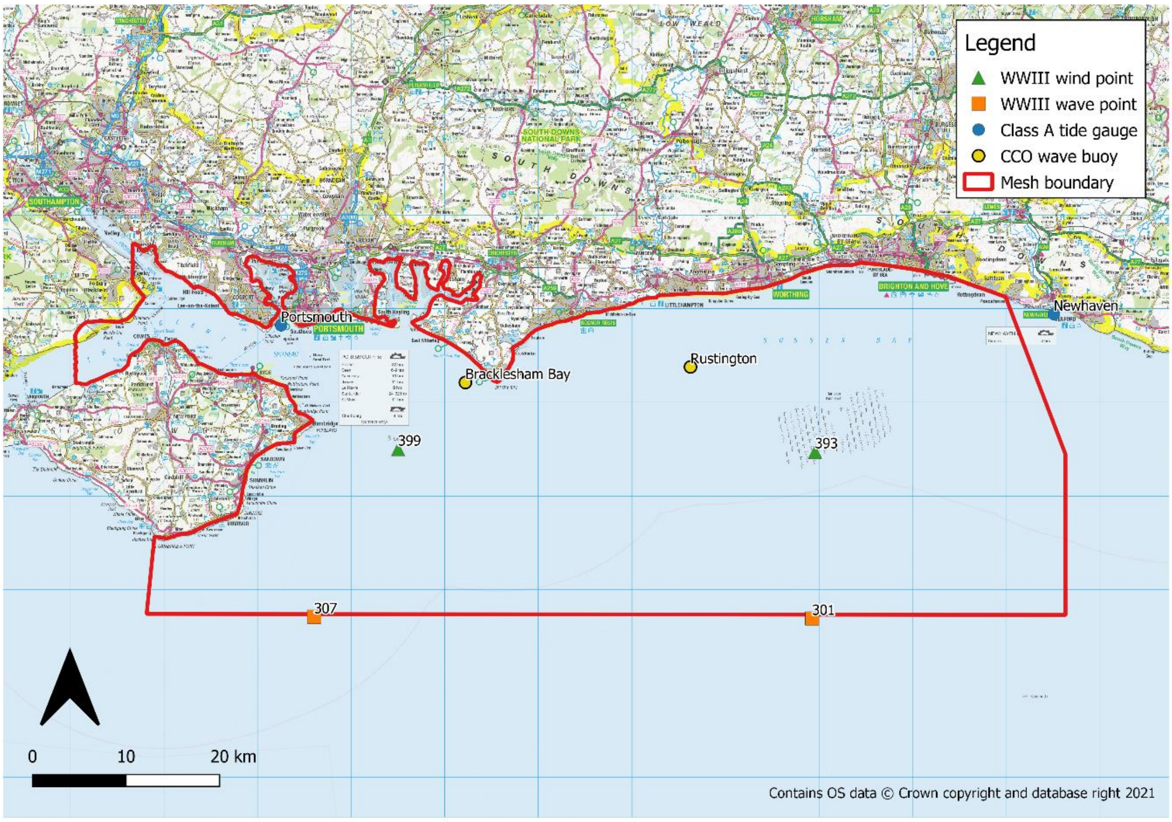

Figure 1-6: Location of CCO wave buoys, WWIII wind and wave points and the new model boundary

The validation storm events detailed in Table 1-1 and Table 1-2 were run through the SWAN model.

Table 1-1: JP12 offshore data

ID	Date/Time	Still water level (mAOD)	Hs (m)	Te (s)	Wave Direction (degrees)	Wind Speed (m/s)	Wind Direction (degrees)	Spread (degrees)
1	15/02/2014 00:00	2.528	8.47	11.8	224	20.7	232	21
2	24/12/2013 01:30	1.406	6.26	8.9	204	21.5	196	31
3	28/10/2013 04:00	1.212	5.61	9.1	218	18.7	211	28

ID	Date/Time	Still water level (mAOD)	Hs (m)	Te (s)	Wave Direction (degrees)	Wind Speed (m/s)	Wind Direction (degrees)	Spread (degrees)
4	08/02/2016 10:30	2.222	6.15	10.3	233	18.1	249	19
5	28/03/2016 02:00	2.377	5.53	8.5	194	20.2	184	32
6	09/02/2014 06:00	1.006	6.73	12.2	229	16.4	254	18
7	03/01/2014 23:00	1.162	5.27	10.7	227	13.7	218	20
8	05/02/2014 13:00	1.225	6.17	11.1	211	16.1	199	29
9	15/05/2013 00:00	1.129	4.07	7.4	222	16.5	230	28
10	03/01/2012 08:30	0.91	5.44	9.1	228	18.5	226	23
11	01/03/2018 19:30	0.99	3.41	6.6	98	17.3	86	26
12	23/09/2012 13:30	-0.115	2.36	5.7	100	11.9	89	28

Table 1-2: JP13 Offshore data

ID	Date/Time	Still water level (mAOD)	Hs (m)	Te (s)	Wave Direction (degrees)	Wind Speed (m/s)	Wind Direction (degrees)	Spread (degrees)
1	24/12/2013 01:30	1.942	6.39	8.5	205	23.0	195	32
2	15/02/2014 00:00	3.465	6.62	9.2	231	20.7	228	27
3	28/03/2016 03:30	2.253	5.62	8.2	195	21.9	183	32
4	05/02/2014 14:00	2.791	4.80	8.2	211	16.0	206	32
5	02/11/2019 12:30	2.304	5.96	8.9	235	21.9	237	27
6	20/11/2019 06:00	1.328	6.96	8.8	220	22.0	247	32
7	13/12/2011 01:00	3.112	5.27	8.0	216	18.3	223	32
8	22/11/2016 03:30	1.915	5.60	8.3	217	19.5	222	28
9	27/12/2013 05:00	2.298	4.38	7.3	206	17.7	211	32
10	28/10/2013 04:30	2.027	5.58	8.3	220	20.1	217	30
11	13/02/2016 13:00	2.638	2.01	5.7	106	11.5	74	46

ID	Date/Time	Still water level (mAOD)	Hs (m)	Te (s)	Wave Direction (degrees)	Wind Speed (m/s)	Wind Direction (degrees)	Spread (degrees)
12	01/03/2018 00:00	1.674	2.81	6.2	87	14.5	76	27
13	30/10/2019 12:00	3.456	1.58	4.9	93	10.9	92	33
14	29/04/2012 01:30	0.533	2.45	5.6	59	14.0	42	31
15	19/11/2018 07:30	1.957	2.68	6.1	77	14.6	73	34

The model results have been compared to the observations at Rustington and Bracklesham Bay wave buoys and are shown in Figure 1-7 to Figure 1-12. The wave conditions at the two wave buoys for each validation event are detailed in Table 1-3 and Table 1-4.

The RMSE for the Hs at the Rustington wave buoy was calculated to be 0.58m and at the Bracklesham Bay wave buoy the RMSE was calculated to be 0.34m. The average RMSE across the two wave buoys was calculated to be 0.46m, this RMSE has increased compared to the RMSE in Hs calculated for previous 2014s0753 modelling project, for which the original model mesh was developed. The RMSE for Hs calculated at the Bracklesham Bay wave buoy is less than the RMSE calculated for the SoN JP12 model. The RMSE for Hs calculated at the Rustington wave buoy is equal to the RMSE for the SoN JP13 model. The wave model produces results with a small negative bias in Hs of -0.09m. The average error in Hs was calculated to be 4%.

The RMSE for the wave period at Rustington wave buoy was 0.5 seconds and at Bracklesham Bay wave buoy it was 0.6 seconds. The average RMSE across the two wave buoys is calculated to be 0.6 seconds. The wave period RMSE calculated at the Bracklesham wave buoy has reduced compared to the RMSE calculated for the SoN JP12 model. The RMSE calculated at the Rustington wave buoy has increased by 0.2 second compared to the RMSE calculated for the SoN JP13 model. The wave model produces results with a small negative bias in wave period of -0.25 seconds. The average error in Tp was calculated to be -3%.

The RMSE for the wave direction at Rustington wave buoy was 9 degrees and at Bracklesham Bay wave buoy it was 19 degrees. The average RMSE across the two wave buoys for direction is 14 degrees.

Since the average RMSE for significant wave height is the same as the previous model mesh and the average error is under 10%, the new model is deemed fit for purpose.

Table 1-3: Validation results at Rustington wave buoy

No	Date	Observed Data			Model results		
		Wave Direction (degrees)	Tz (Tm)(s)	Hs (m)	Mean Direction (degrees)	Tm02 (s)	Hs (m)
1	24/12/2013 01:30	190	8.2	5.72	193	6.9	5.80
2	15/02/2014 00:00	215	7.7	4.97	209	7.3	4.28

No	Date	Observed Data			Model results		
		Wave Direction (degrees)	Tz (Tm)(s)	Hs (m)	Mean Direction (degrees)	Tm02 (s)	Hs (m)
3	28/03/2016 03:30	183	7.4	4.92	182	7.0	5.84
4	05/02/2014 14:00	194	7.1	4.72	185	7.0	3.65
5	02/11/2019 12:30	211	7.3	4.69	213	6.9	4.13
6	20/11/2019 06:00	193	7.3	4.68	203	6.9	4.77
7	13/12/2011 01:00	197	7.0	4.65	202	7.0	3.72
8	22/11/2016 03:30	208	6.6	4.35	202	7.0	3.93
9	27/12/2013 05:00	184	6.7	4.26	198	6.6	3.84
10	28/10/2013 04:30	204	6.8	4.25	199	7.0	4.00
11	13/02/2016 13:00	97	4.5	1.66	113	4.4	1.74
12	01/03/2018 00:00	97	4.0	1.66	109	5.2	2.40
13	30/10/2019 12:00	100	4.0	1.66	109	4.1	1.52
14	29/04/2012 01:30	93	4.2	1.64	91	4.0	1.70
15	19/11/2018 07:30	93	4.3	1.61	107	5.0	2.27

Table 1-4: Validation results at Bracklesham Bay wave buoy

No	Date	Observed Data			Model results		
		Wave Direction (degrees)	Tz (Tm)(s)	Hs (m)	Mean Direction (degrees)	Tm02 (s)	Hs (m)
1	15/02/2014 00:00	208	7.4	4.47	208	7.0	4.72
2	24/12/2013 01:30	208	7.1	4.13	199	6.1	3.76
3	28/10/2013 04:00	207	6.9	4.03	203	6.2	3.70
4	08/02/2016 10:30	211	6.8	4.02	212	6.7	4.19
5	28/03/2016 02:00	197	6.5	3.99	194	6.2	3.77
6	09/02/2014 06:00	208	7.1	3.92	211	6.5	3.89
7	03/01/2014 23:00	207	7.4	3.89	206	6.5	3.61
8	05/02/2014 13:00	204	6.8	3.85	199	6.4	3.67
9	15/05/2013 00:00	214	6.5	3.71	208	5.8	3.17
10	03/01/2012 08:30	212	6.7	3.67	209	6.2	3.67
11	01/03/2018 19:30	90	3.3	0.82	126	3.3	2.33
12	23/09/2012 13:30	94	2.9	0.68	137	2.7	1.00

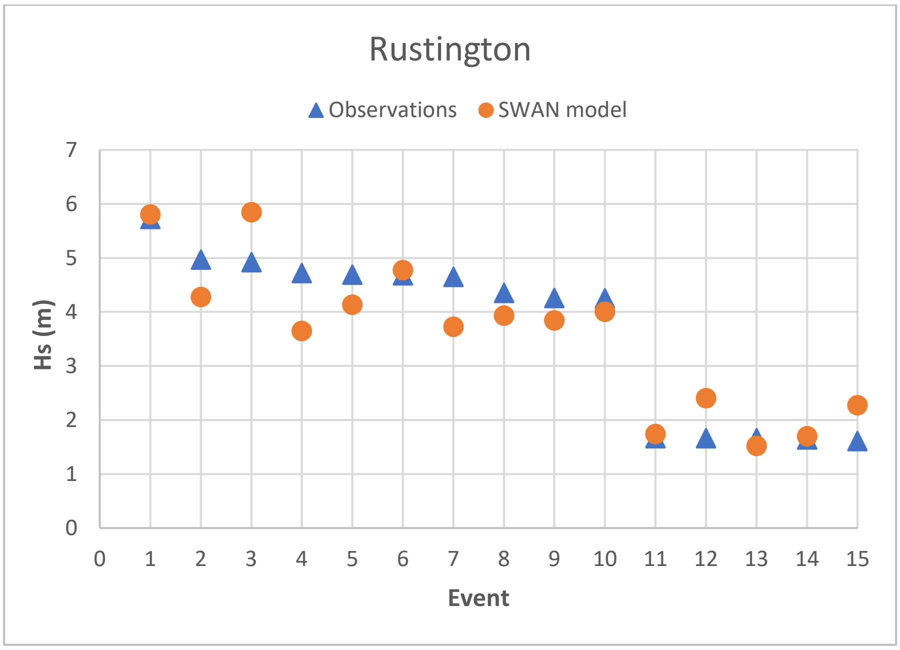

Figure 1-7: Hs for the model validation at Rustington

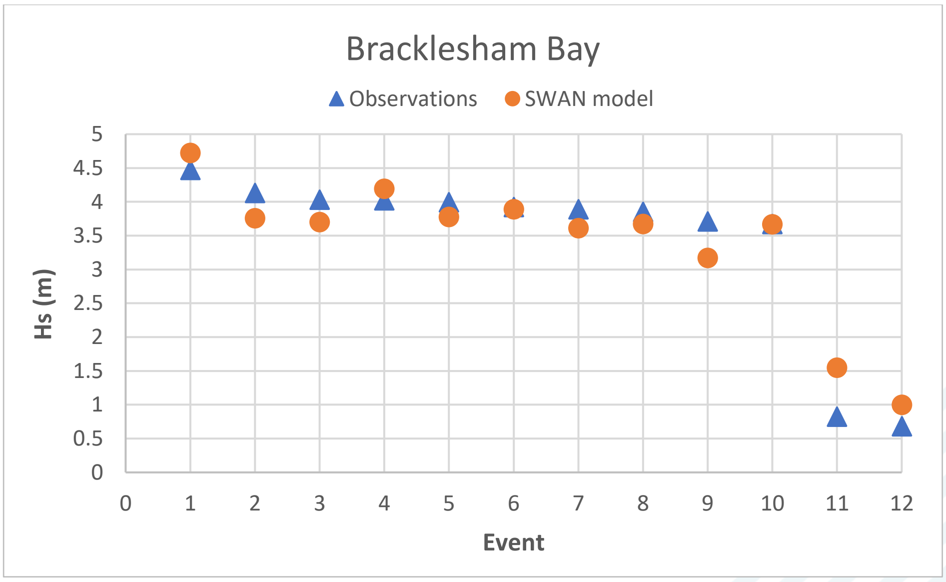

Figure 1-8: Hs for the model validation at Bracklesham Bay

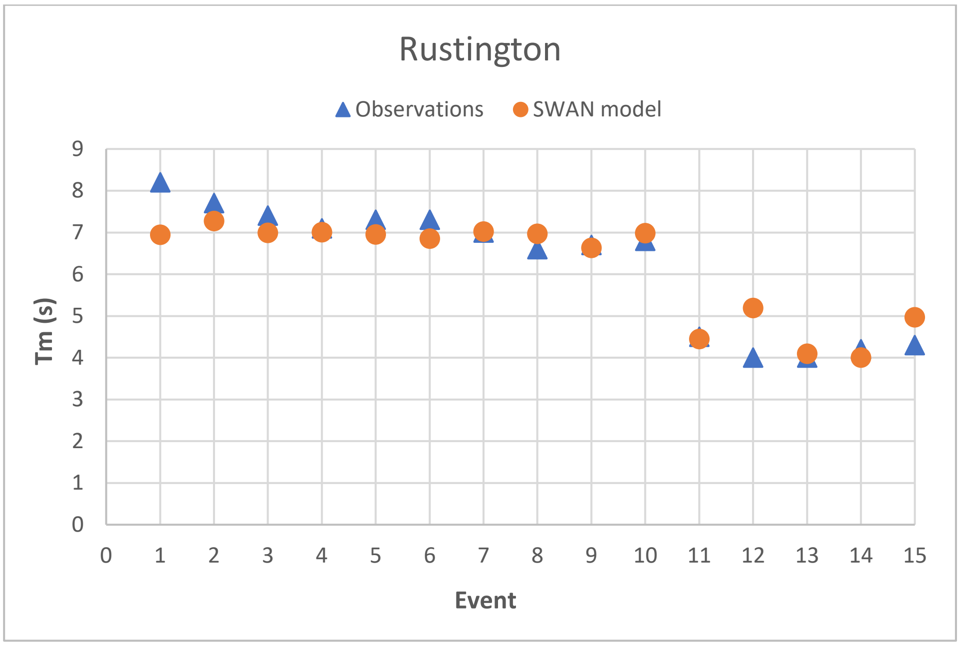

Figure 1-9: Tp for the model validation at Rustington

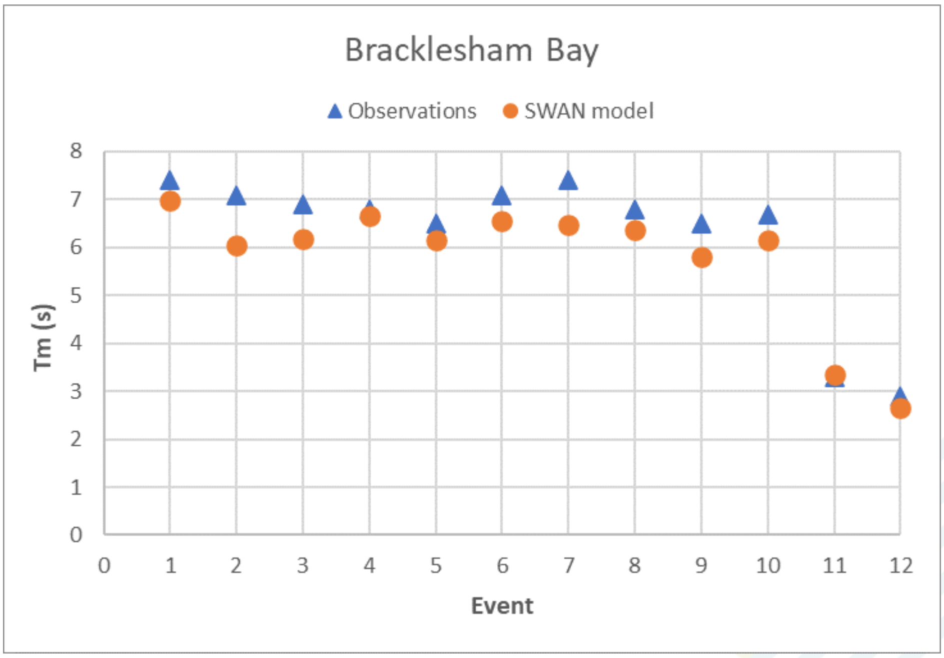

Figure 1-10: Tp for the model validation at Bracklesham Bay

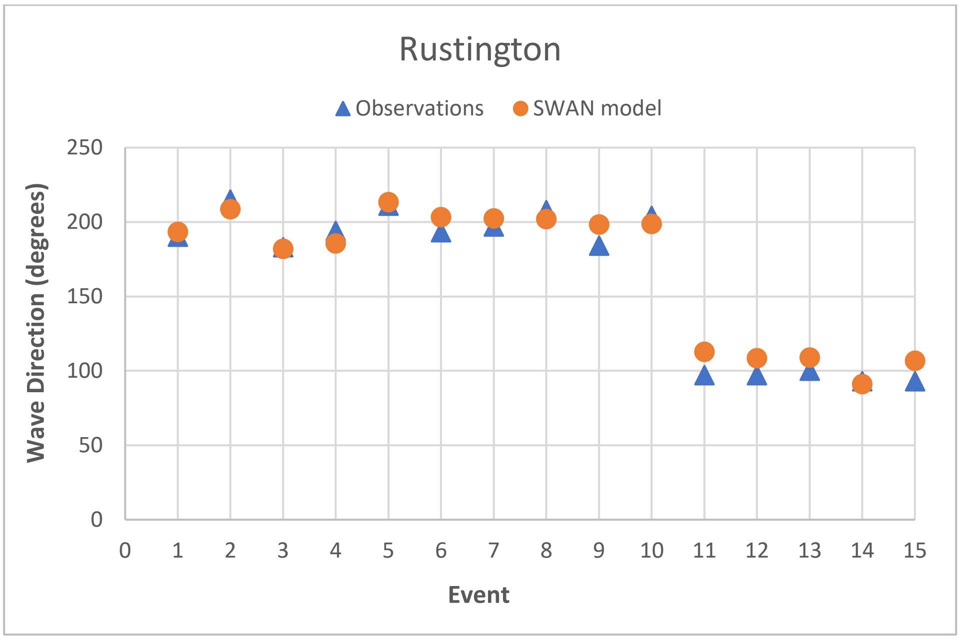

Figure 1-11: Wave direction for the model validation at Rustington

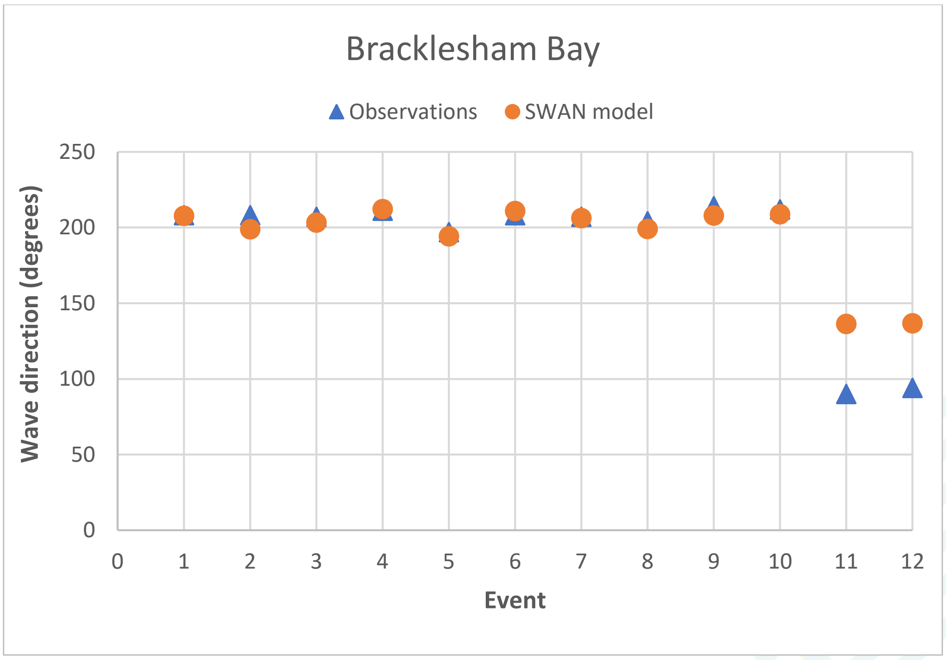

Figure 1-12: Wave direction for the model validation at Bracklesham Bay

2 Wave Emulation

2.1 Multivariate approach

The SoN offshore dataset used in this study is MV-data and comprises of over 500,000 individual storm events. It is therefore not feasible to simulate all these events in SWAN as this is too computationally time consuming. An emulator approach was instead taken. A representative Maximum Distance Algorithm (MDA) sample of 1,000 events was taken from the 500,000 events. The 1,000 sample events represent the maximum and minimum conditions in all variables and an even spread of events from the rest of the dataset. The sample events were simulated in SWAN, the results are then used to create emulators, which are used to calculate the nearshore wave conditions for the full event set.

2.1.1 Method

The emulator approach removes the requirement to simulate all these events, acting in a similar way to a "look-up" table. Each event in the MDA sample is run through the SWAN wave model to calculate the nearshore wave conditions. These nearshore conditions formed the base data on which the emulators were trained to derive data for all events in the SoN offshore dataset. The simulation results were divided, 90% of the results were used to create the emulators (training data), and the remaining 10% of the results were used for validation (validation data).

Interpolation techniques were applied to the training data, selecting the empirical functions that best describes the relationship between the offshore and nearshore conditions. These empirical functions form the emulator, with a separate emulator required for each defence toe. Once the emulators were selected, they were tested using the validation data. The emulators were used to derive the wave conditions at the defence toes for each validation event. The resulting wave conditions were then compared against the validation data. In cases where they were significant differences between the wave conditions derived from the emulator and the SWAN wave model, the emulator was revised, and this process repeated.

The finalised emulators where then used to emulate the entire SoN 10,000-year offshore datasets to derive corresponding nearshore wave conditions at the defence toes.

3 Defence Schematisation

3.1 Schematisation updates

This project makes use of the defended schematisations created for the previous Environment Agency Emsworth to Littlehampton project. The following updates were made to the defended schematisations:

- The elevation of the defence toes were updated to better match the elevation of a nearby mesh node in the SWAN wave transformation model.
- Where the coastline has changed e.g. new walls or embankments the schematisation profiles were updated with new 2020 LiDAR and re-schematised.

3.2 Undefended wave overtopping profiles

The undefended scenarios were used to simulate the undefended still water and wave overtopping flood risk. The previous modelling included risk beach profiles (beach profiles based on worst case or lower than average surveyed conditions), these profiles were used and amended to represent the removal of defences for the undefended scenario in this study. Generally, the following amendments to risk schematisations were applied:

- Raised walls and defences lowered
- Roughness coefficients adjusted to represent the removal of stepped revetments, and rock armour
- Slope angles lowered to represent the removal of vertical slopes following the removal of structures, i.e. gabion baskets

4 Wave Overtopping

4.1 Wave overtopping calculations

The emulator process derived the wave conditions at the defence toe for each event in the 10,000-year multivariate offshore dataset. These wave conditions were run through the EurOtop Neural Network wave overtopping tool to derive a wave overtopping discharge for each event in the offshore dataset. The overtopping rates were then ranked, the largest being the overtopping rate associated with the 0.01% AEP event. Once ranked, the wave and water level conditions could then be extracted for each desired AEP event and run through the Neural Network using a full tidal water level time-series; this generates the wave overtopping discharges that vary through time for each AEP. Wave overtopping discharges were calculated along the coastal frontage at the 84 key sites from Emsworth in the west to Littlehampton in the east.

As noted above the wave overtopping events are ranked in order of magnitude and includes overtopping from waves breaking on or before defences and splashing over the crest and from still water exceeding the crest height. It should be noted that prior to input within the inundation models, the wave overtopping rates are adjusted to remove the volumes associated with still water flooding, as this is also calculated in the inundation model and would result in double-counting. These adjustments can sometimes lead to inconsistencies in the overtopping rates between AEP events. In the overtopping models a single crest level is used, often taken as the lowest or average crest height along a section of coast. In some cases, the wave overtopping at a specific defence section could be discounted to very small volumes, sometimes to zero, as still water flooding is expected based on the extreme water level and average defence crest level. However, in the inundation model, the defence crest of a modelled overtopping defence section, can vary to some degree. This can lead to less still water flooding than expected across the defence section, as only short lengths of the defence will be at risk from still water flooding. Consequently, the adjustments can lead to smaller event simulations predicting more extensive flooding. To avoid inconsistencies in the wave overtopping and modelled outputs, the overtopping discharges are maximised between AEP events in the flood models, so that a larger event always has equal or more overtopping entering the model at each defence asset.

A list of the schematisation profile number and corresponding wave overtopping toe number are presented in Table 4-1 below.

Table 4-1: List of schematisation profile number and the associated overtopping toe number

Schematisation profile	Overtopping toe number
WO_1	1
WO_2	2
WO_3	3
WO_4	4
WO_5	5
WO_6	6
WO_7	7
WO_8	8
WO_9	9
WO_10	10
WO_11	11
WO_111	12
WO_222	13

Schematisation profile	Overtopping toe number
WO_12	14
WO_13	15
WO_14	16
WO_15	17
WO_16	18
WO_17	19
WO_18	20
WO_19	21
WO_20	22
WO_21	23
WO_22	24
WO_23	25
WO_24	26
WO_25	27
WO_26	28
WO_27	29
WO_28	30
WO_29	31
WO_30	32
WO_31	33
WO_32	34
WO_33	35
WO_34	36
WO_35	37
WO_36	38
WO_37	39
WO_38	40
WO_39	41
WO_40	42
WO_41	43
WO_42	44
WO_43	45
WO_44	46
WO_45	47
WO_46	48
WO_47	49
WO_48	50
WO_49	51
WO_50	52
WO_51	53
WO_52	54
WO_53	55

Schematisation profile	Overtopping toe number
WO_54	56
WO_55	57
WO_56	58
WO_57	59
WO_58	60
WO_59	61
WO_60	62
WO_61	63
WO_62	64
WO_63	65
WO_64	66
WO_65	67
WO_66	68
WO_67	69
WO_68	70
WO_69	71
WO_70	72
WO_71	73
WO_72	74
WO_73	75
WO_74	76
WO_75	77
WO_76	78
WO_77	79
WO_78	80
WO_79	81
WO_80	82
WO_81	83
WO_82	84

5 Flood inundation modelling

5.1 Model overview and data summary

The coastal and tidal flood risk on the Hampshire coast was assessed using a 2D hydrodynamic TUFLOW model. The existing models from the Emsworth to Littlehampton study were re-used and updated. Two models were used, one covering the Coast from the River Arun in the east, to East Head in the west and the other covering Chichester Harbour. This section provides a technical overview of the TUFLOW modelling undertaken for this project.

5.1.1 Summary of model requirements

The models were used to simulate Defended and Undefended scenarios for three present day (2021) AEP events (5%, 0.5% and 0.1%). The 0.5% AEP event was simulated for the 2091 and 2121 epochs using the UKCP18 projection pathway in accordance with RCP 8.5 at the 70th and 95th percentile. The 0.5% and 0.1% AEP events were simulated for climate change following H++ guidance.

The undefended scenarios were used to simulate the undefended still water and wave overtopping flood risk. Raised defences were removed from the inundation model whilst the wave overtopping was recalculated using beach risk profiles as well as taking account alterations to defence schematisation such as the removal of raised walls.

The updates made to the existing models are detailed below.

5.2 Model Updates

5.2.1 LIDAR

The models were updated with Environment Agency open-source 2020 LIDAR data at 1m resolution.

Where there were differences between the new LIDAR and existing bathymetry, new shape files were created to smooth the ground elevation between the two data sets.

5.2.2 Bathymetry data

The bathymetry data was not updated in this study.

5.2.3 Defence data

The coastal defences within the model were updated using the AIMs database (released in August 2021) provided by the Environment Agency.

For the undefended model reruns the defences are not read into the model and where defences are present in the LiDAR, these were removed.

5.2.4 Tidal boundaries

The tidal boundaries within the model were updated to use the extreme still water level estimates from the latest Coastal Flood Boundary dataset (CFBD) produced in 2018. These estimates are provided for a baseline year of 2017. The sea levels were updated to account for sea level rise to the years 2021, 2091, 2100 and 2121. The sea level rise for each epoch are outlined in Table 5-1 below. For the climate change model runs the tidal boundaries were uplifted following the lasted UKCP18 guidance for the Representative Concentration Pathway (RCP) 8.5 at the 70th and 95th percentiles and using H++ guidance. For the H++ scenario to 2100, the sea-levels were uplifted by 1.9m of sea-level to 2100 plus 2mm of surge per year from 2017 to 2100.

Table 5-1: Sea level rise

UKCP18 Grid square	2021	70th Percentile		95th Percentile		H++
		2091	2121	2091	2121	
714	0.026	0.648	0.852	1.039	1.397	2.07
713	0.026	0.648	0.853	1.039	1.397	2.07
712	0.026	0.648	0.853	1.039	1.397	2.07
711	0.026	0.648	0.853	1.039	1.397	2.07

The timeseries used in the model tidal boundary quantifies how sea-levels are expected to change through time during an extreme event. It is these design tidal-graphs that are used to drive the still water component of a flood inundation model at its offshore boundaries.

Derivation of the design tidal-graphs required three principal sources of information:

- (1) extreme still water sea-level estimates taken from the latest coastal extreme guidance for the UK[1] (CFBD) for the AEPs of interest;
- (2) a design surge shape taken from the latest coastal extreme guidance for the UK; and
- (3) a design astronomical tide taken from a gauge local to the site.

Extreme sea-level data used in the derivation of design tidal-graphs can be seen in Table 5-2.

Table 5-2: Extreme sea-level data used in the derivation of the design tidal-graphs

Site CFBD Chainage	2021			70th Percentile		95th Percentile		H++	
	5%	0.5%	0.1%	2091 0.5%	2121 0.5%	2091 0.5%	2121 0.5%	0.5%	0.1%
4566	3.78	4.06	4.26	4.70	5.09	4.91	5.45	6.13	6.33
4582	3.40	3.66	3.85	4.30	4.70	4.51	5.05	5.73	5.92
4590	3.24	3.50	3.67	4.14	4.54	4.35	4.89	5.57	5.74
4592	3.20	3.45	3.63	4.09	4.49	4.30	4.84	5.52	5.70
4602	3.05	3.28	3.45	3.92	4.31	4.13	4.67	5.35	5.52
4612	2.95	3.18	3.33	3.82	4.22	4.03	4.57	5.25	5.40

5.2.5 Wave overtopping boundary

Wave overtopping boundaries were applied along the coastal frontage from West Wittering to Littlehampton and on the coastal frontage at Emsworth. A total of 84 sperate wave overtopping boundaries were included in the model. For this study the location of the wave overtopping boundaries has not been updated, only the volume of overtopping at each inflow was recalculated using the emulated nearshore wave condition at each defence toe.

5.3 Results

The results are available in gridded output for flood depth, water level, velocity and hazard.

In some locations the defended output is larger than the undefended because the removal of the defences can allow flood water to flow back into the sea. In the defended scenarios, the presence of the defences prevents the floodwater from flowing back to sea and as the volume of water increases behind the defences, this results in more extensive inland inundation. A full understanding of all the areas at flood risk could be obtained by combining the defended and undefended results.

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