Medway and Swale Strategy Study (MEASS)

Modelling Report

29 March 2018

Environment Agency

Mott MacDonald
Mott MacDonald House
8-10 Sydenham Road
Croydon CR0 2EE
United Kingdom

T +44 (0)20 8774 2000
F +44 (0)20 8681 5706
mottmac.com

Environment Agency

Medway and Swale Strategy Study (MEASS)

Modelling Report

29 March 2018

Mott MacDonald Group Limited.
Registered in England and Wales no.
1110949. Registered office: Mott
MacDonald House, 8-10 Sydenham Road,
Croydon CR0 2EE, United Kingdom

Environment Agency

Issue and revision record

Revision	Date	Originator	Checker	Approver	Description
	18/9/2015	D M Price J J Williams S Costa	J J Williams		First internal draft of HD calibration
	13/11/2015	D M Price J J Williams S Costa	J J Williams	Z. Hutchison	Draft for client review
	01/04/2016	D M Price J J Williams S Costa	J J Williams D M Price	Z. Hutchison	Draft for client review - Updated Chapter 5
	17/11/2016	S Costa	J J Williams	Z. Hutchison	Draft for client review - Updated Sediment Model Calibration
A	28/07/2017	S Costa	D M Price	J J Williams	Draft of final report for client review
B	29/03/2018	L Eyres	B Riley	Z Hutchison	Final report following strategy consultation

Document reference: MMD-347800-M-RE-004-B

Information class: Standard

Contents

Tables

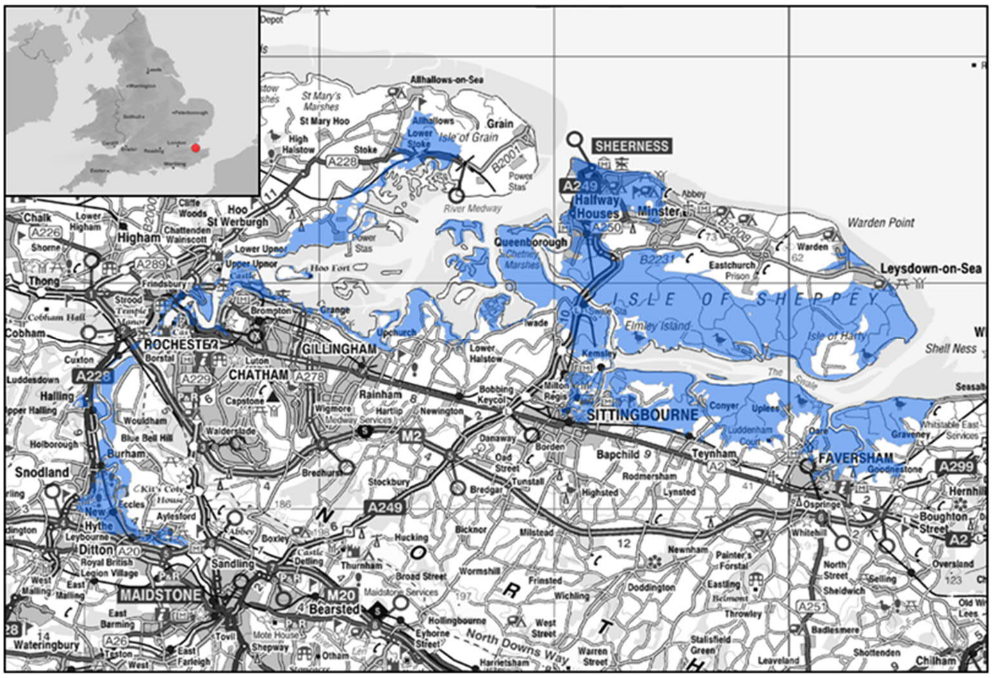
Figures

1 Introduction

The Medway Estuary and Swale Strategy is being developed to identify a long-term, technically sound, environmentally acceptable and economically viable Strategy for the management of the estuaries over the next 100 years. The Strategy will support business case applications for Flood Defence Grant in Aid (FDGiA) in accordance with the Flood and Coastal Resilience Partnership Funding regime. Future capital schemes need to be implemented over the next 100 years to manage the flood and erosion risks to local people and the developed, natural and historic environments.

Flooding is a real risk currently facing communities and landowners in the low-lying areas around Swale and the Medway Estuary. Aging flood defences, rising sea levels and climate change mean that flood and erosion risk to people, properties and agricultural land will significantly increase in the coming years. Further, over the next 100 years it is expected that approximately 18,000 properties will be at an increased risk of tidal flooding in this area. The existing defences around the Medway and Swale are reaching the end of their design life. Ongoing maintenance of these defences is becoming increasingly expensive and problematic, and improvements are required to reduce flood risk in the longer term.

Figure -1: Flood map showing areas at risk in the natural floodplain in a 1 in 200 year tidal event in 2115



Source: Environment Agency, 2015

Much of the area comprises nationally and internationally designated habitat which is under threat from coastal squeeze. As part of the Strategy being developed in the MEASS project it is important to identify how to sustain the extent of these designated habitats by creating compensatory habitats and realigning defences to more sustainable locations. The Strategy aims therefore to consider how the Environment Agency can manage these risks over the next

100 years and sets out the implementation plan which will consider the likely funding and time-scales requirements of each preferred option.

This report presents the MEASS model setup, calibration, validation and results. The MEASS model is a depth-averaged, MIKE21 flexible mesh (FM) model. The hydrodynamic component of the model (i.e. water elevation and currents) is required to determine how a series of managed realignments would impact upon the flooding regime within the Medway and Swale Estuaries. The model includes all of the tidal areas in the estuary system along with land areas that could potentially be flooded under extreme water levels and sea level rise.

The existing hydrodynamic and sediment transport regime needs to be understood as part of a process study. This then allows assessment of the impact from a range of potential realignment sites upon the hydrodynamic, sediment transport and water quality. To address this, a sediment transport model, driven by the hydrodynamic model has been setup and calibrated.

The Chapters in this report are as follows;

Chapter 1 – Introduction

Chapter 2 – Data

Chapter 3 – Model setup

Chapter 4 – Hydrodynamic Model calibration

Chapter 5 – Sediment transport model calibration

Chapter 6 – Baseline model

Chapter 7 – Options development modelling results

Chapter 8 – Managed realignment modelling results

Chapter 9 – Leading Option hydrodynamic modelling results

Chapter 10 – Leading Option sediment modelling results

2 Data

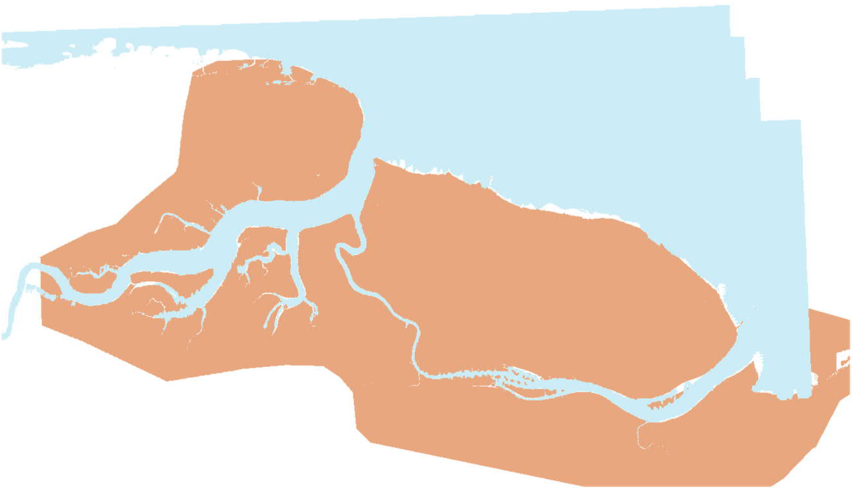
2.1 Introduction

This Chapter describes the data used for setting-up and calibrating the hydrodynamic and sediment transport models used for the Medway Estuary and Swale Strategy Study (MEASS). It is noted that the performance of a hydrodynamic model is closely related to the accuracy of the bathymetry/topography and boundary conditions that are reproduced in the model and here care has been taken to ensure natural conditions are represented as accurately as possible within the constraints imposed by the data available to the study.

2.2 Bathymetry

In the MEASS modelling study, where both the estuarine tidal flows and on-land flooding are required to be simulated, both bathymetry and topography are needed. These are merged together to form a common dataset that is referenced to a common vertical datum. The resulting digital terrain map (DTM) is then interpolated onto the model mesh.

Figure -2: Extent of Seazone bathymetry (light blue) and Lidar (brown) data



Source: Seazone

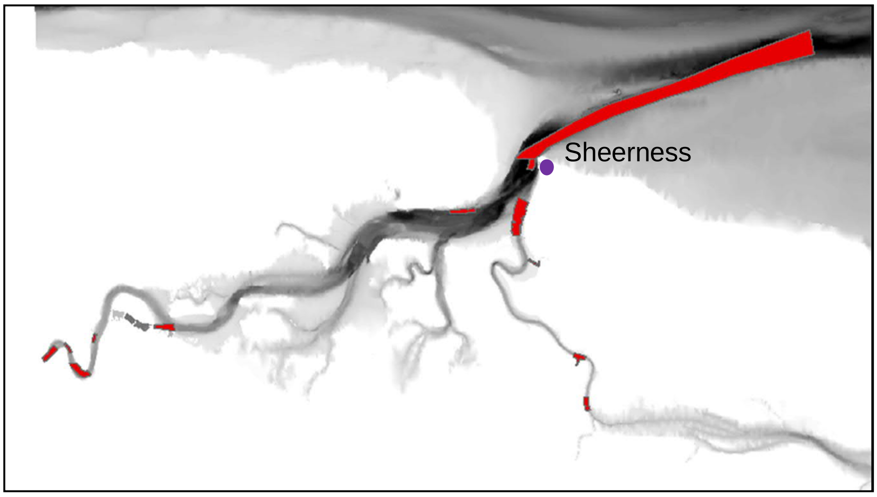
The majority of the bathymetric data used in the model build was purchased from Seazone[1] (Figure -2). The data obtained covered the offshore region of the model in the outer Thames estuary as well as the Medway and Swale Estuaries. This Hydro-spatial data comprises data from Admiralty Charts and surveys. These data are merged and gridded to provide bathymetric data with a resolution of 30m. The vertical coordinates of the data is referenced to Ordnance Datum Newlyn (ODN) which is the common datum used for the modelling.

Additionally, data from Emap (www.emapsite.com) provided digital bathymetry data from Admiralty Charts in the eastern part of the model domain (Thames Estuary) not covered by the

[1] http://www.seazone.com/

Seazone data. This data was converted from Chart Datum (CD) to ODN by adding the conversion of -2.72m for Herne Bay (Admiralty Tide Tables, 2013, Table III).

Figure -3: Extent of bathymetry data supplied by Peel Port (red)



Peel Ports (peelports.com) provided local bathymetry survey data from a range of locations (Figure -3). In this case the depths were converted from CD to ODN using a conversion of -2.9m for the Lower Medway and -2.8m for the upper Medway (Admiralty Tide Tables, 2013. Table III). Being the most up-to-date, Peel Ports data was given priority over other data from the same locations.

In the inter-tidal areas, bathymetry was defined using lidar data (2013) obtained from the Environment Agency (EA). This was undertaken prior to receiving the more recent 2014 data. Following standard practice to negate potential interpolation problems, the different lidar datasets were edited so that there were no overlapping regions.

Additional information on the channel depths and widths in the upper tidal reaches of the Medway estuary were obtained from cross-sections in an existing TUFLOW/ISIS hydrodynamic model (Mott MacDonald, 2007). The original survey was undertaken by the Environment Agency in 2002. The channel could have potentially evolved in shape since this survey, but in the absence of any other suitable data it was felt to be the most appropriate option. These were used to define the bed levels in a region of the model where no other data were available. Where this cross-sectional information was available an approximation of a rectangular channel was made in the model. This was done to avoid increasing model runtimes by too much, but checking that high water levels were reproduced well by the model (as described in calibration section).

2.3 Topography

The primary source of topographic data was lidar obtained from the Environment Agency (for the year 2013). The geographical extent of the lidar data used can be seen in Figure -2. The lidar data was merged with the bathymetry to give coverage of the estuary and all land areas in the study area.

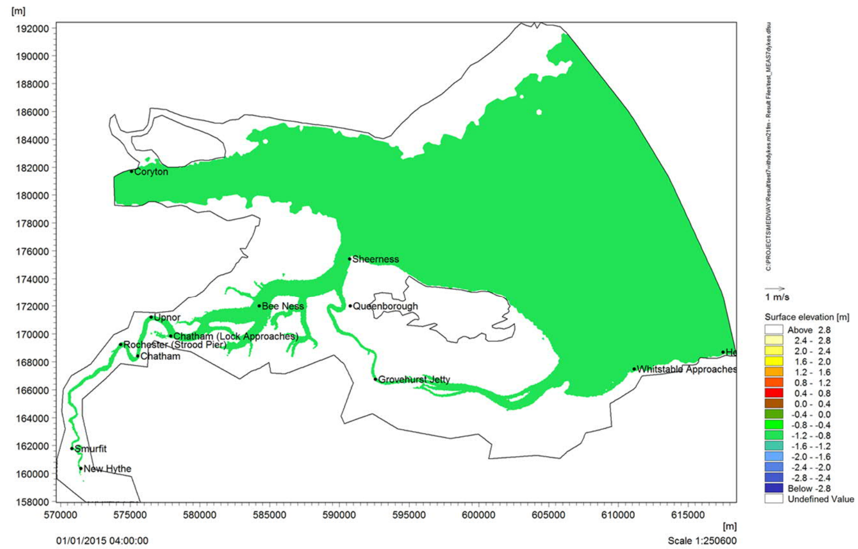
Since the model resolution of topography is not always sufficient to resolve sea defences, the interpolated elevations in the model could not be relied upon to provide of the required accurate representation of these structures. This limitation was addressed through the use of the flood defence heights from the AIMS database and in some cases where there was a discrepancy with flood extents, lidar data were used. These data were incorporated in the model bathymetry as sub-grid scale structures (Dikes) which define the elevation of the edges of model elements (that they cross). This approach also allows water overtopping simulated as a weir flow relationship. In this way the level of any defences could be defined accurately without having to adjust element heights manually thus saving time in the model build.

2.4 Water levels

Water level data provides boundary conditions for the hydrodynamic model and the data with which to compare the model results during the calibration and validation phase of the model set-up. Water level data used included data from tide gauges and data from the Hydrographic Office TotalTide[2] software. Tide gauge data was obtained from four locations; Herne Bay (Channel Coastal Observatory - www.channelcoast.org/), Sheerness (National Tide and Sea Level Facility - www.ntslf.org/), Queenborough (EA) and Smurfit (EA). As these last two (Queenborough and Smurfit) were tide gauge data, which could potentially include meteorological influences, these were analysed harmonically and re-predicted (using the MIKE21 toolbox) to remove meteorological influences for use in the model calibration. The other two locations (Herne Bay and Sheerness) were also available from TotalTide. Additionally, a Water Quality Modelling report (HR Wallingford, 2005) provided measurements of water levels and currents within the Swale. These data included water levels recorded at only times of high and low water and were collected by the National Rivers Authority in 1991. These data were digitised for comparison with the MEASS model during the validation phase.

TotalTide provides predictions of water level and current speed (see 2.5) at a range of locations. Within the Model domain the following water levels are available and can be exported for any time period: Herne Bay; Coryton; Whitstable Approaches; Grovehurst Jetty; Sheerness; Bee Ness; Chatham Lock (approaches); Upnor; Rochester; Chatham; and New Hythe.

Figure -4: Water level data locations (tide gauge and TotalTide)



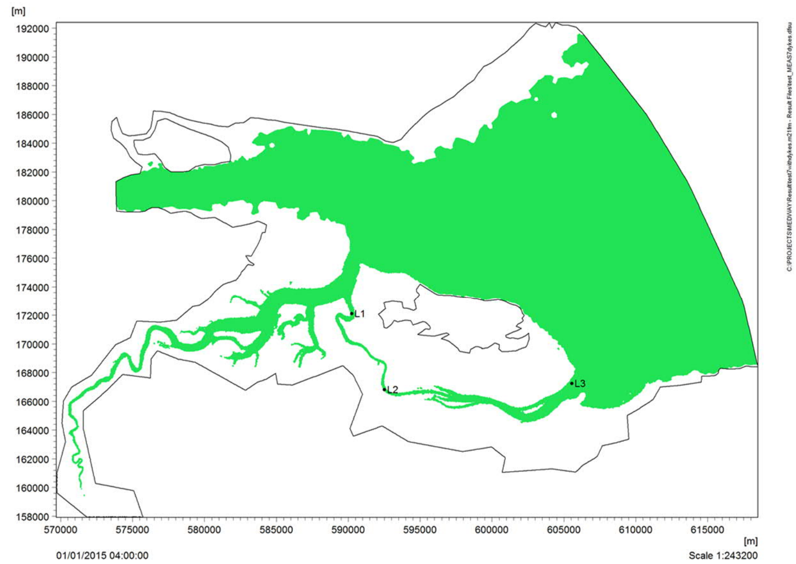
---

2 http://www.ukho.gov.uk/ProductsandServices/DigitalPublications/Pages/ATT.aspx (accesses 18 September, 2015)

The TotalTide water levels at Coryton and Herne Bay were used to provide the boundary conditions to the western and eastern water level open boundaries, respectively. It is noted that the predicted tidal levels from TotalTide are derived from harmonic constituents and do not

contain any meteorological effects. The data shown in Figure -4 has been used for model calibration and/or boundary conditions.

Figure -5: Water level data locations (NRA, 1991)



Source: HR Wallingford Ltd, June 2005

Additionally the NRA (predecessor to the Environment Agency) collected data within the Swale (water level and current speeds) in March 1991 as reported in HR Wallingford (2005). These data are short in duration with the high and low waters recorded over a period of one day and the currents measured over only one tidal cycle. The locations of the water level measurements are shown in Figure -5, which gives the locations in the western, mid- and eastern parts of the Swale. These data have been used for model validation.

In addition, Figure 164 shows the location of the two pressure sensors that were deployed by Mott MacDonald in July/August 2015. Data from these instruments has been used for model validation. Further details of the pressure sensor deployments and data analysis are provided in Appendix A.

2.5 Current speed and direction

Current speed data has been used to calibrate the hydrodynamic model within the estuary channels. For this study two sources of current data were available: (a) from TotalTide in the form of Tidal Diamonds (derived from the data provided on Admiralty Charts); and (b) from four locations within the Swale presented in the Water Quality Modelling report (HR Wallingford, 2005) and collected by the National Rivers Authority in 1991. The latter have been used for model validation whereas the former were used for model calibration.

The specific details about Tidal Diamond data is not always clear and it can have a number of issues that add uncertainty to the calibration comparisons. These include:

- The duration of the measurements used to derive the tidal diamond data is unknown. Often the two tides in a day have slightly different peak speeds, with one being larger than the other due to the asymmetry in the water levels. This is not always evident in tidal diamond data;
- The actual date of the data recording is often unknown. It could be the case that significant bathymetric changes could have taken place since the data was recorded both due to natural or anthropogenic changes;
- It is not known at what depth the measurements were made. They may be near surface (for navigation reasons) or recorded at greater depths;
- Wind, wave or river flow effects can be measured in some coastal or estuarine regions and it is not known if these have been removed from the tidal diamond current speeds and directions; and
- Location accuracy can mean that there is some potential for a discrepancy in the location of the tidal diamond. This is especially important if it is located near an area with large gradients in current speed where a small horizontal distance can make a large difference in current speed.

Despite these uncertainties, tidal diamonds are still useful for model calibration in the absence of other data, especially if there is a number of sites which together show that the models agreement, in general, matches with the data.

Figure -6: Tidal diamond data obtained from TotalTide

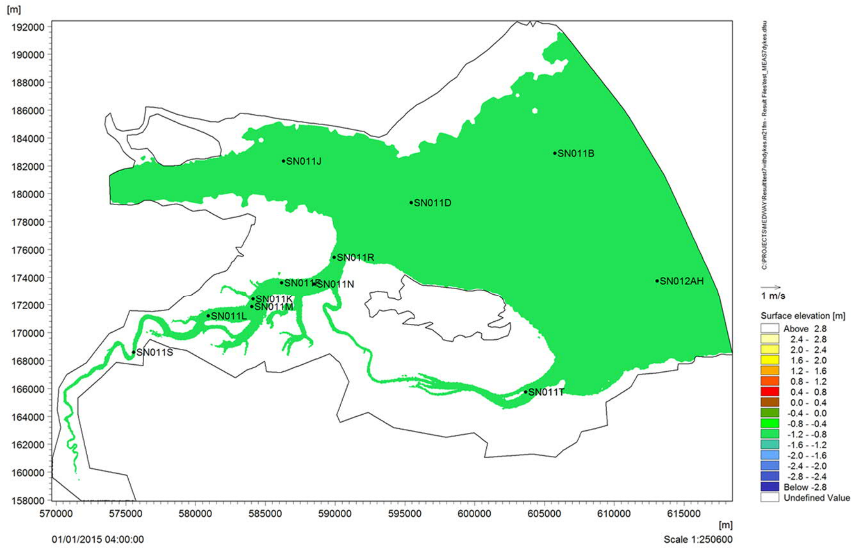
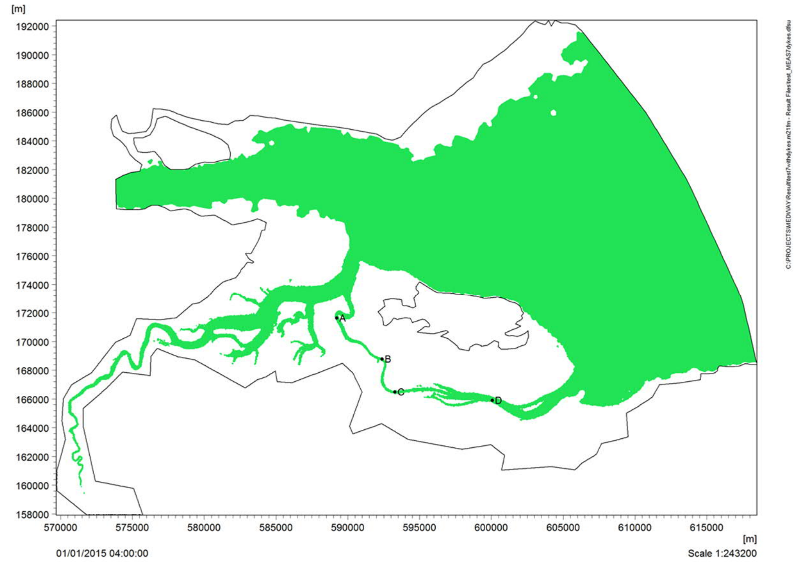


Figure -7: Current Speed data collected by the NRA in 1991



Source: HR Wallingford Ltd, June 2005

In MEASS, it is likely that the Tidal Diamond data have been derived from near-surface measurements as the data was originally collected for navigation purposes. However, since the MEASS model calculates a depth-averaged velocity it was necessary to make adjustments to the Tidal Diamond data by assuming that the tidal currents conform to the 1/7 vertical power rule (i.e. the depth-average current speed is approximately 89% of the surface current speed). Figure -6 shows the locations of the TotalTide Tidal Diamonds and Figure -7 shows the location of the data collected by the NRA in 1991.

2.6 River flows

River flow data from the NRFA website[3] are provided as daily mean flows from 1956 onwards. The data gave a mean daily average flow rate for the Medway of 11.4m^3/s. This value has been used for the calibration/validation scenarios, however a sensitivity to river flow was assessed using a 1:1 year flow rate of 100 m^3/s with very little change to high water levels in the upper portion of the Medway. The 1:1 year flow rate has been used for scenarios where extreme water levels have been considered to be more representative of storm conditions.

2.7 Sediment data

Please refer to Chapter 5 for detailed information regarding the sediment data.

[3] http://www.ceh.ac.uk/data/nrfa/data/search.html (accessed 18 September, 2015)

3 Model setup

3.1 Introduction

The MEASS model is a depth-averaged, MIKE21 flexible mesh (FM) model. The flexible mesh approach provides variable resolution across the model domain, allowing higher resolution where required and reduced resolution further away from areas of interest or in areas with less variability in the bathymetry. This saves considerably the computational time required to run a model as large as MEASS.

3.2 Horizontal and vertical datums

The horizontal coordinate system used in this study is the Ordnance Survey of Great Britain (OSGB). The vertical reference datum is Ordnance Datum Newlyn (ODN).

3.3 Model mesh

Mike21 uses a flexible mesh (FM) approach which enables variable resolution across the model domain comprising triangular elements. The overall model mesh can be seen in Figure -8 which also includes the bathymetry. Resolution in the model is generally coarser in the Thames and finer in the narrow channels of the Swale and Medway Estuaries. Figure -9, Figure -10 and **Figure -11** show the detail of the mesh in the estuary and creeks.

Table -1 shows approximate mesh dimensions in a number of regions of the model.

Table -1 mesh resolution at a range of locations

Location	Approximate mesh edge resolution (m)
Offshore in Thames	400m
Outer Medway and Swale	50m
Upper Medway/mid-Swale	25m
Land areas	25m

Figure -8: Overall MEAS model mesh: Note the darker colour on the lower part of the Figure is due to the fine mesh over this part of the model domain.

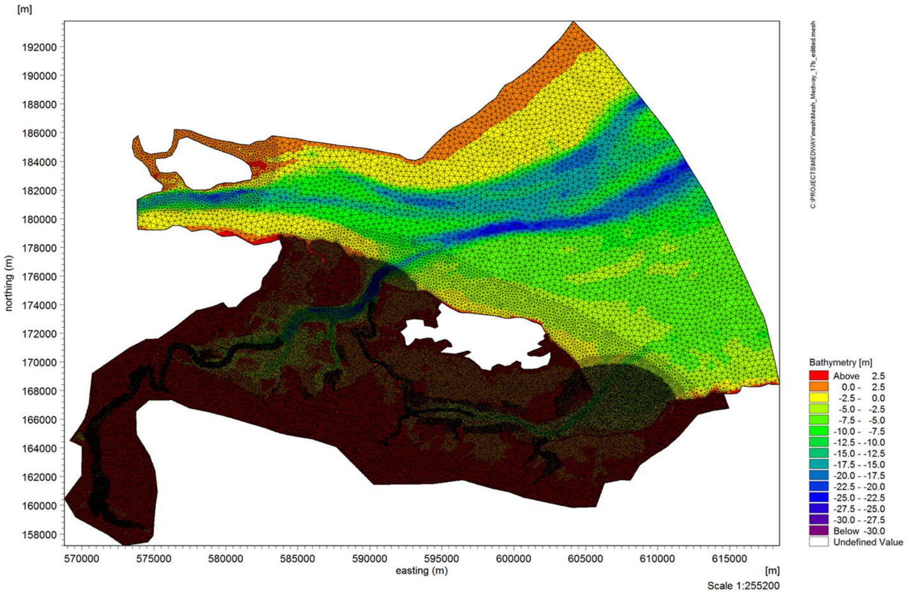


Figure -9: Mesh detail of Faversham Creek

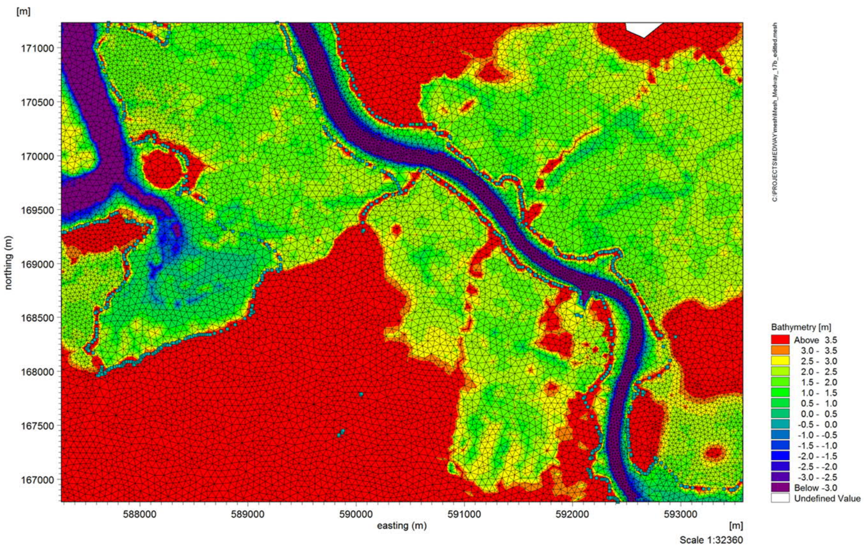


Figure -10: Mesh detail of mid Swale

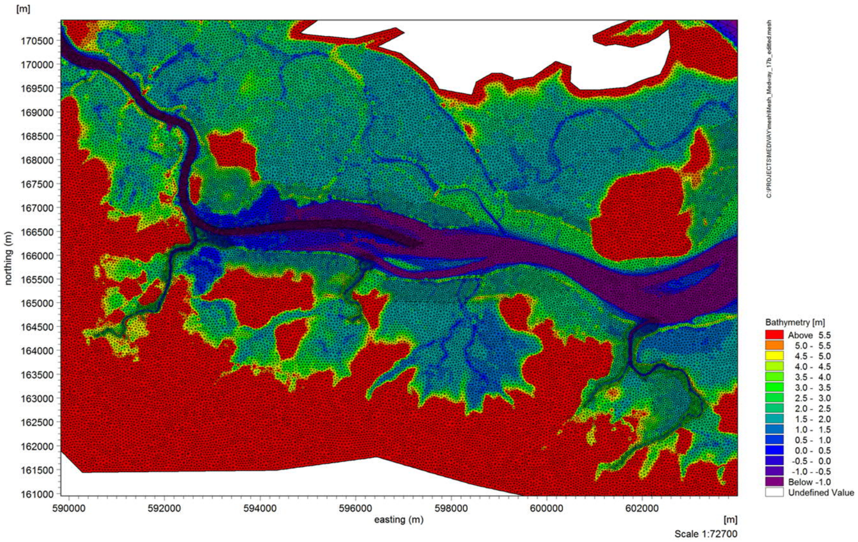
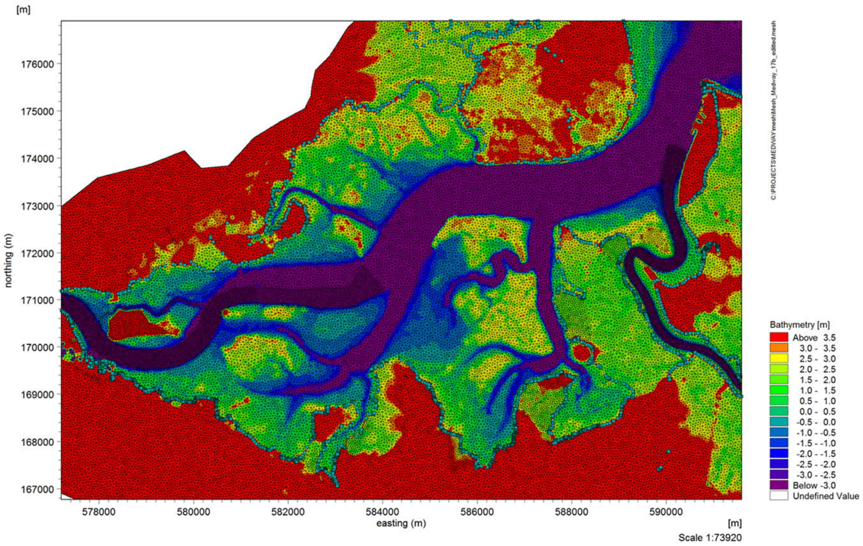


Figure -11: Mesh detail of outer Medway



3.4 Bathymetry

Figure -12 shows the model bathymetry with contours chosen to highlight the range of intertidal and subtidal bed levels. Figure -13 shows the topography for bed levels above mean tidal levels (approximately). These contours were chosen to highlight the levels on land.

Figure -12: Model bathymetry

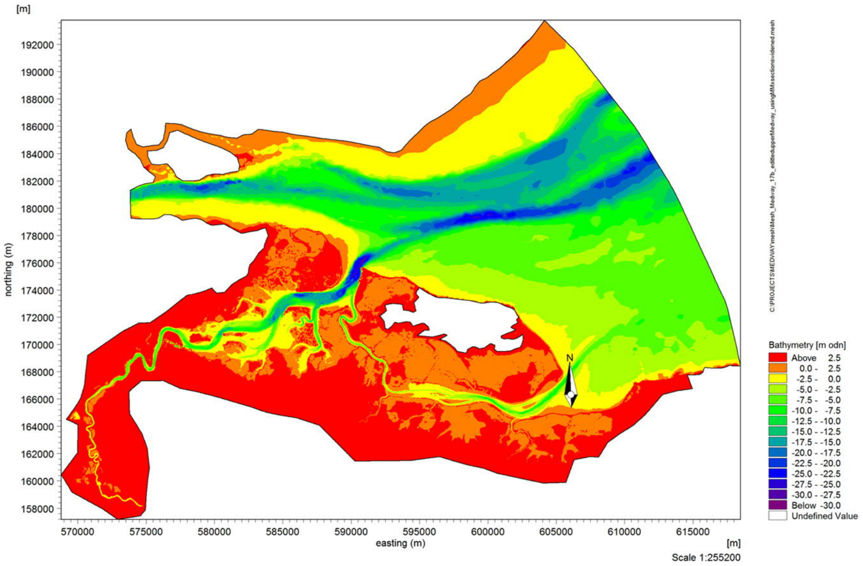
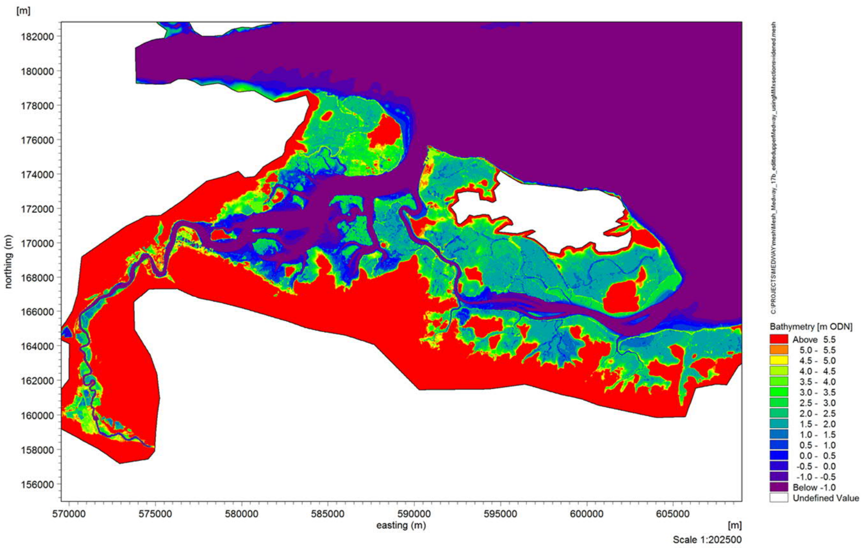
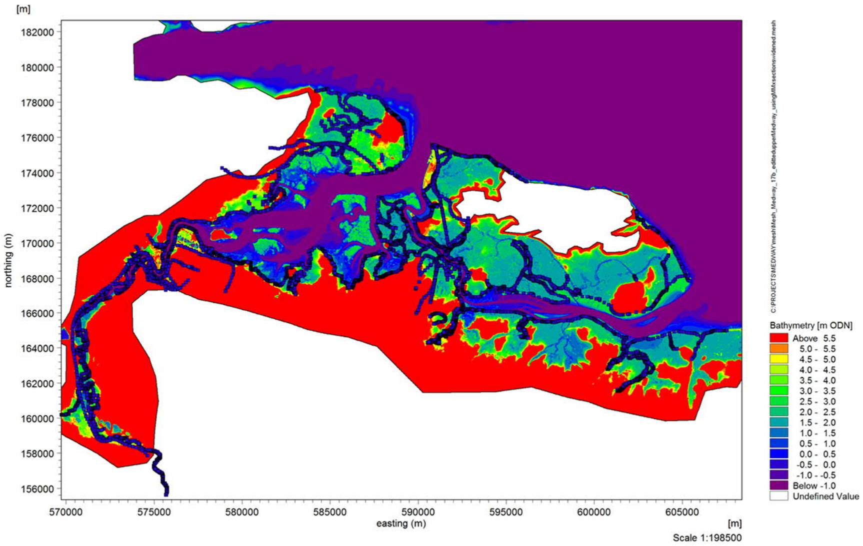


Figure -13: Model topography



The coastal defences and features such as roads/railway lines are represented in the model as sub-grid scale structures called internally in the model as “Dikes”. These over-ride the levels in the model mesh at these locations to create a continuous structure with defined crest levels. This allows features finer than the model mesh to be represented more accurately with a weir equation used to determine the volume of water flowing over these structures when overtopped. These features can be seen in Figure -14. The bridge piers for the Shepway Bridge in the Swale have been included in the model although a sensitivity test (with/without bridge piers) found there not to be a significant overall change to current speeds or water levels. However features such as gates, dams or weirs have not been included specifically but rather included as a defence height represented as a dike. Jetties in the estuaries have not been included in the model as it was believed that these would not have a significant effect upon extreme water levels due to them taking up a small proportion of the estuary cross-section.A lack of bathymetric information in the upper Medway estuary from the sources already described meant that cross sections from an ISIS model were used. The cross-sections were discretised to approximate rectangular channels which were then edited into the model mesh bathymetry.

Figure -14: Model topography with defences and raised features overlain



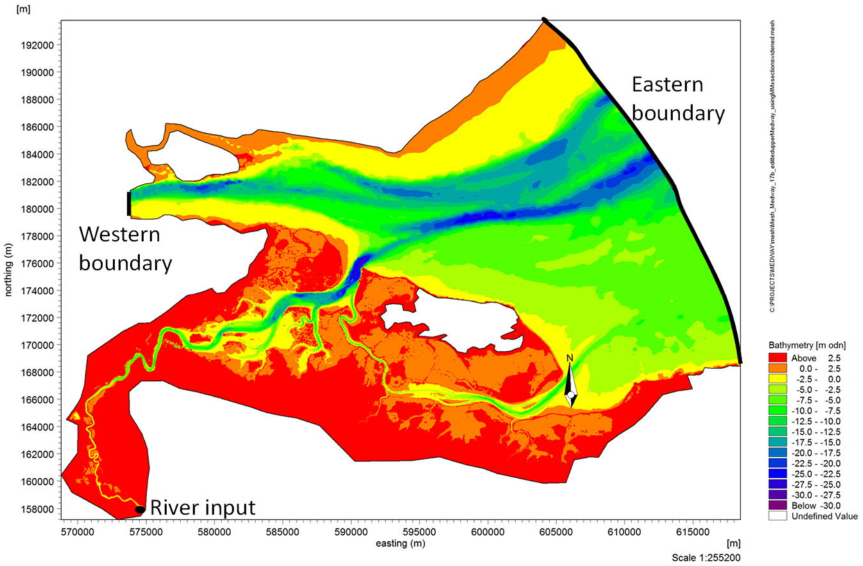
3.5 Boundary conditions

The MEAS model is forced along two tidal boundaries (Figure -15). The western boundary is located close to Coryton and the eastern boundary extends in an arc from Herne Bay on the southern coast. The shape of this arc was chosen to be close to co-tidal and co-phase lines where tidal range and phase is approximately constant. This approach allows application of the tide curve for Herne Bay along the length of the eastern boundary and provides a reasonable approximation in the absence of detailed water level data in this region. At the western boundary, the tidal levels at Coryton were applied across the entire width of the estuary.

The model extends out into the Thames estuary rather than keeping the boundaries close to, or in the mouths of, the Medway and Swale. This ensures that any impacts from realignments/flooding within the estuaries was not unduly affected by having the model boundaries too close and fixed.

At both of the boundary locations, the tidal data were obtained from TotalTide. However, since the model boundary was a little further east (approximately 5km) than the location of the tide gauge at Herne Bay, a small phase adjustment (-10 minutes) was made to the eastern boundary to account for this offset and to reduce any phase error at Sheerness. It is noted that the water levels applied to the model are tidal predictions based upon harmonic analysis of observed data.

Figure -15: Model boundaries



3.6 River flows

The river flow was defined at the upstream end of the Medway at Aylesford Lock. For model calibration purposes a mean daily flow of 11.4m^3/s was applied as a constant flow rate (Figure -15 and Section 2.6). For the extreme water level simulations, a 1:1 year return period river flow of 100m^3/s has been applied as a constant flow rate (Mott MacDonald, 2007).

4 Hydrodynamic Model Calibration and Validation

Executive summary

The MEASS model has two primary functions: (a) to simulate extreme tidal/surge events and any associated flooding; and (b) to investigate the impact of strategy options on the hydrodynamic (water levels/currents) and sediment transport regimes of the study area.

The MEASS model has been run for specific periods coinciding with suitable data that has been collected or is available. Against this data, water levels and current speed/directions from the model have been compared using statistical measures (as well as by visual means) to demonstrate that confidence can be placed in the model performance over temporal time-scales in a clear and understandable way.

The MEASS model has been shown to calibrate and validate well under normal tidal conditions for both water levels and current speeds. In addition the model has been validated against observed extreme water levels during the 5/6th December 2013 storm and flood extents predicted by a TUFLOW model of the Medway and Swale (JBA, 2015). It is considered therefore that the MEASS model has been demonstrated to be calibrated and validated with sufficient accuracy to meet the objectives of the Medway and Swale Strategy Study.

4.1 Introduction

The MEASS model has two primary functions: (a) to simulate extreme tidal/surge events and any associated flooding; and (b) to investigate the impact of strategy options on the hydrodynamic (water levels/currents) and sediment transport regimes of the study area. Therefore not only are the extreme water levels and flood extents needed, but the water levels and current speeds throughout the estuary also requires simulation at a sufficient level of accuracy.

It is noted that frequently flood models are not calibrated against current speeds (and in some instances water levels) if data are unavailable and flood extent is used solely for model calibration purposes. However, in MEASS, flooding and impacts upon water levels/currents/sediment transport are all important for understanding Strategy impacts and thus calibration/validation of these parameters has been undertaken to demonstrate that the MEASS model is fit-for-purpose.

4.2 Calibration and validation processes

Calibration involves varying model parameters, boundary conditions, bathymetry, topography defence heights etc. in order to reproduce real world data as accurately as possible within the models requirements and limitations. Validation is the process of comparing the model against a different set of data (or tidal range) using the model parameters/setup derived during the calibration to prove that the model is robust enough to be applied to different periods of time or input conditions.

It is useful to have a target in mind during the calibration process against which the level of reproduction of the observed data can be measured. For this study we have considered guidance provided by Evan (1993) and Bartlett et al., (1998). The MEASS model has been run for specific periods coinciding with suitable data that has been collected or is available. Against this data, water levels and current speed/directions from the model have been compared using statistical measures (as well as by visual means) to demonstrate that confidence can be placed in the model performance over temporal time-scales in a clear and understandable way.

4.3 Error statistics

Simple statistics that demonstrate the level of agreement between measured/observed data and model prediction at a chosen location in the model domain include the mean and peak differences (often expressed as a percentage) and the standard deviation. In addition Table -2presents a number of quality indices that can be used to demonstrate the statistical agreement between model predictions and observations.

4.4 Guidelines for MEASS model performance

Based on these statistics, guidelines to establish calibration standards for a minimum level of performance for coastal and estuarine hydrodynamic and sediment models are summarised in Table -3, (Williams et al., 2015). The guidelines are based on pragmatic experience gained in projects and they account for the frequent limitations imposed on model calibration processes by the accuracy and the temporal and spatial resolutions of calibration data. Model conformity with these guidelines would not be expected at all locations in the model domain and data availability may mean that these criteria may need to be relaxed.

Table -2 Example statistics to demonstrate the level of agreement between Observed/Simulated data and model prediction. O_i and S_i are the observed and simulated values of a given parameter at time t_i, respectively and N_i is total number of data points.

Quality index	Example	Formulae
Accuracy	Root mean square error	$RMSE = \sqrt{\frac{1}{N_i}\sum_{i=1}^{N_i}(S_i - O_i)^2}$
Bias	**Average Bias**	$Bias = \frac{1}{N_i}\sum_{i=1}^{N_i}(S_i - O_i)$
Correlation	Pearson product-moment coefficient $\bar{O}_i = \frac{1}{N_i}\sum_{i=1}^{N_i} O_i$ and $\bar{S}_i = \frac{1}{N_i}\sum_{i=1}^{N_i} S_i$	$R = \frac{\sum_{i=1}^{N_i}(S_i - \bar{S}_i)(O_i - \bar{O}_i)}{\sqrt{\sum_{i=1}^{N_i}(S_i - \bar{S}_i)^2}\sqrt{\sum_{i=1}^{N_i}(O_i - \bar{O}_i)^2}}$
Agreement	Scatter Index	$SI = \frac{\sqrt{\frac{1}{N_i}\sum_{i=1}^{N_i}(S_i - O_i)^2}}{\frac{1}{N_i}\sum_{i=1}^{N_i} O_i} \times 100$

In considering model accuracy the difference between the measured and modelled data should not generally exceed 10%, although this will be highly variable depending on the parameter being considered and the accuracy of the calibration data used in the model. The accuracy of the modelled data can also be quantified using root mean square error (RMSE) statistic (Table -2). The RMSE value is often expressed as a percentage, where lower values indicate less residual variance and thus better model performance. The bias expresses the difference between an estimator's expectation and the true value of the parameter being estimated and can be defined as being equal to the mean error in the data. Systematic bias reflects external influences that may affect the accuracy of statistical measurements. Detection bias is where a phenomenon is more likely to be observed and/or reported for a particular set of study subjects.

Reporting bias involves a skew in the availability of data, such that observations of a certain kind may be more likely to be reported and consequently used in research.

The agreement or otherwise between measured/observed data and model prediction time-series is frequently quantified using the Pearson product-moment coefficient, R (Table -2). It is essential to test the statistical significance of the correlation coefficient. The widely used Brier skill score, BSS, (Brier, 1950) and Willmott's dimensionless index of agreement (Willmott, 1981) compare the mean square difference between the prediction and observation with the mean square difference between baseline prediction and observation (i.e. skill). The scatter index, SI, is the RMS error normalised with the mean value. In most case the scatter index provides a useful indication of the model performance.

Table -3 Statistical guidelines to establish calibration standards for a minimum level of performance for coastal and estuarine hydrodynamic and sediment models (Williams et al., 2015)

Predictions	RMSE	Bias	R	SI
Water level (coast)	± 10% of the measured level.	< 0.10	> 0.95	< 10%
Water level (estuary)	± 10% (mouth); ± 25% (head) of the measured level.	< 0.20	> 0.95	< 15%
Water level phase (coast)	± 15% of the measured phase.	< 0.20	> 0.90	< 20%
Water level phase (estuary)	± 15% (mouth); ± 25% (head) of the measured phase.	< 0.25	> 0.90	< 20%
Average current speed	± 10% to 20% of the measured speed.	< 0.10	> 0.95	< 10%
Peak current speed	Within <0.05m/s (very good), <0.1m/s (good); <0.2m/s (moderate) & < 0.3m/s (poor) of the measured peak speed.	< 0.15	> 0.90	< 15%
Current direction (coastal)	± 10° of the measured direction.	< 0.25	> 0.90	< 20%
Current direction (estuary)	± 15° of the measured direction.	< 0.30	> 0.90	< 20%
Bed shear stress	± 10% N/m2 of the measured mean stress.	< 0.10	> 0.95	< 10%
Mean SPM concentration	± 20% of the mean measured SPM concentration	< 0.20	> 0.90	< 20%

4.5 Model calibration

4.5.1 Calibration results

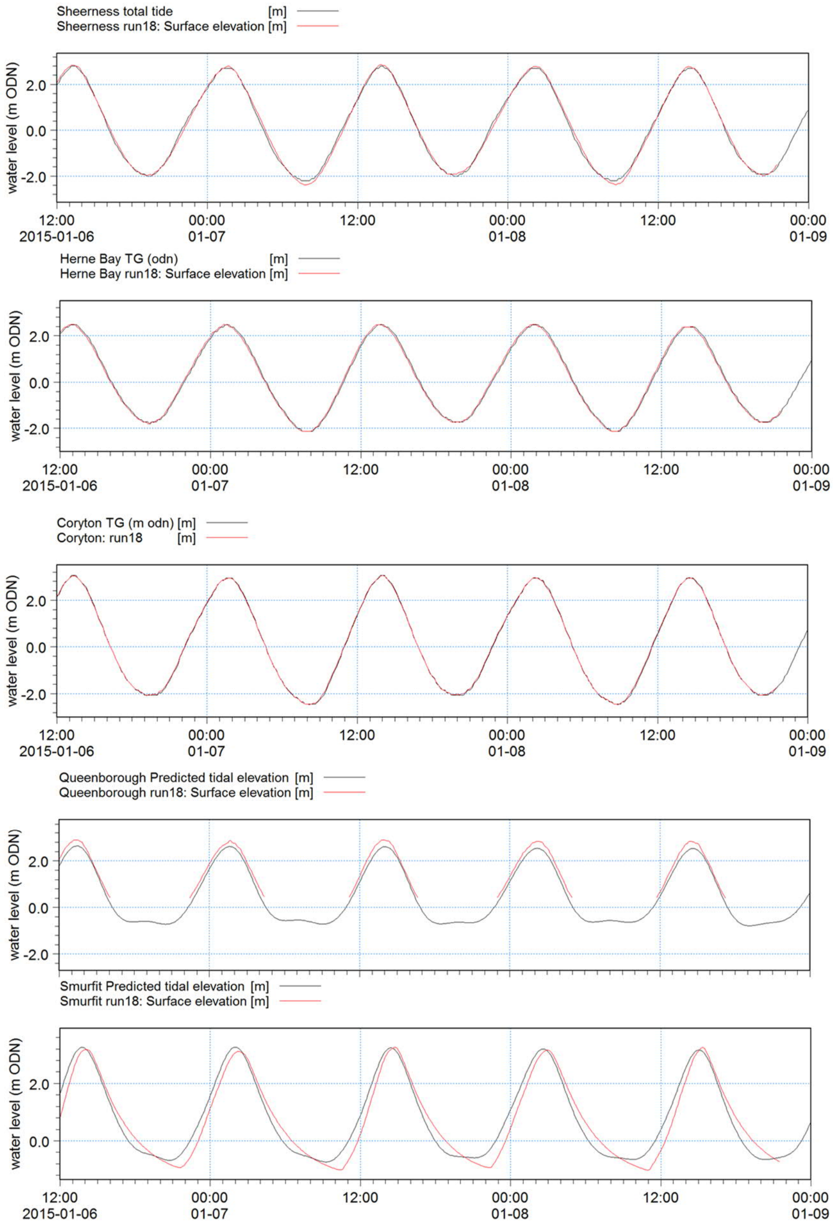
The locations of the various data used in the calibration can be seen in Figure -4 and Figure -5 for water levels and Figure -6 and Figure -7 for current speeds.

4.5.1.1 Water levels

Water level error statistics are shown in Table -4. These statistics are from the final calibration run that had a constant Manning's M (reciprocal of Manning's n) value of 40 in the sub and intertidal regions of the model; a run with a higher roughness of 30 produced higher error statistics overall. Comparisons between tide gauge water level data and model predictions at the same locations are presented in Appendix A.

The final configuration of the bed roughness representation in the MEAS model had a Manning's M value of 40 in the intertidal and sub-tidal areas, 20 on open land and 15 in built-up areas such as towns.

Figure -16: Comparison between harmonic tide gauge water level data(black) and model results (red) – Spring tide



In Figure -16 the comparisons at Herne Bay and Coryton are very good because they are located at the model boundaries. Since current speeds within the estuaries are predominantly dependent upon water levels it is important that water levels at Sheerness (and also at the eastern end of the Swale) are reproduced well in order to achieve a good calibration of current speeds within the estuary. In Figure -16 it can be seen at Sheerness that there is a very good agreement between the model predictions (red) and the data (black). The slight over-prediction of the low water on alternate tides is thought to be due in part to the harmonic boundary conditions not capturing sufficient constituents for the reproduction of this feature.

Despite an obvious vertical shift in the data, comparison between measured and predicted water levels at Queenborough are good. This offset has also been observed previously (personal communication with client Project Manager) during storm events. The offset is also highlighted in the statistical analysis (Table -4) where the bias shows a vertical error of 0.3m. Correcting for bias by adding a vertical shift to the data reduces the RMS error down to 0.09m. After closer examination of the tide gauge data it was found that drying levels of the gauge were approximately -1 to -0.7m ODN for the period 2005 to the end of 2012 and then approximately -0.25m ODN from the beginning of January 2013. This may account for some of the differences in drying level at low water, although this is located at a point which lay between available lidar data and bathymetry data and therefore there is some uncertainty in the exact level of the bed in the model. There is also some visual evidence to suggest that high water levels are greater from 2013 onwards when compared to previous years. It should be noted that the North Kent Modelling undertaken by JBA also found an issue with the Queenborough tide gauge when compared to their model (JBA, 2015) which overestimated the recorded data by 0.51m.

A water level comparison between measured and modelled data at Smurfit (located in the upper reaches of the tidal Medway) shows a greater amount of asymmetry in the predicted flood and ebb phases. This is most likely due to the compromise in model resolution in the upper reaches that allows the model to run in a reasonable time. However, it should be noted carefully the primary focus for the calibration of the model at this location is the high water levels. These are shown in Figure -16 to match well (within 0.15 m) with the measured data. While the RMS error of 0.4m (Table -4) highlights the differences between measured and predicted values on the flood and ebb tides, it does not show how well the high waters are matched and is therefore misleading in this context. The high water levels in the upper reaches of the Medway were sensitive to the bathymetry and therefore sensitivity tests were undertaken by adjusting the bathymetry using profile data from Mott MacDonald (2007).

A number of simulations were undertaken using a range of river flows, from zero, the mean flow of 11.4m^3/s and 100m^3/s. Very little or no difference can be seen towards high water with increases in water level only observed at low to mid tide levels.

Figure -17: Comparison between Totaltide water level data(black) and model results (red) – Spring tide

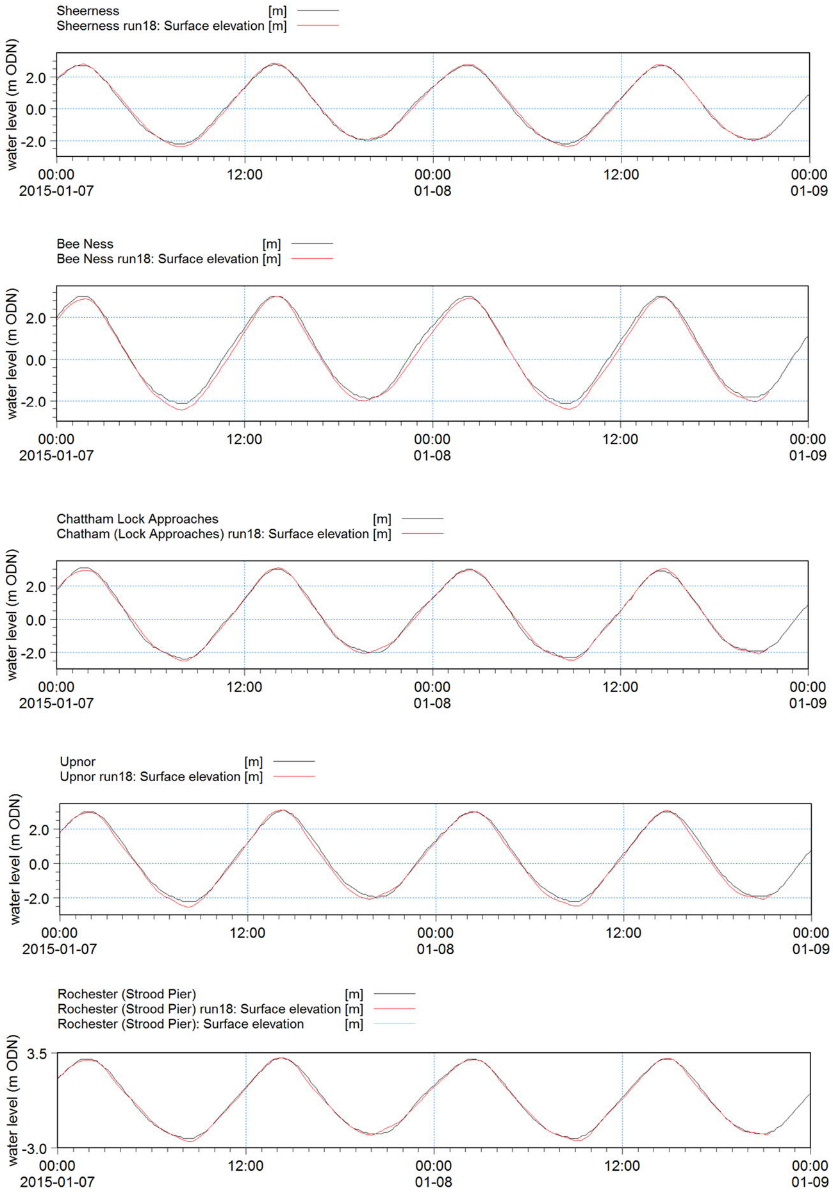


Figure -17 shows comparisons between predicted water levels and TotalTide water level data for the outer to mid-part of the Medway estuary. It can be seen that in general the comparisons are very good. Small differences can be seen at some of the locations, typically at low water and during the flood tide at Bee Ness. However, in Table -4 it can be seen that the RMS error is generally less than 0.2m or 4% of the spring tidal range (over 5.0m).

Table -4 Error statistics between observed and model water levels

locationName	rmsError	bias	correlation	skill	scatterIndex
Sheerness	0.10	0.00	0.998	1.00	51
Queenborough	0.25	0.24	0.997	0.98	15
Queenborough with vert. shift of 0.3m to data	0.09	-0.06	0.997	1.00	5
Smurfit	0.40	-0.08	0.959	0.98	48
Grovehurst Jetty	0.35	0.10	0.976	0.99	75
Grovehurst Jetty (shift -20min)	0.16	0.09	0.996	1.00	32
Whitstable Approaches	0.28	-0.03	0.985	0.99	126
Whitstable Approaches (shift +20min)	0.07	-0.03	0.999	1.00	32
BeeNess	0.20	-0.17	0.998	1.00	53
Chatham Lock	0.10	0.00	0.999	1.00	43
Upnor	0.16	-0.10	0.998	1.00	47
Rochester	0.11	-0.04	0.999	1.00	37
New Hythe	0.52	-0.45	0.980	0.96	38

Figure -18: Comparison between TotalTide water level data(black) and model results (red) – Spring tide

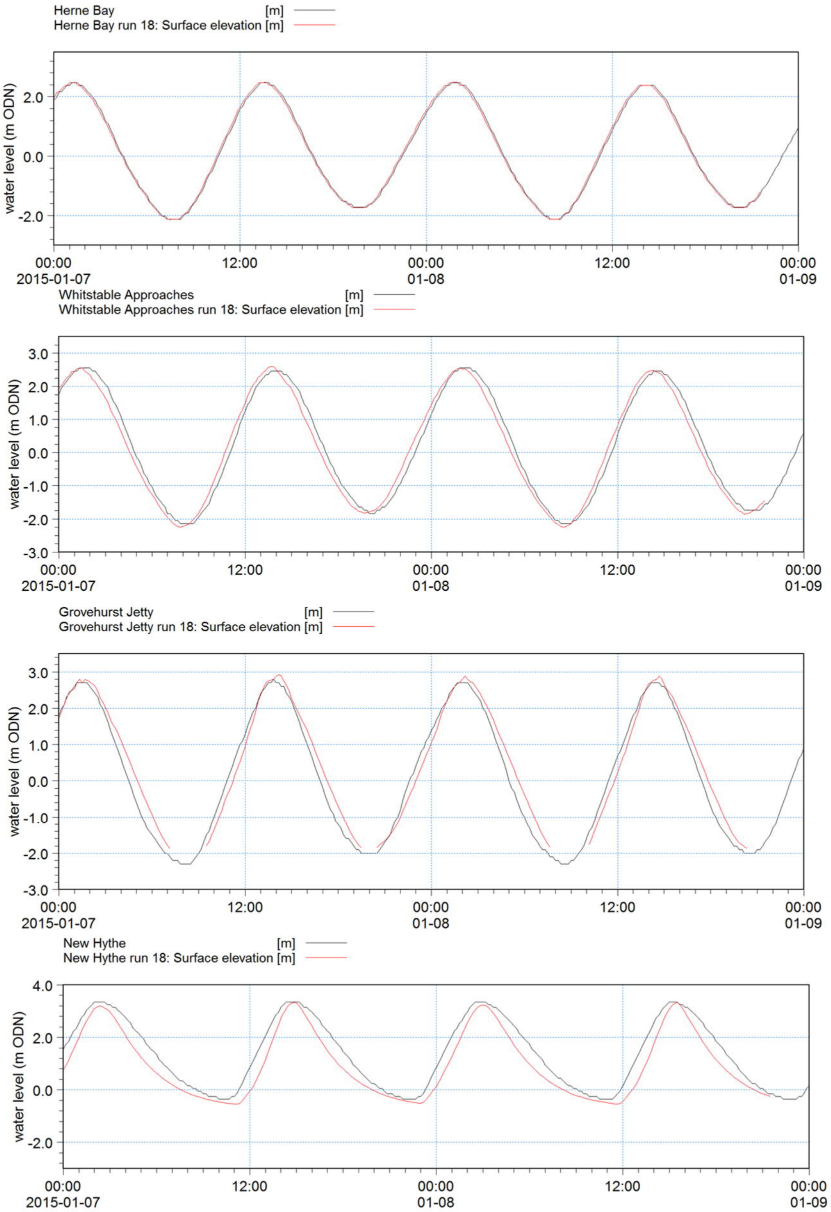
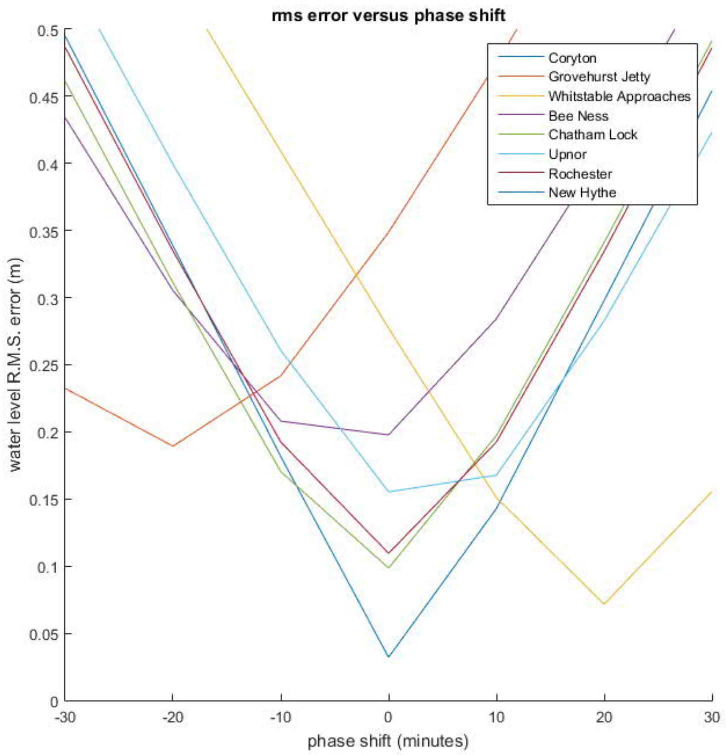


Figure -18 shows comparisons between measured and predicted water levels at locations from Herne Bay to New Hythe through the Swale. Herne Bay is at the model boundary and as expected a good match is produced. There appears to be a positive and a negative phase error in the data compared with the model at the Whitstable and Grovehurst Jetty locations, respectively. This did not appear at any other location and it is believed that the TotalTide data may be inaccurate at this location; high water at Grovehurst Jetty appears earlier than that at Whitstable which is not as expected. The observed peaks in water elevation lag the model prediction at Whitstable Approaches. Conversely, good agreement between measured and predicted water levels is demonstrated at Herne Bay and Sheerness.

Figure -19: RMS errors between model and observed water levels with different phase shifts applied to the observed data.



In order to define the magnitude of the phase shift, the RMS error in water level predictions was obtained for a range of locations demonstrating either positive or negative phase shifts (Figure -19). The minimum RMS error for each location indicates the phase shift between the model and the observed data. For Grovehurst Jetty the minimum RMS error is -20 minutes, whereas at Whitstable Approaches the RMS error is +20 minutes. At all the other locations the minimum RMS error is at or close to the zero phase shift. Assuming that the +/- 20 minute phase shift is attributable to errors in the data (arising from sources identified above), the RMS errors (shown in Table -4) drop from 0.35 to 0.16m at Grovehurst Jetty, and from 0.28 to 0.07m at Whitstable Approaches.

Comparisons during a period of neap tides can be seen in Figure -20, Figure -21 and Figure -22. As with the spring tides, the neap results show similar features and levels of agreement between predicted and observed data.

Figure -20: Comparison between harmonic tide gauge water level data(black) and model results (red) – Neap tide

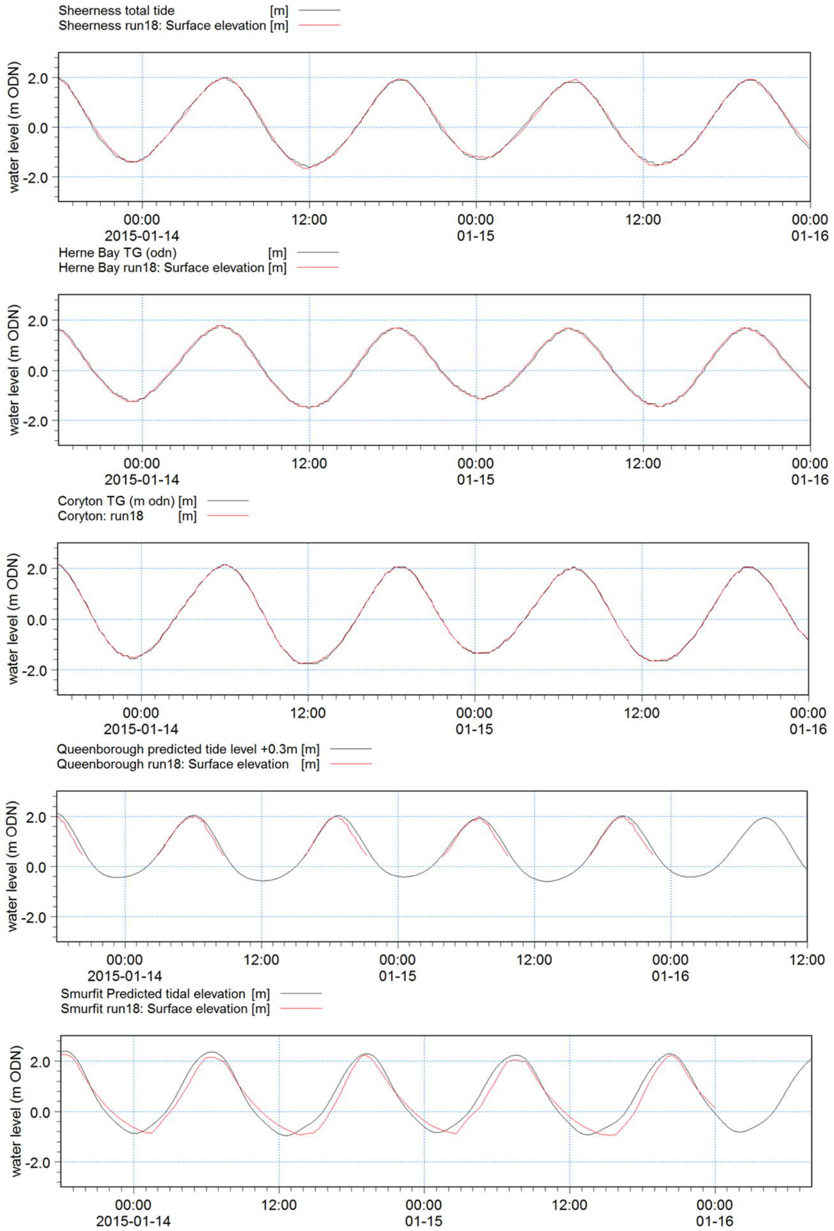


Figure -21: Comparison between TotalTide water level data(black) and model results (red) – Neap tide

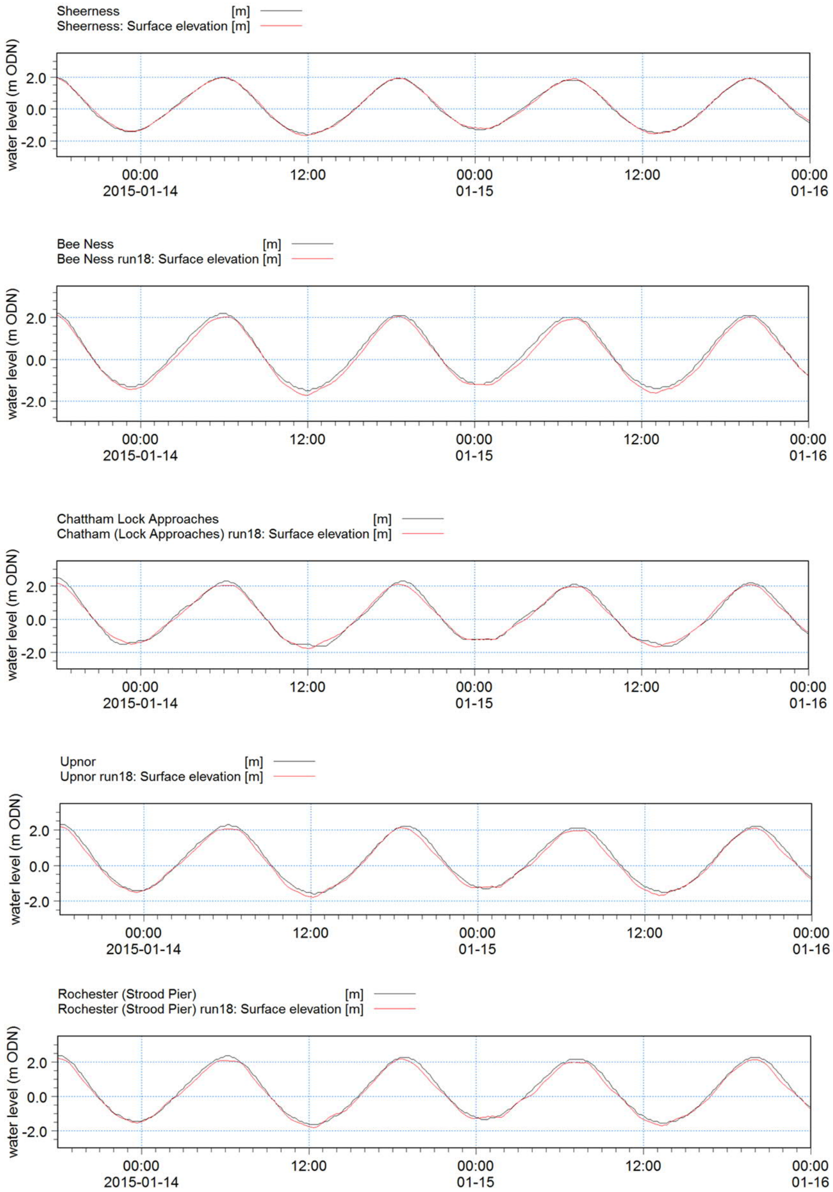
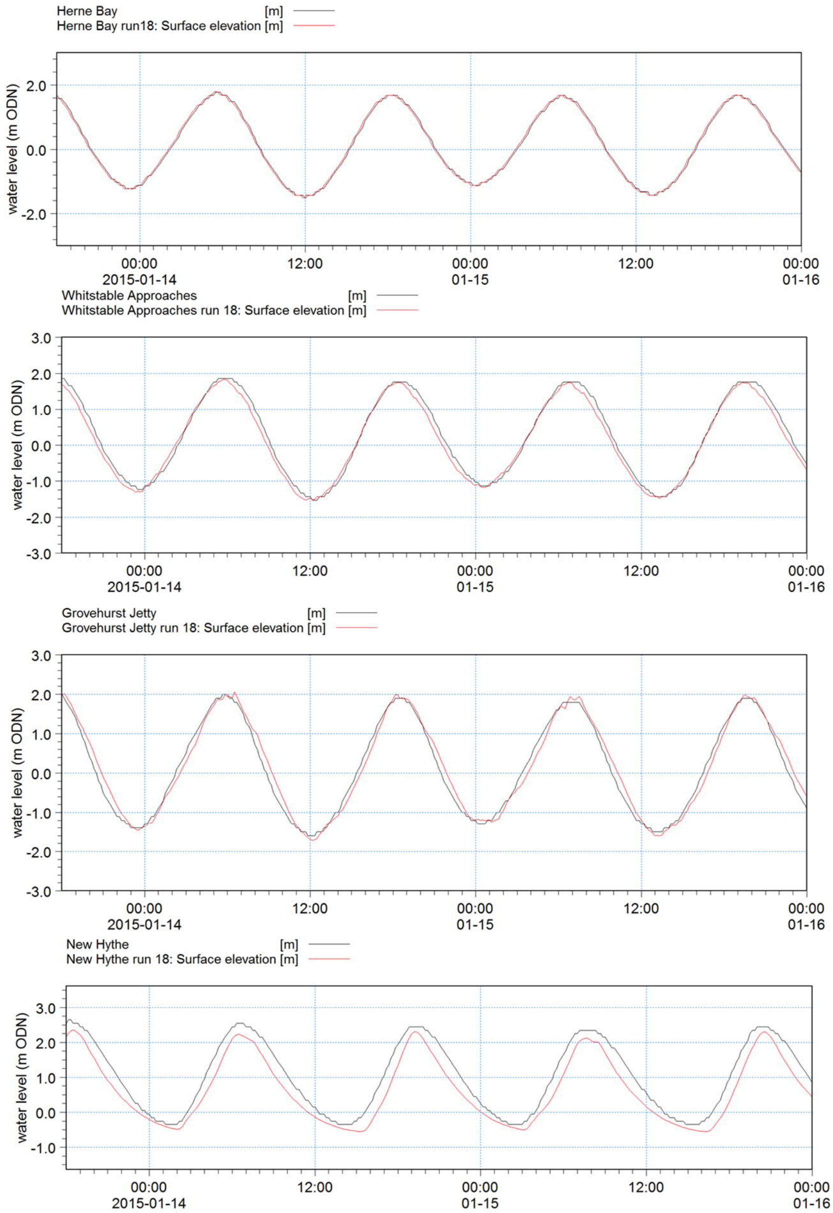


Figure -22: Comparison between TotalTide water level data(black) and model results (red) – Neap tide



4.5.1.2 Current speeds

Comparisons between the TotalTide spring tide current speeds and the model predictions at the locations shown in Figure -6 and Figure -7 are shown in Figure -23, Figure -24 and Figure -25.

Figure -23: Comparison between TotalTide current data(black) and model results (red) – Spring tide

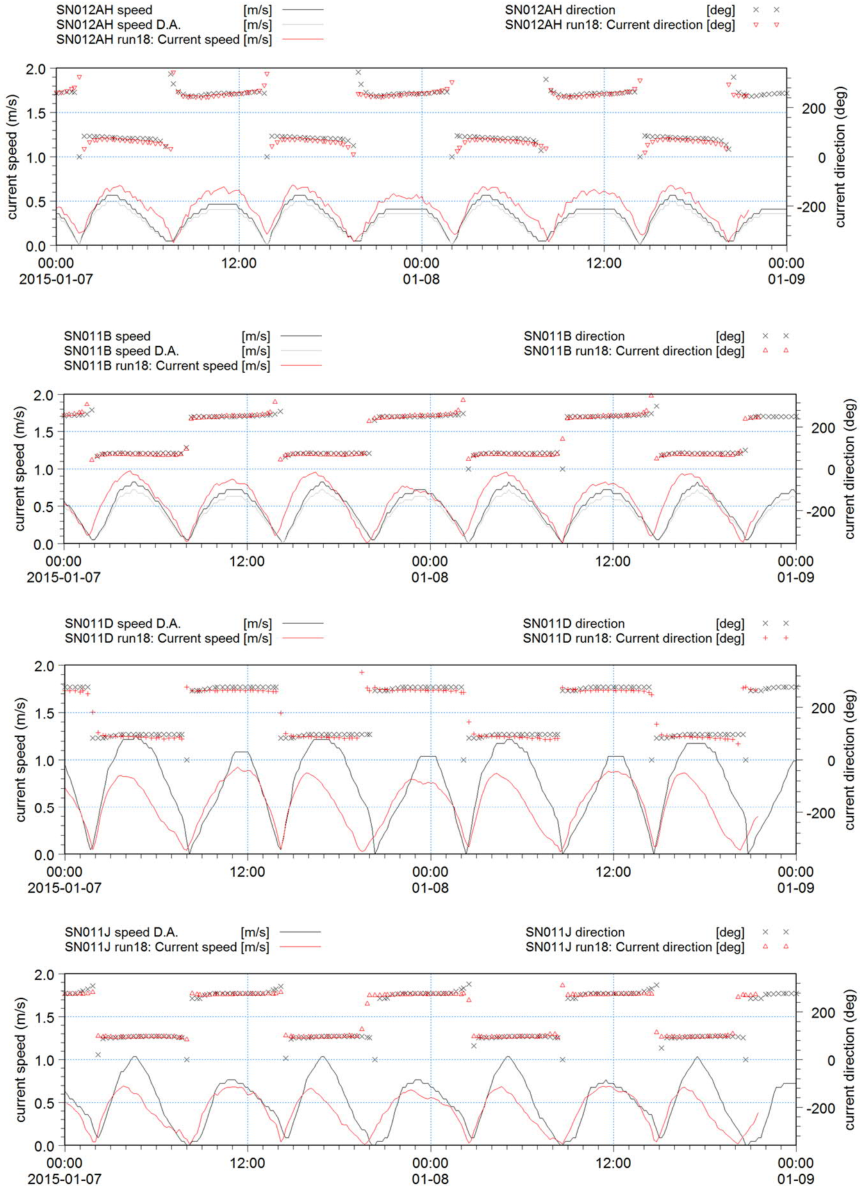


Figure -24: Comparison between TotalTide current data(black) and model results (red) – Spring tide

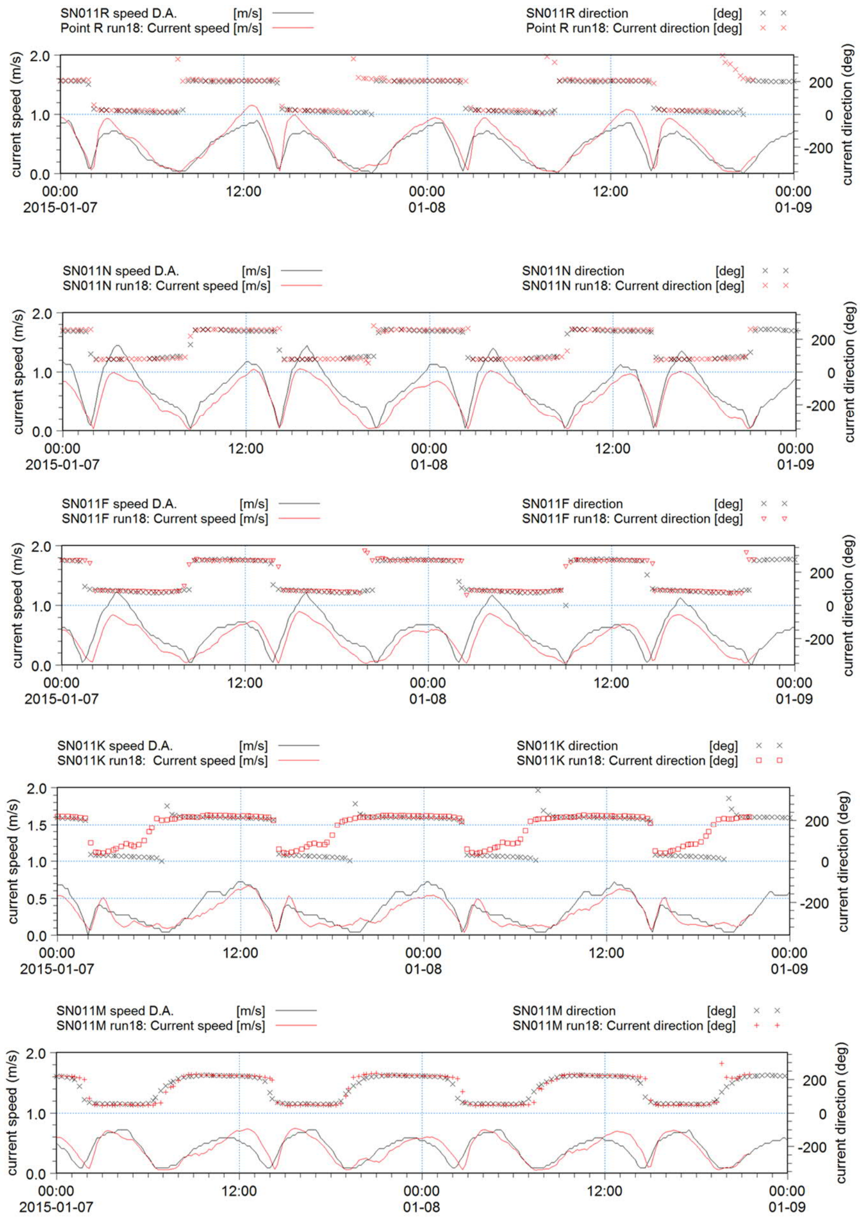


Figure -25: Comparison between TotalTide current data(black) and model results (red) – Spring tide

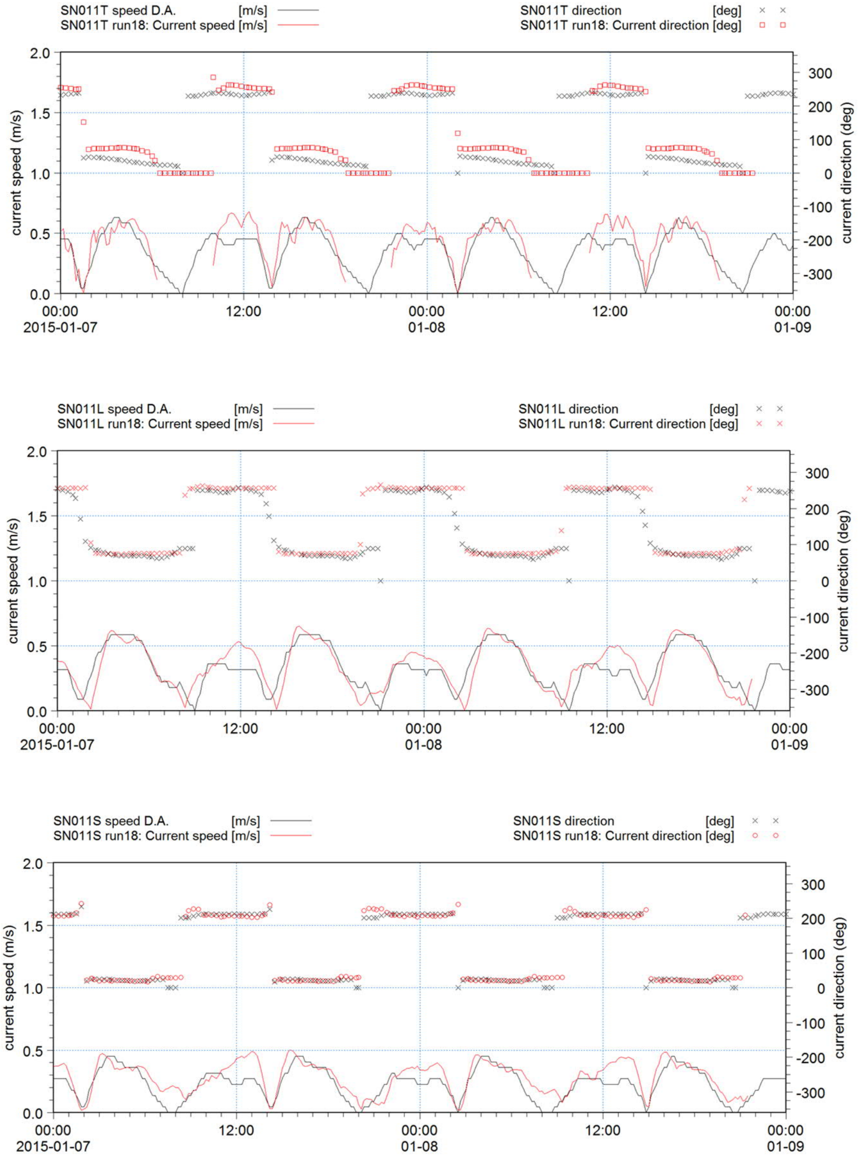


Figure -23 shows comparisons between measured and predicted spring tide current speed and direction for locations in the Thames Estuary. Although these locations are strictly outside the primary area of interest they are helpful for indicating where the model is applicable. Comparisons in Figure -23 between measured and predicted depth-averaged current speeds at location AH and B (to the east of the model) show that the model tends to over-predict current speeds by 0.1-0.2m/s. However, locations D and J located in the mid and western parts of the Thames region of the model show an under-prediction by the model at times of peak speed of 0.5m/s. The discrepancy could not be resolved with available information. However, since the largest discrepancies concern the ebb phase of the tide, it is hypothesised that freshwater flows within the main Thames estuary may increase the ebb current speeds slightly. Equally, the discrepancy may also be partly attributable to errors in bathymetry at the measurement locations and further upstream.

Whilst this match in current speeds is not as good as we would have hoped at these four locations in the Thames, this area is outside of the Medway and Swale estuaries which is the main focus of this strategy study. Water levels at the mouths of the estuaries are reproduced well and this is what drives the flows within. For the sediment modelling the Thames portion of the model is effectively one long boundary condition supplying sediment at a particular concentration to the Medway and Swale estuaries. Although speeds in the model are under-predicted towards the eastern end of the Thames portion of the model it is not believed that this adversely affects the suspended sediment concentration entering the estuaries as this is dominated by the concentration applied at the boundaries rather than solely relying on erosion of the underlying sediment. We acknowledge however that under or over –prediction of current speeds will have an effect upon the erosion and deposition of sediment in the model but that this is in addition to many other uncertainties that are present in simulating sediment transport with little physical background data.

Figure -24 compares measured and predicted depth-averaged spring tide current speeds in the mid to out part of the Medway Estuary. In general the model results compare favourably with the measured data, and exhibit very similar shapes for the flood and ebb phases of the tide at all locations. However, there is evidence of some over- and under-prediction of current speeds which may be attributable to local features in the bathymetry which may have changed over time. It is considered that in general the visual comparison between the measured and predicted data is good.

Differences between measured and predicted peak current speeds during the ebb and flood phases (tidal asymmetry) is generally reproduced well, although the magnitude of the differences are not always as large as that measured. Here the potential issues/inaccuracies associated with Tidal Diamond data should be borne in mind. Similarly, for current direction, the match between measured and predicted direction and phasing of the tide is good, possibly with the exception of location K. Here differences are attributable to the very low current speeds during the ebb phase of the tide which are difficult to simulate accurately.

Figure -25 shows comparisons between measured and predicted current speeds and directions for location T in the Swale and location L and S in the mid-part of the Medway. Comparisons are generally good on the ebb phase of the tide but are over-predicted on the flood phase. Directions comparisons are also generally good, although at Location T, due to the location being at the downstream end of a mud bank, the agreement is not as good as at other locations.

Figure -26: Comparison between TotalTide current data(black) and model results (red) – Neap tide

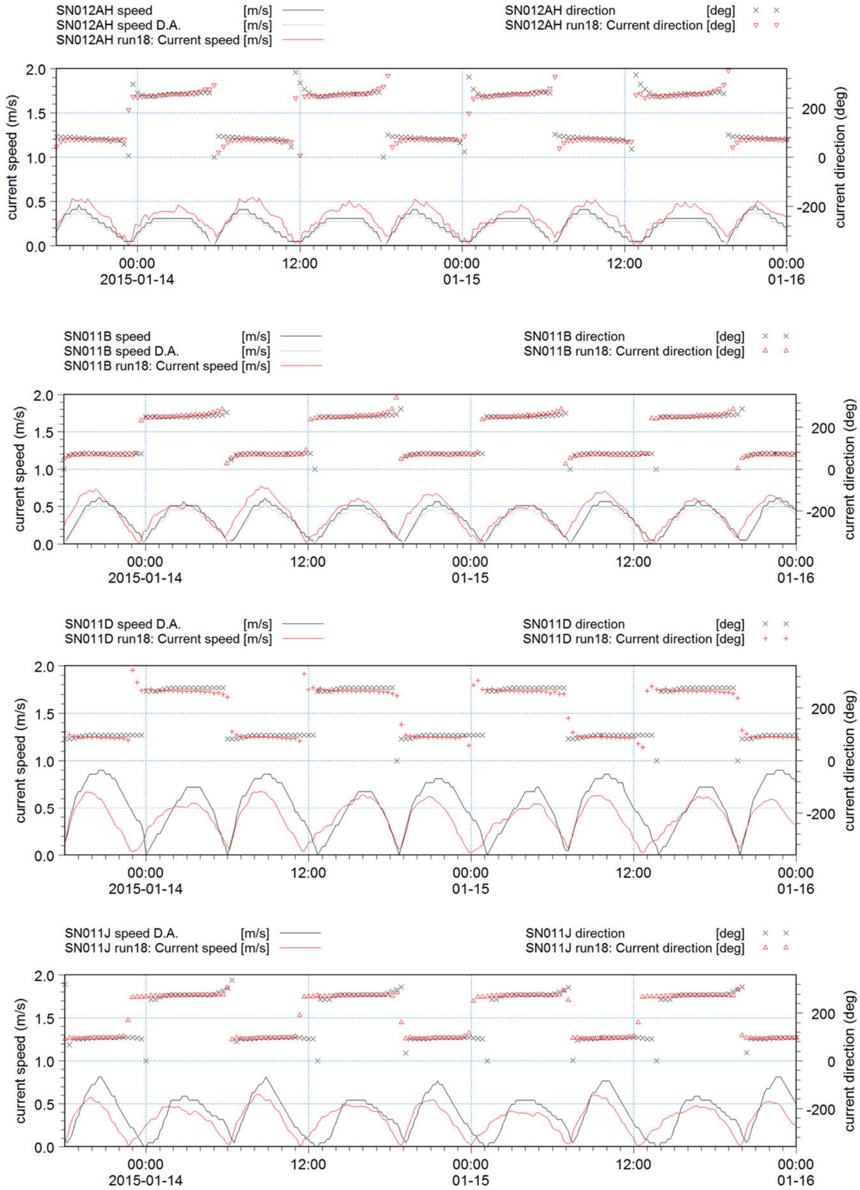


Figure -27: Comparison between TotalTide current data(black) and model results (red) – Neap tide

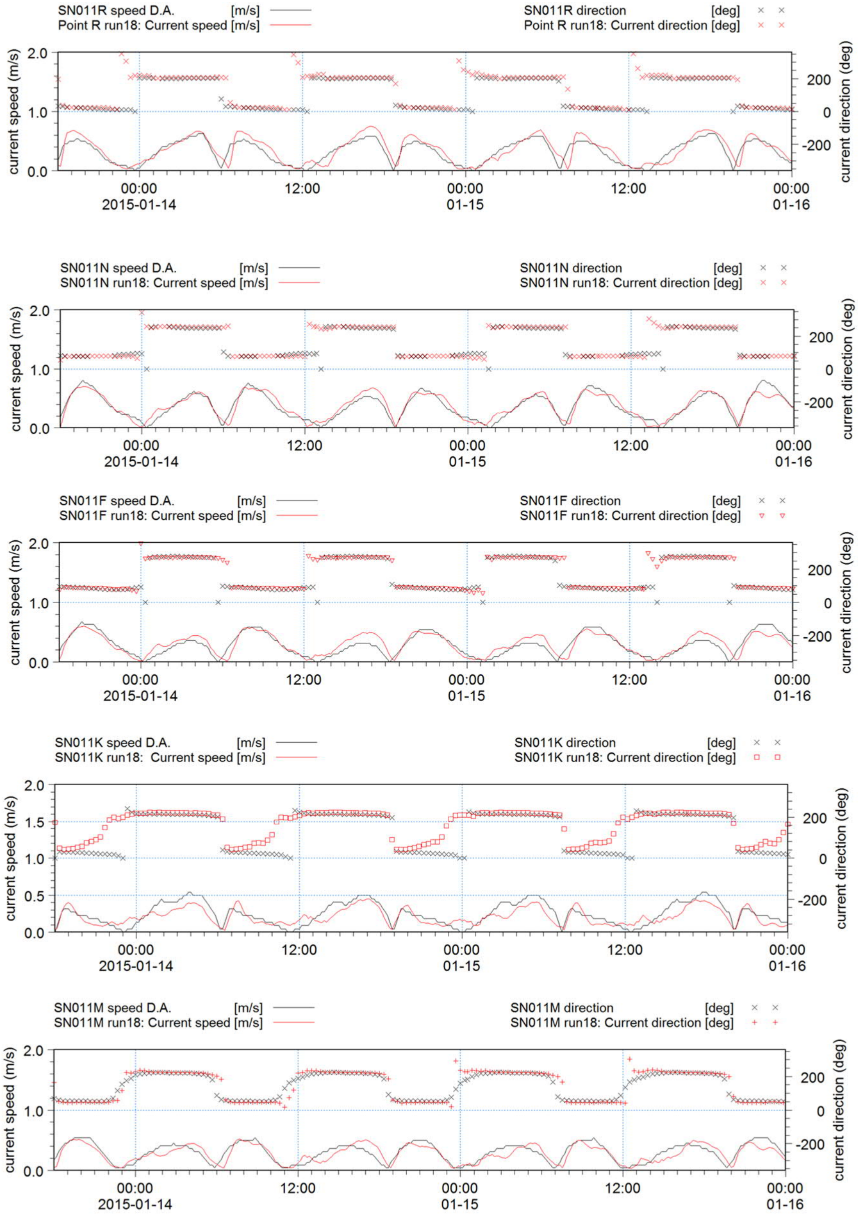


Figure -28: Comparison between TotalTide current data(black) and model results (red) – Neap tide

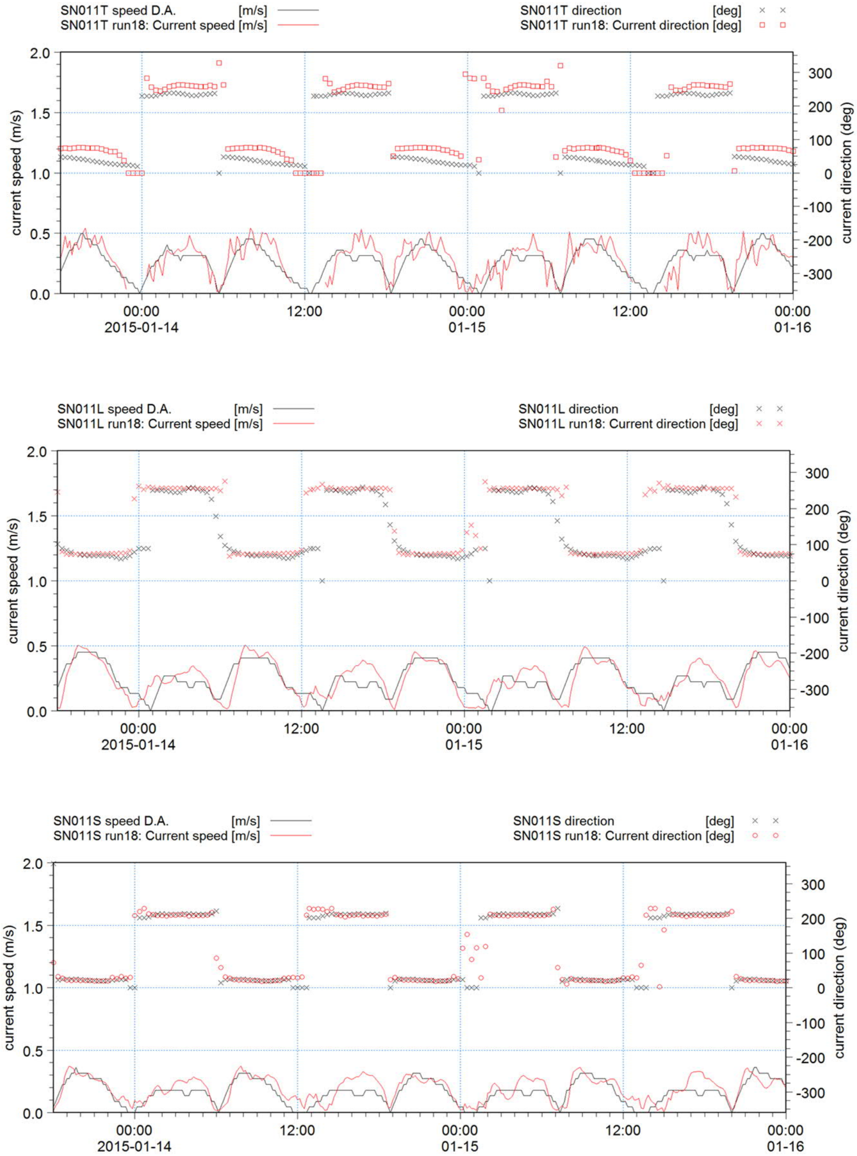


Figure -26,Figure -27 and Figure -28 show the comparisons between measured and predicted current speeds and directions for neap tides at the same locations as shown in Figure -6. A similarly good level of agreement was found during these smaller range tides.

Error statistics between the observed and model results for a spring tide are shown in Table -5.

Table -5 Error statistics between observed and model spring tide current speeds

locationName	rmsError	peak speed	rms as %peak speed	bias	correlation	skill	scatterIndex
SN011AH speed	0.12	0.60	21	0.11	0.95	0.85	38
SN011J speed	0.27	1.05	26	-0.17	0.78	0.72	47
SN011D speed	0.40	1.30	31	-0.29	0.76	0.61	48
SN011B speed	0.15	0.80	19	0.10	0.88	0.90	33
SN011L speed	0.11	0.60	18	-0.03	0.83	0.90	28
SN011M speed	0.14	0.70	20	-0.06	0.83	0.89	30
SN011K speed	0.15	0.70	22	-0.10	0.90	0.85	38
SN011F speed	0.25	1.20	21	-0.20	0.89	0.79	40
SN011N speed	0.31	1.40	22	-0.27	0.96	0.80	37
SN011R speed	0.10	0.90	11	0.01	0.96	0.98	18
SN011S speed	0.09	0.45	19	0.02	0.80	0.88	33
SN011T speed	0.11	0.65	17	0.00	0.77	0.87	23

4.6 Model validation

4.6.1 Validation results

Figure -29: Comparison between NRA high/low water level data (black) and model results (red).

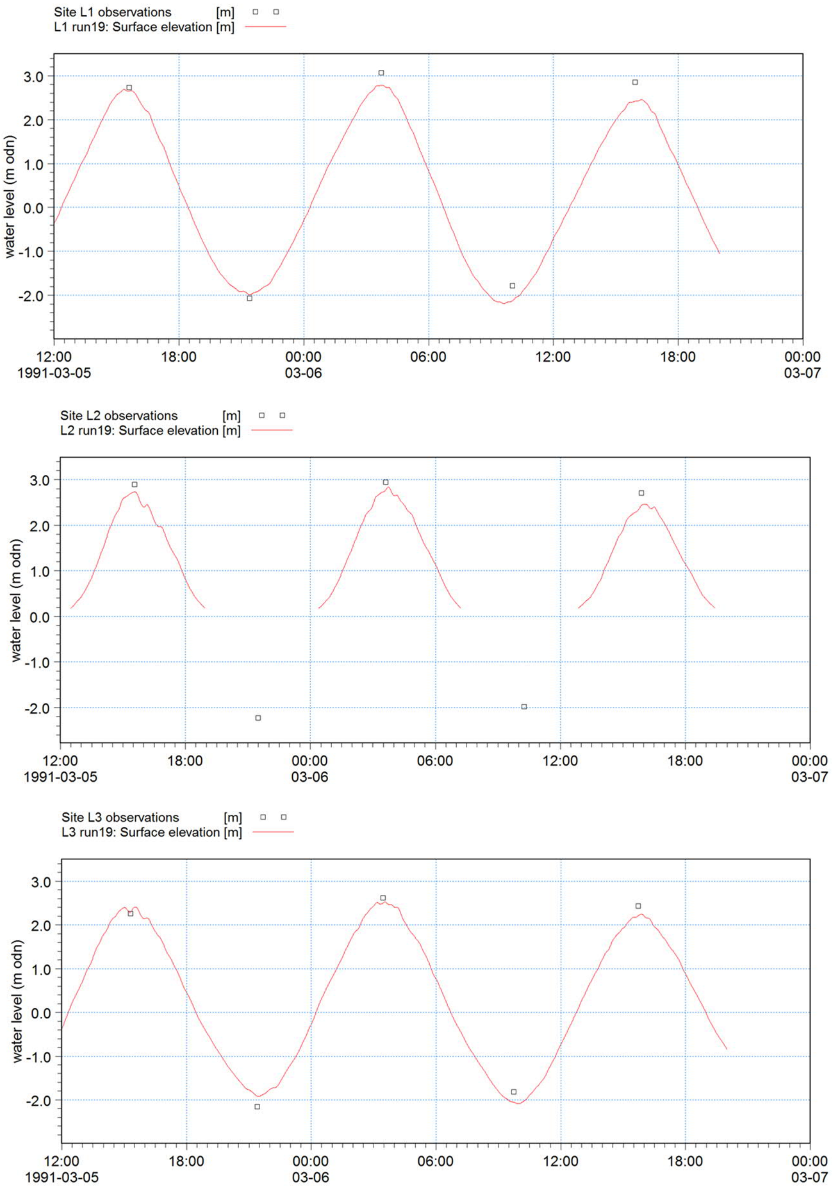
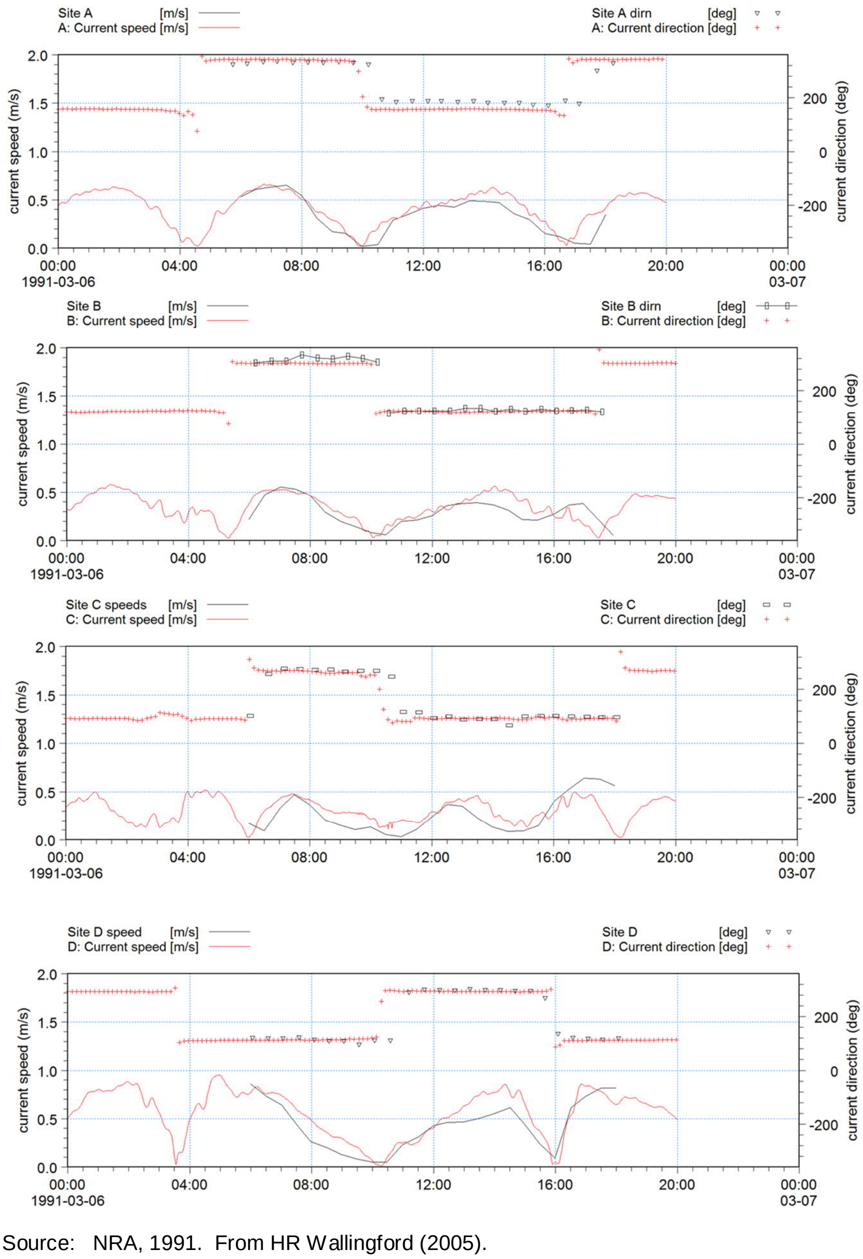


Figure -30: Comparison between NRA current speed data(black) and model results (red).



Source: NRA, 1991. From HR Wallingford (2005).

Figure -29 presents the comparisons between the NRA water level data and the model. Only high- and low-water level data are available and therefore comparisons that can be made are limited. Additionally, it should be noted that the NRA water level data may contain meteorological effects which are not included in the model boundary conditions, as the data was only recorded over a period of one day, it was not possible to remove such effects from the data. At all sites the tidal range and phasing is reproduced well. Location L2 in the model is in an area that dries (locations were only approximate) and so low water levels were not captured fully. However, it can be seen in Figure -29 that the comparison with the model is good in terms of high water level. Similarly at location L3, the comparison of tidal range and levels is good.

Comparisons between measured and predicted current speeds at the four locations shown in Figure -7 are shown in Figure -30. At Site A the comparison between measured and predicted values is good with only a small over-prediction of speeds on the flood tide. It should be noted that the exact location of the sites was not known and changes to bathymetry in the Swale and beyond could have taken place thus adding to the uncertainty in the comparison. The asymmetry in the tide can also be seen in Figure -30 with the ebb currents being slightly higher than the flood, although the difference in the model is not so great.

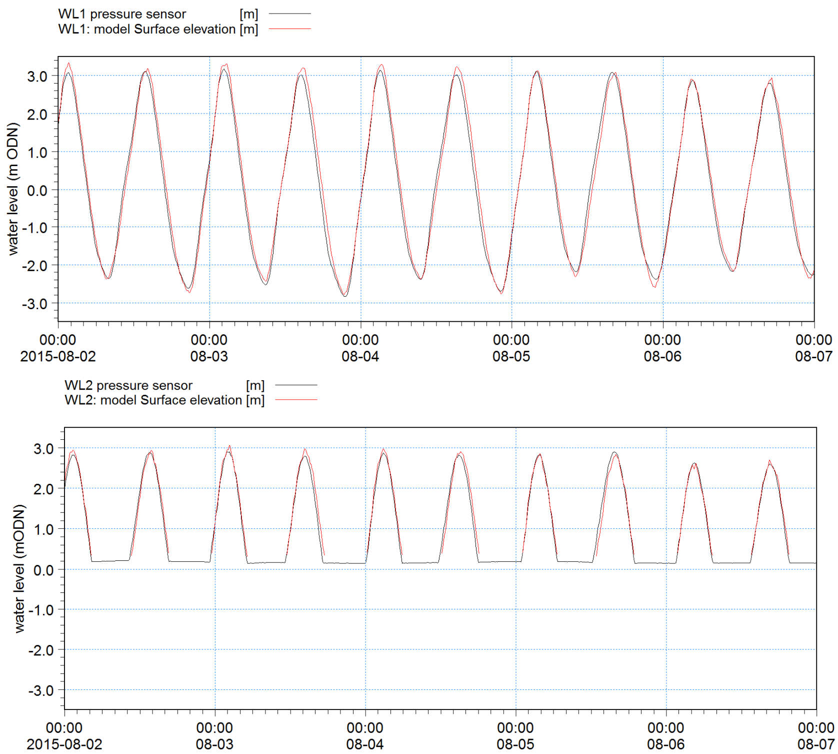
Figure -30 shows also that comparisons between measured and predicted values at the other three locations show similar temporal distributions of current speed although the model has a tendency to over-predict. Uncertainty in the bathymetry occurring since the survey was undertaken, and location errors contribute to these discrepancies.

On the basis of the evidence presented it is considered that the model has reproduced the current regime of the Swale well. The error statistics for the four locations are shown in Table -6.

Table -6 Error statistics between observed and modelled current speeds in the Swale

locationName	rmsError	bias	correlation	skill	scatterIndex
1991 A speed	0.08	0.06	0.95	0.94	21
1991 B speed	0.09	0.06	0.87	0.87	31
1991 C speed	0.11	0.09	0.78	0.70	58
1991 D speed	0.14	0.10	0.93	0.91	38

Figure -31: Comparison between pressure sensor water level data(black) and model results (red)



In August 2015, Mott MacDonald deployed two pressure sensors in the Swale Estuary for the purposes of validating the model in this region. Figure -31 shows the comparisons between model water levels (red) and observed water levels (derived from the pressure sensors) at WL1 (Sheppey Bridge) and WL2 (Shell Ness). The pressure sensor data includes meteorological effects whilst the model does not (astronomic tidal boundary conditions) and therefore an exact match would not be expected. However it can be seen that the level of agreement is very good at the two locations, with the model reproducing the increase in high water level from Shell Ness (WL2) to the middle of the Swale at Sheppey Bridge (WL1).

4.7 Extreme water level validation

4.7.1 Introduction

Sections 4.5 and 4.6 presented the calibration and validation of the MEASS hydrodynamic model. These concentrated on the water levels and current speeds within the normal tidal limits of the Medway and Swale estuaries. One of the purposes of the MEASS model is to examine the effect that a range of proposed schemes has upon the tidal flooding within the estuaries. This section therefore presents the validation of the model water levels and flood extents under extreme water level conditions.

A number of datasets are available for this validation. Firstly tide gauge data is available at three locations within the Medway (Sheerness, Queenborough and Smurfit) and secondly flood extents are available from the output of the TUFLOW flood model of the Medway and Swale estuaries, JBA (2013).

During this validation process, issues with some defence levels within the MEASS model were identified and adjusted, mainly from comparisons against flood extents in the TUFLOW model. Where a difference was identified, the defence level (default was from the AIMS database) in the MEASS model was compared with both the TUFLOW model and the latest lidar (2014) data and the most appropriate level was then chosen and the simulation repeated.

A comparison of the MEASS model water levels has been made against recorded levels during the large surge tide experienced on the 5/6th December 2013 and the comparison of flood extents was made for the 1:20 and 1:200 year return period extreme water levels (defined at Sheerness). For the latter two simulations a river flow of 100m^3/s was applied. This represents the 1:1 year return period and is the value used in Mott MacDonald (2007). There was no recorded river flow for the Medway during the December 2013 event and a value of 100m^3/s applied initially raised low water levels too much and therefore a mean flow rate (11.4m^3/s) was applied in the simulation. As discussed earlier the river flow has very limited impact upon high water levels.

For the extreme water level simulations that will be undertaken as part of this Strategy Study and reported in later sections of this report, a constant flow rate of 100 m^3/s has been applied. Whilst slightly conservative, the effect of the higher flow was only observed at low to mid-level water levels and thus do not affect the high water levels significantly. This was felt to be a slightly conservative approach…

4.7.2 Extreme water level validation

On the 4th to 6th December 2013 a storm and associated surge affected much of the UK with one of the worst affected areas being along the southeast coast of England. A report entitled The Kent and South London Winter 2013/2014 Floods (Environment Agency, 2015) presents in some detail information on the tidal/surge characteristics and the areas affected by flooding.

For validation of the MEASS model suitable boundary conditions were developed which allowed the surge from Sheerness to be applied to the open boundaries of the model. The surge was obtained from the Class ‘A’ tide gauge data freely downloaded from the National Tide and Sea Level Facility (NTSLF) website (http://www.ntslf.org/) which provided measured water level, astronomical tide and residual (or surge) component. The surge tide was adjusted for phasing as described above and applied to the eastern (Herne Bay) and western (Coryton) boundaries.

The tide gauges at Sheerness, Queenborough and Smurfit were used to compare against the water level results from the MEASS model. The Queenborough gauge data was shifted vertically upwards by 0.3m to account for the discrepancy previously determined (Table -4).

Figure -32: Comparison between modelled and observed 5/6th December 2013 water levels during large surge event. data(black) and model results (red)

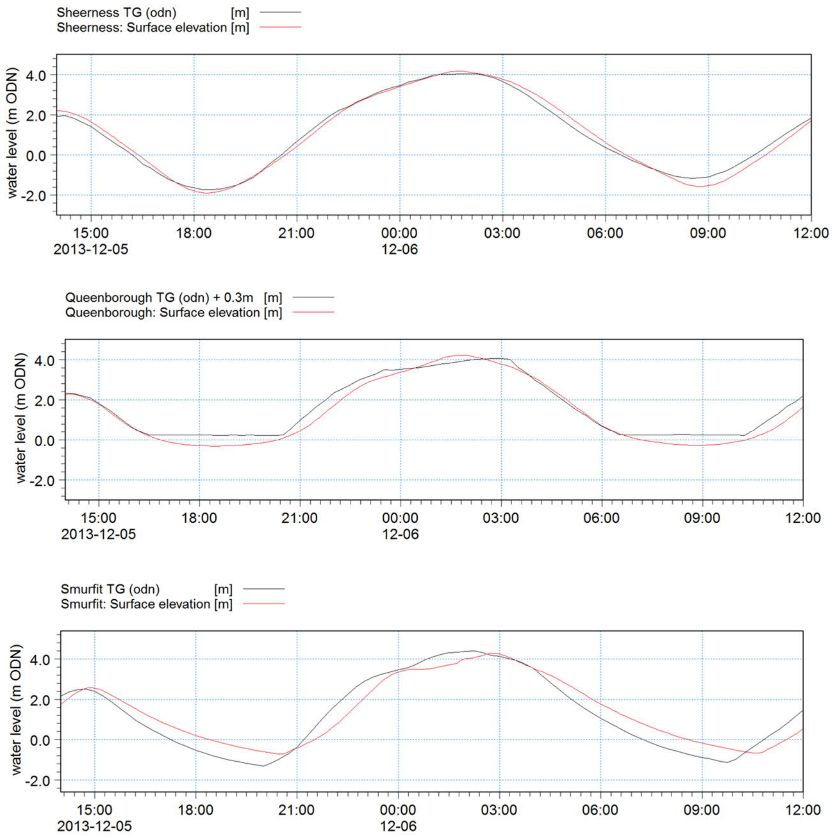


Figure -32 shows the comparisons between the MEASS model and the recorded water levels during the period of the high surge tides. The water levels at the peak high water on the morning of the 6th December 2013 (model and observed) can be seen in Figure -32 along with the difference between the two.

Water levels at Sheerness are predicted to be 4.16m, 0.13m above the observed value of 4.03m. However, boundary conditions for the model are defined at Herne Bay and Coryton which makes it difficult to get the water level to exactly match the measured value at Sheerness. It is noted that the difference between measured and predicted values of 0.13m falls within 10% of the measured level as defined in Table -3.

Table -7 water level comparison for high water on the morning of 6th December 2013

	Model water level (m ODN)	Tide gauge level (m ODN)	Difference (m)
Sheerness	4.16m	4.03m	+0.13m
Queenborough	4.22m	4.06m	+0.16m
Smurfit	4.26m	4.40m	-0.14m

Following a vertical adjustment of 0.3m made to the gauged levels at Queenborough the modelled levels overestimate the recorded levels by 0.16m which falls within the 10% goal set out in Table -3.

At Smurfit on the upper reaches of the tidal Medway, predicted high water levels are 0.14 m below the measured levels. There does however appear to be a phase shift of about 35 minutes, with the modelled high water appearing later than the observed. Additionally there is a double peak in both the observations and the model results and the phase shift is more evident than at the time of high water. As the model is being used to determine flood levels and extents, it is felt that the phase difference is of secondary importance compared with the high water levels which are well within the 10% goal set out in Table -3 for the mouth of the estuary (and within 25% at the head of the estuary).

4.7.3 Flood extent validation

A TUFLOW model, JBA (March 2015) had been previously developed to provide flood maps for a range of return period events, defence options and sea level rise. This model has been adopted previously by the EA as their main tool for examining flooding in the Medway and Swale estuaries.

However, the purpose of the MEASS model is to inform the Strategy Study and needs to consider changes to intertidal and subtidal flows, fine sediment transport and flood extents brought about by the various options under consideration. Consequently there are differences between the two models (resolution, boundary specification, defence levels etc.) which prevent results from the two models being directly comparable.

For the extreme water level simulations the boundary conditions were built up from a number of components (Figure -33); an astronomic tide and a surge. The unit surge profile was taken from the CFB study for Sheerness. This was scaled and added to a mean spring tide (with its peak aligned with low water - as was the case for the TUFLOW modelling) so that the combined mean spring tide peak high water matched the target return period water level at Sheerness. Figure -33 shows these components as well as the combined surge + tide time-series (green line) which has been used as the boundary condition at the eastern boundary; the western boundary underwent the same process. As the model boundaries are some way away from Sheerness (western boundary is 17km, eastern is 22km), and the required peak water level at Sheerness was not attained on the first simulation, some iteration was required by adjusting the scaling applied to the unit surge at the two boundaries and rerunning the model until it was. Table -8 presents the target extreme water level and the final simulated water levels at Sheerness following this process of adjusting the surge scaling.

Figure -33 Components of the boundary curve applied at Herne Bay

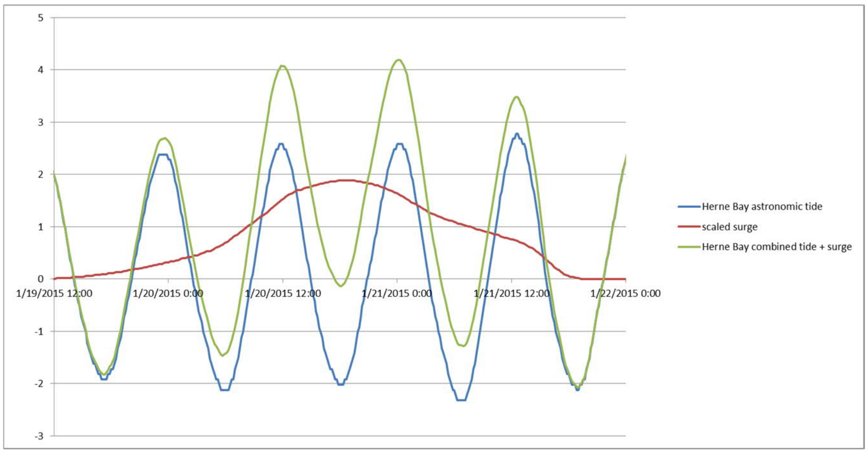


Table -8 target and final attained water levels at Sheerness

Return period (year)	Target water level at Sheerness (m ODN) (from CFB study)	MEAS model water level at Sheerness (m ODN)
1:20	4.130m	4.133m
1:200	4.640m	4.644m

Figure -34: 1:20 year flood extent (present day defenced), with 1:20 year TUFLOW model results highlighted (grey line). Note that the grey shaded area outlined in black is undefined.

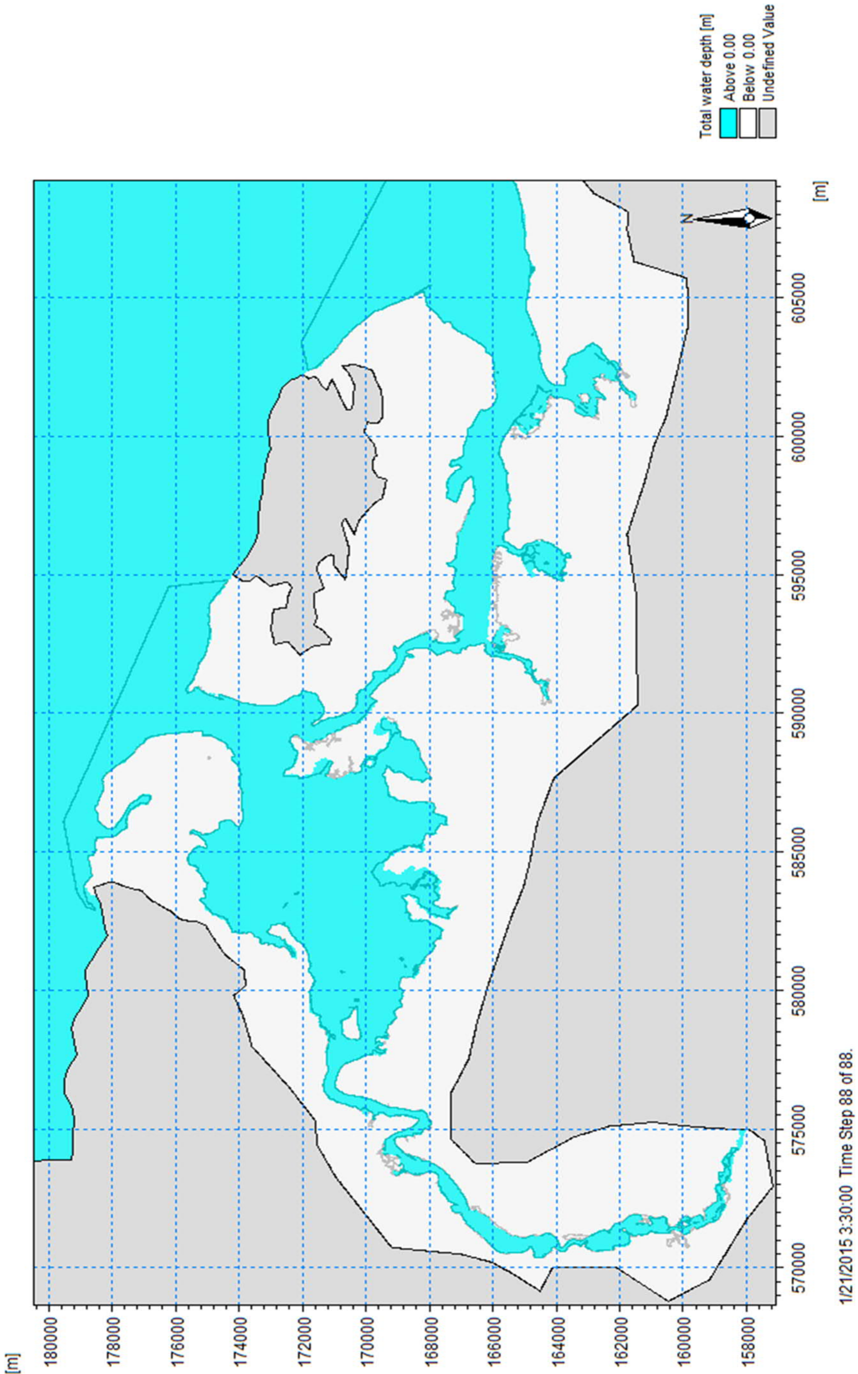
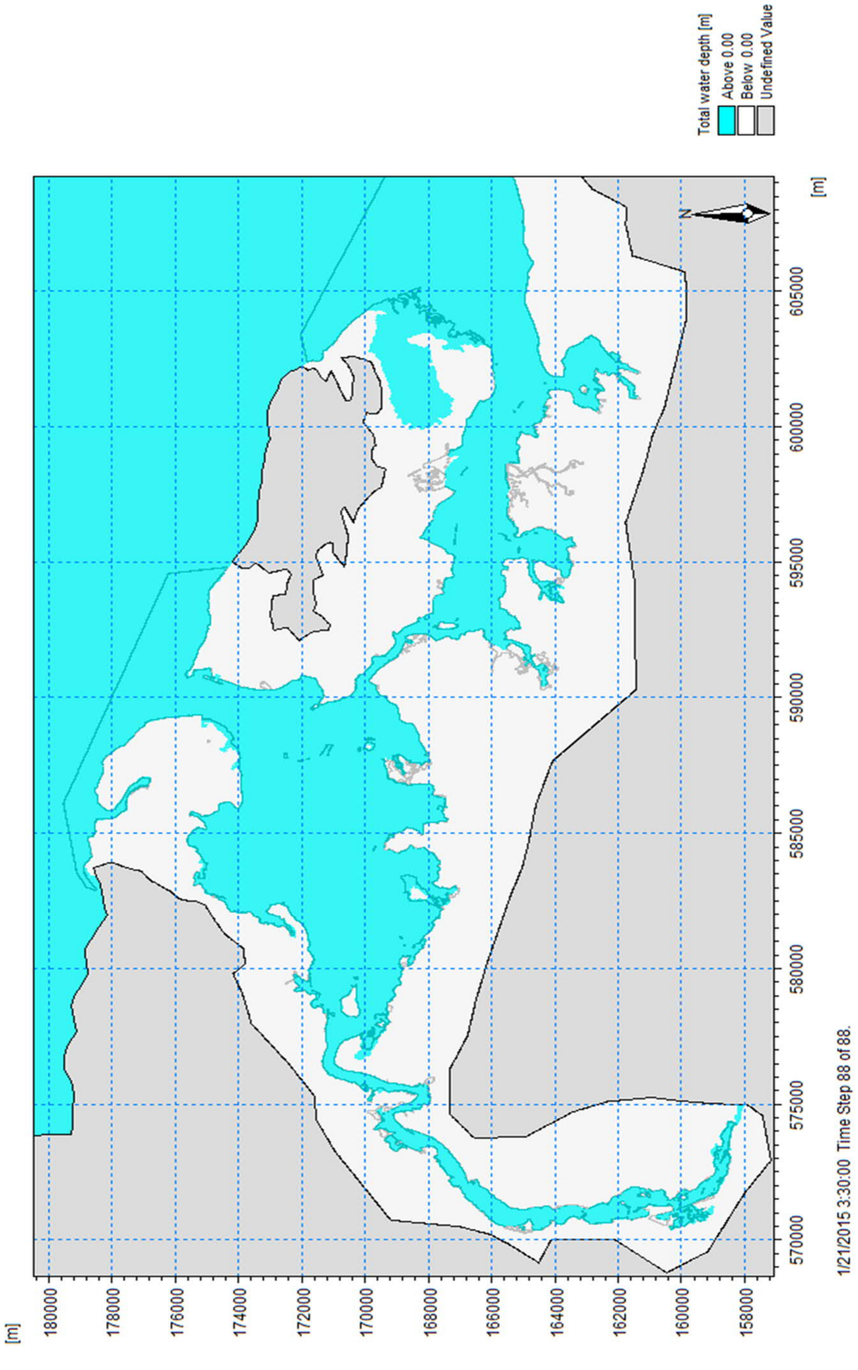


Figure -35: 1:200 year flood extent (present day defenced), with 1:200 year TUFLOW model results highlighted (black line). Note that the grey shaded area outlined in black is undefined.



Flood extents predicted by the MEASS model are shown in Figure -34 (1:20 year) and Figure -35 (1:200 year). In both of these figures the extent of the predicted TUFLOW model (JBA, 2015) flood extent is shown as a grey line. The blue polygon shown in these figures represents the maximum flood extent for the period between the beginning and the end of the simulation. Flood extents between the two models match well; they would not be expected to be exactly the same due to different model setups (including boundary configurations), bathymetry, topography, defence heights resolution etc.

After a careful inspection of the differences in flood extent predicted by each model, adjustments were made to the defence height in the MEASS model Initially the default defence height used was from the AIMS database, but where there were significant differences between flood predictions from each model lidar data from 2014 was examined and where necessary the defence level were updated in the MEASS model. The results shown in Figure -34 and Figure -35 include the final defence heights following this process.

Differences in flood extent are less obvious for the 1:20 year event, however there are still some differences that can be seen (Figure -34). For the 1:200 year flood extent (Figure -35) the main differences appear to be at the eastern end of the Isle of Sheppey, and on the north and south banks of the Swale (approximate easting 598000mE). At the eastern end of the Isle of Sheppey, the lidar and Aims levels are both lower than that in the TUFLOW model.

4.8 Summary

The MEASS model has been shown to calibrate and validate well under normal tidal conditions for both water levels and current speeds. In addition the model has been validated against observed extreme water levels during the 5/6th December 2013 storm and flood extents predicted by a TUFLOW model of the Medway and Swale (JBA, 2015). It is considered therefore that the MEASS model has been demonstrated to be calibrated and validated with sufficient accuracy to meet the objectives of the Medway and Swale Strategy Study. Further, the good representation of hydrodynamics in the models will now allow use of a MIKE sediment transport module to simulate the behaviour of the cohesive sediments that dominate the study area, and thereby inform studies of morphodynamics.

5 Sediment transport model

Executive summary

In order to simulate the mobilisation, transport and accretion of the cohesive sediments that dominate the Medway and Swale estuaries, the MIKE21 Mud Transport (MT) module was added to the MIKE21 HD model. The establishment of the baseline MT model will enable subsequent first-order assessment of the potential environmental impacts on estuarine sediments that may arise as a result of implementing one or more managed realignment schemes.

Reported studies of the sediment dynamic in the Medway are rather contradictory. With these opposing views of estuarine sediment dynamics, the approach to calibration of the MT model has been founded on what was believed to be the most reliable data available, albeit limited in spatial and temporal extent to achieve the best modelling outcome possible.

It must be noted that the Medway and Swale estuaries are part of the Water Quality Archive which provides data on water quality measurements carried out by the Environment Agency. Suspended sediment concentration and turbidity measurements are used in this study to support the model validation process and the understanding of the sediment dynamics in the estuaries.

Following DHI guidance the MT model was set up using all available information and estimates of a number of required site specific parameters including the threshold for erosion and accretion and for bulk density.

It is considered that within the constraints imposed by the available calibration and validation data, the modelled sediment concentrations over the whole MEASS area are representative. This is evidenced by the generally good agreement between predicted suspended sediment concentrations and measured values. Further, the predicted net deposition rates compare favourably with rates reported in the literature.

It is important to note that the MEASS model is only simulating the dynamics of the mud fraction in the Medway and Swale estuaries for Spring and Neap tide conditions and constant offshore sediment concentrations. Nevertheless, it has been demonstrated here that through the model calibration and validation processes using as many site-specific parameter settings as possible, of the overall behaviour of suspended sediment and net sedimentation patterns in the Medway and Swale estuaries are reproduced favourably.

For the purposes of assessing schemes impacts it is the relative differences between baseline and scheme cases that has greatest utility and in this respect the present MT model is judged to be appropriate for use in this strategy study.

5.1 Introduction

The impacts of options put forward as part of the strategy should be assessed with regards to water levels, current speeds, flood extents and the sediment regime and associated intertidal saltmarsh and mudflats. Thus as part of this strategy study this section of the report details the establishment, calibration and validation of a model that provides a baseline understanding of the sediment regime in the Medway and Swale estuaries. This is particularly important for assessing wider environmental impacts of potential realignment schemes.

It is noted from the outset that in common with many studies of this nature, the availability of data relating to bed sediment composition and the concentration and provenance of suspended sediments are extremely limited. While these data limitations have been supplemented by field measurements and laboratory analyses, it has been necessary to make a range of broad assumptions during the model build and calibration phases. These assumptions are based on experienced gained in past studies and the skill and knowledge of the modelling team and have been examined systematically in a number of sensitivity analyses reported below. This approach provides a well-founded basis for subsequent comparative studies of scheme impacts for this strategy.

In order to simulate the mobilisation, transport and accretion of the cohesive sediments that dominate the Medway and Swale estuaries, the MIKE21 Mud Transport (MT) module was added to the MIKE21 HD model. The establishment of the baseline MT model reported here will enable subsequent first-order assessment of the potential environmental impacts on estuarine sediments that may arise as a result of implementing one or more managed realignment schemes.

The MIKE MT module is based on the cohesive sediment formulae from Mehta et al. (1989). The model is driven by MIKE21 HD derived currents that define the bottom shear stress and include descriptions of bed sediment strength, sediment entrainment and deposition thresholds and suspended sediment settling velocities (accounting for flocculation and hindered settling, Lumborg et al., 2012). The MT module is considered to be appropriate for estuaries where a large proportion of the sediments have cohesive properties. In the present case 52% of the total area of the Medway Estuary is dominated by mudflats (Halcrow, 2010) composed of silty sands, clays, and remnants of consolidated sediment. Similarly, the Swale is dominated by mudflats (2414ha), which become more sandy and gravelly towards the eastern mouth. Use of the MT model is thus appropriate.

Reported studies of the sediment dynamic in the Medway are rather contradictory. On one hand Kirby (2013) describes the Medway as being a sediment-starved, erosion-dominated estuary with a net seaward transport of fine sediment. Similarly, Deloffre et al. (2007) also described Medway Estuary as a sediment starved system with relative stable mudflats. On the other hand, Halcrow (2010) describe both Medway and Swale as undergoing net accretion and refer to previous studies that draw similar conclusions (e.g. IECS, 1993; MESO, 2001, Dalton & Cottle 2002; and Halcrow, 2002). Further, in the Medway and Swale SMP, Halcrow (2010) describes the estuaries as being a weak sink for fine sediment and that the volumes of sediment being deposited onto the saltmarshes are greater than that being lost in the erosion of the saltmarsh cliffs and mudflats. Irrespective of these differing opinions it is clear that losses or gains of sediment in the estuary are low and consequently present day morphological changes are very slow. This remains an important point to keep in mind when assessing the impacts of any proposed realignment in the Medway-Swale estuaries.

From a sedimentological point of view, the Medway exhibits two distinct characteristics according to Deloffre et al. (2007): (a) the absence of sands on intertidal mudflats; and (b) the reworking of fine particles within the estuary. This last feature is a consequence of an absence of a significant external sediment supply and again supports the view that net sediment erosion/accretion is low throughout the estuaries.

With these opposing views of estuarine sediment dynamics in mind, our approach to calibration of the MT model has been founded on what we believe to be the most reliable data available, albeit limited in spatial and temporal extent to achieve the best modelling outcome possible.

It must be noted that the Medway and Swale estuaries are part of the Water Quality Archive which provides data on water quality measurements carried out by the Environment Agency. Samples are taken from sampling points around the estuaries dating from 2000 to 2015. Suspended sediment concentration and turbidity measurements are used in this study to support the model validation process and the understanding of the sediment dynamics in the estuaries.

It should be specifically noted that although the model is unable to provide accurate specific values for sediment erosion and accretion it will allow assessment of the relative changes that may result from realignment schemes. It is considered therefore that the model has a capability to address concerns associated with potential changes to estuarine sediment budgets and morphology as required in this study.

5.2 MT model setup, calibration, and validation

Following DHI guidance the MT model was set up using all available information and estimates of a number of required site specific parameters including the threshold for erosion and accretion and for bulk density. Following standard practice, the model calibration was undertaken iteratively, using successive model results to guide adjustments to key MT parameters (erosion/accretion properties, bed thickness initial conditions, initial SSC, boundary conditions, etc.) and to define the initial conditions for subsequent MT model runs. By this means, it was possible to converge the SSC values and accretion rates predicted by the MT model towards values defined by the calibration and validation data described below. The selection of initial values for MT parameters was guided by DHI recommendations and the experience of the modelling team in other projects.

The MT model calibration aimed fundamentally to optimise agreement between model predictions and measurements of suspended sediments and accretion rates in the Medway and Swale estuaries. Calibration of the model for suspended sediments was undertaken for a Spring tide period that was selected to be coincident with the suspended sediment measurements obtained in the Swale by Mott MacDonald in July 2015. Additionally, sediment accretion rates predicted by the model were compared with measured accretion rates (Cundy et al., 2007; Deloffre et al., 2007) on a saltmarsh in the upper reaches of the Medway. In this case both spring and neap tide simulations were run and the net accretion was combined proportionally.

The calibration periods selected were:

- **Spring tide**: 18/07/2015 to 23/07/2015 – Tide range of approx. 5.2m (at Sheerness) covering the period of suspended sediment sampling in the Swale; and
- **Neap tide**: 28/07/2015 to 30/07/2015 – Tide range of approx. 3.1m (at Sheerness).

Validation is the process of comparing the model against a different set of data using the model parameters/setup derived during the calibration to prove that the model is robust enough to be applied to different periods of time or input conditions.

MT model validation was undertaken using the data from the Water Quality Archive of the Environment Agency. The database contains water quality samples, including but not limited to SSC and turbidity, from 2000 to 2015. These extensive dataset is described in more detail in Section 1.2.2.

5.2.1 Calibration data

Although an extensive review of the published literature was undertaken to identify suitable datasets, only a limited amount of data was identified as being suitable for the purposes of calibrating the model. These data include observations and measurements of: (a) suspended sediment concentrations (SSC); and (b) sediment accretion rates.

5.2.1.1 Suspended sediment concentrations (SSC)

Generally suspended sediment concentrations in the Medway and Swale estuaries are low and are typically in the range 0.1 mg/l to 30 mg/l. The suspended load mostly comprise re-suspended fine sediments. Kirby (2013) reports minor sediment exchange with the Greater Thames Estuary while Halcrow (2010) suggests that the most significant supply of sediment for the Medway and Swale is from the Greater Thames Embayment.

Co-located measurements of SSCs and current speeds were obtained by Cundy et al. (2007) in the intertidal mudflats and saltmarshes of the Horrid Hill site, Medway. This location is more than 2km from the main estuarine channel in a sheltered (i.e. from prevailing south-westerly winds) location behind an artificial spit used to supply a former cement works, Figure 36. Here measurements of SSC were obtained using a combination of established and novel (high-resolution) suspended sediment recording devices including:

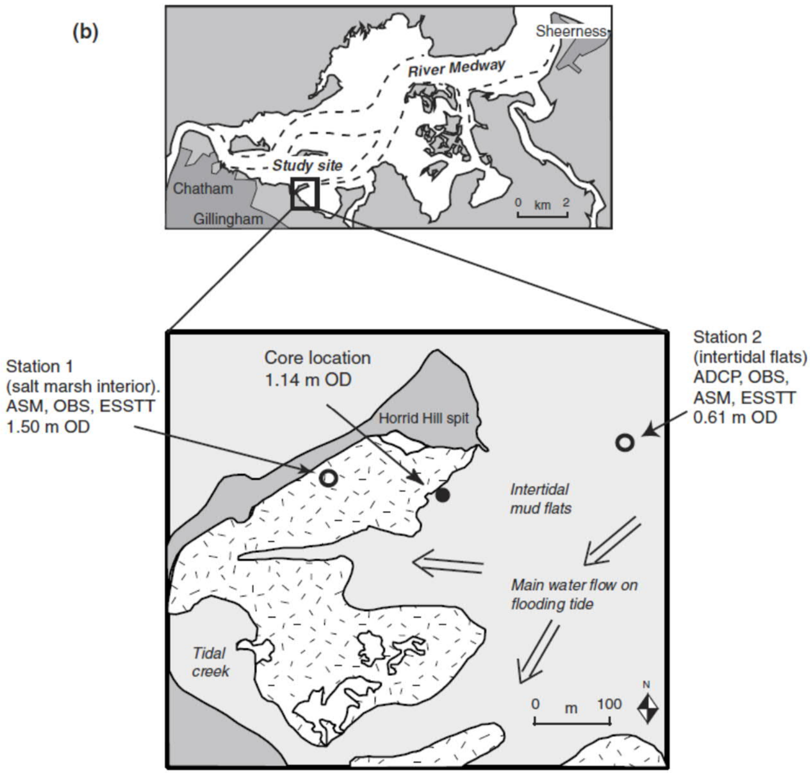
- Acoustic Doppler Velocimeters (ADV);
- Optical Backscatter Sensors (OBS);
- Acoustic Doppler Current Profilers (ADCP); and
- Multi-sensor OBS systems (Argus Silt Meter or ASM)).

The measurements were performed over 4 tidal cycles between 15th and 17th September 2003 at two locations:

- Station 1 - located in the marsh interior; and
- Station 2 – located on the fronting intertidal mudflat.

Passive Estuarine Suspended Sediment Trapping Tubes (ESSTTs) were also installed to estimate total suspended sediment flux.

Figure 36: Cundy et al. (2007) measurements locations in the Medway Estuary



Source: Modified from Cundy et al.(2007)

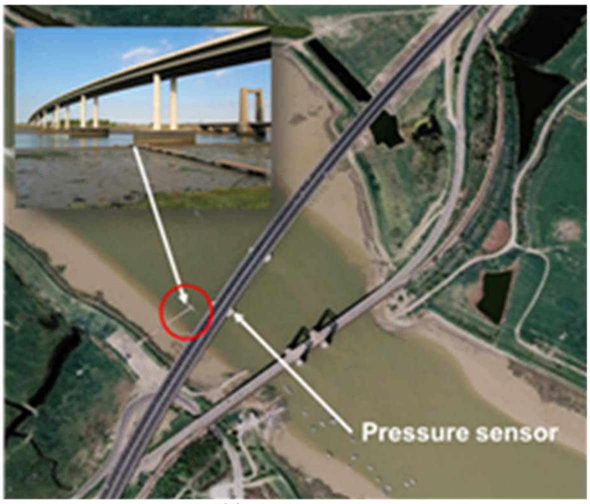
Deloffre et al. (2007) estimated near-bed SSC in the Medway marshes at the same location as the Cundy et al. (2007) study (Figure 36) using the backscatter signal recorded by a 6-MHz Nortek ADV deployed during several spring semi-diurnal tidal cycles under low river flow conditions between 20/06/03-18/08/05. Both Deloffre et al. (2007) and Cundy et al. (2007) reported low SSC values around 100mg/l at the saltmarsh location.

The Medway Estuary suspended sediment load has also been reported by the Environment Agency (2011) as part of principal parameters values of interest in coastal dispersion modelling. While there is no information in the report regarding the source or method used to obtain the presented concentrations of 24mg/l, the value is similar to that reported by Deloffre et al. (2007) and Cundy et al. (2007).

Given that the data from Cundy et al. (2007) and Deloffre et al. (2007) may not be representative of SSC values in the wider estuarine environment and to uncertainty regarding the methodology used by the EA to derive overall SSC values it was judged necessary and prudent to obtain water samples in situ and to analyses these to determine variations in SSC through a typical tidal cycle. This sampling work was undertaken by Mott MacDonald during the site visit to deploy the two pressure sensors in the Swale (please refer to hydrodynamic model calibration and Appendix A).

On 20/07/2015 water samples were obtained at 30 minute intervals between low waters from a pontoon extending into the Swale beneath the Sheppey crossing (Figure 37). These included: (a) near-bed; and (b) mid-water samples.

Figure 37: Location of water sampling



Source: Mott MacDonald, 2016

Selected water samples though the tidal cycle were analysed with and without organic content to determine SSC. The resulting data provided valuable supplementary data on SSC from an area where no other information is available. A full description of SSC sampling, analysis and results is presented in Appendix B.

5.2.1.2 Accretion rates

Deloffre et al. (2007) measured the changes in elevation of the mudflats in the Medway Estuary (Horrid Hill - Figure 36) using Micrel ALTUS altimeter placed at 4.0 to 6.5 m above the lowest sea level. This instrument measured bed elevation at relatively high-frequency (1 acoustic pulse every 20 min), with a spatial resolution of 0.2 cm and a vertical accuracy of 0.06 cm. The instrument was deployed between 20/06/03 and 18/08/05 and the resulting data analysis indicated annual variations in bed-level of around ±1 cm.

Using a closed barrel vibrocorer Cundy et al. (2007) determined medium to long-term sediment accumulation rates via ^{137}Cs and ^{210}Pb dating of sediment cores collected from the low marsh-mudflat boundary at Horrid Hill (Figure 36). Core sub-samples were counted for at least 8 hours on a Canberra well-type ultra-low background HPGe gamma ray spectrometer to determine the activities of ^{137}Cs, ^{210}Pb and other gamma emitters. According to the study, vertical accretion rates at the core location were around 4-5mm/year.

The Environment Agency (2011) also provide an overall guide to sedimentation rate for the Medway Estuary as part of the principal parameters value of interest for coastal dispersion modelling. Similar to the SSC values quoted by the EA, there is no information regarding the source or method used to obtain the presented deposition rates (0.5kg/m^2/year). An estimation of how this value might relate to accretion depths is given in 5.3.1.2.

5.2.1.3 Summary of available data

Table 9 is presenting a summary of the data collected by the Deloffe *et al*. (2007) and Cundy *et al*. (2007) papers.

Table 9: Published information related to sediment properties in the Medway

Property	Deloffre et al. (2007)	Cundy et al. (2007)
Carbonate content	9% to 15%	Not given
Organic matter content	9.5% to 19%.	Not given
Primary grain-size modes	20µm and 40µm	Not given
Sand content	None	Not given
SSC	10mg/l	1 to 100mg/l
Annual variations in bed-level	±1 cm	+4-5mm/year

Source: Mott MacDonald, 2016

5.2.2 Validation data

The Water Quality Archive provides data on water quality measurements carried out by the Environment Agency. Samples are taken from points around the country and then analysed to determine aspects of the water quality or the environment at the sampling point. The archive provides data on these measurements and samples dating from 2000 to 2015. It is a very extensive archive containing 58 million measurements from approximately 4 million samples at 58 thousand sampling points.

Kent and South London region data was downloaded for several years (2005 to 2015 depending on availability). The data was plotted in GIS and filtered in order to analyse only sampling points located in the Medway and Swale estuaries.

Table 10 presents a list of the attributes available in the downloaded data.

Table 10: WIMS (Water Information Management System) data attributes

Heading Left	Heading Right
@id	ID of the sample
determinand.label	Determinands identify a property which can be measured on a sample or the sampling environment, together with the units in which the result of that measurement will be expressed. There are over 7000 such determinands within the Water Quality Archive.
determinand.definition	The definition of the Determinand
determinand.notation	A string or other literal which uniquely identifies the Determinand
determinand.unit.label	The units in which the Determinand is measured
result	A property for conveying the numeric value of a measurement. The units of measure for interpreting the measurement result are a property of measurements determinand. Some measurements have a coded result (determinand.unit=def-units:0992) in which case an additional codedResult property is present that which references the interpretation of the coded value
codedResultInterpretation.interpretation	An open domain property that carries a result code
resultQualifier.notation	A qualifier for the result, e.g. to indicate that the stated result is a lower or upper bound for the actual value
sample.sampleDateTime	A property for expressing the date and time that a sample was collected

Heading Left	Heading Right
sample.samplingPoint	An open-domain property for making reference to a sampling point
sample.samplingPoint.label	An open-domain property for making reference to a sampling point
sample.samplingPoint.easting	easting
sample.samplingPoint.northing	northing
sample.sampledMaterialType.label	The type of material sampled
sample.isComplianceSample	An attribute of a Sample used to indicate whether the sample has been collected for a compliance purpose. The detailed purpose for which the sample has been collected can be determined by examining its purpose property.
sample.purpose.label	A name for the purpose.

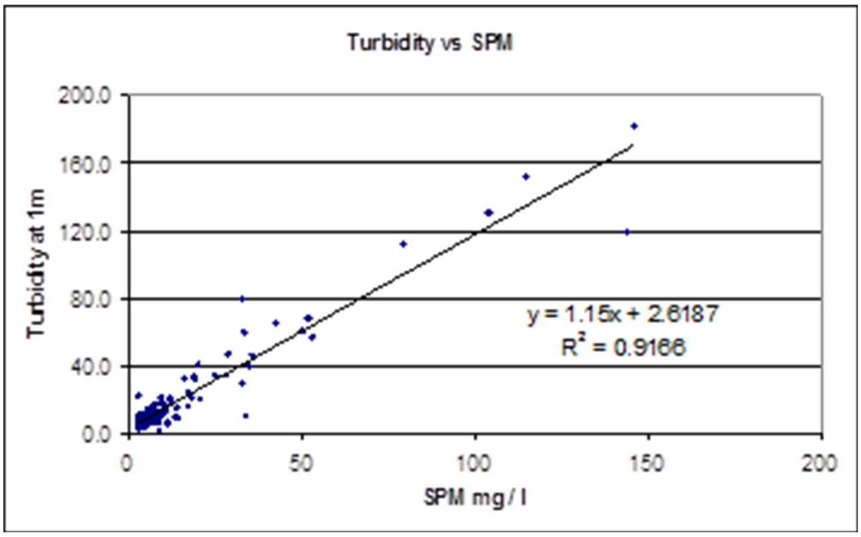
Source: Environment Agency, 2016

The data contained more than 380 determinands (measured parameters). For model validation purposes only suspended sediment concentrations (SSC) and turbidity measurements in estuarine water were relevant. SSC are recorded in the database as Solids, Suspended at 105 C (mg/l). Please note that 105°C refers to the temperature at which the analysis was undertaken.

Turbidity samples are measured in FTU (Formazin Turbidity Unit) which is a measure of the “cloudiness” of the water due to suspended solids. These suspended solids are not necessarily only sediment and may also reflect the presence of algae, decaying matter, phytoplankton etc.

A relationship between turbidity and Suspended Particulate Matter in Transitional Waters was established for WFD (Water Framework Directive) water column assessment (Environment Agency, 2010). Figure 38 shows the relationship used to transform turbidity measurements into SSC for the model validation purposes.

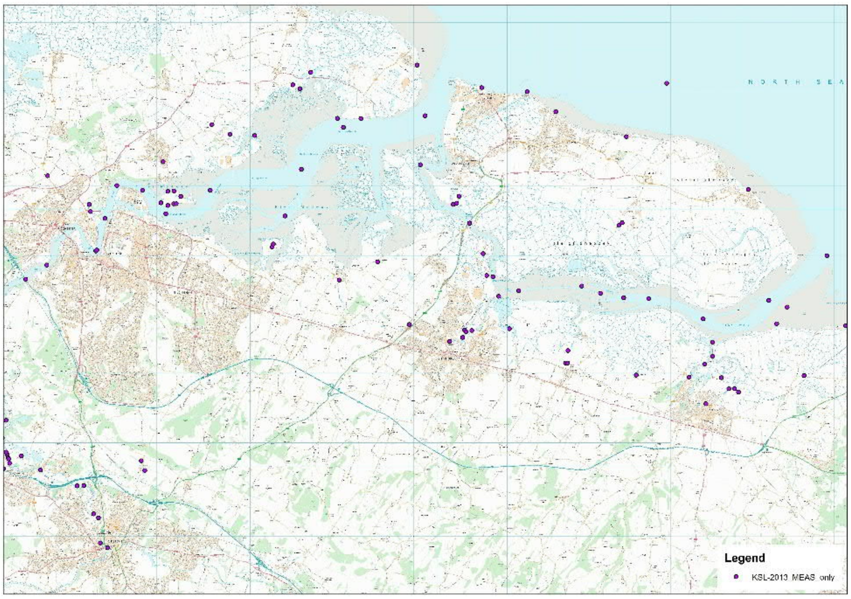
Figure 38: Graph of SPM vs. turbidity, data



Source: Environment Agency, 2010

Figure 39 presents an example of the sampling points available for the Medway and Swale estuaries. It is noted that not all these sampling points contain SSC/turbidity measurements.

Figure 39: Example of WIMS data available from the Medway and Swale estuaries. Note that not all these sampling points contains suspended sediment or turbidity measurements.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016 and Environment Agency data 2016.

Samples from the Water Quality Archive database, have not been recorded in a way that allows the resolution of variations in suspended sediments/ turbidity values over a tidal or spring-neap cycle. Rather they have been recorded ad hoc at much less frequency intervals (typically several measurements per year). Nevertheless, these data are helpful and provide insight into the mean and general variation of the suspended sediment concentrations in the model area. For model validation purposes, the minimum, mean, and maximum model values at several locations in the Medway and Swale estuaries have been compared to this extensive dataset.

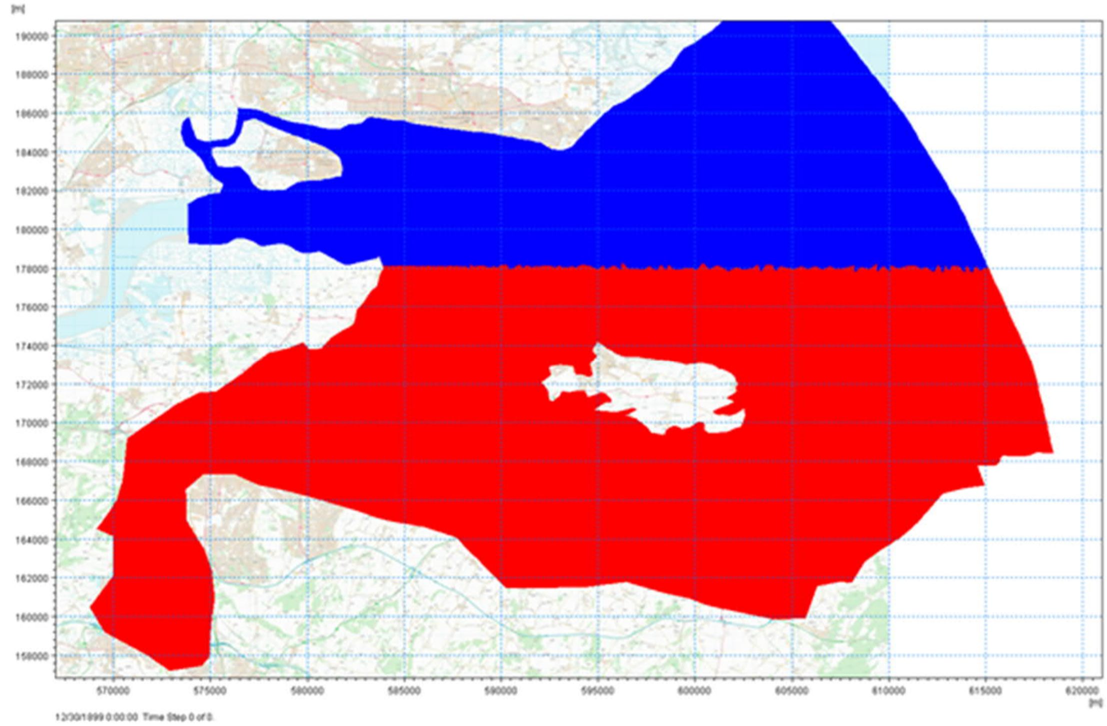
5.2.3 Mud Transport model inputs and parameter setting

In the MT model the erosion, transport and accretion of sediments is governed by the hydrodynamic conditions derived from the MIKE21 HD model. The bottom sediments are described using a three layer structure with each layer having a defined thickness, a bulk density value and erosion/accretion properties. The bed layers are organised so that the "weakest" layer (typically fluid mud or newly deposited sediment) is defined as the uppermost layer. Layers beneath this have increasing bulk density and shear strength to reflect the natural consolidation and compaction of cohesive sediments. The properties of these layers are defined further in section 5.2.3.2. If mobilised the transport of the suspended sediment is calculated in the MT model using the advection-dispersion equation.

5.2.3.1 Hydrodynamic and suspended sediment parameters

Critical bottom shear stress values are defined in the MT model to describe when the suspended sediment will start to erode and accrete. Following MT model guidelines, the accretion of the suspended sediments was assumed to be constant across the model domain, with critical shear stresses for deposition set to 0.07 N/m^2. This is only an approximation as in reality the threshold bed shear stress for erosion and accretion may be different (cf. Whitehouse et al., 2000). Furthermore, in order to maintain the sediment into suspension, and to allow it to enter the estuary, no sediment deposition was allowed in the offshore area of the MT model (Figure 40).

Figure 40: Map of the critical sheer stress for deposition in model setup. Red – Deposition critical sheer stress= 0.07N/m2, Blue - Deposition critical sheer stress= 0 N/m2



Source: Mott MacDonald, 2016

In the MT module, the model uses a constant settling velocity when suspended sediment concentrations are below 0.01kg/m^3. Above this concentration, the model calculates a settling velocity value that depends upon the suspended sediment concentration and the shear stress in the water column. It also accounts for the flocculation of the suspended sediment particles when the ambient conditions are suitable, and particle concentrations are sufficiently high.

As noted above, Deloffre et al, 2007, Cundy et al. 2007, Halcrow, 2010 and Kirby, 2013 all report that SSC values in the Medway and Swale estuaries are low and that the highest observed SSC values within the estuary tend to occur close to high water on spring tides. Deloffre et al. (2007) reported maximum concentration of 250mg/l near the bed in the Medway Estuary. In all case, SSC over the mudflats are lower and typically around 100mg/l. It is further noted that these values are an order of magnitude more that values reported by the Environment Agency (2011) and measured in the Swale in July 2015 (Table 37). As a compromise reflecting the differences in reported SSC values, the initial suspended sediment concentration in the MT model was set to 0.01kg/m^3 (10mg/l).

5.2.3.2 Bed parameters

As there is no information available to define the variability in either bed or suspended sediment properties across the model domain, for simplicity the erosion and deposition characteristics of the sediments in the MT model are defined as being spatially invariant. Thus the properties of each of the three sediment layers across the MT model domain are defined as being constant in composition.

Appropriate values for the erosion coefficient, critical bed shear stress and dry bulk density of each layer were estimated using recommended empirical equations in Whitehouse et al. (2000) for the Medway Estuary. A transition coefficient (representing consolidation) can be used in the MT module to determine a rate at which the properties of the sediment from upper layers are transformed to that of the sediment in lower layers. This coefficient was set to a value of 10^{-8} Kg/m^2/s for the transition between layer 1 and layer 2, and a value of 10^{-9} Kg/m^2/s for the transition between layer 2 and layer 3. These values are founded on experience and broadly in agreement with DHI recommendations, where transition values between 10^{-8} Kg/m^2/s and 10^{-6} Kg/m^2/s are indicated (DHI, 2006). It is noted that in the MT model, the consolidation of bed sediments is generally only relevant over times-scales of several weeks or more. Therefore, over the period of the present simulations, changes in bed consolidation were expected to be negligible and thus will have no detectable impact on the model calibration and results.

As limited information was available to define the density of the sediment in the Medway and Swale estuaries, bulk density values of 1220 kg/m^3 (dry density of approx. 300 kg/m^3) from Whitehouse et al. (2000) were assumed. To account for different sediment consolidation in the MT model, the density of the three layers were variable with a value of: (a) 180 kg/m^3 defined the uppermost soft unconsolidated layer; (b) 300 kg/m^3 for the middle layer; and (c) 450 kg/m^3 for the deepest third layer (Table 11).

Table 11: Inputs parameter for bed layers

Layers	Layer thickness (m)	Erosion Coefficient x 10^{-4} (kg/m^2/s)	Critical Sheer Stress (N/m^2)	Dry Density (kg/m^3)
1	0.01	7	0.59	180
2	0.20	7	0.8	300
3	1.00	7	1	450

Source: Whitehouse et al., (2000); Mott MacDonald, 2015

After the initial run, the thickness of the sediment layers was adjusted using a data post-processing routine so that sediments were not present at locations where the peak bed sheer stress exceeded the critical stress for erosion of a given sediment layer. It is considered that this approach approximates to what would naturally happen if a uniform sediment bed was exposed to the variable bed shear stress distribution in the estuary. Following MT simulation runs used the final bed thickness value from the previous simulation. In effect this provided a 'hot start' for each of the layers and improved model efficiency.

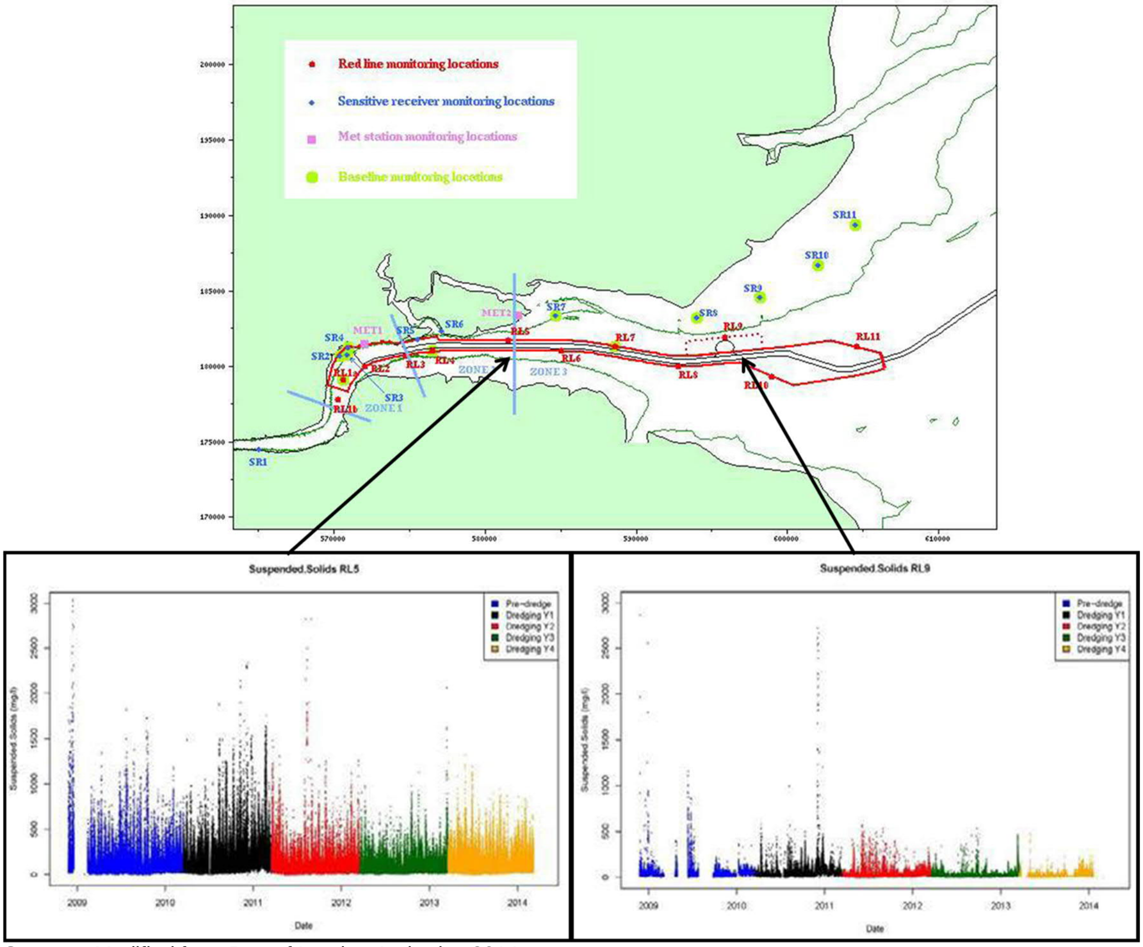
5.2.3.3 Boundary conditions

Given the low suspended loads from fluvial sources, the offshore boundary is the most likely source of suspended sediments for the estuary system. According to Halcrow (2010), the most significant source of sediment to the Medway is the offshore supply of suspended material from the Greater Thames Embayment.

A programme of water sampling at discrete points in the estuary downstream of Gravesend Reach was undertaken in July 2001 by HR Wallingford (2002). The HRW study reported a pronounced concentration gradient with spring tide near-bed concentration values up to 2000 mg/l in Lower Hope Reach. These SSC values decreased to 1000 mg/l at Coryton and further still to less than 100 mg/l at Southend-on-Sea. A similar pattern emerged from the neap tide measurements with maximum SSC values of 500 mg/l in Lower Hope Reach and minimum values of less than 100 mg/l at Southend-on-Sea (Port of London Authority, 2014).

More recently, suspended sediment concentrations (SSCs) were monitored along the Thames Estuary (Sra Reach) between January and December 2009 as part of the London Gateway baseline surveys (prior to the capital dredging and reclamation works). In addition to this baseline monitoring, SSCs were also measured for a variety of locations for a four-year period (2010 to 2014) during the required capital dredging for the London Gateway development. The results from this monitoring, which include the 2009 baseline (blue), are provided in Figure 41. Please note that only the monitoring stations relevant to Medway and Swale numerical model in this Section. For additional information please refer to Port of London Authority (2014).

Figure 41: London Gateway SSC monitoring (2009 – 2014)



Source: Modified from Port of London Authority, 2014

From the results London Gateway SSC monitoring (2009 – 2014), Figure 41 shows that SSC values around the western and eastern boundary of the model are highly variable with values in the western sector ranging between 10mg/ to 3000mg/l and in the eastern sector between 10mg/l and 1000mg/l. Although it is thought likely that the highest SSC values are probably associated with some degree of wave agitation (and possibly fluvial inputs), available information cannot confirm this hypothesis. In the MT calibration processes 'average' SSC values of 500mg/l and 200mg/l were imposed at the western (Medway) and eastern (Swale) offshore boundaries, respectively.

5.2.4 MT model sensitivity tests

Model sensitivity tests seek to establish and to quantify how the MT model output values are affected by changes to the model input values. Although constrained by data availability, sensitivity tests have been undertaken to assess model responses to uncertainties in:

- Offshore boundary conditions;
- Sediment settling velocity; and
- Wave action.

5.2.4.1 Offshore SSC boundary conditions

As shown in Section 1.2.3, there is significant variability in SSC in the Thames Estuary. Further, according to Halcrow (2010), the most significant source of sediment to the Medway is the offshore supply of suspended material from the Greater Thames Embayment. However, Kirby (2013) reports minor sediment exchange with the Greater Thames Estuary.

Information available regarding daily, monthly, seasonal, or annual variations in the offshore SSC boundary conditions adjacent to the model is therefore limited. As part of the model calibration process, SSC boundary data were varied to obtain the best agreement between measured and predicted SSC at key locations within the Medway and Swale model domain.

Taking the measured variation in SSC in the Thames Estuary into account in the calibration process, boundary concentration values of 50mg/l, 100mgl/l, 200mg/l were tested. In addition, a case with spatially varying SSCs was also tested in which SSC was set to 200mg/l close to the coast to account for wave re-suspension and to 100mg/l in the offshore area.

5.2.4.2 Settling velocity

The settling velocity is dependent on the size of the particles in the water column. If the concentration of suspended sediment is high enough, or if other factors act such as salinity and/or temperature changes, sediment particles can bind together to form larger particles known as flocs. When this happens collisions between particles/flocs will increase and floc size will increase further leading to higher settling velocities.

In the MT module, the settling velocity is constant when suspended sediment concentration values are less than 0.01kg/m^3 (10mg/l). Above this concentration value, the MT model defines the settling velocity by accounting for the SSC value and the shear stress in the water column, so that flocculation of the particles is included. In the sensitivity test, the settling velocity coefficient in the model was reduced by 50% in order to determine its effect on SSC values and deposition rates.

5.2.4.3 Waves action

If sufficiently large waves can increase the instantaneous bed shear stress and result in higher erosion rates and higher SSC values. In order to test MT model sensitivity to waves, two wave scenarios were examined:

- **Dominant waves and wind conditions:** Waves and wind conditions were obtained from the CEFAS wave buoy located at 51.4967 deg. N, 1.0187 deg. E from 1980 to 2000 (recorded every 3 hours) and from 2001 to 2015 (recorded every 1 hour). Frequency tables were derived from the data to determine the dominant wave and wind direction. As a result of the analysis a constant wave height of 0.5 m from the ENE with a period of 6s was applied to the model boundary in combination with ENE wind with a speed of 7 m/s. The model sensitivity was assessed for Spring tide conditions.

- **Constant waves over the model domain:** Constant small waves (Hs = 0.1 m, Tp = 0.5 s and Dir = 45 deg. N) were applied for Spring tide conditions over the entire domain. It is noted that while these small waves will not affect the deeper areas of the model, they will impact to some extent on the intertidal areas and mudflats possibly affecting accretion/erosion rates and SSC.

5.3 Model results

5.3.1 Calibration results

5.3.1.1 Suspended sediment concentrations

The results of the SSC sampling that was undertaken in the Swale on the 20th July 2015 are presented in Table 12. As mentioned in Section 5.3.1, three samples collected at different stage of the tide were analysed for MT model calibration purposes. For additional information regarding the sampling and analysis process please refer to Appendix B.

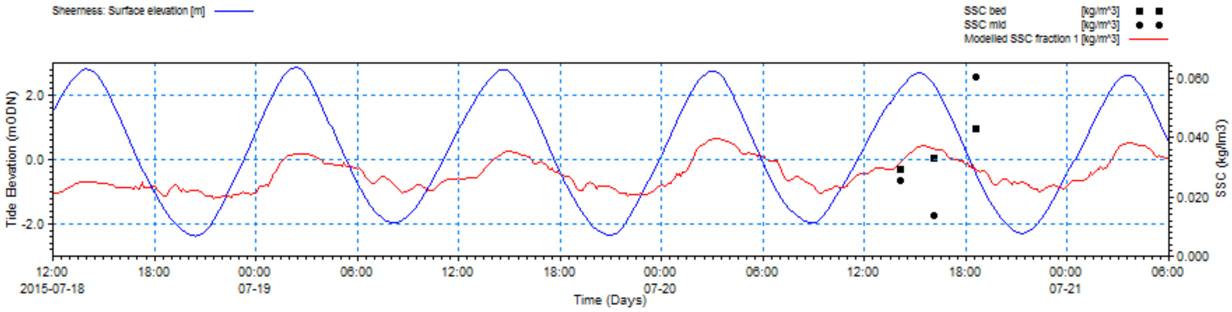
Table 12: Results of the water sample analysis from the Swale, 20/7/2015.

Time	h (m)	h/2 (m)	SSC mid depth (mg/l)	SSC bed level (mg/l)
14:05	2.06	1.030	29.2	25.6
16:05	3.25	1.625	33.2	13.6
18:35	1.37	0.685	42.8	60.4

Source: Mott MacDonald, 2016

Figure 42 shows a comparison between the Spring SSC predicted by the MT model and the measured concentrations in the Swale. These SSC data indicate that over a Spring tide, concentrations reach maximum values close to 0.04Kg/m^3 (40mg/l), with average values around 0.03Kg/m^3 (30mg/l).

Figure 42: Comparison between measured and modelled suspended solid concentration during Spring tide conditions at the sampling location. Please note that the model SSC is expressed in kg/m^3 instead of mg/l – 0.1kg/m^3 is equal to 100mg/l.

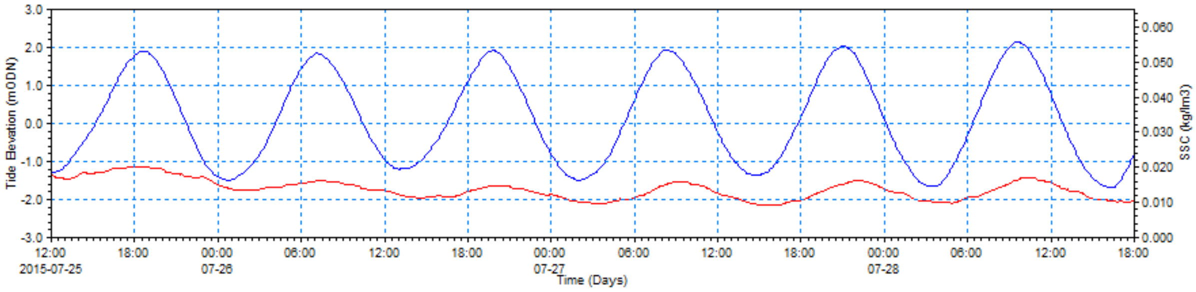


Source: Mott MacDonald, 2016

In general, predicted SSCs have some similarity with the measured concentrations in the Swale during Spring tide. It is noted that the measured data include only 3 samples and therefore, do not cover a complete tide cycle. However, the average values of the modelled sediment concentrations are broadly in accordance with the measured and expected values in the Swale. It is noted also that visually the relationship between water elevation and SSC predicted by the MT model is complex with peak concentrations being reached closed to high water.

Figure 43 presents the modelled SSC at in the Swale during a Neap tide. As there is no measured data, inter-comparison is not possible. From the figure it can be observed that SSC during Neap tides in the Swale are considerably lower than during Spring tides, reaching maximum values around 0.02Kg/m^3 (20mg/l), with average values around 0.01Kg/m^3 (10mg/l).

Figure 43: Modelled suspended solid concentration during Neap tide conditions at the sampling location. Please note that the model SSC is expressed in kg/m^3 instead of mg/l – 0.1kg/m^3 is equal to 100mg/l.

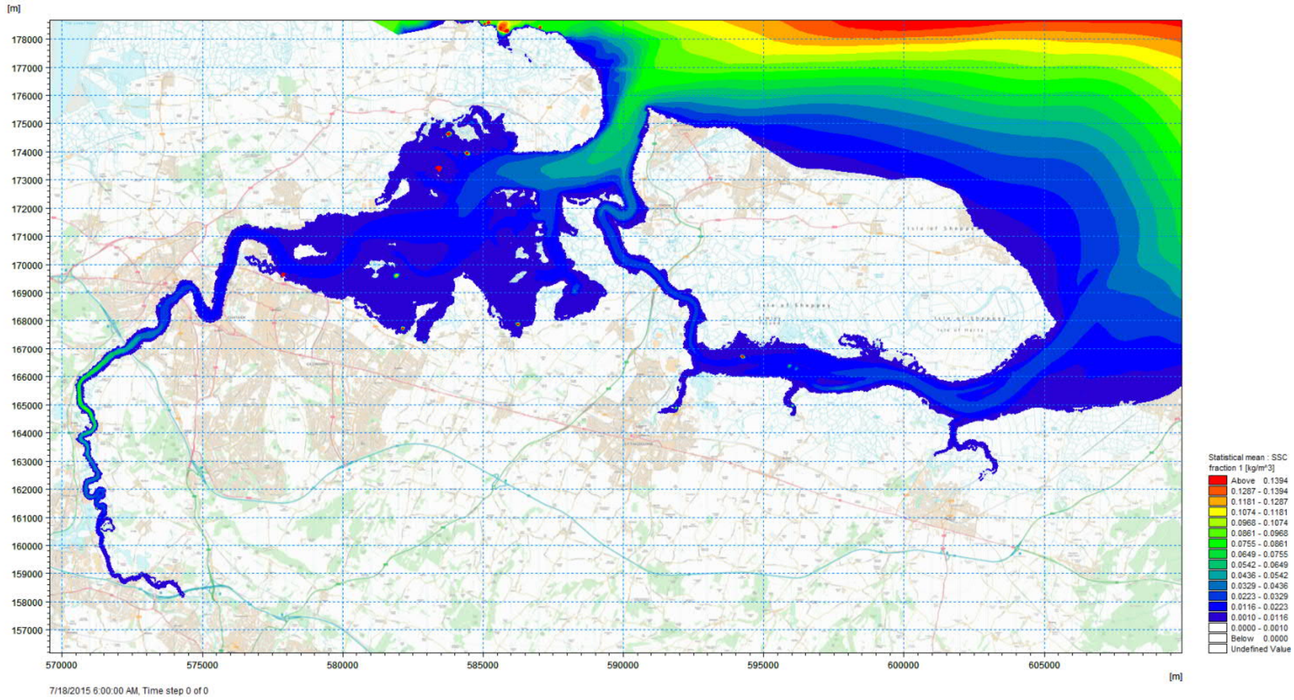


Source: Mott MacDonald, 2016

For the present Strategy study, the priority has been to parameterise the MT model so that the overall distribution of SSC in the Medway and Swale estuaries is reproduced as effectively as possible. It is noted also that understanding relative differences between baseline and future estuaries conditions is an important part of the assessment and thus the absolute accuracy of the model results is arguably less important than ensuring relative differences are simulated well. It is considered that reasonable model skill is demonstrated in Figure 42 and Figure 43. This is further evidenced in Figure 44, which show that the predicted SSC values for the mean Spring tide fall within the typical range of observed values reported above.

Deloffre et al. (2007) report that the SSC measured on Horrid Hill mudflat was always low at around 100mg/l and SSC values in the Medway Estuary reported by the EA are typically around 24mg/l. Both these values are consistent with the mean SSC presented in Figure 44, which shows that most of the Medway and Swale estuaries have mean SSC values between 20-40mg/l.

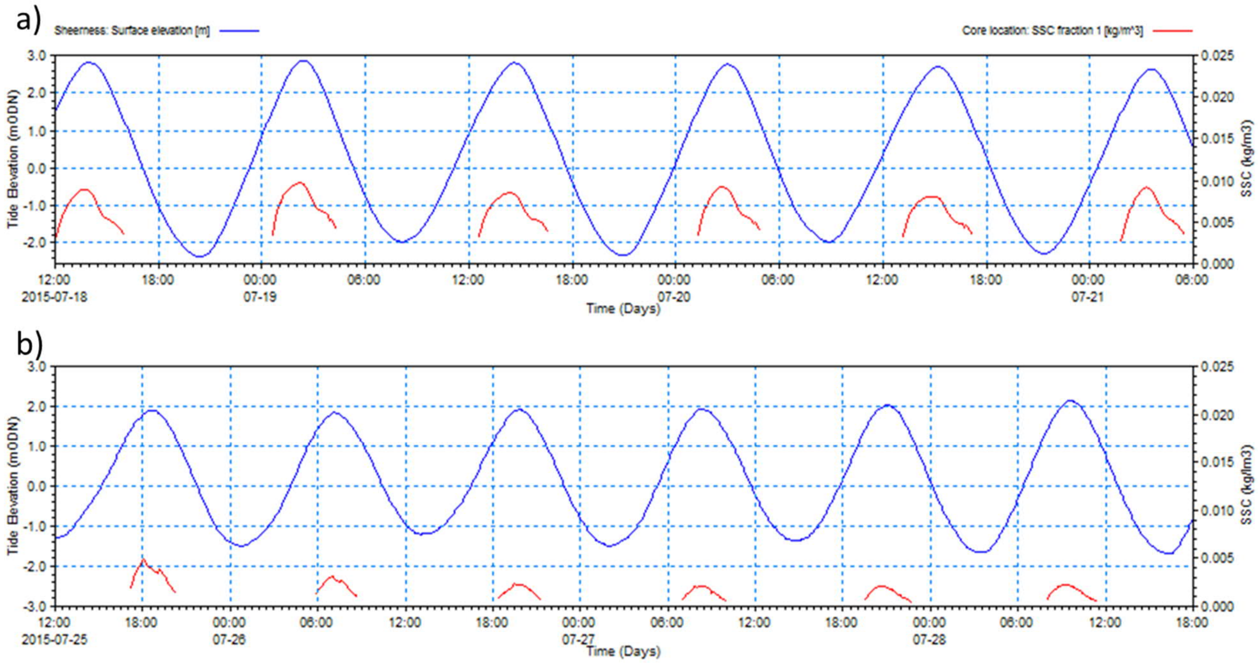
Figure 44: Mean SSC during Spring tide condition. Please note that the model SSC is expressed in kg/m^3 instead of mg/l – $0.1kg/m^3$ is equal to 100mg/l.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 45 shows the SSC for Spring and Neap tide conditions at the location of Cundy et al. (2007) and Deloffre et al (2007) studies. SSC values at this location are low, only reaching maximum values smaller than 10mg/l during both Spring and Neap tide conditions, respectively. The model results are therefore consistent with the low SSC values measured at this location in both studies, which reported low SSC values around 1mg/l to100mg/l at the saltmarsh location.

Figure 45: Modelled suspended solid concentration during Spring (a) and Neap (b) tide conditions at the core location form Cundy et al. (2007) study. Please note that the model SSC is expressed in kg/m^3 instead of mg/l – 0.1kg/m^3 is equal to 100mg/l.



Source: Mott MacDonald, 2016

5.3.1.2 Accretion rates

For the Medway Estuary, Cundy et al. (2007) report a mean sedimentation rate of 4-5 mm/year at Horrid Hill. Using the MT model the net sedimentation at this location was calculated using: (a) the sediment dry density of the third layer (450 kg/m^3); (b) a higher sediment density, as recommended in the Environmental Agency (2011) report for sea water average packed sediments (dry density of approx. 900 kg/m^3); and (c) an intermediate dry density value of approx. 600 kg/m^3.

Net deposition rates were obtained at the core and Station 1 locations (Figure 36) over two tidal periods both for Spring and Neap tide conditions. It was assumed that Spring and Neap tide conditions will dominate the deposition rate in the estuary 50% of the time, respectively. Table 13 presents the results of the calculations.

Table 13: Net modelled deposition rate at the measurement location of Cundy et al. (2007) study.

	Yearly net deposition (mm/year)	
Dry density of the sediment (kg/m^3)	Core location	Station 1
450	3	2
611	2	1.5
937	1.5	1

Source: Mott MacDonald, 2016.

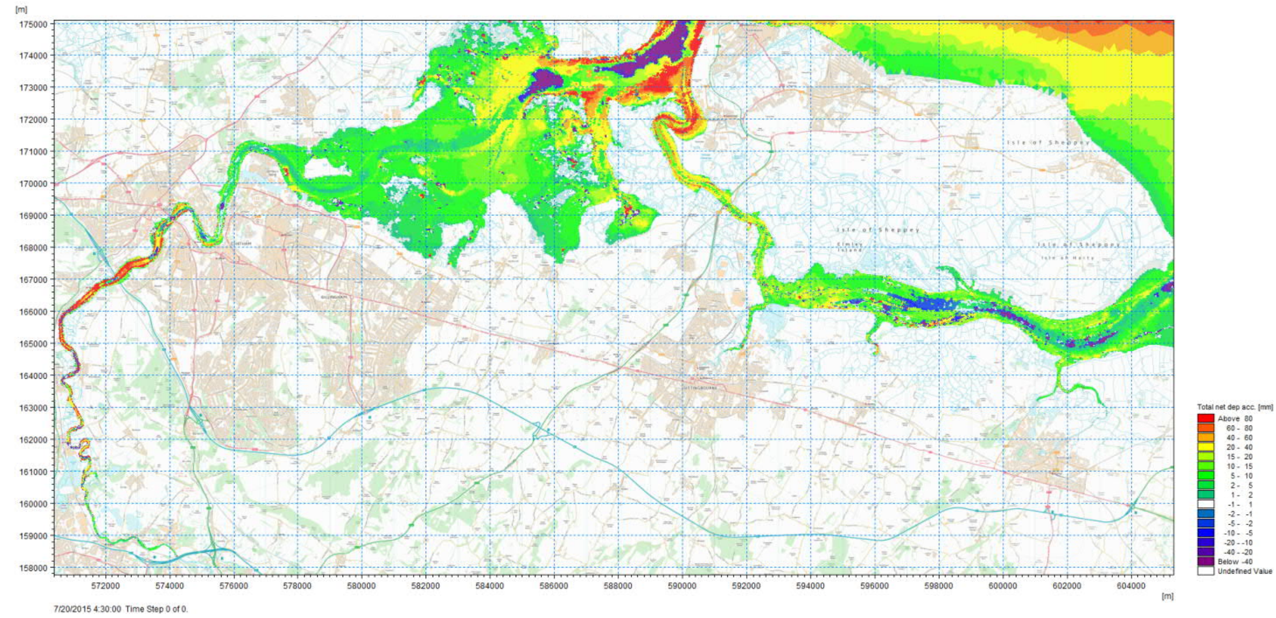
Table 13 shows that the net deposition at the Cundy et al. (2007) study location varies between 1 mm/year to 3 mm/year depending on the density of the sediment. Considering that measurements undertaken by Cundy et al. (2007) study are located higher in the tidal frame, it can be assumed that the sediment density is higher than the lower part of the Medway estuaries (e.g. main channels) and they are exposed to wind, desiccation and consolidation processes for longer than sediments at lower elevations. It is therefore expected that bulk sediment densities will be higher.

Figure 46 shows an annual modelled net sediment accretion rate distribution combining Spring and Neap tide condition and using a bulk wet sediment density of 1400 kg/m^3. Similar, Figure 47 presents the net annual accretion rate distribution calculated using a bulk wet sediment density of 1600 kg/m^3.

It is noted that the distribution and values of net annual accretion rates shown in both Figure 46 and Figure 47 are similar. In reality the bulk sediment density will vary across the Medway and Swale estuaries according to the sediment properties, tidal explosion and estuarine processes. Due to the limited available information, the values used in the MT model to define sediment density may be incorrect spatially and temporally for the both estuaries and thus the results must be treated with caution.

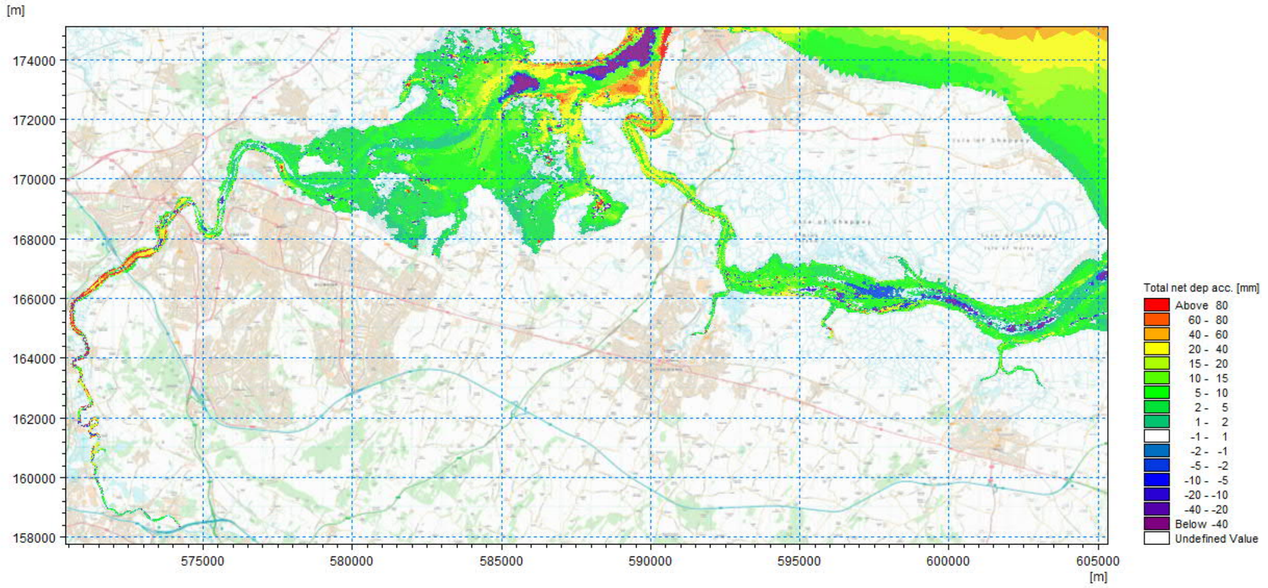
Furthermore, net accretion rates in Figure 46 and Figure 47 have been calculated without considering seasonal variations in the estuaries in terms of tidal range, offshore concentration, storms, river flows, rainfalls, etc. While these processes have not been captured in the sediment model, the simulated results are considered to indicate approximately the patterns and order of magnitude of sediment accretion rates.

Figure 46: Annual modelled deposition map combining Spring and Neap tide condition and using a bulk wet sediment density of 1400 kg/m^3



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 47: Annual modelled deposition map combining Spring and Neap tide condition and using a bulk wet sediment density of 1600 kg/m3



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

According to the Environment Agency (2011), the net accretion rate in the Medway estuary is 0.5 kg/m^2/yr. Since the report does not specify where in the Estuary this deposition takes place, it was assumed that the reported value correspond to the main channels of the Medway Estuary. This deposition rate corresponds to 0.8 -1.1mm/year, using a dry density of 450kg/m^3 and 611kg/m^3 respectively. Rates of this magnitude can be seen in the Medway and Swale in Figure 46 and Figure 47.

Deloffre et al. (2007) study reported that Medway mudflats have relatively stable elevation throughout the year with annual changes in vertical levels around ±100mm. The model results show there are no areas where accretion exceed 100mm.

5.3.1.3 Sensitivity test results

1) Offshore SSC boundary conditions

As noted in Section 5.2.4.1 adjustments were made to SSC values at the offshore boundary of the model during the model calibration process. During calibration, it was found that while changes to SSC values in the eastern boundary had an effect in areas immediately offshore from the estuaries, the effect on SSC in the Swale and Medway, and on deposition rates were small.

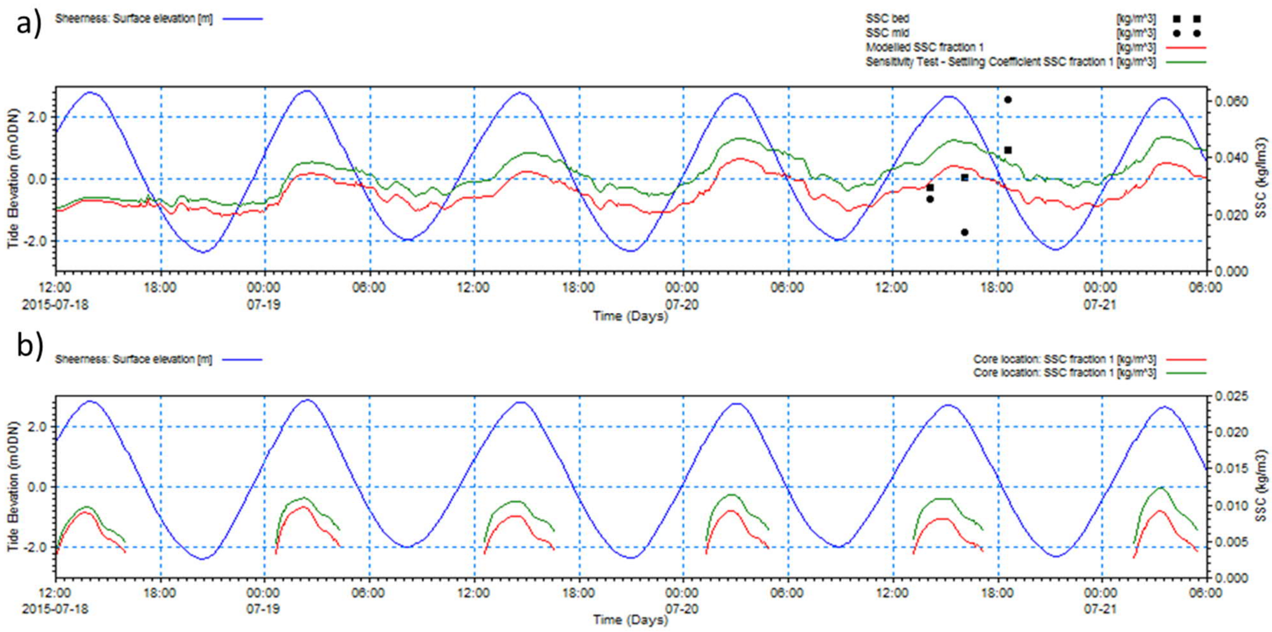
The calibrated model selected 200mg/l on the eastern boundary and 500mg/l on the western boundary. These SSC values gave predicted SSC values that agreed well with two offshore WIMs data points and the best agreement between measured and predicted SSC values at all location in the MEASS model domain. This is discussed further below.

2) Settling velocity

As expected, and as shown in Figure 48, reducing the settling velocity coefficient in the model by 50% from 10 to 5, the modelled SSC increased in both the Medway and Swale estuaries. The figure indicates that slightly higher concentrations of sediments are predicted in the Swale (around 40-50 mg/l). At the same time the accretion rate at the core location reduced by approximately 10% compared to the baseline Spring results presented in the previous section.

Thus while settling velocity has been demonstrated to control to some extent SSC values and accretion rates, the effect is significantly smaller that the variation in reported values and for the range of settling velocity values tested it judged therefore to have relatively little effect on the overall sedimentation regime.

Figure 48: Modelled suspended solid concentration during Spring tide conditions in: (a) the Swale; and (b) at the core location (Cundy et al., 2007). The predicted SSC values using a reduced settling velocity are shown by the green line. Please note that the model SSC is expressed in kg/m^3 instead of mg/l – 0.1kg/m^3 is equal to 100mg/l.



Source: Mott MacDonald, 2016

3) Waves forcing

While waves have little impact on the mean bed shear stress owing to their oscillatory nature, if large enough they can contribute to increase instantaneous bed shear stress, leading to higher erosion/accretion rates and thus to higher concentrations of suspended sediment.

Specifically, sediment mobility under waves and currents has a potential to induced higher SSC in the estuaries. Higher concentrations in the water column could result in turn in larger deposition rates for some areas of the estuaries. Conversely, wave action can potentially enhance rates of erosion while at the same time reducing accretion rates in some part of both Medway and Swale estuaries.

To examine the model sensitivity to wave action, two wave scenarios described above were tested in the MT model:

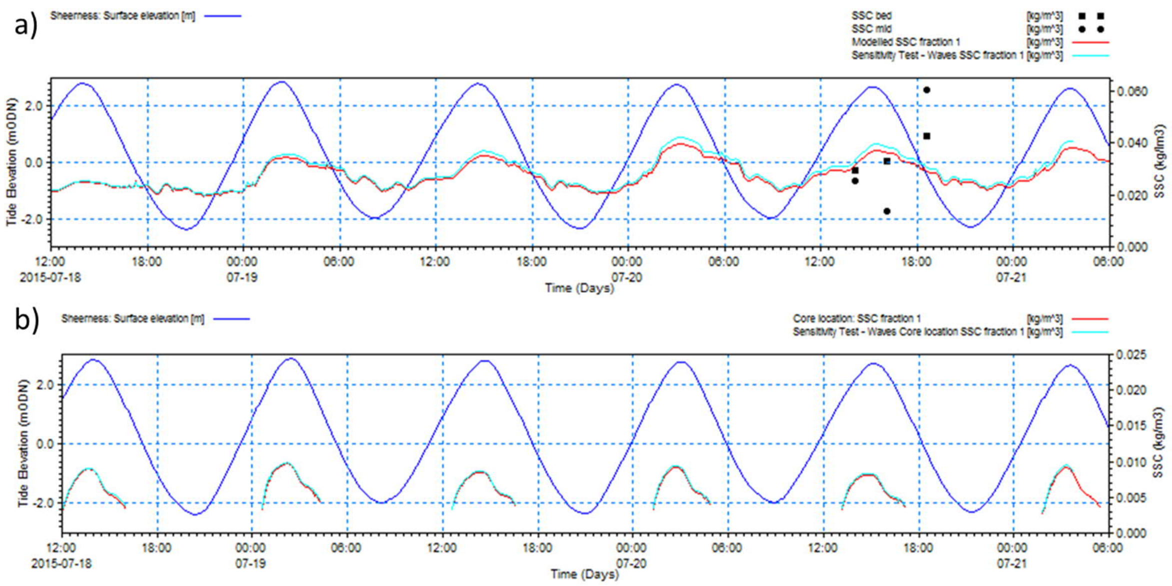
- The dominant waves and wind conditions characterising the study area; and
- Constant moderate waves over the model domain.

In both scenarios, a small increase in the SSC in the Medway and Swale estuaries was observed and demonstrated. Figure 49 shows the modelled SSC for Spring tide conditions in the Swale and at the core location for both wind and wave scenarios.

Since both the Medway and Swale estuaries are sheltered system, the penetration of offshore waves is limited. Further, owing to fetch limitations, local wind generated waves inside the Medway Estuary are small and can only develop during high-water conditions. It is therefore not unexpected that the effect of waves on SSC and on accretion/erosion rates is limited. Model sensitivity tests showed that differences between the accretion rates at the core location were only around 2% larger when waves were included. Given the previously acknowledged assumptions in the MT model, this affect is not considered to be significant.

The results obtained from the wave sensitivity analysis are consistent with the Deloffre et al. (2007) study, which reported that Horrid Hill mudflats shown no evidence of wind-generated erosion events, reflecting the sheltered morphology the Estuary.

Figure 49: Modelled suspended solid concentration during Spring tide conditions in the Swale (a) and at the core location (b) including predominant waves and wind conditions (light blue). Please note that the model SSC is expressed in kg/m^3 instead of mg/l – 0.1kg/m^3 is equal to 100mg/l.

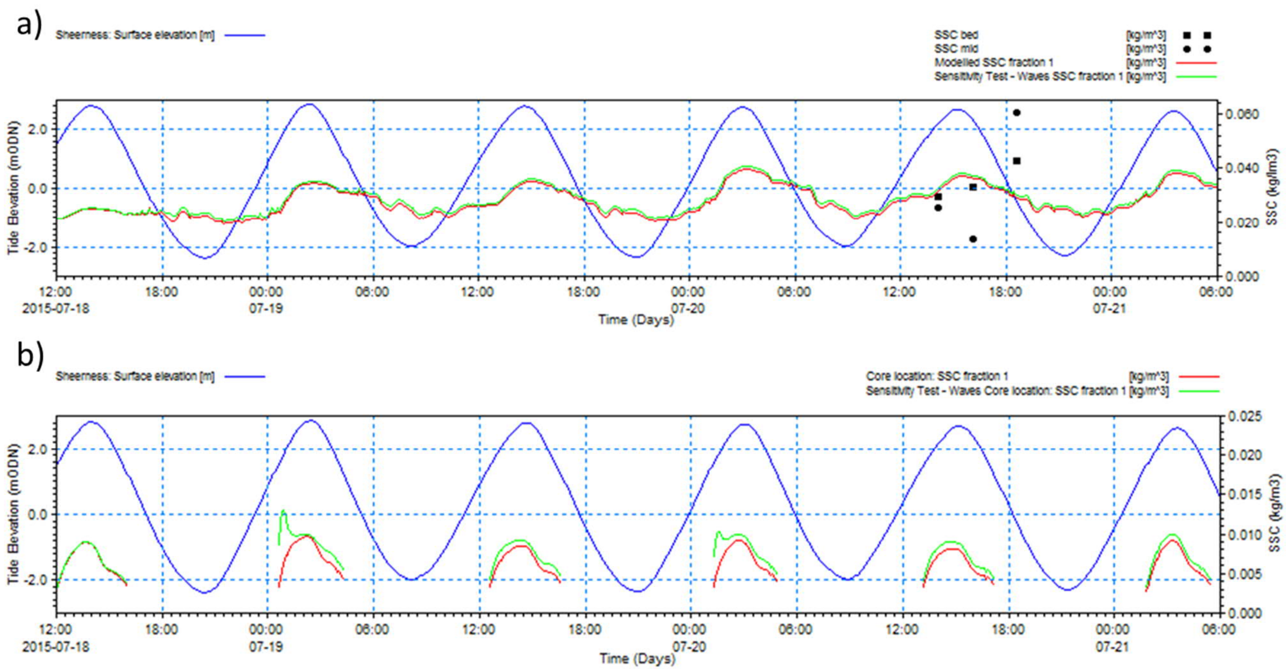


Source: Mott MacDonald, 2016

Figure 50 shows the modelled SSC at the core location for Spring tide conditions with constant waves of 0.1m high across both estuaries. In common with the dominant wave conditions, a small increase in the SSC in both estuaries can be seen.

Accretion rates at the core location are around 10% higher when waves are present. This arises primarily due to the enhancement of SSC values which provide a greater availability of sediment at this location.

Figure 50: Modelled suspended solid concentration during Spring tide conditions in the Swale (a) and at the core location (b) - Including constant waves in light green. Please note that the model SSC is expressed in kg/m^3 instead of mg/l – 0.1kg/m^3 is equal to 100mg/l.



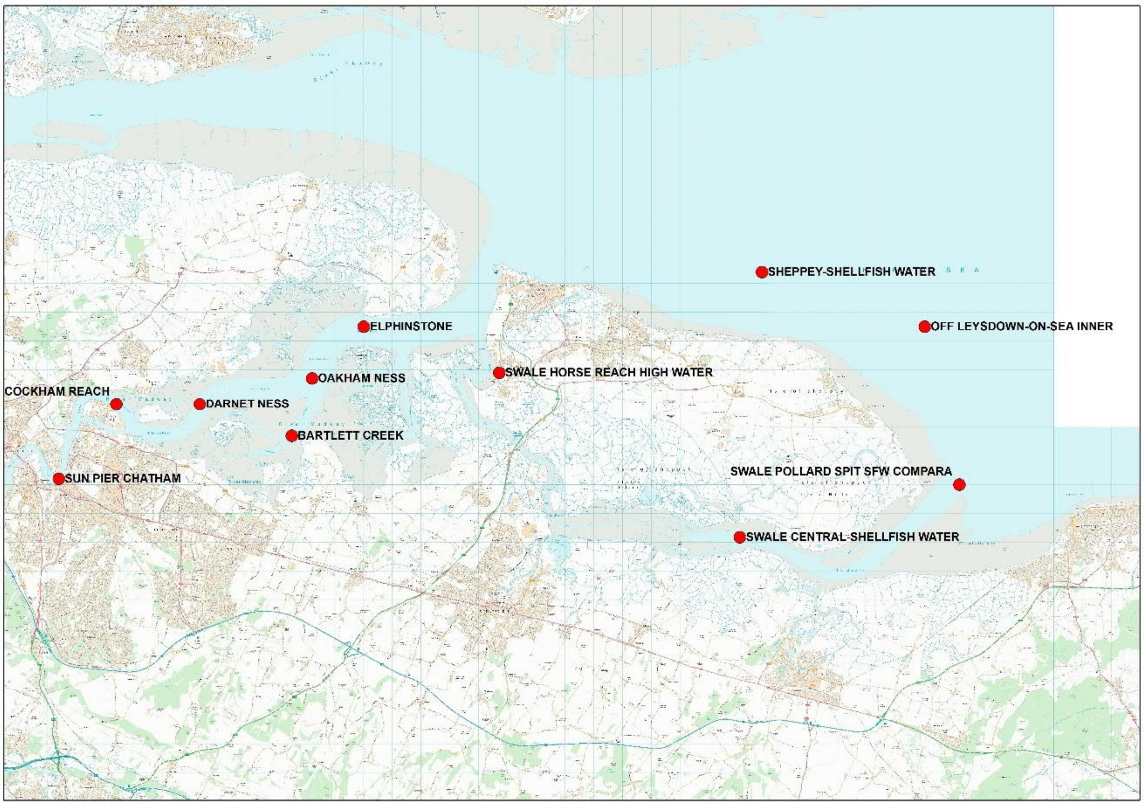
Source: Mott MacDonald, 2016

While both estuaries are largely sheltered from external wave effects, local wind-generated waves inside the Medway Estuary could potentially increasing SSC and modify local accretion/erosion rates. While the Deloffre et al. (2007) and Cundy et al. (2007) studies do not detect any wave impacts on the mudflats at Horrid Hill, the results of the model sensitivity tests for waves indicate that this might be a factor to include in sediment budget calculations at other locations exposed to a long fetch. Although it is not possible with the present model to quantify accurately what this effect might be, the present results indicate that it will be negligible and well within the other uncertainties associated with simulating sediment dynamics for the study site.

5.3.2 Validation results

From the available Water Quality Archive database, 11 sampling stations covering the Medway and Swale estuaries were selected for the model validation. The sample locations, shown in Figure 51, were selected to demonstrate model agreement with the recorded available data in the Swale, in the Medway intertidal areas and offshore of Isle of Sheppey.

Figure 51: Selected WIMS sampling locations for model validation



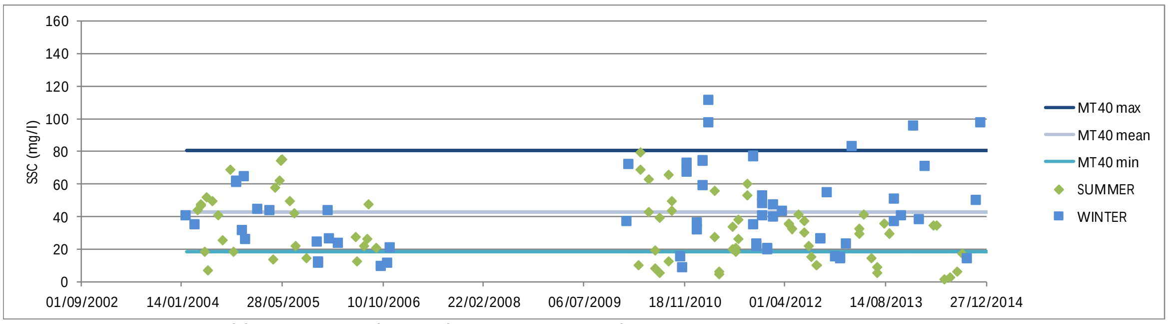
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016 and Environment Agency data 2016.

Offshore of the Isle of Sheppey, the model results were compared to the data recorded at "Sheppey Shellfish Water" and "Off Laydown-on-Sea" stations. The results are presented in Figure 52 and Figure 53 respectively.

At both locations, it can be observed, from the recorded data, that during the winter, SSC tends to be higher than during the summer months, reaching SSC concentration higher than 100mg/l. The model results, at these locations, are correctly representing the variability observed in the data. The model is showing average values of approx. 40mg/l with maximum SSC of 80mg/l.

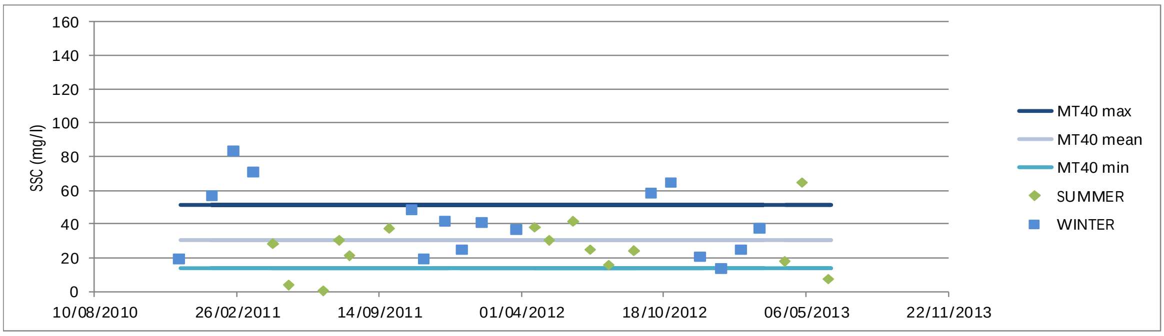
It must be noted that the SSC at the model boundary are constant from the modelled Spring tide conditions, and therefore, offshore SSC variability due to seasons and storm events is not represented in the model. However, results are indicating that the model is successfully representing the SSC observed offshore of Isle of Sheppey simulating the patters and the order of magnitude of SSCs.

Figure 52: SHEPPEY-SHELLFISH WATER SSC data compared to the model minimum, mean and maximum at this location.



Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

Figure 53: OFF LEYSDOWN-ON-SEA INNER SSC data compared to the model minimum, mean and maximum at this location.



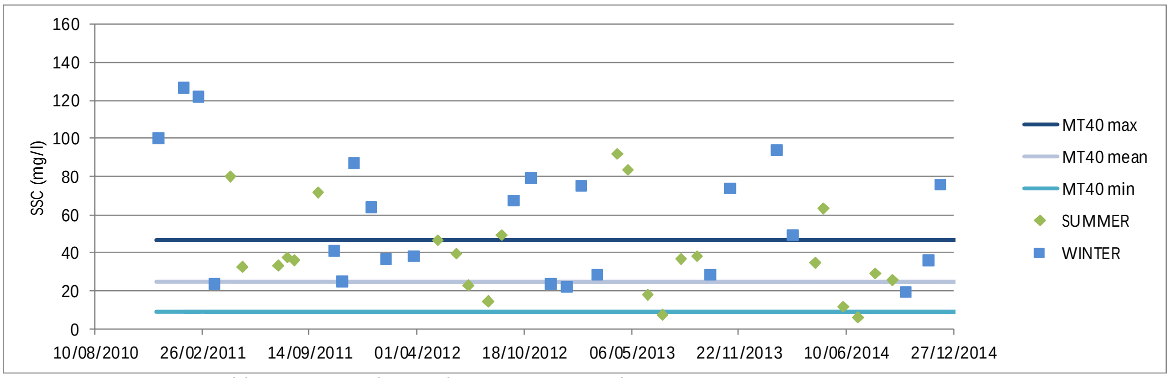
Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

At the Swale entrance, SSC values are similar to the recorded offshore on the Isle of Sheppy, with slightly larger values during the winter months (Figure 54). At this location, “Swale Polland Spit”, the model is slightly underestimating the SSC variability observed in the sampling data. Higher recorded values could be related to waves action in the intertidal areas of the Swale, where sediments are constantly being re-eroded and re-suspended, increasing the concentrations recorded at this station. The model is not completely representing all the variability observed in the data at this location. However, the simulated concentrations are of the right order of magnitude.

Further in the main Swale, the model was validated using the data of “Swale Central Shellfish Water” sampling point (Figure 55). At this location, the model is correctly representing the SSC variability. From the results, it can be observed that recorded SSC reach values of 140mg/l. These higher values, during the winter months, once again could be related to storm events and erosion/re-suspension of sediments from the intertidal areas due to wave action. The model maximum SSC are approximately 80mg/l, slightly lower than the recorded data.

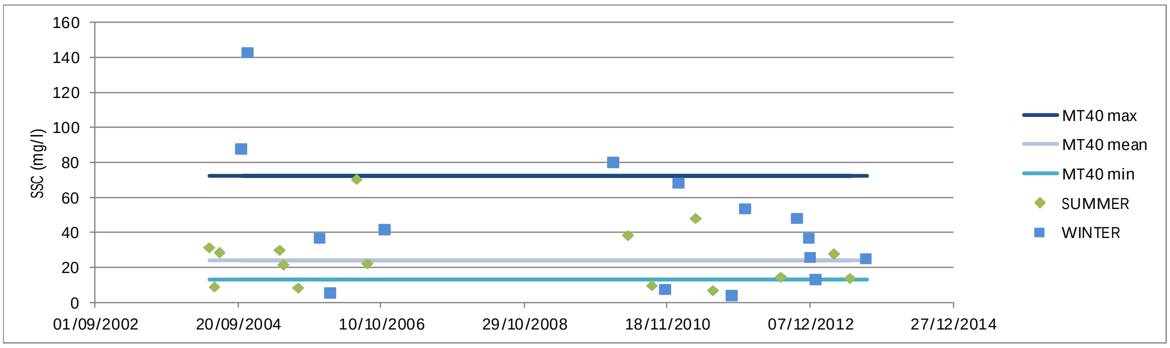
At the western end of the Swale, at “Swale Horse Reach High Water” station (Figure 56), recorded SSC are very like the previously described. The model, at this location, is correctly representing the SSC variability observed with maximum concentrations of approximately 80mg/l.

Figure 54: SWALE POLLARD SPIT SFW COMPARA INNER SSC data compared to the model minimum, mean and maximum at this location.



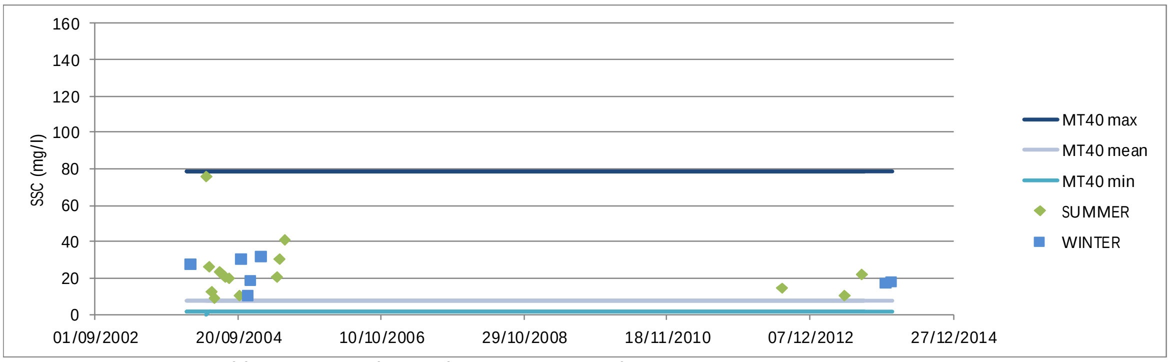
Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

Figure 55: SWALE CENTRAL-SHELLFISH WATER SSC data compared to the model minimum, mean and maximum at this location.



Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

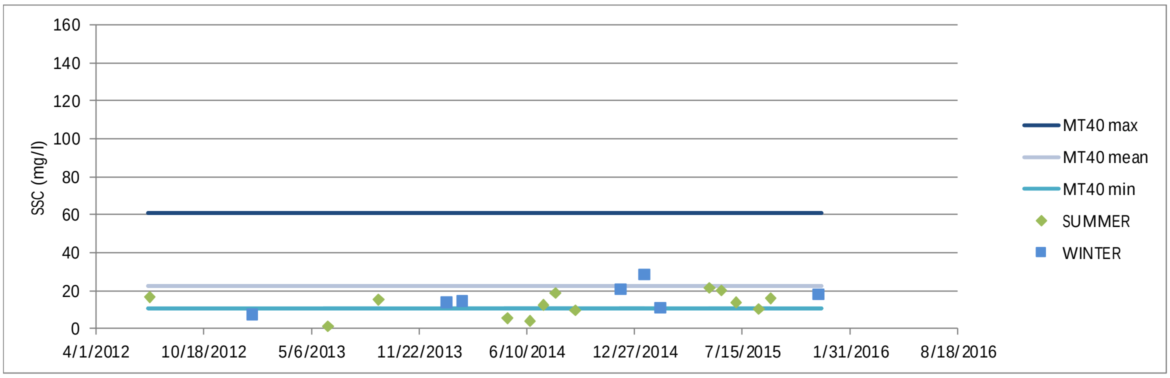
Figure 56: SWALE HORSE REACH HIGH WATER SSC data compared to the model minimum, mean and maximum at this location.



Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

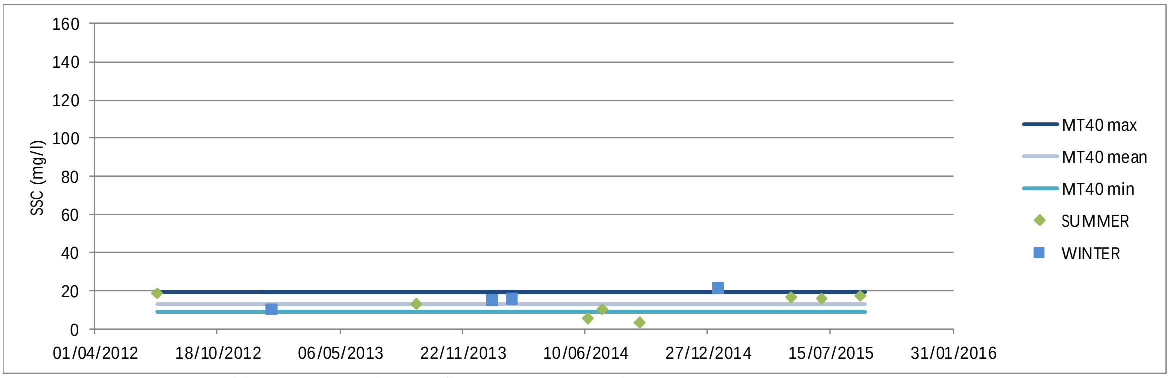
In the main Medway Estuary, SSC are considerably lower than the Swale and the offshore area. The recoded concentrations are less variable and do not exceed 40mg/l with mean values around 20mg/l. Figure 57 to Figure 61 show the recorded SSC and the model predictions from several locations in the main Medway Estuary and intertidal areas. It can be observed that at all the stations, the model is successfully representing the patterns and order of magnitude of SSC. Slightly higher SSC are observed at Chatham (Figure 62) were both the recorded data and the model predictions show maximum values of 60mg/l.

Figure 57: OAKHAM NESS SSC data compared to the model minimum, mean and maximum at this location.



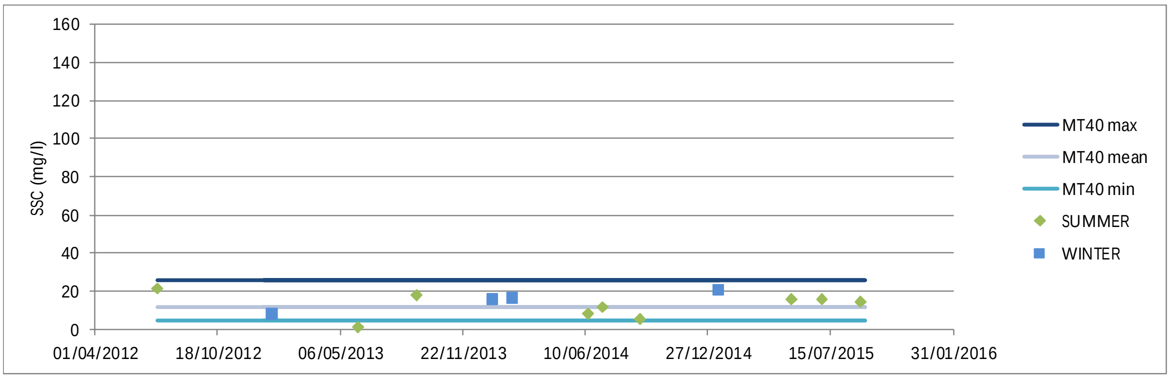
Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

Figure 58: DARNET NESS SSC data compared to the model minimum, mean and maximum at this location.



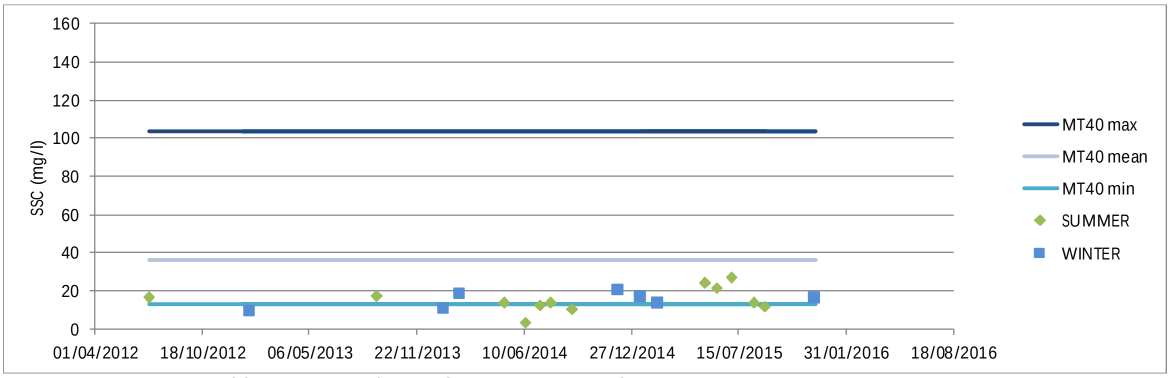
Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

Figure 59: BARTLETT CREEK SSC data compared to the model minimum, mean and maximum at this location.



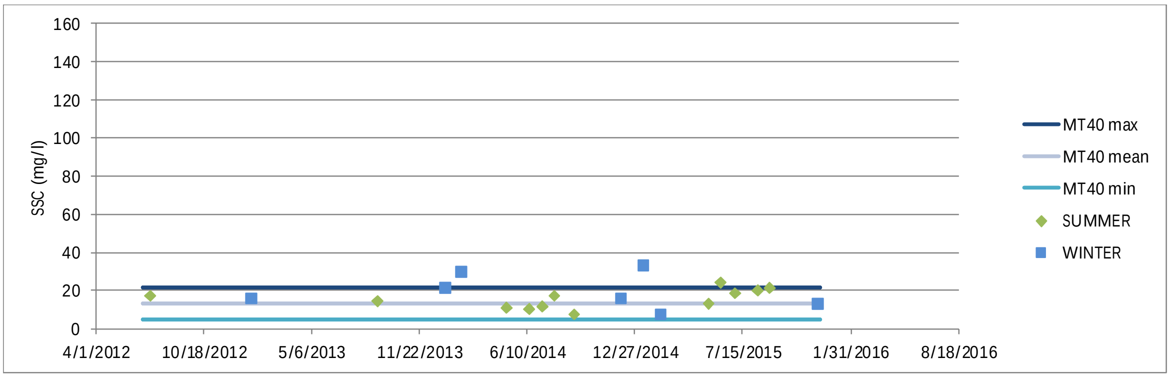
Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

Figure 60: ELPHINSTONE SSC data compared to the model minimum, mean and maximum at this location.



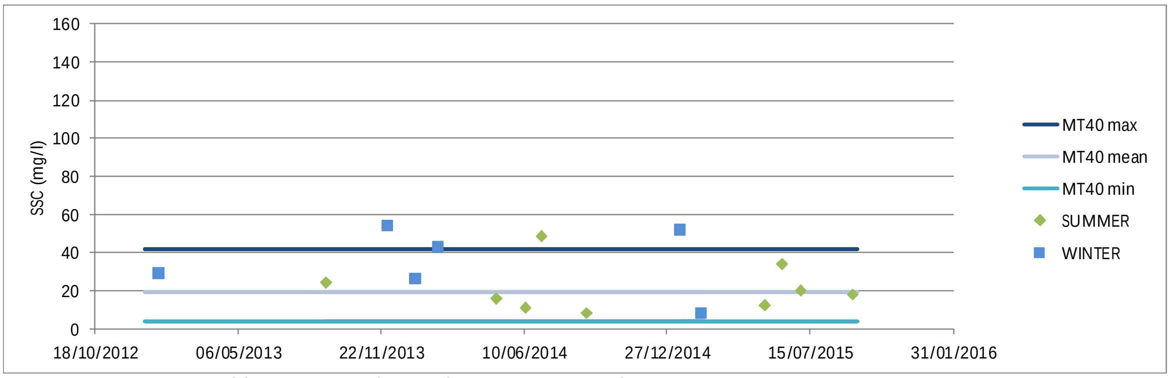
Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

Figure 61: COCKHAM REACH SSC data compared to the model minimum, mean and maximum at this location.



Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

Figure 62: SUN PIER CHATHAM SSC data compared to the model minimum, mean and maximum at this location.

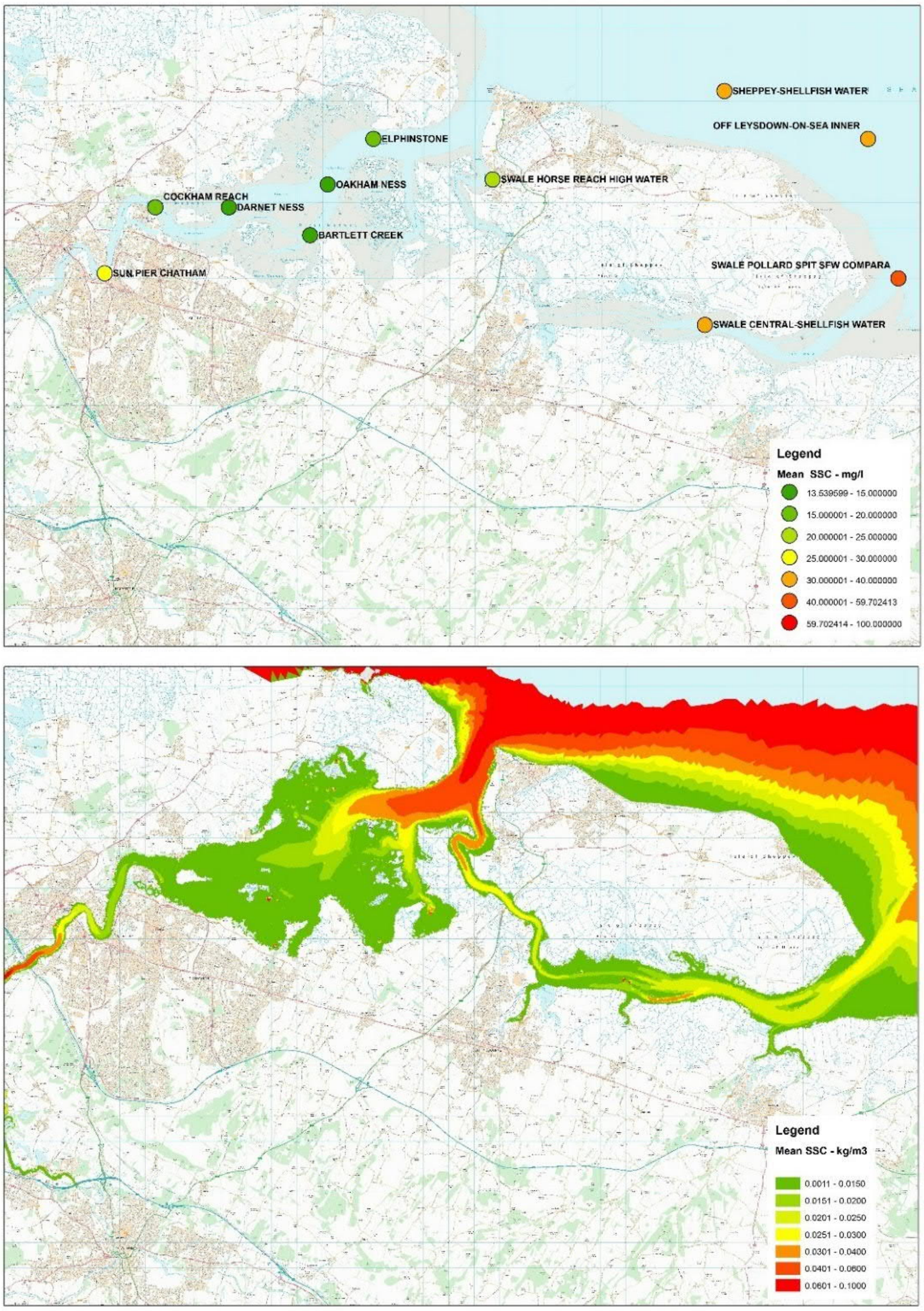


Source: Mott MacDonald, 2016. Contains Environment Agency data 2016.

Figure 63 compares the recorded mean SSC from the Water Quality Archive stations (a) and the modelled mean SSC during a Spring tide (b). It can be observed, that both images show a very similar distribution of SSC i.e. higher concentrations in the Swale and the offshore area and lower concentrations in the main Medway Estuary.

The only evident difference between the model and the measured data is at the “Swale Polland Spit” sampling point. As previously mentioned, the model slightly underestimates the SSC at this location (Figure 54). Wave action over the intertidal areas could be responsible for the higher SSC due to re-suspension and local erosion at this sampling location and this process has not been completely captured in the model. However, the results indicate a good general agreement and show an increase in the SSC towards the eastern end of the Swale, similar to the pattern observed in the measured data.

Figure 63: Mean SSC from the WIMS database (a) compared to the modelled mean SSC (b). Please note that the model SSC is expressed in kg/m^3 instead of mg/l – 0.1kg/m^3 is equal to 100mg/l.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016 and Environment Agency data 2016.

5.3.3 Model calibration and validation summary

The Water Quality Archive data has been used to calibrate the MEASS MT model and through the validation process to demonstrate that the model is correctly representing the SSCs in the

Medway and Swale estuaries. It is considered that within the constraints imposed by the available calibration and validation data, the modelled sediment concentrations over the whole MEASS area are representative. This is evidenced by the generally good agreement between predicted suspended sediment concentrations and measured values. Further, the predicted net deposition rates compare favourably with rates reported in the literature.

It is important to note that the MEASS model is only simulating the dynamics of the mud fraction in the Medway and Swale estuaries for Spring and Neap tide conditions and constant offshore sediment concentrations. In reality, tidal range, offshore concentrations, storms, river flows, etc. will vary over the year. Further, the properties of the fine-grained sediments are very complex and difficult to describe theoretically and therefore modelling of cohesive sediment transport is a complex task with many unknowns and significant uncertainty.

Nevertheless, it has been demonstrated here that through the model calibration and validation processes using as many site-specific parameter settings as possible, of the overall behaviour of suspended sediment and net sedimentation patterns in the Medway and Swale estuaries are reproduced favourably.

For the purposes of assessing schemes impacts it is the relative differences between baseline and scheme cases that has greatest utility and in this respect the present MT model is judged to be appropriate for use in this strategy study.

6 Baseline model

Executive summary

The frontages of the Medway and Swale estuaries have been grouped into various 'Benefit Areas'. The Benefit Areas are broadly based on flood cells and erosion boundaries, as well as taking account of similar land uses. Eleven 'Benefit Areas' have been proposed, each with sub-areas.

A baseline scenario is developed for the Medway and Swale estuaries with the purpose to set out a baseline against which all other Strategy options would be assessed per each of the benefit areas.

Using the calibrated hydrodynamic model and the information available in the literature, the Medway and the Swale hydrodynamic, sediment transport and present/future flood risk have been described.

In general, the Medway is a macro tidal estuary with semi-diurnal tides with a small diurnal inequality; an ebb-dominant system exhibiting higher velocities on the ebb tide, however at times the shallower inner estuaries become flood dominant. The tide amplitude increases along the Medway estuary until approximately New Hythe and Adlington Lock. At Rochester, the spring tide range increases approx. 0.5m compared to the mouth of the estuary and high water occurs approx. 30min later than at Sheerness

The Swale estuary is exposed to tidal influences from both mouths and therefore has a complicated tidal regime. In terms of tidal asymmetry, the Swale is not presenting a clear flood or ebb dominance. Current speeds and durations are similar for the ebb and the flood tide. In the Swale, the tidal range variation can also be observed; however, this difference is smaller compared to the Medway.

The Medway Estuary is dominated by mudflats, comprised of silty sands, clays, and remnants of consolidated sediment. The Swale is also largely mudflats, which become more sandy and gravelly towards the eastern mouth. Saltmarshes cover a small area of both estuaries.

Studies show contradictions of the sediment dynamic in the Medway. Some studies describe the Medway as a super-starved sedimentary system, erosion dominant; while others, argue that the Medway and Swale are undergoing net accretion. Irrespective of these differing opinions, it is clear that losses or gains of sediment in the estuary are low and consequently present day morphological changes are very slow.

Generally suspended sediment concentrations in the Medway and Swale estuaries are low and are typically in the range 0.1 mg/l to 30 mg/l. The suspended load mostly comprise re-suspended fine sediments. Using the sediment transport model, deposition/erosion rates, in the Medway as in the Swale were calculated and found, small. Both the main Medway Estuary and the Swale are showing depositions rates between 1 and 3mm/yr, with some erosion in the main channels and in the estuaries mouths.

Flooding is a real risk currently facing communities and landowners in the low-lying areas around Swale and the Medway Estuary. Present defended scenario modelling results indicate that the several areas of the estuaries are at risk of flooding from 1:2 years event, while the present undefended scenario is showing that the majority of the benefit areas are flooded during this same event.

Considering the sea level rise predictions, 0.75m in the next 100 years according to UKCP09 (Medium Emission 95%ile), the risk of flooding in the study area is considerably increased. From the future defended modelling results, it can be observed, that a large portion of estuaries coastal areas are at risk of flooding from 1:2 years event.

6.1 Introduction

This Chapter describes the work carried out to develop the baseline model for the Medway and Swale Strategy Study against which all other Strategic Options (Chapter 7 and Chapter 8) can be compared to assess impacts. The chapter comprises:

- Section 6.2: Introduction and brief description of the study area;
- Section 6.3: Hydrodynamic baseline, including:
  - Tidal dynamics
  - Water level
  - Extreme water levels
  - Waves and overtopping
  - Freshwater inputs
- Section 6.4: Sediment transport baseline, including:
  - Sediment dynamics
  - Erosion and accretion processes
- Section 6.5: Present day flood risk, including:
  - Present defended scenario
  - Present undefended scenario
- Section 6.6: Future day flood risk, including:
  - Future defended scenario
  - Future undefended scenario

6.2 Study area

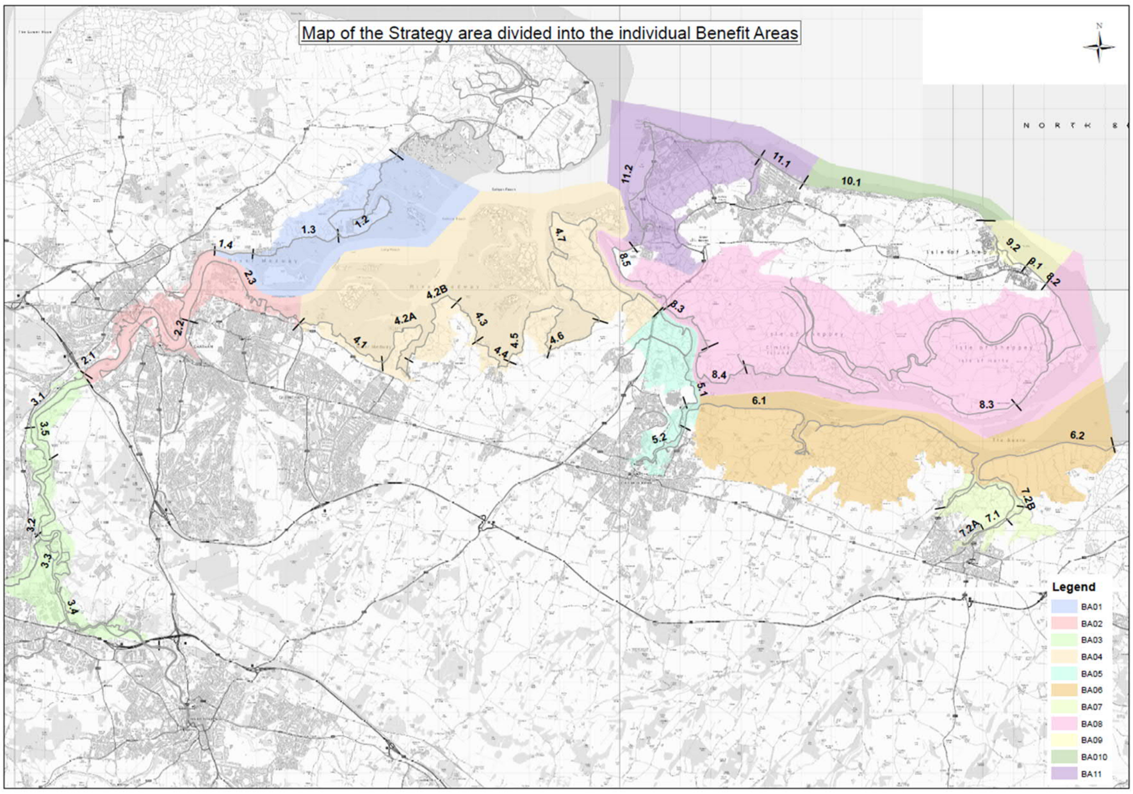
The Medway and Swale estuaries are located in the southern section of the Greater Thames Embayment, which lies within the southern part of the North Sea. The Medway extends 41km from its mouth at Sheerness to the tidal limit at Allington Lock, with its mouth lying between the Isle of Grain and the Isle of Sheppey. The Swale is essentially a tidal channel with two mouths: one connected to the Medway estuary; and the other entering the Greather Thames embayment on the eastern side of the Isle of Sheppey. The Swale estuary has a length of 18.4km from its mouth to Kingsferry Bridge.

The frontage is currently covered by two SMPs:

- Isle of Grain to South Foreland Shoreline Management Plan (SMP) - This SMP covers the open coastline of the English Channel from the Isle of Grain in North Kent around the north of the Isle of Sheppey and then along the coastline of the mainland from Faversham Creek to South Foreland in East Kent; and
- Medway Estuary and Swale Shoreline Management Plan (SMP) - This SMP covers the Medway Estuary & the Swale from the tidal limit at Allington Lock down river to the mouth between the Isle of Grain and Sheerness; and along the Swale from the Medway to its mouth in the east, between Shell Ness (Isle of Sheppey) and Faversham Creek.

For the Strategy Study, the SMPs Policy Units have been grouped into various ‘Benefit Areas’. The Benefit Areas are broadly based on flood cells and erosion boundaries and take account of similar land uses. Eleven ‘Benefit Areas’ have been proposed, each with sub-areas (i.e. BA1.1, 1.2, 1.3 and 1.4) (Figure 64).

Figure 64: Benefit Areas defined for the Medway and Swale Strategy.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

A general description of the 11 benefit areas defined for the Strategy frontage is provided in Table 14. Detailed information and maps for each of the benefit areas are available in the Option Technical Report (Mott MacDonald, 2017).

Table 14: Summary of the benefit areas defined for the Medway and Swale Strategy

Benefit Area	Name	Coverage and General description
BA01	North Medway	Benefit area 1 covers the Hoo Peninsula including the settlements of Stoke and Hoo Marina Park. The land use along the river is varied with agricultural land on the marshes Stoke to significant industrial area around Kingsnorth Power Station, and a marina at Hoo Marina Park. The majority of the benefit is protected by walls or embankments.
BA02	Medway Towns	Benefit Area 2 covers the heavily urbanised area of the Medway Towns from Upnor to the Medway bridge and back along to Danes Hill, covering the settlements of Strood, Rochester, Chatham and St Mary’s Island. This urban area is heavily defended by various types of flood and erosion risk protection measures.

Benefit Area	Name	Coverage and General description
BA03	Upper Medway	Benefit area 3 covers the tidal section of the River Medway from the Medway Bridge to Aylesford. The land use along the river is varied with agricultural land on the marshes around Wouldham and significant industrial and residential areas at New Hythe, Snodland, Aylesford and Halling. The area is protected by sea walls and embankments.
BA04	Medway Marshes	Benefit Area 4 covers the Medway Marshes and is a mainly low-lying agricultural area extending from Grange and Lower Twydall in the west to the Sheppey crossing in the east. The area is dominated by agricultural land use interspersed with small settlements at Lower Rainham, Upchurch, Lower Halstow and Iwade. The area is currently defended by earth embankments.
BA05	Milton Creek and Sittingbourne	Benefit Area 5 covers the Swale Estuary from the Sheppey crossing, down Milton Creek to Sittingbourne. The flood risk area mainly consists of industrial developments, especially along Milton Creek and urban areas. The shoreline is defended mainly by sea walls and embankments.
BA06	Swale Mainland	Benefit Area 6 includes the Swale Mainland (i.e. the southern bank of the Swale Estuary). It is a low-lying agricultural area extending from Murston Pits near Sittingbourne in the west, past Conyer and Oare Creeks to the Sportsman Pub near Seasalter in the east. The area is defended by embankments.
BA07	Faversham Creek	Benefit Area 7 includes the settlements of Faversham, Davington and Oare. This area includes a number of residential and commercial properties in addition to industrial areas.
BA08	South Sheppey	Benefit Area 8 includes the northern bank of the Swale Estuary (also the southern coastline of the Isle of Sheppey). The area is defended by primary and secondary embankments.
BA09	Leysdown	Benefit Area 9 is characterised by soft Warden Cliffs to the west, an embayment at Warden Bay and the low lying settlement of Leysdown to the east.
BA10	Minster Cliffs	Benefit Area 10 includes the Minster Cliffs from Minster along to Warden Bay. The area is characterised by unprotected cliffs vulnerable to erosion.
BA11	Sheerness	Benefit Area 11 includes the north western coastline of the Isle of Sheppey covering the settlements of Minster, Sheerness and Queenborough. These low lying urban areas are heavily defended by various types of flood and erosion risk protection measures.

Source: Mott MacDonald, 2016

According to the Medway and Swale SMP (Halcrow, 2010), the Medway estuary is a spit enclosed estuary which can be divided in three main regions:

- Outer estuary – Sheerness to Chetney Marshes - bordered by narrow and steep mudflats;
- Middle estuary – Chetney Marshes to Gillingham –with extensive intertidal areas; and
- Inner or Upper estuary – Gillingham to Allington Lock –with narrow meandering channel and limited intertidal areas.

Similar to the Medway Estuary, the Swale is defined as a spit enclosed estuary. However, this estuary, is relatively uniform in width with extensive intertidal mudflats.

6.3 Hydrodynamic baseline processes

6.3.1 Tidal dynamics

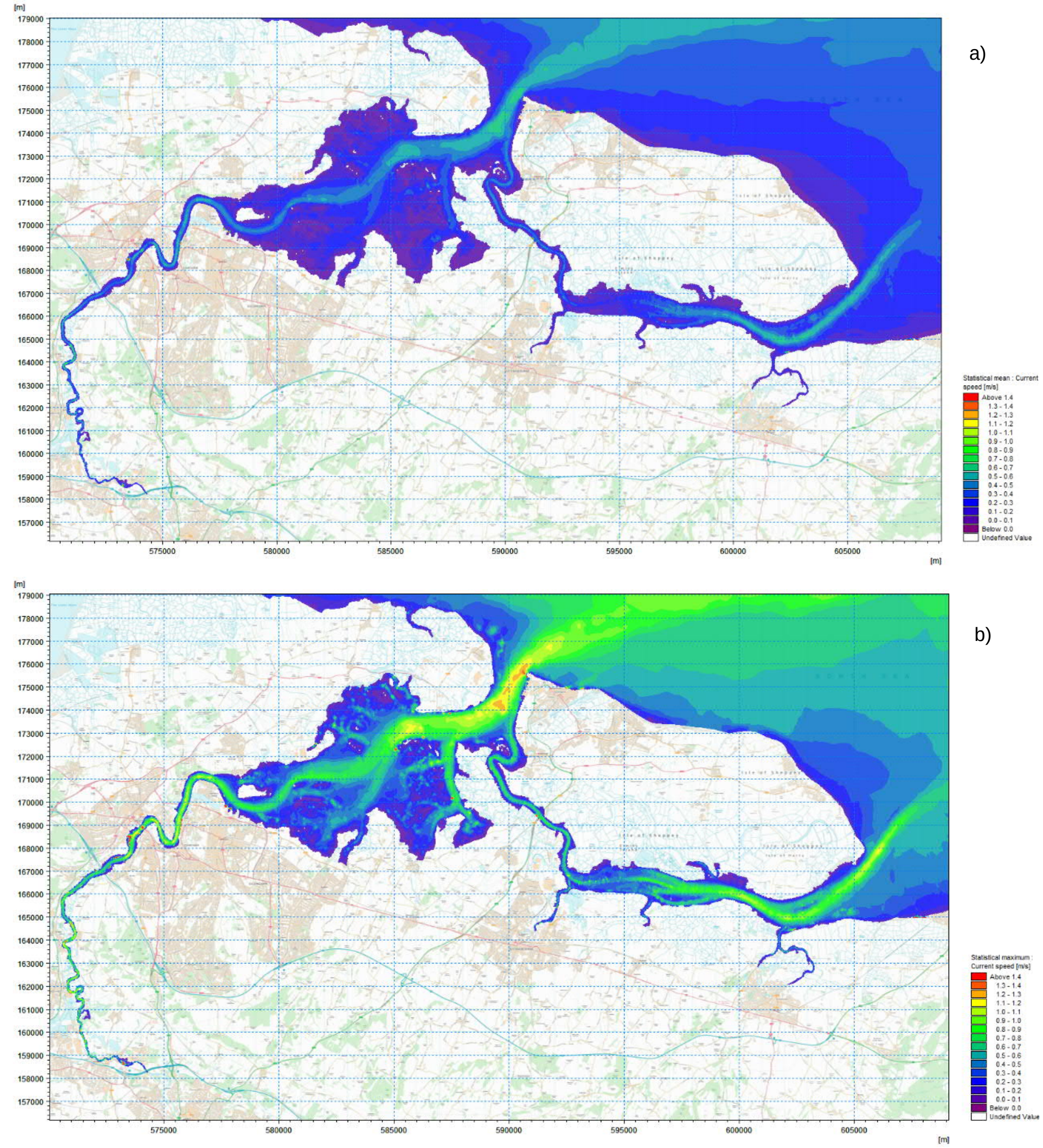
The Medway estuary is a macro tidal estuary with semi-diurnal tides with a small diurnal inequality of 0.1m on high water spring tides at Chatham (Halcrow, 2010). Figure 65 shows the mean and maximum spring tide conditions obtained from the calibrated numerical model (Chapter 4). In general, the figure shows that the Medway exhibits slighter higher mean and maximum current speeds than the Swale.

At Sheerness, mean spring currents speed reach 0.6-0.7m/s, with maximum values of 1.3m/s. In the central section of the Medway Estuary, mean and maximum flood velocities reduce to 0.4-0.5m/s and 0.7-0.8m/s respectively. Within the Upper Medway channels, currents speeds increase again; the model is simulating mean current speeds up to 0.8m/s, reaching maximum values above 1.4m/s.

Lower spring currents speeds, in general, are observed in the Swale. Mean values vary between 0.1m/s and 0.6m/s, reaching maximum current speeds between 0.3m/s and 1.1m/s. In the Swale, the larger spring currents speeds are observed in the east mouth, close to Shellness, and around Long Reach, reaching maximum values of 1.1m/s.

In both estuaries peak current speeds are observed on the bends in the channels and creeks. Higher current speeds are also expected for short periods over the mudflats during ebb tide, when the rapid drainage of water results in higher flow speeds.

Figure 65: MEASS baseline model showing (a) mean spring tide current speed; and (b) maximum spring tide current speed.



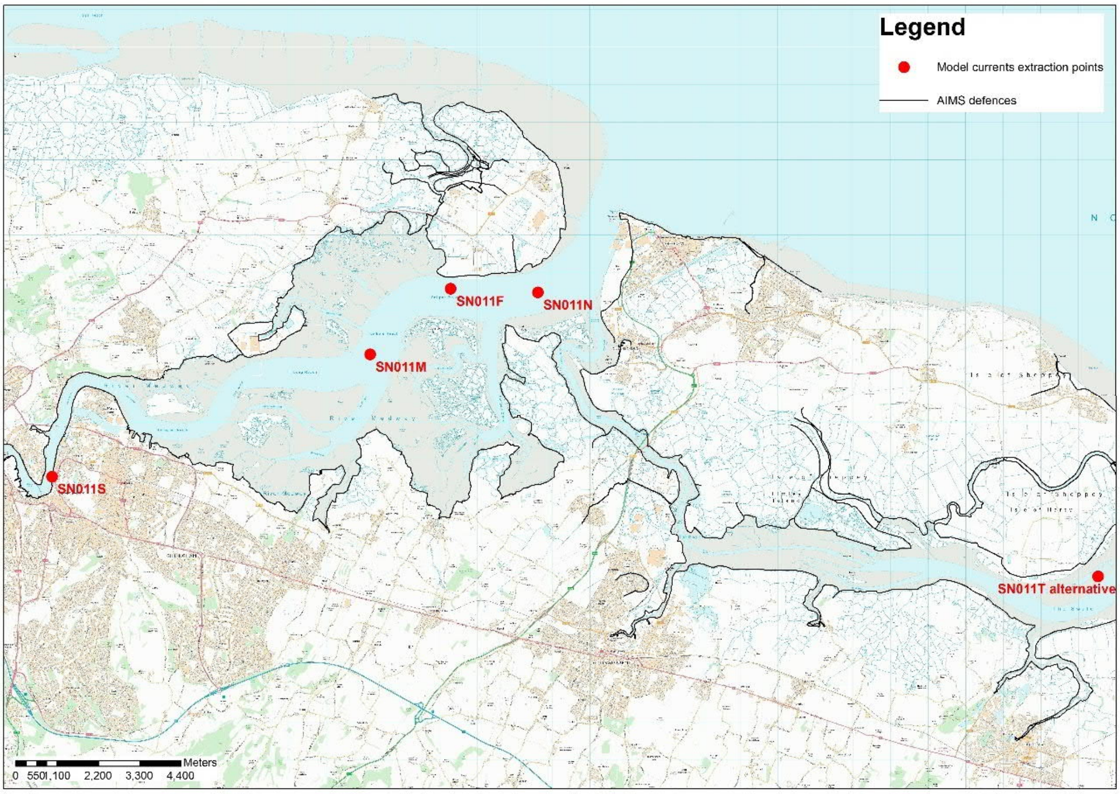
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

The Medway is described by Kirby (2013) as an ebb-dominant system exhibiting higher velocities on the ebb tide. However, at times the shallower inner estuaries can become flood dominant. According to Halcrow, (2010) the estuary can be divided into areas of flood and ebb dominance; with the outer estuary being ebb-dominant, middle being flood dominant and inner being ebb dominant.

Using the calibrated MEASS model, the ebb-dominant characteristics of the Medway can be observed. Figure 66 shows current speed extraction points in the Medway and Swale, used to describe the baseline currents of the estuaries.

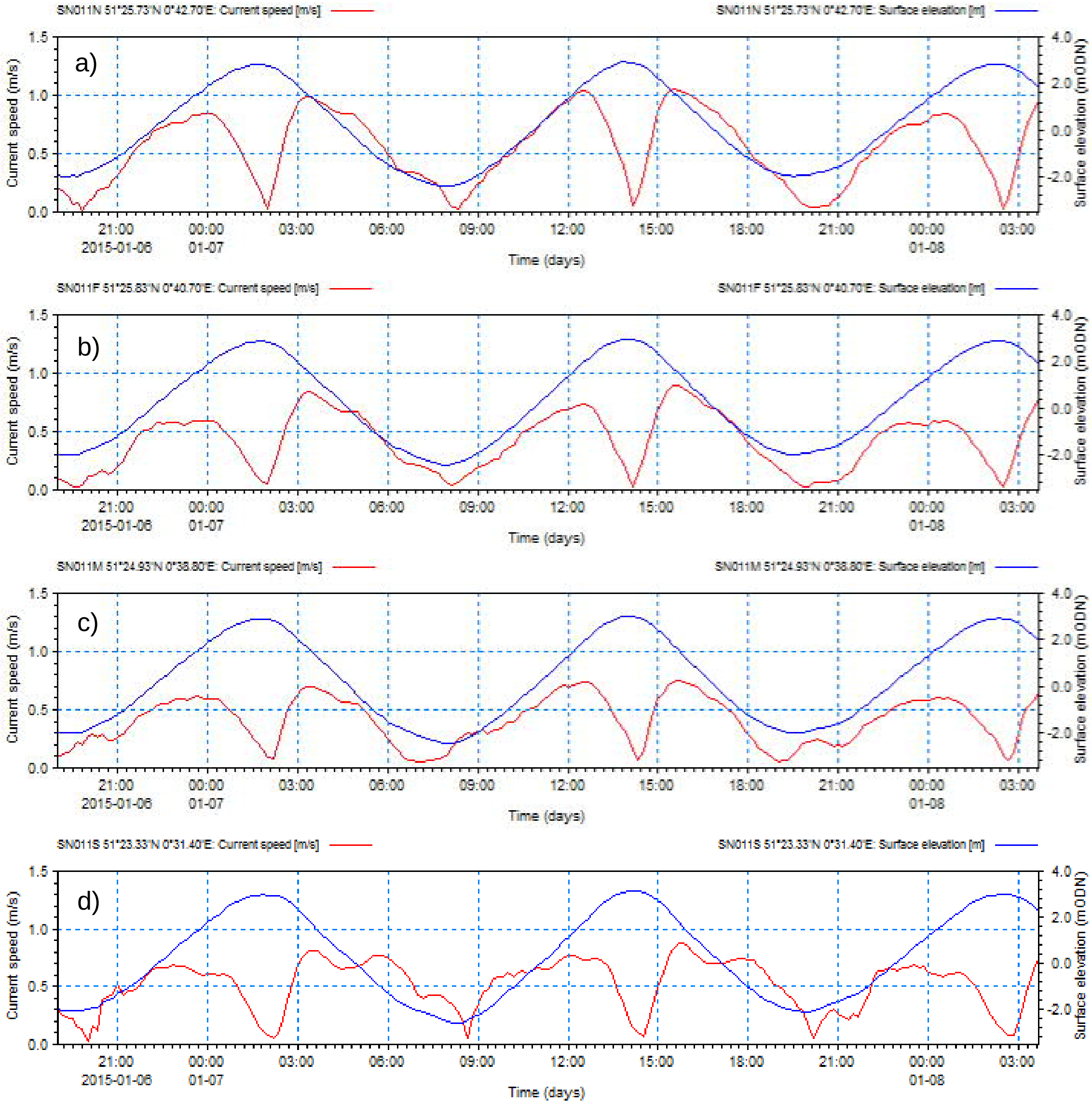
Figure 67, shows the current speed time-series for Point SN011N, SN011F, SN011M, and SN011S, located in the Medway estuary. It is noted that the ebb tide in the estuary tends to have higher current speeds and shorter duration than the flood tide. This ebb-dominance, is well-shown in the outer estuary (Figure 67a and Figure 67b).

Figure 66: Location of current speed extraction points



Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016.

Figure 67: Spring tide modelled current speeds in the Medway Estuary as per locations shown in Figure 67. (a) Point SN011N – Medway mouth, (b) Point SN011F – Main Medway channel, (c) Point SN011M – Medway main estuary, and (d) Point SN011S – Chatham area. Please note the ebb-dominance of the results.

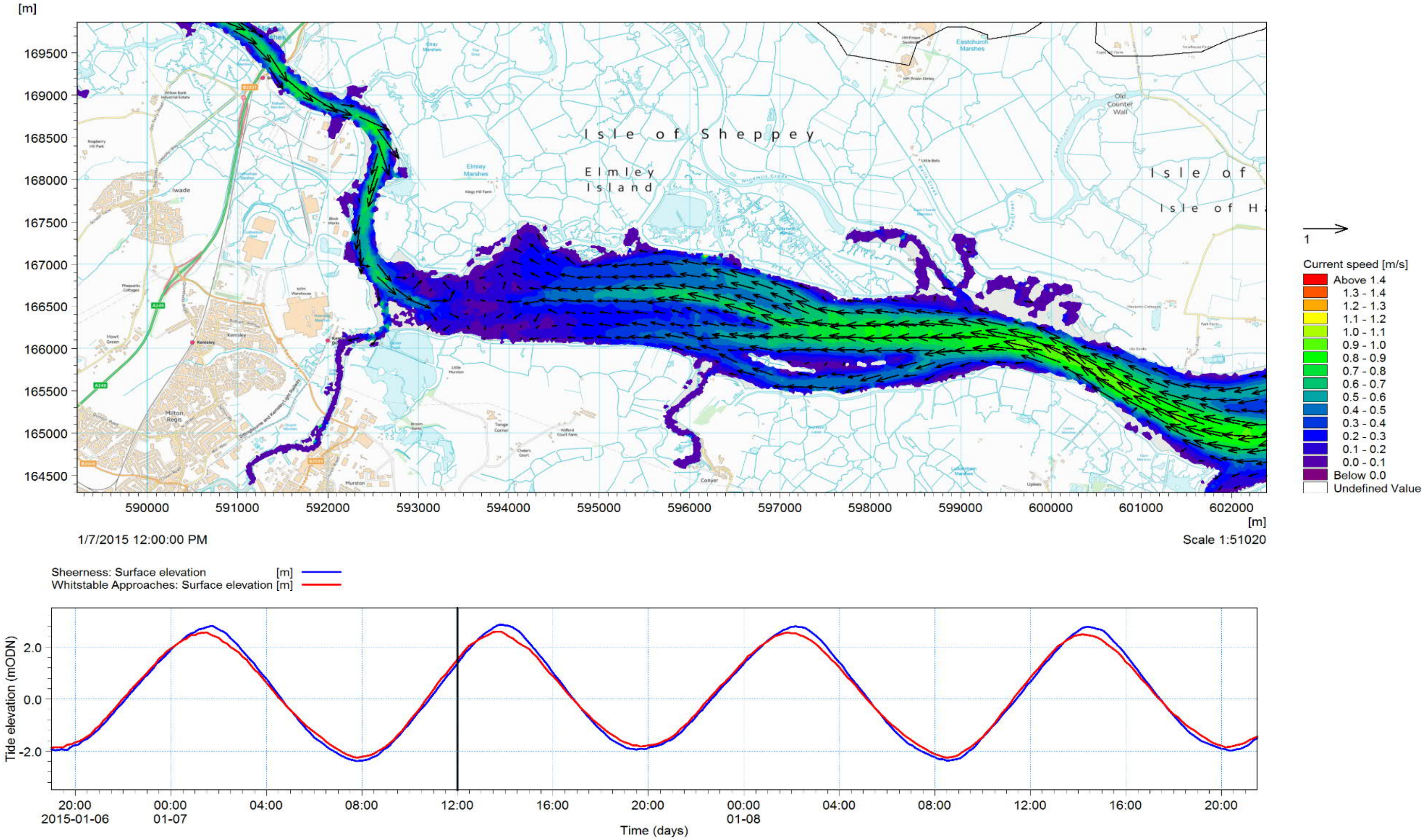


Source: Mott MacDonald, 2017

The Swale estuary is exposed to tidal influences from entrances in the Medway and The Greater Thames Embayment and therefore has a complicated tidal regime, (Halcrow, 2010). After slack water, the flood tide runs inwards, entering both mouths, with the two streams meeting at approximately Fowley Island (Halcrow, 2010). Approximately 5min after high water the flow is directed seawards towards Shellness until 1hr 5min after high water. After this time, west of Longwood, the flow changes direction and runs westwards and enters the Medway. The tide then flows in easterly and westerly separate directions until slack water. The position of the separation point is variable and dependant on tidal range and surge conditions (Halcrow, 2010). The complex tidal dynamics observed in the Swale is well-reproduced by the model results presented in Figure 68 to Figure 71. The figures show conditions: 2hr before high tide (Figure 68); high tide (Figure 69); 1hr after high tide (Figure 70); and 2hrs after high tide (Figure 71).

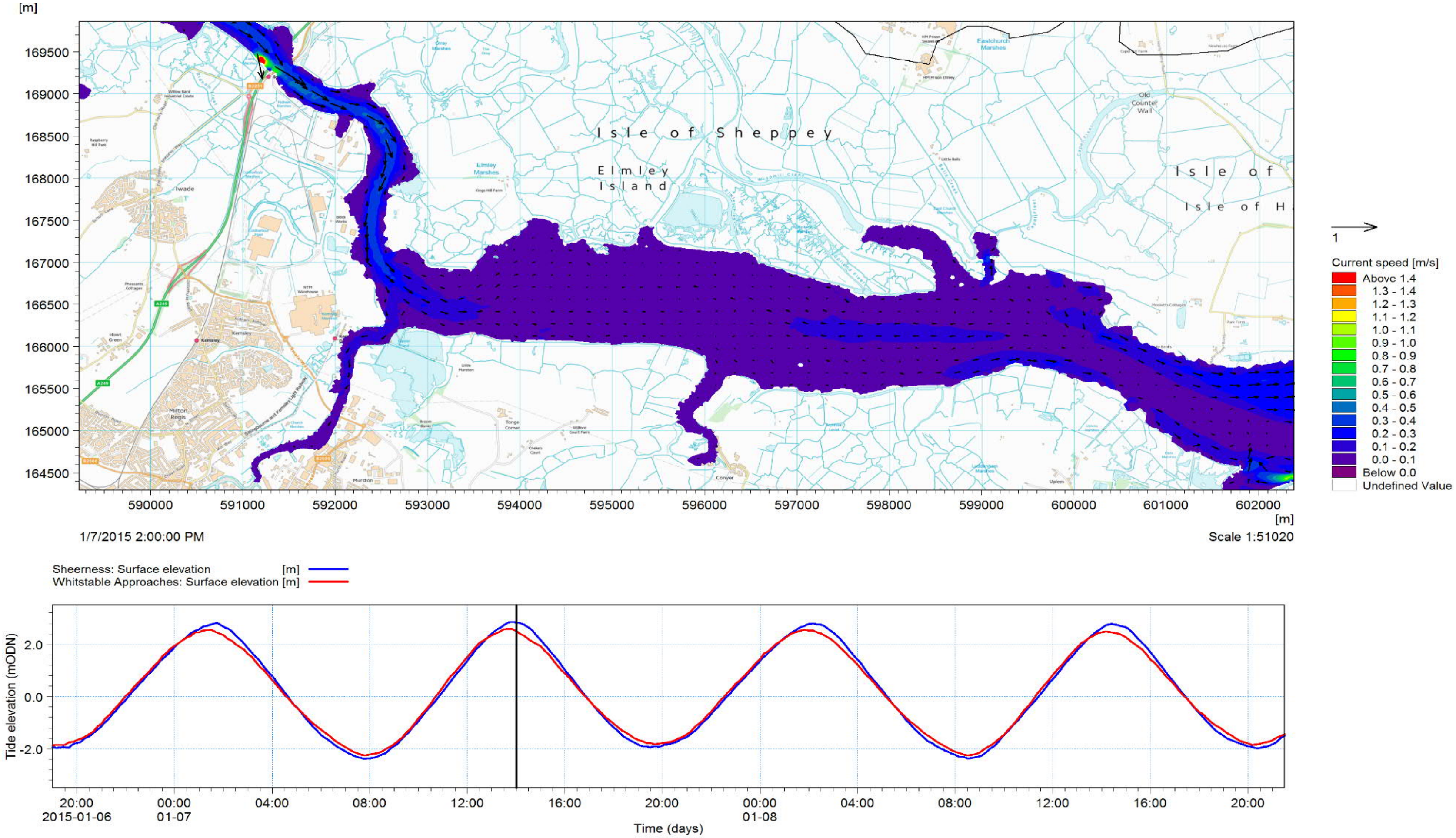
Figure 68 shows that during the flood tide, just before high water, water enters both the estuaries entrances and floods the central area of the Swale, with similar current speeds in the eastern and western end of the channel. At high water, current speeds reduce significantly, especially in the area of Elmely Reach (Figure 69). Just after high tide (Figure 70), the current speeds increase quickly and water flows towards the east entrance of the Swale. At 2.5hr after high tide, the separation of the flows at Clay Reach can be observed (Figure 71) with higher currents speeds towards the east entrance of the Swale.

Figure 68: Modelled spring tidal dynamic in the Swale – 1 hr before high water



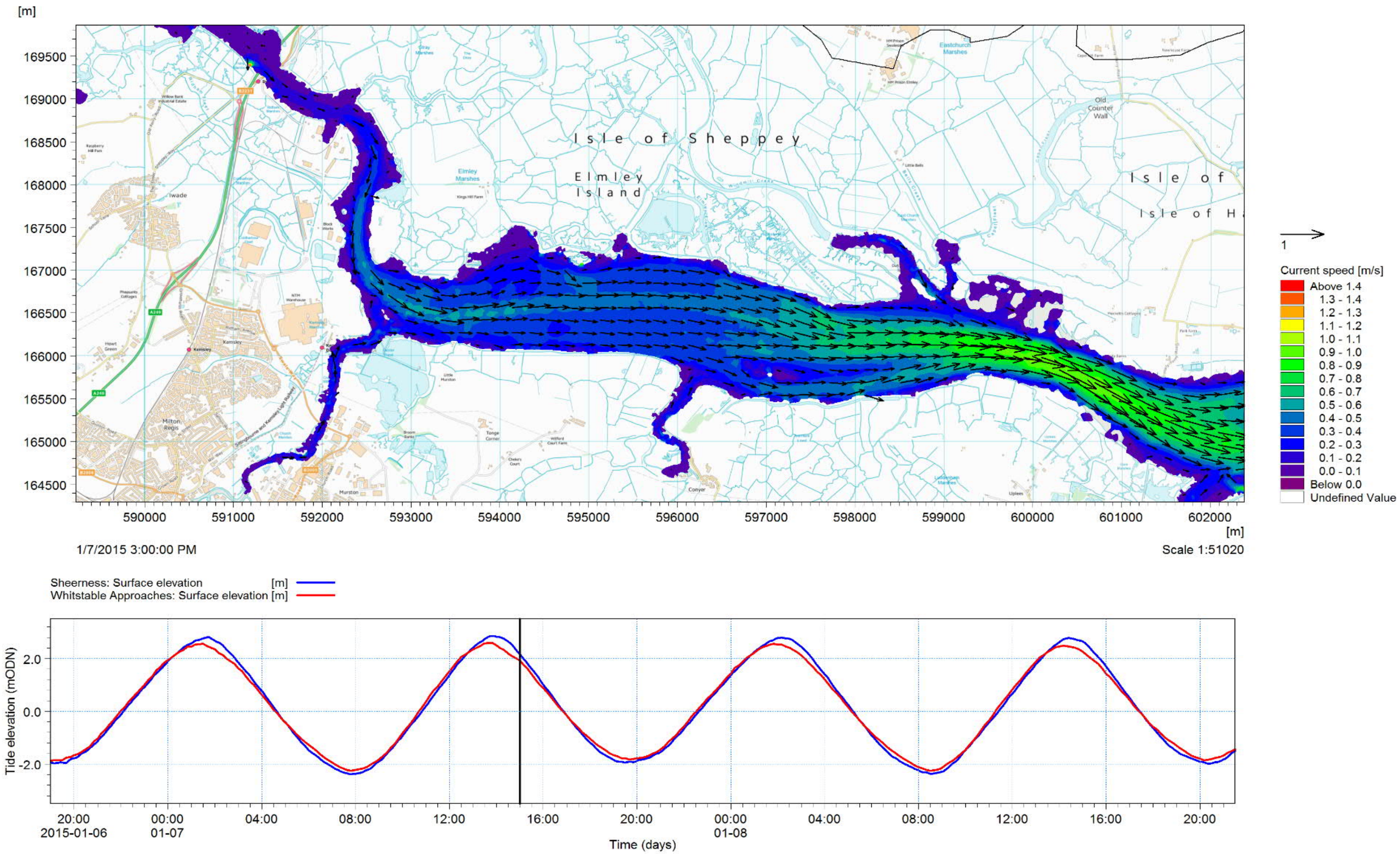
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

Figure 69: Modelled spring tidal dynamic in the Swale – high water



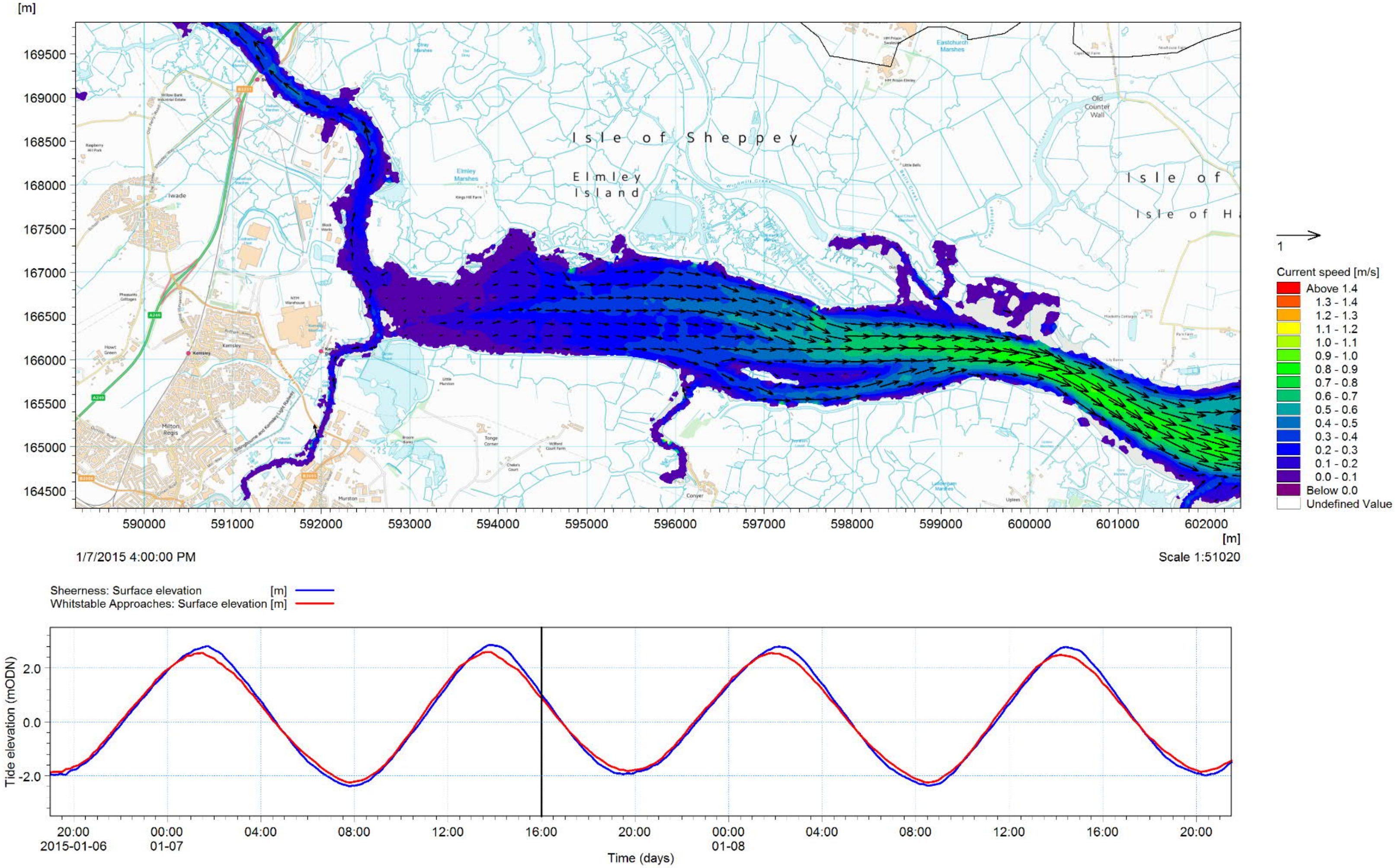
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

Figure 70: Modelled spring tidal dynamic in the Swale – 1 hr after high water



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

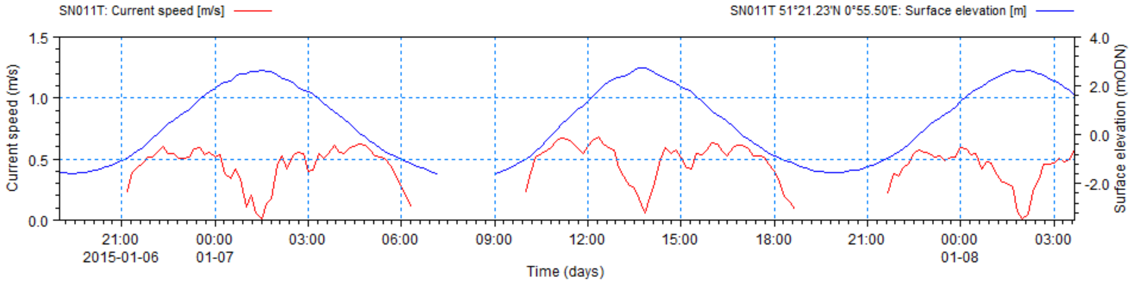
Figure 71: Modelled spring tidal dynamic in the Swale – 2 hr after high water



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

In terms of tidal asymmetry, the Swale has no clear flood or ebb dominance. Current speeds and durations are similar for the ebb and the flood tide. This can be seen in Figure 72, which shows currents speeds for Point SN011T located in the Swale main channel (Figure 66).

Figure 72: Example of spring tide modelled current speeds in the Swale Estuary.



Source: Mott MacDonald, 2016

6.3.2 Water levels

Tide levels at areas throughout the Medway and Swale estuaries are shown in Table 15. The mean spring tide range at Sheerness is 5.2m, increasing to 5.7m at Chatham and Rochester.

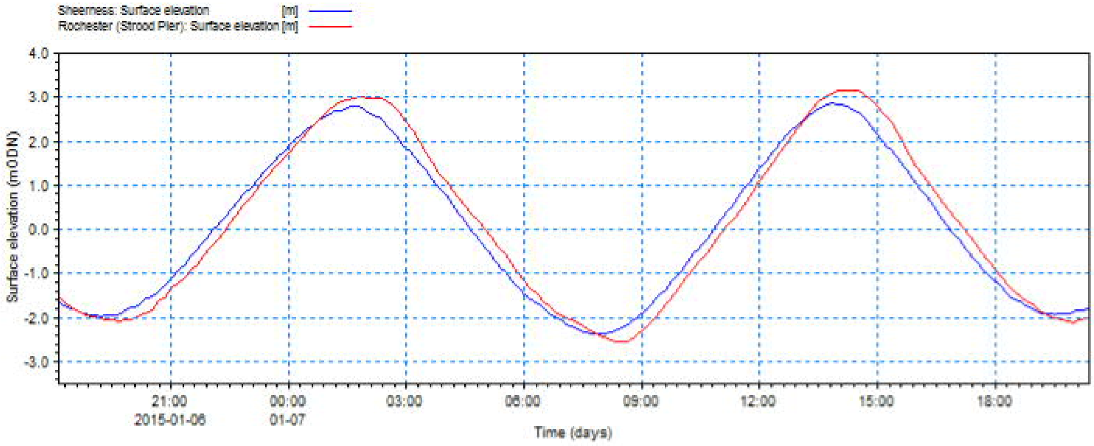
Table 15: Summary of tidal levels (mODN) in the Medway and Swale estuaries

Medway	MHWS	MHWN	MLNW	MLWS
Sheerness	2.9	1.8	-1.4	-2.3
Bee Ness	3.2	2	-1.3	-2.2
Bartlett Creek	3.1	1.9	No data	No data
Chatham	3.3	2	-1.4	-2.4
Wouldham	3.26	2.16	-1.44	-2.44
New Hythe	3.49	2.29	-1.61	-1.81
Allington Lock	3.55	2.35	-0.35	-0.35
Swale				
Chetney Marshes	3.0	1.8	-1.30	-2.30
Grovehurst Jetty	2.9	1.8	-1.4	-2.4
Faversham	2.8	1.7	No data	No data

Source: Total Tide, 2016

The tide amplitude increases along the Medway estuary until approximately New Hythe and Allington Lock. Figure 73 shows the difference in water level between Sheerness and Rochester. At Rochester, the spring tide range increases by approximately 0.5m compared to the mouth of the estuary. It can also be seen that there is a phase shift in the high and low water peaks across the Estuary. At Rochester, high water occurs approximately 30min later than at Sheerness due to the time that it takes for the tide to travel up the estuary.

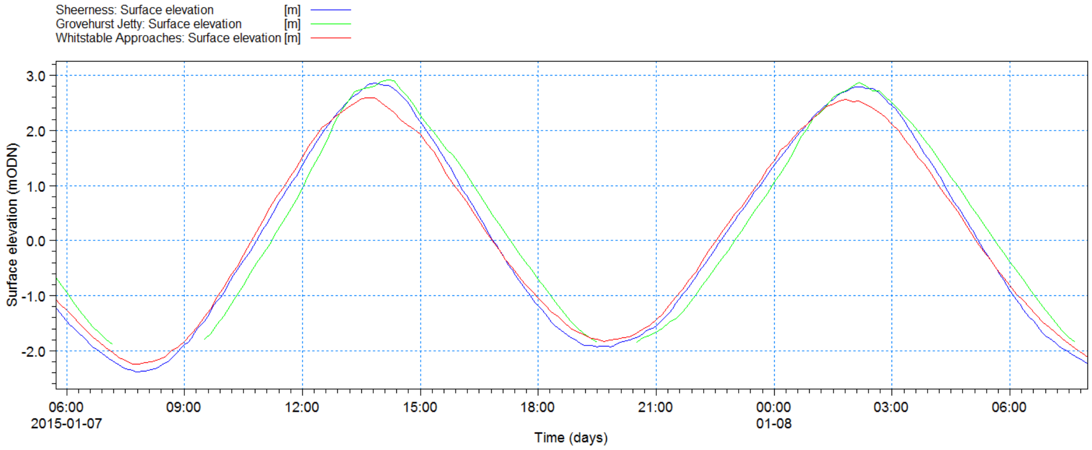
Figure 73: Modelled spring tide for Sheerness and Rochester, in the Medway. Please note the different in the tide range (approx. 50cm) and the phase shift (approx. 30min).



Source: Mott MacDonald, 2016

In the Swale, a tidal range variation can also be observed at different locations. However, this difference is smaller than those observed in the Medway. Figure 74 shows modelled water level comparisons between Sheerness, Grovehurst Jetty and Whitstable. It can be observed that in the east mouth of the Swale (Whitstable) the tide range is approximately 20cm smaller than in the main Swale channel (Grovehurst Jetty) and 35cm smaller than sheerness.

Figure 74: Modelled spring tide for Sheerness, Grovehurst Jetty and Whitstable, in the Medway.



Source: Mott MacDonald, 2016

6.3.3 Extreme water levels

Water levels during extreme events can exceed the maximum values associated with the astronomical tide due to surges which increase water levels through a combination of reduced atmospheric pressure and wind stress. Extreme offshore still water levels from the “Coastal flood boundary conditions for UK mainland and islands” (EA, 2011), are shown in Table 16 for Sheerness.

Table 16: Extreme water levels (mODN) at Sheerness (Site chainage 4,314 Km) – CFB conditions (EA, 2011)

Return Period	Water level (mODN)
1	3.61
2	3.72
5	3.87
10	4.00
20	4.13
25	4.18
50	4.32
75	4.41
100	4.47
150	4.57
200	4.64
250	4.69
300	4.74
500	4.87
1,000	5.05
10,000	5.75

Source: EA, 2011

Since 1950 the most significant storms are as follows (Halcrow, 2010):

- 1953- a greater than 1 in 100 year event;
- 1978- a 1 in 20 year event
- 1996- a 1 in 10 year event

The 1953 event caused: (a) the Isle of Sheppey to be significantly inundated with flood water; (b) Whitstable to be flooded; and (c) flooding of the Faversham to Thanet railway line at the Seasalter Marshes. In addition approximately 2,000 people were made homeless (Halcrow, 2010).

6.3.4 Waves and overtopping

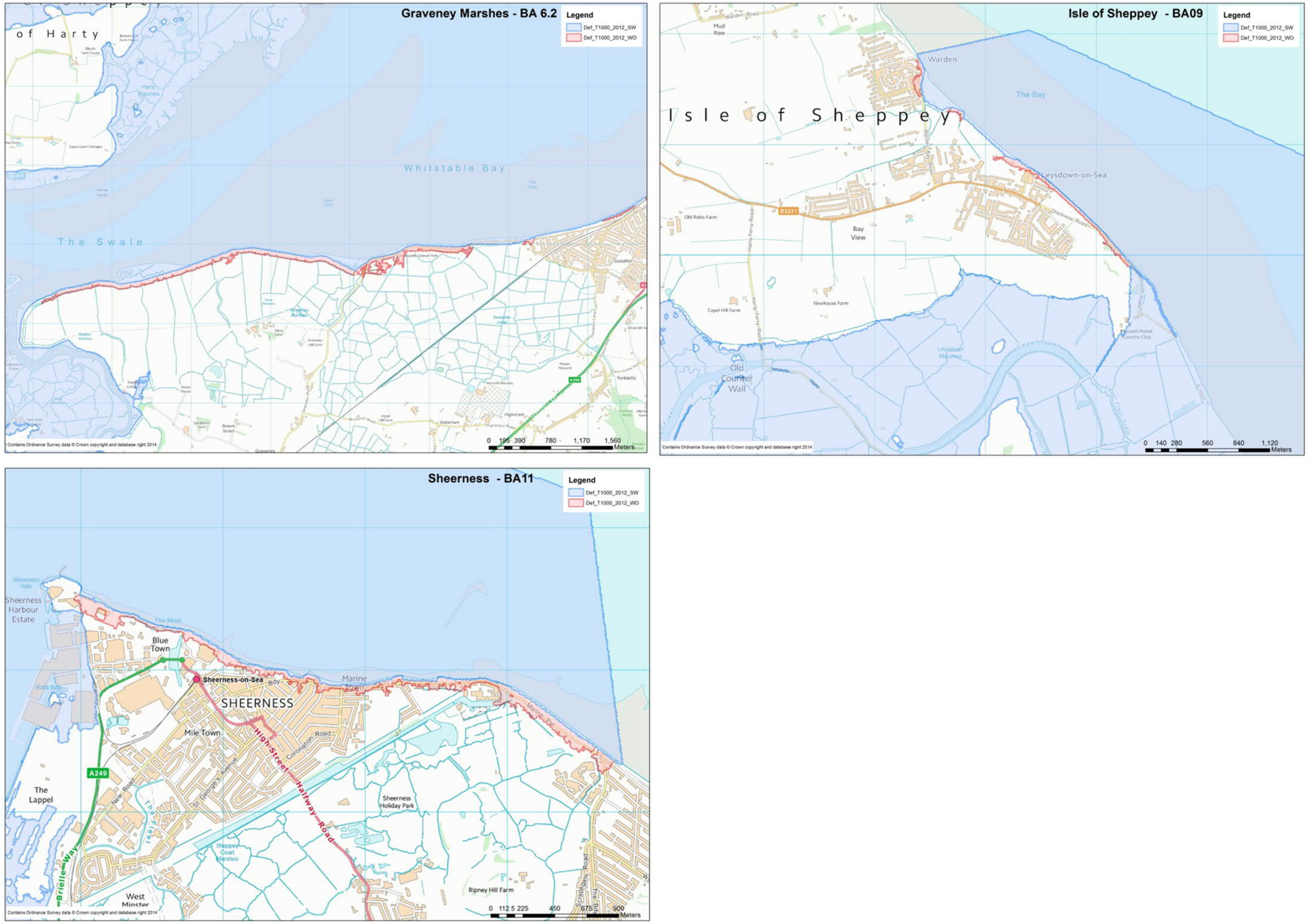
The waves reaching the Thames Embayment have a long fetch extending into the North Sea (Halcrow, 2010) and the waves from the north-northeast have a significant swell component. However, the estuaries are sheltered from wave action due to the narrowness of the mouth, the protection of the Isle of Sheppey and the presence of offshore banks. that the most significant wave action occurs in the outer reaches of the estuaries and decreases into the estuary where wave processes are dominated by internally generated wind waves. Previous reports have found that the wave heights in the estuary are usually <1m and extreme waves do not exceed 2m (Halcrow, 2010).

JBA consulting (2013) provided wave overtopping calculations from a flood modelling study (North Kent Coastal Modelling, Volume 2 - Isle of Grain, Medway, Swale up to and including Whitstable, 2013). The influence of wave overtopping on the flood extent was determine for the Isle of Sheppey, Sheerness, Leysdown on Sea, Faversham and Whitstable using nearshore wave characteristics from the wave transformation model, extreme sea-level information and defence geometry data. Discharge rates (obtained using EurOtop) were incorporated into the 2D flood inundation model along defence lines (for additional information, please refer to JBA, 2013). The results indicated that there is some very limited increase in the flood extent of the areas of interest if wave overtopping of the defences is considered so that at:

- Sheerness the wave overtopping is restricted to the coastline;
- the Isle of Sheppey, wave overtopping impact is very limited; and
- Graveney Marshes in the Swale, wave overtopping impact is very limited.

Figure 75 shows the flood extends obtained by the North Kent Coastal Modelling (JBA, 2013) including and excluding wave overtopping. In summary, wave overtopping is restricted to the exposed/outer part of the estuaries and the effect of it upon the flood extent is limited.

Figure 75: Flood extent for 1:100-year return period for still water (blue extent) and considering wave overtopping (red extent).



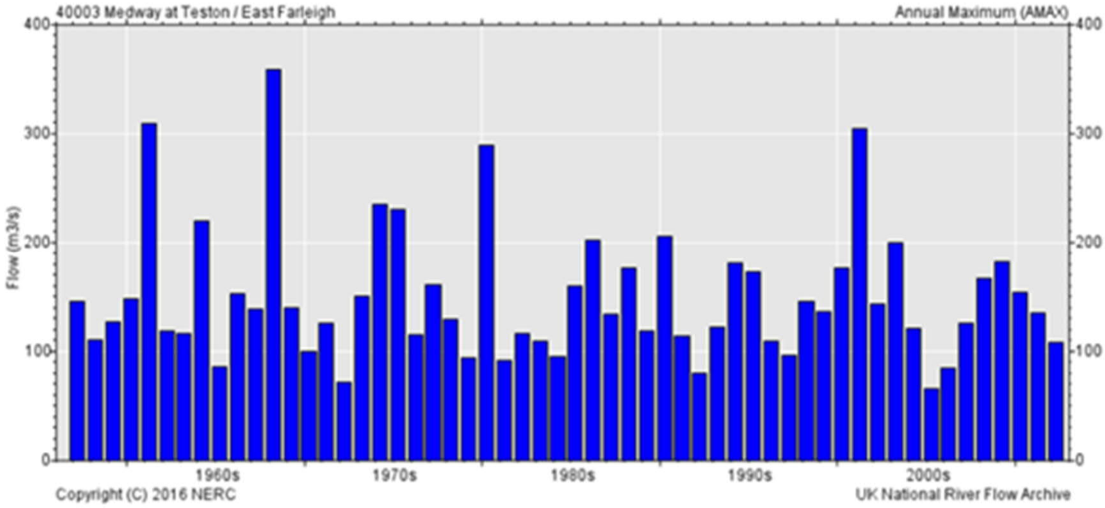
Source: Mott MacDonald, 2016. Contains modelling results from JBA, 2013 and OS data, © Crown Copyright and database right 2016.

6.3.5 Freshwater inputs

The inputs of freshwater to the Medway and Swale are relatively minor compared to the volumes of water which enter and leave the estuary on each tide (Halcrow, 2010). The Medway Estuary has a catchment area of 1,761km^2 with the most significant freshwater input coming via land drainage from the River Medway. Freshwater inputs into the Swale channel come from a series of creeks at Faversham, Oare, Conyer and Milton and smaller input from small creeks on the Isle of Sheppey (Halcrow, 2010).

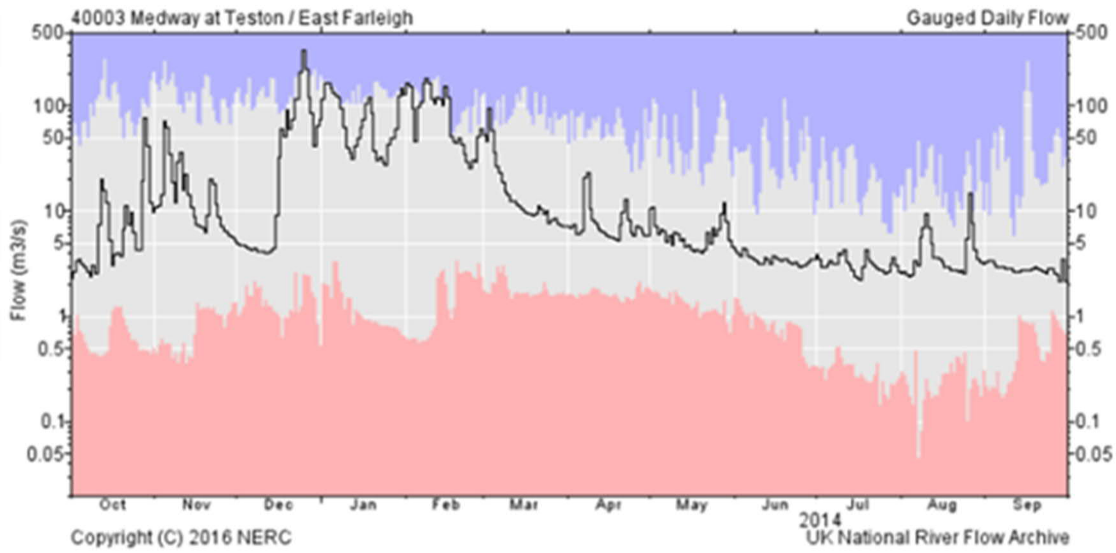
The gauge station on the River Medway at Teston / East Farleigh (Centre for Ecology and Hydrology data) recorded flow data from 1956 to 2014. Over this period, a daily average flow of 11m^3/s was measured. Annual maximum flows in Figure 76 show the time-series of maximum instantaneous peak flows within a given year (October to September). Daily flows are presented in Figure 77 for 2014.

Figure 76: Annual maximum (AMAX) flow data for station 40003 - Teston / East Farleigh.



Source: CEH and NERC, National River Flow Archive, 2016

Figure 77: Medway at Teston / East Farleigh daily flows for 2014.



Key: Red and blue envelopes represent lowest and highest flows on each day over the period of record.
Underlying data supplied by the Environment Agency

Source: CEH and NERC, National River Flow Archive, 2016

6.4 Sediment transport baseline

6.4.1 Sediment dynamics

The shoreline and sub-tidal zone of both estuaries comprise London Clay and glacial drift. The Medway Estuary is dominated by mudflats, comprised of silty sands, clays, and remnants of consolidated sediment. The Swale is characterised by extensive mudflats, which become more sandy and gravelly towards the eastern mouth. Saltmarshes cover a small area of both estuaries. Please refer to the Coastal Squeeze Technical Note (Mott MacDonald, 2016) for additional information regarding saltmarsh and mudflats in the estuaries.

As described in the "*Sediment transport model calibration*" chapter (Chapter 5), there are conflicting views about the sediment dynamic in the Medway. Kirby (2013) describes the Medway as a super-starved sedimentary system that is erosion dominant with fine sediment being discharged seaward. Deloffre *et al.* (2007) also described Medway estuary as sediment starved system with relatively stable mudflats at different time scales.

On the other hand, Halcrow (2010) describe both Medway and Swale as undergoing net accretion with reference to previous studies (IECS, 1993; MESO, 2001, Dalton & Cottle 2002; and Halcrow, 2002). A study of aerial photographs, showed that although erosion has continued between 1961 and 2000 there was a net gain of 1-2 ha year^{-1} between 1961 and 2000 according to Dalton & Cottle (2002) (Halcrow, 2010). These areas of accretion are new Spartina marshes (van der Wal & Pye, 2004 in Halcrow, 2010), which could affect the erosional trend. However, Kirby (2013) argues that this is unlikely due to the overwhelmingly erosion nature of the area.

In the Medway and Swale SMP, Halcrow (2010) describe the estuaries as being a weak sink for fine sediment and that the volumes of sediment being deposited onto the saltmarshes are greater than that being lost in the erosion of the saltmarsh cliffs and mudflats. Kirby (2013) also describes the input of sediment to be minor with a potential exchange with the Thames. Conversely, Halcrow (2010) suggests that the most significant supply of sediment is from the Greater Thames Embayment.

From a sedimentological point of view, Deloffre *et al.* (2007) argue that the Medway exhibits two distinct characteristics : (a) the absence of sands on intertidal mudflats; and (b) the re-working of fine particles within the estuary. This last feature is a consequence of the absence of significant external sediment supply. While some mudflats are slowly accreting, erosion processes dominate.

According to Cundy *et al.* (2007), the Medway estuary is undergoing erosion and a general loss of salt marsh areas. Suspended sediment fluxes are of the order of 0.03 $g/m^3/s$, and the marsh system has low rates of vertical accretion (sediment accumulation rates are *ca*. 4mm/y). Current velocity data from this study (at a location of upper mudflat and marsh) indicate higher velocities on the ebb tide than occur on the flood tide, as previous observed, which may be sufficient to remobilise sediments deposited on the previous tide and force a net removal of material from the marshes. The Cundy *et al.* (2007) study indicates that the Medway is dominated by fine sediments that are reworked within the estuary.

The Deloffre *et al.* (2007) study indicates that Medway mudflats show no evidence of wind generated erosion events, which is consistent with the sheltered morphology of this estuary. According to the study, no trend of net erosion or sedimentation was observed during the analysis. In the mudflats environment, hydrodynamic conditions such as tidal currents and turbulence are minimal and thus do not cause erosion of the mudflat. In addition, no source of sediment was identified for this mudflat, indicating a reworking of the fine particles inside the estuary and little erosion of tidal flats and saltmarshes.Irrespective of these differing opinions it is clear that losses or gains of sediment in the estuary are low and consequently present day morphological changes are very slow.

6.4.2 Bed load and suspended load

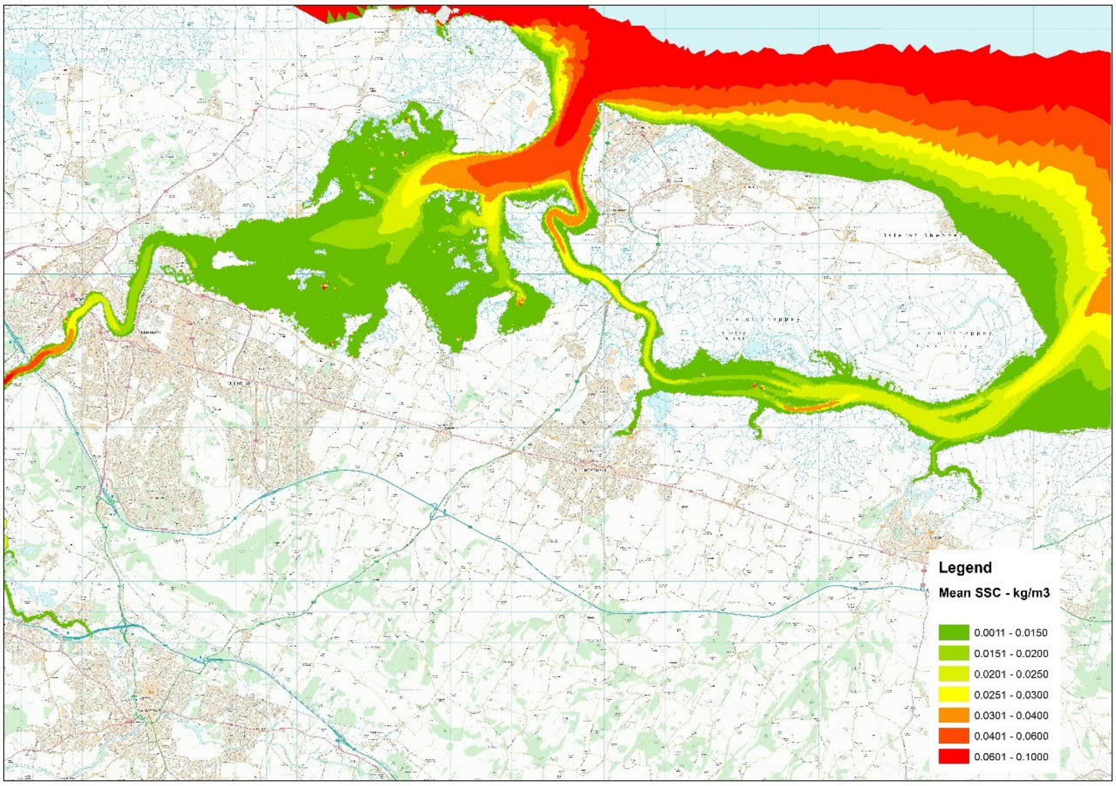
Generally suspended sediment concentrations in the Medway and Swale estuaries are low and are typically in the range 0.1 mg/l to 30 mg/l. The suspended load mostly comprises re-suspended fine sediments. Deloffre *et al*, 2007, Cundy *et al.* 2007, Halcrow, 2010 and Kirby, 2013 all report that SSC values in the Medway and Swale estuaries are low and that the highest observed SSC values within the estuary tend to occur close to high water on spring tides. Deloffre *et al*. (2007) reported maximum concentration of 250mg/l near the bed in the Medway Estuary. In all case, SSC over the mudflats are lower and typically around 100mg/l. These data are accounted for in the the sediment transport model calibration (Chapter 5), where suspended sediments in the estuaries are low, with slightly higher values during the winter period, especially for the offshore area, reaching maximum values of 100mg/l.

In the Swale east entrance, the SSC values are similar to those offshore from the Isle of Sheppey, with slightly larger values during the winter months. Peak SSC of 140mg/l have been recorded in the WIMS database and are used to calibrate the sediment transport model. These higher values observed during the winter months are probably related to storm events and erosion/re-suspension of sediments from the intertidal areas due to wave action.

At the western end of the Swale, the SSC values are very like the eastern side of the estuary. Modelled and recorded data show maximum concentrations of approximately 80mg/l. In general terms, in the Swale, winter SSC tends to be higher than during the summer months, reaching SSC concentration higher than 100mg/l and mean values of around 30-40mg/l. Conversely, in the main Medway Estuary, SSC are considerably lower than the Swale and the offshore area. The recoded and modelled concentrations are less variable and do not exceed 40mg/l with mean values around 20mg/l.

Figure 78 shows the mean SSC modelled during a spring tide as part of the sediment model calibration (Chapter 5). It can be observed that the SSC values are generally low, with the higher values in the offshore area and both estuaries entrances. The figure also shows that the mean SSC in the Swale are higher than in the main Medway Estuary and that in the Upper Medway, mean suspended sediment tends to increase to values higher than 60mg/l.

Figure 78: Mean modelled SSC for a spring tide. Please note that the model SSC is expressed in kg/m3 instead of mg/l – 0.1kg/m3 is equal to 100mg/l.



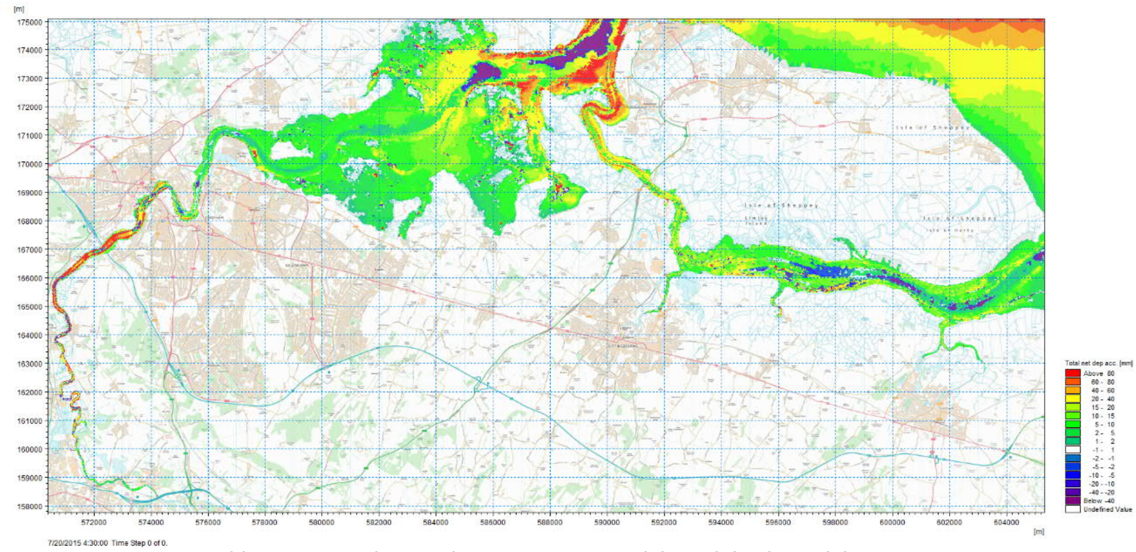
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

6.4.3 Erosion and deposition processes

In the Medway Estuary, Cundy *et al.* (2007) report a mean sedimentation rate of 4-5 mm/year at Horrid Hill(Figure 36). According to the Environment Agency (2011), the net accretion rate in the Medway estuary is 0.5 kg/m^2/yr. This deposition rate corresponds to 0.8 -1.1mm/year, using a dry density of 450kg/m^3 and 611kg/m^3, respectively. In addition, the Deloffre *et al*. (2007) study reported that Medway mudflats have relatively stable elevation throughout the year with annual changes in vertical levels around ±100mm.

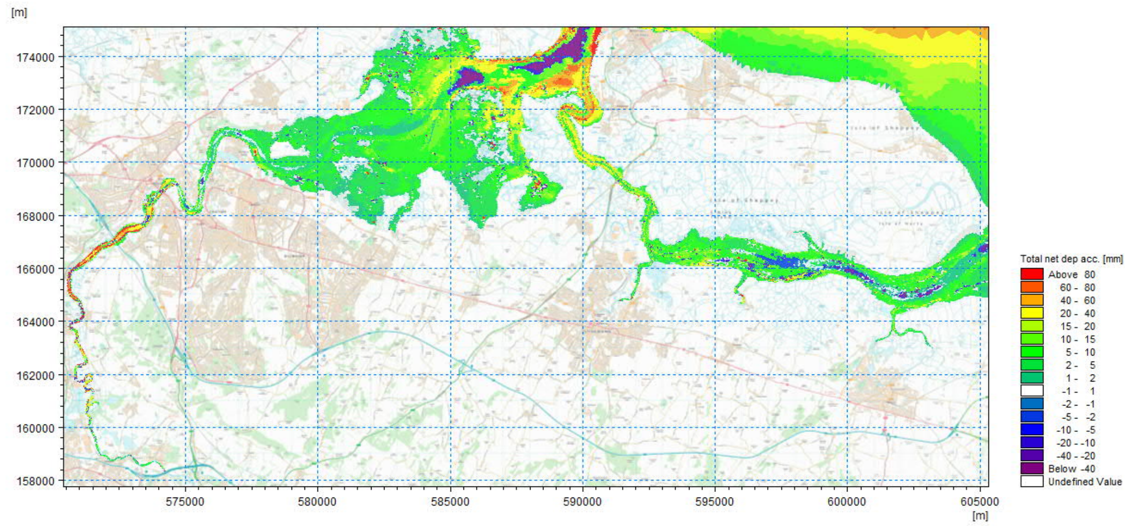
Using the sediment transport model, the net annual sedimentation in the Medway and Swale estuaries was calculated using two different dry densities (450 kg/m^3 and 900 kg/m^3) (Figure 79 and Figure 80 respectively). From both figures, it can be noted that the annual deposition/erosion rates, in the Medway as in the Swale, are small. Both the main Medway Estuary and the Swale how deposition rates between 1 and 3mm/year, with some erosion in the main channels and in the estuaries mouths. The model results show there are no areas where accretion exceed 100mm. Please note that these baseline deposition/accretion maps should be read in combination with the Chapter 5, where all assumption and limitations of the sediment modelling are stated.

Figure 79: Annual modelled deposition map combining Spring and Neap tide condition and using a bulk wet sediment density of 1400 kg/m^3 (dry density of 450kg/m^3)



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 80: Annual modelled deposition map combining Spring and Neap tide condition and using a bulk wet sediment density of 1600 kg/m^3 (dry density of 900kg/m^3)



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

6.5 Present day flood risk

Flooding is a present-day risk to communities and landowners in the low-lying areas around Swale and the Medway Estuary. Aging flood defences, rising sea levels and other climate change impacts mean that flood and erosion risk to people, properties and agricultural land will significantly increase in the future. Further, over the next 100 years it is expected that approximately 18,000 properties will be at an increased risk of tidal flooding in this area. The existing defences around the Medway and Swale are reaching the end of their design life. Ongoing maintenance of these defences is becoming increasingly expensive and problematic, and improvements are required to reduce flood risk in the longer-term.

The baseline results (present day defended and undefended scenarios) from the model are presented in Figure 81 and Figure 82 for the 1:2, 1:20, 1:50, 1:100, 1:200 and 1:1000 years return period events. The flood extend for each of the return period events is summarised in the tables of the next sections. Additional details related to the economic, environmental and social features at risk of flooding are presented in the Option Technical Report (Mott MacDonald, 2017).

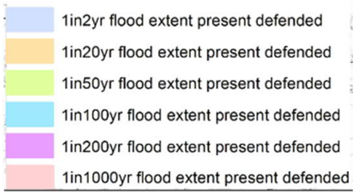
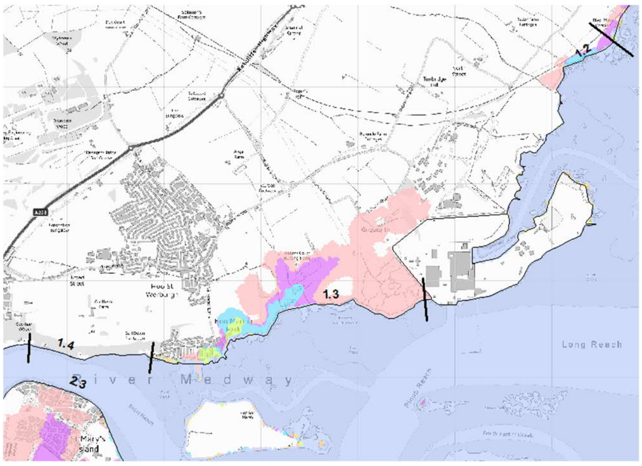
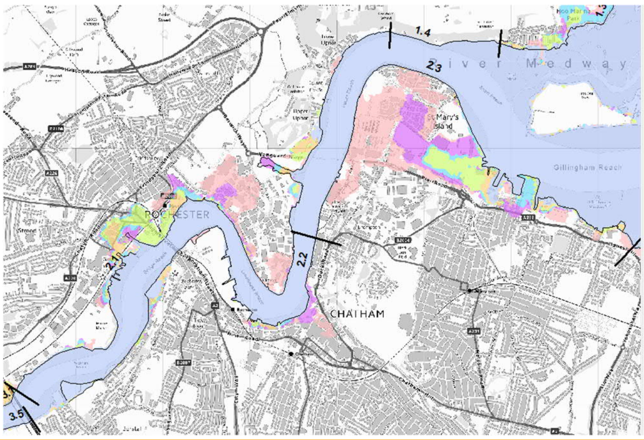
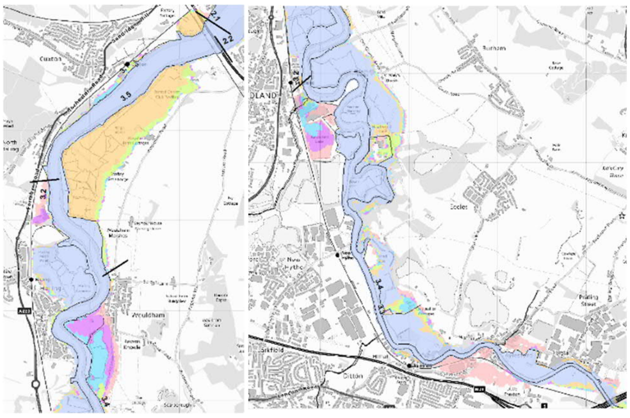
6.5.1 Present Defended scenario

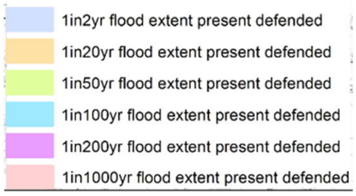
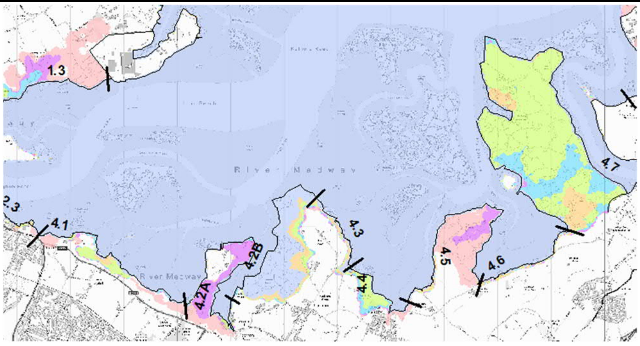
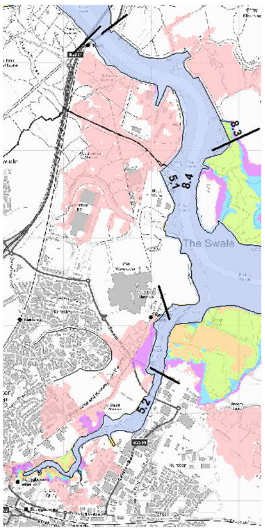
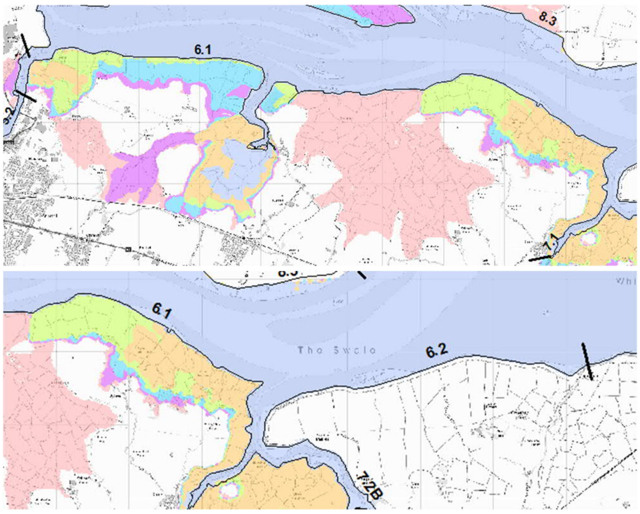
Present defended scenario results, shown in Figure 81, and detailed per each benefit area in Table 17, show the Medway and Swale estuaries flood risk.

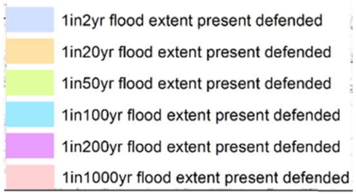
From the results, it can be observed:

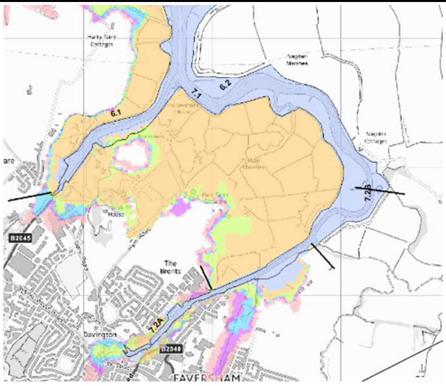
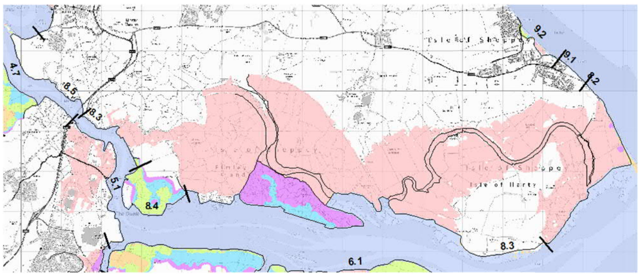
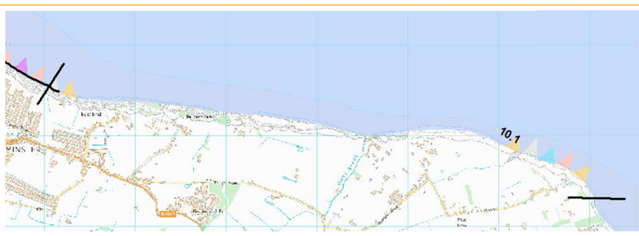
- That there are several areas of the estuaries are at risk of flooding from 1:2 year event: the upper Medway, BA 4.2B and Conyer Creek in BA 6.1. A large number of urban and industrial areas are located in the Upper Medway, and therefore, at risk of flooding from a 1:2 year event.
- During 1:20 year event, the flood risk extends to Faversham creek area (BA07), the eastern side of Milton Creek (BA 6.1), Rochester and St Mary Island areas (BA02) and isolated flooding areas in BA04.
- From the 1:50 year event the flood risk extends to the majority of the sub-benefit areas of BA04 and BA06. Elmely also flooded during this event.
- During 1:100 year event, the northern part of the Swale low lying areas (Spitend marshes – BA 8.3) is at risk of flooding. In the rest of the estuary, the flood risk increases with this return period. For the 1:1000 year event, most of the southern areas of the Isle of Sheppey are flooded, as well as most of the low lying areas of BA06, BA04 and the urban/residential areas in the Upper Medway.

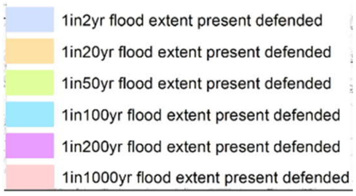
Table 17: Summary of modelled flood extent for the 2, 20, 50, 100, 200 and 1000 years return period evets at present day.

Benefit area	Flood risk	
BA01	No flooding of the frontage is observed for the 1: 2 to 1:20 year events. According to the model results, the defences are overtopped by 1: 50 year event in sub-benefit area 1.3. Overtopping of the defence line also observed for the 1:100 year event in BA1.1. During 1:1000 year event, the model results are showing overtopping of the defences along the almost the entire length of the frontage, with the exception of the power station. The flood extent is limited due to the topography of the land.	
BA02	Flooding is observed from 1:20 year event at Rochester, Chatham and in some St Mary's Island. From the 1:50 year event, High Street at Rochester, roads B2002 and A207; and the railway are flooded. The 1:1000 year flood extent also affect the Maritime Way and Pier Road in St. Mary Island.	
BA03	Halling marshes, Holbourough marshes, Burham marshes and Lower Cut are flooded under 1:2 year events. The risk of flood extent to Ring Marsh, the cricket grounds and the urban areas in 1:20 year. In 1:50 and 1:100 year flood extent are very similar, extending the risk of flooding around the urban areas at Snotland and Forstal. According to the model results for 1:200 and 1:1000 events the flood extent in this area increases considerably, endangering the rail line at several locations and other infrastructure (sewage, recycling, business park, etc.).	

Benefit area	Flood risk	
BA04	Horsham marsh area is flooded, according to the model results, from 1:2 year events, Chetney Marshes in 1:20 year event and Barksore marshes in 1:200 years events and they are completely flooded in 1:1000 years event. At risk of flooding there are also the small settlements at Lower Rainham, Upchurch, Lower Halstow, Iwade Raspberry lane and the B2004.	
BA05	There is not significant flood risk for the resulting from the 1:2, 1:20, 1:50, and 1:100 year events. The overtopping of the defences can be observed form 1:200 year events, flooding the urban/industrial areas around Milton Creek and Sittingbourne. 1:1000 year flood extends to the industrial areas around Ridham Marshes, Coldharbour Marshes and Coldharbour Fleet.	
BA06	During 1:2 year event only the low lying agricultural area near Conyer floods. The flood extent considerably increases during 1:20 year event, covering the low lying agricultural area near Conyer, Oare marshes and Creek. The 1:50 and 1:100 year event results area showing that the most of the low lying area behind the defence line are flooded. The flood extent in these low lying agricultural areas increase significantly with the 1:200 and 1:1000 year event, covering must of the agriculture land. Sub-benefit area 6.2 does not flood under any return period.	



Benefit area	Flood risk	
BA07	Very limited flooding is observed in the numerical modelling results for 1:2 year events, however, the defences are overtopped for the 1:20 year event, flooding must of the Ore creek low lying areas, including Ham marshes. Faversham urban area starts to flood during 1:20 year events.	
BA08	Shell Ness area, in the east of Isle of Sheppey and Elmley marshes are flooded under a 1:50 years events. The defence in the central section of Elmley Island are overtopped in 1:100 year event and the flood extent increases considerably during 1:200 year events. During 1:1000 yearevent, the flooding covers the majority of the low lying areas of the south of the Isle of Sheppey. Sub-benefit area 8.5 does not flood under any return periods.	
BA09	Very limited flooding is observed in the benefit area under 1:2 and 1:20 year events. According the model results, during higher return period events, a portion of the caravan park at Leydown-on-Sea will be flooded.	
BA10	This area is vulnerable to cliff erosion and no flooding is observed due to the high ground.	

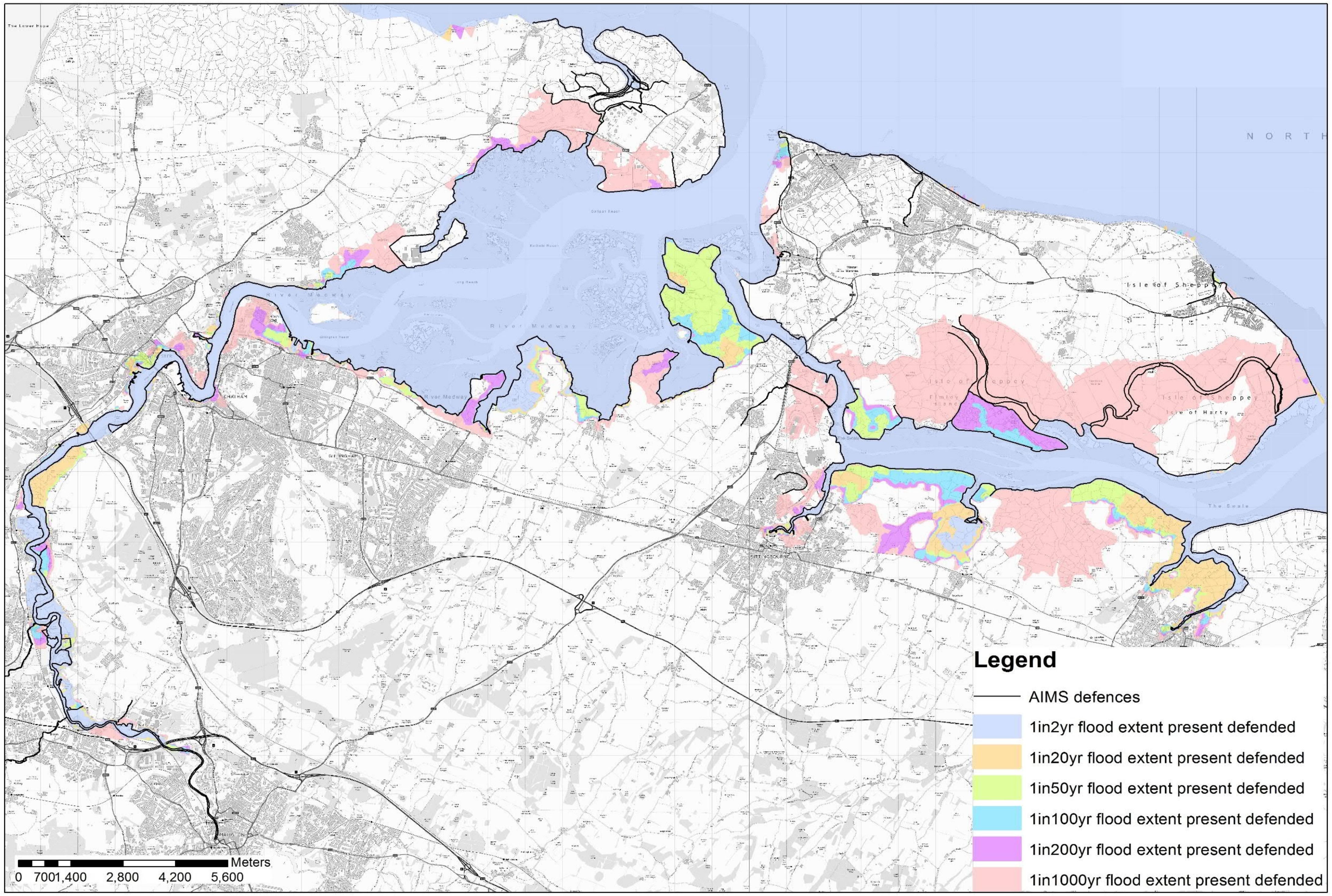
Benefit area	Flood risk	
BA11	No flooding is observed at Mister and Sheerness, indicating that the defences have a high SoP. Flooding of the Port area is observed from 1:100 year event. During 1:1000 year event, flooding is observed around the north of Queenborough.	

Source: Mott Macdonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

6.5.2 Present Undefended scenario

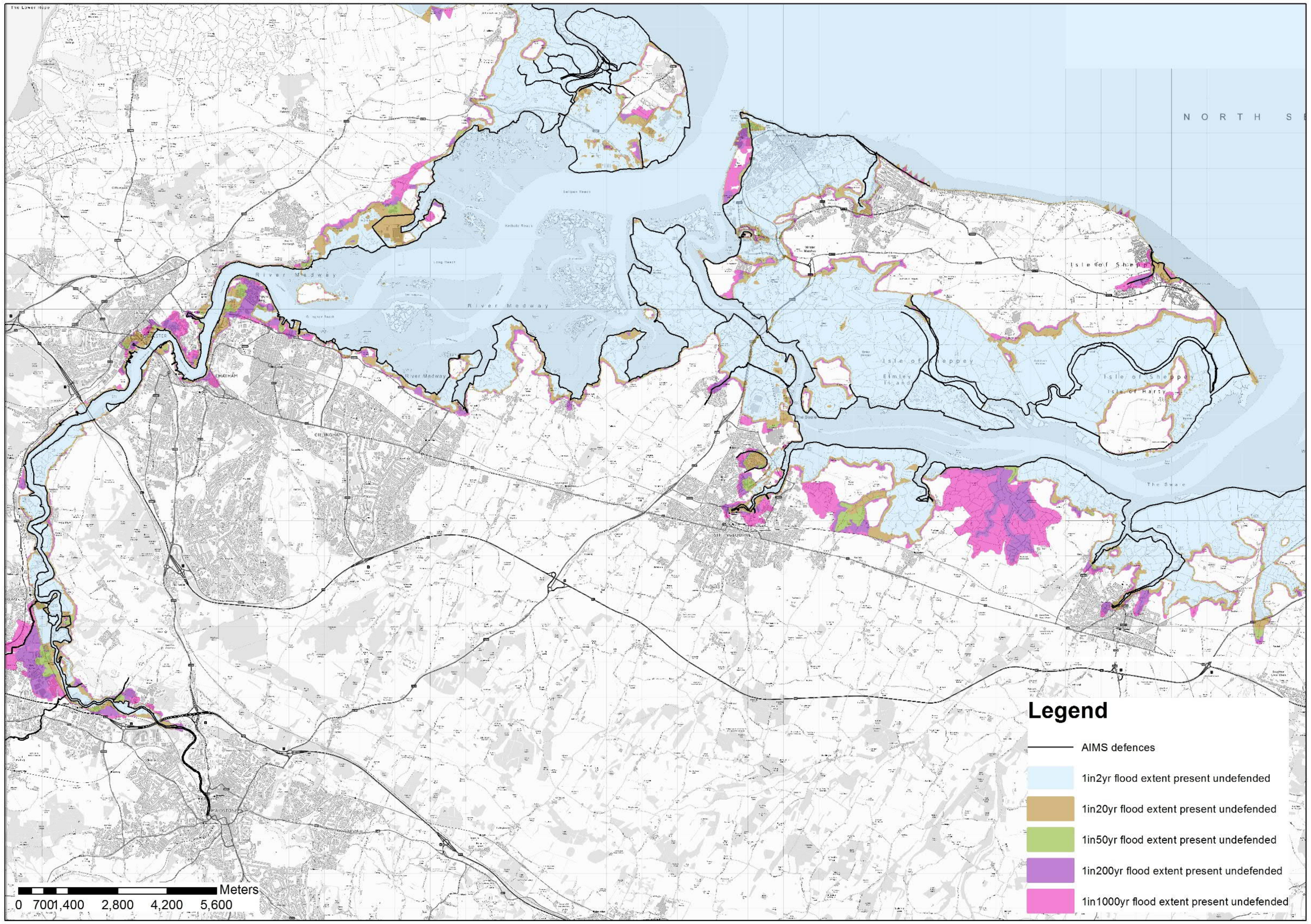
Present day undefended results are shown in Figure 82. It can be observed that the flood risk, under the undefended scenario, increases considerably for both the Medway and Swale area. For the 1:2 years event, the majority of the benefit areas are flooded. The flood extent is only limited by the topography and therefore, the results are very similar for higher return periods. Only BA 6.1 flood risk increases considerably during 1:1000 year event, compared to lower return periods.

Figure 81: Flood extent for the present defended scenario.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

Figure 82: Flood extent for the present undefended scenario.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

6.6 Future day flood risk

According to UKCP09 (Medium Emission 95%ile), sea level rise is expected to be 0.75m in the next 100 years and thus the risk of coastal flooding in the study area will be increased.

The future day (2116) modelling results (future day defended and undefended scenarios) are presented in Figure 83 and Figure 84 for the 1:2, 1:20, 1:50, 1:100, 1:200 and 1:1000 years return period events.

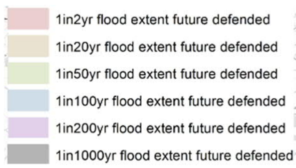
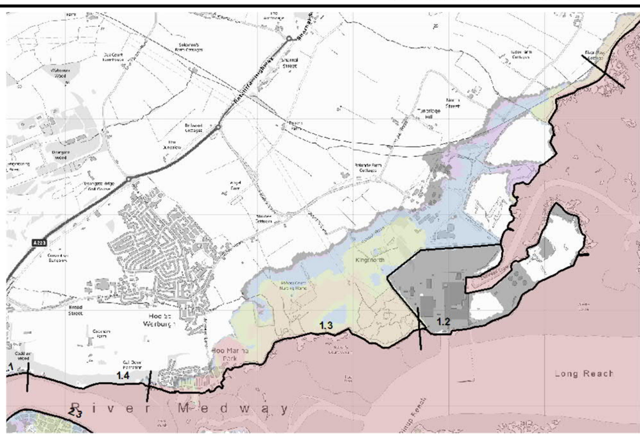
The flood extent for each of the return period events in 2116 is summarised in the tables and figures of the next sections. Additional details related to the economic, environmental and social features at risk of flooding are presented in the Option Technical Report (Mott MacDonald, 2017).

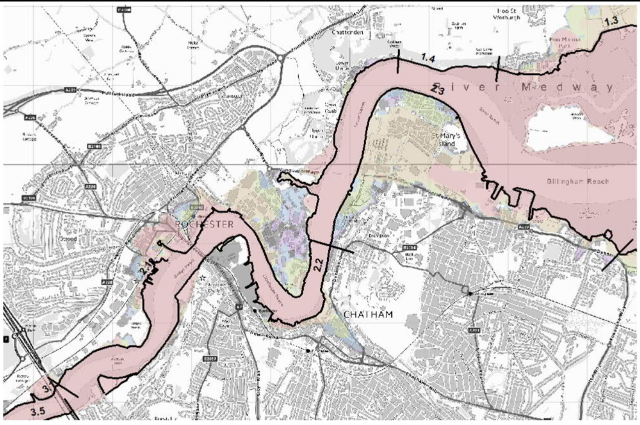
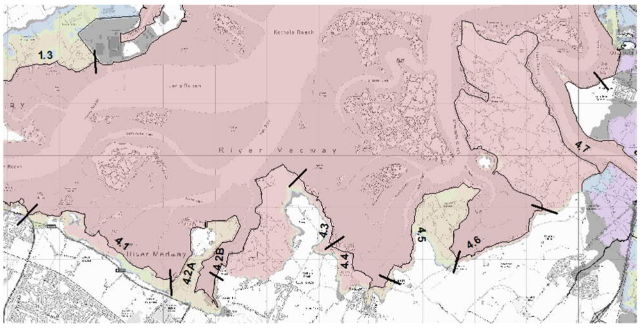
6.6.1 Future Defended scenario

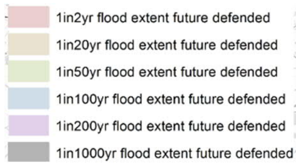
Present defended scenario results, presented in Figure 83 and detailed for each benefit area in Table 18, show the Medway and Swale estuaries flood risk 100 years in the future in 2116.

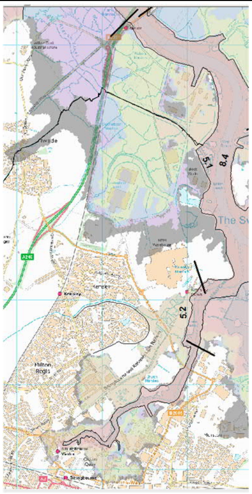
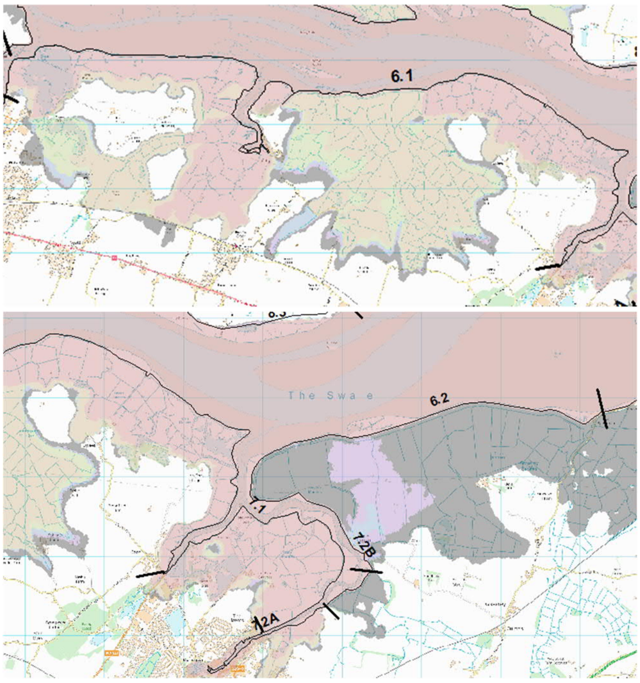
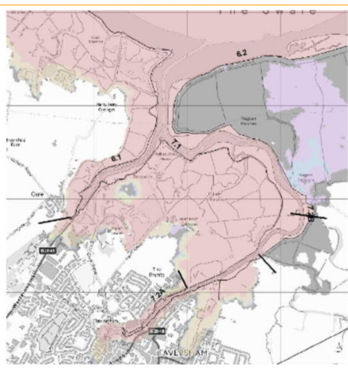
Iit can be seen that a large portion of estuaries coastal areas are at risk of flooding from 1:2 year event. This risk includes most the upper Medway, BA 4.2B and BA 4.7, BA 6.1, all the area around Faversham Creek (BA07) and the low-lying areas of the Isle of Sheppey (Elmely and Spitend marshes). Comparing the future defended scenario with the present-day results, it can be seen that the future 1:2 year event has a similar flood risk to the 1:100 years present day event.

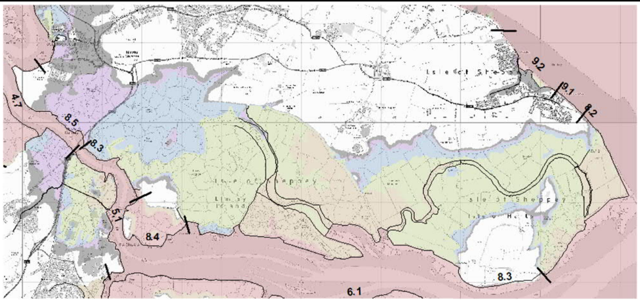
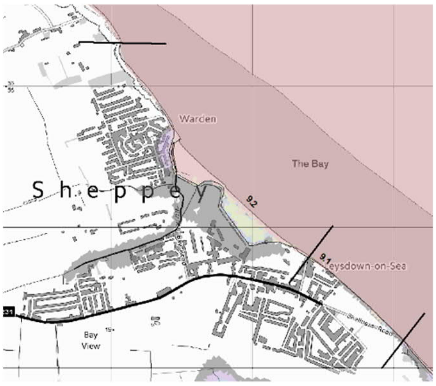
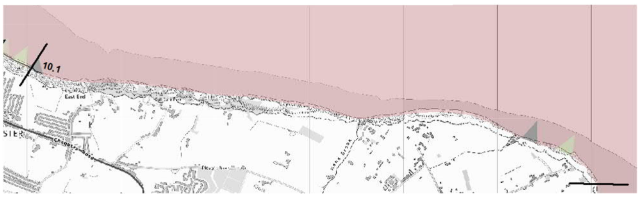
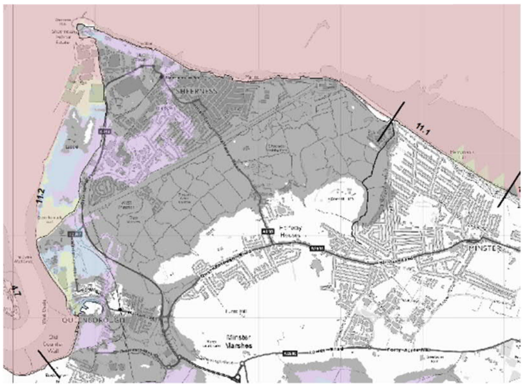
Table 18: Summary of modelled flood extent for the 1:2, 1:20, 1:50, 1:100, 1:200 and 1:1000 years return period evets at future day (2116).

Benefit area	Flood risk	
BA01	Flooding of the frontage is observed for the 1: 2 year event at Hoo Marina. According to the model results, the defences are overtopped by 1: 20 year event in the rest of the sub-benefit area 1.3. Overtopping of the defence line is observed for the 1:50 year event in BA1.1. During 1:1000 year event, the model results are showing overtopping of the defences along the almost the entire length of the frontage, including the power station.	

Benefit area	Flood risk	
BA02	Flooding is observed from 1:20 year event at Rochester, Chatham and in some St Mary's Island. From the 1:50 year event, High Street at Rochester, roads B2002 and A207; and the railway are flooded. The 1:1000 year flood extent also affect the Maritime Way and Pier Road in St. Mary Island.	
BA03	Halling marshes, Holbourough marshes, Burham marshes, Lower Cut, Ring Marsh, the cricket grounds, the urban areas at Snotland, Aylesford and Forstal are flooded under 1:2 year event. According to the model results for 1:50 and higher return period events the flood extent in this area increases considerably, endangering the rail line at several locations and other infrastructure (sewage, recycling, business park, etc.).	
BA04	Horsham marsh area is flooded, according to the model results, from 1:2 year events as well as Chetney Marshes. During a 1:20 year event Barksore marshes and Motney Hill water treatment facilities are at risk of flooding. At risk of flooding there are also the small settlements at Lower Rainham, Upchurch, Lower Halstow, Iwade Raspberry lane and the B2004 form the 1~:50 years event.	



Benefit area	Flood risk	
BA05	The overtopping of the defences can be observed form 1:20 year events, flooding the urban/industrial areas around Milton Creek and Sittingbourne. From the 1:50 years flood extends to the industrial areas around Ridham Marshes, Coldharbour Marshes and Coldharbour Fleet.	
From	During 1:2 year event the low lying agricultural area near Conyer floods as we, Oare marshes and Creek and Little Murston. For higher return period events, the results area showing that most of the low lying area behind the defence line are flooded. The flood extents and reaches Lower Road and the railway line for the 1:100 year event. Sub-benefit area 6.2 floods from 1:100 year return period.	
BA07	The defences are overtopped for the 1:2 year event, flooding must of the Ore creek low lying areas, including Ham marshes and Faversham urban area.	

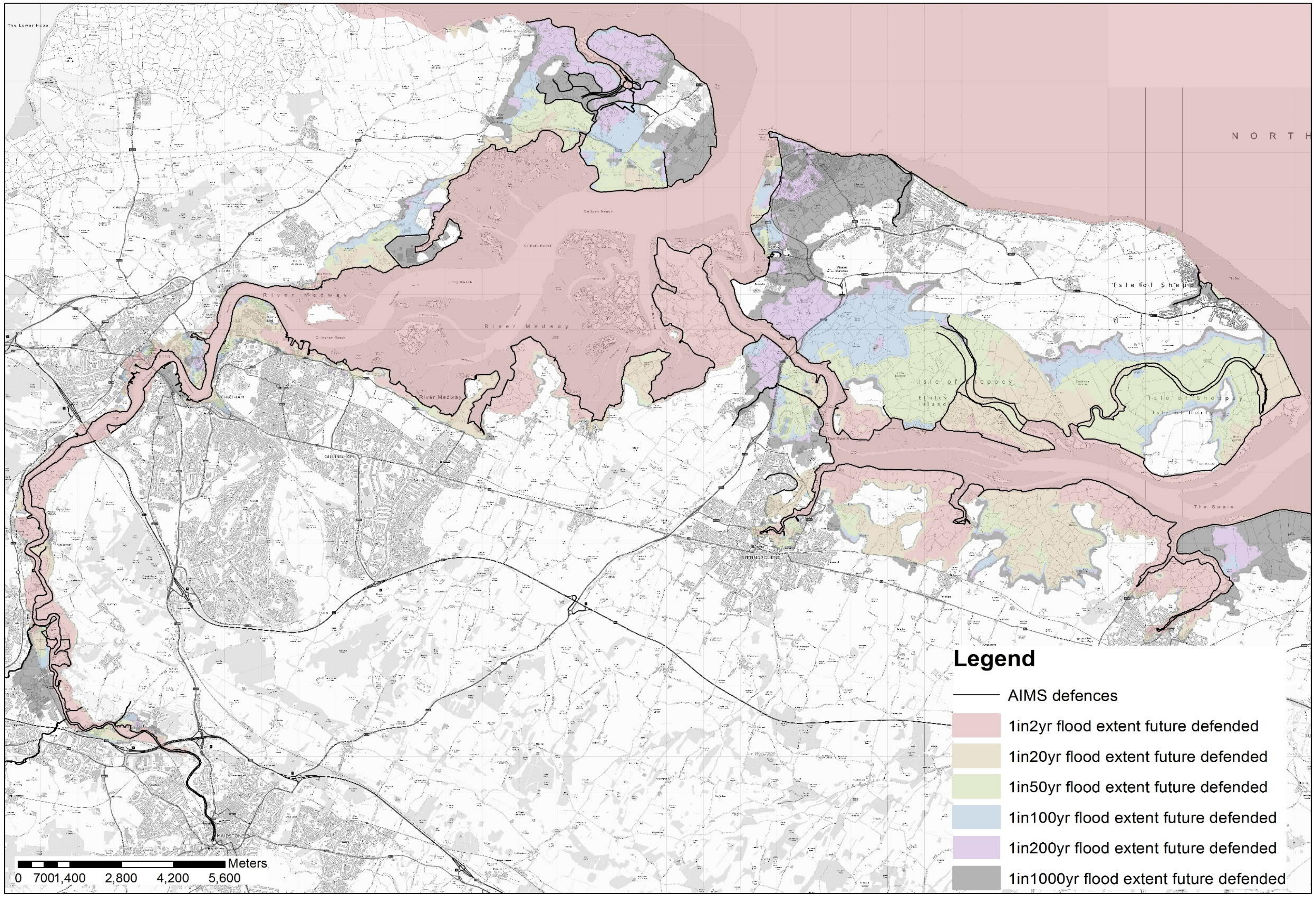
Benefit area	Flood risk	
BA08	Shell Ness area, in the east of Isle of Sheppey and Elmley marshes are flooded under a 1:2 year events. The defence in the central section of Elmley Island are overtopped in 1:20 year event and the flood extent increases considerably during 1:50 year events. During 1:1000 year event, the flooding covers the majority of the low lying areas of the south of the Isle of Sheppey. Sub-benefit area 8.5 floods only from the 1:200 year event.	
BA09	The caravan park at Leydown-on-Sea is flooded form the 1:2 year event. The 1:200 year events is flooding the part of the residential areas in the north of Warden, while the 1:1000 years event is flooding a larger portion of Warden, including Warden Bay Road.	
BA10	This area is vulnerable to cliff erosion and no flooding is observed due to the high ground.	
BA11	No flooding is observed at Mister indicating that the defences have a high SoP. Flooding at Sheerness is observed form the 1:200 years return period event. Flooding of the Port area is observed from 1:2 year event. From the 1:50 year event, flooding is observed around the north of Queenborough. The flood in this area considerably extends for the 1:1000 year event, affecting some of the major road infrastructure.	

6.6.2 Future Undefended scenario

Future day undefended results are presented in Figure 84. Results show that the flood risk under the undefended scenario increases considerably for both the Medway and Swale area and is similar to what was observed for the present-day results.

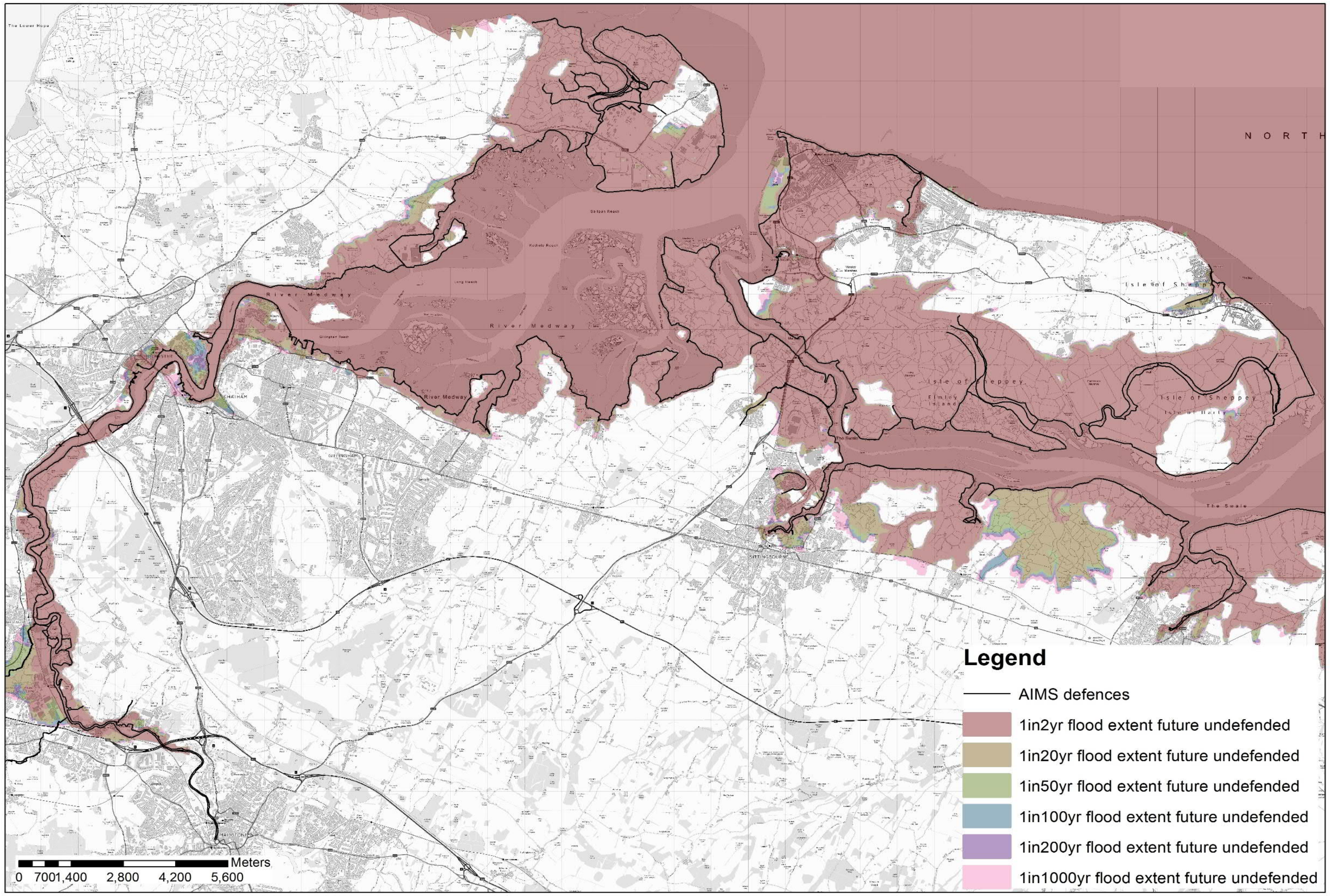
From the 1:2 year event, the majority of the benefit areas are flooded. The flood extent is only limited by the topography and therefore, the results are very similar for the higher return periods. Present and future undefended results are also very similar for this same reason.

Figure 83: Flood extent for the future defended scenario.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

Figure 84: Flood extent for the future undefended scenario.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

7 Options development modelling results

Executive summary

As part of the Medway and Swale Strategy long-term, technically sound, environmentally acceptable and economically viable options for the frontages have been developed.

Three types of "hold the line" (HTL) options were developed for the Medway and Swale estuaries. The HTL options consist of hold the existing defence line so that the position of the shoreline remains and include:

- Maintain – maintain the current crest level;
- Sustain – increase the crest level in phases in line with sea level rise; and
- Upgrade – increase the crest level at the start of the 100 years, so that it will continue to provide protection in 100-years time (i.e. accounts for sea level rise).

Present Sustain scenario result show that that both the Medway and the Swale estuaries are protected up to the 1:100 year event. Present Upgrade results show that all the frontages are protected from the 1:1000 year event and therefore, no flooding is predicted by the model for any of the benefit areas.

The Future Sustain and Future Upgrade results show that the crest levels defined for these scenarios protect the Medway and Swale frontages from a 1:200 year event.

The results from the modelling of the options are clearly indicating that increasing the defence crest levels to "Present Upgrade" heights will considerably decrease the present-day flood risk, protecting both estuaries to 1:1000 years present day event. The modelling results are also indicating that the 1:1000 years standard of protection, archived with the upgrade of the defence, decreases to 1:200 years in the future (considering 100 years of sea level rise).

It is noted that the selection of a preferred option for each benefit area will be based, not only on the modelling results presented in this Chapter, but also in a comprehensive assessment of other criteria (economic value, ecological, ecosystems services, stakeholders, etc.).

7.1 Introduction

As part of the Medway and Swale Strategy, long-term, technically sound, environmentally acceptable and economically viable options for the frontages have been developed. Consequently, three types of "hold the line" HTL options were developed for the Medway and Swale estuaries including:

- Maintain – maintain the current defence crest level;
- Sustain – increase the defence crest level in phases to accommodate sea level rise; and
- Upgrade – increase the defence crest level to ensure they will continue to provide protection in 100 years' time (i.e. account for predicted changes in sea level due to climate change). For clarity, these HTL options are defined in in Figure 85.

Figure 85: "Hold the line" (HTL) options for the Medway ad Swale Strategy

Source: Mott MacDonald, 2016

7.2 Options model setup

The MEASS model was set up for each of the options by modifying the crest levels of the existing defences and dikes in the model domain. Two scenarios per option were modelled:

- Present day - present day mean sea level elevation (i.e. no climate change); and
- Future - including sea level rise over 100 years (2116 mean sea level elevation).

It is noted that the Maintain option involves maintaining the current crest level of the defence line, and therefore no changes were required in the model. Present defended and future defended results (presented in Chapter 6.5 and Chapter 6.6 respectively) reflect the Maintain scenarios.

As part of the optioneering process the crest levels of the defences of each benefit areas were determined for each option and each scenario. Please see the Option Technical Report (Mott MacDonald, 2017) for additional information regarding these levels. Table 19 shows the crest levels defied in the model for each of the options.

Table 19: Defence crest levels (mODN) per each HTL options and scenarios.

Benefit area	Sustain (mODN)		Upgrade (mODN)	
	Present	Future	Present	Future
1.2	5.3	6.6	6.6	6.6
1.3	5.0	6.1	6.1	6.1
2.1	5.1	6.2	6.2	6.2
2.2	5.4	6.8	6.8	6.8
2.3	5.1	6.3	6.3	6.3
3.1	5.3	6.5	6.5	6.5
3.2	5.1	6.1	6.1	6.1
3.3	6.0	7.4	7.4	7.4
3.4	5.9	7.5	7.5	7.5
3.5	5.0	6.0	6.0	6.0
4.1	4.9	5.9	5.9	5.9
4.2A	4.9	5.9	5.9	5.9
4.2B	4.9	5.8	5.8	5.8
4.3	4.8	5.7	5.7	5.7
4.4	5.2	6.0	6.0	6.0
4.5	4.9	5.9	5.9	5.9
4.6	4.8	5.7	5.7	5.7
4.7	4.8	5.7	5.7	5.7
5.1	5.2	6.5	6.5	6.5
5.2	4.9	6.0	6.0	6.0
6.1	4.8	5.9	5.9	5.9
6.2 (Faversham Creek)	5.2	6.0	6.0	6.0
6.2	5.4	6.4	6.4	6.4
7.1	4.5	5.4	5.4	5.4
7.2A	4.8	6.0	6.0	6.0
7.2B	5.7	6.4	6.4	6.4
8.2	4.8	6.1	6.1	6.1
8.3	4.8	5.8	5.8	5.8
8.4	4.9	5.6	5.6	5.6
8.5	5.8	6.5	6.5	6.5
9.2	4.9	6.2	6.2	6.2
11.2	5.4	6.9	6.9	6.9

Source: Mott MacDonald 2016

Table 19 shows that the Future Sustain and Future Upgrade options have the same crest levels and they both considered sea level rise to 2116. For this reason, only one model was set up for these two options.

7.3 Options results – Flood extent

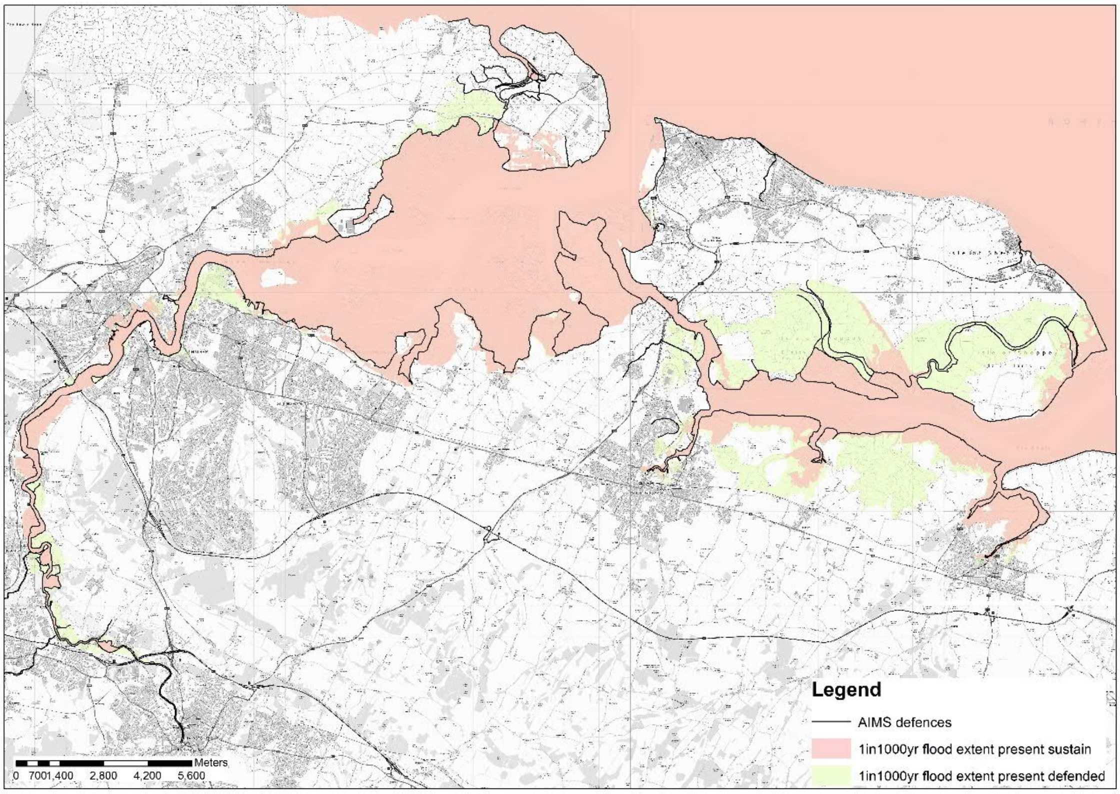
In this section, modelling results showing flood extent are presented and are compared with the baseline results (Chapter 6.3).

7.3.1 Present sustain

The flood extent for the Present Sustain scenario is shown in Figure 88. The results show that the crest levels defined for this scenario protect the Medway and Swale frontages for 1:100 year event. Flooding on the Upper Medway is observed for the 1:200 year event, mainly in benefit areas 3.2 and 3.5. Additional flooding is observed in Faversham Creek, in benefit area 7.1.

However, the estuaries, are not protected against the 1:1000 year event. The flood extent of Figure 88 shows flooding in almost every benefit area. The observed flooding is, however, limited compared the present defended flood extent for the same return period (Figure 81). The comparison between the baseline scenario present defended and the present sustain results for the 1:1000 year event is presented in Figure 86.

Figure 86: Flood extent for the 1:1000 year event for the baseline present defended (in green) and present sustain (in red) scenarios.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

7.3.2 Present upgrade

The flood extent for the Present Upgrade scenario is shown in Figure 89. The results show that the crest levels defined for this scenario protect the Medway and Swale frontages for the 1:1000 year event and no flooding is observed in any of the benefit areas.

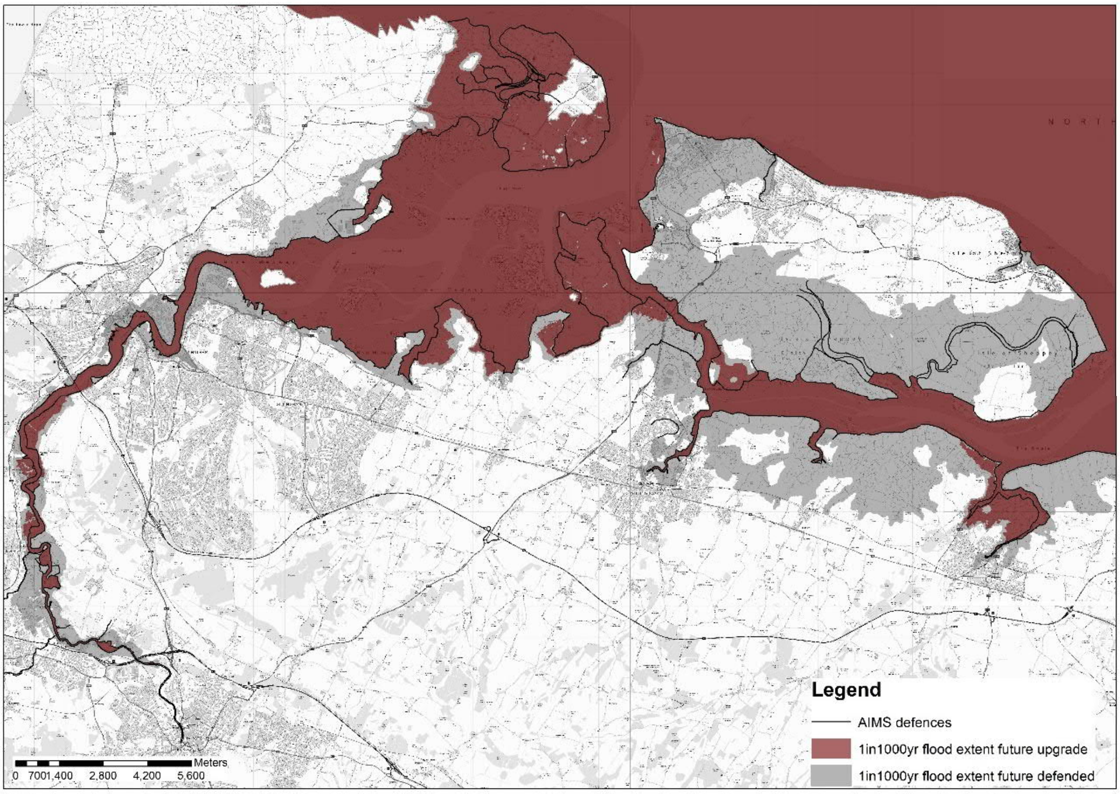
7.3.3 Future Sustain and Future upgrade

The flood extent for the Future Sustain and Future Upgrade scenarios is shown in Figure 90. The results show that the crest levels defined for these scenarios protect the Medway and Swale frontages for the 1:200 year event. Flooding in the Upper Medway is observed for the

1:1000 year event mainly in benefit areas 3.2 and 3.5. Additional flooding is observed in the main Medway estuary, in benefit area 4. Faversham Creek, in benefit area 7.1, and the eastern boundary of benefit area 6.2, are also at risk of flooding during the 1:100 year event. In the Isle of Sheppey, only Elmely is flooded during these extreme events. The predicted flooding for the 1:1000 year event is limited compared the baseline future defended flood extent (Figure 83).

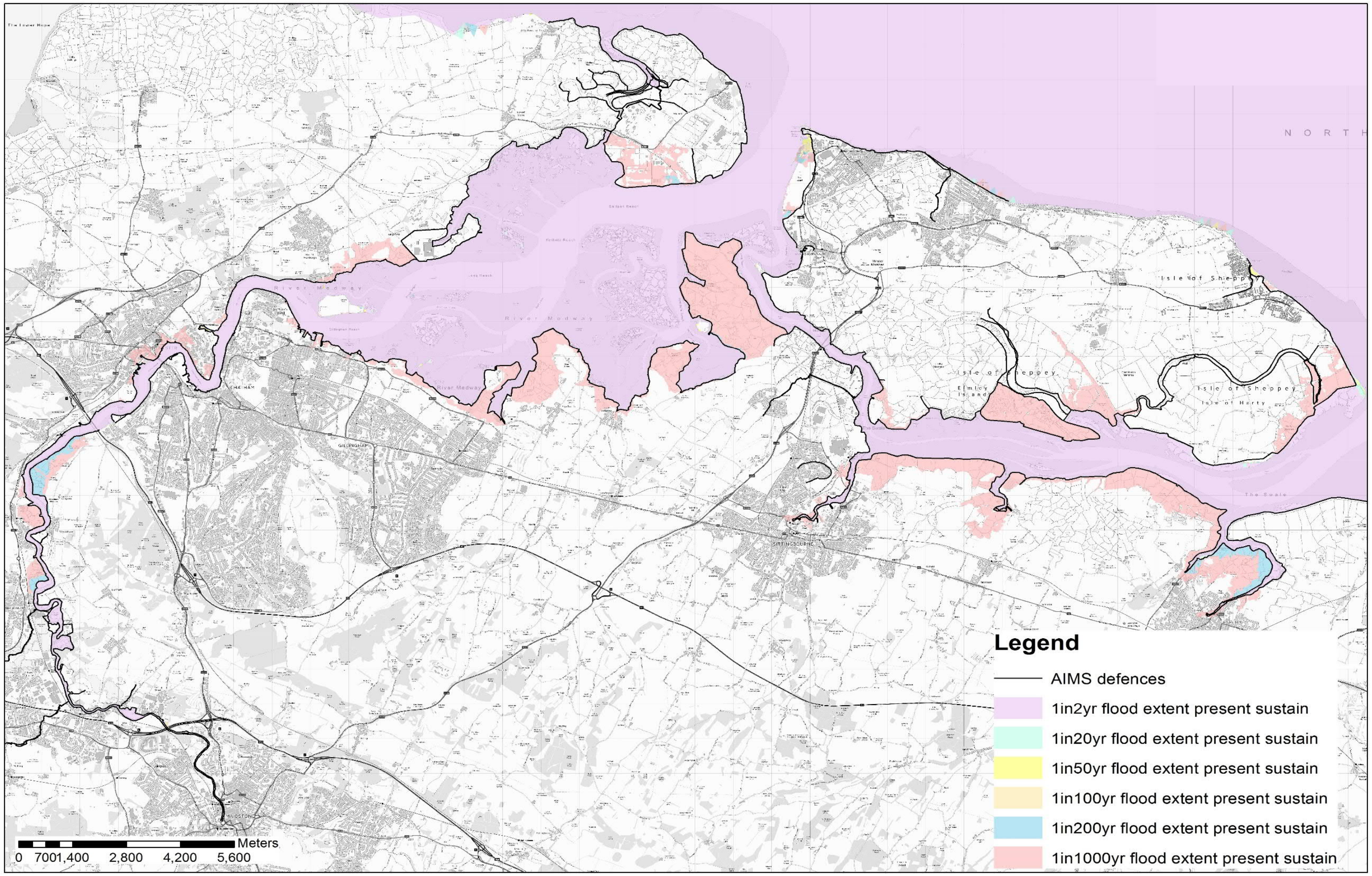
Figure 90 shows a comparison between the baseline scenario future defended and the future upgrade results for these extreme events. From the figure, the considerably reduction of the future flood risk, due to the upgrade of the defence crest levels, can be observed.

Figure 87: Flood extent for the 1:1000 year event for the baseline future defended (in grey) and future sustain/upgrade (in red) scenarios.



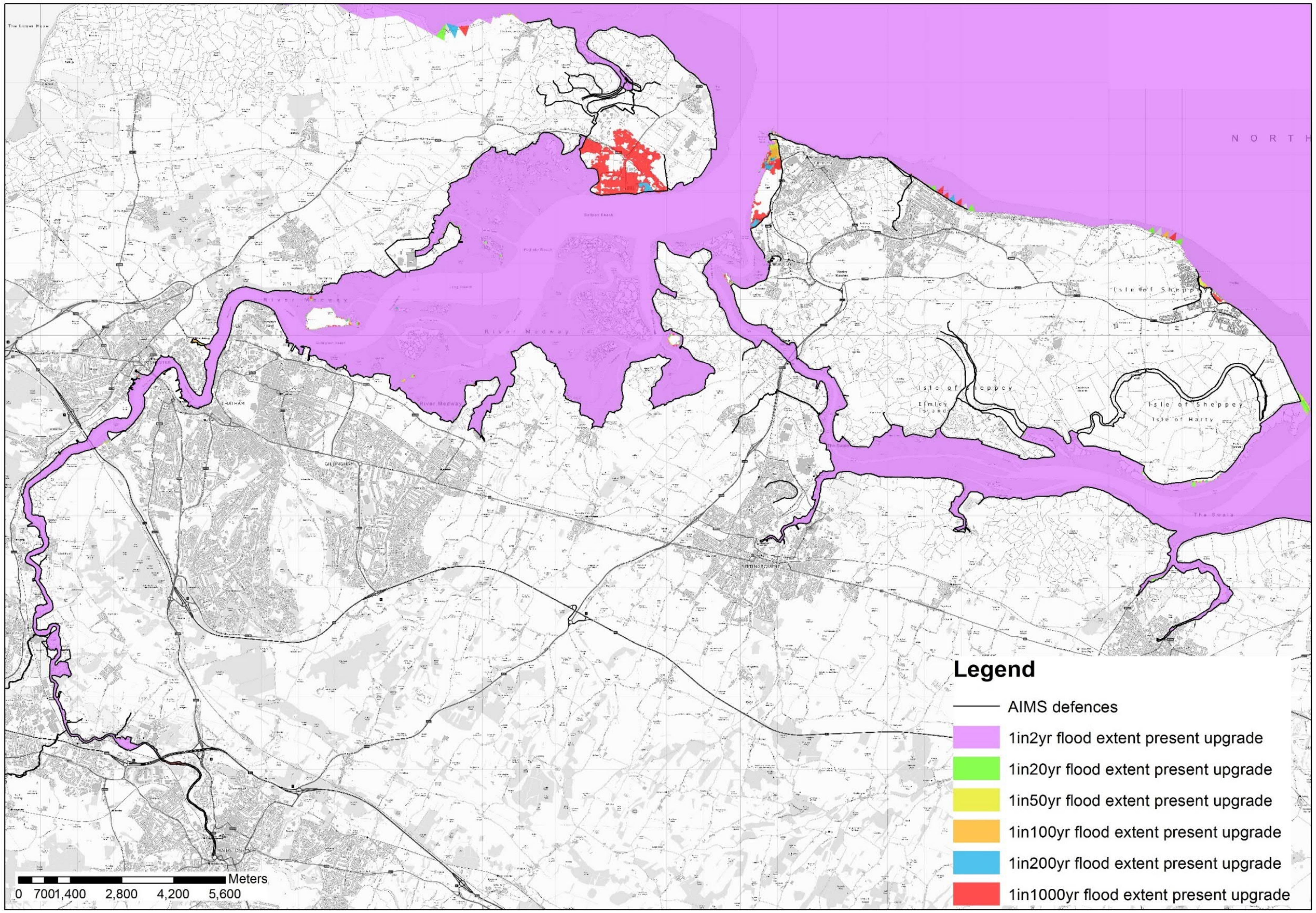
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

Figure 88: Flood extent for the Present Sustain scenario.



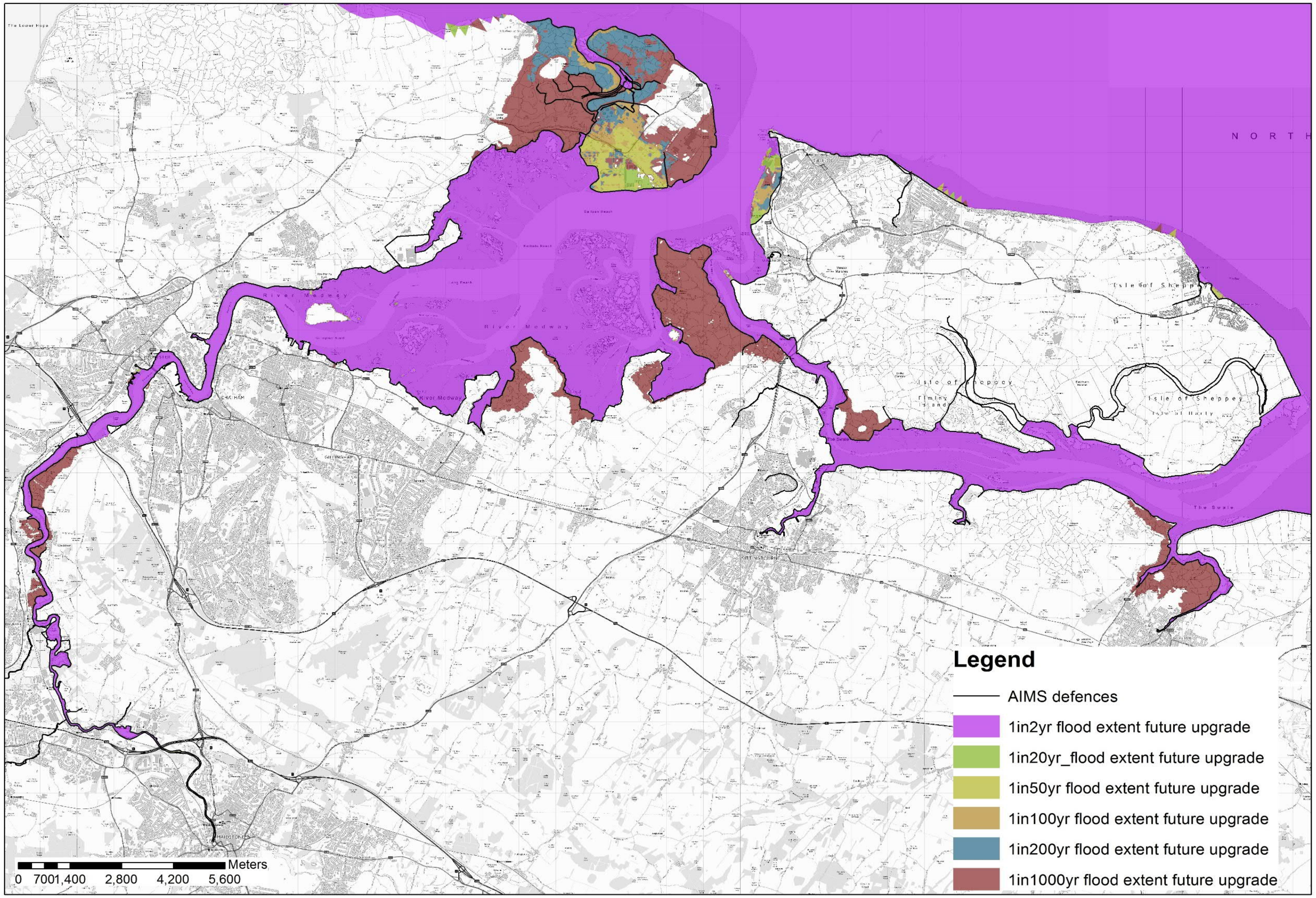
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

Figure 89: Flood extent for the Present Upgrade scenario.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

Figure 90: Flood extent for the Future Sustain and Future Upgrade scenario.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016.

7.4 Summary

The modelling results show clearly that increasing the defence crest levels to "Present Upgrade" heights (Table 19) will decrease the present day flood risk and provide flood protection to both estuaries for the 1:1000 year present day event.

The results show also that the 1:1000 year standard of protection archived with the defence upgrade decreases to a 1:200 year event in the future when 100 years of sea level rise Is accounted for.

It is noted that while the selection of a preferred option for each benefit area will be based on the modelling results, it will also take consideration of economic value, ecological value, ecosystems services, stakeholders, etc.

For additional information regarding the preferred option assessment please refer to main MEASS Strategy Report (Mott MacDonald, 2017). The modelling results of the selected preferred option are presented in Chapter 9, in terms of hydrodynamic, and Chapter 10 in terms of sediment transport.

8 Managed realignment modelling results

Executive summary

The MEASS hydrodynamic model has been run with the inclusion of all the 22 potential management realignment sites currently selected as being favourable, and for selected groups of realignment sites to examine their relative impacts on the Medway and Swale estuaries. Each of these sites has been breached in one or more locations to allow the efficient ingress and outflow of water during flood and ebb tides. In all cases three tidal cycles have been simulated with the maximum water levels attained during a given cycle set to: (a) the predicted 1:200-year event (4.65m ODN at Sheerness); and (b) the maximum spring tide level (2.85m ODN at Sheerness).

After an initial assessment of the impacts, further model runs were defined to quantify how realignment sites, either individually or collectively, impacted on the estuaries. A systematic sequence of the model runs was undertaken dividing the Swale and the Medway estuaries in order to determine if the two estuaries are working as separate systems and the effects of the realignments sites are limited to the estuary in which they are located. In addition, the proposed realignment sites in the Swale were split into two groups (East and West sites) to understand the impacts observed.

MEASS model simulations of all 22 proposed management realignment sites for the 1:200-year event demonstrates that realignment sites are predicted to:

- Increase in the maximum water levels and current speeds in the Swale by up to 13cm (c. 2% increase in the maximum tidal range) and around 25cm/s, respectively;
- Decrease the current speed in the middle section of the Swale around Elmley Reach by around 7cm/s;
- Decrease water levels by 10cm to 17cm (c. 2.6% decrease in the maximum tidal range) and increases the current speeds by around 20cm/s in the upper Medway, with maximum values of c. 25cm/s at some locations during the ebb tide.

MEASS model simulations of all the 22 proposed management realignment site for a spring tide demonstrates that realignment sites are predicted to:

- Decrease in maximum water levels and increase in maximum current speeds in the middle-Swale by approximately -12cm and around 10cm/s, respectively;
- Decrease maximum water levels and increases in maximum current speeds in the upper Medway by approximately -17cm and up to 15cm/s, respectively;
- Decrease the current speeds in the upper Medway above potential managed realignment site 8 by up to 5cm/s; and
- Decrease the current speeds in the Swale around Elmley Reach by up to 5cm/s.
- If some very minor interactions are ignored the MEASS simulations show that Swale-only realignment sites only impact the Swale estuary and Medway-only realignment sites only impact the Medway estuary.

Separate independent simulations of east Swale and west Swale realignment site impacts showed that:

- Any realignment sites in the Swale will create an increased water level gradient between the western and eastern mouths of the estuary that will increase water levels, especially in the central part of the Swale estuary;
- The eastern realignment sites alone have almost the same impact on water elevation and tidal current speeds as all the sites in the Swale; and
- The western realignment sites alone elevate water levels and increase flow speed, but by a lesser amount compared with the eastern sites.

All Present Maintain MEASS simulations (1:200 year and spring tide) showed:

- A water level increase of 4cm above the predicted maximum value of 17cm for the Present Upgrade case in the Swale owing to the limitations imposed on flood extent by the setback defences and flood regulation through the breach sites;
- An increase in tidal currents speeds up to 30cm/s in the Swale and up to 20cm/s in the Medway; and
- A decrease in maximum tidal current speed up to 10cm/s around Elmley Reach.

It is concluded that there is no increase in flood risk in either the Medway or the Swale during spring tides: rather, peak water levels are predicted to decrease in both estuaries.

It has been demonstrated that even relatively small changes to tidal current speeds will have a disproportionally large impact on the mobilisation and transport of cohesive and non-cohesive sediments. These changes are likely to impact on channels, meandering and flow patterns, changes to saltmarsh and mudflat exposure in the tidal frame, estuarine sediment import and export, waves-induced sediment resuspension, habitat loss due to erosion, water quality, sand transport, navigation, salinity, scour around structures.

8.1 Introduction

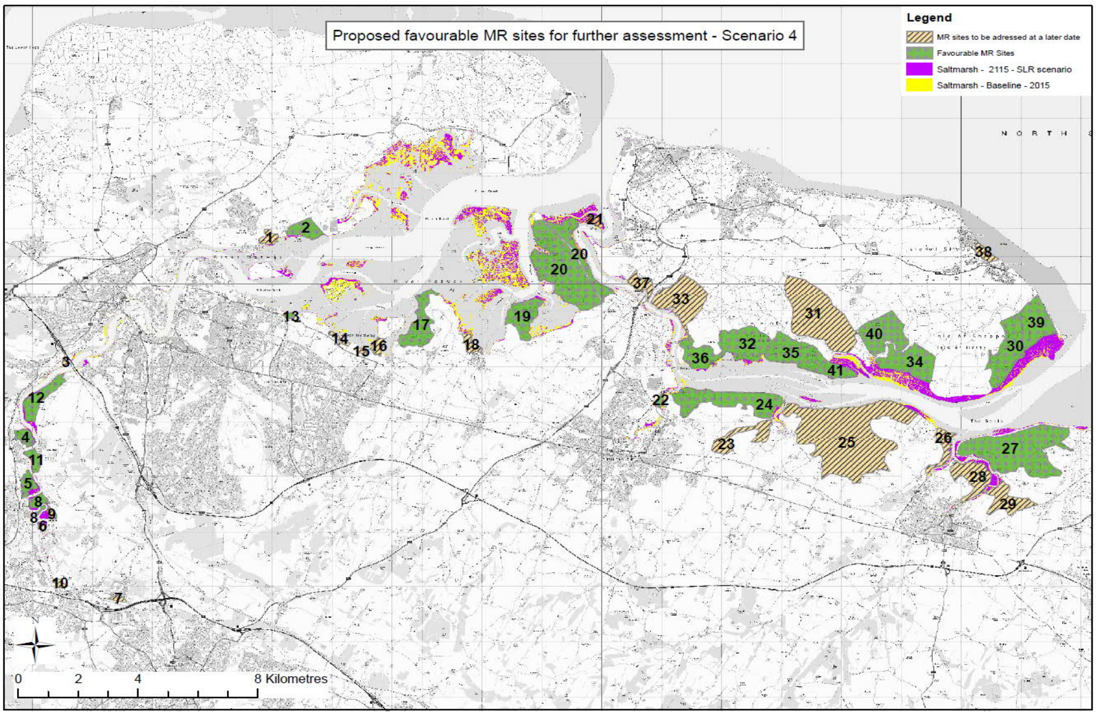
This report first presents results for the Medway and Swale Strategy Study (MEASS) numerical model that quantify the impacts of proposed managed realignment sites on water levels, tidal currents speeds and flood extents in the Medway and Swale estuaries. The MEASS model is built using MIKE by DHI flexible mesh software. Details are provided in MEASS model calibration chapter. The wider impacts at a range of spatial and temporal scales concerning the potential mobilisation, transport and accretion of estuarine sediments and estuarine morphology are then discussed.

The terms Present Maintain and Present Upgrade refer in both case to the present day mean sea level elevation (i.e. no climate change) and include all managed realignment setback defences. Maintain reflecting maintenance of the existing flood defences and Upgrade reflects works to raise the elevation of existing flood defences and defined in Option Technical Report (Mott MacDonald, 2017).

8.1.1 Proposed managed realignment site

As part of the site appraisal process, 22 potential managed realignment sites were selected for further investigation (Figure 91). In the modelling scenarios reported here these sites have been included in the calibrated MEASS hydrodynamic model to investigate impacts from: (a) all 22 sites; (b) groups of sites at western and eastern location in the Swale; and (c) sites in the Medway.

Figure 91: The location of the 22 proposed managed realignment sites (shown in green)



Source: Mott Macdonald, 2016. Contains OS data, © Crown Copyright and database right 2016

8.2 Modelling approach

8.2.1 Managed realignment breaches and setback defences

Attempts to determination appropriate dimensions for the defence breaches were initially undertaken using the approach based on hypsometry given by Townend (2008). However, this methodology was rejected on the grounds that it is too complex to apply for 22 proposed managed realignment sites and inappropriate for Strategy Level study. Instead the minimum, maximum, and average elevation in each managed realignment site was determined using GIS and the mean water depth and volume across each site was calculated based on the HAT level. From this information, initial breach widths between 50m and 100m was implemented for each site and the MEASS model was run. The breach locations were selected by examining the present day baseline flow patterns in the estuary and the locations of existing natural channels thorough the intertidal habitat. To limit the extent of flooding and to protect assets, setback defences were implemented in the MEASS model only where the site did not naturally tie back into high ground.

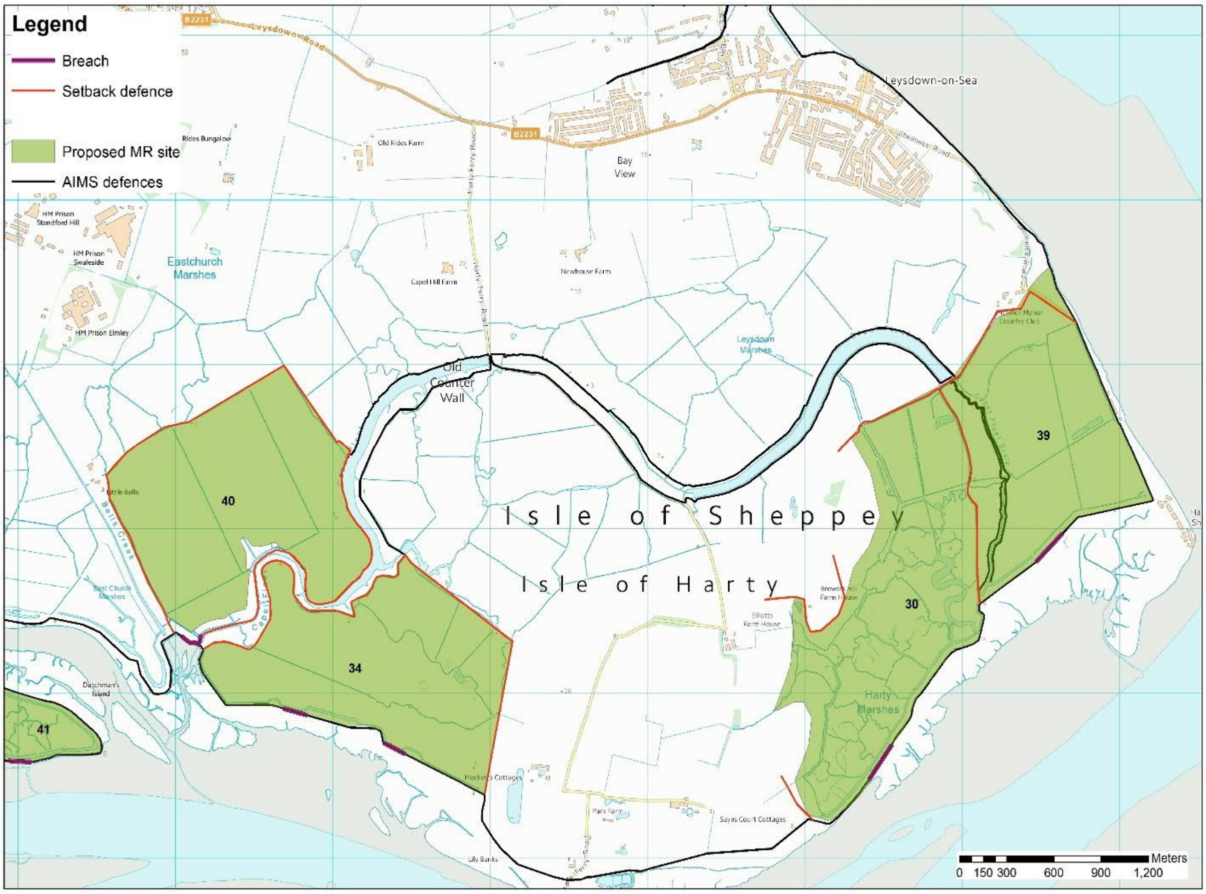
Based on the results, the breach widths were modified interactively so that the final width allowed sufficient water ingress to completely flood the available volume in each managed realignment site. In some case, due to the size of the site, two breaches were required. Further, to reflect the typical breach width for functioning Managed Realignment sites elsewhere in the UK, the maximum breach width was limited to around 250m. The derived breach widths to achieve this at each site is shown in Table 20. The location and width of breaches in the existing coastal defences are shown in Figure 2 to Figure 8.

Table 20: Derived breach widths for all 22 proposed Managed Realignment sites

MR	Breach width (m)	MR	Breach width (m)
MR8_Small	50	MR20_Breach3	144
MR22	64	MR41	150
MR13	70	MR27_Breach1	152
MR5	80	MR4	152
MR11	82	MR34_Breach1	156
MR24_Breach2	96	MR17	159
MR12	98	MR20_Breach1	163
MR2	101	MR34_Breach2	166
MR24_Breach1	105	MR40	189
MR36_Breach1	114	MR20_Breach2	190
MR32_Breach2	123	MR27_Breach2	202
MR36_Breach2	127	MR35	209
MR8	129	MR39	244
MR32_Breach1	131	MR30	259
MR19	142		

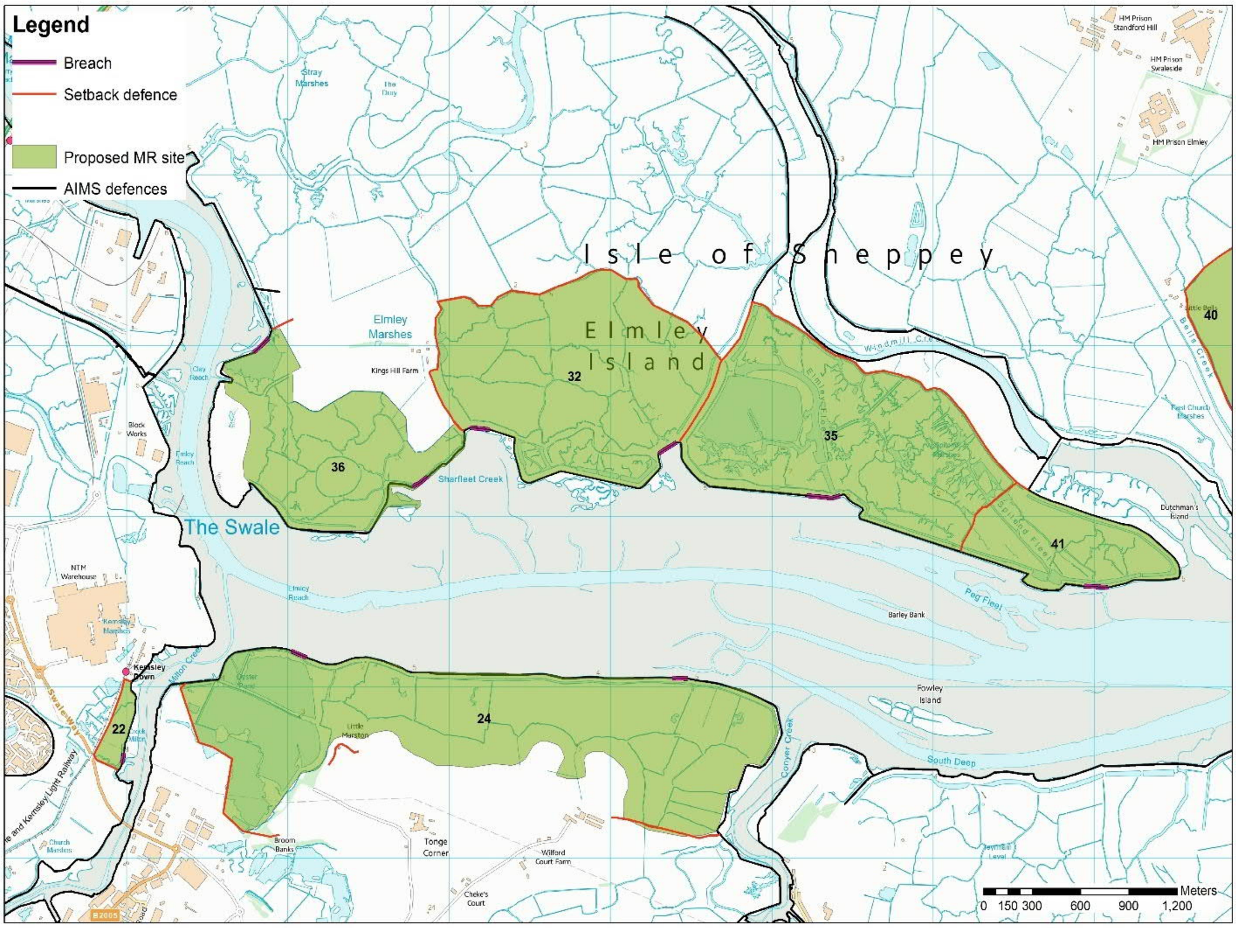
Source: Mott MacDonald, 2016

Figure 92: Location of setback defences and breaches for the proposed sites in the eastern part of the Isle of Sheppey.



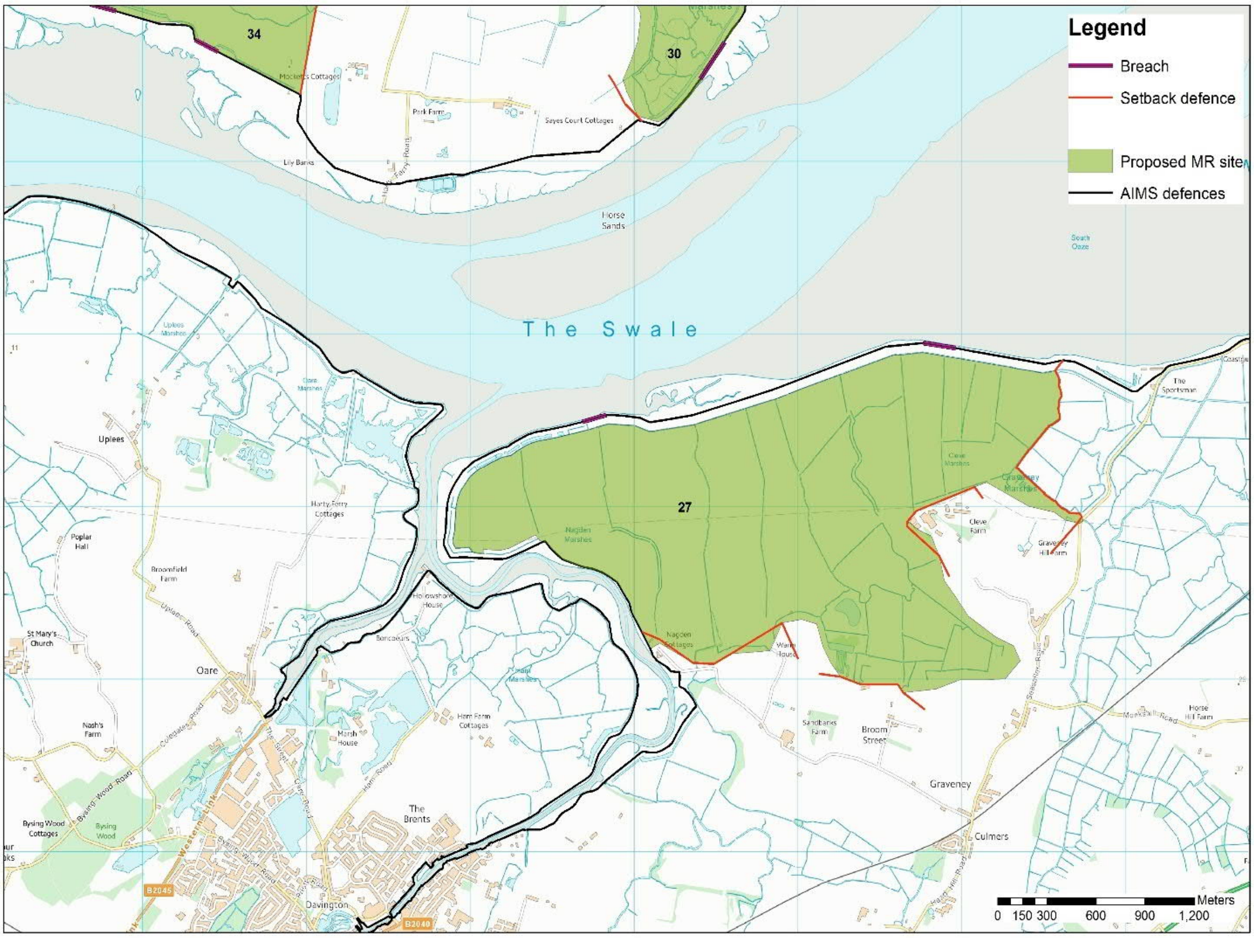
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 93: Location of setback defences and breaches for the central part of the Swale and Isle of Sheppey.



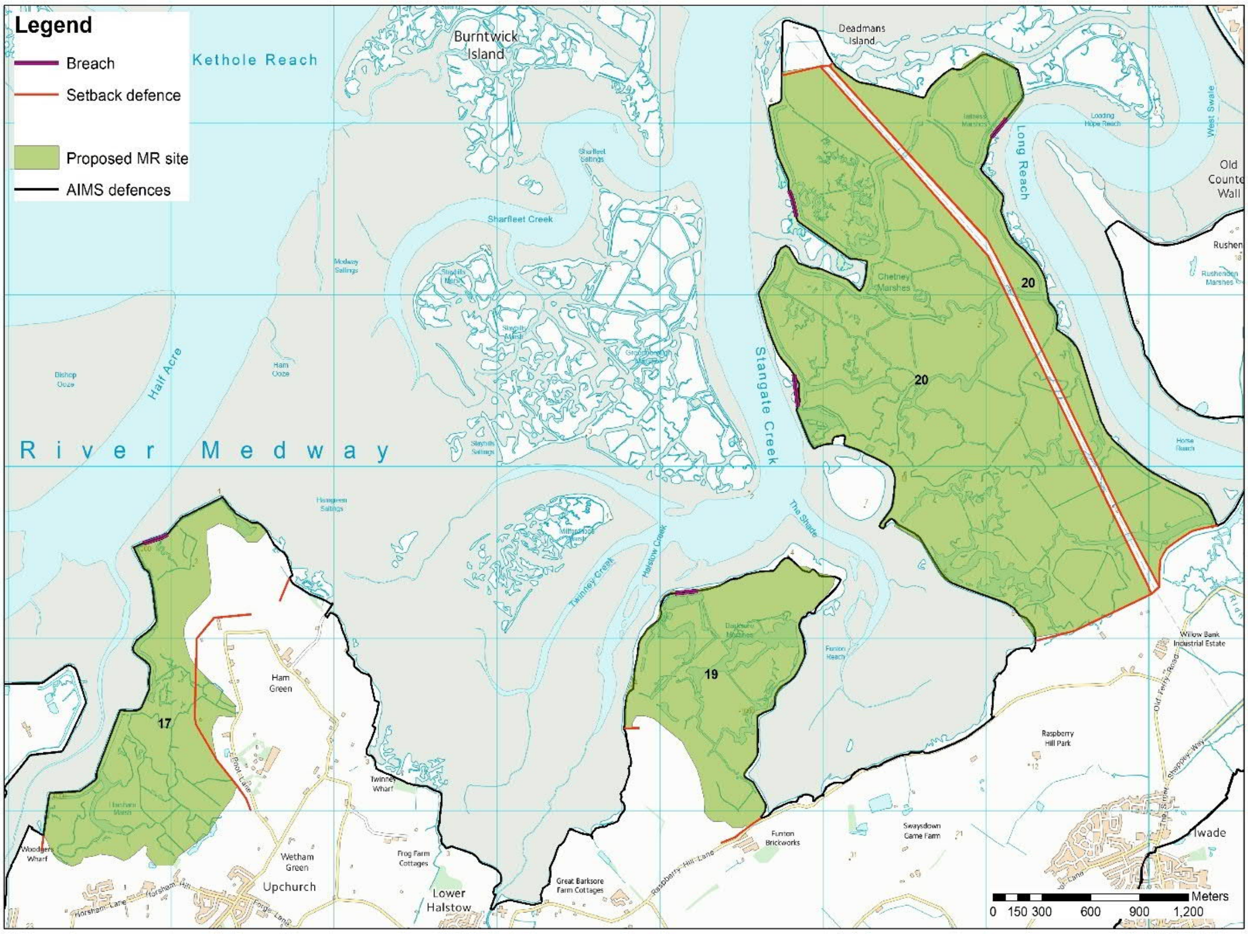
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 94: Location of setback defences and breaches for the proposed sites in eastern part of the Swale.



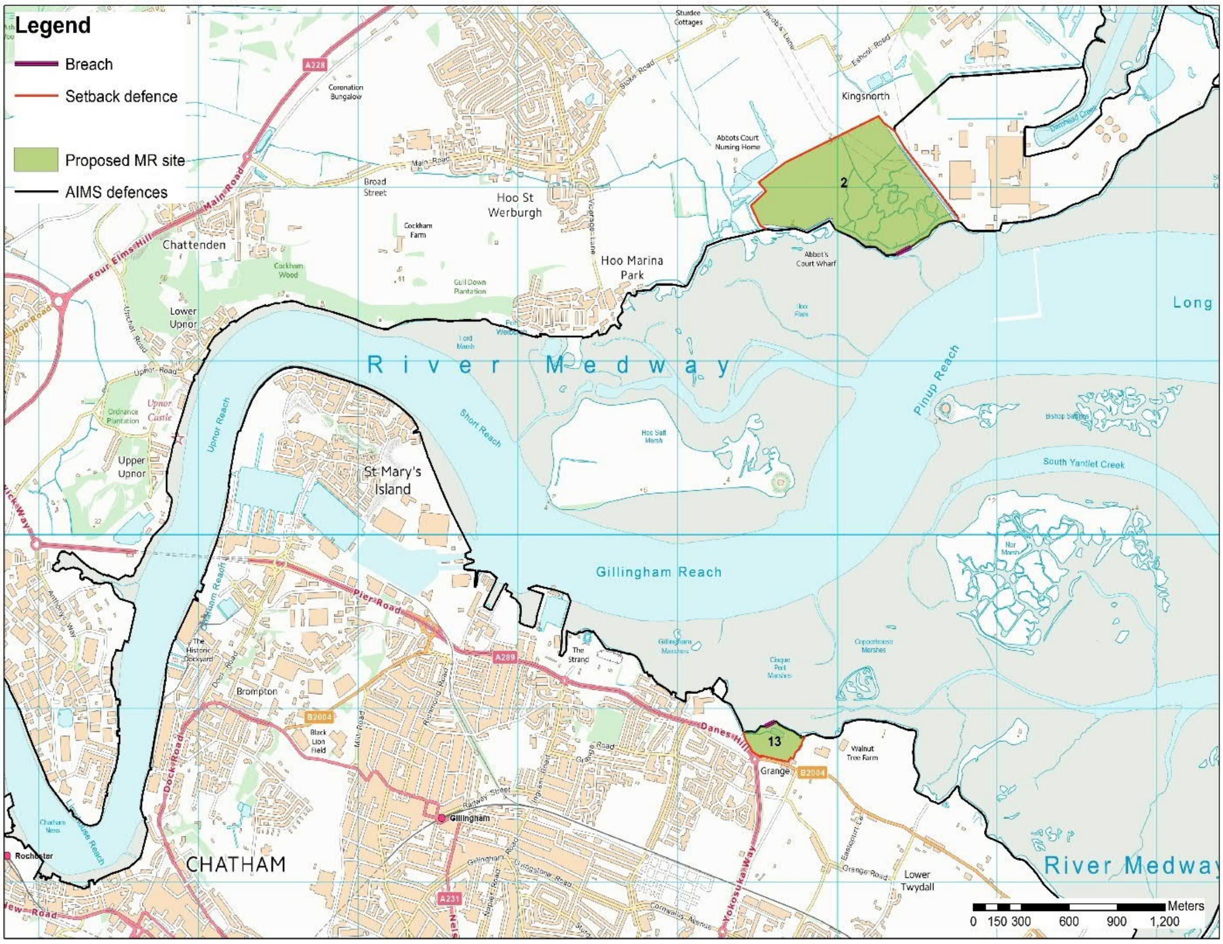
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 95: Location of setback defences and breaches for the proposed sites in the northern Medway east bank.



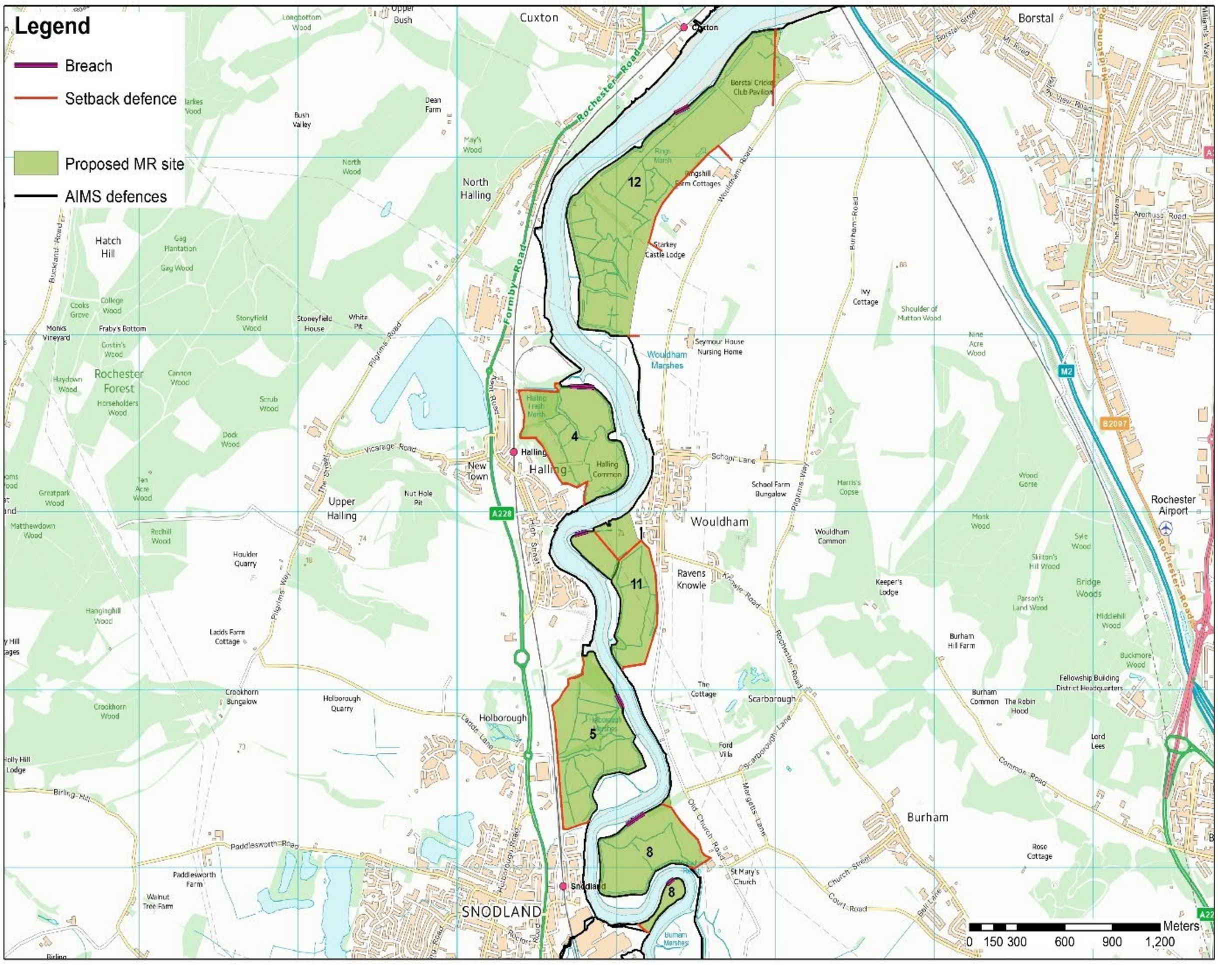
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 96: Location of setback defences and breaches for the proposed sites in the northern Medway west bank.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 97: Location of setback defences and breaches for the proposed sites in the Upper Medway.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

8.2.2 Model runs

The hydrodynamic impacts of realignment sites on the Medway and Swale estuaries was investigated using the MEASS hydrodynamic model for: (a) present day spring tide conditions (2.85m ODN at Sheerness); and (b) a 1:200-year event (0.5% AEP) (4.65m ODN at Sheerness). Initial model runs included all the 22 proposed sites using Upgrade and Maintain scenarios to define the crest elevation of the defences and the setback embankment elevations for a given site. After an initial assessment of the impacts, further model runs were defined to quantify how realignment sites, either individually or collectively, impacted on the estuaries. A systematic sequence of the model runs undertaken are summarised in Table 21 to Table 23.

Table 21: Present Upgrade 1:200-year event model runs

ID	Model Run	Description
1	All managed realignment sites scenario for a 1:200-year event with Present Upgrade defence crest levels.	Run to assess impact of all 22 proposed manage realignment site on estuary hydrodynamics.
2	Swale-only managed realignment site for a 1:200-year event with Present Upgrade defence crest levels.	The run aimed to determine if the Swale sites influence the Medway Estuary or if the two estuaries are working as separate systems.
3	Medway-only managed realignment site for a 1:200-year event with Present Upgrade defence crest levels.	The run aimed to determine if the Medway sites influence the Swale Estuary or if the two estuaries are working as separate systems.
4	East Swale-only managed realignment site for a 1:200-year event with Present Upgrade defence crest levels	The run aimed to examine the impacts of realignment sites in the eastern Swale.
5	Western Swale-only managed realignment site for a 1:200-year event with Present Upgrade defence crest levels	The run aimed to examine the impacts of realignment sites in the western Swale.

Source: Mott MacDonald, 2016

Table 22: Present Upgrade Spring tide model runs

ID	Model Run	Description
6	All managed realignment sites scenario for a spring tide with Present Upgrade defence crest levels.	Run to assess impact of all 22 proposed manage realignment site on estuary hydrodynamics.
7	East Swale-only managed realignment site for a spring tide with Present Upgrade defence crest levels	The run aimed to examine the impacts of realignment sites in the eastern Swale.
8	Western Swale-only managed realignment site for a spring tide with Present Upgrade defence crest levels	The run aimed to examine the impacts of realignment sites in the western Swale.

Source: Mott MacDonald, 2016

Table 23: Present Maintain 1:200-year event model runs

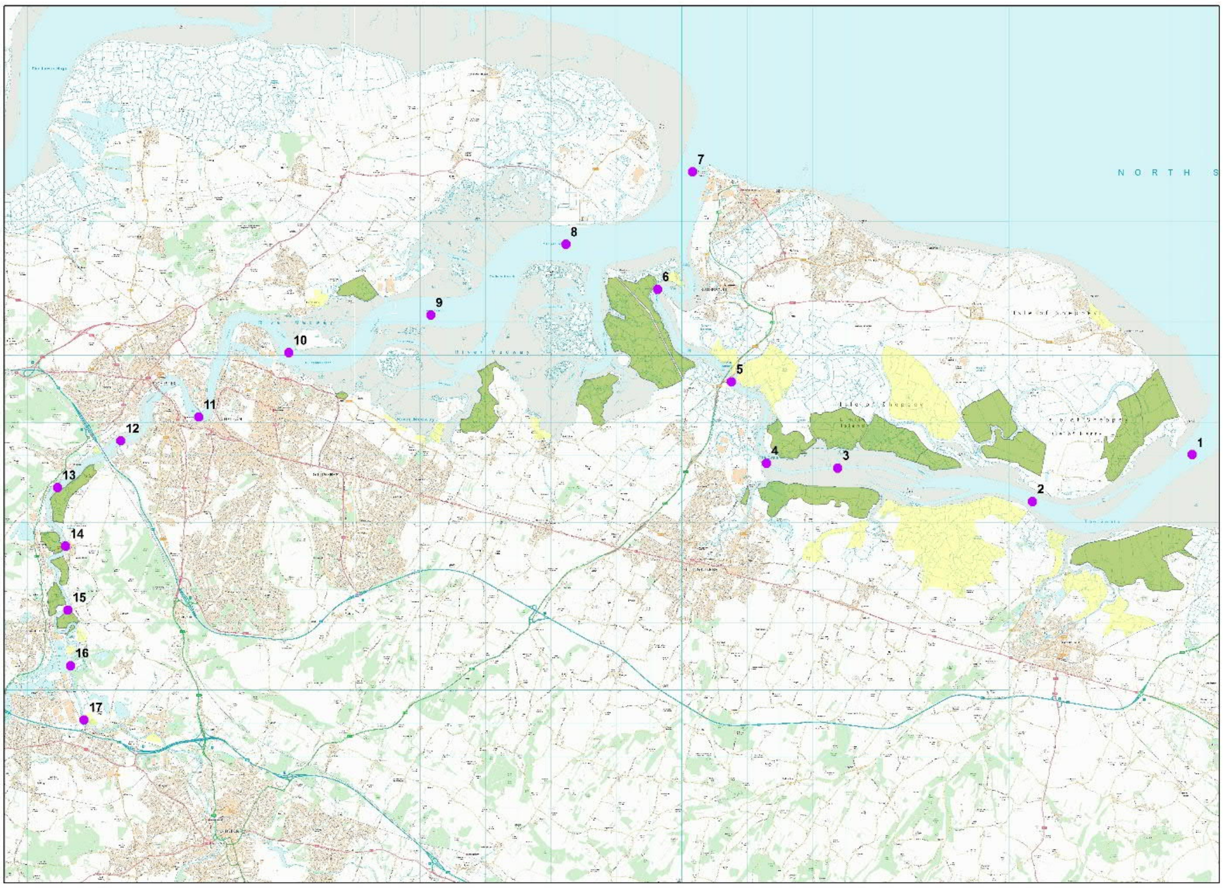
ID	Model Run	Description
9	All managed realignment sites scenario for a 1:200-year event with Present Maintain defence crest levels.	Run to assess impact of all 22 proposed manage realignment site on estuary hydrodynamics.

Source: Mott MacDonald, 2016

8.2.3 Impact analysis

To examine hydrodynamic impacts of the realignment sites in the Swale and in the Medway estuaries over three tidal cycles, water levels and currents speed time-series were extracted from the MEASS model at the locations shown in Figure 98 for (a) the baseline conditions; and (b) for runs that included the proposed managed realignment sites. Maps of maximum water depth and tidal currents speeds were also produced to allow inter-comparisons between baseline and managed realignment scenario results.

Figure 98: The 17 water levels and tidal current data extraction points used to determine the impacts of the proposed managed realignment sites (shown in green).



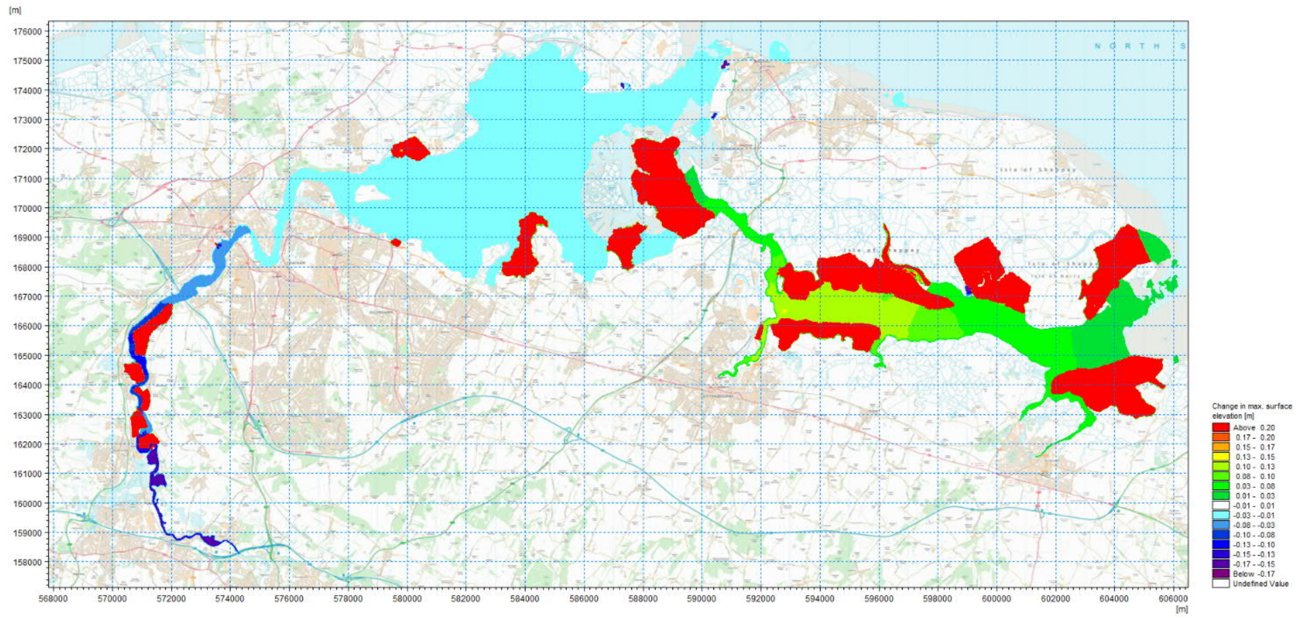
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

8.3 Managed realignment modelling results

8.3.1 All managed realignment sites scenario – 1:200-year event - Present Upgrade (Run 1, Table 21)

The model results from Run 1 (Table 21) show that the 22 proposed managed realignment sites gave rise to changes in water levels and tidal currents speeds at many locations in the MEASS model domain. Figure 99 shows the predicted changes in the maximum water levels across the Medway and Swale estuaries. As might be expected, due to the increase volume of the estuary and the increased volume available close to high water attributable to the managed realignment sites, the maximum 1:200-year water level in the Medway Estuary is reduced. This is most apparent in the Upper Medway, were the water levels drop by 10cm to 17cm (c. 3.6% decrease in the maximum tidal range) compared with the baseline case. However, in the Swale, the water levels increase as a results of the introduction of the realignment sites with maximum water levels raised by 13cm (c. 2% increase in the maximum tidal range within a tidal cycle) above the baseline towards the centre of the Swale and thereby elevating flood risk.

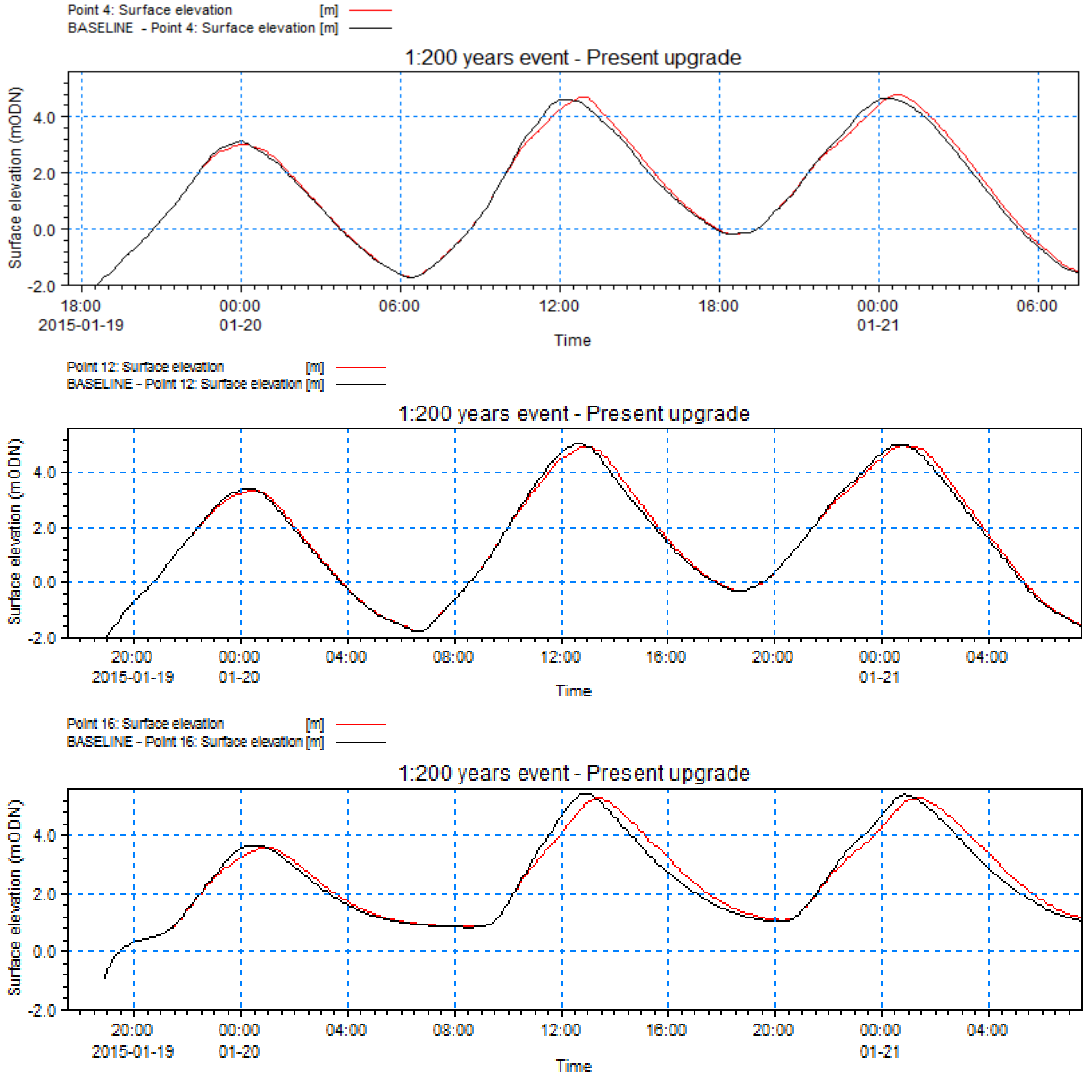
Figure 99: Predicted changes in the maximum water level when all 22 realignment sites are included in the MEASS model, (positive change reflects an increase in water level).



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

The increase in water levels in the Swale is also shown in Figure 100 which shows comparisons between the water levels in the Swale and in the Medway before and after the inclusion of the managed realignment sites in the MEASS model. Figure 100 shows an increase in the water level at Point 4, located in the centre of the Swale, and a decrease in the water levels at Point 12 and Point 16, located in the Medway Estuary. In addition to a change in the extreme water level elevation, the proposed managed realignment sites induced a change in tidal phase that delayed the time of high tide compared with the baseline case (Figure 100). This figure shows that the ebb duration is slightly reduced by the presence of the realignment sites in the estuaries (Figure 100) and results in higher current speeds during the ebb tide (Figure 103 and Figure 104 discussed below).

Figure 100: Comparison between water levels in the Swale (Point 4) and in the Medway (Points 12 and Point 16) for the baseline and full realignment scenarios (22 sites).



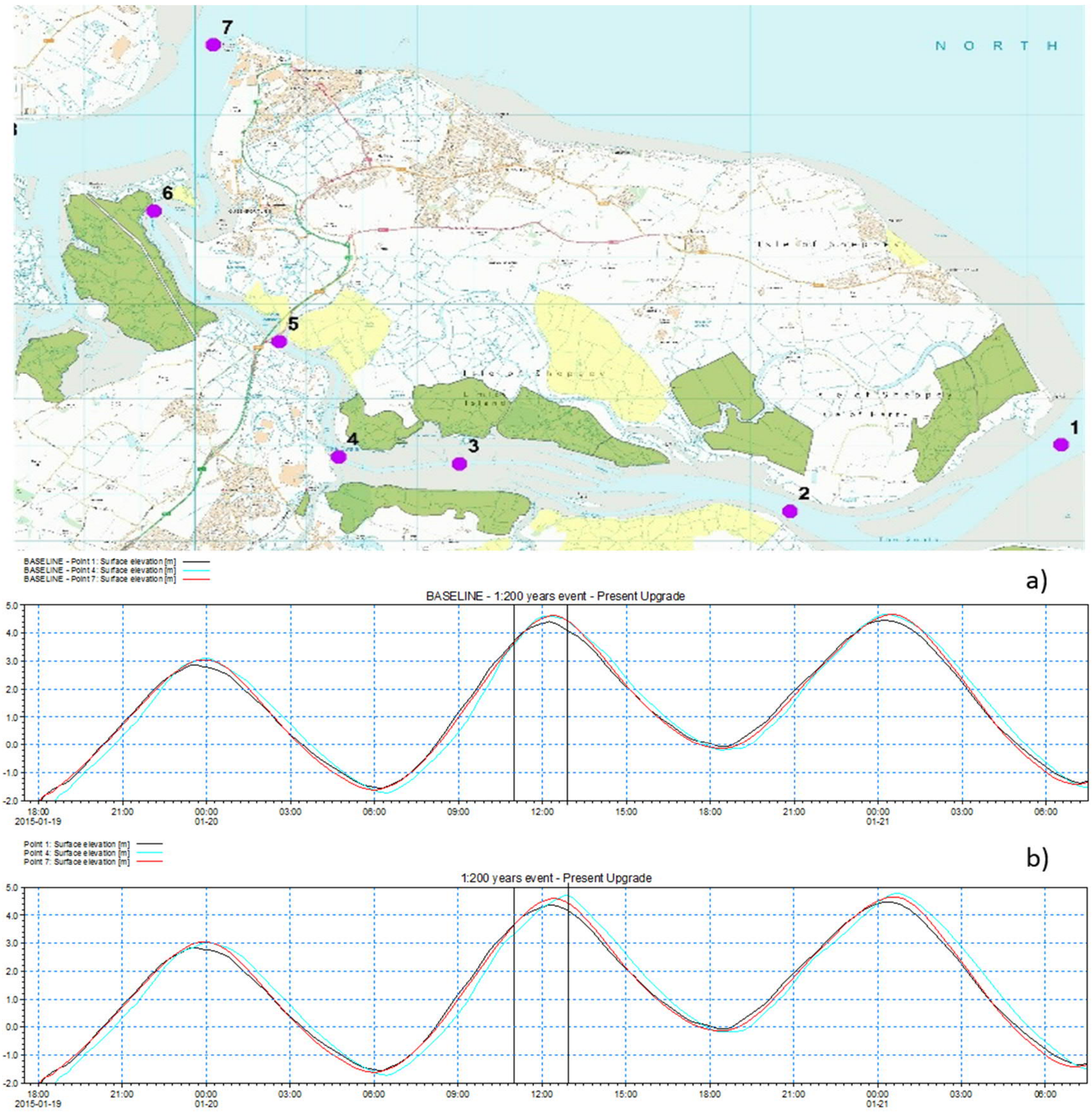
Source: Mott MacDonald, 2016

Although intuitively one would normally expect estuarine volume increases provided by a managed realignment to reduce tidal water levels this is clearly not the case here. Further, this effect has been reported elsewhere (e.g. Pontee, 2015) and here we seek to find an explanation for the model results in the Swale.

In order to understand the water level increase in the centre of the Swale, the changes in water levels gradient between the two entrances of the Swale and the central area of the estuary need to be considered, both for the baseline condition and after the introduction of the managed realignment sites. Figure 101 shows the extreme tide level (both for the baseline condition and the managed realignment scenario for the 1:200-year event) in: (a) the west entrance of the Swale (Point 7); (b) the east entrance (Point 1); and (c) in the centre of the Swale (Point 4). Figure 102 shows horizontal water level profiles between Point 1 and Point 7 at different stages of the tide (Figure 101). This figure shows that little difference is predicted at either end of the Swale but that at Point 4 the high water levels are increased as well as occurring later.

Although one would normally expect that managed realignment would result in reduction of water levels due to the increase in estuarine volume, modelling results indicate this may not occur in the Swale. Similar results have been reported for the Parret Estuary based on model simulations to assess impact from different breach configurations on the Steart Peninsula realignment (Pontee, 2015). Although not explicitly indicating higher water levels, Kirby (2013) suggested that accidental breach of sea defences in the Medway estuary has “severely increased the ponding effect at high water”, which resulted in a significant increase in tidal current speed in the main channel.

Figure 101: 1:200-year water levels for: (a) the baseline condition; and (b) the full managed realignment scenario (22 sites) in the east entrance (Point 1), west entrance (Point 7) and centre (Point 4) of the Swale. The vertical lines in the tide curve indicate the first and last time-step selected to produce the water levels profiles in of Figure 102.

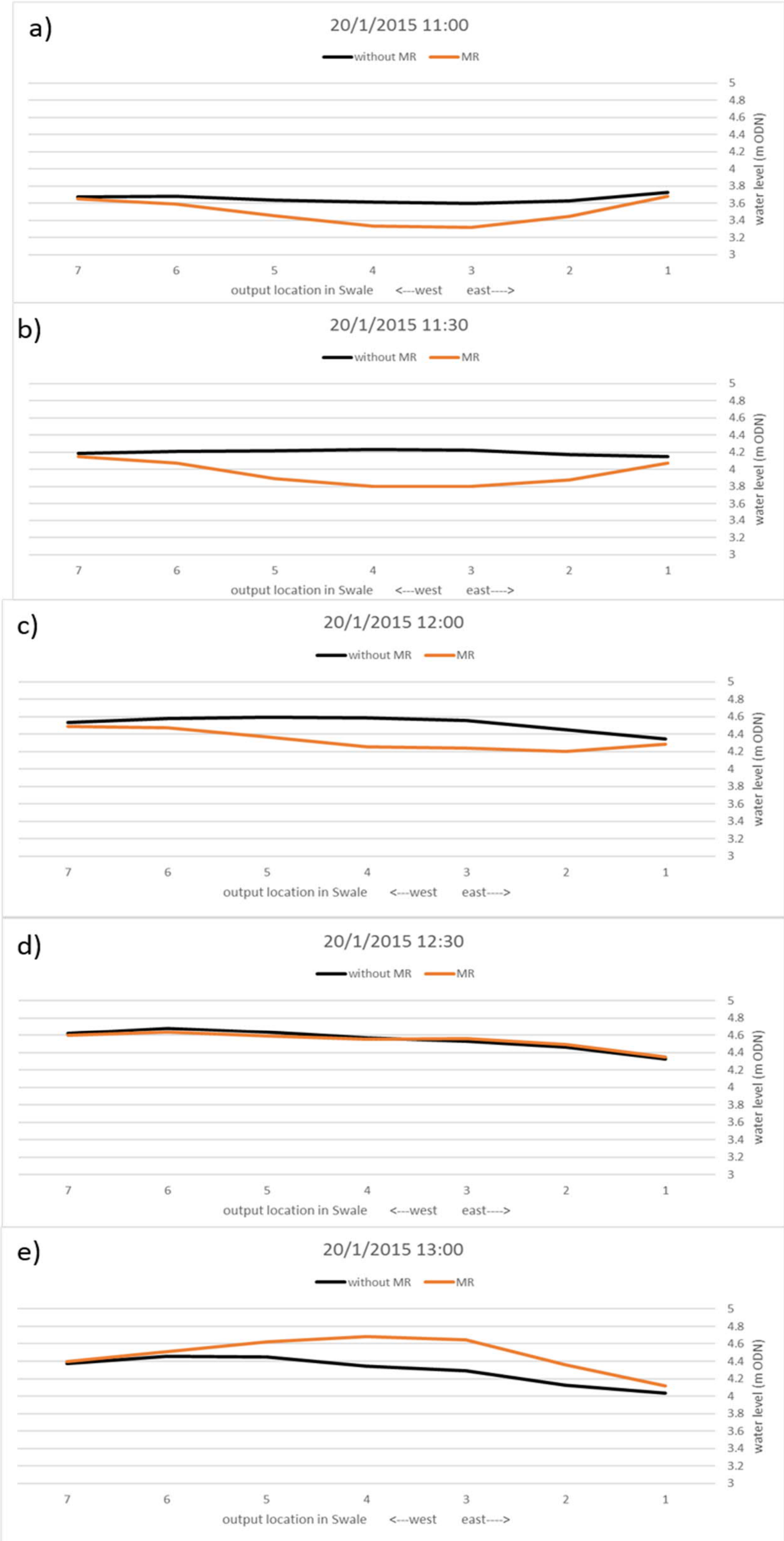


Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

In the baseline condition, prior to high water (11:00 – Figure 102a), there is no significant slope in the water levels towards the centre of the Swale. However, after including the proposed managed realignment sites, a much larger gradient can be observed directed towards the centre of the Swale (Points 3,4, and 5). Just before and at high water (11:30 and 12:00 – Figure 102b and Figure 102c) the situation changes for the baseline condition with the higher water occurring in the centre of the Swale and lower at either entrances. At the same time for the managed realignment scenario, the gradient between the estuarine entrance locations and the water level in the central part of the estuary is still increasing, and adding further to the volume of water in the centre of the Swale. Consequently, the maximum water level predicted in this area is around 10cm higher than the baseline case (Figure 99 and Figure 100). The increased gradient drives faster flood current speeds which adds additional momentum to the incoming water causing an overfilling of the central Swale compared with the baseline.

At 13:00 (Figure 102e), when the baseline condition water level is decreasing in the entrances to the estuary (Point 7 and Point 1) during the ebb, the central area of the Swale has higher water levels. However, when the proposed managed realignment sites are included, the water level in the central Swale at this time is considerably higher than the baseline scenario and higher than the water levels at both entrances. This gradient, now causes more water to flow towards the entrances, and increases the ebb currents speeds (see next sections). It is noted also that there is also a phase change in the high water so that high water occurs later in the central Swale adding further to the gradient in water level.

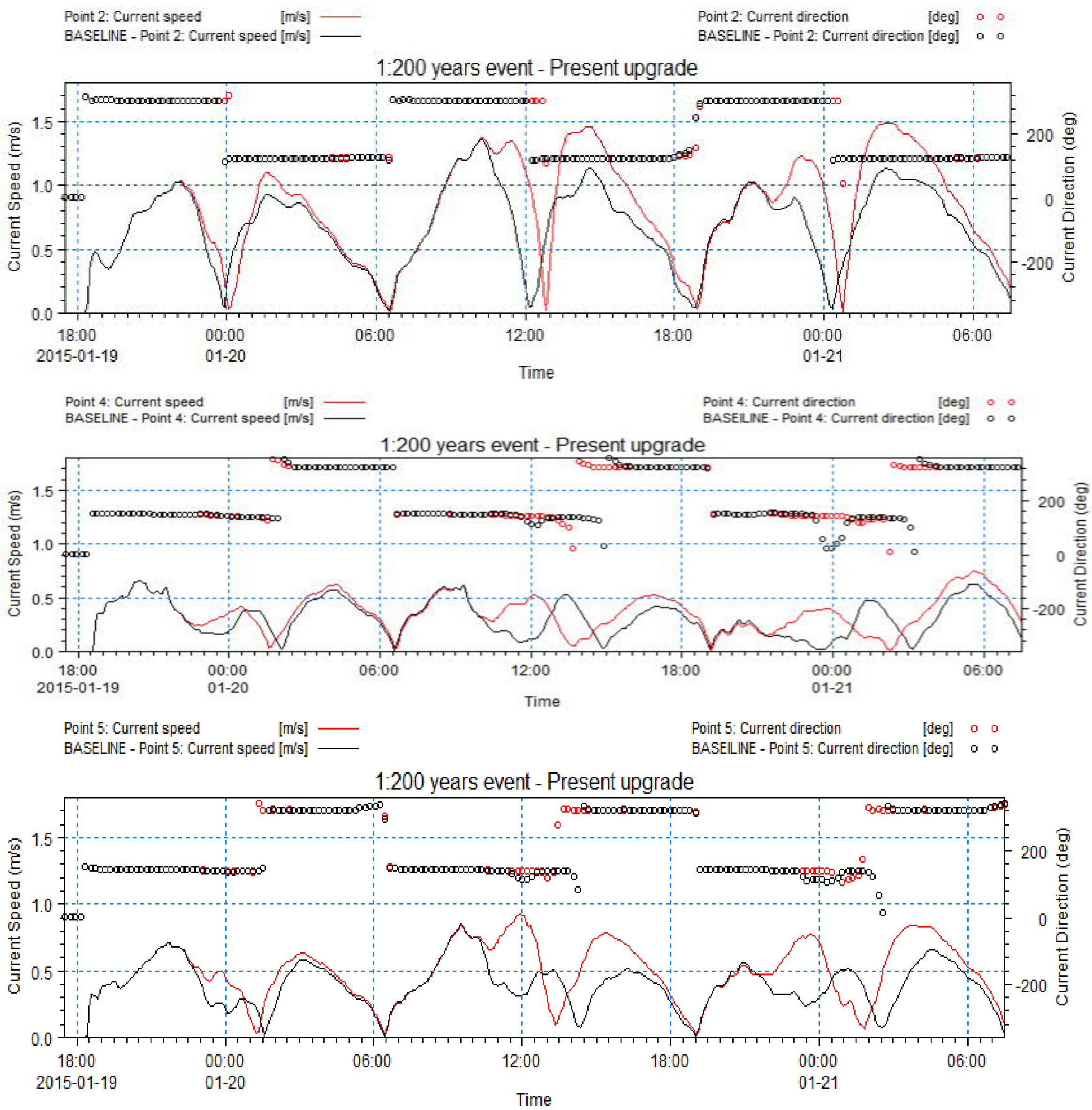
Figure 102: Along-estuary water levels changes in the Swale at different stages of the tide between Point 1 (east entrance) and Point 7 (west entrance).



Source: Mott MacDonald, 2016

The MEASS model also shows that the proposed 22 realignment sites tend to increase the currents speeds across both estuaries. The changes in current speed in the Swale are shown in Figure 103. It is noted that the realignment sites not only increase the current speed at both entrances of the Swale, but also alter the flood/ebb duration and timing. Further, the water flows in the opposite direction to the baseline condition for approximately two hours.

Figure 103: Comparison between predicted current speed and direction in the Swale for the baseline and full realignment scenarios (22 sites) at Points 2, 4 and 5 (Figure 101).

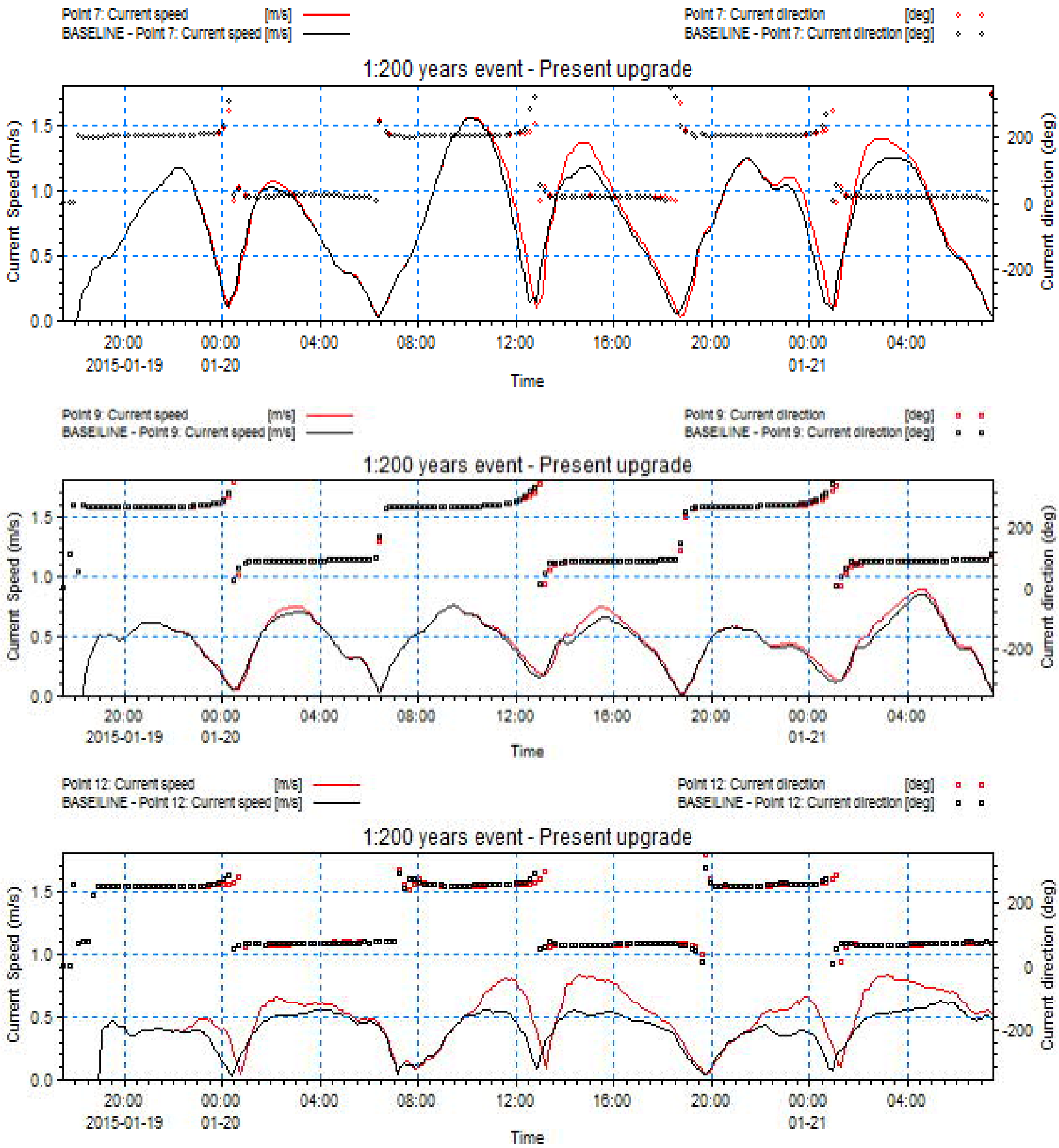


Source: Mott MacDonald, 2016

Figure 104 shows the changes in currents speeds in the Medway and demonstrates that current velocities in the Upper Medway are significantly larger than the baseline case. The mouth of the

Medway Estuary is also affected, especially during ebb tide, owing to the larger volume of water leaving the Estuary compared with the baseline.

Figure 104: Comparison between predicted current speed and direction in the Medway for the baseline and full realignment scenarios (22 sites) at Points 7, 9 and 12 (Figure 101).

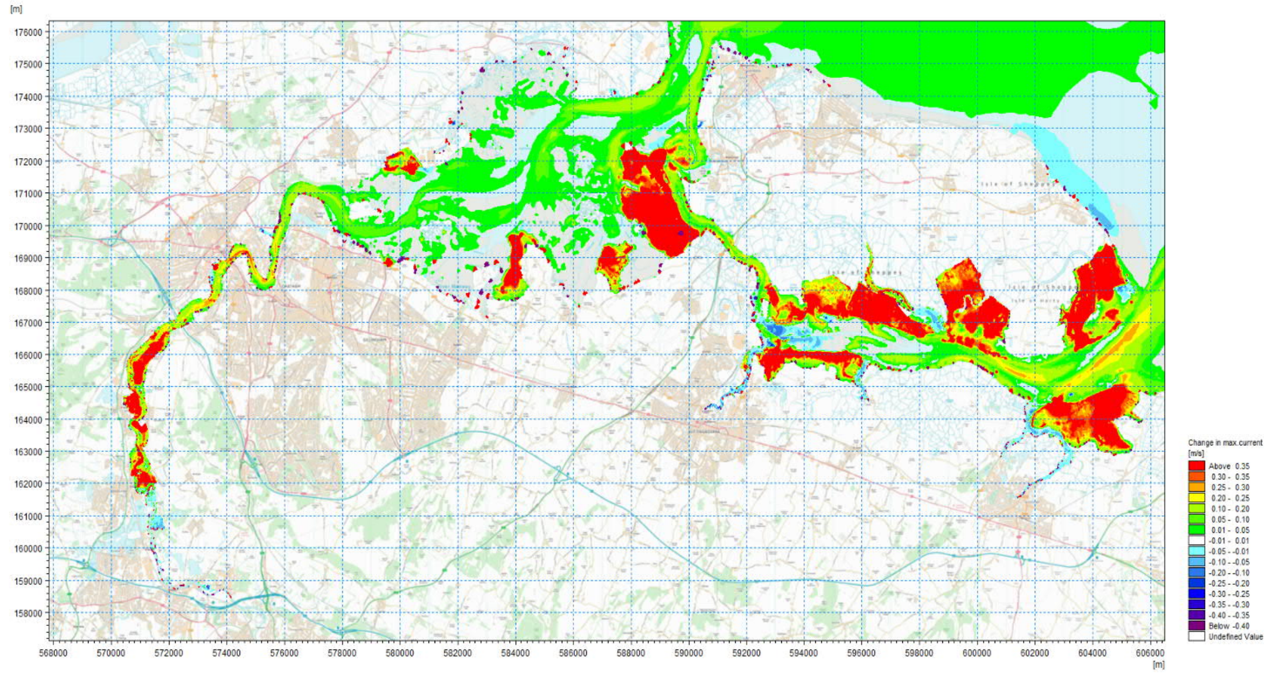


Source: Mott MacDonald, 2016

The spatial distribution of the predicted changes to current speed due to the realignment sites is shown in Figure 105. This figure shows only the change in the maximum current speed and does not convey any temporal information. The figure indicates maximum changes in the current speeds in the Swale of c. 25cm/s to 30cm/s and between c. 15cm/s to 20cm/s in the

Medway. A decrease in the current speeds (c. 5cm/s to 10cm/s) in the central area of the Swale, around Elmley Reach, can also be observed.

Figure 105: Predicted changes to the maximum current speed attributable to inclusion of the 22 proposed managed realignment sites, (positive change reflect an increase in current speed).



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

In addition to the changes in the current speeds, the flow patterns and current directions are significantly affected in the Swale due to the present of the managed realignment sites. Figure 106 to Figure 109 show the current speeds and directions in the centre of the Swale, around Clay Reach and Elmley Reach for: (a) the baseline scenario; and (b) the realignment sites scenario at different stages of the tide. The figures show conditions: 1hr before high tide (Figure 106); high tide (Figure 107); 1hr after high tide (Figure 108); and 2.5hrs after high tide (Figure 109.

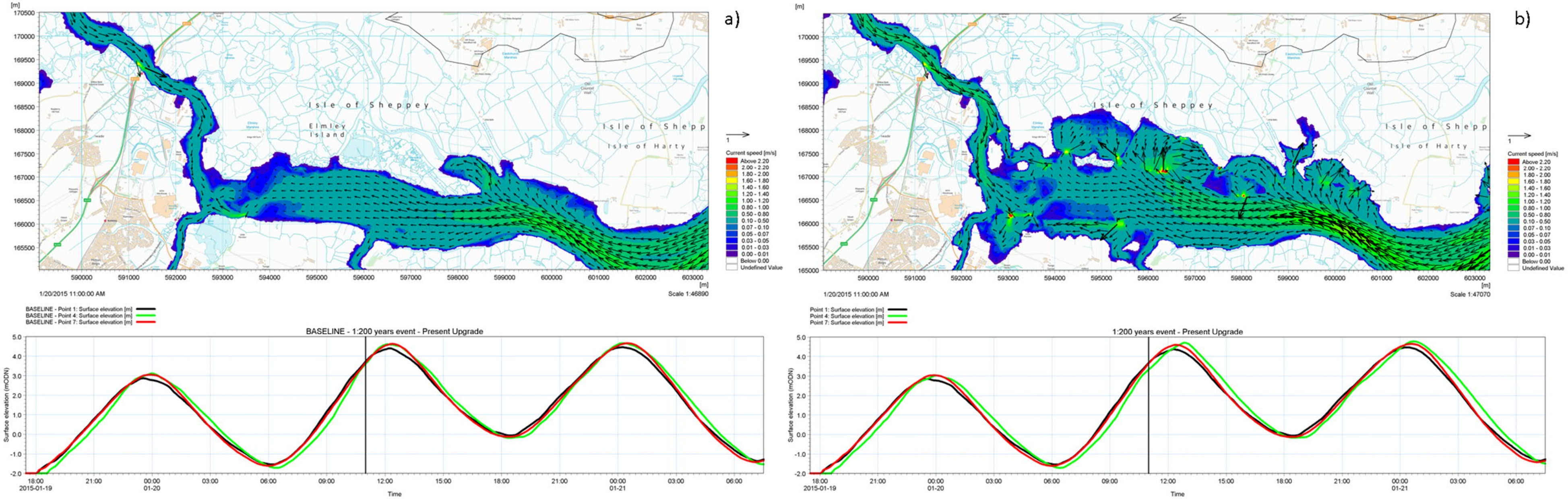
Figure 106b shows that during the flood tide, just before high water, there are stronger currents in the western part of the Swale (Clay Reach) compared to the baseline scenario. At high tide (Figure 107a), the baseline scenario indicates a significant reduction on the current speeds with the water flowing towards the east Swale. After the introduction of the realignment sites (Figure 107b), the water at high tide still flows towards the centre of the Swale from both entrances, and current speeds are similar to the ones shown in Figure 106b.

Current speeds increase for the baseline scenario 1hr after high water (Figure 108a), with the water leaving the estuary towards the east of the Swale. However, in the managed realignment scenario, at this stage of the tide, there is a considerably decrease in the current speed at Clay Reach where the flows separate in both directions (Figure 108b).

2.5hr after high tide, the decrease in current speeds, and the separation of the flows at Clay Reach, can be observed in the baseline scenario (Figure 109a). However, in the managed realignment scenario, the flow separation has moved towards Elmley Reach and current speeds in the west Swale are larger (0.5m/s to 1m/s) than the baseline condition (0.1m/s to 0.5m/s), (Figure 109b).

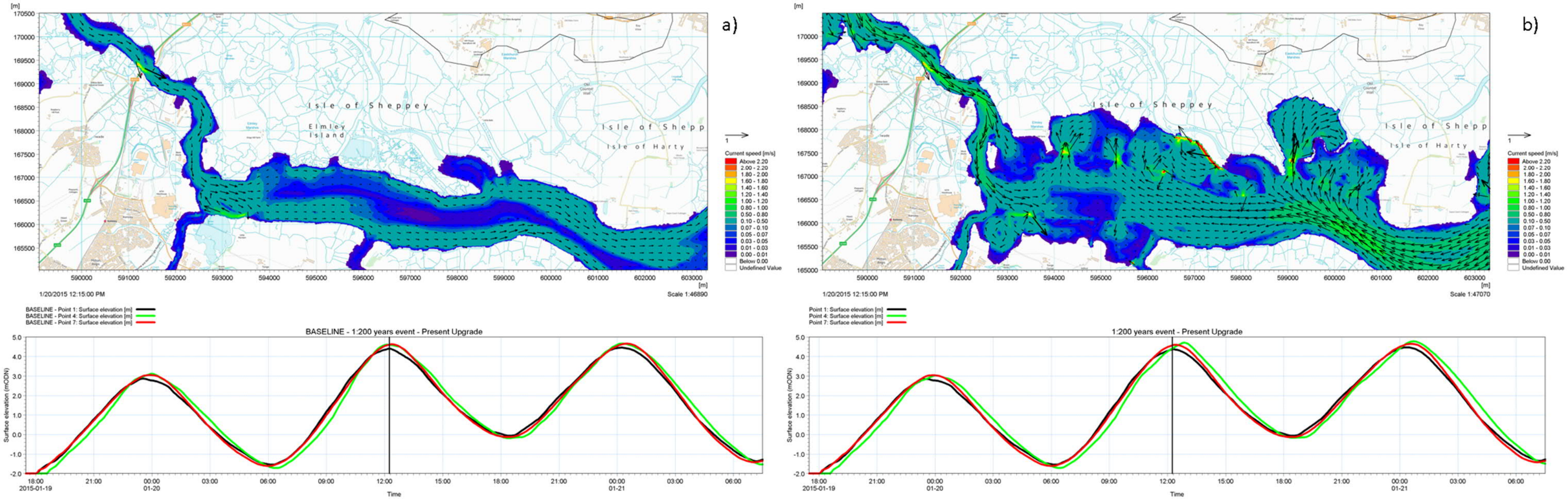
These changes to current speeds and directions in the centre of the Swale, and their impacts on the flow patterns and flood/ebb tide duration in this area, could have impacts on the sediment regime and morphology of the estuary. These impacts will be discussed further in Section 8.4.

Figure 106: Current speed and direction in the central Swale approximately 1hr before high water for: (a) the baseline scenario; and (b) all managed realignment sites.



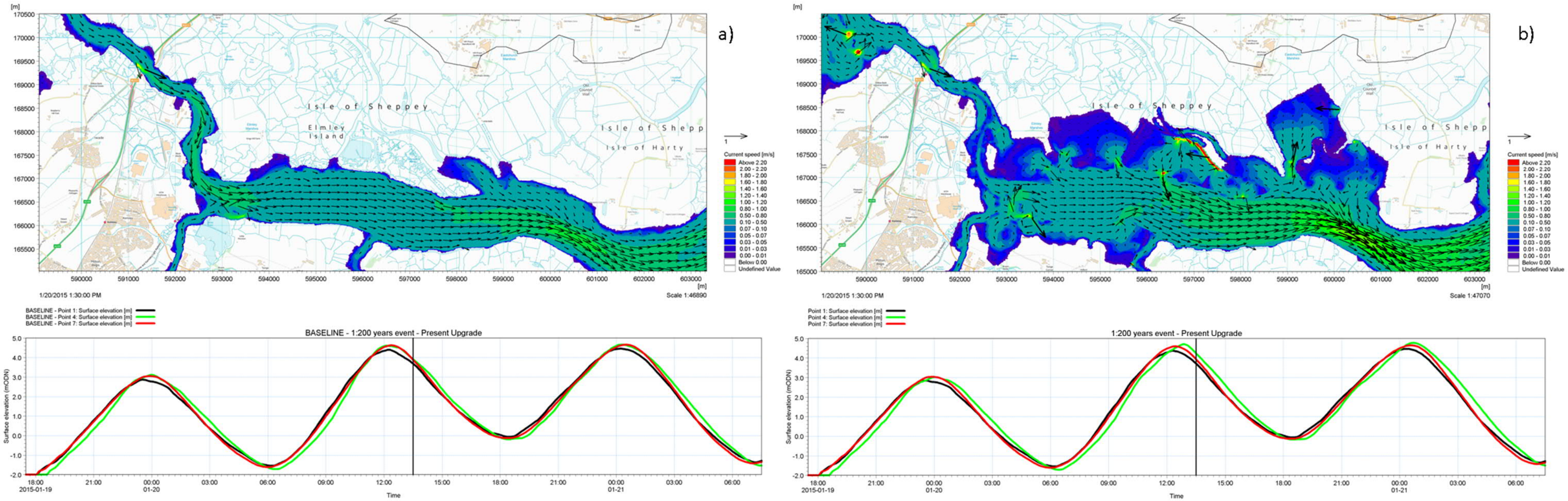
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 107: Current speed and direction in the central Swale at high water for: (a) the baseline scenario; and (b) all managed realignment sites.



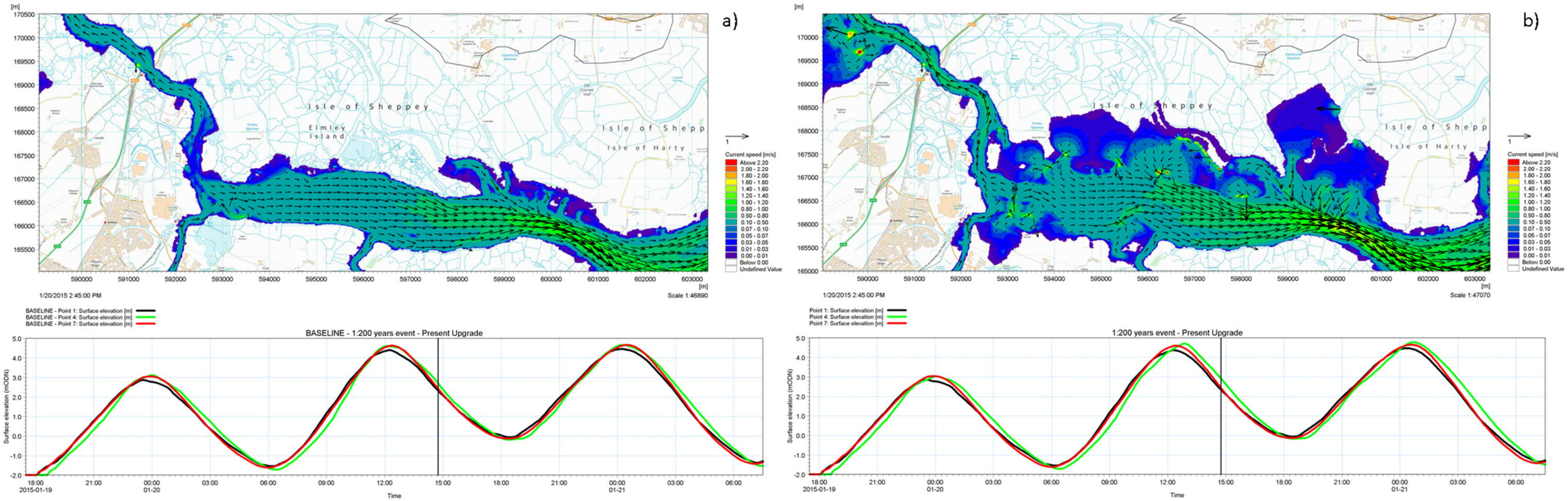
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 108: Current speed and direction in the central Swale approximately 1hr after high water for: (a) the baseline scenario; and (b) all managed realignment sites.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 109: Current speed and direction in the central Swale approximately 2.5 hr after high water for: (a) the baseline scenario; and (b) all managed realignment sites.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Table 24: Summary of predicted changes to the maximum water elevation and tidal current speed attributable to inclusion of the 22 proposed managed realignment sites for the 1:200-year event, present upgrade scenario.

Point	Tidal range (m)	Change in maximum tidal elevation due to realignments (cm)	% change in maximum tidal elevation due to realignments	Change in phase (minutes)	Period water levels exceed baseline condition (minutes)	Change in maximum tidal current speed due to realignments (cm/s)	% change in maximum tidal current speed due to realignments	Period current speeds exceed baseline condition (minutes)
1	6	<1	--	--	--	+24	+26.4	Most the ebb tide
3	6.3	+13	+2	Approx. 30min	Approx. 30min	--	--	--
7	6.2	<1	--	--	--	+18.5	+15.6	Most the ebb tide
12	6.8	-7	-1	Approx. 20min	--	+21.5	+34.5	Both during flood and ebb tide
16	4.65	-17	-3.6	Approx. 30min	--	--	--	--

Source: Mott MacDonald, 2016

8.3.2 Swale-only (Run 2, Table 21) and Medway-only (Run 3, Table 21) managed realignment sites scenario – 1:200-year event - Present Upgrade

In order to determine how the proposed managed realignment in the Swale and in the Medway interact with each other, and the extent of their individual effects on each estuary, model runs were undertaken for a 1:200-year event in which only the realignment sites in the Swale and only the realignment sites in the Medway were included (Table 20).

Figure 110 shows the changes to the maximum water levels for: (a) the realignment sites in the Swale only (Swale-only scenario); and (b) the realignment sites in the Medway only (Medway-only scenario. For the proposed managed realignment sites in the Swale-only, significant changes to water levels were confined mainly to the Swale Estuary, with very limited effect on the Medway Estuary. In the Swale-only scenario, the water levels increased and elevated flood risk as a results of the introduction of the realignment sites. Towards the centre of the Swale the increase in water level reached a maximum value of 13cm (c. 2% increase) above the baseline. It is noted that this increase is larger than the one observed when all the sites are included in the model (Figure 99).

As expected, the maximum 1:200-year water level in the Medway Estuary is reduced when only the sites in this Estuary are considered (Figure 110b). This is most notable in the Upper Medway, were the levels drop by approximately 10cm to 15cm (c. 3% decrease) compared with the baseline case.

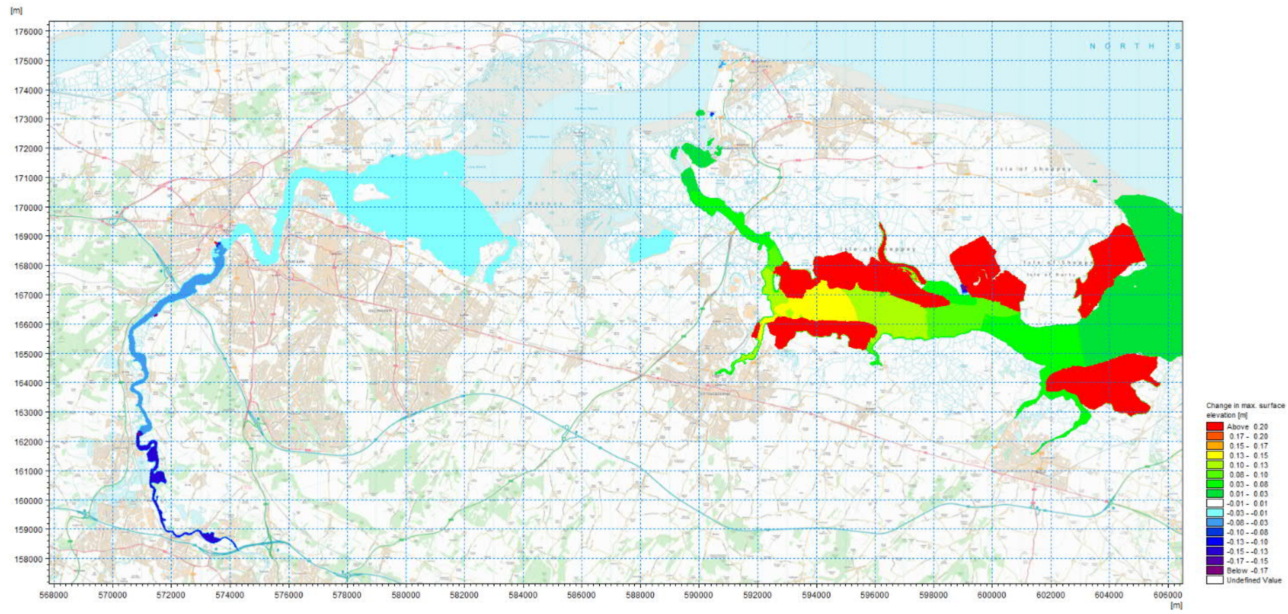
To expand further on the results of the model runs for the Swale-only realignment sites, Figure 174, in Appendix C, shows comparisons between the water levels in the Swale and in the Medway before and after the inclusion of the managed realignment sites in the Swale-only. The figure shows an increase in the water level at Point 4, located in the centre of the Swale, and a decrease of the water levels, at Point 12 (c. 3cm) and at Point 16 (c. 10cm), located in the Medway Estuary.

To expand further on the results of the model runs for the Medway-only realignment sites, Figure 176, in Appendix D, shows comparisons between the water levels in the Swale and in the Medway before and after the inclusion of the managed realignment sites in the Medway only. The figure shows no changes in the water level at Point 4, located in the centre of the Swale, and a decrease of the water levels in the Medway Estuary, c. 8cm at Point 12 and c. 15cm at Point 16.

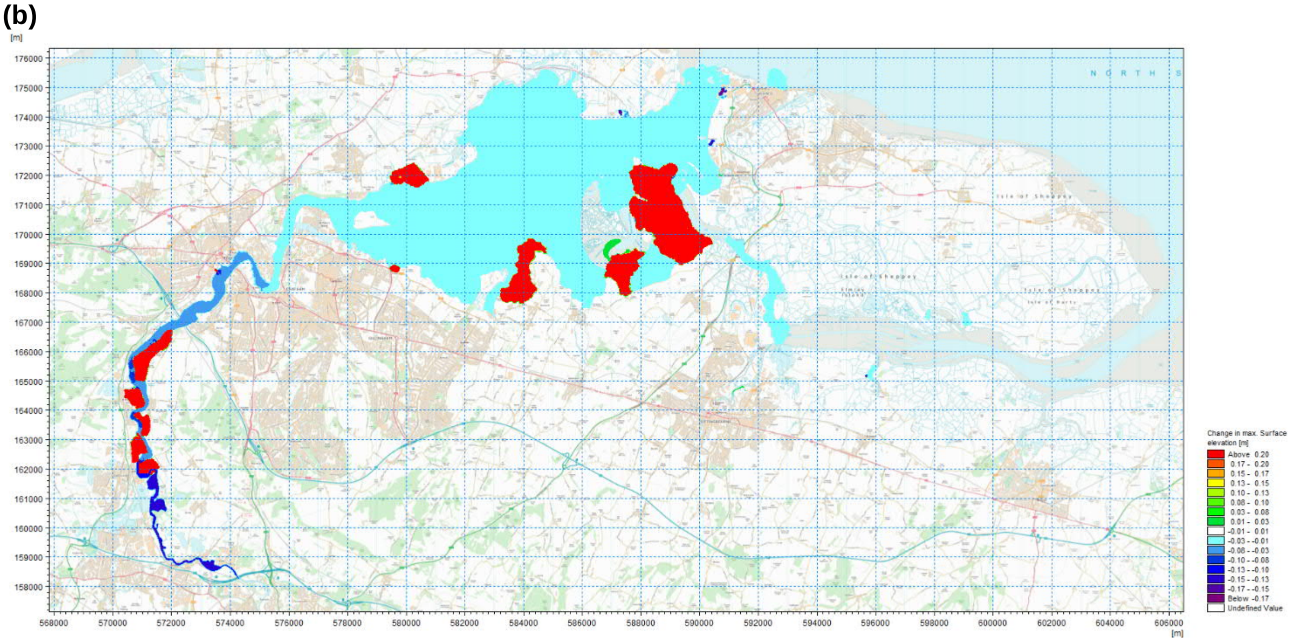
In order to understand the water level increase in the centre of the Swale, the changes in the water level gradient between the two entrances of the Swale and the central area of the estuary have been analysed, both for the Swale-only scenario and the Medway-only scenario. Figure 111 shows the water levels changes in the Swale, between Point 1 (east entrance) and Point 7 (west entrance) at different stages of the tide presented in Figure 101a to Figure 101e for: (i) the baseline scenario; (ii) all managed realignment site scenario; (iii) the Swale-only scenario; and (iv) the Medway-only scenario. Figure 111 shows that the Swale-only managed realignment site effects on the water levels are very similar those predicted when all the sites are included in the model. Conversely, the effect on water levels in the Swale of the Medway-only realignment sites are almost undetectable, with results very like the baseline condition.

Figure 110: Predicted changes in the maximum water level for: (a) Swale-only managed realignment sites; and (b) Medway-only managed realignment sites, (positive change reflect an increase in water level).

(a)

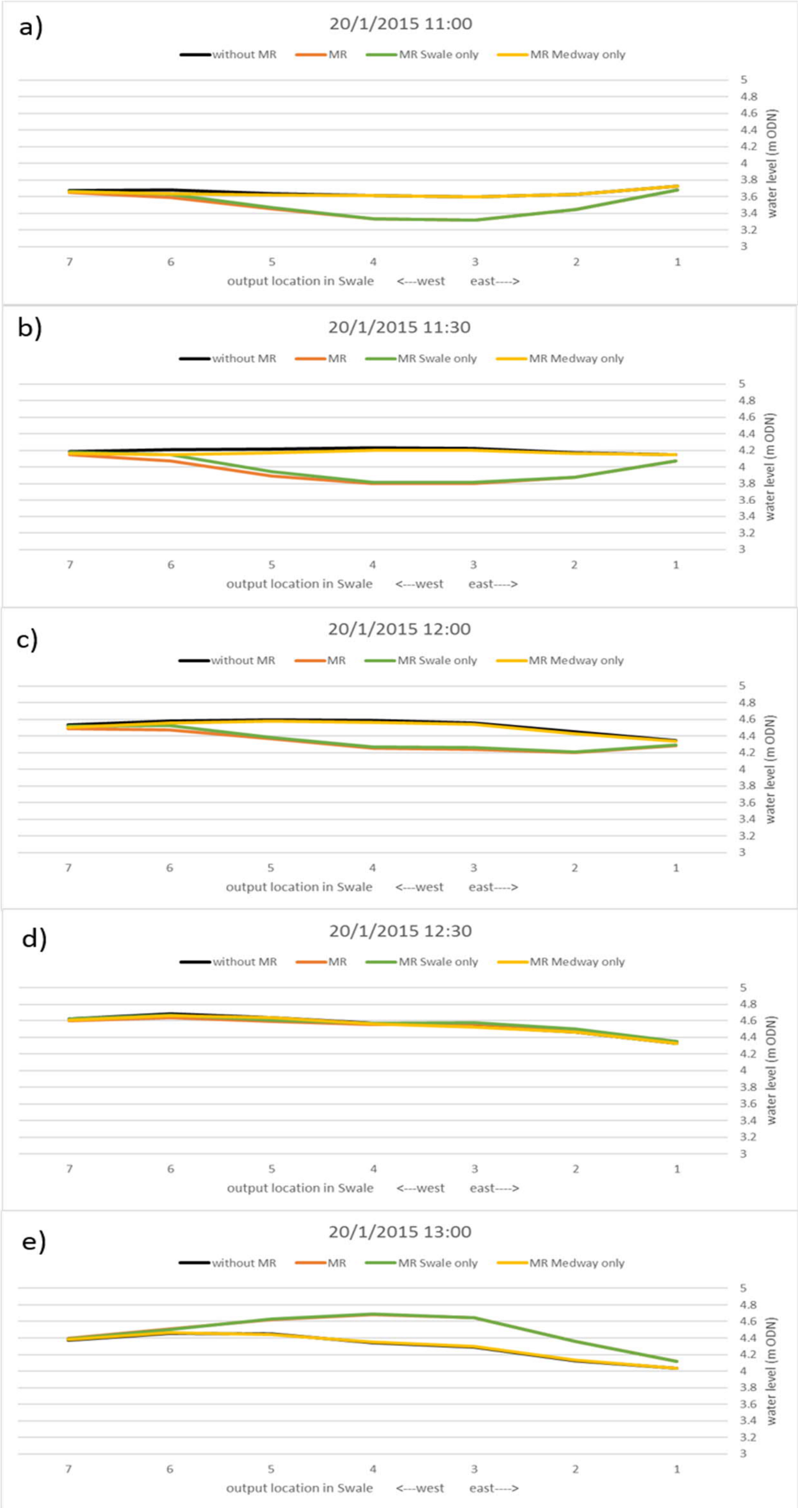


(b)



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 111: Along-estuary water levels changes in the Swale at different stages of the tide between Point 1 (east entrance) and Point 7 (west entrance) for Swale-only realignments.



Source: Mott MacDonald, 2016

The spatial distribution of the predicted changes to current speed in the Medway-only and in the Swale-only scenarios are shown in Figure 112. This figure shows only the change in the maximum current speed and does not convey any temporal information. The figure indicates maximum changes in the current speeds in the Swale are c. 25cm/s to 30cm/s. With the exception of locations in the mouth of the estuary, no changes to the current speed in the Medway estuary attributable to the Swale-only managed realignment sites are evident (Figure 112a). In this case it is noted in Figure 22a that a decrease in current speeds O(5cm/s to 10cm/s) are predicted to occur in the central area of the Swale around Elmley Reach. In the case of the Medway-only scenario (Figure 112b) the current speeds increase in the whole of the Medway by c. 15cm/s to 20cm/s with very limited effects on the Swale current speeds.

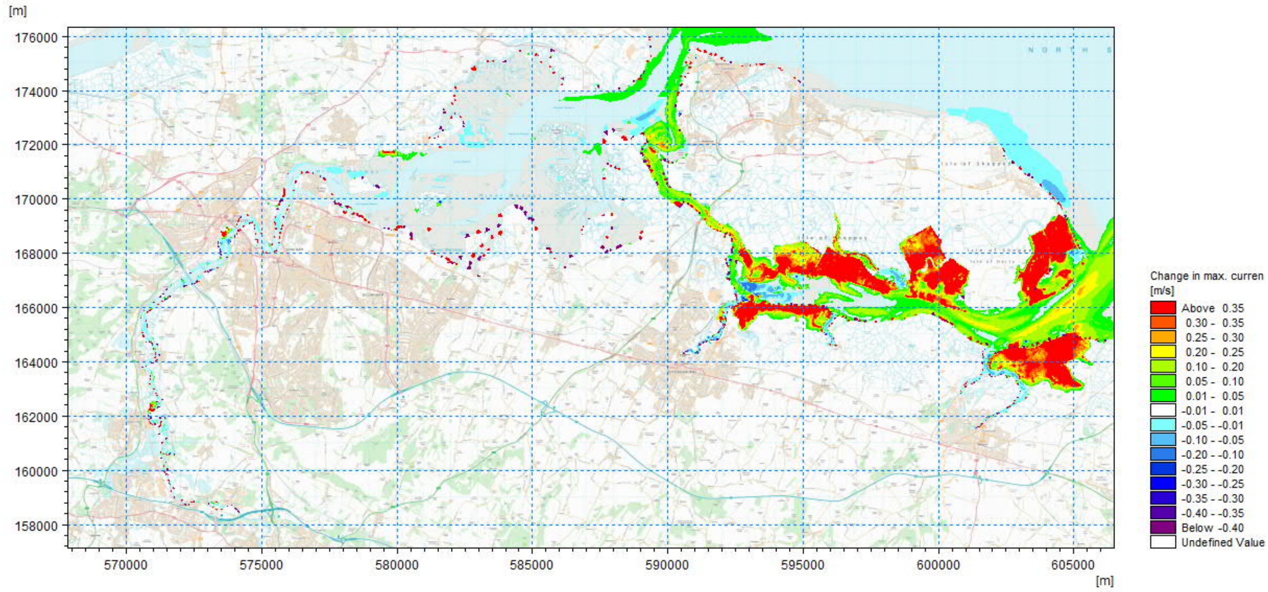
To expand further on the results of the model runs for the Swale-only realignment sites, Figure 175, in Appendix C, shows the changes in current speeds in the Swale (Point 2 and Point 5) and in the Medway (Point 7 and Point 12). The figure shows that an increase in current speeds can be observed during ebb tide in the mouth of the Medway Estuary (Point 7), but not in the upper Medway (Point 12).

To expand further on the results of the model runs for the Medway-only realignment sites, Figure 177, in Appendix D, shows the changes in current speeds in the Swale (Point 2 and Point 5) and in the Medway (Point 7 and Point 12). The figure shows that the increase in current speeds in the Swale is minimal for this scenario (less than 2cm/s at Point 2 during ebb tide). However, in the upper Medway Point 12 current speed are shown to increase by 15cm/s to 20cm/s.

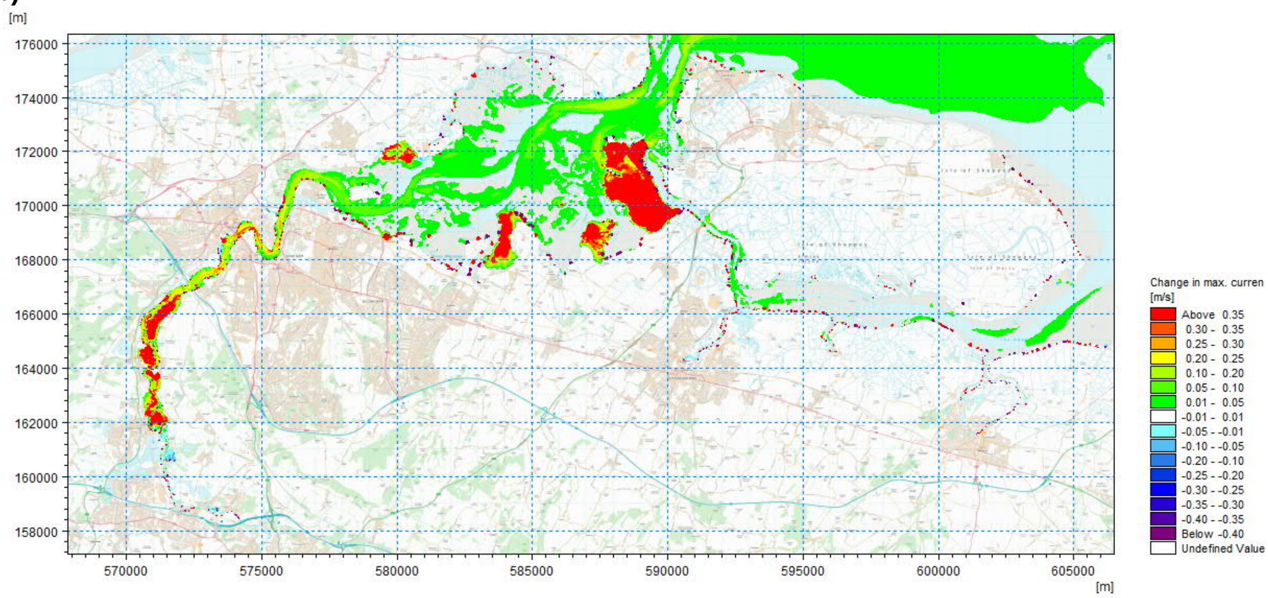
From the model predictions of hydrodynamic impacts, it can be concluded that with regards to water levels and current speeds managed realignment sites in the Swale only affect the Swale area, while the Medway sites have an effect that mainly limited to the Medway Estuary. This result reflects the unusual physical characteristics of the Swale Estuary that has a connection to the open coast in the east and to the Medway Estuary in the west.

Figure 112: Predicted changes in the maximum current speed for: (a) Swale-only managed realignment sites; and (b) Medway-only managed realignment sites, (positive change reflect an increase in current speed).

(a)



(b)



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Table 25: Summary of predicted changes to the maximum water elevation and tidal current speed attributable for Swale-only managed realignment sites for the 1:200-year event, present upgrade scenario.

Point	Tidal range (m)	Change in maximum tidal elevation due to realignments (cm)	% change in maximum tidal elevation due to realignments	Change in phase (minutes)	Period water levels exceed baseline condition (minutes)	Change in maximum tidal current speed due to realignments (cm/s)	% change in maximum tidal current speed due to realignments	Period current speeds exceed baseline condition (minutes)
1	6	<1	--	--	--	+22.8	+24.7	Most the ebb tide
3	6.3	+13	+2	Approx. 40min	Approx. 35min	--	--	--
7	6.2	--	--	--	--	+6	+5.1	Only during ebb tide
12	6.8	--	--	--	--	--	--	--
16	4.65	-14	-3	--	--	--	--	--

Source: Mott MacDonald, 2016

Table 26: Summary of predicted changes to the maximum water elevation and tidal current speed attributable for Medway-only managed realignment sites for the 1:200-year event, present upgrade scenario.

Point	Tidal range (m)	Change in maximum tidal elevation due to realignments (cm)	% change in maximum tidal elevation due to realignments	Change in phase (minutes)	Period water levels exceed baseline condition (minutes)	Change in maximum tidal current speed due to realignments (cm/s)	% change in maximum tidal current speed due to realignments	Period current speeds exceed baseline condition (minutes)
1	6	--	--	--	--	--	--	--
3	6.3	--	--	--	--	--	--	--
7	6.2	<1	--	--	--	+12.5	+10.59	Most the ebb tide
12	6.8	-5.6	-0.8	Approx. 20min	--	+21.8	+35	Both during flood and ebb tide
16	4.65	-14.7	3.1	Approx. 30min	--	--	--	--

Source: Mott MacDonald, 2016

8.3.3 East Swale (Run 4, Table 21) and west Swale (Run 5, Table 21) managed realignment sites scenario – 1:200-year event - Present Upgrade

With the aim of investigating further the predicted impacts on water levels and current speeds attributable to realignments in the Swale, the proposed managed realignment sites were separated into two groups:

- Five east Swale sites (Figure 113a); and
- Six west Swale sites (Figure 113b).
- It is noted that for convenience Run 4 and Run 5 () presented here include all the Medway managed realignment sites since their impact on the Swale has been previously shown to be minimal.

Figure 113: Sites selected for: (a) the east Swale-only realignment sites; and (b) the west Swale-only realignment sites. All the realignment site in the Medway Estuary are included in both scenarios.

(a)

(b)

Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 114 shows changes in the maximum water levels for the 1:200-year event for: (a) the east Swale; and (b) the west Swale. The model predictions show that the east Swale sites have a smaller effect on the extreme water level than the west Swale sites. A maximum increase in the water levels towards the centre of the Swale of c. 5cm is evident when only the east Swale sites are included in the MEASS hydrodynamic model (Figure 114a). However, when only the west Swale sites are considered, the maximum increased in the central Swale is c. 10cm above the baseline scenario (Figure 114b).

To expand further on the results of the model runs for the east Swale realignment sites, Figure 178, in Appendix E, shows the comparisons between the water levels in the Swale and in the Medway before and after the inclusion of the managed realignment sites. The figure shows a smaller increase in the water level at Point 4 (c. 5cm compared to the baseline), located in the centre of the Swale, and a decrease of the water levels, at Point 12 (c. 8cm) and at Point 16 (c. 15cm), in the Medway Estuary.

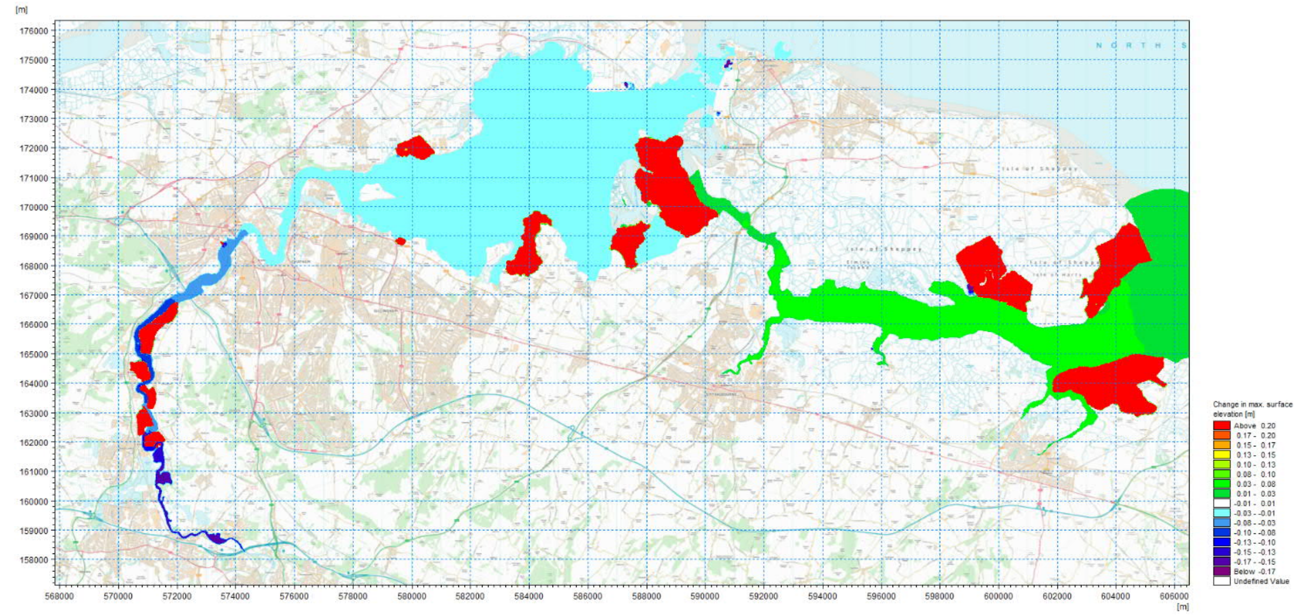
To expand further on the results of the model runs for the west Swale realignment sites, Figure 180, in Appendix F, shows the comparisons between the water levels in the Swale and in the Medway before and after the inclusion of the managed realignment sites. The figure shows an increase in the water level at Point 4 (c. 10cm compared to the baseline), located in the centre of the Swale, and a decrease of the water levels, at Point 12 (c. 8cm) and at Point 16 (c. 15cm), located in the Medway Estuary.

Following previous analysis, the water level increase in the centre of the Swale can again be explained by the realignment-induced changes in the water level gradient between the two entrances of the Swale and the central area of the estuary. To illustrate this, Figure 115 presents the water levels changes along the Swale, between Point 1 (east entrance) and Point 7 (west entrance) at different stages of the tide presented in Figure 101 for: the baseline scenario; all managed realignment site scenario; the east Swale-only scenario; and the west Swale-only scenario.

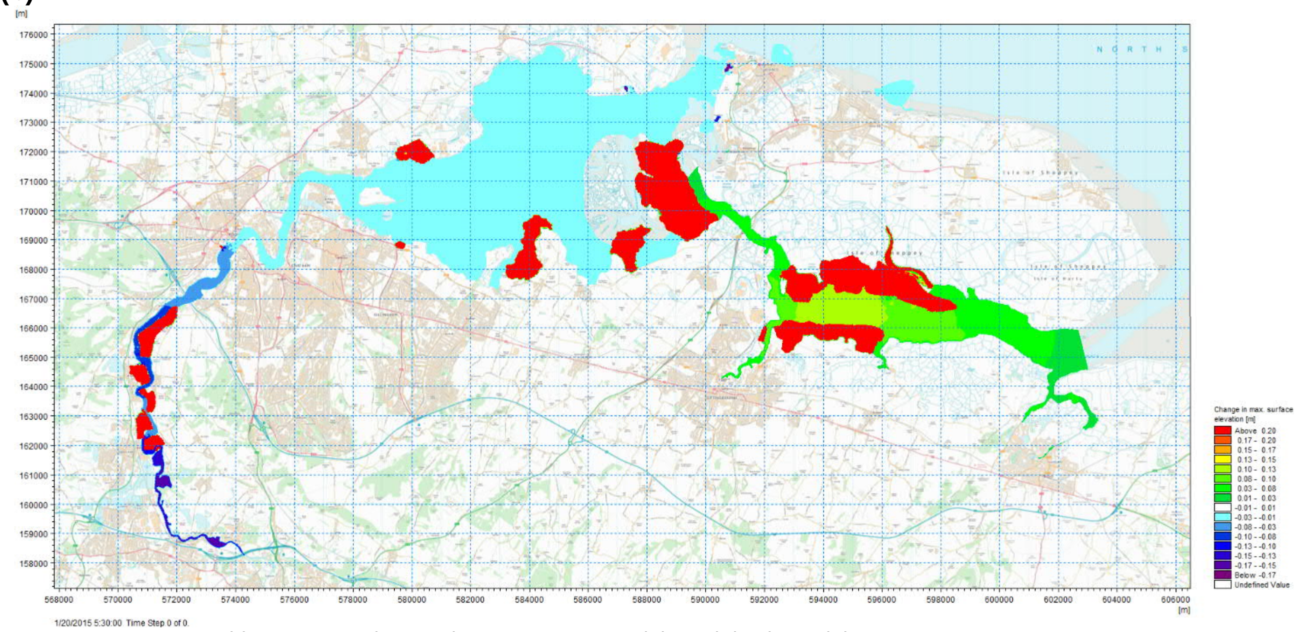
Figure 115 shows that irrespective of the scenario modelled, there is always an effect on the water levels towards the centre of the Swale. The impacts on the water levels are reduced when the western Swale sites are omitted. However, the gradient in water levels created by the east Swale sites only is sufficient to increase the water flowing towards the centre of the Swale and increasing the extreme water levels.

Figure 114: Predicted changes in the maximum water level for: (a) east Swale-only managed realignment sites; and (b) west Swale-only managed realignment sites, (positive change reflect an increase in water level).

(a)

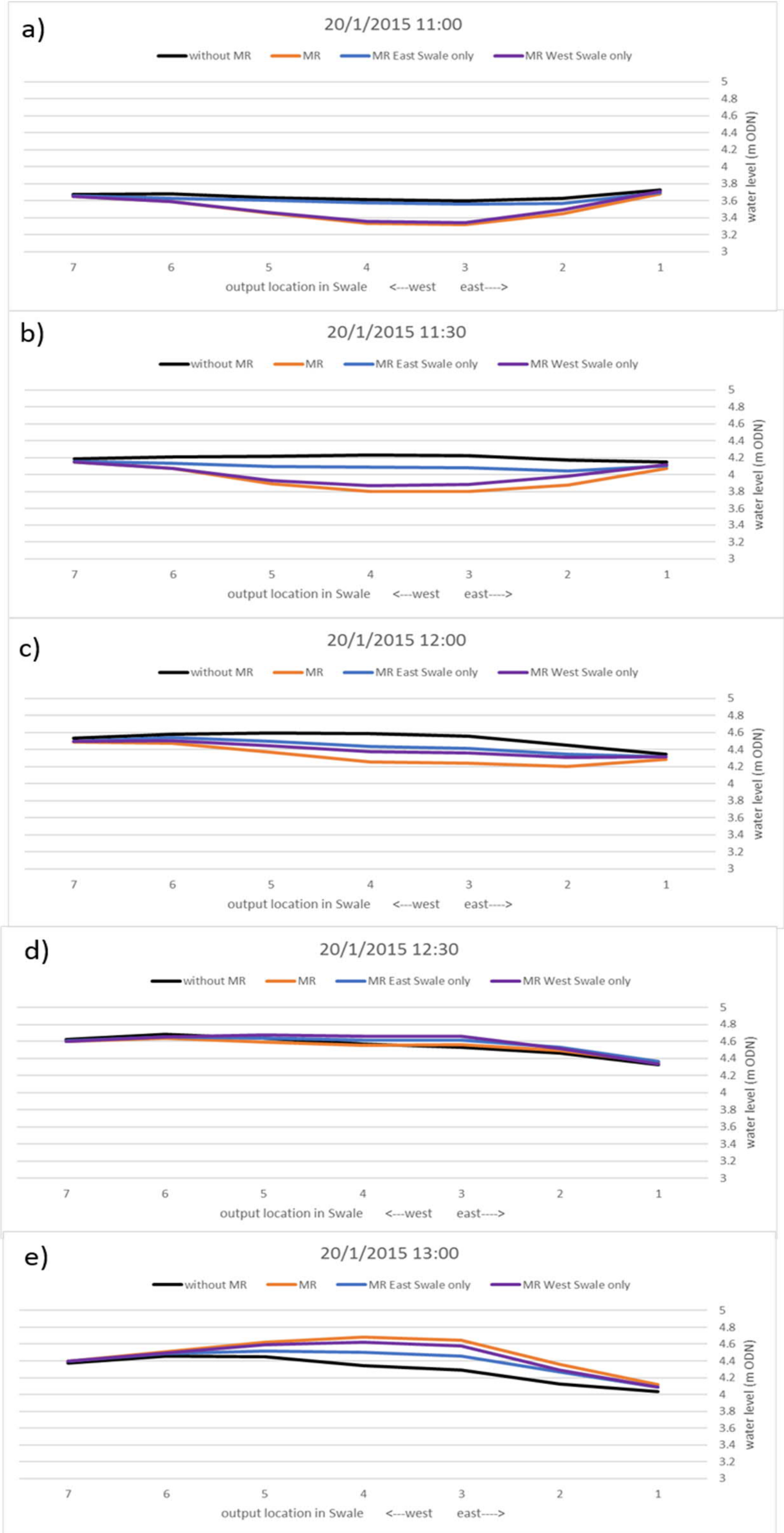


(b)



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 115: Along-estuary water levels changes in the Swale at different stages of the tide (a-e) between Point 1 (east entrance) and Point 7 (west entrance) for Swale-only realignments.



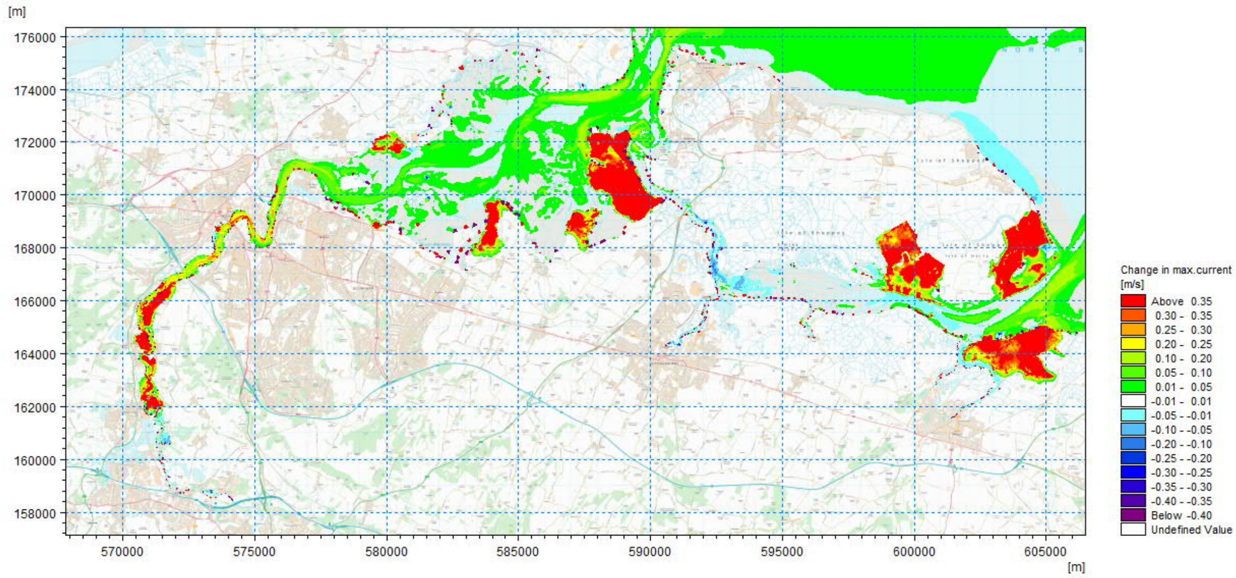
Source: Mott MacDonald, 2016

The spatial distribution of the predicted changes in the maximum current speed due to the realignment sites in the east Swale and in the west Swale-only scenarios are shown in Figure 116. This figure shows only the change in the maximum current speed and does not convey any temporal information. The figure indicates that the western sites (Figure 116a) have a larger spatial effect on the currents in the Swale, (Figure 116b) compared to when only the east sites are considered.

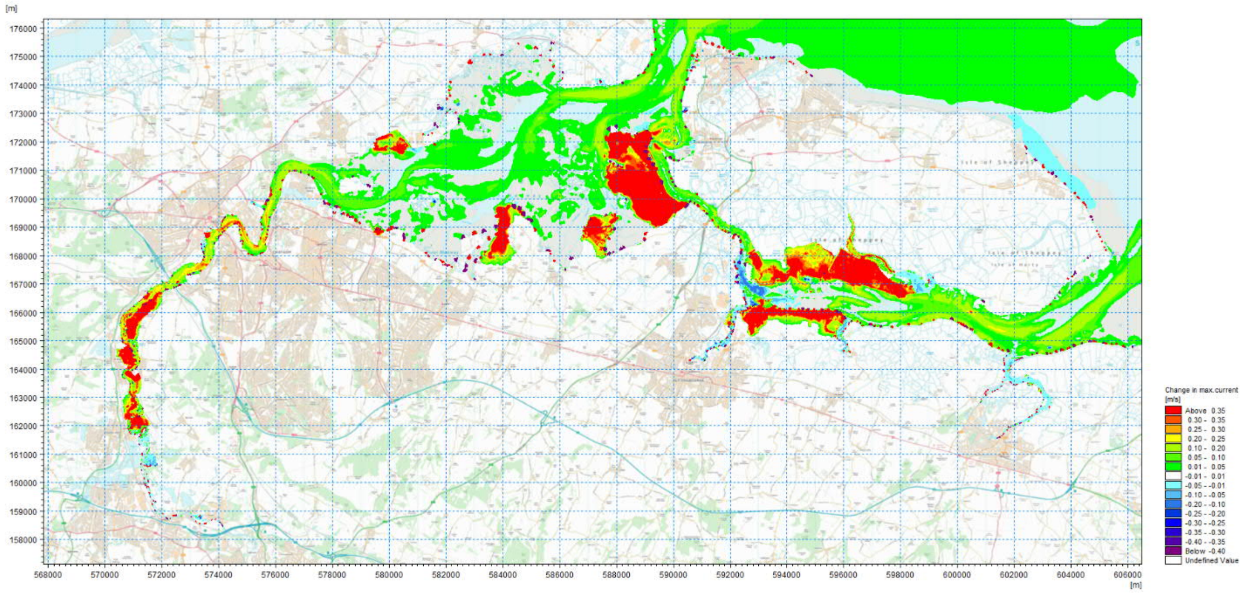
To expand further on these model results, Figure 179, in Appendix E, presents the changes in current speeds in the Swale (Point 2 and Point 5) and in the Medway (Point 7 and Point 12) when only when only the east Swale sites are considered. Figure 181, in Appendix F, presents the changes in current speeds in the Swale (Point 2 and Point 5) and in the Medway (Point 7 and Point 12) when only when only the west sites are considered.

Figure 116: Predicted changes in the maximum current speed for: (a) east Swale-only managed realignment sites; and (b) west Swale-only managed realignment sites, (positive change reflect an increase in current speed).

(a)



(b)



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

The results in Figure 116 indicate that the west Swale sites have a larger effect on the extreme water levels and currents speeds in the Swale. The exclusion of the western realignment sites decreases the effect, but does not eliminate it. These results indicate that any proposed managed realignment site in the Swale could potentially create a change in the water level gradient between the mouths and the centre of the estuary, resulting in an increase in water flowing towards the centre of the Swale and potentially increasing, to some degree, the extreme water levels for this area.

Table 27: Summary of predicted changes to the maximum water elevation and tidal current speed attributable for east Swale managed realignment sites for the 1:200-year event, present upgrade scenario.

Point	Tidal range (m)	Change in maximum tidal elevation due to realignments (cm)	% change in maximum tidal elevation due to realignments	Change in phase (minutes)	Period water levels exceed baseline condition (minutes)	Change in maximum tidal current speed due to realignments (cm/s)	% change in maximum tidal current speed due to realignments	Period current speeds exceed baseline condition (minutes)
1	6	+2	+0.3	--	--	+22.8	+24.7	Most the ebb tide
3	6.3	+5.6	+0.8	Approx. 30min	Approx. 25min	--	--	--
7	6.2	--	--	--	--	+14	+11.8	Only during ebb tide
12	6.8	-5.8	-0.85	Approx. 20min	--	+21.7	+34.8	Both during flood and ebb tide
16	4.65	-15.5	-3.3	Approx. 30min	--	--	--	--

Source: Mott MacDonald, 2016

Table 28: Summary of predicted changes to the maximum water elevation and tidal current speed attributable for west Swale managed realignment sites for the 1:200-year event, present upgrade scenario.

Point	Tidal range (m)	Change in maximum tidal elevation due to realignments (cm)	% change in maximum tidal elevation due to realignments	Change in phase (minutes)	Period water levels exceed baseline condition (minutes)	Change in maximum tidal current speed due to realignments (cm/s)	% change in maximum tidal current speed due to realignments	Period current speeds exceed baseline condition (minutes)
1	6	+2	+0.3	--	--	+11.7		
3	6.3	+11	+1.75	Approx. 30min	Approx. 30min	--	--	--
7	6.2	--	--	--	--	+17	+14.4	Only during ebb tide
12	6.8	-5.8	-0.85	Approx. 20min	--	+22	+35.3	Both during flood and ebb tide
16	4.65	-15.5	-3.3	Approx. 30min	--	--	--	--

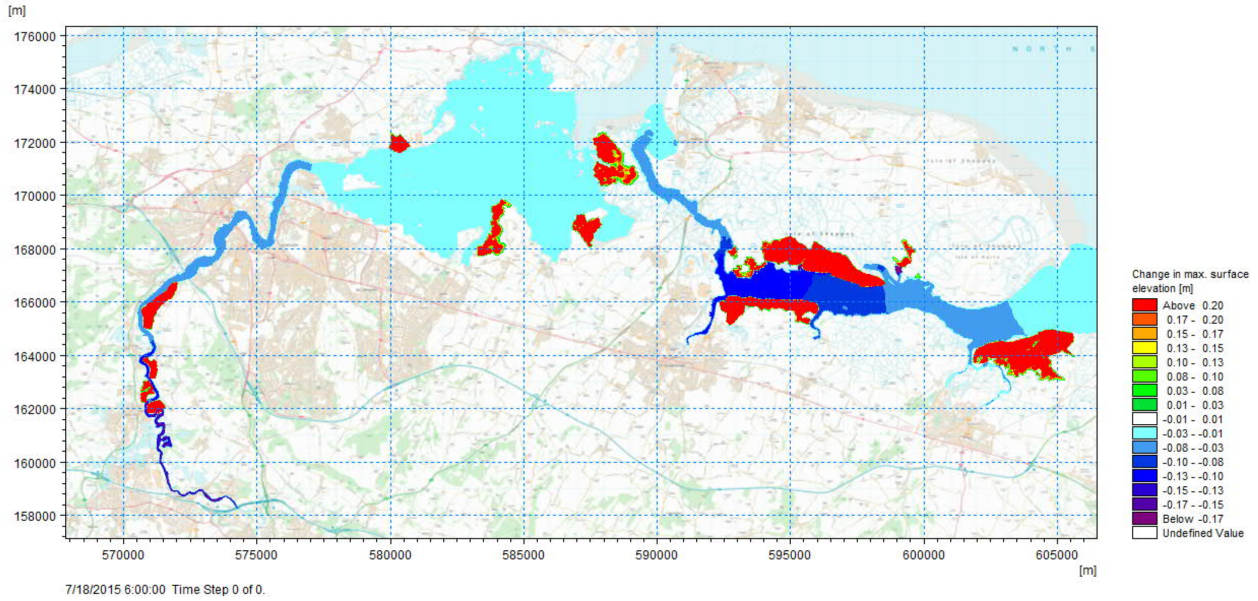
Source: Mott MacDonald, 2016

8.3.4 All managed realignment sites scenario – Spring tide - Present Upgrade (Run 6, Table 22)

To understand the effect of the proposed realignment sites under normal spring tide conditions, the MEASS hydrodynamic model was run with the inclusion of all the proposed managed realignment sites (Table 22). The model results were analysed in order to determine the effect of the proposed sites on the water levels and currents speeds and directions in the Medway and Swale estuaries.

In common with the 1:200-year event, Figure 117 shows that the maximum spring tidal water level in the Medway Estuary is reduced, especially in the Upper Medway, were the maximum levels decrease by approximately 10cm to 17cm (c. 6% decrease on the mean spring tide range) compared with the baseline case. In the Swale Estuary, the effect of the proposed realignment sites on the spring tide water levels is very different from the one observed for the 1:200-year event with water levels towards the centre of the Swale decreasing by as much as 12cm (2.3% decrease) compared to the baseline case.

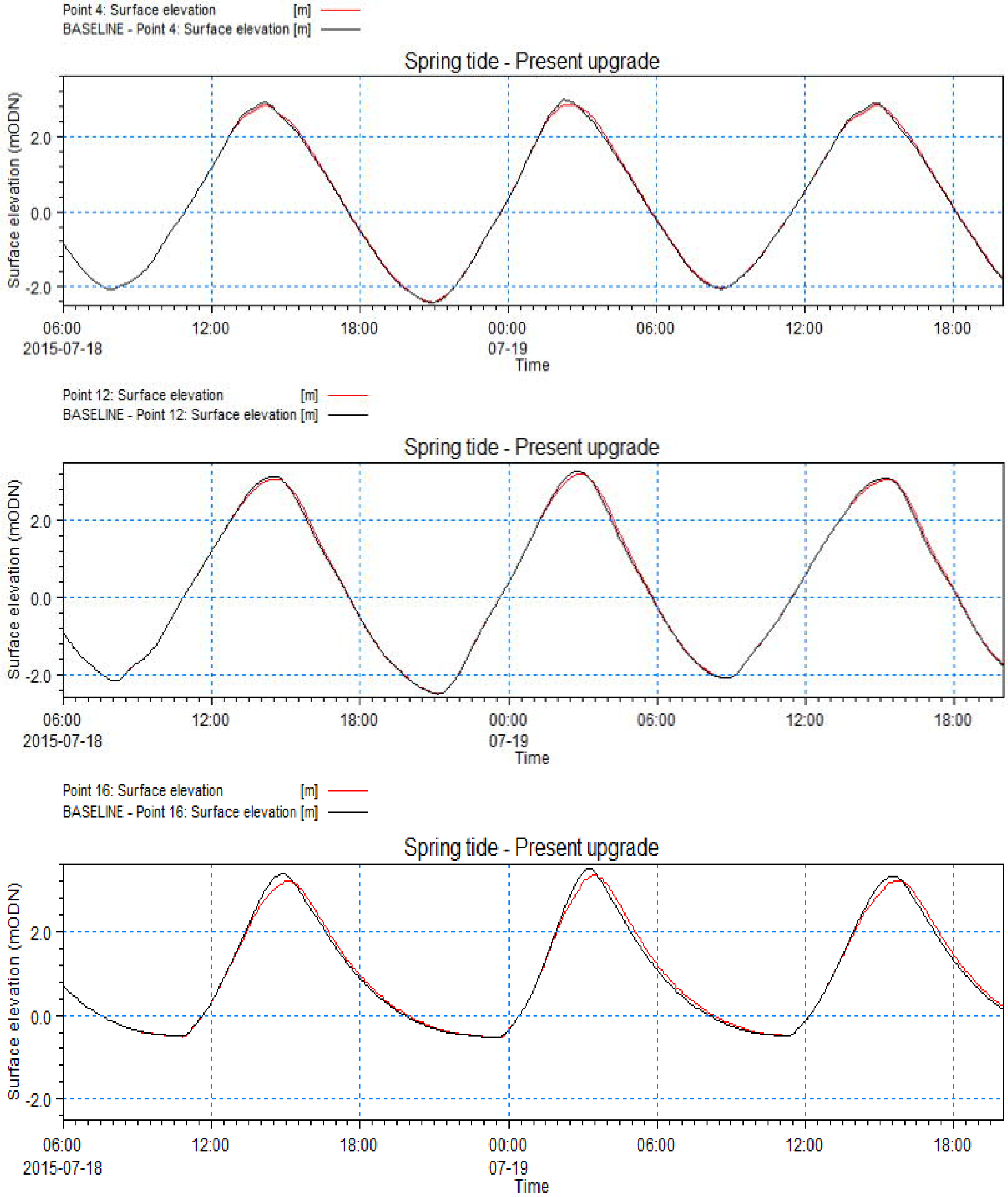
Figure 117: Predicted changes in the maximum water level for all 22 managed realignment sites for a spring tide, (positive change reflects an increase in water depth).



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 118, showing comparisons between the spring tide water levels in the Swale and in the Medway before and after the inclusion of the managed realignment sites in the MEASS model, demonstrates a decrease in maximum spring tide water levels in both estuaries and only a small change in tidal phase where high water is slightly delayed compared to the baseline. The ebb duration is therefore less affected resulting in smaller changes to the current speeds.

Figure 118: Comparison between spring tide water levels in the Swale (Point 4) and in the Medway (Points 12 and Point 16) for the baseline and full realignment scenarios (22 sites).

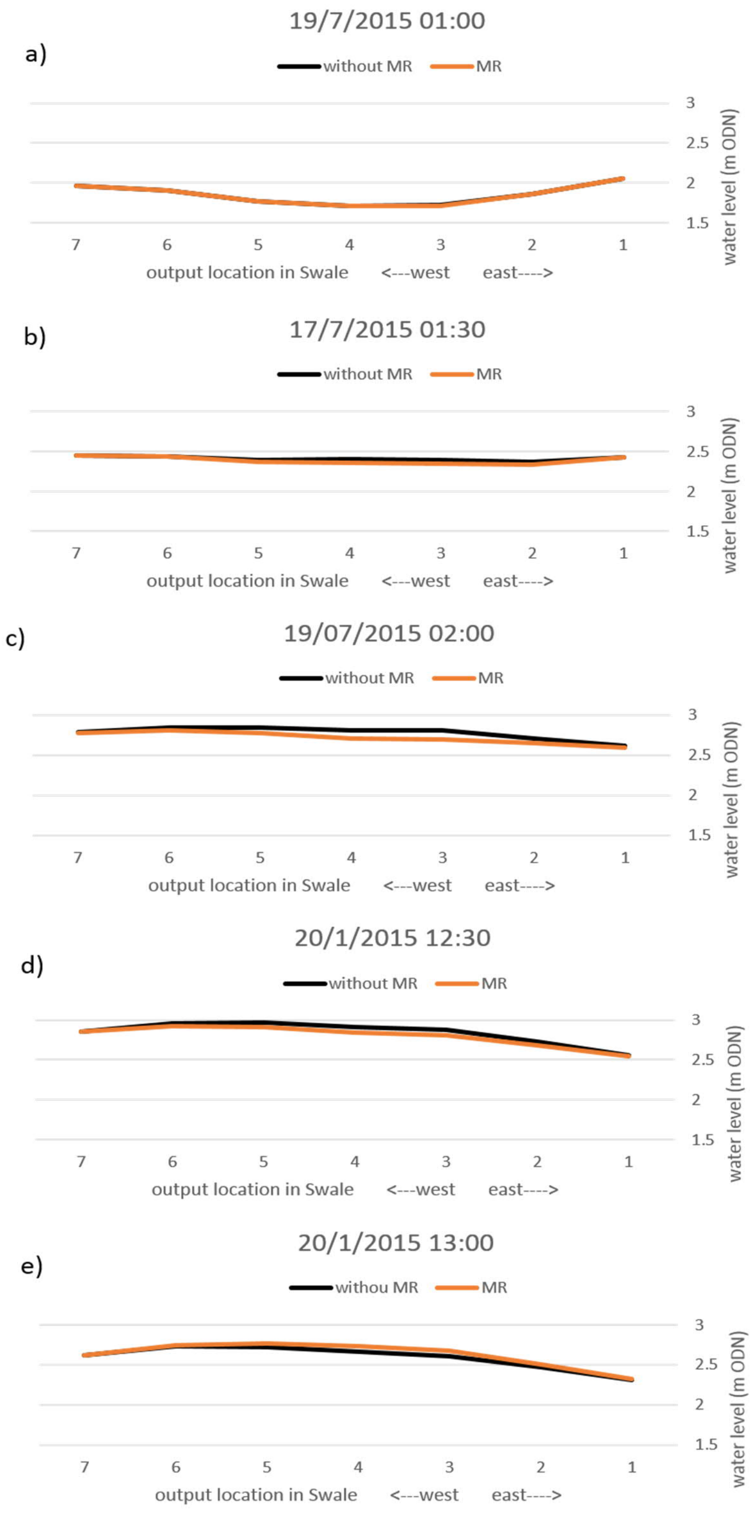


Source: Mott MacDonald, 2016

To understand the results shown in Figure 118, the changes in water levels gradient between the two entrances of the Swale and the central area of the estuary have been analysed, both for the baseline spring tide conditions and for model runs including all the proposed sites. Figure 119 presents the water levels changes along the Swale, between Point 1 (east entrance) and Point 7 (west entrance) at different stages of the Spring tide for the baseline and realignment scenarios.

The results show that the effect on the water levels attributable to the Swale managed realignment sites is much less than that predicted for the 1:200-year event (Figure 102). This is related to the greatly reduced water level gradient in the Swale during springs tides which in turn is related to the reduction in the volume of water entering the realignment sites during a spring tide. This is demonstrated by Figure 120 which shows the flood depths in the proposed managed realignment sites for the spring tide and the 1:200-year event. The figure shows that some of the sites, especially in the Swale, are not completely flooded during the spring tide.

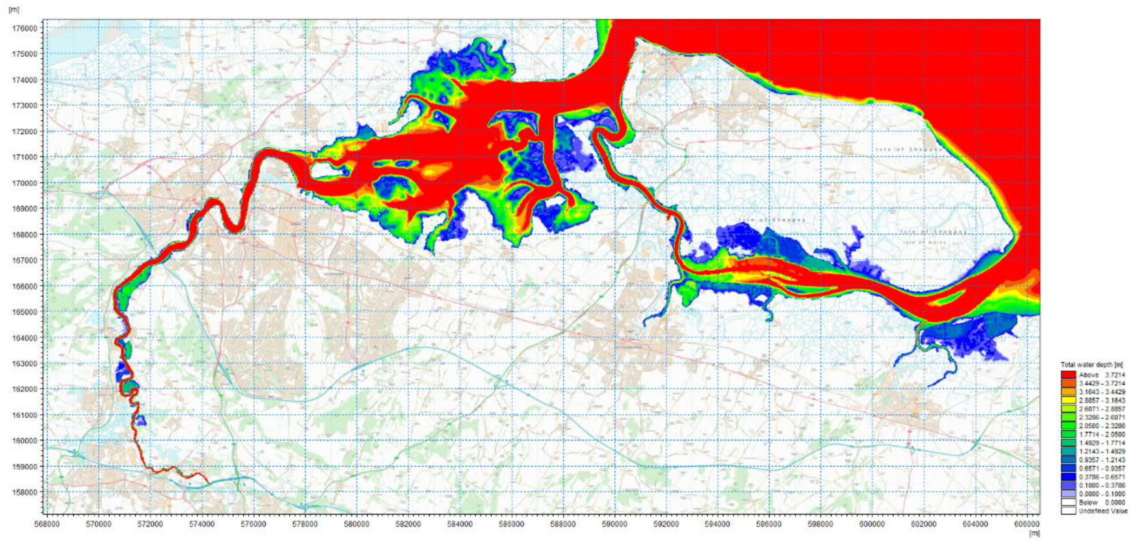
Figure 119: Along-estuary water levels changes in the Swale at different stages of the tide (a-e) between Point 1 (east entrance) and Point 7 (west entrance) for all 22 realignments.



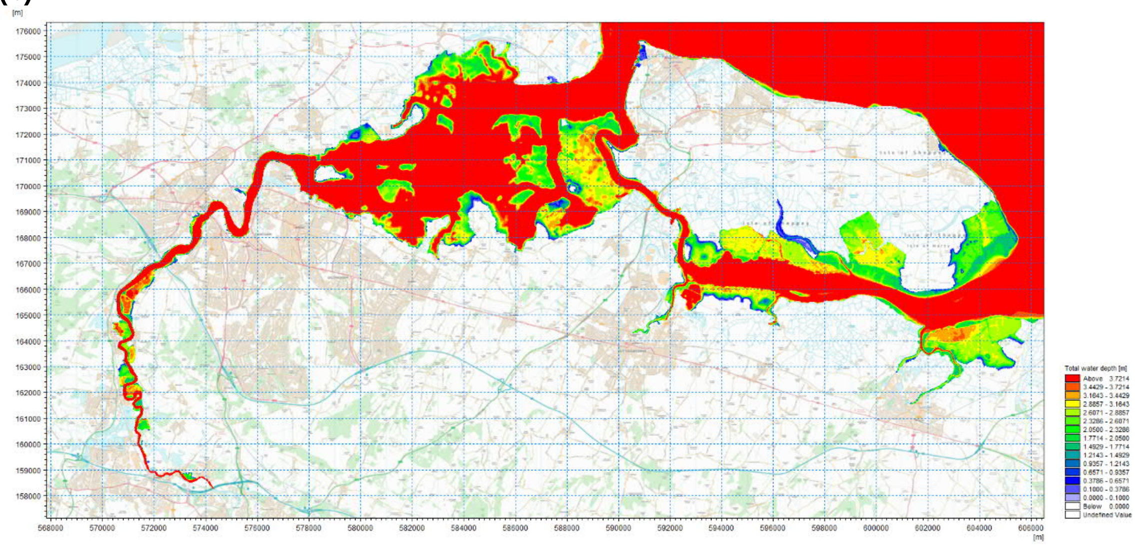
Source: Mott MacDonald, 2016

Figure 120: Maximum predicted flood extents for all 22 managed realignment sites for: (a) spring tide and: (b) a 1:200-year event.

(a)



(b)

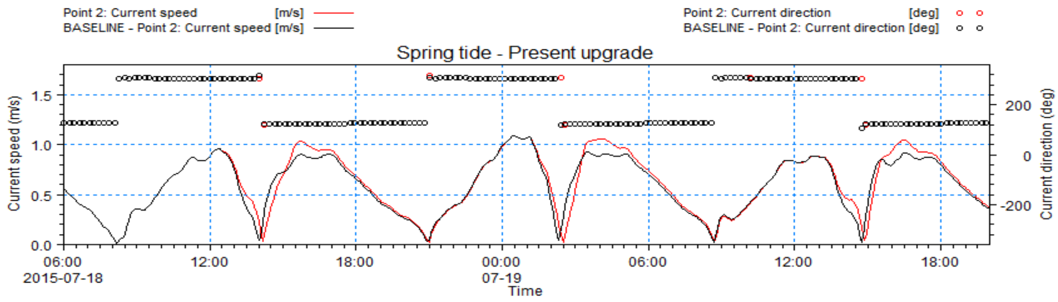


Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

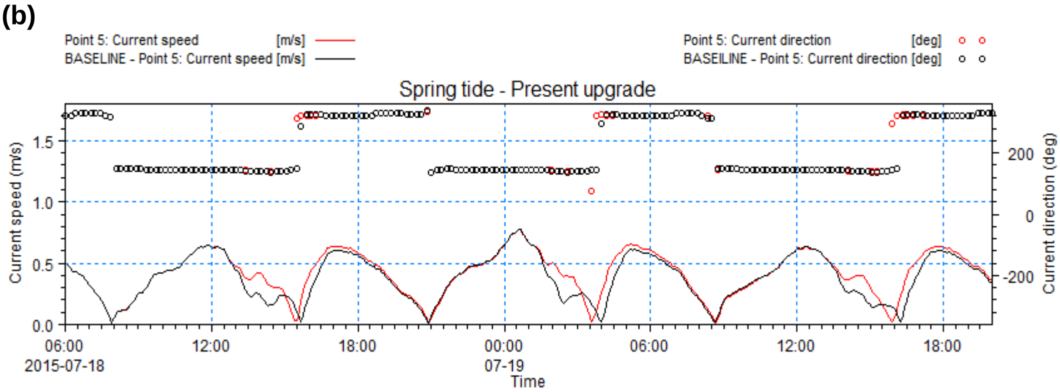
For the spring tide tests, the MEASS model shows that inclusion of the 22 proposed realignment sites tends to increase the currents speeds at most locations in both estuaries. The changes in current speed at Points 2 and 5 in the Swale are shown in Figure 121. During the ebb tide there is an increase in the current speed of c.15cm/s compared to the baseline. This is attributed to the larger volume of water leaving the estuary. It is noted that the realignment sites not only increase the current speed at both entrances of the Swale, but also alter the flood/ebb duration and timing. The changes in current speed at Points 7 and 12 in the Medway are shown in Figure 121. The current speeds at the mouth of the estuary only increase by c. 2cm/s (Point 7), while in the Upper Medway the increase predicted is c. 13cm/s (Point 12), compared to the baseline scenario.

Figure 121: Comparison between predicted current speed and direction during a spring tide in the Swale (Point 2 (a) and Point 5 (b)) and the Medway (Point 7 (c) and Point 12 (d)) for the baseline and full realignment scenarios (22 sites).

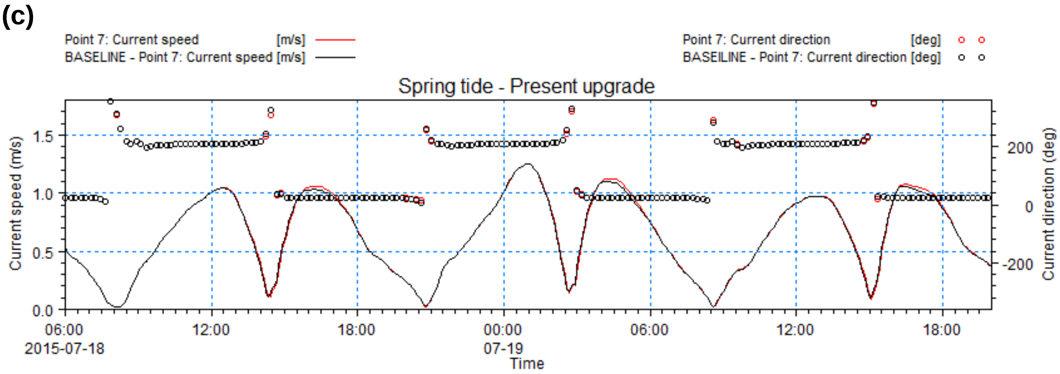
(a)



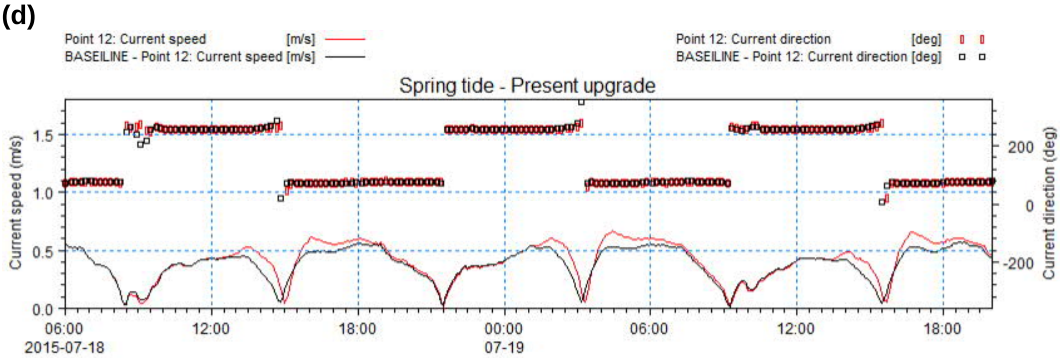
(b)



(c)



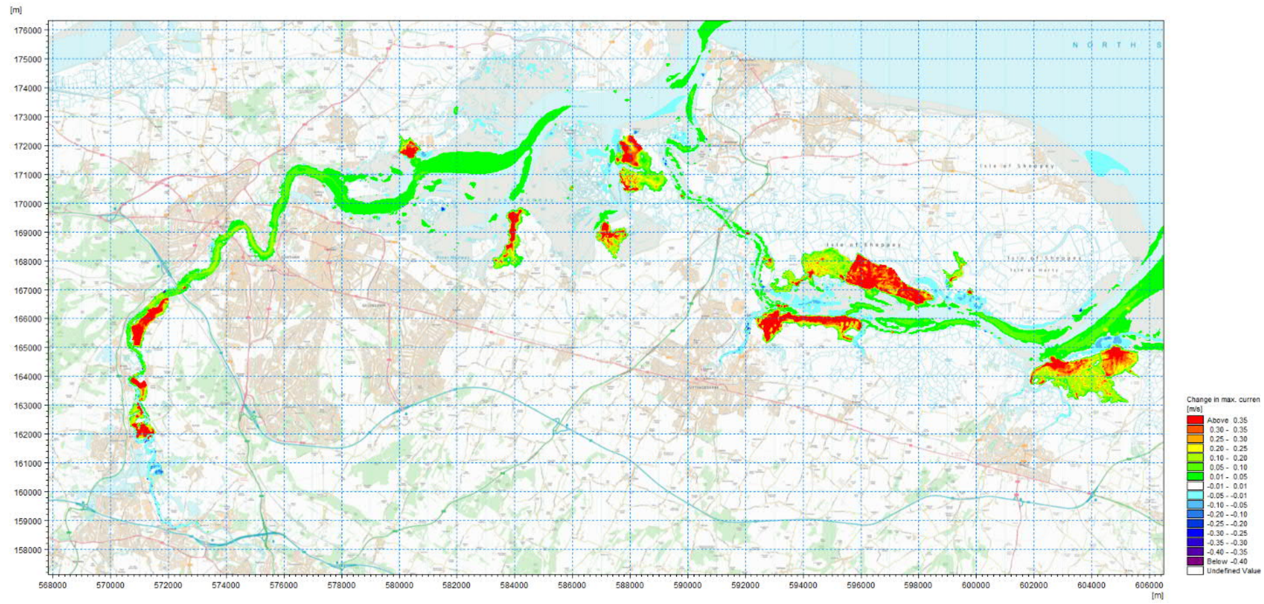
(d)



Source: Mott MacDonald, 2016

The spatial distribution of the predicted changes to current speed due to the realignment sites is shown in Figure 122. This figure shows only the change in the maximum current speed and does not convey any temporal information. The figure indicates maximum changes in the current speeds in the Swale and in the Medway of c. 5cm/s to 15cm/s. Figure 122 shows a decrease in the current speeds (c. 1cm/s to 5cm/s) around Elmley Reach in the central area of the Swale and in the Upper Medway, south of proposed managed realignment site 8.

Figure 122: Predicted changes in the maximum spring tide current speed for all 22 managed realignment sites, (positive change reflect an increase in current speed).



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Following the analysis used to better understand the role played by realignment sites in each estuary undertaken for the 1:200-year event, the Swale proposed managed realignment sites were separated into two groups: east Swale (Run 7, Table 22) and west Swale (Run 8, Table 22) (Figure 113). The results of this analysis are presented, in terms of changes on spring water levels and current speeds, in Appendix **G**. In common with the results for the 1:200-year event the spring tide results demonstrate that the largest changes to the water levels and current speeds in the Swale are related to the western proposed managed realignment sites. Taken together, the spring tide modelling results demonstrate that the 22 proposed managed realignments sites have a smaller impact on the hydrodynamics of the Swale and Medway estuaries compared to the 1:200-year event.

Table 29: Summary of predicted changes to the maximum water elevation and tidal current speed attributable to inclusion of the 22 proposed managed realignment sites for a spring tide, present upgrade scenario.

Point	Tidal range (m)	Change in maximum tidal elevation due to realignments (cm)	% change in maximum tidal elevation due to realignments	Change in phase (minutes)	Period water levels exceed baseline condition (minutes)	Change in maximum tidal current speed due to realignments (cm/s)	% change in maximum tidal current speed due to realignments	Period current speeds exceed baseline condition (minutes)
1	4.9	-1	-0.2	--	--	+5.1	+6	Most the ebb tide
3	5.2	-10	-1.9	Approx. 10min	--	--	--	--
7	5.2	--	--	--	--	+2	+1.8	Only during ebb tide
12	5.8	-6	-1	Approx. 5min	--	+10	+17.6	Both during flood and ebb tide
16	2.9	-16.8	-5.8	Approx. 15min	--	--	--	--

Source: Mott MacDonald, 2016

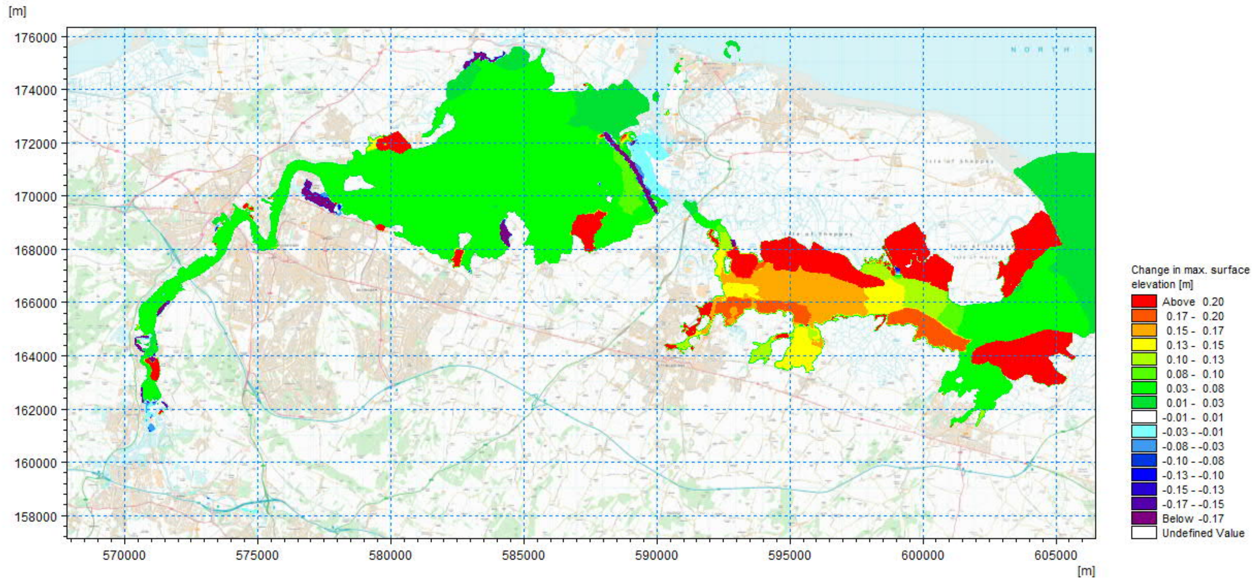
8.3.5 All managed realignment sites scenario – 1:200-year event - Present Maintain (Run 9, Table 23)

In a further series of Present Maintain MEASS model runs, the 22 proposed manage realignment site were included in a 1:200-year extreme event simulation and the defence crest levels in the Swale and Medway estuaries were defined using the present-day crest level (Table 23). Figure 123 shows the changes in the maximum water levels in the Medway and Swale estuaries. As expected the maximum 1:200-year water levels across both the Medway and the Swale estuaries are shown to increase, especially in the centre of the Swale.

In the Swale, the water levels reach a maximum value of c. 17cm (c. 2.7% increase) above the baseline. This is some 4cm larger than the 13cm increase predicted for the Present Upgrade scenario (Section 3.1). Figure 123 also shows that in the Medway, there is a general increase in the extreme water levels of c. 4cm in the Upper Medway and in the intertidal areas.

As previously explained, the increase in the extreme water levels in the Swale are related to the changes in the gradients between the estuary mouths and the centre of the Swale. Please refer to Section 8.3.1 for additional information. Figure 184, in Appendix H shows water levels changes through the Swale, between Point 1 (East entrance) and Point 7 (West entrance) at different stages of the tide for the baseline and this scenario.

Figure 123: Predicted change in the maximum water level elevation for the 1:200-year event for all 22 managed realignment sites in the Present Maintain case, (positive change reflect an increase in water level).

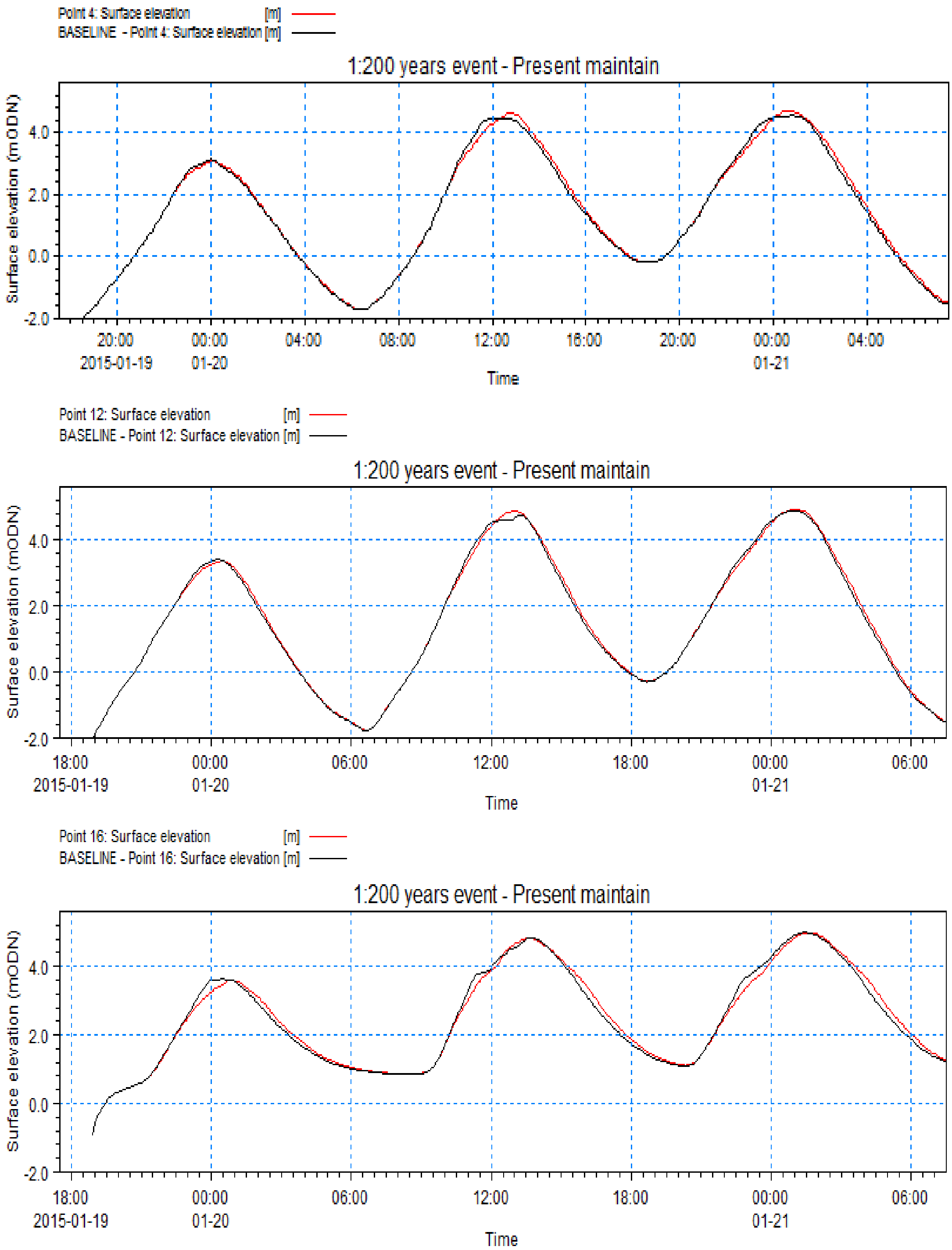


Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

The increase in extreme water levels in the Medway are thought to be related to the flooding of the realignment sites. In the baseline scenario, the flooding of areas currently defined as managed realignment sites, was limited only by the ground elevation (topography). In addition, the flooding occurred when the defence crest levels were overtopped. However, to limit and control the timing of flooding, setback defences and breaches are included in the managed realignment scenario. These flood controls in the Medway are consider to be responsible for the small increase in the predicted water levels in the Medway.

Changes to flooding in the Medway can also be seen in Figure 124 which shows comparisons between the water levels in the Swale and in the Medway before and after the inclusion of the managed realignment sites in the MEASS model. In the baseline at Point 12 and Point 16, the moment of overtopping of the defences can be observed in the water level curve. However, in the managed realignment scenario overtopping of the defences does not occur as water flows into the realignment sites through the breaches.

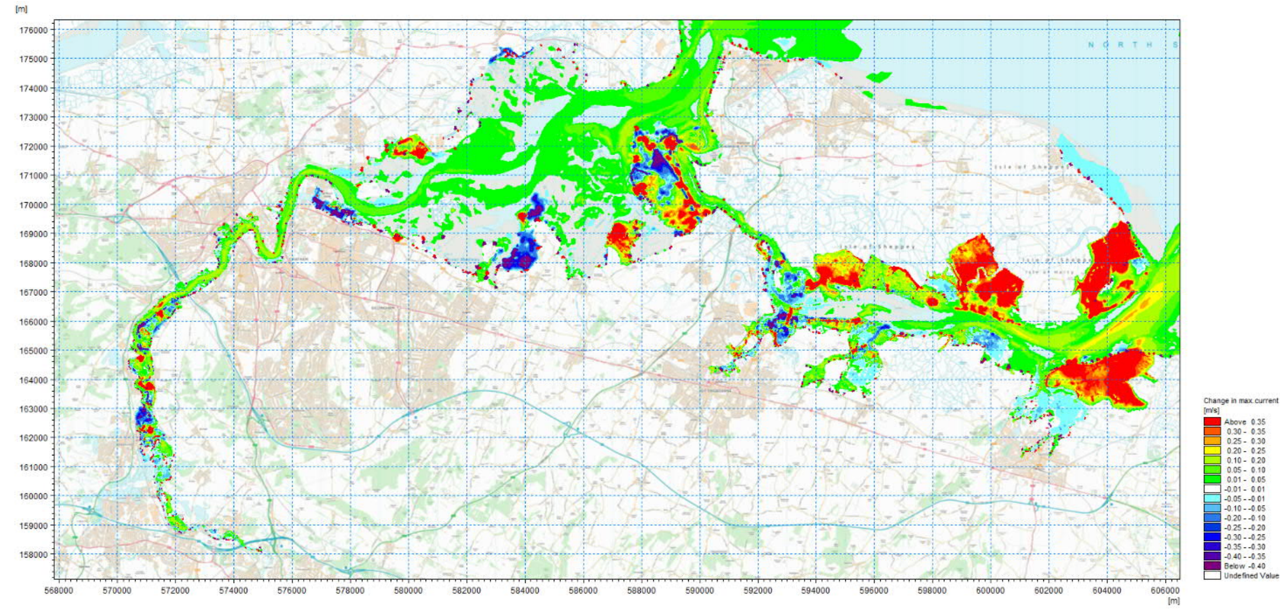
Figure 124: Comparison between 1:200-year water levels in the Swale (Point 4) and in the Medway (Points 12 and Point 16) for all 22 managed realignment sites in the Present Maintain case.



Source: Mott MacDonald, 2016

The spatial distribution of the predicted changes to current speed due to the realignment sites is shown in Figure 125. This figure shows only the change in the maximum current speed and does not convey any temporal information. Results are very like the Present Upgrade scenario (Section 8.3.1), and show that maximum current speeds in the Swale increase by c. 25cm/s to 30cm/s and by c. 15cm/s to 20cm/s in the Medway. A decrease in the predicted current speed (c. 5cm/s to 10cm/s) around Elmely Reach in the central area of the Swale is also demonstrated (Figure 125).

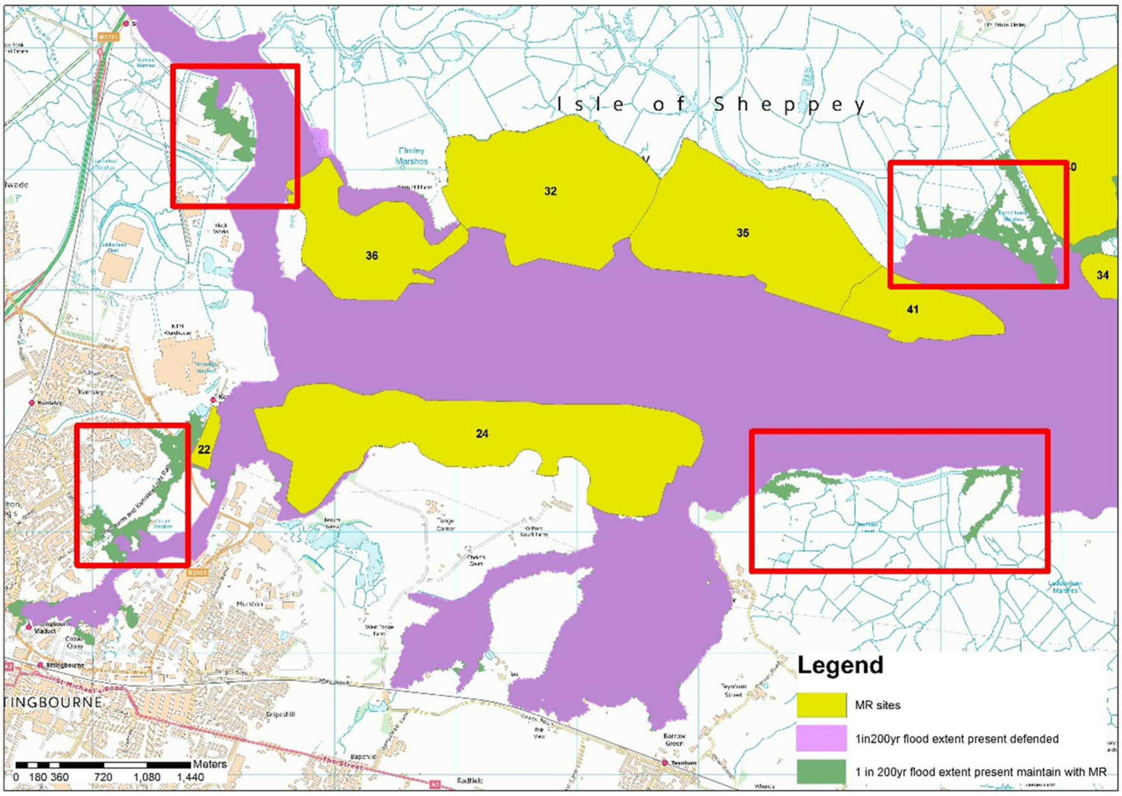
Figure 125: Predicted changes in the maximum 1:200-year current speed for all 22 managed realignment sites in the Present Maintain case, (positive change reflect an increase in current speed).



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

The MEASS model simulations show that without an upgrade of the defence line the proposed managed realignment sites have a potential to increase the flood risk in both the Medway and the Swale estuaries. For the maintain scenario, the flood extent in the Swale is greater than the baseline case (Figure 126) and results from defence overtopping in the centre of the Swale.

Figure 126: Flood extent of the baseline (purple) and the managed realignment sites for the Present Maintain scenario (green) in the central area of the Swale. The highlighted red boxes denote areas were the flood extent is increased compared to the baseline.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Table 30: Summary of predicted changes to the maximum water elevation and tidal current speed attributable to inclusion of the 22 proposed managed realignment sites for the 1:200-year event, present maintain scenario.

Point	Tidal range (m)	Change in maximum tidal elevation due to realignments (cm)	% change in maximum tidal elevation due to realignments	Change in phase (minutes)	Period water levels exceed baseline condition (minutes)	Change in maximum tidal current speed due to realignments (cm/s)	% change in maximum tidal current speed due to realignments	Period current speeds exceed baseline condition (minutes)
1	6	+3	+0.5	--	--	+22.6	+24.2	Most the ebb tide
3	6.3	+16	+2.5	Approx. 30min	Approx. 30min	--	--	--
7	6.2	<1	--	--	--	+10	+7.9	Most the ebb tide
12	6.8	+4	+0.6	--	--	+15.7	+21.5	Both during flood and ebb tide
16	4.65	--	--	--	--	--	--	--

Source: Mott MacDonald, 2016

8.4 Summary and discussion

8.4.1 Summary

The MEASS hydrodynamic model has been run with the inclusion of all the 22 potential management realignment sites currently selected as being favourable, and for selected groups of realignment sites to examine their relative impacts on the Medway and Swale estuaries. Each of these sites has been breached in one or more locations to allow the efficient ingress and outflow of water during flood and ebb tides. In all cases three tidal cycles have been simulated with the maximum water levels attained during a given cycle set to: (a) the predicted 1:200-year event (4.65m ODN at Sheerness); and (b) the maximum spring tide level (2.85m ODN at Sheerness).

8.4.1.1 Present Upgrade MEASS simulations

Impacts of all realignment sites for the 1:200-year event

The results from the hydrodynamic model demonstrate that for the 1:200-year event the proposed 22 managed realignment sites:

- Increased water levels in the Swale (maximum +13cm, or 2% of the 6.3m tidal range);
- Decreased water levels in the upper Medway (maximum -17cm, or 3.6% of the 4.65m tidal range);
- Increases the current speeds and changes in flow patterns in the Swale (typically in the range 10cm/s to 20cm/s, with maximum values of c. 30cm/s in the estuary entrance during the ebb tide);
- Increases the current speeds in the Upper Medway (typically in the range 15cm/s to 20cm/s, with maximum values of c. 25cm/s at some locations during the ebb tide); and
- Decreases the current speeds in the Swale around Elmley Reach by 5cm/s to 10cm/s.

Impacts of all realignment sites for a spring tide

The results from the hydrodynamic model demonstrate that for the spring tide the proposed 22 managed realignment sites:

- Decrease water levels in the middle Swale (maximum -12cm, or 2.3% of the 5.25m spring tidal range);
- Decrease water levels in the upper Medway (maximum -17cm, or 5.8% of the 3m spring tidal range);
- Increases the current speeds in the Swale (typically in the range 5cm/s to 10cm/s, with maximum values of c. 10cm/s in the estuary entrance);
- Increases the current speeds in the upper Medway (typically in the range 5cm/s to 10cm/s, with maximum values of c. 15cm/s);
- Decreases the current speeds in the upper Medway above potential managed realignment site 8 by 1cm/s to 5cm/s; and
- Decreases the current speeds in the Swale around Elmley Reach by 1cm/s to 5cm/s.

Medway-only and Swale-only realignment site impacts

- The impacts of the realignment sites are generally limited to the estuary in which they are located. If some very minor interactions are ignored the MEASS simulations show that

Swale-only sites only impact the Swale estuary and Medway-only sites only impact the Medway estuary.

East Swale and west Swale realignment site impacts

- All the MEASS results demonstrate that any realignment sites in the Swale will create an increased water level gradient which will give rise to increased water levels, especially in the central part of the Swale estuary;
- The western realignment sites alone have almost the same impact on water elevation and tidal current speeds as all the sites in the Swale; and
- Although the eastern realignment sites alone reduce the impacts on water level and current speed, they still elevate water levels and increase flow speed, but by a lesser amount compared with the western sites.

8.4.1.2 Present Maintain MEASS simulations for 1:200-year event

- All Present Maintain MEASS simulations showed an increase in the water levels in the Swale. The predicted maximum value of 16cm in the Swale is 4cm more than the predicted value for the Present Upgrade case;
- All Present Maintain MEASS simulations showed the maximum increase in the water levels in the Medway to be c. 4cm. This is attributed to: the limitations imposed on flood extent by the setback defences; and flood regulation through the breach sites that acts to reduce the rate of flooding compared with overtopping in the baseline case. Further, when defences are overtopped there is a bigger capacity in the managed realignment site than if it was flooded through a breach. By this means, the HW level is reduced when the defence is overtopped;
- All Present Maintain MEASS simulations showed a significant increase in tidal currents speeds with increases of 25cm/s to 30cm/s in the Swale and 15cm/s to 20cm/s in the Medway. There is also a decrease in maximum tidal current speed of c. 5cm/s to 10cm/s around Elmley Reach. These values are similar to the Present Upgrade results.

8.4.2 Discussion of results

Before considering how the changes to the hydrodynamic regime of the estuaries will impact on sediment dynamics, morphology and other environmental and anthropogenic assets, consideration must first be given to model accuracy and reliability. As has been demonstrate through the model calibration process previously reported, there is generally a good agreement between the measured and simulated water levels and current speeds. Although perfect agreement has not been achieved due to a paucity of accurate data and uncertainty in parameter settings (e.g. bed roughness), we are mainly concerned in this report with the relative differences in the estuarine hydrodynamics between the baseline condition and the managed realignment site scenarios.

It is argued therefore that irrespective of small model errors, the increases or decreases in water levels and/or currents speeds due to the managed realignments reflect well the changes that would occur in the natural system should the schemes be implemented in their present form. Further evidence to support this assertion is provided by the results from the systematic study of estuarine responses to different managed realignment schemes. These demonstrate the same trends in hydrodynamic response and do not identify any anomalous results that cast doubt on the ability of the model to simulate the hydrodynamic relative effects of the managed realignments.

8.4.2.1 Increased flood risk

The MEASS model results show that for a 1:200-year event, the peak water levels are higher in the Swale and Medway when managed realignments sites are included. Clearly it is undesirable to implement any schemes that may elevate flood risk. It is also likely that this increase in flood risk may be elevated further when climate change impacts are included in the simulation. However, for this rare event the predicted increase in water level is only 2% of the 6.2m tidal range and should not raise too much concern since modest changes to existing flood defences will mitigate the risk. Less frequent extreme events are likely to have a larger impact and may pose a more serious flooding threat that may need to be considered at a later stage in the project.

There is no increase in flood risk in either the Medway or the Swale during spring tides: rather, peak water levels are predicted to decrease in both estuaries. Although further model runs to identify which AEP events raise the peak water level above the baseline case are interesting, they are beyond the current project scope and would require additional resources.

8.4.2.2 Sediment mobilisation, sediment transport and estuary morphology

Changes to the peak tidal current speeds will have a large impact on the sediments in the estuaries for the following reasons: (a) the bed shear stress responsible for mobilisation and transport of sediment is related to the square of the current speed; and (b) the amount of sediment moved is related to the bed shear stress to a power of at least 1.5 depending on the nature of the sediment and the mode of transport (bedload or suspended load). Thus small changes in current speed will have much larger impacts on sediment dynamics.

Using a simple example to illustrate how current speed impacts on the transport rate of a non-cohesive sediments (sand) we assume a water density ρ = 1023kg/m^3, a typical bed drag coefficient (C_d) of 0.0025, a current speed (U) of 0.5m/s and a velocity required to initiate motion of the sediment (U_t) of 0.25m/s. The excess bed shear stress (τ_e) responsible for sediment transport is given by:

$$\tau_e = \rho Cd(U-U_t)^2 = 0.16N/m^2 \qquad \text{(Eq. 1)}$$

In the simple Meyer-Peter & Müller bedload sediment transport equation, Q_b, is expressed as

$$Q_b = 0.253\tau_e^{1.5} = 0.016kg/m/s \qquad \text{(Eq. 2)}$$

(i.e. mass rate of transport per unit width per second). If the current speed is increased by a modest 20% to 0.6m/s, τ_e increases to 0.31N/m^2 and the bedload transport rate increases by a factor of c. 3 to 0.044. Further, if the suspended load is included, total load transport rates are typically related to the excess shear stress to a power >= 3. Since the increase in predicted current speeds for the realignment options exceed 20% at many locations, the implications for sediment transport are clear: it will increase significantly.

This simple example only considers sandy sediments. However, the Medway and Swale sediments are predominantly muddy with sand being only a small component. The MEASS mud transport (MT) model reflects this and can be used to provide a more accurate indication of how changes to the hydrodynamic regime in the estuaries will impact on the sediment erosion and transport dynamics. Changes to the sediment dynamics will in turn affect estuarine morphology in ways that may be difficult to quantify. These aspects of realignment impacts should be the focus of future work and must be considered during the process of realignment site selection.

The MEASS mud transport model is now calibrated an available to further investigate managed realignment impacts on cohesive sediments in the estuaries. It is believed this model will provide a much clearer picture of potential managed realignment scheme impacts by accounting for: (a) physical and dynamic (flocculation, incipient threshold and settling velocity) sediment properties; (b) vertical and spatial changes in bed properties; and (c) the mode of transport.

8.4.2.3 Channels, meandering and flow patterns in the Swale and Medway.

It is noted that during the simulated spring tide, several of the Swale realignment sites (Sites 39,30,34 and 40) did not flood. However, they will flood during larger spring (e.g. positive surge) and HAT tide conditions. The drainage of these flooded sites will natural develop a channel which will increase in depth over time and allow more frequent inundation. The ensuing positive feedback between channel erosion and water ingress and drainage could potentially affect, not only the habitat in front of the proposed sites (e.g. erosion of saltmarshes), but allow ever larger volume of water to enter the sites. At the estuary scale, this will contribute to the generation of larger gradients between the estuary mouths and the centre of the Swale, leading to a scenario in which normal spring tide water levels increase.

Increases to the tidal current flow speeds, and the corresponding increase in sediment mobilisation and transport has a potential to erode and deepen estuarine channels. This is a natural process and a mechanism by which the estuary adjusts to accommodate the changes in the hydrodynamic regime. The process of erosion, and the higher current speeds may also increase the tendency for the channel to meander. It is possible that channels may migrate towards the margins of the estuary and could result in the erosion of established saltmarsh. In worst-case scenarios channel migration may even threaten the existing flood defences. Although the prediction of such morphological responses is extremely challenging, numerical modelling has demonstrated realistic simulation of meander processes (e.g. Kleinhans et al., 2009; Xiao et al., 2016) and is an aspect of managed realignment impact assessment that may require further consideration.

At a very simple level, the predicted changes to flow patterns resulting from managed realignment in the Medway and Swale estuaries demonstrated by the MEASS model will expose estuarine sediments to a different flow regime. Since these sediments have adjusted to a pre-realignment tidal regime, increases or decreases in flow speed and/or duration will affect their behaviour and may result in either increased sedimentation or erosion in response to changes in the hydrodynamic regime. Consideration must be given therefore not only to the impacts on estuarine morphology (and the impacts any changes will subsequently have on the hydrodynamics) but also to the new transport pathways taken by eroded sediments.

Drainage systems can develop rapidly as a result of water exchange through the breach locations (Esteves and Williams 2015). Although relationships between tidal prism and channel morphology have been modelled, predictions of channel evolution depend on empirically defined coefficient and exponent, which vary with the scale of the system, tidal range, salinity, vegetation, and sediment characteristics (Williams et al. 2002). The required field data rarely exist (Vandenbruwaene et al. 2012), and the use of values defined for other areas may lead to large errors in the prediction of optimal breach width and channel cross-sectional area in managed realignment projects, as reported by Friess et al. (2014) for Freiston Shore.

When projects cause major changes in tidal prism, erosion due to the growth and evolution of the drainage system can be considerable and persistent, as observed for over 13 year in Warm Springs, San Francisco Bay (Williams et al. 2002). The following changes were observed after breaching at Freiston Shore (Friess et al. 2014): (a) the spring tidal prism increased 776,398 m3; (b) all breach channels rapidly increased in width within the first 2.5 months; (c) the cross-sectional area of the breach channels enlarged up to 5200% in four years (the central breach channel expanded from 2 m2 to 107.6 m2); (d) the three drainage creeks seawards of the realignment site showed a considerable headward erosion of up to 400 m a-1 (Symonds and Collins 2007), while the adjacent creeks showed very little change in the same period.

The magnitude of changes in the drainage network at Freiston was not foreseen by the modelling undertaken for the project design. The speed of the flood current at the breaches (up to 2.5 m s-1) and the volume of water entering the site during the equinoctial spring tide after the breaching resulted in a prolonged inundation (12 h) and an ebbing phase over 2.5 times longer than the flood (Symonds and Collins 2007). This extended water retention was attributed to the inadequate size of the breach channels to drain the increased tidal prism (Freiss et al. 2014) and the elevation of the realigned area being lower than the saltmarshes fronting the site (Symonds and Collins 2007).

8.4.2.4 Changes to saltmarsh and mudflat exposure in the tidal frame

The changes to tidal propagation in the estuaries will affect in some case the depth and duration that saltmarsh plant communities are immersed in salt/brackish water. For example, the MEASS model has shown that realignments in the Swale affect the elevation and phase of the tide. Saltmarsh plant communities may need to adapt to the change in tidal regime in ways that are difficult to predict. Any changes to floristic diversity, density etc. may also affect the way saltmarsh plants contribute to sedimentation.

Changes to the tidal regime resulting from managed realignment will also alter the length of time, and the extent to which, mudflats are exposed through the tidal cycle. It is likely that this will affect invertebrates in the sediment as well as affecting in turn bird populations reliant on these intertidal food sources. The MEASS model can provide valuable information to assist expert assessments of the potential impacts.

8.4.2.5 Estuarine sediment import and export

If assessment of sedimentation rates in realignment sites is to be undertaken to determine whether accretion will keep pace with sea level rise, it is important to understand and predict changes to the sediment budget. The predicted changes to the hydrodynamics in the Medway and Swale will alter the amount of sediment entering and leaving these estuaries as well as changing the duration of flow conditions favourable to sedimentation. It may be possible, through the improved conceptual understanding of the system provided by the MEASS model, and though the analysis of mud transport model result in the future, to assess the impacts on medium- to long-term sediment budgets in a qualitative sense.

A far-field impact requiring further consideration concerns the pathways taken by any additional material exported from the estuaries, especially in the period following construction of any breaches. Being fine in nature, these sediments have a potential to travel considerable distance. Being fine in nature, these sediments have a potential to travel considerable distances from their origin. Equally, local processes operating beyond the immediate estuarine environment may favour accretion. If this coincides with the location of shellfish production, for example, it may lead to undesirable consequences.

8.4.2.6 Waves-induced sediment resuspension

A deepening of the estuary in response to the increased tidal prism discussed above will allow greater penetration of waves into the estuaries and an increase in wave-induced sediment erosion and resuspension. Given that at present the estuaries are net exporters of sediment, an increase in erosion will not be balanced by importation. In a worst-case scenario, waves will deepen further the estuary and in turn, through positive feedback, increase wave action still further. However, this process is likely to be limited to some extent by the properties of the estuarine sediments which become much more resistant to erosion with depth.

8.4.2.7 Water quality

The Estuarine Turbidity Maximum (ETM) is a region of locally-elevated suspended matter concentration that occurs near the landward end of salt intrusion in estuaries. It relies on the existence of a region of erodible sediments (the Mud Reach resulting from along-channel sediment transport convergence) which are resuspended on the tidal time-scale. The hydrodynamic impacts of the realignment sites are likely to change the location and intensity of the ETM and may have the following consequences that merit further investigation:

- A reduction in light available for photosynthesis;
- An increase/decrease in mechanical and abrasive impairment to the gills of fish and crustaceans leading to population/behavioural changes;
- An increase/decrease the transports contaminants (particulate nutrients, metals and other potential toxicants);
- Promotion of pathogens and waterborne disease growth;
- Depletion of dissolved oxygen in the water column; and
- A reduction in the production and diversity of species due to increased turbidity levels.

It is suggested that some of these consequences are considered further by water quality/ecology specialist to determine which merit further investigation. The simulation of the key physical processes associated with the ETM would require further study.

8.4.2.8 Sand transport

While the Medway and Swale estuaries are dominated by muddy sediment, a quartz sand and carbonate fraction is present and its behaviour is significantly different to mud. Due to project constraints and the dominance of cohesive sediments, this sediment population has not been included in the MEASS model. It is understood that the main drainage channels of the estuary may contain a higher proportion of sandy material and changes to hydrodynamics may impact these. For example, sand beds exposed to tidal flows usually form bedforms that can grow in height and wavelength in response to changes in current speed. These changes in turn will affect the local flow which may act to dampen bedform growth or enhance it. Such changes to the bed will have a range of hydrodynamic and sediment process consequences that are beyond the present scope. They are nevertheless potentially important.

8.4.2.9 Navigation

The hydrodynamic effects alluded to above may have consequences for navigation safety associated with shifting channels and changes in sedimentation/erosion and wave penetration. These potential impacts may impact of the dredging and survey requirements for commercial shipping (e.g. Sheerness) and leisure craft.

8.4.2.10 Salinity

Changes to the tidal ingress characteristics will have some effect of the salinity on the upper estuarine waters.

8.4.2.11 Scour around structures

Since similar relationships exist between scour processes and current speed as those outline above for sediment transport, the predicted increase in current speed in the vicinity of structures may contribute to a local increase in scour around any structure projecting into the estuarine waters or in situ. Typically, there is a good margin of safety implicit in the design of structures, and in the scour protection employed for key assets. However, if realignments result in an increase in peak flow speeds and/or an increase in the time that structures are exposed to tidal currents, scour may increase. Although the MEASS model can contribute to understanding how scour potential may be altered within the estuary, more specialised numerical or physical modelling may be needed to better quantify the impacts (cf. Khanpour et al., 2016).

8.5 Conclusions

MEASS model accuracy and reliability has been demonstrated previously through the model calibration process and it is asserted that the predicted increases or decreases in water levels and currents speeds due to the realignments reflect well the changes that would occur should the schemes be implemented in the form they are currently represented in the MEASS model. This conclusion is supported by the systematic study of estuarine responses to different managed realignment schemes which demonstrate the same trends in hydrodynamic response and do not identify any anomalous results that cast doubt on the ability of the model to simulate the effects of the realignments.

MEASS model simulations of all 22 proposed management realignment sites for the **1:200-year event** demonstrates that realignment sites are predicted to:

- Increase in the maximum water levels and current speeds in the Swale by up to 13cm (c. 2% increase in the maximum tidal range) and around 25cm/s, respectively;
- Decrease the current speed in the middle section of the Swale around Elmley Reach by around 7cm/s;
- Decrease water levels by 10cm to 17cm (c. 2.6% decrease in the maximum tidal range) and increases the current speeds by around 20cm/s in the upper Medway, with maximum values of c. 25cm/s at some locations during the ebb tide.

MEASS model simulations of all the 22 proposed management realignment site for a **spring tide** demonstrates that realignment sites are predicted to:

- Decrease in maximum water levels and increase in maximum current speeds in the middle-Swale by approximately -12cm and around 10cm/s, respectively;
- Decrease maximum water levels and increases in maximum current speeds in the upper Medway by approximately -17cm and up to 15cm/s, respectively;
- Decrease the current speeds in the upper Medway above potential managed realignment site 8 by up to 5cm/s; and
- Decrease the current speeds in the Swale around Elmley Reach by up to 5cm/s.
- If some very minor interactions are ignored the MEASS simulations show that Swale-only realignment sites only impact the Swale estuary and Medway-only realignment sites only impact the Medway estuary.

Separate independent simulations of east Swale and west Swale realignment site impacts showed that:

- Any realignment sites in the Swale will create an increased water level gradient between the western and eastern mouths of the estuary that will increase water levels, especially in the central part of the Swale estuary;
- The eastern realignment sites alone have almost the same impact on water elevation and tidal current speeds as all the sites in the Swale; and

- The western realignment sites alone elevate water levels and increase flow speed, but by a lesser amount compared with the eastern sites.

All Present Maintain MEASS simulations (1:200 year and spring tide) showed:

- A water level increase of 4cm above the predicted maximum value of 17cm for the Present Upgrade case in the Swale owing to the limitations imposed on flood extent by the setback defences and flood regulation through the breach sites;
- An increase in tidal currents speeds up to 30cm/s in the Swale and up to 20cm/s in the Medway; and
- A decrease in maximum tidal current speed up to 10cm/s around Elmley Reach.

The MEASS model results show that managed realignments sites have a potential to elevate flood risk which may be further increased by sea level rise. However, sight should not be lost of the fact that the predicted increase in water level is only 2% of the 6.2m tidal range for a rare 1:200-year event and modest changes to existing flood defences will mitigate the risk. However, attention must also be given to less frequent extreme events which may pose a more serious flooding threat.

Kirby (2013) indicates that the Medway estuary is ebb-dominated and sediment-starved and has been eroding and loosing sediment for over 200 years. During this time, increased tidal prism due to accidental breaching of flood defences and mud extraction has enhanced tidal currents resulting in deepening of the main channel and intertidal erosion. The lowering of estuarine water levels from spring tide simulations indicate that managed realignment may reduce the tidal prism but would still enhance ebbing currents. Therefore, based on modelling results, it is likely that managed realignment would maintain or enhance the long-term erosion in the Medway.

It is concluded that there is no increase in flood risk in either the Medway or the Swale during spring tides: rather, peak water levels are predicted to decrease in both estuaries.

It has been demonstrated that even relatively small changes to tidal current speeds will have a disproportionally large impact on the mobilisation and transport of cohesive and non-cohesive sediments. These changes are likely to impact on:

- Channels, meandering and flow patterns;
- Changes to saltmarsh and mudflat exposure in the tidal frame;
- Estuarine sediment import and export;
- Waves-induced sediment resuspension;
- Habitat loss due to erosion;
- Water quality;
- Sand transport;
- Navigation;
- Salinity;
- Scour around structures; and
- Any consequence from the above on biota movement, colonisation and phenology impacts.
- Spanning a wide range of temporal and spatial scales, these potential changes to the estuaries brought about by managed realignment may have far-reaching and as yet, unforeseen consequences that merit further detailed study as the site selection process evolves.

- Given the high-level strategic nature of the MEASS study, the MEASS model has demonstrated relative and systematic differences in hydrodynamics that can be explained and can be attributed to the managed realignment options examined. The MEASS model results presented here will provide information to assist further decisions concerning the feasibility of the proposed managed realignment sites and thus at this stage in the Strategy study the model meets the objectives defined at project inception.

8.6 Recommendations

The MEASS modelling results presented in this report only consider hydrodynamics. From these results we have inferred some potential impacts on estuarine processes, ecology and activities. Before embarking on further work, these results need to be considered carefully when taking site selections forward.

The most important result from the hydrodynamic modelling concerns the increases in maximum water levels and tidal current speeds attributable to managed realignment. While these impacts raise concerns, it has been demonstrated at other managed realignment sites that breach designs can be engineered to regulate tidal ingress into sites and mitigate these effects. While being outside the present scope of the project, we consider that an investigation of flow control structures would be very informative.

Attention has been drawn in this report to the highly non-linear and complex relationships between hydrodynamic forcing and sediment mobilisation, transport, and accretion. It is recommended therefore that the mud transport modelling is now undertaken using the hydrodynamics of normal spring tide conditions for all 22 proposed managed realignment sites before making any site selections. Groups of sites identified through a consultation process should also be simulated after these initial results are disseminated.

It is noted that the MT models was not calibrated for extreme conditions, when strong winds and wave stirring offshore combine with higher water levels and enhance current speeds to affect suspended sediment concentration. We recommend therefore that the MT model is best suited to examine the impacts of the realignment sites during normal spring tidal conditions, and we consider that results from the MT model in its present form cannot be relied upon to simulate accurately extreme events.

The MEASS model calibration is based on available data and while achieving an acceptable accuracy for a Strategic study there is a requirement to improve model performance at the design stage. In particular, up-to-date bathymetry, and data related to bed sediment compositions and properties and suspended sediment concentrations and properties would be valuable.

9 Leading Option hydrodynamic modelling results

9.1 Introduction

As part of the Medway and Swale Strategy, long-term, technically sound, environmentally acceptable, and economically viable options have been developed. From the “hold the line” (HTL) option tested in Chapter 7, the managed realignment (MR) options developed in Chapter 8, and an economic benefit analysis, a Leading Option was developed and has been modelled for a 1:200-year event, for present day and future (2116) scenarios.

Following modelling of the Leading Option (presented in this chapter of the report), the options were refined to a final preferred option for the Strategy. The final preferred option was not modelled at this stage, but it is presented in the main Strategy document (Mott MacDonald, 2017).

For more information regarding the economic benefit analysis please also refer to Mott MacDonald main Strategy Report (Mott MacDonald, 2017).

9.2 Leading Option

The Leading Option is a combination of the previously tested options, presented in Chapter 7 and Chapter 8, namely:

- Maintain – maintain the current defence crest level;
- Sustain – increase the defence crest level in phases to accommodate sea level rise;
- Upgrade – increase the defence crest level to ensure they will continue to provide protection in 100 years’ time (i.e. account for predicted changes in sea level due to climate change); and
- Managed realignment sites.

For each of the benefit areas (Figure 64), one or more of the above options was selected based on the modelling results and an economic benefit analysis assessment, both for the present day and for the future (2116).

Table 31 shows the resulting Leading Option for the present and the future scenarios. Table 32 shows the crest levels required for each of the benefit areas according to the option selected. When managed realignment sites are included, the setback defence crest levels are also specified in Table 32.

Table 31: Leading Option for each of the benefit areas for the present day and future (2116).

Benefit area	Leading Option – present day	Leading Option – Future day (2115)
1.2	Hold the Line (HTL) Sustain	HTL Sustain
1.3	HTL Maintain	No Active Intervention (NAI)
1.4	NAI	NAI
2.1	HTL Sustain	HTL Sustain
2.2	Localised HTL Sustain	Localised HTL Sustain
2.3	HTL Sustain	HTL Sustain
3.1	NAI	NAI
3.2	Localised HTL Sustain	Localised HTL Sustain and MR Site 4
3.3	HTL Maintain	HTL Sustain
3.4	Localised HTL Sustain	Localised HTL Sustain and MR site 11
3.5	MR Maintain site 12	MR Maintain site 12
4.1	HTL Sustain and MR site 13	HTL Sustain and MR site 13
4.2a	NAI	NAI
4.2b	HTL Maintain	NAI
4.3	NAI	NAI
4.4	Localised HTL Sustain	Localised HTL Sustain
4.5	NAI	NAI
4.6	NAI	NAI
4.7	HTL Maintain	NAI
5.1	HTL Maintain	HTL Sustain
5.2	HTL Sustain and MR site 22	HTL Sustain and MR site 22
6.1	HTL Sustain	HTL Sustain and MR site 24
6.2	MR Maintain site 27	MR Maintain site 27
7.1	HTL Maintain	NAI
7.2a	HTL Sustain	HTL Sustain
7.2b	HTL Maintain	HTL Sustain
8.2	HTL Maintain	HTL Maintain
8.3	HTL Maintain	HTL Maintain
8.4	NAI	NAI
8.5	NAI	NAI
9.1	HTL Maintain	HTL Maintain
9.2	HTL Maintain	HTL Maintain
10.1	NAI	NAI
11.1	HTL Maintain	HTL Maintain
11.2	HTL Sustain	HTL Sustain

Source: Mott MacDonald, 2017
*NAI – No Active Intervention
*HTL – Hold the Line

Table 32: Leading Option for each of the benefit areas for the present day and future (2116) – Defences crest levels

Benefit area	Leading Option – Present day - Defence Crest Level (mODN)	Leading Option – Future day - (Defence Crest Level (mODN)	Present day – Setback defences	Future day – Setback defences
1.2	5.30	6.60		
1.3	Existing - Present defended	Defences removed		
1.4	Defences removed	Defences removed		
2.1	5.1	6.20		
2.2	5.40	6.80		
2.3	5.10	6.30		
3.1	Defences removed	Defences removed		
3.2	5.10	6.10		6.10
3.3	Existing - Present defended	7.40		
3.4	5.90	7.50		6.66
3.5	Existing - Present defended	Existing - Present defended	6.0	6.0
4.1	4.90	5.90	5.90	5.90
4.2a	Defences removed	Defences removed		
4.2b	Existing - Present defended	Defences removed		
4.3	Defences removed	Defences removed		
4.4	5.20	6.00		
4.5	Defences removed	Defences removed		
4.6	Defences removed	Defences removed		
4.7	Existing - Present defended	Defences removed		
5.1	Existing - Present defended	6.50		
5.2	4.90	6.00	6.0	6.0
6.1	4.80	5.90		5.90
6.2	Existing - Present defended	Existing - Present defended	5.55	5.55
7.1	Existing - Present defended	Defences removed		
7.2a	4.80	6.00		
7.2b	Existing - Present defended	6.40		
8.2	Existing - Present defended	Existing - Present defended		
8.3	Existing - Present defended	Existing - Present defended		
8.4	Defences removed	Defences removed		
8.5	Defences removed	Defences removed		
9.1	Existing - Present defended	Existing - Present defended		
9.2	Existing - Present defended	Existing - Present defended		
10.1	Defences removed	Defences removed		
11.1	Existing - Present defended	Existing - Present defended		
11.2	5.40	6.90		

Source: Mott MacDonald, 2017

9.3 Model setup

The MEASS model was set up for each of the options by modifying the crest levels of the existing defences and dikes in the model domain. Model dikes were removed in the location of No Active Intervention (NAI). It is noted that the Maintain option involves maintaining the current crest level of the defence line, and therefore no changes were required to the model dikes at these locations.

Two scenarios per option were modelled:

- 1:200-year event - Present day - present day mean sea level elevation (i.e. no climate change); and
- 1:200-year event - Future - including sea level rise over 100 years (2116).

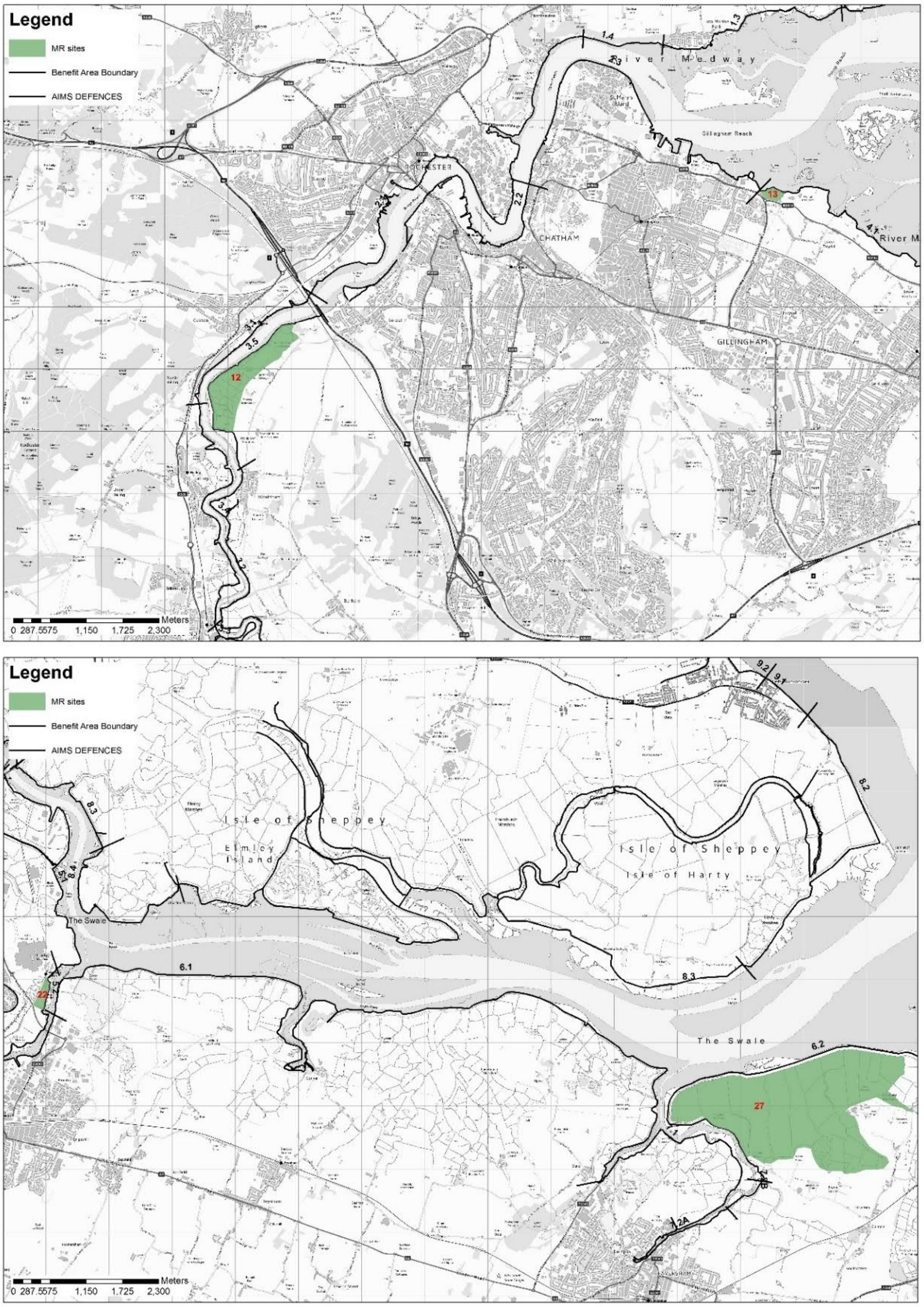
For the managed realignment options, breaches and setback defences were set up as described in Chapter 8. Table 33 shows a summary of the managed realignment and their corresponding breaches, which have been included in the Leading Option for the present, future or both scenarios.

Table 33: Derived breach widths for all 22 proposed Managed Realignment sites

MR	Breach width (m)	Scenario	Benefit Area
MR4	152	Future	3.2
MR11	82	Future	3.4
MR12	98	Present and Future	3.5
MR13	70	Present and Future	4.1
MR22	64	Present and Future	5.1
MR24_Breach1	105	Future	6.1
MR24_Breach2	96	Future	6.1
MR27_Breach1	152	Present and Future	6.2
MR27_Breach2	202	Present and Future	6.2

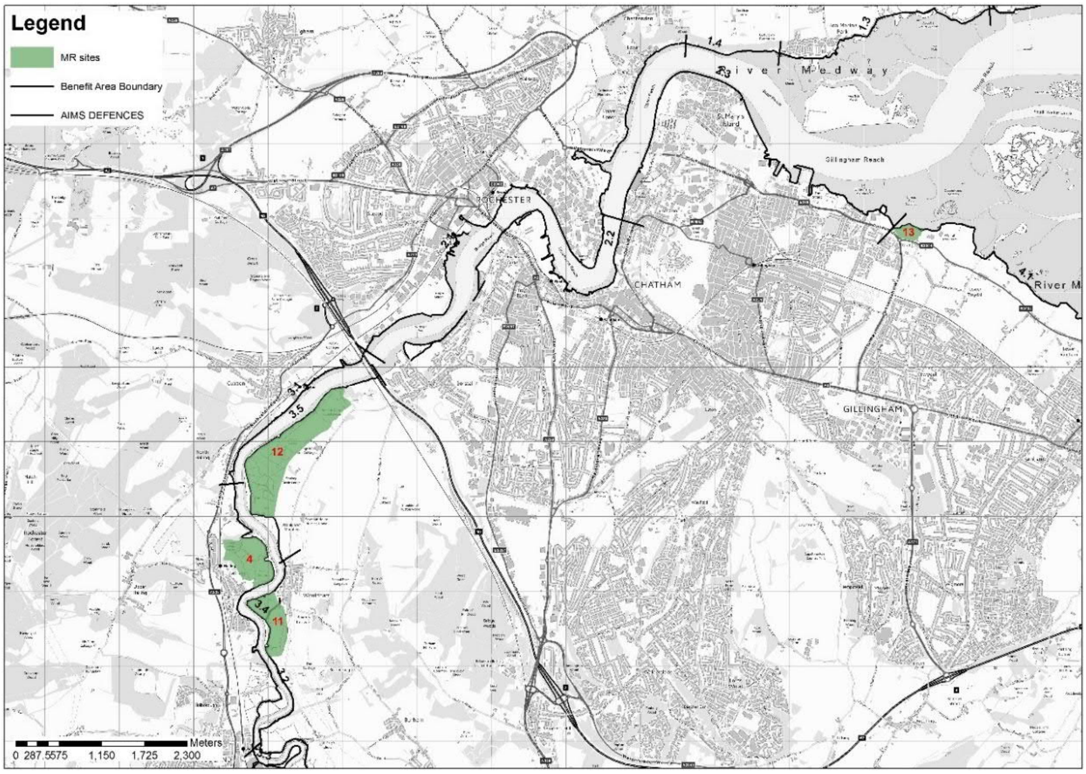
Figure 127 and Figure 128 show the managed realignment sites included in the present day and future model runs respectively.

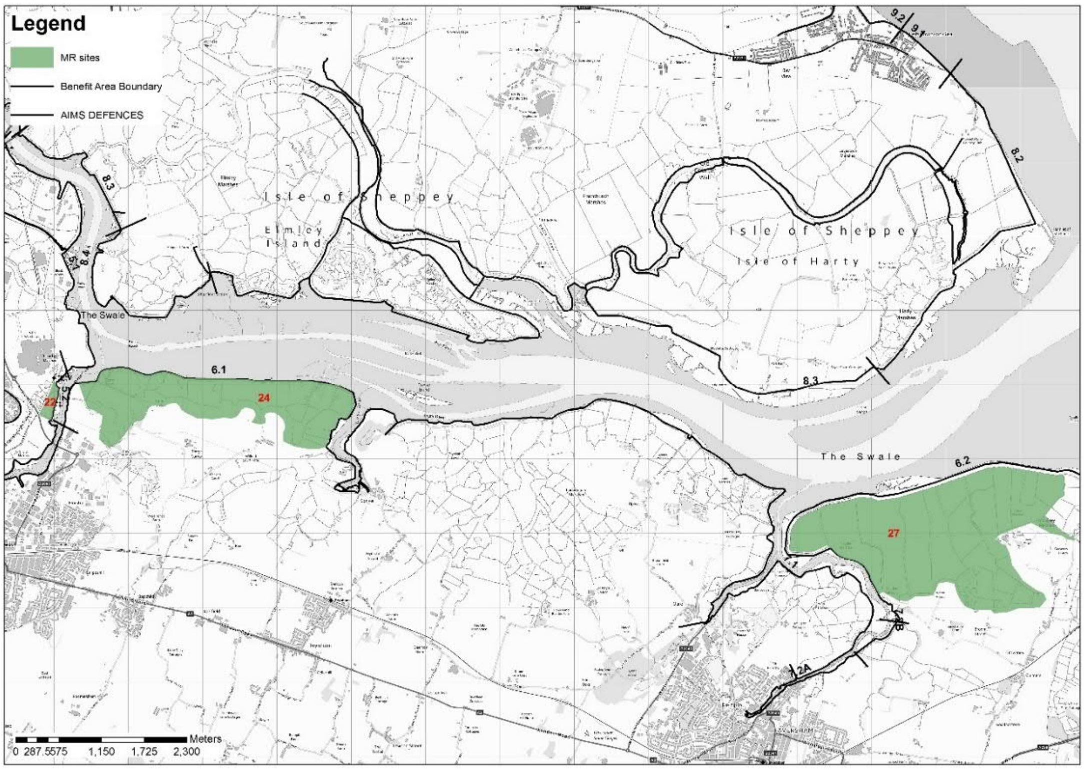
Figure 127: Proposed managed realignment site for the Leading Option – Present day



Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016

Figure 128: Proposed managed realignment site for the Leading Option – Future (2016)



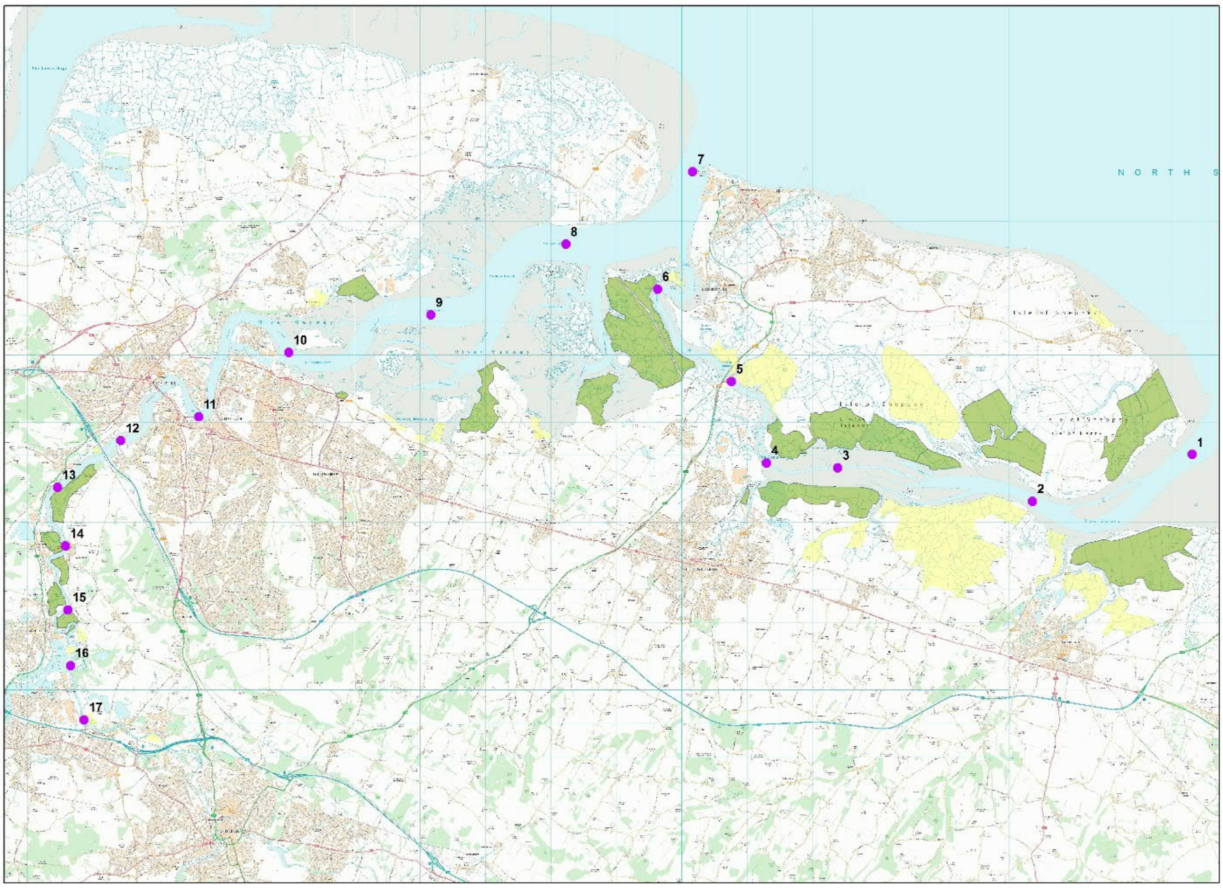


Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016

9.4 Hydrodynamic impact analysis on extreme events

To examine hydrodynamic impacts of the Draft Leading Options in the Swale and Medway estuaries, water levels and current speed time-series were extracted from the MEASS model at the locations shown in Figure 129 for: (a) the baseline conditions (present and future defended, 1:200-year event); and (b) for runs that included the proposed Leading Options. Maps of maximum water depth and tidal currents speeds were also produced to allow inter-comparisons between baseline and Leading Options scenario results.

Figure 129: The 17 water levels and tidal current data extraction points used to determine the impacts of the proposed managed realignment sites (shown in green).



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

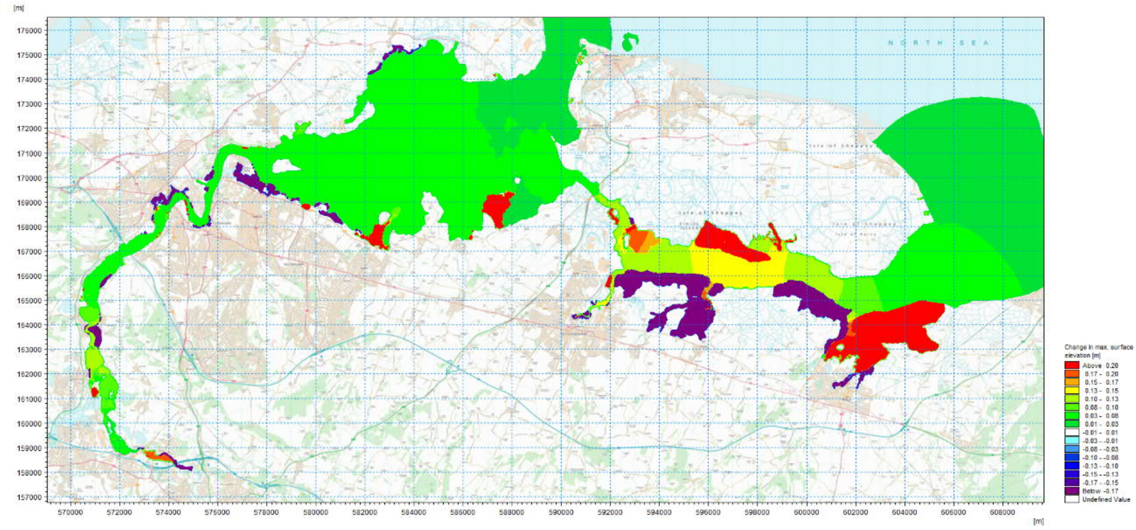
9.4.1 Present day – 1:200-year event

The model results for the present day 1:200-year event scenario, including the Leading Options, indicate a general rise in the water levels and tidal currents speeds within the Medway and Swale estuaries. Figure 130 shows the predicted changes in the maximum water levels across the Medway and Swale estuaries (positive values represent an increase in water levels compared with the Baseline simulation and negative values denote a decrease in water levels compared with the Baseline simulation).

Both in the Swale and in the Medway, water levels increase as a result of the introduction of the proposed Leading Option, with maximum water levels raised by approximately 13 cm (c. 2%

increase in the maximum tidal range within a tidal cycle) above the baseline towards the centre of the Swale.

Figure 130: Predicted changes in the maximum water level when the Leading Option is implemented in the MEASS model, (positive change reflects an increase in water level) – Present day – 1:200-year event.



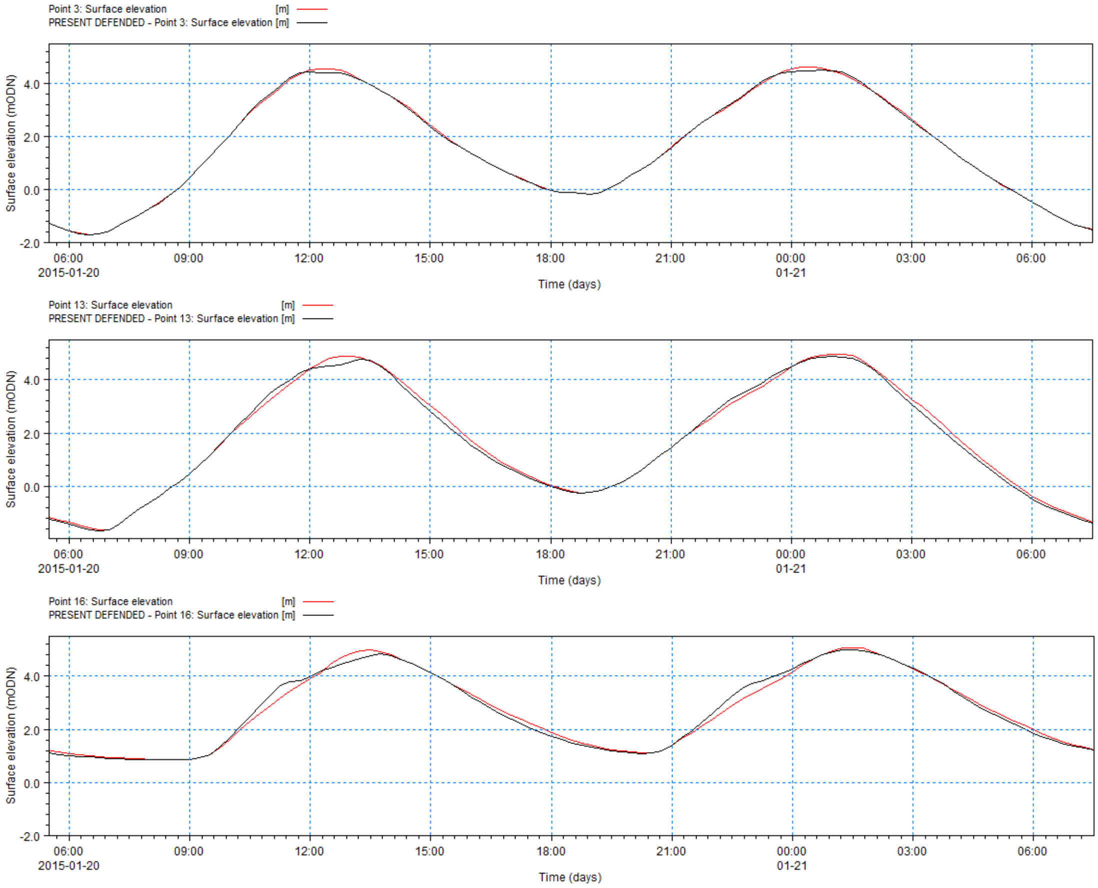
Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016

The small increase in water levels in the estuaries is also evident in Figure 131 which shows comparisons between the water levels in the Swale and in the Medway before and after the inclusion of the Leading Options in the MEASS model. Figure 131 shows an increase in the water level at Point 3, located in the centre of the Swale, and at Point 13 and Point 16, located in the upper Medway Estuary. In addition to a small change in the extreme water level elevation, the proposed Leading Option induced a minor change in tidal phase (Figure 132 and Figure 133, discussed below).

The small increase in extreme water levels in the Medway could be related to the reduction of the overtopping due to the increase on the defence crest levels since the Leading Option defences are now limiting overtopping and flooding in some areas and therefore increasing the volume of water in the upper estuary.

In Figure 131, the moment of overtopping of the defences can be observed in the water level curve of Point 13 and Point 16. However, in the Leading Options scenario overtopping of the defences does not occur, as the defences are raised resulting in the observed increase water levels.

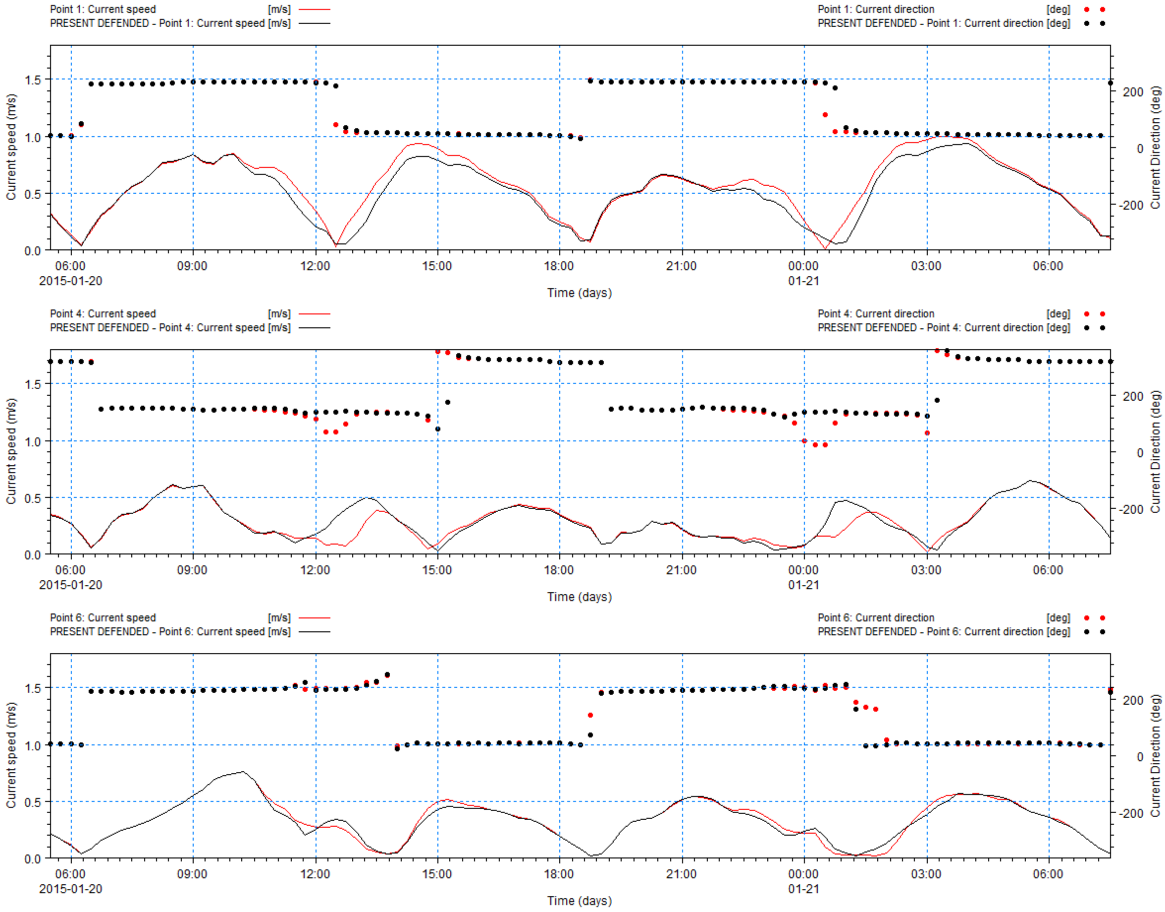
Figure 131: Comparison between water levels in the Swale (Point 3) and in the Medway (Points 13 and Point 16) for the baseline (black line) and Leading Option scenarios (red line) – Present day – 1:200-year event. Please note that the red line indicates the Leading Option results.



Source: Mott MacDonald, 2016

The MEASS model also shows that the selected Leading Options tend to slightly increase the currents speeds across both estuaries. The changes in current speed in the Swale are shown in Figure 132. It is noted that the selected Leading Options for the Swale increase the current speed in the east entrance of the Swale (Point 1), mainly during ebb tide. A minor increase in the current speed can be also observed in the west side of the Swale at Point 6. The duration and timing of the ebb/flood tide is also slightly altered.

Figure 132: Comparison between predicted current speed and direction in the Swale for the baseline (black line) and Leading Option scenario (red line) at Points 1, 4 and 6 (Figure 129) – Present day – 1:200-year event.

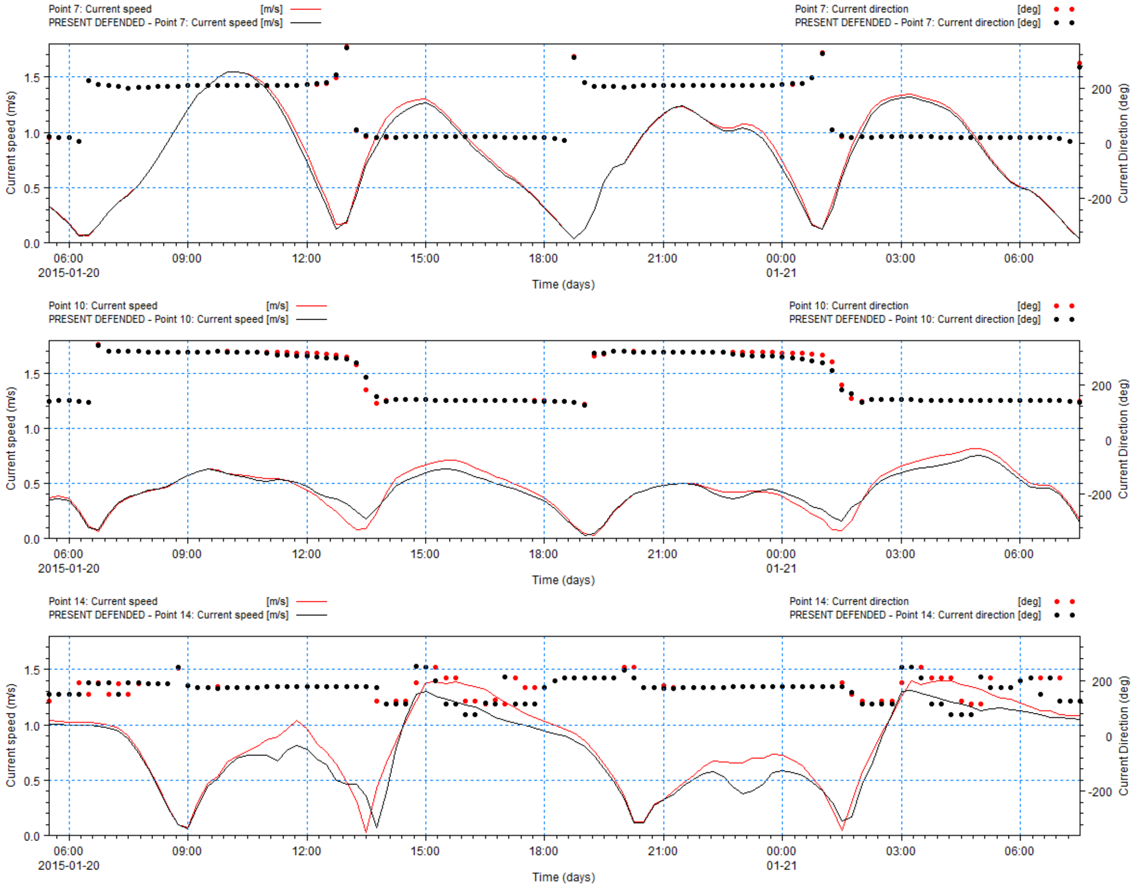


Source: Mott MacDonald, 2016

Figure 133 shows the changes in currents speeds in the Medway and demonstrates that current speeds in the Upper Medway are slightly larger than the baseline case. The mouth of the Medway Estuary (Point 7) is almost unaffected by the Leading Options, with only a small increase during ebb tide owing to the larger volume of water leaving the Estuary compared with the baseline.

The current velocities in the upper Medway are more affected by the Leading Option. It is considered that this reflects the changes in the flood extents due to the removal of the defences in large areas of the upper Medway. The removal of the defences (No Active Intervention - NAI option) increases flood extent and gives rise to the larger currents speeds, especially during the ebb tide.

Figure 133: Comparison between predicted current speed and direction in the Medway for the baseline (black line) and Leading Option scenarios (red line) at Points 7, 10 and 14 (Figure 129) – Present day – 1:200-year event.



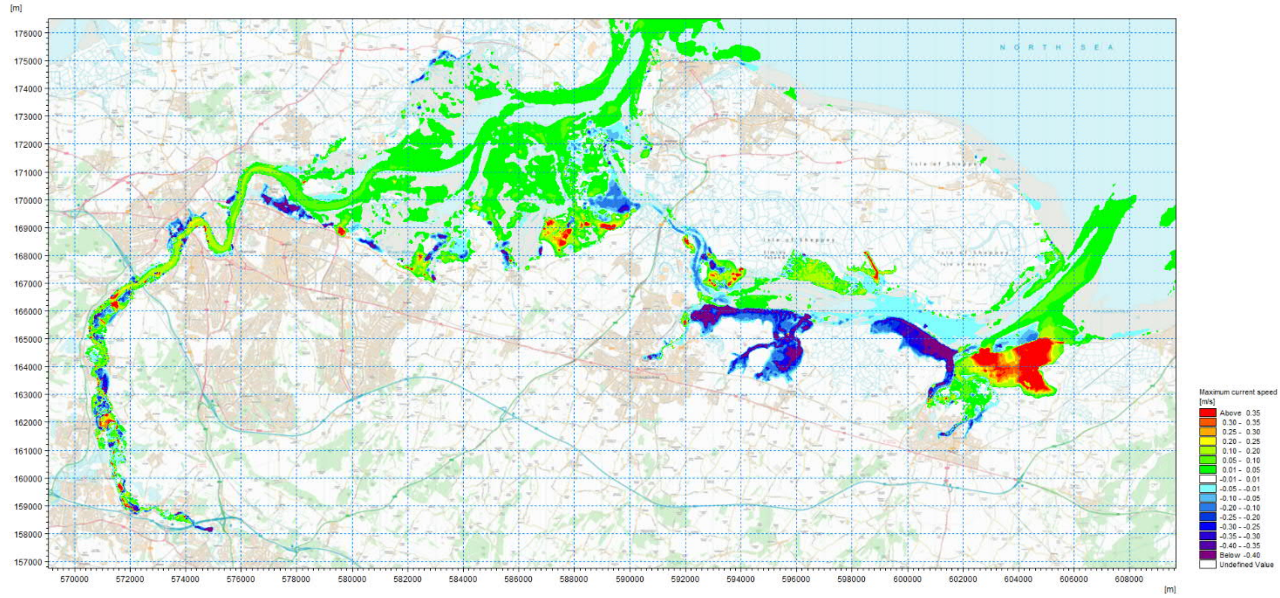
Source: Mott MacDonald, 2016

The spatial distribution of the predicted changes to current speed due to the Leading Options is shown in Figure 134. This figure shows only the change in the maximum current speed and does not convey any temporal information. The figure indicates very small changes in the current speeds in the Swale western mouth (*c*. 5 cm/s to 10 cm/s). A general decrease in the current speeds (*c*. 5 cm/s to 10 cm/s) in the central area of the Swale, around Elmley Reach, can also be observed.

In the upper Medway, a general increase in the currents speeds between *c*. 10 cm/s to 20 cm/s is observed in Figure 134. In the rest of the Medway estuary, including Medway mouth, the maximum currents speeds increase slightly, only between 1 cm/s to 5 cm/s.

Please note that in Figure 134, the large areas of current speed decrease (dark blue) over land simply show areas which are no longer flooded during the Leading Option scenario. Similarly, the areas of large current increase (red) are show flooding where previously none was not observed. In most cases this “new” flooding is related to the proposed managed realignment sites and to areas in which the defences have now been removed. For additional information regarding the changes in flood extent, please refer to Section 9.5.

Figure 134: Predicted changes to the maximum current speed when the Leading Option is implemented in the MEASS model, (positive change reflects an increase in current speed) - Present day – 1:200-year event.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

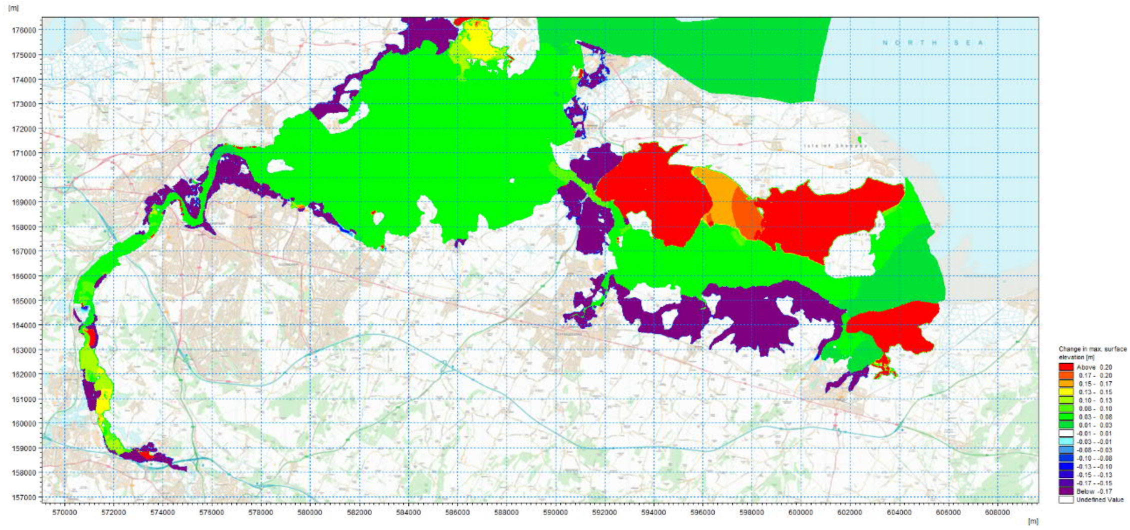
9.4.2 Future (2116) – 1:200-year event

The model results from for the future (2116) 1:200- year event scenario, including the Leading Options indicate smaller changes in the water levels of the estuaries, compared to the present-day results, presented in the previous section. A general rise in the water levels and tidal currents speeds in the MEASS model domain can still be observed. However, in the case of the water levels, this is significantly smaller. Figure 135 shows the predicted changes in the maximum water levels across the Medway and Swale estuaries.

Both in the Swale and in the Medway, water levels increase as a result of the introduction of the proposed Leading Options with maximum water levels raised by c. 5 cm above the baseline both in the Swale and in the main Medway estuary.

The increase in the maximum water level observed in the future scenario is considerably smaller than that observed in the present-day model results, especially in the central area of the Swale. However, in the Upper Medway, the increase in the maximum water levels is more evident in the future scenarios, with +14 cm around the Snodland area.

Figure 135: Predicted changes in the maximum water level when the Leading Option is implemented in the MEASS model, (positive change reflects an increase in water level) – Future day – 1:200-year event.

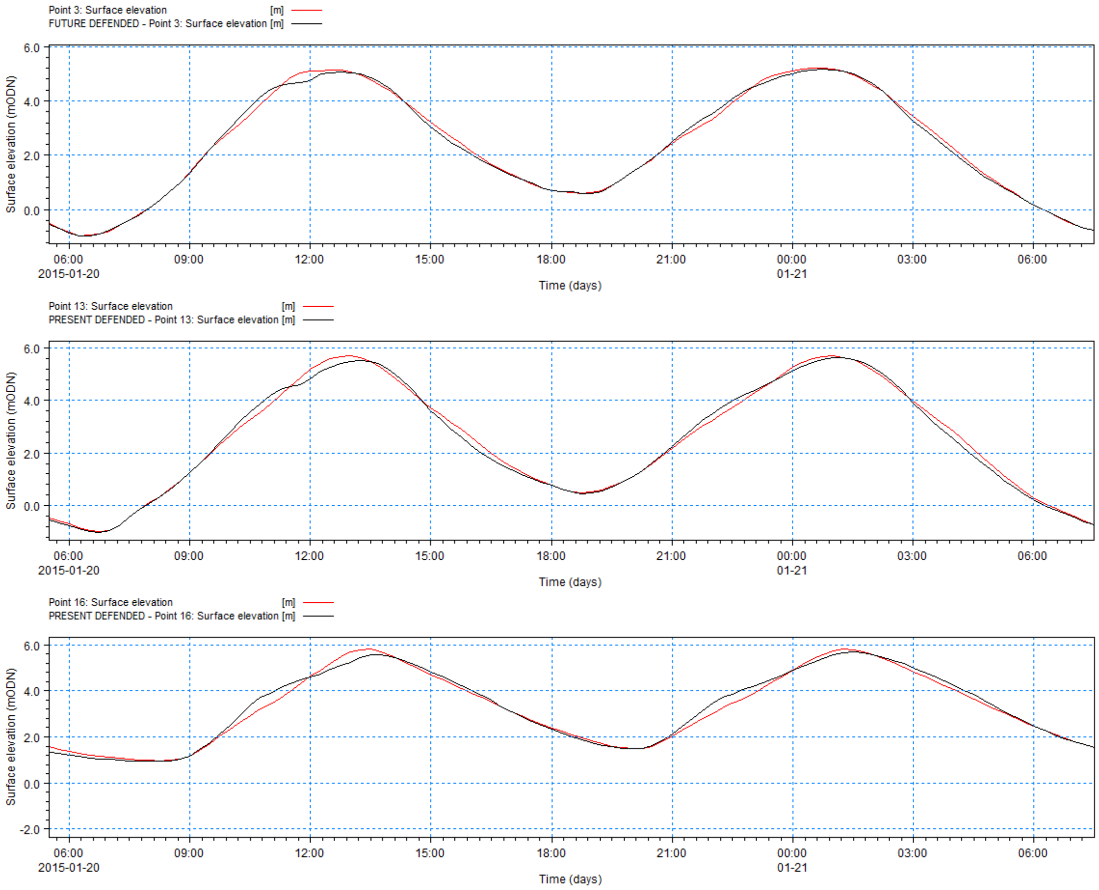


Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016

The small increase in water levels in the estuaries is also shown in Figure 136 which shows comparisons between the water levels in the Swale and in the Medway before and after the inclusion of the Leading Options in the MEASS model for the future scenario. Figure 136 shows an increase of approx. +5 cm in the water level at Point 3, located in the centre of the Swale, +8 cm at Point 13 and +14 cm Point 16, both located in the upper Medway Estuary.

The time-series results indicate that the increase in water levels, both in the Swale and in the Medway may be related to the reduction of the overtopping of the previous defences (now raised) and the inclusion of the now proposed managed realignment site which flood in a "controlled" way. As previously observed (Chapter 8), Figure 136 shows the moment of the defence overtopping in the baseline (black line). However, the overtopping of the defences is less evident when the Leading Options are included in the model (red line), due to the increase of the defence crest high in some of the benefit areas.

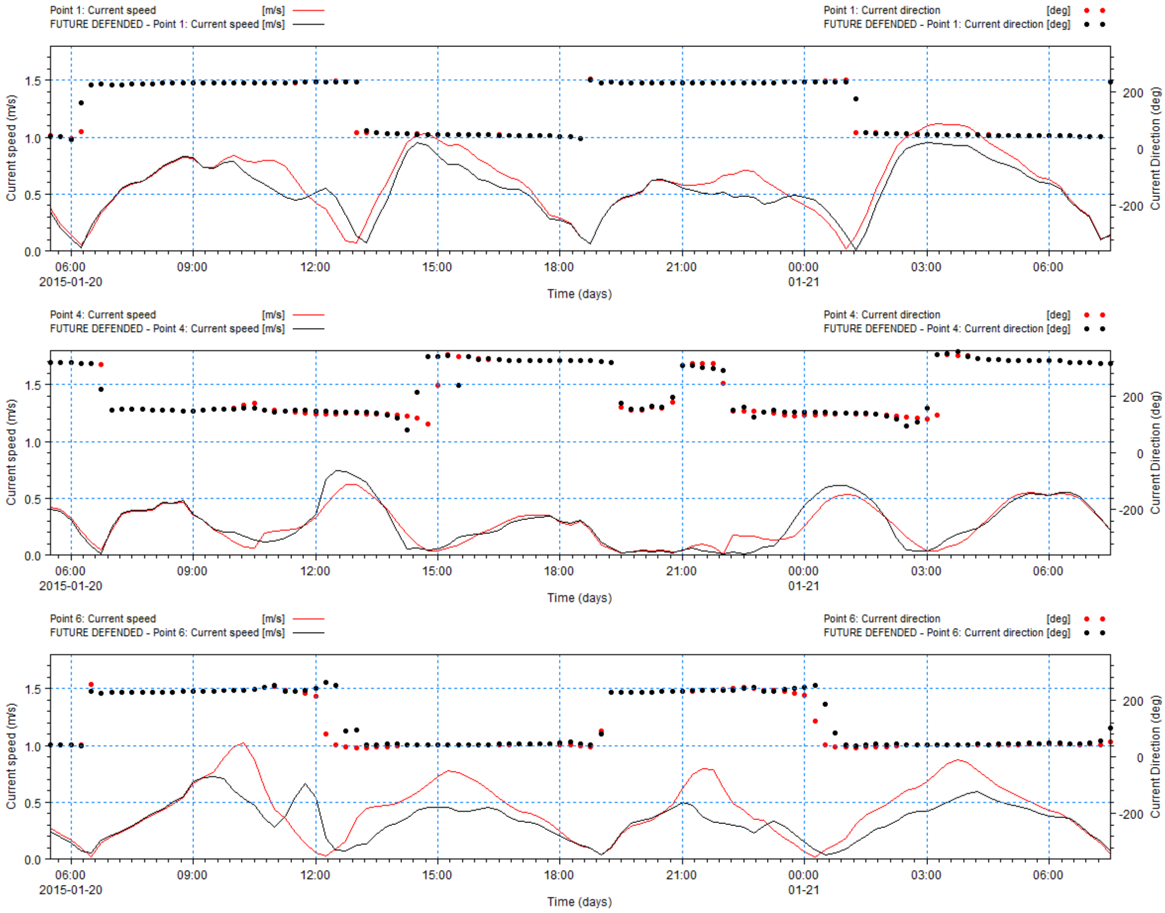
Figure 136: Comparison between water levels in the Swale (Point 3) and in the Medway (Points 13 and Point 16) for the baseline (black line) and Leading Option scenarios (red line) – (2116) – 1:200-year event.



Source: Mott MacDonald, 2016

The MEASS model also shows that the selected Leading Options tend to slightly increase the currents speeds across both estuaries. The changes in current speed in the Swale are shown in Figure 137. It is noted that the selected Leading Options for the Swale increase the current speeds in both the entrances of the Swale (Point 1 and Point 6), mainly during ebb tide. This is probably related to the larger volume of water leaving the estuary (tidal prism) created by the realignment sites and the removal of the defences. On the other hand, current speeds are reduced in the central area of the Swale (Point 4), during both the ebb and flood tides. The selected options also slightly alter the duration and timing of the ebb/flood tide.

Figure 137: Comparison between predicted current speed and direction in the Swale for the baseline (black line) and Leading Option scenario (red line) at Points 1, 4 and 6 (Figure 129) – Future day – 1:200-year event.

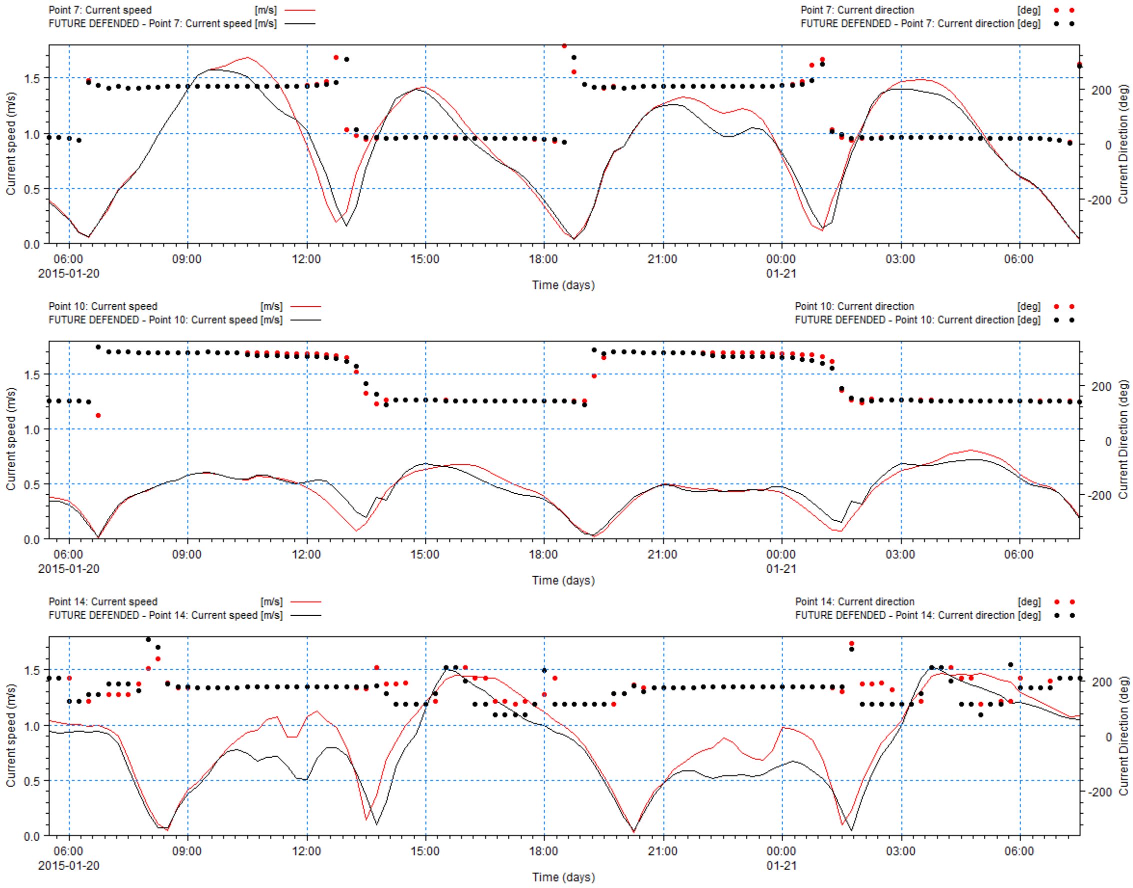


Source: Mott MacDonald, 2016

Figure 138 shows that in the Medway estuary the changes in currents speeds are more significant than the changes observed for the present-day results (previous Section). The current speeds at the mouth of the Medway Estuary (Point 7) are affected by the Leading Options, showing an increase during both flood and ebb tide owing to the larger volume of water leaving the Estuary compared with the baseline and the present-day scenario.

In the Upper Medway, results show an increase in the current speeds due to the Leading Option in this part of the estuary. The changes are related to the removal of defences and the inclusion of managed realignment sites. The removal of the defences (NAI option) increase the flood extent and the water volume (tidal prism), in addition to the managed realignments, and therefore result in larger current speeds, especially during the ebb tide.

Figure 138: Comparison between predicted current speed and direction in the Medway for the baseline (black line) and Leading Option (red line) scenarios at Points 7, 10 and 14 Figure 129) – Future day – 1:200-year event.



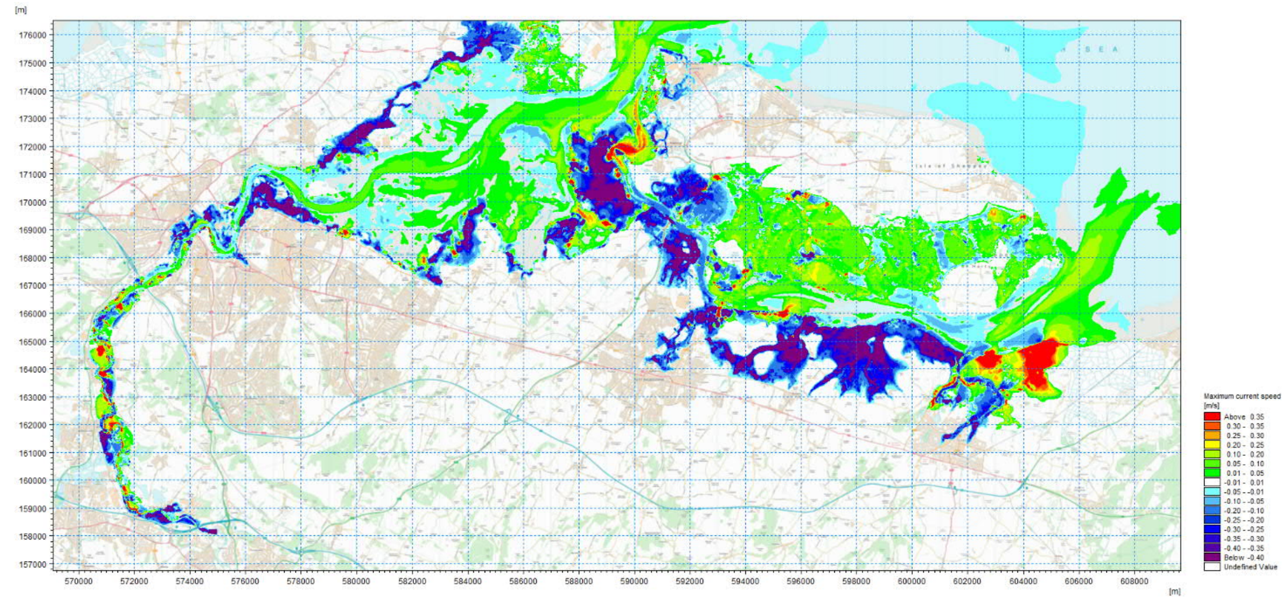
Source: Mott MacDonald, 2016

The spatial distribution of the predicted changes to current speed due to the Leading Options is shown in Figure 139 for the future scenario. This figure shows only the change in the maximum current speed and does not convey any temporal information. The figure indicates changes in the current speeds in the Swale east mouth of *c*. 10 cm/s to 20 cm/s and, for Swale west mouth of *c*. 30 cm/s to 35 cm/s. The larger increase in the west of the Swale could be related to the removal of the defences in benefit area 4.7. The flooding of this area changes the current speeds in the Queensburgh area. In common with the present scenario results a general decrease in the current speeds (*c*. 10 cm/s to 20 cm/s) in the central area of the Swale, around Elmley Reach can also be observed.

In the upper Medway, a localised increase in the currents speeds between *c*. 10 cm/s to 20 cm/s could be observed in Figure 139. In the rest of the Medway estuary, including the mouth of the Medway, the maximum currents speeds increase slightly, only between 1 cm/s to 5 cm/s.

Please note that large areas of current speed decrease (dark blue) over land are indicating areas which are no longer flooded during the Leading Option scenario. Similarly, the areas of large current increase (red) are indicating flooding were previously this was not observed. This “new” flooding is related, in its majority, to the proposed managed realignment sites and to areas in which the defences have now been removed. For additional information regarding the changes in flood extent, please refer to Section 9.5.

Figure 139: Predicted changes to the maximum current speed when the Leading Option is implemented in the MEASS model, (positive change reflects an increase in current speed) - Present day – 1:200-year event.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

9.5 Flood extent impacts on extreme events

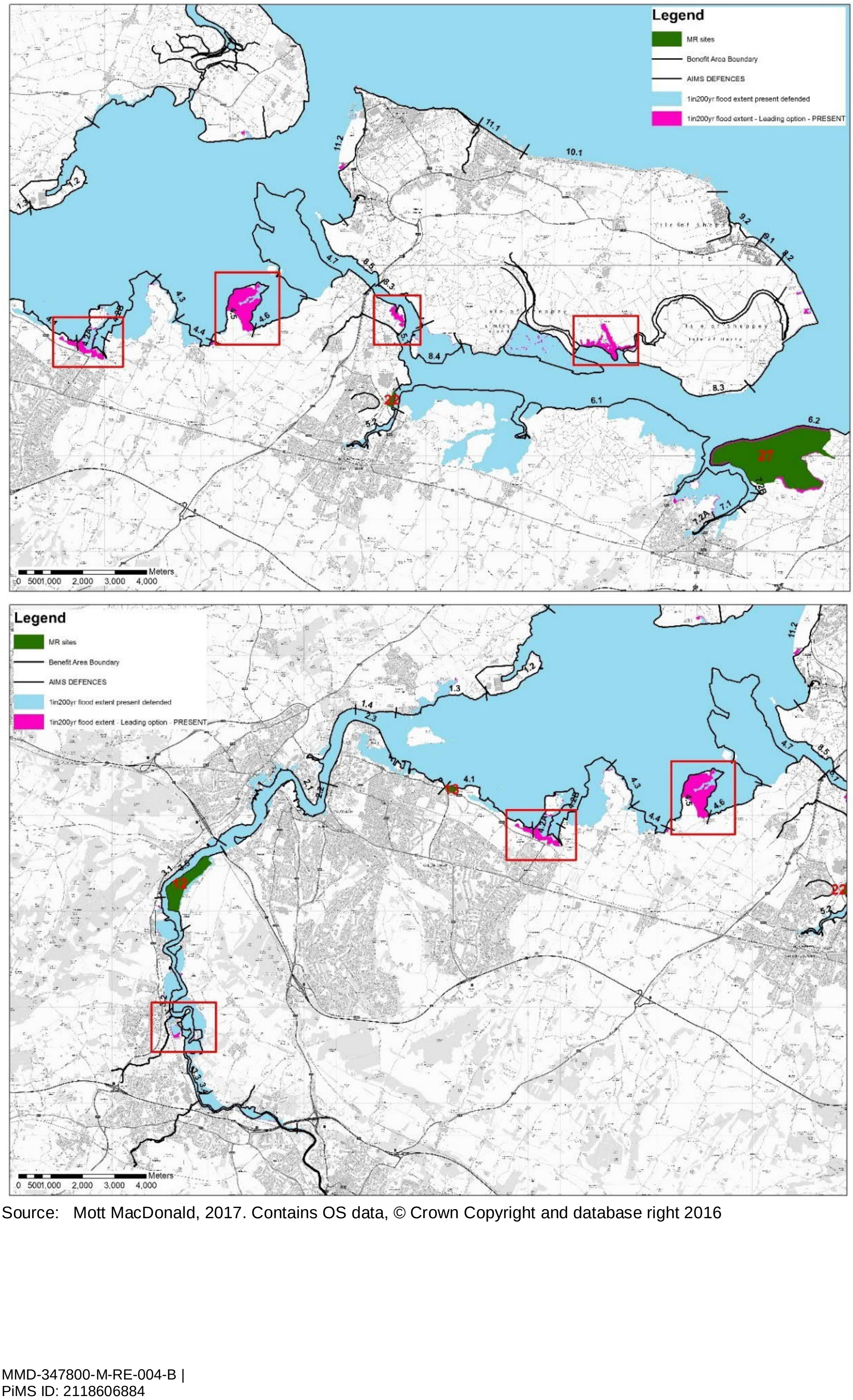
The maximum flood extent for the Leading Options present and future scenarios, was compared to the present and future defended scenarios for the 1:200-year events (baselines) in order to determine if the proposed Leading Options are causing an increase in the flood risk in the study areas.

The results show that the Leading Options flood extent is greater than the present defended flood extent in some localised areas (Figure 140) for the present 1:200-year event. In two areas of the Swale, the defences are overtopped slightly due to the 10-15 cm increase in maximum water levels in the central area of the Swale.

The greater flood extent observed in the main Medway estuary, in benefit area 4.5 and 4.2a is related to the removal of defences, as per the proposed Leading Options, and not to an increase of the maximum water levels. The small increase observed in the Upper Medway, in benefit area 3.3, is related to a small increase in the maximum water level, as described in Section 9.4.

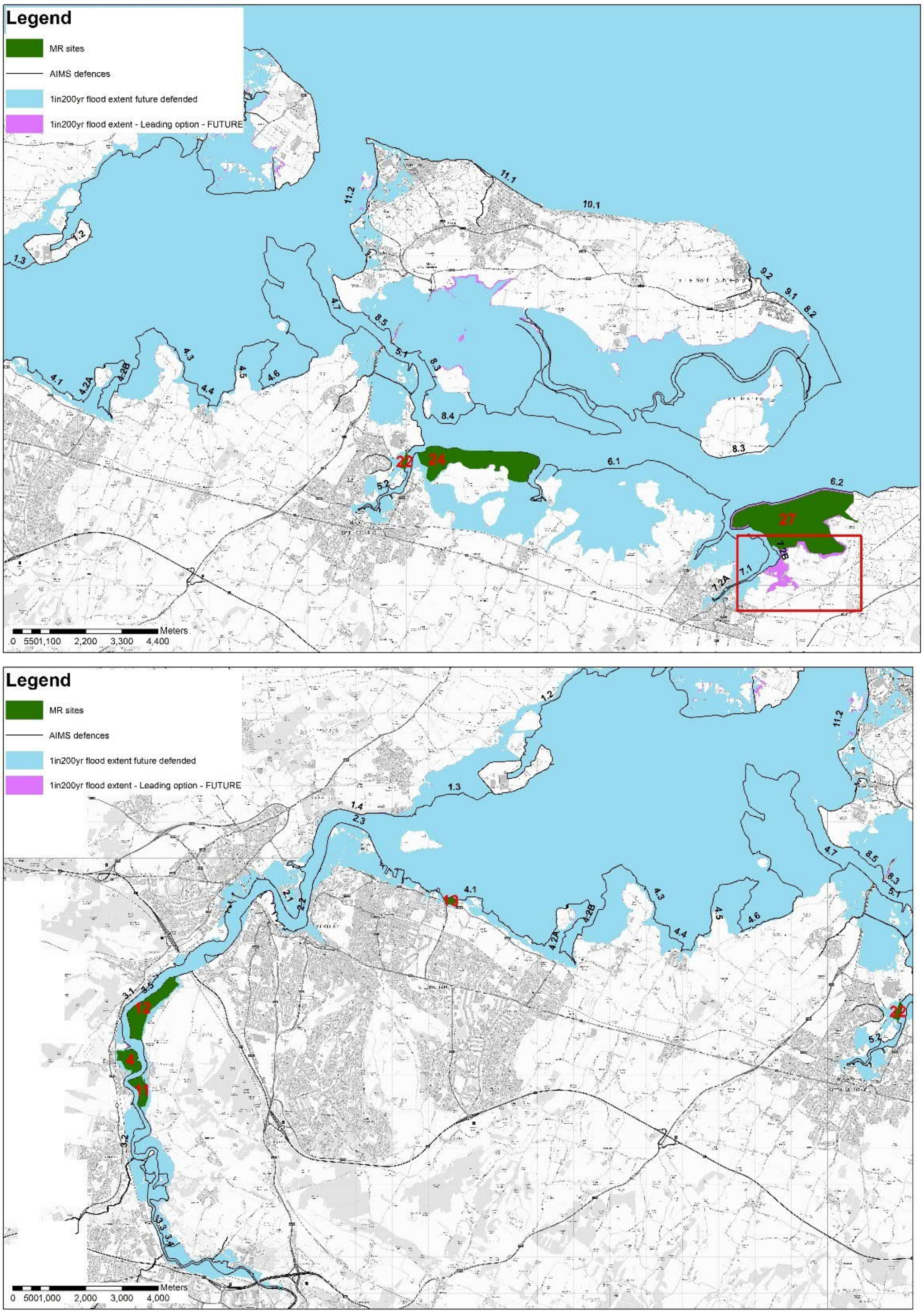
In the future scenario (Figure 141), the increase in the observed flood extent resulting from the implementation of the Leading Options is observed in the boundary between benefit area 7.2b and 6.2. The greater flood extent appears to be the result of a combination between the option selected for benefit area 6.2 (HTL- Maintain) and the slightly higher maximum water level in the area compared to the baseline future defended scenario. As a result, the defences crest levels are not high enough to avoid overtopping in 100 years' time. Maps indicating the benefit areas in which the flood risk has been reduced by the implementation of the Leading Options are shown in Figure 142 and Figure 143. The Leading Option flood extent maps are presented in Figure 144 and Figure 145, for the 1:200-year event, present and future scenarios respectively.

Figure 140: Flood extent of the baseline (light blue) and the Leading Option (pink) results for the 1:200-year present scenario in Swale and Medway estuaries. The highlighted red boxes denote areas were the flood extent is increased compared to the baseline.



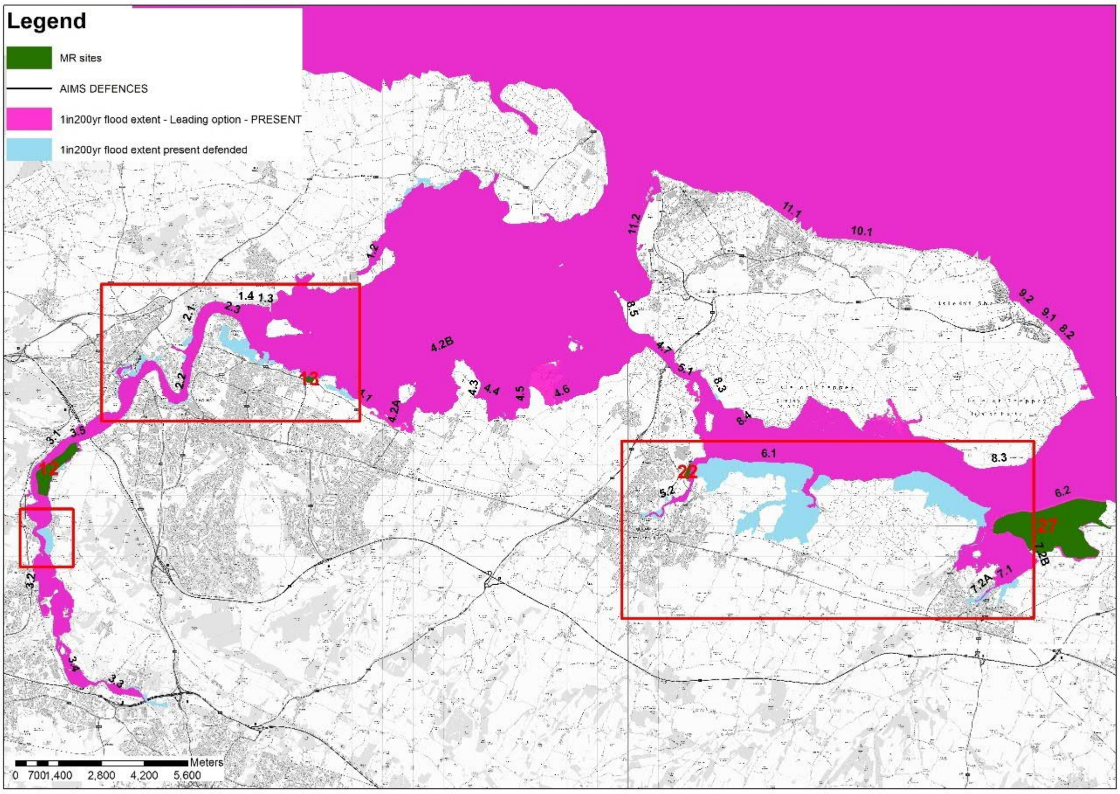
Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016

Figure 141: Flood extent of the baseline (light blue) and the Leading Option (purple) results for the 1:200-year future scenario in Swale and Medway estuaries. The highlighted red boxes denote areas were the flood extent is increased compared to the baseline.



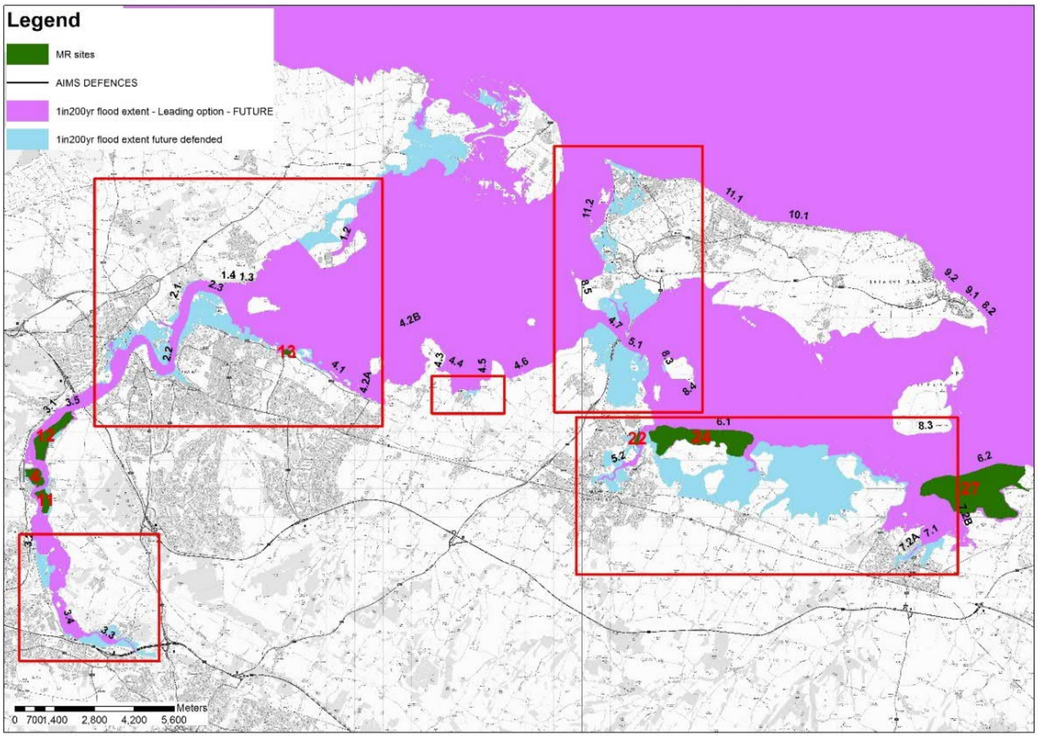
Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016

Figure 142: Flood extent of the baseline (light blue) and the Leading Option (pink) results for the 1:200-year present scenario in Swale and Medway estuaries. The highlighted red boxes denote areas were the flood extent is decreased compared to the baseline.



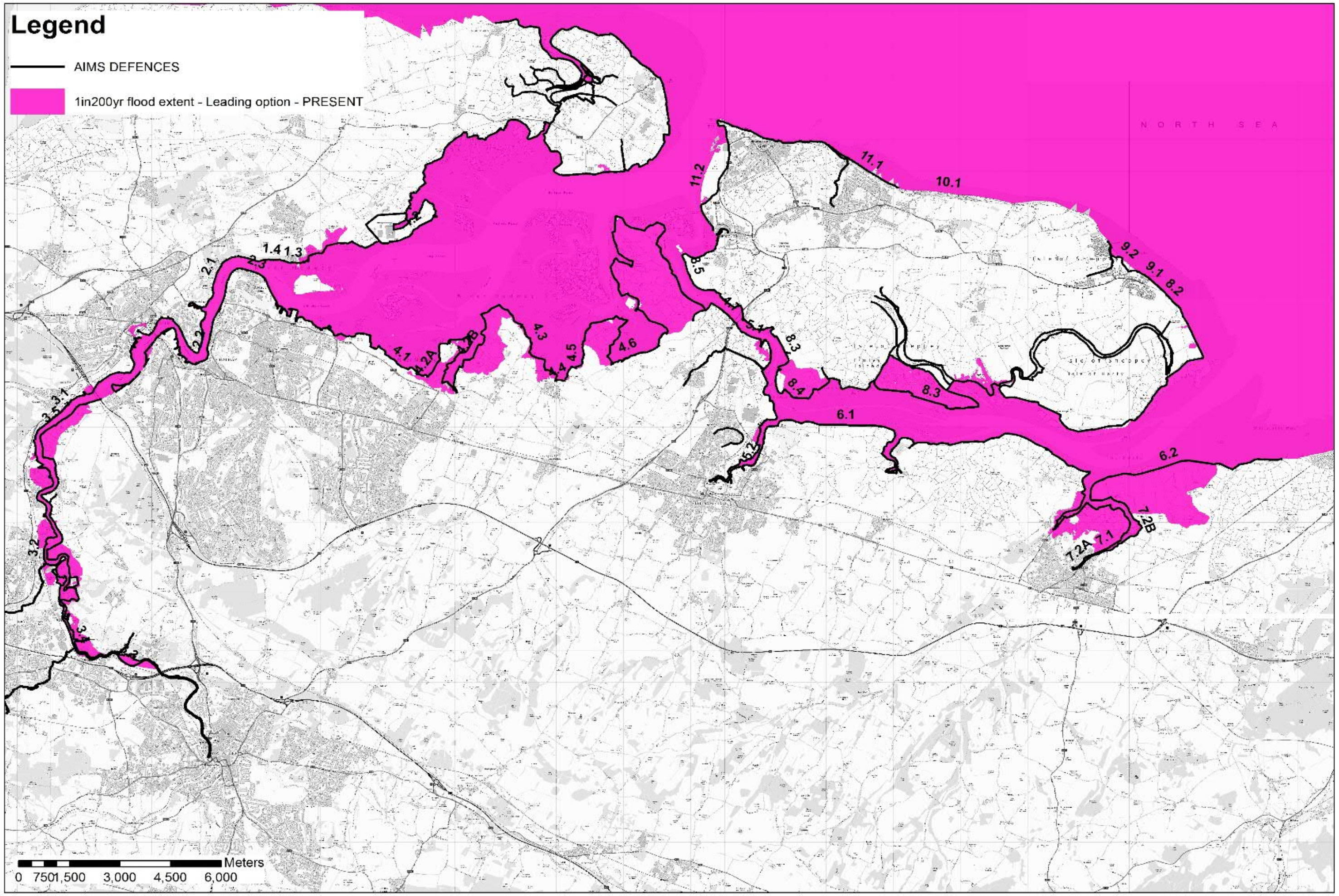
Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016

Figure 143: Flood extent of the baseline (light blue) and the Leading Option (purple) results for the 1:200-year future scenario in Swale and Medway estuaries. The highlighted red boxes denote areas were the flood extent is decreased compared to the baseline.



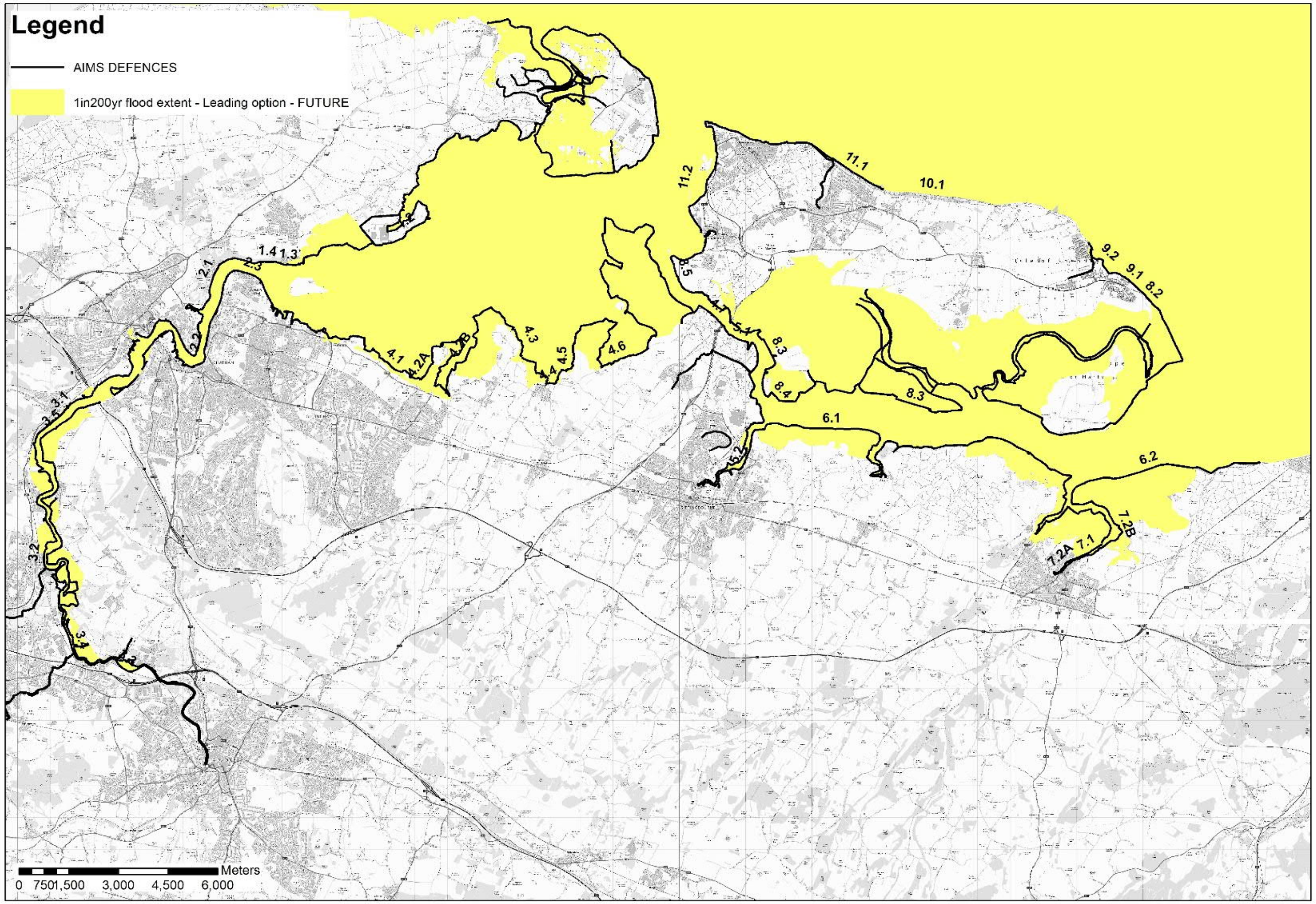
Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016

Figure 144: Flood extent for the 1:200-year event – Present scenario – Leading Options results.



Source: Mott MacDonald, 2017. Contains OS data, © Crown Copyright and database right 2016

Figure 145: Flood extent for the 1:200-year event – Future scenario – Leading Options results.



Source: Mott MacDonald 2017. Contains OS data, © Crown Copyright and database right 2016

9.6 Summary

The results from the hydrodynamic model demonstrate that for the present 1:200-year event the proposed Leading Options:

- Spring high water levels increase in the Swale (maximum +13 cm, or 2% of the 6.3 m tidal range);
- Spring high water level increase in the Medway (maximum +8 cm, or less than 2% of the 4.65 m spring tidal range);
- Current speeds in the Swale eastern entrance increase by around 5 cm/s to 10 cm/s;
- Current speeds in the Upper Medway typically increase by around 10 cm/s to 20 cm/s, with maximum increases of c. 35 cm/s at some locations during the ebb tide;
- Current speeds in the Swale decrease around Elmley Reach by 5 cm/s to 10 cm/s; and
- At most locations, there is a significant decrease in the flood risk for the 1:200-year event, apart from two areas in the Swale (benefit areas 5.1 and 8.3) and a minor portion in benefit area 3.3.

The results from the hydrodynamic model demonstrate that for the future 1:200-year event the proposed Leading Options:

- Art most locations, water levels in the Swale and the Medway increase to a maximum of +5 cm;
- In the Upper Medway, local water levels increase by +14 cm (3% of the 4.65 m spring tidal range);
- Current speeds in the Swale eastern entrance increase by around 10 cm/s to 20 cm/s;
- Currents speed in the western entrance and in the Queensburgh area increase by around 30 cm/s to 35 cm/s;
- Current speeds at most locations in the Upper Medway increase by around 10 cm/s to 20 cm/s, with maximum increases of *c.* 35 cm/s at some locations during the ebb tide;
- Current speeds in the Swale around Elmley Reach decrease by around 10 cm/s to 20 cm/s; and
- At most locations, there is a significant decrease in the flood risk for the 1:200-year future event, in the estuary, except for one area in Faversham Creek (benefit area 7.2b).

10 Leading Option sediment modelling results

Executive summary

As part of this MEASS Strategy, the impacts of the Leading Options have been assessed with regards to normal hydrodynamic conditions (Spring tide) and the associated cohesive sediment transport regime. The existing calibrated and validated spring tidal model described in Chapter 5 was used to model the Leading Option for Present and Future scenarios, with some minor modifications and adjustments to some of the setup files.

The results presented in this chapter show that the proposed Leading Options alter the hydrodynamic and sediment conditions of the Swale and Medway estuaries. The changes in the hydrodynamics include an increase of the tidal prism of the estuaries, and a consequent increase in the current speeds, especially during ebb tides, due to the large volume of water leaving the estuaries.

The model shows these hydrodynamic changes increase the amount of suspended sediment in the estuaries, both for present day and future scenarios. Consequently, across the Medway and the Swale, a general increase in accretion is observed, including within the proposed managed realignment sites. In broad terms, the results show that there is net importation of sediment into the estuaries and an increase in accretion.

A general increase in erosion of sediments in the main channel is also predicted as a result of the Leading Options implementation. This erosion is related to the large volume of water leaving the estuaries and the corresponding increase in the current speeds.

10.1 Introduction

As part of MEASS, the impacts of the options require assessment with regards to extreme currents, water levels and flood risk (Chapter 9), normal water levels and currents speeds and sediment regime. For normal (spring tide) hydrodynamic conditions, this section of the report details the impacts of the Leading Option on the sediment dynamics in the estuaries using the calibrated and validated baseline mud transport (MT) model described in Chapter 5.

10.2 Leading Option

The Leading Options are described in detail in Chapter 9. Those same options were implemented in the calibrated and validated MT model to assess impacts of sediment dynamics.

10.3 Model setup

The MT modelling was undertaken for two main scenarios:

- Spring tide - Present day - present day mean sea level elevation (i.e. no climate change) and including the present day managed realignment site (Figure 127); and
- Spring tide - Future - present day mean sea level elevation (i.e. no climate change) and including the future (2016) managed realignment site Figure 128).

It is noted that without anthropogenic activities, the morphology of the two estuaries would naturally evolve over the next 100 years to accommodate the increased tidal prism related to sea level rise. However, the MEASS model cannot simulate bathymetric evolution over such long time-scales. It was initially found that by simply imposing the 2116 tidal level on the present-day bathymetry, and simulating the sediment response, resulted in excessive erosion in some areas due to the disequilibrium between the morphology of the estuary and the artificially imposed tidal regime. The future Leading Option model runs reported here therefore used the present-day estuary bathymetry and sea level. Please note that for consistency and simplicity the future Leading Options, modelled with the present day mean sea level, will be referred to henceforth as “Future scenario”.

The MT model, for both scenarios, was setup using the calibrated and validated spring tide model described in Chapter 5. However, as described below, some minor changes and adjustments were required in order to successfully integrate the proposed Leading Options.

The critical sheer stress of the third layer in the MT model was modified in order to take into consideration the flooding of land. The managed realignment sites and the areas defined as No Active Intervention by the Leading Options can now flood and therefore, to better represent the actual conditions, the critical shear stress for the third bed layer was increased to a higher value representative of consolidated soil. In the absence of data, threshold shear stress values of 6.23N/m^2 reported by Watt *et al*., (2003), were used to define the underlying agriculture soil of the realignment sites and a map was created for all land areas including the managed realignment breaches with a critical bed shear stress set to 6 N/m^2. A value of 1 N/m^2 was applied in the rest of the estuary for the third bed layer (Table 11).

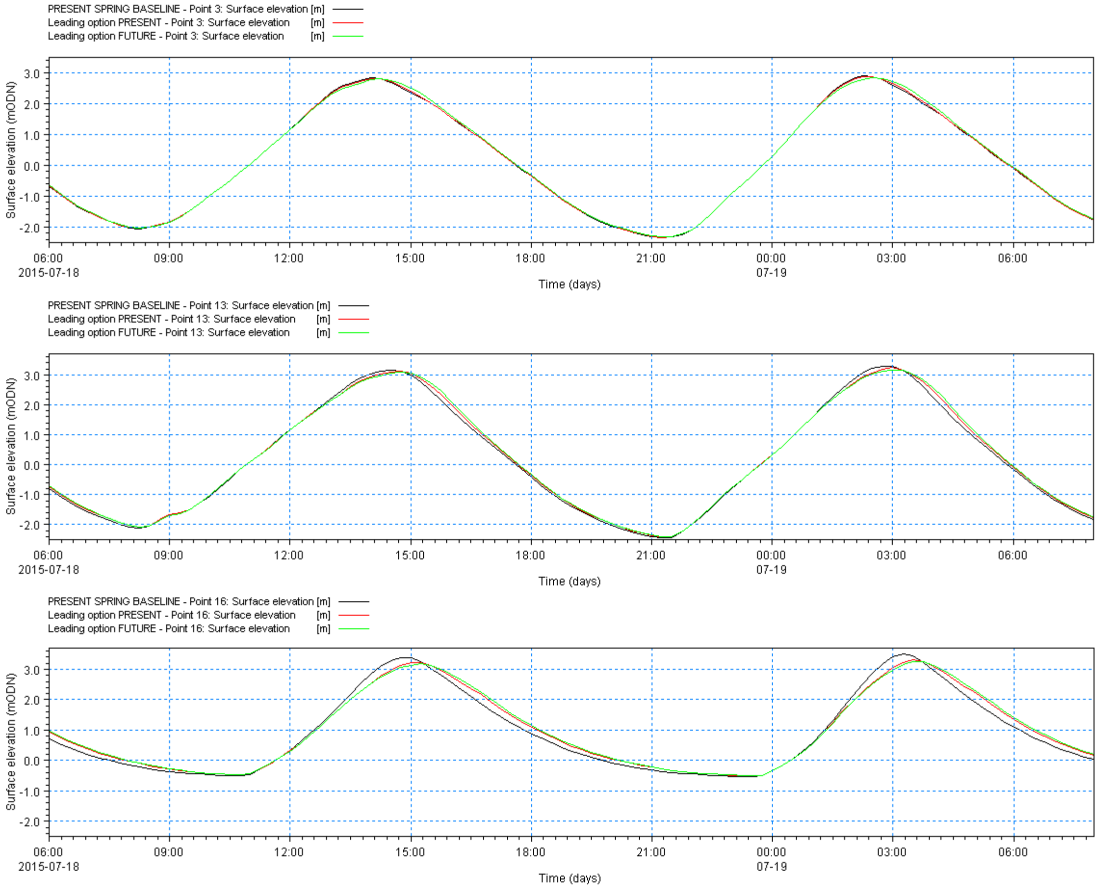
The primary aim of the MT modelling study was to model the impact of the Options upon the estuary naturally sediment transport regime in the medium-term, rather than changes over short period following breaching, when the breach channel would undergo significant erosion and bring about short-term impacts. By this means it was possible to ensured that sediments at the local breach sites with critical erosion thresholds less than the peak bed shear stress were removed from the model and thus better reflected would happen naturally if a uniform sediment bed was exposed to bed shear stresses higher than the critical bed shear stress value.

10.4 Impacts on the spring tide hydrodynamic conditions

The impact of the Leading Options on the sediment transport regime is closely related to the changes brought about by the Options on the hydrodynamic conditions. To examine this in the Swale and in the Medway estuaries, water levels and currents speed time-series were extracted from the MEASS model for a spring tide at the locations shown in Figure 129 for (a) the baseline conditions (spring tide - present); and (b) for runs that included the proposed Leading Options.

Both in the Swale and in the Medway, water levels decrease because of the introduction of the proposed Leading Options, both for the present and future scenarios (Figure 146). The figure shows a decrease in the water level at all points. At Point 3, located in the centre of the Swale, a small decrease in the high-water levels can be seen (less than -1 cm); at Point 13 and Point 16, located in the upper Medway Estuary the decrease is larger, between -10 cm and -20 cm. In addition to a small change in the spring tide water level elevation, the proposed Leading Options are causing a minor change in tidal phase that delayed the time of high tide compared with the baseline case (Figure 146). This figure shows that the ebb duration is slightly reduced by the proposed Leading Options, both for the present and future scenarios, and result in higher current speeds during the ebb tide (Figure 147 and Figure 148 discussed below).

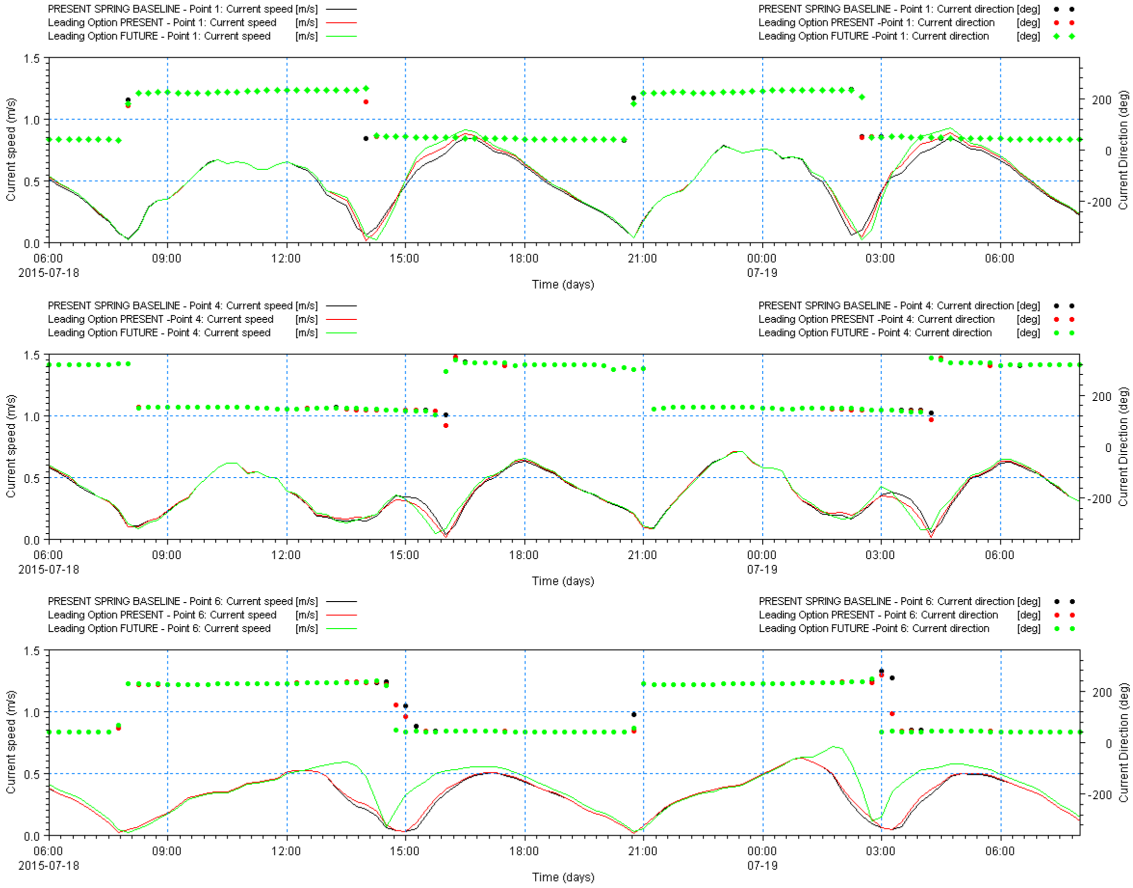
Figure 146: Comparison between water levels in the Swale (Point 3) and in the Medway (Points 13 and Point 16) for the baseline (black line) and Leading Option scenarios (red line for Present and green line for Future) – Spring tide conditions.



Source: Mott MacDonald, 2017

The changes to current speed in the Swale are shown in Figure 147. The selected Leading Options for the Swale increase the current speed in both entrances of the Swale, mainly during the ebb tide. Both entrances show a maximum increase of c. +6 cm/s to +7 cm/s for the future scenario. In the western entrance of the Swale, in the Queensburgh area, the flood tide current speed is also increased (c. +10 cm/s) for the future scenario. This is related to the removal of the defences in benefit area 4.7 and result in considerably changing the hydrodynamic patterns in the area. The duration and timing of the ebb/flood tide is also altered due to the selected options for all the modelled scenarios.

Figure 147: Comparison between predicted current speed and direction in the Swale for the baseline (black line) and Leading Option scenarios (red line for Present and green line for Future) at Points 1, 4 and 6 (Figure 129) – Spring tide conditions.

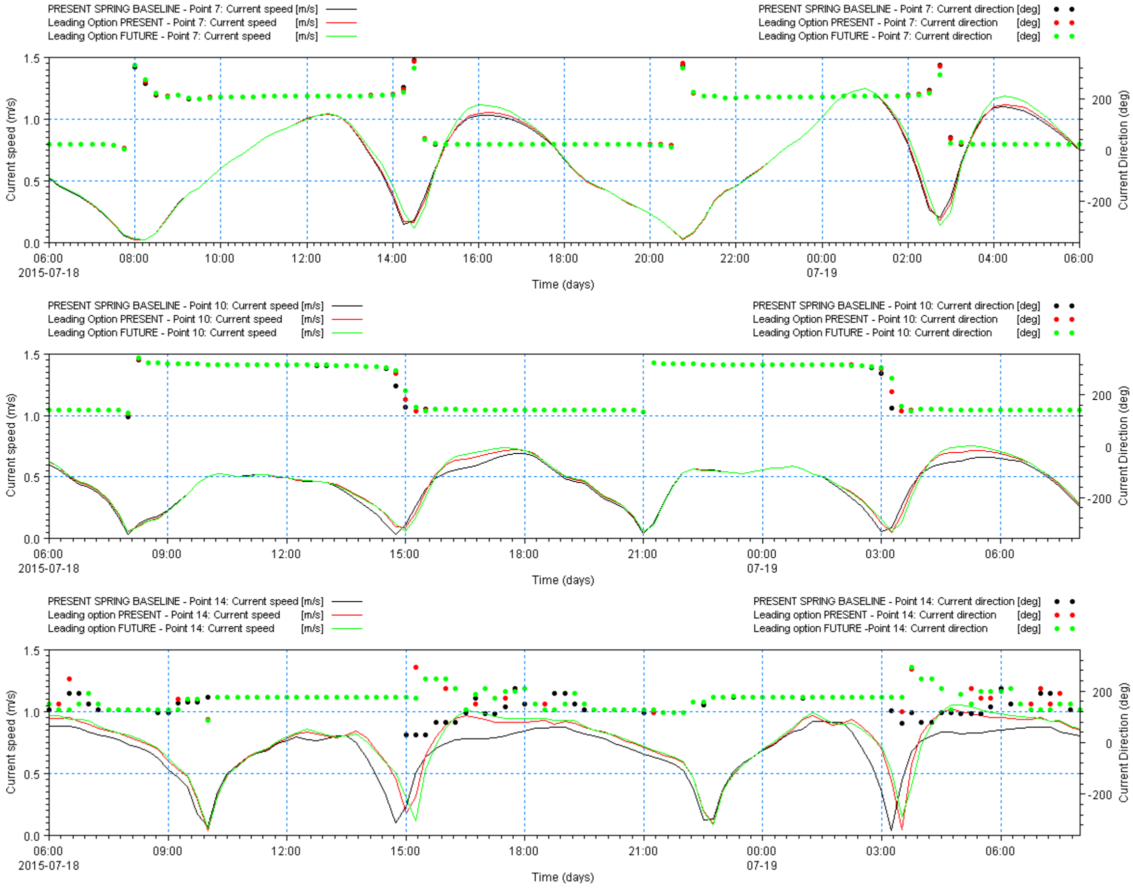


Source: Mott MacDonald, 2017

Figure 148 shows the changes in the spring tide currents speeds in the Medway and demonstrates that current velocities in the Upper Medway are slightly larger than the baseline case, both for the present and future scenarios. The mouth of the Medway Estuary (Point 7) is almost unaffected by the Leading Options, showing only a small increase (c.+6 cm/s) during ebb tide – future scenario, owing to the larger volume of water leaving the Estuary compared with the baseline and present scenario.

The current velocities in the upper Medway are more affected by the Leading Options. This is likely to be related to the changes in the spring flood extents due to the removal of the defences in large areas of the upper Medway. The removal of the defences (No Active Intervention - NAI option) is increasing the spring flood extent and hence the tidal prism) in addition to the managed realignments, and therefore causes the larger currents speeds, especially during the ebb tide.

Figure 148: Comparison between predicted current speed and direction in the Medway for the baseline (black line) and Leading Option scenarios (red line for Present and green line for Future) at Points 7, 10 and 14 (Figure 129) – Spring tide conditions.



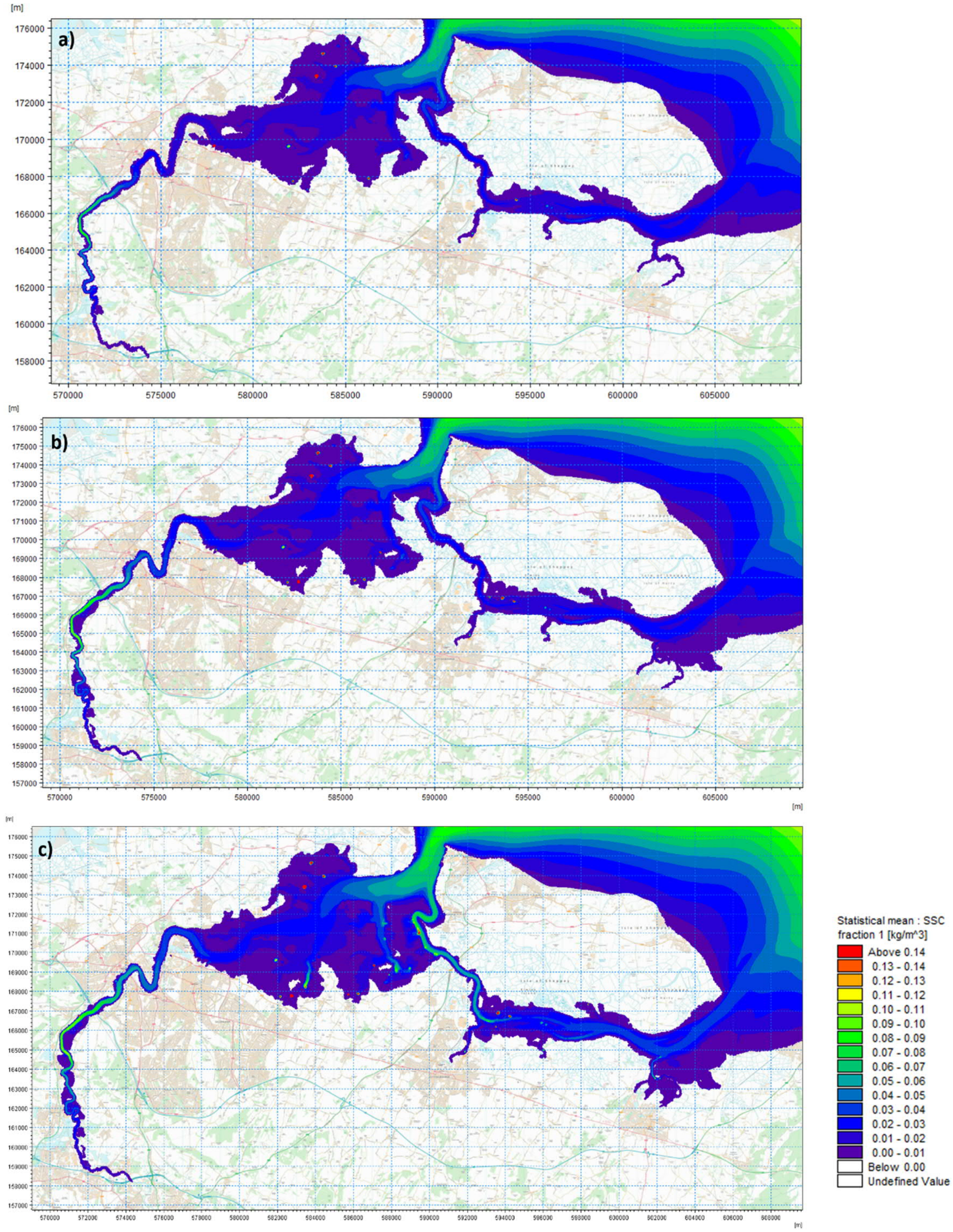
Source: Mott MacDonald, 2017

10.5 Suspended Sediments

The prediction of differences in estuary-wide suspended sediment concentration (SSC) between present-day and future conditions is required to assess the impacts of the Leading Options on estuarine sediment dynamics. The predicted differences from the MT model in Figure 149 show: (a) the mean spring tide SSC for the baseline conditions; and SSC after the implementation of the Leading Option for: (b) the present; and (c) future scenarios.

Figure 149 shows that the typical range of SSC is between 20-40 mg/l and is not changed significantly by the implementation of the options. For the present case, a small increase in the SSC can be observed in the mouth of the Medway estuary. This is further enhanced in the future scenario. There are two possible reasons for this local increase for the Leading Options: (a) The changes to the tidal prism result in an increased amount of suspended sediment being drawn into the estuaries; and (b) higher current speeds increase the quantity of sediment that is eroded from the centre of the channels on the ebb tide. It is also likely that both these factors play a role in the elevated SSC values. A more detailed analysis regarding the fluxes of sediments into the estuaries is undertaken in Section 10.7.

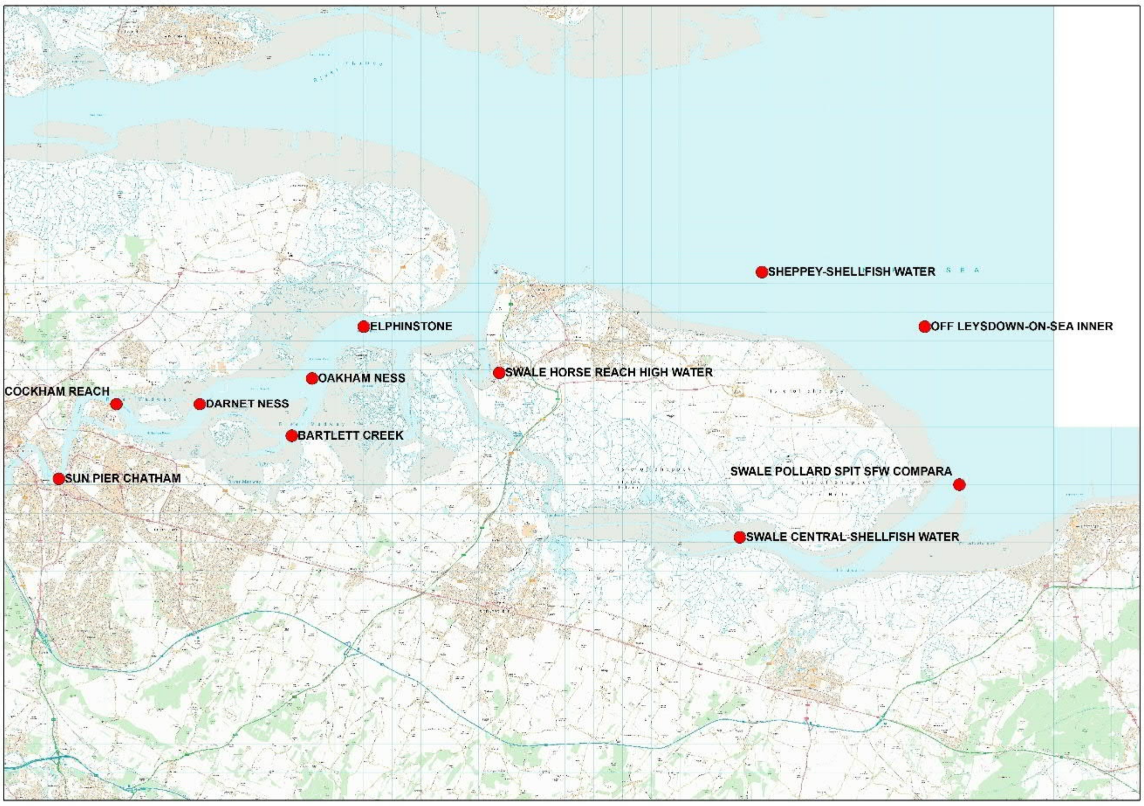
Figure 149: Mean modelled SSC for a spring tide. Please note that the modelled SSC is expressed in kg/m^3 instead of mg/l – 0.1kg/m^3 is equivalent to 100mg/l. (a) Baseline model, (b) Leading Options Present and (c) Leading Options Future.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

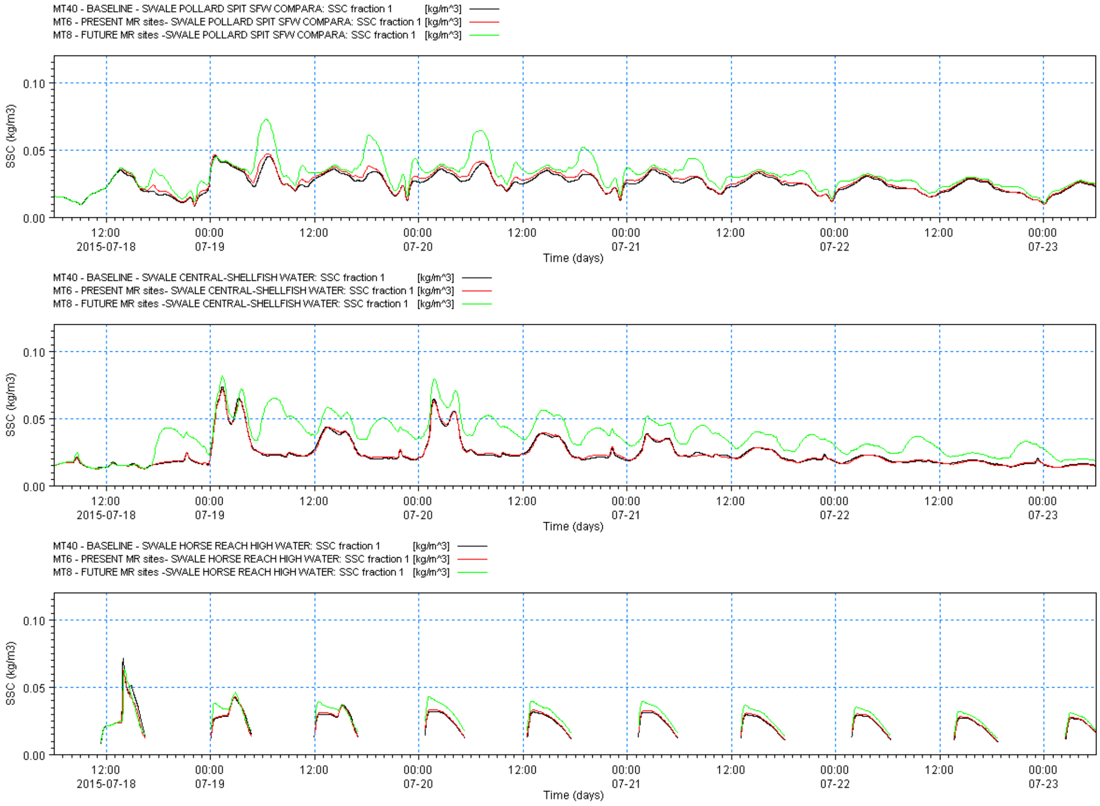
The predicted changes in SSC were compared with the available data from the Water Quality Archive database at the sampling stations selected for the model validation shown Figure 150. The comparisons between the baseline model and the Leading Option results for the present and future scenarios, in the Swale, Medway and Upper Medway are shown Figure 151, Figure 152 and Figure 153, respectively.

Figure 150: Selected WIMS sampling locations for SSC analysis



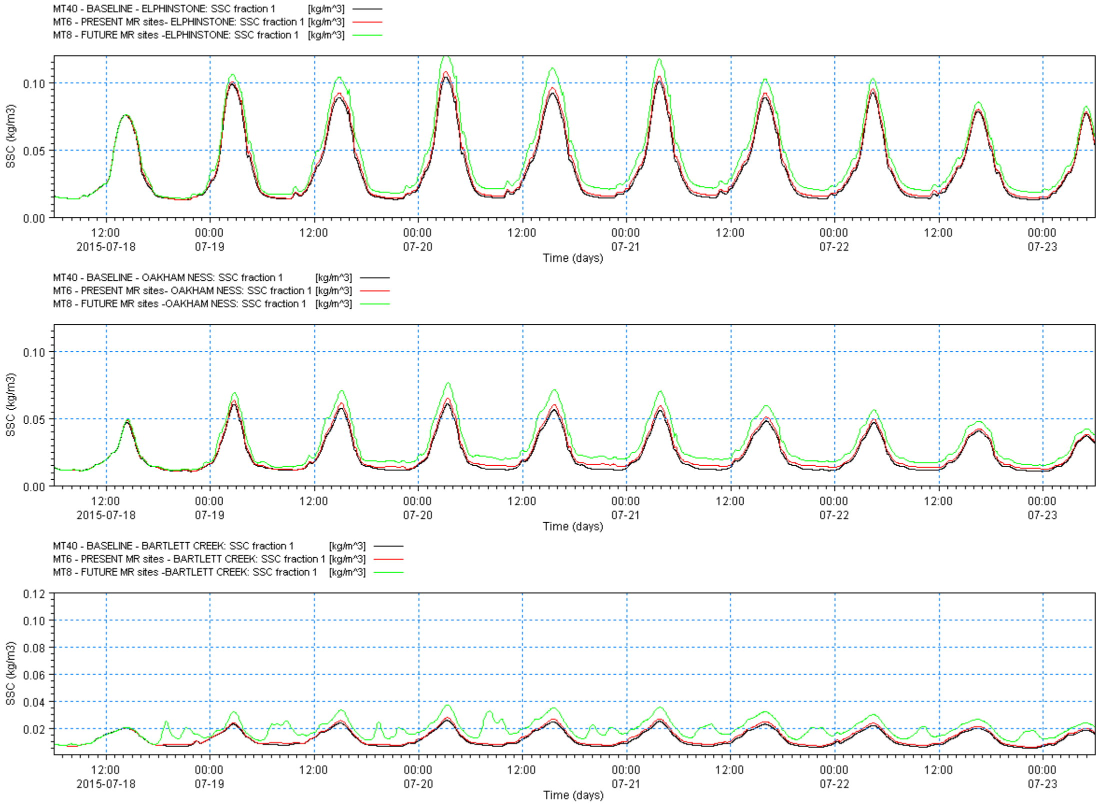
Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016 and Environment Agency data 2016.

Figure 151: Comparison between predicted SSC in the Swale for the baseline (black line) and Leading Option scenario (red line for Present and green line for Future) at WIMS sampling locations Figure 150) – Spring tide conditions.



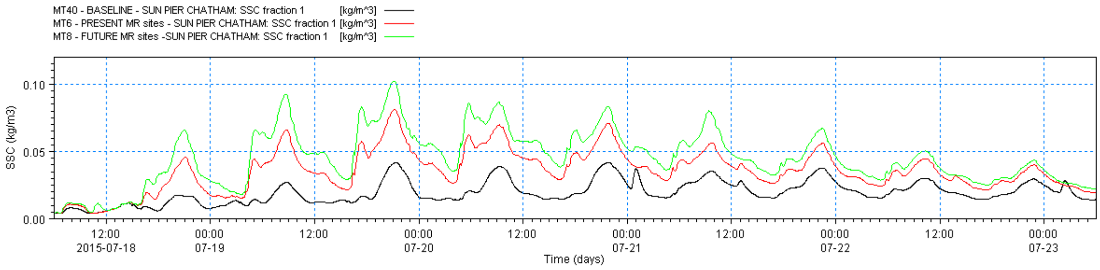
Source: Mott MacDonald, 2017

Figure 152: Comparison between predicted SSC in the Medway for the baseline (black line) and Leading Option scenarios (red line for Present and green line for Future) at WIMS sampling locations (Figure 150) – Spring tide conditions.



Source: Mott MacDonald, 2017

Figure 153: Comparison between predicted SSC in the upper Medway for the baseline (black line) and Leading Option scenarios (red line for Present and green line for Future) at WIMS sampling locations (Figure 150) – Spring tide conditions.



Source: Mott MacDonald, 2017

In general, the results in Figure 151, Figure 152 and Figure 153 show a very small increase in the SSC for the present day scenario, and a more evident increase for the future scenario when compared to the baseline, across both estuaries. In the Swale (Figure 151), the increase of SSC for the present day is negligible. In the future scenario, however, this increase is larger, especially at the eastern mouth of the Swale (Swale Pollard Point) and in the central area of the Swale (Swale Central Shellfish Point). It is considered that the observed increase is related to an increase in the current speeds and to the volume of water imported into the estuary.

In common with the changes to SSC observed in the Swale, (Figure 151), the changes in SSC in the main Medway estuary between the baseline and the present-day scenario are very small. For the future scenarios, the SSC increases in the main Medway estuary due to an increase in the reworking of the existing sediments (increased current speeds) and due to an increase in the mass of sediment imported to the estuary.

In the upper Medway (Figure 153), the changes in SSC are larger, both for the present and future scenarios. SSC values at Sun Pier Point are twice those for the present-day scenario during the modelled spring tide. These increases are related to the larger current speeds in the upper Medway which result in greater re-suspension and re-working of the deposited sediments. It also appears that this area is associated with a turbidity maximum and therefore increased currents have helped to increase this feature. In the future scenarios, this increase in SSC is amplified even further.

10.6 Erosion and deposition impacts

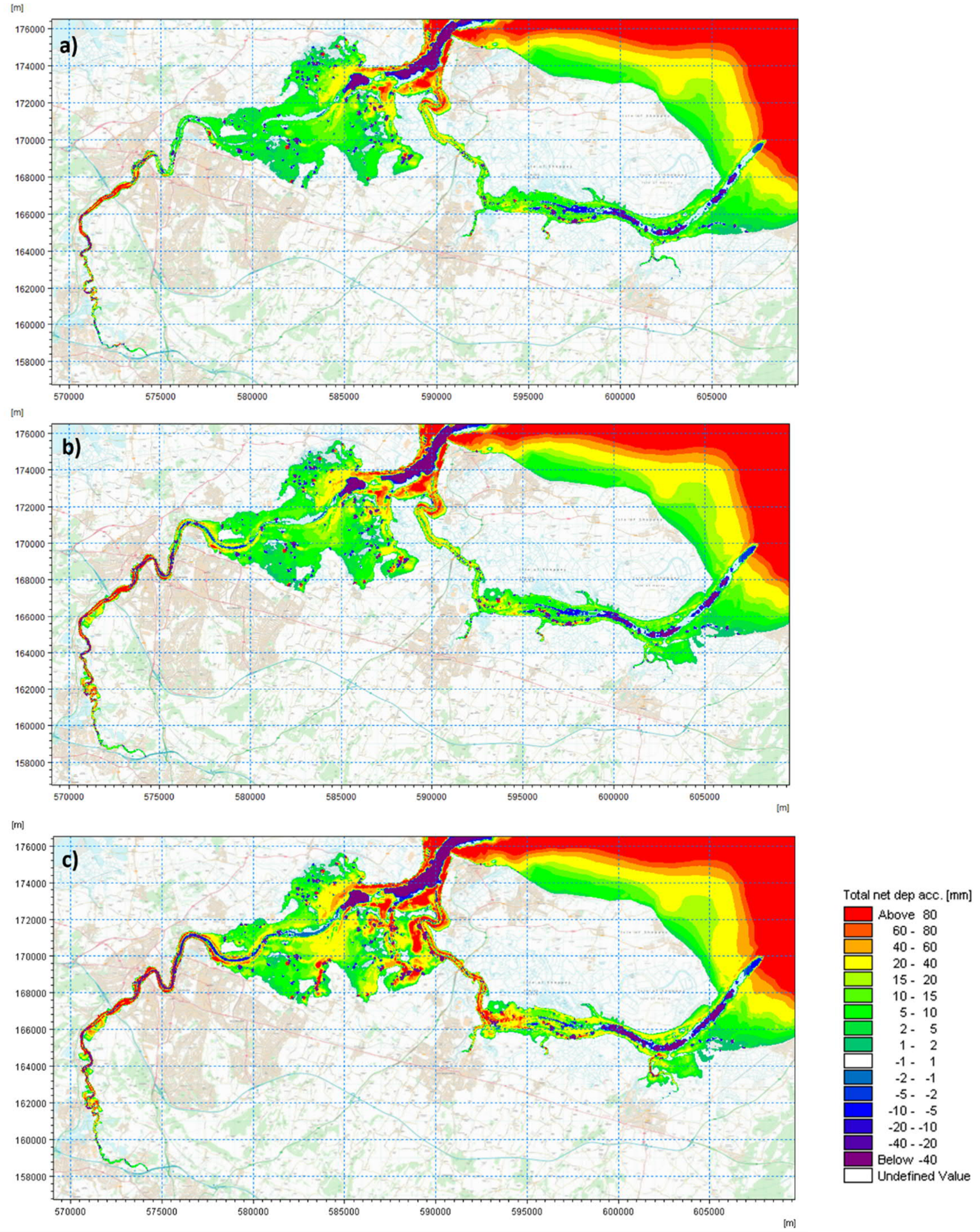
As presented in Chapter 5, the reported mean sedimentation rates for the Medway estuary are between 4-5 mm/year. Using the MT model, the net sedimentation was calculated for the baseline, present and future Leading Options scenarios using: (a) an intermediate sediment dry density of the third layer (611 kg/m^3); and (b) a higher sediment density, as recommended in the Environmental Agency (2011) report for sea water average packed sediments (dry density of approx. 900 kg/m^3).

These modelled net sedimentation rates were calculated using the above densities and assuming:

- Spring tide deposition rates for 50% of the year – obtained using the MT spring tide modelling results; and
- An estimated neap tide deposition rate for the other 50% of the year – Since no neap tide model results were undertaken for the Leading Options scenarios, it was assumed that the neap tides deposit a smaller quantity of suspended sediment than the spring tide (due to the smaller proportion of SSC). After examination of the relative net sedimentation rates for baseline conditions this fraction was estimated to be 25% of the spring tide net deposition.

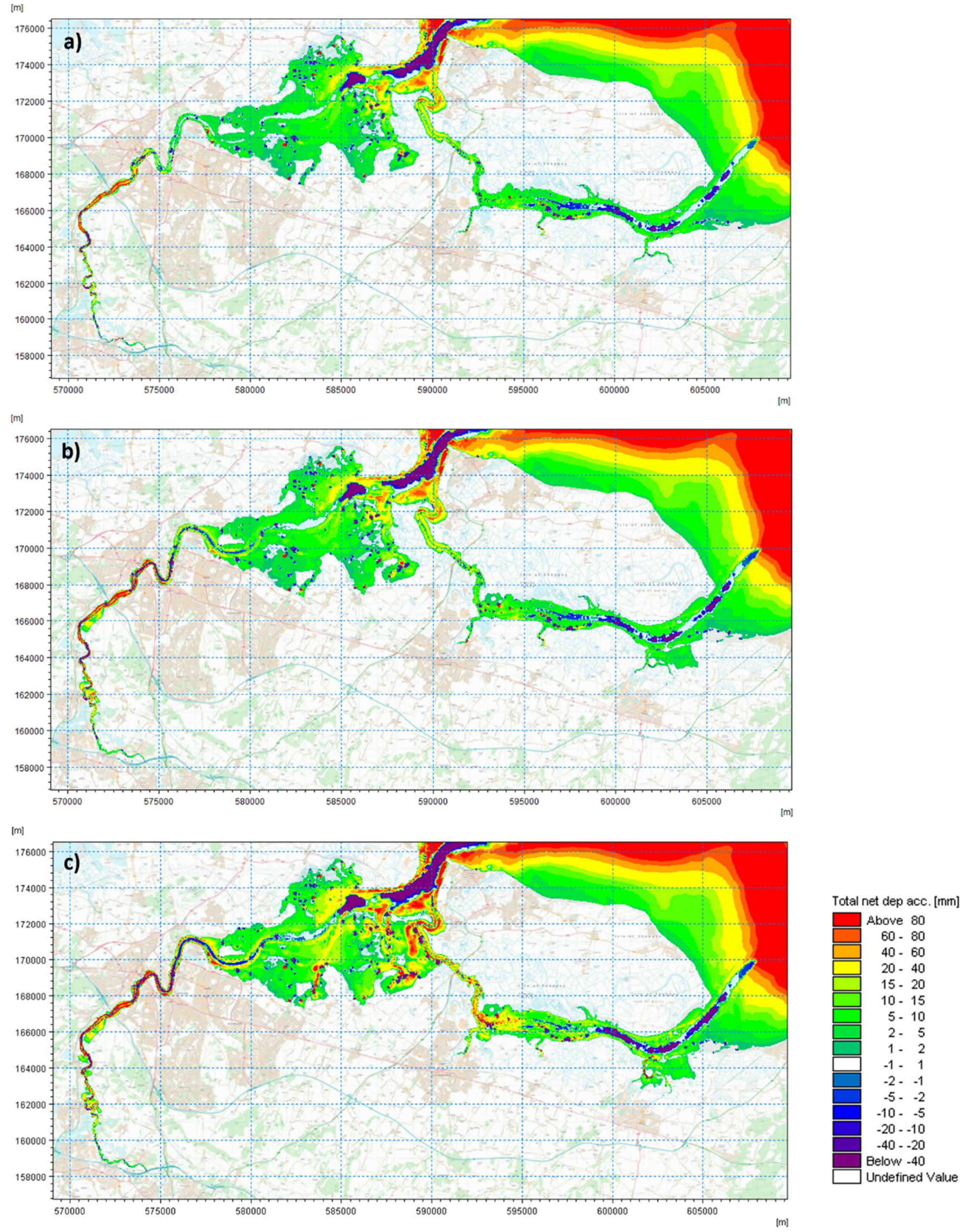
Figure 154 shows the spatial distribution of the annual predicted net sediment accretion rate using a bulk wet sediment density of 1400 kg/m^3 (611 kg/m^3 dry density) for the baseline and the two Leading Options scenarios. Similarly, Figure 155 presents the net annual accretion rate distribution calculated using a bulk wet sediment density of 1600 kg/m^3 (937 kg/m^3 dry density). It is noted that the distribution and values of net annual accretion rates shown in both Figure 154 and Figure 155 are similar. However, the bulk sediment density will vary across the Medway and Swale estuaries according to the sediment properties, tidal exposure, biological activity etc. and the approach here assumes that these density values represent some amount of consolidation.

Figure 154: Annual modelled deposition map combining Spring and estimated Neap tide condition and using a bulk wet sediment density of 1400 kg/m^3 (dry density of 611kg/m^3) - (a) Baseline model, (b) Leading Option Present and (c) Leading Option Future.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 155: Annual modelled deposition map combining Spring and estimated Neap tide condition and using a bulk wet sediment density of 1600 kg/m^3 (dry density of 900kg/m^3) - (a) Baseline model, (b) Leading Option Present and (c) Leading Option Future.



Source: Mott MacDonald, 2016. Contains OS data, © Crown Copyright and database right 2016

Figure 154 and Figure 155 show that the managed realignment areas, especially MR27 located in the east of the Swale, have deposition rates similar to those observed on the intertidal areas of the estuaries, with estimated annual deposition rates between approximately 3 mm and 10 mm per year. Future scenario deposition rates are slightly higher in the realignment areas, up to 17 mm per year in MR27 and 27 mm per year in MR24. These results are unsurprising given the increased SSC in the main estuary channels.

In the upper Medway, the deposition rates in the managed realignment areas (MR12 for the present and future scenarios, and MR4 and MR11 for the future only scenario) are higher, both for the present and future scenarios, reaching maximum deposition of 30 mm per year. These high values are related to the higher SSC observed in the upper Medway.

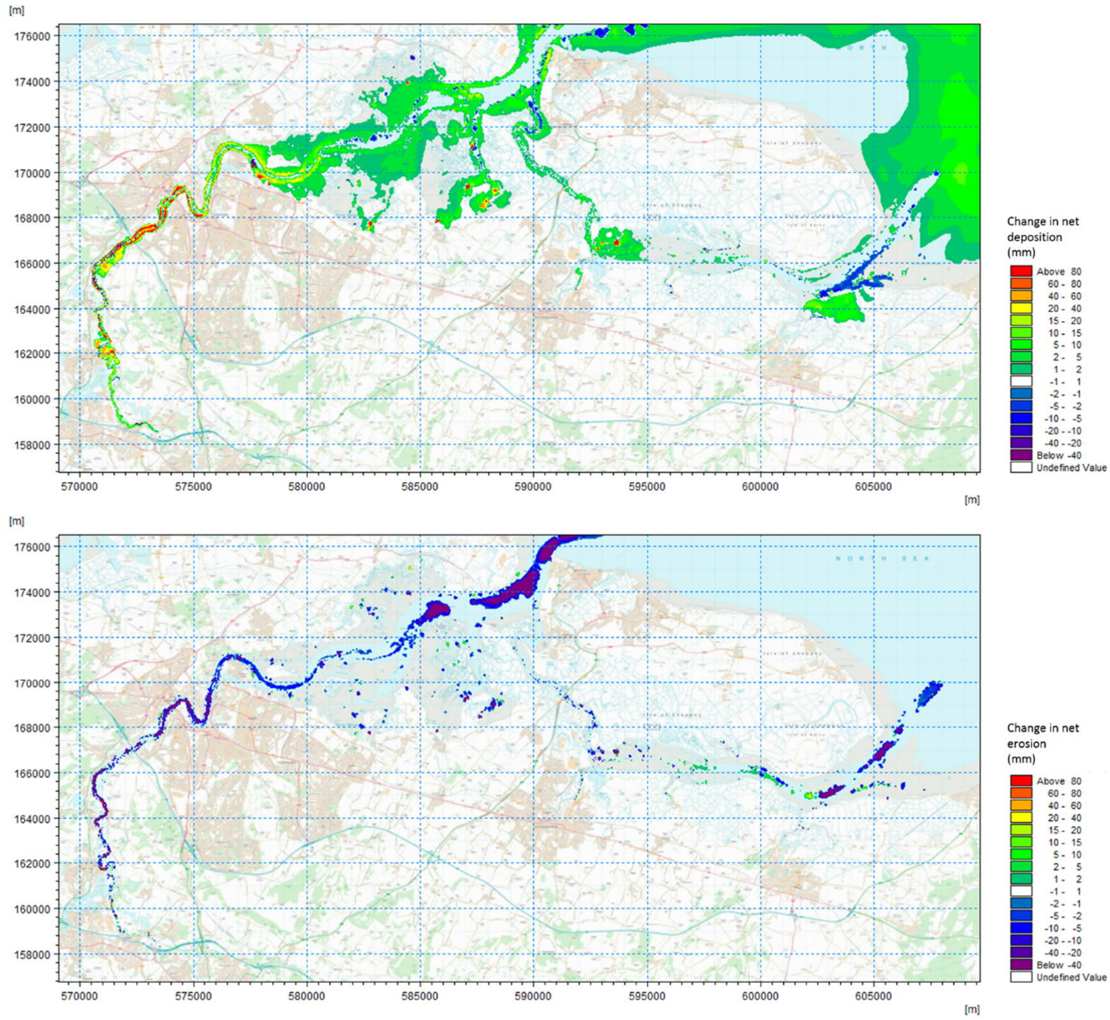
The results also show that for the future scenarios there is a general increase in the net deposition in the intertidal areas of the Medway, and in areas where the defences have been removed (e.g. No Active Intervention in benefit area 4.7).

10.7 Spatial changes in Erosion and deposition

The spatial changes in the deposition and erosion patterns of the estuaries were determined for the present and future scenarios by comparing with the baseline. The changes were calculated separately for erosional and depositional areas in order to determine the effect of the Leading Options in the sedimentation patterns of the Medway and Swale estuaries.

Figure 156 presents the changes in erosion and deposition between the baseline and the Leading Options present day scenario. Figure 156(a) indicates the change in the deposition only. An increase in the deposition is represented by a positive number. On the other hand, a decrease in the deposition, but not to be confused to erosion, is represented by a negative number. Figure 156(b) indicates the change in the erosion only. An increase in the erosion is represented by a negative number. A decrease in the erosion rate, but not to be confused to deposition, is represented by a positive number.

Figure 156: Changes in annual modelled deposition/erosion patterns between the baseline and the present-day Leading Option scenario and using bulk wet sediment density of 1400 kg/m^3 (dry density of 611kg/m^3). In the deposition areas (a) a positive change reflects an increase in the deposition rate. In the erosion areas (b) a positive change reflects a decrease in the erosion rate.



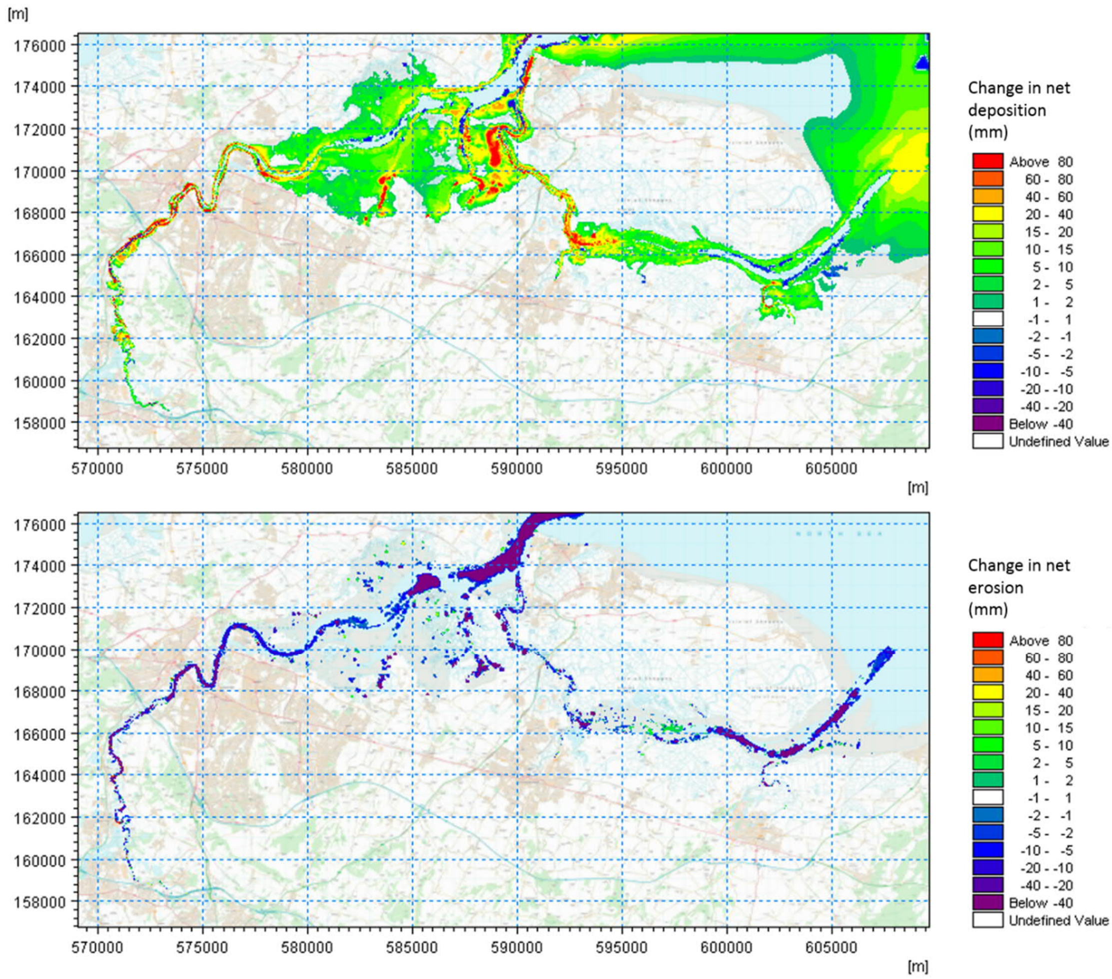
Source: Mott MacDonald, 2017 Contains OS data, © Crown Copyright and database right 2016

Figure 156(a) shows a decrease in deposition on the intertidal areas in front of MR27 (eastern end of the Swale) due to the implementation of the Leading Options. This results from a decrease in available suspended sediment attributable to the sedimentation now taking place in the managed realignment site. Figure 156(a) also shows that in general, the present-day Leading Options cause an increase in the deposition rates across the Medway and Swale estuaries likely associated with an increase in the tidal prism and increased current speeds in the main channels.

Figure 156(b) indicates that due to the implementation of the present day Leading Options, there is an increase in the erosion of the main channels of the Medway and the east of the Swale. These increases in the erosion rates are directly related to the increase in the currents speeds described in section 9.4. The exact amount of erosion will be dependent on the availability of sediment and the erodibility of sediment in these areas. At present, there is insufficient information to quantify this.

Figure 157 shows the changes in sediment: (a) erosion and; (b) deposition between the baseline and the Leading Option future day scenario. The figures show an increase in deposition across the Medway and Swale estuaries (Figure 157a), with only localised areas where the deposition has been reduced by the implementation of the schemes. The changes in erosion rates (Figure 157b) are similar to the those described for the present-day scenario and show erosion rates increase in all the main channels, both in the Medway and in the Swale, as well as in the estuary mouths due to the increase in the currents speeds previously described.

Figure 157: Changes in annual modelled deposition/erosion patterns between the baseline and the future Leading Option scenario and using bulk wet sediment density of 1400 kg/m^3 (dry density of 611kg/m^3). In the deposition areas (a) a positive change reflects an increase in the deposition rate. In the erosion areas (b) a positive change reflects a decrease in the erosion rate.

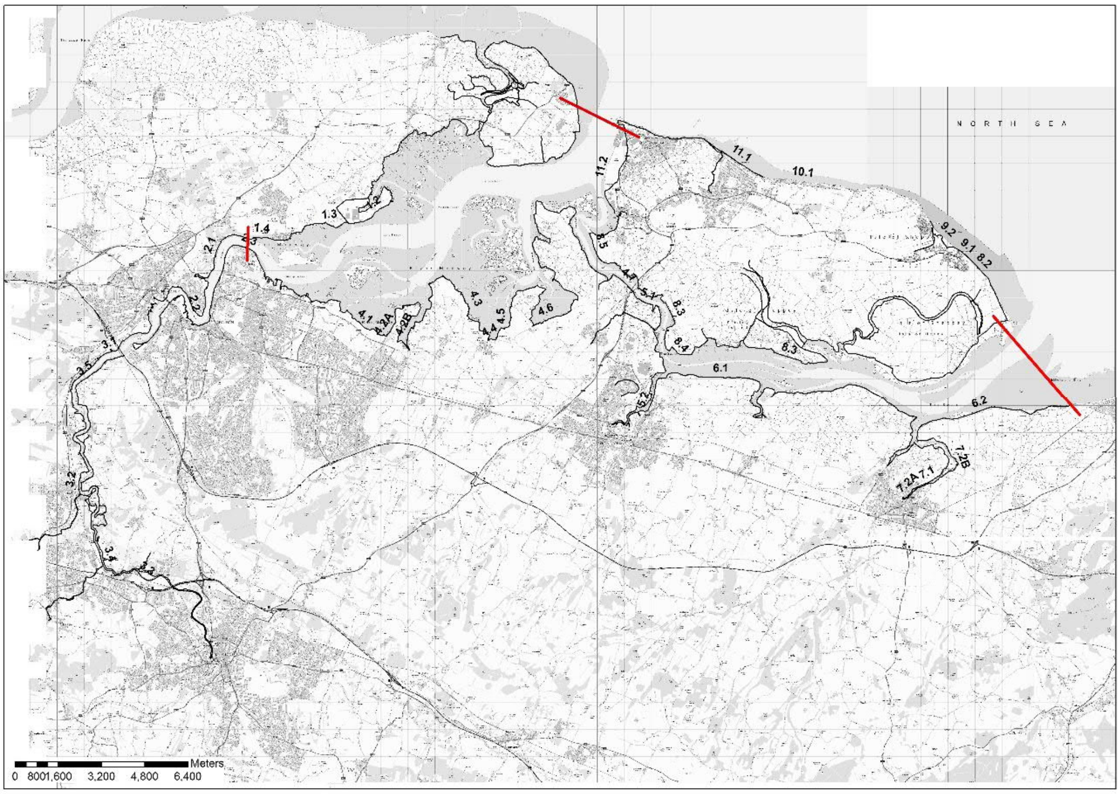


Source: Mott MacDonald, 2017 Contains OS data, © Crown Copyright and database right 2016

10.8 Changes to the sediment fluxes of the estuaries

The effect of the Leading Options on the amount of sediment imported into the estuaries has been examined by considering the accumulated volume/mass flux of suspended sediments through a cross section, over one spring tide. This was determined for the baseline, present and future scenarios. Cross sections were defined at the mouth of the Medway, at the eastern mouth of the Swale and in the upper Medway (Figure 158).

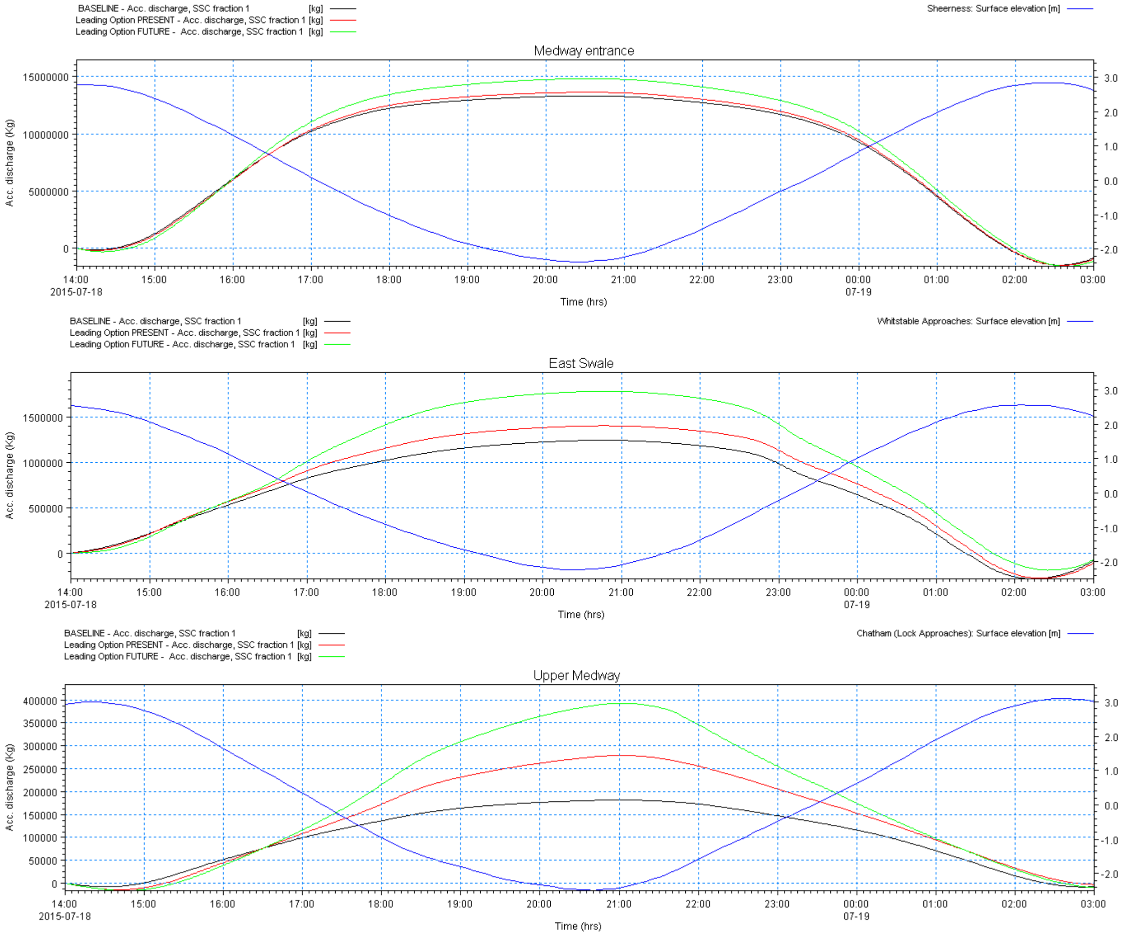
Figure 158: Approximate location of the cross section (red lines) defined in order to determine the changes in the flux of sediments.



Source: Mott MacDonald, 2017 Contains OS data, © Crown Copyright and database right 2016

Figure 159 shows the results of the cross-section analysis for the three locations in the estuary together with the spring tide water level for a nearby location. The accumulated flux of sediment across the sections is presented, with an increasing mass representing sediment moving downstream and a decreasing value representing the mass of sediment moving upstream. The total mass of sediment exiting the estuaries can be determined from the difference between the value at high water and that at low water, and *vice-versa* for the amount entering. The figure shows that, compared with the baseline, the flux of sediment though the defined cross-sections is increased by the Leading Option, both for the present and future scenarios.

Figure 159: Accumulated suspended sediments through a cross section during a spring tide. Baseline (black line) and Leading Option scenarios (red line for Present and green line for Future). The blue line is the water surface elevation at a nearby location. Please note that the vertical axis is not the same for all the plots.



Source: Mott MacDonald, 2017

The results indicate that implementation of the options increases the importation of suspended sediment into the estuary, which leads to the increased deposition observed in Section 10.6. The figure shows that there is a greater mass of sediment brought into the estuary due to the modelled options. This increase is related to the increase in the tidal prism as shown in Table 34 for the Leading Options, both in the present and future scenario.

Figure 159 is also shows that the amount of sediment entering the estuaries during the flood tide is larger than the amount of sediments leaving the estuary during the ebb tide, and therefore, there is a net import of sediment into the estuary, as observed in Section 10.6. In addition, Figure 159 shows that the accumulated flux of sediment through the Medway's mouth is more than ten times larger than the observed flux of sediment through the eastern entrance to the Swale.

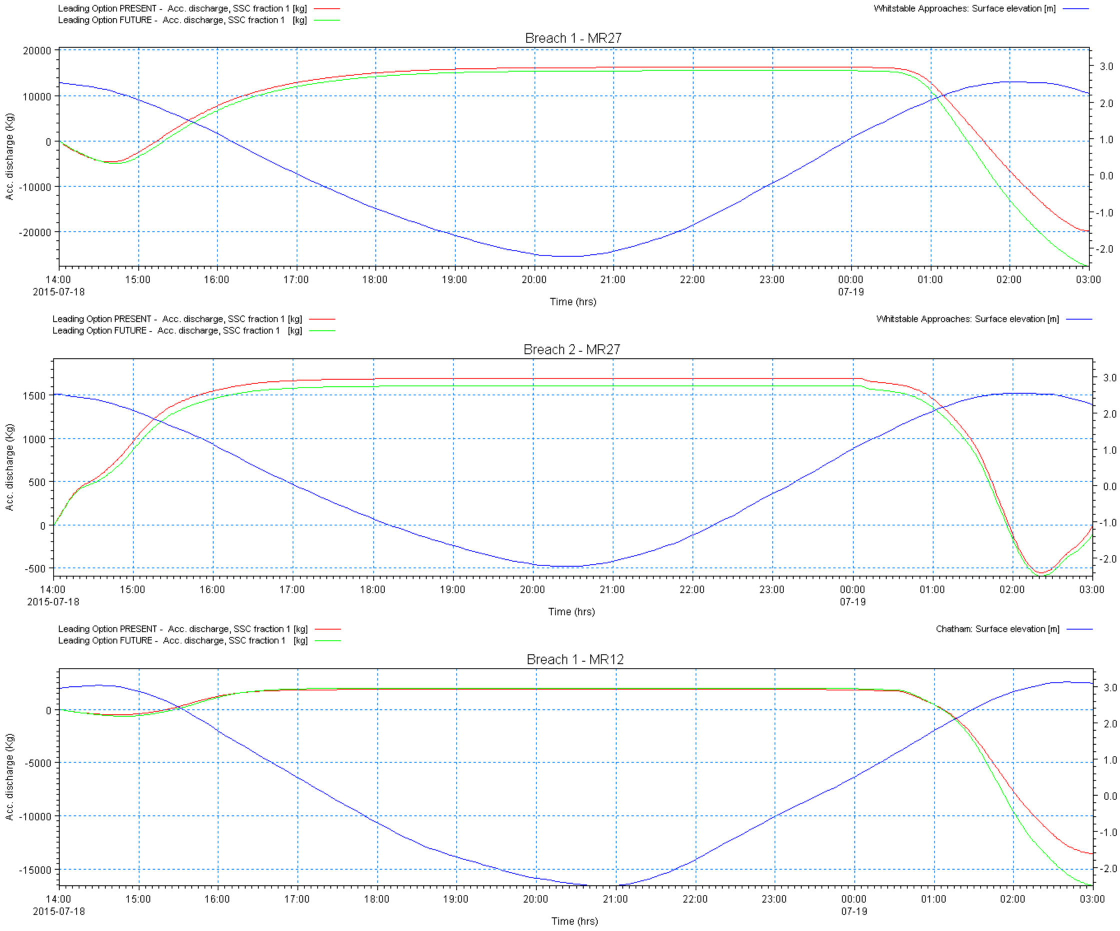
Table 34: Changes in the tidal prism of the Medway and Swale estuaries due to the implementation of the Leading Options.

Scenario	Medway tidal prism (m^3)	Swale east tidal prism (m^3)	TOTAL system tidal prism (m^3)
Baseline	228,471,000	77,072,200	305,543,200
Leading Option – PRESENT	228,712,000	78,213,300	306,925,300
Leading Option - FUTURE	231,163,000	77,259,500	308,422,500

Source: Mott MacDonald, 2017

The same approach to determine how much sediment is imported over one spring tide, both for the present and the future scenarios was applied at two managed realignment sites where cross sections were defined in the breaches of MR27 and MR12. The results are shown in Figure 160. These show that the sediment flux through the breaches for the future scenario are larger than the present day. The results also show that the amount of sediment entering the realignment site is significantly larger than the amount of sediment leaving the site during the ebb tide. The results are therefore consistent with the deposition observed in the realignment areas in Section 10.6.

Figure 160: Accumulated suspended sediments through a cross section at the breaches location of managed realignment sites MT27 and MR12 during a spring tide. For the Leading Option scenarios (red line for Present and green line for Future). Please note that the vertical axis is not the same for all the plots.



Source: Mott MacDonald, 2017

10.9 Summary and conclusions

The results presented in this chapter indicate that the proposed Leading Options change the hydrodynamic and sediment conditions in the Swale and Medway estuaries. The most significant of the changes identified include:

- An increase of the tidal prism of the estuaries, and a consequent increase in the current speeds, especially during ebb tides, as the larger volume of water leaves the estuaries;
- Higher suspended sediment concentrations in the estuaries, both for present day and future scenarios. The higher SSC values are related to an increase in the importation of sediments into the estuaries (larger tidal prism) and the higher current speeds;
- An increase in sediment accretion in the estuaries and the proposed managed realignment sites attributable to more sediment entering the estuaries;
- Sediment accretion rates in the proposed managed realignment sites in the range 3 mm to 10 mm, reaching a maximum value of 30 mm in some localised areas; and

- A general increase in the erosion in the main channel for the Leading Option implementation. This is related to the large volume of water leaving the estuaries and increasing the current speeds.

Based on the predicted intertidal accretion rates, it appears that in the short-term, accretion will keep pace with the SLR. Although it might be argued that this may not be the case as SLR accelerates in the future, changes in SLR may be offset by accretion in the estuaries and the MR sites and the associated reduction in the tidal prism. By this feedback mechanism, it might be anticipated that the estuary will accommodate any change brought about by the Leading Option and over time attain a quasi-equilibrium state again.

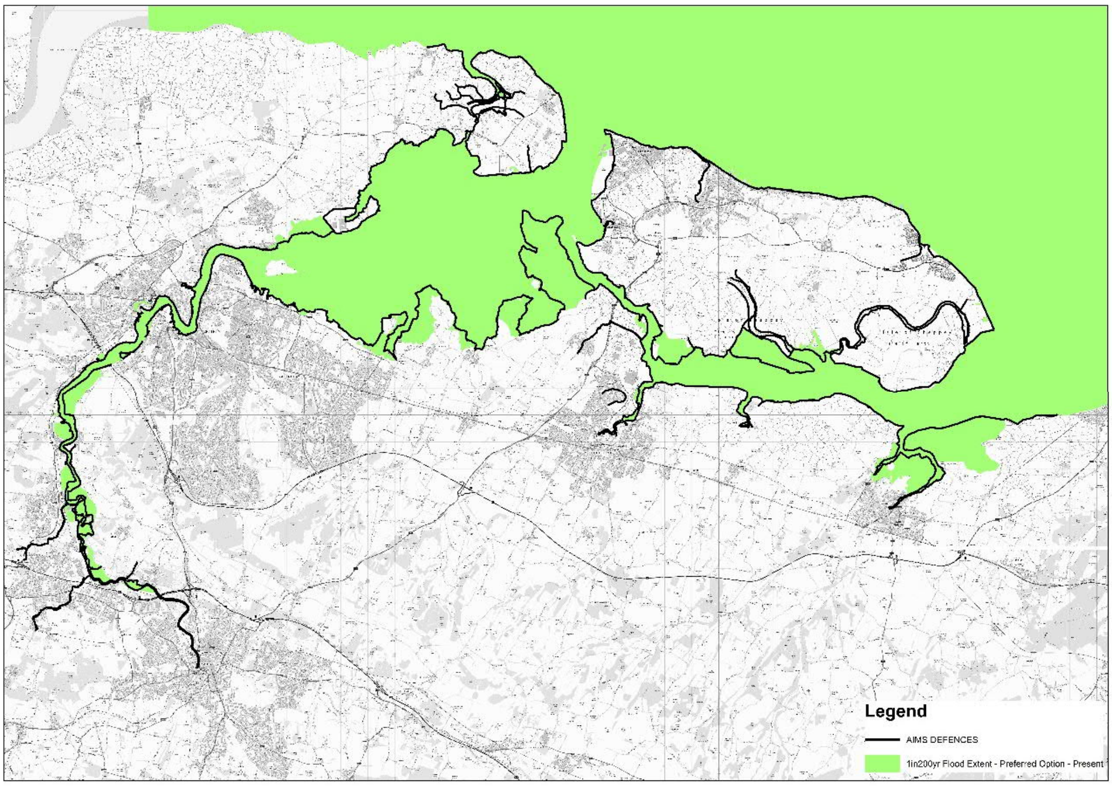
11 Preferred Option

Following the assessment of the Leading Options, the draft Strategy went through consultation with statutory consultees, land/ asset owners, the MEASS Stakeholder Engagement Group and the wider public. The aims of these consultations were to gain support for the strategy and identify if there are any key blockers/ opposition. Following the consultation, the comments were reviewed and the DLOs updated accordingly.

The majority of the comments received were relating to further details or key risks in the area and have influenced the Implementation Plan and key risks for each BA. However, a number of discussions on the HRA led to option updates.

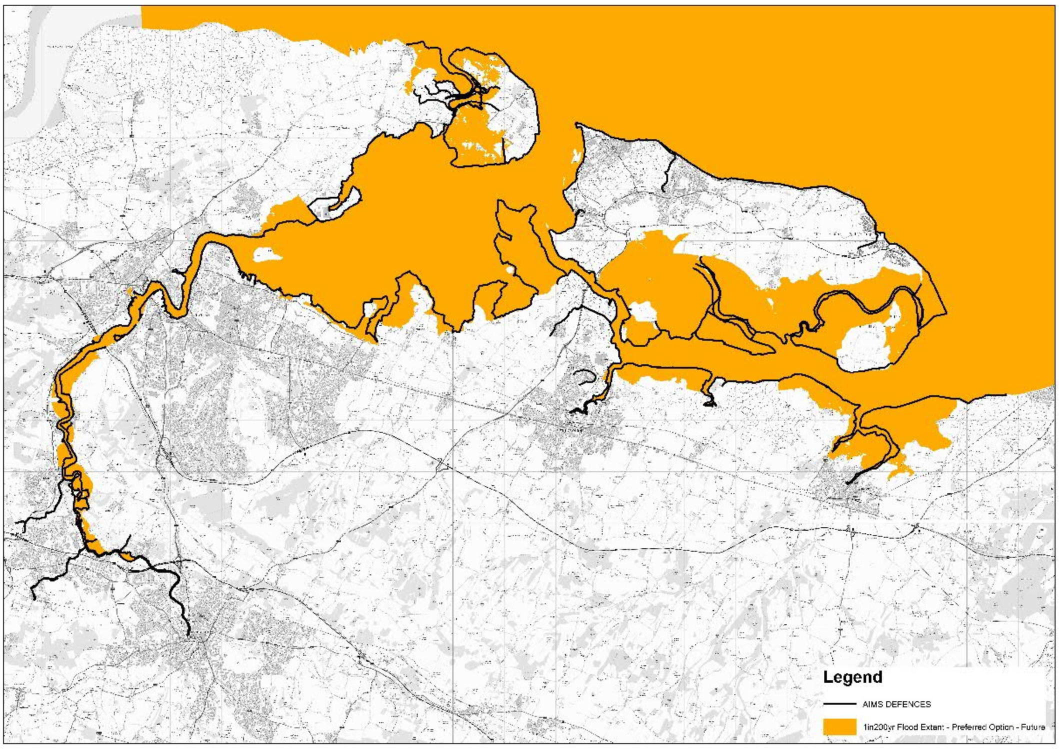
Following this the modelling undertaken in Section 9 was re-run following the small option changes. There are minimal differences, but final results are presented in Figure 161, Figure 162 and Figure 163.

Figure 161: Updated Flood Extent Following Consultation – 1in200yr Present Scenario



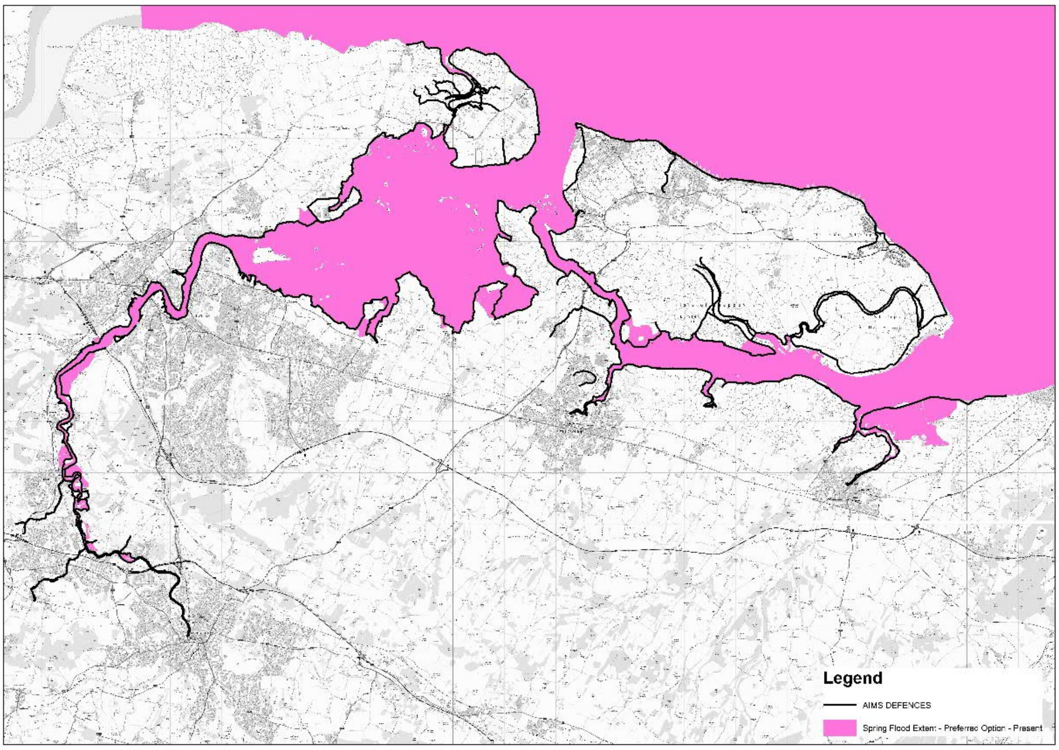
Source: Mott MacDonald, 2018 Contains OS data, © Crown Copyright and database right 2016

Figure 162: Updated Flood Extent Following Consultation – 1in200yr Future Scenario



Source: Mott MacDonald, 2018 Contains OS data, © Crown Copyright and database right 2016

Figure 163: Updated Flood Extent Following Consultation – Spring Present Scenario



Source: Mott MacDonald, 2018 Contains OS data, © Crown Copyright and database right 2016

12 References

Admiralty Tide Tables, 2013. United Kingdom and Ireland Vol 1, NP201-13.

Bartlett, J. M., 1998. Quality Control Manual for Computational Estuarine Modelling, Binnie, Black & Veatch, R&D Technical Report W113, Environment Agency, 80pp.

Brier, G. W., 1950. Verification of forecasts expressed in terms of probabilities. Monthly Weather Review, 78, 1-3.

Burd, F.H., 1992. Erosion and Vegetation Change on the Saltmarshes of Essex and North Kent between 1973 and 1988. No. 42. In: Research and Survey in Nature Conservation. Nature Conservancy Council, Peterborough.

Cundy A.B., Lafite R., Taylor J.A., Hopkinson L., Deloffre J., Charman R., Gilpin M., Spencer K.L., Carey P.J., Heppell C.M., Ouddane B., De Wever S. and Tuckett A. 2007. Sediment transfer and accumulation in two contrasting salt marsh/mudflat systems: the Seine estuary (France) and the Medway estuary (UK). Hydrobiologia. 588 (1):125-134.

Deloffre, J. R. Verney, R. Lafite, P. Lesueur, S. Lesourd, A.B. Cundy. 2007. Sedimentation on intertidal mudflats in the lower part of macrotidal estuaries: Sedimentation rhythms and their preservation. Marine Geology. 241 (2007): 19–32

Danish Hydraulic Institute (DHI), 2006. MIKE 21 Flow Model, Mud transport Module (MT), User's Manual, 80pp.

Environment Agency, 2010. Relationship of Turbidity to Suspended Particulate Matter in Transitional Waters: Justification to replace SPM measurement with field turbidity measurement for Water Framework Directive. Coleman Marine Monitoring Officer 1 (Data)

Environment Agency, 2011. Parameter values used in coastal dispersion modelling for radiological assessments. Report: SC060080/R3

Environment Agency, 2015. Kent and South London Winter 2013/2014 floods, December 2013 tidal surge. V0.1 Final Report June 2015.

Esteves, L. S. and Williams, J. J. 2015. Changes in coastal sediment dynamics due to managed realignment. Coastal Sediments 2015 (San Diego, USA, 11 – 15 May 2015), 14p, DOI: 10.1142/9789814689977_0165.

Evans, G. P., 1993. A framework for marine and estuary model specification in the UK. Report No. FR0374, Foundation for Water Research, 58pp.

French, P.W., 1999. Managed retreat: a natural analogue from the Medway Estuary, UK. Ocean & Coastal Management 42: 49-62.

Friess, D. A., Möller, I., Spencer, T., Smith, G. M., Thomson, A. G., & Hill, R. A. 2014. Coastal saltmarsh managed realignment drives rapid breach inlet and external creek evolution, Freiston Shore (UK). Geomorphology, 208, 22-33.

Halcrow, 2010. Medway and Swale Shoreline Management Plan - Appendix C: Baseline Process Understanding.

Halcrow, 2010a. Isle of Grain to South Foreland Shoreline Management Plan Review - Appendix C: Baseline Process Understanding

HR Wallingford, 2002e. London Gateway Port Development. Technical Report: Results and implications of further flow, sediment transport and morphological studies. Appendix B – Sediment transport and morphological studies. HR Wallingford Report EX4632.

HR Wallingford Ltd, June 2005. Water Quality Model Development for the Medway and Swale. Report EX4662 (Revision 1), June 2005.

JBA Consulting. 2013. North Kent Coastal Modelling Volume 2 - Isle of Grain, Medway, Swale up to and including Whitstable – Final report. August 2013.

Khanpour, M., Zarrati, A. R., Kolahdoozan, M., Shakibaeinia, A. & Amirshahi, S. M., 2016. Mesh-free SPH modeling of sediment scouring and flushing. Computers & Fluids, 129, 6-78.

Kirby, R., 2002. Chapter 4: Distinguishing accretion from erosion-dominated muddy coast. From Muddy coast of the word: Process, deposition and function. Elsevier Science

Kirby, R. 2013. The Long-term sedimentary regime of the outer Medway Estuary. Ocean & Coastal Management. 79 (2013): 20-33.

Lumborg, U. & Windelin A., 2003. Hydrography and cohesive sediment modelling: application to the Rømø Dyb tidal area. Journal of Marine Systems, 38,287-303.

Mott MacDonald. 2017. Option Technical Report – In progress.

Mott MacDonald. 2017. MEASS Strategy Report – In progress.

Mott MacDonald. 2016. Coastal Squeeze Section (Technical Note). February 2016.

Mott MacDonald. 2015. Medway Estuary and Swale Strategy - Option Appraisal Method Statement. November 2015.

Mott MacDonald, December 2007. Lower Medway, 2D Modelling & Flood Risk mapping, Phase 5. Reference 230869/01/A.

Pontee, N. I., 2015. Impact of managed realignment design on estuarine water levels. In Proceedings of the Institution of Civil Engineers-Maritime Engineering, 168(2), 48-61. Thomas Telford Ltd.

Port of London Authority, 2014. Maintenance Dredge Protocol and Water Framework Directive Baseline Document.

Symonds, A. M., & Collins, M.B. 2007. The establishment and degeneration of a temporary creek system in response to managed coastal realignment: The Wash, UK. Earth Surface Processes and Landforms, 32, 1783–1796.

Townend, I. H., 2008, March. Hypsometry of estuaries, creeks and breached sea wall sites. Proceedings of the Institution of Civil Engineers-Maritime Engineering, 161(1), 23-32. Thomas Telford Ltd.

Vandenbruwaene, W., Maris, T., Cox, T. J. S., Cahoon, D. R., Meire, P., & Temmerman, S. 2011. Sedimentation and response to sea-level rise of a restored marsh with reduced tidal exchange: Comparison with a natural tidal marsh. Geomorphology, 130(3–4), 115-126.

Watt, C.W., T.J Tolhurst,K.S Black,A.P Whitmore. In situ measurements of erosion shear stress and geotechnical shear strength of the intertidal sediments of the experimental managed realignment scheme at Tollesbury, Essex, UK. Estuarine, Coastal and Shelf Science, 58 (3), 611-620

Williams, J. J., Numerical Model Calibration and Validation Guidance. Coastal Engineering (submitted).

Williams, P. B., Orr, M. K., & Garrity, N. J. 2002. Geomorphic Design Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects. Restoration Ecology, 10(3), 577-590.

Wilmott, C.J., 1981. On the validation of models. Physical Geography 2, 184–194.

Whitehouse, R. J., Soulsby, R. L., Roberts, W. & Mitchener, H. J., 2000. Dynamics of estuarine muds. Thomas Telford.

Xiao, Y., Zhou, G. & Yang, F. S., 2016. 2D numerical modelling of meandering channel formation. Journal of Earth System Science, 125(2), 251-267.

Appendices

A. Water Level Measurements

A.1 Introduction

Following an appraisal of available data it was identified that additional measurements of water levels were required to improve the calibration of the MIKE21 FM/HD model for the Medway-Swale Estuary Strategy study. Consequently, with the assistance of the Environment Agency (EA), Level Troll 400 pressure sensors (PS) were deployed to measure water levels on 20/07/2015. Level Troll 400 pressure sensors (PS) Level Troll 400's are accurate, fully autonomous instruments which are capable of measuring the total pressure of the atmosphere and the water column. They also record water temperature used in subsequent data processing. PS1 was deployed from the southern Sheppey crossing road support pillar (Figure 1) and PS2 at Shell Ness at the mouth of the Swale Estuary at the eastern end of the Isle of Sheppey (Figure 164).

Figure 164: Pressure sensor (PS) deployment locations

Source: Google Earth.

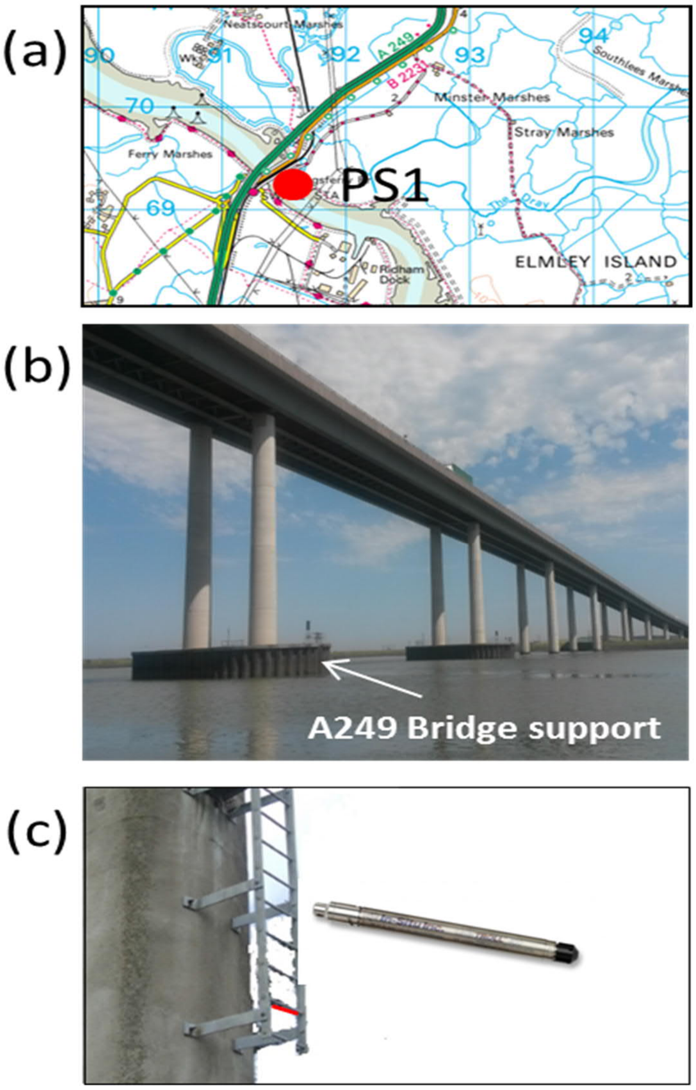
A.2 Deployment

Using a small canoe to access the access ladder to the southern bridge support pillar, PS1 was deployed from the lowest rung using a wire to suspend it beneath the water surface at low water (Figure 165). PS2 was attached using a stainless steel jubilee clip to a stout wooded pole hammered approximately 1.5m into the soft estuarine sediments offshore from Shell Ness (Figure 166). The deployment method statement for the instruments provided to the EA is given in Appendix B.

The location of PS1 (Sheppey Crossing) and the elevation referenced to AOD was determined from on-site field measurements and drawings provided by the Highways Agency (Figure 165;

Table -35).

Figure 165: Deployment location for PS1: (a) Sheppey crossing; (b) southern bridge support; and (c) PS1 deployed beneath the bridge access support access ladder (always submerged).



Source: (a) Streetmap; (b) & (c) Mott MacDonald.

The location of PS2 (Shell Ness) and the elevation referenced to AOD was measured in the field by Omega Geomatics Ltd for the EA using the Leica Smartnet Network (Figure 166; Figure 167;

Table -35).

Figure 166: Deployment location for PS2: (a) Shell Ness; (b) view of mudflats looking east across the mouth of the Swale Estuary; and (c) PS2 deployed adjacent to a drainage channel at the lowest accessible access location (submerged for approximately half the tidal cycle).

(a)

(b)

(c)

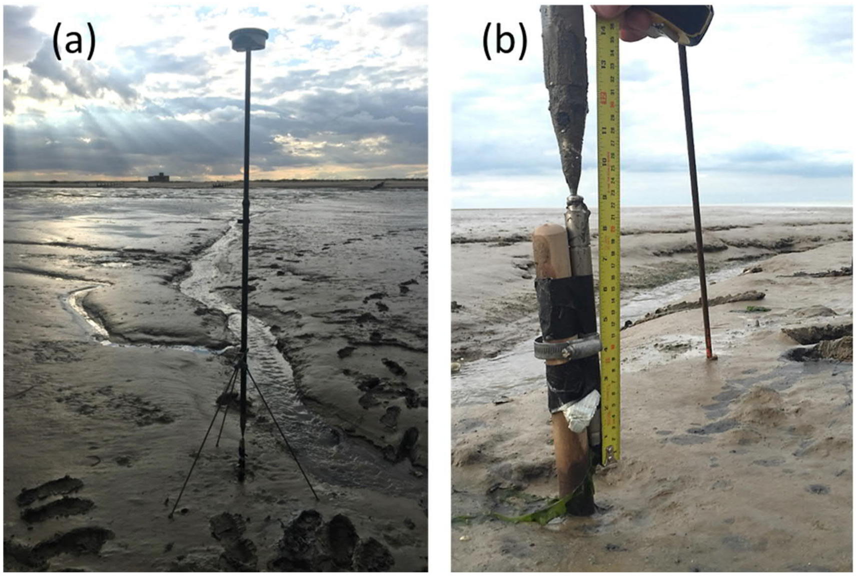
Source: (a) Streetmap; (b) & (c) Environment Agency.

Table -35: Measured locations and elevations of PS1 and PS2 and the benchmark at Shell Ness.

Location	mE	mN	mAOD
PS1 (Sheppey crossing)	591349.439	169372.215	2.135
PS2(Shell Ness)	605478.228	167554.440	0.317
Benchmark E20730270	605191.240	168167.932	4.132

Source: Omega Geomatics Ltd.

Figure 167: Measuring the location of PS2 at Shell Ness on 29 July, 2015: (a) Leica station positioned above PS2; (b) close up of position measurement.



Source: Omega Geomatics Ltd.

Measurements of tidal water level and water temperature were obtained at 10 minute intervals during the period spanning 10:00 on 20/07/2015 to 10:00 on 17/08/2015. This sampling interval was judged to be adequate to record the local tidal characteristics. With the assistance of the EA the sensors were recovered on 17/08/2015 and the recorded data was downloaded using In Situ[4] software.

Meteorological conditions during the deployment including barometric pressure, air temperature and wind speed and direction were obtained from the Sheerness weather station[5].

A.3 Data analysis

While an approximation to the actual water depth above the sensor measured by the instruments is provided through the In Situ software, account is not taken of variations in atmospheric pressure and water temperature (affecting density) and thus post-processing of the raw pressure signal was undertaken by MM using a Matlab script to obtain corrected water depth data.

Water depth, h (m), is related to the pressure, P (N/m^2), by

$$h = P/\rho g \qquad \text{(Eq. A1.1)}$$

where ρ is the water density (kg/m^3) and g is the acceleration due to gravity (9.81 m/s^2). Since the pressure sensors are unvented, they record total pressure and thus the atmospheric pressure must be subtracted from the total pressure data to obtain the pressure attributable to the water column only. Interpolated atmospheric pressure (N/m^2) data 10 sampled at minute intervals spanning 20/07/2015 to 17/08/2015 were obtained for Sheerness and subtracted from the total pressure recorded by the pressure sensors.

---

4 https://in-situ.com/

5 http://www.wunderground.com/

The density of sea water was calculated as a function of salinity and temperature using

$$r = (A1F1 + A2F2 + A3F3 + A4F4)*10^3 \text{ [kg/m}^3\text{]} \qquad \text{(Eq. A1.2)}$$

where

A = (2T-200)/160

B = (2Sal-150)/150

T = Temperature

Sal = salinity (assumed to be 20ppt, Bassindale, 1943)

A1 = 4.032219 G1 + 0.115313 G2 + 3.26*10-4 G3

A2 = -0.108199 G1 + 1.571*10-3 G2 - 4.23 * 10-4 G3

A3 = -0.012247 G1 + 1.74*10-3 G2 - 9.0*10-6 G3

A4 = 6.92*10-4 G1 - 8.7*10-5 G2 - 5.3*10-5 G3

and

F1 = 0.5, F2 = A, F3 = 2A2 – 1, F4 = 4A3 - 3A, G1 = 0.5, G2 = B and G3 = 2B2 – 1.

Eq. A1.2 yields the value 1015 kg/m3 for ρ. This value was used in all subsequent calculations.

A further correction to the pressure data concerns the distance between the bed and the pressure sensor itself. On deployment this distance was nominally 25 cm. It remains unknown whether or not the bed level changes during the deployment as a result of sediment erosion/accretion and thus some uncertainty remains.

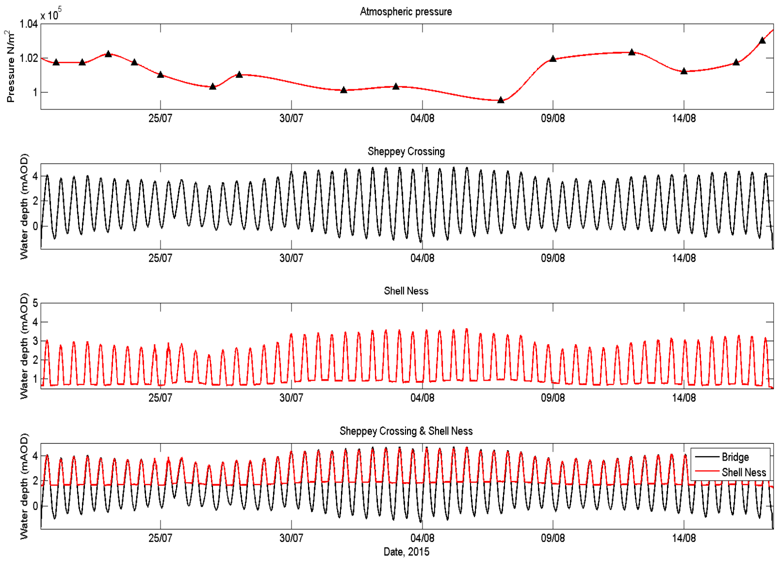
A.4 Results

Time-series plots of the data spanning the period 10:00 on 20/07/2015 to 10:00 on 17/08/2015 are shown in Figure 168.

Figure 168 shows: (a) the atmospheric pressure record at Sheerness; (b) water depth measured from the Sheppey crossing support pillar; (c) water depth measured at Shell Ness; and in (d) plots in (b) and (c) are combined. The data show that PS1 was beneath the water at all states of the tide with maximum and minimum levels of 4.71 mAOD and -1.86 mAOD, respectively. The data show also that PS2 was only submerged during approximately half the tidal cycle with peak tidal levels reaching 4.64 mAOD.

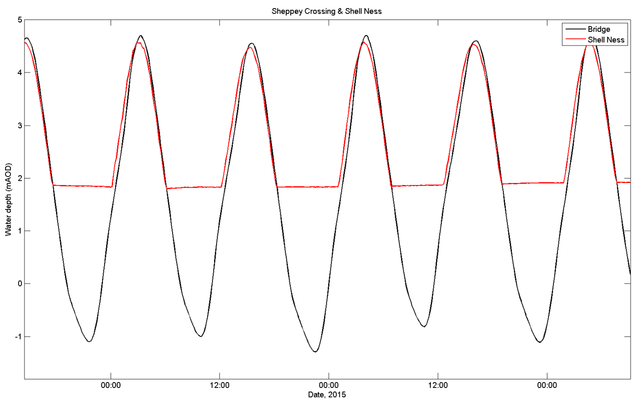
Figure 169 shows a short section of the measured water level time-series spanning approximately 3 days during Spring tides around 4 August 2015. While good agreement between water levels measured by PT1 and PT2 is shown there is a slight phase shift with high water occurring at PS2 before PS1.

Figure 168: Time-series plots showing: (a) the atmospheric pressure record at Sheerness ; (b) water depth measured from the Sheppey crossing support pillar (PS1); (c) water depth measured At Shell Ness (PS2); and (b) and (c) combined.



Source: Mott MacDonald

Figure 169: Time-series plots showing in detail water depth measured from the Sheppey crossing support pillar (PS1) and at Shell Ness (PS2) over a period of approximately three days during Spring tides around 4 August 2015.



Source: Mott MacDonald

A.5 Conclusions

- The Level Troll 400 pressure sensors have provided accurate water level data at two locations in the vicinity of the proposed Greatham South Managed Realignment site;
- The data are assessed as being accurate and reliable and thus fit-for-purpose with regards to model calibration; and
- These data will greatly assist in the MIKE 21 FM/HD model calibration process.

The study has demonstrated that the use of pressure sensors is a relatively simple, accurate and cost-effective means of obtaining water level data at locations where existing data are lacking. Their use in future studies is therefore recommended.

A.6 References

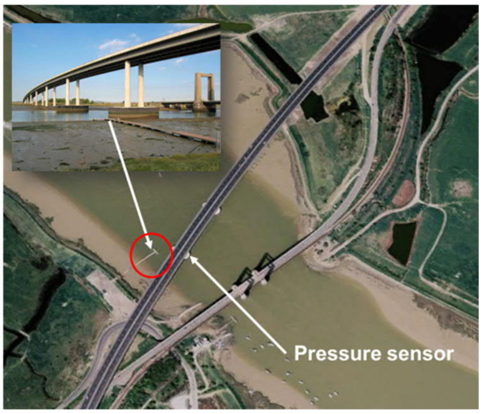
Bassindale, R., 1943. A Comparison of the Varying Salinity Conditions of the Tees and Severn Estuaries. Journal of Animal Ecology, 12(1), 1-10.

B. Water Sampling

B.1 Introduction

Efforts to identify suitable data for calibration of the MEASS model with regards to suspended sediment have met with very limited success and it was judged necessary to obtain samples to assist the calibration process. Advantage was taken of the opportunity to undertake sampling work while also deploying the two pressure sensors in the Swale. The location chosen was from a pontoon extending into the Swale beneath the Sheppey crossing (Figure 170). This site was opposite the deployments site of the pressure sensor on the bridge support pier.

Figure 170: Location of water sampling

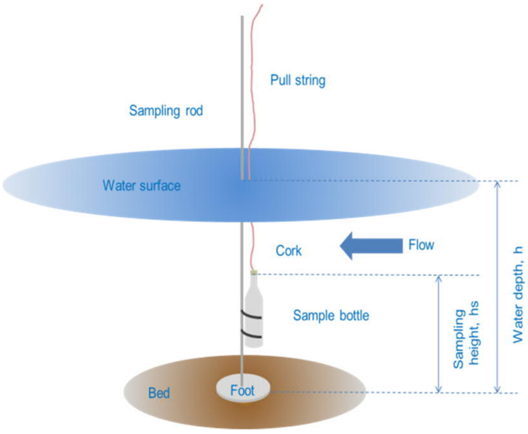


Source: Google Earth & Mott MacDonald

B.2 Method

After first measuring the water depth, h, a clear plastic sample bottle (250 ml) marked with a sample identification number was secured to the sampling rod at a height equal to half the water depth, hs (Figure 171). A cork, attached by a pull string, was inserted into the mouth of the bottle and the bottle was lowered into the water on the sampling rod. A period of 30 seconds was allowed to ensure that any sediment disturbed by the foot was advected away from the sampling location. The cork was then removed using the pull string, allowing water to enter the bottle and thereby sample the water. When bubbles rising to the surface could no longer be observed (approx. 30s), the bottle was recovered and capped securely. Samples were obtained every 30 minutes from 12:35 to 18:35 BST on 20 July 2015. Additional samples were also obtained by the same method at 25 cm above the bed at 30 minute intervals between 13:35 and 18:35 BST.

Figure 171: Schematic of the water sampling method employed in the Swale



Source: Mott MacDonald

B.3 Sampling record

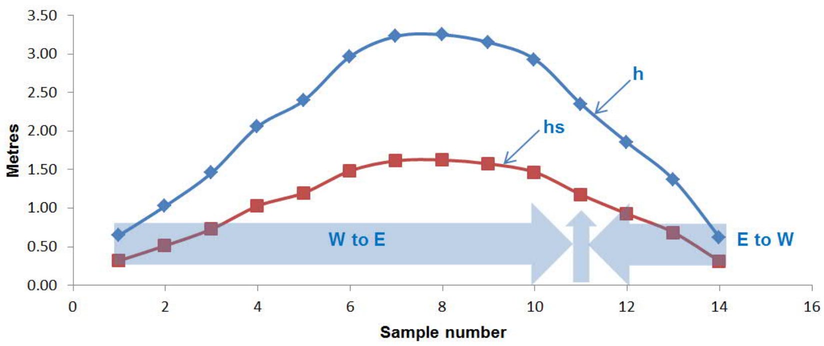
Samples obtained are summarised in Table 36. These include mid-water samples (1-14) and near-bed samples (3b-14b). It was noted that all samples appeared visually to have relatively low suspended load.

Table 36: Summary of water samples obtained on 27/07/2015.

Sample No.	Time	Water depth (m)	Mid-water depth (m)	Mid-water sample?	Observed current direction
1	12:35	0.65	0.32	NO	Currents W to E
2	13:05	1.03	0.52	NO	Currents W to E
3	13:35	1.46	0.73	YES (3b)	Currents W to E
4	14:05	2.06	1.03	YES (4b)	Currents W to E
5	14:35	2.4	1.2	YES (5b)	Currents W to E
7	15:35	3.23	1.62	YES (7b)	Currents W to E
8	16:05	3.25	1.63	YES (8b)	Currents W to E
9	16:35	3.15	1.58	YES (9b)	Currents W to E
10	17:05	2.93	1.47	YES (10b)	Currents W to E
11	17:35	2.35	1.18	YES (11b)	Slack
12	18:05	1.85	0.93	YES (12b)	Currents E to W
13	18:35	1.37	0.69	YES (13b)	Currents E to W
14	19:05	0.62	0.31	YES (14b)	Currents E to W

Figure 172 shows the measured temporal variation in water depth and associated mid-water sampling depths during the sampling period. Also indicated is the approximate time of slack water and flow reversal.

Figure 172: Measured temporal variation in water depth and associated mid-water sampling depths.



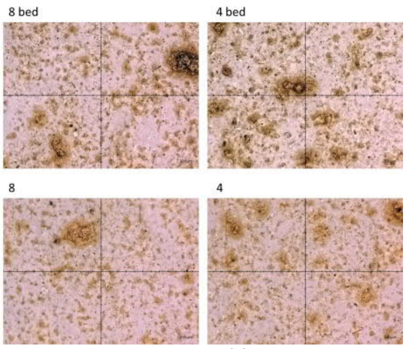
Source: Mott MacDonald

B.4 Sample analysis

The volume (ml) of each sample (V) was measured and then filtered using a manual pump. Solids were retained on Whatman glass microfiber filters Grade GF/C (1.2 um particle retention). The weight (mg) of dry filters (Fd) were recorded before filtering in a balance with precision 0.0001 g.

Filters with retained solids were photographed using a high resolution 3D electronic microscope (examples shown in Figure 1).

Figure 173: Retained solids (samples 4 and 8)



Source: Mott MacDonald

Filters with retained solids were dried at 100ºC for 24h in a muffle furnace. The weight of dry filters (mg) with retained solids (Fs) were recorded when filters reached room temperature in a desiccator. The concentration (mg/l) of total retained solids (Ts) was calculated using the formula: 1000*(Fs-Fd)/V.

Organic matter was removed through the method of loss on ignition (24h in muffle furnace at 375ºC). The weight of filters with retained solids after ignition (Fi) was measured when filters reached room temperature in a desiccator. The concentration (mg/l) of suspended solids after ignition (Ti) was calculated using the formula: 1000*(Fi-Fd)/V.

B.5 Results

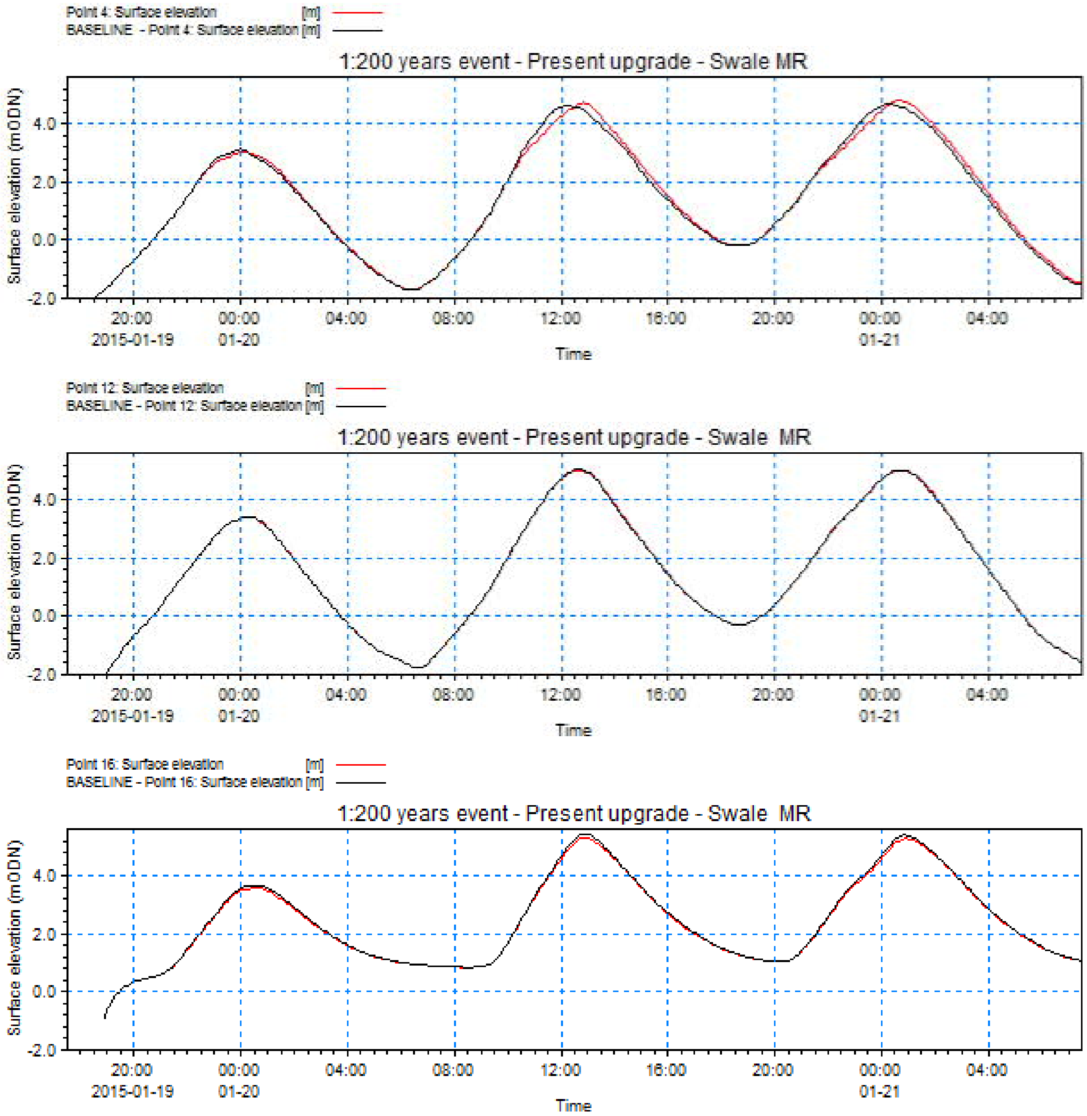
Table 37: Results of water sample analyses.

				With organics (mg/l)		Without organic (mg/l)	
Sample No.	Time	Water depth (m)	Water mid-depth (m)	SSC mid	SSC bed	SSC mid	SSC bed
4.00	14:05	2.06	1.03	41.2	42.4	29.2	25.6
8.00	16:05	3.25	1.625	56.8	33.6	33.2	13.6
13.00	18:35	1.37	0.685	56.8	85.6	42.8	60.4

Results of the water sample analysis are shown in Table 37. Peak SSC values are observed around 13:00. It was noted during sampling that during the falling tide, sediments were re-suspended by the flows draining the sides of the estuary at the sampling location. This material probably contributed to the elevated SSC values around this time.

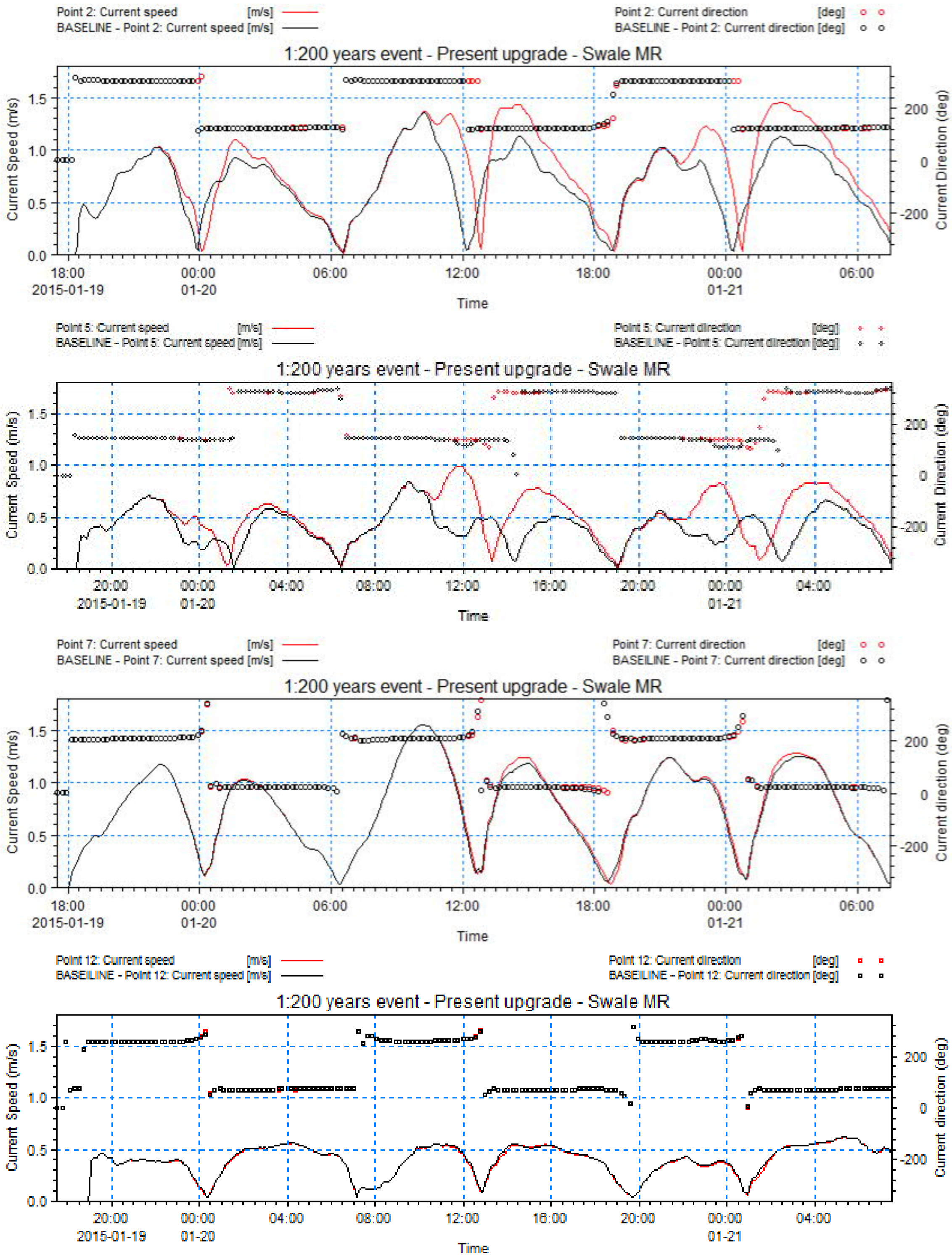
C. Swale-only managed realignment sites - 1:200-year event - Present Upgrade

Figure 174: Water level changes in the Swale (Point 4) and in the Medway (Points 12 and Point 16) for the Swale-only managed realignment sites.



Source: Mott MacDonald, 2016

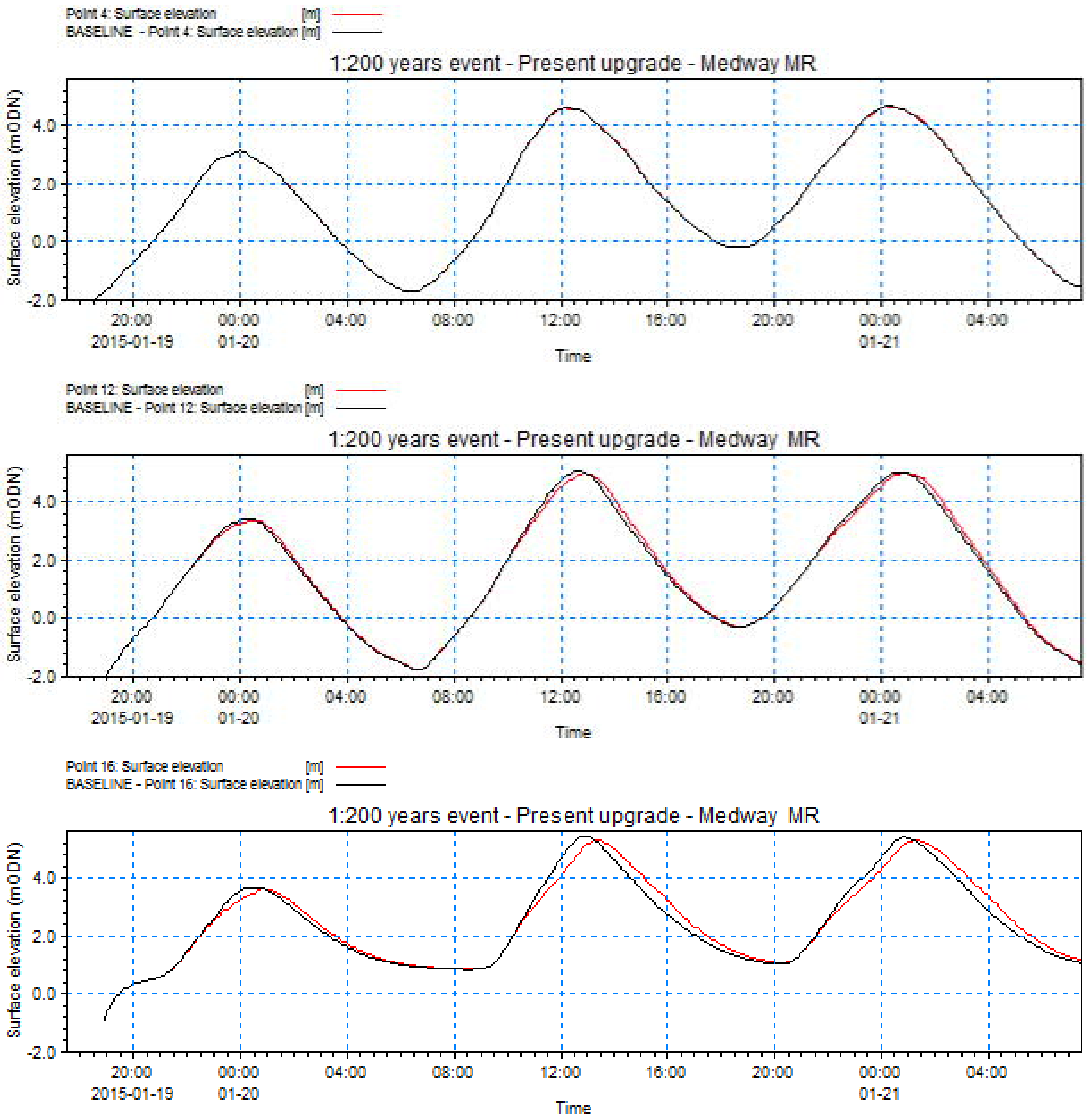
Figure 175: Current speed changes in the Swale (Point 2 and Point 5) and in the Medway (Point 7 and Point 12) for the Swale-only managed realignment sites.



Source: Mott MacDonald, 2016

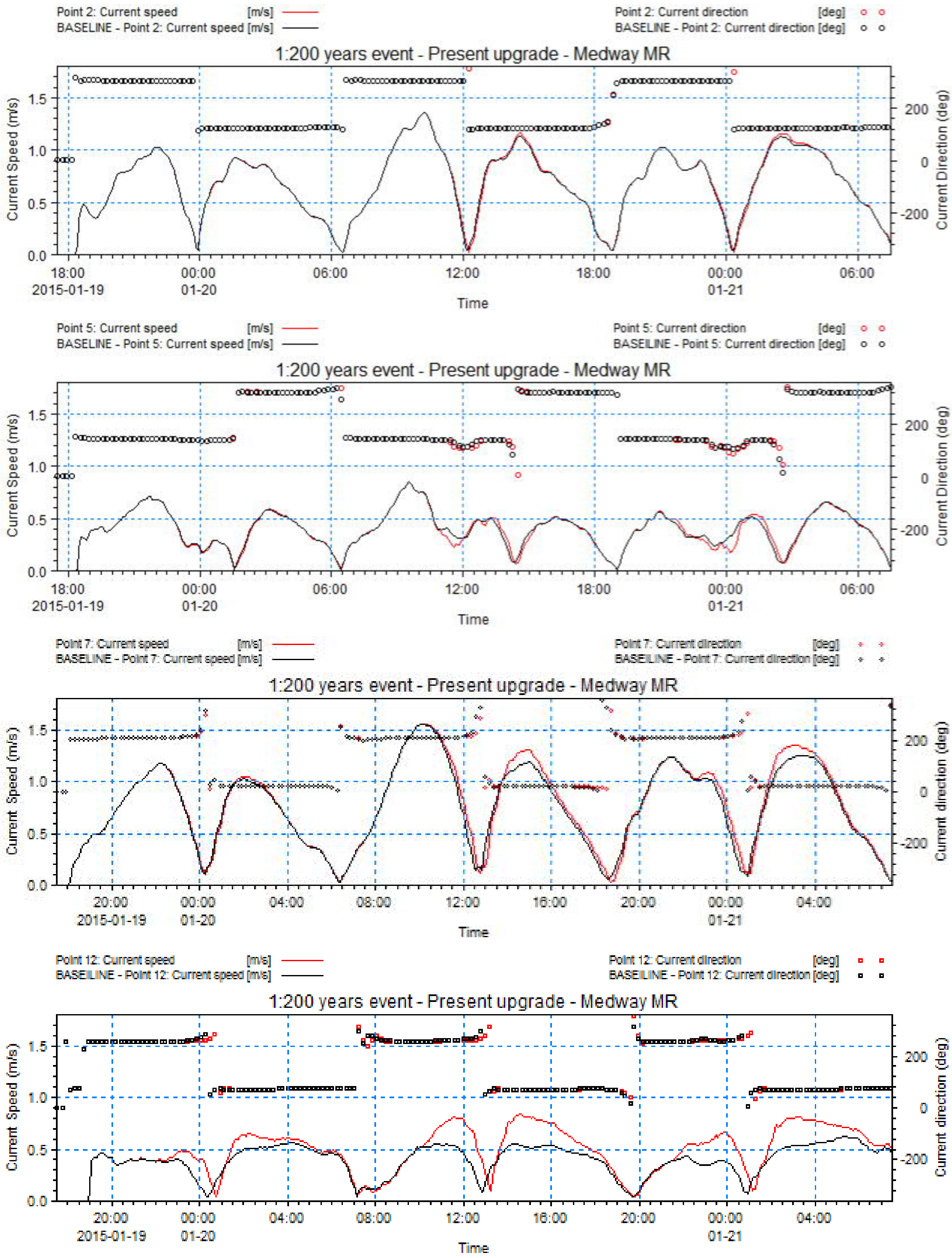
D. Medway-only managed realignment sites - 1:200-year event - Present Upgrade

Figure 176: Water level changes in the Swale (Point 4) and in the Medway (Points 12 and Point 16) for the Medway-only managed realignment sites.



Source: Mott MacDonald, 2016

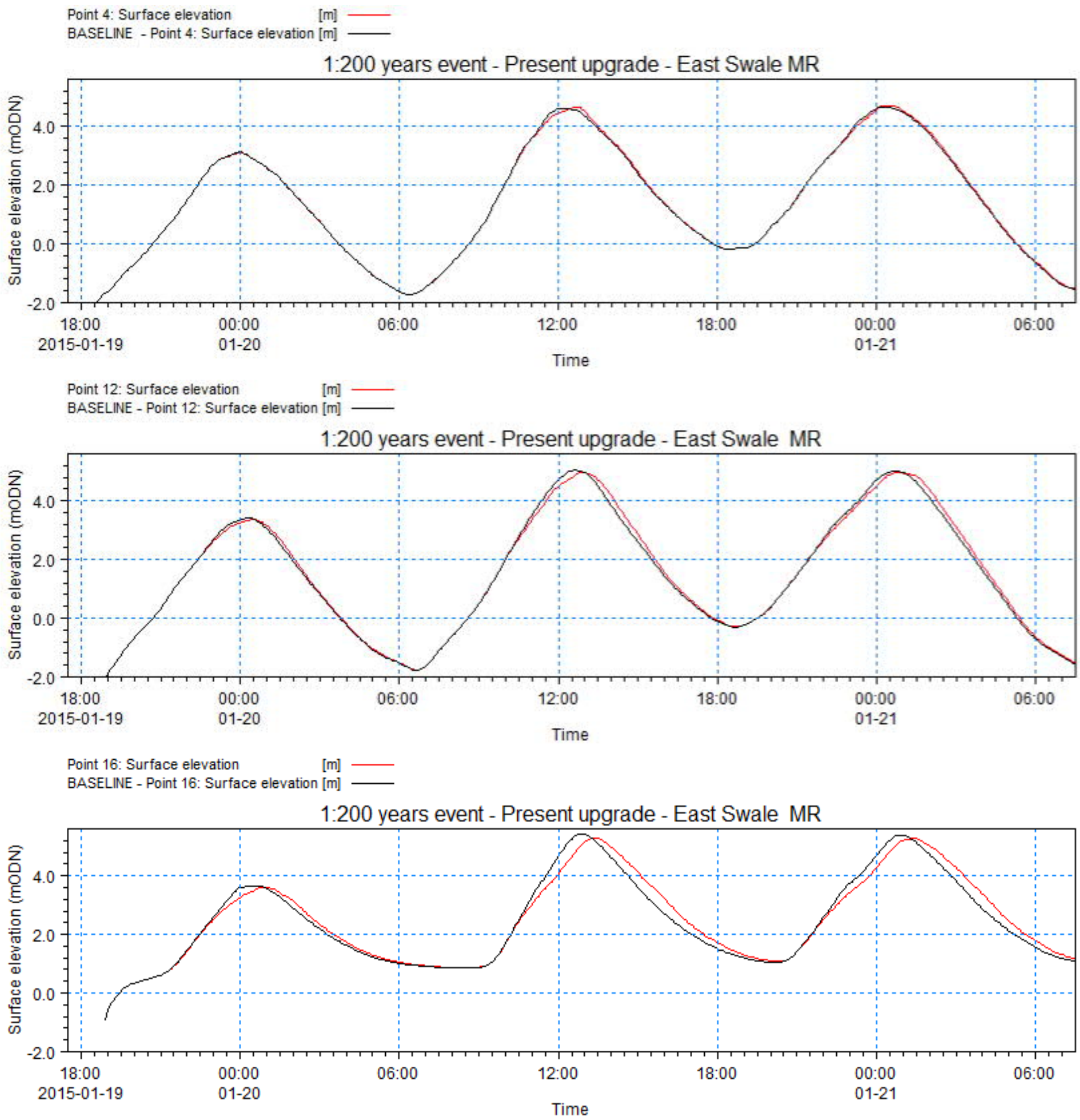
Figure 177: Current speed changes in the Swale (Point 2 and Point 5) and in the Medway (Point 7 and Point 12) for the Medway-only managed realignment sites.



Source: Mott MacDonald, 2016

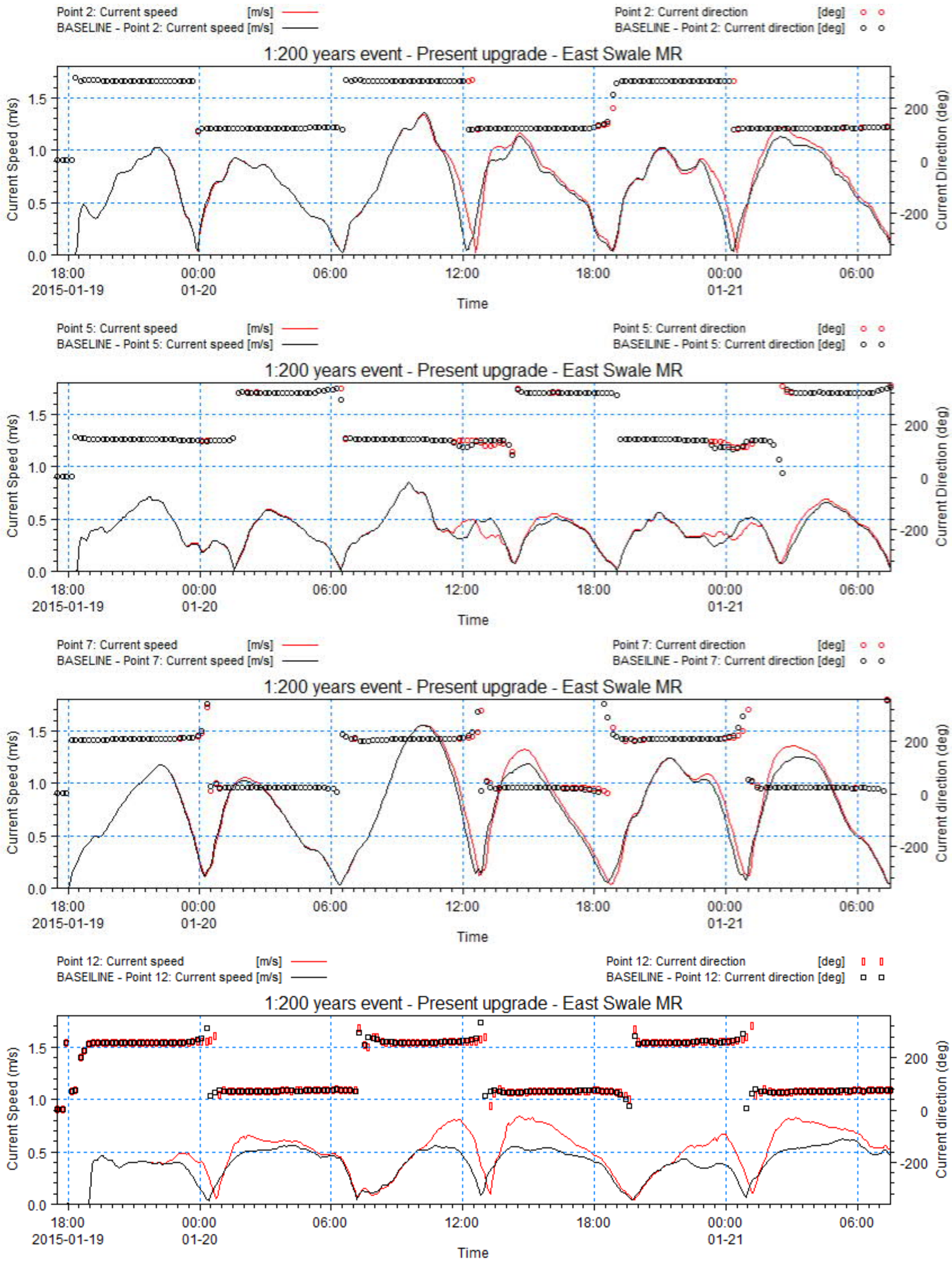
E. East Swale managed realignment sites - 1:200-year event - Present Upgrade

Figure 178: Water level changes in the Swale (Point 4) and in the Medway (Points 12 and Point 16) for the east Swale-only managed realignment sites.



Source: Mott MacDonald, 2016

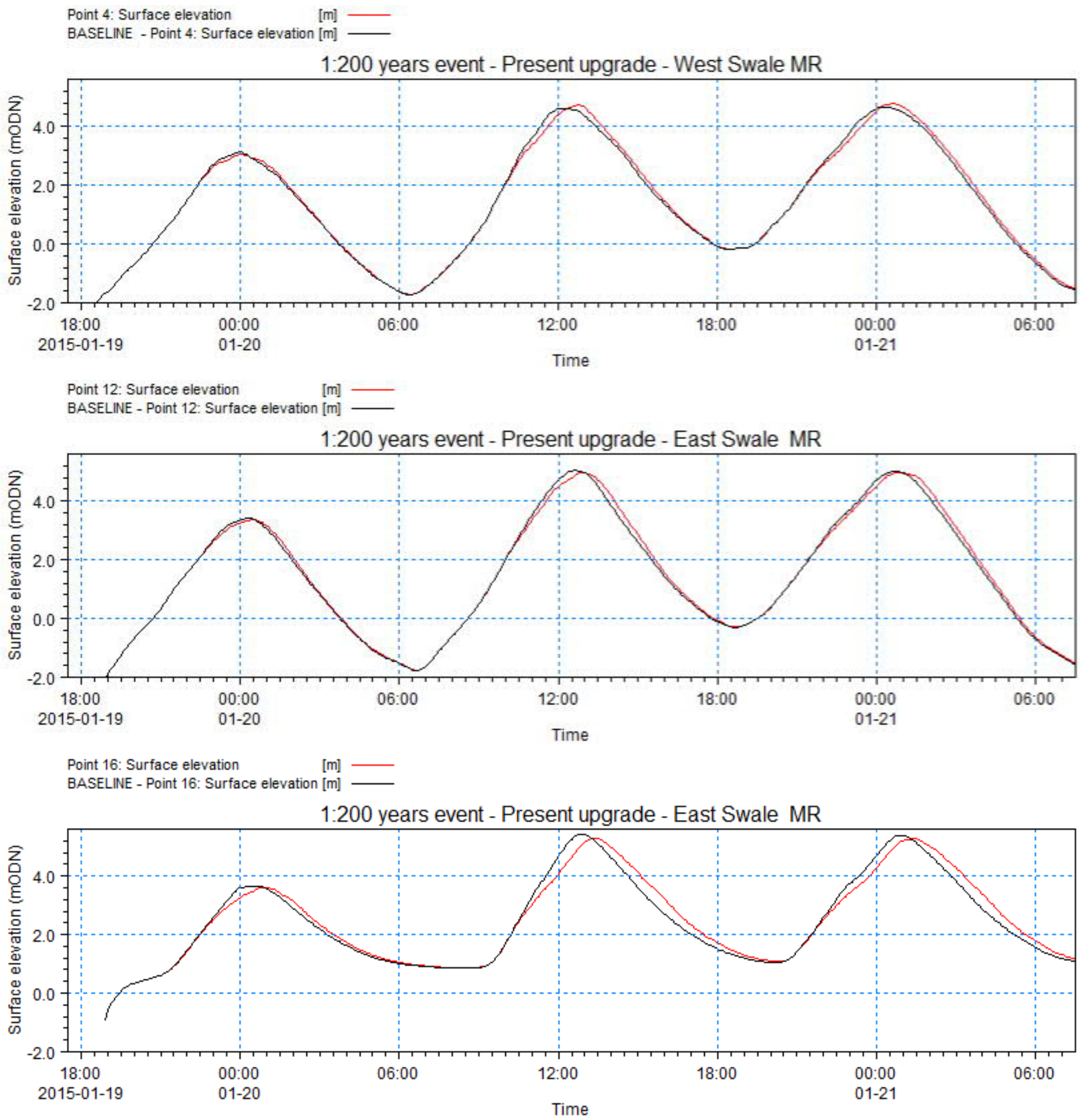
Figure 179: Current speed changes in the Swale (Point 2 and Point 5) and in the Medway (Point 7 and Point 12) for the east Swale-only managed realignment sites.



Source: Mott MacDonald, 2016

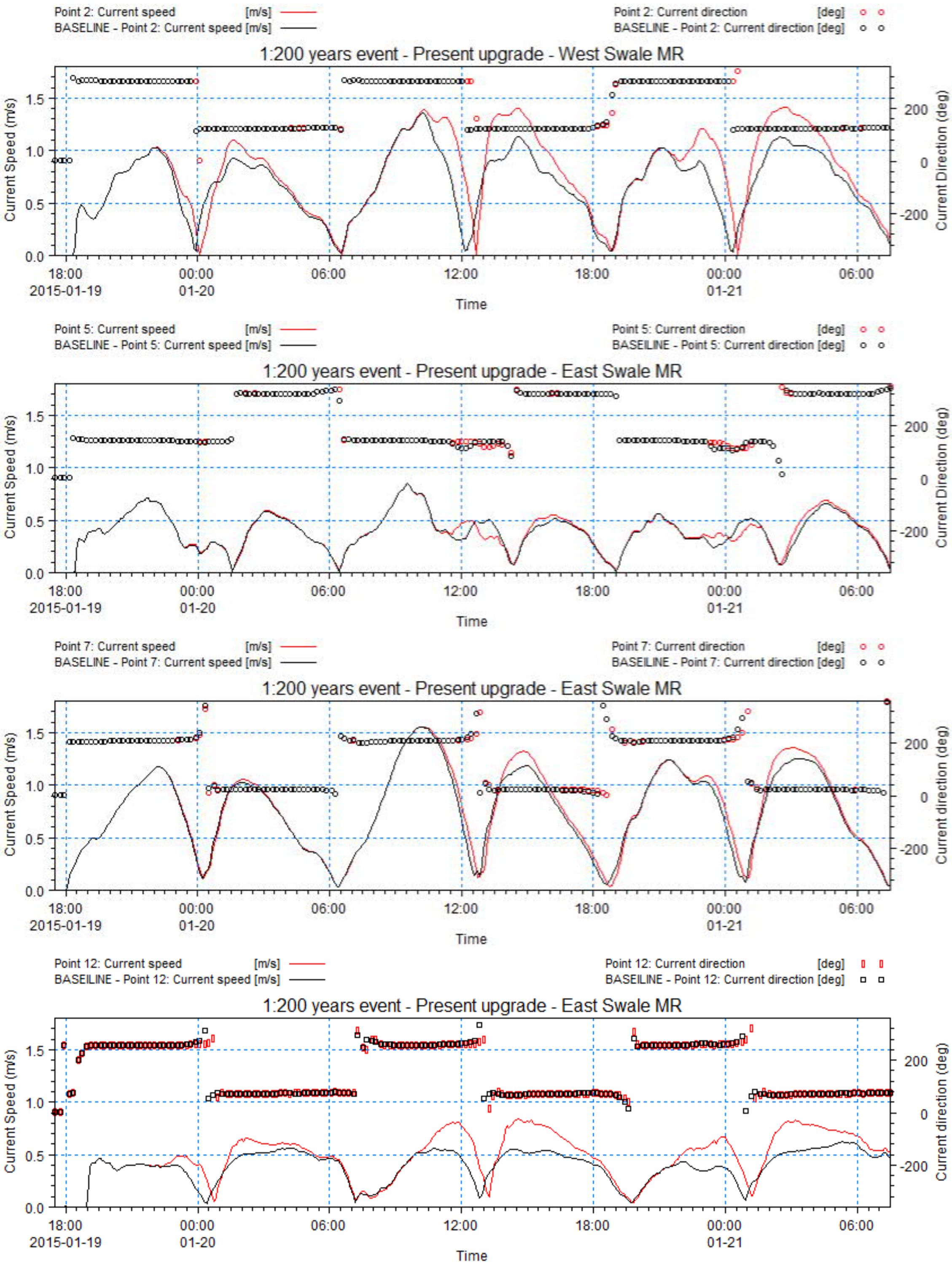
F. West Swale managed realignment sites - 1:200-year event - Present Upgrade

Figure 180: Water level changes in the Swale (Point 4) and in the Medway (Points 12 and Point 16) for the west Swale-only managed realignment sites.



Source: Mott MacDonald, 2016

Figure 181: Current speed changes in the Swale (Point 2 and Point 5) and in the Medway (Point 7 and Point 12) for the west Swale-only managed realignment sites

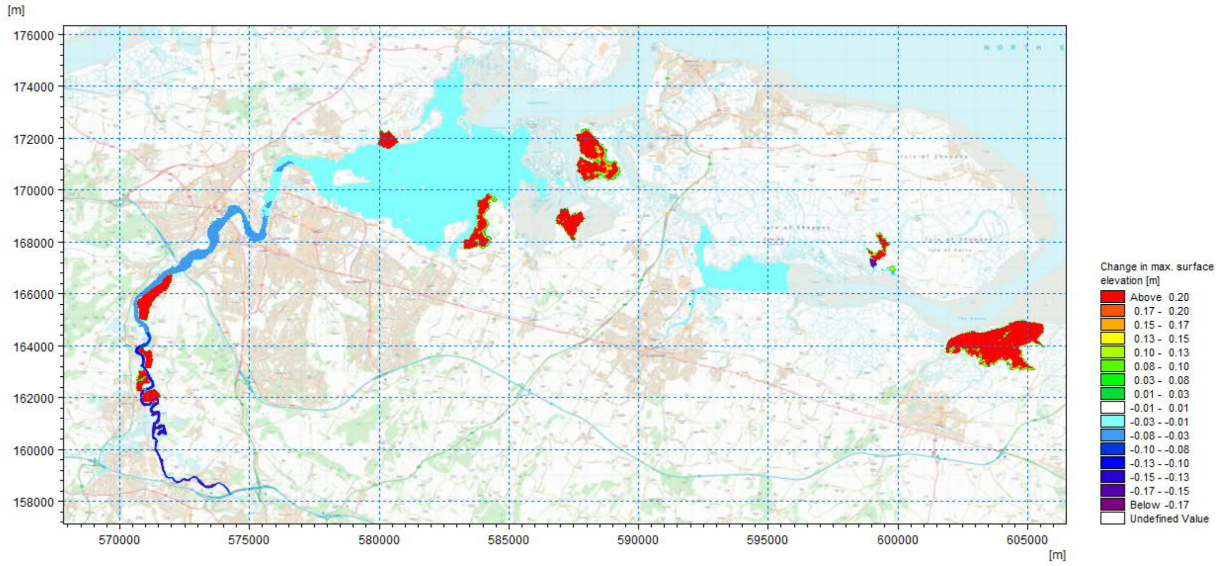


Source: Mott MacDonald, 2016

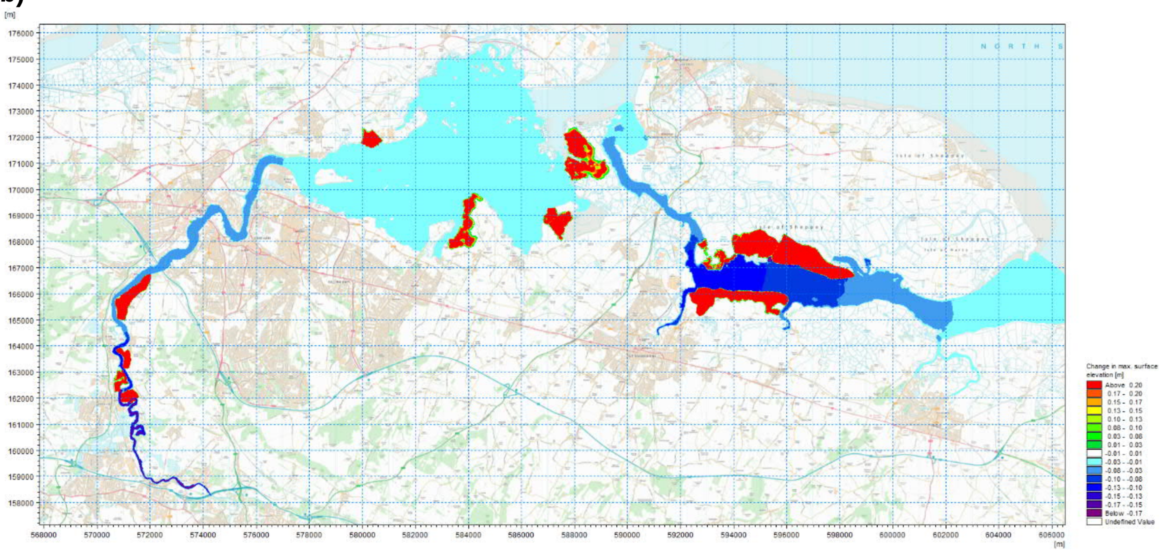
G. East Swale and West Swale managed realignment sites – Spring tide - Present Upgrade

Figure 182: Change in the maximum water level for a spring tide for: (a) east Swale-only managed realignment sites; and (b) west Swale-only managed realignment sites, (positive change indicates an increase in the water level)

(a)



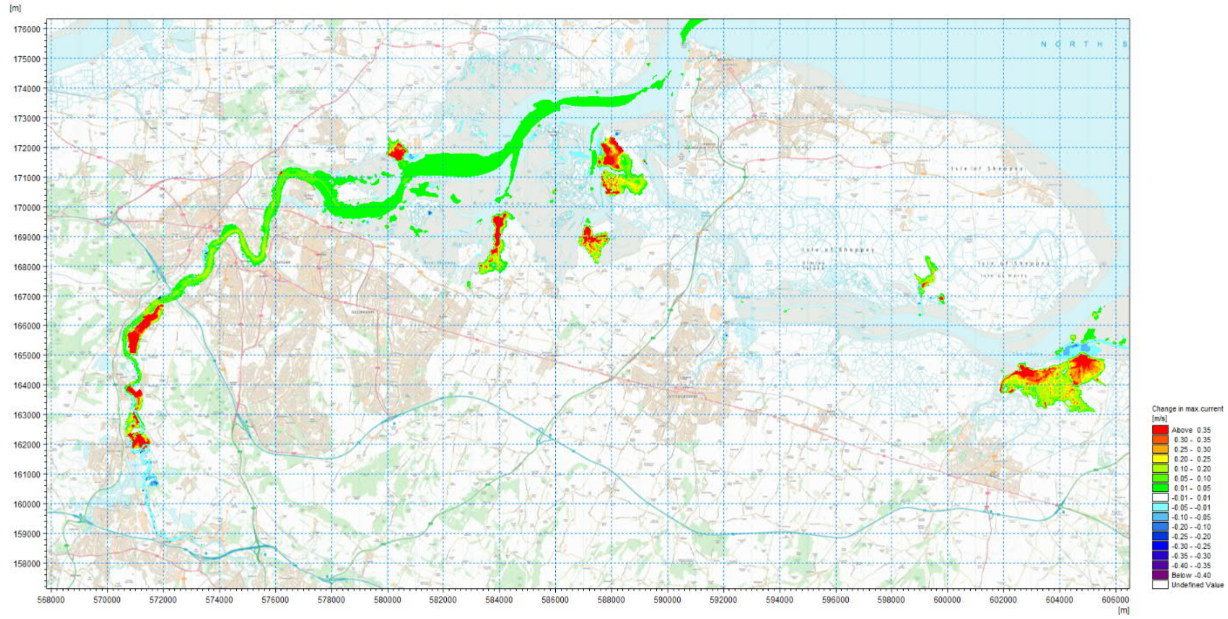
(b)



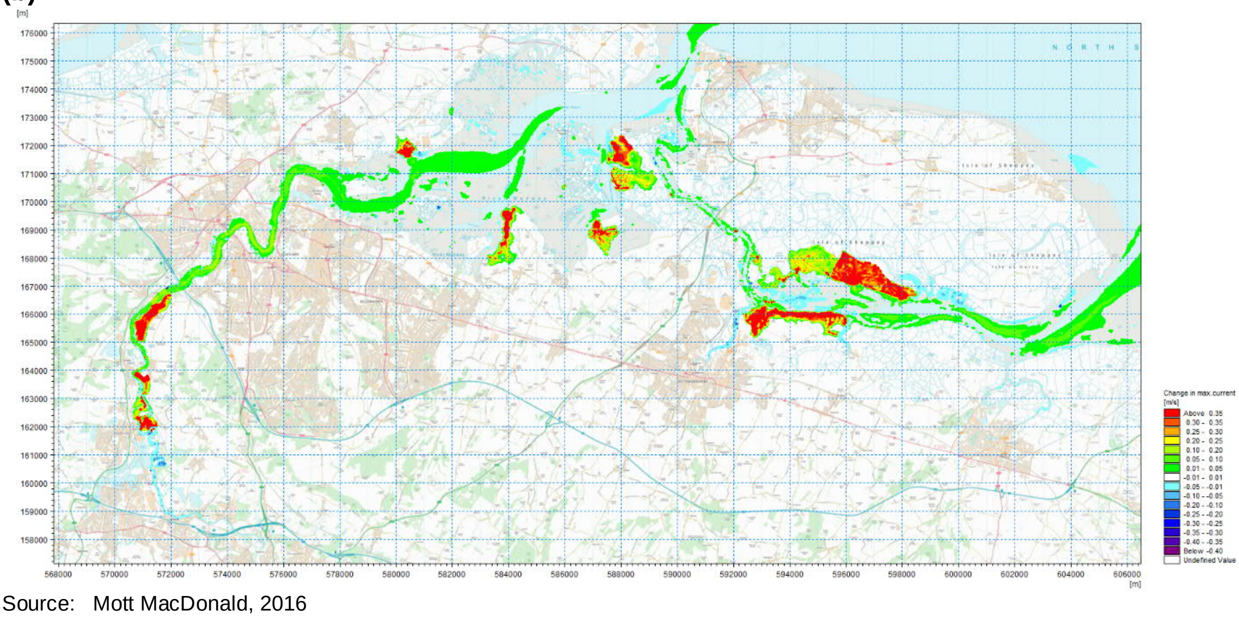
Source: Mott MacDonald, 2016

Figure 183: Change in the maximum current speed for a spring tide for: (a) east Swale-only managed realignment sites; and (b) west Swale-only managed realignment sites, (positive change indicates an increase in the current speed)

(a)



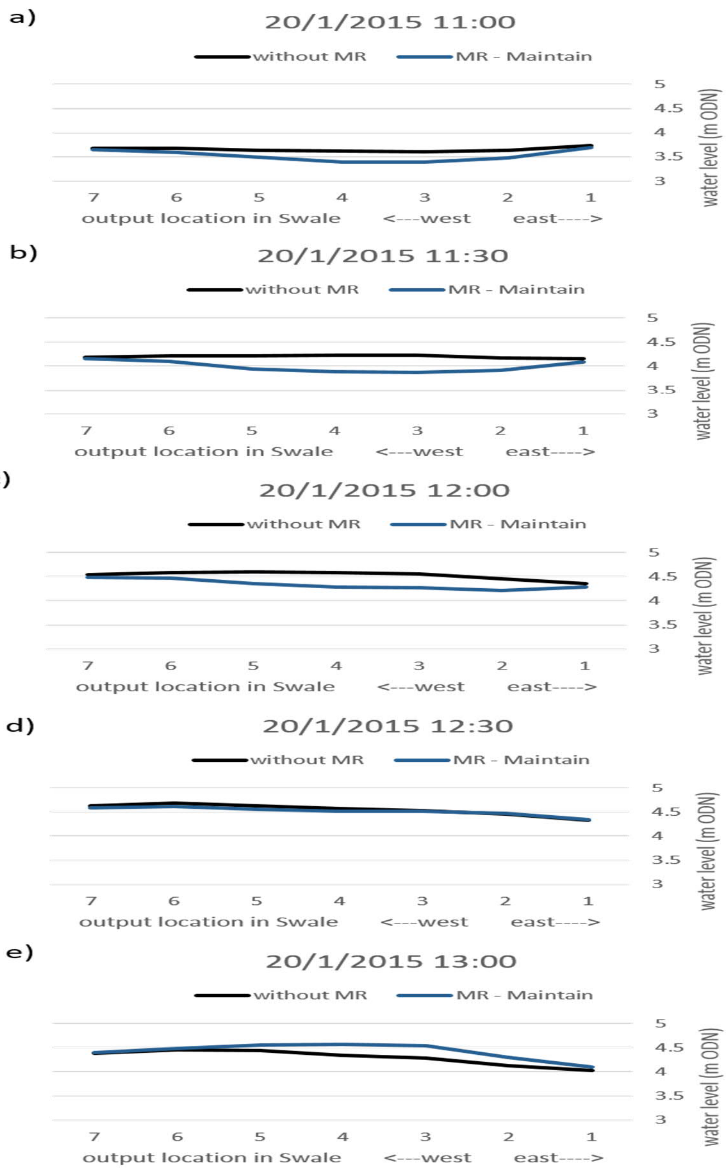
(b)



Source: Mott MacDonald, 2016

H. All managed realignment sites - 1:200-year event - Present Maintain

Figure 184: Along-estuary water levels changes through the Swale, between Point 1 (East entrance) and Point 7 (West entrance) at different stages of the tide.



Source: Mott MacDonald, 2016

mottmac.com