SECTION D – EXISTING ENVIRONMENT & IMPACT OF THE DISCHARGE(S)

Attachment D1: Marine Modelling Study Report

- **Attachment D.1a: Phase 1 Model Scoping report**
- **Attachment D.1b: Phase 2 Survey Interpretative report**
- **Attachment D.1c: Phase 3 Model Calibration report**
- **Attachment D.1d: Phase 4 Modelling report**

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Youghal Marine Modelling Study

Model Calibration Report

Irish Water

Project number: 60619448

30th September 2020

Quality information

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1. Introduction

1.1 Background

AECOM has been commissioned to complete a Marine Modelling Study to help in the assessment of discharges of treated wastewater from Youghal Wastewater Treatment Plant (WwTP) to the tidal River Blackwater Estuary.

A Licence Review of the existing Licence, which has been granted under the Wastewater Discharge Authorisation Regulations, is to be submitted to the Environmental Protection Agency (EPA) which must be supported with an assessment of the potential impacts on environmental water quality. The aim of this report is to outline the work completed to date to assess the significance of the discharges and to identify any further work which must be carried out in order to determine the environmental impact of the discharges and to inform the Licence Review.

The Marine Modelling Study is undertaken in four phases and this report is the deliverable for Phase 3: Model Calibration and Validation. The previous phases of the project have produced the deliverables listed below. Where appropriate relevant key information has been copied from them to this report.

- Phase 1: Model Scoping Report (MSR) (AECOM, 2020a).
- Phase 2: Survey Interpretive Report (SIR) (AECOM, 2020b).

1.2 Objective

The purpose of this report is to demonstrate that the numerical model of the hydrodynamics and water quality of the River Blackwater, Youghal Harbour and surrounding sea has been calibrated and validated against a range of data. This includes water levels, current (speed and direction and component vectors), temperature and salinity and different water quality parameters.

The report also sets out the sensitivity of the models to changes in input parameters. This is to demonstrate that the model outputs are not overly sensitive to perturbations, but that changes in input parameters do result in changes to the results.

Finally, the report makes the recommendation of the production runs required for the project.

1.3 Approach

The calibration of the model was undertaken in stages. The hydrodynamic model was calibrated first followed by the water quality model. The models are calibrated for four defined events as described in the Technical Standard[1] and reproduced in Table 1.1. An additional event (referred to as Event E) has also been included that utilises the data from the survey of a spring tide in January.

[1] Irish Water Technical Standards: Marine Modelling IW-TEC-100-015 Rev 2 March 2020

Table 1.1. Calibration and validation events

Event	Description
A	Calibration of the water levels against water levels generated by predicted tides and typical fluvial flows over 15 days.
B (14th to 29th January 2020)	Calibration of the water levels against observed water levels and fluvial flows over 15 days.
C (28th January 2020)	Calibration of the current speed and direction, salinity and temperature against observed or predicted current speeds and directions over 13 hours of a spring tide.
D (21st January 2020)	Validation of the current speed and direction, salinity and temperature against observed or predicted current speeds and directions over 13 hours of a neap tide.
E (17th January 2020)	Validation of the current speed and direction, salinity and temperature against observed or predicted current speeds and directions over 13 hours of a spring tide.

1.4 Sensitive Receptors

The sensitive receptors for the study area were set out and discussed in the MSR and a tiered assessment undertaken. The modelling requirements for each sensitive receptor are summarised in Table 1.2.

Table 1.2. Summary of the sensitive receptors, concerns and modelling requirements.

Receptor	Modelling requirement
WFD water bodies including (Figure 1-1): • Transitional waterbodies of Upper Blackwater Estuary, Lower Blackwater Estuary, Lackaroe (Glendine Estuary) and the Womanaugh Estuary and • Coastal waterbodies of East Celtic Sea, West Celtic Sea, Youghal Bay and Ballycotton Bay.	BOD, DIN, Ammonia, Phosphate
Designated bathing beaches Ardmore Beach, Youghal Front Strand Beach, Youghal Claycastle, Redbarn (Figure 1-2)	Bacteria (IE and EC)
Nutrient Sensitive Areas:- Lower Blackwater Estuary, Upper Blackwater Estuary (Figure 1-3).	Phosphate and DIN
Designated Shellfish Waters of Youghal Bay and Ballmacoda Bay (Figure 1-4)	Bacteria (IE and EC)[2]

[2] In the absence of a regulatory standard in the water column for shellfish waters, the Good Bathing Water Status shall be used.

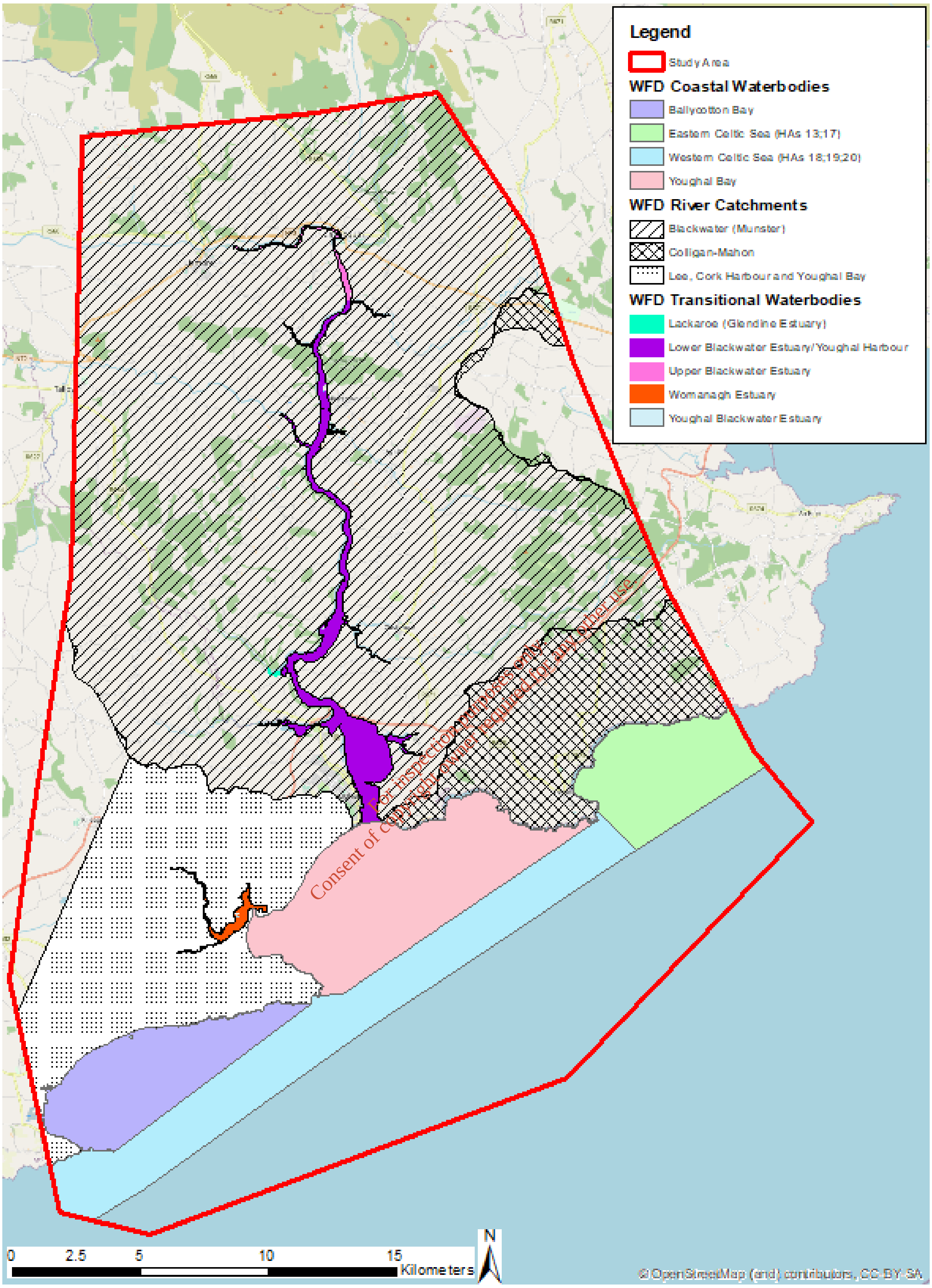


Figure 1-1. WFD River Catchments, Coastal Waterbodies and Transitional Waterbodies

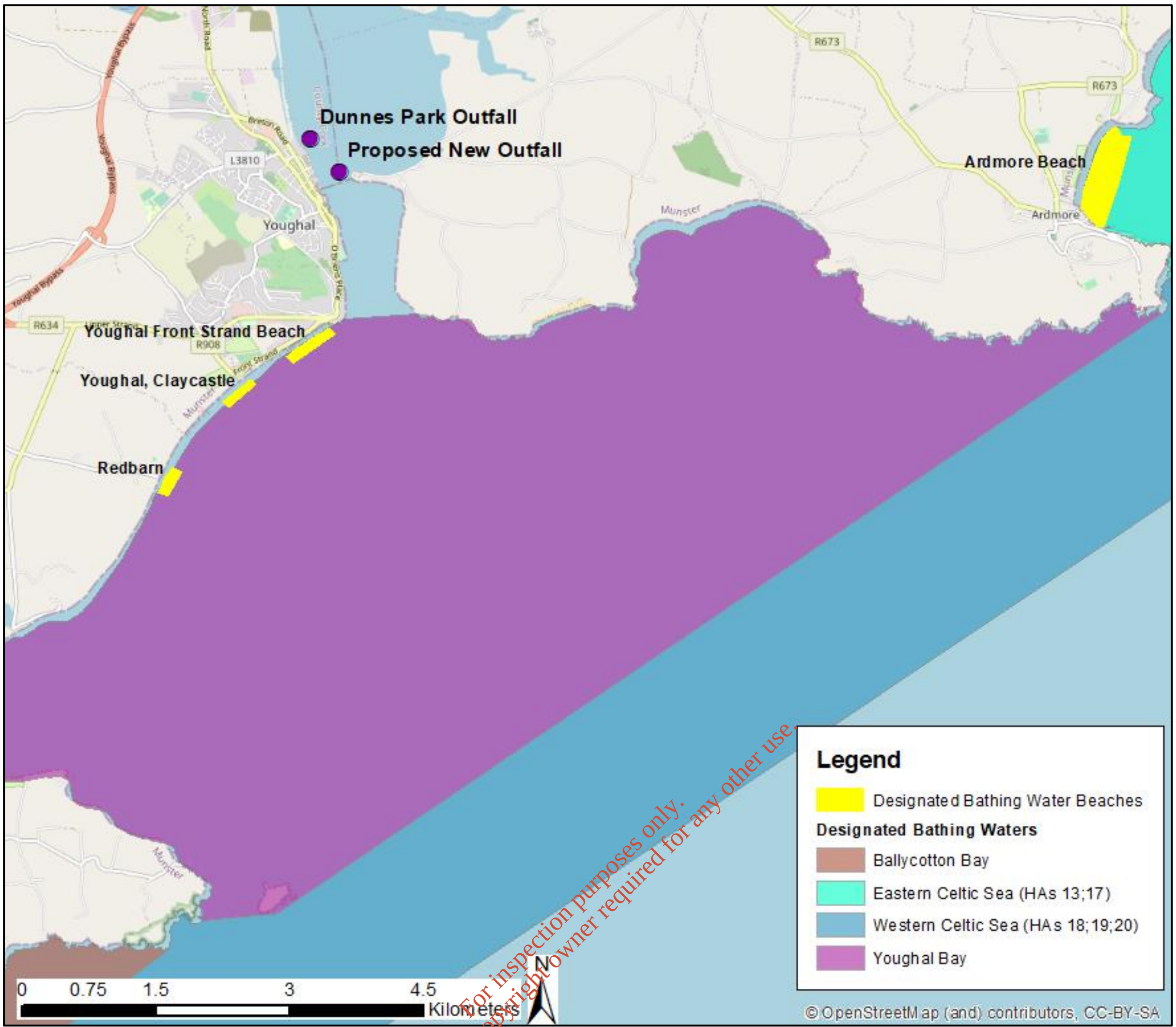


Figure 1-2. Designated Bathing Waters and Beaches at Youghal

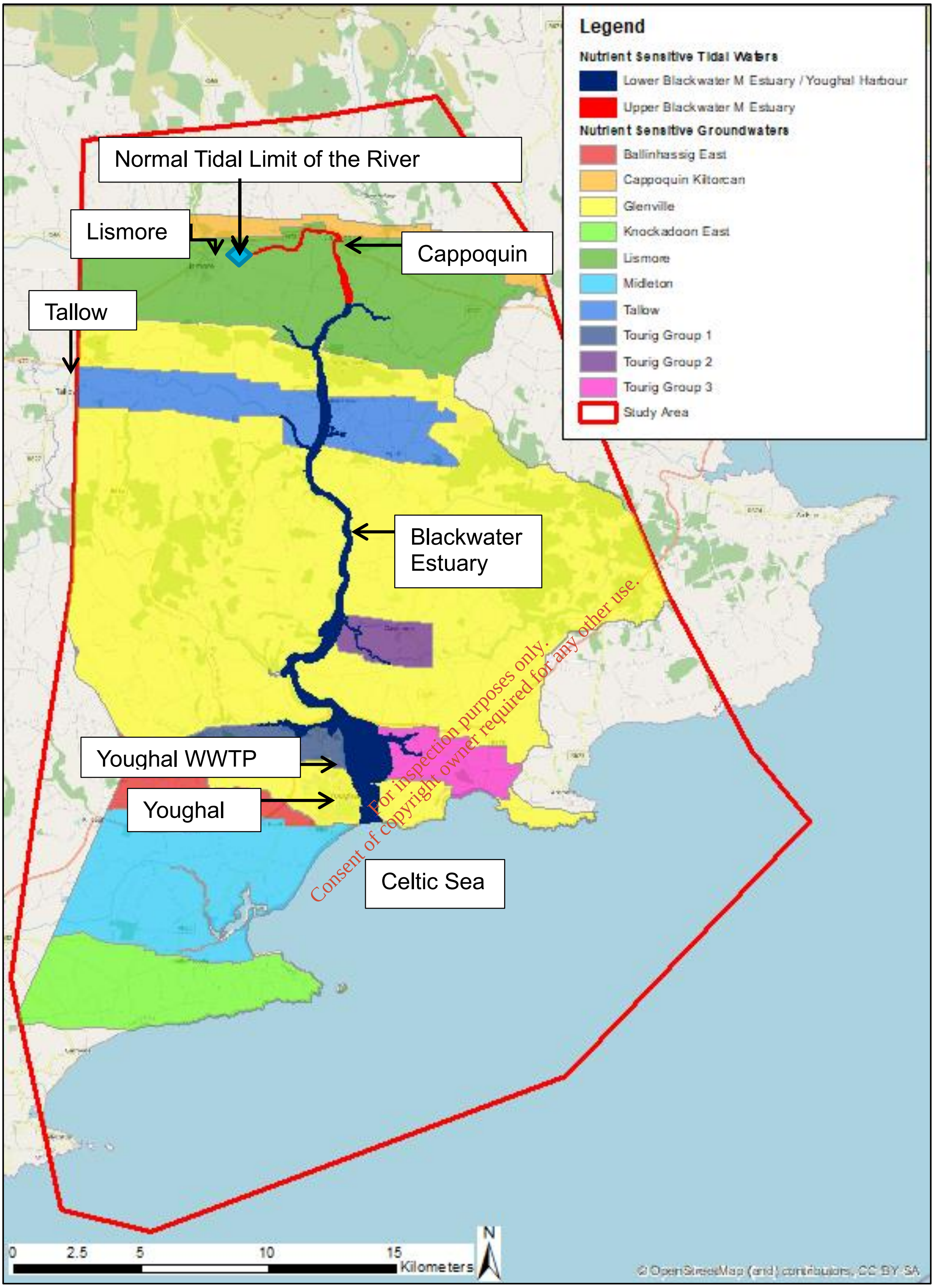


Figure 1-3. Nutrient Sensitive Tidal Waterbodies and Ground waters

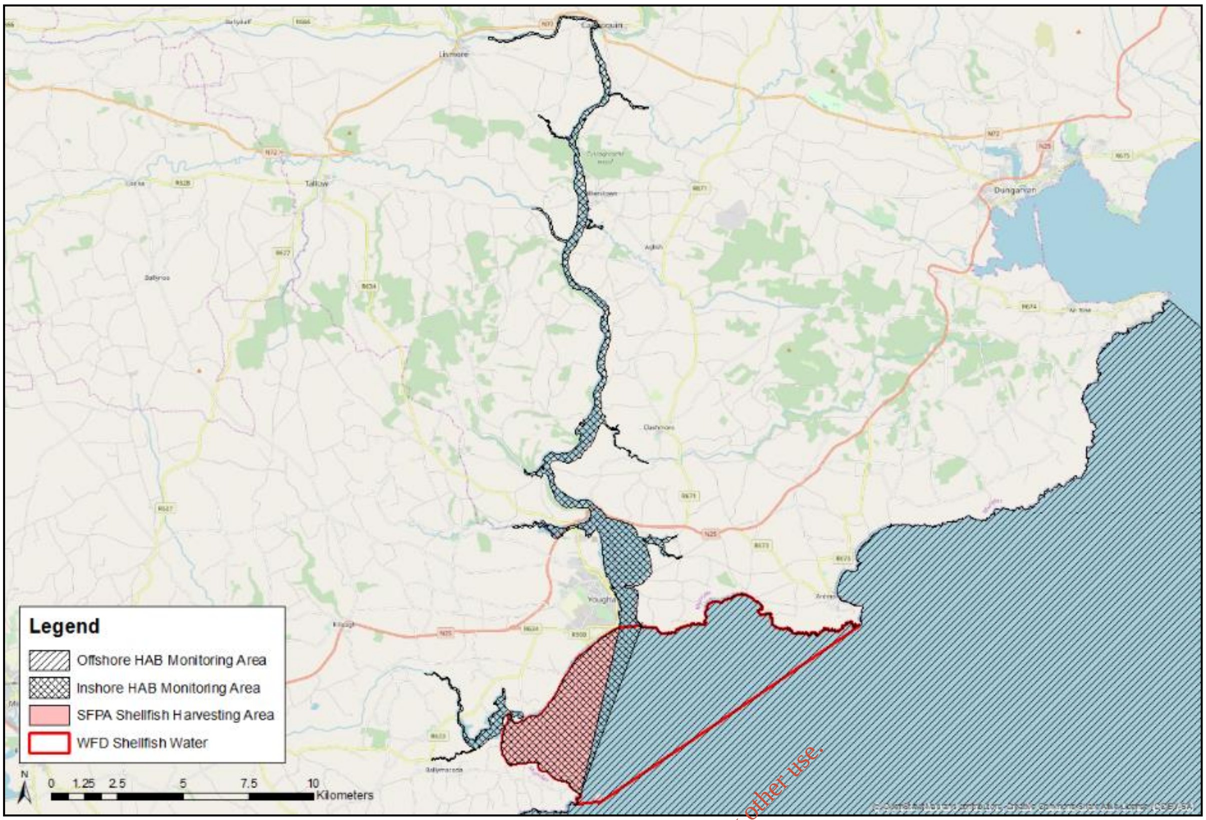


Figure 1-4. Designated classified production areas, Designated Shellfish Waters and HAB Monitoring Areas at Youghal

1.5 Discharges

The MSR identified the different discharges to the study area and identified that only the WwTP at Cappoquin and Youghal were of significance to the study. The existing discharge for Youghal is through the Dunnes Park outfall and there is a proposed outfall closer to Ferry Point. The Cappoquin WwTP discharge is into the river at Cappoquin, part of the Upper Blackwater Estuary. The locations of these discharges are shown in Figure 1-5.

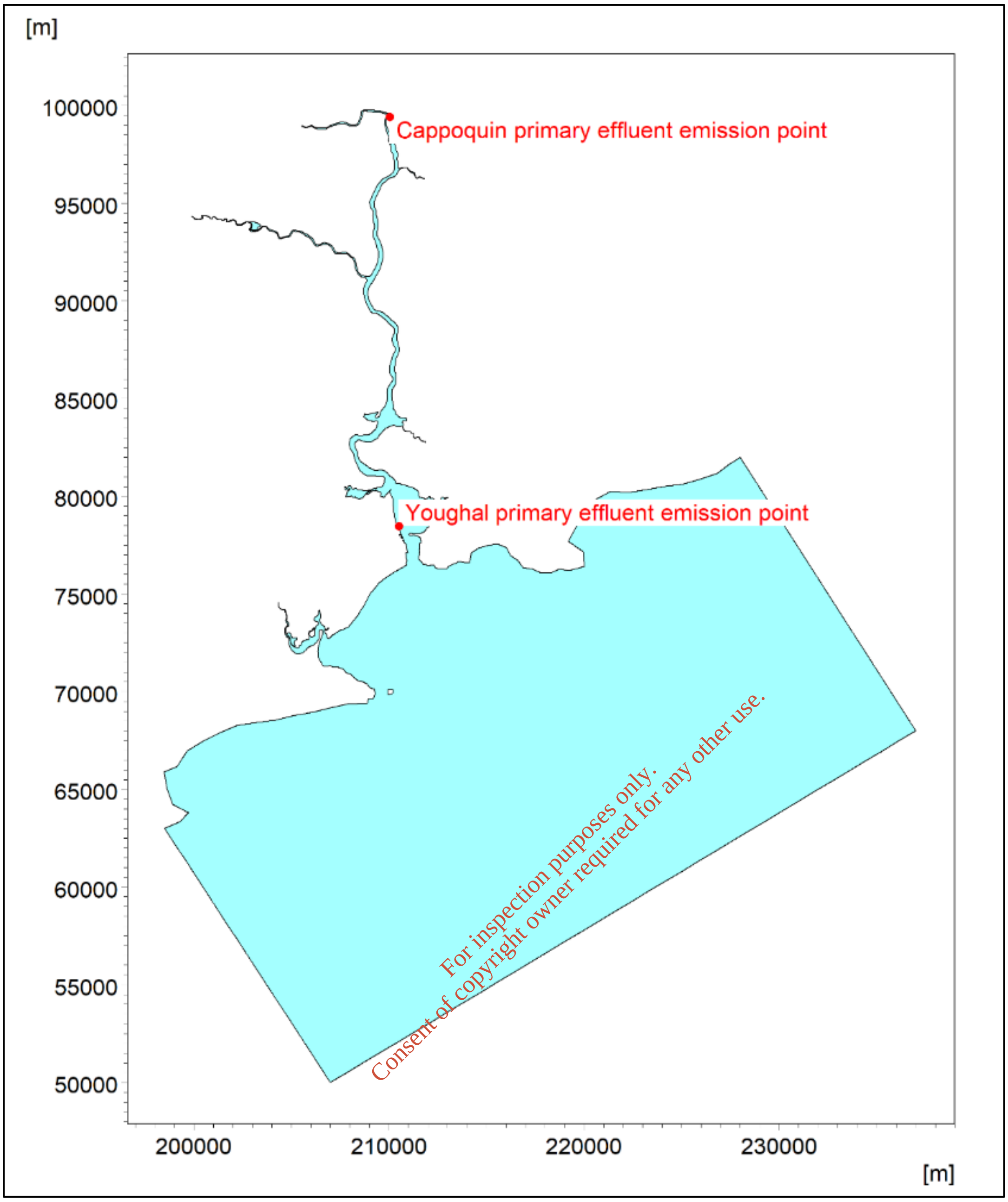


Figure 1-5. Locations of the discharges within model domain

1.6 Dimensionality

The Model Scoping Report (AECOM, 2020a) and the Survey Interpretive Report (AECOM, 2020b) both posed the question of whether a 2D or 3D model would be required to suitably represent the hydrodynamic and mixing processes within the estuary. The intention was that a 2D model would be initially developed and if it was able to simulate the mixing correctly, then that model could be progressed and utilised.

The 2D model of the estuary resulted in the freshwater flushing the estuary and forced the mixing zone out into the open sea. Even with very high or low horizontal dispersion it was not possible to simulate a mixing zone in the estuary. These initial investigations showed that a 2D model is not able to adequately represent the mixing processes and the decision was therefore made to develop a 3D model during the model development stage.

2. Calibration

2.1 Data used for calibration

The data collected during the field surveys and collated from other data sources was presented in the SIR and the key data used for calibration is presented within each calibration plot. The observed data is not reviewed further in this report other than to comment on the model performance. The principle data for the calibration of each event is summarised in Table 2.1. Note that Events C, D and E cover a single tidal cycle within the period covered by Event B and therefore the data used for Event B is also used for events C, D and E.

Table 2.1. Summary of the calibration data to be used for each event.

Event	Type	Parameter	Calibration Data
A: Tide only 15 days	HD	Water level	Harmonically analysed water level at Youghal OPW gauge
	HD	Currents	Tidal diamond data.
B: 15-day event	HD	Water level	Youghal OPW gauge Camphire Bridge CTD (Bed) Cappoquin tide gauge
	HD	Temperature and salinity	Fixed CTD stations at Youghal (bed and 0mOD), Camphire Bridge (bed and 0mOD) and Cappoquin (bed and surface).
C: Spring tide D: Neap tide E: Spring tide (17th January)	HD	Temperature and salinity	150+ vertical profiles in Youghal Harbour.
	HD	Currents	Vertical velocity profile and depth averaged current speed and direction and vertical profiles at four locations within Youghal Harbour.
	WQ	BOD, DIN, MRP, ammonia	Sampling at Cappoquin and three locations in Youghal Harbour. EPA monitoring 2014 to 2019.
	WQ	EC, IE	Sampling at Cappoquin and three locations in Youghal Harbour.

2.2 General weather conditions during the survey period

Several named and un-named storms[3] occurred during the preceding month and the survey period (Figure 2-1). This resulted in significant rainfall occurring in the southern counties and periods of high fluvial flows, particularly during Storm Brendan (13th January 2020) and the following un-named storm (16th January 2020) just before the survey on the 17th January 2020. It is likely that these high flow fluvial events will have an influence on individual water quality parameters. No detailed data are available on the relationship (if any) between the fluvial events and corresponding changes in the concentrations of different water quality parameters in the Blackwater river and estuary. Importantly it is not just a change in peak or average concentration during a period of high flow but also the way that the concentration and river flow rates change through time. It is assumed that the timing of EPA surveys is independent of the weather and therefore events such as these are potentially included in the long-term surveys. Whilst assumptions could be made, these would not be based on

[3] Named storms include those named by the UKMO and Met Eireann, other storms may have been named by other meteorological organisations.

evidence and therefore the differences between surveyed data and long-term averages are simply highlighted in the presentation of the model calibration.

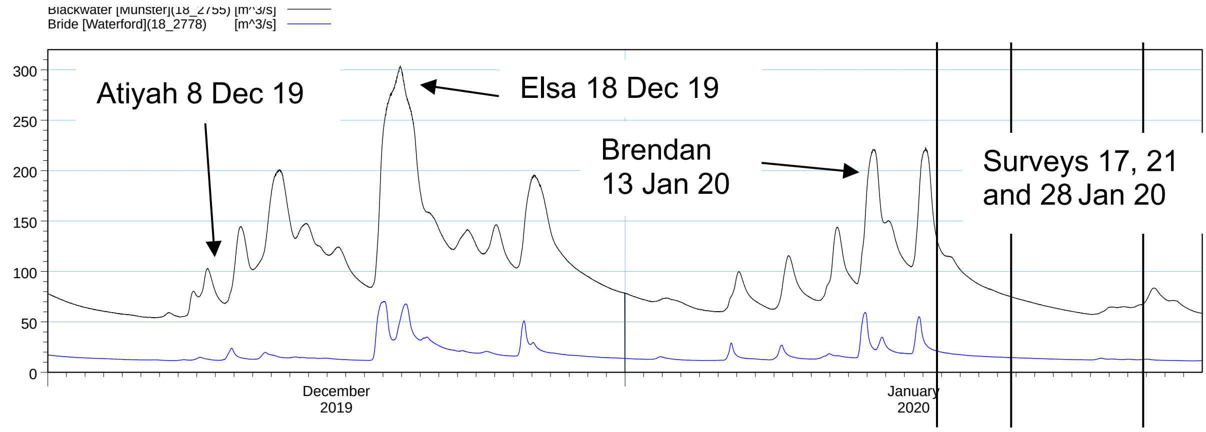


Figure 2-1. Measured flow rates in the River Blackwater and River Bride for December 2019 and January 2020 showing the survey dates (vertical lines), named storms and other periods of high fluvial flow.

2.3 Additional data used in calibration

The proposed scenarios require that the model is run for the summer period. For the bacteria IE and EC, this potentially requires a different decay coefficient, or T_{90}. The EPA monitoring data for the beaches just outside of Youghal Harbour has been downloaded from Beaches.IE[4] for Youghal Front Strand and Youghal Clay Castle beaches. The data has been analysed to identify the key statistics for the periods for which data is available (Table 2.2). Two periods have been used for the analysis: pre-2018 and post-2018. The analysis is based on all samples and is intended to provide the range of values and statistics for the purposes of calibration of the model. The analysis is not attempting to replicate the determination of the bathing water quality (which would allow the identification of outliers) and therefore the statistics should not be used to imply a specific bathing water quality.

Table 2.2. Summary statistics for Youghal Front Strand and Clay Castle Beaches

Location	Bacteria	Period	Min	Mean	50%	90%	95%	Max
Youghal Front Strand	EC	Pre 2018	10	232	144	565	786	1723
		2018 to 2020	10	67	20	147	347	615
	IE	Pre 2018	0	27	21	62	68	110
		2018 to 2020	1	9	3	30	41	55
Youghal Clay Castle	EC	Pre 2018	10	146	84	340	605	987
		2018 to 2020	10	84	10	160	498	909
	IE	Pre 2018	1	22	14	49	71	120
		2018 to 2020	1	13	4	28	50	120

[4] Beaches.IE accessed on 15th September 2020, data for Youghal Front Strand and Youghal Clay Castle downloaded.

3. Hydrodynamic model

3.1 Model set-up

3.1.1 Time step and model duration

The calibration events are all in the period 15th January to 30th January 2020. The model has been run from 10:00 on 1st January 2020 to provide a two-week warm-up period for the model. This has been demonstrated to be sufficient for the hydrodynamics and the water quality models to reach stability.

The model has been run using a reporting time step of 5 minutes; calculations are undertaken using the adaptive time step of MIKE3 with a minimum time step of 0.01 s and a maximum of 30 s. For the baseline model the average time step of the calculation is approximately 0.6 seconds.

3.1.2 Bathymetry

The bathymetry has been generated using a range of data as listed in Table 3.1. There was generally very little spatial overlap between the datasets and the most recent data has been used where possible.

Table 3.1. Summary of data sources for bathymetry

Data	Area
Irish Water survey of Youghal Harbour area, January 2020	Youghal Harbour
OPW river cross section data	River Blackwater upstream of the Youghal Bridge River Bride
OPW LiDAR data	Inter-tidal areas of the tributaries such as the River Tourig and salt marsh areas.
Bathymetry data from survey conducted by IHD on May 13th and 15th 2009	Small areas where other data were not available.
UKHO Admiralty Chart and INFOMAR data	Offshore areas outside of the estuary.

The bathymetry has been created using the mesh generator within MIKE Zero. The coastline and river edges have been taken from Ordnance Survey Ireland data and adjusted based on aerial photographs and river sections from the models supplied by OPW. The resolution of the model is variable with smaller elements used in areas of interest or rapid change. The tributaries have been simplified to be a rectangular cross-section with a bed level below low water. The bathymetry within the River Bride and the River Blackwater above the confluence with the River Bride uses a single cell with a bed level associated with the thalweg of the river channel. The bathymetry and the locations of key features are shown in Figure 3-1 to Figure 3-3.

The resolution of the mesh could affect the ability of the model to replicate the observed data. A key consideration was the hydraulic performance of the river sections of the model. The sections of the main channel of the Blackwater estuary are characterised by a deep incised subtidal channel for much of the length of the estuary. The width of the inter-tidal area changes significantly and the depth of the thalweg rises and falls along the channel creating pockets of deep water. A key consideration in the calibration is the timing of the high and low water levels. The timing is a function of the speed of the tidal wave propagation which is related to the depth of water. The elevation can also be affected;

however, the bed resistance tends to provide the dominant control of this. A more detailed bathymetry was developed that followed the thalweg by changing the number of elements each side of the thalweg and included the inter-tidal areas. An example of the two mesh files are shown below in Figure 3-4.

Sensitivity tests were undertaken to evaluate a more detailed bathymetry and the results are presented in section 3.4.1.

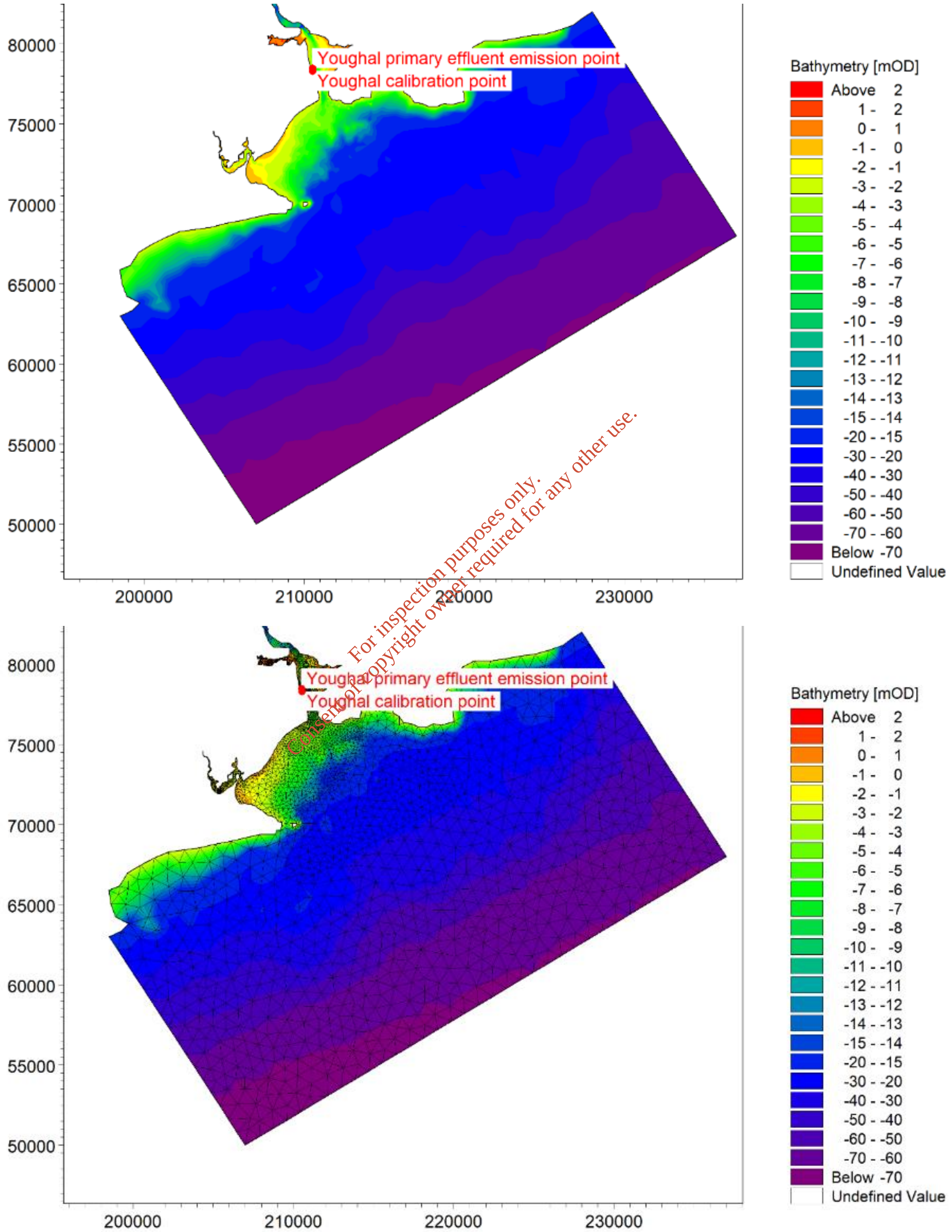


Figure 3-1. Plot of the bathymetry showing the non-river sections of the model domain with and without the mesh structure.

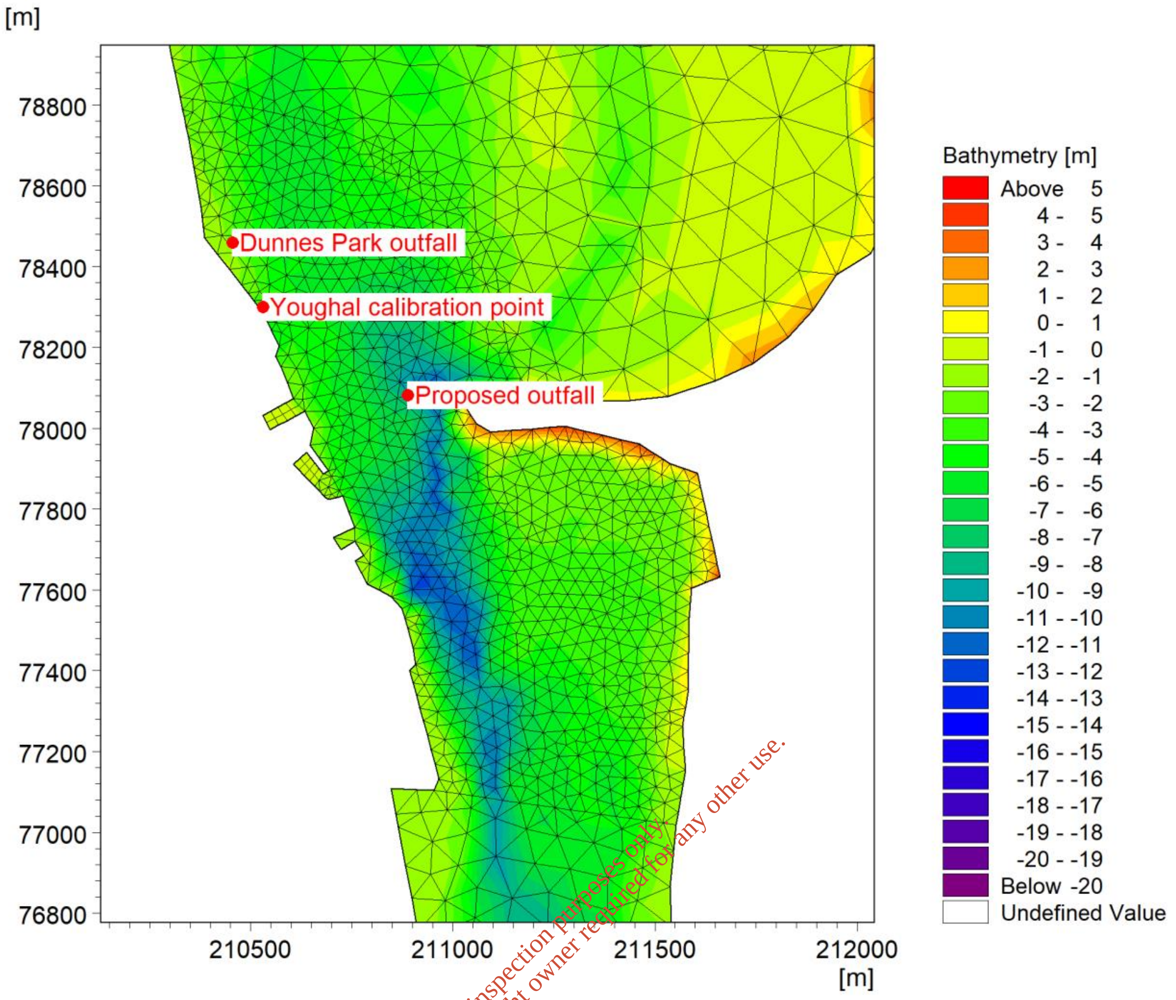


Figure 3-2. Plot of the bathymetry and mesh showing the area around the Dunnes Park and proposed outfall locations.

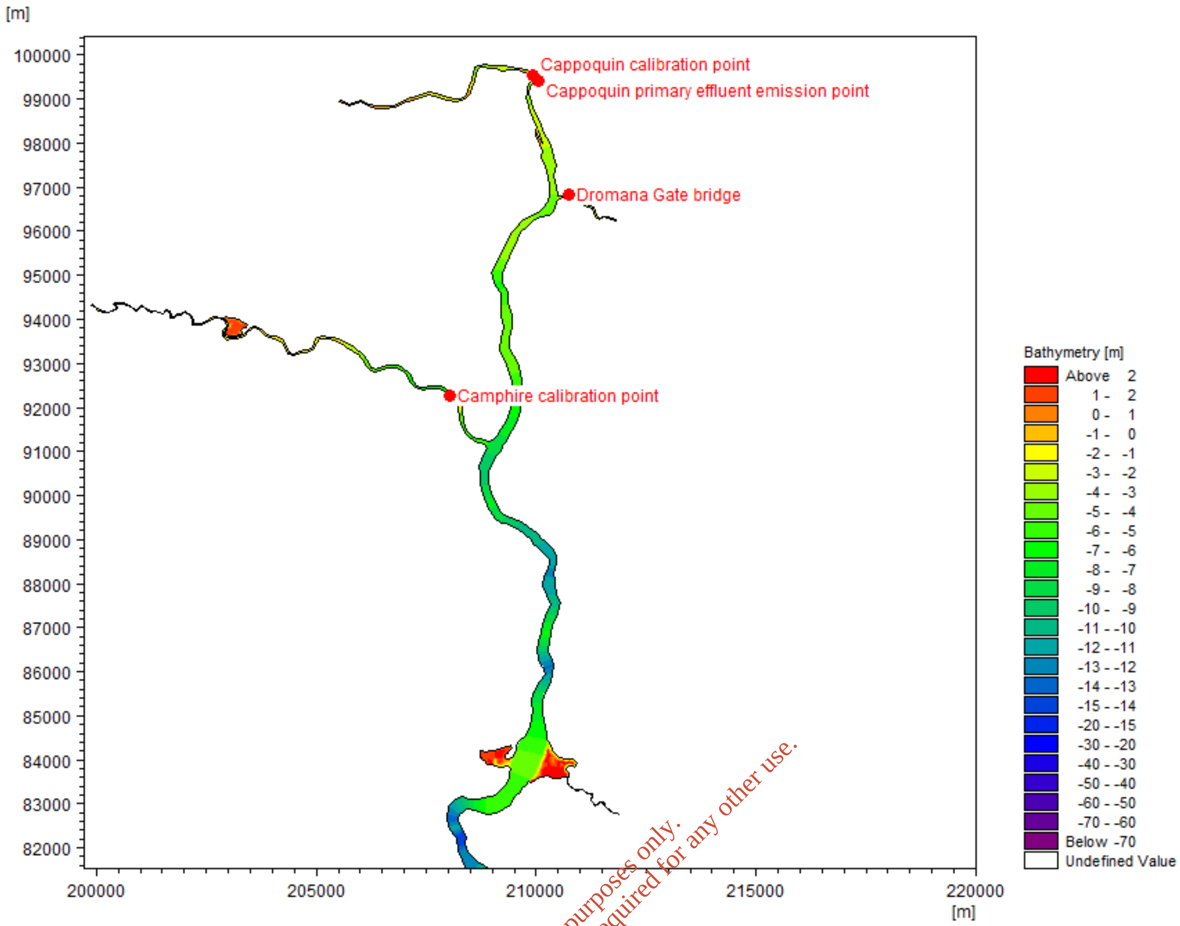


Figure 3-3. Plot of the bathymetry showing the river sections of the model domain.

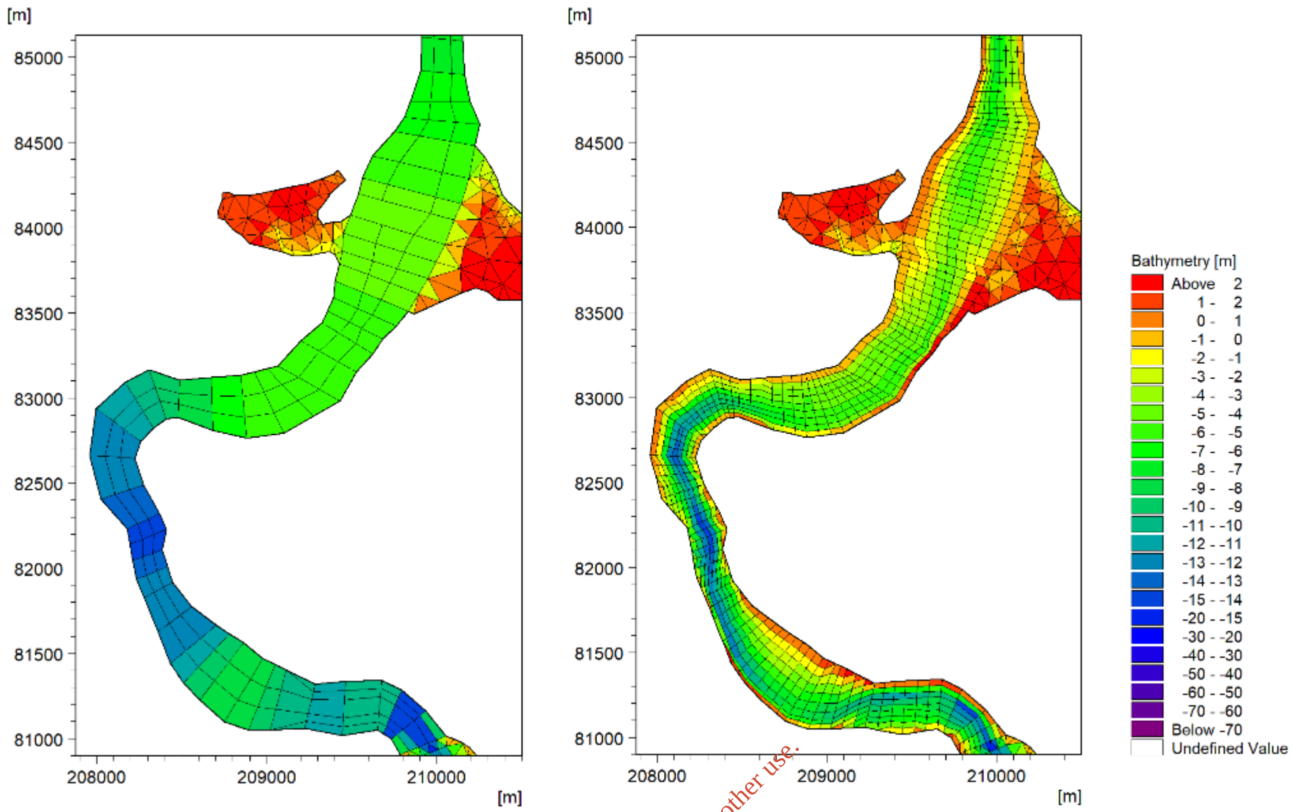
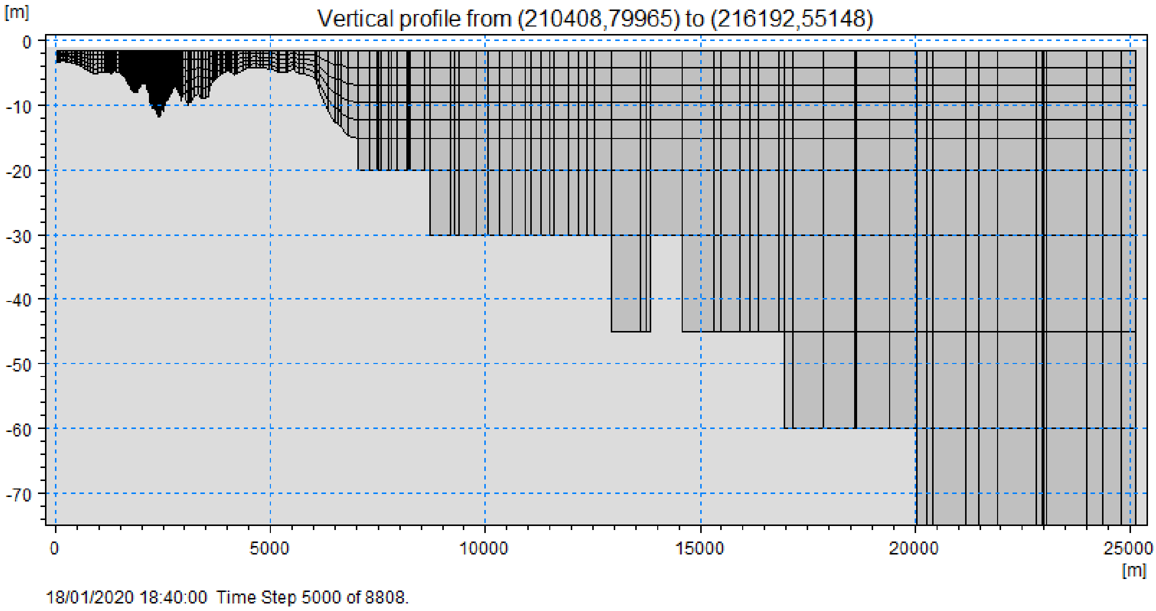


Figure 3-4. Comparison of the detailed and less detailed meshes of the Blackwater estuary.

3.1.3 Vertical mesh

Various schematisations were tested due to the complexity of the model domain. The offshore sea bed level is approximately -75 mOD whilst the river channel narrows to less than 100 m and has water depths of less than 0.5 m in the upper reaches. There is a dynamic mixing zone within the harbour area. The channel bed level through the harbour and lower estuary ranges between -18 mOD and -4 mOD with deep areas upstream of shallow areas.

The final schematisation used five sigma-layers and five z-layers (Figure 3-5). The sigma-layers were evenly distributed between the water surface and -15 mOD. The five z-layers were each 5, 10, 15, 15 and 15 m deep. This represents the area of the model in which most mixing will take place (Youghal Harbour) with at least five sigma layers. The use of z-layers in this area would have simplified some of the bathymetry and this was considered to not be acceptable in this important area. However, further offshore the simplification of z-layers was considered acceptable and allows the deeper water to be layered.



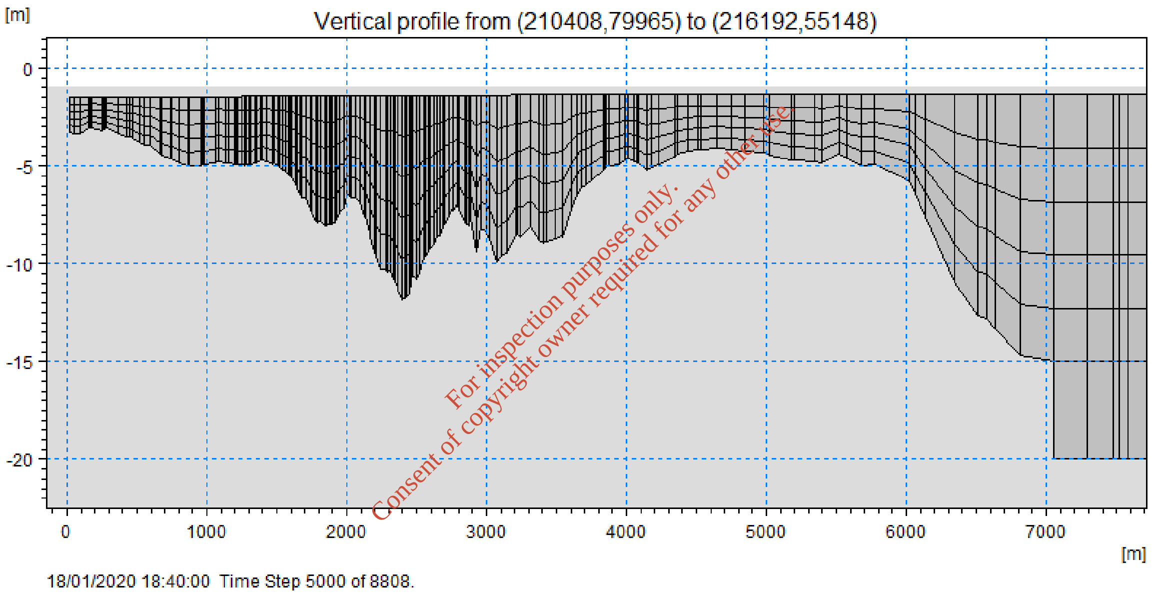


Figure 3-5. Section through the estuary and out to the south boundary of the model (top) and landward end of the section (bottom). Both show the top five (sigma) layers. The top plot also shows the bottom five (z) layers.

3.1.4 Open sea boundary conditions

The open sea boundaries of the model are identified as the west, south and east, as shown in Figure 3-6. The Irish Marine Institute's (MI) model of the northeast Atlantic was reviewed for extended periods of time during the model development. It was noted that high freshwater flow events in the region could result in lower surface salinity along the coast with impacts of each estuary being identifiable but limited in spatial extent. The boundaries have been positioned to minimise the risk of the freshwater discharge from the Blackwater reaching the boundary.

Additionally, the flood and ebb tide currents in the MI model showed that the currents were approximately parallel to the shore meaning that a boundary also parallel to the shore would have minimal flux across the boundary.

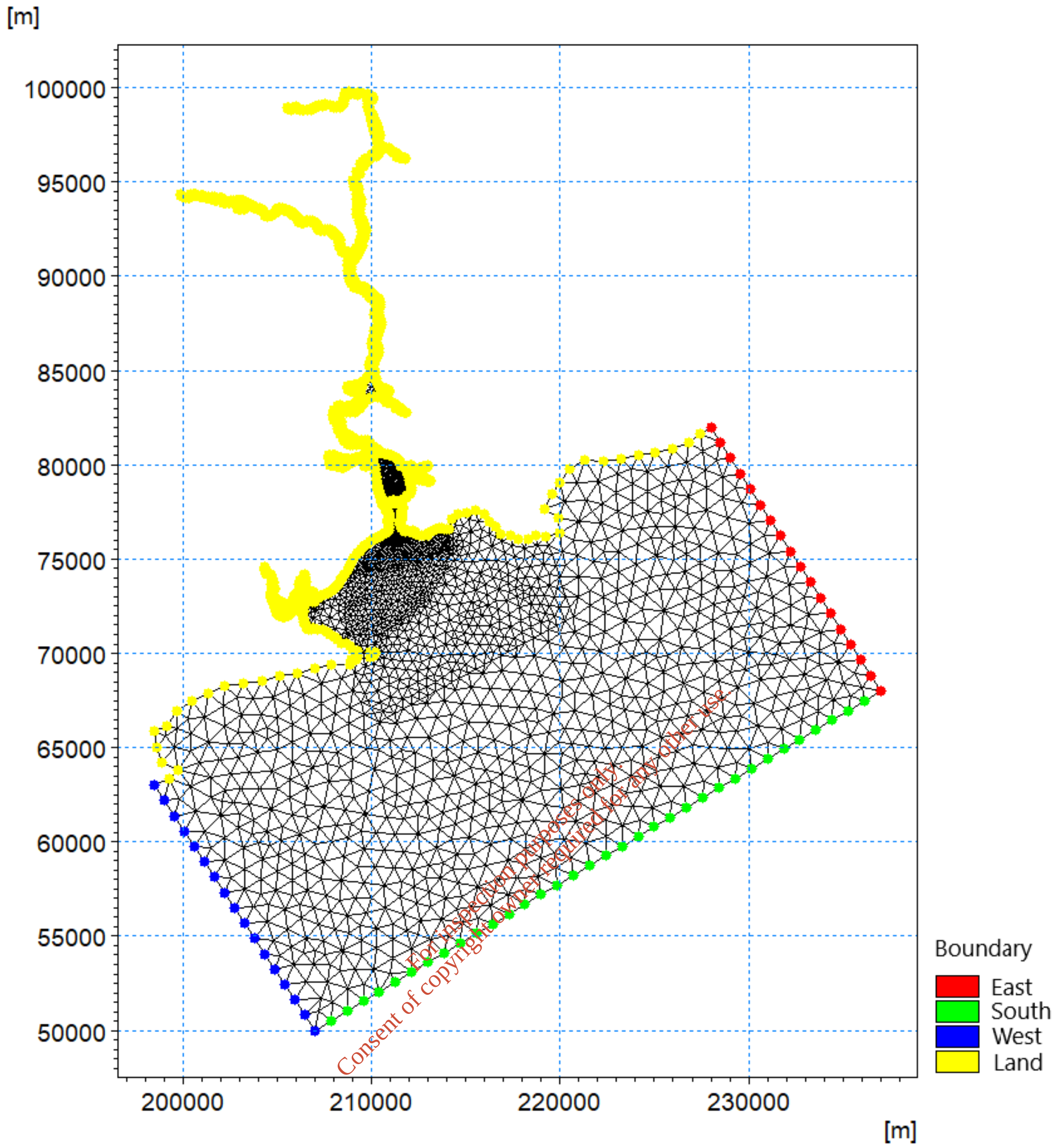


Figure 3-6. Plot of the model domain showing the locations of all open boundaries.

The boundary data has been obtained from the Marine Institute's Northeast Atlantic Regional Ocean Modelling System (ROMS) model. The MI model uses 40 sigma layers. The data provided by the MI is in a standard MATLAB® format data file and includes the following data for each boundary:

- Bed level.
- Surface elevation time series along the boundary and predefined points.
- A time series of the absolute elevation (m MSL) of each of the sigma layers and the mid-point of each sigma layer (as this is the location of the other data provided).
- Orthogonal current components (U and V) for each point along the boundary and each of the 40 vertical layers.
- Temperature and salinity data for each of the 40 vertical layers within the MI model.

These data were processed to provide appropriate file formats for use as boundary data. The data provided covers the period 00:00 1st December 2019 to 00:00 1st March 2020.

Several tests were undertaken to review the suitability of the data to be used as a boundary for the model. The first test was to simply use the data as the model boundary. The modelled high water levels at Youghal were found to be low compared to the observed water levels.

The second test compared the MI water level data for the south-west and south-east corners of the model domain with the DHI predicted tidal constituents[5] and the observed OPW data at Youghal Quay. The comparisons for the south-west corner of the model domain are provided in Figure 3-7; the comparison for the SE corner shows a similar difference. The MI data (blue line) is consistently below the DHI predicted tides (red line) and observed Youghal Quay tides (black line) at high tide but not at low tide. This means that it cannot simply be a systematic shift up or down in elevation nor is it a consistent application of atmospheric pressure. The DHI data appears to provide a better estimate of observed conditions with the differences likely to be weather related.

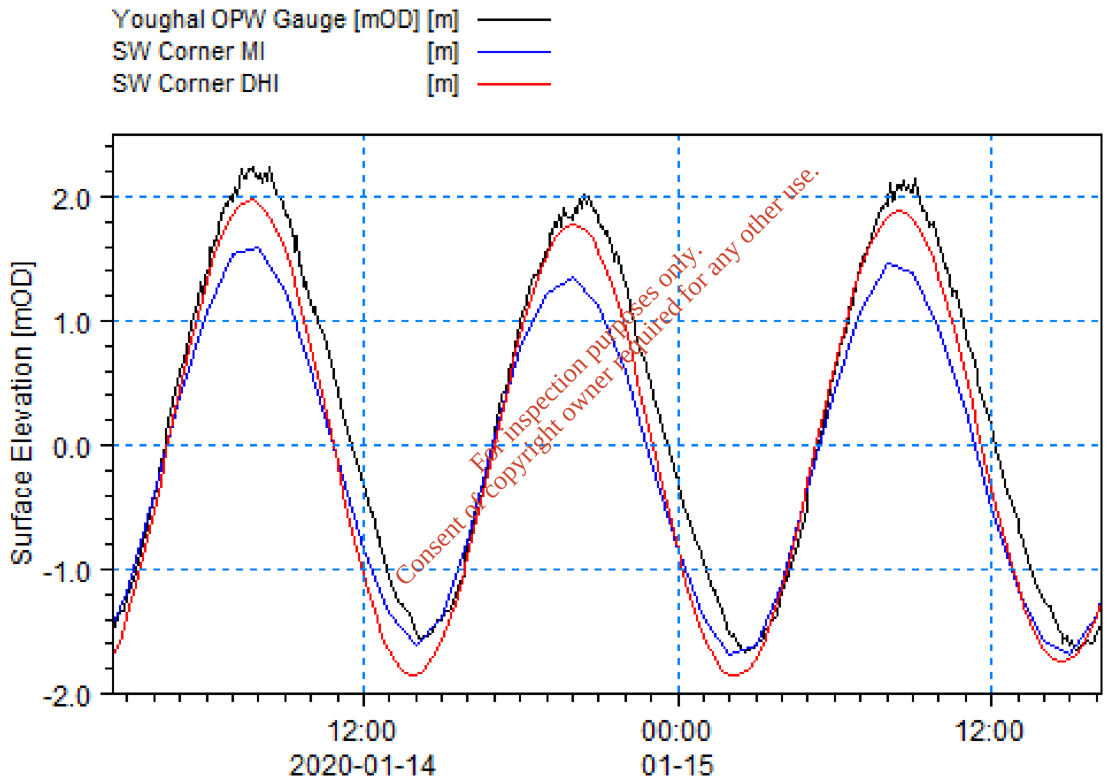


Figure 3-7. Comparison of the Youghal OPW gauge, MI and DHI predicted water level (without surge) in the southwest corner of the model domain.

A harmonic analysis of the MI water level data was undertaken and compared to the constituents from the DHI tidal database. A summary of the key constituents is shown in Table 3.2 and confirms that the mean level (Z0) of the MI data is approximately 0.33 m and 0.34 m too low in the southwest and southeast corners, respectively. The harmonic analysis of the MI data surface elevations identified that the amplitudes of the M_2 tide are approximately 0.16 and 0.18 m smaller in the southwest and southeast corners respectively

[5] The MIKE21 Global Tidal database provides 10 constituents at 0.125˚ x 0.125˚ resolution. The data is based on the analysis of satellite altimetry. The data is easily used within the MIKE21 modelling suite. Further information on how the data has been derived can be found at https://www.space.dtu.dk/English/Research/Scientific_data_and_models/Global_Ocean_Tide_Model.aspx.

and there is also a smaller difference in the S_2 tide, but still reducing the amplitude of the tide in the MI data. The differences in the amplitude of these constituents account for approximately 0.30 m to 0.35 m difference in tidal range. Given that the low tide levels of the MI data and the observed data are similar the adjustment would raise the mean sea level of the data by approximately 0.2 m.

The DHI data set was adjusted to take account of the atmospheric pressure. Atmospheric pressure data from Roches Point (approximately 30km to the west of the study site) was compared to the observed pressure at Youghal. The two pressure traces were similar in magnitude and shape. A further comparison to the M5 buoy identified that Roches Point was a better fit to the Youghal data.

A comparison of the resulting water levels is provided in Figure 3-8 that shows for both high and low tides, the adjusted DHI data is a good match for the observed data and the phase of the tide appears reasonable. For some high tides there remains a small discrepancy which could be due to other factors such as local changes in pressure or wind. However, the DHI data only provides water levels along the three boundaries. It was found that models forced with this data provided good estimates of the water levels at Youghal, Camphire and Cappoquin but that the general circulation in the open sea was not acceptable. Initially the tide flooded west to east and ebbed east to west (as expected), but by the end of the five-week simulation the flood and ebb tide currents were in the same direction, with results varying depending on the Coriolis correction applied. Tests with different combinations of Coriolis correction on the boundaries produced different results, but none of the tests provided a reasonable and consistent general circulation in the open sea and Youghal Bay.

The conclusion of this review was that the MI boundary data should be used to drive the model using a Flather boundary utilising the surface elevation and the velocity components, U and V, from each of the 40 sigma layers in the MI model.

Table 3.2. Principle tidal constituents from analysis of the MI and DHI data.

SW Corner		Tidal Constituent					
		Z0	M2	S2	N2	K1	O1
DHI	Amp	0.000	1.384	0.398	0.254	0.047	0.037
	Phase		146.120	194.420	125.740	144.920	44.730
MI	Amp	0.346	1.225	0.359	0.226	0.033	0.023
	Phase		144.130	195.840	125.760	172.010	58.150
Diff.	Amp	0.346	-0.159	-0.039	-0.029	-0.014	-0.014
	Phase		-1.990	1.420	0.020	27.090	13.420

SE Corner		Tidal Constituent					
		Z0	M2	S2	N2	K1	O1
DHI	Amp	0.000	1.406	0.397	0.259	0.042	0.046
	Phase		149.940	198.670	130.750	163.670	36.550
MI	Amp	0.332	1.222	0.370	0.224	0.042	0.029
	Phase		147.070	200.540	130.180	177.300	58.250
Diff.	Amp	0.332	-0.184	-0.027	-0.034	0.001	-0.017
	Phase		-2.870	1.870	-0.570	13.630	21.700

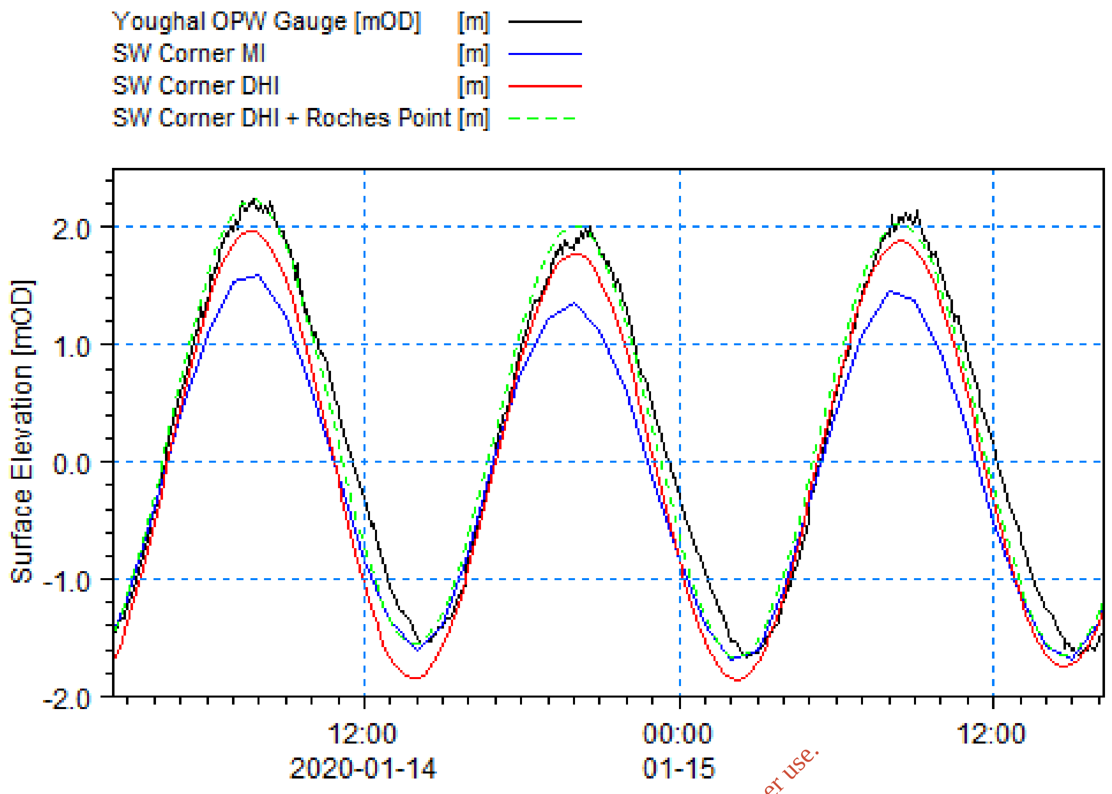


Figure 3-8. Comparison of the Youghal OPW gauge, MI and DHI predicted (without surge) and DHI predicted (adjusted for atmospheric pressure at Roches Point) water level in the southwest corner of the model domain.

The MI surface elevation data was then scaled such that each high water in the southwest corner of the model domain was the same elevation as the corresponding high water level at Youghal. The scaling factor was applied to the water level relative to the preceding low water (flood tide) and following low water (ebb tide). The extracted and scaled water levels at the southwest corner of the model domain are shown below in Figure 3-9.

These scaled MI water level data were applied in combination with the currents from the MI model. The calibration of the model using these data is presented in chapter 3.3. The current speeds have not been scaled as the increase in water depth is small compared to the overall water depth along the boundaries.

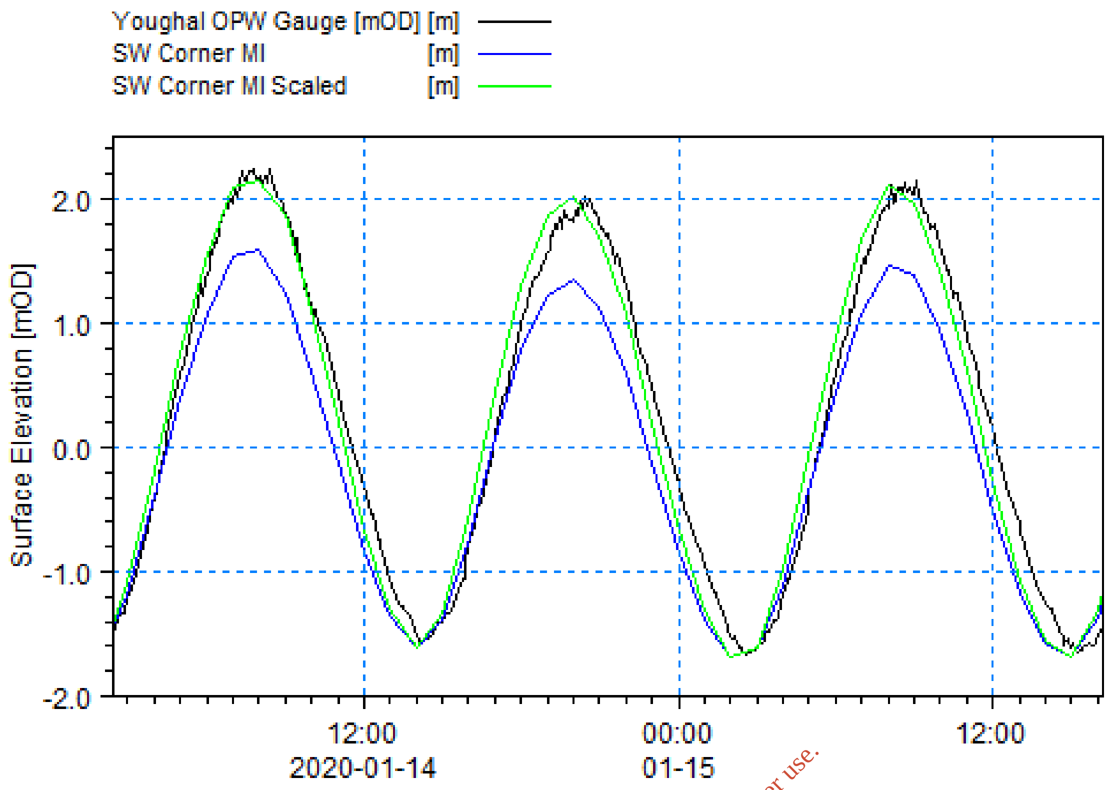


Figure 3-9. Comparison of the Youghal OPW gauge, MI and MI (scaled) water levels in the southwest corner of the model domain.

3.1.5 Bed roughness

The applied bed roughness map is shown in Figure 3-10. The bed roughness has been set based on typical values and the assumption that longer roughness lengths are required in areas of natural roughness in the bed. This means that smooth inter-tidal areas have a lower bed roughness length than rocky outcrops or upper, steeper reaches of the riverbed. Additionally, areas of saltmarsh or periodic inundation with high vegetation or incised channels have higher roughness values.

The bed resistance in the model is specified as a roughness length. The open sea is defined as 0.04 m with the rocky area around Capel Island southwest of Youghal defined as 0.05 m to achieve stability. The main river channel is 0.05 m and the inter-tidal saltmarsh areas 0.5 m. The upper reaches of the main channel vary from 0.05 to 0.4 m based on aerial photographs and the appearance of the bed with modifications to try and maintain hydraulic equivalence.

Sensitivity of the model to bed roughness was undertaken and is covered in section 3.4.1.

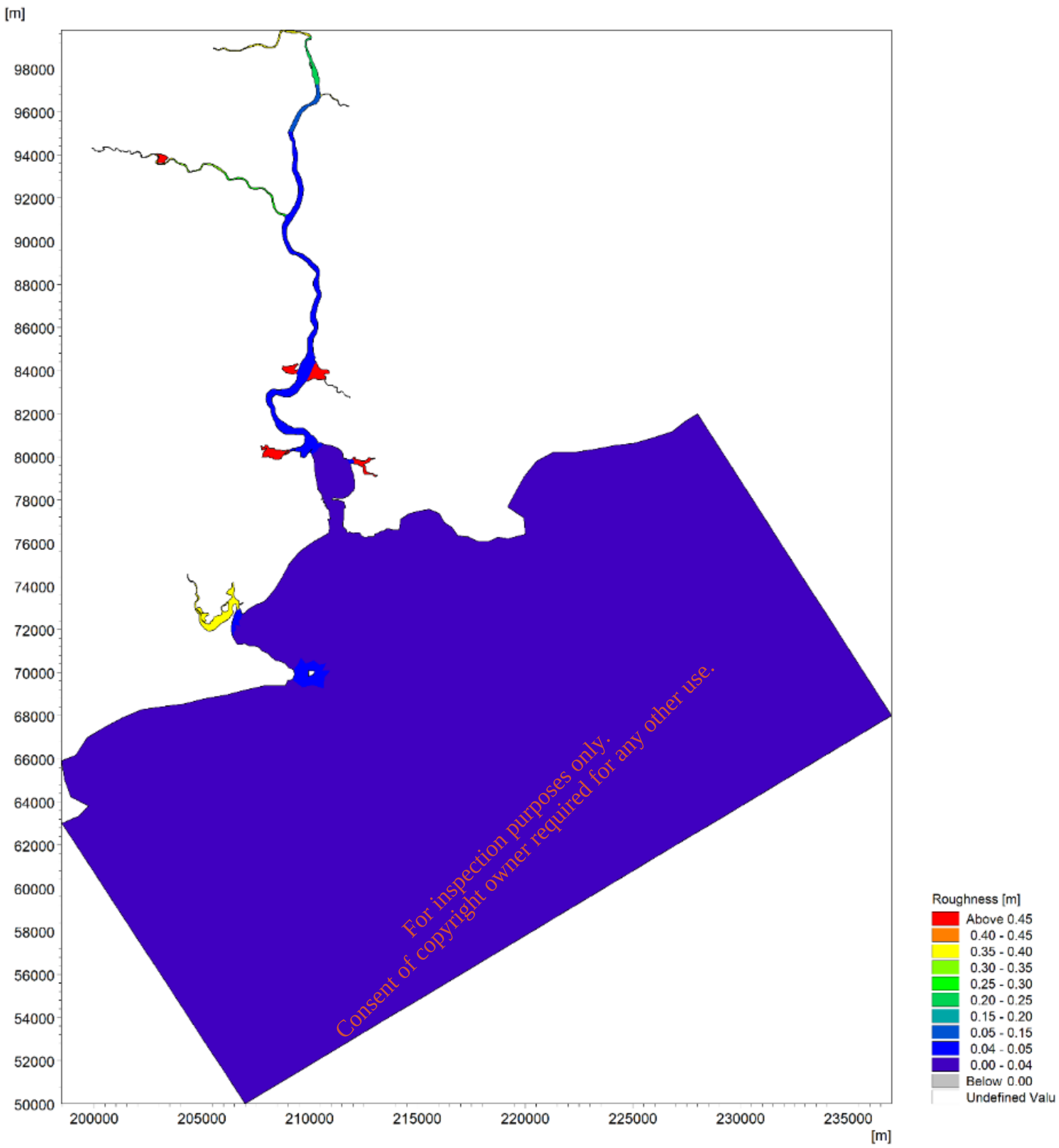


Figure 3-10. Plot of the bed roughness throughout the model domain.

3.1.6 River boundary conditions

The river boundary conditions have been developed based on the OPW hydrometric stations gauged water levels at Mogeely (18001 on the River Bride) and Ballyduff (18002 on the River Blackwater (Munster)). The data have been downloaded from the WaterLevel.ie website. The many other tributaries to the Blackwater estuary have also been included by using the flow duration curves from the River Bride and the tributaries. The assumption has been made that if the flow rate in the River Bride is equivalent to a Q45 on the flow duration curve, then the flow rate on each of the tributaries is also a Q45 for the appropriate flow duration curve. This means that all tributaries rise and fall together with the River Bride in the time series used for the boundary condition.

The locations of all tributaries that are included in the model are shown in Figure 3-11. The Q95 and Q30 values (for reference) are provided in Table 3.3. The total and percentage contribution to the freshwater flow are also shown on the right-hand side of the table.

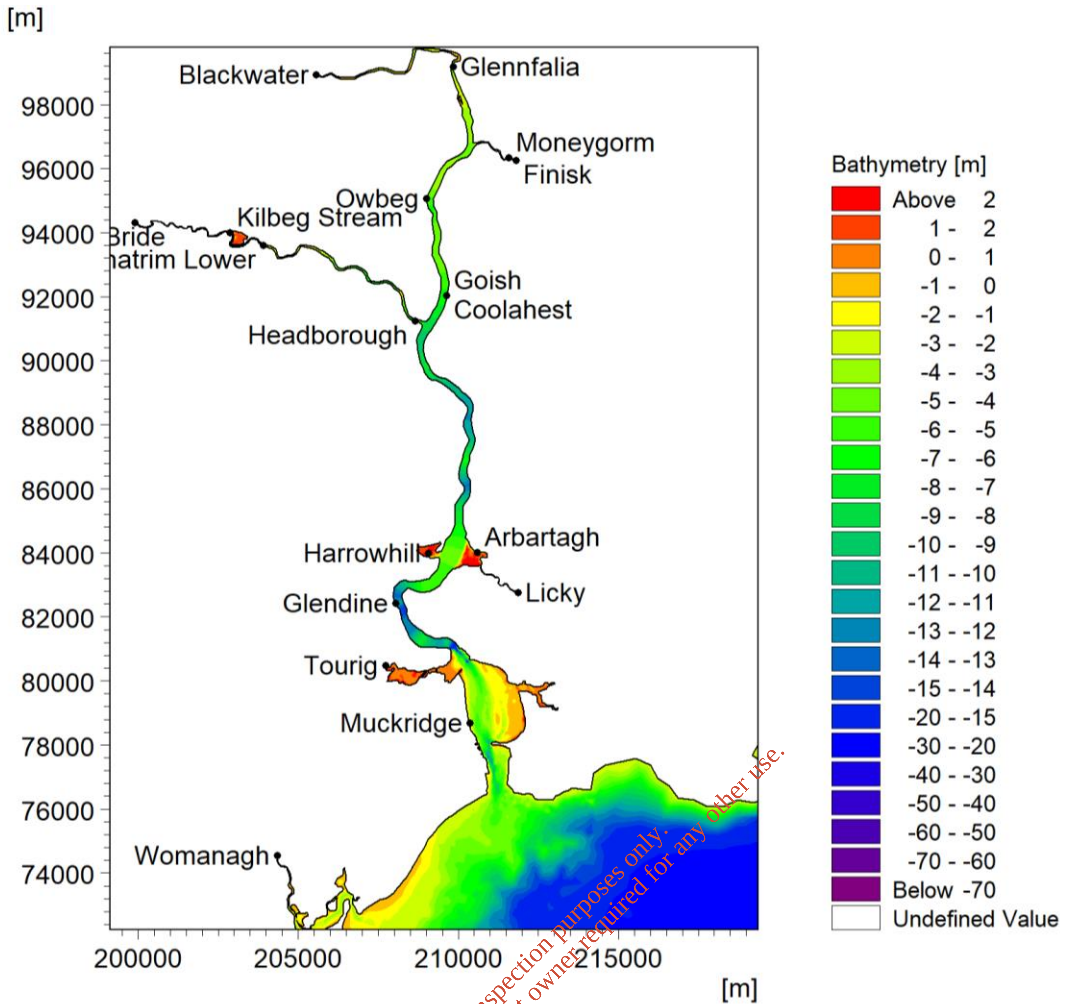


Figure 3-11. Locations of the river discharges included in the model

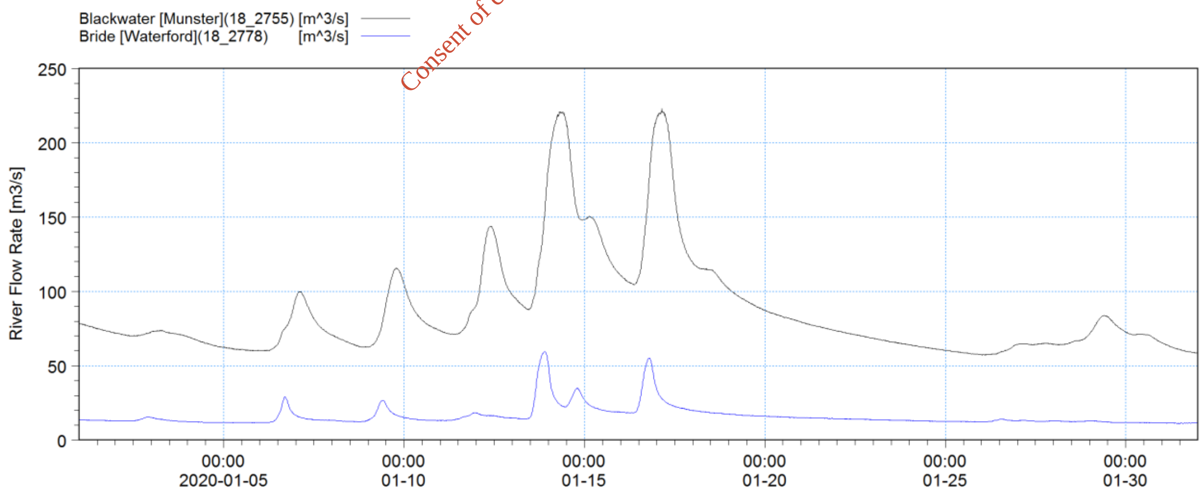


Figure 3-12. River flows in the Blackwater and Bride for January 2020. Other rivers are scaled from the River Bride.

Table 3.3. River flow rates (Q30 and Q95, [m^3/s]) for each of the tributaries

River	Q30	Q95	River Group	Q30	Q95
Blackwater [Munster](18_2755)	47.47	8.34	Blackwater	47.47	8.34
GLENNAFALLIA 18(18_2766)	1.32	0.20	Bride	15.37	1.05
MONEYGORM(18_2772)	0.15	0.02	Others	14.26	1.71
Finisk(18_2770)	2.54	0.31		77.10	11.10
Owbeg [Waterford](18_2776)	0.41	0.07			
COOLAHEST(18_2805)	0.27	0.05	Blackwater	62%	75%
Goish(18_2808)	0.83	0.07	Bride	20%	9%
HEADBOROUGH(18_2800)	0.29	0.04	Others	19%	15%
MONATRIM_LOWER(18_2790)	0.38	0.04			
Kilbeg Stream(18_2786)	0.41	0.04			
Bride [Waterford](18_2778)	15.37	1.05			
ABARTAGH(18_2818)	0.42	0.05			
Licky(18_2820)	1.44	0.04			
HARROWHILL(18_2814)	0.44	0.06			
Glendine [Blackwater](18_2822)	0.56	0.07			
Tourig(18_2824)	1.38	0.12			
MUCKRIDGE(18_967)	0.14	0.02			
Womanagh (19_1941_2)	3.28	0.51			

Sensitivity of the model to different river flow rates has been undertaken and is presented in Section 3.4.3. The sensitivity tests have used the flow rates equal to the Q95 (constant throughout the model duration) and observed flow rate ± 20% to provide three comparisons to the baseline model that uses the observed flow rates.

3.1.7 Eddy viscosity and Dispersion coefficients

The hydrodynamic model uses the default values for the Smagorinsky formulation for eddy viscosity.

Both the horizontal and vertical dispersion coefficients are calculated by scaling the eddy viscosity. Sensitivity tests for the scaling factors have been undertaken and the results are provided in section 3.5. Values of 1 and 2 have been applied for the horizontal and 0, 0.5 and 1 for the vertical scaling factors for the dispersion coefficient.

3.2 Simulations

The model set up described in the preceding sections has been used to define three initial runs, referenced as S1a, b and c. S1b was selected as the baseline run for all sensitivity and used the scaled MI data, the lower resolution river bathymetry and other parameters as set out above. A list of the calibration and sensitivity runs is provided in Table 3.4.

Table 3.4. List of calibration and sensitivity runs

Run Code	Description
S1a	Unscaled Marine Institute surface elevation data and currents
S1b	Scaled Marine Institute surface elevation data and currents
S1c	S1b + detailed mesh
S2a	S1b + Q95 river flows
S2b	S1b + -20% river flows
S2c	S1b + +20% river flows
S3a	S1b + -20% Bed roughness in rivers
S3b	S1b + +20% Bed roughness in rivers
S4a	S1b + horizontal disp = 1 Vertical disp = 0
S4b	S1b + horizontal disp = 1 Vertical disp = 0.5
S4c	S1b + horizontal disp = 1 Vertical disp = 1

3.3 Calibration and Validation

3.3.1 Introduction

For each of the events the observed and modelled water levels and currents have been compared where possible. The following sections reference the time series comparisons for each event. The time series comparison sheet provides the statistics and a visual comparison between observed data and modelled data. The review of the data in the SIR noted that there was a high degree of scatter in the data with only some of the profiles showing a clear vertical structure of the currents in the water column. The statistics presented are based on the assessment criteria set out in the technical standard (Irish Water, 2020). For the purposes of the assessment the following assumptions have been made:

1. Location:
   a. Youghal OPW gauge is at the mouth of the estuary
   b. Camphire Bridge is at the head of the estuary
   c. Cappoquin is at the head of the estuary
2. Tide type
   a. Event C is a spring tide
   b. Event D is a neap tide
   c. Event E is a spring tide

3.3.2 Time Series Comparators (TSCs)

The time series comparators (TSC) for the water level at Youghal, Camphire Bridge and Cappoquin for each of the events B to E are provided in Appendix C. The time series plots provided in the section on sensitivity tests has shown that there is generally a good comparison of water levels at all sites for all events. The TSCs provide a quantified evaluation. When reviewing the TSC it is important to remember that the assessment of the model is both quantitative and qualitative. Additionally, it is reasonable that an absolute value is in tolerance whilst the relative value is not (or *vice versa)*. It is the overall assessment that is important.

For the purposes of calibration, the preferred model set-up is **S1b**.

An example of a TSC is provided in Figure 3-13. The TSC provides a range of statistics and a chart of the water levels being compared; up to five data sets can be compared to the control data set. Depending on the event and purpose of the model different statistics will be considered. For example, the target HW is not relevant to the assessment of 15 days in Event B but is for the assessment of Event C. Each TSC has a title that describes the event and control data set and dates under consideration. The following sections are included on every TSC:

1. List of data sets and time step of the data set.
2. Statistics relating to the target HW and following LW.
3. Tidal range.
4. RMSE for the time series, time series above a threshold and all HWs.
5. Time difference analysis for all HWs.
6. Adjustment values to allow sensitivity tests on the data: particularly important with large time steps or data sets with different time steps.
7. Irish Water tolerances for the parameter are under the table and each statistic is shaded Green (in tolerance) or Red (outside of tolerance).

Comparison of model data with

Baseline: Youghal OPW Tide Gauge (15 minutes)

Event: B (C Spring)

During: 16/01/2020 06:00 to 31/01/2020 06:00

Datasets used	Time step of data	Target HW and following LW									Adjust. dataset time and value		RMSE of each dataset to Dataset 1			Time Difference of all HWs		
		Date and Time		HW Elevation		LW Elevation		Range										
No / Label	[mins]	Actual	Diff [mins]	Actual [mOD]	Diff [m]	Actual [mOD]	Diff [m]	Range [m]	Diff. [m]	Diff %	Time [mins]	Vertical [m]	All Data [m]	>0.00 mOD [m]	All HWs [m]	Min [mins]	Avg [mins]	Max [mins]
Youghal OPW Tide Gauge (15 minutes)	15	21/01/20 15:00		1.12		-1.74		2.85			0	0						
S1a MI Data Unadjusted	5	21/01/20 14:30	-30	0.62	-0.49	-1.88	-0.14	2.50	-0.35	-12%	0	0	0.36	0.06	0.53	-45	-4	30
S1b MI Adjusted Data	5	21/01/20 14:30	-30	1.11	-0.01	-1.88	-0.15	2.99	0.14	5%	0	0	0.11	0.09	0.09	-45	-3	60
S1c MI Adjusted Data + Detailed Mesh	5	21/01/20 14:30	-30	1.11	-0.01	-1.87	-0.14	2.98	0.13	5%	0	0	0.12	0.10	0.08	-45	-3	60
Not used											0	0						
Not used											0	0						
		Tolerance	15		0.10		0.10		0.10	15%			0.1	0.1	0.1		15	

Parameters defining the analysis

Start Date Time	16/01/2020 06:00	All datasets start before analysis start dat
End Date Time	31/01/2020 06:00	All datasets end after analysis end date
Axis Label time step	48	hrs
Threshold	0.00	mOD
Target HW No	11	21/01/2020 15:00 1.12
		21/01/2020 15:00 0.00

Location

Estuary (mouth)

Tide type

Spring

Comments

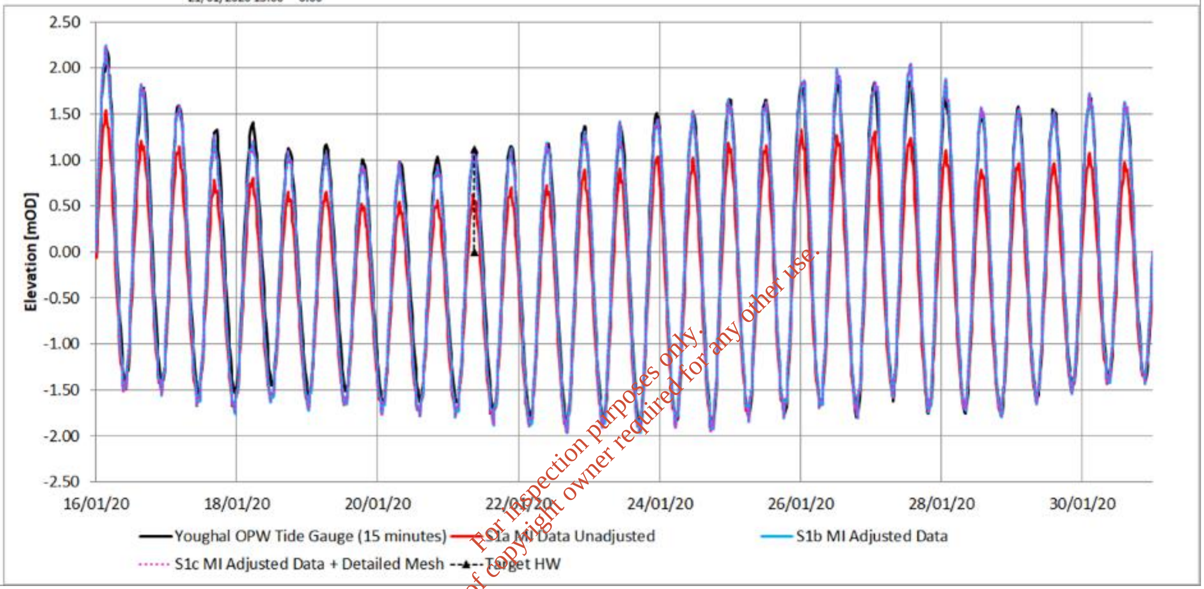


Figure 3-13. Example TSC for Event B at Youghal

3.3.3 Currents

The currents in Youghal Harbour were measured using a downward looking ADCP mounted on the side of the vessel. The ADCP recorded the 3-dimensional currents in up to 40 bins throughout the water column. The review of the survey data identified that there was a high degree of scatter in the current speeds and directions. The approximate location of each transect is shown in Figure 3-14. The actual transect path varied with each transect as the vessel traversed the estuary.

The four points where the transects A to D intersect with transect E were identified and the observed and modelled data extracted for these four points at the time of the transect. This provided a total of 94 comparisons over all three surveys. A visual comparison of all 94 sets has been made and a quantified analysis of the depth averaged current has been completed. Representative images of the comparison are provided in the different sections for each event.

The tidal diamonds and tidal stream arrows on the Admiralty charts for the area provide indicative tidal currents for the purposes of navigation. Whilst these are not directly observed currents for the model period, they do provide additional information on the tidal currents. The tidal currents have been extracted for the locations corresponding to the two tidal stream arrows and two tidal diamonds, as shown in Figure 3-15.

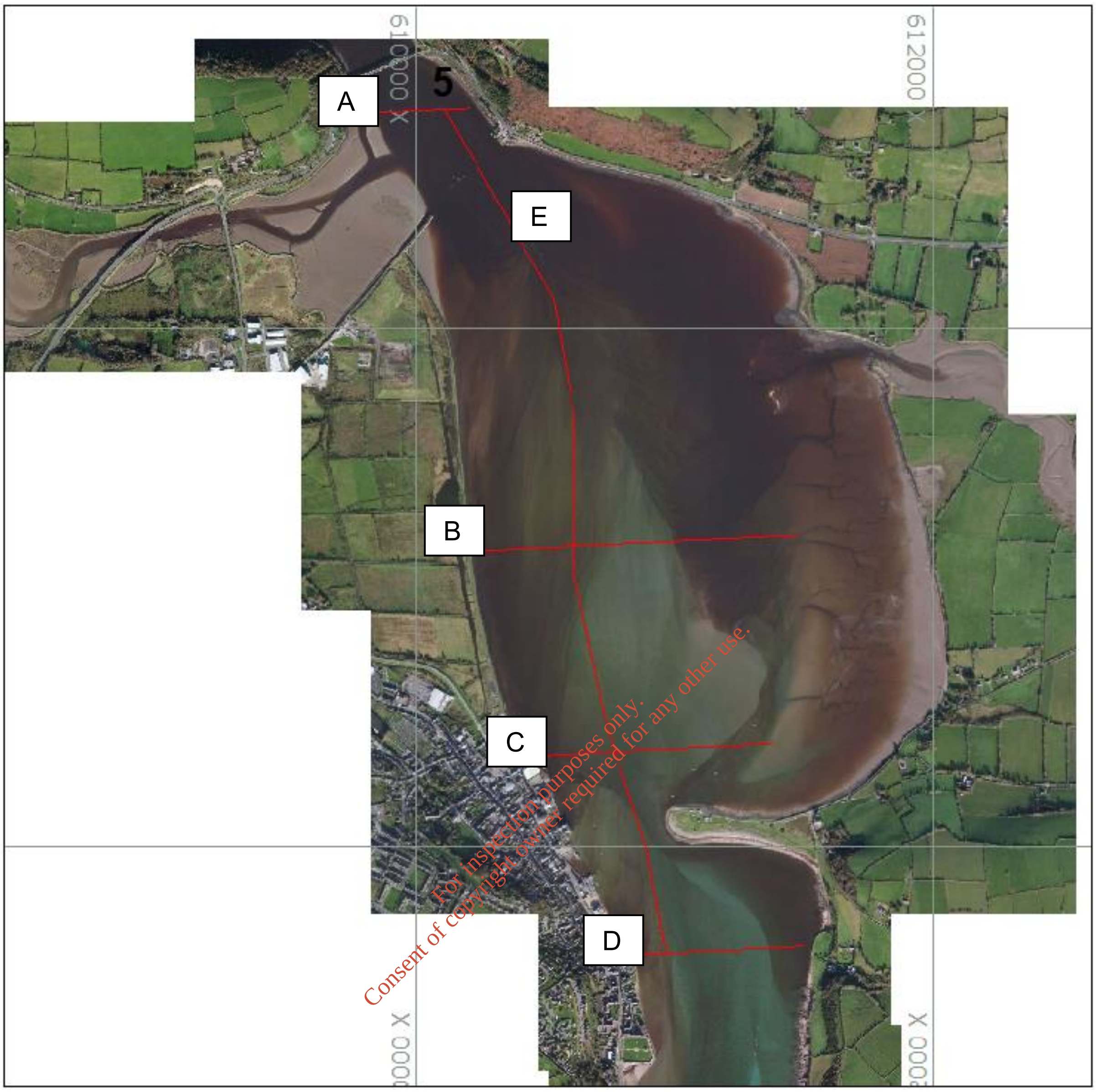


Figure 3-14. Transect locations for all surveys.

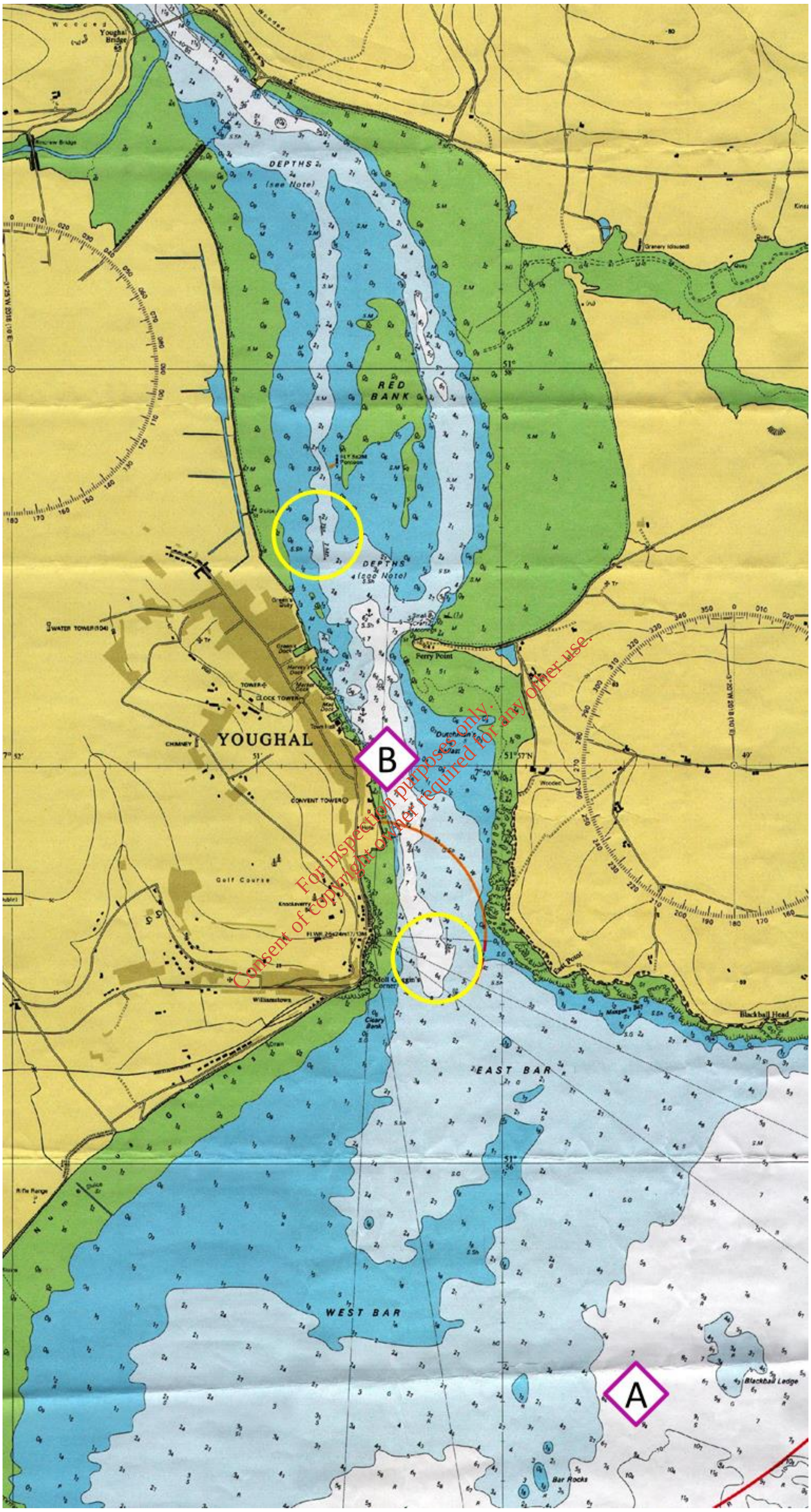


Figure 3-15. Extract from Admiralty chart 1154 showing the locations of the tidal diamonds (A and B) and tidal stream arrows (in yellow circles).

3.3.4 Event A

The model is being driven by the MI data that includes the non-tidal effects of surge due to wind and atmospheric pressure variations. An initial model was developed that used the DHI tidal database to drive the open sea boundaries. Although the water levels at Youghal, Camphire Bridge and Cappoquin were reasonably well replicated, the currents in the offshore area were not reasonable.

To drive a purely tidal model the boundaries would need to be provided from a model of the tide, without any surge component. Consideration has been given to harmonically analysing the surface elevation and velocity components for each of the MI model sigma layers and then predicting a purely tidal boundary condition. This approach could result in a tidal boundary that appears stable but has instabilities within the layers but cannot be identified. The only calibration point available would be Youghal for which the OPW data could be harmonically analysed and compared to the model data. Therefore, it has not been possible to simulate a tide only scenario.

The implication of this is that the model will need to be driven by MI data for the summer scenarios and this will include the effects of the atmospheric pressure and wind on the hydrodynamics. However, the advantage of this will be that the water temperature and salinity in the sea will be variable in time and space rather than using “average” values for the water quality simulations.

3.3.5 Event B

TSCs for Event B are provided in Appendix C.1.

For Event B the primary statistics of interest are on the right-hand side of the table on the TSC. These show the RMSE of the water levels and the timing of high water for each model compared against the observed data.

The TSC for Youghal shows that the RMSE for all water levels for scenario S1b is within tolerance for a site at the mouth of the estuary for water levels above 0mOD and all HWs in the 15 days. The RMSE for all data (0.11 m) is just outside of the tolerance of 0.1 m. The average timing difference of HW is very good at 3 minutes; however, there is a wide range of timing differences between -45 minutes and + 60 minutes. This is examined in more detail in Event E.

The TSC for Camphire shows that the model (simulation S1b) is within tolerance for the RMSE of all water levels and high waters and the average timing of high water is 7 minutes late.

The TSC for Cappoquin is also within tolerance of each of the RMSE statistics and the average timing of high water (simulation S1b).

There is no comparison of currents for Event B as the observed currents were for the shorter periods of Events C, D and E.

3.3.6 Event C

3.3.6.1 Water levels

TSCs for Event C are provided in Appendix C.1.

The TSC for Youghal shows that the model overestimates the target high water level of 1.69 mOD by 0.19 m, which is outside of the tolerance of 0.1 m for a point close to the mouth of an estuary. However, the low water is within 0.03 m although the tidal range is estimated to be slightly high (0.16 m) but the 5% difference in the relative range within the target of 15%.

The TSCs for Camphire Bridge and Cappoquin show that all the absolute and relative statistics are in tolerance for a point at the head of an estuary (simulation S1b).

3.3.6.2 Currents

The summary statistics for simulation S1b for the absolute and relative differences in the current component vectors (U and V) along with speed and direction are shown in Table 3.5. Figure 3-16 shows a plot of the current profile for a single point in time and location (simulation S1b).

The plot demonstrates the wide scatter of the observed speed and direction and the lack of significant vertical structure. However, the plot also shows that the model predicts the depth-average current and direction reasonably well. For this reason the comparison of the current speed and direction has been made using the depth-average current. The summary statistics for the depth-average current for Event C show a wide range of values.

The comparison of the modelled data to the tidal diamond and tidal stream data is provided in Figure 3-17.

Table 3.5. Summary statistics for the depth averaged current for each transect, green cells are within tolerance of ±0.2 m/s and ±20°.

Transect	U [m/s]	V [m/s]	Speed [m/s]	Dir. [˚]
A14	0.29	0.34	-0.21	65
A15	-0.12	1.05	-1.02	-24
A16	-0.25	0.67	-0.69	-10
A17	0.21	0.40	-0.31	-33
A18	-0.08	0.51	-0.22	135
A19	0.32	0.39	-0.14	46
B21	-0.21	-0.69	-0.72	2
B22	-0.07	-0.59	0.26	152
B23	0.30	-1.02	0.18	-139
B24	0.12	-0.54	0.47	-43
B25	0.01	-0.52	-0.52	1
B26	-0.18	-0.51	-0.52	-10
C20	-0.32	-0.45	-0.45	-19
C21	-0.09	-0.53	-0.39	-161
C22	-0.27	-0.80	0.37	86
C23	-0.07	-0.67	0.37	91
C24	0.12	-0.71	-0.72	26
C25	-0.53	-0.84	-0.89	-27
C26	-0.37	-0.60	-0.61	-19
C27	-0.11	0.48	0.43	163
D16	-0.27	-0.57	-0.54	-27
D17	-0.18	-0.49	0.15	70
D18	0.20	-0.13	0.18	-13
D19	0.35	-0.76	0.81	-55
D20	0.23	-1.13	-0.43	167
D21	-0.27	-0.79	-0.75	-20
D22	-0.26	-0.72	-0.69	-24

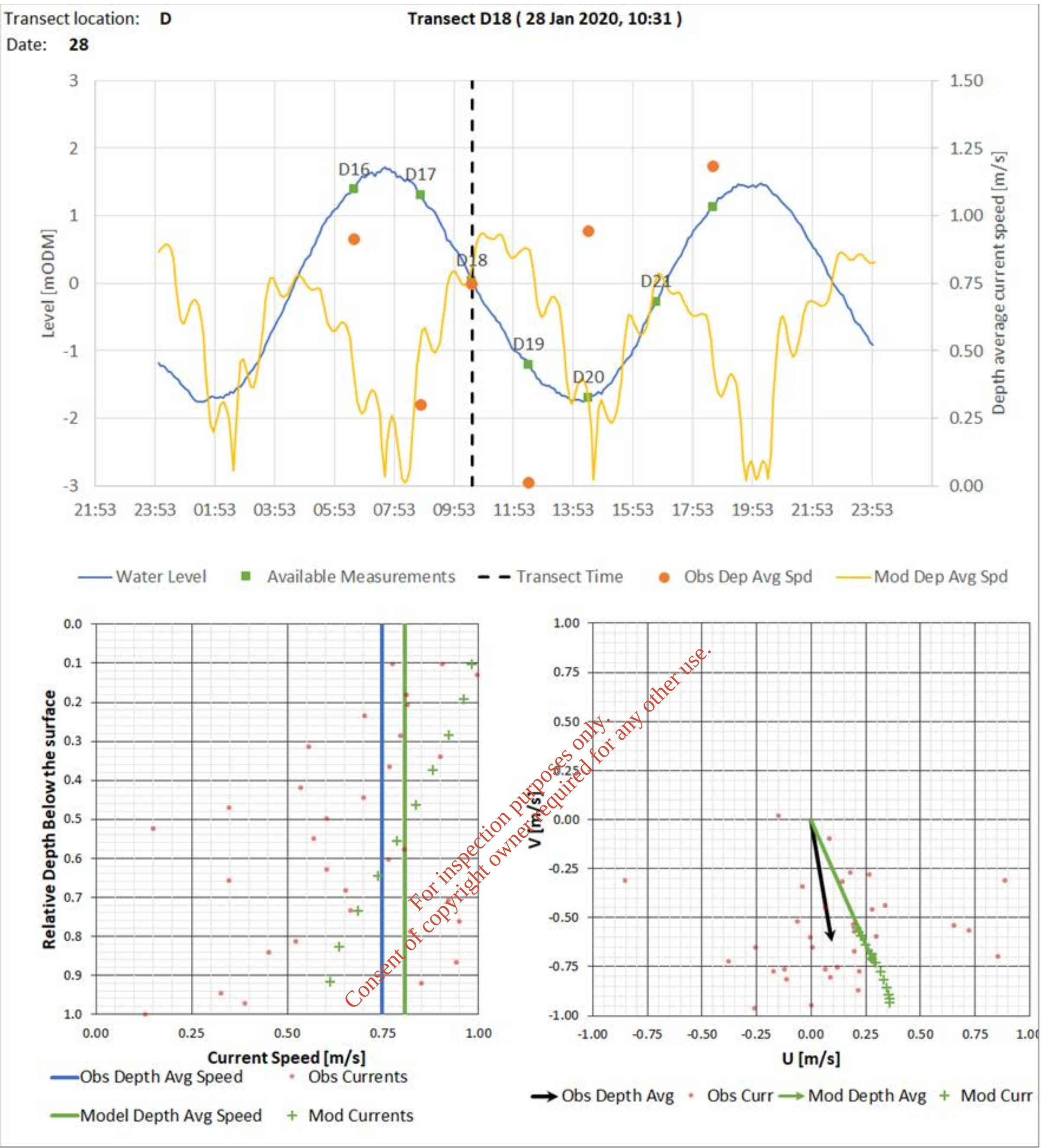


Figure 3-16. Example plot of currents for Event C showing good agreement of the depth averaged current speed and direction.

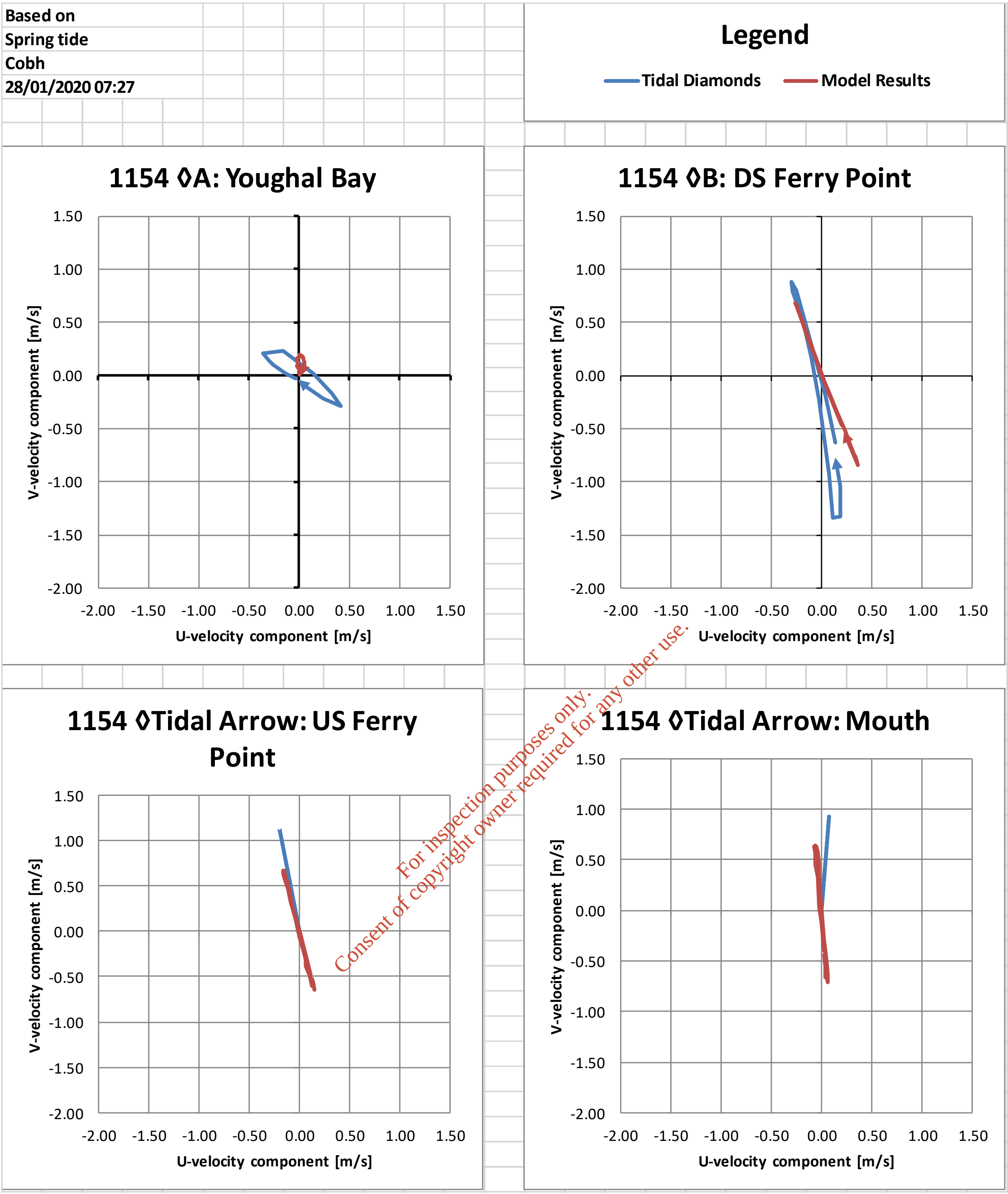


Figure 3-17. Comparison of the modelled currents with the Admiralty chart tidal diamond and tidal stream arrows for Event C.

3.3.7 Event D

3.3.7.1 Water levels

TSCs for Event D are in Appendix C.2.

The TSC for Youghal shows that the target high water level is reproduced very well by the model (-0.01 m); however, the low water level is under-estimated (-0.15 m) and the absolute tidal range is slightly too large (+0.14 m). However, the relative tidal range (+5%) is within tolerance. The timing of the high water (-30 minutes) is just outside of the tolerance however it should be noted that the time step of the observed data is 15 minutes and the high water is 30 minutes early in the model.

The TSC for Camphire Bridge shows that the model using the adjusted MI data is within tolerance for all statistics for Event D. The TSC for Cappoquin shows that high water level and low water level are reproduced very will and are within tolerance. However, the timing of high water (-30minutes) is just outside of the tolerance but it should be noted that the time step of the observed data is 15 minutes and the high water is 30 minutes early in the model.

3.3.7.2 Currents

The summary statistics for the absolute and relative differences in the current component vectors (U and V), the speed and direction are shown in Table 3.6. The number of samples that are within tolerance is higher than for Event C.

A comparison of the modelled currents with the Admiralty tidal diamond and tidal stream data is provided in Figure 3-18. These show that the model is replicating the indicative currents well.

Table 3.6. Summary statistics for the depth averaged current for each transect, green cells are within tolerance of ±0.2 m/s and ±20°.

Transect	U [m/s]	V [m/s]	Speed [m/s]	Dir. [˚]
A9	0.30	-0.16	0.28	-32
A10	0.03	0.01	0.01	-11
A11	-0.04	0.21	0.14	32
A12	0.00	0.33	0.06	87
A13	0.07	0.22	-0.17	-21
B12	0.27	-0.24	0.12	-42
B13	0.26	-0.20	-0.14	-96
B14	0.20	-0.14	-0.17	16
B15	-0.11	0.07	0.06	-11
B16	0.00	-0.45	-0.45	1
B17	-0.04	-0.53	-0.54	1
B18	-0.15	-0.37	0.11	117
B19	0.19	-0.63	0.28	-124
B20	0.41	-0.70	0.21	-95
C11	0.09	-0.29	0.30	-5
C12	0.08	-0.61	0.44	116
C13	-0.06	-0.09	-0.08	-11
C14	0.10	-0.14	-0.16	7
C15	-0.16	-0.31	-0.30	-12
C26	-0.29	-0.28	-0.29	-20
C7	-0.12	-0.24	-0.22	-69
C18	-0.06	-0.30	0.23	70
C19	0.30	-0.33	0.30	-38
D9	0.08	-0.28	0.29	3
D10	0.19	0.15	-0.10	-17
D11	0.22	-0.54	0.48	-153
D12	0.13	-0.48	-0.49	-3
D13	-0.11	-0.54	-0.51	-16
D14	0.28	-0.49	0.31	-144
D15	0.12	-0.21	0.24	-4

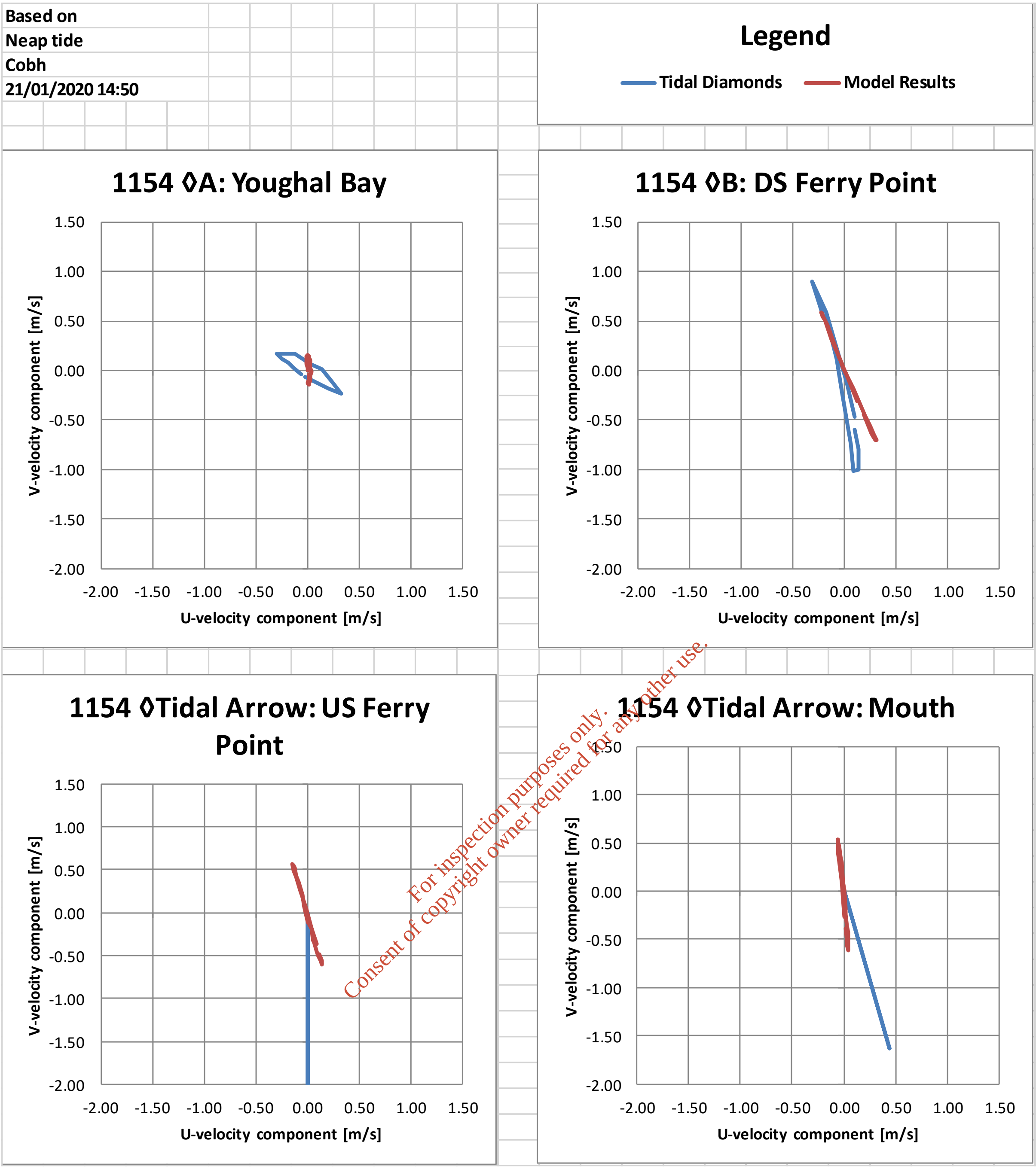


Figure 3-18. Comparison of the modelled currents with the Admiralty chart tidal diamond and tidal stream arrows for Event D.

3.3.8 Event E

3.3.8.1 Water levels

The TSCs for Event E are in Appendix C.3.

The LW for Event E at Youghal is just outside of the tolerance (+0.11 m) however the HW elevation and relative tidal range are both within tolerance. The timing of the high water (-30 minutes) is just outside of the tolerance however it should be noted that the time step of the observed data is 15 minutes and the high water is 30 minutes early in the model.

For Camphire the HW and LW levels and timing and the tidal range are all within tolerance.

The TSC for Cappoquin shows that high water level and low water level are reproduced very well and are within tolerance. However, the timing of high water (-30minutes) is just outside of the tolerance but it should be noted that the time step of the observed data is 15 minutes and the high water is 30 minutes early in the model.

3.3.8.2 Currents

Figure 3-19 shows an example of a good comparison of the vertical structure and speed and direction throughout the profile. The statistics of the quantitative assessment of the currents are presented in Table 3.7 and a comparison of the modelled currents to the tidal diamond and stream data is provided in Figure 3-20.

In general, the model is representing the observed currents well for Event E.

Table 3.7. Summary statistics for the depth averaged current for each transect, green cells are within tolerance of ±0.2 m/s and ±20°.

Transect	U [m/s]	V [m/s]	Speed [m/s]	Dir. [˚]
A1	0.00	0.08	0.06	9
A2	0.08	-0.13	-0.15	-2
A3	0.08	0.05	-0.04	26
A4	-0.14	0.37	-0.39	-8
A5	0.08	0.14	-0.09	-15
A6	0.10	0.08	-0.01	-11
A7	-0.01	0.12	-0.09	-6
A8	-0.04	0.35	-0.04	117
B1	-0.16	-0.45	-0.47	-9
B2	-0.16	0.00	-0.02	-15
B3	-0.03	-0.41	-0.41	-1
B4	0.20	-0.21	-0.25	19
B5	0.07	-0.34	-0.18	-176
B6	-0.10	-0.61	-0.04	158
B7	0.20	-0.55	0.40	-72
B8	0.00	-0.58	0.58	-11
B9	0.18	0.20	-0.22	-11
B10	0.27	-0.17	0.00	-57
B11	0.03	-0.45	-0.45	4
C1	-0.13	-0.41	-0.40	-15
C2	-0.04	-0.07	-0.07	-4
C3	-0.07	-0.03	-0.02	-6
C4	0.06	0.16	0.13	16
C5	0.14	0.32	-0.35	-9
C6	0.08	0.26	-0.26	-9
C7	0.08	0.47	-0.46	-7
C8	0.14	-0.29	0.32	-11
C9	0.15	-0.58	0.12	175
C10	0.14	-0.33	-0.36	4
D1	-0.07	-0.49	-0.46	-13
D2	0.03	-0.40	-0.40	-9
D3	-0.04	-0.07	-0.06	-20
D4	-0.19	0.15	-0.22	9
D5	0.14	-0.18	0.21	-5
D6	0.07	-0.24	0.25	3
D7	0.15	-0.66	-0.06	165
D8	-0.06	-0.46	-0.43	-12

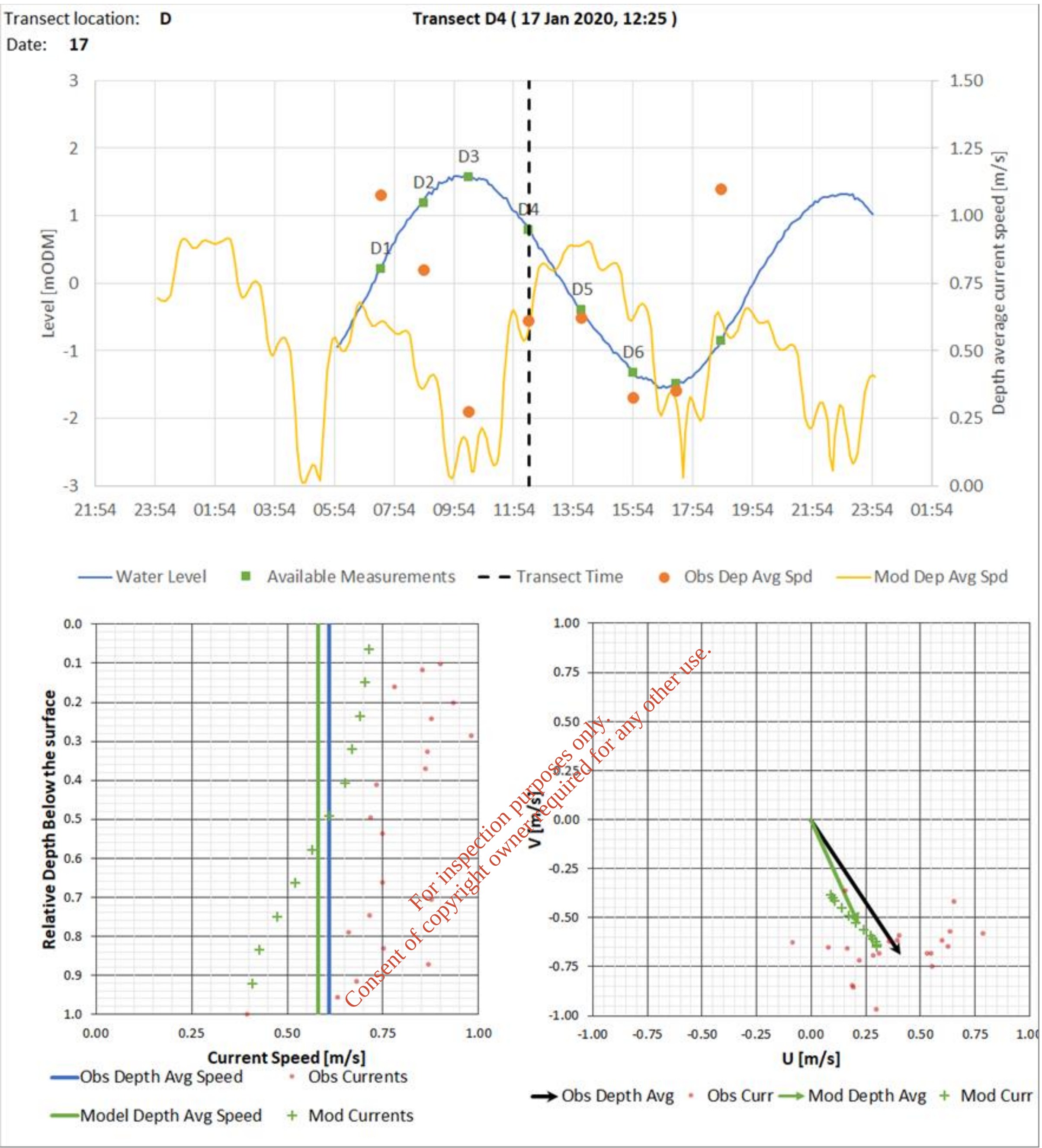


Figure 3-19. Example plot of currents for Event E showing good agreement of the depth averaged current speed and direction.

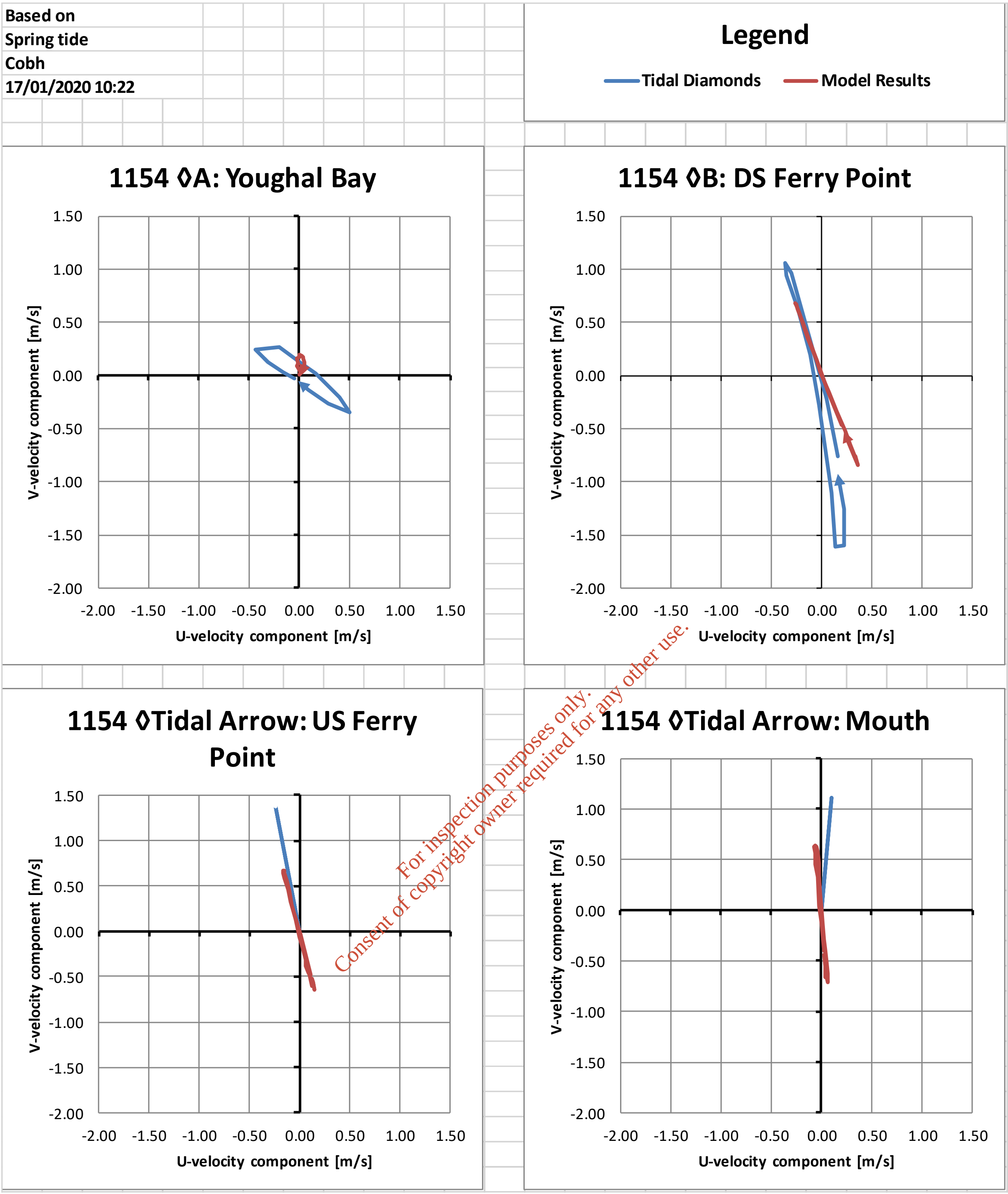


Figure 3-20. Comparison of the modelled currents with the Admiralty chart tidal diamond and tidal stream arrows for Event E.

3.3.9 Summary

Overall the model using the adjusted MI data reproduces the water levels at all three sites very well both qualitatively and from quantitative assessment. The currents are generally well reproduced and look reasonable in terms of expectations. Where there is wide scatter of the observed data in terms of speed and direction the model does not match the data so well, primarily Event C. The current data does however provide a reasonable comparison to the tidal diamond and stream data for Event C.

3.4 Sensitivity tests

3.4.1 Model open sea boundary conditions and mesh resolution in the river sections

The modelled water level for the different boundary conditions and mesh resolution are plotted for each of the events (B to E) at the three locations: Youghal (Figure 3-21 to Figure 3-24), Camphire Bridge (Figure 3-25 to Figure 3-28) and Cappoquin (Figure 3-29 to Figure 3-32). Additionally, the TSCs presented in Appendix C provide the statistical comparison to the observed data.

These show clearly that the unadjusted MI data is not able to generate the observed high water levels at any of the locations for any of the events. Also, the higher resolution mesh does not significantly affect the water levels for any of the locations or events.

The significantly higher computational time (more than 5x) for the detailed mesh was considered unreasonable for the potential benefits in differential dispersion across the river channel given that the discharge of interest is in the harbour area (for which the resolution was unchanged) and the Cappoquin discharge is significantly upstream of the primary area of interest. The more detailed mesh of the river has therefore not been used for investigations.

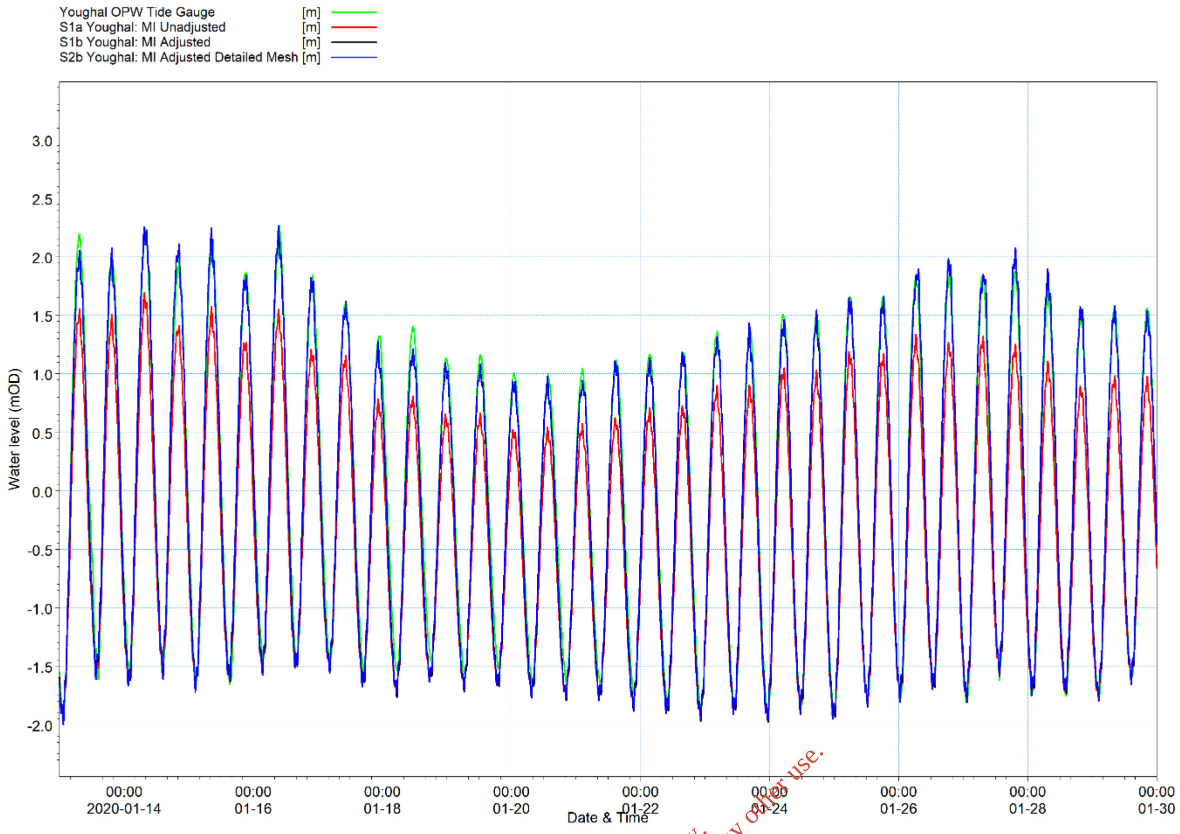


Figure 3-21. Sensitivity of water level at Youghal for Event B for different boundary conditions and mesh resolutions.

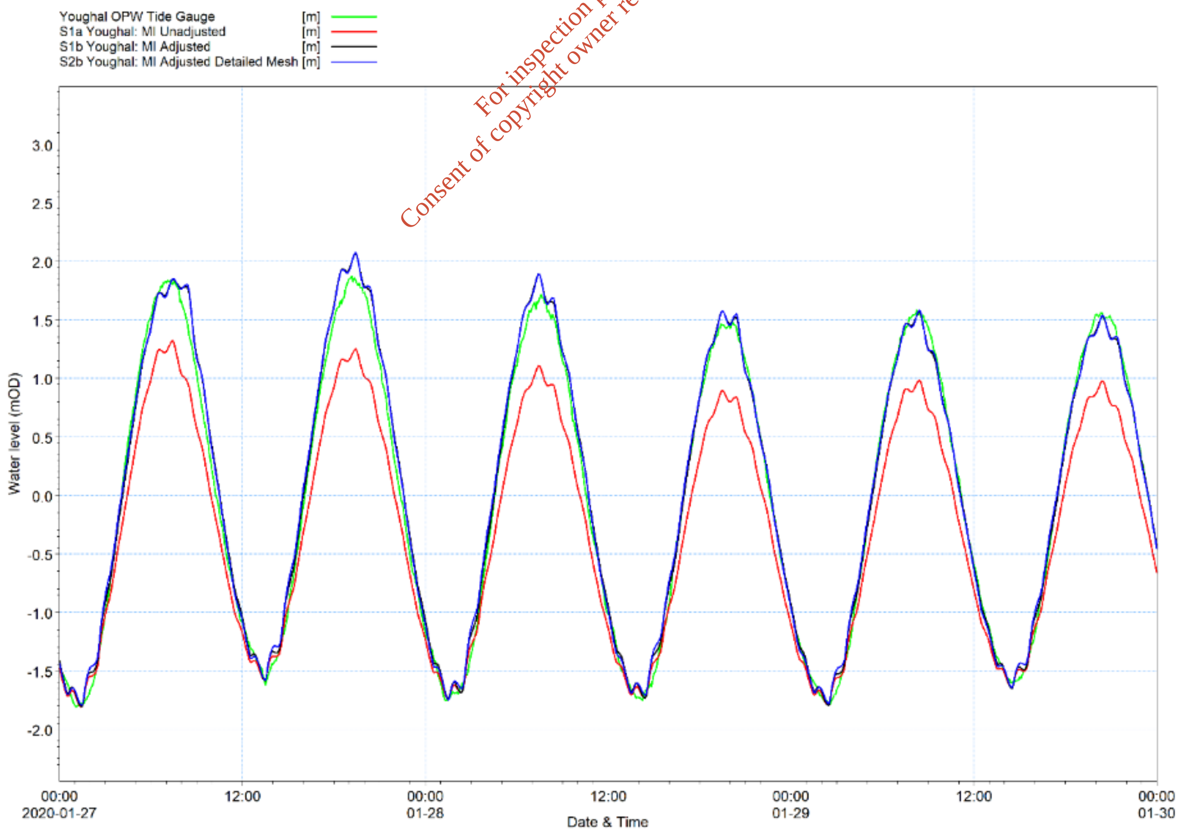


Figure 3-22. Sensitivity of water level at Youghal for Event C for different boundary conditions and mesh resolutions.

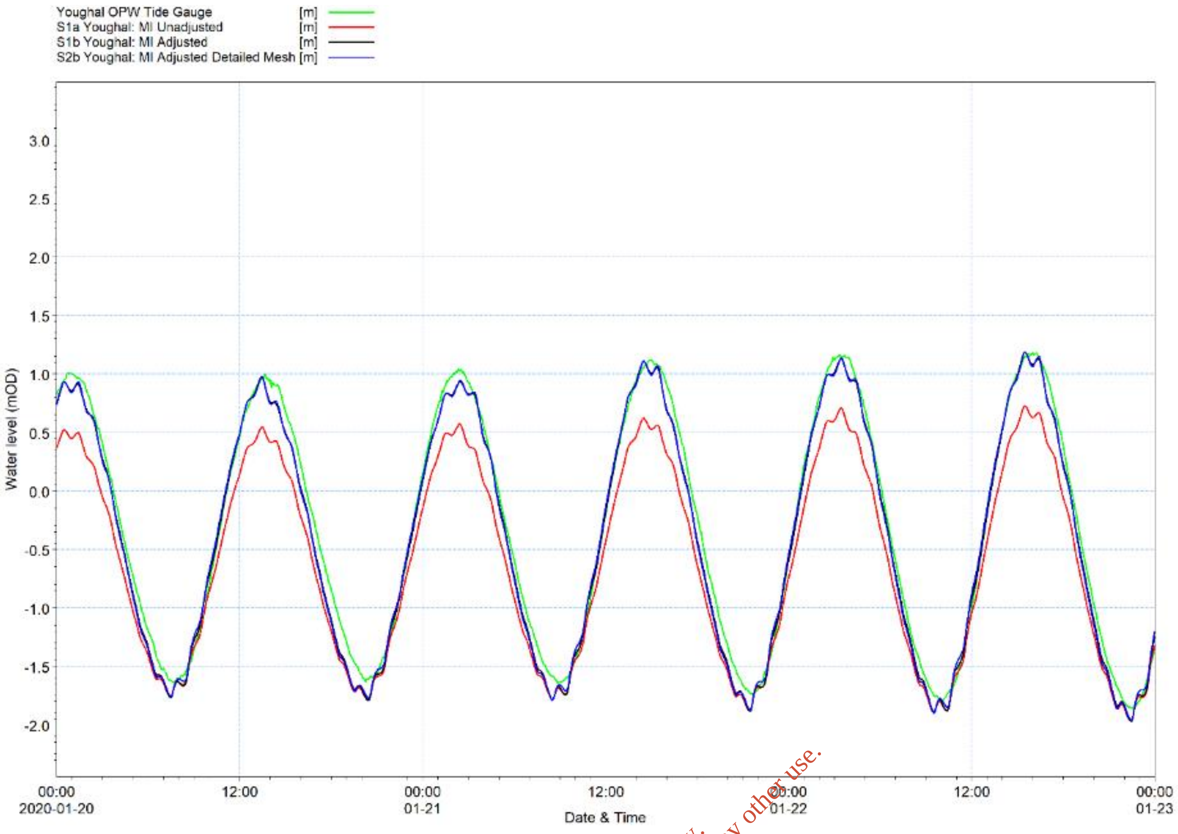


Figure 3-23. Sensitivity of water level at Youghal for Event D for different boundary conditions and mesh resolutions.

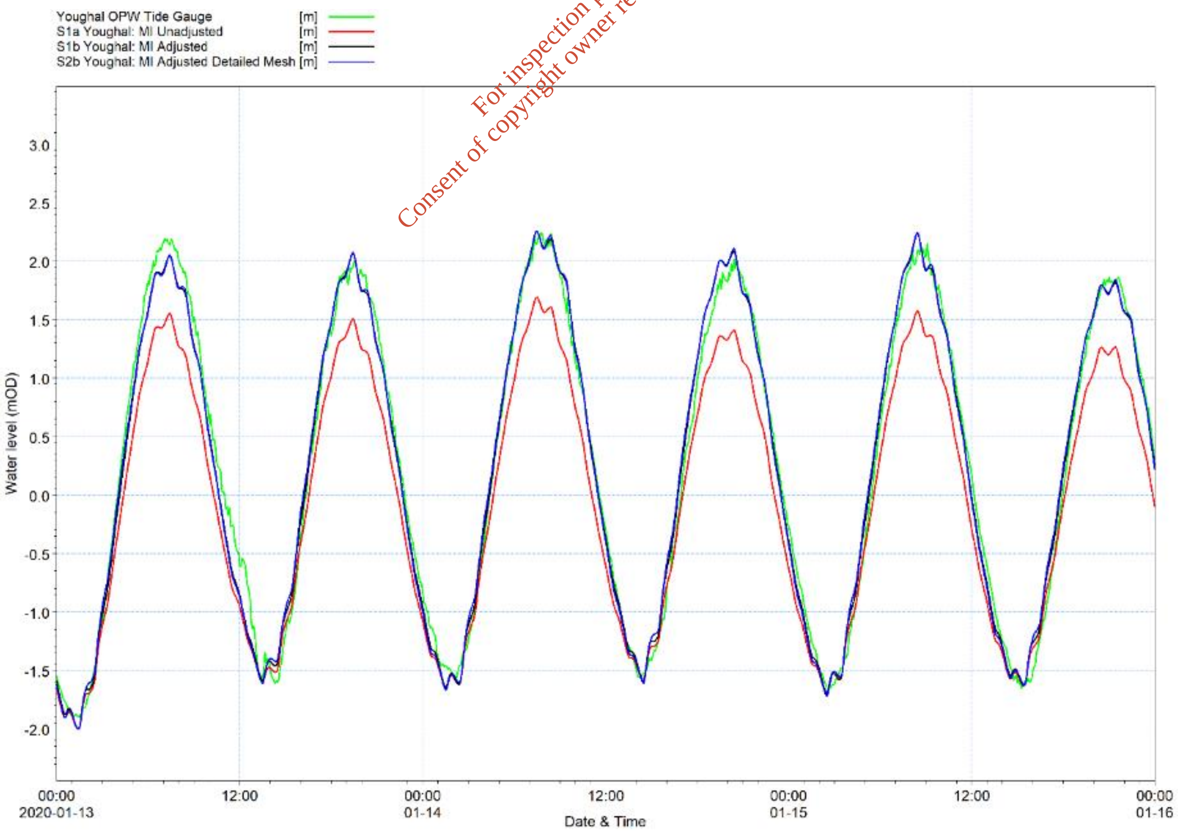


Figure 3-24. Sensitivity of water level at Youghal for Event E for different boundary conditions and mesh resolutions.

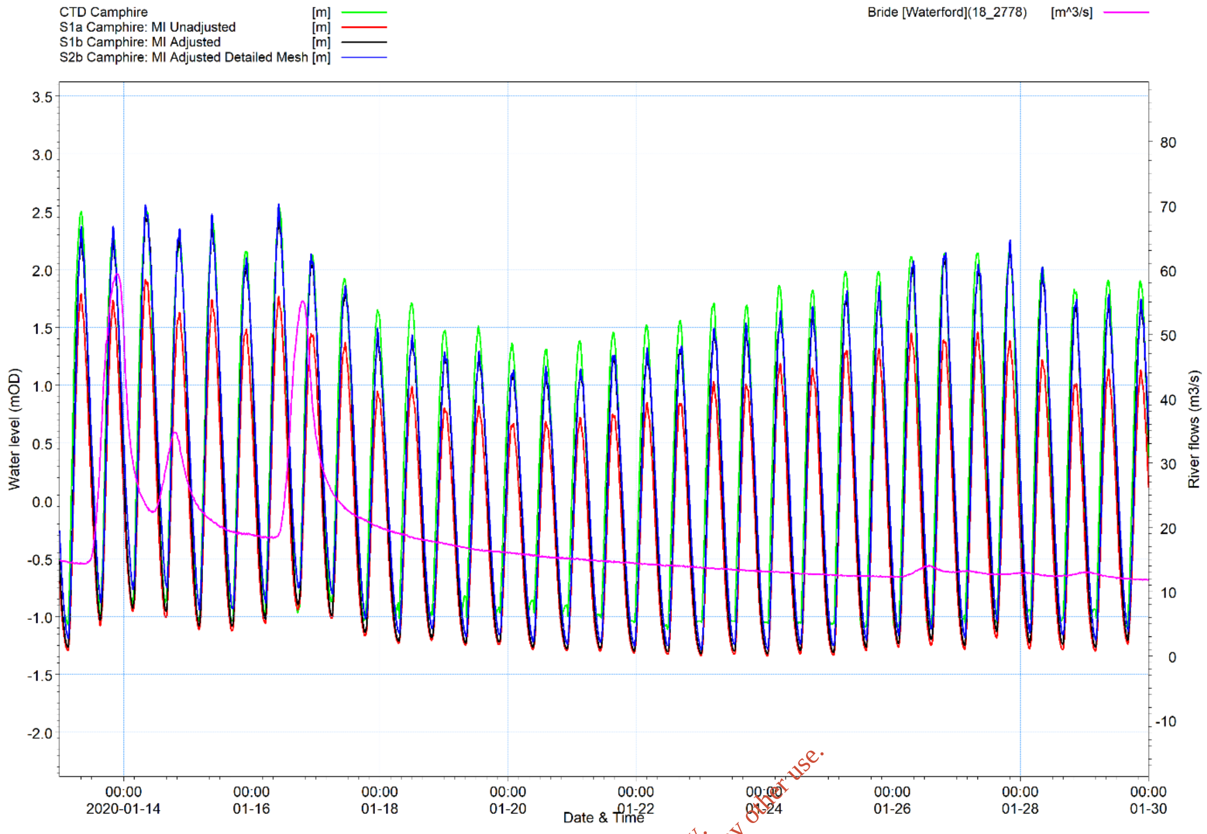


Figure 3-25. Sensitivity of water level at Camphire Bridge for Event B for different boundary conditions and mesh resolutions.

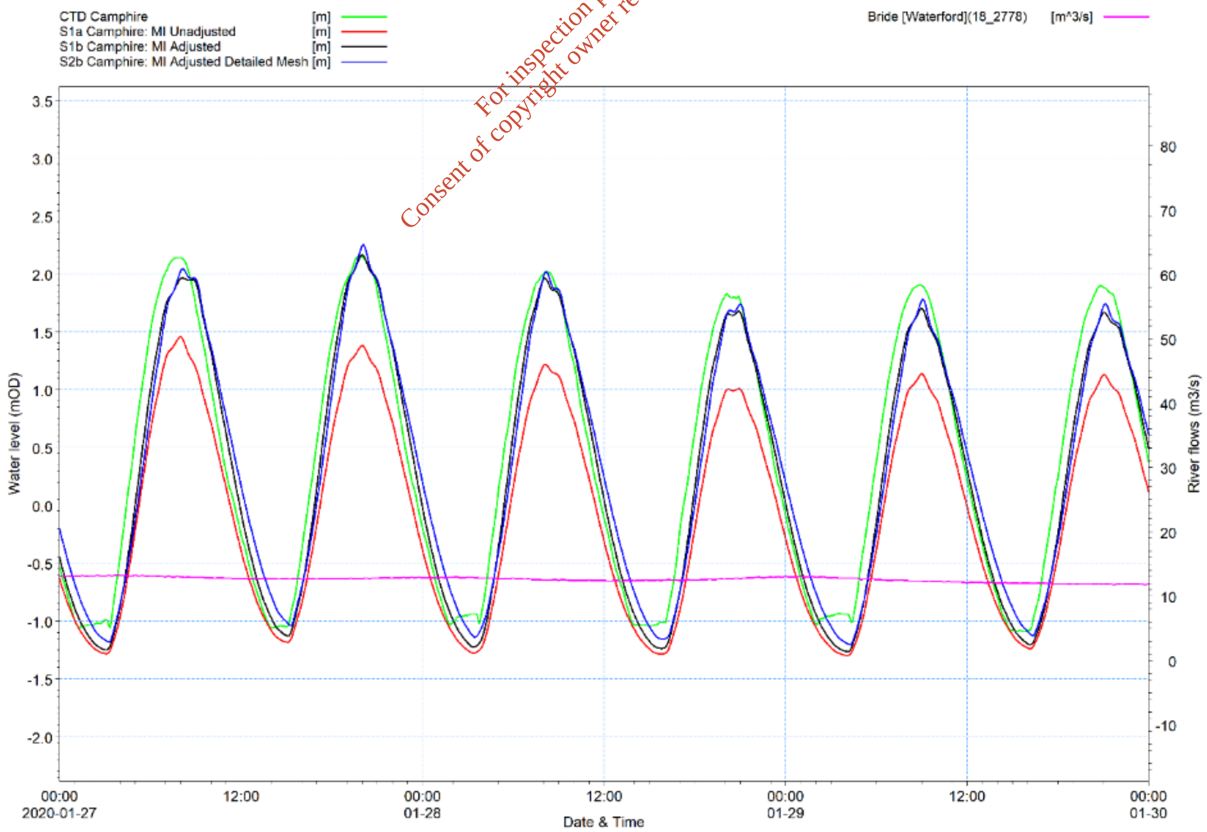


Figure 3-26. Sensitivity of water level at Camphire Bridge for Event C for different boundary conditions and mesh resolutions.

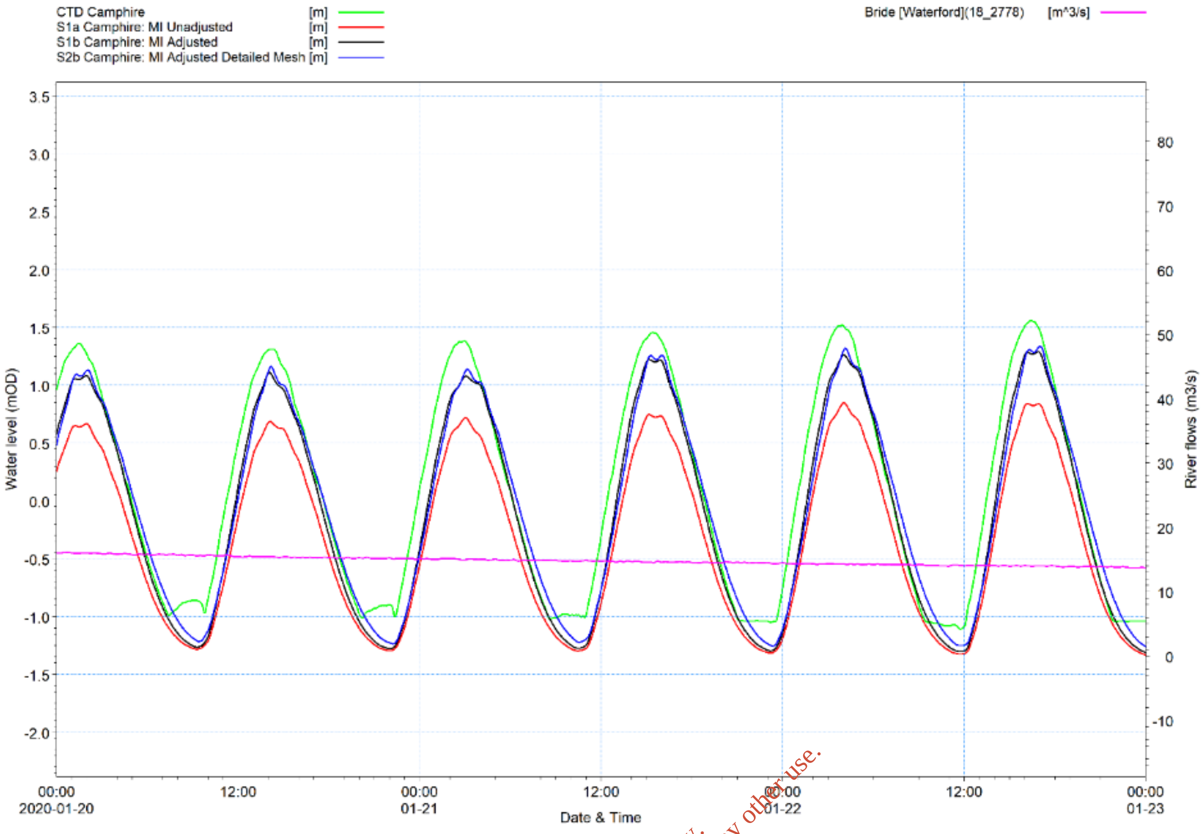


Figure 3-27. Sensitivity of water level at Camphire Bridgefor Event D for different boundary conditions and mesh resolutions.

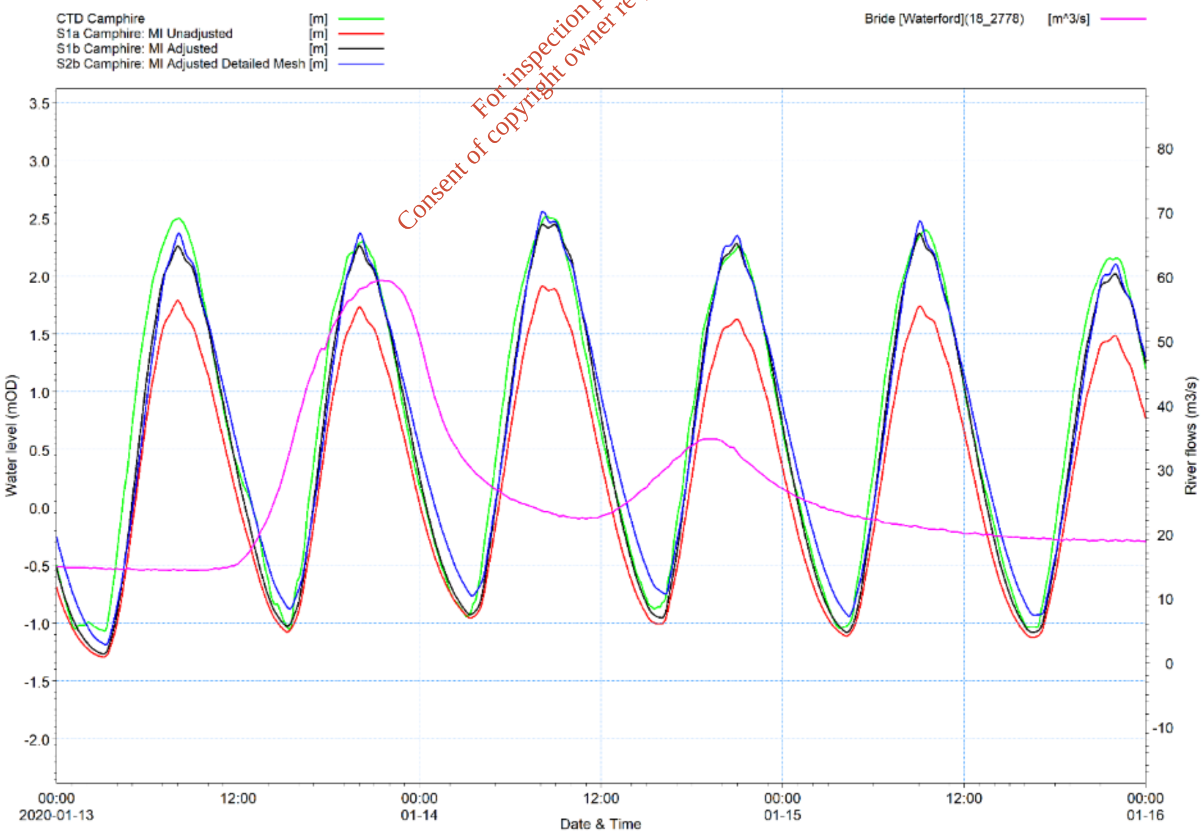


Figure 3-28. Sensitivity of water level at Camphire Bridge for Event E for different boundary conditions and mesh resolutions.

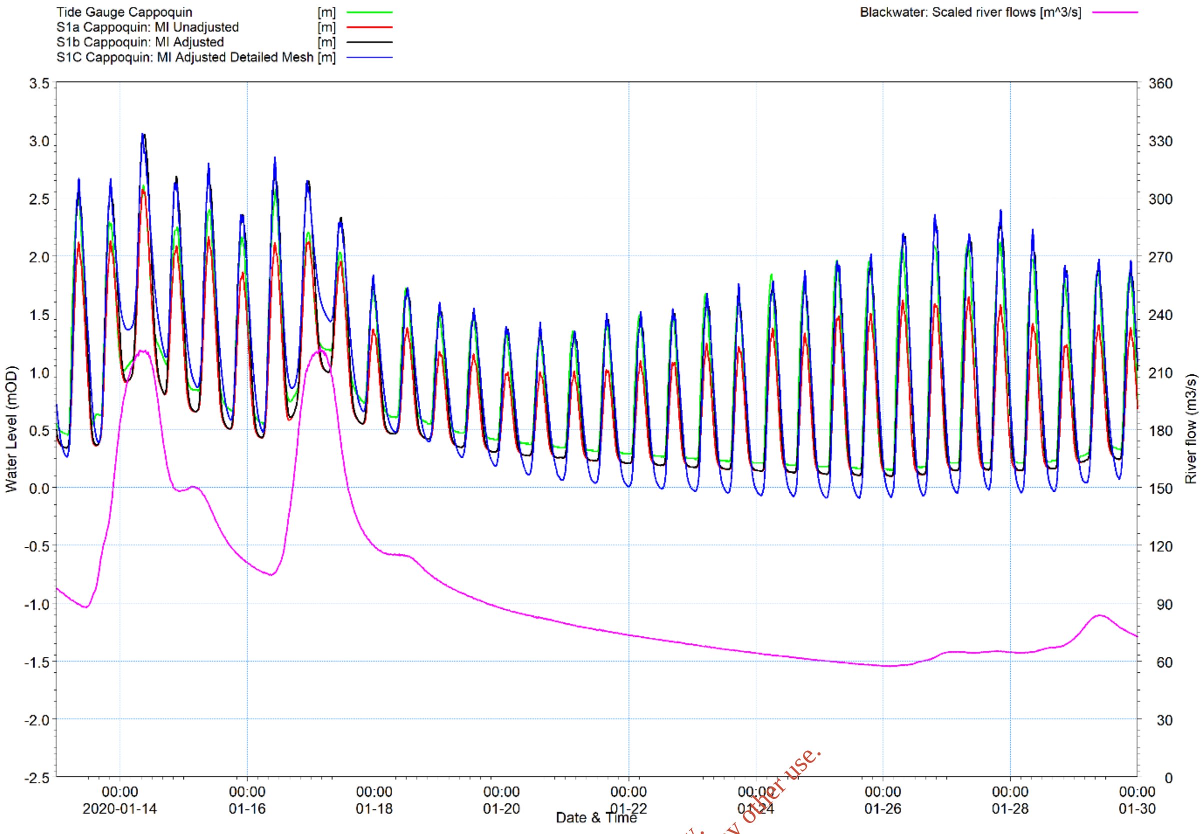


Figure 3-29. Sensitivity of water level at Cappoquin for Event B for different boundary conditions and mesh resolutions.

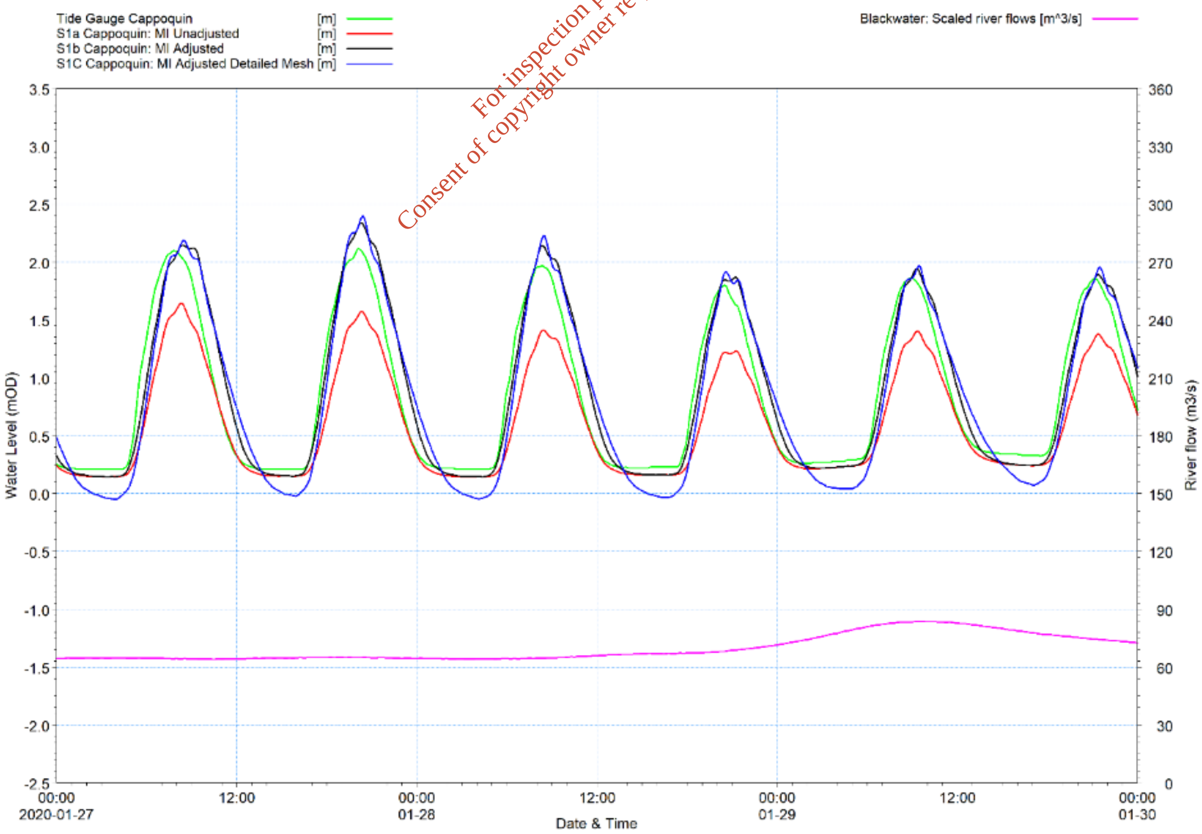


Figure 3-30. Sensitivity of water level at Cappoquin for Event C for different boundary conditions and mesh resolutions.

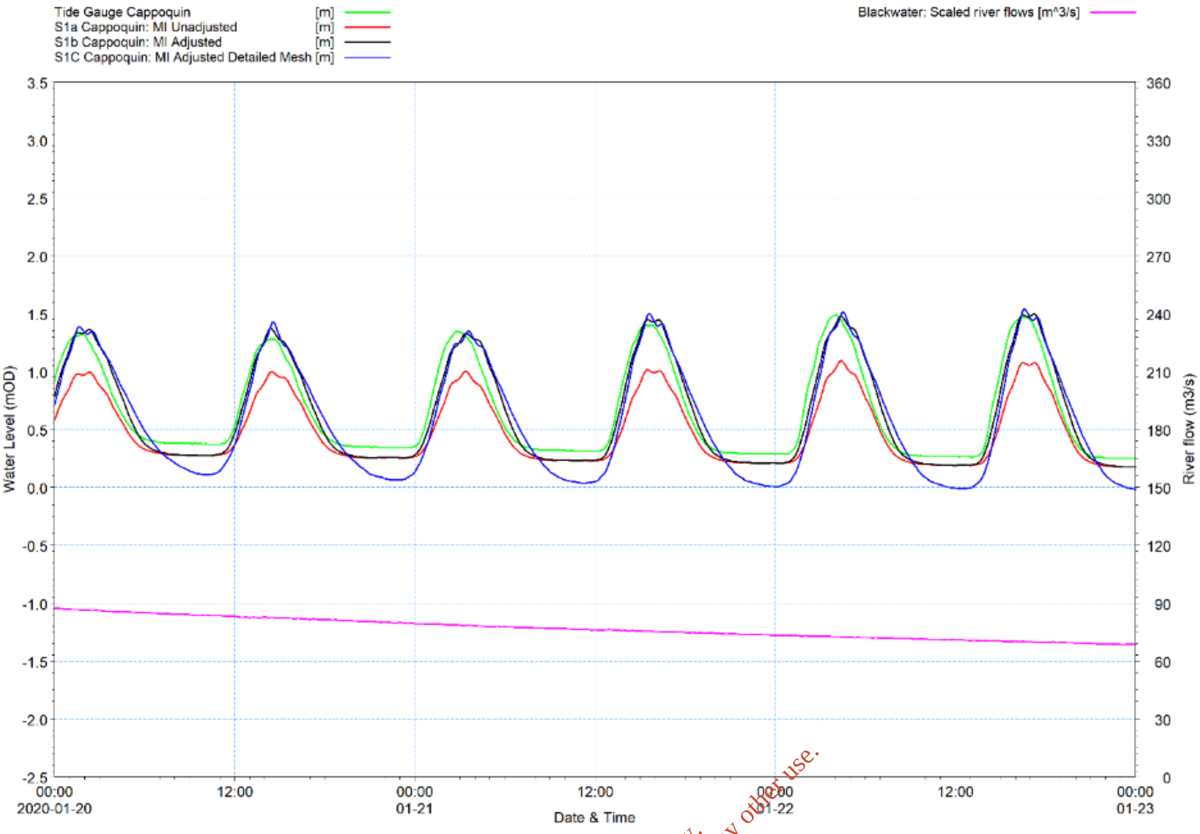


Figure 3-31. Sensitivity of water level at Cappoquin for Event D for different boundary conditions and mesh resolutions.

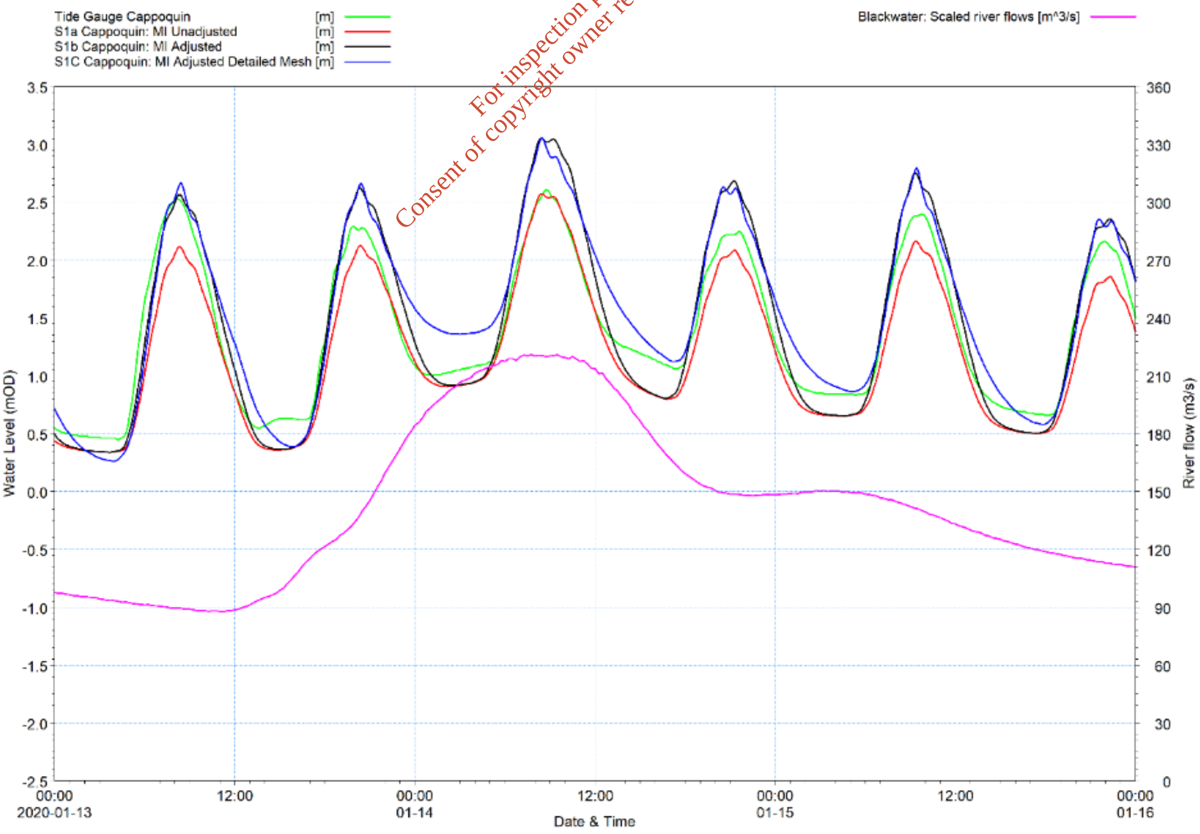


Figure 3-32. Sensitivity of water level at Cappoquin for Event E for different boundary conditions and mesh resolutions.

3.4.2 Bed resistance in river channel

The sensitivity of the model to changes in bed roughness in the main Blackwater estuary channel was undertaken. The resulting water levels at Cappoquin for Event B are shown in Figure 3-33. This shows that there is minimal discernible difference in the water levels. This is most likely because the channel is deep enough to convey the water under the influence of the tide and the changes in roughness from 0.05 m to 0.04 m and 0.06 m is relatively small compared to the depth of water.

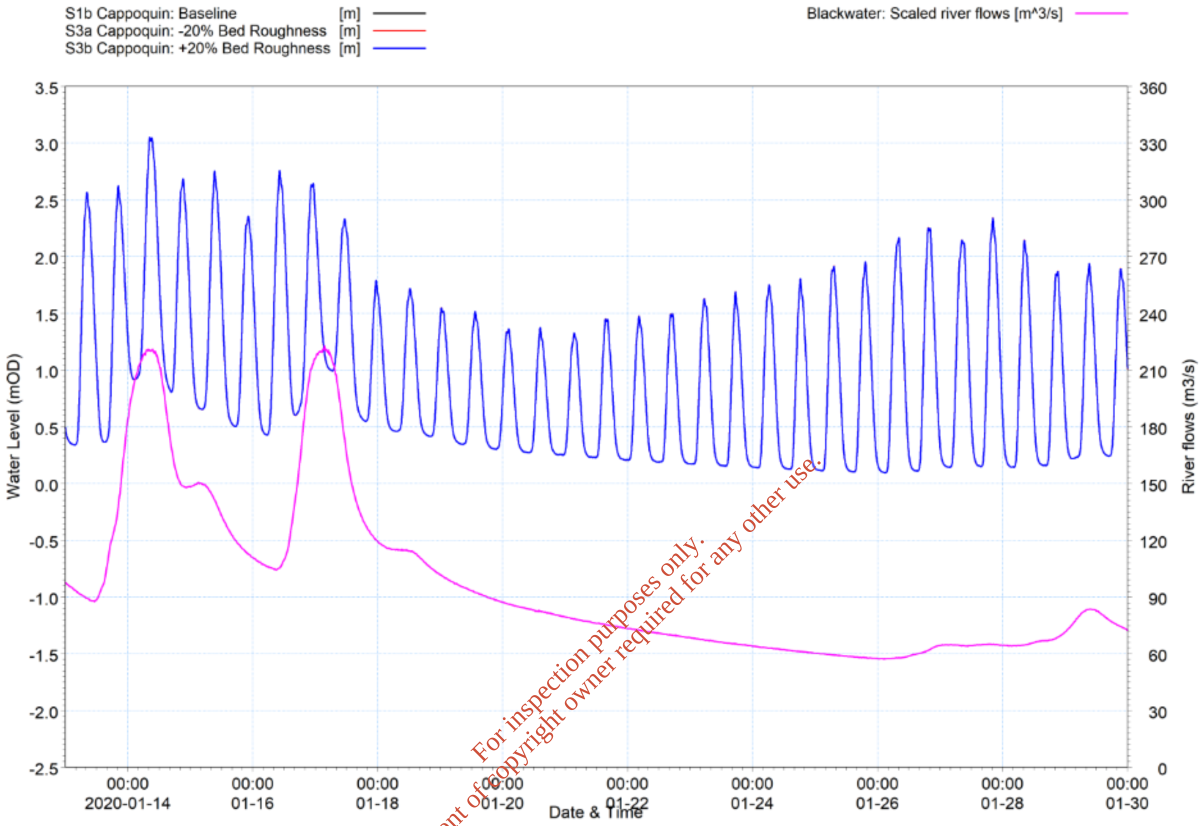


Figure 3-33. Sensitivity of water level at Youghal for Event B for different bed roughness conditions.

3.4.3 River flows

The water levels at Cappoquin and Camphire and possibly the stratification within Youghal Harbour are likely to be sensitive to the volume of freshwater that enters the system. It is clear that Cappoquin and Camphire low water levels are determined by the freshwater flow in the rivers; however, it is not clear whether this affects the high water levels. Additionally, there may be changes in the vertical structure of the currents under higher or lower river flows.

Sensitivity tests have therefore been undertaken that utilised the calibration period for Event B but changed the river flows to be:

- Q95 for all rivers (constant value)
- -20% for all rivers (variable time series)
- +20% for all rivers (variable time series)

The resulting water level plots are provided for each site and event and are summarised in Figure 3-34 to Figure 3-45. Note that where it is difficult to distinguish between lines this is because there is only a small difference between values. These figures have been presented to show the spring-neap-spring cycle of 15 days and 3 days centred on each survey date.

The water level at Youghal (Figure 3-34 to Figure 3-37) is not significantly affected by the river flows, other than a small difference at low water. This is reasonable and not unexpected.

The water level at Camphire Bridge (Figure 3-38 to Figure 3-41) is affected by river flow rates. The affect is seen most dramatically with the dry weather flow rates (Q95). It is not clear if the water level is a function of just the flow rate in the River Bride or if the backwater from the confluence with the main channel of the Blackwater estuary is the control mechanism. However, the water levels at Camphire Bridge do respond to changes in the river flow rates, as would be expected.

The water level at Cappoquin (Figure 3-42 to Figure 3-45) is the most affected by river flow rates. At low tide the channel is functioning as a river with minimal to no tidal influence. At high tide the high water level can be increased by river flow. The effect on high water is most notable at the start of Event B (Figure 3-42) and Event E (Figure 3-45).

The river flow rate does affect the water level within the channel. An accurate calibration will therefore be dependent upon the accuracy of any variability in the river flow rate during the calibration period. Based on the results presented in section 3.3 the river flows as estimated based on the observed data at Mogeely and Ballyduff are considered to be reasonable for the calibration period.

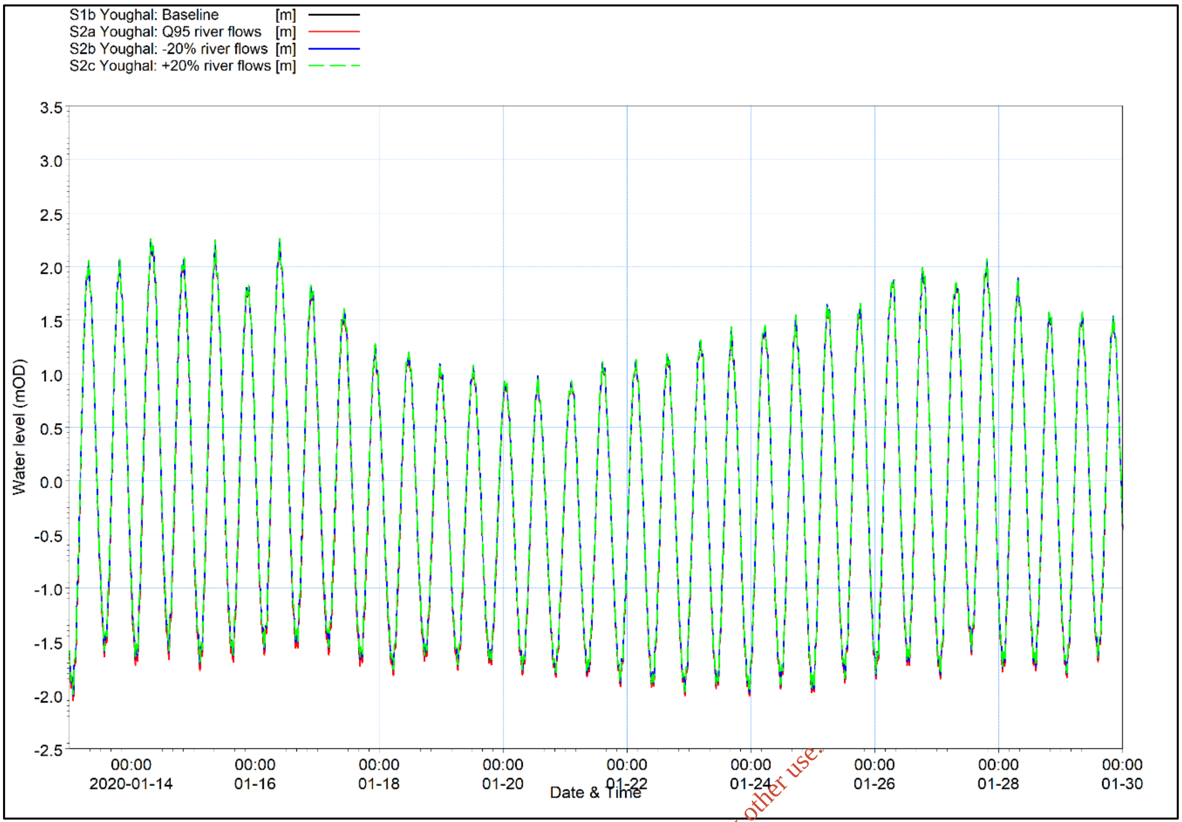


Figure 3-34. Sensitivity of water level at Youghal for Event B with different river flow rates

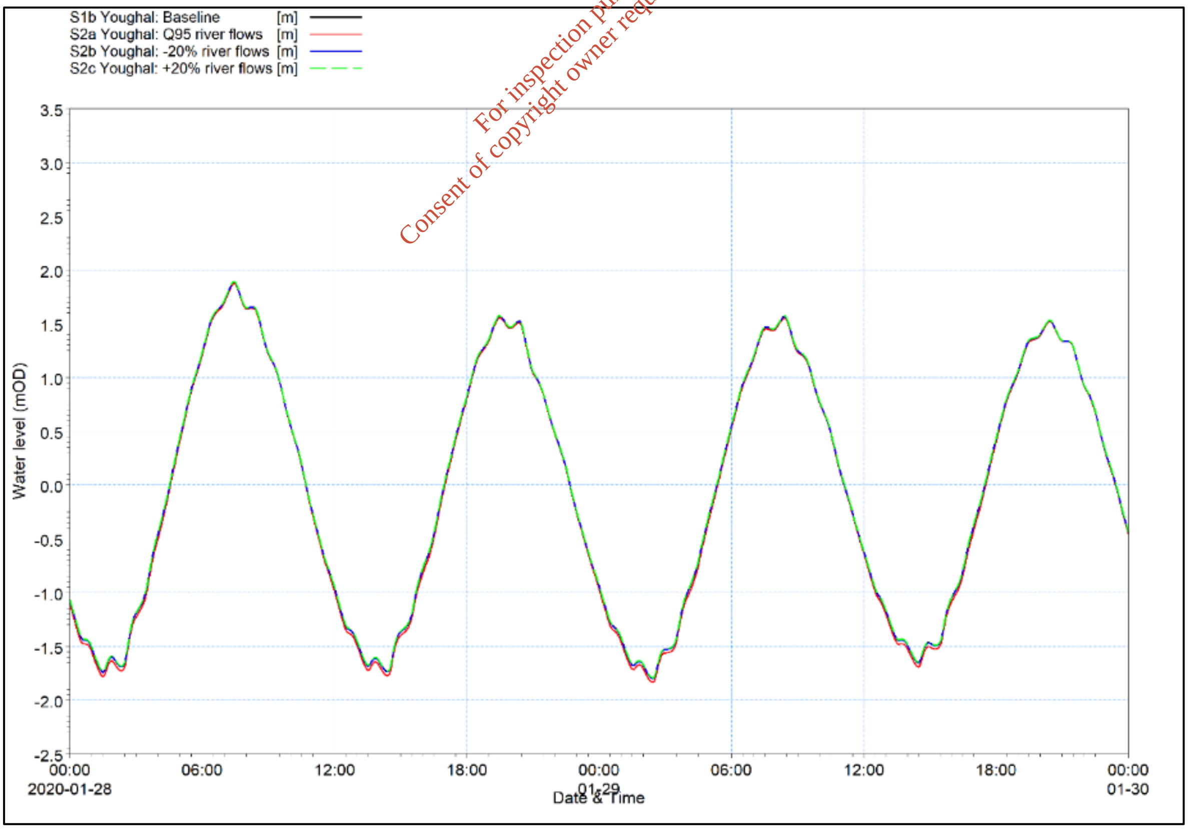


Figure 3-35. Sensitivity of water level at Youghal for Event C with different river flow rates

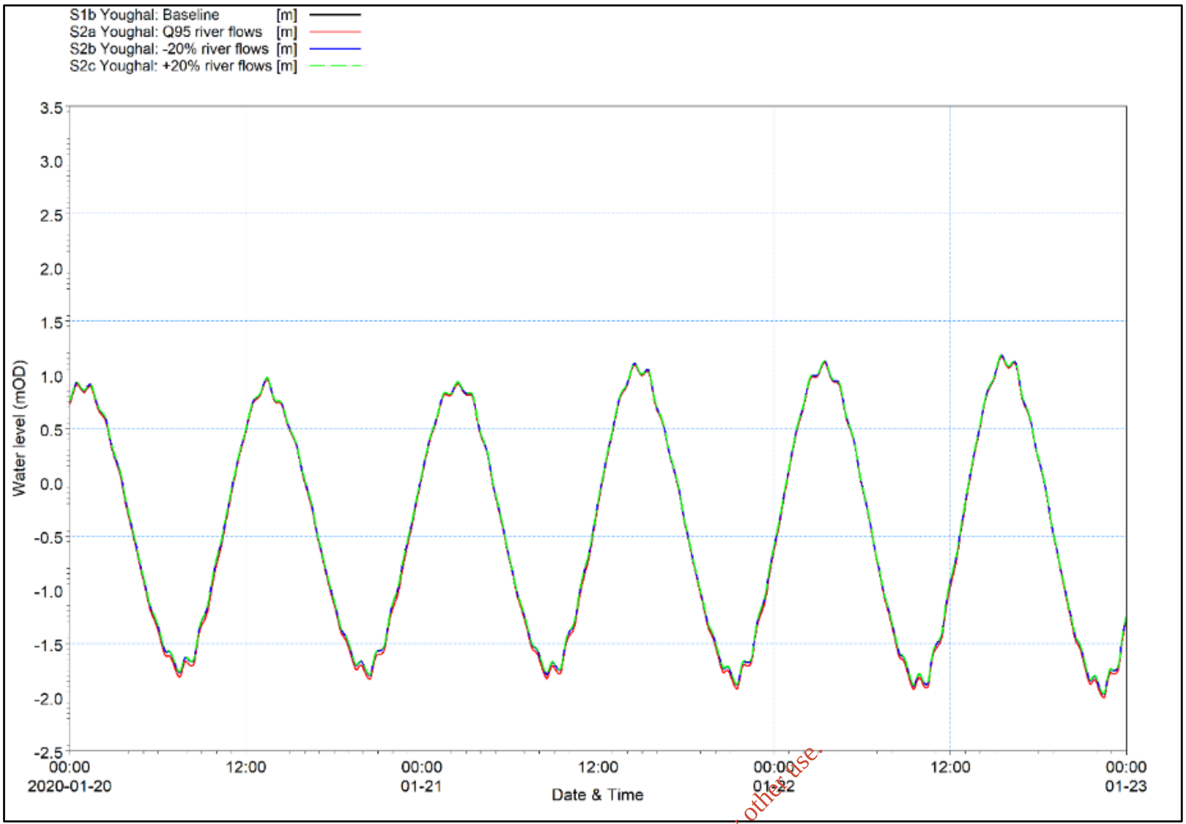


Figure 3-36. Sensitivity of water level at Youghal for Event D with different river flow rates

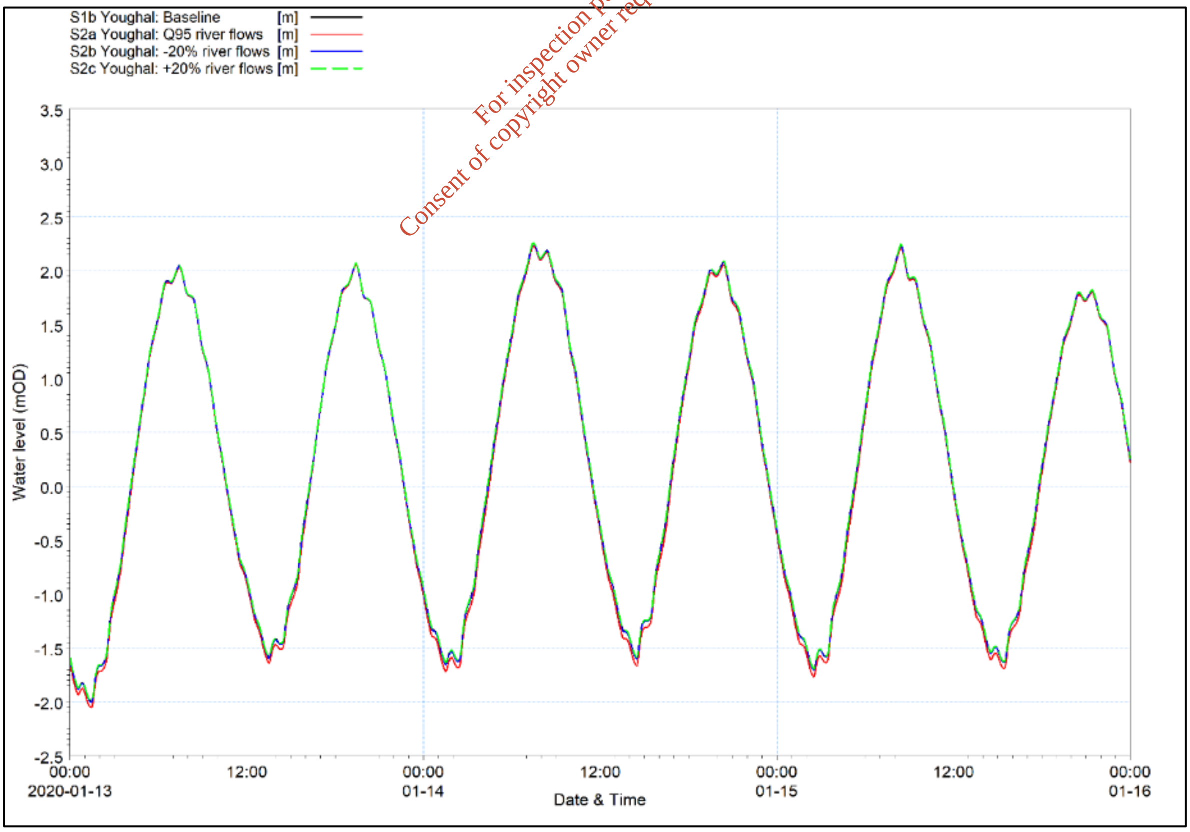


Figure 3-37. Sensitivity of water level at Youghal for Event E with different river flow rates

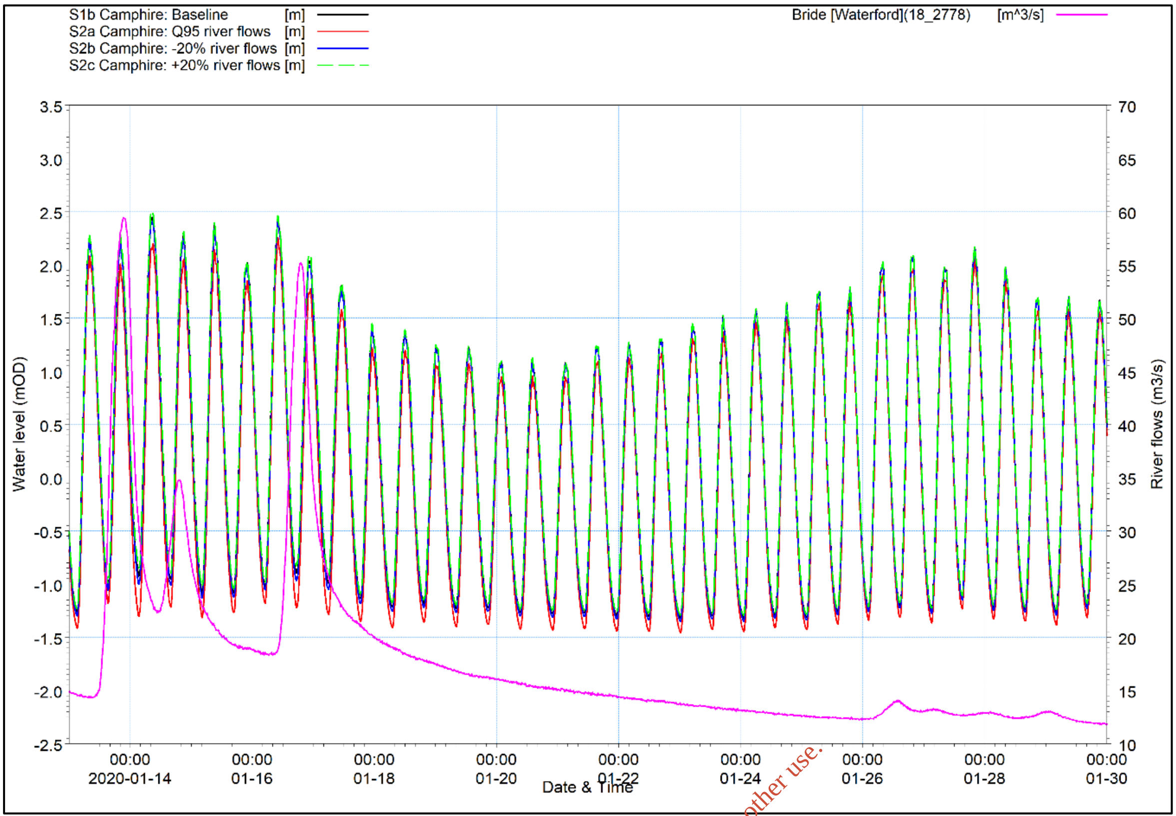

S1b Camphire: Baseline [m]
S2a Camphire: Q95 river flows [m]
S2b Camphire: -20% river flows [m]
S2c Camphire: +20% river flows [m]
Bride [Waterford](18_2778) [m^3/s]
Water level (mOD)
River flows (m3/s)
Date & Time
00:00 2020-01-14
00:00 01-16
00:00 01-18
00:00 01-20
00:00 01-22
00:00 01-24
00:00 01-26
00:00 01-28
00:00 01-30

Figure 3-38. Sensitivity of water level at Camphire Bridge for Event B with different river flow rates

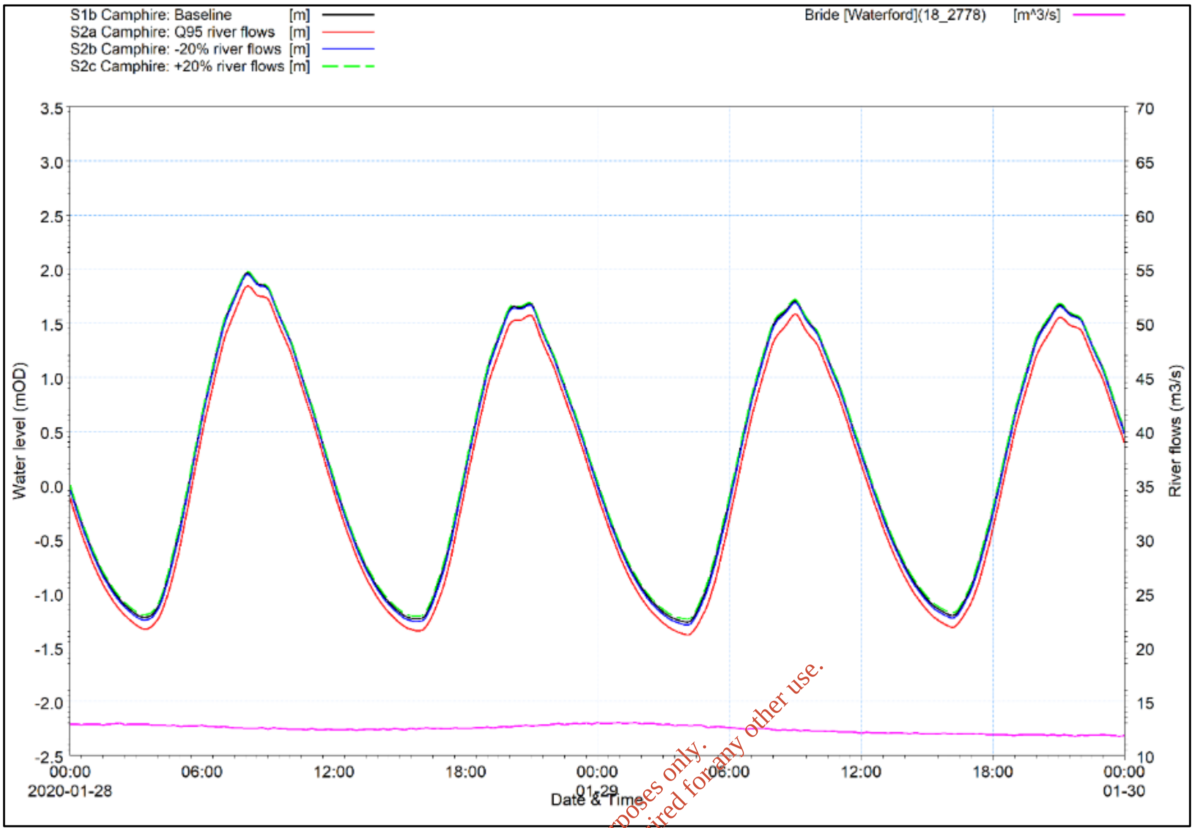


Figure 3-39. Sensitivity of water level at Camphire Bridge for Event C with different river flow rates

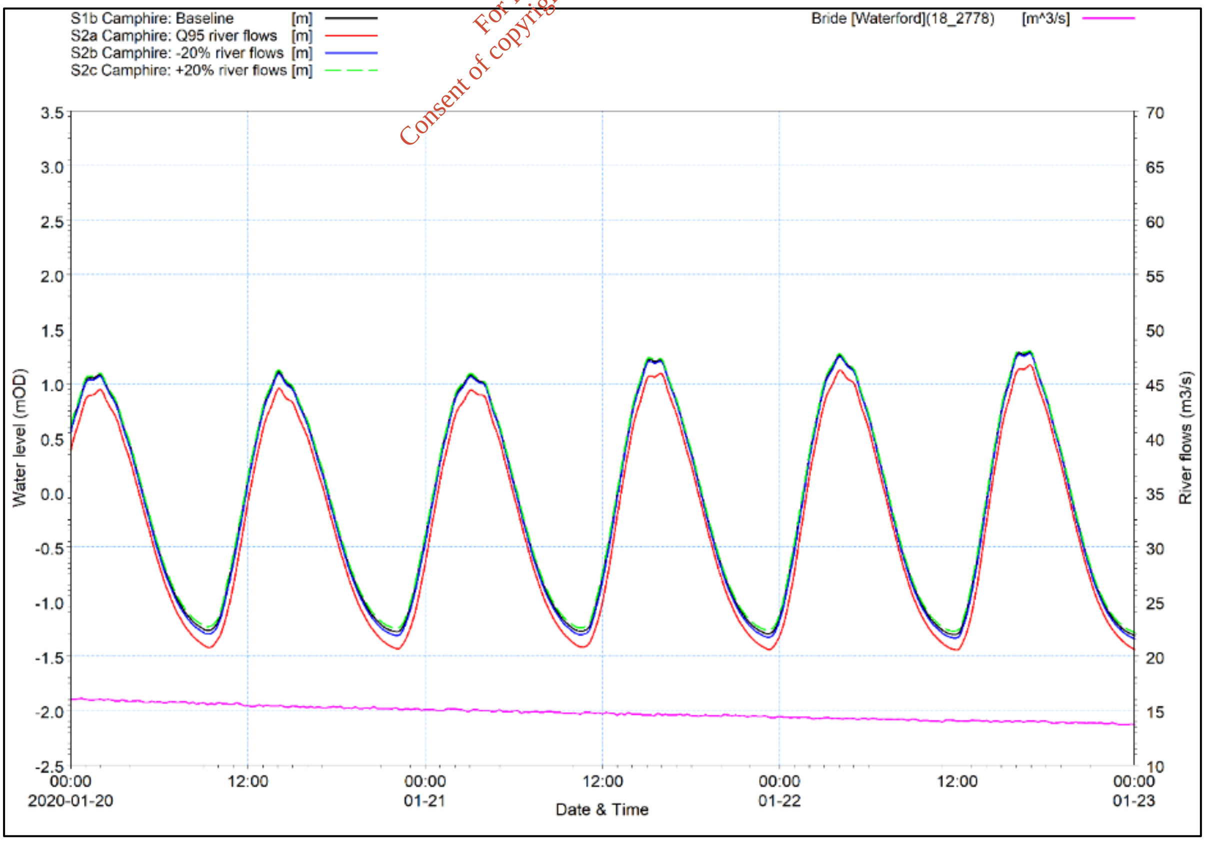


Figure 3-40. Sensitivity of water level at Camphire Bridge for Event D with different river flow rates

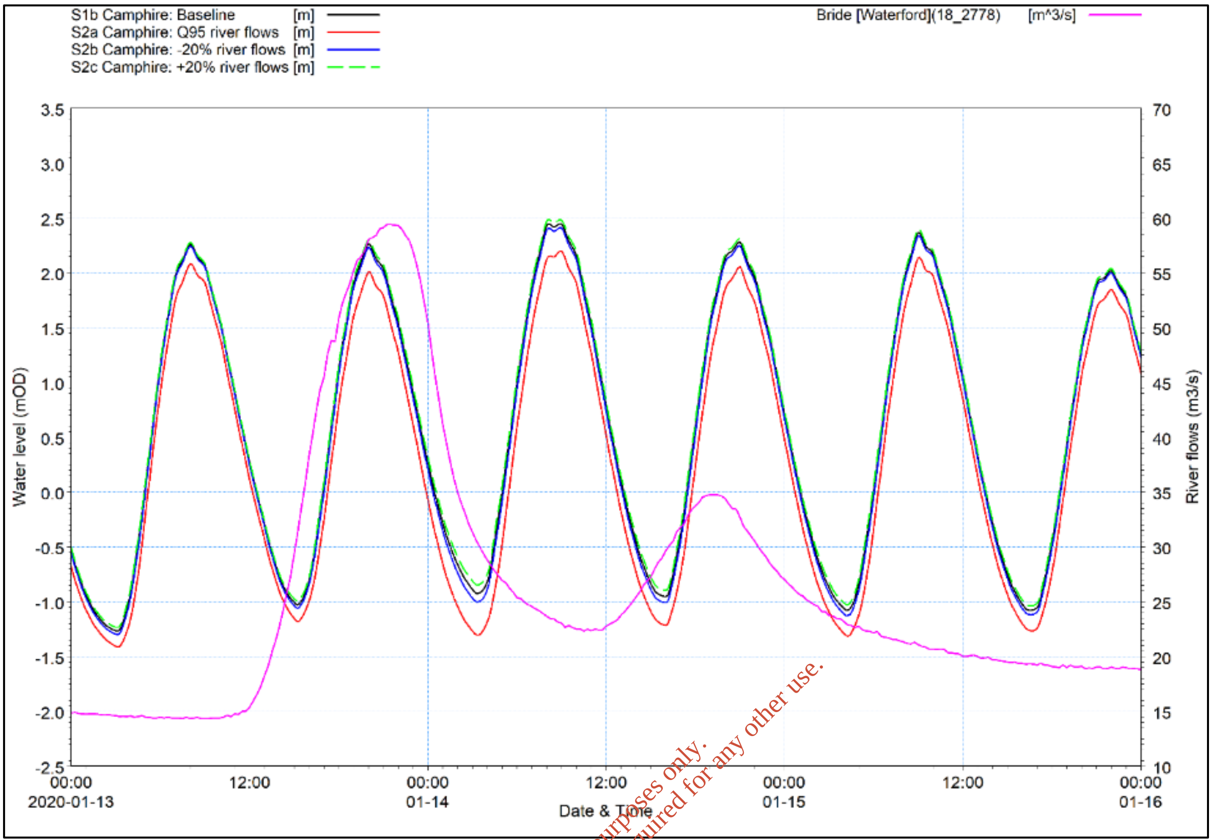


Figure 3-41. Sensitivity of water level at Camphire Bridge for Event E with different river flow rates

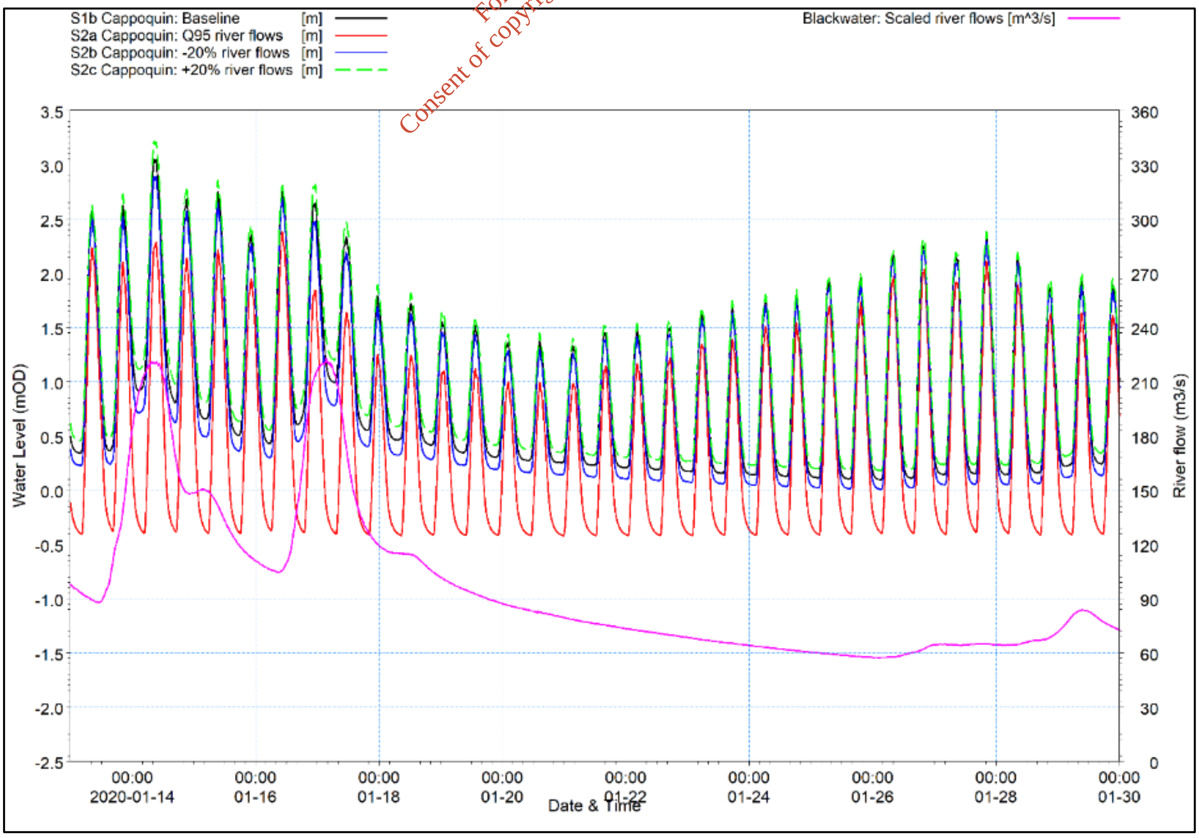


Figure 3-42. Sensitivity of water level at Cappoquin for Event B with different river flow rates

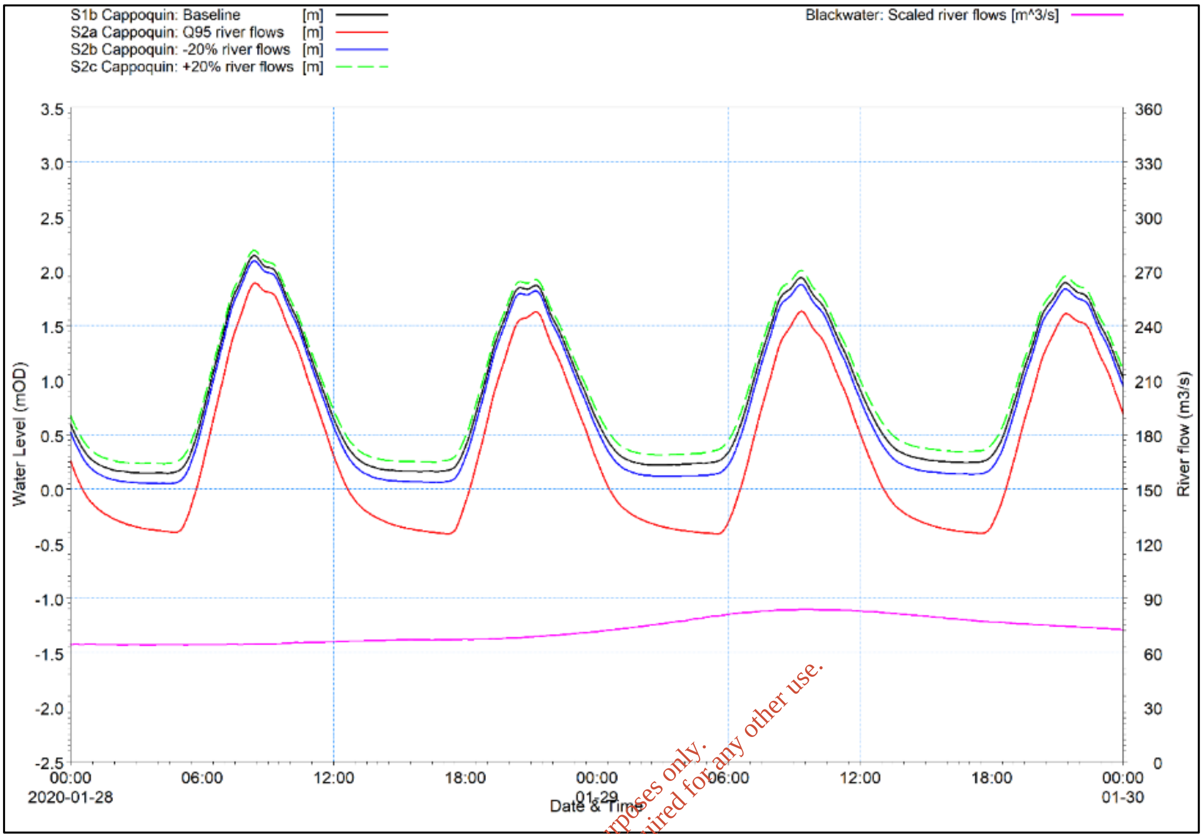


Figure 3-43. Sensitivity of water level at Cappoquin for Event C with different river flow rates

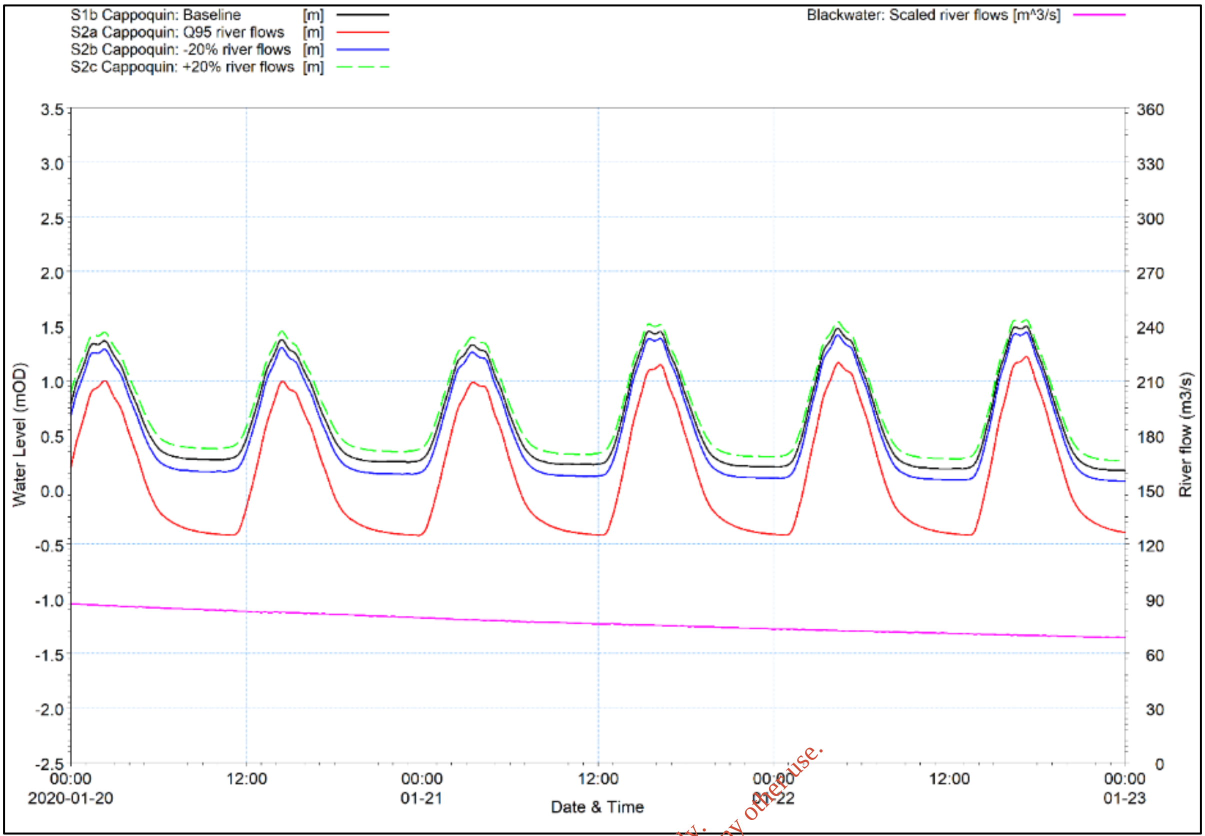


Figure 3-44. Sensitivity of water level at Cappoquin for Event D with different river flow rates

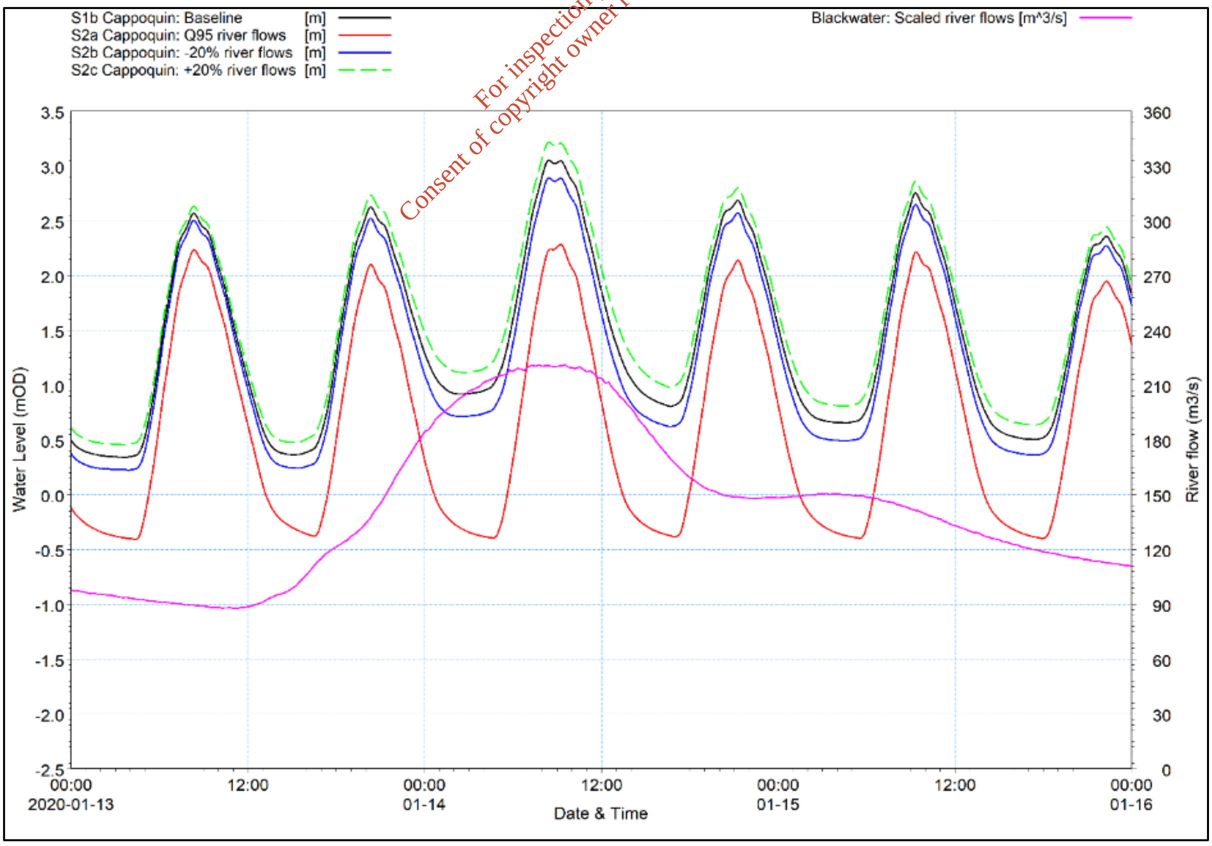


Figure 3-45. Sensitivity of water level at Cappoquin for Event E with different river flow rates

3.5 Temperature and salinity

The temperature and salinity in the model are governed by the initial conditions, the properties of the open sea and the rivers flowing into the estuary and the exchange of heat energy with the atmosphere. The open sea values are based on the data provided by the Marine Institute from their Northeast Atlantic model. The rivers are assumed to have a salinity of 0 psu and a temperature based on the values recorded at Camphire and Cappoquin. All tributaries are assumed to have the same temperature as Camphire. The air temperature is as measured during the surveys with values for the start of January (1^{st} to 5^{th} January) taken from Roches Point.

The initial conditions were established by running the model for the first two weeks of January and then using the resulting values as the initial conditions for the start of January.

The Youghal Harbour area is a dynamic hydrodynamic environment where the freshwater from the rivers is mixing with the sea water. The depth of the harbour area is variable and therefore the mixing occurs in different locations as the tide rises and falls. Additionally, the river flow rates can significantly affect the stratification. This is also the area that the WwTP discharges into and therefore it is the area that the surveys collected the most data for. The surveys of the Cappoquin, Dromana Gate and Camphire Bridge locations all showed freshwater (<0.5 psu). However, for completeness the model results for these locations are presented.

A total of 160 CTD profiles ("drops") were undertaken over the three surveys. The drops at Cappoquin, Dromana Bridge and Camphire were consistently located; the Youghal Harbour drops were not consistent in their location (Figure 3-46). The harbour samples have been grouped into three groups referenced as Youghal Harbour 1, 2 and 3.

A range of horizontal and vertical scaling factors (HSF and VSF) for the calculation of the dispersion coefficient from the eddy viscosity have been tested to identify the sensitivity of the model outputs to the different values. The combinations tested are shown in Table 3.8 and the results of the tests shown in Table 3.9. The RMSE is calculated for each survey and location using all readings in each drop. There is good agreement for the river sites, although some of the values at Dromana Bridge do exceed the 1˚C tolerance. This is likely due to the difference in the river temperature at Camphire Bridge and Dromana Bridge; the Camphire Bridge value is used as the boundary condition for all tributaries other than the River Blackwater.

The salinity values for the surveys on the 21^{st} and 28^{th} (Events D and C respectively) were measured using a CTD that was later found to be erroneous. The values returned included some as high as 40 psu. The data from these samples has been rescaled to the range 0 to 35 to allow comparison, but if the observed data is high then there is a risk that this is due to the erroneous readings and that the scaling has not fully corrected the data. This issue affects all Youghal Harbour values for events C and D and therefore only the general structure can be considered. For Event E however all the survey values are considered to be reliable.

Table 3.10 shows the RMSE for each drop in the survey for Event E, arranged in chronological order. These show that for all combinations of HSF and VSF the RMSE are reasonably consistent. Figure 3-47 to Figure 3-51 show the profiles for drops in the Youghal Harbour 3 area. These show that the "best" combination both statistically and visually is HSF = 1 and VSF = 0.

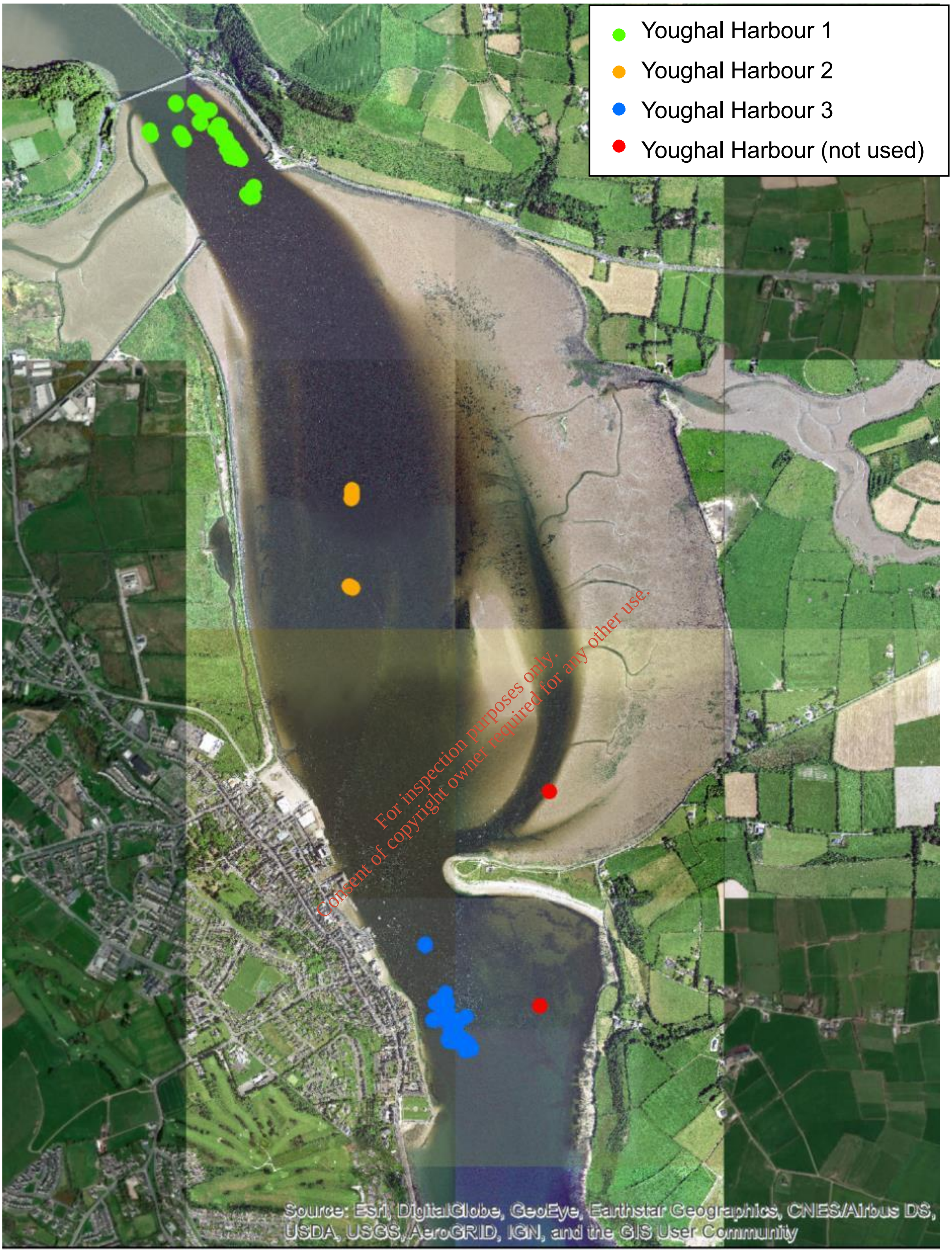


Figure 3-46. Locations of each sample for the Youghal Bay 1, 2 and 3 locations and excluded samples.

Table 3.8. Horizontal and vertical scaling factors for the dispersion coefficient from the scaled eddy viscosity.

Simulation	Horizontal	Vertical
S1b	2	1
S4a	1	0
S4b	1	0.5
S4c	1	1

Table 3.9. RMSE for temperature and salinity for each of the surveys at each location.

Event	Location	S1b		S4a		S4b		S4c	
		Temp.	Salinity	Temp.	Salinity	Temp.	Salinity	Temp.	Salinity
E	Camphire Bridge	0.42	0.11	0.61	0.11	0.41	0.11	0.42	0.11
	Cappoquin Bridge	0.04	0.09	0.07	0.09	0.04	0.09	0.04	0.09
	Dromana Bridge	0.88	0.14	0.69	0.14	0.87	0.14	0.88	0.14
	Youghal Harbour1	1.18	6.99	0.71	4.71	1.03	4.92	1.19	6.97
	Youghal Harbour2	No drops in this area during this survey							
	Youghal Harbour3	1.48	11.36	0.71	5.31	1.34	9.88	1.48	11.31
D	Camphire Bridge	0.75	0.12	0.84	0.12	0.75	0.12	0.75	0.12
	Cappoquin Bridge	0.24	0.13	0.25	0.13	0.24	0.13	0.24	0.13
	Dromana Bridge	1.36	0.13	1.37	0.13	1.36	0.13	1.36	0.13
	Youghal Harbour1	0.63	3.30	0.66	4.55	0.57	2.51	0.64	3.36
	Youghal Harbour2	No drops in this area during this survey							
	Youghal Harbour3	0.43	7.22	0.73	0.13	0.41	5.48	0.44	7.17
C	Camphire Bridge	0.35	0.13	1.06	0.13	0.35	0.13	0.35	0.13
	Cappoquin Bridge	0.70	0.13	0.79	0.13	0.70	0.13	0.70	0.13
	Dromana Bridge	0.45	0.13	0.69	7.93	0.45	0.13	0.45	0.13
	Youghal Harbour1	0.95	7.54	0.75	9.13	0.80	6.76	0.94	7.48
	Youghal Harbour2	2.16	16.10	1.16	4.63	1.94	14.07	2.15	16.04
	Youghal Harbour3	0.58	3.17	1.10	0.00	0.60	2.77	0.58	3.15

Note: Tolerance of ±1˚C and ±5 psu in Youghal Harbour and ±1 psu at the other sites (Irish Water, 2020).

Table 3.10. RMSE for temperature (tolerance of ±1˚C) and salinity (tolerance of ±5 psu) for the drops in Youghal Harbour for Event E.

Profile[1]	Time	S1b		S4a		S4b		S4c	
		Temp.	Salinity	Temp.	Salinity	Temp.	Salinity	Temp.	Salinity
110 YH1	0818	0.42	0.11	0.61	0.11	0.41	0.11	0.42	0.11
111 YH1	0943	0.04	0.09	0.07	0.09	0.04	0.09	0.04	0.09
134 YH3	1020	1.36	0.13	1.37	0.13	1.36	0.13	1.36	0.13
112 YH1	1129	0.88	0.14	0.69	0.14	0.87	0.14	0.88	0.14
113 YH1	1139	1.18	6.99	0.71	4.71	1.03	4.92	1.19	6.97
135 YH3	1420	0.63	3.30	0.66	4.55	0.57	2.51	0.64	3.36
115 YH1	1511	1.48	11.36	0.71	5.31	1.34	9.88	1.48	11.31
136 YH3	1604	0.43	7.22	0.73	4.38	0.41	5.48	0.44	7.17
116 YH1	1641	0.75	0.12	0.84	0.12	0.75	0.12	0.75	0.12
137 YH3	1731	0.35	0.13	1.06	0.13	0.35	0.13	0.35	0.13
117 YH1	1806	0.24	0.13	0.25	0.13	0.24	0.13	0.24	0.13
138 YH3	1848	0.70	0.13	0.79	0.13	0.70	0.13	0.70	0.13

Notes: 1. YH1 = Youghal Harbour 1 and YH3 = Youghal Harbour 3
2. Tolerance of ±1˚C and ±5 psu in Youghal Harbour and ±1 psu at the other sites (Irish Water, 2020).

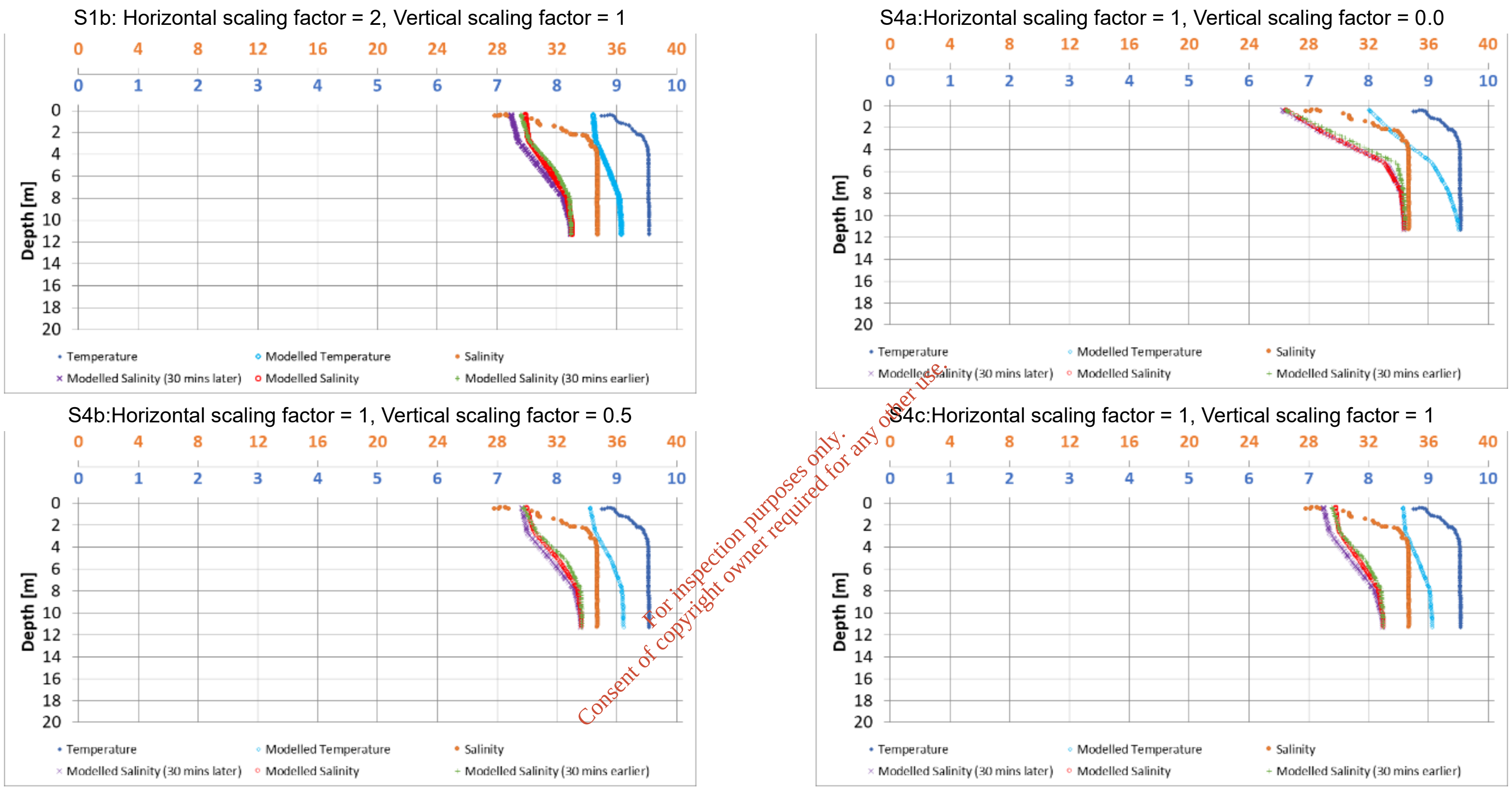


Figure 3-47. Profile 134: Youghal Harbour 3: Event E: 1020 17th January 2020: Showing good agreement between all data sets: "best fit" HSF = 1, VSF = 0.

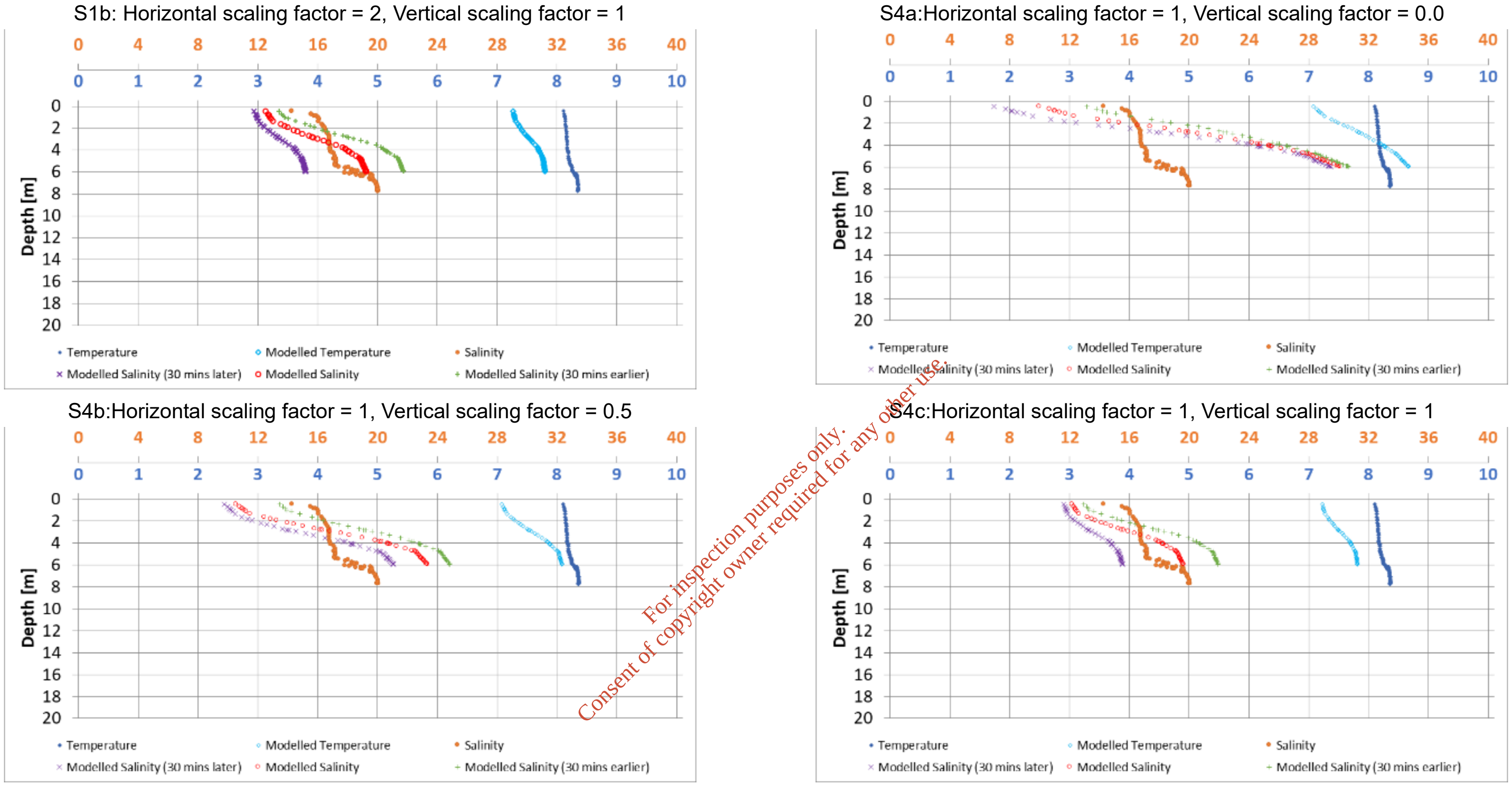


Figure 3-48. Profile 135: Youghal Harbour 3: Event E: 1420 17th January 2020: Showing different levels of agreement between data sets: “best fit” HSF = 1, VSF = 1.

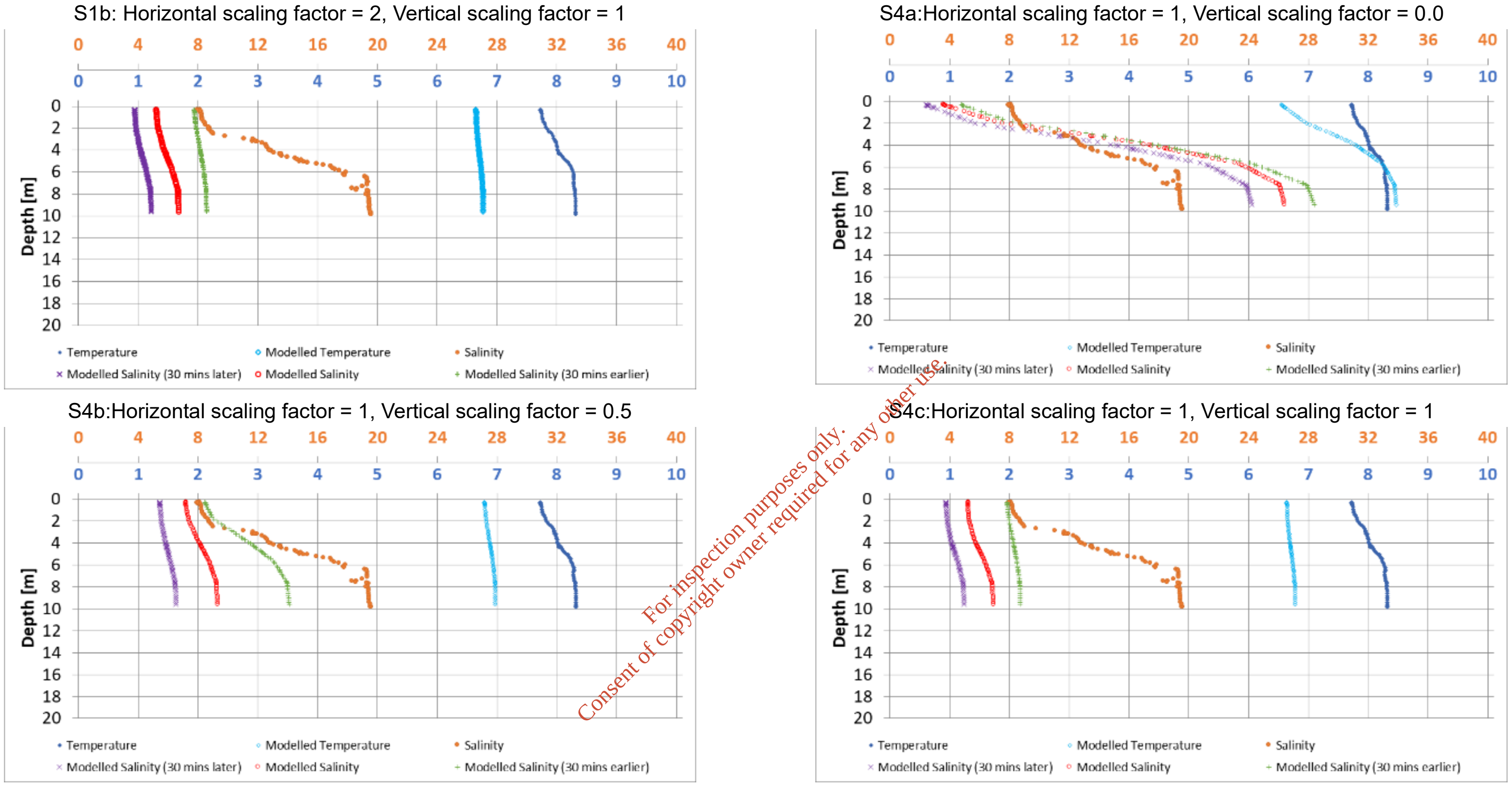


Figure 3-49. Profile 136: Youghal Harbour 3: Event E: 1604 17th January 2020: Showing different levels of agreement between data sets: "best fit" HSF = 1, VSF = 0.

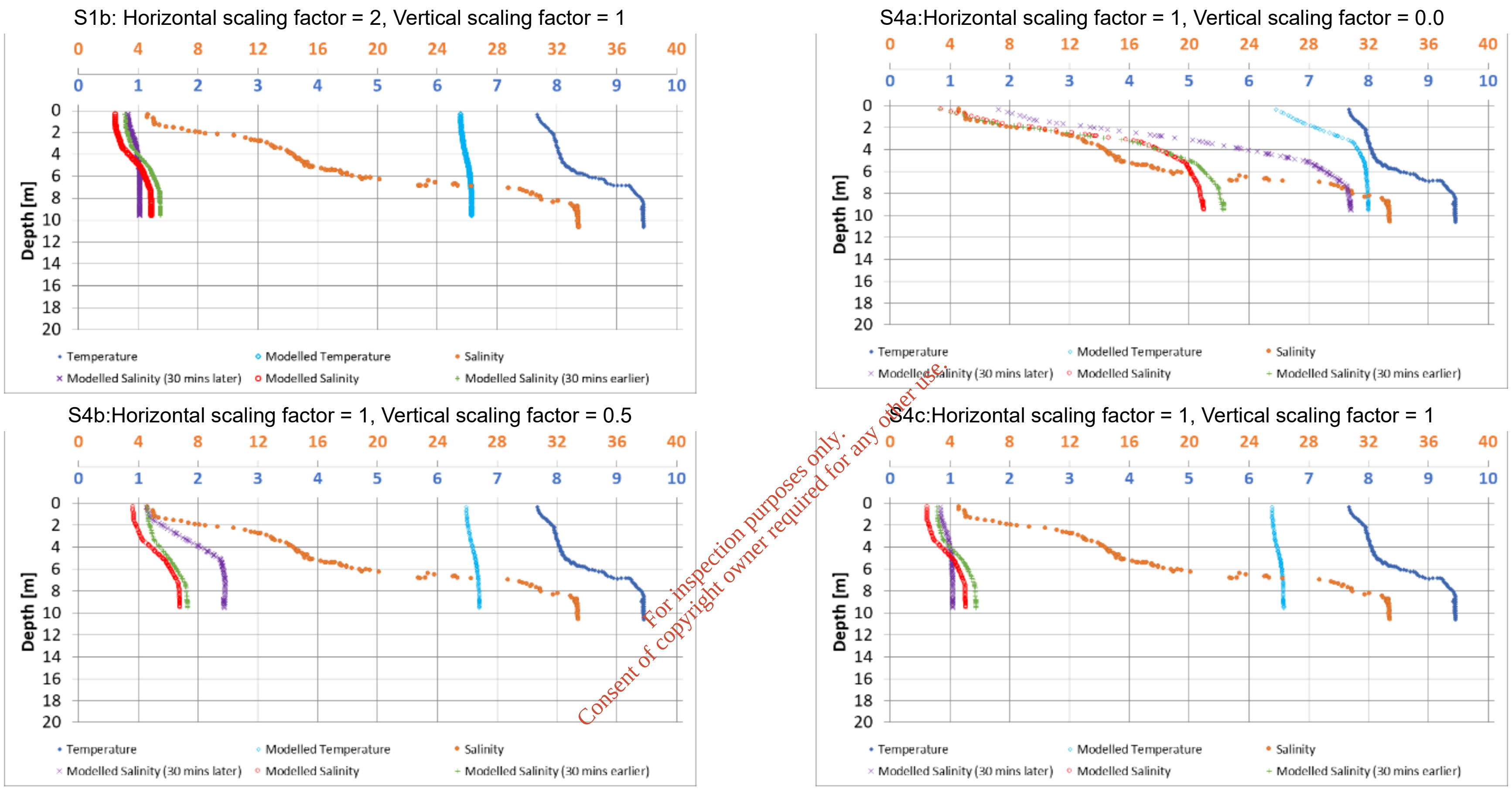


Figure 3-50. Profile 137: Youghal Harbour 3: Event E: 1731 17th January 2020: Showing different levels of agreement between data sets: "best fit" HSF = 1, VSF = 0.

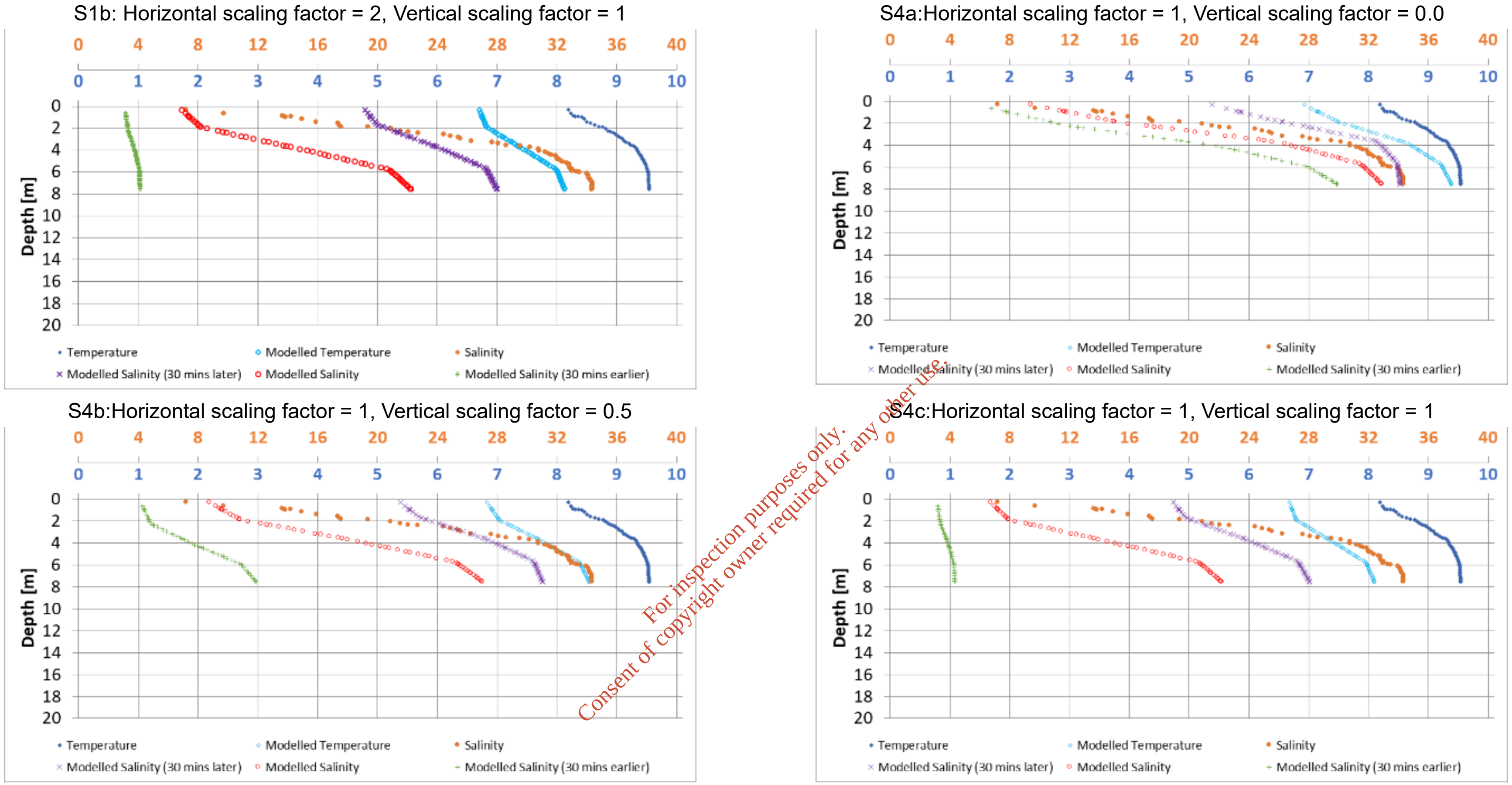


Figure 3-51. Profile 138: Youghal Harbour 3: Event E: 1848 17th January 2020: Showing different levels of agreement between data sets: “best fit” HSF = 1, VSF = 0.

3.6 Summer 2019

The hydrodynamic model was calibrated for hydrodynamics, temperature and salinity for the survey period of January 2020. Several of the proposed production runs are for the summer and therefore the model was set-up and run using the scaled MI data for August 2019 and Q95 river flows. The model used average values for river water temperature (15°C) and the MI data for offshore temperature and salinity. The modelled water levels at the OPW gauge was compared to the observed data (Figure 3-52) and show that the model is representing the measured water levels reasonably well. No calibration data is available with sufficient spatial or temporal coverage to calibrate the currents, temperature or salinity for this period.

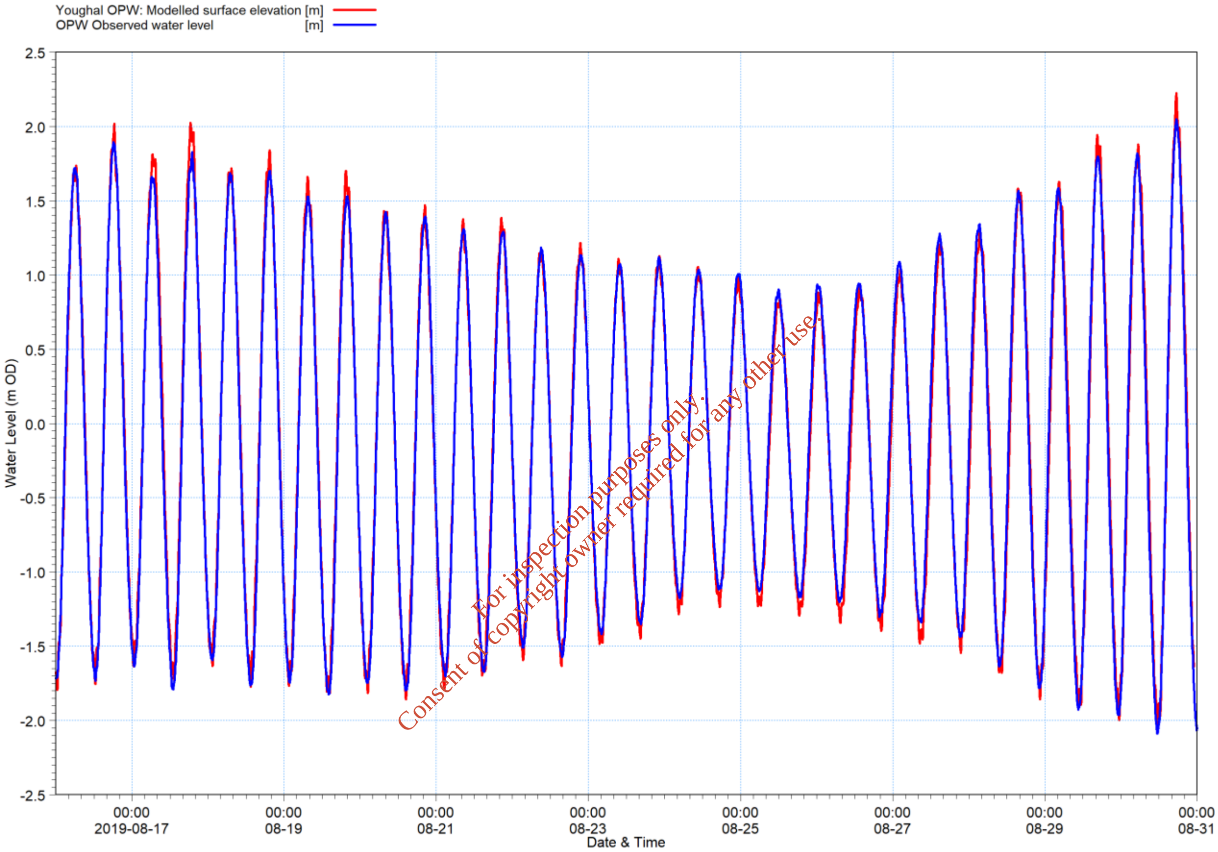


Figure 3-52. Comparison of the modelled and observed water levels at the OPW gauge for August 2019.

3.7 Conclusion

The model set-up S1b has been selected as calibrated for hydrodynamics (water levels and currents). This model has then been used to calibrate for temperature and salinity using a range of scaling factors for the dispersion coefficient as a function of the eddy viscosity. Model set-up S1b was still considered to be the best overall calibration for the estuary.

The hydrodynamic model has been calibrated against the data obtained during the Irish Water survey in January 2020 and the OPW tide gauge data for summer 2019. The water quality model has been calibrated against EPA data for both the summer and winter periods to be used for the production runs.

The model is considered able to simulate the hydrodynamics of the study area including the dynamic mixing of the freshwater from rivers and saline water from the sea in the estuary and area outside of the estuary. The model has demonstrated sensitivity to the forcing functions of the tide and changes in freshwater flows with respect to the hydrodynamics, temperature and salinity. The use of the 15-day period and three separate events within that period has tested a range of conditions. The model is considered suitable for use in investigations of the water quality in the estuary in relation to the discharge from the Youghal WwTP.

The production runs include summer events and it will be necessary to utilise the MI data for the offshore boundary conditions and, combine these with the data for the river flows (assumed to be Q95). The MI data will provide the temperature and salinity for the open sea boundaries.

4. Water quality model calibration

4.1 Introduction

The hydrodynamic model is to be used to investigate the potential impact of the discharge from the Youghal WwTP on the receiving waters. The hydrodynamic model has demonstrated that the dynamic mixing zone is within the harbour and just outside of the estuary is significantly affected by the freshwater flow. High river flows can flush the estuary resulting in the whole water column having a low salinity. The net flow of water, and therefore any parameter of interest, is out of the estuary.

To demonstrate calibration, the following process has been followed:

1. Demonstrate that the effluent from Youghal WwTP is entering the water quality model.
2. For each parameter:
    a. Undertake an initial run using the median values from the EPA data to provide the boundary conditions. Compare the model results with:
        i. EPA statistics at BR110, BR220, BR230 and BR240.
        ii. Irish Water survey data.
    b. Undertake sensitivity tests on one or more of the following to improve the calibration:
        i. Initial condition;
        ii. River or open sea concentration;
        iii. Decay rate.
    c. Investigate propagation of a "pulse load" (for some parameters).
    d. Investigate discharge from Youghal WwTP and Cappoquin in the surface layer of the water column.

The results for each parameter are presented in a separate section and a summary provided at the end of the chapter.

The final model parameters for the calibrated models are presented in the Model Log in Appendix A.

4.2 Model set-up

The MIKE3 HD model provided HD output files that have been used to run the AD module in decoupled mode. All parameters have been modelled with 1st order decay and the decay rates are specified within the section for each parameter. The decay rates have been selected based on published literature, Irish Water information or experience and are summarised in Table 4.1. The T_{90} values are presented although the AD module uses decay per second. A conversion table between T_{90} in hours, and decay per second and decay per day is provided in Appendix B.

For the bacteria (EC and IE) Irish Water (2020) provides a range of decay rates in coastal and estuarine water for summer and winter. The estuary is known to flush with freshwater and therefore the salinity of the water in the river and much of the estuary is likely to be lower than sea water. Guidance from the WRc (1990) "Design guide on marine treatment schemes" suggests that bacterial decay rates can be 2 to 9 times as long in freshwater than in sea water.[6]

Values used for sensitivity correspond to 0.5, 1, 2, 4, 6 and 8 times the standard decay rates for each bacteria species in coastal water during winter.

Table 4.1. Decay rates used for each parameter.

Parameter	Decay Rate Range	Comments on the source
BOD	550 hours with sensitivity tests of 175 and 300 hours.	No standard published values available. Values used are based on experience and calibration results.
EC	12, 24, 48, 96, 144, 192 hours.	WRc, 1990.
IE	24, 48, 96, 192, 288, 384 hours.	See discussion in text above table.
DIN	800, 950, 1200 hours.	No standard published values available. Values used are based on experience and calibration results.
MRP	950 and 1600 hours.	No standard published values available. Values used are based on experience and calibration results.
Ammonia	275, 480, 720 hours.	No standard published values available. Values used are based on experience and calibration results.

4.3 Data used for calibration

The EPA has collected data for many years in the estuary at the sites shown in Figure 4-1. The historical EPA samples for Cappoquin (BR110), two sites within the harbour (BR220, BR230), one in the estuary mouth (BR240) have been analysed and the statistics are summarised in App Table F-1. No data is available for EC or IE from these samples. Normally only the data from the last three years would be used for calibration; however, there are fewer samples taken during the winter and therefore all samples collected have been used.

The water samples collected during the survey have been analysed and the results discussed in the SIR. The key statistics for these parameters are reproduced in App Table F-2. The potential effects of the weather on the samples is discussed in Chapter 2.

[6] Section 3.5.1 of WRc (990) states that the mortality (decay) rate is a complex process affected by, amongst other parameters, light, temperature, turbidity and salinity. No specific values are provided in the guidance, but the relative relationship of decay rates in light between fresh and sea water are stated as being 2 to 9 times longer in fresh water.

Figure 4-1. Locations of the EPA sampling points with the points used for calibration highlighted.

4.4 Mass balance

A mass balance assessment for 15-day period has been undertaken for each of the parameters. The analysis is shown in Table 4.2 and presents the median concentration of each parameter, the total flow and calculates the proportion of the total load that is attributable to the Youghal WwTP. This shows that the Youghal WwTP is responsible for a small proportion of the total load of each individual parameter entering the estuary.

Table 4.2. Mass balance calculation for a 15-day period using actual river and WwTP flows and median concentrations.

Source	Total Flow (m3)	Median concentration [mg/l] or [cfu/100ml]					
		Ammonia	BOD	DIN	MRP	EC	IE
Blackwater [Munster]	108.7E+06	0.03	1.00	3.08	0.03	650	150
GLENNAFALLIA 18	1.7E+06	0.03	0.55	2.06	0.02	650	150
MONEYGORM	268.3E+03	0.01	0.50	3.71	0.02	650	150
Finisk	3.3E+06	0.01	0.50	3.71	0.02	650	150
Owbeg [Waterford]	688.7E+03	0.01	0.75	4.71	0.02	650	150
COOLAHEST	478.7E+03	0.01	0.50	2.91	0.01	650	150
Goish	1.1E+06	0.01	0.50	2.91	0.01	650	150
HEADBOROUGH	384.4E+03	0.01	0.50	2.91	0.01	650	150
MONATRIM_LOWER	499.4E+03	0.01	0.75	4.71	0.02	650	150
Kilbeg Stream	545.2E+03	0.01	0.75	4.71	0.02	650	150
Bride [Waterford]	20.2E+06	0.03	0.80	4.24	0.03	650	150
ABARTAGH	542.2E+03	0.01	0.50	2.71	0.01	650	150
Licky	1.9E+06	0.01	0.50	2.71	0.01	650	150
HARROWHILL	526.0E+03	0.01	0.70	2.93	0.02	650	150
Glendine [Blackwater]	739.8E+03	0.01	0.70	2.93	0.02	650	150
Tourig	1.8E+06	0.01	0.70	2.93	0.02	650	150
MUCKRIDGE	165.9E+03	0.01	0.70	2.93	0.02	650	150
Womanagh	4.2E+06	0.01	0.70	2.93	0.02	650	150
Cappoquin	3.9E+03	0.14	103.41	4.35	1.67	1782	445
Youghal	61.4E+03	1.08	8.11	2.34	1.12	89301	9713
Total Flow [m3]	147.9E+06						
	Total Load [Kg] or cfu/100ml	4 156	137 185	479 615	4 275	101.6E+09	22.8E+09
	Average Concentration [mg/l] or [cfu/100ml]	0.03	0.93	3.25	0.03	687	154
Youghal WwTP	Load [kg]	66.3	497.7	143.6	68.5	5.5E+09	596.0E+06
	% of Total Load	1.59%	0.36%	0.03%	1.60%	5.39%	2.62%

4.5 Youghal WwTP plume (without other sources)

To demonstrate that the discharge is present in the model and that the discharge can be identified, the water quality model was run using no initial background concentration and no sources other than the Youghal WwTP.

The measured daily discharge rate was used with the concentrations for each parameter as set out in Table 4.3. These are the rates used for all calibration runs unless noted otherwise.

Table 4.3. Concentrations for each parameter from the Youghal WwTP.

Parameter	Concentration
BOD	8.11 mg/l
EC	89000 cfu/100ml
IE	9700 cfu/100ml
DIN	2.34 mg N /l
MRP	1.12 mg P /l
Ammonia	1.08 mg N /l

The plot of the maximum absolute concentration of EC in surface layer over the 15 days corresponding to Event B is shown in Figure 4-2. This shows that for EC, the maximum concentration on the surface is less than 250 cfu/100 ml within the harbour and less than 5 cfu/100 ml for the majority of the area. The 95%ile surface concentration is less than 5 cfu/100ml throughout the model. The figure confirms that the effluent is entering the model.

Figure 4-3 shows a vertical slice through the harbour from approximately 250 m upstream to 250 m downstream of the discharge for four separate tidal conditions. The plume can be seen to extend up and downstream depending on the tidal state and to rise through the water column due to mixing; however, the highest concentrations are near the bed.

The effluent is warmer than the receiving waters (12˚C compared to 7 to 10˚C) and has a salinity of 0 psu. The effluent is therefore considered to be buoyant and, as demonstrated in the tiered assessment, at risk of rising as a plume to the surface. However, it is clear that the plume does not rise in the manner expected and it is reasonable to confirm that the model resolution is appropriate.

The model resolution is selected based on an understanding of the hydrodynamic processes of the receiving water. The plume is affected by the processes of advection[7] and dispersion with the length scale of the model selected to represent the relative importance of the two processes within an area of the model. The cell containing the discharge has a horizontal resolution of approximately 40 m and an approximate area of 800 m^2. At low tide the bottom (sigma) layer of the model has a depth of approximately 0.5 m. The volume of the receiving cell is therefore approximately 400 m^3 at low tide. The discharge rate of 0.02 m^3/s represents approximately 0.005% of the total volume each second, an initial dilution of 20 000 within 20 m of the discharge location. At higher water levels the dilution would be higher as the cell would be deeper. This means that the temperature and salinity of the receiving cell will change by less than 0.005% of the absolute difference between the effluent and receiving waters. The horizontal resolution would need to be of the order 1.5 m for the discharge rate to be approximately 1% of the cell volume and this is considered to be smaller than the length scale of the hydrodynamic processes in the area which have currents in excess of 1 m/s.

[7] Advection and dispersion are easily described by considering 20 oranges dropped into the water. Advection will move the group of oranges in a single general direction due to the current. The oranges will however start to separate due to dispersion until such time as some of them may be influenced by different currents and therefore advect in different directions or at different speeds. The processes also apply in the vertical dimension, although horizontal currents and dispersion are normally significantly higher than those in the vertical direction.

The model is considered to have a reasonable resolution in the area of the discharge and to have demonstrated that the effluent is entering the model as expected for a discharge point close to the bed.

As part of the sensitivity tests the discharge location was moved from near the bed to the surface layer of the model; effectively simulating a rapidly rising plume. The results for this test are shown in the sections for each parameter.

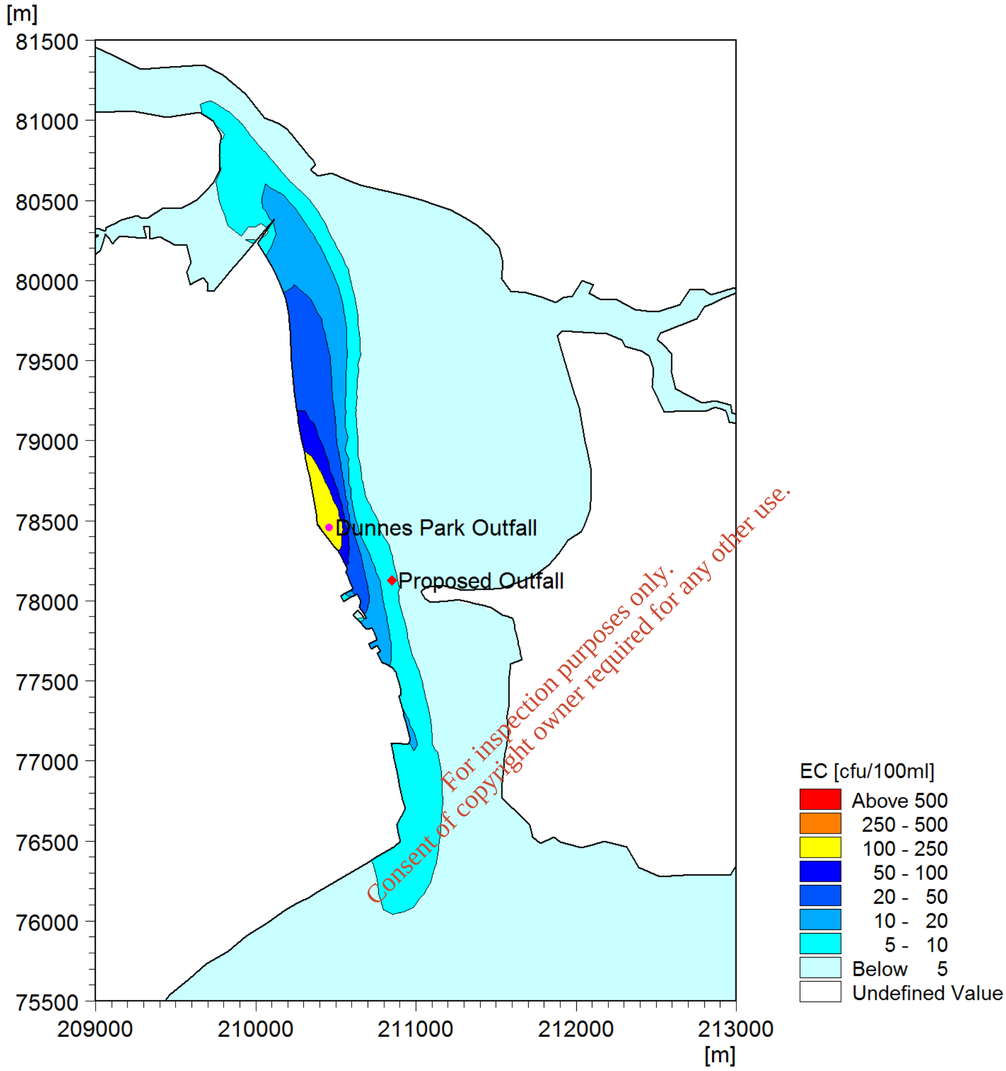


Figure 4-2. Maximum concentration of EC [cfu /100ml] in the surface layer during the 15 days of Event B.

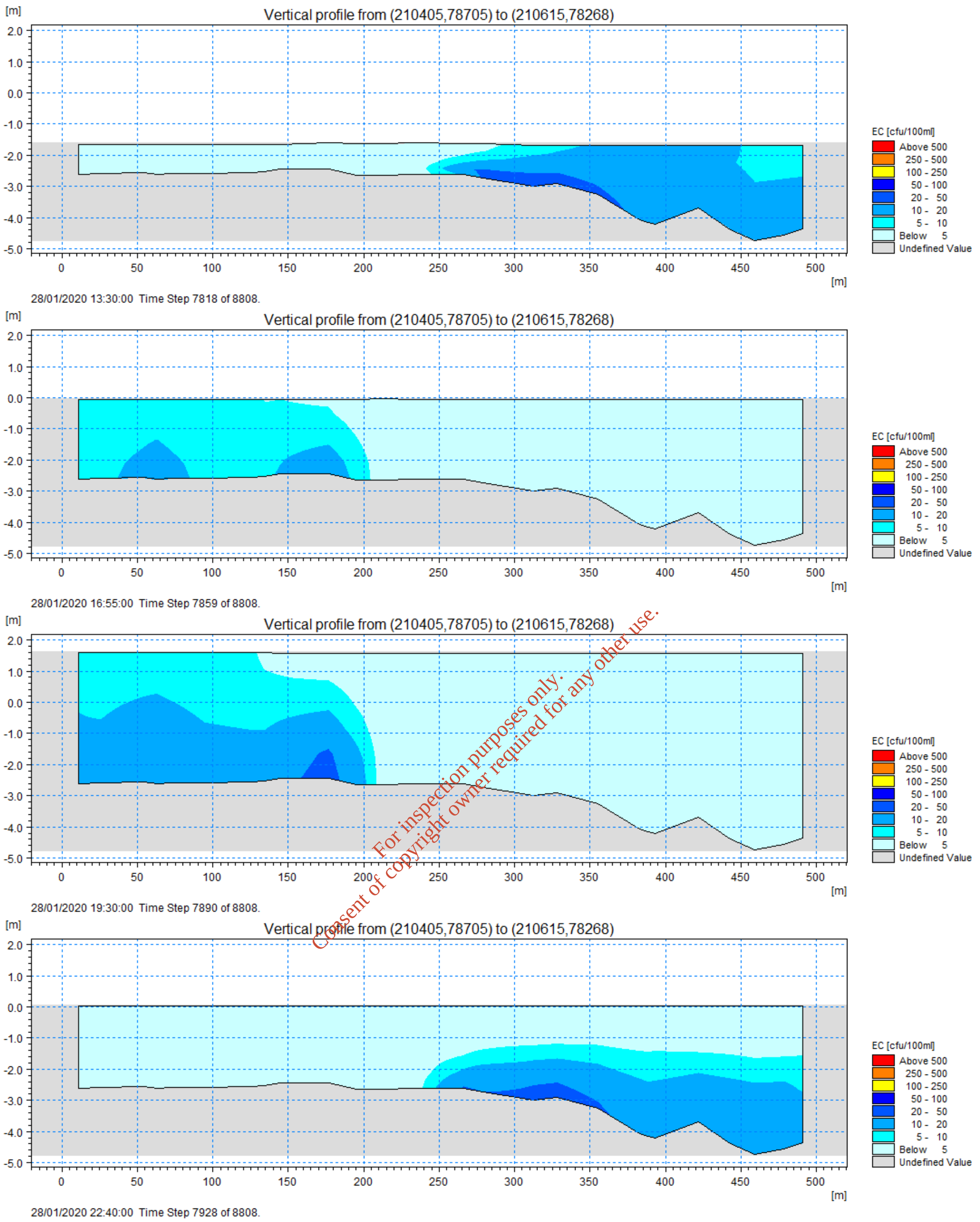


Figure 4-3. Vertical slice through the discharge location showing the concentration of EC [cfu/100ml] for different tidal states (from top to bottom): low, mid-flood tide, high and mid-ebb tide.

4.6 BOD

A summary of the model runs simulating BOD is provided in Table 4.4.

Table 4.4. Summary of the simulations for calibration of BOD against the EPA monitoring data and Irish Water survey data.

Run Code	Description	Initial Conditions [mg/l]	Open Sea Boundary [mg/l]	T_{90} [hours]
01.00	Youghal WwTP only	0.0	0.0	550
01.01	Median concentrations for all rivers and WwTP's with actual flows.	1.0	1.0	550
01.02	As 01.01 with decreased T_{90}	1.0	1.0	300
01.03	As 01.01 with decreased T_{90}	1.0	1.0	175
01.04	As 01.01 with a pulse discharge (River Blackwater) of 5 mg/l for 6 hours during a high flow fluvial event	1.0	1.0	550
01.11	As 01.01 with changed initial and open sea boundary values	1.2	1.2	550
01.21	As 01.01 with changed initial and open sea boundary values	4.5	4.5	550
01.80	As 01.00 but with Youghal WwTP discharge in the surface layer of the model	0.0	0.0	550
01.81	As 01.01 but with Youghal WwTP discharge in the surface layer of the model	1.0	1.0	550

The maximum surface concentration of BOD for the discharge from Youghal WwTP for the discharge near the bed is shown in Figure 4-4 and in the surface layer in Figure 4-5. The first figure shows that the surface concentration of BOD is generally below 0.002 mg/l. The second plot shows a higher maximum concentration close to the discharge point and slightly higher surface concentrations over the 15 days. These plots provide a reference for the relative importance of other sources (for example rivers) and the background concentration for the purposes of calibration.

The results of the water quality model using actual flows and median concentrations for all river and WwTP's are shown in Figure 4-6. The model appears to be slightly under-predicting all of the summary statistics, implying the overall load within the system is low. An increase of the initial condition and open sea boundary condition from 1.0 to 1.2 mg/l increases the model performance against the statistics (Figure 4-7). To confirm that the model will reach similar "steady state" values it was started with initial conditions of 0 and 4.5 mg/l (maximum observed value during the surveys) everywhere, all boundary conditions and inflows remained the same as before. The results (Figure 4-8) show less than 0.05 mg/l variation in the summary statistics for Event B.

The charts in Figure 4-6 and Figure 4-7 also show the variation in concentration with the tide over time. Event B starts during a period of spring tides and ends with the start of the next period of spring tides, it is likely that the decrease in concentration is due to the lower sea water exchange during neap tides. Just after the end of the Event B there is a step up in the concentrations at each of the monitoring points in the lower estuary. This increase corresponds to a high fluvial flow event.

The observed data for Event B is also plotted on all of the charts. These show a greater range of values than the EPA data for all sites. For Event C (28th January) all apart from one sample exceed the EPA 95%ile value for Dunnes Park and exceed the median value for Paxes Lane (no samples were taken for Youghal Bay during Event C). This is likely because there are limited EPA winter samples, only 10 over the past 13 years. All of the values could be interpreted as being at or below the limit of detection (LOD) of 1 mg/l as they are all recorded as 0.5, 0.9999 or 1.0.

Figure 4-9 shows a theoretical 6-hour pulse of BOD of 5 mg/l during the rising river flow, timed to coincide with the early part of Event B. Figure 4-10 shows the results of the simulation. The pulse can clearly be seen at Cappoquin and has been attenuated to provide a maximum surface concentration of approximately 1.5 mg/l at Dunnes Park, 1.2 mg/l at Paxes Lane and 1.0 mg/l in Youghal Bay. Notably the affect is present for several tides and is first visible approximately 24 hours after the pulse started. The resulting concentrations in the lower estuary are comparable to the observed values during the survey in January.

The EPA data suggests that the levels of BOD in the estuary are generally low; however, the observed data from January 2020 shows that there are periods when the BOD is elevated. The model has shown that if there is a period of elevated concentrations at one of the tributaries, then this will propagate through the system and, over several tides, result in similar concentrations as the observed values. Although it is likely that the “pulse” would be present in multiple tributaries, the overall effect will be to raise the BOD concentrations for a short period of time.

A comparison of the summary statistics for the simulations of the discharge near the bed and at the surface has also been undertaken by comparing Figure 4-11 with Figure 4-6 that shows there is no significant difference in the summary statistics.

The model of BOD that is considered to provide the best representation of the EPA data and observed data is run code 01.81.

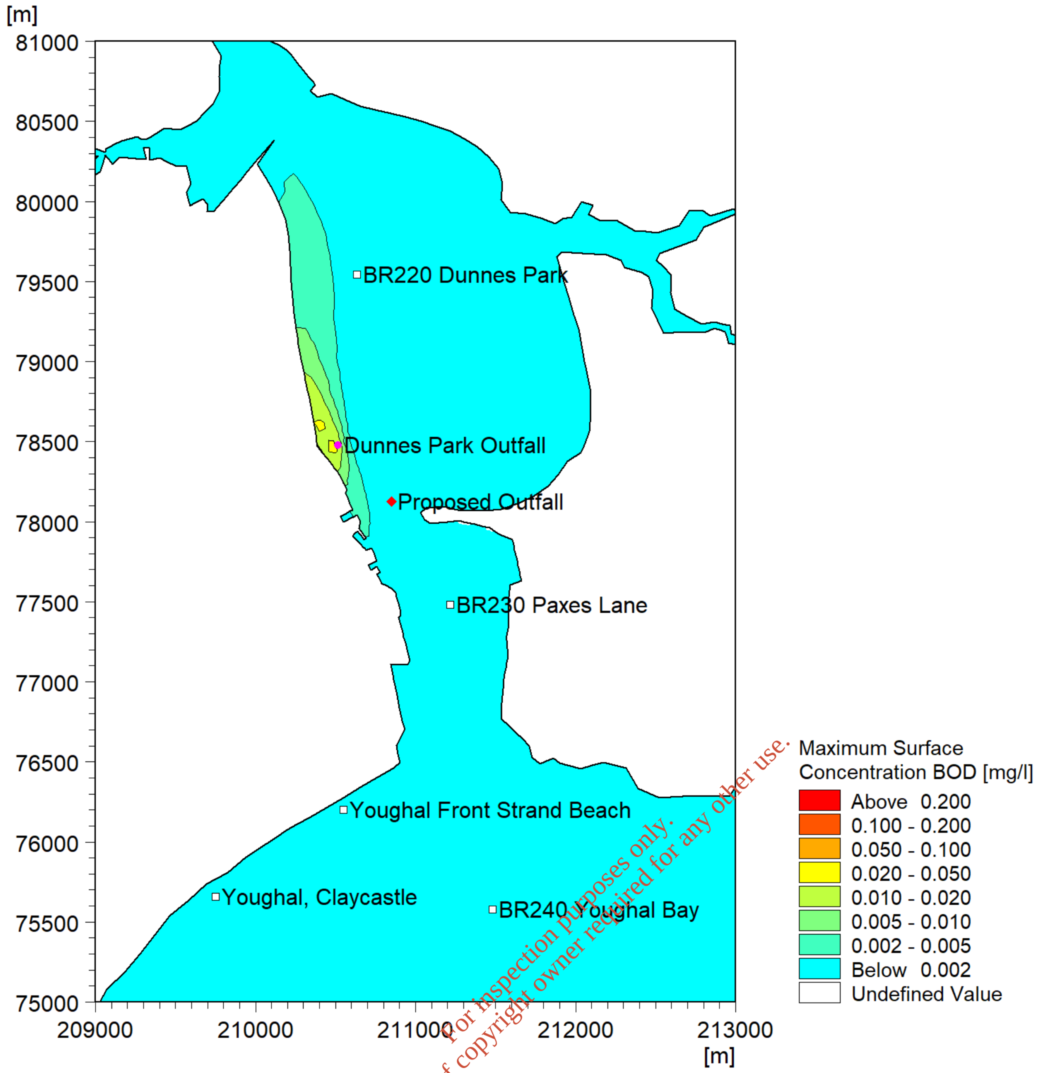


Figure 4-4. Maximum surface concentration of BOD (mg/l) for the discharge from Youghal WwTP through Dunnes Park Outfall over the 15 days of Event B (run code 01.00).

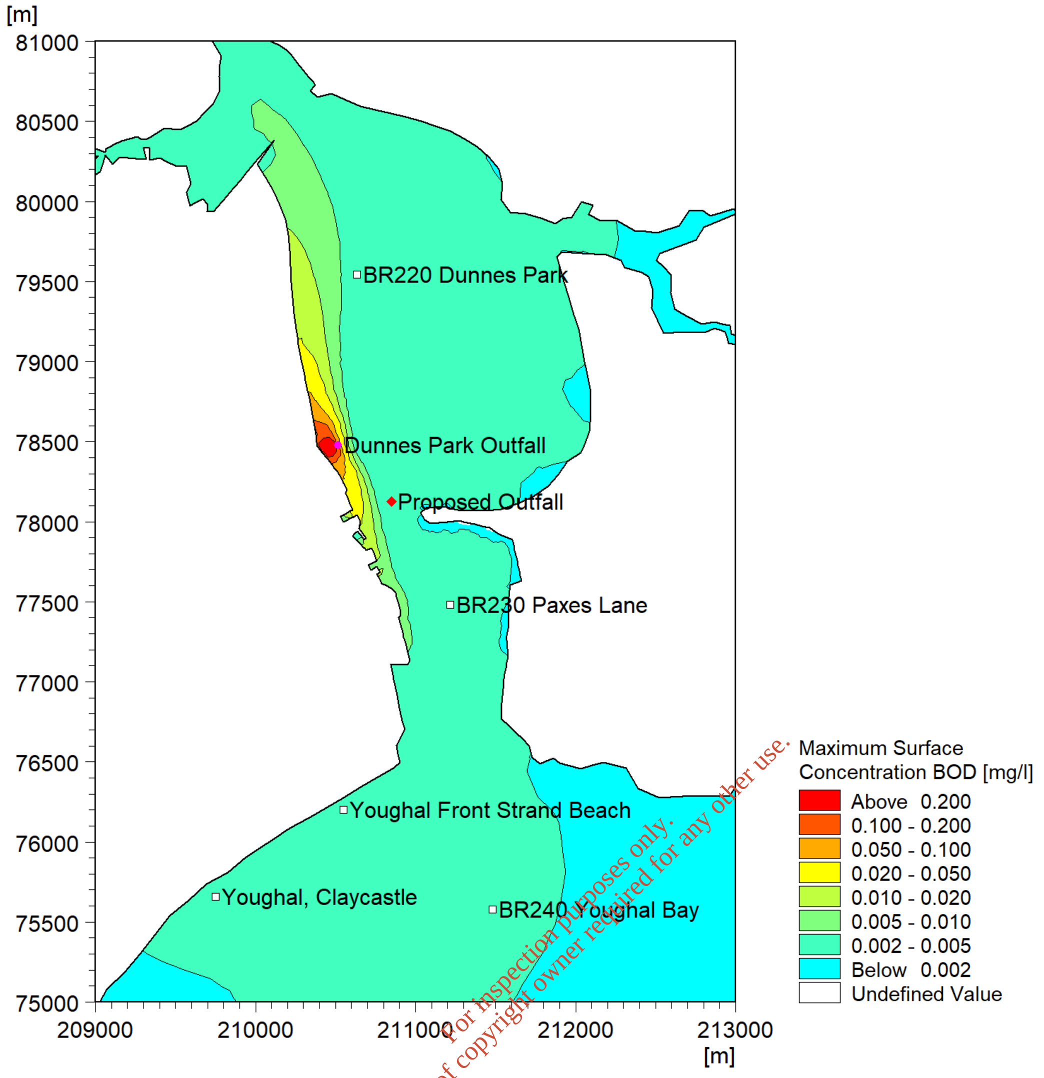
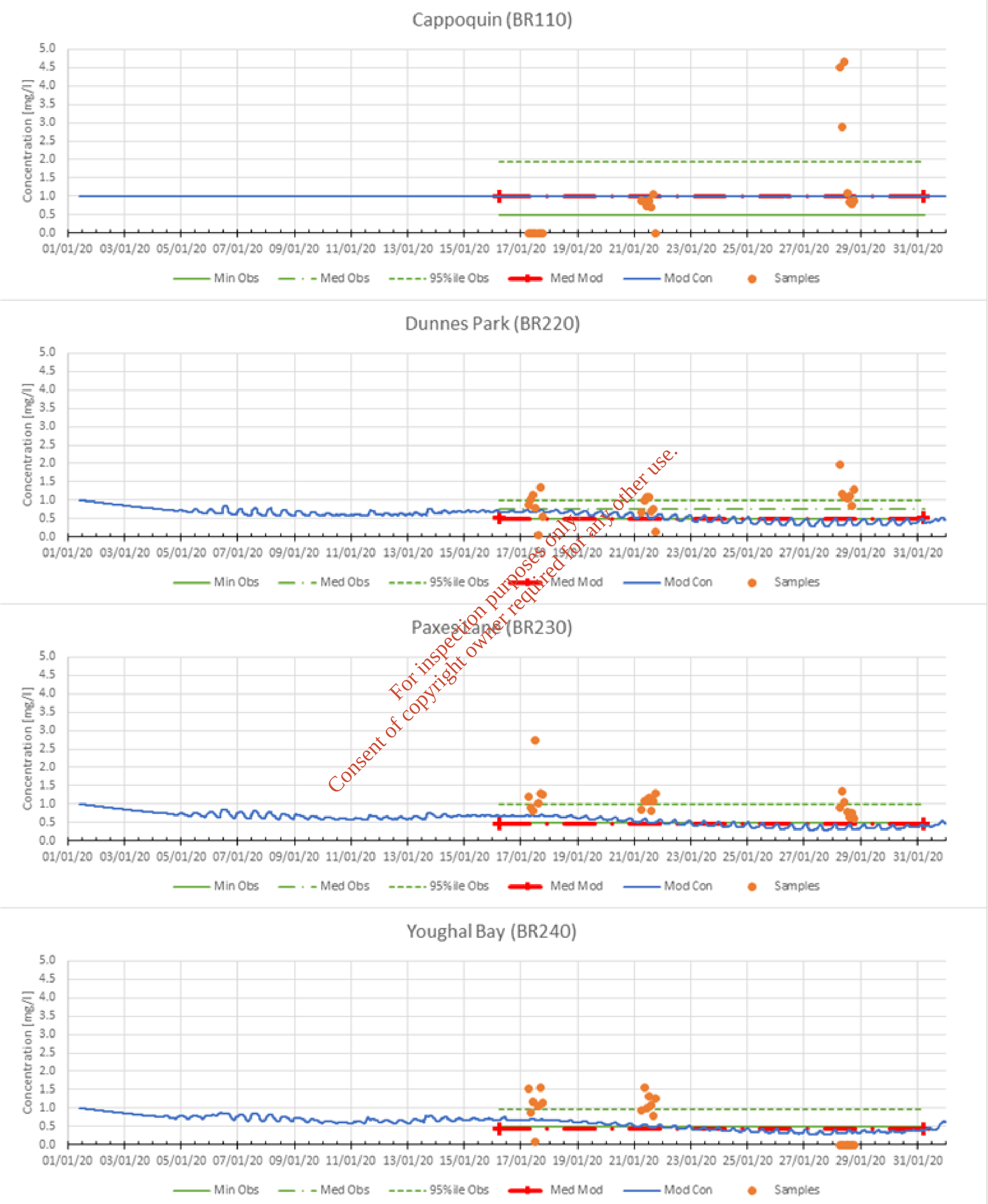


Figure 4-5. Maximum surface concentration of BOD (mg/l) for the discharge from Youghal WwTP through Dunnes Park Outfall (surface layer) over the 15 days of Event B (run code 01.80).

BOD [mg/l]

Location	Calibration Data Min	Calibration Data Mean	Calibration Data Median	Calibration Data 95%ile	Calibration Data Max	Modelled Min	Modelled Mean	Modelled Median	Modelled 95%ile	Modelled Max	Median Mod-Obs	Median % Obs	95%ile Mod-Obs	95%ile % Obs
Cappoquin (BR110)	0.50	1.11	1.00	1.94	2.00	0.98	0.99	0.99	0.99	0.99	-0.01	-1%	-0.95	-49%
Dunnes Park (BR220)	0.50	0.75	0.75	1.00	1.00	0.29	0.51	0.49	0.70	0.74	-0.26	-35%	-0.30	-30%
Paxes Lane (BR230)	0.50	0.67	0.50	1.00	1.00	0.28	0.48	0.45	0.68	0.71	-0.05	-10%	-0.32	-32%
Youghal Bay (BR240)	0.50	0.67	0.50	0.95	1.00	0.28	0.46	0.42	0.68	0.75	-0.08	-16%	-0.27	-28%

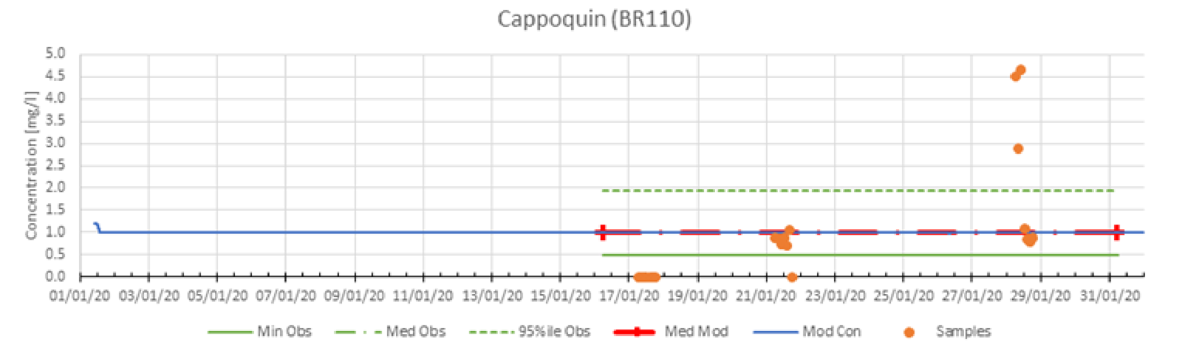


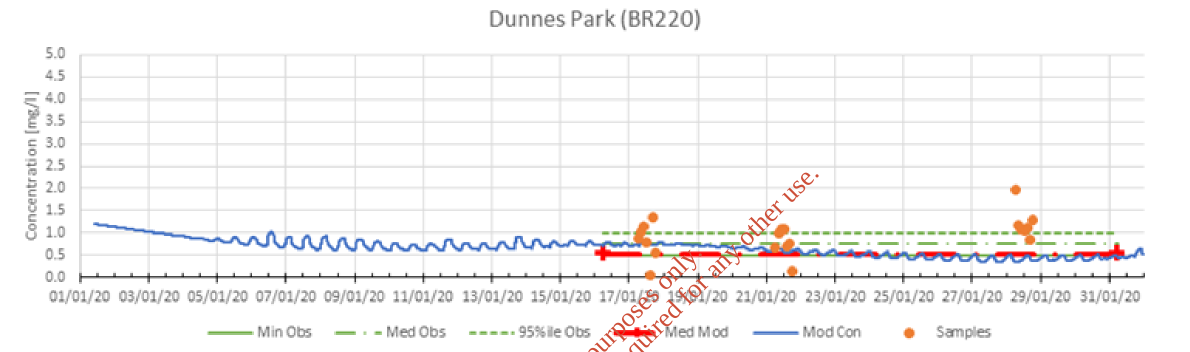
02.01.01_BOD_Base case of estimated values

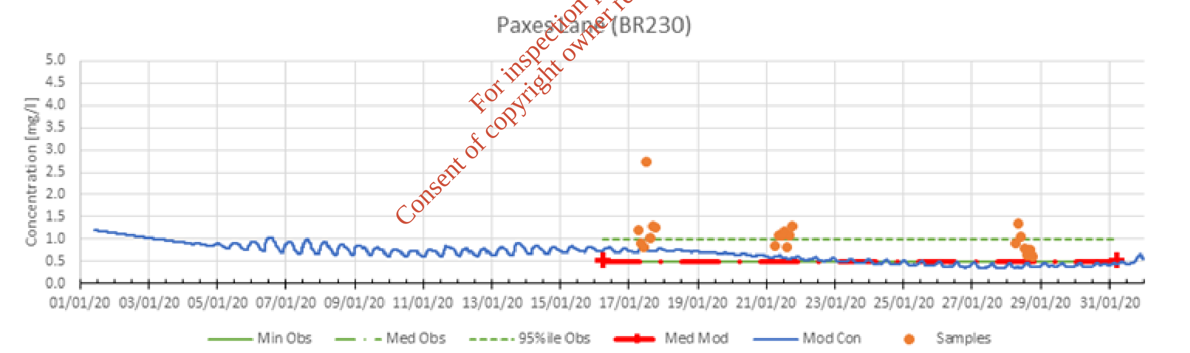
Figure 4-6. Summary statistics (mg/l) and plots for the model using median concentrations for BOD (run code 01.01).

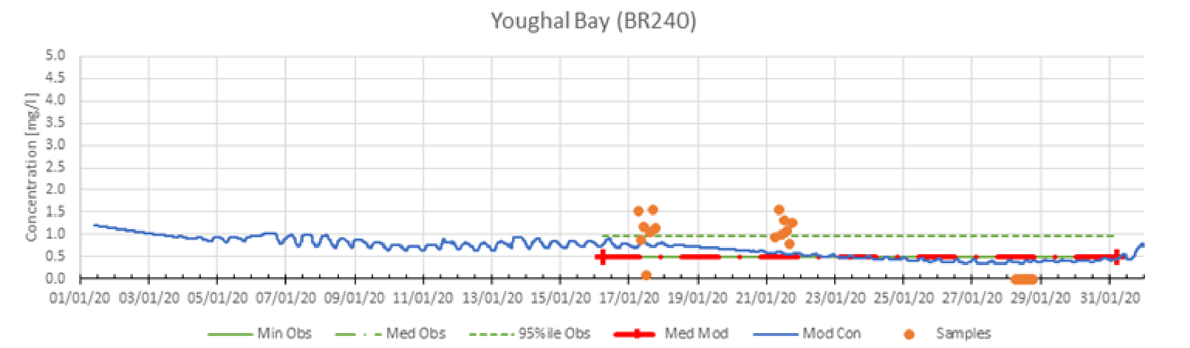
BOD [mg/l]

Location	Calibration Data					Modelled					Median		95%ile	
	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max	Mod-Obs	% Obs	Mod-Obs	% Obs
Cappoquin (BR110)	0.50	1.11	1.00	1.94	2.00	0.98	0.99	0.99	0.99	0.99	-0.01	-1%	-0.95	-49%
Dunnes Park (BR220)	0.50	0.75	0.75	1.00	1.00	0.33	0.55	0.52	0.75	0.80	-0.23	-30%	-0.25	-25%
Paxes Lane (BR230)	0.50	0.67	0.50	1.00	1.00	0.33	0.53	0.50	0.76	0.83	0.00	-1%	-0.24	-24%
Youghal Bay (BR240)	0.50	0.67	0.50	0.95	1.00	0.33	0.53	0.48	0.79	0.90	-0.02	-5%	-0.16	-17%









02.01.11_BOD_Modified Base Case- 2.YY.11

Figure 4-7. Summary statistics (mg/l) and plots for the initial model with modified open sea boundary for BOD (run code 01.11).

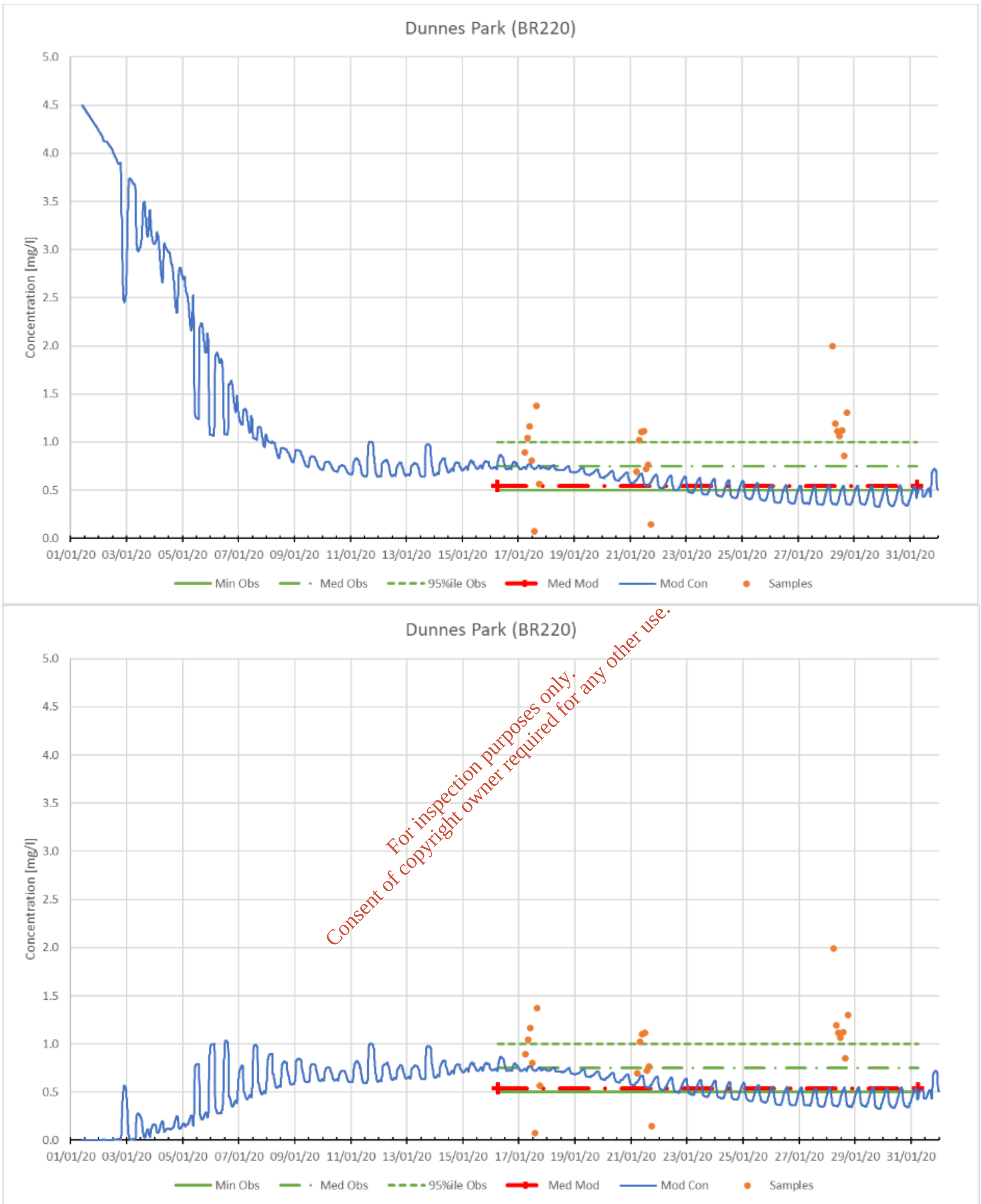


Figure 4-8. Comparison of the modelled concentration at Dunnes Park for different initial conditions (4.5 mg/l (top) and 0 mg/l (bottom) conditions for BOD.

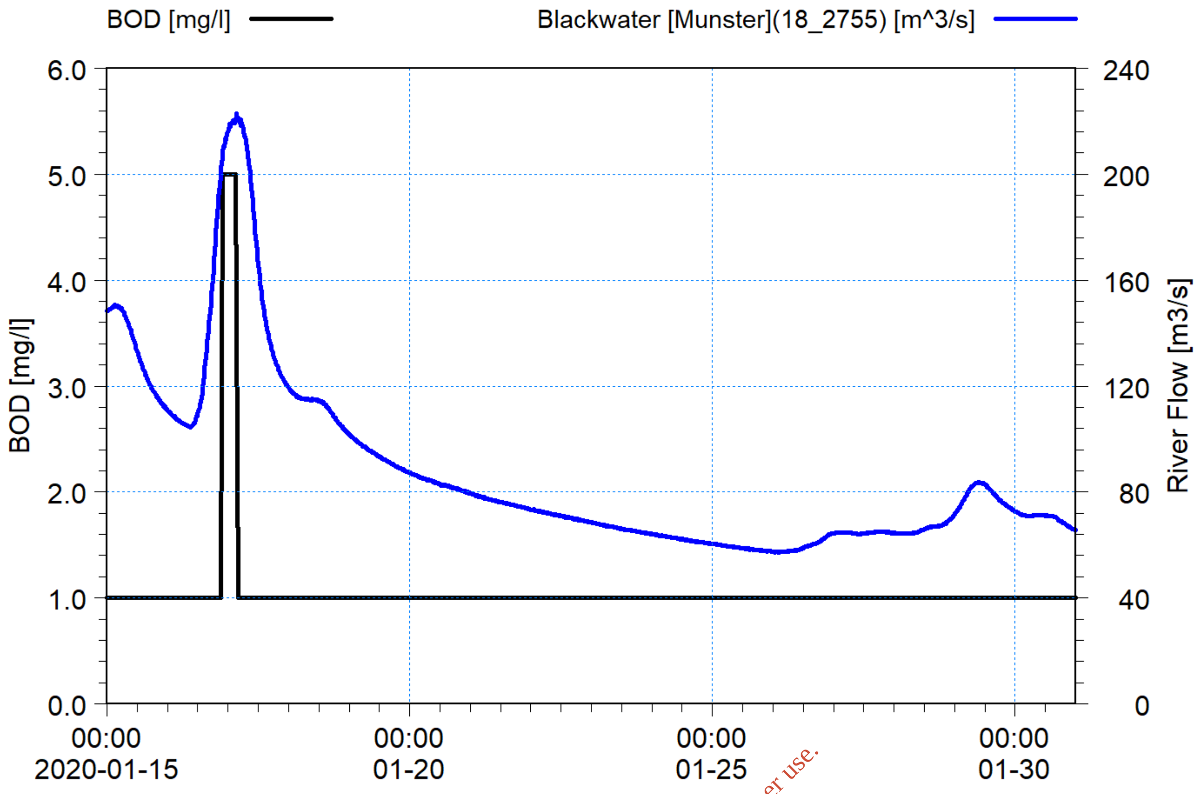
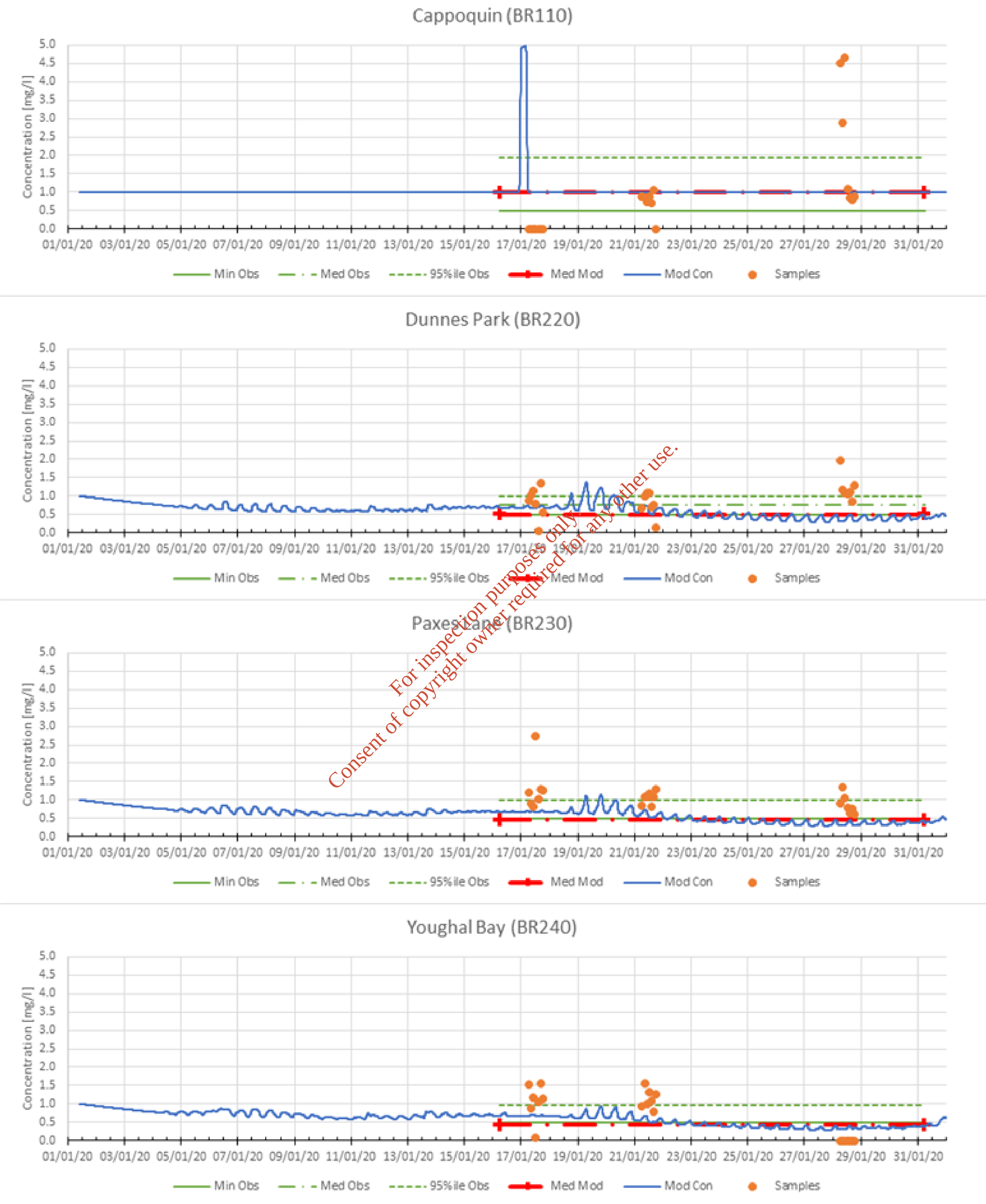


Figure 4-9. Time series plot of the theoretical 6-hour pulse of BOD at 5 mg/l coinciding with a rising river flow.

BOD [mg/l]

Location	Calibration Data					Modelled					Median		95%ile	
	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max	Mod-Obs	% Obs	Mod-Obs	% Obs
Cappoquin (BR110)	0.50	1.11	1.00	1.94	2.00	0.98	1.05	0.99	0.99	4.97	-0.01	-1%	-0.95	-49%
Dunnes Park (BR220)	0.50	0.75	0.75	1.00	1.00	0.29	0.55	0.50	0.98	1.36	-0.25	-33%	-0.02	-2%
Paxes Lane (BR230)	0.50	0.67	0.50	1.00	1.00	0.29	0.51	0.46	0.81	1.13	-0.04	-8%	-0.19	-19%
Youghal Bay (BR240)	0.50	0.67	0.50	0.95	1.00	0.28	0.48	0.43	0.74	0.94	-0.07	-15%	-0.21	-22%

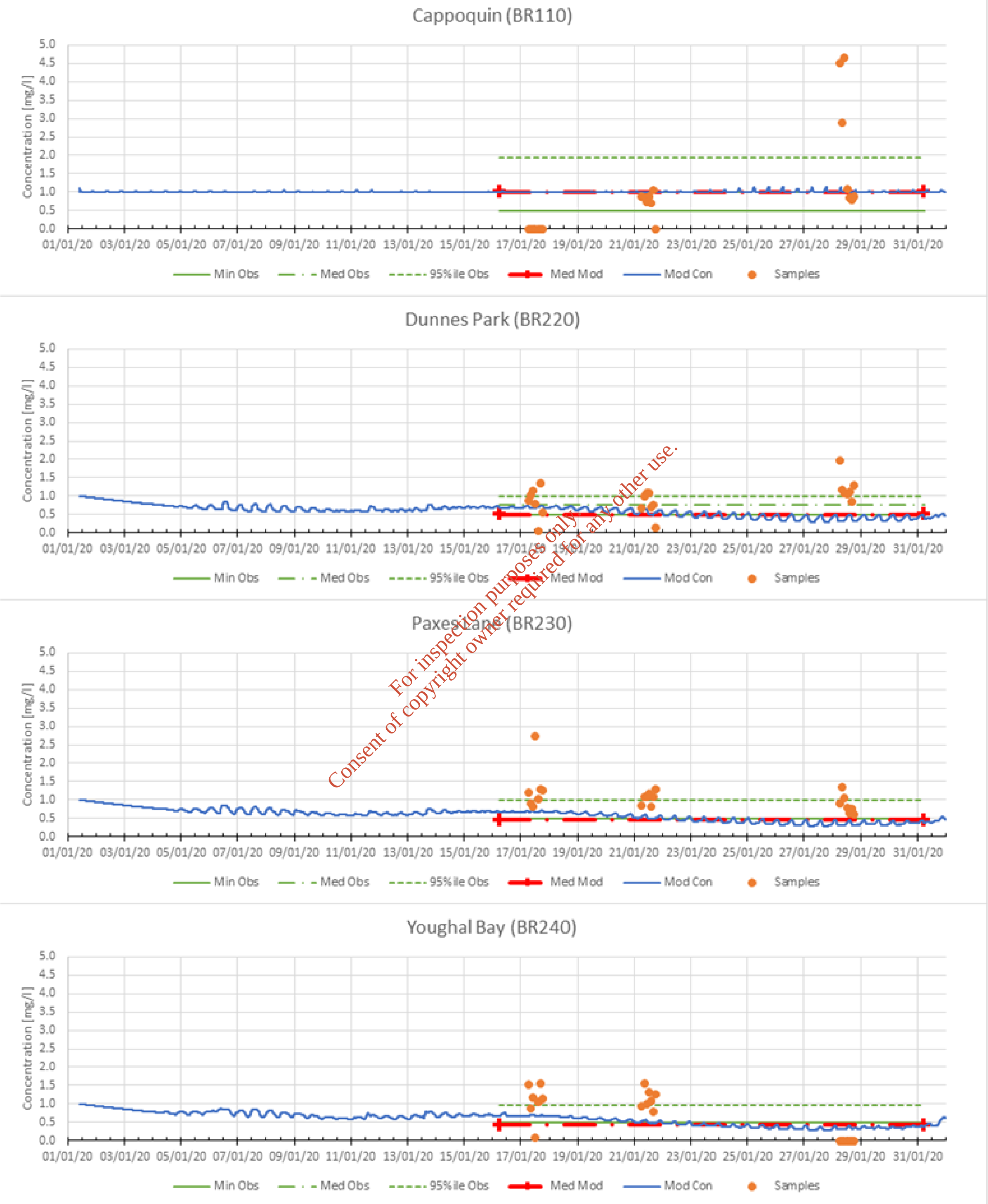


02.01.04_BOD_Pulse discharge in River Blackwater 2.YY.04

Figure 4-10. Summary statistics (mg/l) and plots for a 6-hour pulse of 5 mg/l to coincide with a high fluvial flow event at the start of Event B for BOD (run code 01.04).

BOD [mg/l]

Location	Calibration Data Min	Mean	Median	95%ile	Max	Modelled Min	Mean	Median	95%ile	Max	Median Mod-Obs	% Obs	95%ile Mod-Obs	% Obs
Cappoquin (BR110)	0.50	1.11	1.00	1.94	2.00	0.99	1.00	1.00	1.04	1.14	0.00	0%	-0.90	-46%
Dunnes Park (BR220)	0.50	0.75	0.75	1.00	1.00	0.29	0.51	0.49	0.70	0.74	-0.26	-34%	-0.30	-30%
Paxes Lane (BR230)	0.50	0.67	0.50	1.00	1.00	0.28	0.48	0.45	0.68	0.71	-0.05	-10%	-0.32	-32%
Youghal Bay (BR240)	0.50	0.67	0.50	0.95	1.00	0.28	0.46	0.42	0.68	0.75	-0.08	-15%	-0.27	-28%



02.01.81_BOD_Surface Discharge Median values

Figure 4-11. Summary statistics (mg/l) and plots for the model (surface discharge) using median concentrations for BOD (run code 01.81).

4.7 DIN

A summary of the model runs simulating DIN is provided in Table 4.5.

Table 4.5. Summary of the simulations for calibration of DIN against the EPA monitoring data and Irish Water survey data.

Run Code	Description	Initial Conditions [mg/l]	Open Sea Boundary [mg/l]	T_{90} [hours]
04.00	Youghal WwTP only	0.00	0.00	950
04.01	Median concentrations for all rivers and WwTP's with actual flows.	0.24	0.24	950
04.02	As 04.11 with increased T_{90}	0.00	0.00	1200
04.03	As 04.11 with decreased T_{90}	0.00	0.00	800
04.04	As 04.11 with a pulse discharge (River Blackwater) of 5 mg/l for 6 hours during a high flow fluvial event.	0.00	0.00	950
04.11	As 04.01 with changed initial and open sea boundary values	0.00	0.00	950
04.21	As 04.01 with changed initial and open sea boundary values	1.00	0.00	950
04.80	As 04.00 but with Youghal WwTP discharge in surface layer of water column	0.00	0.00	950
04.81	As 04.01 but with Youghal WwTP discharge in surface layer of water column	0.24	0.24	950

The maximum surface concentration of DIN for the discharge from Youghal WwTP is shown in Figure 4-12 for the discharge in the bottom layer and Figure 4-13 for the discharge in the surface layer. These show that the surface concentration of DIN is below 0.005 mg/l within the lower estuary. These plots provide a reference for the relative importance of other sources and the background concentration for the purposes of calibration.

The results of the water quality model using actual flows and median concentrations for all river and WwTP's are shown in Figure 4-14. This shows that the model reproduces general range of values in the lower estuary reasonably well; although the modelled concentrations are slightly higher than the EPA monitoring data. The January 2020 survey data agrees reasonably well with the EPA monitoring data, although there are some high values in the EPA monitoring data that could be the result of fluvial flushing. The model does show fluvial flushing occurring at the start of the Event B period.

The mass balance for the estuary estimates a median concentration of 3.25 mg/l. This is higher than the EPA monitoring data in the lower estuary and therefore there must be significant dilution with sea water.

Decreasing the T_{90} from 950 hours to 800 hours (Figure 4-16) improves the statistics. The peak values in the estuary are most likely determined by the load in the fluvial water entering the estuary. A pulse load of 5 mg/l for 6 hours results in an increase of approximately 0.5 mg/l in the lower estuary, but has minimal impact on the statistics of the lower estuary (Figure 4-17).

The discharge to the surface layer results in slight changes to the summary statistics (Figure 4-18) however the median values are reproduced reasonably well. It is recommended that the run 04.81 is adopted as the calibrated model for DIN.

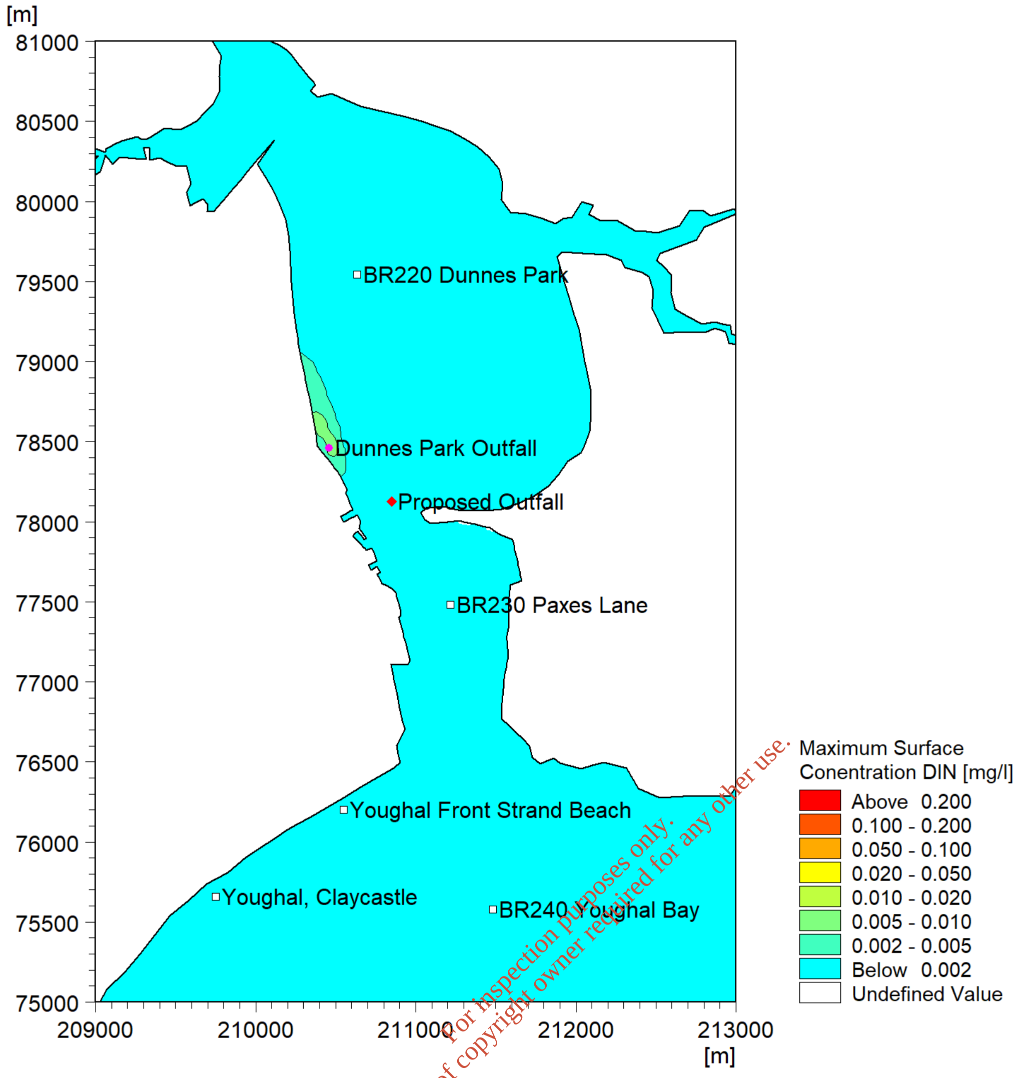


Figure 4-12. Maximum surface concentration of DIN (mg/l) for the discharge from Youghal WwTP through Dunnes Park Outfall over the 15 days of Event B (run code 04.00).

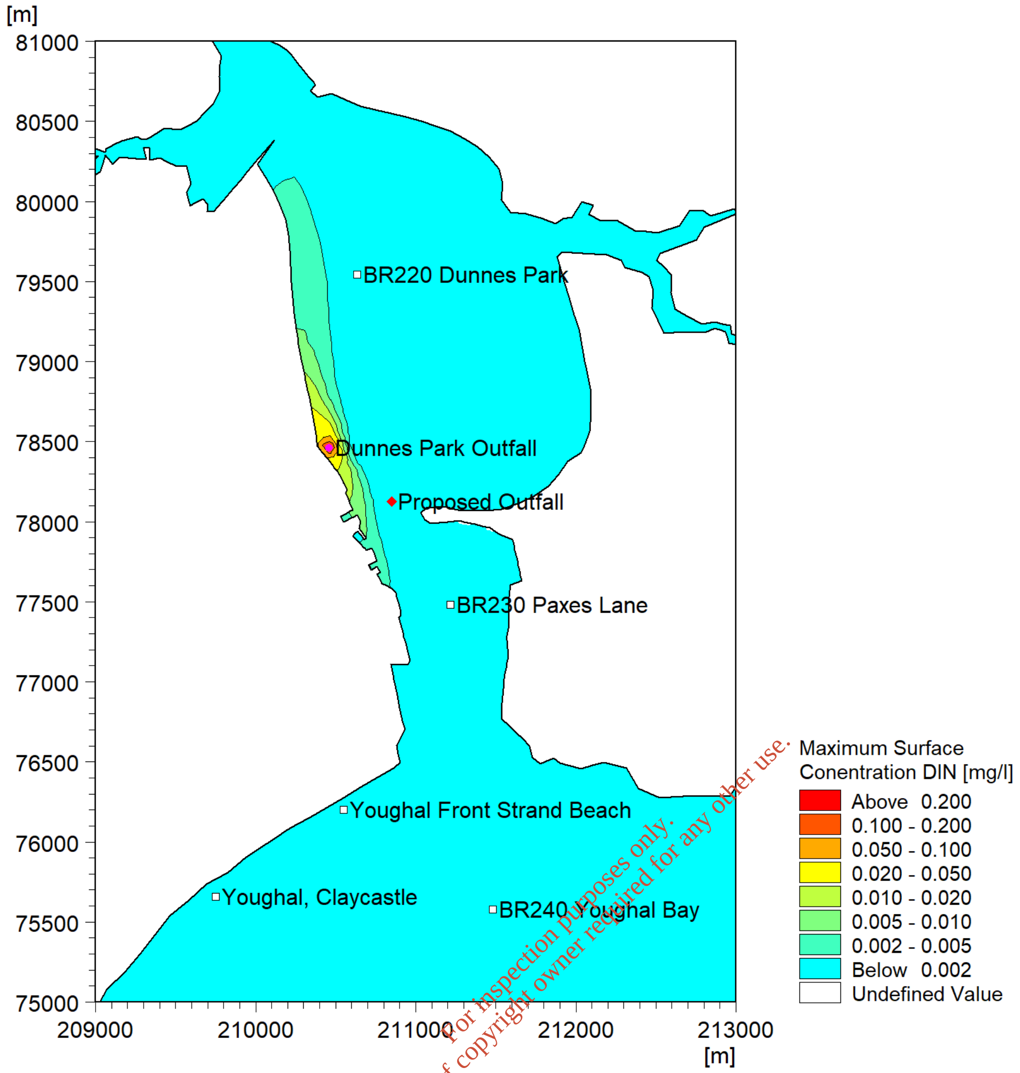
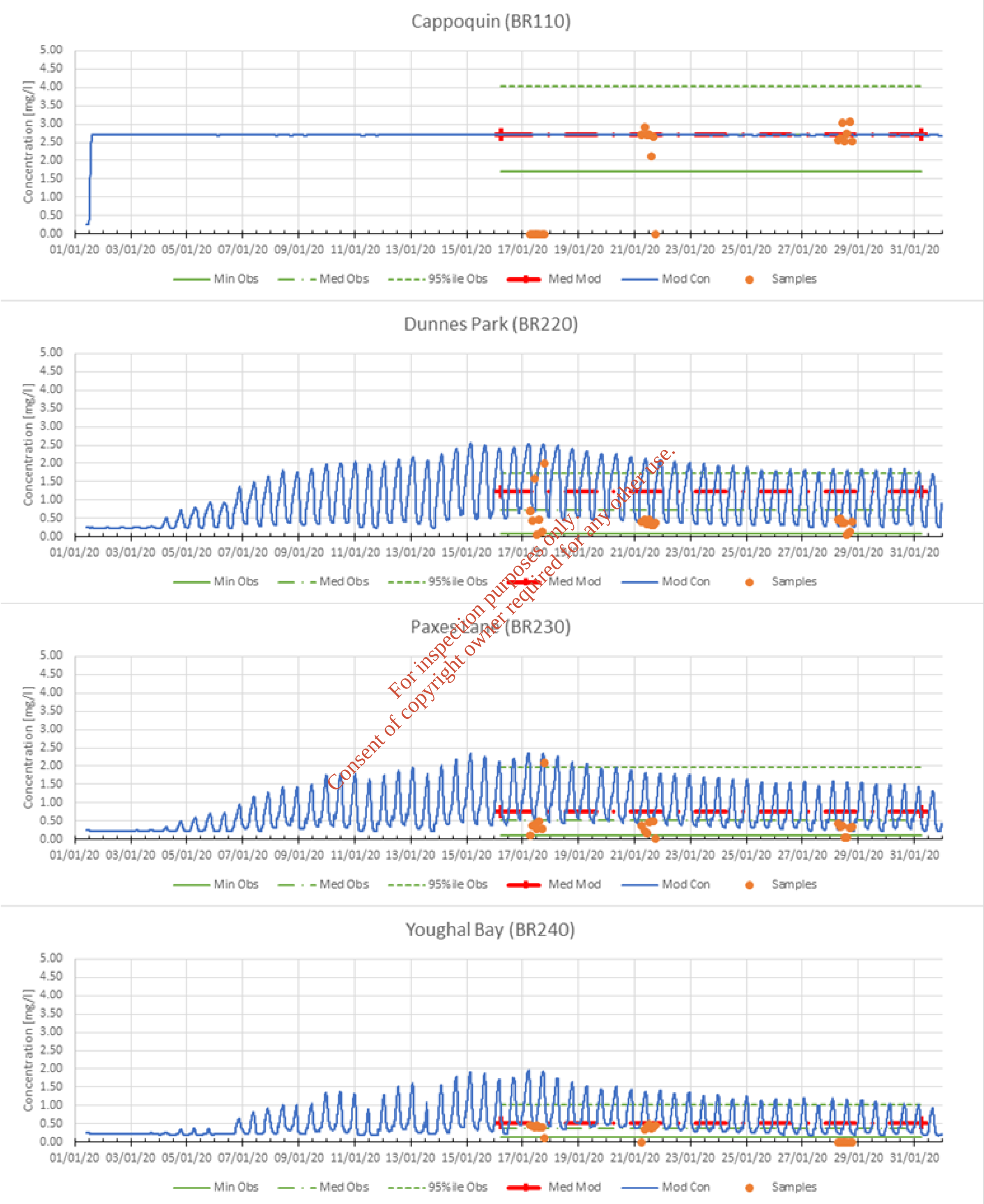


Figure 4-13. Maximum surface concentration of DIN (mg/l) for the discharge from Youghal WwTP through Dunnes Park Outfall (surface layer) over the 15 days of Event B (run code 04.80).

DIN [mg/l]

Location	Calibration Data					Modelled					Median		95%ile	
	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max	Mod-Obs	% Obs	Mod-Obs	% Obs
Cappoquin (BR110)	1.71	2.83	2.72	4.04	4.32	2.68	2.70	2.70	2.71	2.71	-0.02	-1%	-1.33	-33%
Dunnes Park (BR220)	0.08	0.79	0.72	1.72	1.84	0.25	1.19	1.22	2.27	2.54	0.50	70%	0.55	32%
Paxes Lane (BR230)	0.11	0.80	0.53	1.98	2.85	0.23	0.91	0.75	1.90	2.36	0.22	41%	-0.07	-4%
Youghal Bay (BR240)	0.15	0.49	0.36	1.02	1.03	0.18	0.66	0.51	1.42	1.96	0.14	39%	0.40	39%

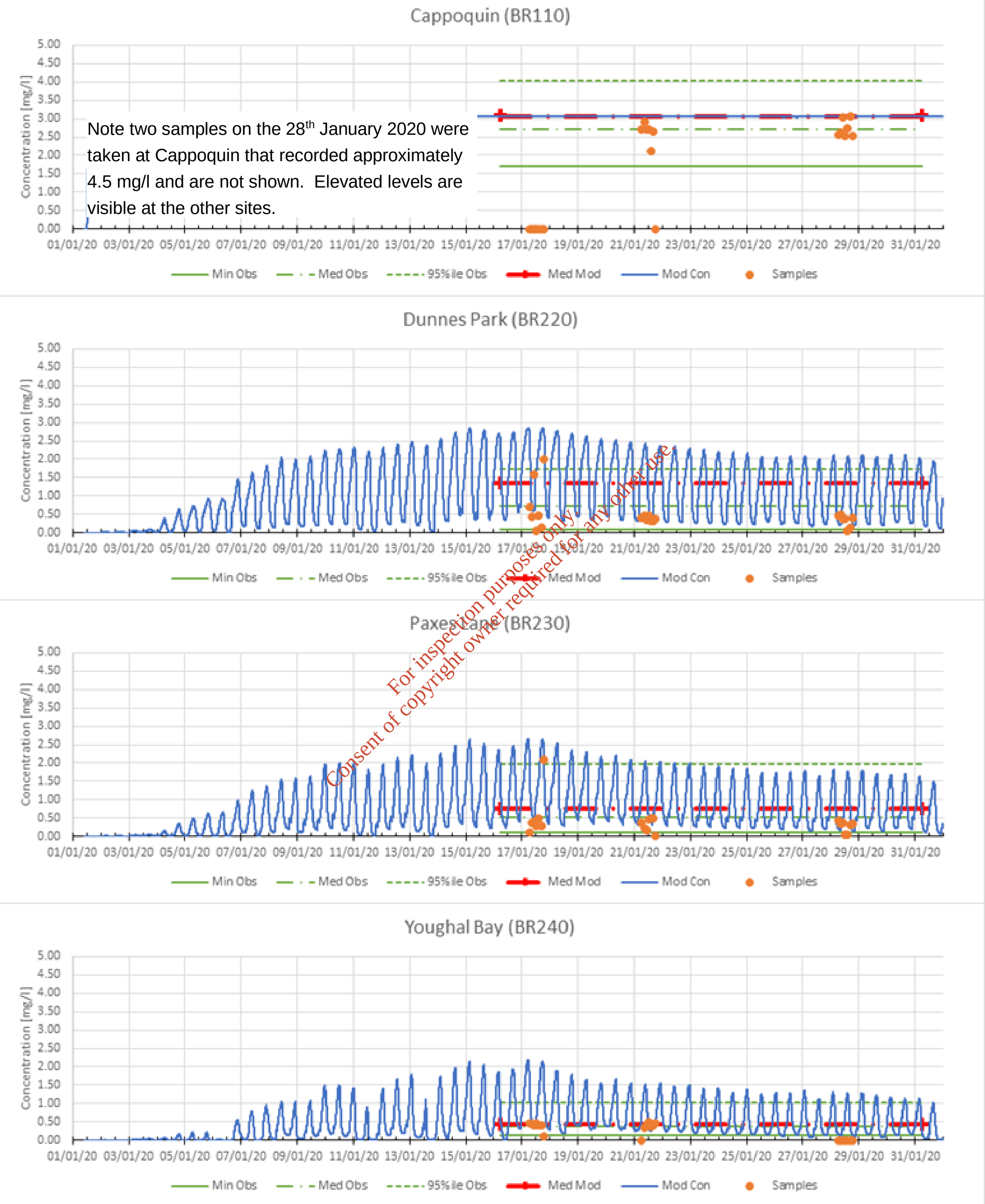


02.04.01_DIN_Base case of estimated values

Figure 4-14. Summary statistics (mg/l) and plots for the initial model using median concentrations for DIN (run code 04.01).

DIN [mg/l]

Location	Calibration Data					Modelled					Median		95%ile	
	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max	Mod-Obs	% Obs	Mod-Obs	% Obs
Cappoquin (BR110)	1.71	2.83	2.72	4.04	4.32	3.04	3.06	3.06	3.07	3.07	0.35	13%	-0.97	-24%
Dunnes Park (BR220)	0.08	0.79	0.72	1.72	1.84	0.17	1.29	1.33	2.54	2.85	0.61	85%	0.82	48%
Paxes Lane (BR230)	0.11	0.80	0.53	1.98	2.85	0.14	0.95	0.75	2.11	2.66	0.21	40%	0.13	7%
Youghal Bay (BR240)	0.15	0.49	0.36	1.02	1.03	0.02	0.64	0.43	1.53	2.18	0.06	17%	0.51	50%



02.04.02_DIN_Revised Decay Rates (EC 12 hrs IE 24 hrs)

Figure 4-15. Summary statistics (mg/l) and plots for the initial model using median concentrations for DIN with initial and open sea boundary conditions of 0 mg/l (run code 04.02).