Grand Canal Storm Water Outfall Extension Water Quality Assessment

Numerical Model Report

Technical Report

March 2022

The expert in **WATER ENVIRONMENTS**

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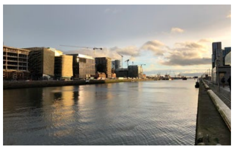

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Photo of the River Liffey in the vicinity of the GCSWOE

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1 Background

Following the delivery of a Scoping Report [1] regarding the proposed Grand Canal Tunnel (GCT) into the River Liffey, Dublin, it was identified that there was a need to undertake additional data collection surveys and modelling to provide confirmation of the anticipated estuarine controls on flow and water exchange in this part of the River Liffey.

The proposed extension will divert the existing outfall from its present location within the Grand Canal Basin (GCB) through a newly constructed pipe into a new outfall to the Liffey at Sir John Rogerson’s Quay. It is noted that the existing system discharges the mixed canal and outfall discharge water from the GCB into the Liffey through the sluice and lock gates at the North East corner of the basin. The new asset has been termed the Grand Canal Storm Water Outfall Extension (GCSWOE).

The data collection surveys proposed in the Scoping Report [1] sought to confirm and quantify the understanding of the key estuarine processes that are likely to control the fate of any discharge at the proposed outfall location in the River Liffey. The Survey Interpretive Report [2] then sought to provide a detailed review of the survey data and compare/analyse in combination with relevant data from other sources to present an improved understanding of the physical and water quality environment to be established.

Key to the process understanding is the rate of flushing from this location, under a range of river flow/tidal conditions, and the salinity structure along the water column in the proximity of the proposed discharge which may alter the timing of water exchange with the sea.

Following the surveys, which confirmed the presence of a salt-wedge structure and a simplified empirical assessment of the flushing, it was considered that further assessment was required to quantify the proposed Outfall extension against the Water Framework Direction (WFD) Environmental Quality Standards (EQS).

As such, a further study was commissioned, using a simplified numerical model of the lower Liffey Estuary, utilising the measured data summarised in the Survey Interpretative Report and designed to represent the controlling salt-wedge feature.

This report summarises that further study and is organised as follows. Section 2 provides a summary of the hydrodynamic model developed for this application. Section 3 presents the advanced water quality model setup and discusses the data summarised in the previous section. Section 4 provides a summary of the results of the water quality modelling Finally, Section 5 presents the conclusions of the report.

2 Hydrodynamic Modelling methodology

2.1 Model selection

The hydrodynamic modelling has been performed using the MIKE 3 modelling package developed by DHI. MIKE 3 includes the simulation tools to model 3D free surface flows and associated sediment or water quality processes. The following modules available within MIKE 3 were used during this study:

- HD – Hydrodynamics: This module simulates the water level variations and flows in response to a variety of forcing functions. It includes a wide range of hydraulic phenomena in the simulations and it can be used for any 3D free surface flow. The Flexible Mesh version, which uses a depth and surface adaptive vertical grid, is particularly suitable in areas with a high tidal range.

The MIKE 3 Model used for the present study was version 2021 [3].

The Hydrodynamic Module is the basic computational component of the entire MIKE 3 Flow Model FM, and has been developed for applications within oceanographic, coastal, and estuarine environments [3]. The hydrodynamic module provides the basis for the other modules such as sand transport, mud transport, particle tracking, and MIKE ECO Lab, used for water quality studies.

The computational mesh is based on the unstructured grid in the horizontal direction, an approach that gives maximum degree of flexibility when handling problems in complex domains. In the vertical direction, a sigma (σ) discretisation is used meaning that model elements are represented as 3-sided prisms (Figure 2.1)

The MIKE3 modelling system is based on the numerical solution of the three-dimensional incompressible Reynolds Averaged Navier-Stokes (RANS) equations, invoking the assumptions of Boussinesq, and of hydrostatic pressure. Thus, the MIKE 3 flow model consists of continuity, momentum, temperature, salinity, and density equations and is closed by a turbulent closure scheme. In the horizontal domain, both Cartesian and spherical coordinates can be used. The free surface is considered using a sigma-coordinate transformation approach.

The spatial discretisation of the primitive equations is performed using a cell-centred finite volume method. The spatial domain is discretised by subdivision of the continuum into non-overlapping element/cells. In the horizontal plane, an unstructured grid is used while in the vertical domain a structured discretisation is used. The elements can be prisms or bricks whose horizontal faces are triangles and quadrilateral elements, respectively. An approximative Riemann solver is used for the computation of the convective fluxes, which makes it possible to handle discontinuous solutions.

For the time integration, a semi-implicit approach is used where the horizontal terms are treated explicitly, and the vertical terms are treated implicitly.

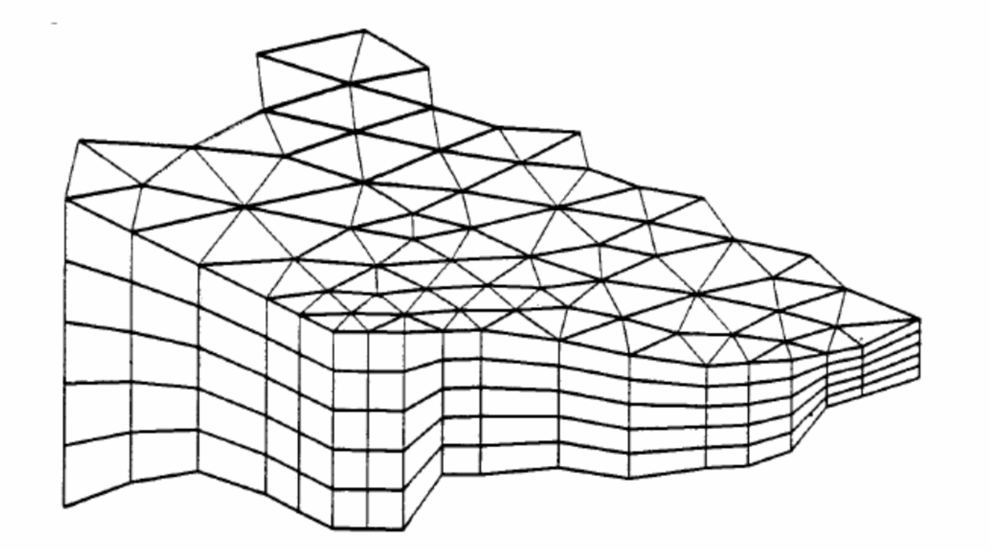

Figure 2.1 Example of an unstructured mesh in MIKE3 with 5 sigma (σ) layers.

2.2 Hydrodynamic model setup

2.2.1 Domain, mesh, and bathymetry

Reference systems

A common horizontal and vertical reference system was adopted for the modelling study. This was projected coordinate system UTM zone 30U and Ordnance Datum Malin (OD Malin).

Coastline

The Dublin City Council (DCC) development plan shapefile was used to derive the coastline boundary for the model.

Bathymetry datasets

The bathymetric datasets available for the modelling were the following:

- High-resolution Multi-Beam Echosounder surveys (MBES) of Dublin Port provided by Dublin Port Authority.
- Cross-sections surveys of the R. Liffey and R. Dodder provided by DCC

Model Domain

The model domain includes the area starting downstream at the ferry terminal quays (Terminal 5) and ending at the Islandbridge sill in the River Liffey and at Ballsbridge in the River Dodder. Dublin Port land contours were simplified discarding docks and terminals. The model has three (3) open boundaries. Two, corresponding to the Liffey and Dodder rivers, where discharges are specified and one (1), corresponding to the seaward limit, where the water level is specified. Discharges for the River Liffey were obtained from four (4) river gauges, these are: Leixlip (09001), Lucan (09002), Killeen Road (09035) and Leixlip Power Station (P.S.). Discharges for the River Dodder were obtained from two (2) river gauges, these are: Waldron's Bridge (09010) and Frankfort (09011).

Computational Mesh

The computational mesh was based on a mixture of unstructured rectangular and triangular elements with varying spatial resolution. The coarsest mesh resolution was at the upstream and downstream boundaries with rectangular element sizes typically 80m×10m.

The resolution increases gradually with distance towards the region of interest, i.e., in the proximities of the GCSWOE, with rectangular element sizes of 35m×10m.

All bathymetric datasets were converted to the vertical reference of Ordnance Datum Malin (OD Malin) before being interpolated to the computational mesh. OD Malin was taken to be 2.51 m above CD (invariant in the domain).

Figure 2.2 shows the computational mesh and bathymetry for the entire model domain, while Figure 2.3 provides a more detailed graphic showing the areas of interest mentioned above.

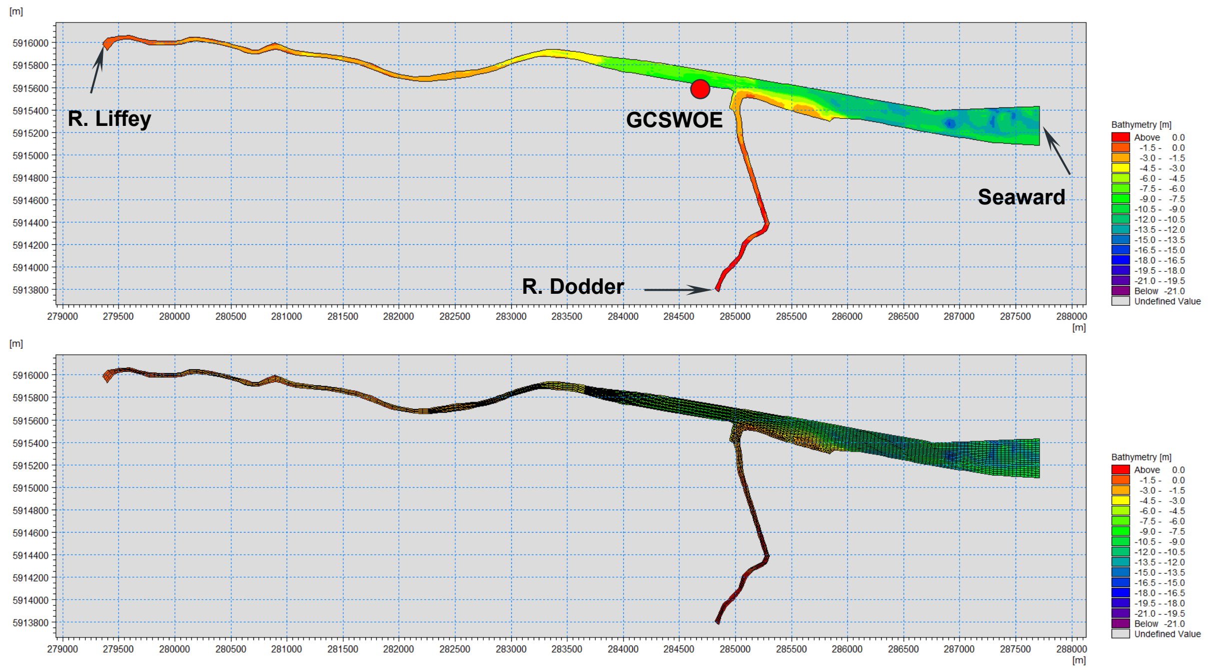

Figure 2.2 Bathymetry (top panel) and computational mesh (bottom mesh) for the entire domain.

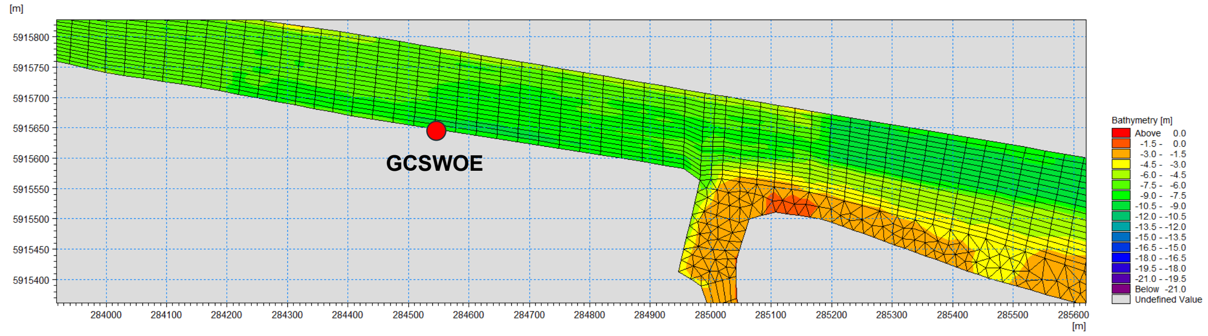

Figure 2.3 Bathymetry and computational mesh in the proximities of the GCSWOE.

2.2.2 Boundary conditions

The model was driven by temporally and spatially varying water levels, and temporally varying wind velocities, salinity profiles and specified discharges applied across the open boundaries. Discharges from the GCSWOE were input as a source discharge. A constant bottom roughness height of 0.05m was defined in all the domain.

The hydrodynamic model was run considering the baroclinic terms (as a function of both, salinity and temperature) and with heat exchange enabled.

Table 2.1 Details of the boundary conditions.

Boundary	Type	Data
Seaward	• Specified water level: varying in time, constant along boundary. • Salinity: varying in time, constant along boundary. • Temperature: constant value • Turbulence: constant valued	• Water level data from Port of Dublin. • Salinity data interpolated from from observations (ARR Ltd. Survey). • Temperature, inferred from observations, 10.5°C. • Turbulence: Default settings
R. Liffey	• Specified discharge: varying in time, constant along boundary • Salinity: constant value • Temperature: varying in time, constant along boundary • Turbulence: constant valued	• Discharge data retrieved from the EPA Hydronet platform (https://www.epa.ie/hydronet) and from Leixlip Power Station. Includes discharges from: Leixlip (09001), Lucan (09002), Killeen Road (09035) and Leixlip Power Station. • Salinity: Fresh water (0 psu) • Temperature: extrapolated from observations made in a UK river. • Turbulence: Default settings
R. Dodder	• Specified discharge: varying in time, constant along boundary • Salinity: constant value • Temperature: varying in time, constant along boundary • Turbulence: constant valued	• Discharge data retrieved from the EPA Hydronet platform (https://www.epa.ie/hydronet) and from: Leixlip Power Station. Includes discharges from: Waldron's Bridge (09010) and Frankfort (09011). • Salinity: Fresh water (0 psu) • Temperature: extrapolated from observations made in a UK river. • Turbulence: Default settings
GCSWOE	• Source - Specified discharge: varying in time, constant along boundary • Source - Salinity: constant value • Source - Temperature: varying in time, constant along boundary	• Discharge data: Long-term flow monitor (LTF28) at manhole S0163205011_289, monitored by Irish Water. • Salinity: Fresh water (0 psu) • Temperature: extrapolated from observations made in a UK river.
Domain - surface	• Wind: Varying in time, constant in domain • Heat exchange: - Specified net short wave radiation: Varying in time, constant in domain - Longwave radiation: empirical - Atmospheric conditions - Air temperature, relative humidity, clearness coefficient: Varying in time, constant in domain	• Wind: data from Dublin Airport. • Heat exchange variables: obtained from observations in a UK lake.
Domain - bottom	Roughness height	Constant throughout the domain, 0.05m

2.2.3 Hydrodynamic model settings

Table 2.2 summarises the settings applied in the hydrodynamic model. The model was run in decoupled form for a period of 61-days for calibration and validation purposes, corresponding to the ARR Ltd. survey campaigns period, and for 371 days (more than a year) for production runs. The model considered forcing under tidal, meteorological effects (wind velocities), river discharges and baroclinic effects. Forcing time series were obtained as described in Table 2.1.

Table 2.2 Summary of the configuration of the hydrodynamic model for the initial dispersion study.

Setting	**Description/Value**
Mesh resolution	Varying flexible mesh typically 10-20m in the areas of interest
Vertical mesh	10 layer, sigma type evenly spaced
Number of elements	3,304 elements per layer giving a total of 33,040 elements
Simulation period	• Calibration / Validation: 61 days (2020-10-05 to 2020-12-06) • Production: 371 days (2020-12-25 to 2020-12-31)
Output time interval	15 minutes
Basic equations	Shallow waters
Solution technique	Low-order calculation, fast order algorithm
Density	Baroclinic – Function of temperature and salinity
Eddy viscosity	Smagorinsky formulation with a constant value of 0.28
Temperature / Salinity module	
Equation	Default settings
Solution technique	Low-order calculation, fast order algorithm
Dispersion	• Scaled eddy viscosity formulation - constant - Horizontal: 0.5 - Vertical: 0.001
Heat exchange	Included
Turbulence module	
Equation	Default settings
Solution technique	Low-order calculation, fast order algorithm
Dispersion	Default settings

2.3 Hydrodynamic Model validation

The hydrodynamic model was qualitatively validated against observations made during the ARR Ltd survey campaigns [4]. Figure 2.4 to Figure 2.7 compares observed and modelled contour plots of u-velocity component at different tide times for a longitudinal transect between the Samuel Beckett Bridge (SBB) and Tom Clarke Bridge (TCB).

Figure 2.8 shows a comparison of observed and modelled vertical profiles of velocity vectors at different hours before and after the high tide at a position ~100 m downstream the Samuel Beckett Bridge (i.e. ~200 m upstream the GCSWOE) centred in the middle of the cross-section of the River Liffey.

Figure 2.9 shows contour plots of salinity during a tidal cycle for a longitudinal transect between the Samuel Beckett and Tom Clarke bridges. The model can capture the salinity wedge measure during the survey campaign (see [2]).

It can be inferred from the validation figures that the hydrodynamic model is able to capture the main hydrodynamic processes and salinity structure observed in the study region.

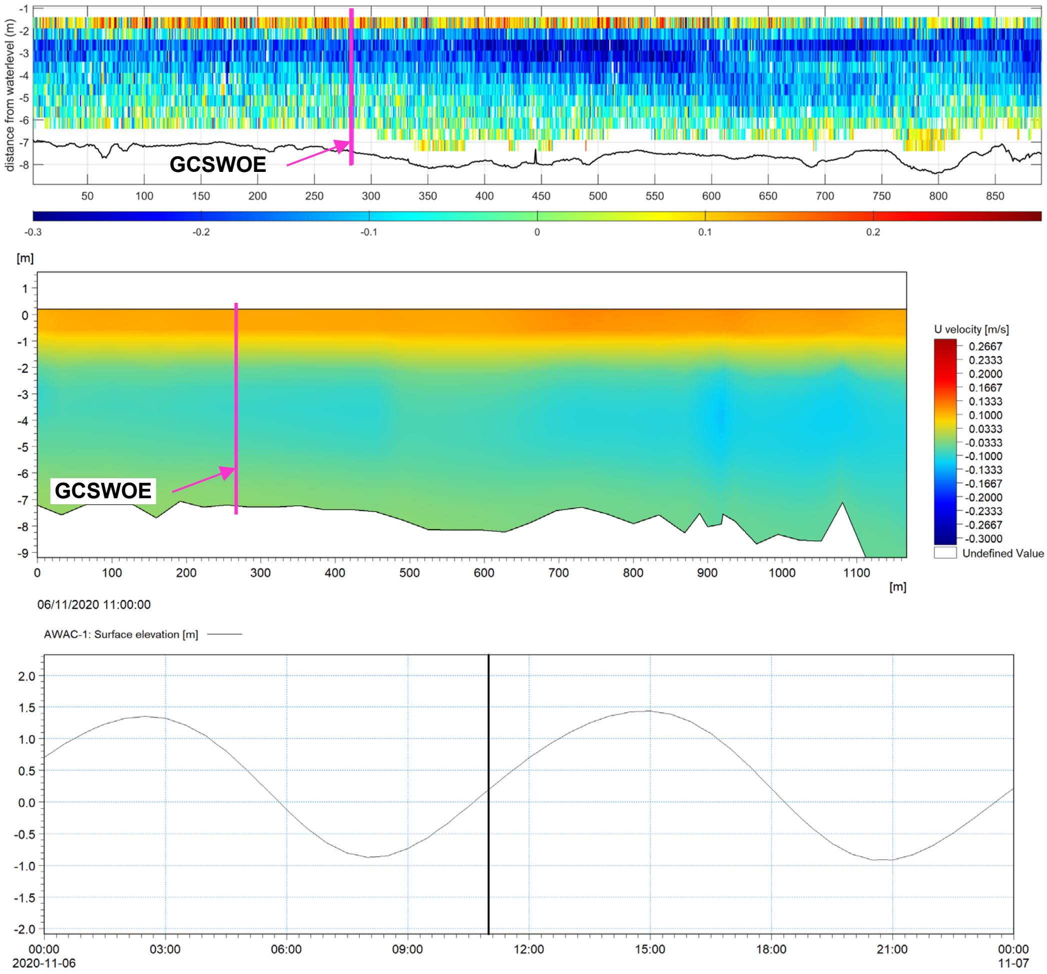

Figure 2.4 Comparison of observed (top panel) and modelled (centre panel) contour plots of u-velocity component during flood tide for a longitudinal transect between the Samuel Beckett and Tom Clarke bridges. Bottom panel shows the tide phase.

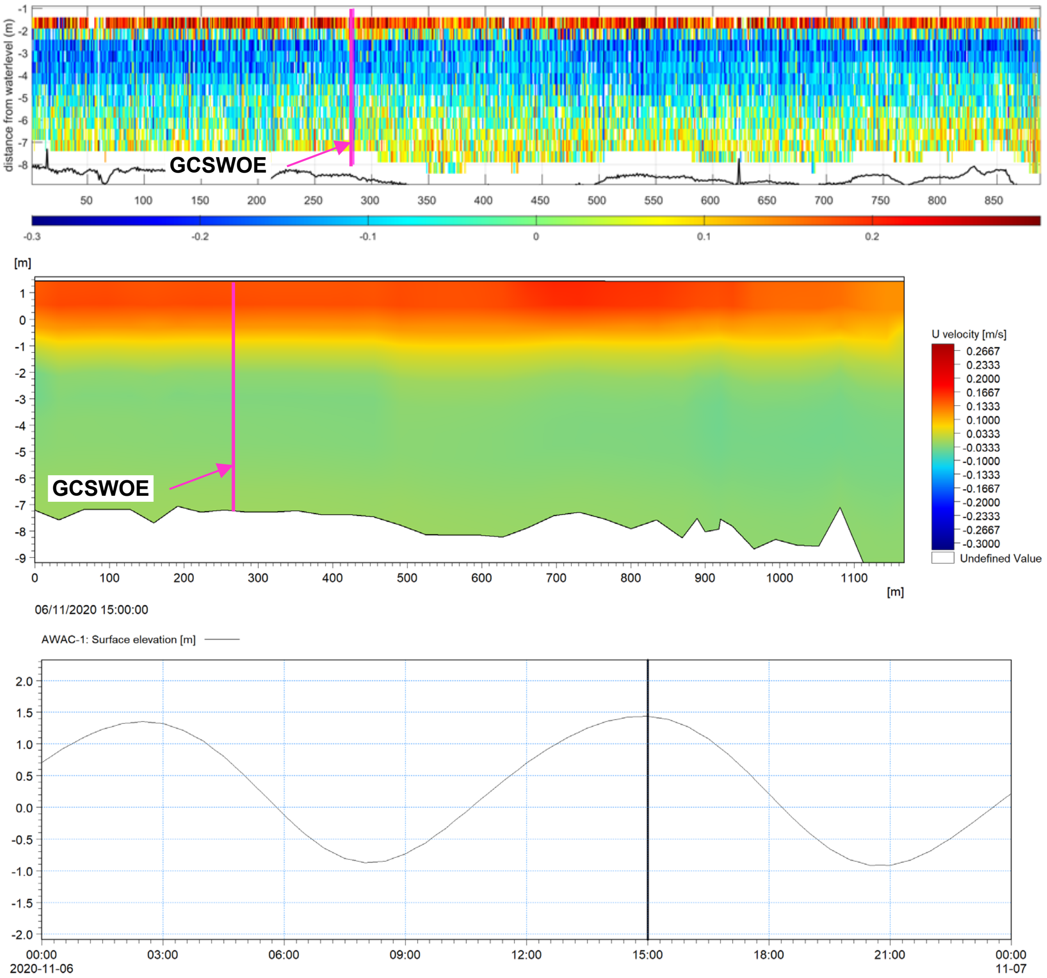

Figure 2.5 Comparison of observed (top panel) and modelled (centre panel) contour plots of u-velocity component during high tide for a longitudinal transect between the Samuel Beckett and Tom Clarke bridges. Bottom panel shows the tide phase.

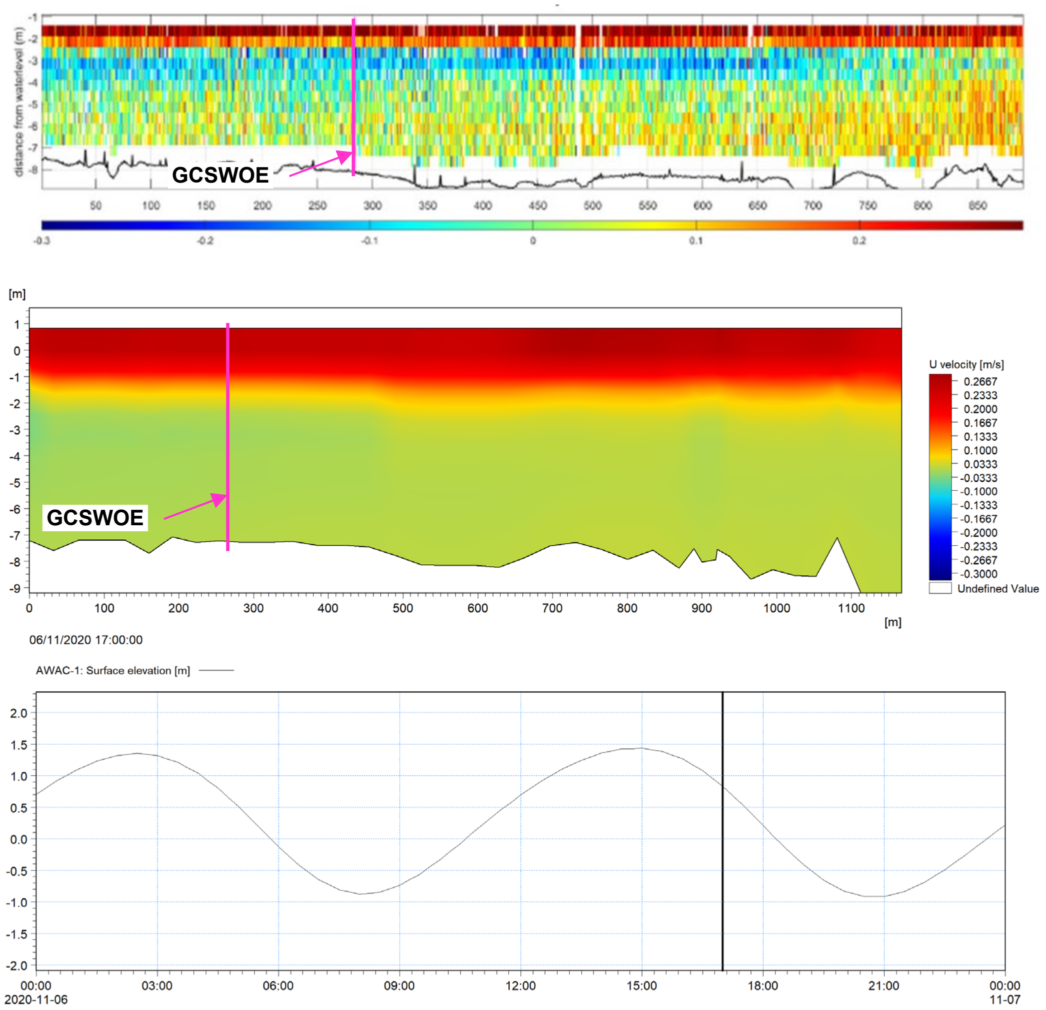

Figure 2.6 Comparison of observed (top panel) and modelled (centre panel) contour plots of u-velocity component during ebb tide for a longitudinal transect between the Samuel Beckett and Tom Clarke bridges. Bottom panel shows the tide phase.

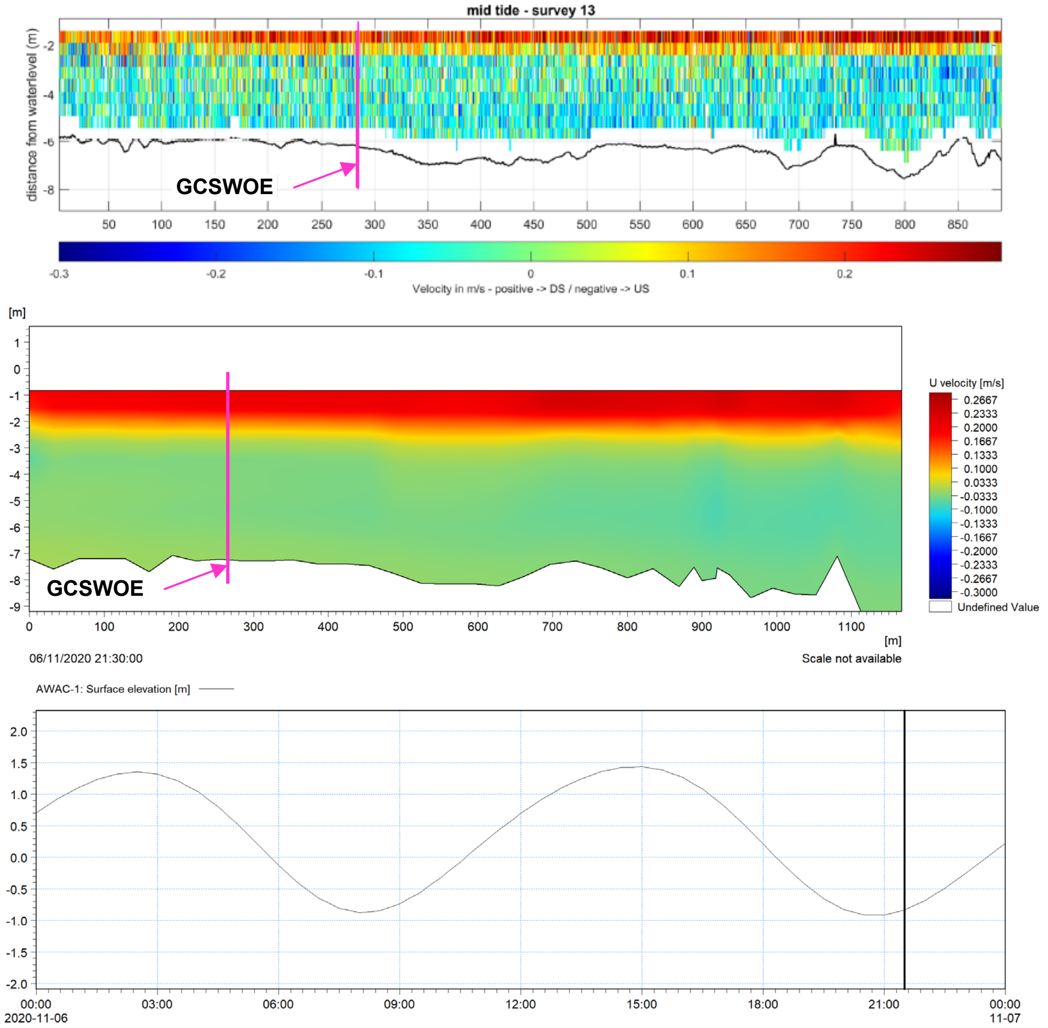

Figure 2.7 Comparison of observed (top panel) and modelled (centre panel) contour plots of u-velocity component during low tide for a longitudinal transect between the Samuel Beckett and Tom Clarke bridges. Bottom panel shows the tide phase.

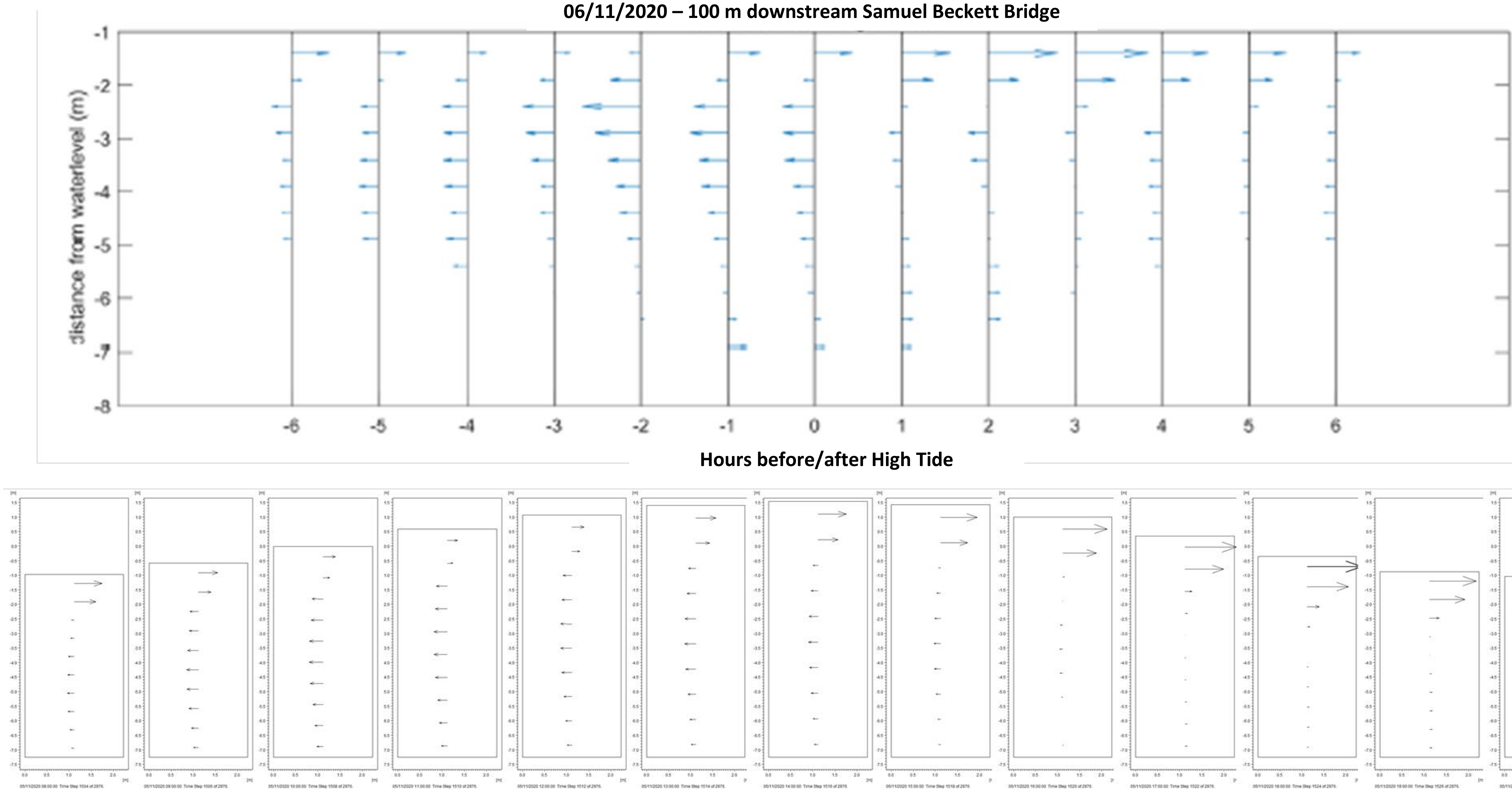

Figure 2.8 Comparison of observed and modelled vertical profiles of velocity vector at different hours before and after the high tide at a position ~100 m downstream of the Samuel Beckett Bridge centred in the middle of the river.

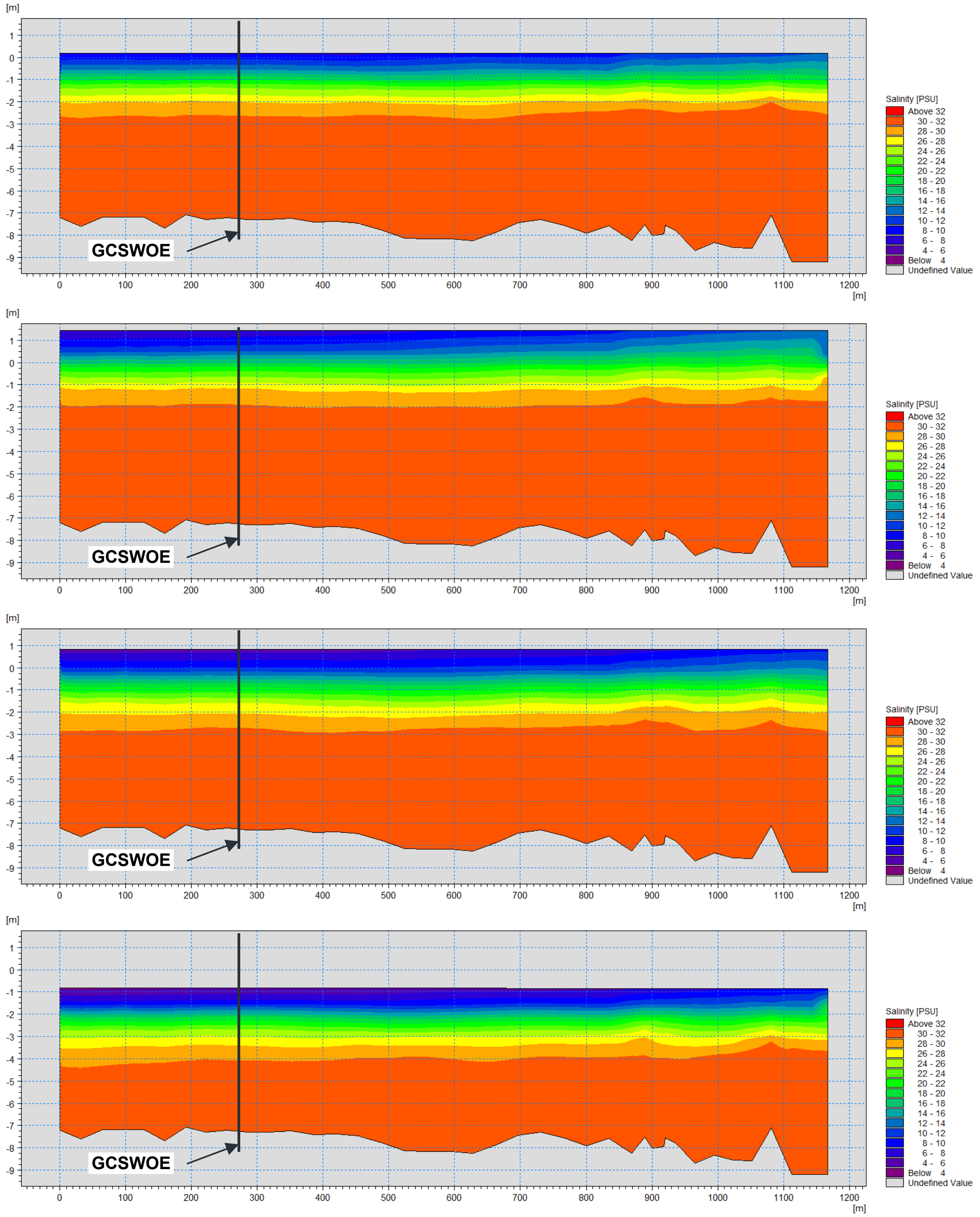

Figure 2.9 Contour plots of salinity during a tidal cycle for a longitudinal transect between the Samuel Beckett and Tom Clarke bridges. From top to bottom: flood, high, ebb and low tide.

3 Water Quality model setup

With the previously developed hydrodynamic model, the MIKE ECO-Lab add on module was applied to assess the key water quality parameters of interest. The model was run for a one-year period from 1st January 2020 to 31st December 2020 to coincide with the measured data with a suitable spin up period. For this study it was agreed following the scoping stages that the parameters of interest for transitional nutrient sensitive waters were were:

- DIN
- MRP
- E. Coli
- BOD

It is noted that E. Coli only has relevance with respect to bathing waters, however, it was included in this assessment to ensure that the understanding of the potential impact of this change to an indicator of concern was incorporated.

The applied water quality model is a merger of two of DHI's standard MIKE ECO Lab templates:

- DHI Eutrophication Model 1 - ECO Lab Template (mikepoweredbydhi.help)
- DHI E. Coli and Enterococci Model - ECO Lab Template (mikepoweredbydhi.help)

Modifications to these and the setup of the boundary conditions are detailed in the following sections.

3.1 Template modifications

For application in this study, a series of alterations were made to the standard MIKE ECO-Lab templates.

- Benthic vegetation (BC) was removed in the EU1 template as it was not deemed relevant for the purpose of this study.
- E. Coli as a state variable (and associated decay processes) was instead added to the EU1 template.
- A derived output for BOD was created, by calculating Total Organic Carbon (Detritus Carbon DC+ phytoplankton carbon PC+ zooplankton carbon ZC) and multiplying with a BOD: TOC ratio due to the correlation between these two parameters. The ratio used for simulations was set to 1.8.

3.2 Key model settings

The model was developed to be representative of an entire year, with the use of relevant parameters to resolve the processes of interest.

- Horizontal dispersion, using a scaled eddy viscosity formulation, was applied for all parameters. A constant value of 0.1 was applied.[1]
- Vertical dispersion, using a scaled eddy viscosity formulation, was applied for all parameters. A constant value of 0.01 was applied.
- Low order scheme in both time and space was chosen due to its temporal advantages.

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[1] Default dispersion coefficients of 1.0 resulted in mass balance errors. A low dispersion coefficient can be seen as conservative in a study such as this.

3.3 Boundary conditions

Model data used as the initial conditions was based on the winter values from the available EPA TSAS monitoring. Due to the rapid flushing in the system, these values were seen to rapidly stabilise within 2-3 days (subject to location) to the boundary forcing conditions.

3.3.1 River Liffey

Values for DIN, MRP, DO and E. Coli were set to values based on the measurement campaign from the New Bridges assessment [5]. The River Liffey input was based on the measurements at Station 40090. As these were typically spot measurements, it was necessary to develop seasonal averages for these values temporally to provide continuous input to the model for the year. It should also be noted that:

- BOD in the model is predominately made up by DC (Detritus Carbon) which was estimated as average measured BOD/1.8
- Values of DN (Detritus Nitrogen) and DP (Detritus Phosphorous) were set to 0.3 and 0.02
- Default values of PC (phytoplankton carbon), PN (phytoplankton nitrogen), CH (chlorophyll-a), and ZC (zooplankton) were used.

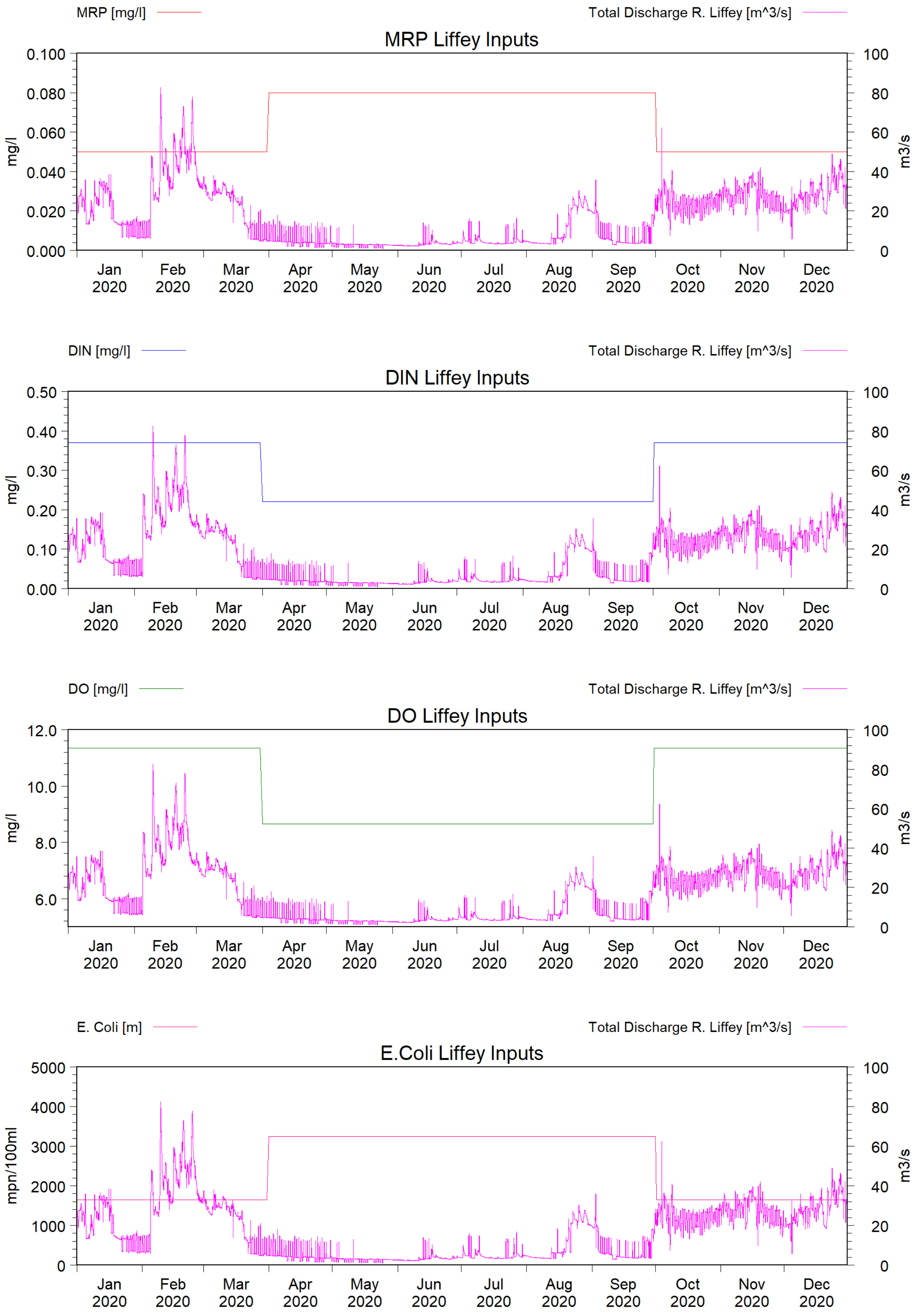

Figure 3.1 Boundary conditions for the River Liffey applied in the water quality model.

3.3.2 River Dodder

Based on the work from the scoping and data collection stages, the values of DIN, MRP, E. Coli and DO were set to be equal to the seasonally averaged values reported for station 40095 at the downstream end of the Dodder.

BOD in the model is predominately made up by DC (Detritus Carbon) which was estimated as average measured BOD/1.8

- Values of DN and DP were set to 0.3 and 0.02
- Default values of PC, PN, PC, CH, and ZC were applied.

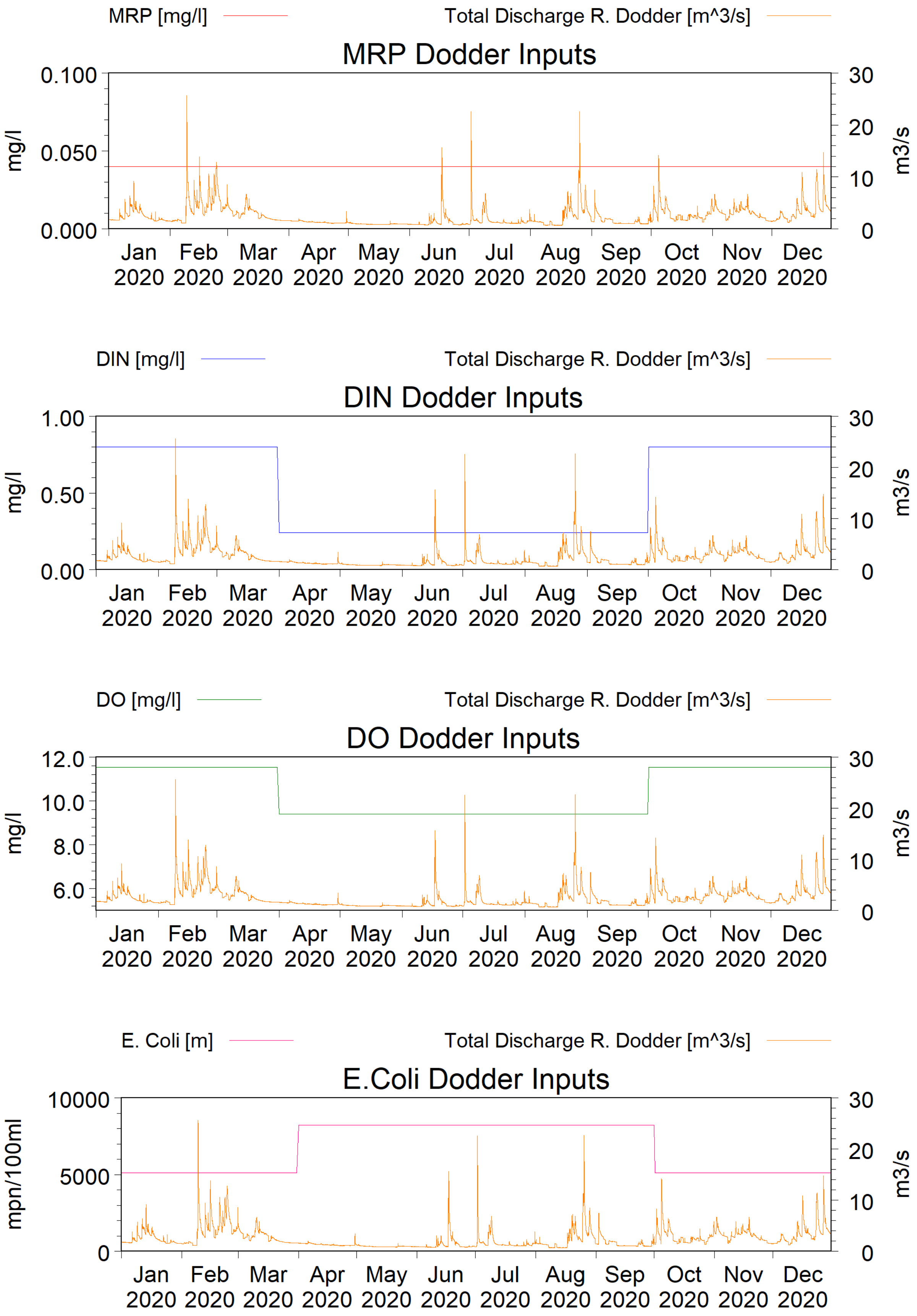

Figure 3.2 Boundary conditions for the River Dodder applied in the water quality model.

3.3.3 Open sea

- Default model values of DC, DN, DP, PC, PN, PC, CH, ZC and DO were applied.
- Values of MRP, DIN, DO and E. Coli as per Figure 3.3 based on the EPA monitoring

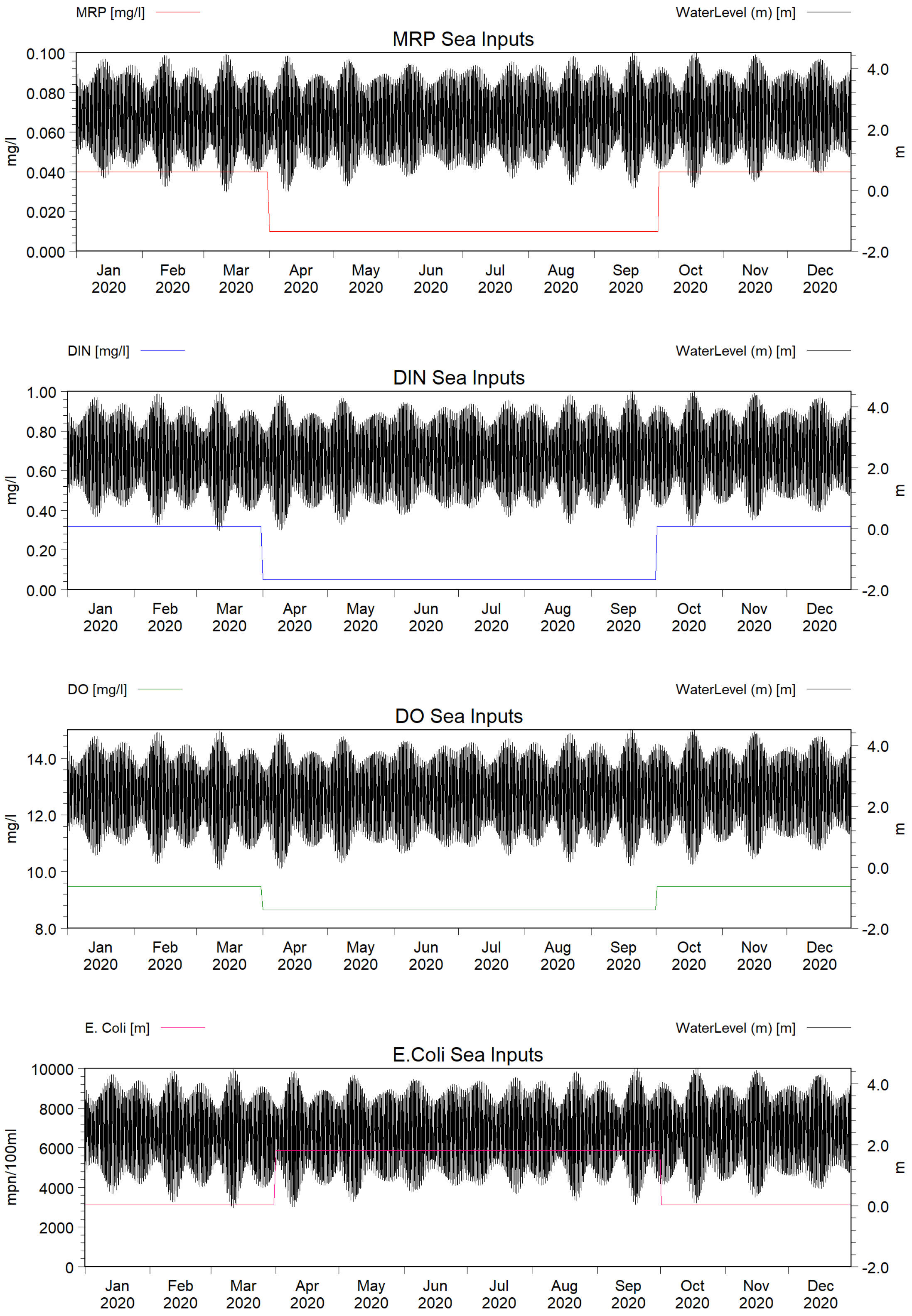

Figure 3.3 Boundary conditions for the Open Sea boundary applied in the water quality model.

3.3.4 Other boundary conditions

The Ecolab model requires a range of additional boundary conditions which are summarised in Figure 3.4. Due to the lack of available local data, some of these forcings, such as continuous river temperature, have been obtained from UK rivers at similar latitudes and are judged to be representative for this particular case.

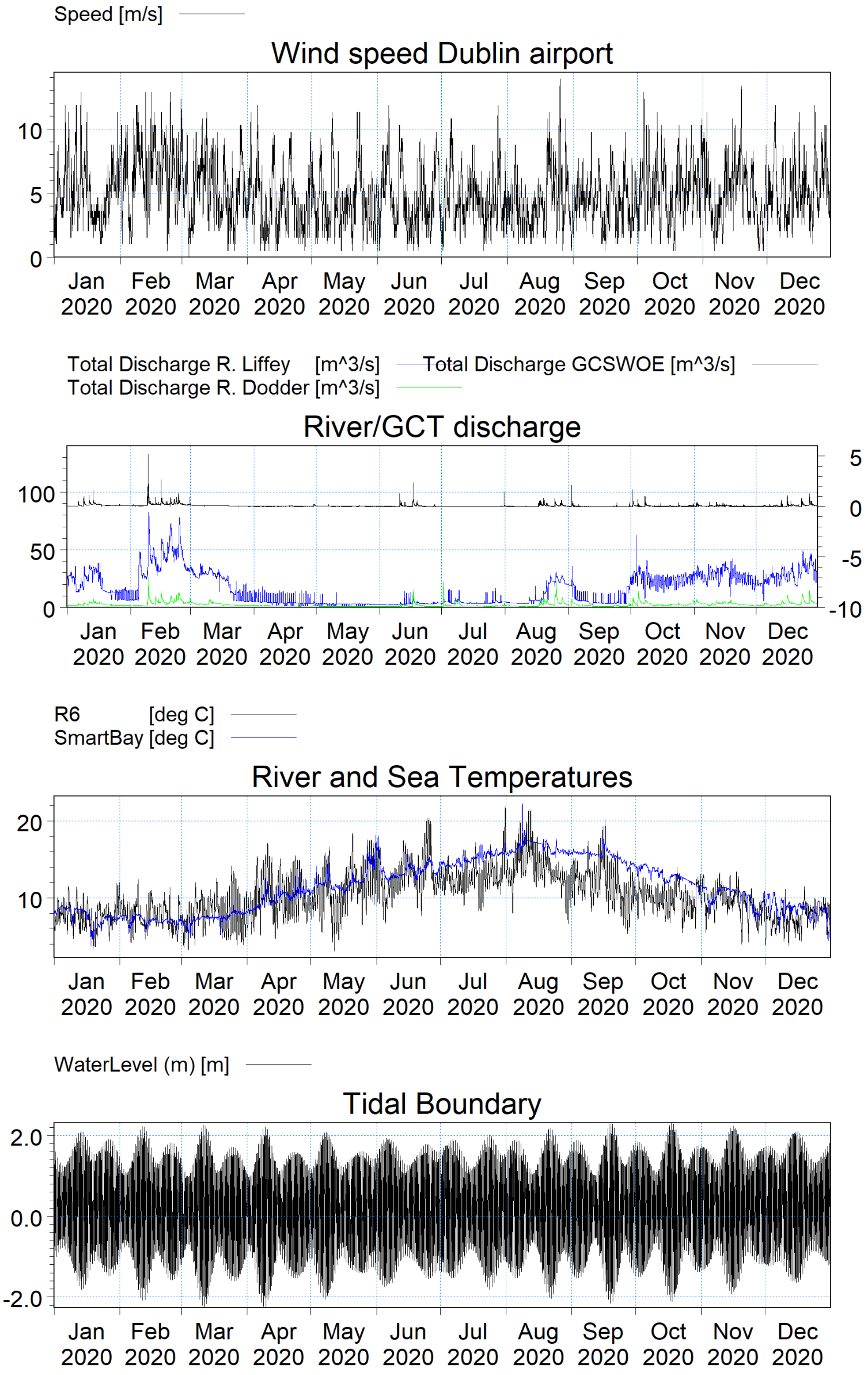

Figure 3.4 Summary of the annual data applied for additional boundary forcing’s in the model

3.4 Model stability/calibration

All simulated state variables have been confirmed to not produce any mass balance errors which are larger than 1% of the total mass at any point in time, with the specified setup specifications.

Model validation has shown that qualitatively the results match up well within the measured range of data. No specific calibration of the water quality model variables has been undertaken due to the limited data sets that are independent from those used as boundary inputs. Priority in this simple model has been given to the boundary data

3.5 Source load scenarios from the GCSWOE

3.5.1 Baseline

In this scenario it is assumed that the concentration of all the sources is as per the ambient or baseline conditions as described in Section 3.3. As such the excess concentration is equal to zero. As such, the assumption for this part of the modelling is that the GCSWOE still discharges water into the Estuary and thus adds mass to the system, but with no effect on ambient concentration levels.

3.5.2 Time Varying Load

This scenario applies the seasonal average source concentrations of DIN, MRP and E. Coli as reported for C_{GCSWOE} at the Estate Cottages location and are shown in Figure 3.5 below. In addition, other variables within the template (PC, PN, PP, CH, ZC) are assumed as 0.

Due to the nature of the measured data for E. Coli in the GCSWOE tunnel, no clear relationship between flow and E. Coli is possible. As such the proposed approach is to apply the average measured concentration (5,862 MPN/100ml) when flows in the tunnel are below 0.1m3/s. For flows above this value, only 3 measurements are available (see Figure 3.6). As the highest of these is equivalent to the highest value measured in the tunnel, it is proposed that these are used for a linear fit to the remaining two data points. This provides the relationship for E. Coli concentration for flows above $0.1m^3/s$. As the average concentration of E. Coli value intersects this line at 0.13m3/s, this is the cut off between the average value being applied and the storm led value based on the relationship with flow.

The application of this fit results in the E. Coli v’s flow relationship for the measured flows in the GCSWOE presented in Figure 3.7. This equates to 90% of the one-year model run the concentration is at the average for E. Coli, 9% of the time it is in the range 10-50,000 MPN/100ml, , 0.8% of the time it is between 50-100,000 and 0.1% of the time it is in excess of 100,000 MPN/100ml.

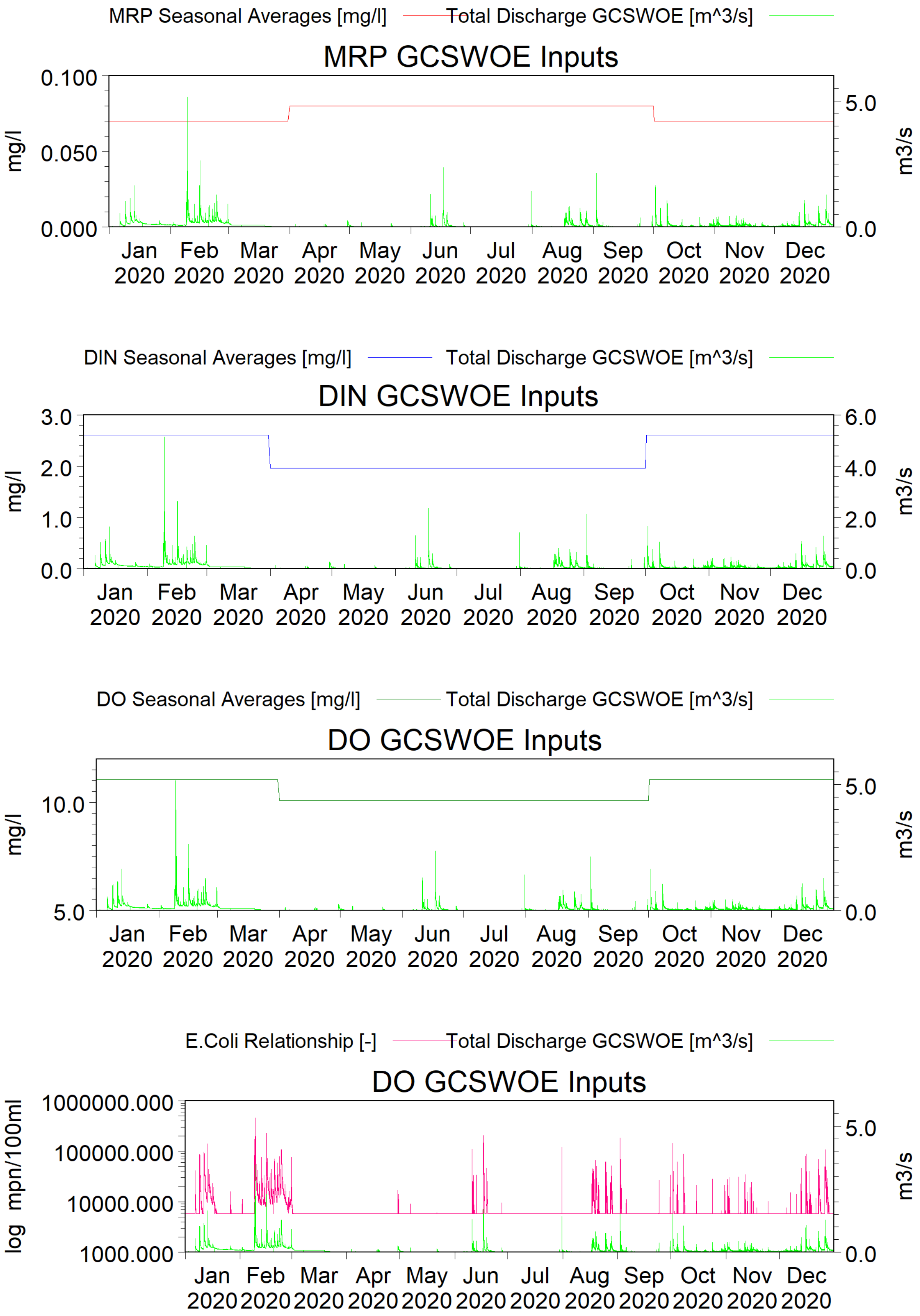

Figure 3.5 Boundary conditions for the C_{GCSWOE} applied in the water quality model.

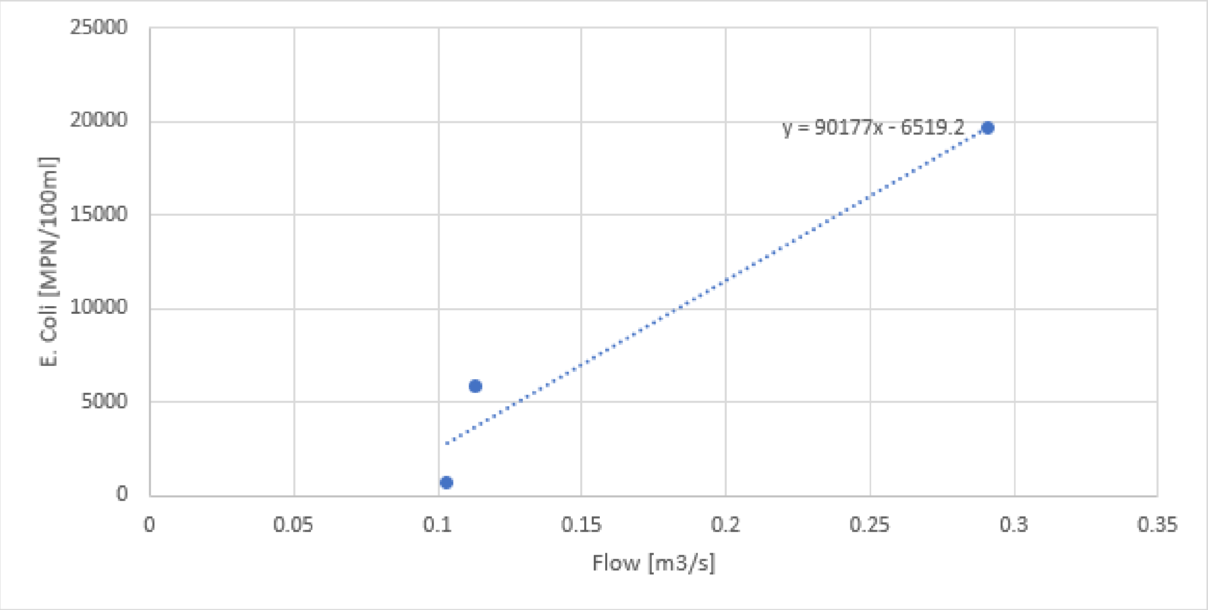

Figure 3.6 Fit of the E. Coli measured data in the GCSWOE tunnel with the resultant flow for flows in excess of 0.1m^3/s

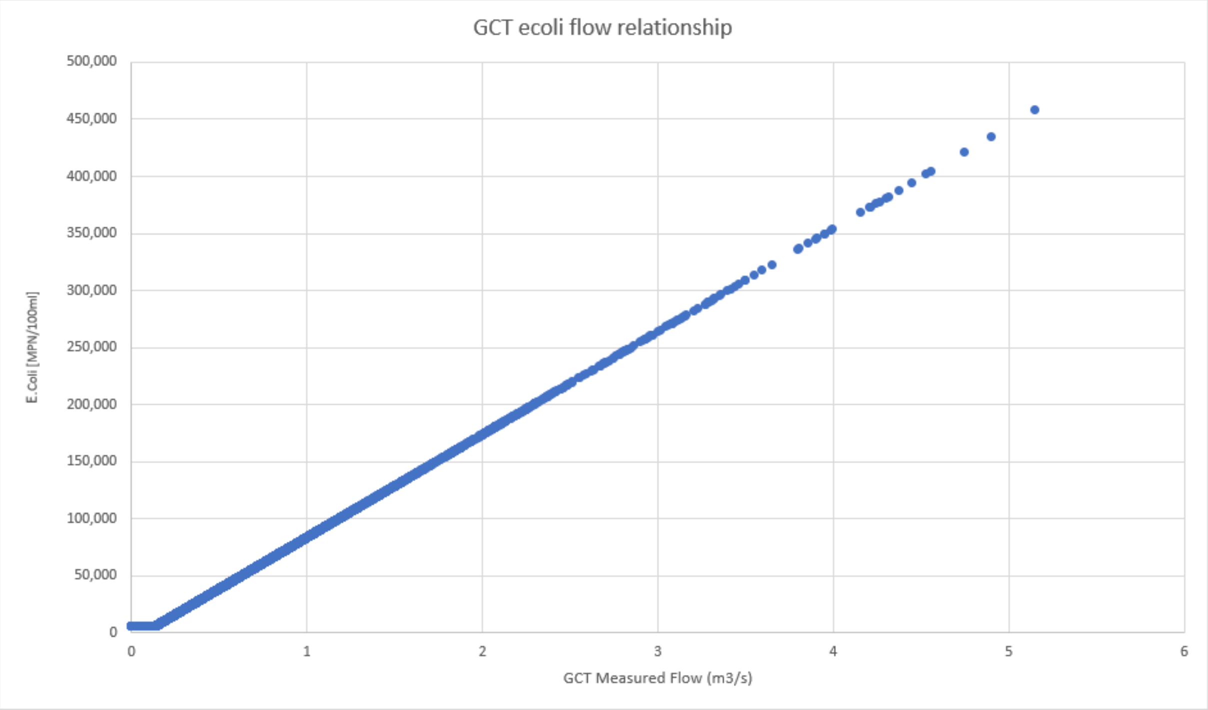

Figure 3.7 E. Coli v's flow relationship in the GCSWOE tunnel for flows in excess of 0.1m^3/s based on the fit from Figure 3.6

3.5.3 Storm Based E. Coli Scenario

As there remained some uncertainty on the exact concentrations of E. Coli values coming from the GCSWOE, due to the potential for mixing between the CSO and the stormwater compartment in the tunnel, an additional storm-based assessment was proposed that considered the potential for more extreme concentrations, at levels similar to default sewage concentrations under storm conditions.

Similar to the 'time varying' scenario for E. Coli the discharge volume is based on the measured data from the period, however the concentration of E. Coli is set to be 5,000,000 MPN/100ml (a value considered representative of a storm water outfall discharge) constantly for 3 hours over the 10 highest discharges in the period of measurement, to provide a storm led conservative assessment of the potential of a sewage discharge under storm conditions. This equates to 30 hours of discharge or 0.4% of the entire year.

The value of spills has been selected based on an assessment of the single year of measurement data, where the number of significant outflows (>1m3/s) from the GCSWOE have been identified throughout the year, totaling 13. In addition, reference is made to the Urban Pollution Manual [6] where values of between 3 and 10 spills per year for designated bathing waters and designated shellfish waters respectively. As part of this worst case assessment the upper value from the UPM of 10 has been used.

At all other times (99.6%), the discharge is at the background level of E. Coli in the system of 5,862 MPN/100ml.

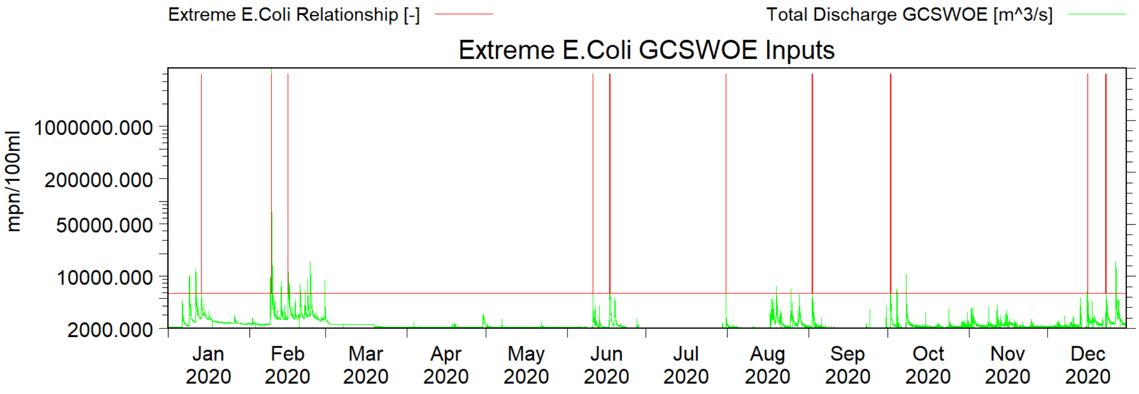

Figure 3.8 Boundary conditions for the C_{GCSWOE} applied in the water quality model for extreme storm discharge.

3.6 Outputs

The following outputs are available from the MIKE ECO Lab model:

- 3D volume file containing all state variables and derived outputs
- Mass balance file for all state variables
- Time series of surface layer values at the location of New Bridges measurement stations.
- Vertical transect along the main transitional waters of the domain.

3.7 Post-Processing

For each of the three scenarios, the median or 95%ile temporal value is calculated from the entire year of data, subject to the parameter of interest. From this the vertical maximum or the average through the water column is calculated for the entire 3D domain and exported as a 2D layer for further analysis. Relative to an averaged value, or a single surface value the maximum value through the water column can be considered a conservative assessment. The average value is considered most comparable to the EQS based measurements.

For the baseline, a summary plot is produced showing the result of the existing situation compared against the EQS for that parameter.

For time varying and storm-based E.Coli scenarios which are run with the GCSWOE in operation, then a plot is produced showing:

- The difference between the scenario and the baseline averaged through the water column for the EQS threshold
- The % difference between the scenario and the baseline averaged through the water column
- The % difference between the scenario and the baseline for the maximum value through the water column

The first plot provides a clear assessment of whether the EQS is exceeded, using the same method as applied by the EPA. The second plot shows the % difference (always positive as the concentrations increase) in the same method. The third plot again shows % difference, however for the maximum value through the water column, which is a more stringent application of the analysis methodology.

For each of the parameters of interest the following values, based on the EPA salinity interpolated EQS's for TSAS nutrients, are used as an assessment of the potential impact on water quality:

- DIN
    - Winter (Exceedance criteria <0.506 mg/l at median)
    - Summer (Exceedance criteria <0.442 mg/l at median)
- MRP
    - Winter (Exceedance criteria <0.044 mg/l at median)
    - Summer (Exceedance criteria <0.043 mg/l at median)
- E. Coli (Exceedance criteria < 500 MPN/100ml at 95% percentile for Good quality)
- BOD (Exceedance criteria < 4.0 mg/l at 95% percentile)

It is noted that for E. Coli, the receiving waters of the Liffey are not designated bathing waters and as such there are no applicable bacteriological standards, however in-lieu of any specific standards the bathing water standard has been used as an indicator of the potential risk to designated and non-designated bathing areas.

4 Results

The results of the water quality models are summarised in the following sections for the Baseline Scenario, the Time varying scenario and for the Storm E. Coli scenario. The outputs displayed show the existing situation with respect to the EQS thresholds for the baseline, and then for the two scenarios with the GCSWOE outfall, the outputs show the difference to the baseline.

4.1 Baseline

From assessment of the results there is variability seen through the year that leads to the final calculated results. As the model is a 3D model, the values can vary through water depth and the key feature controlling circulation in this part of the Liffey is the presence of the salt wedge. In many situations, the surface values are higher than the bottom values due to this circulation. To compare to EQS values, a vertically averaged value is used. The Baseline scenario seeks to determine, based on the available data, a representation of the present situation.

4.1.1 DIN

For DIN, it is apparent that the Dodder provides a significant input of lower quality water, which travels downstream past the Tom Clarke Bridge. In addition, the River Liffey concentrations are also poorer, however, the apparent mixing of water with the tidal component from the sea reduces the impact of this. For the summer values, a similar pattern is seen however the effect of the Dodder is less noticeable. The model shows that the values are always below the exceedance threshold in the existing situation. DIN values in the measurements [2] in the area between the two bridges show similar ranges to the model results, with values from 0.3-0.4 mg/l seen in the winter to 0.05-0.1 mg/l seen in summer.

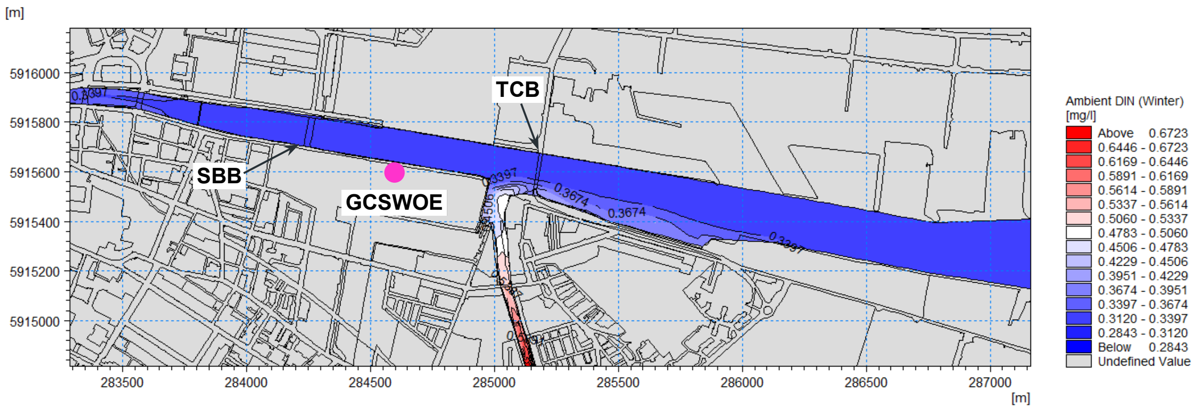

Figure 4.1 Baseline - Winter temporal median DIN values, vertically averaged.

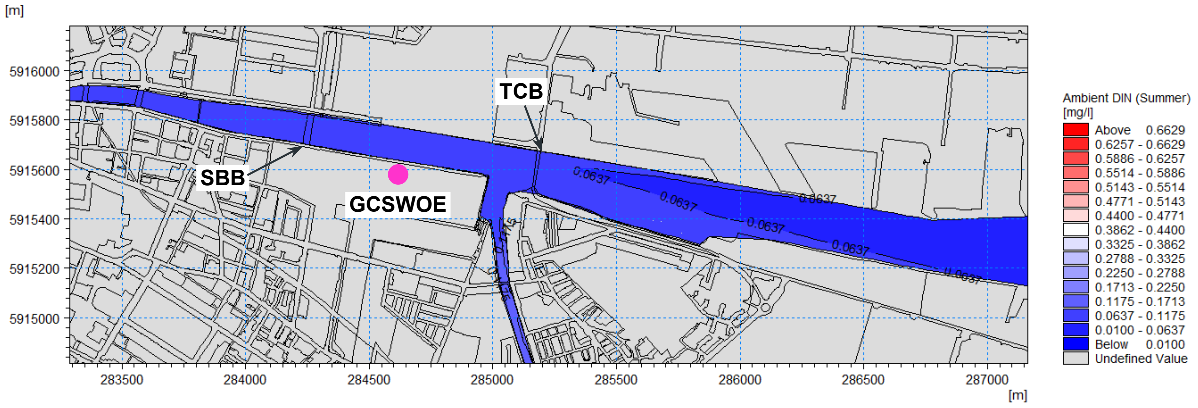

Figure 4.2 Baseline - Summer temporal median DIN values, vertically averaged.

4.1.2 MRP

For MRP, the Liffey is the main contributor, along with the background values from the sea. Compared to the EQS, it is seen that in both the existing winter and summer conditions, MRP is below the EQS threshold. It is noted that in winter the main water body shows a relatively time invariant median value, with figures being 0.04 through much of the water column. Again, compared to the measurements [2], the range of MRP from 0.040-0.042 in winter and around 0.01 in summer seen in the model is considered representative of the existing situation. Again, surface plumes coming from the Liffey and the Dodder are noted.

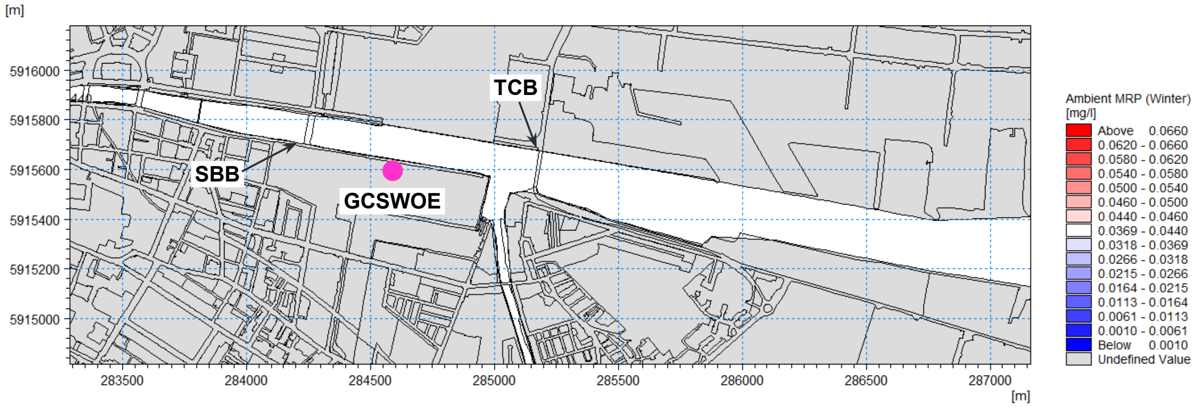

Figure 4.3 Baseline - Winter temporal median MRP values, vertically averaged.

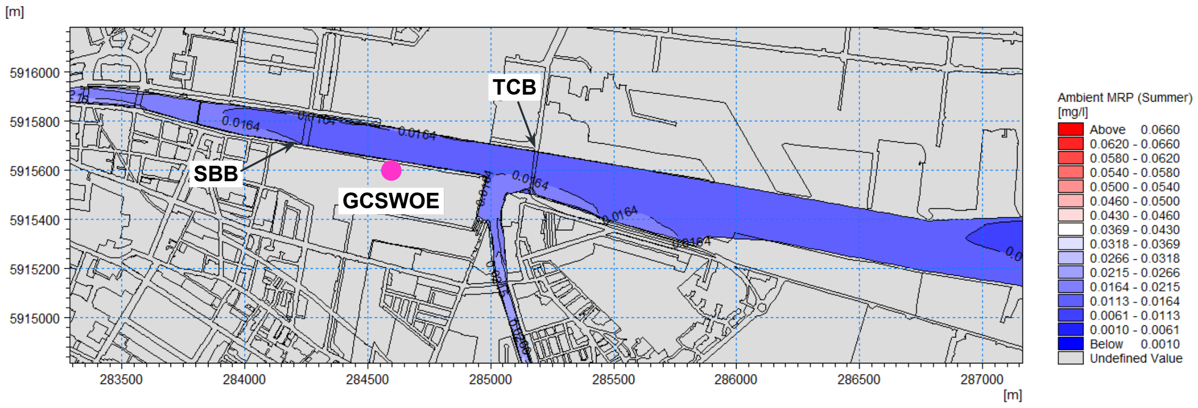

Figure 4.4 Baseline - Summer temporal median MRP values, vertically averaged.

4.1.3 E. Coli

For E. Coli, a similar pattern to DIN is seen, with some of the highest values seen to be coming from the Dodder, however also the background values from the sea being high leads to an increased level in the immediate receiving waters. The effect of the Liffey is to dilute the levels of E.Coli seen from the Dodder and the sea. Compared to the measurements in the Survey Interpretative report [2], the values seen in the results of the 95%ile outputs are considered comparable to the loads seen in the measurements with 3-4,000 MPN/100ml in the area upstream of the GCSWOE and in excess of 5,000 MPN/100ml downstream.

It has been noted that this section of the river is not designated as bathing water, however, for non-designated bathing waters, a status of *Good* has been considered when E. Coli concentrations fall within 501-1000 MPN/100ml based on the 95%ile values. Lower values are seen for single sample status assessment criteria, however due to the time varying nature of the model the 95%ile values have been selected. This level has been used in the following assessments as an indicator of the likely bacteriological loading.

As seen in the Survey Interpretative report, the actual concentrations of E. Coli in the receiving water body are already above this threshold. Model results show that in the vicinity of the GCSWOE, the ambient 95%ile values are 4 times in excess of the Sufficient status. It should be noted that the nearest designated bathing water is outside of the entrance to the harbour and therefore outside the model domain. Of note is that the Dodder is seen to be a significant source of E.coli in the local area, with values in excess of 5,000 MPN/100 ml at the 95%ile value. It is also noted that the seaward boundary provides similar orders of magnitude and the freshwater flow from the Liffey acts to reduce the concentrations.

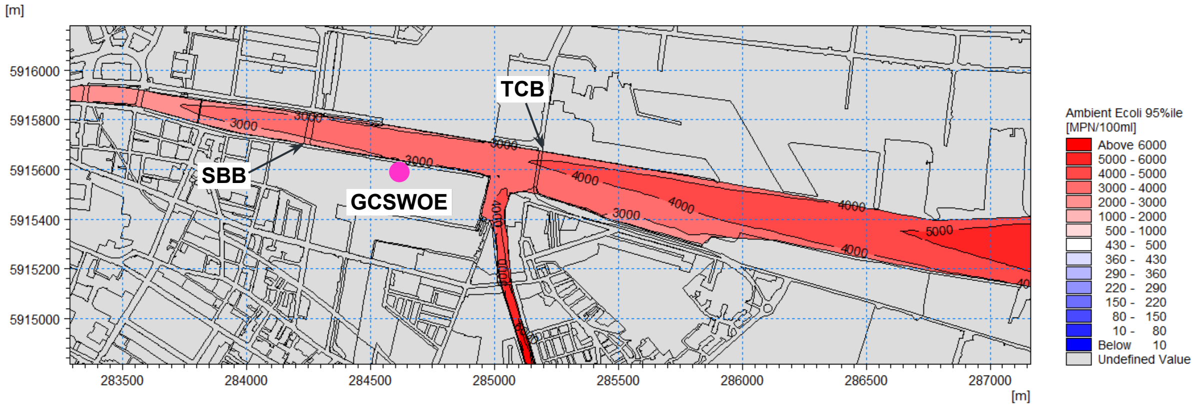

Figure 4.5 Baseline – All year 95%ile E. Coli values, vertically averaged.

4.1.4 BOD

For BOD, again, the values are seen to be high coming from the Dodder, however, the median values remain relatively constant, suggesting that BOD maxima are relatively infrequent in the model period. Importantly for the EQS, it is seen to be below the threshold 100% of the time, suggesting no exceedance for this parameter in the existing situation.

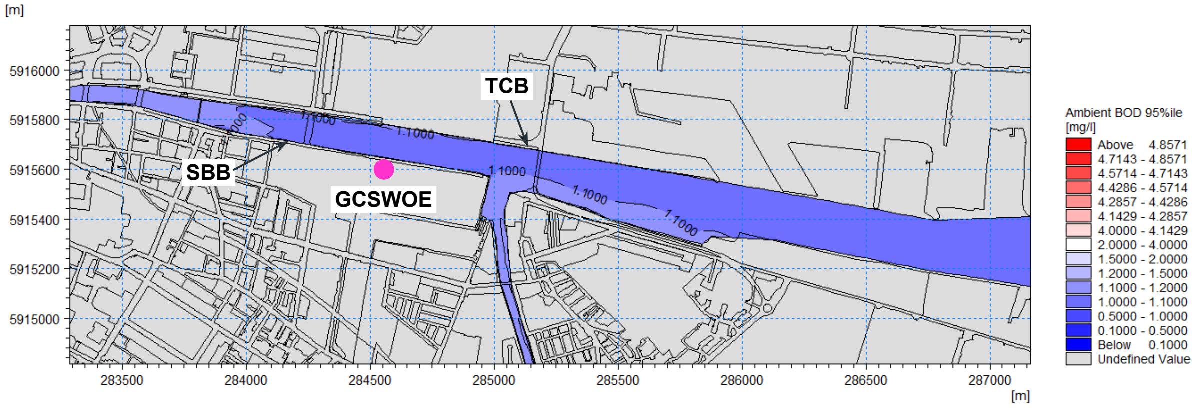

Figure 4.6 Baseline – All year 95%ile BOD values, vertically averaged.

4.2 Time Varying Scenario differences

Following the baseline runs, the two principal scenarios have been developed. The following sections provide a summary of the differences between the baseline and the tested scenarios. This is to highlight how much the presence of the GCSWOE influences the water quality environment.

From the general circulation and control of waters in this part of the Liffey estuary, it is seen that pollutants leave the proposed outfall as a freshwater plume in predominantly saline bottom waters and are seen to rise toward the surface. Here it mixes with the outflowing river water and is transported seaward, with the principal barrier being the rise and fall of the tide constraining and then assisting the flushing of this part of the estuary. A snapshot of the results of this process is shown in Figure 4.7 specifically for E.Coli.

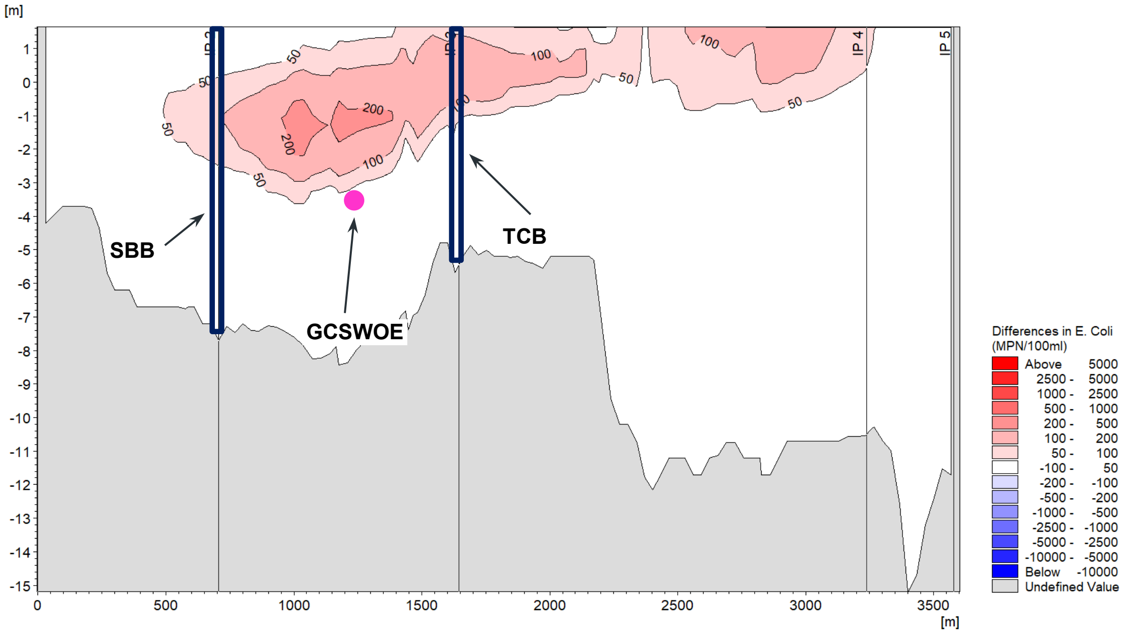

Figure 4.7 Long section through the model from upstream of the Samuel Beckett Bridge to the seaward end of the model domain. Result shows difference between 95%ile values between the baseline and the time varying scenario.

4.2.1 DIN

The results for winter DIN show that there is no exceedance of the EQS threshold for the modelled period in either winter or summer. Considering the percentage difference plots it is possible to see the time varying extent of the plume from the GCSWOE outfall, however the values only suggest maximum increases of ~5% in the immediate vicinity of the outfall for the winter conditions. In summer, it is seen that the extent of the increase is broader and with a higher peak difference to the baseline, with flow spreading both up and downstream. For the maximum values the plume extends further downstream along the south bank of the Liffey underneath the Tom Clarke bridge. This is associated with the maximum often being contained in the surface plume, which tends to move downstream.

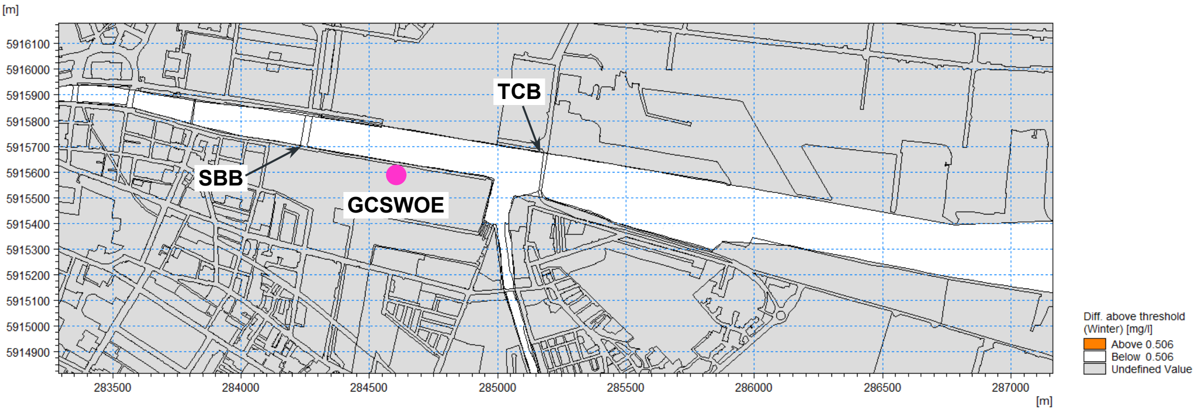

Figure 4.8 Difference in Winter DIN (median) against EQS threshold, vertically averaged.

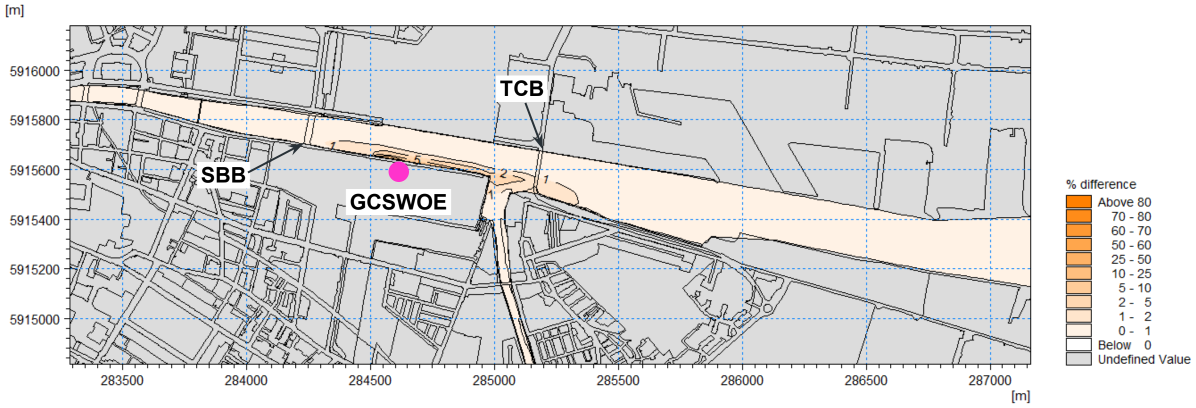

Figure 4.9 Percentage Difference in Winter DIN (median), vertically averaged.

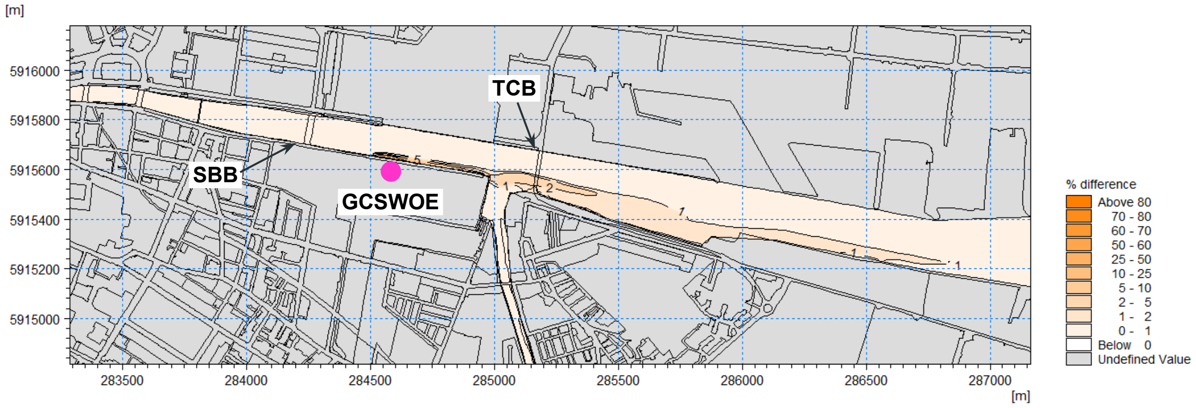

Figure 4.10 Percentage Difference in Winter DIN (median), maximum through the water column.

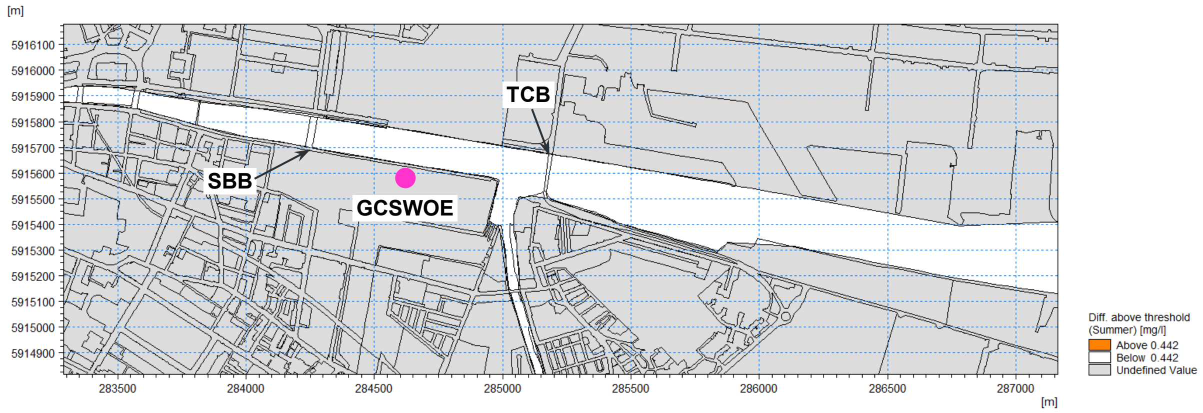

Figure 4.11 Difference in Summer DIN (median) against EQS threshold, vertically averaged.

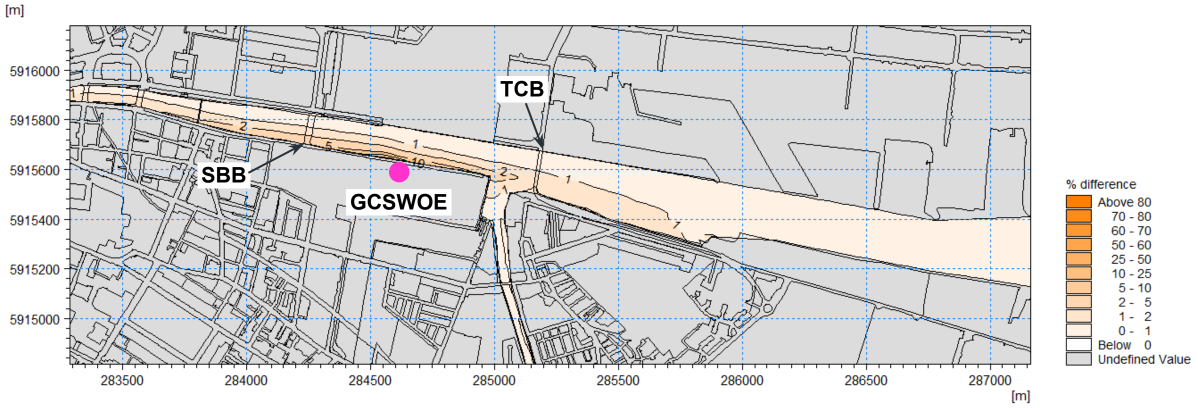

Figure 4.12 Percentage difference in Summer DIN (median), vertically averaged.

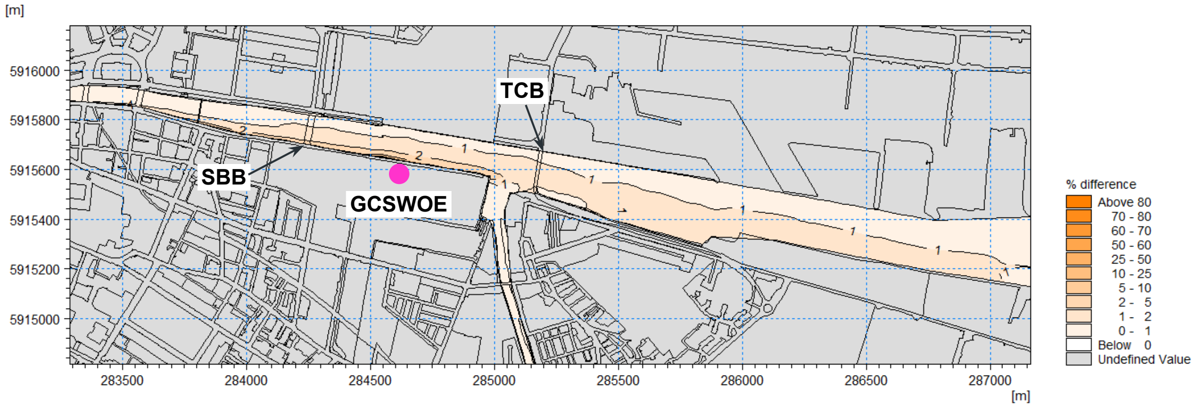

Figure 4.13 Percentage difference in Summer DIN (median), maximum through the water column.

4.2.2 MRP

For MRP, again there is no exceedance of the EQS in either the Summer or Winter scenarios. In winter there is a minor difference in the general water body of less than 1%, at the immediate location of the outfall the difference is just above 1%. In summer a similar pattern is seen in the wider water body, but the peak difference is 2% associated with the GCSWOE and again localised to the region of the outfall.

For the maximum values, there is an imperceptible difference for MRP, suggesting no additional impact from MRP in the scenario tested.

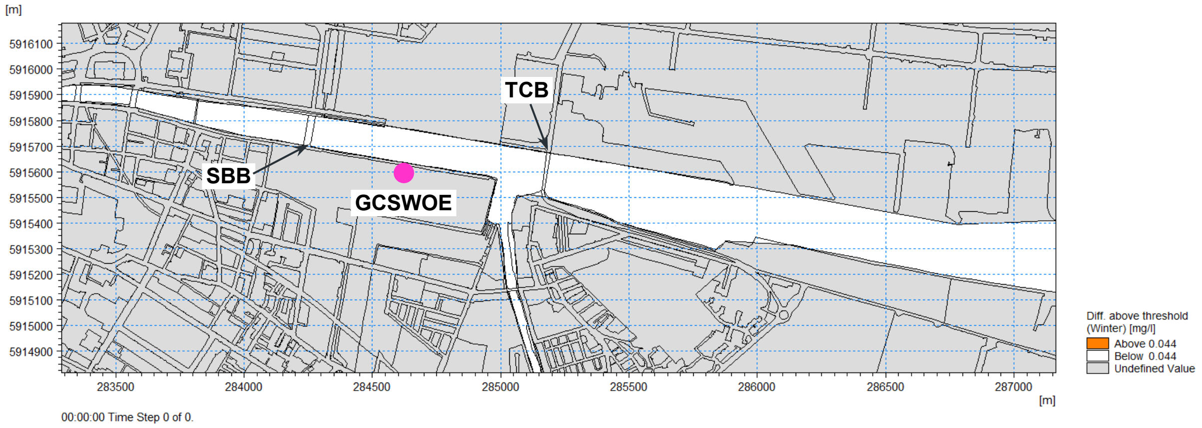

Figure 4.14 Difference in Winter MRP (median) against EQS threshold, vertically averaged.

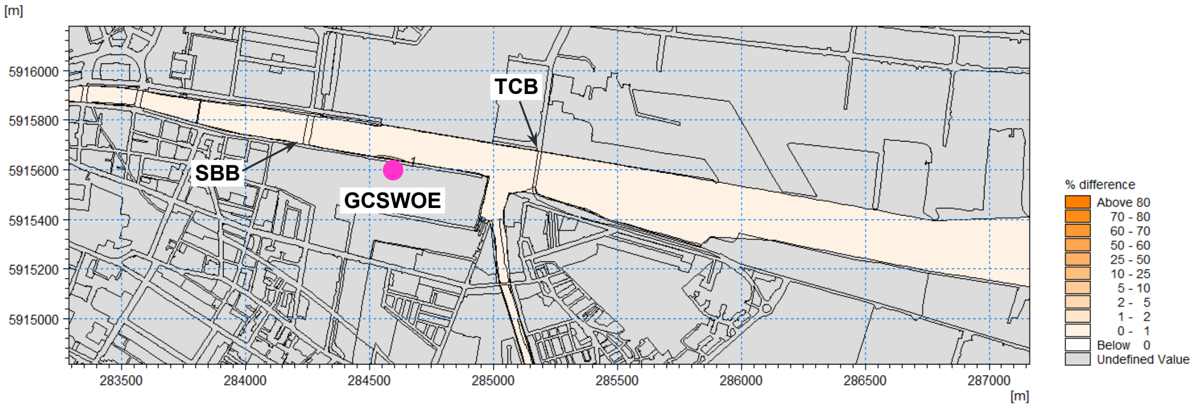

Figure 4.15 Percentage Difference in Winter MRP (median), vertically averaged.

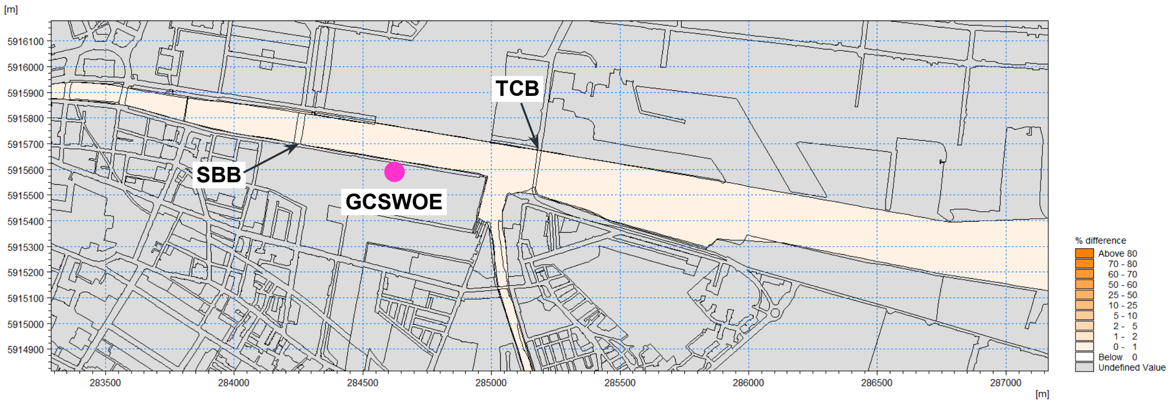

Figure 4.16 Percentage Difference in Winter MRP (median), maximum through the water column.

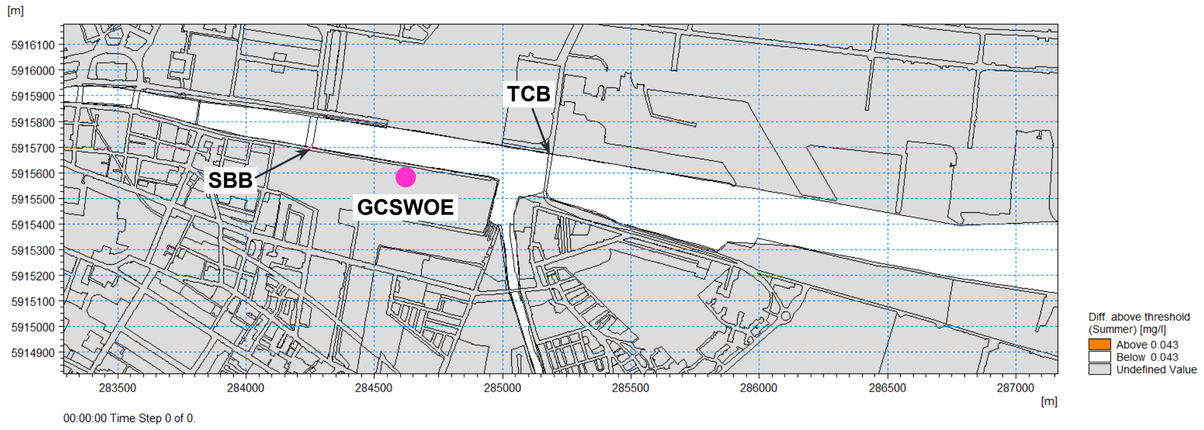

Figure 4.17 Difference in Summer MRP (median) against EQS threshold, vertically averaged.

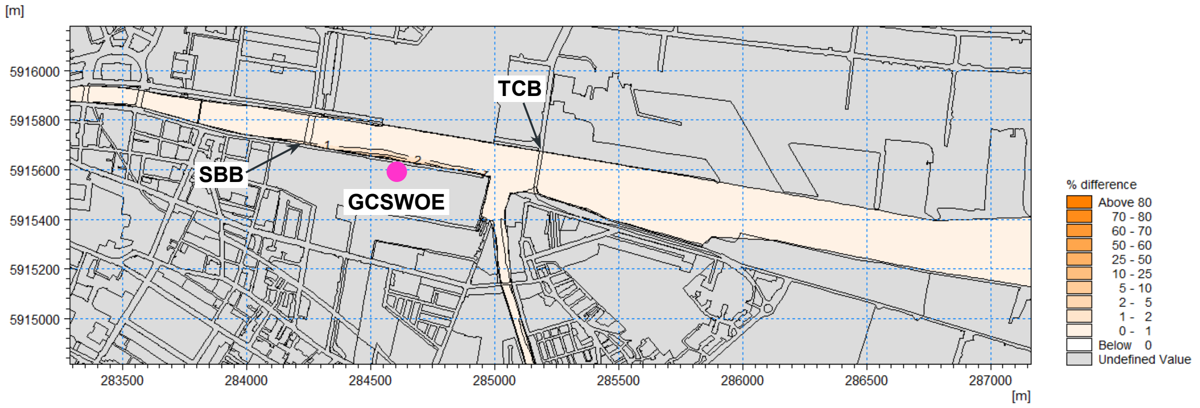

Figure 4.18 Percentage difference in Summer MRP (median), vertically averaged.

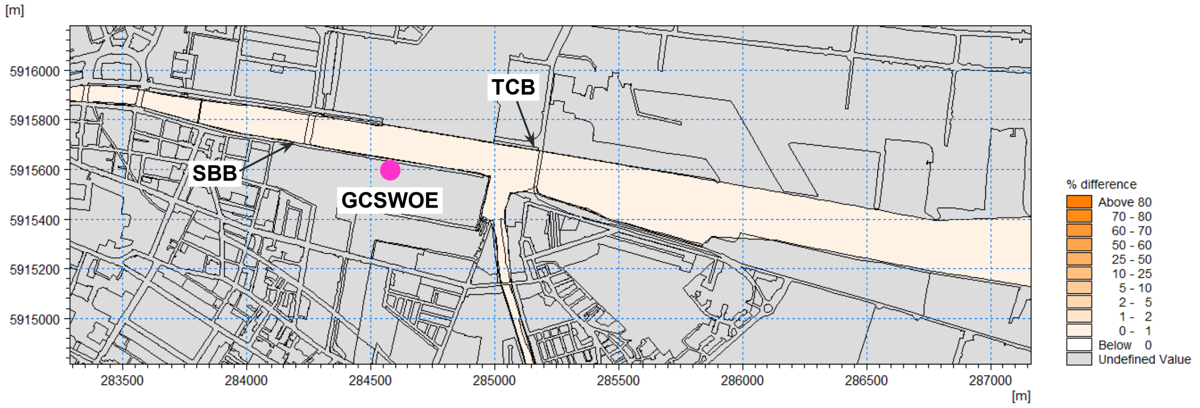

Figure 4.19 Percentage difference in Summer MRP (median), maximum through the water column.

4.2.3 E. Coli

For E. Coli, as previously noted, the model results show exceedance of the nominal 95%ile EQS in all locations. When considering the patterns and magnitude of the change, for the vertically averaged results, the greatest change is up to 10% increase in the immediate vicinity of the outfall, however this falls rapidly to only 0.02% increase at the seaward boundary of the model.

For the maximums, the differences are smaller, and the patterns show that in addition to the localised increased at the GCSWOE, there is an area of 1-2% increase seen between the Tom Clarke bridge and the marina.

At the very downstream end of the model, indicative of the outflow towards the sea, the difference reduces to a maximum of 0.01% difference between the baseline and the time varying scenario.

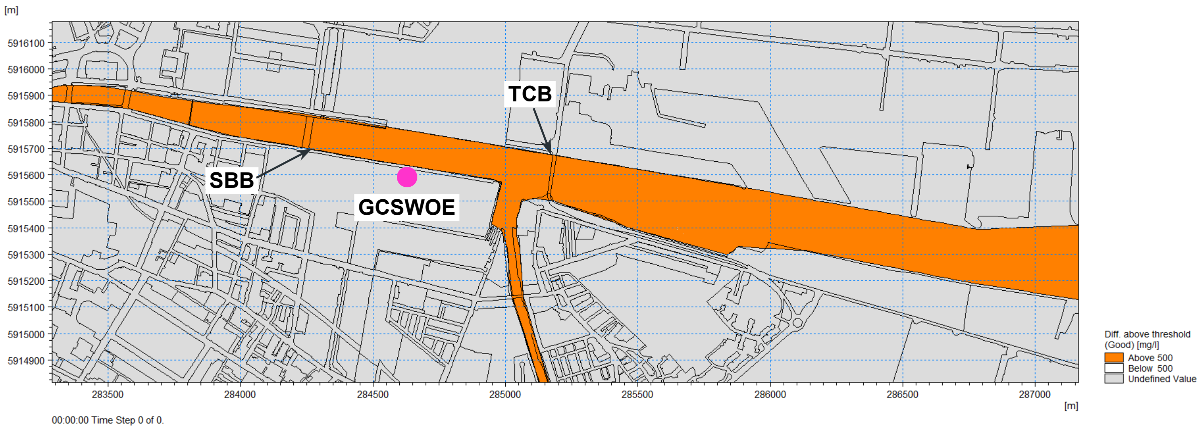

Figure 4.20 Difference in all year 95%ile of E. Coli against EQS threshold, vertically averaged.

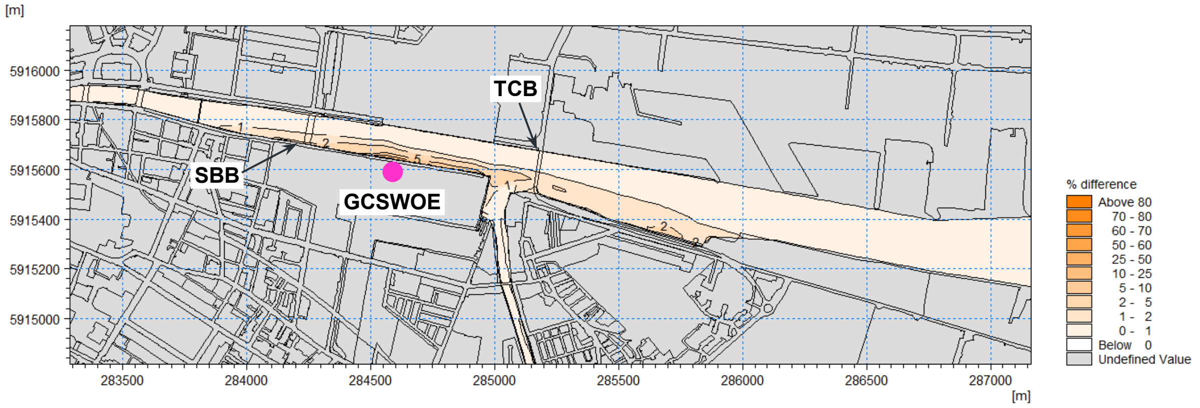

Figure 4.21 Percent difference in all year 95%ile of E. Coli, vertically averaged.

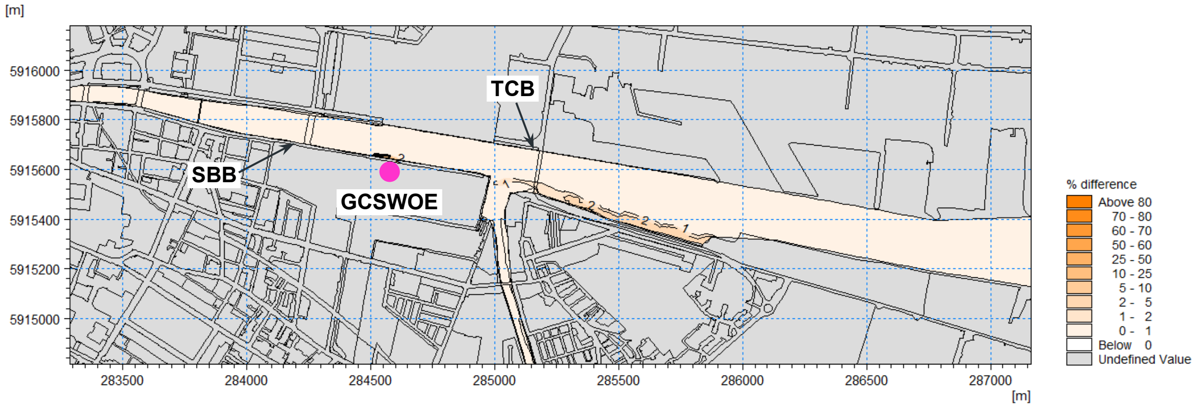

Figure 4.22 Percentage difference in all year 95%ile of E. Coli, maximum through the water column.

4.2.4 BOD

BOD is seen to be below the 95%ile EQS at all locations, suggesting no specific exceedance. It is noted that BOD shows the largest percentage differences from the modelling runs, suggesting a more extensive impact than other parameters including DIN, MRP and E. Coli.

Again, the main increase in impact is noted to be localised to the immediate area of the outfall, however the region of change in excess of 2% is seen to be greater than any of the other parameters, with localised increases around the outfall of 70% for the vertically averaged conditions and up to 90% for the maximum through the water column. Consequently, for BOD a large change is seen as the values in the receiving waters were low. Importantly, the absolute values of this change peak at 1.6 mg/l. With the ambient conditions of 1.1 mg/l this remains well below the EQS, suggesting a low risk.

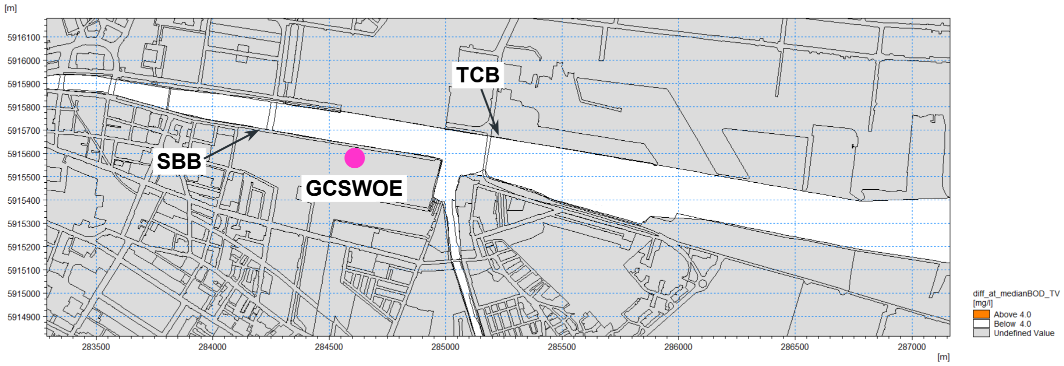

Figure 4.23 Difference in all year 95%ile of BOD against EQS threshold, vertically averaged.

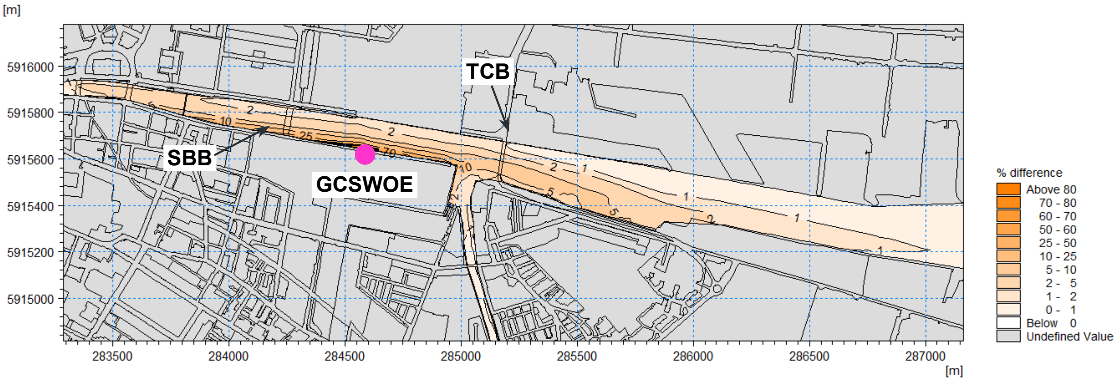

Figure 4.24 Percent difference in all year 95%ile of BOD, vertically averaged.

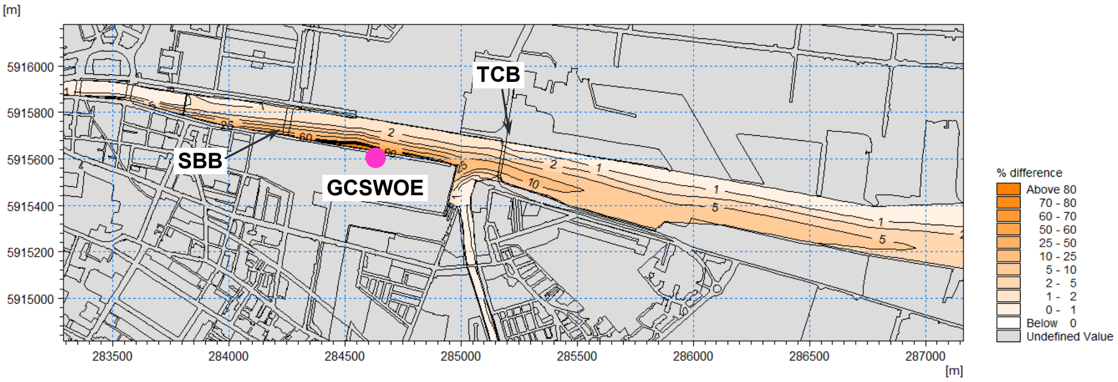

Figure 4.25 Percentage difference in all year 95%ile of BOD, maximum through the water column.

4.3 Storm Based E. Coli Scenario differences

The extreme situation of storm-based outflow was tested for the entire year to assess the response of the system to intermittent storm conditions. The results show that in the same manner as seen in the time varying E.Coli run, the 95%ile values are always in excess of the 500 MPN/100ml with values in the range 2,500-5000 MPN/100ml, similar to that seen in the baseline.

The difference plots show that generally there is a worsening of conditions of about 2% over much of the Lower Liffey, with a near outfall peak to 5% difference. The extent of the impact is greater than in the time varying result, due to the extreme concentration of the outflow, with higher concentrations focused along the southern bank. This is seen to be also more extensive upstream of the Samuel Beckett bridge than in the time varying run. Downstream, the 1% difference contour is slightly further downstream than the time varying run, though is again seen to be finishing close to the southern bank.

At the very downstream end of the model, indicative of the outflow towards the sea, the difference reduces to less than 1% between the baseline and the storm-based scenario.

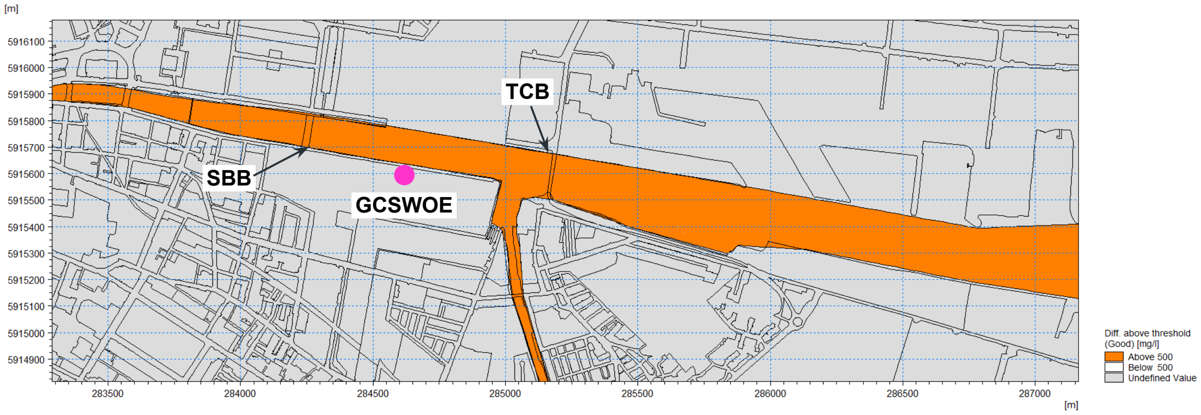

Figure 4.26 Difference in all year 95%ile of E. Coli against EQS threshold (Storm conditions), vertically averaged.

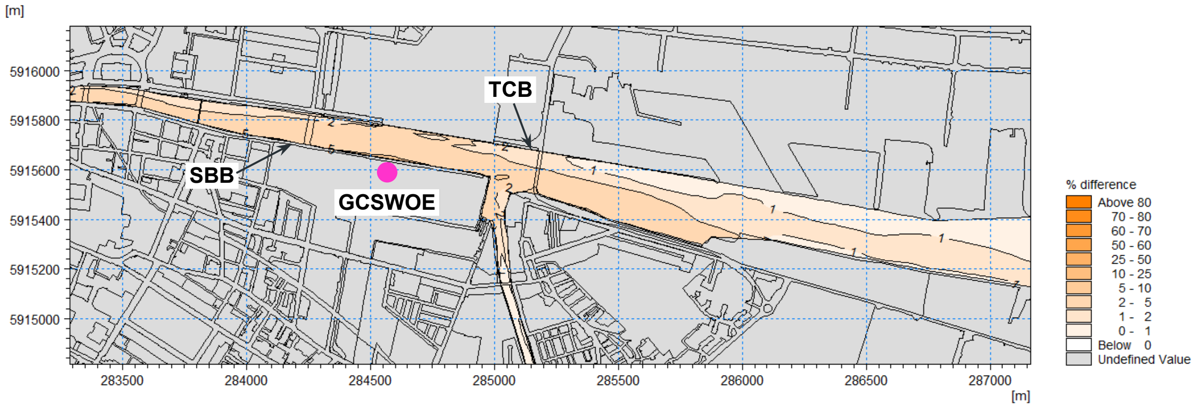

Figure 4.27 Percent difference in all year 95%ile of E. Coli (Storm conditions), vertically averaged.

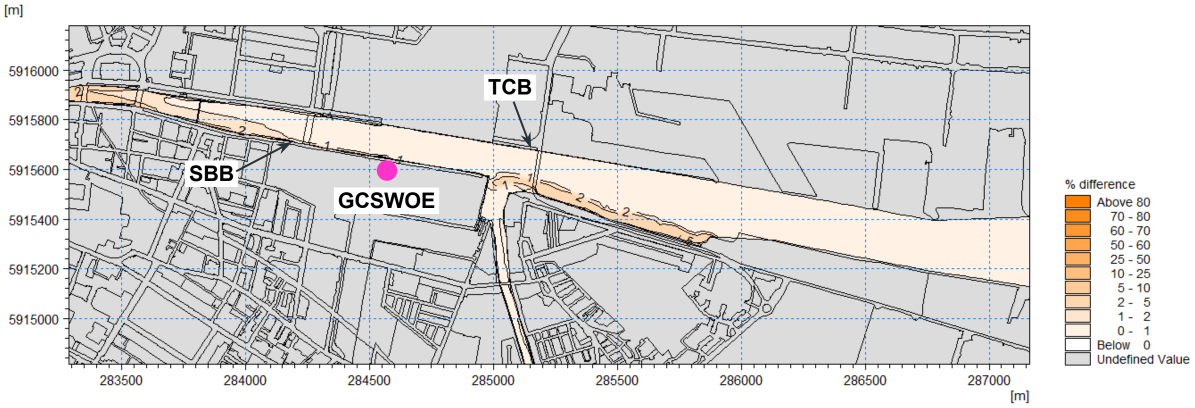

Figure 4.28 Percentage difference in all year 95%ile of E. Coli (Storm conditions), maximum through the water column.

5 Conclusions

A 3D truncated numerical model of the receiving waters of the Liffey estuary has been developed to resolve the controlling hydrodynamic processes. The presence of a salt-wedge has been previously confirmed through detailed survey data collection. The focus of the model development was to create a one-year representation of the system that could then be used to understand the long-term fate of pollutants from a proposed outfall from the Grand Canal Tunnel, running under Sir John Rogerson's Quay.

Previous work as part of a Scoping Study [1] using a simplified empirical assessment had suggested that there would be a limited impact for the proposed outfall, which was related to the significant increase in both dilution and flushing associated with the outfall discharging into the Liffey rather than the GCB. The Scoping assessment took no specific account of the effect of the tide in controlling the pattern of flushing from this location. Of concern was the potential for the salt-wedge in this location to lead to upstream flow, extending the area of impact and potentially leading to a trapping of any additional pollutants coming from the new outfall.

In order to understand and address these concerns a numerical model was developed using measured and modelled data as boundary conditions for the hydrodynamics and was demonstrated to re-create the key hydrodynamic processes known to control this part of the estuary. The model was validated against field data available for the area. This was coupled with advanced ecological models to provide an assessment of the fate of four key water quality parameters including DIN, MRP, E. Coli and BOD. The benefit of modelling pre and post situations is to allow an assessment of the magnitude of change that is being seen.

The results of the one-year model run show that whilst the proposed outfall is located in this complex hydrodynamic situation, the flushing effect in this part of the estuary remains significant, with net transport of material out of the system.

Specifically in relation to water quality parameters, the model sought to assess the potential for exceedance of the EQS for the water quality parameters. The modelling identified that:

- For DIN there was **no discernible change** in the achievement of the EQS compared to the baseline, with difference in pollution in much of the Lower Liffey being below 1% and the higher levels constrained to the outfall area.
- For MRP there was **no discernible change** in the achievement of the EQS compared to the baseline, with difference in pollution in much of the Lower Liffey being minor (less than 1% difference).
- For E. Coli the increases due to the GCSWOE were seen to be less than 2% in the time varying scenario reducing rapidly away from the outfall and between 2 and 5% for the storm-based scenarios. Importantly, at the downstream boundary of the model these both reduced to less than a 1% increase compared to the baseline, suggesting that there would likely be **no discernible effect** from the GCSWOE on downstream bathing sites.
- BOD showed **no discernible change** in the achievement of the EQS compared to the baseline, however this parameter showed the greatest increases compared to the baseline. It was noted that even with this large percentage increase, the resultant values were still well below the EQS thresholds.

All of the modelling highlighted the potential for localised increases in the occurrence of the key water quality parameters, however the ability of the hydrodynamic system to dilute and remove these increases over relatively short spatial scales as demonstrated by the rapid reduction seen in the results at increasing distance from the proposed GCSWOE.

Whilst E. Coli numbers from the model simulations are seen to be up to 5% worse in the situation with the GCSWOE, it is noted that this area of the Liffey is not designated as a bathing water and therefore the assessed achievement of EQS has been used indicatively.

The situation with respect to E.Coli is limited to only the immediate vicinity of the outfall, with no discernible effect on designated bathing waters outside of the Harbour entrance due to the GCSWOE outfall.

6 Bibliography

[1] DHI, “Grand Canal Scoping Report - Version Final 3.1,” 2020.

[2] DHI, “Grand Canal Outfall Water Quality Assessment - Survey Interpretative Report,” 2021.

[3] DHI, “MIKE 21 & MIKE 3 Flow Model FM, Hydrodynamic and Transport Module, Scientific Documentation,” 2020. [Online]. Available: https://manuals.mikepoweredbydhi.help//2021/Coast_and_Sea/MIKE3HD_Scientific_Doc.pdf. [Accessed February 2021].

[4] ARR Ltd, “Survey report: Grand Canal Outfall Water Quality Assessment. DHI-GC-201021-REP-01-CB-C.,” 2020.

[5] Dublin City Council , “New Bridges Survey Data - Weeks 1-24 (June 2021),” 2021.

[6] FWR, “Urban Pollution Management Manual,” [Online]. Available: http://www.fwr.org/UPM3/index.htm.

APPENDIX A – ARR Ltd. survey data

A ARR Ltd. survey data

A.1 Vectors of current speed through the water column at different tide hours

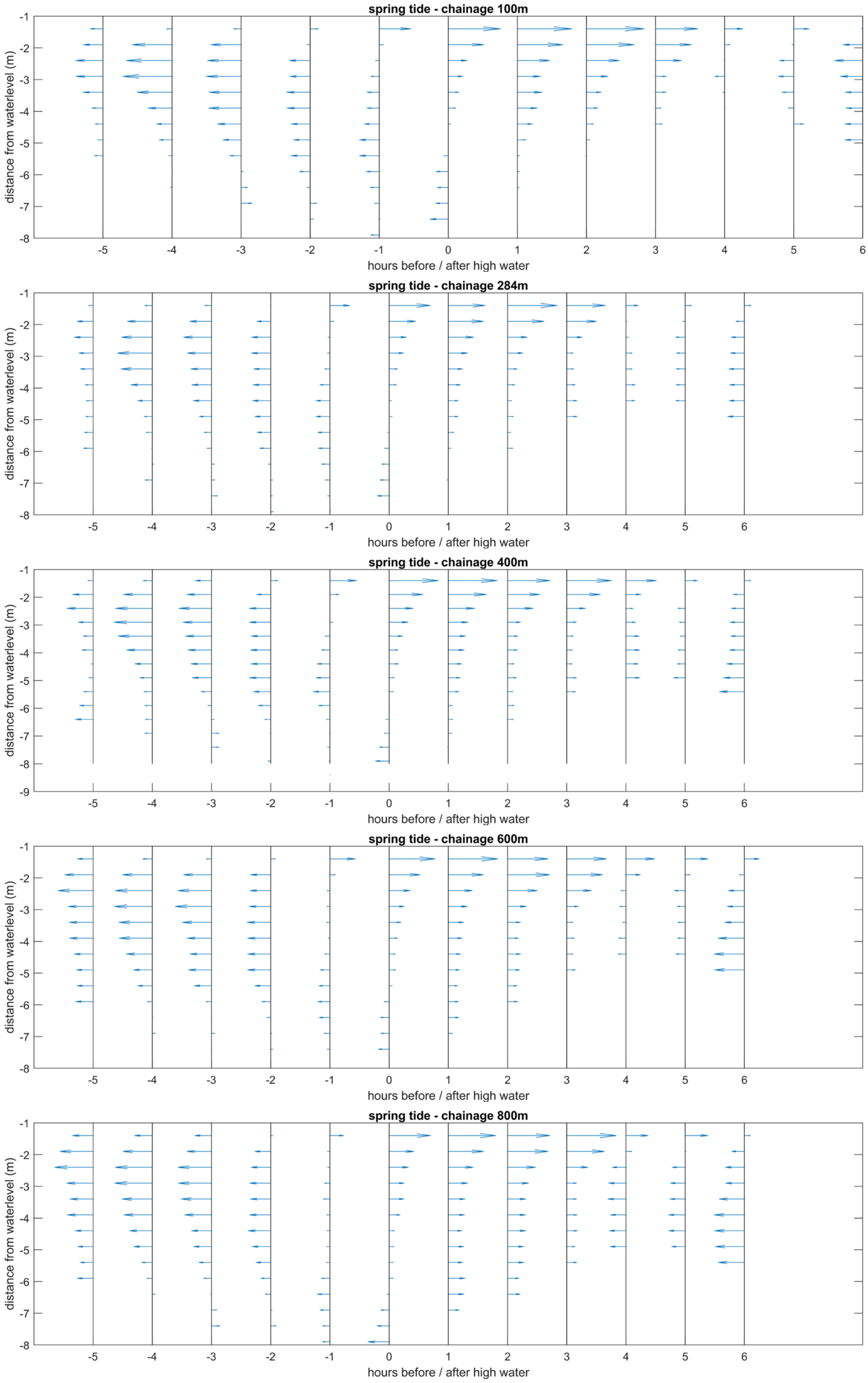

Figure B. 1 Vectors of current speed through the water column at different tide hours before and after high tide during a spring tide cycle (17/10/2020). Arrows pointing towards the left and right represent currents flowing upstream and downstream, respectively. Each of the panels presents results at different distances downstream point CTD01b. The second panel from the top (chainage 284m) corresponds to the position of the GCSWOE.

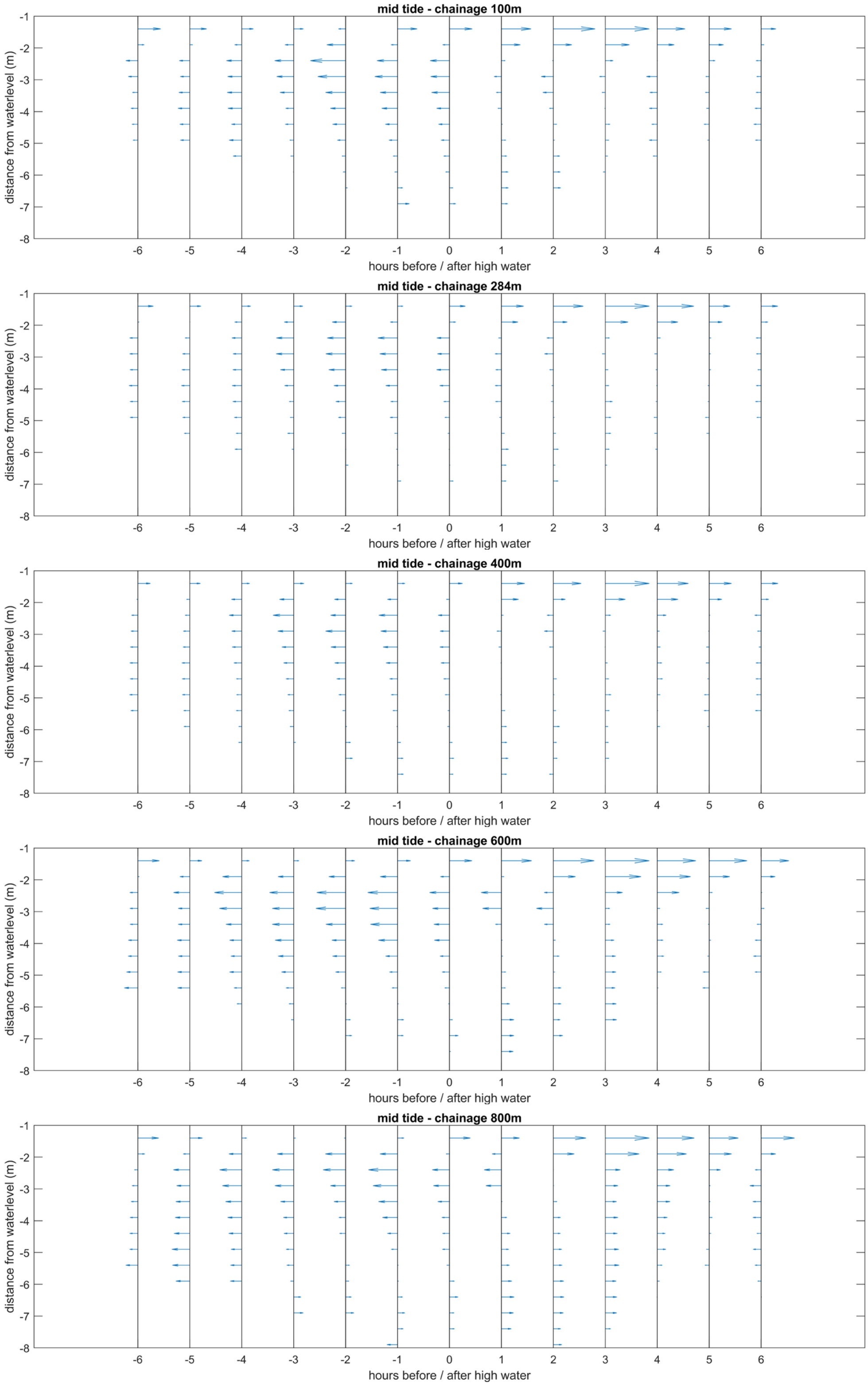

Figure B. 2 Vectors of current speed through the water column at different tide hours before and after high tide during a mid-range tide cycle (06/11/2020). Arrows pointing towards the left and right represent currents flowing upstream and downstream, respectively. Each of the panels presents results at different distances downstream point CTD01b. The second panel from the top (chainage 284m) corresponds to the position of the GCSWOE.

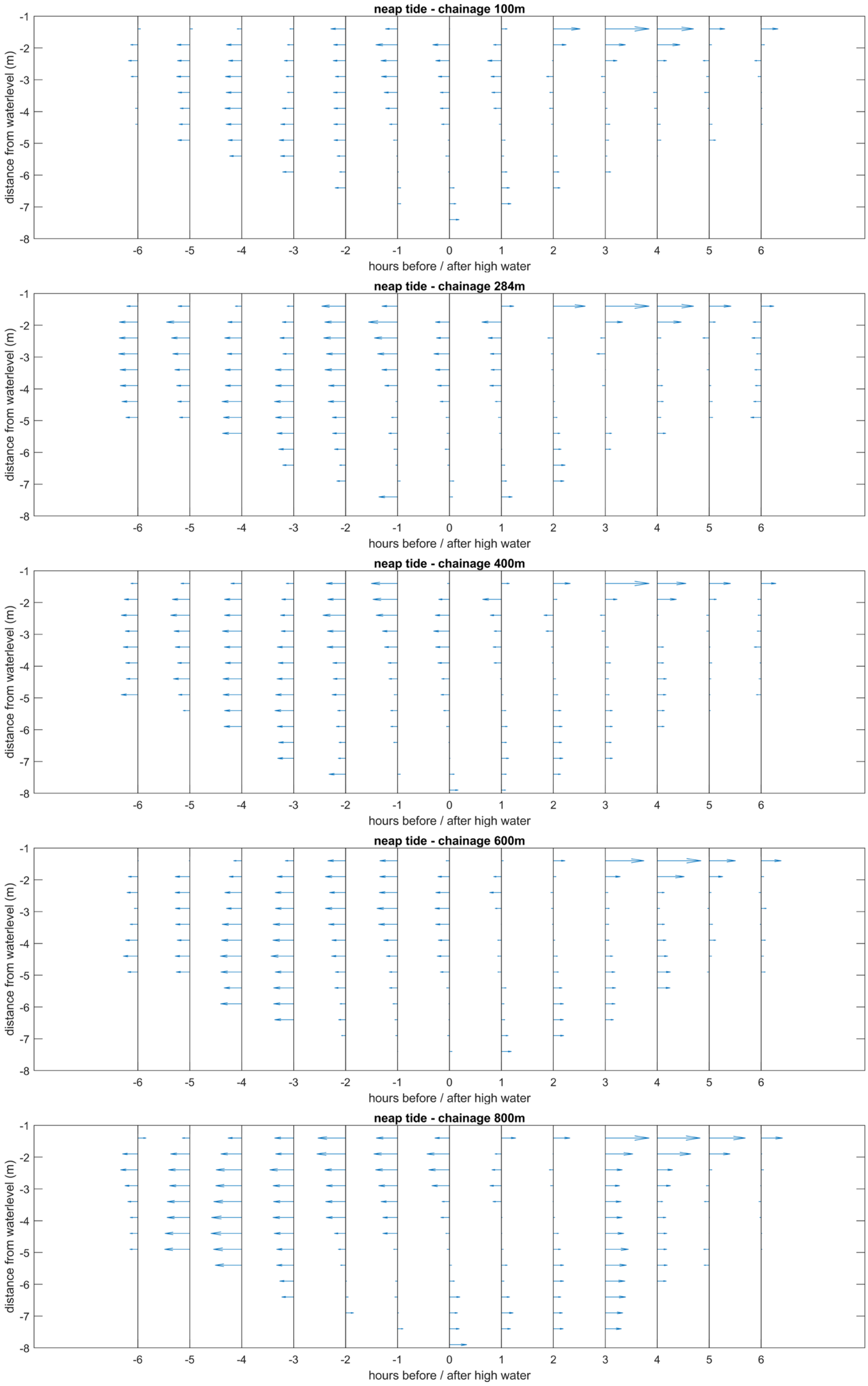

Figure B. 3 Vectors of current speed through the water column at different tide hours before and after high tide during a mid-range tide cycle (01/11/2020). Arrows pointing towards the left and right represent currents flowing upstream and downstream, respectively. Each of the panels presents results at different distances downstream point CTD01b. The second panel from the top (chainage 284m) corresponds to the position of the GCSWOE.