Irish Water

PROJECT:

Ringsend Wastewater Treatment Plant Upgrade Project

DOCUMENT:

DCPM Modelling Assessment of Potential Impact of WWTP Upgrade on the Tolka Estuary

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Section 1: Water Quality Impact Assessment – Methodology

1.1 Introduction

As part of the Ringsend Environmental Impact Assessment this document outlines modelling undertaken to assess future impacts on the Tolka Estuary following upgrades to the Ringsend Waste Water Treatment Plant (WWTP). The Tolka Estuary is not currently achieving good ecological status under the Water Framework Directive (WFD) in part because of a proliferation of benthic macroalgae on the mudflats in the estuary. This modelling exercise takes the outputs – the predicted nitrogen (N) and phosphorus (P) concentrations – from the DHI MIKE model (see Appendix 1) as inputs to a separate, Dynamic Combined Phytoplankton & Macroalgae (DCPM) Model. The DCPM model had previously been calibrated for the Tolka Estuary. The DCPM model then predicts nutrients, chlorophyll and macroalgal biomass in the Tolka Estuary for the proposed characteristics of the upgraded Ringsend WWTP discharge (see Figure 1-1).

1.2 Dynamic Combined Phytoplankton & Macroalgae (DCPM) Model

The DCPM model was specifically developed to assess the biological response (phytoplankton and opportunistic macroalgae) to nutrient (nitrogen and phosphorus) inputs in estuaries. The DCPM Model was developed by the UK Centre for Environment Fisheries and Aquaculture Science (CEFAS) for the Environment Agency of England and Wales. The model has also been used by the EPA to assess the impact of nutrients in Irish estuaries, specifically Argideen and Blackwater (Ní Longphuirt, O'Boyle, Wilkes, Dabrowski, & Stengel, 2016). It has proven useful in which deciding factors are growth-limiting for phytoplankton and macroalgae in a range of Irish estuaries including: nitrogen, phosphorus, light or habitat.

The model is used in this instance to assess the relationship between nutrient levels and phytoplankton as evidenced by chlorophyll concentrations, and macroalgal biomass in the Tolka Estuary. The Tolka Estuary experiences extensive growths of opportunistic macroalgae during the summer, and the estuary's ecological status, under the Water Framework Directive (WFD), has been downgraded to moderate status as a result. On the EPA's catchments.ie website the most recent status report for the Tolka Estuary indicates that it is also 'Moderate' for both oxygenation conditions and for summer ortho-phosphate (under SI 272 of 2009) over the 2010–2015 period.

The Liffey Estuary Lower, into which the Ringsend WWTP discharges its final effluent, has been generally compliant under the WFD in terms of its phytoplankton, invertebrate plus the supporting oxygenation and nutrient conditions. In the 2010–2015 assessment, however, the status of its fish populations has been downgraded to 'Moderate' – fish were assessed as being at Good status in the previous two WFD assessments. Dublin Bay itself currently achieves High or Good status for all the relevant ecological quality elements, both biological and physico-chemical. This continues the situation observed since 2010.

The purpose of the DCPM modelling exercise is to assess the Tolka Estuary in terms of the existing impacts on its status and any potential future changes when the Ringsend WwTP is fully upgraded, and the final effluent is improved. Specifically, it models the changes in nutrient regime and any resulting changes in the macroalgae and phytoplankton growth patterns over the course of a typical year in the Tolka Estuary. This will provide an overall assessment of the likely impact on ecological status in the Tolka Estuary.

The DCPM model is a simpler model than the MIKE-3 high resolution flexible mesh model used for the main modelling exercise. The nutrients and hydrodynamic inputs to the DPCM model are based on the outputs generated by the MIKE-3 model – the two models are decoupled. In Appendix 1 of this report, DHI provide a mapped assessment of the baseline and future outcomes for a range of modelled scenarios. This latter appendix provides a detailed discussion of the hydrodynamic regime in the bay, including salinity, current flows, etc., which is valuable in assessing the relative hydrodynamic importance of the water bodies adjacent to the Tolka Estuary.

The DCPM model has been previously calibrated for the Liffey Estuary Lower and Tolka Estuary water bodies based on monitoring data for the period 2007-2013 (Limnos Consultancy, 2015) as the 2015 data were not yet available when the original model was calibrated.

1.3 Model Build and Calibration

1.3.1 Introduction

The DCPM model (Version 2.0) is here calibrated against the summer and winter DIN, MRP and Chlorophyll monitoring results for the Tolka Estuary for the 2013–2015 period. For the Future discharge conditions, following upgrading of the Ringsend WWTP, the corresponding boundary conditions or adjacent seawater concentrations for summer and winter DIN, MRP and Chlorophyll, were derived from the MIKE-3 model output results.

A detailed description of the DCPM model has been published by the original creators of the model and by EPA and Marine Institute scientists who have used the model on Irish estuaries (Aldridge et al., 2008; Aldridge, Painting, Tett, Capuzzo, & Mills, 2013; Ní Longphuirt et al., 2016). The model is coded in MATLAB with a spreadsheet input/output user interface. MATLAB is a widely used proprietary mathematical modelling language (developed by Mathworks) and is provided with the model as a compiled 'runtime' unit.

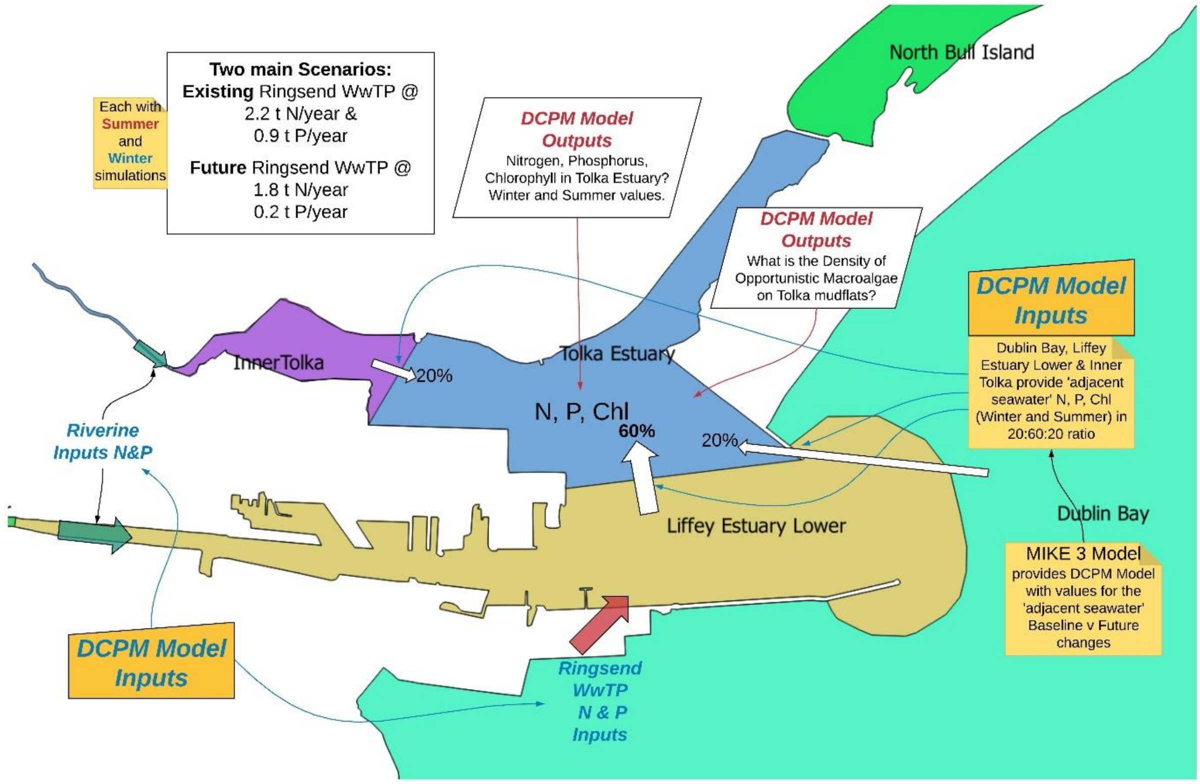

Figure 1-1. Schematic of DCPM Model for Tolka Estuary.

No, or very minimal, changes were made to the default model parameters of equations determining the ecological functions such as nutrient uptake by phytoplankton or macroalgae in the model. The required local hydromorphological, e.g., area, tidal range, bathymetry, and hydrodynamic factors such as residence time and exchange efficiency, are based on available charts, tide gauges, salinity profiles and previously published reports on Dublin Bay (CDM, DCC, & DHI, 2009). Light attenuation is based on Secchi disc transparency as measured by the EPA during WFD surveys. The DCPM model requires summer (April to September) and winter (October to March) nutrient and chlorophyll concentrations for the adjacent water bodies – and is relatively sensitive to these. The 2013–2015 WFD monitoring data were the primary dataset used, in addition to a longer time series from 2007 to 2013 which provided a degree of validation for the calibration based on the 2013–2015 data. Riverine nutrient loadings (in terms of kg/year) were calculated from longer term flow and water chemistry data, averaged on a monthly basis over 2007–2013.

1.3.2 Available Data

Since 2007, the EPA's WFD 3-year cycle monitoring programme has provided a range of physico-chemical data for the main water bodies defined for WFD purposes in the Dublin Bay Area: including dissolved inorganic nitrogen (DIN), molybdate reactive phosphorus (MRP) and chlorophyll *a*. Salinity, temperature, depth and time of sampling plus sample location and a range of other determinands are also available as published by the EPA – the 2013-2015 survey cycle data were used as the baseline scenario in the DCPM and MIKE models. Dublin City Council have also undertaken intensive surveys of Dublin Bay and provided extensive datasets for this study.

The EPA's biological surveys of intertidal habitats using a hovercraft have also been mapped during WFD monitoring surveys and a map of the 2013 available intertidal habitat suitable for macroalgae and the 2013 mapped occurrence of macroalgae, in the Tolka Estuary, were also made available by the EPA and used in the calibration of the model.

Historical hydrometric flow data and water chemistry for the important inflowing rivers to Liffey Estuary Lower and Tolka Estuary up to 2015 were also made available by the ESB and EPA.

Riverine nutrient loads to the Liffey Estuary Lower and Tolka Estuaries were calculated by multiplying averaged monthly flows by mean monthly nutrient concentrations to give mass flow as kg N or kg P per month and then summed to give annual loads as required by the DCPM model.

1.3.3 Calibration of DCPM Model

Calibration is achieved by adjusting the hydrographic characteristics – the relative contribution of the Liffey, Dublin Bay and Inner Tolka Estuary and exchange efficiency of the Tolka with the adjacent sea water – in order to match the predicted seasonal winter/summer changes in nutrients, particularly levels of DIN and MRP. Chlorophyll concentrations are also matched for summer and winter conditions. Macroalgal biomass is also modelled and included in the calibration process, matching it against the observed biomass in the Estuary. A calibrated model must match the seasonal DIN, MRP, chlorophyll and macroalgal biomass within a ±20% band – as per the criteria in recent paper published by EPA and Marine Institute scientists (Ní Longphuirt et al. 2015.) In addition to calibrating the model, a wide range of sensitivity tests was carried out. The model's sensitivity to individual components such as mixing efficiency or light penetration was assessed in order to ensure a robust modelling process. The modelling process was most sensitive to the nutrient concentrations in the adjacent seawater and the exchange rate between the estuary and the adjoining sea water as the tide ebbs and flows over its daily cycle and these were carefully calibrated to ensure best match between observed and modelled for the baseline or 'status quo' scenario representing the present situation before any changes are made to the WWTP discharge characteristics.

Table 1-1 shows the calibration comparison between the observed seasonal nitrogen (N), phosphorus (P) and chlorophyll concentrations in the Tolka Estuary and the DCPM model predictions of same for the period 2013-2015.

Table 1-1: Comparison of observed nutrient and chlorophyll concentrations in the Tolka Estuary with the DCPM Model predictions for the Baseline calibration.

	N Winter Mean (mg/l N)	P Winter Mean (mg/l P)	N Summer Mean (mg/l N)	P Summer Mean (mg/l P)	Chlorophyll Winter Mean (µg/l)	Chlorophyll Summer Mean (µg/l)
2013-2015 Tolka Data	1.36	0.0468	0.39	0.0681	2.21	6.45
DCPM Model Predictions	1.20	0.0527	0.42	0.0551	1.85	5.57
Deviation of above DCPM Model Predictions from Observed Monitoring Results for 2013-2015						
Percentage Deviation	11%	13%	8%	19%	16%	14%

The DCPM models produced for the Tolka Estuary are believed to be robust and to produce reasonable predictions for the evolution of changes in nutrient levels and biomass following the introduction of various nutrient reduction scenarios for Ringsend WWTP. An important aspect of the modelling process is that, once calibrated, no further changes are made to the structure of the calibrated model. The only changes made in the Future scenario runs for the Tolka are to the nutrient concentrations in the adjacent sea water (boundary conditions) and these are based on the outputs predicted for the Future scenarios by the DHI MIKE model for DIN and MRP for Dublin Bay, Liffey Estuary and Inner Tolka Estuary, following upgrading of the Ringsend WWTP.

Table 1-2 shows the percentage increase or decrease in winter and summer DIN and MRP concentrations that are modelled as inputs to predict the future impact on the Tolka Estuary. The nutrient changes are based on output data from the DHI MIKE-3 model.

Table 1-2: Percentage changes in depth-averaged nutrient concentrations modelled for water bodies adjacent to the main Tolka Estuary – future scenarios compared with the baseline situation – based on DHI model outputs.

Water Body	Winter DIN	Summer DIN	Winter MRP	Summer MRP
Dublin Bay	0.0%	3.5%	-4.4%	-66.7%
Liffey Estuary Lower	-3.2%	1.5%	-13.9%	-62.5%
Inner Tolka Estuary	0.0%	-0.4%	-16.1%	-57.1%

Note that no changes are predicted in chlorophyll or macroalgae 'Future' boundary conditions at this point, as future predicted nutrient levels appear to be still above the levels at which either P or N would become limiting for growth. The sensitivity analyses undertaken here, and a previous modelling exercise undertaken using the DCPM model (Limnos Consultancy, 2015), suggest that further major reductions in ambient nutrient concentrations would be required to significantly reduce the biomass of macroalgae growing on the mudflats in the estuary or to alter the response of phytoplankton/chlorophyll in the water column. The earlier study also modelled the potential impact of a long sea outfall (i.e. discharging directly to the Irish Sea outside of Dublin Bay). The DCPM model did not predict any reduction in the abundance of macroalgae in the Tolka Estuary if such a pipeline were to be constructed.

In the process of calibrating the model, it was noted that the Tolka Estuary had somewhat higher DIN than was readily predicted by a combination of the Liffey Estuary Lower and Dublin Bay entering the Tolka Estuary. The DHI MIKE Model baseline and future scenario models suggested that there is a significant flow of water from Dublin Bay into the Tolka Estuary on the flood tide. Similarly, the MIKE model shows significant plumes from the Lower Liffey Estuary entering the Tolka Estuary at various stages of the tidal cycle and with seasonal variation as freshwater inputs from the River Liffey gain in importance. Nonetheless, it was quite difficult to match the summer DIN mean value of 0.39 mg/l N observed for the 2013-2015 period in the Tolka Estuary using almost any combination of Dublin Bay and Liffey Estuary Lower on their own – i.e. even at a mass balance ratio of 90:10 Liffey Estuary Lower to Dublin Bay, flowing into the Tolka on the tidal cycle, the predicted values were too low. It was even more difficult to match the observed greater summer mean DIN values for the longer 2007–2013 monitoring period.

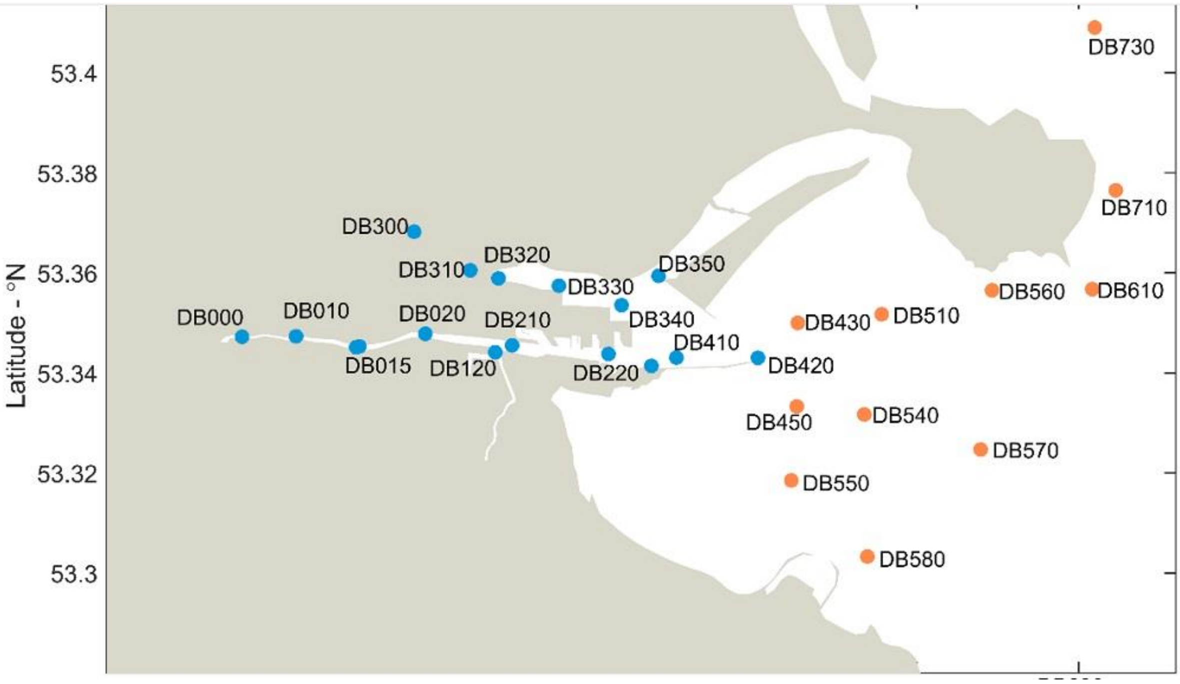

Figure 1-2: WFD Monitoring Points in the Dublin Bay area water bodies. The Tolka Estuary monitoring points include from inner to outer estuary: DB300, DB310, DB320, DB330, DB340 and DB350.

This phenomenon was explained on further examination of the results for individual monitoring points within the Tolka Estuary – this revealed a significant dichotomy within the water body. The six monitoring points in the estuary (DB300-DB350) are shown in Figure 1-2. The inner Estuary monitoring stations DB300, DB310 and DB320 had much higher DIN concentrations than the outer three, DB330, DB340 and DB350. The last freshwater monitoring site: Tolka River, 09T011150, Footbridge 400 m downstream of Drumcondra Bridge, also has similarly high DIN, albeit not excessive in terms of typical freshwater concentrations in the lower reaches of urban rivers. There is a steady drop in DIN concentration from the inner to outer estuary and this is mirrored to a greater or lesser extent by MRP, ammonia and BOD. Thus, the inner Tolka Estuary was treated as an 'adjacent' or boundary condition water body for the purposes of calibration, together with the Liffey Estuary and Dublin Bay boundary condition inputs (Table 1-2). The higher DIN concentrations in the inner part of the Tolka Estuary were judged as being unrelated to the Ringsend WWTP and due to a more local source in the inner estuary.

In a sense this illustrates the utility of modelling in gaining an understanding of how these complex physical systems work and hence in predicting how they will respond to future changes.

1.3.4 Relative Nutrient Loads

It is estimated that over the 2013-2015 period the Ringsend WWTP emitted an average of 2,168 t N and over 386 t P per annum (based on an average discharge of 4.91 m^3/s and average concentrations of 14.0 mg/l N and 2.49 mg/l P, respectively). This compares with an estimate of some 1,500 t N and 43 t P from the combined riverine sources entering the Bay. The future scenarios modelled by DHI using the MIKE-3 model calibrated for Dublin Bay include the average annual discharge from Ringsend WWTP increasing to 6.95 m^3/s but at reduced annual average concentrations of 8 and 0.7 mg/l for DIN and MRP, respectively. This yields annual emissions of 1,753 t N and 153 t P from the WWTP. Thus, a reduction in both N and P loading from Ringsend is predicted, with the P load being particularly significant compared with the current baseline loads from the plant.

1.3.5 Results for Baseline versus Future Scenario

The results of the DCPM simulations of the Tolka Estuary for the Baseline and Future scenarios following upgrading of the Ringsend WWTP are shown in Figure 1-3Figure 1-2 to Figure 1-6. These plot the modelled Baseline and Future outcomes over a full year, demonstrating the potential impact of the proposed improvements at the Ringsend WWTP on the estuary. In these graphs, the Y axes show concentrations of the relevant nutrient or biological quality element and the X axes show time, representing a typical year, where Julian day 1 is the 1st January and day 365 corresponds to 31st December. The model includes biologically important drivers such as changes in light, temperature, tidal exchange, etc., based on the morphology and location of the Tolka Estuary. Clear seasonal patterns are apparent as the phytoplankton and macroalgae take up nutrients and respond to light and temperature increases during the growing season. Note that there is competition between the phytoplanktonic algae in the water column and the benthic macroalgae growing on the mudflats for both light and nutrients and the DCPM model includes these, quite subtle, interactions in its equations in order to give as realistic as possible picture of the complexities of estuarine ecology.

DIN

Figure 1-3 plots DIN on a daily basis across the course of a typical year for the Baseline conditions and the Future scenario, representing the situation following the proposed improvements to the Ringsend WWTP. Winter DIN (October to March) is shown to decrease in the Tolka Estuary while the summer DIN shows a slight increase for this scenario. The median winter DIN concentration predicted here for the future following upgrading of the WWTP is 1.05 mg/l N which at a salinity of 17 psu yields would equate to Good status for Winter DIN if the Tolka were a coastal water body (as per SI 272 of 2009, DIN is not used to classify transitional water bodies such as the Tolka under the WFD).

MRP

Figure 1-4 shows the Baseline versus Future concentrations of MRP predicted by the DCPM model for the Tolka Estuary. In this case, highly significant reductions in concentration are predicted right across the year. This is to be expected as reducing the WWTP's discharge to a future mean concentration of 0.7 mg/l P from 2.49 mg/l in the 2013-2015 period could lead to a halving of the total loading of phosphorus to the Liffey Estuary Lower and the wider Dublin Bay. The median summer MRP at 0.055 mg/l P for the Baseline puts the Tolka Estuary at Moderate status for MRP but this will improve to High status at a predicted 0.014 mg/l P for the Future scenario.

Chlorophyll

Figure 1-5 shows the DCPM predictions for chlorophyll concentrations through the year for the Baseline and Future scenarios. Clear seasonal changes can be seen as temperature and light levels limit growth during the winter months. In this case no change is predicted – the graph lines for baseline and future overlay each other completely. This implies that the absolute changes in nutrient levels and the increase in N:P ratios, following the drop in MRP relative to DIN, are unlikely to change the chlorophyll concentrations in the Tolka Estuary. Chlorophyll/phytoplankton status for the Tolka Estuary was 'High' for the 2010-2015 assessment period.

Macroalgae

Figure 1-6 plots the annual cycle of opportunistic macroalgae in the estuary. The macroalgae – which have been the main cause of the Tolka Estuary failing to meet good ecological status under the WFD – show a similar pattern to chlorophyll, with no change predicted by the DCPM model when comparing the Baseline with the Future situation, following the changes in DIN and MRP shown above. The macroalgae are likely to be primarily nitrogen limited and the availability of suitable intertidal habitat plus the light regime in the estuary will play an important role in determining their occurrence and abundance. In the Tolka Estuary some 60% of its area is suitable for macroalgal growth (R Wilkes pers. comm., 2016).

Summary

Table 1-3 compares the aggregated seasonal average values for winter and summer DIN, MRP and chlorophyll in the Tolka Estuary –modelled DCPM predictions for the Baseline and the Future scenarios following upgrading of the Ringsend WWTP.

Table 1-3: Comparison of DCPM Model predictions of seasonal DIN, MRP and chlorophyll concentrations in the Tolka Estuary comparing modelled Baseline for 2013-2015 with Future scenarios for upgraded Ringsend WWTP.

DCPM Model Run	N Winter Median (mg/l N)	P Winter Median (mg/l P)	N Summer Median (mg/l N)	P Summer Median (mg/l P)	Chlorophyll Winter Mean (µg/l)	Chlorophyll Summer Mean (µg/l)
Predicted Baseline 2013-2015	1.25	0.05	0.26	0.55	1.85	5.57
Predicted Future following upgrade of Ringsend WWTP	1.05	0.04	0.28	0.01	1.85	5.57

1.4 Discussion

The calibrated DCPM model for the Tolka Estuary predicts changes in DIN and MRP that mirror those from the MIKE model for the Future scenario representing the impact of the upgrading of the Ringsend WWTP. This is not unexpected, as the MIKE Model outputs provided the boundary conditions for the DCPM model. The important result, however, is the impact of this new nutrient regime on the biological quality elements of the Tolka Estuary. The DCPM model suggests that there will be no change in phytoplanktonic chlorophyll (currently high status) nor in the biomass of macroalgae (currently moderate status).

This result is in line with an earlier modelling exercise that attempted to predict the impact of a long sea outfall where the full discharge from the Ringsend WWTP was to be piped out to the outer edges of Dublin Bay (Limnos Consultancy, 2015). This earlier DCPM modelling exercise concluded that reducing N and P to the levels observed in the Irish Sea outside of Dublin Bay would not be sufficient to reduce the macroalgal biomass. The Tolka Estuary has a significant intertidal area that provides suitable habitat for opportunistic benthic macroalgae and this, together with even relatively low nutrient concentrations – such as those of the Irish Sea itself, would still provide conditions for extensive macroalgal growth.

1.4.1 Future Compliance with WFD Status in the Tolka Estuary.

In the main DHI report, Appendix 1, compliance with the environmental quality standards set under the WFD Regulations (SI 272 of 2009 and SI 386 of 2015) for transitional and coastal water bodies is shown for the Baseline and Future predicted situation. Predicted concentrations are mapped for the individual parameters, with colour-coded bands depicting the basic EQS thresholds for DIN, ammonia, MRP and BOD standards for the WFD for the current Baseline situation and the modelled Future situation following upgrading of the WWTP. Note that the mean or median concentrations are ultimately assessed against a sliding salinity scale for final WFD ecological status assessment.

Chlorophyll and macroalgae are additional key components in the assessment of eutrophication. Based on the modelling above for the Tolka Estuary it is unlikely that the status will change in any significant way for these in particular – Figure 1-5 and Figure 1-6 suggest that there will not be any change in phytoplankton growth or macroalgal production in the Tolka Estuary. As discussed above, this was also the predicted situation for the complete removal or redirection of the Ringsend discharge via a long sea outfall. The predicted reductions in total nitrogen and phosphorus discharged from the upgraded Ringsend WWTP over the course of a year compared with the current baseline will also help the Tolka Estuary to meet its MRP environmental quality standards (EQS) under S.I. 272 of 2009 (median concentrations of ≤0.06 mg/ P for salinity in the range 0-17 psu up to 0.04 mg/l P for salinity of 35 psu). As indicated above DIN concentrations will also decline. MRP status will improve from Moderate to High status for summer MRP and remain at Good status for winter MRP.

1.4.2 Impact During Construction Phase

The proposed scheme describes an impact during the construction phase, whereby the level of DIN in the final effluent is estimated to increase to 18 mg N / l. This impact is expected to occur during the winter 2019 / 2020.

This change is not anticipated to alter the status of the Tolka Estuary, and, since the increase will arise during the winter months, the overall impact on the growth of phytoplanktonic algae or benthic macroalgae should not be significant.

1.4.3 Conclusions

The scenarios modelled by the DCPM model are based on the outputs of the DHI MIKE-3 model (Appendix 1) – the MIKE model outputs are used as inputs to the DCPM model. The DCPM model specifically addresses the likely impacts on the Tolka Estuary, especially with respect to phytoplankton and opportunistic macroalgae. It is concluded that, while there will be general reductions in the level of nutrients in the Tolka Estuary, the reductions will not be sufficient of themselves to alter the growth patterns of phytoplankton, as evidenced by chlorophyll levels in the water column, nor of the opportunistic macroalgae growing on the mudflats. While phytoplankton status in the Tolka Estuary is currently indicative of high quality conditions, the change in the N:P ratio with much reduced phosphorus may result in changes in the species make-up of the phytoplankton community bringing it closer to its ecological reference condition – but this is difficult to predict with any certainty. As noted above there is also still a reasonably high direct loading of nutrients to the Tolka Estuary via the Tolka River.

The current situation is that the Lower Liffey Estuary achieved Moderate ecological status under WFD environmental quality standards for 2010–2015 (failing only on its fish community) and Dublin Bay achieves Good or High status for many of its key quality elements. The Tolka Estuary will undoubtedly improve to some extent due to the predicted significant drop in MRP levels and a lesser overall reduction in DIN – but perhaps not sufficiently to eliminate the opportunistic macroalgae on its mudflats. As indicated above, however, this is also likely to be the outcome even if a long sea outfall were to be installed.

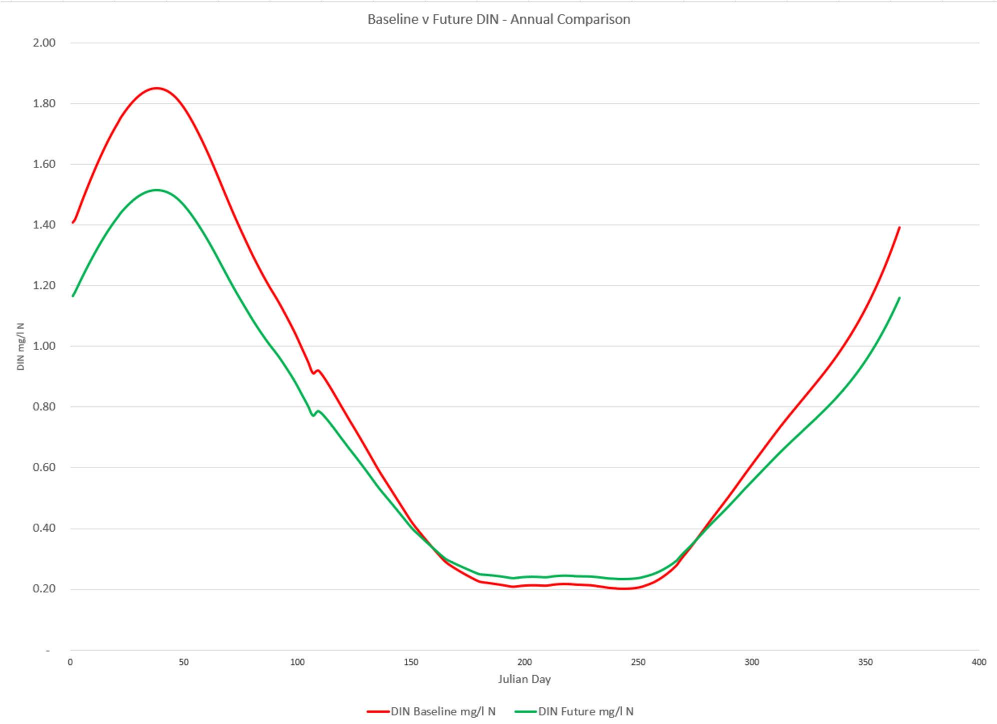

Figure 1-3: Baseline DCPM Model prediction of DIN in the Tolka Estuary, over an annual cycle, compared with Future scenario based on inputs from DHI MIKE Model.

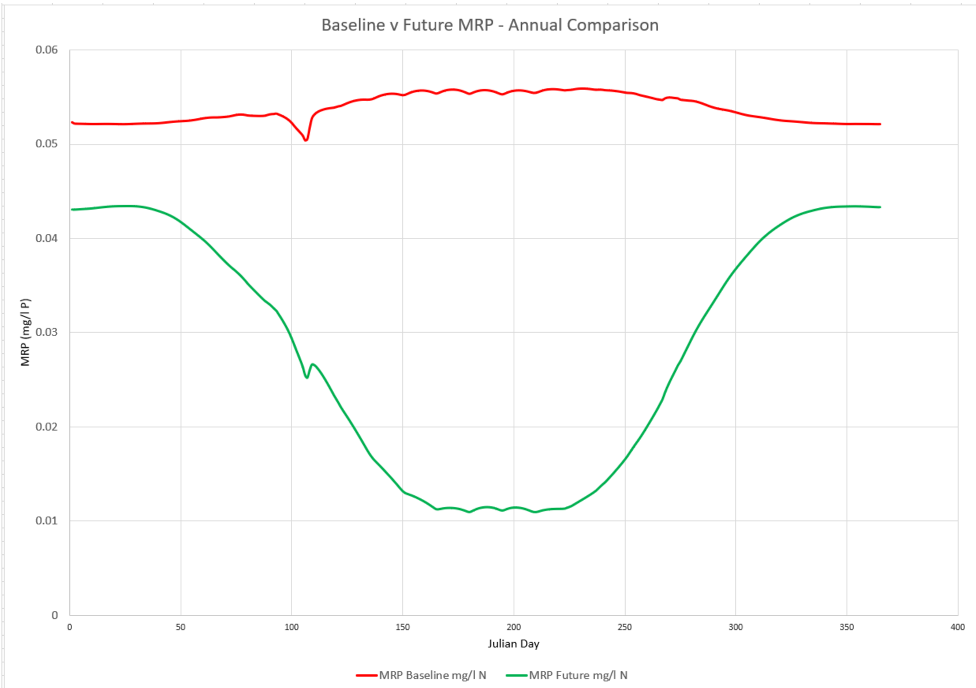

Figure 1-4: Baseline DCPM Model prediction of MRP in the Tolka Estuary, over an annual cycle, compared with Future scenario based on inputs from DHI MIKE Model.

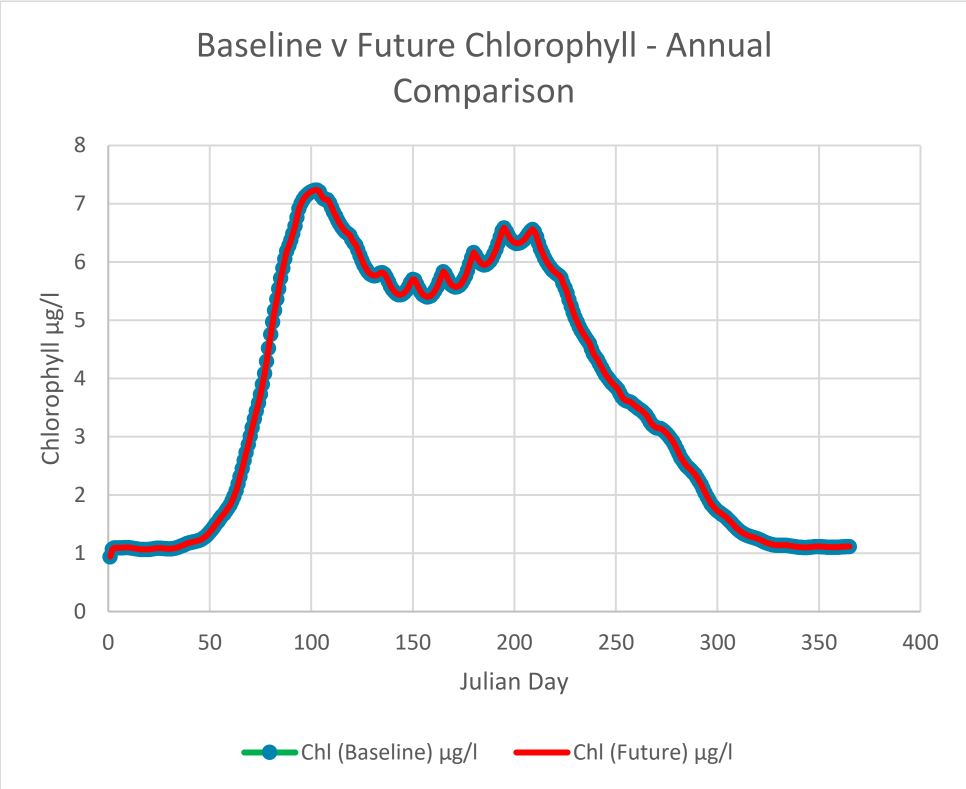

Figure 1-5: Baseline DCPM Model prediction of chlorophyll in the Tolka Estuary, over an annual cycle, compared with Future scenario based on predicted nutrient concentrations from DHI MIKE Model. Note that the Baseline and Future lines overlap each other as the model predicts no change in the phytoplankton abundance.

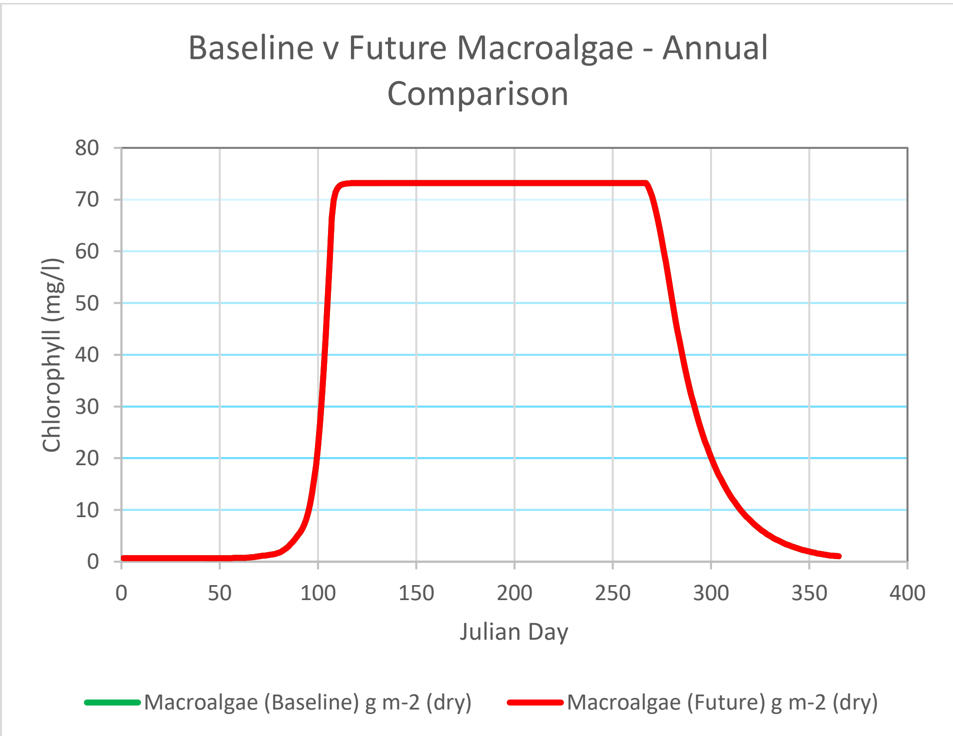

Figure 1-6: Baseline DCPM Model prediction of macroalgae in the Tolka Estuary, over an annual cycle, compared with Future scenario based on predicted nutrient concentrations from DHI MIKE Model. Note that the Baseline and Future lines overlap each other as the model predicts no change in the macroalgal abundance.

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