



**19/062-004 Lot 2 Engineering Design Services for Malahide
WWTP Upgrade**

MALAHIDE BAY NUTRIENT BOX MODELLING NOTE

MAY 2024

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Client	Uisce Éireann
Project No.	6013
Project Title	19/062-004 Lot 2 Engineering Design Services for Malahide WWTP Upgrade
Report Title	Malahide Bay Nutrient Box Modelling Note

Rev.	Status	Author(s)	Reviewed By	Approved By	Issue Date
0	Draft	R Norreys	JP Creavin	N Rajasakran	Sept 2022
1	Revised Draft	R Norreys	JP Creavin	N Rajasakran	October 2022
2	Revised Draft	R Norreys	JP Creavin	N Rajasakran	May 2023
3	Revised Draft	R Norreys	JP Creavin	P Scally	October 2023
4	Final	R Norreys	JP Creavin	P Scally	May 2024

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TECHNICAL NOTE: A NUTRIENT BOX MODELLING APPROACH WITHIN MALAHIDE BAY TO QUANTIFY THE IMPACT ASSOCIATED WITH MALAHIDE WWTP'S DISCHARGE

1 Introduction

Malahide Bay and the Broadmeadow Water are located to the north of the City of Dublin, in Fingal, County Dublin. The modelled domain described in this note incorporates Broadmeadow Water a transitional waterbody (IE_EA_060_0100) and Malahide Bay a coastal waterbody (IE_EA_060_0000). Malahide Wastewater Treatment Plant (WWTP) discharges to Malahide Bay, at a point close to the cascade where Broadmeadow Water flows into Malahide Bay, as shown in Figure 1.

A box modelling approach was applied to quantify the impact the final effluent discharge from Malahide WWTP has on nutrient concentrations in Malahide Bay. The box model provides a dynamic simulation of the spread of pollutants into defined areas or “boxes” within a body of water in response to changes in the boundary conditions, such as larger river inflows, or loadings from point sources.

This work has been based on previous work in Courtmacsherry Bay which itself was based on a model of the Argideen estuary undertaken by researchers from the National University of Ireland, Galway, McGovern et al (2019 and 2020).

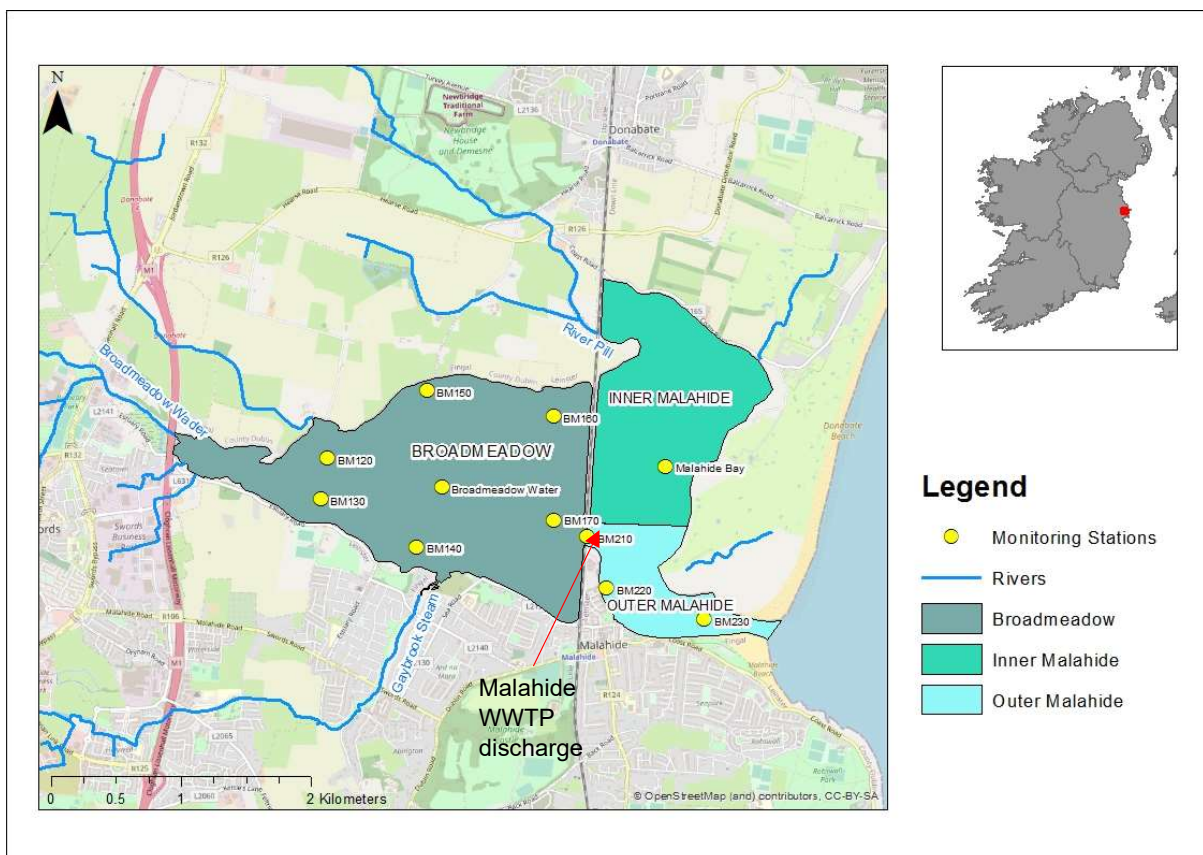


Figure 1 Malahide Bay Box Model location plan.

2 Modelling Approach

The following approach was applied to the modelling to build the box model of the Malahide Bay/Broadmeadow water domain.

- Run the model for average winter and summer flows and nutrient concentrations.

- Run the box-model to recreate the concentrations of Dissolved Inorganic Nitrogen (DIN) and Molybdate Reactive Phosphorus (MRP) for the two discharge scenarios from the existing Malahide WWTP used in the tiered assessment (Ryan Handley Stantec, 2022) and a zero-discharge scenario, to provide baseline values to compare the other scenarios with.
- Calculate baseline concentrations of DIN and MRP in the estuary excluding any wastewater discharges from the WWTP and the net increase in DIN and MRP over the baseline, which is effectively the rise in concentration introduced by the wastewater discharge.

3 The Box Model

The model method used to describe the interactions between boxes was taken from the Dynamic Combined Phytoplankton & Macroalgae (DCPM) model produced by Aldritch et al (2013 and 2014). The box model used daily timesteps and considers the interaction between the freshwater sources, pollutant sources and the sea.

3.1 Model Build

3.1.1 Box Model Calculation Engine

Ryan Hanley Stantec (RHS) were unable to obtain the DCPM model from the developers the UK Environment Agency and CEFAS. The box exchange model used for this analysis was built using the methodology taken from Aldritch et al (2013 and 2014) and McGovern et al (2019 and 2020).

The numerical model software was developed in Python and run using Jupyter Notebook. All the input data was held in an Excel workbook, interaction between boxes was calculated using Python code and all the interfacing was done in a Jupyter notebook.

The key physical parameters are listed in Table 4, which are: the downstream connection between boxes, the average volume and the exchange rate E , which is the proportion of the box's volume that is exchanged with the downstream box each day as a result of the tide coming in and out.

3.1.2 Box Model physical parameters

The Box Model of the Malahide Bay was built using physical and hydrodynamic data taken from a MIKE21 model updated in an earlier phase of this study.

A MIKE21 hydrodynamic model of Dublin Bay was produced during the Greater Dublin Drainage (GDD) outfall project, but this lacked any useful detail within Malahide Bay, so it was upgraded to include Malahide Bay and Broadmeadow Water. The Dublin Bay model was needed to provide calibrated currents and levels to drive the flows in and out of Malahide Bay and Broadmeadow Water.

The Dublin Bay MIKE21 model was created for Marcon to model sediment transport associated with the dredging for then proposed GDD outfall project. The work was undertaken for Jacobs. The physical parameters of Malahide Bay and the Broadmeadow Estuary were taken from a topographic survey undertaken by Fingal Council in 2010 for a flood modelling project. The survey data was processed in MIKE21 and merged with the Dublin Bay MIKE21 model to create a mesh to describe the bathymetry in Malahide Bay and Broadmeadow Water.

The Dublin Bay MIKE21 model featured two open sea boundaries at the north and south of the domain where tidal constituents acquired from the FES2004 global tidal model were used to generate time varying water surface elevations to induce tidal circulation within the model domain. The FES2004 is a global tide model which assimilates both tide gauges and altimeter data to provide amplitudes and phases of 15 tidal constituents at a $1/8^\circ$ latitude and longitude grid resolution. Six major tidal constituents, namely, M2, N2, S2, O1, K1, and P1 were applied, with the FES2004 $1/8^\circ$ data interpolated along the north and south boundaries of the model to obtain spatially varying amplitudes and phases of the above constituents. Constituents were then modified, with reference to nearby UKHO

published harmonic data, to achieve model calibration. The MIKE21 Dublin Bay with enhance Malahide Bay model was run for a month to estimate current and water level data throughout the domain for a spring to neap tidal cycle from 18/04/2015 to 18/05/2015.

A regular grid of time varying water depths were extracted from the simulation and used to calculate the time varying volumes within the separate boxes of the proposed model. A check was done to confirm that the changes of volumes in the boxes matched the flows through the boundaries between the boxes. Figure 2 shows the MIKE21 model and the grids used to extract depth data across the model domain.

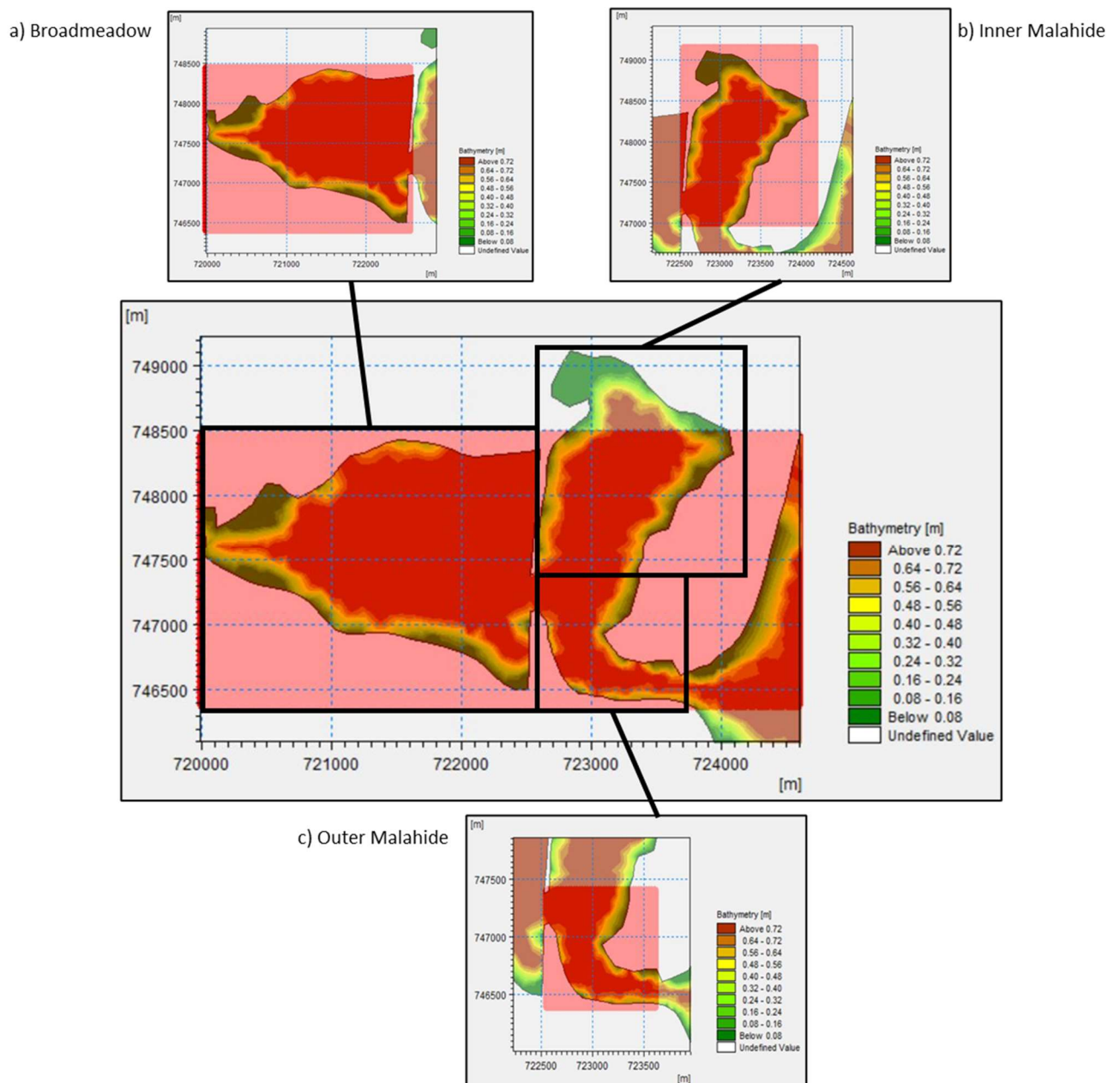


Figure 2 Malahide MIKE21 bathymetry used to extract water depths in the estuary. [UTM 30N / WGS84 ODM Malin Datum)

3.1.3 Riverine flows and water quality.

River flow statistics come from the Hydrotool and were gathered from the EPA website for Gaybrook Stream and Broadmeadow Water which both flow into the Broadmeadow nutrient box and River Pill which flows into the Inner Malahide nutrient box as shown in Figure 1.

The flows were divided into winter months (Oct-Mar) and summer months (Apr-Sept), and the mean flow of each season was calculated in Excel. The flows were then converted from m³/sec (m³/s) to m³/day (m³/d) so they can be used as inputs in the Box Model. Table 2 shows the winter and summer flows in m³/s to m³/d.

Table 1: River flow data for Malahide Bay.

Flow Into		Broadmeadow		Inner Malahide
River Name		Broadmeadow Water	Gaybrook Stream	River Pill
Summer Flow	Mean summer flow for each river	1.25	0.06	0.10
	Mean summer flow for each area (m ³ /s)	1.31		0.10
	Mean summer flow for each area (m ³ /d)	113,083		8438
Winter Flow	Mean Winter flow for each river (m ³ /s)	3.06	0.10	0.22
	Mean winter flow for each area (m ³ /s)	3.16		0.22
	Mean winter flow for each area (m ³ /d)	273,067		19,037
Annual Mean Flow	Average Monthly Flow (m ³ /s)	2.28	0.09	0.17
	Annual flow (m ³ /s)	2.37		0.17
	Sum of Annual flow (m ³ /d)	204,336		14,429
	Ratio Summer/Annual Flow	0.55		0.58

Salinity, Dissolved Inorganic Nitrogen (DIN) and Molybdate Reactive Phosphorus (MRP) data were provided by the EPA. This data is from the 3 monitoring sites in Outer Malahide and the 7 monitoring sites in Broadmeadow as shown in Figure 1. The salinity data was gathered between 2015 and 2022 and the DIN and DIP data was gathered between 2016 and 2021.

The data for the Irish Sea was taken from the Portmarnock monitoring site which is the furthest monitoring station north in the Irish Sea Dublin Coastal Waterbodies and the closest monitoring station in the sea to Malahide Bay. There was no data for DIN and although there was some limited TA sampling this didn't coincide with the Total Organic Nitrogen (TON) sampling. The TON was taken to represent DIN instead, this was a reasonable assumption because TA concentrations would be expected to be low. The marine salinity data was available for 2017 to 2022 whilst the MRP and TON data was available from 2013 to 2022.

All the data from Outer Malahide, Broadmeadow, and the Irish Sea was divided into winter and summer months and the seasonal medians were calculated for DIN and MRP for each box. The data is summarised in Table 2. Broadmeadow is expressed as a range of values because the water quality varied so much spatially. No data was available for Inner Malahide.

The Trophic Status Assessment Scheme (TSAS) definition was used to define the seasons, Winter is November to early March (first 2 weeks only). Summer is May to September

Table 2: Observed water quality data for Malahide Bay

Box	Season	Statistics	Salinity PSU	MRP mg/L	DIN mg/L
Outer Malahide	Summer	Median	33.1	0.010	0.025
	Winter	Median	31.3	0.030	0.390
Broadmeadow	Summer	Median	27.1- 31.8	0.022- 0.054	0.026- 0.243
	Winter	Median	14.7- 23.65	0.0215- 0.041	0.773- 1.5
Irish Sea	Summer	Median	33.4	0.01	0.03
	Winter	Median	33.3	0.02	0.194

3.1.4 Swords WWTP

Swords WWTP discharges to the Broadmeadow River, downstream of the EPA water monitoring stations at Lissenhall Bridge (RS08B021000 and TW09001008BM1008) but upstream of Broadmeadow Water.

Data was provided by Irish Water, for the flow, Total Ammonia (TA), Total Nitrogen (TN) and Total Phosphorus (TP) concentrations and loads from Swords WWTP from 01/01/2019 to 31/12/2022. This data was used to calculate the load inputs to Broadmeadow Water. It was assumed that the TN load approximated the DIN load to the estuary and that TP approximated the MRP load. The data showed that there was not a significant seasonal difference between the average flows, or the concentrations discharged, the values set out in Table 3 were applied to the model.

Table 3 Average flows and loads from Swords WWTP.

Season	Flow (m ³ /day)	DIN Load (kg/day)	MRP Load (kg/day)
Summer	14,014	650.3	99.1
Winter	14,014	650.3	99.1

3.2 Model Calibration

Once the volumes of the boxes had been established and inflows from the various tributaries represented, the model was calibrated.

The main calibration parameter is E, the Exchange Rate with the downstream cell, which was calibrated using salinity, a conservative substance. The model was run for two river flow scenarios, a winter and summer (Figure 3), with typical winter and summer concentrations applied. The model was run for a year with a step-change used for the transition between winter and summer. The E values were adjusted until the salinity in the boxes matched the observed data. The model shows good agreement with the observed concentrations. The results were extracted for one summer day (day no. 175) and one winter day (day no. 325) once concentrations had stabilised. Comparison of observed winter and summer salinity average over 2015-2022 versus the model simulations are presented in Table 6.

The river water quality was also gathered from the EPA website. The Broadmeadow River data was collected, Gaybrook Stream which also discharges to the Broadmeadow was lumped in with the Broadmeadow River. The Stream has very small catchment (5 km²) compared with the Broadmeadow (172 km²) and considered insignificant compared to this much larger input. . The nutrient concentrations

in the River Pill were assumed to be of the same as for Broadmeadow River, this was considered an over-estimate as the catchment for the Broadmeadow contains a large percentage of arable farming and could be expected to have a higher nutrient concentration. Molybdate Reactive Phosphorus (MRP) data was available however DIN was not so Total Organic Nitrogen (TON) was used instead, TON is a slight under-estimate of DIN, which includes Total ammonia which would be about 2% of the DIN this difference is marginal and can be disregarded. Table 7 shows the nutrient estimates from the calibrated model compared against observed concentrations. It is noted that the modelled data is generally showing reasonable agreement with the observed data but, the Broadmeadow waterbody's modelled MRP values are conservatively higher in both Winter and Summer than observed values.

The modelling software could be improved with time variable river concentrations, but for the purposes of this stage 1 study to compare different scenarios with only varying discharges from the WWTP the above detailed approach was deemed adequate.

Table 4 Physical Parameters of Box Model

Parameter	Outer Malahide	Inner Malahide	Broadmeadow	Unit	Description
Downstream	Sea	Out Malahide	Out Malahide		Downstream box
V mean	1,273,046	1,521,521	7,223,557	m ³	Average volume
Area	317,638	1,667,410	3,290,860	m ²	
Mean depth	4.01	0.91	2.20	m	
Mean seabed	5.00	0.00	1.50	Rel. to LAT	
Mean spring level	3.70	3.70	3.70	Rel. to LAT	
Tidal range	3.40	3.40	3.40	m	
E	2.00	0.50	0.25	1/d	Exchange rate with downstream cell

Table 5 Boundary Conditions for the box modelling

Parameter	Outer Malahide (Sea)	Broadmeadow (Broadmeadow Water + Gaybrook Stream)	Inner Malahide (River Pill)	Unit
Average freshwater flux into cell (annual mean)	0.00	14,429	204,336	m ³ /d
River discharge ratio summer/annual	0.50	0.58	0.35	ratio
DIN river conc. (mg/l)	0.00	0.55	1.67	mg/l
MRP river conc. (mg/l)	0.00	0.02	0.06	mg/l
Salinity river (psu)	0.00	0.00	0.00	psu
Daily DIN load (kg/d)	67.10	0.00	650.34	kg/d
DIN load ratio (summer/annual)	1	1	1	ratio
Daily MRP load (kg/d)	12.20	0.00	99.06	kg/d
MRP load ratio (summer/annual)	1.00	1.00	1.00	ratio

Table 6 Box Model Calibration - Observed 2016-2019 vs modelled using scenario 2 WWTP Discharges

Salinity (PSU)			
EPA Sample Site / Box it is in	Season	Observed	Modelled
Outer Malahide	Summer	33.00	33.0
	Winter	33.0	33.0
Broadmeadow	Summer	29.2	30.0
	Winter	22.0	25.0

Table 7 Comparison of the calibrated concentrations in the Box Model.

EPA Sample Site / Box it is in	Season	DIN (mg/L)		MRP (mg/L)	
		Observed	Modelled	Observed	Modelled
Outer Malahide	Summer	0.025	0.056	0.023	0.023
	Winter	0.29	0.220	0.024	0.024
Broadmeadow	Summer	0.131	0.46	0.04	0.07
	Winter	1.08	0.75	0.028	0.08

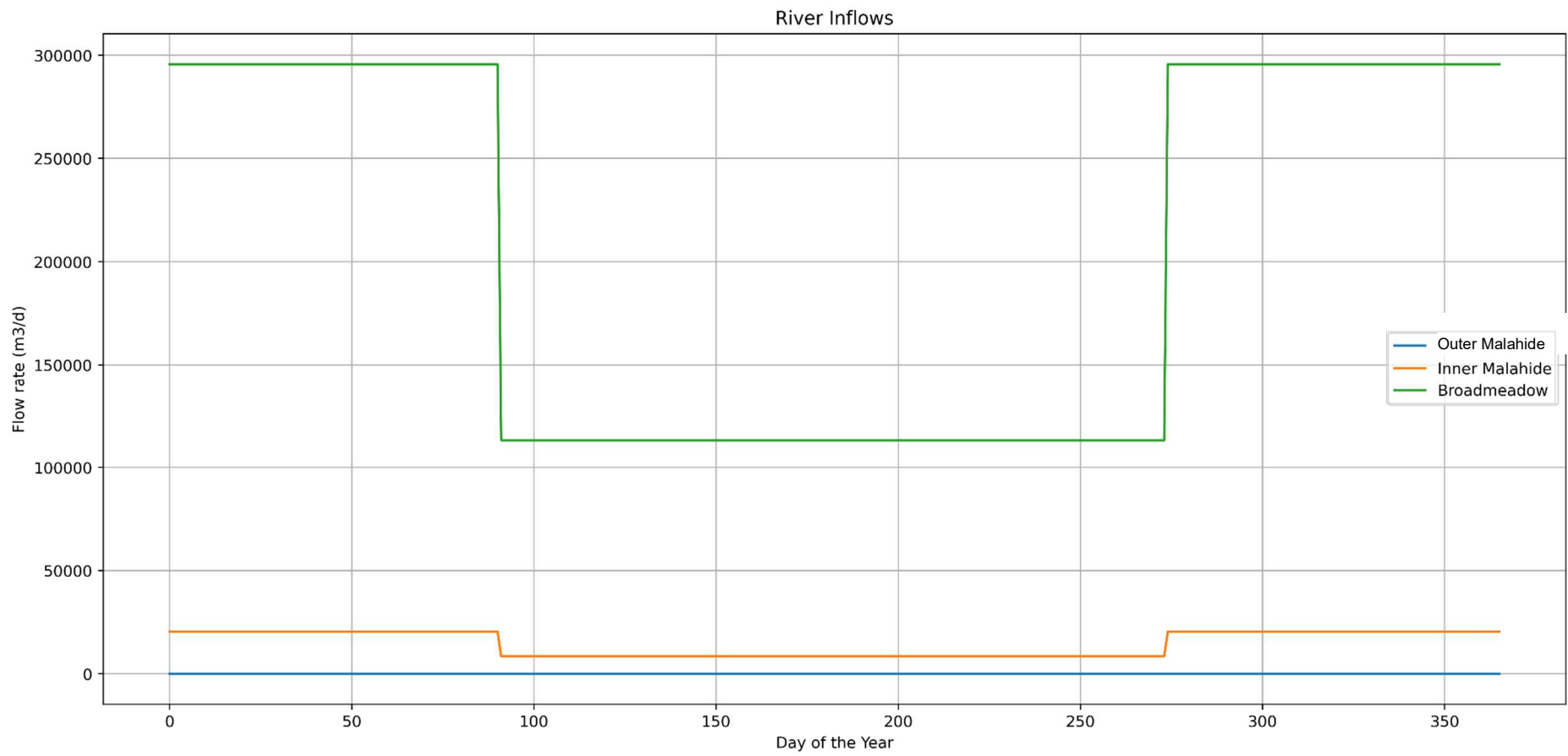


Figure 3 Freshwater Flows into the box model.

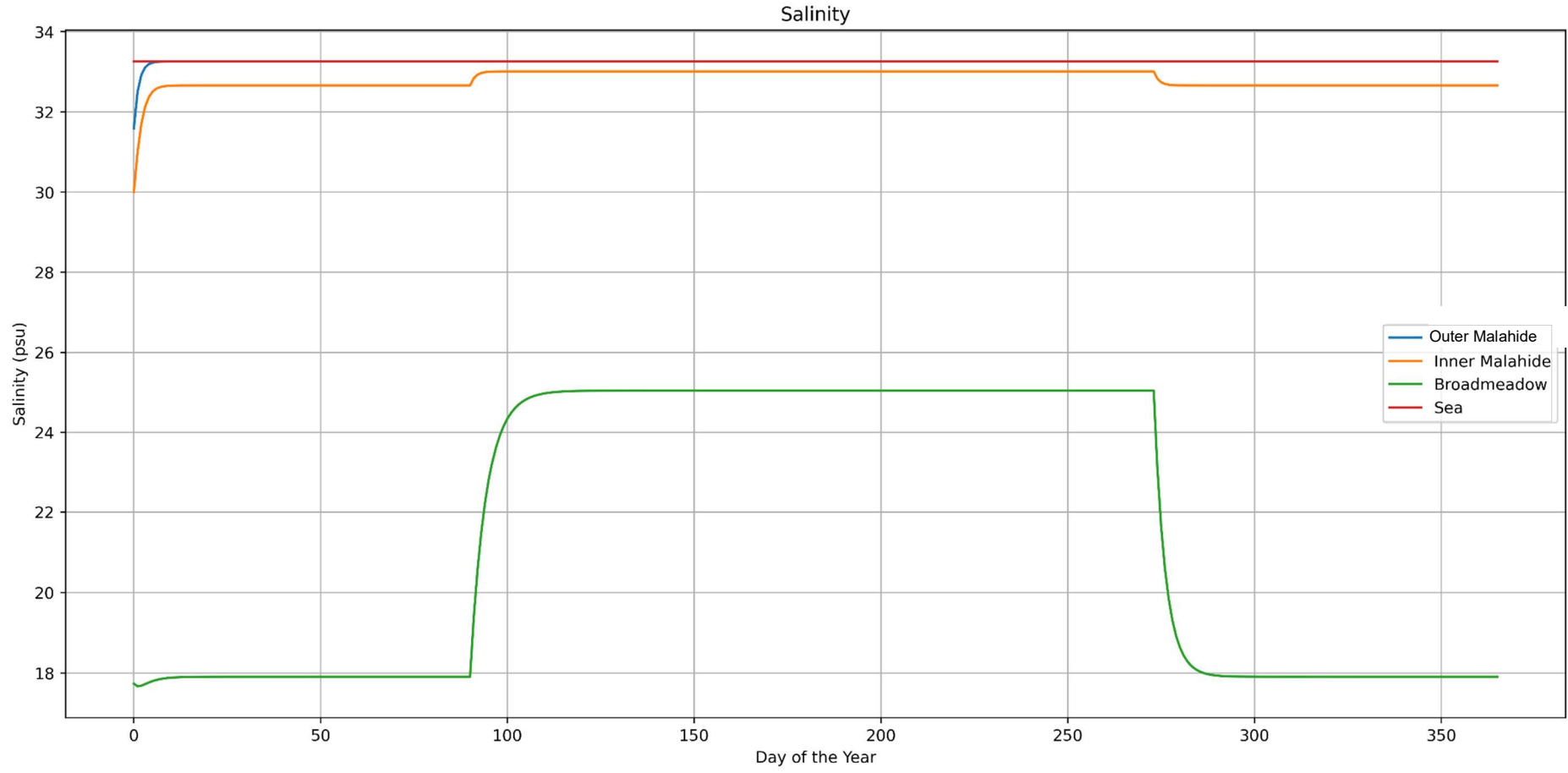


Figure 4 Modelled Salinity

3.3 Model Wastewater Loading Scenarios

Table 8 summarises the loading scenarios from Malahide WWTP used in the box modelling. The Malahide WWTP current provides tertiary treatment. The assessment was undertaken for five different loading scenarios.

Scenario 0 is a zero-discharge scenario, to provide baseline values to compare the other scenarios with. It is effectively the bay with the WWTP discharge removed.

Scenario 1a is based on the current Malahide WWTPs observed effluent flows and performance for DIN and MRP with a headroom of 20% applied to the current effluent performance to allow for occasional poorer episodes.

Scenario 1b is based on the current WWTPs observed effluent flows and stricter Article 5 level treatment standards for DIN and MRP.

Scenario 2a investigates the WWTPs projected 2035 effluent flows and the same effluent standards modelled in Scenario 1a.

Scenario 2b investigates the WWTPs projected 2035 effluent flows and the same effluent standards modelled in Scenario 1b.

The assessment calculates the rise in concentration in the boxes relative to no WWTP discharge as well as to calculate the absolute concentrations.

Table 8 Malahide Wastewater Loading Scenarios

Scenario Description	PE	Flows (l/s)	MRP (mg/l)	DIN (mg/l)	Daily Load MRP (kg/d)	Daily Load DIN (kg/d)	Annual Load MRP (kg/yr.)	Annual Load DIN (kg/yr.)
0 Baseline	0	0	-	-	0.0	0.0	0.0	0.0
Calibration (2021 observations)*	Used in calibration	71	2	11	12.3	67.5	4,481	24,646
1a Current flows with 20% headroom applied to effluent quality	21054	72	4	20	25.0	125.1	9,135	45,677
1b Current flows with Article 5 treatment	21054	72	1.8	14.5	11.3	90.7	4,111	33,116
2a 2035 growth flows with 20% headroom applied to effluent quality	25478	88	4	20	30.3	151.3	11,056	55,278
2b 2035 growth flows with Article 5 treatment	25478	88	1.8	14.5	13.6	109.7	4,975	40,076

3.4 Results

The results of the simulations for DIN and MRP are shown in Table 9 and Table 10 along with a compliance assessment. Table 11 and Table 12 show the differences between the two scenarios and the baseline scenario (zero discharge), showing how much the discharge from the WWTP increases the nutrient concentrations in the various boxes of the model.

Table 9 Modelled median DIN Concentrations in Malahide Bay with compliance assessment (A non-regulatory target in Broadmeadow)

Scenario	Determinant	Outer Malahide	Inner Malahide	Broadmeadow
Calibration	DIN_summer (mg/l)	0.06	0.06	0.46
0	DIN_summer (mg/l)	0.03	0.04	0.44
1a	DIN_summer (mg/l)	0.08	0.08	0.49
1b	DIN_summer (mg/l)	0.07	0.07	0.47
2a	DIN_summer (mg/l)	0.09	0.09	0.50
2b	DIN_summer (mg/l)	0.07	0.08	0.48
Salinity adjusted standards	DIN_summer (mg/l)	0.33	0.35	0.89*
Calibration	DIN_winter (mg/l)	0.22	0.23	0.75
0	DIN_winter (mg/l)	0.19	0.20	0.73
1a	DIN_winter (mg/l)	0.24	0.25	0.77
1b	DIN_winter (mg/l)	0.23	0.24	0.76
2a	DIN_winter (mg/l)	0.25	0.26	0.78
2b	DIN_winter (mg/l)	0.24	0.25	0.77
Salinity adjusted standards	DIN_winter (mg/l)	0.33	0.37	1.38*

Note: * This is a non-regulatory target, not an EQS

Table 10 Modelled MRP Concentrations in Malahide Bay with compliance assessment (A non-regulatory target in Malahide Bay)

Scenario	Determinant	Outer Malahide	Inner Malahide	Broadmeadow
Calibration	MRP_summer (mg/l)	0.015	0.015	0.069
0	MRP_summer (mg/l)	0.010	0.010	0.065
1a	MRP_summer (mg/l)	0.020	0.020	0.074
1b	MRP_summer (mg/l)	0.014	0.014	0.069
2a	MRP_summer (mg/l)	0.022	0.022	0.076
2b	MRP_summer (mg/l)	0.015	0.015	0.070
Salinity adjusted standards	MRP_summer (mg/l)	0.042*	0.042*	0.051
Calibration	MRP_winter (mg/l)	0.029	0.029	0.080
0	MRP_winter (mg/l)	0.024	0.024	0.076
1a	MRP_winter (mg/l)	0.034	0.033	0.084
1b	MRP_winter (mg/l)	0.028	0.028	0.080
2a	MRP_winter (mg/l)	0.036	0.035	0.086

2b	MRP_winter (mg/l)	0.029	0.029	0.080
Salinity adjusted standards	MRP_winter (mg/l)	0.042*	0.043*	0.059

Note: * This is a non-regulatory target, not an EQS

Table 11 Modelled Changes in DIN Concentrations in the Malahide Estuary because of the different WWTP discharges.

Assessment	Season	Outer Malahide (mg/l)	Inner Malahide (mg/l)	Broadmeadow (mg/l)*
scenario 1a	Summer	0.049	0.049	0.047
scenario 1a	Winter	0.049	0.048	0.041
scenario 1b	Summer	0.036	0.035	0.034
scenario 1b	Winter	0.036	0.035	0.030
scenario 2a	Summer	0.059	0.059	0.057
scenario 2a	Winter	0.059	0.058	0.050
scenario 2b	Summer	0.043	0.043	0.041
scenario 2b	Winter	0.043	0.042	0.036

Note: * This is a non-regulatory target, not an EQS

Table 12 Modelled Changes in MRP Concentrations in the Malahide Estuary because of the different WWTP discharges.

Assessment	Season	Out Malahide (mg/l)*	Inner Malahide (mg/l)*	Broadmeadow (mg/l)
scenario 1a	Summer	0.010	0.010	0.009
scenario 1a	Winter	0.010	0.010	0.008
scenario 1b	Summer	0.004	0.004	0.004
scenario 1b	Winter	0.004	0.004	0.004
scenario 2a	Summer	0.012	0.012	0.011
scenario 2a	Winter	0.012	0.012	0.010
scenario 2b	Summer	0.005	0.005	0.005
scenario 2b	Winter	0.005	0.005	0.005

Note: * This is a non-regulatory target, not an EQS

The rises due to the WWTP discharge are above typical limits of detection, 0.007 mg/l N for TA and TON the components of DIN and 0.001 mg/l P for MRP (NWQMC, 2007). The absolute changes resulting from the wastewater discharges are higher than the limits of detection for both scenarios.

The data analysis shows that the WWTP currently does not exceed the EQS for DIN in Malahide Bay. The modelling shows that even under the largest loading scenario (2a) with growth and with current treatment performance the estuary will meet the EQS for DIN and the non-regulatory target for MRP.

The data analysis and model calibration suggest that Broadmeadow Water fails its EQS for MRP in both winter and summer although this is difficult to state with confidence because the water quality is so spatially variable and additionally as noted in Section 3.2. the modelled MRP values obtained during the calibration process are conservatively higher than observed values in the Broadmeadow water. The Malahide WWTP under the various scenarios does make a small contribution to the rise in nutrients but this is small, ranging between 3-15%.

The modelling demonstrates that the WWTP has an observable impact on all three boxes, though the impact is greater in the Inner and Outer Malahide Bay boxes.

4 The impact of Malahide WWTP on macro-algae Loads within Malahide Bay

Opportunistic Macroalgae are a component of the Trophic Status Assessment Scheme and are the only parameter currently failing to achieve at least good status in Malahide Bay per the most recent assessment which recorded an Ecological Quality Ratio (EQR) of 0.456 versus a Good Status limit of 0.6 (this represents a failure by approximately 24%). It is understood that *Ulva* sp. form the vast majority of the opportunistic macroalgae in Malahide bay per the findings of Wan et al (2017).

This section of the report investigates the impact different options for operating Malahide WWTP will have on macroalgae communities in Malahide Bay, more specifically Inner Malahide Bay, as shown in Figure 1 above.

As earlier mentioned, RHS were unable to obtain the DCPM model from the developers the UK Environment Agency and CEFAS. DCPM is a complex multiparameter model and therefore difficult to apply with any confidence to a surface water body without doing extensive survey work measuring many parameters. Consequently, a simple method to estimate the potential for macroalgae biomass production in Malahide Bay was developed. These estimates are likely to be a significant over-estimate as they assume that all available nutrients are bioavailable and converted into biomass, growth is not seasonally limited, all the biomass has substrate to grow on and none of it is predated by herbivores.

4.1 Macro-algae Modelling Methodology

The box model presented in Section 3 was used to determine the daily mean concentration DIN and MRP in the three boxes of the model.

The area of specific interest to this note is Malahide Bay represented by the Inner Malahide Box. The following macroalgae biomass production modelling steps were undertaken:

- The total load of nutrients available in the bay to produce macroalgae was assumed to be the product of the average volume of the box and the mean daily concentration.
- It is assumed that MRP is equivalent to the total amount of bioavailable phosphorus (P) and DIN is equivalent to the total amount of bioavailable nitrogen (N).
- A check was done to see which was the limiting nutrient, this assumed that the internal N:P ratio of most macroalgae was 30:1 based on the findings of Atkinson et al (1983). Therefore, if the N:P ratio is less than 30 the *Ulva* sp. production is going to be limited by N.
- Where N was the limiting nutrient, the potential dry weight of *Ulva* sp. was calculated assuming N is 3.5% of *Ulva* tissue as dry weight per Fong et al (1994). So 1 kg of DIN yields 28.6 kg of dry macroalgae biomass.
- The modelled median DIN and MRP concentrations resulting from the four WWTP scenarios presented in Tables 9 and 10 respectively were processed to generate resultant potential macroalgae biomass production. The modelling produced a median concentration, but because the scenarios run were simple the median and the mean concentrations are the same.
- The differences in potential macroalgae biomass production were compared.

As earlier mentioned, these macroalgae biomass production estimates are likely to be a significant over-estimate as they assume that all available nutrients are bioavailable and converted into biomass, growth is not seasonally limited, all the biomass has substrate to grow on and none of it is predated by herbivores. Notwithstanding this it is assumed that since these assumptions are applied proportionally for each scenario this macroalgae assessment represents a reasonable means of comparison between the various scenarios.

The volume and area of the Inner Malahide Bay is presented in Table 13. This was utilised in combination with the modelled median DIN and MRP concentrations resulting from the four WWTP scenarios presented in Table 14 and the macroalgae biomass production model generated for this study to determine the potential biomass generation figures for the different operational scenarios, run in the box modelling. The calculated potential macroalgae biomass generation figures are outlined in Table 15.

Table 13 Modelled characteristics of Inner Malahide Bay

Parameter	Inner Malahide	Unit
Average Volume	1,522,000	m ³
Average Area	1,667,000	m ²
Average depth	0.91	m

Table 14 Modelled median DIN and MRP concentrations and resultant N:P Ratios

Season	Scenario 1a Current flows with 20% headroom applied to effluent quality	Scenario 1b Current flows with Article 5 treatment	Scenario 2a 2035 Growth flows with 20% headroom applied to effluent quality	Scenario 2b 2035 Growth flows with Article 5 treatment
MRP Concentration (mg/l)				
Winter	0.033	0.028	0.035	0.029
Summer	0.020	0.014	0.022	0.015
DIN Concentration (mg/l)				
Winter	0.25	0.24	0.26	0.25
Summer	0.08	0.07	0.09	0.08
N:P Ratio				
Winter	7.6	8.6	7.4	8.6
Summer	4.0	5.0	4.1	5.3

As shown in Table 14 the N:P ratio is consistently <30 therefore the system is N limited and the potential Ulva Sp. Macroalgae load generation is dependent on the available quantity of DIN. The annual Ulva sp. Macroalgae load generated was calculated as follows:

- Annual DIN Load =

$$\frac{\text{Mean Volume} \times (\text{Median DIN Summer Concentration} + \text{Median DIN Winter Concentration}) \times 365}{2}$$

- As N was determined to be system limiting an assumption was made that every kg of DIN load equates to the generation of 28.57kg of Ulva sp. Macroalgae load (this is based on the assumption per Fong et al (1994) that DIN comprises 3.5% of Ulva Sp. Dry tissue weight).

4.2 Macro-algae Modelling Results

The calculated Ulva Sp. Macroalgae loads generated are outlined in Table 15 below.

Table 15 Potential macroalgae biomass generation figures

Parameter	Scenario 1a Current flows with 20% headroom applied to effluent quality	Scenario 1b Current flows with Article 5 treatment	Scenario 2a 2035 Growth flows with 20% headroom applied to effluent quality	Scenario 2b 2035 Growth flows with Article 5 treatment
Annual load of DIN in Inner Malahide Bay (kg)	91,662	86,107	97,218	91,662
Annual load of Ulva Sp. In Inner Malahide Bay (kg Dry weight)	2,618,927	2,460,204	2,777,650	2,618,927
%age reduction In Ulva Sp. Loads with Article 5 treatment	N/A	6.1%	N/A	5.7%

As demonstrated in Table 15 the addition of Article 5 treatment at Malahide WWTP is estimated to reduce potential macroalgae biomass loads in Malahide Bay by only approximately 6%. Based on the most recent TSAS assessment by the EPA a 6% improvement would not alter the classification of Malahide Bay for opportunistic algae, which is currently failing the target EQR by 24%. It is once again noted that the projected macroalgae biomass production figures are likely to be conservatively high.

5 Conclusions

A box model of the Malahide Bay coastal water and the Broadmeadow Water, transitional waters in Fingal, County Dublin has been applied and used to investigate concentrations within the waterbodies arising from effluent discharges associated with the scenarios listed in Table 8 from Malahide WWTP. The following conclusions have been made.

- Nutrient level in Malahide Bay currently do not exceed the EQS for DIN and non-regulatory target value for MRP.
- The proposed future operational scenarios for Malahide WWTP will not result in an exceedance in the Winter or Summer EQS's for DIN and non-regulatory targets for MRP in Malahide Bay. Nutrient concentrations are higher in winter.
- The Malahide WWTP currently (based on the modelled outputs) provides 13% (winter) & 50% (summer) of the total DIN load and 17% (winter) & 33% (summer) of the total MRP load to Malahide Bay. It is notable that the higher proportional contributions are in summer when there is currently 95% and 77% assimilative capacity headroom for observed DIN and MRP concentrations respectively.
- The N:P ratio in the effluent is smaller than 30:1 so the DIN loads are the limiting factor on the growth of *Ulva* macro algae in Malahide Bay.
- The addition of Article 5 treatment at Malahide WWTP is estimated to reduce potential macroalgae biomass loads in Malahide Bay by only approximately 6%.
- A potential 6% reduction in macroalgae biomass load would have no effect on the overall trophic status of the Malahide Bay. Based on the most recent TSAS assessment by the EPA a 6% improvement would not alter the classification of Malahide Bay for opportunistic algae, which is currently failing the target EQR by 24%.
- Uisce Éireann can be satisfied that there would be no effect on the trophic status as a result of more stringent removal of nutrients as set out in Article 5 of the UWWTD.
- There are significant costs associated with upgrading and operating the treatment works to implement more stringent removal of nutrients, including CAPEX, OPEX, energy consumption and embodied carbon.
- **The upgrade of the works to provide more stringent removal of nutrients at Malahide WWTP is not recommended. This is in accordance with section 4.(4)b of SI 254/2001:**
 - *Sub-article (3) shall not operate to require the reduction of nutrients in discharges to estuaries, bays or coastal waters where the sanitary authority is satisfied that such reduction will have no effect on the level of eutrophication in the receiving waters.*

6 References

- Aldridge J.A., Painting S.J., Mills D.K., Tett P., Foden J. and Winpenny K., The Combined Phytoplankton and Macroalgae (CPM) Model: predicting the biological response to nutrient inputs in different types of estuaries in England and Wales, CEFAS Technical Report C1882. 2014
- Aldridge J.A., Painting S.J., Tett P., Capuzzo E., Mills D.K., The Dynamic Combined Phytoplankton and Macroalgae (CPM) Model, version 2.0 April 2013.
- Alex H. L. Wan, Robert J. Wilkes, Svenja Heesch, Ricardo Bermejo, Mark P. Johnson, Liam Morrison, Assessment and Characterisation of Ireland's Green Tides (*Ulva* Species), 2017.
- DHI (2017). MIKE 21 Flow Model FM - Hydrodynamic Module User Guide. DHI Group, Hørsholm.
- M. J. Atkinson, S. V. Smith, C:N:P ratios of benthic marine plants, 1983.
- McGovern Joseph V., Nash Stephen, Hartnett Michael, Modelling Irish Transitional and Coastal Systems to Determine Nutrient Reduction Measures to Achieve Good Status, EPA Research Report No. 359. 2015-W-FS-17, November 2020. [https://www.epa.ie/publications/research/water/Research_Report_359_.pdf accessed Oct 2021]
- McGovern Joseph V., Nash Stephen, Hartnett Michael, Interannual Improvement in Sea Lettuce Blooms in an Agricultural Catchment, *Frontiers in Marine Science*, Vol 6, 2019, [<https://www.frontiersin.org/article/10.3389/fmars.2019.00064> accessed June 2021].
- National Water Quality Monitoring Council (NWQMC), Nutrient Requirements for the National Water Quality Monitoring Network for U.S., Coastal Waters and their Tributaries, November 13, 2007 [<https://acwi.gov/monitoring/network/nutrients.pdf> accessed April 2022]
- Peggy Fong, Regina M. Donohoe and Joy B. Zedler, Nutrient concentration in tissue of the macroalga *Enteromorpha* as a function of nutrient history: an experimental evaluation using field microcosms, 1994.
- Ryan Hanley Stantec (RHS), Estimating the potential for opportunist macroalgae in Malahide Bay, Memo No.1, November 17, 2021.
- Ryan Hanley Stantec (RHS), Marine Water Quality Modelling Run No. 1 Results, Memo No.2, November 17, 2022
- Atkinson, M.S., V. Smith .1983. C: N:P ratios of benthic marine plants. *Limnology and Oceanography*. Volume 28, Issue 3 p. 568-574
- Wan AHL, Wilkes RJ, Heesch S, Bermejo R, Johnson MP, Morrison L (2017) Assessment and Characterisation of Ireland's Green Tides (*Ulva* Species). *PLoS ONE* 12(1): e0169049. [<https://doi.org/10.1371/journal.pone.0169049> accessed April 2022]

**Addendum i: Ambient Monitoring Data Review,
Contextualisation of Total DIN Loads being discharged to
Malahide Bay & Macro-Algae Modelling Approach
Discussion**



**19/062-004 Lot 2 Engineering Design Services for Malahide
WWTP Upgrade**

**NUTRIENT BOX MODELLING REPORT ADDENDUM: AMBIENT
MONITORING DATA REVIEW, CONTEXTUALISATION OF TOTAL DIN
LOADINGS BEING DISCHARGED TO MALAHIDE BAY & MACRO-ALGAE
MODELLING APPROACH DISCUSSION**

MAY 2024

RYAN HANLEY



Stantec

Client	Uisce Éireann
Project No.	6013
Project Title	19/062-004 Lot 2 Engineering Design Services for Malahide WWTP Upgrade
Report Title	NUTRIENT BOX MODELLING REPORT ADDENDUM: AMBIENT MONITORING DATA REVIEW, CONTEXTUALISATION OF TOTAL DIN LOADINGS BEING DISCHARGED TO MALAHIDE BAY & MACRO-ALGAE MODELLING APPROACH DISCUSSION

Rev.	Status	Author(s)	Reviewed By	Approved By	Issue Date
0	Draft	JP Creavin / R Norreys	JP Creavin / R Norreys (Peer Review)	P Scally	May 2024
1	Final	JP Creavin / R Norreys	JP Creavin / R Norreys (Peer Review)	P Scally	May 2024

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1. Ambient Monitoring Data Review

The Malahide Bay Nutrient Box Model utilised available EPA monitoring data covering the period 2018-2022 in order to ensure that the Box Model was calibrated/validated to most current conditions (at the time of Box Model development) as opposed to historical conditions which it was felt may not be fully representative of the nutrient loading within the Broadmeadow river, Broadmeadow estuary and Malahide Bay. A summary of potentially significant changes within the overall catchment system is presented below (beginning upstream within the Broadmeadow river) and working downstream to Malahide Bay.

1.1. Review of DIN/MRP Ambient Monitoring data at Monitoring Station RS08B020800 on the Broadmeadow River (located approximately 0.9km upstream of the Swords WWTP Discharge Pt.)

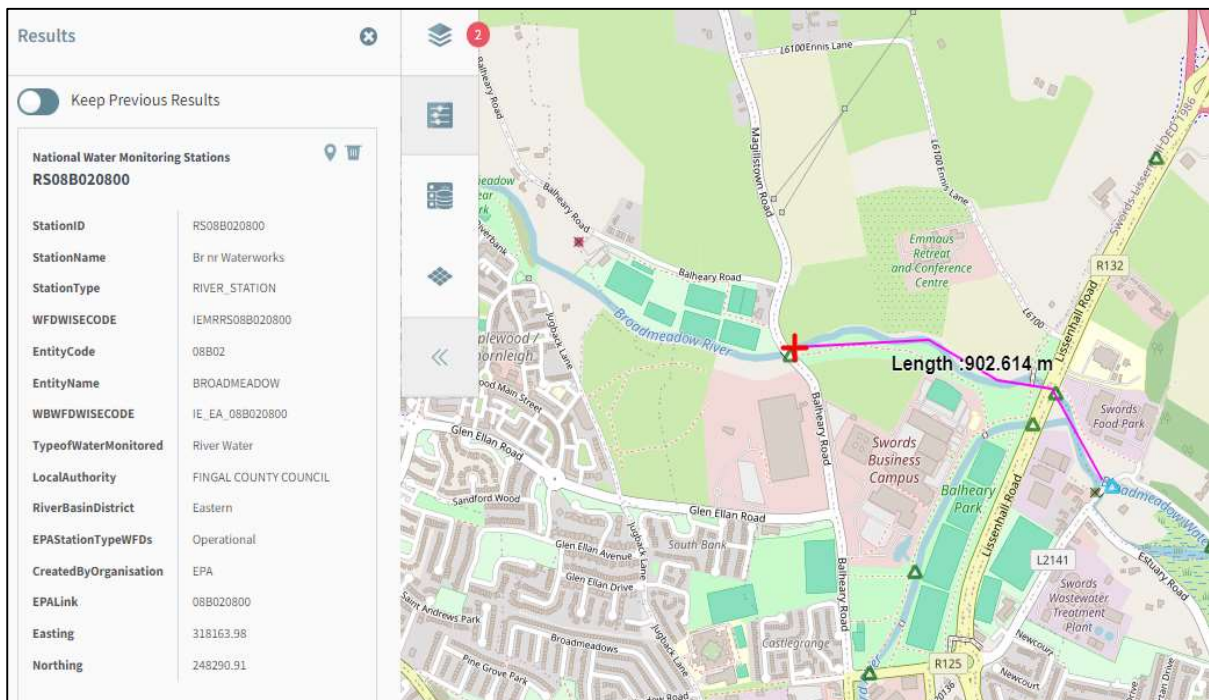


Figure 1: Monitoring Station RS08B020800 (red Crosshair), Swords WWTP Primary Discharge Point (SW1) located 902.6m downstream

As shown in Figures 2-5 below the general nutrient concentrations trend for DIN and MRP has been slightly upwards between 2007 and 2024 with the exception of Winter DIN which has shown a slight reduction.

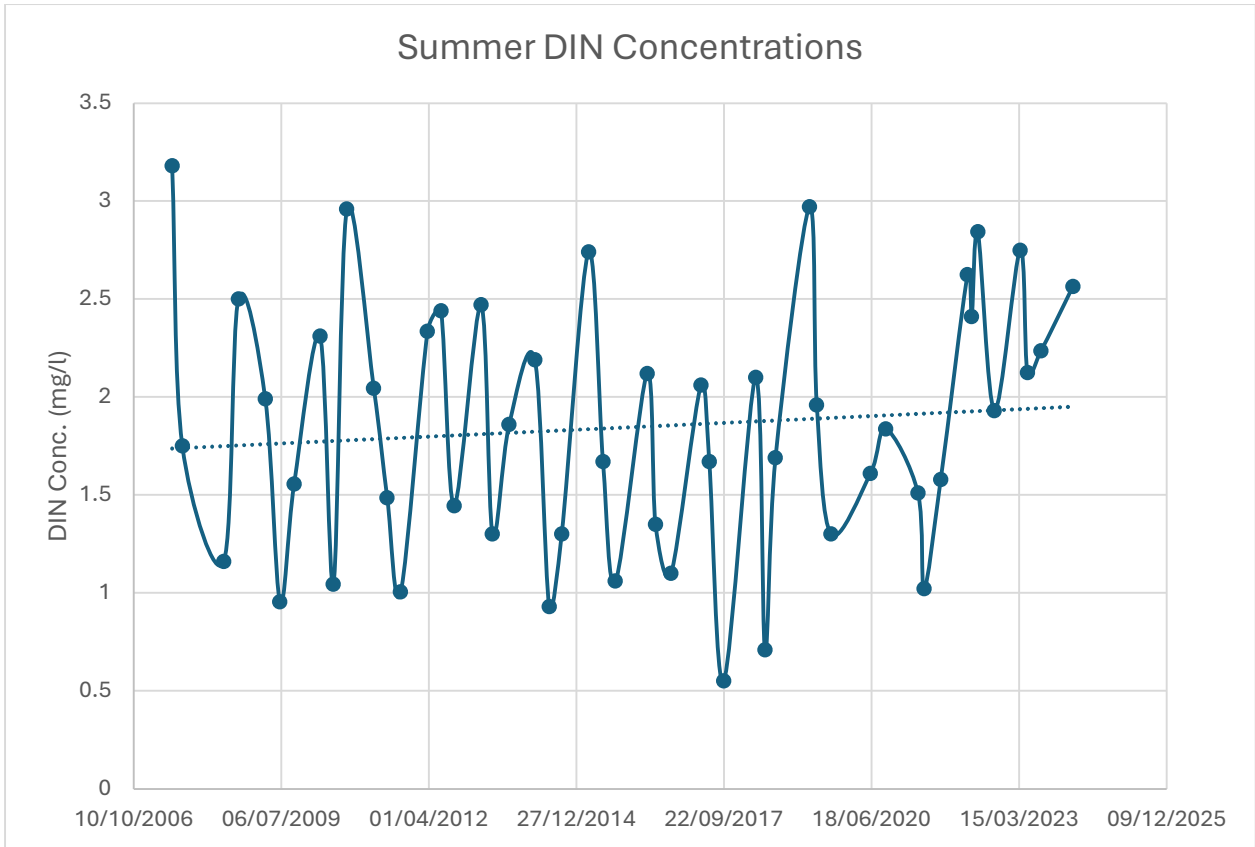


Figure 2: Summer DIN Trend at Monitoring Station RS08B020800 on the Broadmeadow River

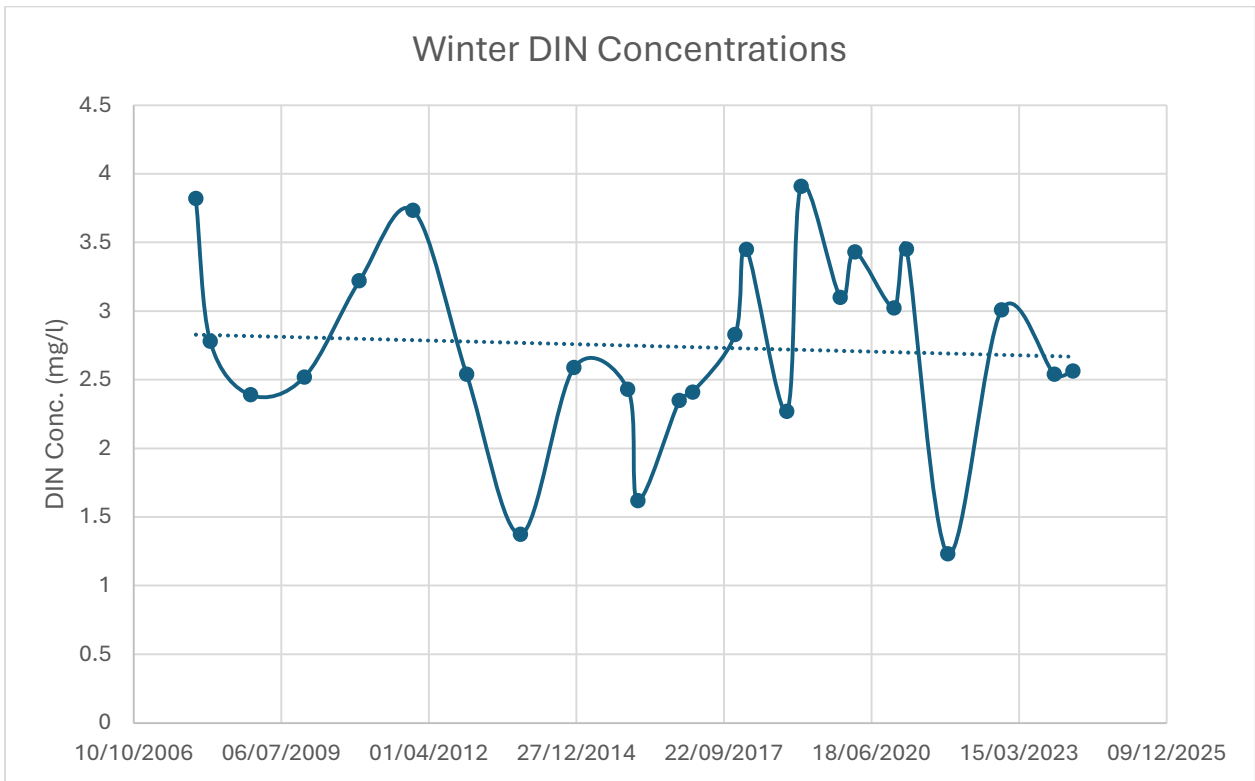


Figure 3: Winter DIN Trend at Monitoring Station RS08B020800 on the Broadmeadow River

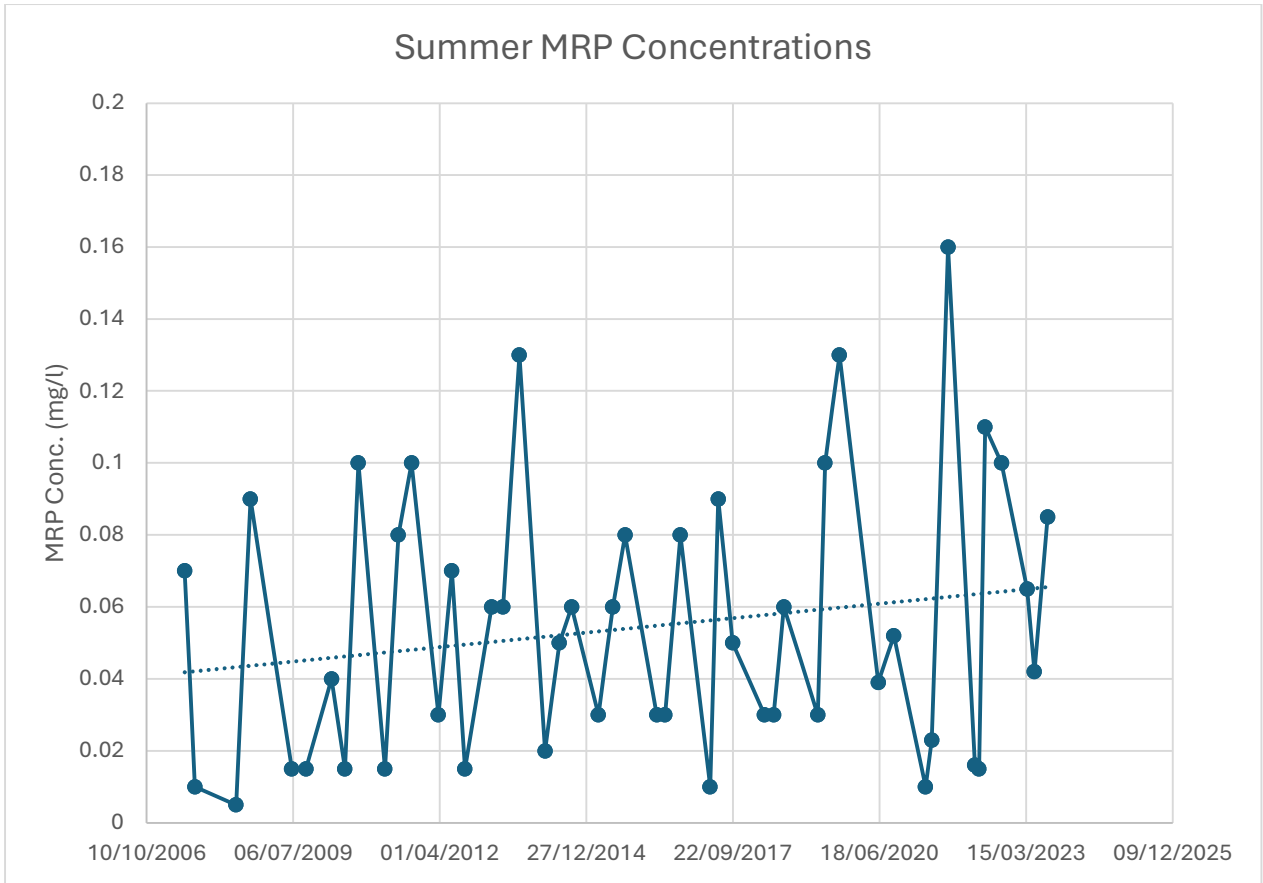


Figure 4: Summer MRP Trend at Monitoring Station RS08B020800 on the Broadmeadow River

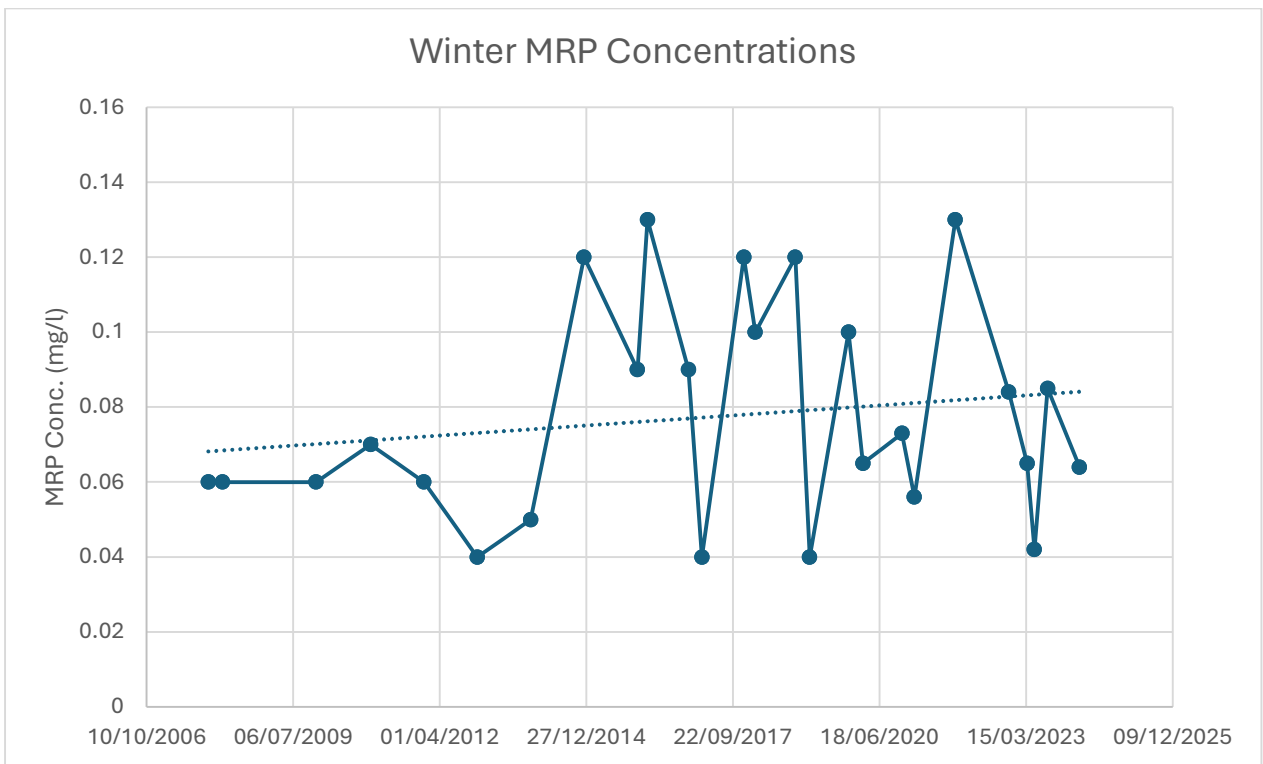


Figure 5: Winter MRP Trend at Monitoring Station RS08B020800 on the Broadmeadow River

The Broadmeadow_040 WFD River waterbody is assigned as moderate status with two identified significant pressure sub-categories in the form of Farmyards and Agriculture per the Broadmeadow's WFD Cycle 2 sub-catchment report. Based on the increase in agricultural activity nationally and generally ongoing deterioration in water quality it was felt appropriate to use recent data to validate the box model.

Furthermore, it is noted that the two most major towns upstream of the analysed monitoring Station RS08B020800 of Ashbourne and Rathoath (respective Populations of 15,680 and 10,077) which have both experienced rapid population growth since the 1991 census have their wastewater treated at the Ringsend WWTP and thus should not be contributing in any meaningful way to the nutrient loading of the Broadmeadow river.

1.2. Review of DIN Loading from Swords WWTP

As shown in Figure 6 below there has been a slightly upward trend in DIN load emission from the Swords WWTP. It is hypothesised that this general upward trend is associated with requirements for Uisce Éireann (UÉ) to conduct aeration upgrades at the WWTP and consequent slightly poorer episodes of DIN quality in the final effluent. UÉ are engaging with the EPA's Office of Environmental Enforcement in respects to an aeration upgrade project.

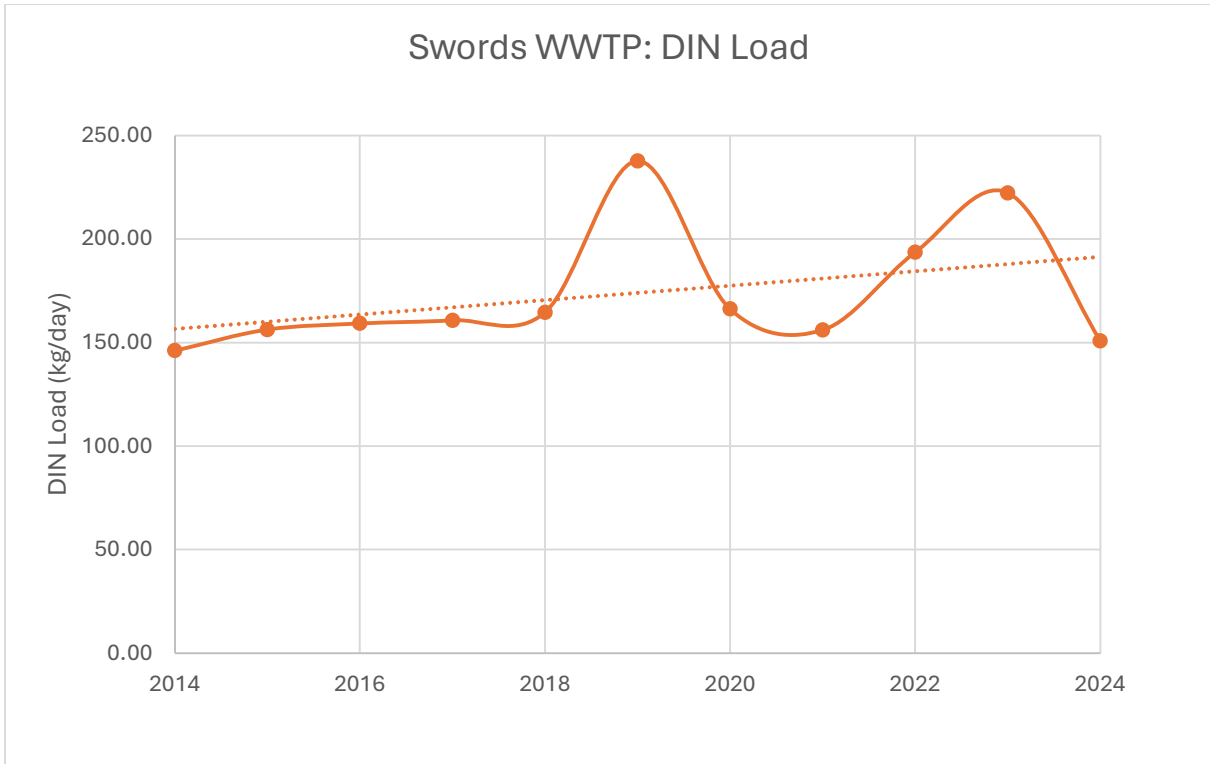


Figure 6: Daily DIN Load from Swords WWTP

1.3. Review of MRP Loading from Swords WWTP

As shown in Figure 7 below there has been a slightly downward trend in MRP load emission from the Swords WWTP between 2014 and 2024. It is hypothesised that this general downward trend is associated with the commissioning of enhanced MRP nutrient reduction as part of the Swords WWTP Phase 2A Expansion project commissioned in 2017.

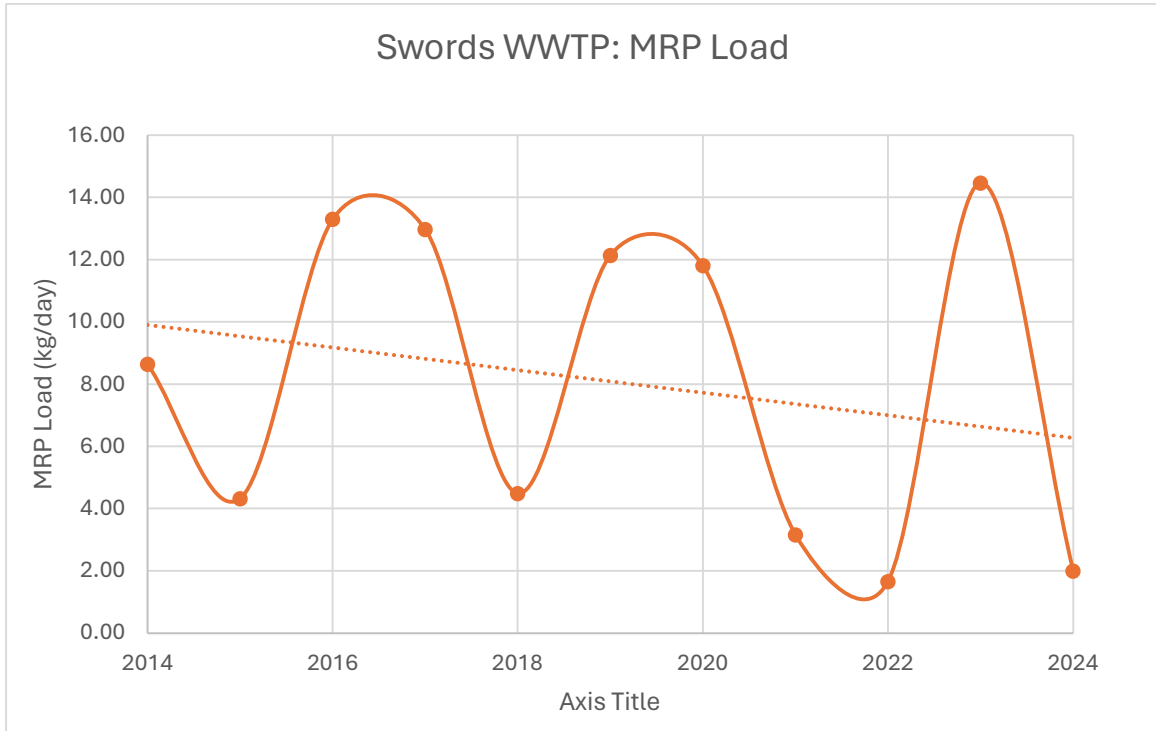


Figure 7: Average Daily MRP Load from Swords WWTP

1.4. Review of DIN/MRP Ambient Monitoring data at Monitoring Station BM130 on the Broadmeadow Estuary (located approximately 1.8km downstream of the Swords WWTP Primary Discharge Pt. SW001)



Figure 8: Monitoring Station BM130 (red Crosshair), Swords WWTP Primary Discharge Point (SW1) located 1.779km upstream

As shown below in Figures 9-12 below the general nutrient concentrations trend for Summer DIN and MRP has been slightly upwards between 2013 and 2024 while the general trend for Winter DIN and MRP has shown a slight reduction.

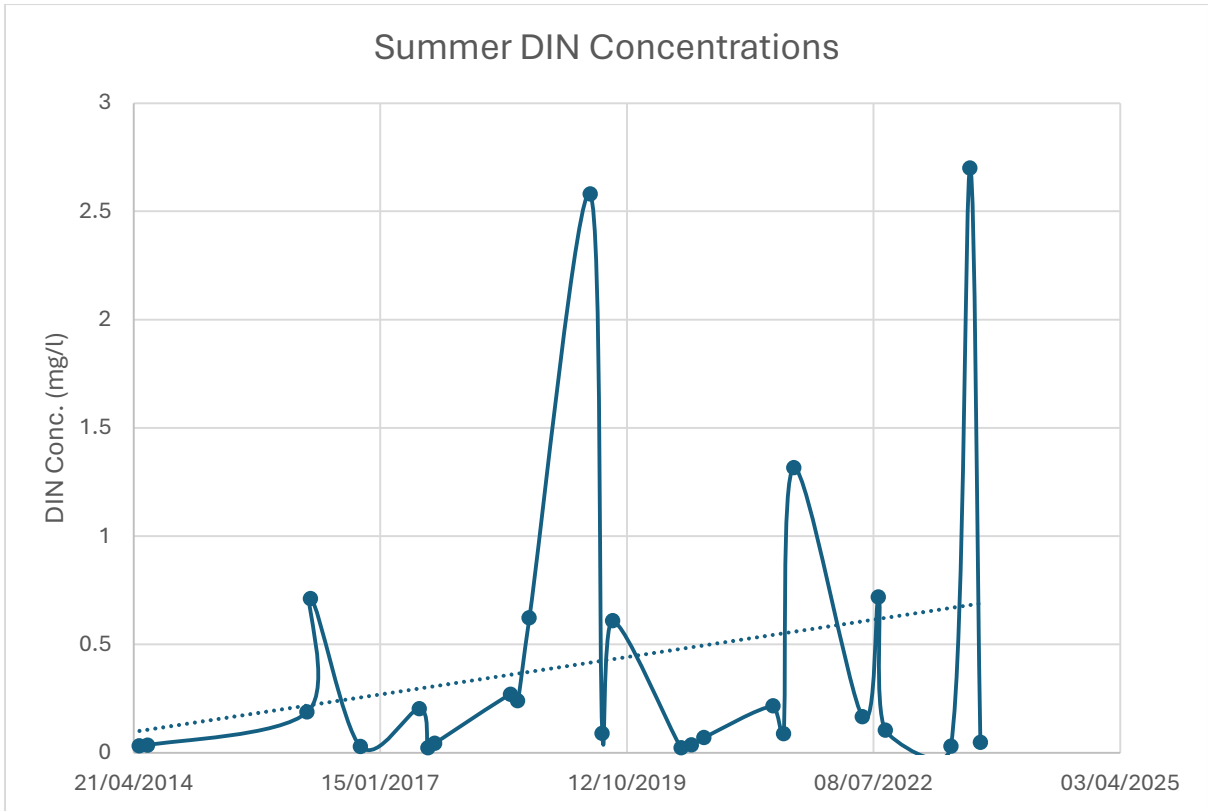


Figure 9: Summer DIN Trend at Monitoring Station BM130 on the Broadmeadow Estuary

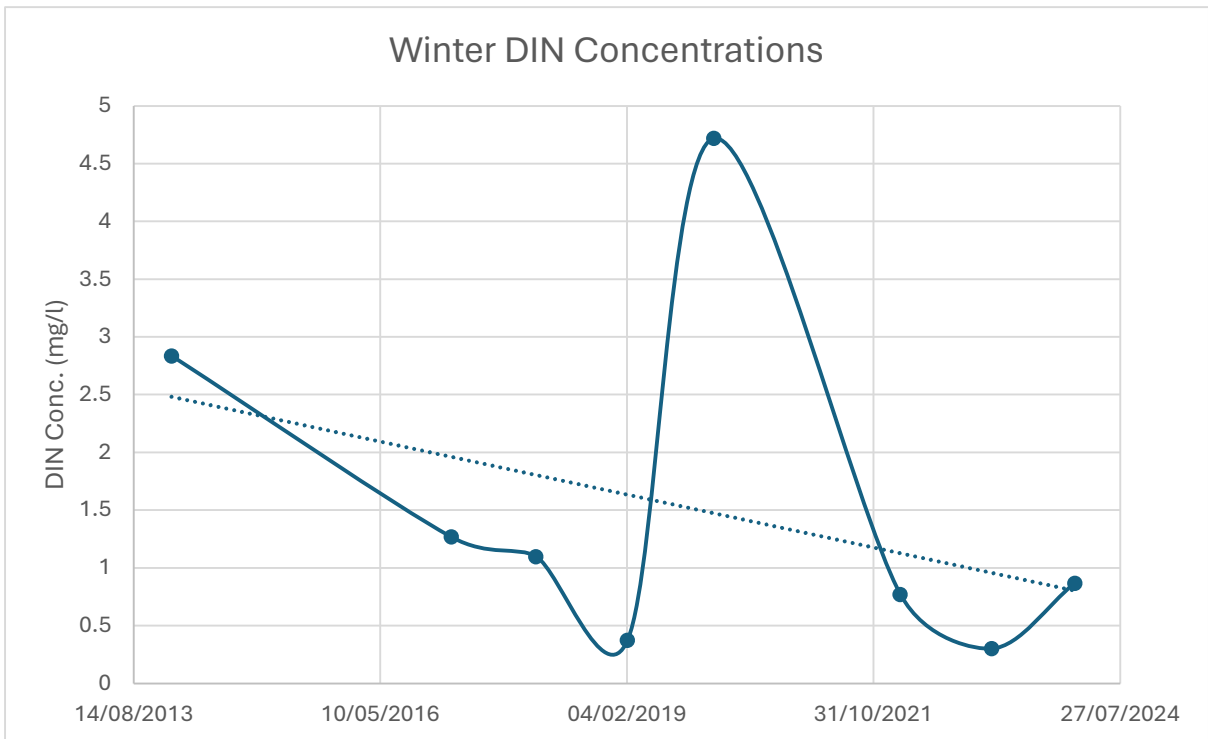


Figure 10: Winter DIN Trend at Monitoring Station BM130 on the Broadmeadow Estuary

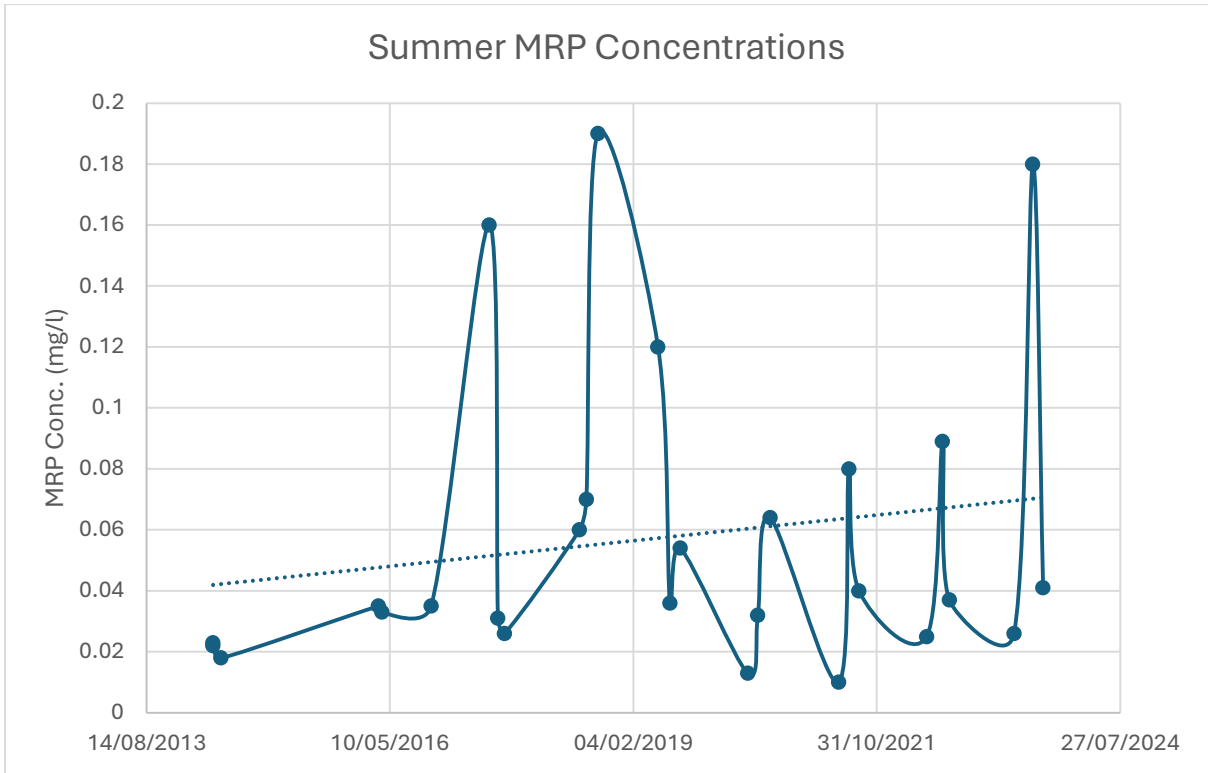


Figure 11: Summer MRP Trend at Monitoring Station BM130 on the Broadmeadow Estuary

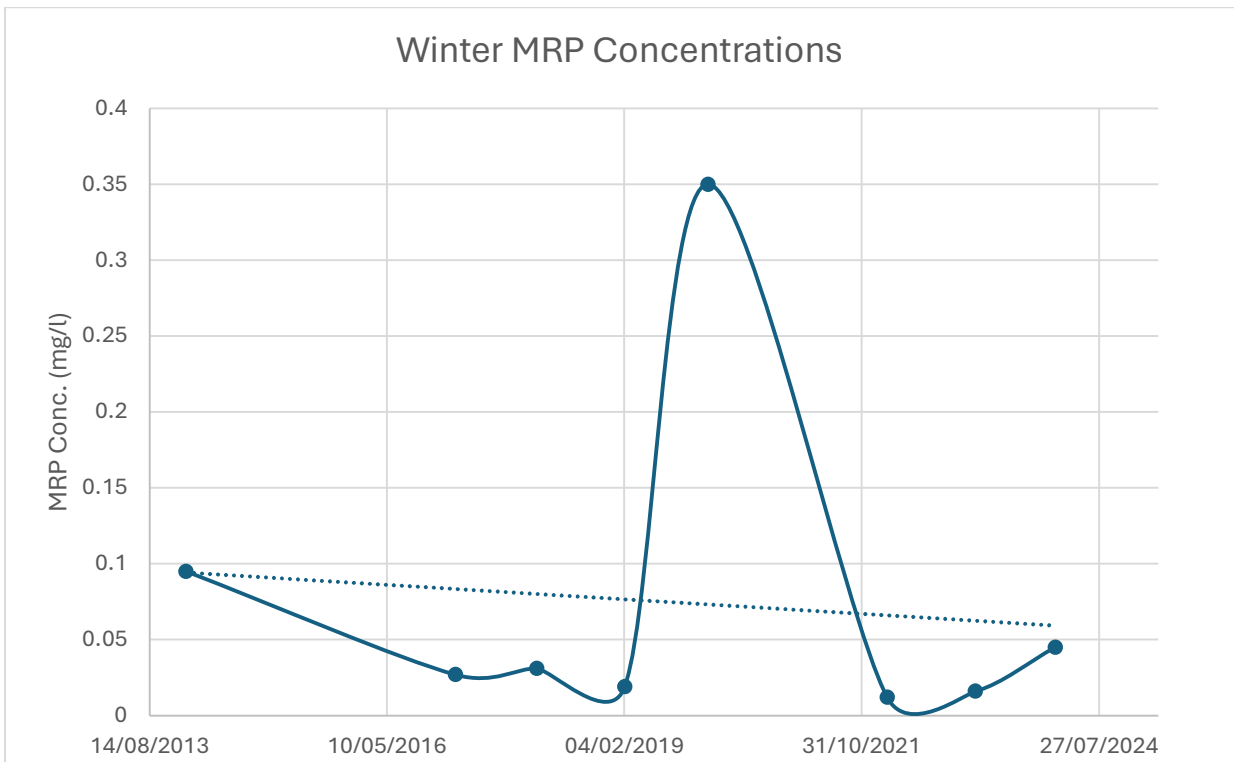


Figure 12: Winter MRP Trend at Monitoring Station BM130 on the Broadmeadow Estuary

1.5. Review of DIN Loading from Malahide WWTP

As shown in Figure 13 below there has been a slightly downward trend in DIN load emission from the Malahide WWTP. It is noted that the DIN loading is very consistent with the exception of 2016 when issues were noted with the blowers onsite per the 2016 AER which were quickly remedied.

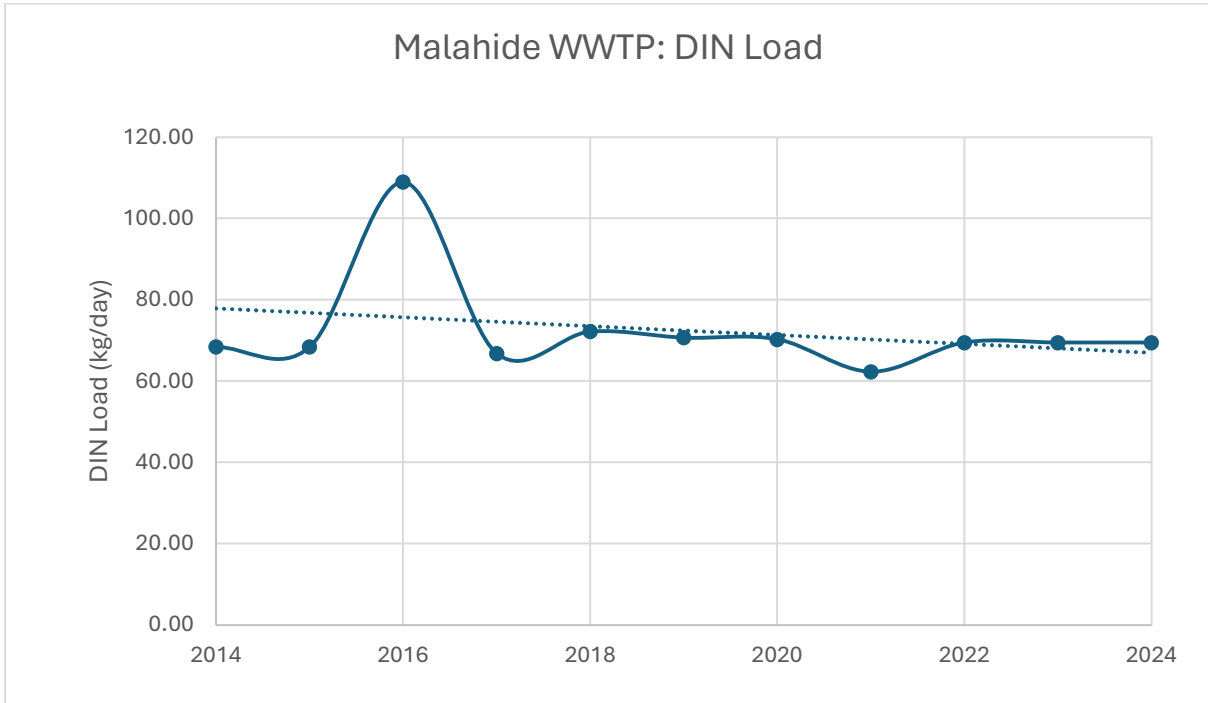


Figure 13: Daily DIN Load from Malahide WWTP

1.6. Review of MRP Loading from Malahide WWTP

As shown in Figure 14 below there has been a significant downward trend in MRP load emission from the Malahide WWTP.

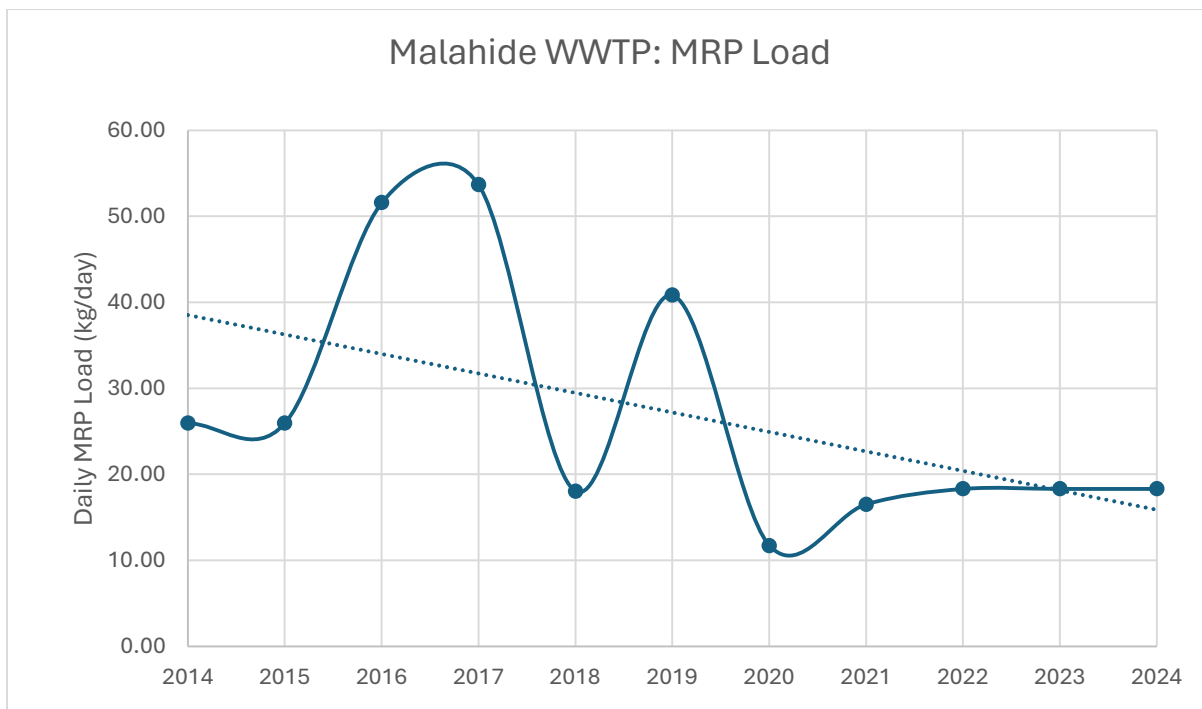


Figure 14: Daily MRP Load from Malahide WWTP

1.7. Review of DIN/MRP Ambient Monitoring data at Monitoring Stations BM210/220/230 in Malahide Bay

As shown below in Figures 15-18 below the general nutrient concentrations trend for Summer and Winter DIN and Summer MRP has been significantly downwards between 2013 and 2023 while the general trend for Winter MRP has been flat.

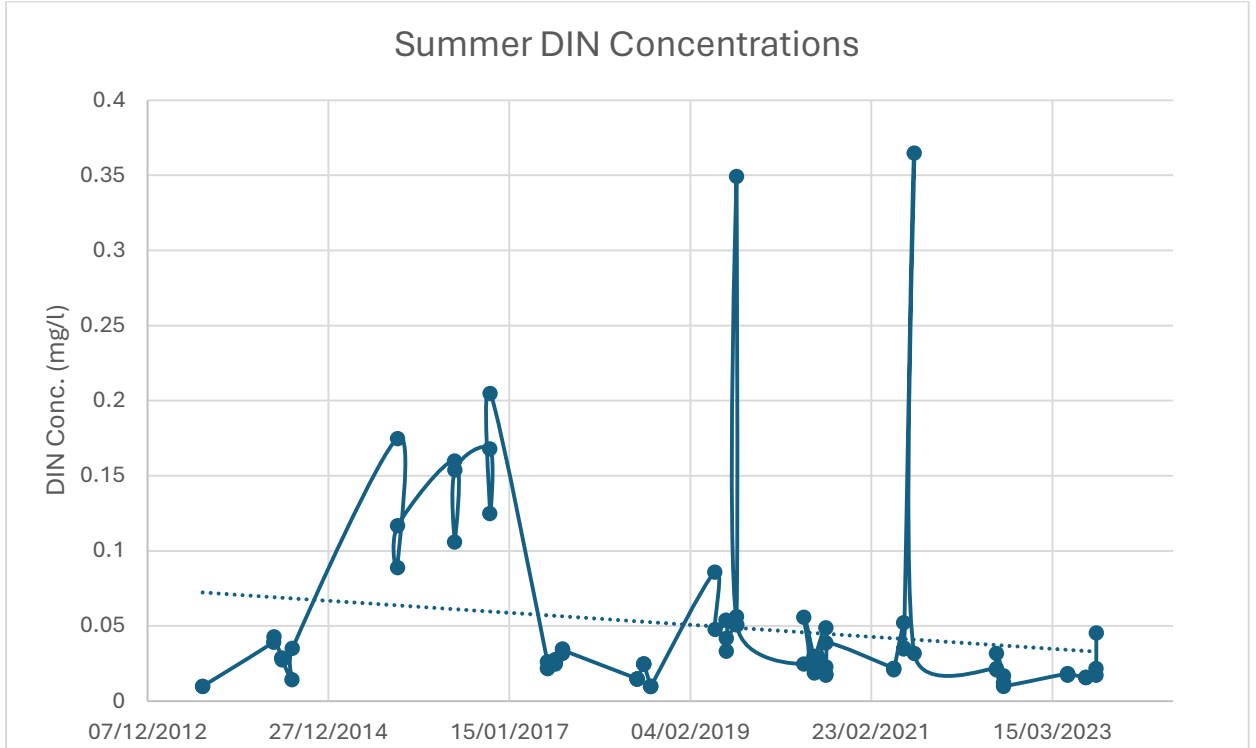


Figure 15: Summer DIN Trend at Monitoring Stations BM210/220/230 in Malahide Bay

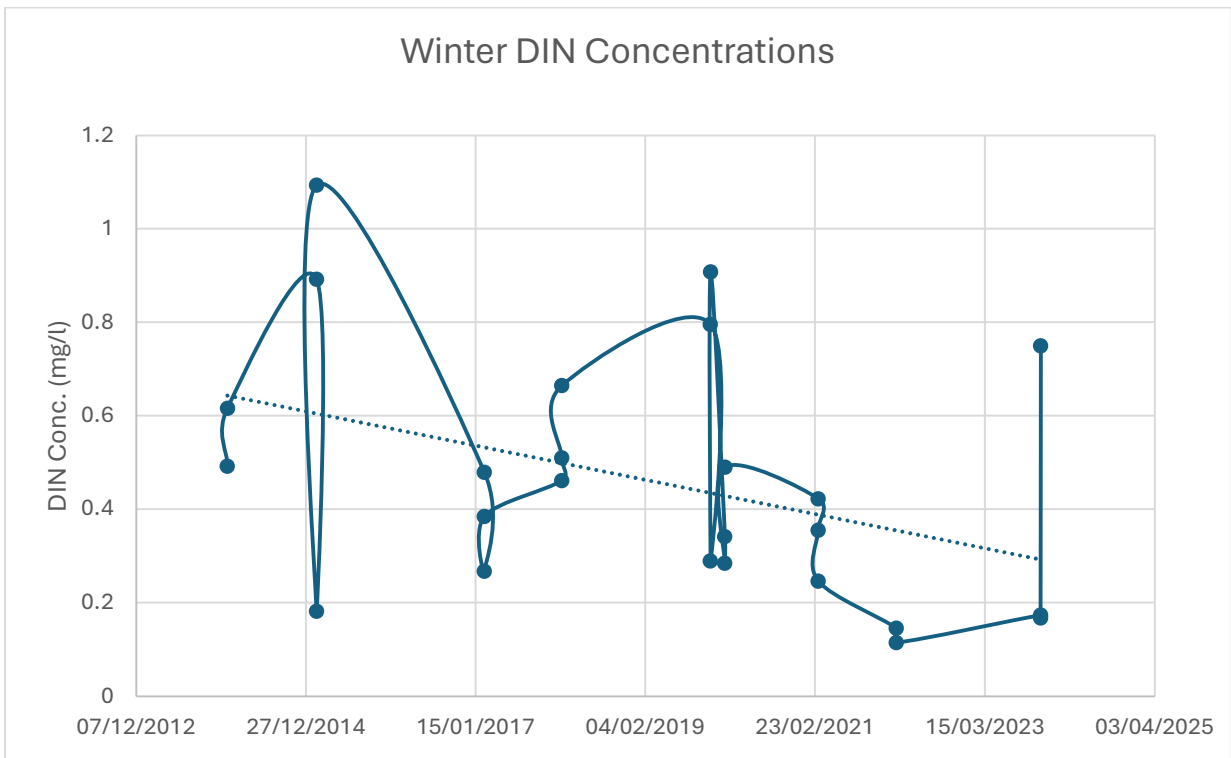


Figure 16: Winter DIN Trend at Monitoring Stations BM210/220/230 in Malahide Bay

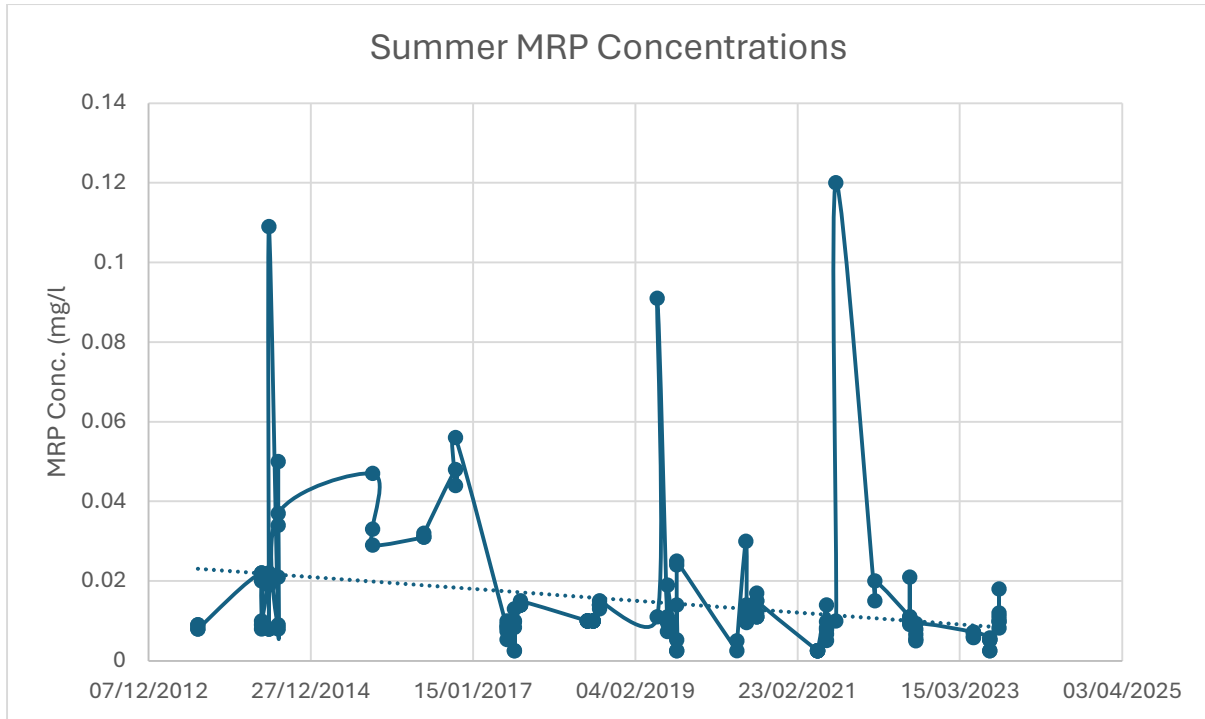


Figure 17: Summer MRP Trend at Monitoring Stations BM210/220/230 in Malahide Bay

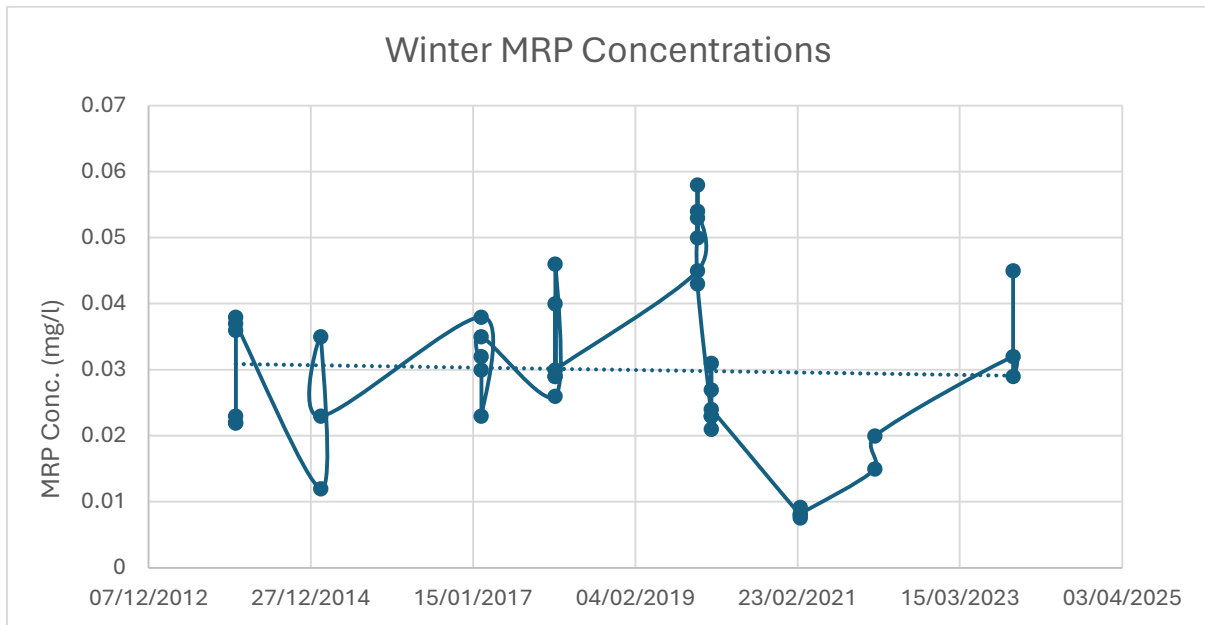


Figure 18: Winter MRP Trend at Monitoring Stations BM210/220/230 in Malahide Bay

1.8. Comparison of 2015-2024 and 2018-2022 Ambient Monitoring Data

As earlier mentioned, the Malahide Bay Nutrient Box Model utilised available EPA monitoring data covering the period 2018-2022 in order to ensure that the Box Model was calibrated/validated to most current conditions at the time of development. As shown in Sections 1.1 to 1.7 above there is a small degree of variability in ambient nutrient concentrations evident when reviewing specific monitoring stations and the nutrient loading being emitted from the Swords and Malahide WWTPs also shows a

small degree of variability. This is to be expected in a dynamic real-world setting with a limited number of ambient monitoring samples. Notwithstanding this when reviewing ambient concentrations within the overall waterbodies of the Broadmeadow Estuary and Malahide Bay it is apparent that the values for the periods 2018-2022 and 2015-2024 are quite similar. Noticeably the indicative water quality classification has not changed for any parameter when reviewing the 2018-2022 and 2015-2024 datasets. Based on these findings it is considered appropriate that the Model was calibrated/validated based on the more recent 2018-2022 ambient monitoring data and it is not proposed to re-calibrate/validate the model using the 2015-2024 dataset.

Table 1: Summary of Broadmeadow Estuary Median Concentrations (2018-2022) & (2015-2024)

Parameter	unit	2018-2022	2015-2024	Difference %
Winter DIN	mg/l	1.0795	0.983	8.94%
Summer DIN	mg/l	0.108	0.101	6.48%
Winter OrthoP	mg/l	0.028	0.022	21.43%
Summer OrthoP	mg/l	0.04	0.036	10.00%
Winter Salinity	PSU	21.8	23.55	-8.03%
Summer Salinity	PSU	29.4	29.65	-0.85%

Table 2: Summary of Malahide Bay Estuary Median Concentrations (2018-2022) & (2015-2024)

Parameter	unit	2018-2022	2015-2024	Difference %
Winter DIN	mg/l	0.3895	0.3855	1.03%
Summer DIN	mg/l	0.025	0.0275	-10.00%
Winter OrthoP	mg/l	0.028	0.029	-3.57%
Summer OrthoP	mg/l	0.01	0.01	0.00%
Winter Salinity	PSU	31.55	31.55	0.00%
Summer Salinity	PSU	33.2	33.2	0.00%

2. Contextualisation of Total DIN Loadings being discharged to Malahide Bay

In order to provide visual context on the relative DIN loads entering Malahide Bay an additional assessment was conducted to quantify the DIN loads that have been discharged via the Broadmeadow and Ward rivers, the Swords and Malahide WWTP. For the treatment works, DIN loads were conservatively assumed to be equal to the Total Nitrogen loads based on the reported figures in the respective AERs.

Two separate approaches were used to quantify the Total DIN loads that have been discharged via the Broadmeadow and Ward rivers.

The first approach utilised the modelling rating curve derived by Halcrow Barry for Hydrometric gauge No. 08008 located on the Broadmeadow river as shown in Figure 19 (obtained from the OPW) to produce an estimated flow series, and thus produce a flow weighted mass balance calculation of the annual DIN loads. Based on quantitative review the modelled rating curve flow outputs appear reasonable for higher flows but in comparison to the EPA HydroTool output flow values are potentially underestimating very low flows.

The second approach used the observed level series from the aforementioned Hydrometric gauge along with the downstream Hydrotool Flow Duration Curve, to similarly produce the resultant flow weighted mass balance calculation of annual DIN loads. Both assessments utilised known ambient DIN concentrations per EPA monitoring.

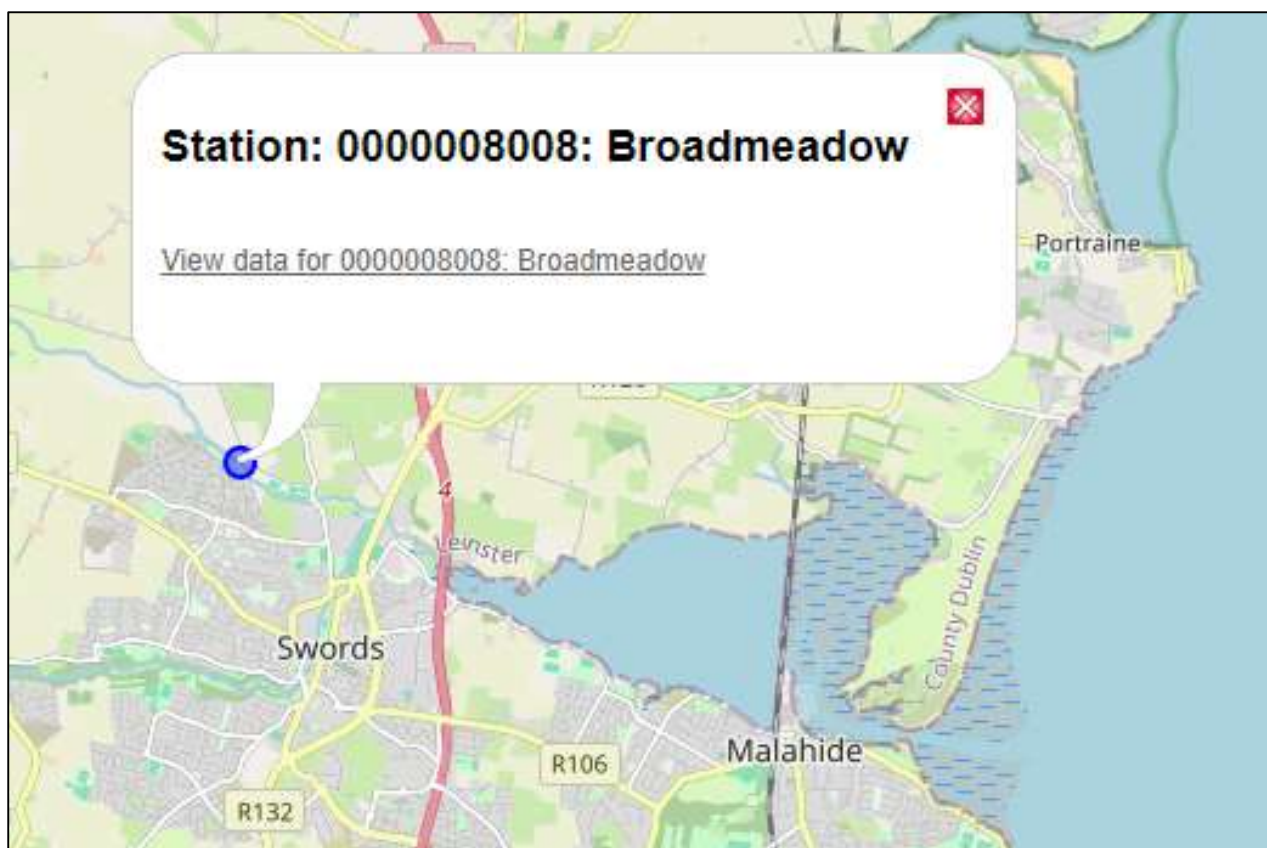


Figure 19 Hydrometric gauge No. 08008 located on the Broadmeadow river

The results of both methods of estimating the Total DIN Loadings being discharged to Malahide Bay are presented below in Figures 20 and 21 on the following pages. As is evidenced by both assessments the Malahide WWTP represents a minor contribution only of the Total DIN load entering Malahide Bay. It is noted that both assessments are high-level exercises with an inherent degree of uncertainty due to the available number of annual ambient monitoring samples but nonetheless it is considered that these assessments provide a useful means of contextualising the respective DIN contributions to Malahide Bay.

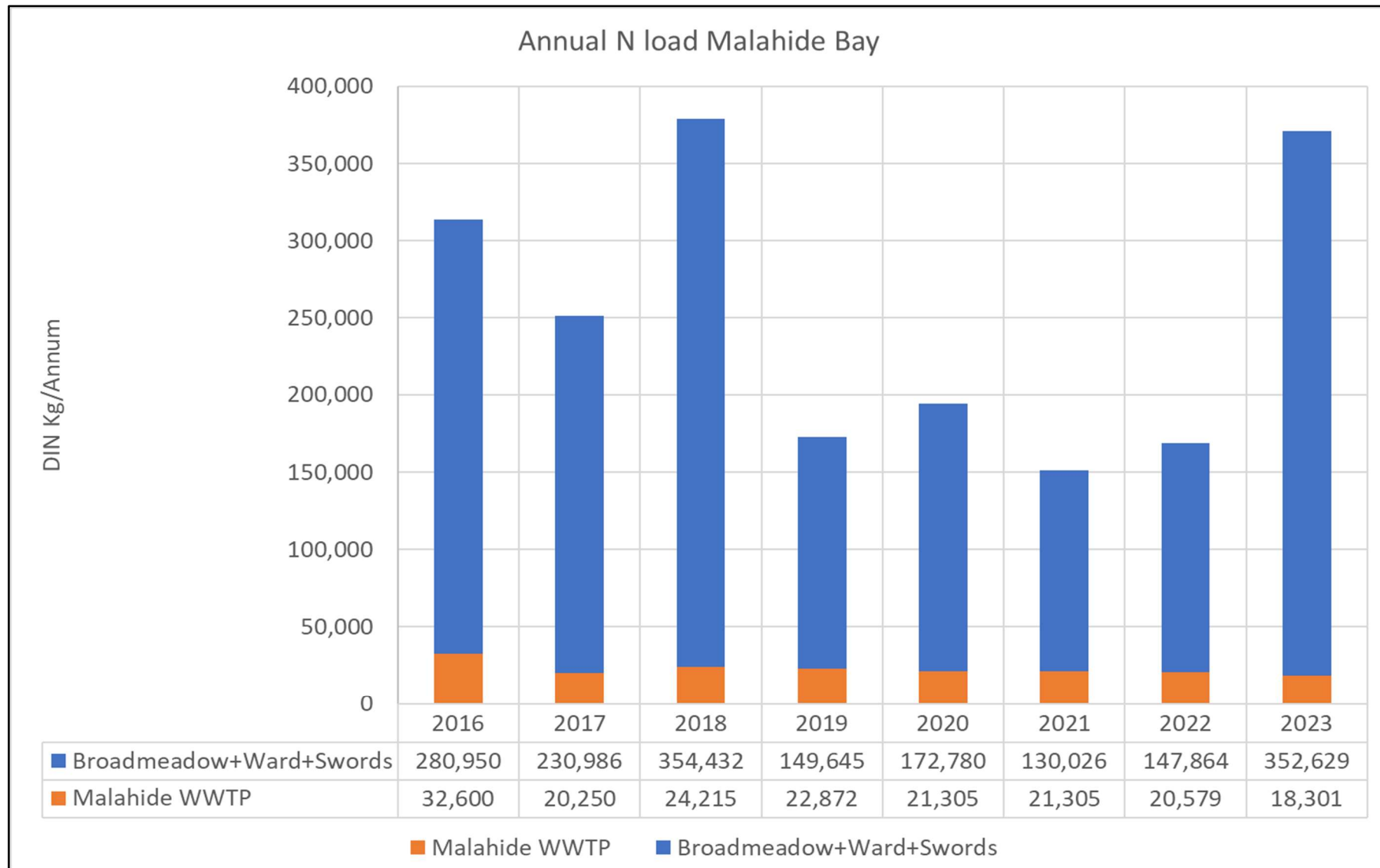


Figure 20: Method 1 (Flow Rating Curve) resultant DIN Load to Malahide Bay Estimation

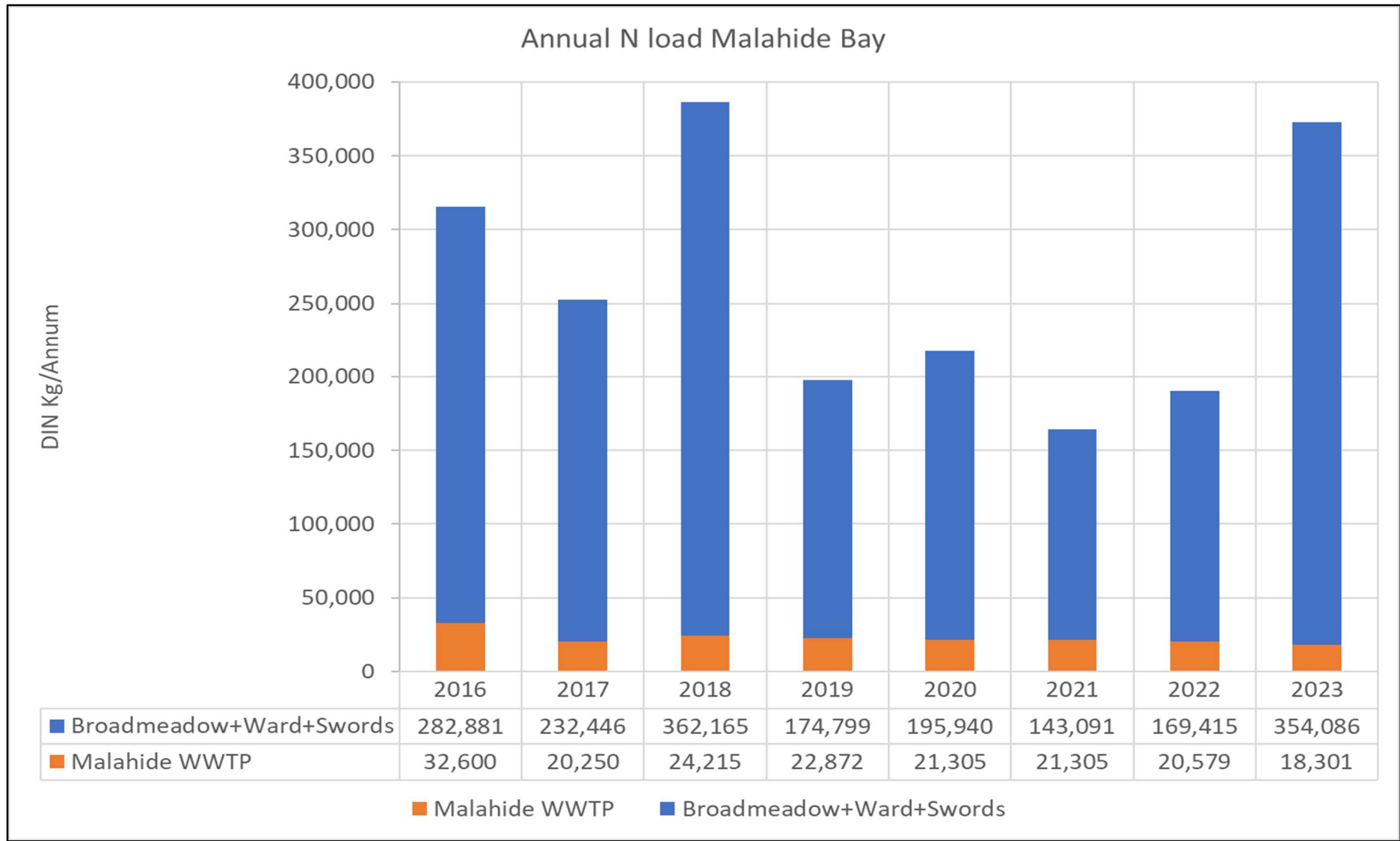


Figure 21: Method 2 (Level Gauge/Hydrotool Flow Relationship) resultant DIN Load to Malahide Bay Estimation

3. Macro-Algae Modelling Discussion

3.1. Review of Relationship between TSAS Data and Macro-Algae Model

The TSAS data provide for 10 sampling periods between 2010 and 2023 show that over the period the estimated biomass of macroalgae has reduced, whereas the coverage of affected area has steadily increased by at least 60% as shown in Figure 23.

The nutrient box model was run for the years 2014 to 2023 inclusive to see if any trends became discernible from the combined influence of the onshore loads and offshore concentrations, no strong pattern was observed, the modelled nutrient concentrations are relatively stable (Figure 22). The nutrient concentrations also met their EQS throughout the period too.

The TSAS data estimates the mean annual wet weight of macroalgae in Malahide Bay sampled between 2010 and 2023 is 435 tonnes. The mean estimated potential algae dry weight based on the conservative calculation carried out as part of the study for the various scenarios run in this study is 2620 tonnes (Table 15, RHST, 2024), which would yield about 19,540 tonnes as wet weight (RHS, 2021). Based upon this conservative estimate, which includes a number of assumptions as detailed in the Box Modelling Note (RHST, 2024), the nutrient loading to Malahide Bay has the potential to replace the macroalgae already present 40 times, this suggests that there may be a surplus of nutrients in the Bay but there are additional factors other than just nutrients loads determining the macroalgae growth.

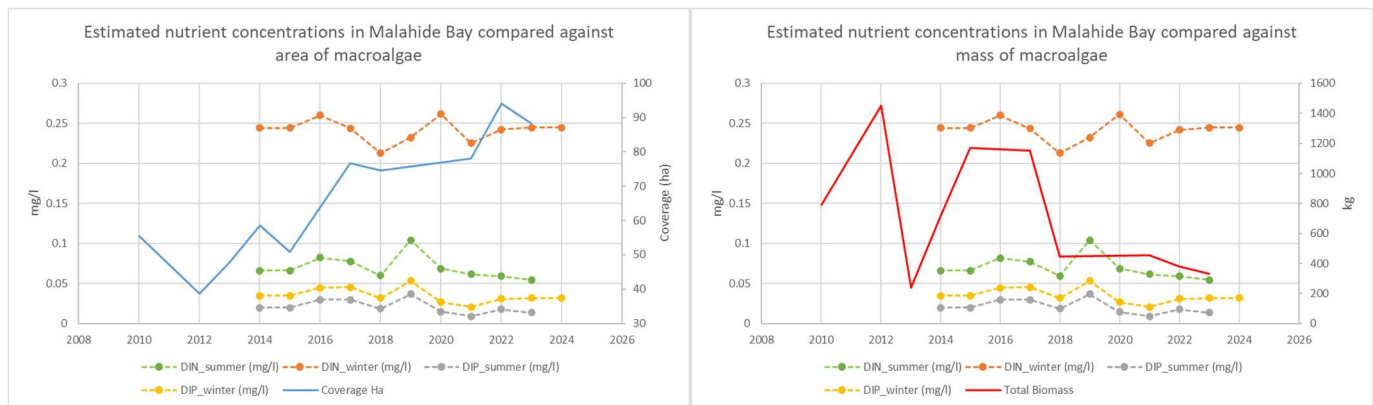


Figure 22 Estimated concentrations of nutrients in Malahide Bay compared against (left) the area of macroalgae (right) wet weight of macroalgae.

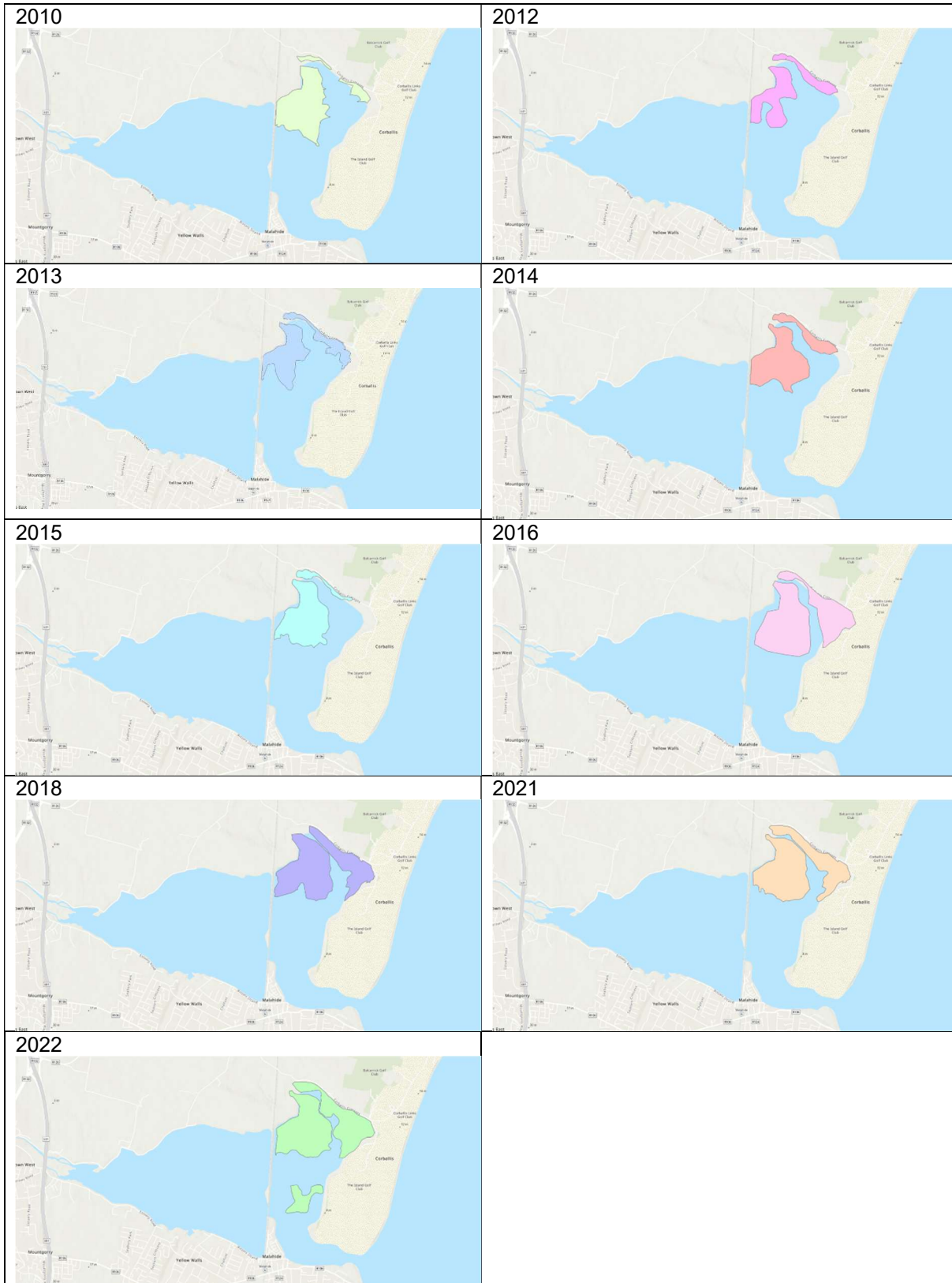


Figure 23 Development of Macroalgae coverage in Malahide Bay observed over the most recent 12 years of TSAS assessments

All these other factors affecting the success of macroalgae in addition to nutrients, aren't under UE's control. Some of these being legacy nutrients in the sediments of Malahide Bay, the recycling of nutrients from Broadmeadow Water, the communities of herbivores and light limitation or temperatures. While these factors can be included in other macroalgal modelling tools such as DCPM (with the

exception of sediment processes from nutrient cycling in the system which per (Aldridge et al., 2013) is a noted limitation of the DCPM model), neither the DCPM tool nor other macroalgal modelling tools was available to the project team. It is however considered unlikely that the above noted individual factors will have been calibrated to precisely simulate the situation in Malahide Bay even if the DCPM model or similar had been made available.

3.2. DCPM (Dynamic Combined Phytoplankton and Macroalgae model) Request Timeline

Contact Details	Date Response Received	Summary of Response Received
Contacted John Aldridge at Cefas 04 June 2021	07 June 2021	“The DCPM and all previous versions are owned & funded by the EA and my understanding is that, although it might be shared with other public sector funded bodies, it would not be licensed for use in the commercial sector. “
Contacted Karen Edwards at EA + EA enquiries	28 April 2021	“We (UK-EA) share IPR with Cefas for the DCPM model and unfortunately it is not for use outside Cefas/EA and other non-commercial partners”
Contacted John Aldridge at Cefas 11 April 2024	15 April 2024	“UK EA as they have IP/ownership of the model. The new version of the DCPM which is just a rewrite from MatLab into Python + some Fortran.”

4. Conclusions

As demonstrated in Section 1 when reviewing ambient concentrations within the overall waterbodies of the Broadmeadow Estuary and Malahide Bay it is apparent that the values for the periods 2018-2022 and 2015-2024 are quite similar. Noticeably the indicative water quality has not changed for any parameter when reviewing the 2018-2022 and 2015-2024 datasets. Based on these findings it is considered appropriate that the Model was calibrated/validated based on the more recent 2018-2022 ambient monitoring data and it is not proposed to re-calibrate/validate the model using the 2015-2024 dataset.

As is evidenced by both methods in Section 2 of quantifying the DIN loads that have been discharged via the Broadmeadow and Ward rivers, the Swords and Malahide WWTP it is apparent that the Malahide WWTP represents a minor contribution only of the Total DIN load entering Malahide Bay.

Lastly, as demonstrated in Section 3, the approach taken to determine the appropriate level of treatment of effluent for Malahide WWTP by considering the concentrations of DIN and MRP in Malahide Bay, is considered the most appropriate, the values obtained from the Nutrient Box Model are the combined impacts of all of the biggest influences the various rivers, but principally the Broadmeadow, the two relevant WWTPs serving Swords and Malahide respectively and the Irish Sea. The models and data suggest that although the nutrients loads have not increased (within the bands of uncertainty) in the last 10 years, the areal coverage of macroalgae has increased significantly. The modelling provided a means of determining source apportionment and the direct impact of the sources on nutrient concentrations within Malahide Bay and how relatively small the changes in nutrient concentration in the Bay are as a result of more stringent removal of nutrients at Malahide WWTP.

References

1. Aldridge, J.N., Painting, S., Tett, P., Capuzzo, E. and Mills, D.K., 2013. The Dynamic Combined Phytoplankton and Macroalgae (CPM) Model, version 2.0. Centre for Environment, Fisheries and Agriculture Science, Lowestoft, UK
2. OPW Hydrodata Website, Accessed: May 2024
3. Ryan Hanley Stantec (RHS), Estimating the potential for opportunist macroalgae in Malahide Bay, Memo No.1, November 17, 2021
4. Ryan Hanley Stantec (RHS), Malahide Bay Nutrient Box Modelling Note, Final, February 2024