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Chapter 1 Introduction

1.1 The background

The lead author of this report was commissioned by Mott MacDonald Pettit (MMP) to undertake a detailed Environmental Impact Assessment of the improvement in water quality as a result of the proposed Lower Harbour Main Drainage Scheme. At present the towns of Cobh, Passage West, Monkstown, Glenbrook, Ringaskiddy, Crosshaven and Carrigaline all discharge untreated sewage into Cork Harbour. The proposed scheme aims to collect all of this waste and treat it to a secondary standard at a waste water treatment plant to be located near Carrigaline. The treated effluent is to be discharged through the existing Carrigaline/Crosshaven outfall near Dognose Bank.

As part of the study a computer model which covers an area from the Old Head of Kinsale to the Waterworks weir in Cork City has been developed (Fig. 1.1). This model simulates the discharge, transport and decay of bacteria, viruses and three species of nitrogen from all the relevant outfalls. By simulating the discharge of untreated waste and comparing it with the discharge of treated waste an informed assessment of the improvement in water quality can be made. The boundary conditions for this model are provided by data from the Proudman Oceanographic Laboratory (POL), UK as described in section 2.2.3.

The hydrodynamic parameters of this model are based on a calibration and validation of a model covering a smaller area which reaches from Roches Point to the Waterworks weir (Fig. 1.2). The boundary conditions for this model are provided by recorded water levels from Roches Point in section 2.2.2.

The larger model has been labelled the 'Old Head_2' model (OH_2) in this report while the smaller model is referred to as the 'Roches Point_2' model (RP_2).

The OH_2 model has been validated against measurements of water level taken at Cobh and Tivoli. The error is within 20cm which is a satisfactory agreement between the modelled and measured data.

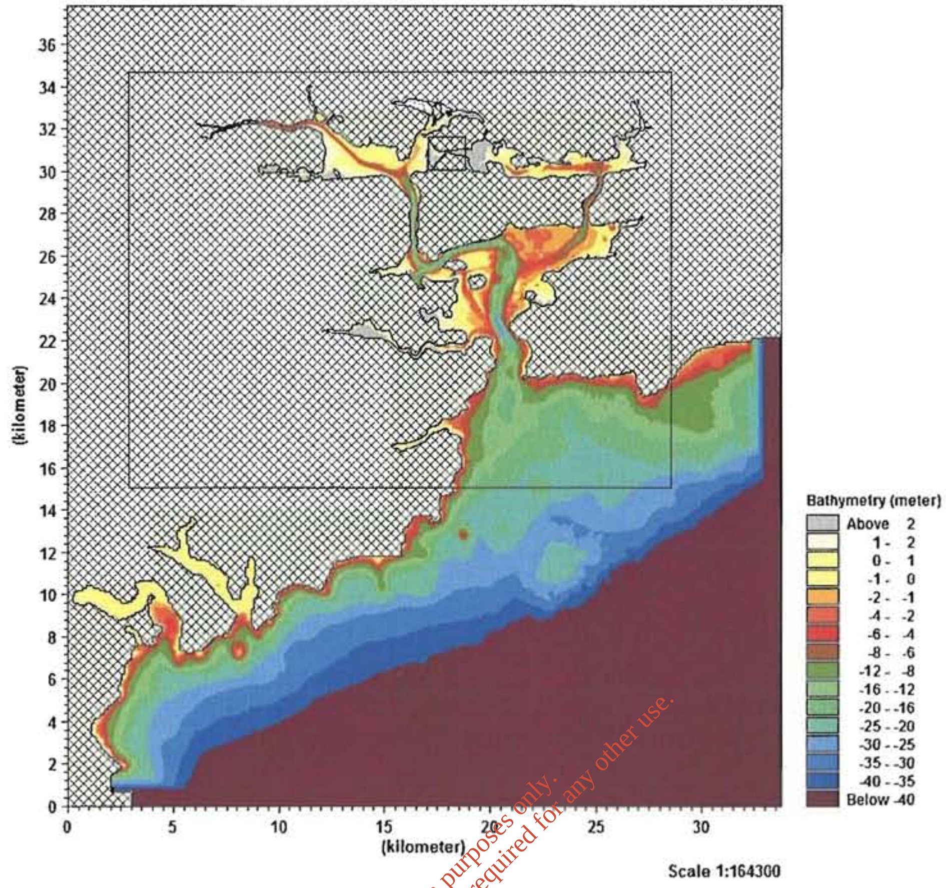

Fig. 1.1 Layout of the OH_2 model. The resolution of the 3 nested grids are 90m, 30m and 10m

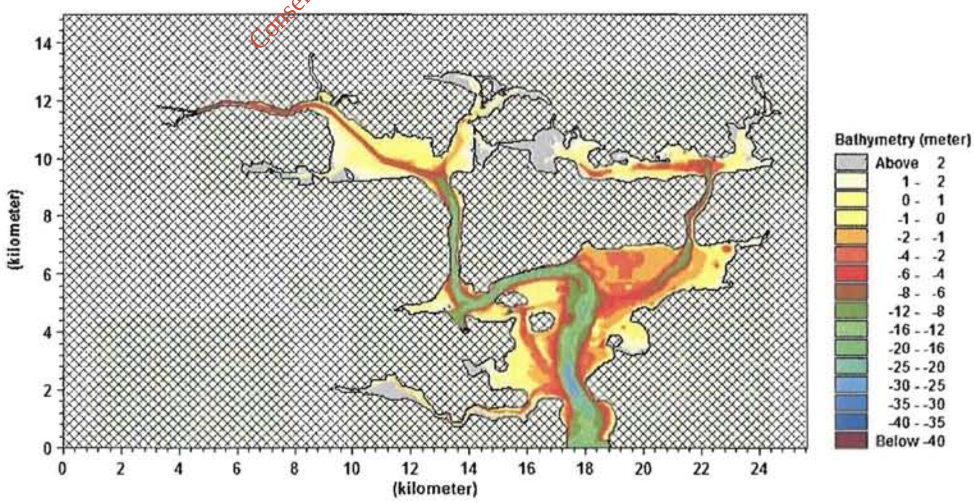

Fig. 1.2 Layout of the RP_2 model. The resolution of the 2 nested grids are 30m and 10m

The OH_2 model consists of two parts: the hydrodynamic model and the advection-dispersion model. The hydrodynamic model is based on the concepts and scientific principles of geometry and classical physics[2], and on relevant data[3]. It predicts the numerical variation in water level and the speed and direction of currents throughout Cork Harbour. We have achieved satisfactory agreement with measurements of these quantities. Pilots and sailors have also identified and confirmed the location of transient tidal eddies predicted by the model. We can predict with confidence, many, but not all, aspects of the motion of the waters of Cork Harbour under different conditions of tide, wind and river inflow.

The second part is the advection-dispersion model. This model simulates the release, transport and decay of particles discharged at any location in the harbour. We have considered faecal coliforms, intestinal enterococci, *Escherichia coli*, nitrogen and *Norovirus* for this study.

1. **Faecal Coliforms**
   - The number of Faecal Coliforms per 100ml is a recognised standard by which water quality is assessed in the relevant EU Directives.
2. **Intestinal enterococci**
   - The number of Intestinal enterococci per 100ml is a recognised standard by which water quality is assessed in the relevant EU Directives.

[2] These are represented as partial differential equations, expressing conservation of mass and linear momentum, with attendant boundary and initial conditions, and environmental forcing functions.

[3] Bathymetry of the Harbour from the Waterworks Weir to the Old Head of Kinsale; wind speed and direction; river flow and the tide at the mouth.

3. *Escherichia Coli*

- The number of *E. coli* per 100ml is a recognised standard by which water quality is assessed in the relevant EU Directives.

4. Simple Nitrogen Cascade

- The forcing exerted on the Harbour ecosystem by organic nitrogen, nitrate and ammonia is examined using a simplified nitrogen cascade model. Nitrogen has been included in this Environmental Impact Statement because the Water Framework Directive aims for good ecological status of all waters. High concentrations of nitrogen, when limiting, may lead to the over-fertilisation, or eutrophication, of aquatic ecosystems resulting in excessive growth of algae.

5. *Norovirus*

- The *Norovirus* or "Winter Vomiting bug" is the primary pathogen in outbreaks of gastroenteritis following consumption of raw oysters. The *Norovirus* is endemic in many countries. Outbreaks of "winter vomiting" may occur all year round and are often made public in Ireland by the closure of hospitals to visitors.

The models predict the changing concentration of the bacteria, three species of nitrogen, and *Norovirus*, under various physical forcing by the tide, wind and river flows. The variation in concentration at any site within the harbour may then be examined. From this it may be determined if the concentrations of the micro-organisms from the proposed scheme satisfy the water quality standards as stipulated in the relevant EU Directives:

- Bathing Water Directive (2006/7/EEC)
- Shellfish Waters Directive (79/923/EEC)

We understand there are no designated bathing water areas within Cork Harbour. The nearest one is at Fountainstown 5.25 km outside the harbour mouth. At present there are also no designated shellfish production areas within

Cork Harbour although oyster production has occurred in the past in the North Channel and Outer Harbour.

For this study we have not considered the discharges of treated effluent from Carrigrennan, Midleton or Cloyne. Neither have we considered the untreated discharges from the outfalls serving the towns on the eastern side of the harbour such as Rostellan, Farsid, Aghada and Whitegate. Stormwater overflows have not been included. The results presented in the report are therefore not representative of the absolute water quality in the harbour and surrounding waters. They present the contribution from the outfalls considered in the simulation runs.

We have examined the measurements of background concentrations of coliforms and nitrogen from the harbour. There are no measurements of *Norovirus* in water anywhere in the world. The sampling error and the spatio-temporal variability of coliforms and nitrogen throughout the harbour make any estimate of the background concentrations very uncertain. Consequently, in our view, it is sufficient to model the improvement in concentrations due to the proposed treatment plant and outfall.

It is possible to model the background concentrations but this would require substantially more resources and time than were available for this comparative study.

In order to illustrate the overall benefit of the proposed scheme four separate cases have been considered in the study and are listed in the following table.

	Year	Treatment	Total Flow Rate
Case 1 – no treatment 2001	2001	None	7,516 m^3/d
Case 2 – no treatment 2010	2010	None	10,371 m^3/d
Case 3 – With treatment 2010	2010	Secondary – 90% removal of organic matter	10,371 m^3/d
Case 4 – With treatment 2030	2030	Secondary – 90% removal of organic matter	14,873 m^3/d

Table 1-1 The four cases considered in the study

The loading on each outfall was determined by Mott MacDonald Pettit as part of a detailed and comprehensive preliminary study into the proposed scheme[4]. The loadings for the future years were calculated based on the predicted growth in population and industry for the relevant towns[5]. We have used the values from this report in our numerical model. Table 1-1 lists the values used for the 2001 situation, case 1 in the table above.

For case 2 we have assumed that the combined flow of 10,371m^3/d is divided between the outfalls as in the 2001 situation. Cases 2 and 3 have been simulated with the model. Because the model is linear, cases 1 and 4 can be calculated easily by rescaling.

Outfall Location	**UTM** E	**UTM** N	**Flow (DWF)** m3/day	**Flow (DWF)** m3/sec	**Faecal Coli Conc (raw)** fc/ m3
Carrigaline/Crosshaven	550249	5740738	4,075	0.04716	1E+11
Passage West	545351	5747371	547	0.00633	1E+11
Glenbrook	546006	5745605	327	0.00379	1E+11
Monkstown	546081	5744680	185	0.00215	1E+11
Pilots Pier Outfall (Cobh)	549632	5744757	353	0.00410	1E+11
Corbett Outfall (Cobh)	549277	5744708	178	0.00206	1E+11
Kings Quay Outfall (Cobh)	548854	5744611	444	0.00515	1E+11
West Beach Outfall (Cobh)	548647	5744568	668	0.00774	1E+11
White Point Outfall (Cobh)	547098	5743748	634	0.00735	1E+11
Ringaskiddy Village Outfall	547064	5742895	101	0.00117	1E+11
Total Catchment			7,515	0.087	

Table 1-2 Loading on outfalls from MMP report

[4] Cork Harbour Main Drainage Scheme Preliminary Report, Volumes 1-5, E.G., Pettit & Company

[5] The growth in population was estimated by considering the Cork Area Strategic Plan as well as the future development plan for each individual town as reported by E.G., Pettit & Company in the report referenced above.

1.2 Previous study of the *Norovirus* by the Authors

The lead author of this report was asked by Cork County Council in 2006 to carry out an objective study into the contamination of the oyster farm in the North Channel of Cork Harbour by the *Norovirus*. The primary objective of the study was to estimate the relative contribution of all significant sources of municipal and domestic effluent to the contamination of the oyster bed.

A number of computer models, similar to the models used in this Environmental Impact Assessment, were developed as part of the study. These models simulated the transport and decay of *Norovirus* in Cork Harbour from all the relevant outfalls. This study is referenced on a number of occasions in this report.

1.3 Model Assumptions

The advection-dispersion models described in this report have a number of inherent assumptions. Models are a simplification of reality; there is always something missing. It is a matter of judgement what to include and what to exclude. The following are the most important assumptions:

1. The densities of bacteria and *Norovirus* are approximately the same as seawater and are neutrally buoyant.
2. Adsorption of *Norovirus* and bacteria onto sediment is not included in the models. The interaction of sediment and micro-organisms in the marine environment is a complex process and is incompletely understood in the scientific literature. Simple assumptions are appropriate in this case.
3. Density gradients and stratification due to variations in salinity are excluded. These are unlikely to occur in the areas of interest in the outer harbour and outside the mouth.

1.4 Structure of the report

Chapter one introduces the study and the models. Chapter two summarises the various datasets that were used in the development of the 'Old Head_2' model.

Chapter three describes the model and its parameters. The results for faecal coliforms, *Norovirus* and Nitrogen are given in chapters 4, 5 and 6 respectively.

Chapter 2 The Datasets

2.1 Introduction

The data used to develop the Old Head_2 model are listed below and described in section 2.2.

Data type	Format	Period	Source
Bathymetric data of Cork Harbour (type 1)	X,Y,Z soundings	-	Irish Hydrodata
Bathymetric data of the Belvelly Channel (type 2)	X,Y,Z stereoscopic data	-	DLR (German Aerospace Agency)
Water level recordings from the harbour	Time series	Feb – Mar 1992	Irish Hydrodata / Port of Cork
Current speed & direction recordings from the harbour	Time series	Feb – Mar 1992	Irish Hydrodata
Hydrodynamic output from CS3 model	Time series	Jan- Dec 2004	Proudman Laboratory (UK)
River flows from the Lee, Owenacurra and Owenboy Rivers	Time series	Jan - Dec 1992 & 2004	ESB/EPA
Wind speed & directions from Cork Airport	Time series	Jan - Dec 1992 & 2004	Met Eireann
Location of each outfall	UTM coordinates	-	MMP
Flow Rates from the Various Outfalls	Values in m^3/sec	-	MMP
No of fc per cubic metre	Spreadsheet	-	MMP
Efficiency of the proposed treatment plant	Spreadsheet	-	MMP

Table 2-1 Datasets

2.2 Datasets

2.2.1 Bathymetric data

Irish Hydrodata Ltd. undertook a bathymetric survey of Cork Harbour in 1992 as part of a study of locations for an outfall from the Cork Main Drainage Scheme. A number of other surveys have since been carried out by Irish Hydrodata Ltd. for smaller localised areas. These surveys were commissioned by different parties to update the bathymetry in site-specific areas as part of various modelling studies. The main bathymetric datafile used in this study is an amalgamation of all these surveys and represents the most up-to-date dataset of the harbour bed profile that exists at present. A comprehensive quality-assurance of the dataset was carried out as part of the authors' previous study of the *Norovirus* in Cork Harbour[6].

2.2.2 Water Level & Current Speed Direction Recordings – 1992

In conjunction with the bathymetric survey undertaken for the 1992 outfall study, Irish Hydrodata Ltd placed a number of gauges in the harbour to record water levels, current speeds and current directions. Six automatic level recorders were deployed for a period of three months from the 6th of December 1991 until the 14th of March 1992. Readings were taken every minute. The current speed and direction meters recorded data from mid-December to mid-February, a period of approximately 65 days at 10 minute intervals. A number of the water level gauges shifted on their mountings during the first month of deployment and these data were discarded. Fig. 2.2 shows the location of the gauges. Table 2-2 lists the grid coordinates and dates of deployment.

These data were used to calibrate and validate the RP_2 and OH_2 models which are described in the following chapter. A comprehensive quality-assurance of the dataset was carried out as part of the authors' previous study of the *Norovirus* in Cork Harbour.

[6] O'Kane, J.P.J., & Barry, K. J., Modelling the *Norovirus* contamination of an oyster farm in Cork Harbour, Final Report to Cork County Council

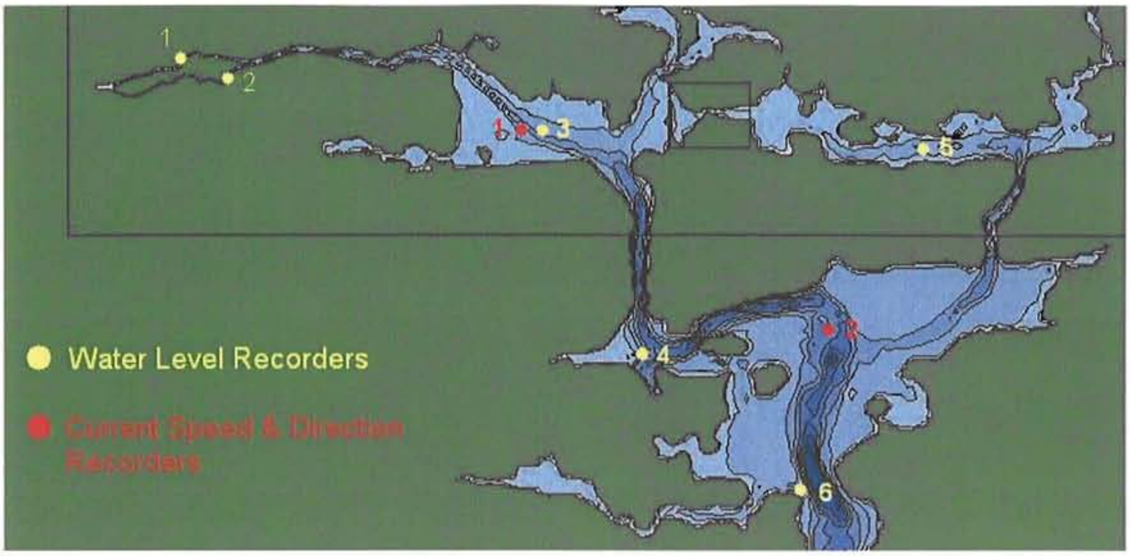

Fig. 2.1 Location of Gauges in Harbour

Site	From	To	Comments	I.N.G. Coordinates	
Lee Maltings	06 Dec 1991	06 Jan 1992	Not used	166760	71885
	06 Jan 1992	07 Feb 1992	Not used	166760	71885
	19 Feb 1992	16 Mar 1992	Not used	166760	71885
Albert Quay	06 Dec 1991	06 Jan 1992	Not used	167990	71750
	06 Jan 1992	06 Feb 1992	Not used	167990	71750
	10 Feb 1992	11 Mar 1992	Not used	167990	71750
Lough Mahon	06 Dec 1991	08 Jan 1992	Data invalid	175225	70400
	09 Jan 1992	06 Feb 1992	-	175225	70400
	10 Feb 1992	14 Mar 1992	-	175225	70400
Pfizer Jetty	06 Dec 1991	08 Jan 1992	Data invalid	177550	65225
	10 Jan 1992	26 Jan 1992	-	177550	65225
	08 Feb 1992	13 Mar 1992	-	177550	65225
Belvelly	06 Dec 1991	07 Jan 1992	-	183830	69580
	07 Jan 1992	08 Feb 1992	-	183830	69580
	08 Feb 1992	11 Mar 1992	-	183830	69580
Fort Camden	09 Dec 1991	08 Jan 1992	-	180870	62000
	09 Jan1992	07 Feb 1992	-	180870	62000
	07 Feb 1992	11 Mar 1992	-	180870	62000

Table 2-2 List of Water Level Gauges

Site	From	To	Comments
Spit Bank	08 Dec 1991	14 Feb 1992	4m above bed
Lough Mahon	15 Dec 1991	14 Feb 1992	2m above bed

Table 2-3 List of Current Speed and Direction Gauges

2.2.3 The POL CS3 model – Boundary Conditions of the OH_2 model

The Applications Group at the Proudman Oceanographic Laboratory (POL), UK, supplies hindcasts[7] of (a) tide-plus-surge, and (b) tide-only levels on a grid covering part of the North Atlantic Shelf at frequencies of 1 hour for (a) and 20 minutes for (b) respectively. The centre uses its POL CS3 model to provide the annual hindcast at the end of each calendar year. Hindcasts are available from 1992 onwards. The model makes use of meteorological data from the UK Met Office Operational Storm Surge Local Area Model (1992 to 1998) and the Mesoscale model (1999 onwards). The hindcasts from the POL CS3 Model use a combination of measured and modelled meteorological data. Surface elevations and currents in component form are provided at each grid point. The POL CS3 numerical model grid, which covers part of the North Atlantic Shelf, has a resolution of approximately 12km (Fig. 2.2). The level data has a relative accuracy of approximately 3% of the sea level range[8]. The absolute accuracy is unknown on the southern Irish Coast. A previous study[9] (1997-2001) of the Cashen Estuary in the outer Shannon showed that such data could provide very good boundary conditions for hydrodynamic models of Irish coastal waters. The Cashen/Feale model agreed with measurements within the estuarine network to within 10cm.

Two years of hindcast data (1992 & 2004) were purchased from POL for this project. Data from the three points closest to the mouth of Cork Harbour were selected from the CS3 grid and used to drive the hydrodynamics of the 'Old Head_2' hydrodynamic model by acting as the boundary conditions. The locations of these points relative to Cork Harbour are highlighted in Fig. 2.3.

[7] A hindcast is where a numerical model is run for a fixed historic period of time in the past with recorded forcing functions (measurements of tide, wind etc) from that period.

[8] Smith, J. A. (1994). The Operational Storm Surge Model Data Archive, Proudman Oceanographic Laboratory, Report, No 34, 34pp

[9] Martin, J., 2002, De-Watering the Lower Feale – "A Virtual Water World", *Ph.D. Thesis*, Department of Civil and Environmental Engineering, National University of Ireland, Cork

Minor adjustments to the data provided by the Proudman Laboratory in this study.

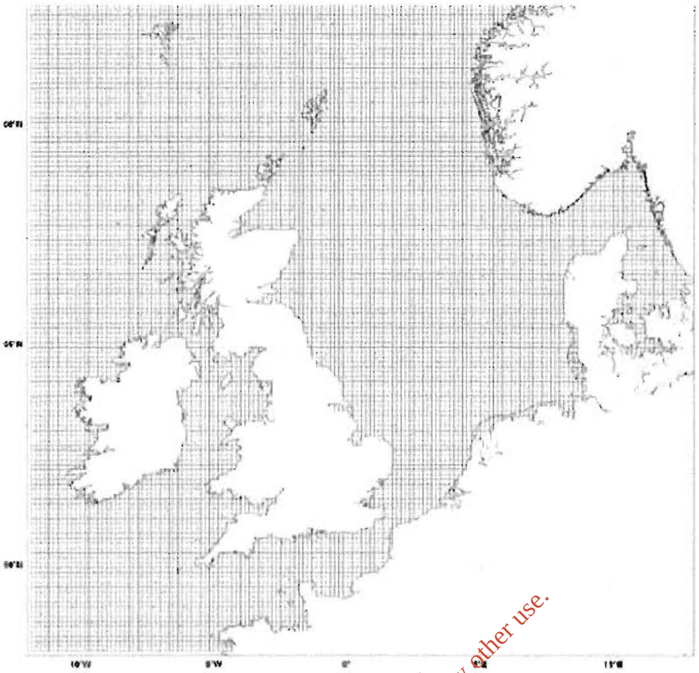

Fig. 2.2 CS3 grid (12km resolution)

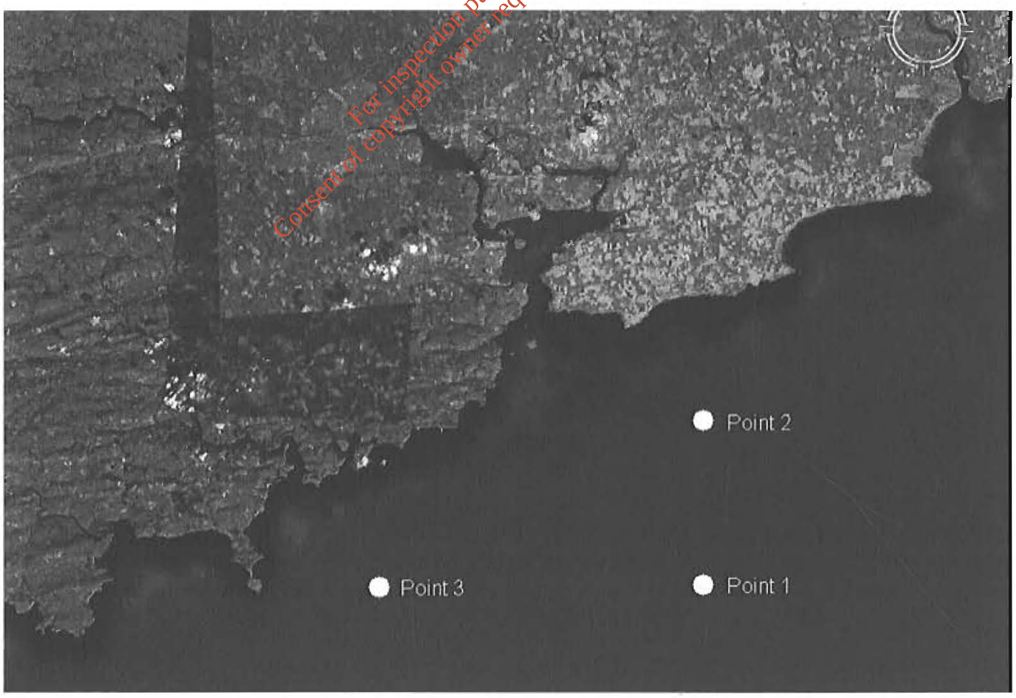

Fig. 2.3 Location of points on the CS3 grid used for the OH Hydrodynamic model boundary conditions (Image from Google Earth)

2.2.4 River & Wind Files

River flows and wind influence the hydrodynamics of the estuary. Cork County Council, EPA, OPW and the ESB supplied measurements of flow in all the rivers discharging into Cork Harbour for 1992 and 2004. In this Environmental Impact Statement we have included the influence of the River Lee, Owenboy and Owenacurra rivers.

The archive of the 1992 survey carried out by Irish Hydrodata Ltd contained the wind records at Cork Airport (Met Eireann), Roches Point (Met Eireann). and Ringmahon Point (Bord Gais/Cork Corporation). The 1992 survey report by Irish Hydrodata Ltd states that the Cork Airport and Roches Point datasets "show very similar wind patterns". It also states in reference to the Cork Airport and Ringmahon Point sites that there is "little difference between the sites". Consequently, we have relied on the data from Cork Airport exclusively.

2.2.5 Water level recordings from Cork Harbour

The Port of Cork supplied time series of water level from the gauges they maintain at Tivoli and Cobh. This data has been used to validate the OH_2 model.

2.2.6 Outfall Loading

As part of the preliminary investigation carried out for the proposed scheme, Mott MacDonald Pettit undertook a comprehensive study of the population and industry serving each outfall in 2001[10]. We have used the values given in this report in our models. The projected loadings for 2010 and 2030 were also taken from this report.

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[10] Cork Harbour Main Drainage Scheme, Volumes 1-5, EG Pettit & Company

Chapter 3 The 'Old Head_2' Model

The previous chapter was concerned with the datasets which were used to construct the models used in this Environmental Impact Assessment. This chapter describes the Old Head_2 (OH_2) model which was used to simulate the bacteria, *Norovirus* and the Nitrogen Cascade for the different cases considered in this report.

All of our work makes use of the well-known MIKE 21 modelling system supplied under licence by the Danish Hydraulics Institute (DHI)[11]. DHI provides very extensive documentation on this system and is not included in this report.

3.1 OH_2 model layout

The development of every numerical model involves a compromise between a high resolution grid[12] which resolves the flow in great detail and the time it takes for a computer to calculate the results[13]. The model run time is a function of the number of grid points in a model[14] and the timestep. Generally if the grid spacing is halved the model runtime increases by a factor of 8. Given that the run time for models such as the OH_2 could be in the order of days, and not hours, the issue of resolution and run time is always of concern.

Nested grids are the means by which this problem can be overcome. A nested grid implies that different areas of the model are resolved with different grid spacing. Areas that are of great importance to the study may be resolved with a high resolution while the area surrounding it may be resolved with a lower resolution. The higher resolution grid must sit inside (hence the 'nested' term)

[11] http://www.dhigroup.com/

[12] We use the ULTIMATE high-accuracy finite difference scheme in MIKE 21.

[13] The size of the generated result files is also a concern. High resolution grids generate larger result files than those with a lower resolution. Files larger than 4GB are quite problematic for any personal computer today.

[14] Determined by the extent of the model and the grid spacing

the coarser grid. At the boundary the water level and fluxes are passed from one grid to the next so that a single unified model is developed. For MIKE 21 the nested grid must be exactly 3 times smaller than the coarser grid. A 30m grid can be nested within a 90m grid but not a 100m grid. The 90m grid may then be nested within a 270m grid. MIKE 21 allows up to 9 grids to be successively nested within each other. All the models developed as part of this study use nested grids.

The layout of the OH_2 model is presented in Fig. 3.1. The model consists of three separate nested grids each with a different spatial resolution. The outer grid has a 90m resolution and covers from the Old Head of Kinsale to Robert's Cove. The second grid has a 30m resolution and covers from Robert's Cove to the Waterworks weir. A third grid of 10m resolution resolves the flow through the narrow Belvelly Channel in the inner harbour.

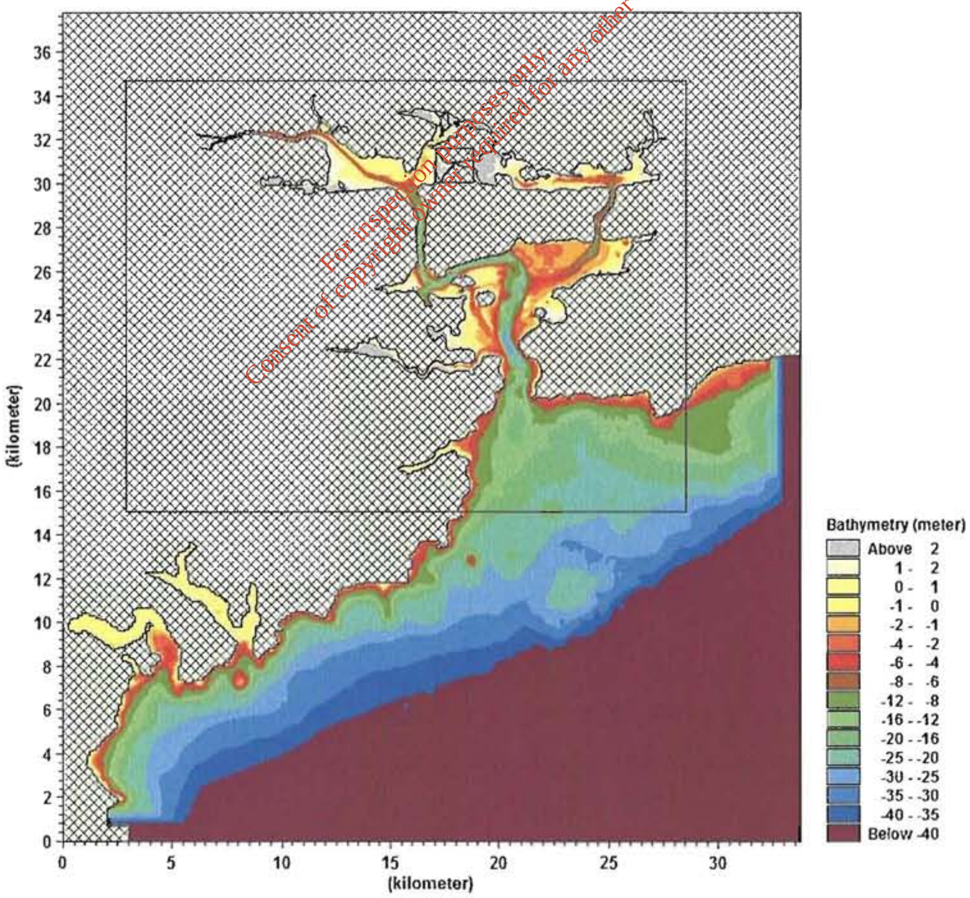

Fig. 3.1 Layout of the OH_2 model

The extent of the 90m grid is determined by the location of the 3 grid points from the CS3 model from which the boundary conditions are obtained.

Modelling a large area also ensures that discharges from the outfalls are not lost through the boundary. If the boundary had been located at Roches Point, as it is for the RP_2 model, particles released from the Carrigaline/Crosshaven outfall will be carried past the boundary at Roches Point on the ebb tide and taken out of the model. On the ensuing flood tide the model will underestimate the concentrations in the harbour as the particles which should be transported from outside Roches Point back into the harbour have been lost. This may lead to an unacceptable error in the results. Consequently, the RP_2 model is of questionable accuracy in simulating the release of bacteria or viruses from the Carrigaline/Crosshaven outfall. This problem is overcome by using the OH_2 model.

We have resolved the harbour and area immediately outside Roches Point with a 30m grid. This resolution is more than sufficient to resolve the flow through the East and West passage, Lough Mahon and the North Channel behind Great Island.

3.2 Boundary Conditions – CS3 model

The boundary conditions of the OH_2 model were provided by the output from the CS3 numerical model, maintained by the Proudman Laboratory in the UK which covers part of the North West Atlantic Shelf. In other words, the OH_2 model is itself embedded in an even larger model.

Boundary conditions for numerical models such as the OH_2 model are typically provided by recorded measurements of water levels[15]. Such an approach was too expensive for this project[16]. In addition there is a substantial risk of the

[15] Coupled in some cases with recorded velocities.

[16] Deploying gauges in the open sea, such as near the Old Head of Kinsale, is far more expensive than doing so within estuaries. At the start of the project a quote was obtained to

gauges being lost when deployed in the open sea. We have used the Proudman data as our boundary conditions for the OH_2 model in a direct and simple manner.

There are limitations in our approach:

1. Any errors in the CS3 model are propagated into the OH model.
2. The resolution of the CS3 model is 12km. Therefore the data derived from it cannot contain detail at scales less than 24km (Nyquist sarnpling theorem).
3. No downscaling, or intermediate grid, has been used to transfer data from the 12km grid of the CS3 to the 90m outer grid of the OH_2 model. To overcome this particular problem would have required additional data for points further out in the Celtic sea and the development of a much larger OH_2 model.

These limitations, however, do not lead to unrealistic boundary conditions. As we will see in the next section, the output from the model driven with the Proudman data, when adjusted slightly, is capable of reproducing the observed tides in Cork Harbour to within an error of 20cm.

The annual hindcasts for 1992 and 2004 of tide-plus-surge, and tide-only levels from the three grid points closest to the mouth of Cork Harbour were purchased from the Proudman Laboratory for the previous *Norovirus* study. The tide-plus-surge data (1 hour frequency) were interpolated between the data points, and extrapolated between the data points and the land, to form a profile series[17]. The two profile series describe the variation in water level and fluxes along the two open boundaries of the model and drive the hydrodynamics. See Fig. 3.2.

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deploy 3 gauges measuring water levels and velocities some distance outside the harbour mouth. The cost was far in excess of the proposed budget for the project.

[17] A profile series contains data, which describes the variation in time of a variable along a line in space.

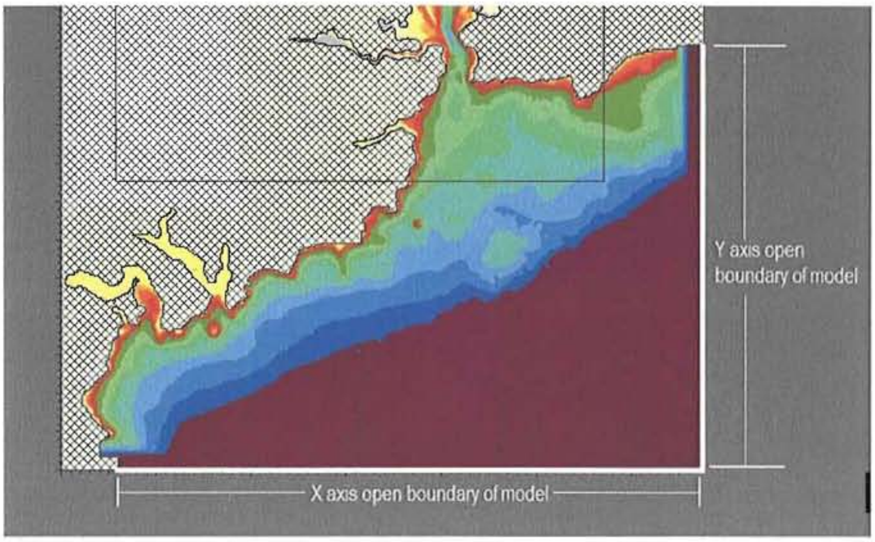

Fig. 3.2 Extent and location of the open boundaries of the OH_2 model

3.3 Calibration of the OH_2 model

The OH_2 model has been validated using parameters taken from the RP_2 model. The RP_2 model has been calibrated and validated using recorded water levels, current speeds and direction from the 1992 data survey. This is described in Appendix A of this report. The validation of the OH_2 model is presented in the following section.

3.4 Validation of the OH model

The validation of the OH_2 model is presented in the following plots. The spring tide water level validation for the gauge at Cobh is presented in Fig. 3.3. We can see from the plot that the difference between the modelled and the measured is less than 20cm with the exception of the first two high tides in the plot where it is less than 25cm. We can also see that the gauge at Cobh has a number of erroneous readings at three of the recorded high tides. The gauge has topped-out for approximately 3 hours on each of these 3 occasions.

The spring tide water level validation for the gauge at Tivoli is presented in Fig. 3.4. We can see from the plot that the difference between the modelled and the measured within 25cm except for two of the tides[18].

From this we can conclude that the OH_2 model is capable of reproducing the tides in Cork Harbour to within a satisfactory level.

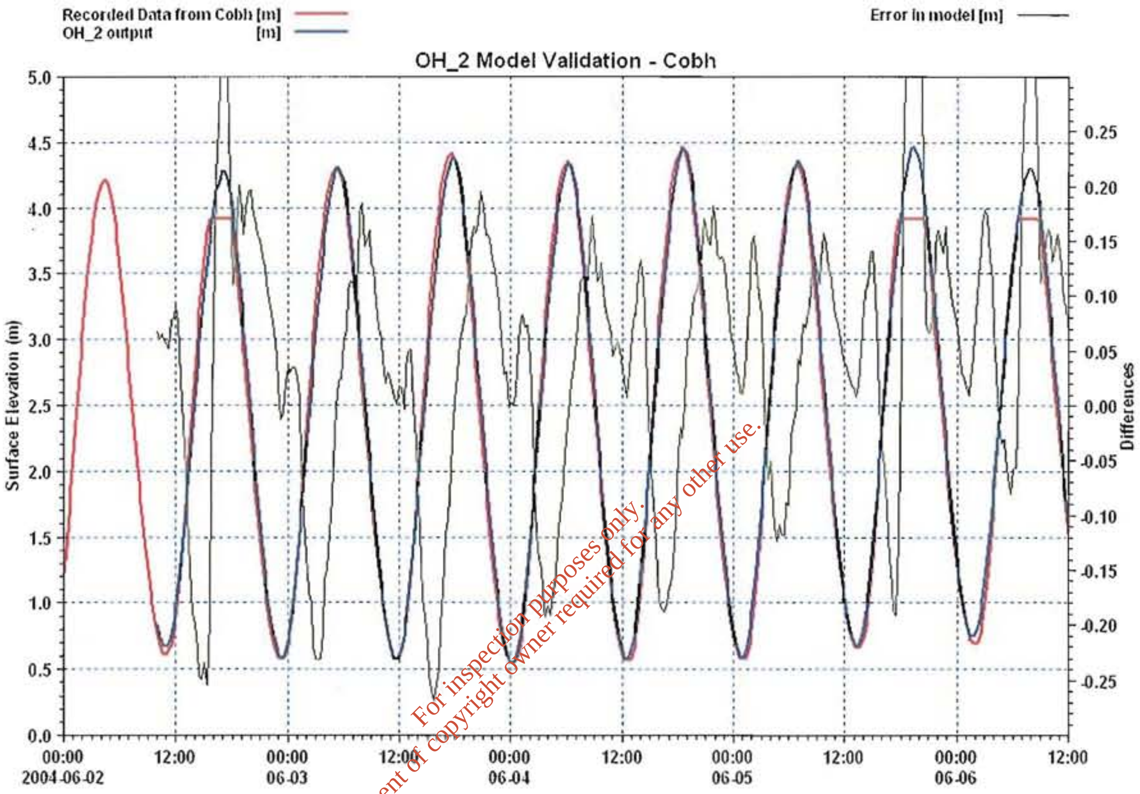

Fig. 3.3 Cobh Spring Tide Water Level Validation

[18] No current speed or direction measurements were available for this validation period.

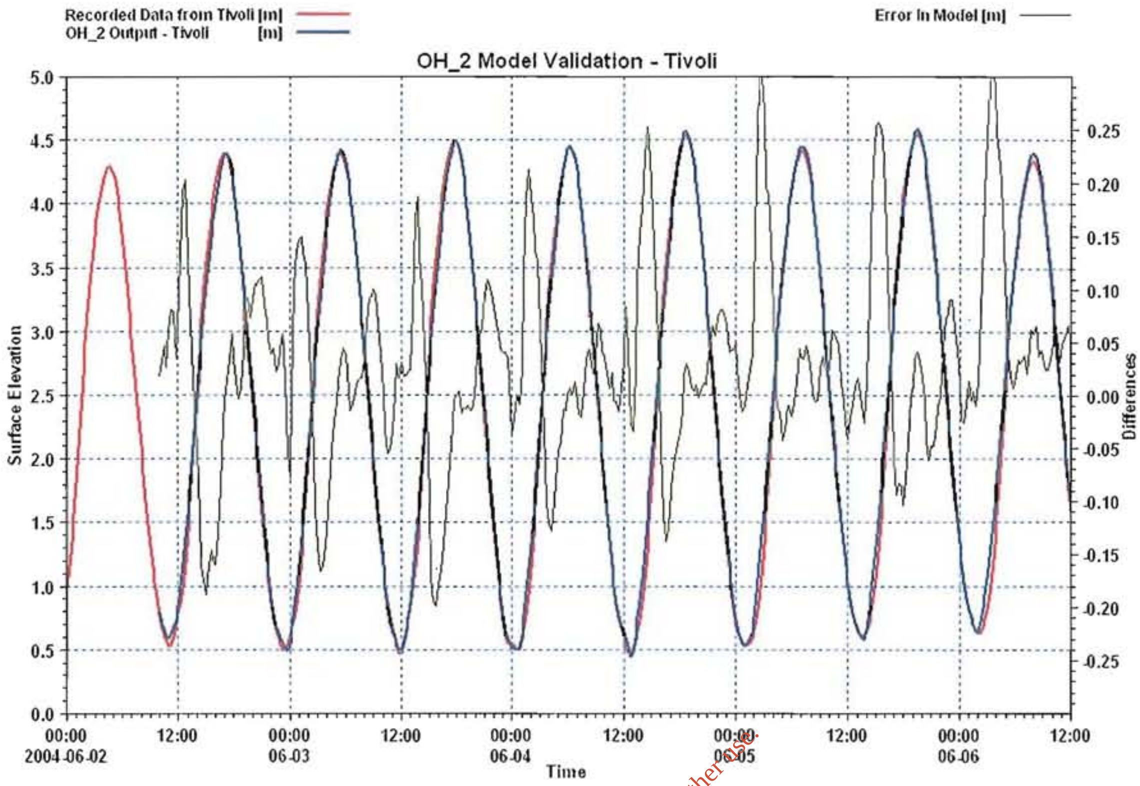

Fig. 3.4 Tivoli Spring Tide Water Level Validation

3.5 OH_2 model parameters

The OH_2 model has two parts. The first is the hydrodynamic model, which predicts the numerical variation in water level and the speed and direction of currents throughout Cork Harbour. Coupled with this is the Advection-Dispersion (AD) model, which describes the dispersal and decay of bacteria, *Norovirus* and Nitrogen discharged at any location in the Harbour. Numerous parameters are required for each model. Some of the values used were obtained through the calibration and validation as described in the previous section. Some were chosen based on experience and guidance from the literature.

3.5.1 Hydrodynamic Model Parameters

The main parameters in the RP model are listed as:

- **Δx – grid resolution**. 3 different resolutions were used in the OH_2 model as described in the last section.

- **Δt – timestep.** A timestep of 6 seconds was used for the model. This reasonably low value was found necessary to ensure the Advection Dispersion model remained stable.

- **Eddy Viscosity.** A flux-based formulation of the eddy viscosity, which varies over the entire grid, has been used. The eddy viscosity parameter is shown in the figure below. These values were determined by calibration.

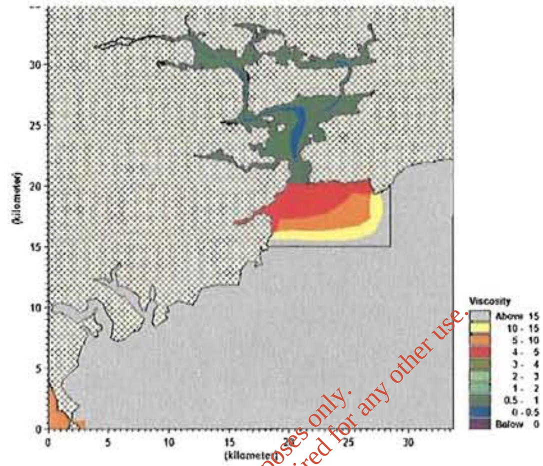

Fig. 3.5 Map of eddy viscosity values used for the OH_2 model

- **Bed Resistance.** The bed resistance was defined using the Manning's M number. The parameter varied over the entire grid as can be seen in the figure below. These values were determined from the calibration of the model.

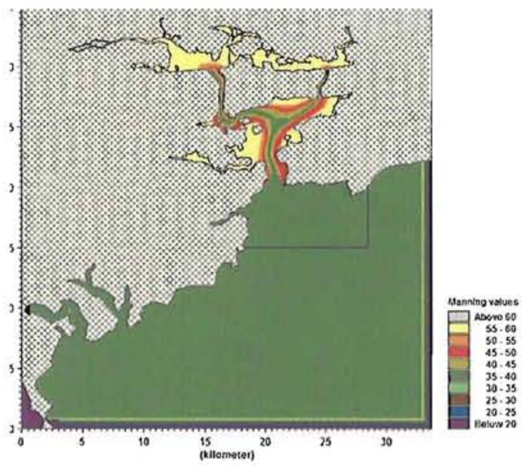

Fig. 3.6 Manning's M value used in model. Manning's M ($m^{1/3}/s$) is the reciprocal of Manning's n.

- **Flooding and Drying depths.** MIKE 21 allows the simulation of flow in areas that are subject to flooding and drying. When an area dries out the grid cells are removed from the computations. When the tide returns and floods the area the grid cells are included in the computations again. The flooding and drying depths control this inclusion and exclusion of computational points. The default values in MIKE 21 are 0.2m (drying) and 0.3m (flooding). Therefore when the depth of water in a grid cell is less than 0.2m the cell is removed from the computations. When the tide is on the flood and the water level is calculated to be above 0.3m, the grid cell is once again included in the computations. Values of 0.1m and 0.2m were used in this study.

3.5.2 AD Model Parameters

There are a number additional parameters required for the Advection dispersion model. These parameters are:

- **Initial conditions.** These were set to zero across the entire grid i.e. it was assumed that the concentrations of bacteria, *Norovirus* and Nitrogen were zero across the entire harbour at the start of the simulation.

- **Boundary Conditions.** The boundary conditions at the mouth were set to zero for the duration of the simulations.

- **Decay specification.** Bacteria and *Norovirus* decay exponentially with time. We have assumed that Faecal Coliforms have a T90 of 12 hours. We have also simulated the decay with a T90 of 24 hours as part of a sensitivity analysis. We have assumed that *Norovirus* has a T90 of 30 days. This applies to winter conditions which is a worse case scenario.

- **Dispersion Coefficient.** The dispersion coefficients in MIKE 21 may be defined as either independent of the current or proportional to the current. The results presented in this report use the independent option. A value of $1 m^2/sec$ in both the x- and y-direction has been used across all three grids in the OH_2 model.

- **Feedback.** By including the hydrodynamic (HD) density terms in the advection dispersion model, horizontal density gradients become another forcing function in the hydrodynamic model[19]. The influence of salinity and temperature may be included in this way. The results presented in this report do not include feedback[20] due to the unavailability of high-frequency measurements of salinity.

3.6 Discussion

The OH_2 model has been developed in MIKE 21 to simulate the discharge and transport of Bacteria, *Norovirus* and three species of Nitrogen from various outfalls in Cork Harbour. The first part of the OH_2, the hydrodynamic model, predicts the variation in water level and current speed from the Old Head to the Waterworks weir. The second part of the OH_2, the Advection-Dispersion model, describes the dispersal and decay of Faecal Coliforms, *Norovirus* and three species of Nitrogen for the same area.

The hydrodynamic parameters of the OH_2 model are based on the calibration and validation of a separate model, the RP_2 model, which covers an area from Roches Point to the Waterworks weir.

The boundary conditions of the OH_2 model are supplied by output from a numerical model of part of the North Atlantic Shelf which is maintained and run by the Proudman Oceanographic Laboratory in the UK. From the validation of the OH_2 model we may conclude that it reproduces the tides in Cork Harbour to an error within 20cm.

[19] In addition to the tide, wind and river flows.

[20] Significant horizontal density gradients are unlikely to occur in the areas of interest in the outer harbour and outside the mouth.

Chapter 4 Faecal Coliform Results

4.1 Introduction

This chapter presents the results of the faecal coliform modelling. We have assumed that there are $1.0*10^{11}$ faecal coliforms in every cubic metre of raw sewage which is equivalent to $1.0*10^{7}$ faecal coliforms in every 100ml[21]. This concentration, multiplied by the flow rate for each town (as listed in Chapter 1) gives the loading for each outfall. We have assumed that the proposed waste water treatment plant will remove 90% of the organic matter so that there are $1.0*10^{10}$ faecal coliforms in every cubic metre of treated effluent which is equivalent to $1.0*10^{6}$ faecal coliforms per 100ml.

We have used the results of the faecal coliform model to predict the concentrations of intestinal enterococci and *Escherichia coli* (sections 4.6 & 4.7).

A complete list of the production runs for the faecal coliform modelling is presented in the following table. Further production runs were simulated as part of a sensitivity analysis which is presented in sections 4.5. We examine the change in faecal coliform concentrations when a T90 of 24hours and different wind forcing are used.

	PR	Boundary	Forcing	T90
Case 1	**1**	Rpt Springs	Recorded wind & river flows	12hr
"	**2**	Rpt Neaps	Recorded wind & river flows	12hr
Case 2	**3**	Rpt Springs	Recorded wind & river flows	12hr
"	**4**	Rpt Neaps	Recorded wind & river flows	12hr
Case 3	**5**	Rpt Springs	Recorded wind & river flows	12hr
"	**6**	Rpt Neaps	Recorded wind & river flows	12hr
Case 4	**7**	Rpt Springs	Recorded wind & river flows	12hr
"	**8**	Rpt Neaps	Recorded wind & river flows	12hr

*Table 4-1 List of Production Runs **(PR)** for faecal coliform modelling. Recorded river flows were used for each run.*

[21] Tchobanoglous, G.; Burton, F.L. and Stensel, H.D.(2003). Wastewater Engineering: Treatment and Reuse/Metcalf & Eddy Inc. 4th Ed./Revised.

4.2 Spatially varying maps of Faecal Coliform concentration

This section presents the spatially varying maps of the maximum and averaged concentration for the entire model area. Over the course of the model run the number of faecal coliforms at each grid point will, at some specific moment, reach a maximum value. These maxima, at each and every grid point, may be extracted from the result files of a production run and plotted together on a single diagram. This diagram illustrates the spatially varying maximum concentrations for the simulation period for Cork Harbour. The times at which the concentrations reached their individual peak value are not considered.

In the same way there will be an average value in concentration for each grid point over the course of the simulation run. These averages, at each and every grid point, may be extracted from the result files of a model run and plotted together on a single diagram.

To aid the reader, the same colour palette is used for each plot and is shown on the right-hand side in each case. The full range of colours in the palette is used for the existing situation. Fewer colours are required for the proposed situation indicating a substantial relative reduction in concentration for faecal coliforms.

4.2.1 Repeating Spring Tides – Spatially Varying Maxima

Fig. 4.1 presents the maximum concentrations for Case 1, production run PR1. We can see from the figure that the highest concentrations are located just upstream of each of the outfalls. As the T90 is 12 hours in this run the bacteria decay rapidly upon being released from the outfall. There is a substantial drop in the maximum concentrations within a short distance of the outfall.

The bacterial plumes with concentrations in excess of 500 fc/100ml (red colour and above in the palette) do not extend[22] into the North Channel.

[22] The lowest value on the palette is 2 fc coliforms per 100ml. Values below this are not shown.

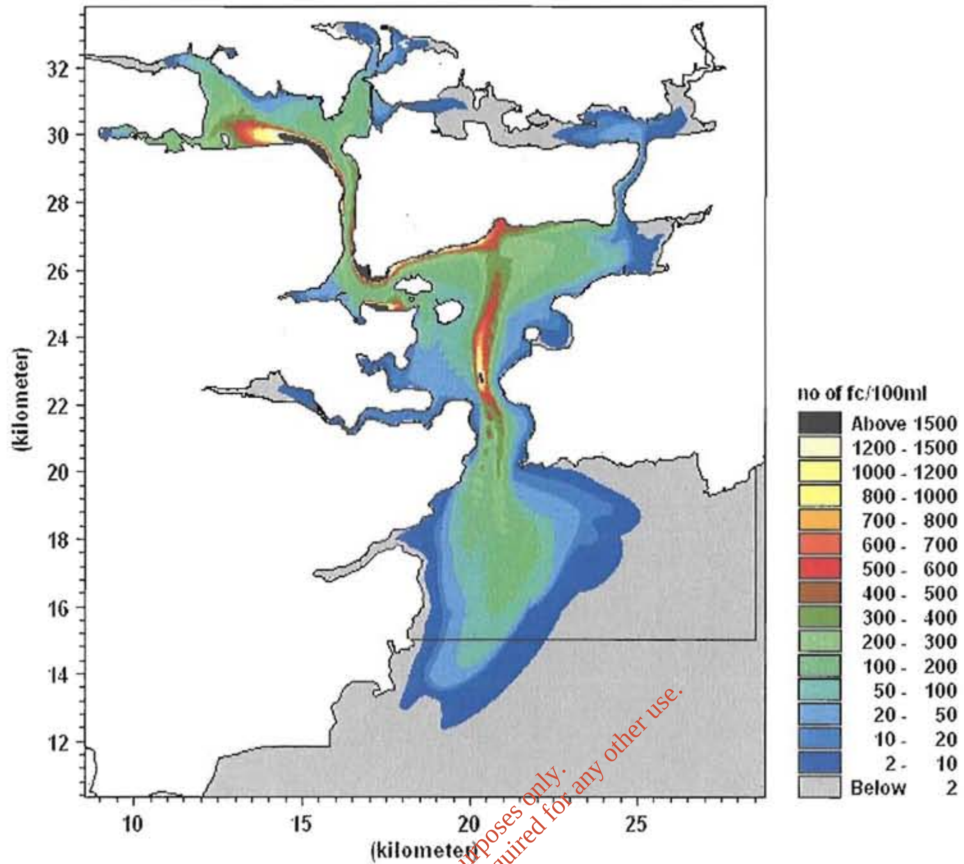

Fig. 4.1 Case 1, Production Run (PR) 1 – Maximum Concentrations[23]

Fig. 4.2 presents the maximum concentrations for Case 2, PR3. We can see how the maximum concentrations in the harbour increase as a result of the projected growth in population.

[23] We can see from Fig. 4.1 that discontinuities exist in the bands of concentration in the plot. If we follow a line due south from the location of the outfall we can see that patches of light red shading (400 -500 fc/100ml) are contained within the dark green shading (300 -400 fc/100ml). This is an artefact of the 15min sampling of the results generated by the model every 6 seconds (Δt = 6 seconds). Results were saved every 15 minutes and so some peak values were aliased in the writing of the result file. The error in the interpretation of the figure is not significant.

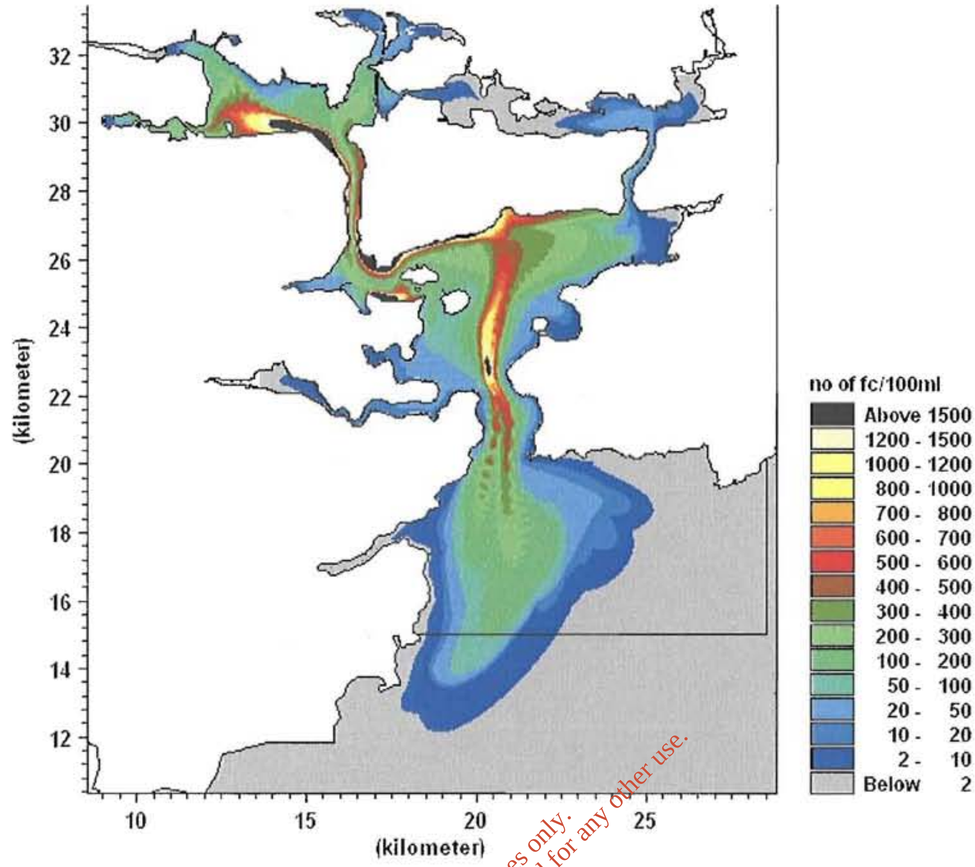

Fig. 4.2 Case 2, PR 3 – Maximum Concentrations

We have assumed that the 2010 design population is divided between the individual towns in the same way as it was for the 2001 situation. The individual flow rates are presented in the following table.

Outfall	CASE 1 (2001) – no teatment	CASE 3 (2010) - with treatment	**CASE 2 (2010) - no treatment**
Carrigaline/Crosshaven	4,075 m	10,371	**5624**
Passage West	547	0	**755**
Glenbrook	327	0	**451**
Monkstown	185	0	**255**
Pilots Pier Outfall	353	0	**487**
Corbett Outfall	178	0	**246**
Kings Quay Outfall	444	0	**613**
West Beach Outfall	668	0	**922**
White Point Outfall	634	0	**875**
Ringaskiddy Outfall	101	0	**139**
Total Flow Rate	7,515	10,371	***10,371***

Table 4-2 Design flow rates (m^3/day) for Case 2.

The flow rates for Case 2 given in the table above were obtained by multiplying the 2001 flow rates by 1.38. This scaling factor is obtained by dividing the combined flow rate for 2010 (10,371m3/day) by the combined flow rate for 2001

(7,515m3/day). Because the model is linear we may multiply all the concentrations in the harbour for 2001 by 1.38 to obtain 2010.

For both situations we can see that the concentrations of faecal coliforms, with the exception of the areas immediately surrounding the outfalls, range from 2 - 1200 fc/100ml.

Fig. 4.3 presents the maximum concentrations for Case 3, PR5. We can see from the figure that there has been a reduction in the number of faecal coliforms over the entire harbour with the introduction of the proposed treatment plant at Carrigaline. With the exception of the area immediately surrounding the proposed outfall the concentration of faecal coliforms is less than 300/100ml.

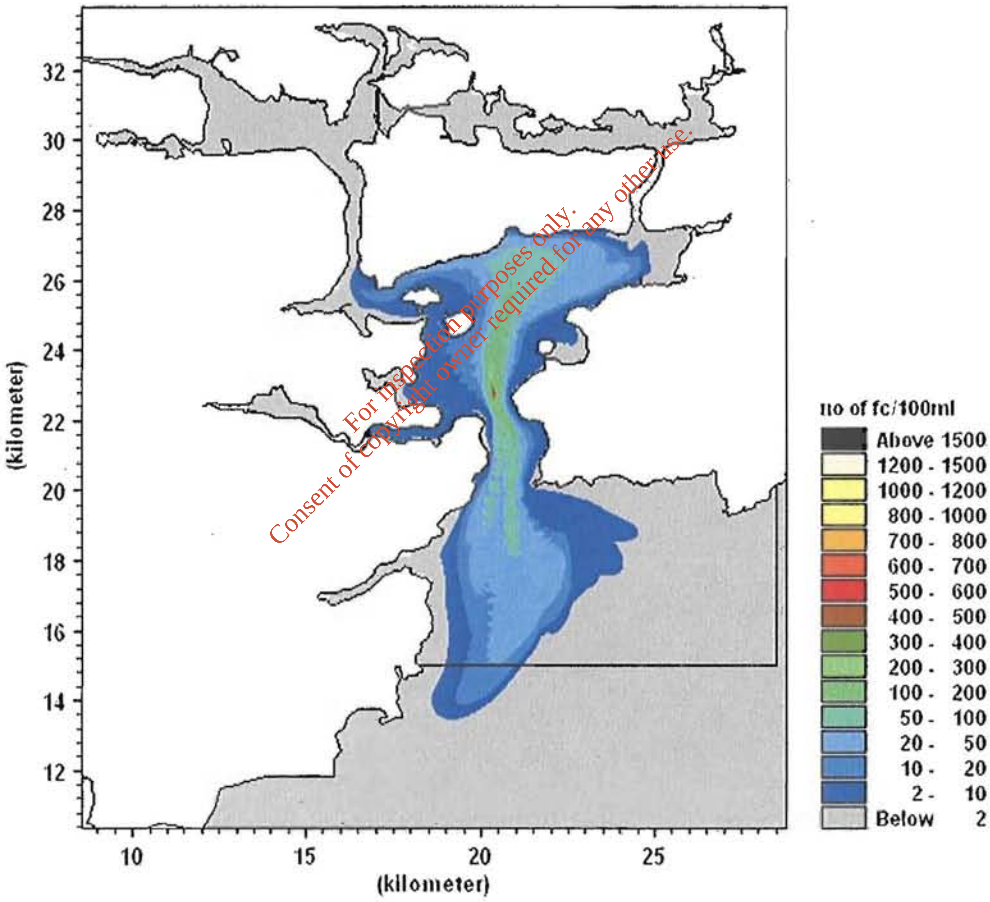

Fig. 4.3 Case 3, PR 5 – Maximum Concentrations

In order to quantify this improvement in water quality we can express the maximum concentrations with the treatment plant in place as a percentage of the maximum concentrations without the treatment plant in place (Fig. 4.4). We do this by dividing the maximum concentrations for Case 3 by the maximum concentrations for Case 2 and multiply the answer by 100. We can see from Fig. 4.4 that there has been a considerable relative reduction in the number of faecal coliforms across the entire harbour. The concentrations with the treatment plant in place are at least less than 20% of the concentrations without the treatment plant in place for the entire area i.e. there is an 80% relative reduction in the number of faecal coliforms. For the Inner harbour and the East and West Passages the concentrations are less than 5% i.e. there is a 95% relative reduction in the number of number of faecal coliforms. This represents a significant improvement in water quality.

Fig. 4.5 presents the maximum concentrations for Case 4, PR 7. As we can see from the figure there is an increase in the maximum concentration over the entire grid. The values in this plot are the values presented in Fig. 4.3 (Case 3, PR5) multiplied by 1.431. All of the models presented in this report obey the principles of superposition and scaling in both time and space. This allows us to scale up or down the results of a simulation run based on either an increase or decrease in the input concentrations or flow rates[24]. In this instance we have multiplied the values for PD5 by 1.431. This scaling factor is obtained by dividing the combined flow rate for 2030 (14,837m3/day) by the combined flow rate for 2010 (10,371m3/day). The principle of superposition allows us to multiply all the concentrations in the harbour for PR5 by 1.431 to obtain PR7.

[24] The necessary conditions for the theorem of superposition are (1) the boundary conditions must be zero, and (2) all carrier flows must be present in each individual case in both the hydrodynamic and water quality parts of the model. The proof of the theorem follows immediately from the linearity of the partial differential equation that describes the water quality dynamics.

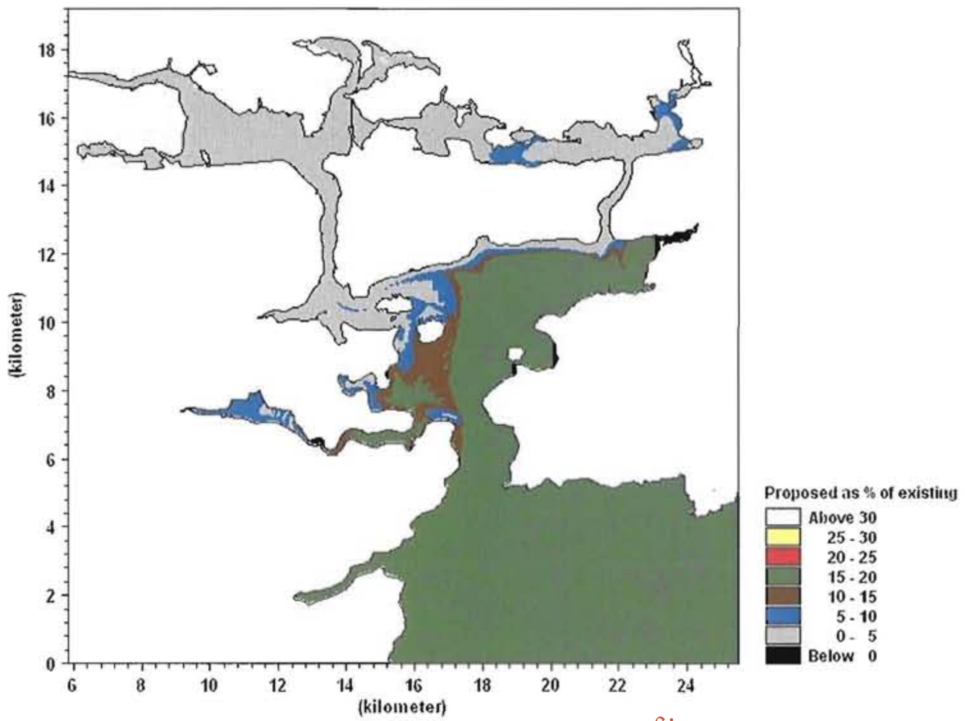

Fig. 4.4 PR3 as a % of PR5 - Maximum Concentrations

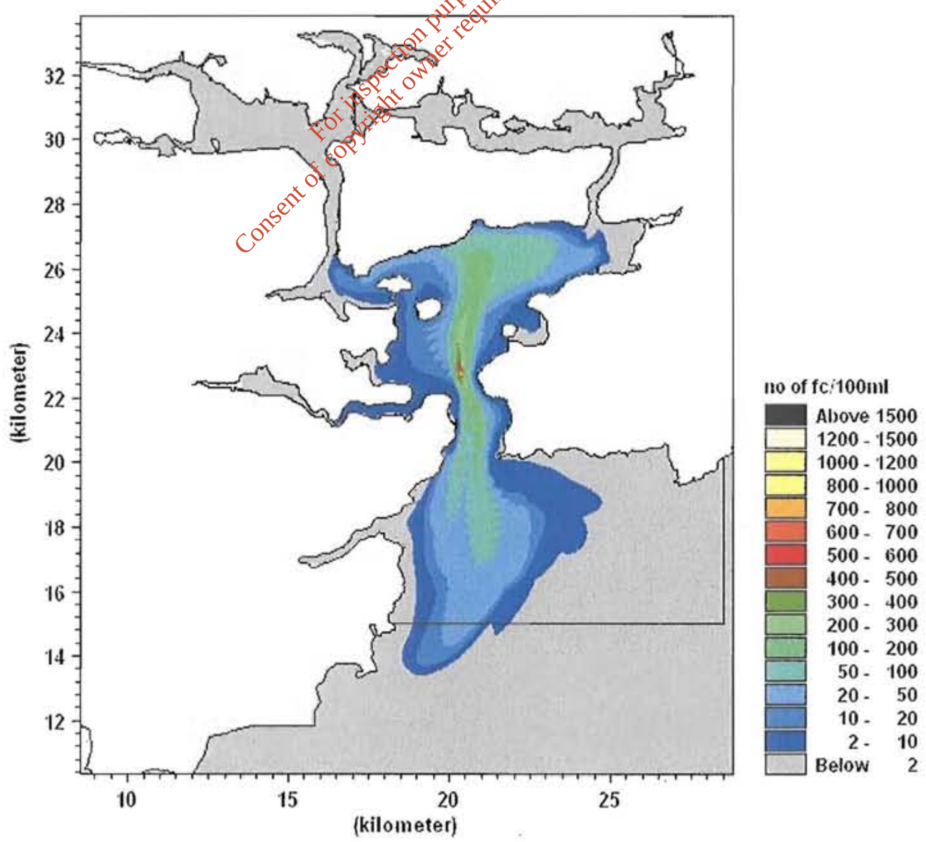

Fig. 4.5 Case 4, PR 7 – Maximum Concentrations

4.2.2 Repeating Spring Tides – Spatially Varying Averages

The spatially varying averages are now presented. The averaged concentrations for Case 2[25] are highlighted in Fig. 4.6. We can see from the figure that the concentrations are much less than the maximum concentrations presented in the previous section. With the exception of the areas adjacent to the outfalls the averaged concentrations are less than 200 fc/100ml.

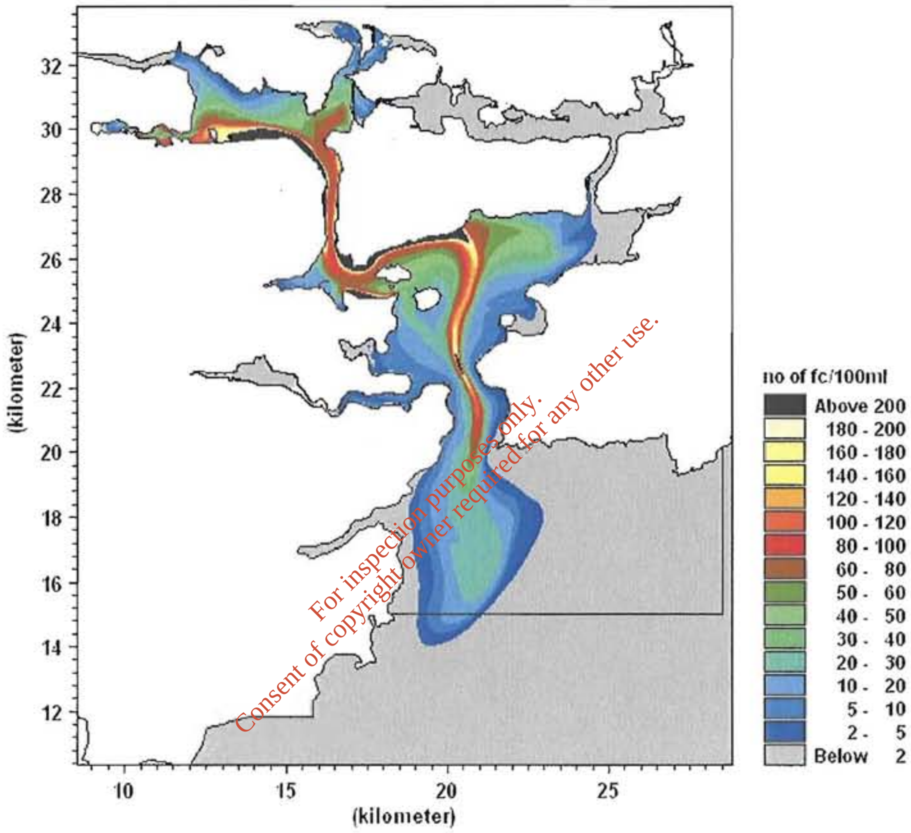

Fig. 4.6 Case 2, PR 3 – Averaged Concentrations

The averaged concentrations for Case 3, PR 5 are presented in Fig. 4.7. We can see from the figure that the averaged concentrations with the proposed treatment plant in place are greatly reduced. To quantify this improvement in water quality we can, as before, express the averaged concentrations for PR5 as

[25] The averaged concentration map for Case 1 has been omitted as it is visually very similar to this plot. The equivalent plots for the neap tides in the next two sections have also been omitted for the same reason.

a percentage of the averaged concentrations for PR3. This is shown in Fig. 4.8. We can see from the figure that the improvement for the averaged concentrations is similar to that of the maximum concentration (Fig. 4.4). The number of faecal coliforms is reduced by at least 80% for the entire model area. For the inner harbour they are reduced by at least 95%.

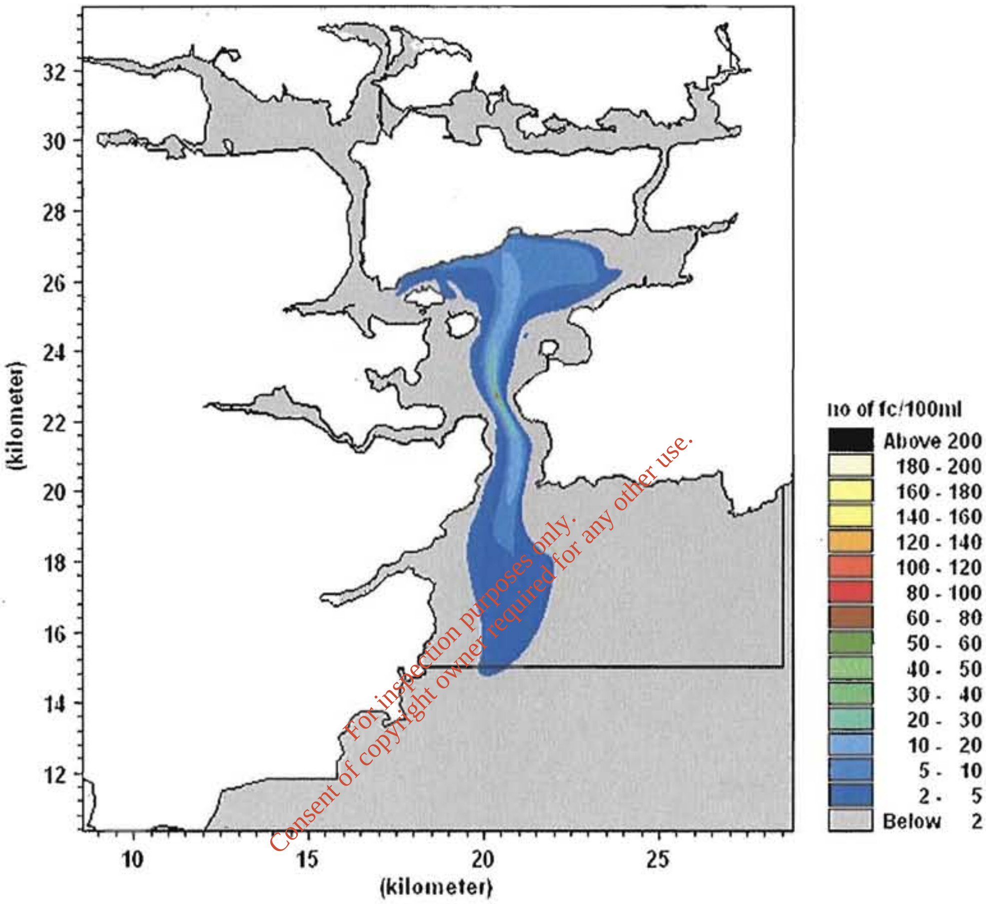

Fig. 4.7 Case 3, PR 5 – Averaged Concentrations

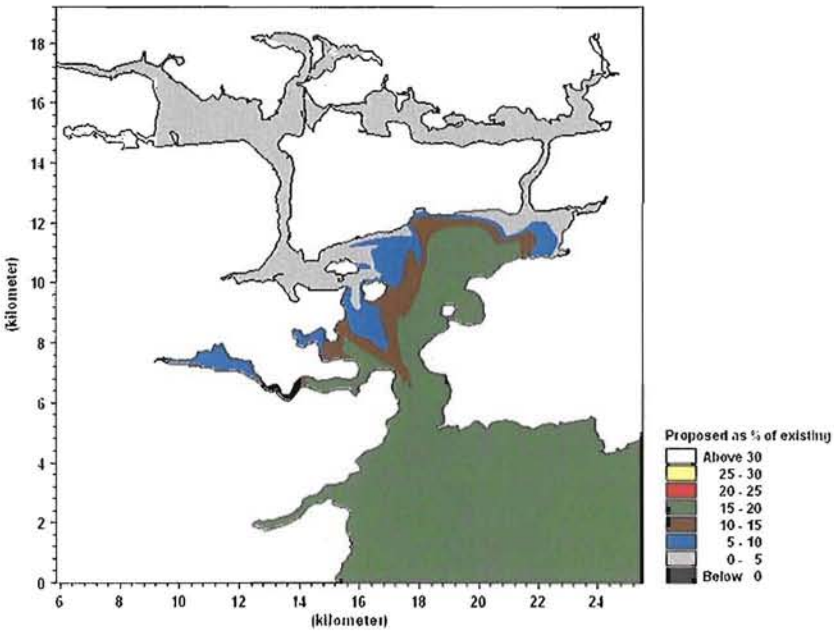

Fig. 4.8 PR3 as a % of PR5 - Averaged Concentrations

4.2.3 Repeating Neap Tides – Spatially Varying Maxima

The spatially varying maximums for the neap tides are presented in this section. We can see from Fig. 4.9 that the concentrations in the harbour are comparable to the equivalent spring tide simulation (Fig. 4.2). The extent of the plume however differs outside the harbour mouth.

For PR6 (Fig. 4.10) we can see that there is a reduction in the number of faecal coliforms per 100ml with the introduction of the proposed treatment plant. With the exception of the area immediately adjacent to the proposed outfall the number of faecal coliforms per 100ml ranges from 2 to 500 fc/100ml.

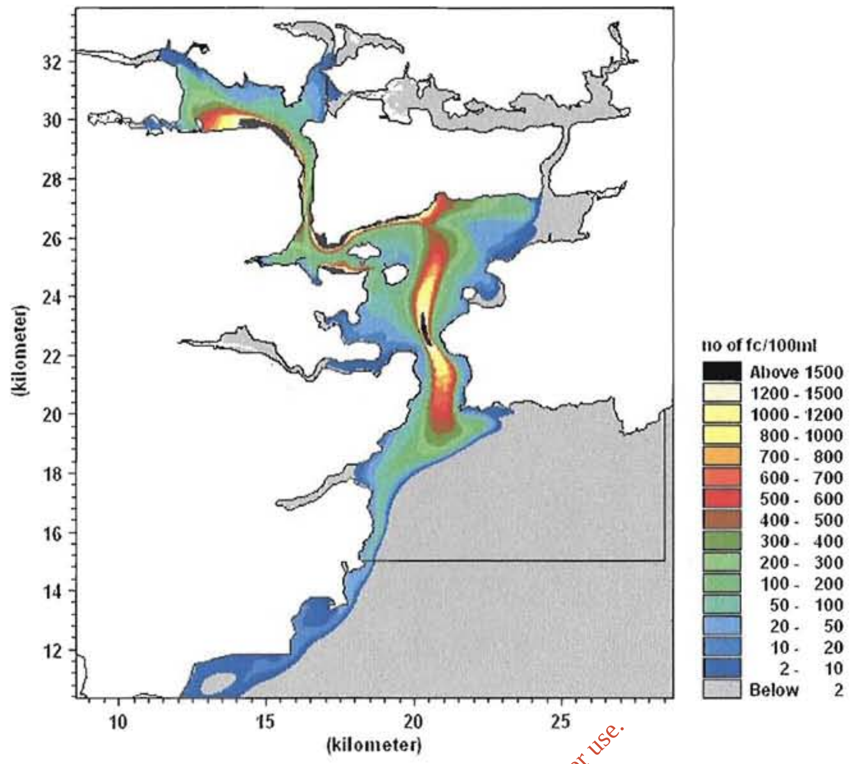

Fig. 4.9 Case 2, PR 4 – Maximum Concentrations

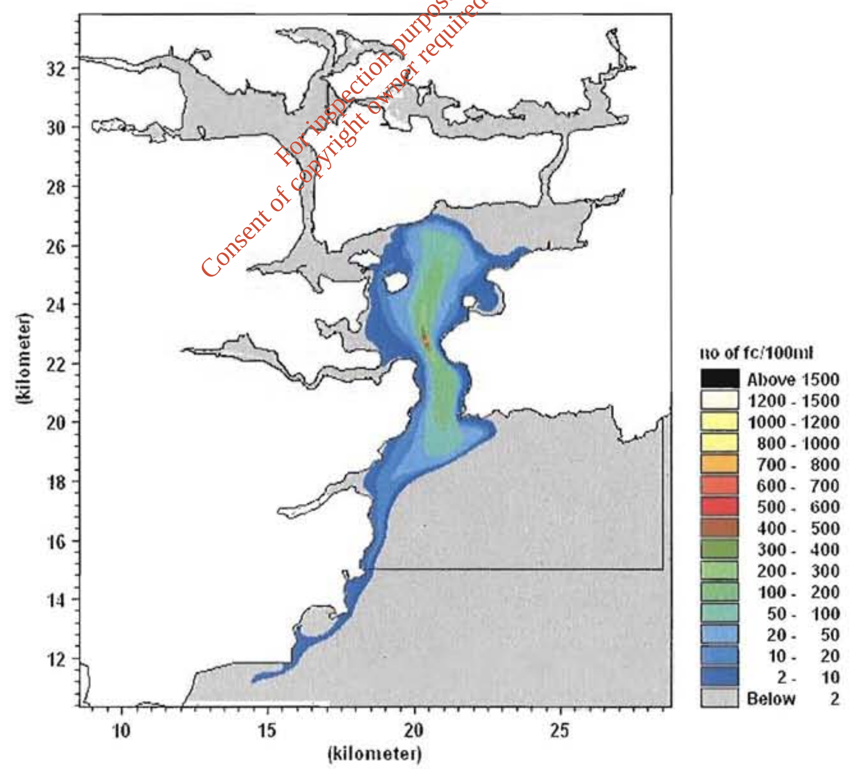

Fig. 4.10 Case 3, PR 6 – Maximum Concentrations

4.2.4 Repeating Neap Tides – Spatially Varied Averages

The spatially varying averages for the repeating neap tides are now presented. We can see from Fig. 4.11 (PR 4, Case 2) that the averages for the neap tides are similar to those of the spring tides. As with the equivalent maximum concentrations the extent of the plume is different outside the harbour mouth. PR 6 is presented in Fig. 4.12. We can see from the figure that the averaged concentrations are greatly reduced with the introduction of the proposed scheme.

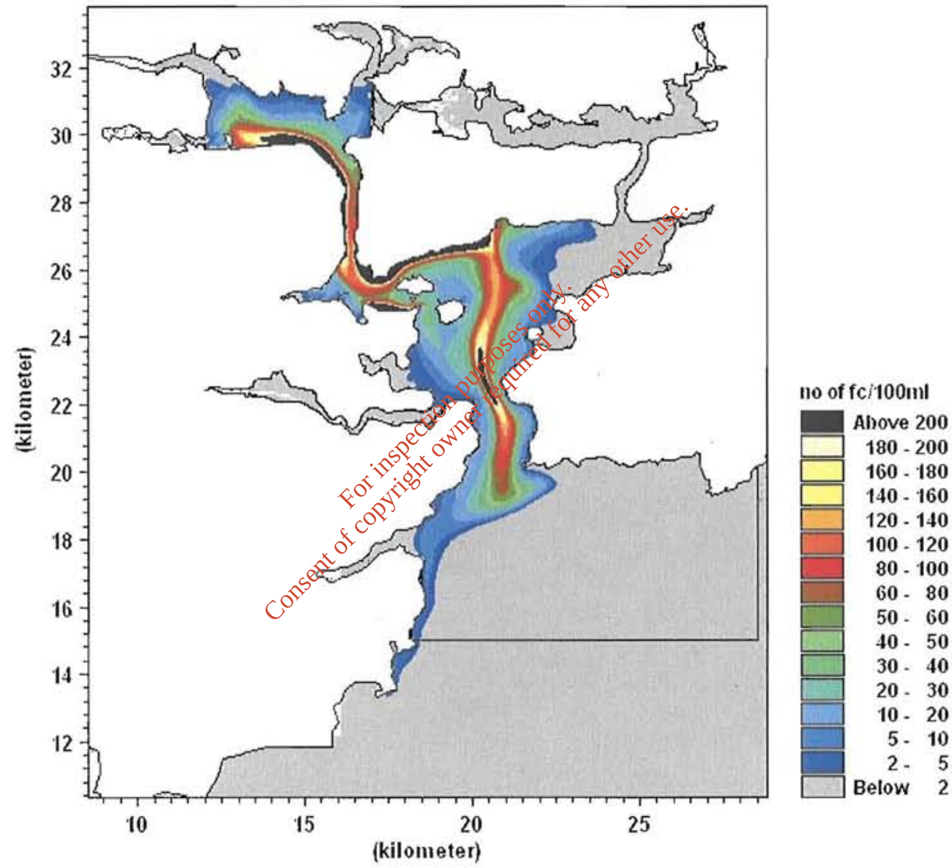

Fig. 4.11 Case 2, PR 4 – Averaged Concentrations

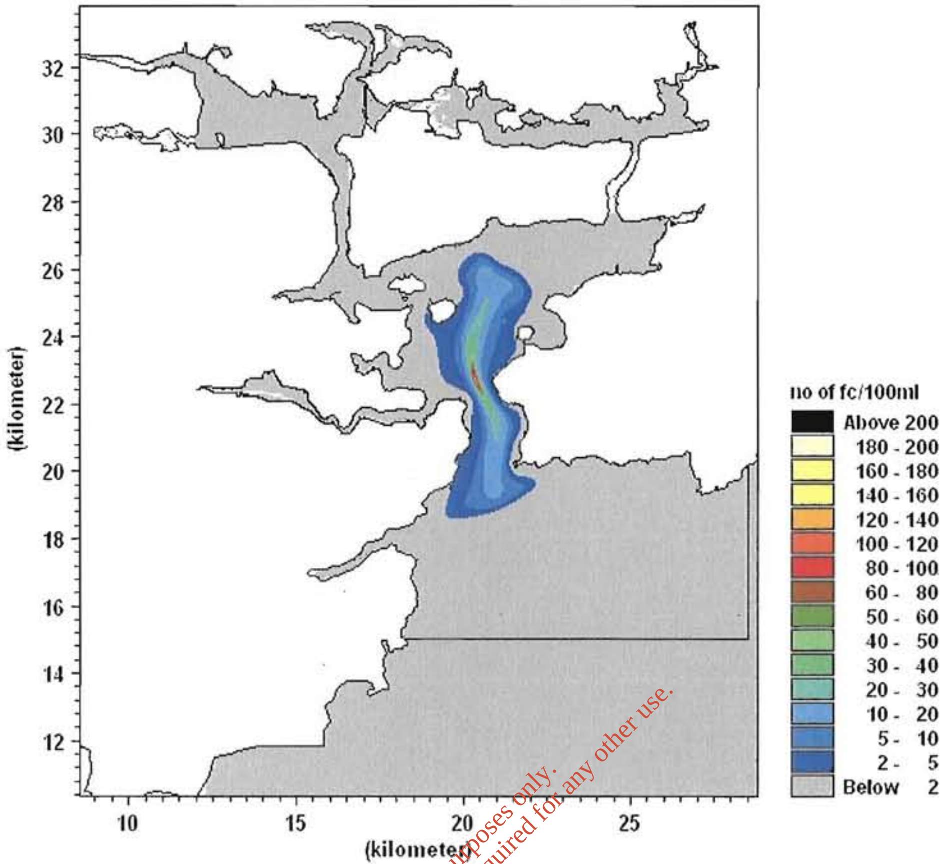

Fig. 4.12 Case 3, PR 6 – Averaged Concentrations

4.3 Time series of Faecal Coliform Concentrations

The previous section presented spatially varying maps of concentration across the entire harbour area. In order to evaluate the benefit of the proposed outer harbour drainage scheme at a particular point in the harbour we must extract the time series of concentration from that location in the model. For this Environmental Impact Statement 15 points of special interest have been identified. These are listed in the following table and plotted in Fig. 4.13.

The maximum and average value of faecal coliforms for each location is presented in Table 4-4 and Table 4-5.

Point No	Location	E (UTM)	N (UTM)
1	Fountainstown	547588	5736208
2	Myrtleville	548700	5737121
3	Roches Point	550651	5738138
4	Crosshaven	548497	5739695
5	Ringaskiddy Ferry	546466	5742772
6	Monkstown Creek	545166	5743316
7	Oyster Farm - North Channel	552712	5748103
8	Marlogue Point	554291	5745574
9	Oyster Farm - Outer Harbour	555451	5744826
10	Cobh - Recreational Area	548617	5744396
11	Spike Island - Proposed Heritage Area	549349	5742451
12	Shoreline Closest to Existing Outfall	547959	5741601
13	200m Upstream of Existing Outfall[26]	550203	5740759
14	West Passage	546223	5744496
15	Entrance to Lough Mahon	545505	5747784

Table 4-3 List of the sites of interest

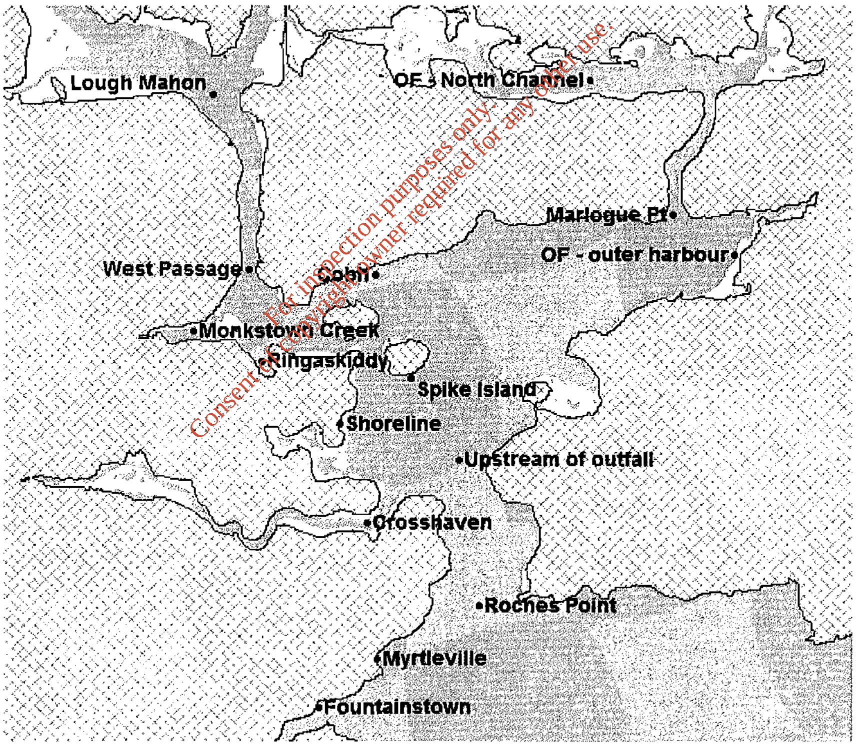

Fig. 4.13 Points of Special Interest to study

In order to make an assessment of the improvement in water quality resulting from the proposed wastewater treatment plant, time series for Case 2 and Case

[26] This point lies just outside the near field mixing zone

3 are presented in this section for both repeating spring and neap tides. The time series for Case 4 (2030) are not presented. The principle of superposition allows us to simply multiply the time series for Case 3 by 1.431 to get case 4.

Two plots are presented for each of the 15 points of special interest in this study. The first is the repeating spring tides for Case 3 (PR3) and Case 4 (PR3). The second is the repeating neap tide for Case 3 (PR5) and Case 4 (PR6).

For the repeating spring tide graphs, Case 2 is plotted with a blue line while Case 3 is plotted using red. The line is labelled “existing” in the legend indicating the existing scenario of no treatment.

For the repeating neap tide graphs Case 2 is plotted with a green line while Case 3 is plotted using dark red. This line is labelled “proposed” in the legend indicating the proposed treatment infrastructure.

The reader should be aware that the scale on the right-hand side, which indicates the number of faecal coliforms per 100ml, varies considerably for each of the 13 locations. The scale is the same however for the spring and neap graphs at each individual particular point. This allows us to determine what tidal conditions yield the highest concentration at each location.

The reader should also be aware that the dates labelled along the x-axis in all the time series refer to the period in 2004 which was chosen to simulate the model. Simultaneous measurements of wind, river flows and Proudman Data were available for this period. The simulated hydrodynamics are typical of any year and have been used for the three different cases considered in this report (2001, 2010 & 2030).

Year	2001		2010		2010		2030	
Treatment	none		none		Treated		Treated	
Repeating Tide	Spring MAX	Neap MAX	Spring MAX	Neap MAX	Spring MAX	Neap MAX	Spring MAX	Neap MAX
Fountainstown	0.8	0.4	1.0	0.5	0.2	0.1	0.3	0.1
Myrtleville	2.7	3.2	3.7	4.5	0.7	0.8	1.0	1.2
Roches Point	256.7	402.7	354.3	555.8	65.3	102.5	93.5	146.7
Crosshaven	17.7	4.1	24.5	5.6	3.8	1.5	5.4	2.2
Ringaskiddy	42.8	17.2	59.1	23.8	0.0	0.0	0.0	0.0
Monkstown Ck	24.5	85.6	33.8	118.1	0.0	0.0	0.0	0.0
Oyster F - NC	5.7	0.0	7.8	0.0	0.1	0.0	0.2	0.0
Marlogue Point	26.1	0.8	36.1	1.1	0.3	0.0	0.4	0.1
Oyster F - Outer	2.7	0.0	3.7	0.0	0.6	0.4	0.9	0.6
Cobh	346.7	344.5	478.4	475.4	23.2	0.9	33.2	1.4
Spike Island	47.8	70.3	66.0	97.0	9.1	17.8	13.1	25.5
Shoreline	11.0	10.1	15.2	14.0	2.2	1.2	3.2	1.8
Upstream Outfall	1332.5	1662.5	1838.8	2294.3	333.7	423.0	477.6	605.3
West Passage	140.9	178.0	194.4	245.6	1.0	0.0	1.5	0.0
Lough Mahon	155.8	136.5	215.0	188.4	0.1	0.0	0.2	0.0

All concentrations are expressed in no of fc per 100ml

Table 4-4 Maximum faecal coliform concentrations for locations of interest

Year	2001		2010		2010		2030	
Treatment	None		None		Treated		Treated	
Repeating Tide	Spring AVG	Neap AVG	Spring AVG	Neap AVG	Spring AVG	Neap AVG	Spring AVG	Neap AVG
Fountainstown	0.21	0.06	0.29	0.09	0.05	0.02	0.07	0.02
Myrtleville	0.57	1.27	0.79	1.75	0.14	0.32	0.20	0.46
Roches Point	46.22	55.97	63.79	77.24	11.65	14.25	16.67	20.39
Crosshaven	4.32	0.93	5.96	1.28	0.95	0.19	1.36	0.28
Ringaskiddy	13.67	5.72	18.86	7.89	0.01	0.00	0.02	0.00
Monkstown Ck	8.38	6.14	11.56	8.47	0.01	0.00	0.01	0.00
Oyster F - NC	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Marlogue Point	2.62	0.03	3.62	0.04	0.04	0.00	0.06	0.00
Oyster F - Outer	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Cobh	81.96	111.59	113.10	153.99	5.32	0.05	7.62	0.07
Spike Island	10.31	13.94	14.22	19.24	1.55	3.16	2.21	4.53
Shoreline	3.33	0.65	2.71	0.89	0.56	0.10	0.47	0.15
Upstream Outfall	83.78	209.64	115.62	289.31	20.12	53.32	28.79	76.30
West Passage	56.00	81.47	77.28	112.43	0.08	0.00	0.11	0.00
Lough Mahon	45.94	42.47	63.40	58.61	0.01	0.00	0.01	0.00

All concentrations are expressed in no of fc per 100ml

Table 4-5 Average faecal coliform concentrations for locations of interest

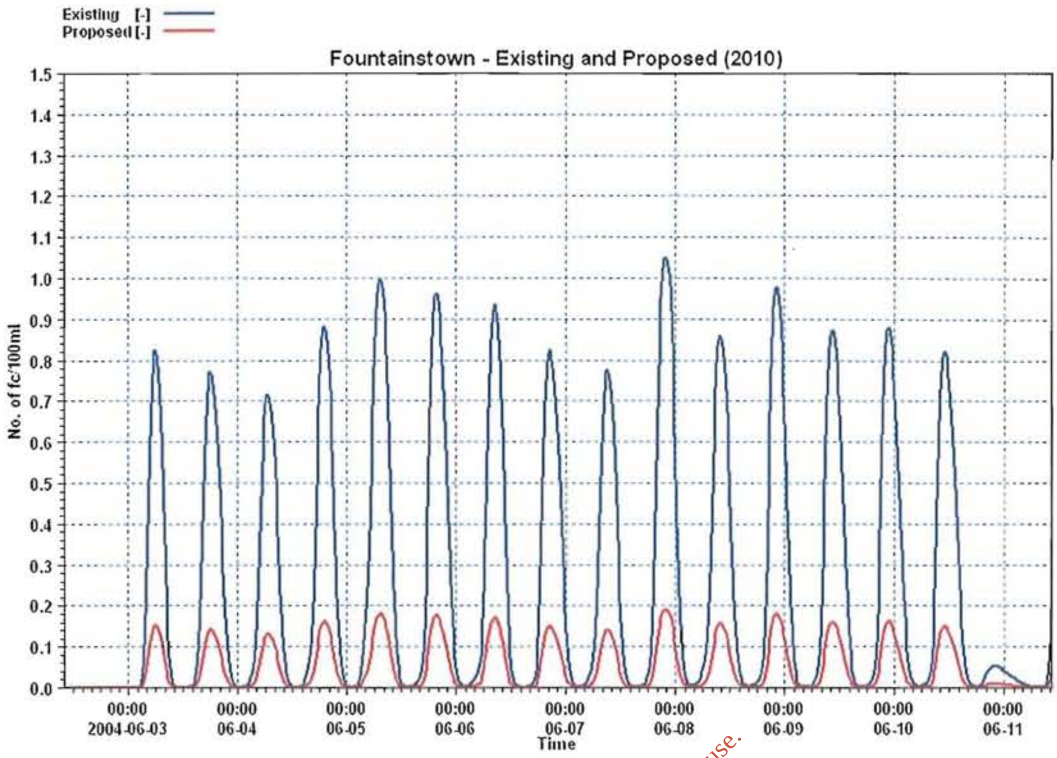

Fig. 4.14 Fountainstown – Repeating Spring Tide

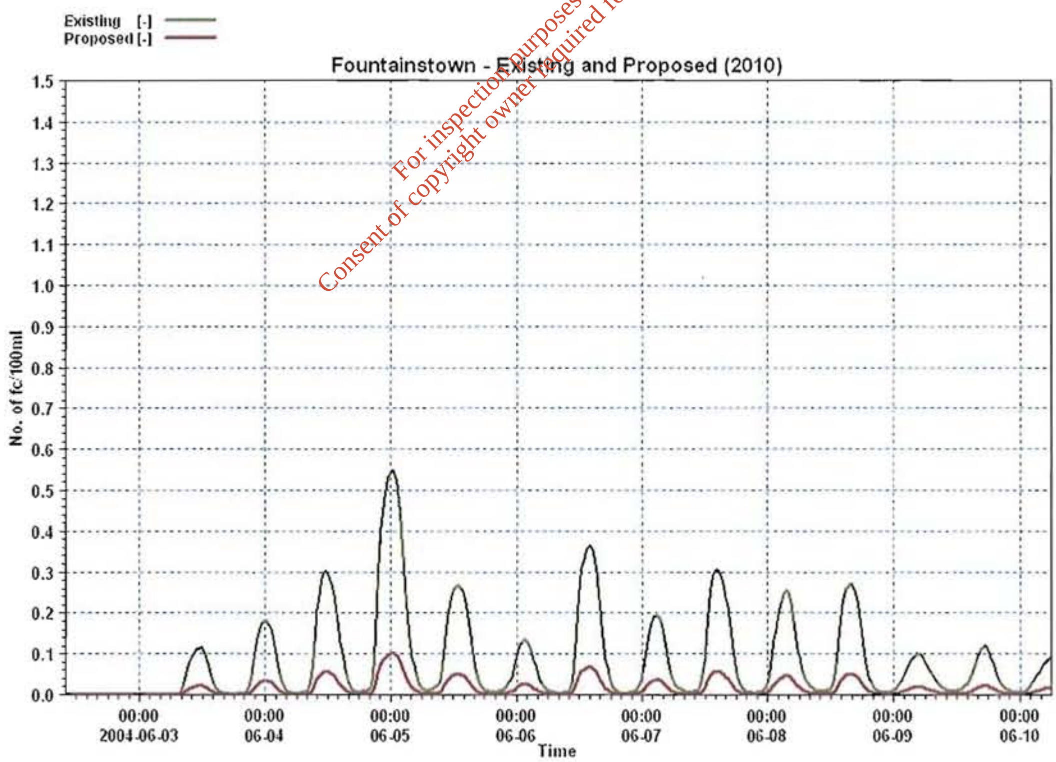

Fig. 4.15 Fountainstown – Repeating Neap Tide

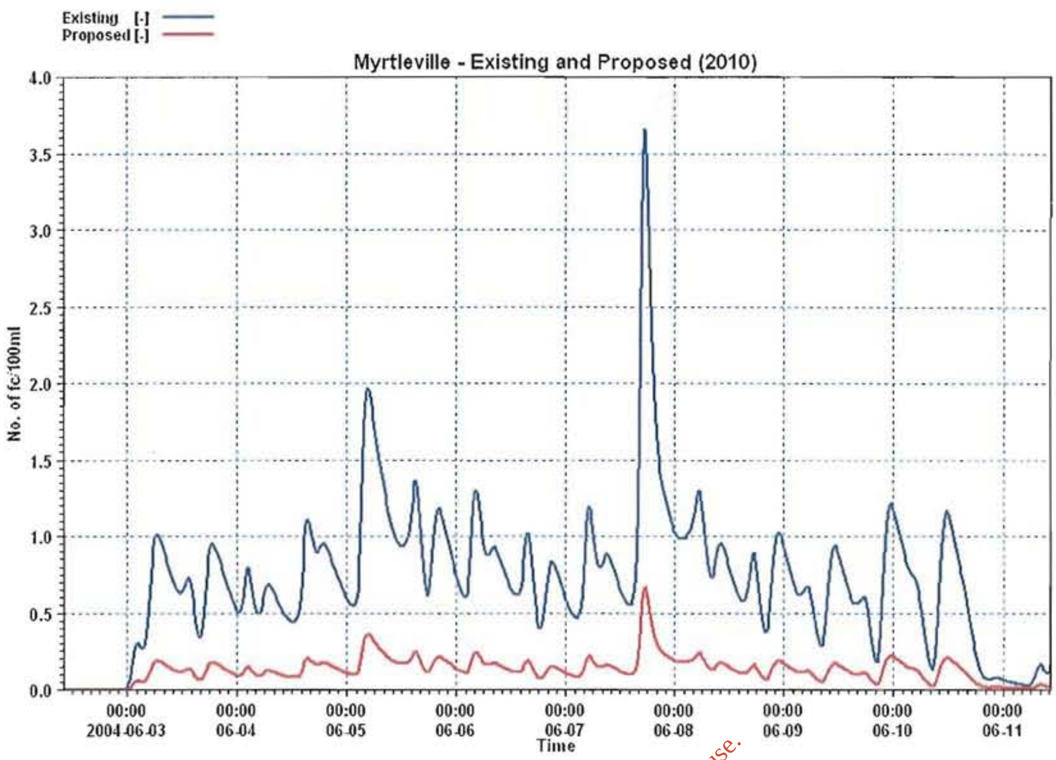

Fig. 4.16 Myrtleville – Repeating Spring Tide

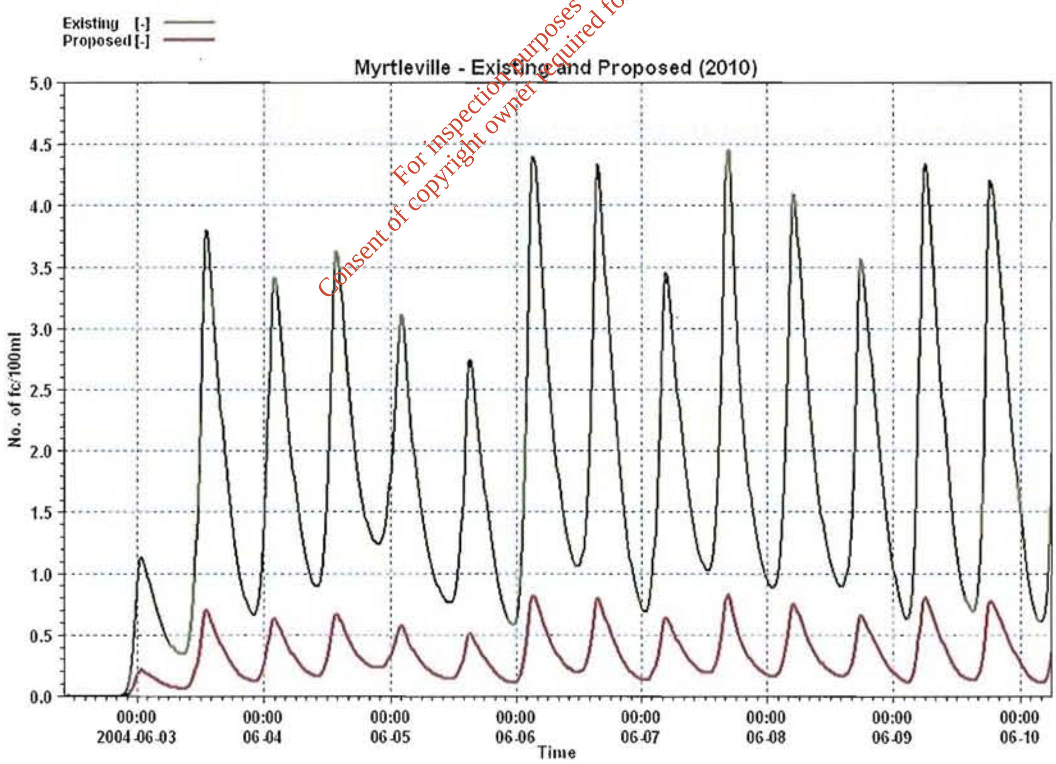

Fig. 4.17 Myrtleville – Repeating Neap Tide

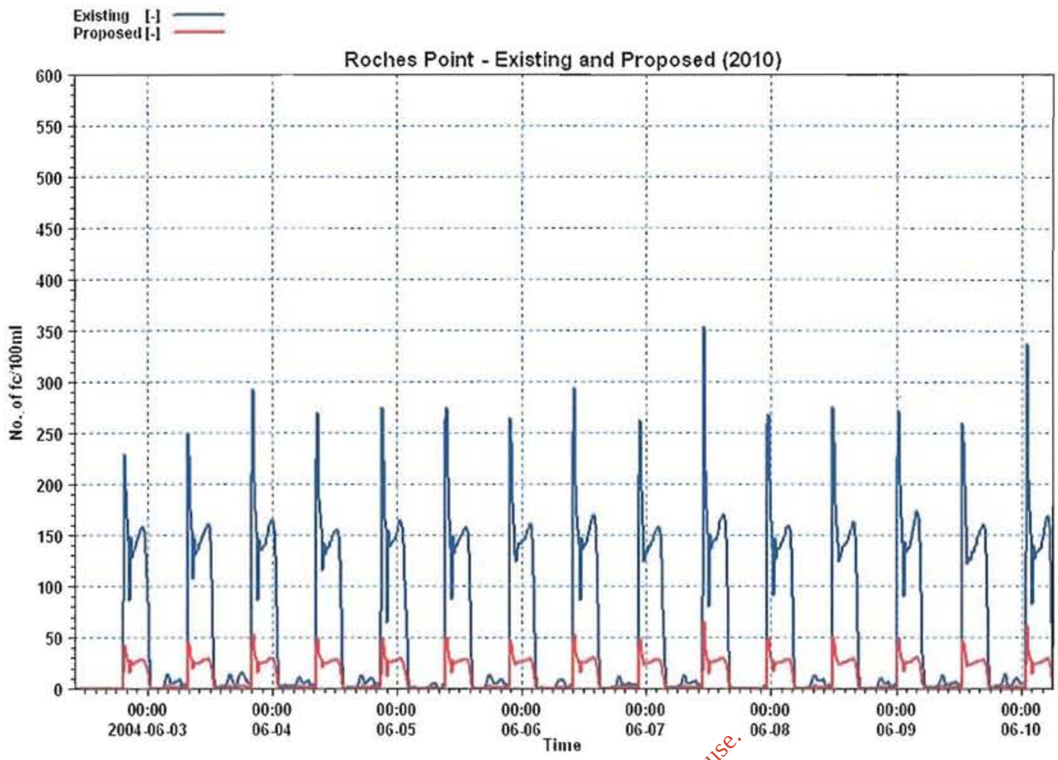

Fig. 4.18 Roches Point – Repeating Spring Tide

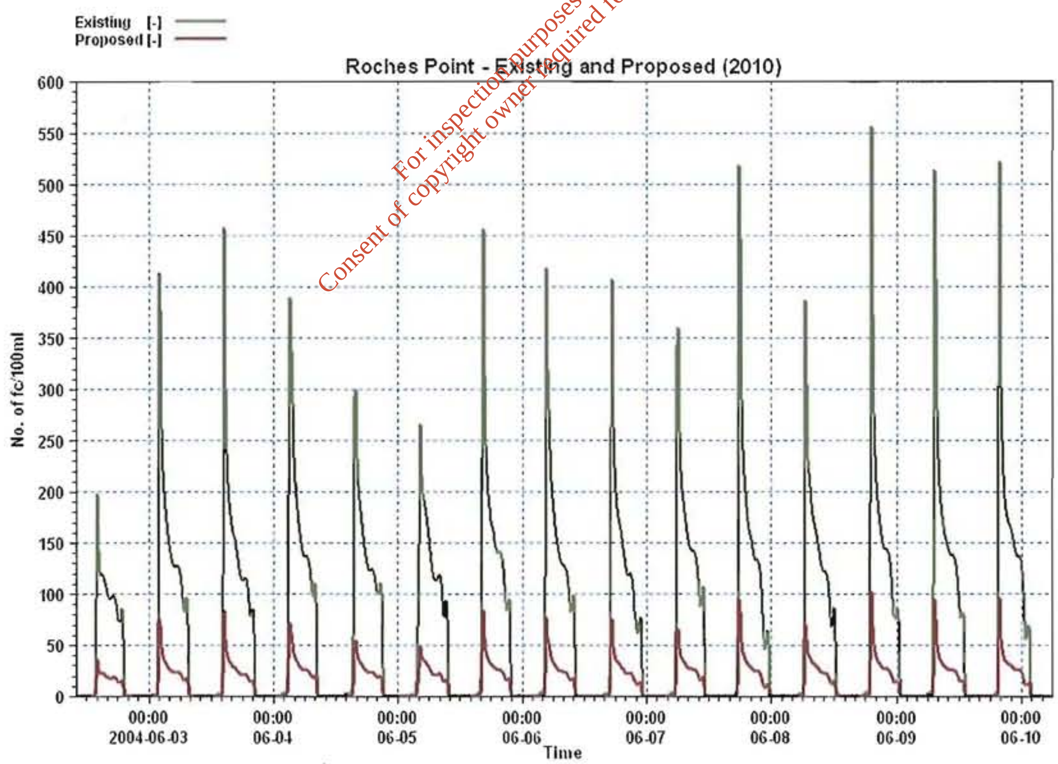

Fig. 4.19 Roches Point – Repeating Neap Tide

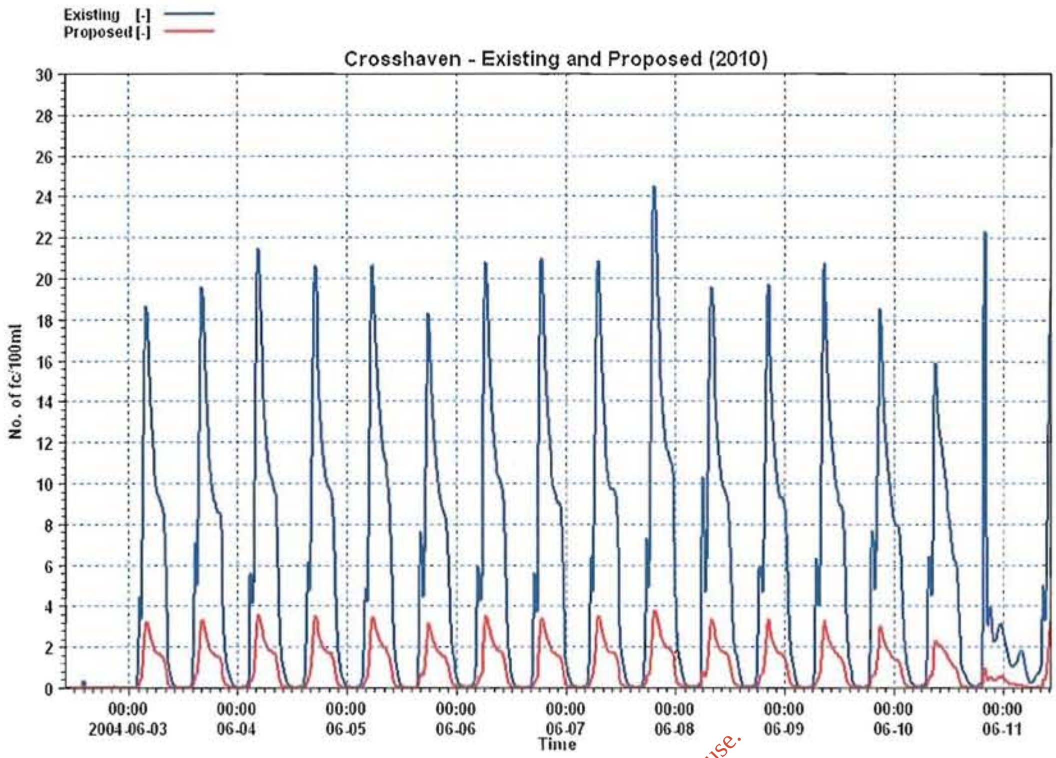

Fig. 4.20 Crosshaven – Repeating Spring Tide

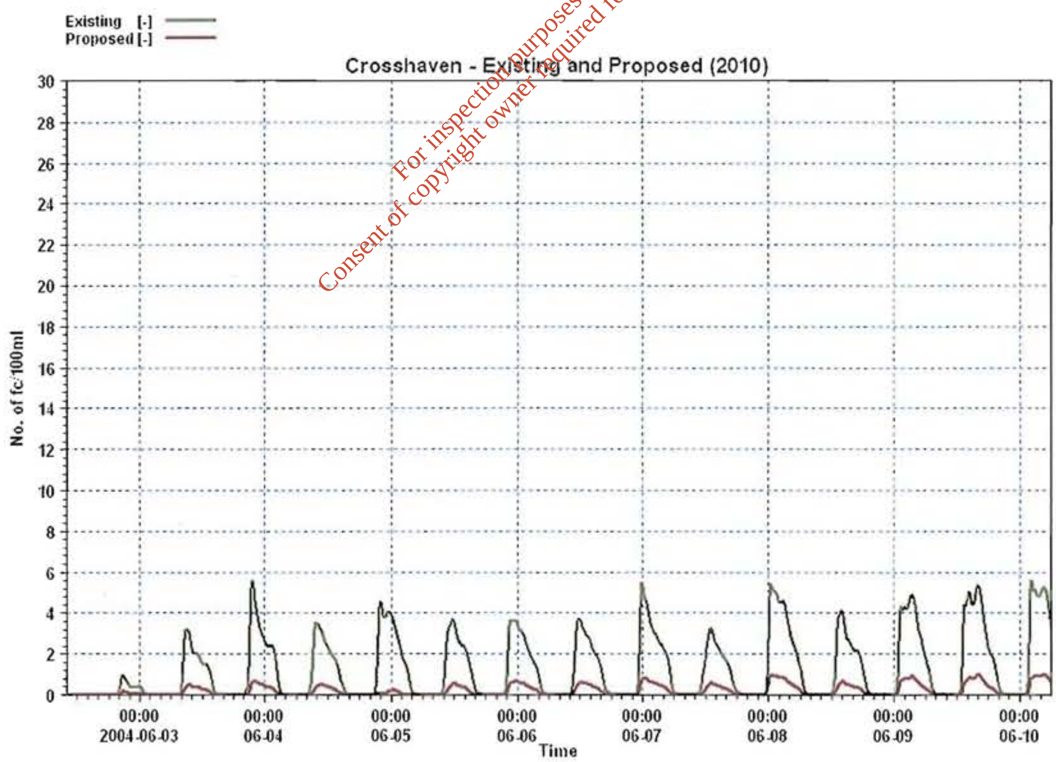

Fig. 4.21 Crosshaven – Repeating Neap Tide

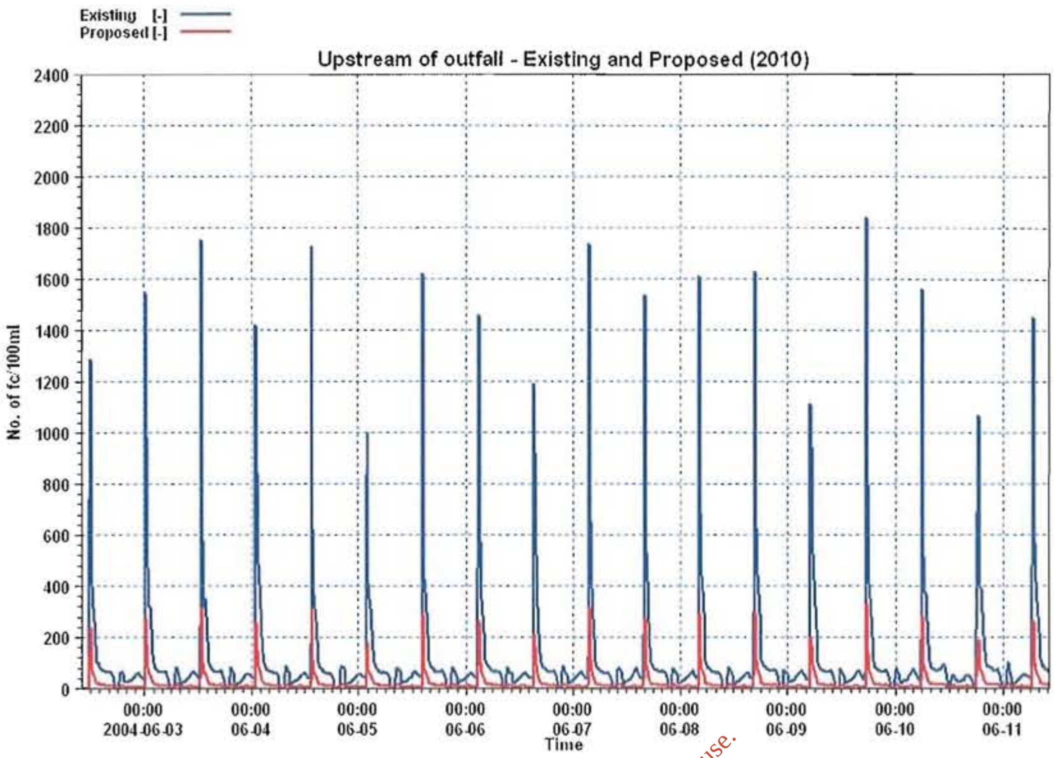

Fig. 4.22 200m upstream of outfall – Repeating Spring Tide

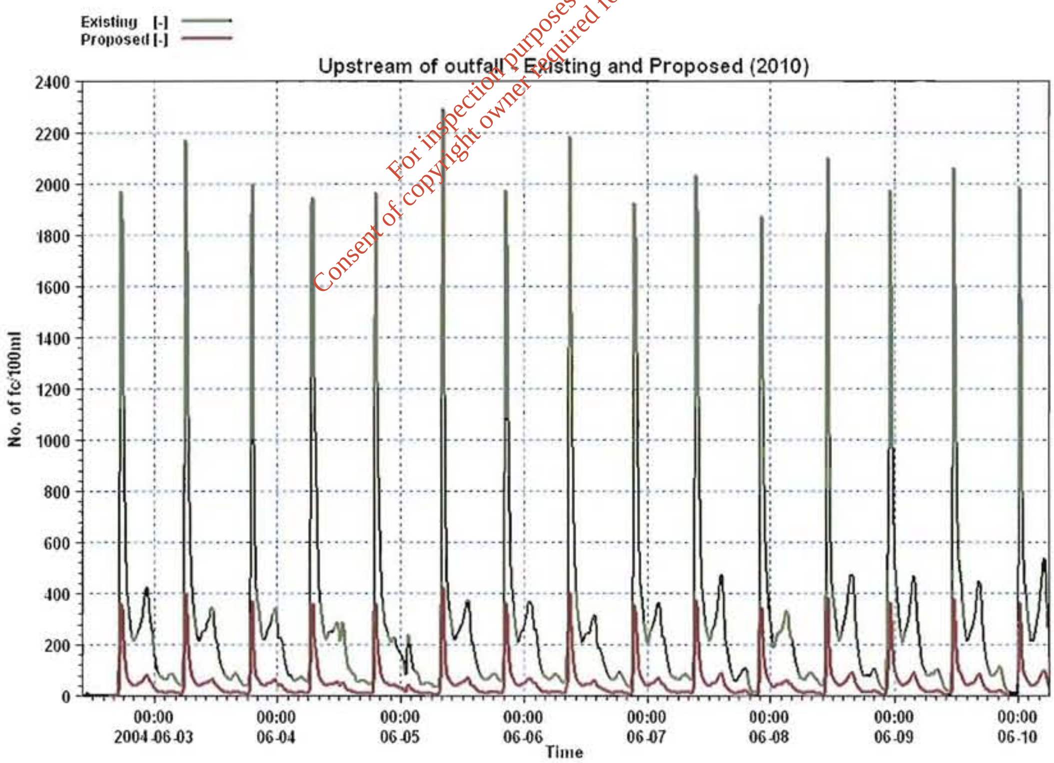

Fig. 4.23 200m upstream of outfall – Repeating Neap Tide

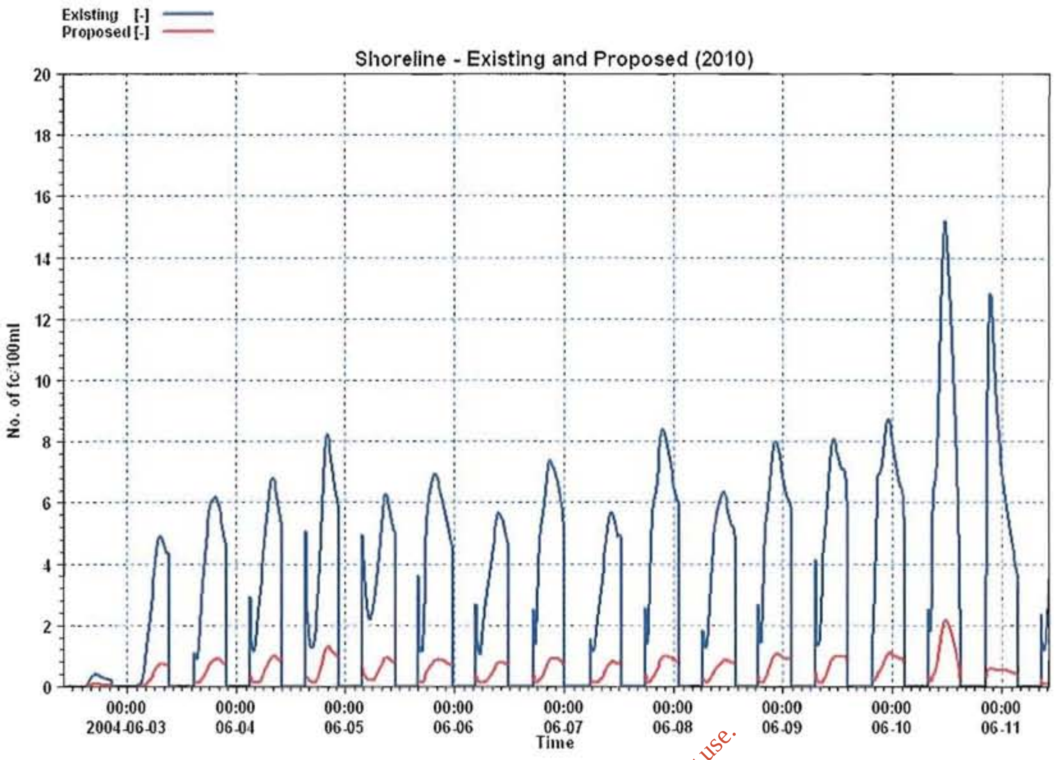

Fig. 4.24 Shoreline closest to outfall – Repeating Spring Tide

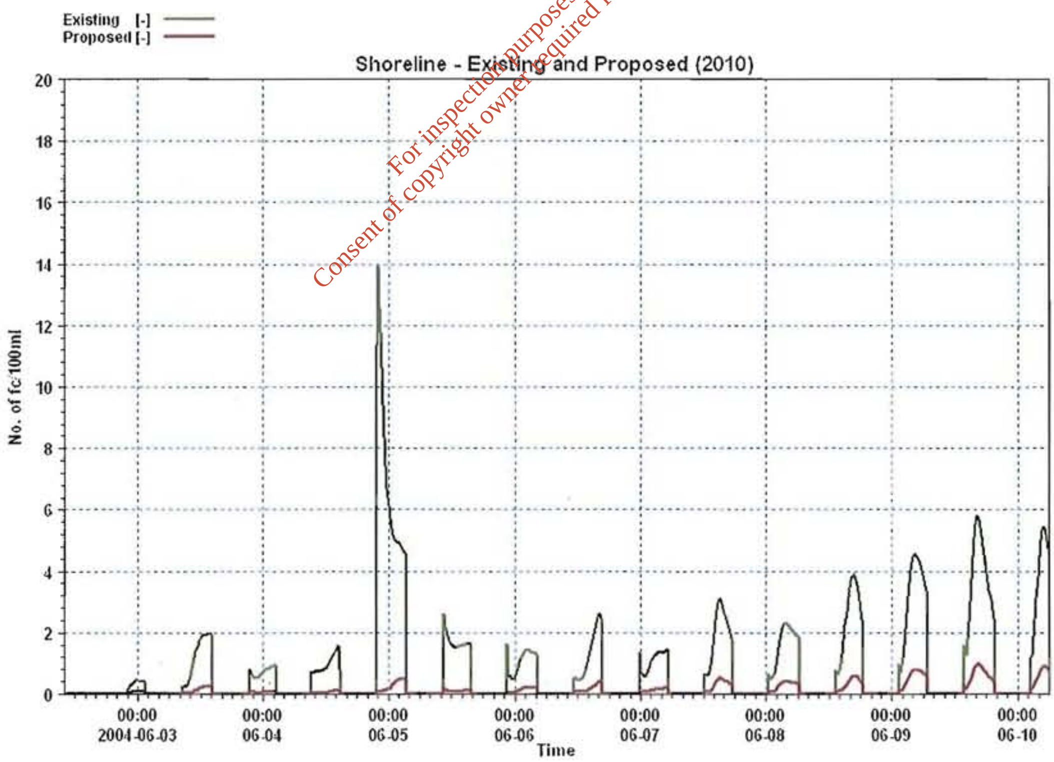

Fig. 4.25 Shoreline closest to outfall – Repeating Neap Tide

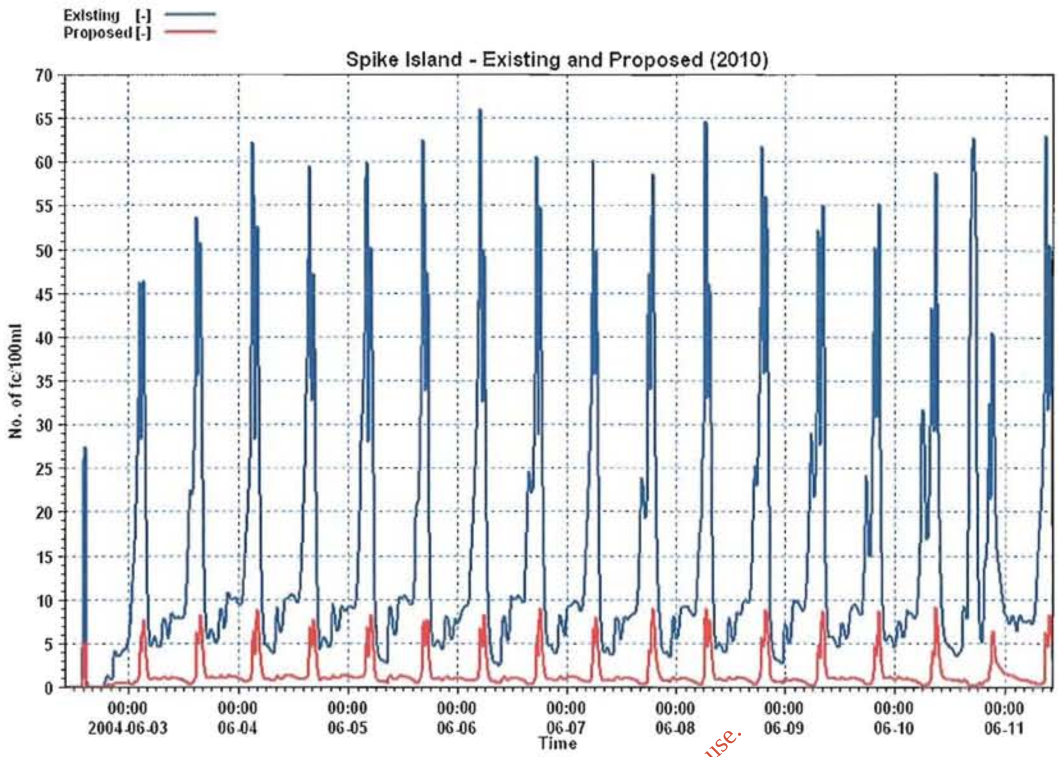

Fig. 4.26 South of Spike Island – Repeating Spring Tide

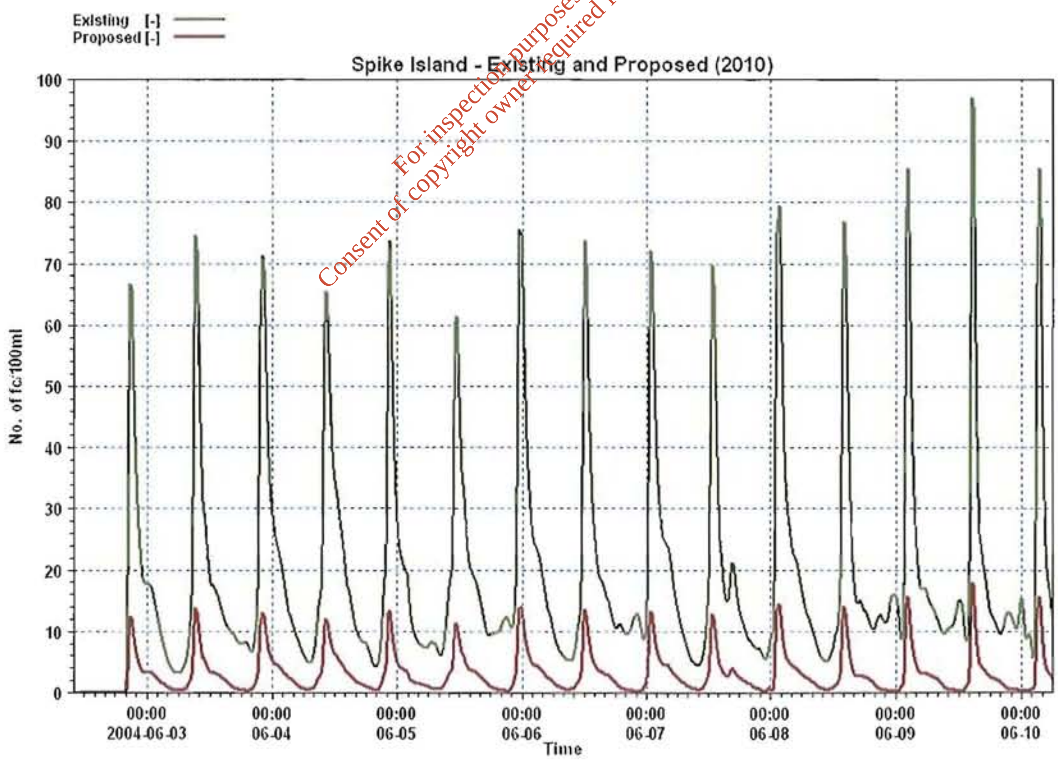

Fig. 4.27 South of Spike Island – Repeating Neap Tide

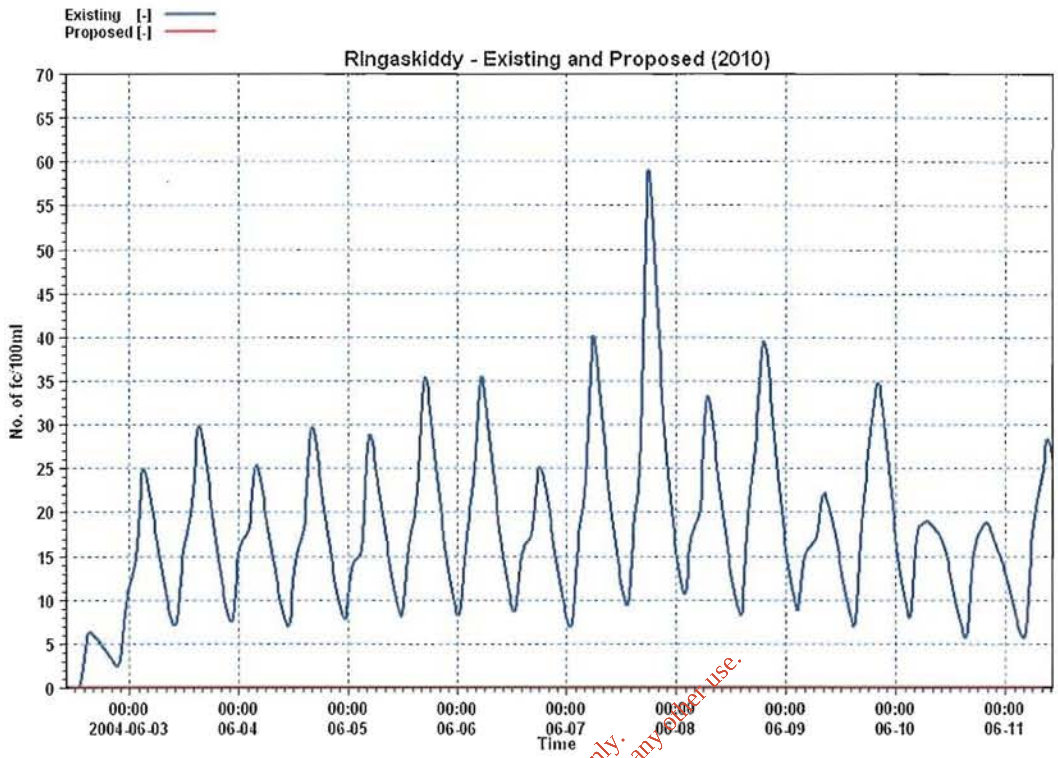

Fig. 4.28 Ringaskiddy – Repeating Spring Tide

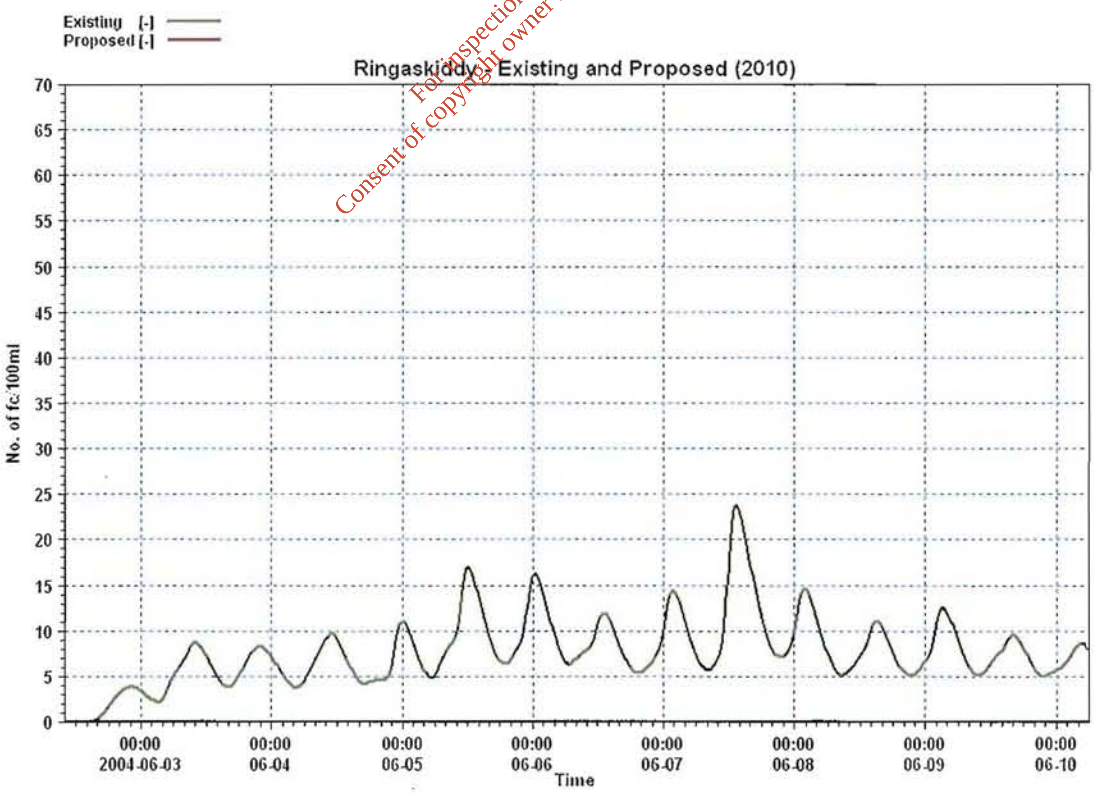

Fig. 4.29 Ringaskiddy – Repeating Neap Tide

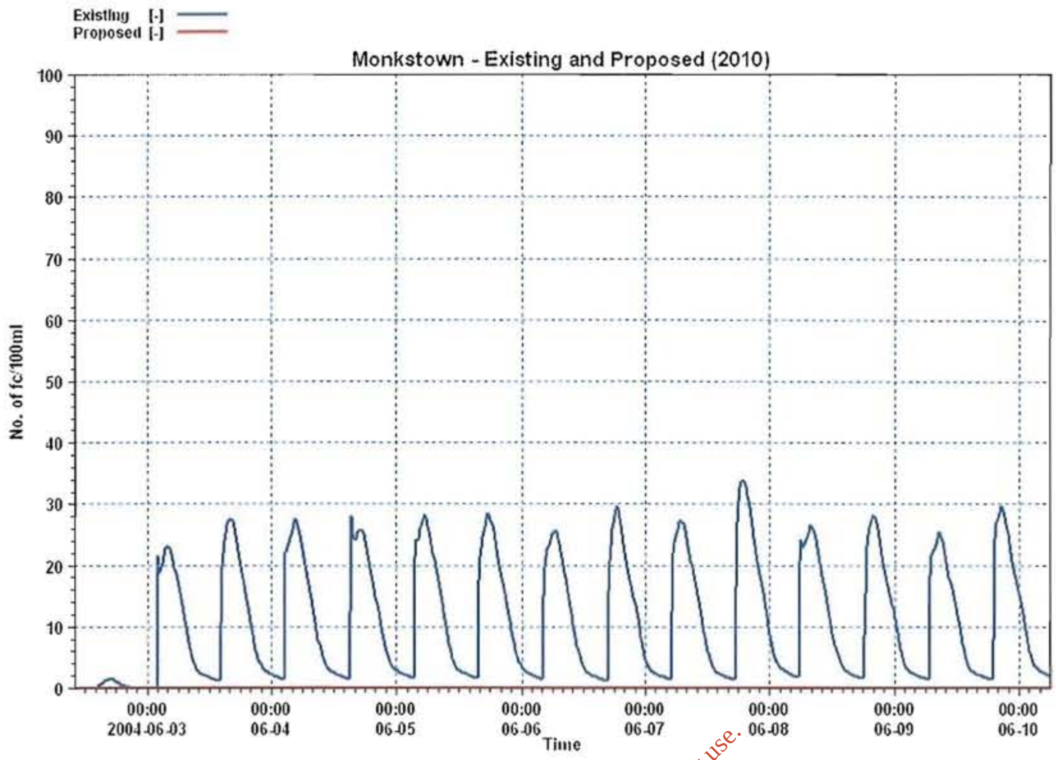

Fig. 4.30 Monkstown Creek – Repeating Spring Tide

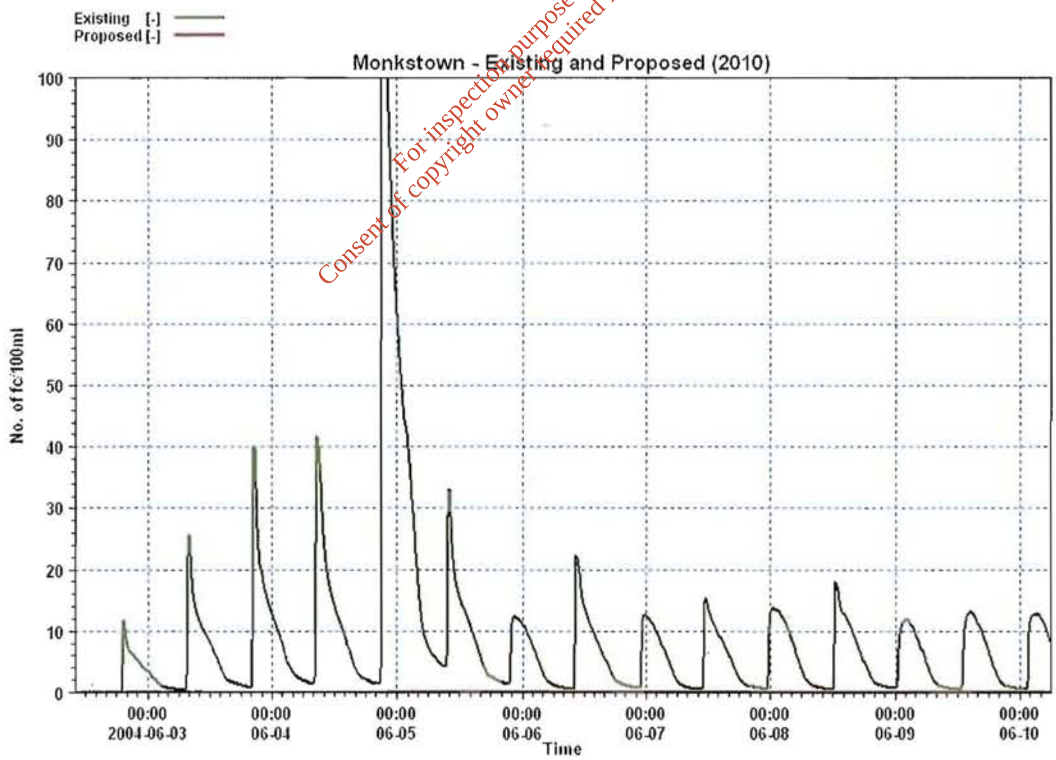

Fig. 4.31 Monkstown Creek – Repeating Neap Tide

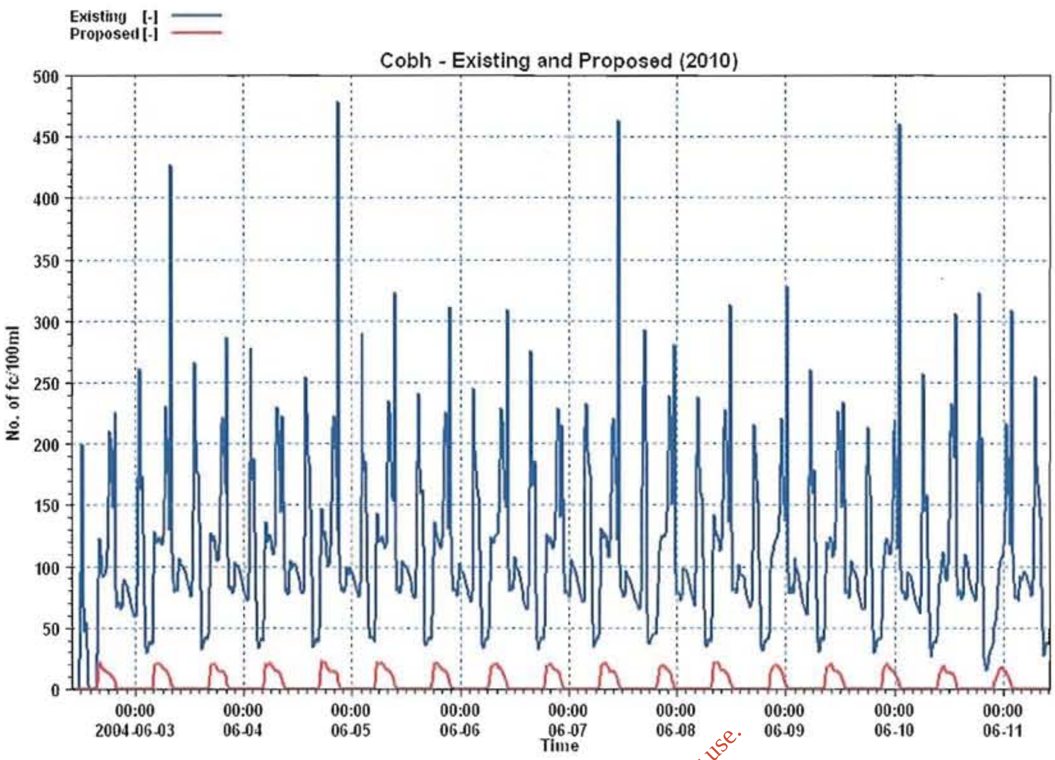

Fig. 4.32 Cobh – Repeating Spring Tide

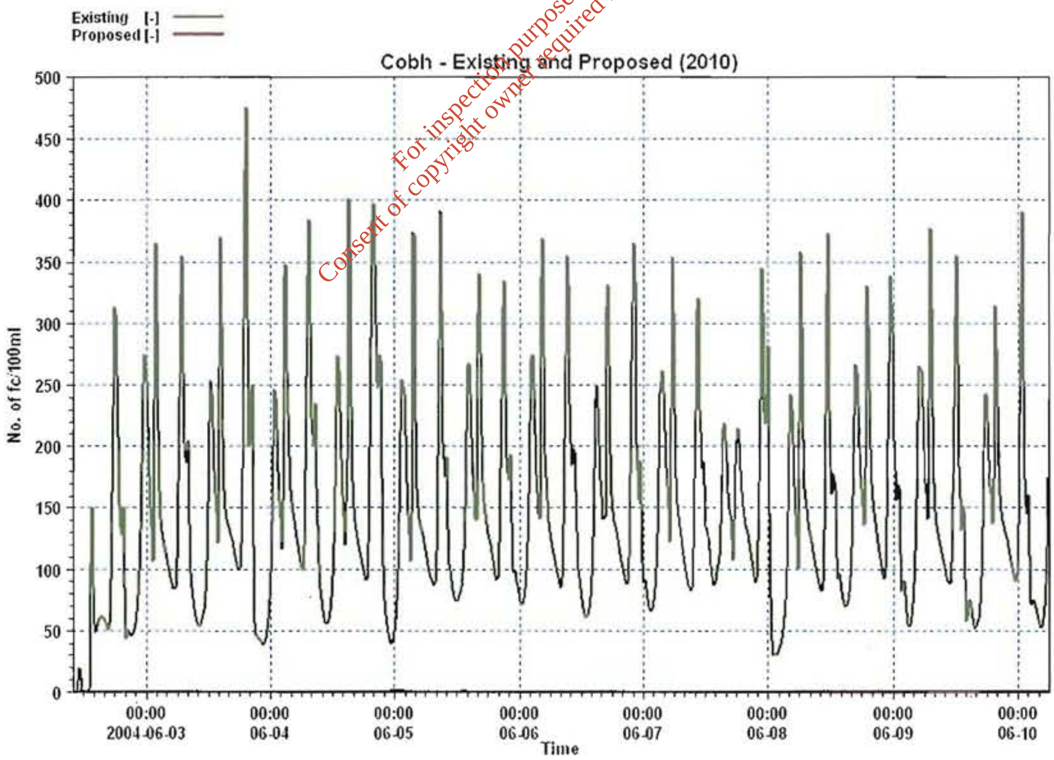

Fig. 4.33 Cobh – Repeating Neap Tide

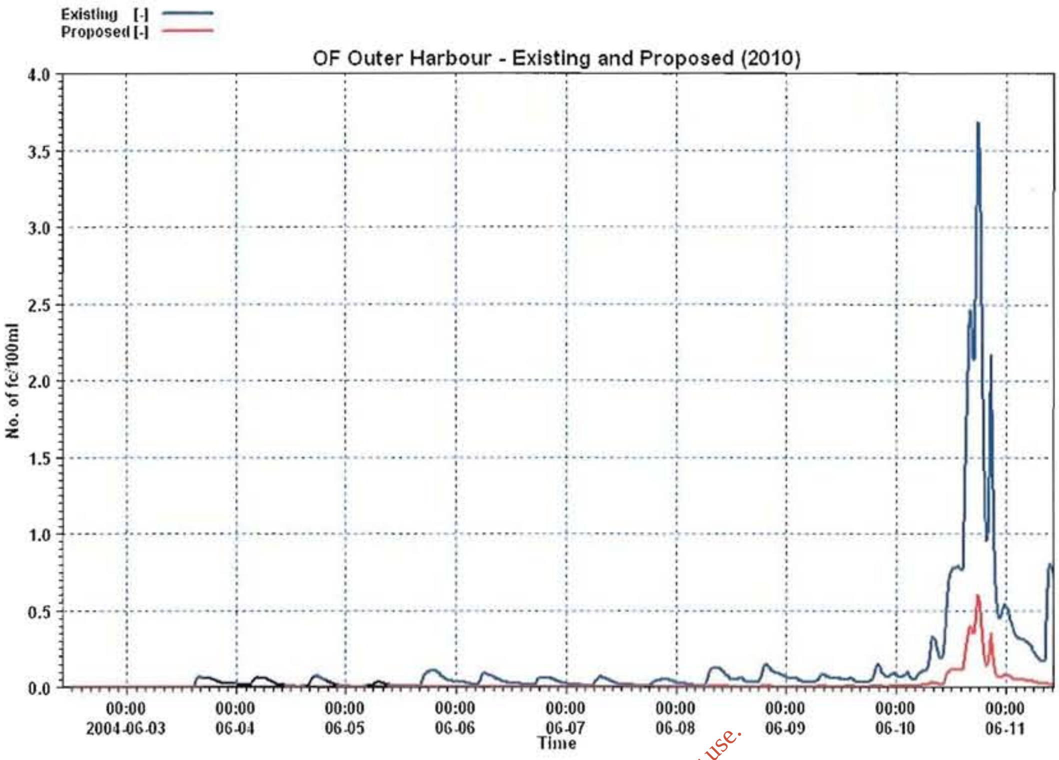

Fig. 4.34 OF - Outer Harbour – Repeating Spring Tide

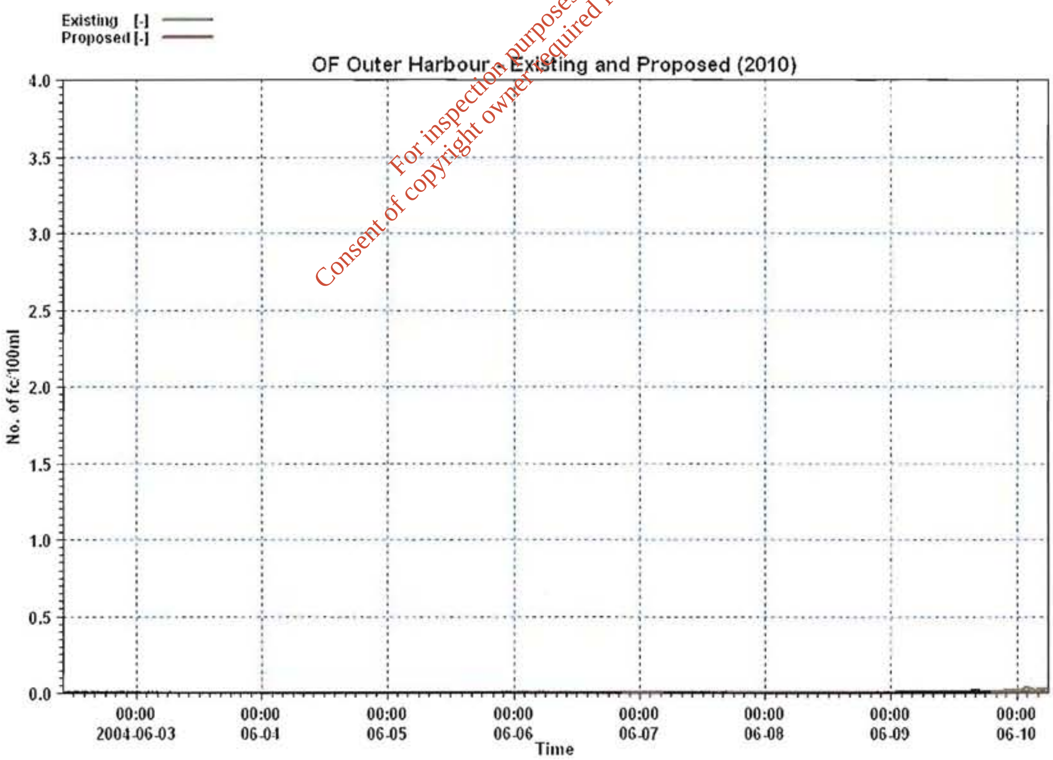

Fig. 4.35 OF - Outer Harbour – Repeating Neap Tide

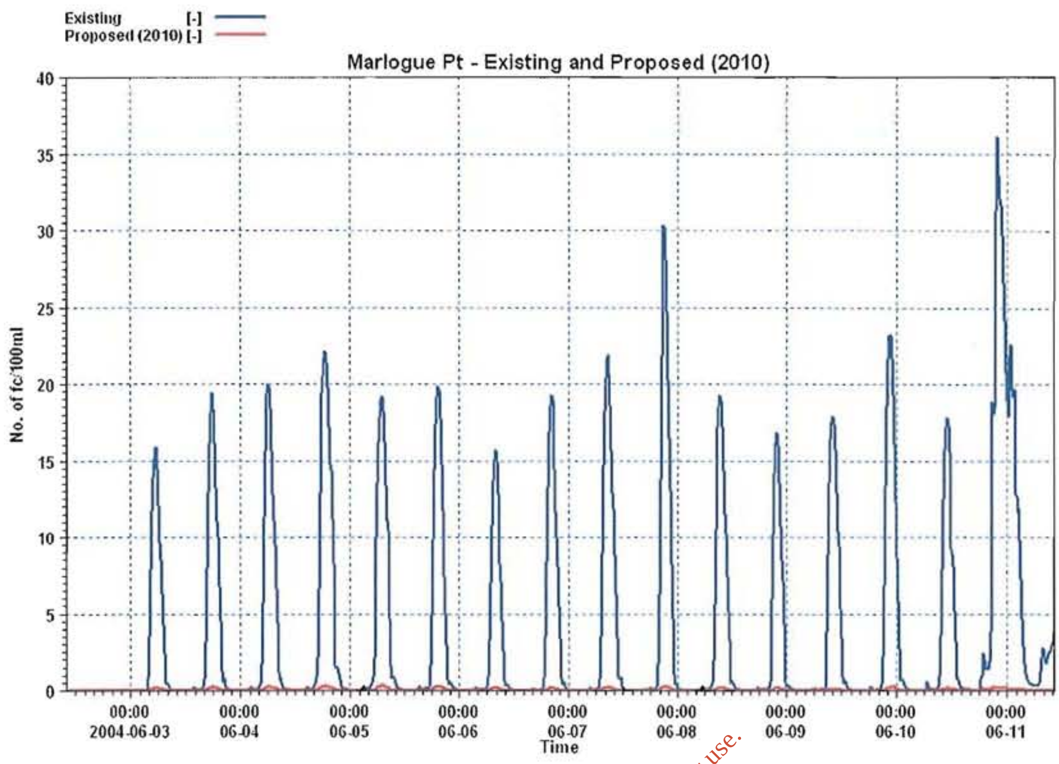

Fig. 4.36 Marlogue Point – Repeating Spring Tide

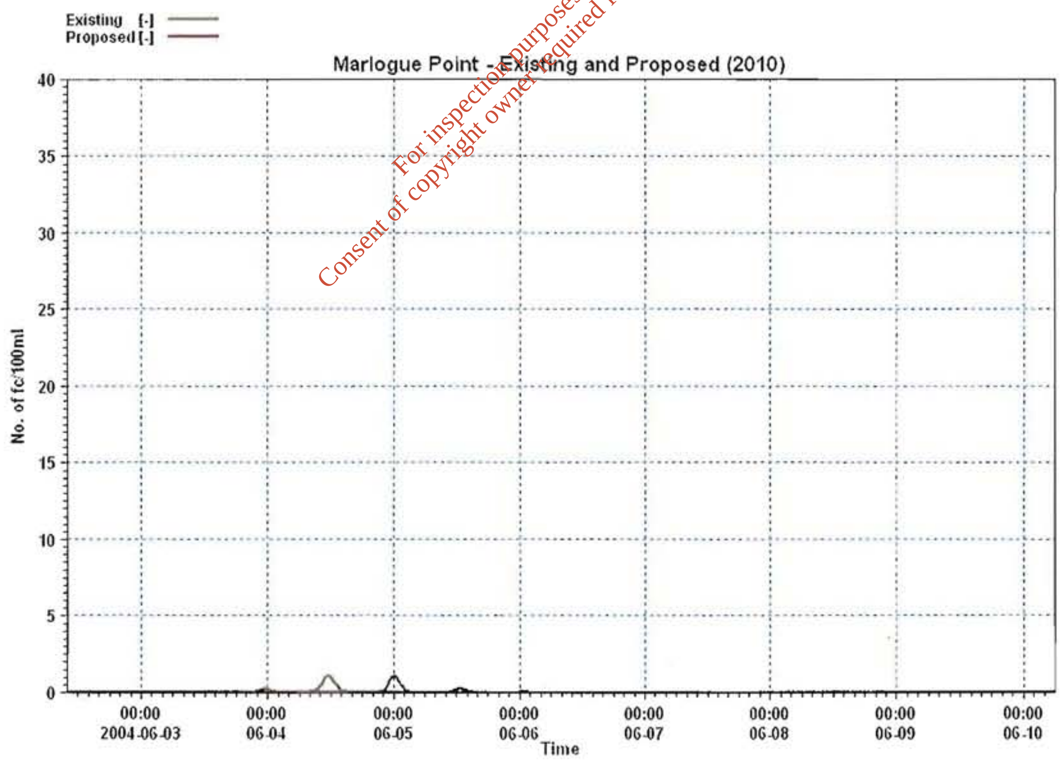

Fig. 4.37 Marlogue Point – Repeating Neap Tide

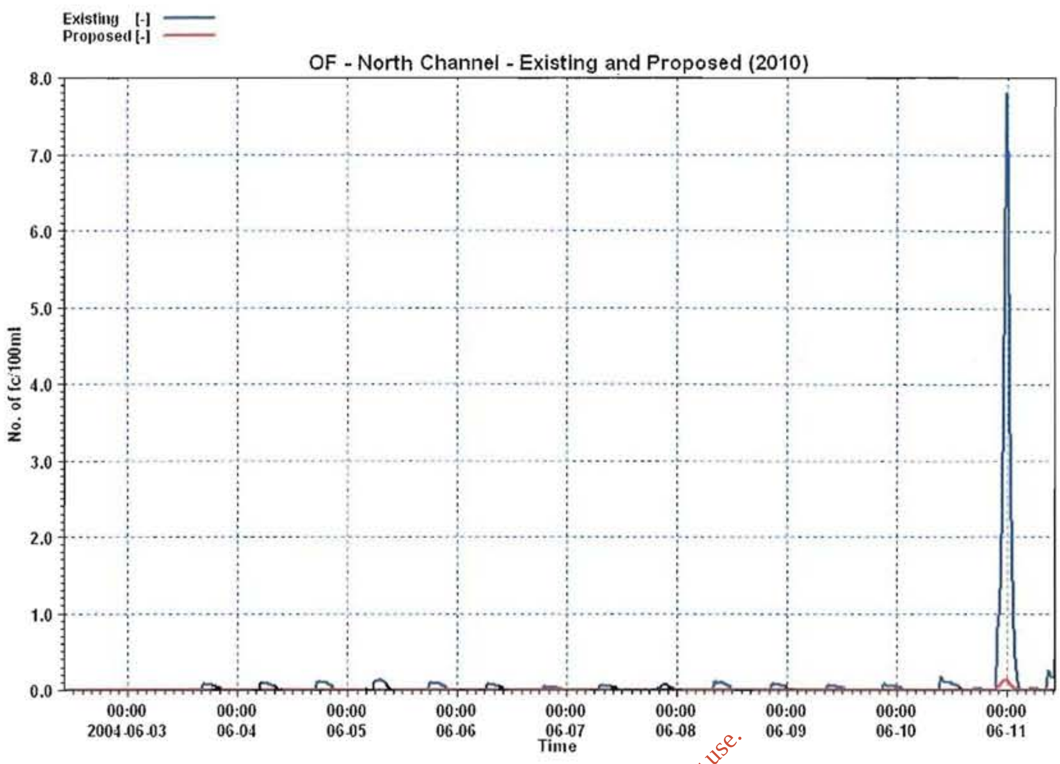

Fig. 4.38 OF – North Channel – Repeating Spring Tide

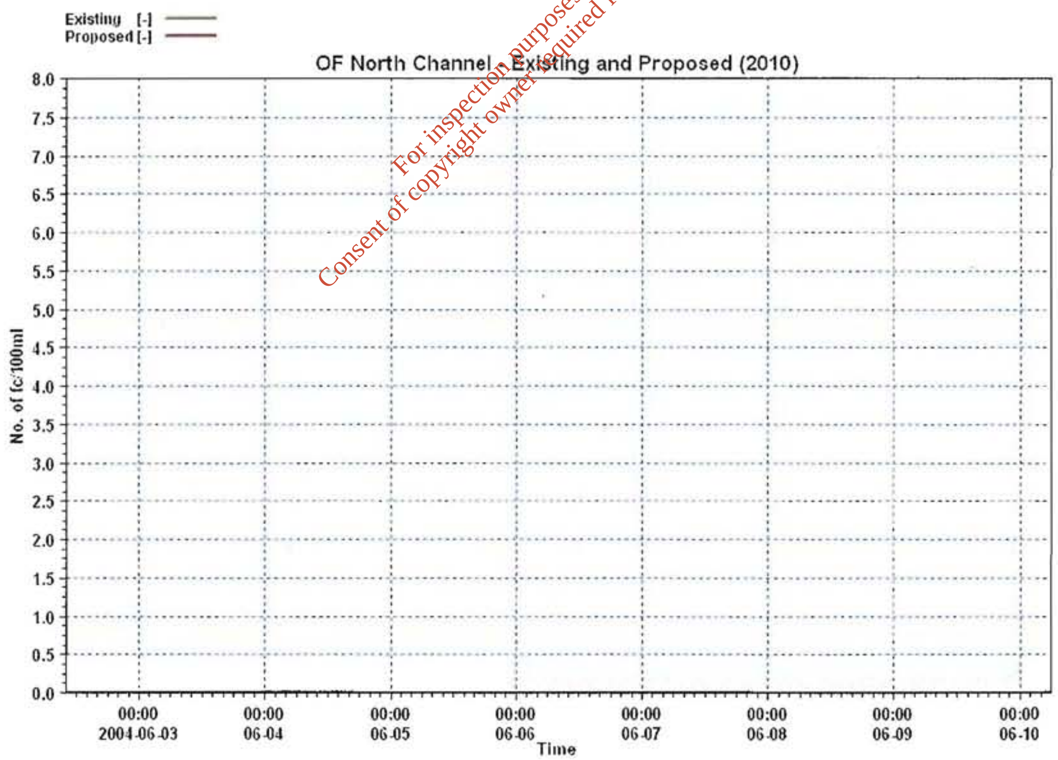

Fig. 4.39 OF – North Channel – Repeating Neap Tide

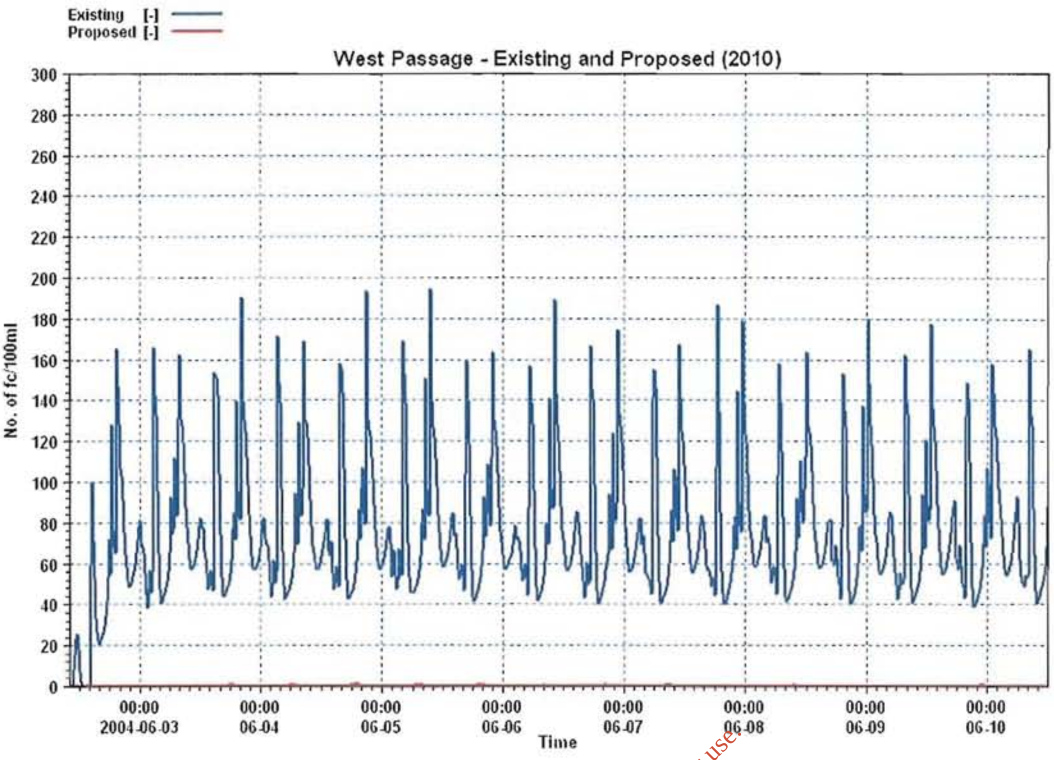

Fig. 4.40 West Passage – Repeating Spring Tide

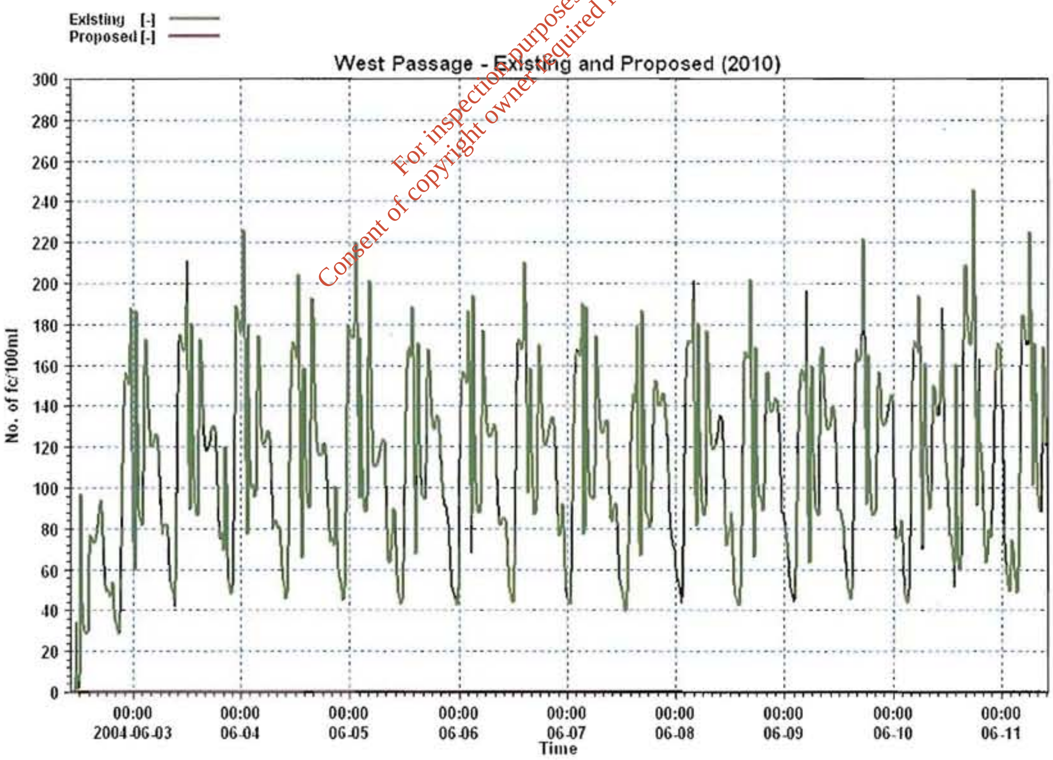

Fig. 4.41 West Passage – Repeating Neap Tide

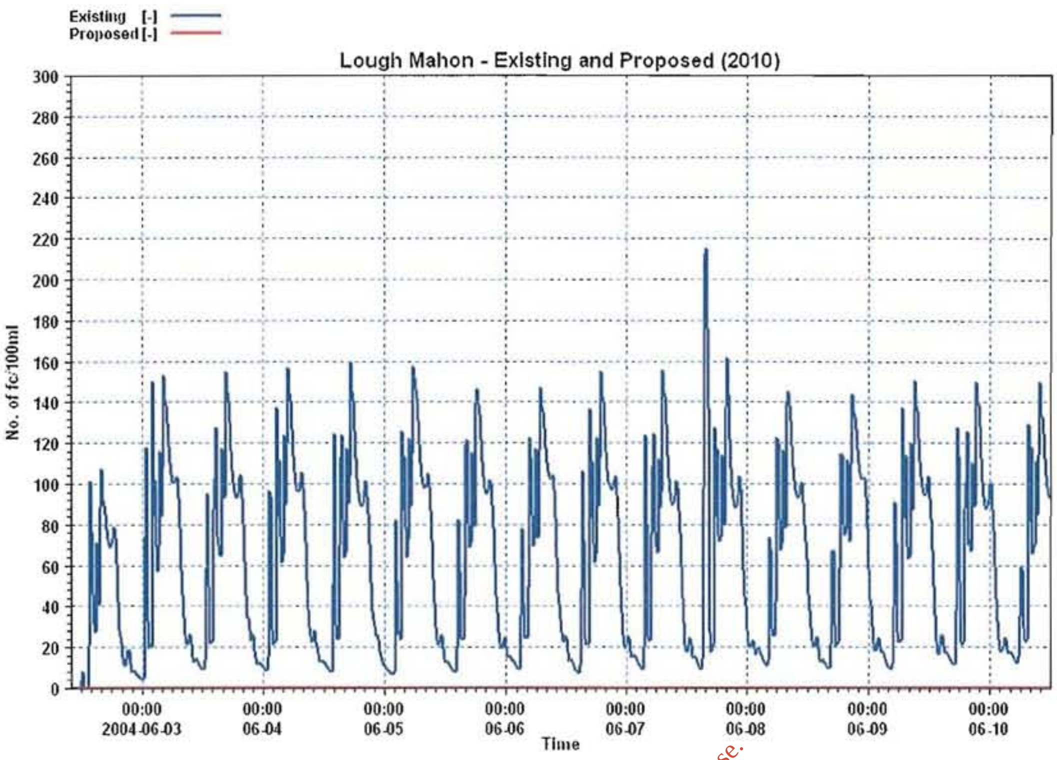

Fig. 4.42 Lough Mahon - Repeating Spring Tide

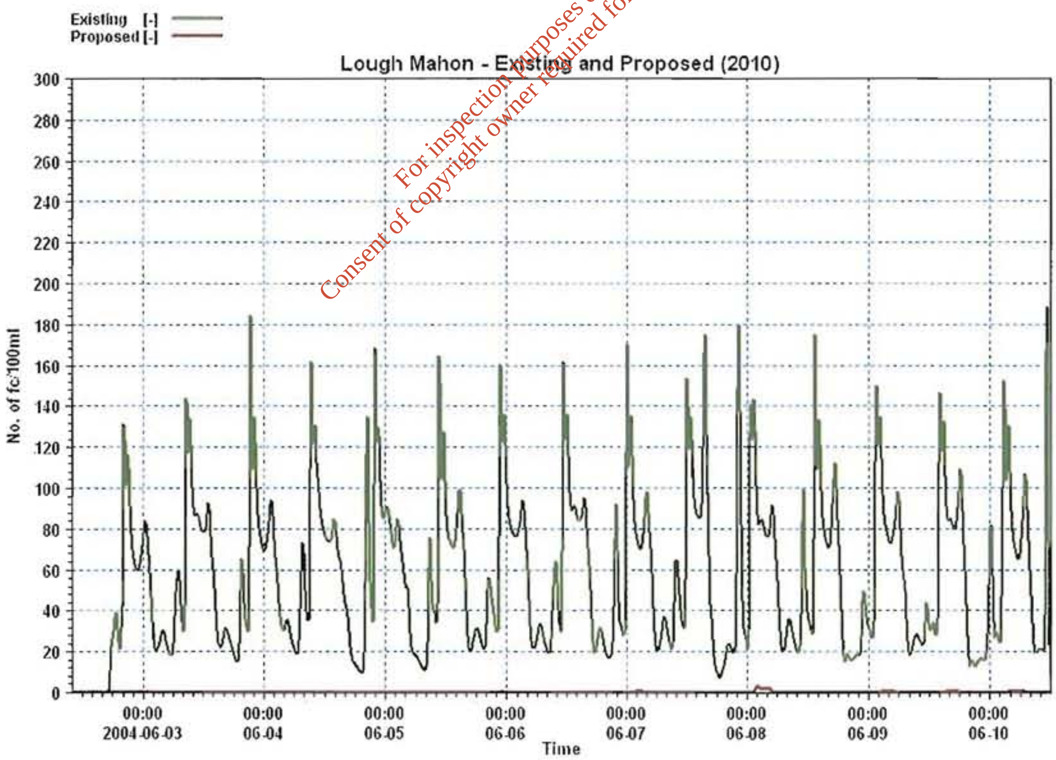

Fig. 4.43 Lough Mahon - Repeating Neap Tide

4.4 Discussion on the faecal coliform Time series

We can see from the plots that the proposed treatment plant will lead to significant relative improvements in water quality throughout the harbour.

4.4.1 Fountainstown

We can see that there is a reduction in the number of faecal coliforms per 100ml for the repeating spring tide simulation with the introduction of the proposed wastewater treatment plant. It should be noted however that even without the treatment the number of faecal coliforms is relatively minor (< 1/100ml). We can also see that the concentrations of faecal coliforms are higher with the repeating spring tide simulation. The drop in concentration on the 10th of June is attributable to a strong wind from the south west (Fig. 4.61).

4.4.2 Myrtleville

We can see that there is a reduction in the number of faecal coliforms per 100ml for both of the simulations with the introduction of the proposed waste water treatment plant. For this location the concentrations of faecal coliforms are higher with the repeating neap tide boundary condition.

4.4.3 Roches Point

We can see that there is a reduction in the number of faecal coliforms per 100ml for both of the simulations with the introduction of the proposed waste water treatment plant. Again we can see that the concentrations of faecal coliforms are higher with the repeating neap tide boundary condition.

4.4.4 Crosshaven

We can see that there is a reduction in the number of faecal coliforms per 100ml for both of the simulations with the introduction of the proposed waste water treatment plant. There is a significant difference in the concentrations for the repeating spring and repeating neap tides for Crosshaven. We can see that the concentrations for the springs are up to 4 times greater than the neaps for Case 2 (no treatment plant).

4.4.5 200m upstream of Existing Outfall

The concentrations at this location are the highest of all the 15 points of interest. We can see that with the introduction of the proposed treatment plant there is a reduction in the number of faecal coliforms per 100ml.

The model does not resolve the near-field of the diffuser and results from our model very close to the diffuser may not be accurate so a point 200m upstream has been chosen to examine the faecal concentrations outside this area.

4.4.6 Shoreline Closest to Existing Outfall

We can see that there is a reduction in the number of faecal coliforms per 100ml for both of the simulations with the introduction of the proposed waste water treatment plant. This location is subject to drying out at low tide hence the zero concentrations after each peak in concentration.

4.4.7 Spike Island - Proposed Heritage Area

We can see that there is a reduction in the number of faecal coliforms per 100ml for both of the simulations with the introduction of the proposed wastewater treatment plant. For Case 2 the repeating neap tides give a higher concentration of faecal coliforms than the repeating spring tides.

4.4.8 Ringaskiddy Ferry

We can see that there is a reduction in the number of faecal coliforms per 100ml for both of the simulations with the introduction of the proposed wastewater treatment plant. It is interesting to note that with the introduction of the proposed wastewater treatment plant the number of faecal coliforms at Ringaskiddy is very close to zero.

4.4.9 Monkstown Creek

We can see that there is a reduction in the number of faecal coliforms per 100ml for both of the simulations with the introduction of the proposed wastewater treatment plant. Again we can see that with the introduction of the proposed treatment plant the number of faecal coliforms at this location is close to zero.

4.4.10 Cobh - Recreational Area

We can see that there is a reduction in the number of faecal coliforms per 100rnl for both of the simulations with the introduction of the proposed waste water treatment plant. With the treatment plant in place the concentrations of faecal coliforms for the repeating neap tides are almost zero.

4.4.11 Oyster Farm - Outer Harbour

For both of the Cases we can see that the number of faecal coliforms is relatively minor. There is a spike in concentration towards the end of the simulation, which is attributable to a strong wind from the south west (Fig. 4.61).

4.4.12 Marlogue Point

We can see that there is a reduction in the number of faecal coliforms per 100ml for the spring tide simulation with the introduction of the proposed waste water treatment plant. For Case 2 there is a significant difference in concentration between the repeating spring and neap tides.

4.4.13 Oyster Farm - North Channel

For both of the Cases we can see that the number of faecal coliforms entering the North Channel is very minor. With a strong wind from the south west however the concentration does increase as we can see with the 'spike' occurring around the 11th of June.

4.4.14 West Passage

We can see for both cases that there is a reduction in the number of faecal coliforms at this location with the proposed scheme in place.

4.4.15 Lough Mahon

We can see for both cases that there is a reduction in the nurnber of faecal coliforms at this location with the proposed scheme in place.

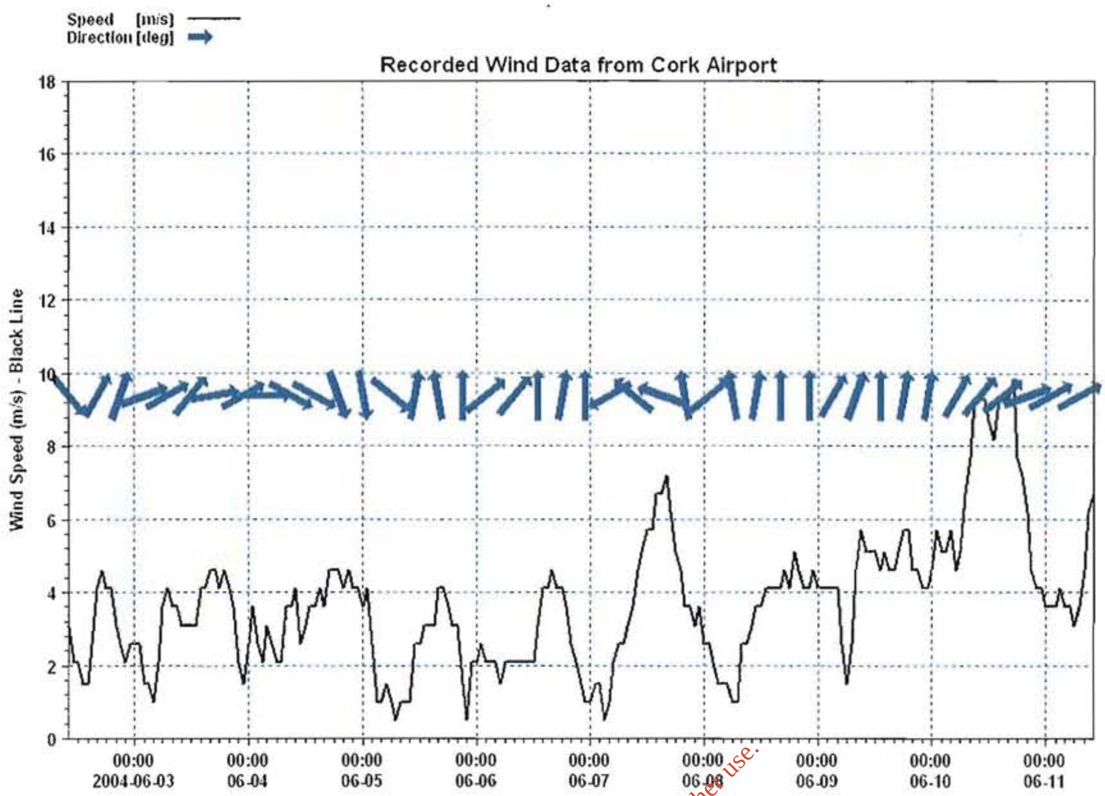

Fig. 4.44 Recorded Wind data. The wind speed is plotted with the black line on the left-hand axis. The wind direction is indicated with the direction of the blue arrow. We can see a strong wind from the south west acting on the 10th of June.

4.5 Faecal Coliform Sensitivity Analysis

A sensitivity analysis has been carried out as part of this Environmental Impact Assessment for Case 3 with repeating spring tides (PR5). The purpose of a sensitivity analysis is to identify the effect of uncertainties in the model on the results. In this case we wish to determine the highest possible concentration of faecal coliforms that may result when the proposed wastewater treatment plant is operational in 2010. The parameters, which we have varied, are:

1. **The T90 of the faecal coliforms.** We have simulated the faecal coliforms with a longer decay time: T90 of 24 hours.
2. **Wind Forcing.** We have replaced the recorded wind forcing with 4 separate wind forcings. Each of the four has the same wind speed of 10m/s but differ in the direction from which they blow: (1) West, (2) North,

(3) East, (4) South. These wind forcings are constant in space, time, magnitude and direction.

4.5.1 Decay rate sensitivity

The results of the decay sensitivity are presented using time series, maximum and averaged values and spatially varying maps of concentrations. By subtracting the spatially varying maps of maximum concentrations for the two different decay rates from each other we can see the difference in concentration between the two. This map is shown in Fig. 4.45. As the concentrations for the slower decay rate are higher we have subtracted the 12 hour decay concentrations *from* the 24 hour decay concentrations. We can see from the figure that the differences in the maximum concentrations range from 1 to 40 fc/100ml. From this we can conclude that if the faecal coliforms were to have a T90 of 24 hours their concentrations would increase by as much as 40 counts per 100ml relative to the case where the T90 is 12 hours.

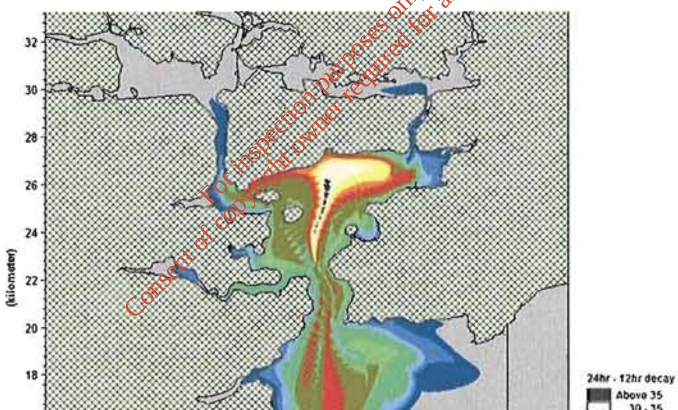

Fig. 4.45 The numbers in this plot are the differences between the maximum concentrations for the 12 and 24hr decay values.

The following set of graphs present the results of the decay rate sensitivity for the 15 points of interest in the study. Two plots are included on each of the graphs. The first is the faecal coliform concentrations for the Case 3 (PR5) with a T90 of 12 hours (blue line). The second is the faecal coliform concentrations for

Case 3 with a T90 of 24 hours (green line). The boundary condition is supplied by repeating spring tides.

The maximum and average concentrations for the decay sensitivity (Fig. 4.67) are presented in the following two tables. The corresponding concentrations for the 12 hour decay (as presented in Table 4-4 and Table 4-5) are shown to aid the reader in making a comparison.

Year	**2010**	**2010 - Sensitivity**	**2030**	**2030 - Sensitivity**
	MAX	MAX	MAX	MAX
Fountainstown	0.2	1.2	0.3	1.8
Myrtleville	0.7	2.6	1.0	3.8
Roches Point	65.3	79.4	93.5	113.7
Crosshaven	3.8	11.2	5.4	16.0
Ringaskiddy Ferry	0.0	0.3	0.0	0.5
Monkstown Creek	0.0	0.4	0.0	0.6
Oyster F - NC	0.1	0.9	0.2	1.3
Marlogue Point	0.3	2.0	0.4	2.9
Oyster F - Outer	0.6	3.4	0.9	4.8
Cobh	23.2	40.0	33.2	57.3
Spike Island	9.1	21.5	13.1	30.7
Shoreline	2.2	8.4	3.2	12.0
Upstream Outfall	333.7	357.1	477.6	510.9
West Passage	1.0	4.3	1.5	6.2
Lough Mahon	0.1	0.9	0.2	1.3

Table 4-6 Summary of 24hr decay sensitivity – Maximum concentrations

Year	**2010**	**2010 - Sensitivity**	**2030**	**2030 - Sensitivity**
	AVG	AVG	AVG	AVG
Fountainstown	0.05	0.4	0.07	0.5
Myrtleville	0.14	1.0	0.20	1.4
Roches Point	11.65	16.6	16.67	23.8
Crosshaven	0.95	3.6	1.36	5.1
Ringaskiddy Ferry	0.01	0.2	0.02	0.3
Monkstown Creek	0.01	0.1	0.01	0.2
Oyster F - NC	0.00	0.0	0.00	0.0
Marlogue Point	0.04	0.3	0.06	0.4
Oyster F - Outer	0.00	0.1	0.00	0.1
Cobh	5.32	10.6	7.62	15.1
Spike Island	1.55	5.0	2.21	7.1
Shoreline	0.56	1.6	0.47	2.3
Upstream Outfall	20.12	25.7	28.79	36.8
West Passage	0.08	0.6	0.11	0.8
Lough Mahon	0.01	0.1	0.01	0.1

Table 4-7 Summary of 24hr decay sensitivity – Average concentrations

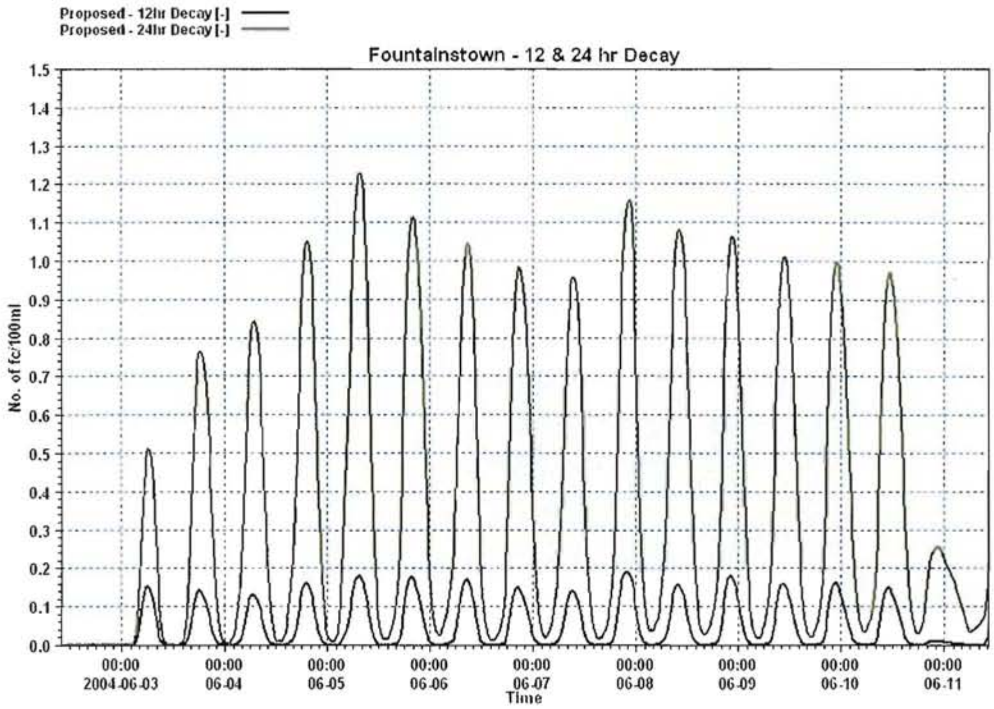

Fig. 4.46 Fountainstown - 24hr decay sensitivity

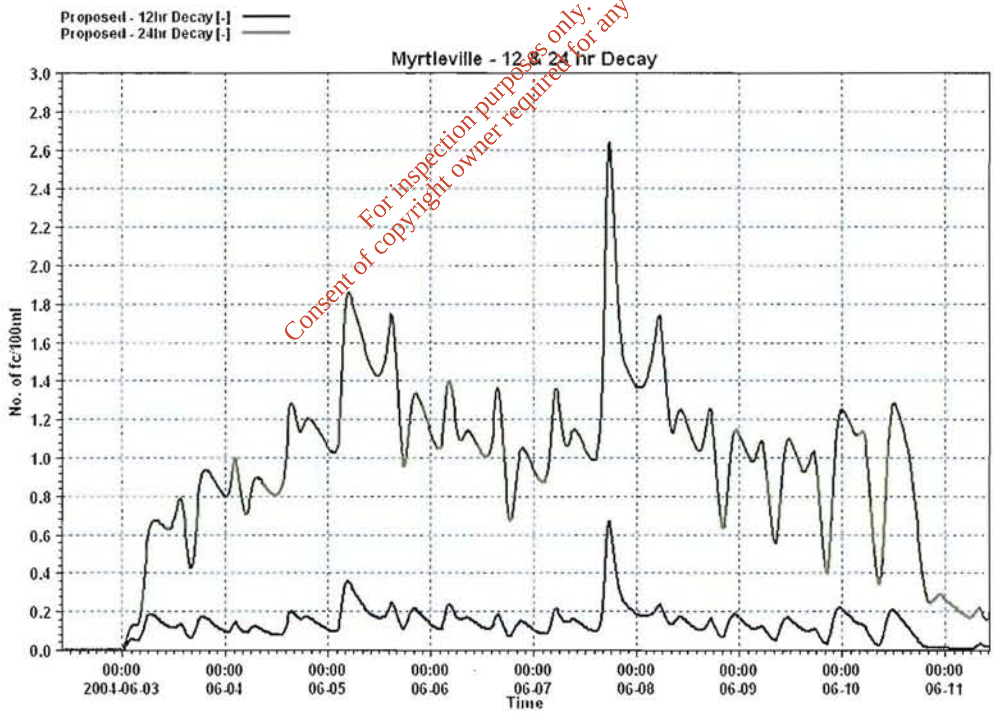

Fig. 4.47 Myrtleville - 24hr decay sensitivity

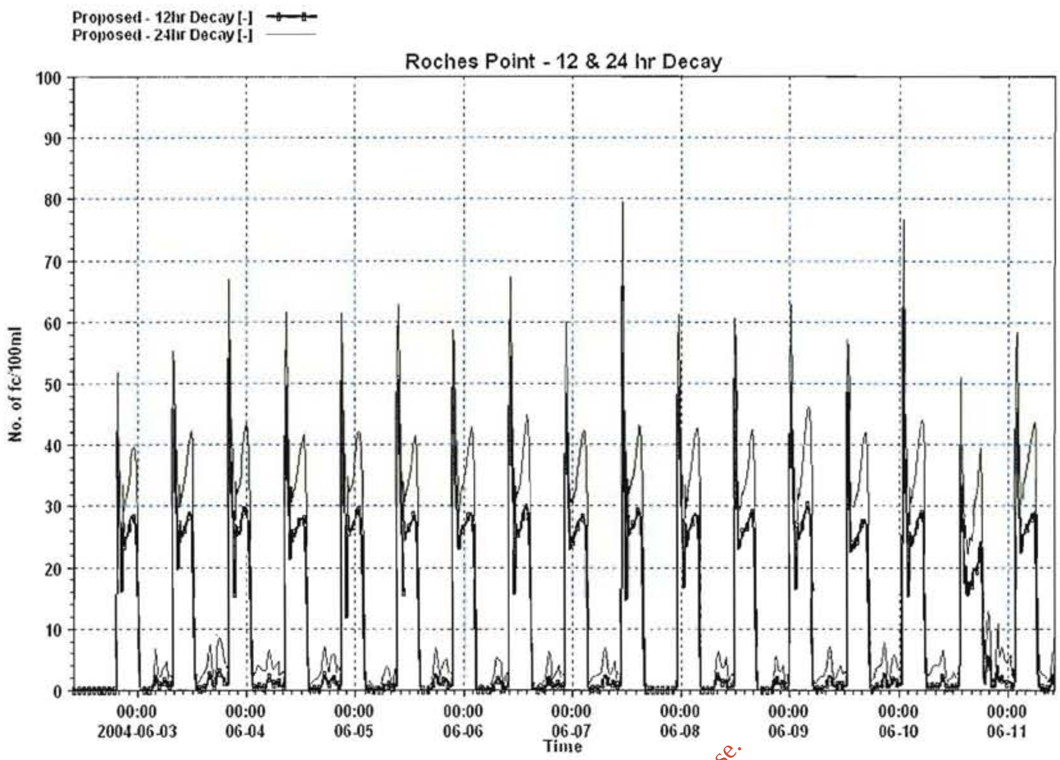

Fig. 4.48 Roches point - 24hr decay sensitivity

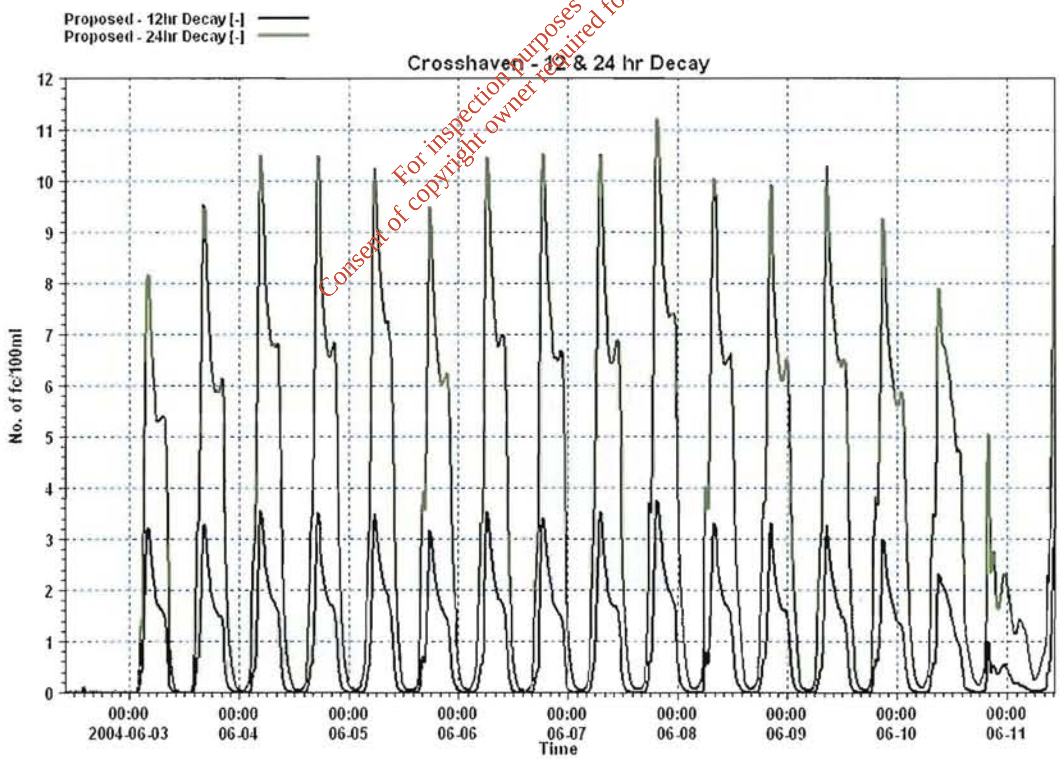

Fig. 4.49 Crosshaven - 24hr decay sensitivity

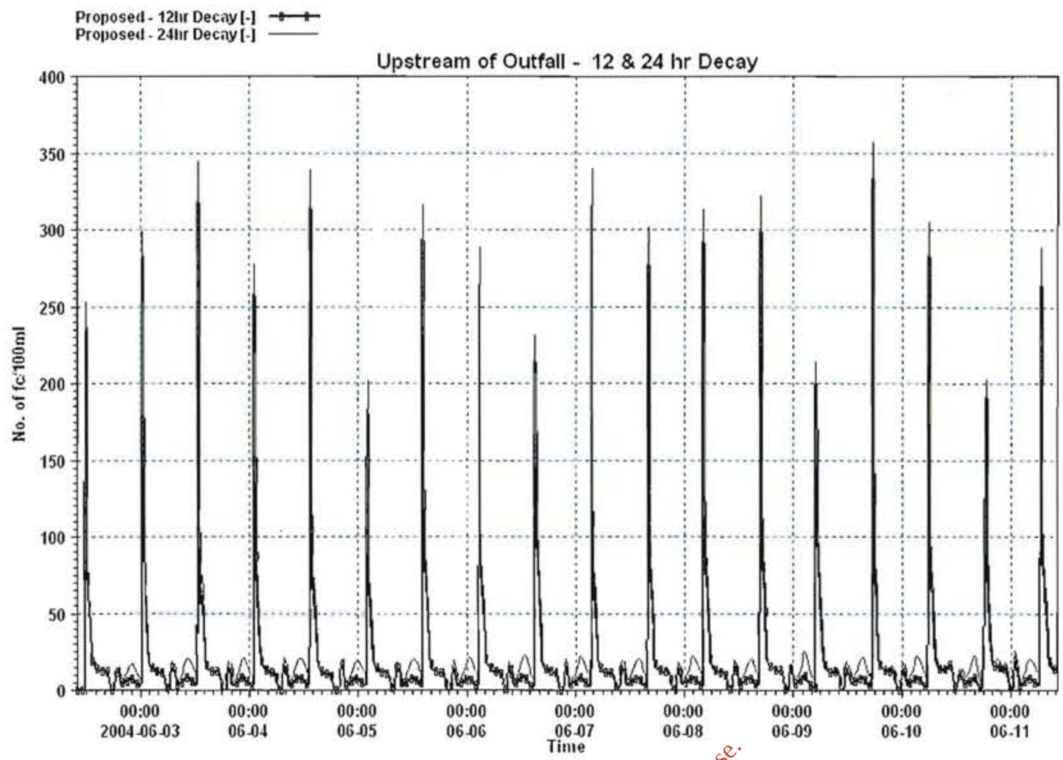

Fig. 4.50 200m upstream of outfall - 24hr decay sensitivity

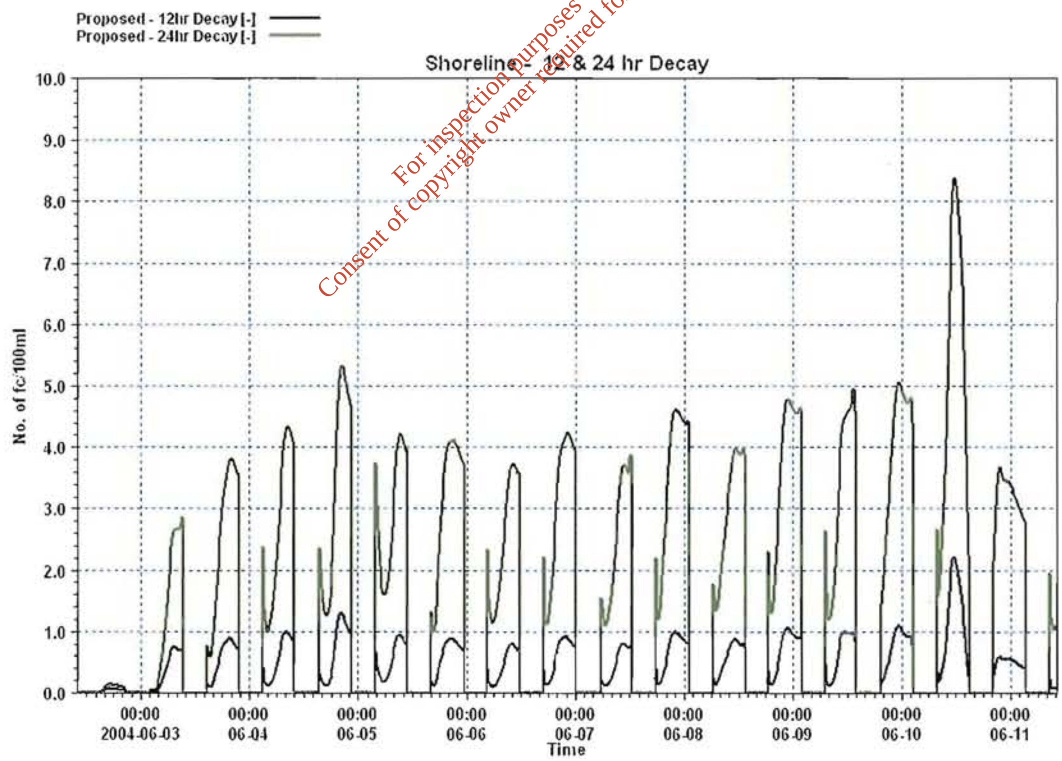

Fig. 4.51 Shoreline - 24hr decay sensitivity

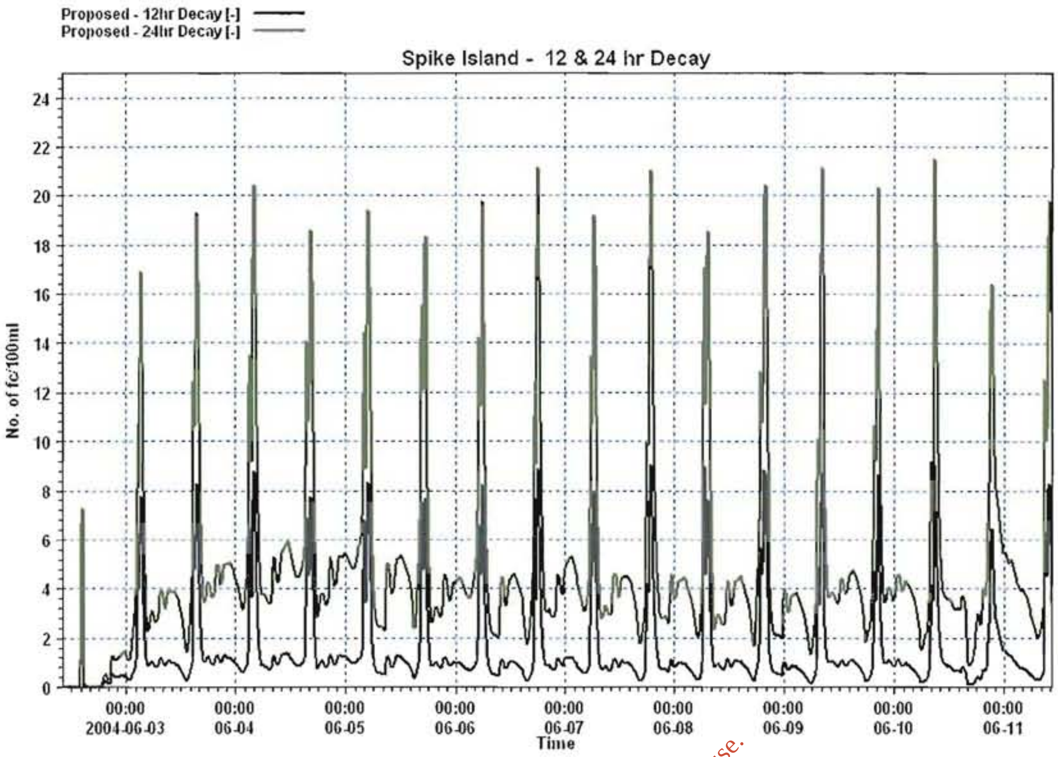

Fig. 4.52 Spike Island - 24hr decay sensitivity

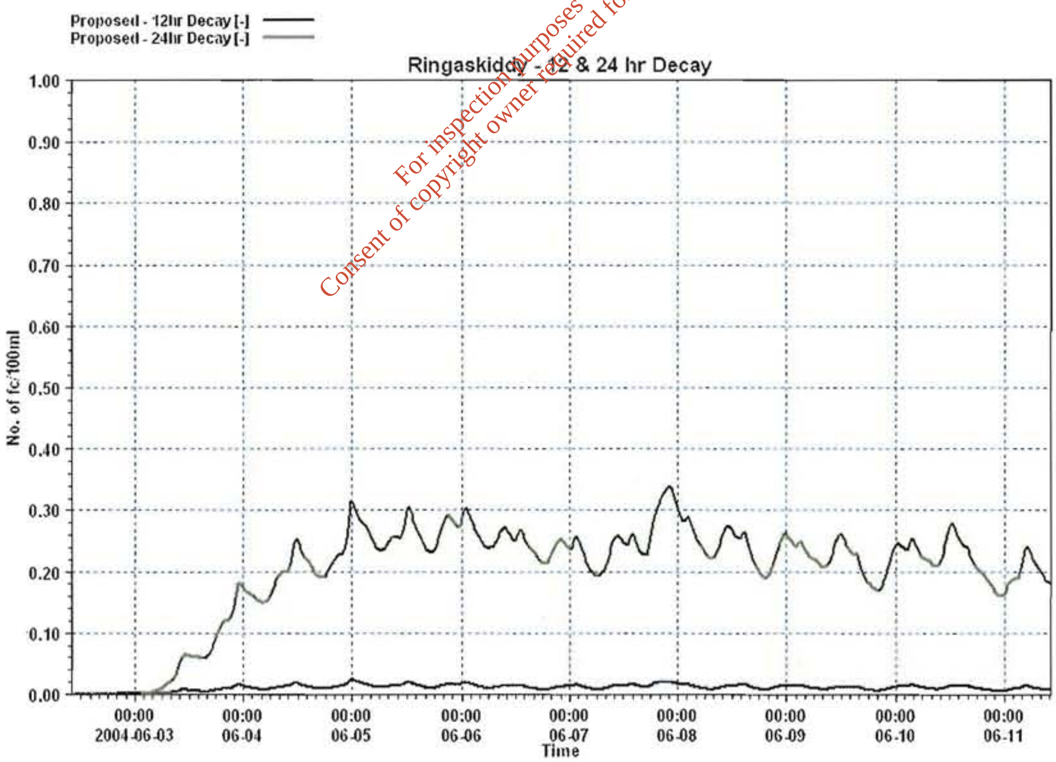

Fig. 4.53 Ringaskiddy - 24hr decay sensitivity

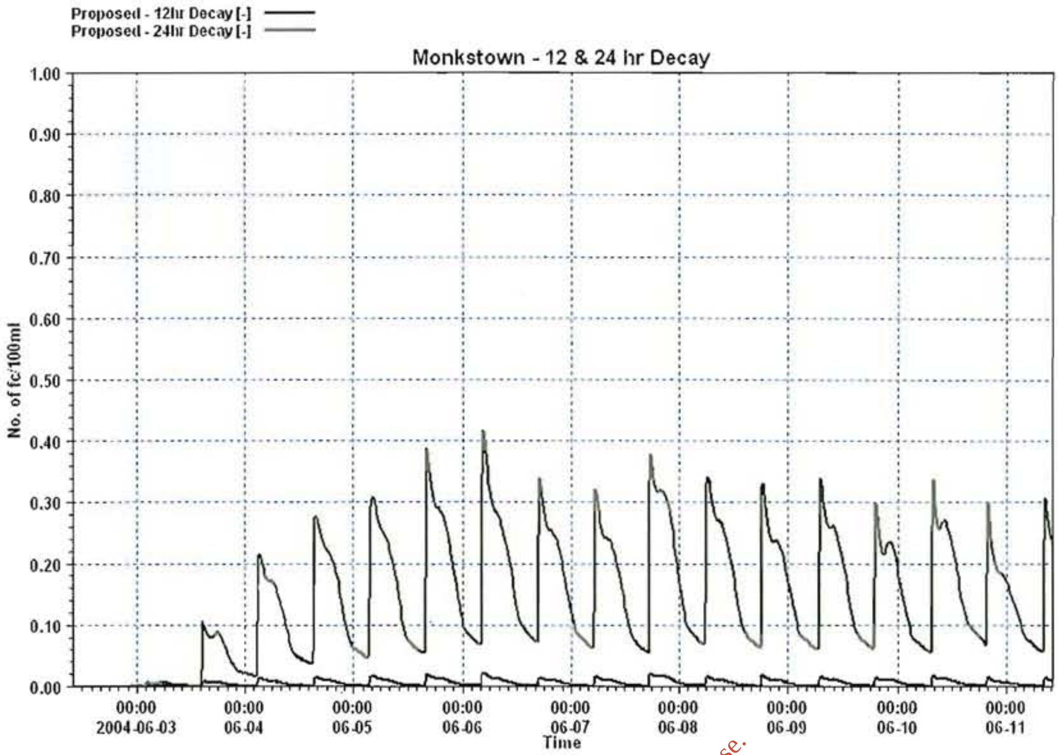

Fig. 4.54 Monkstown - 24hr decay sensitivity

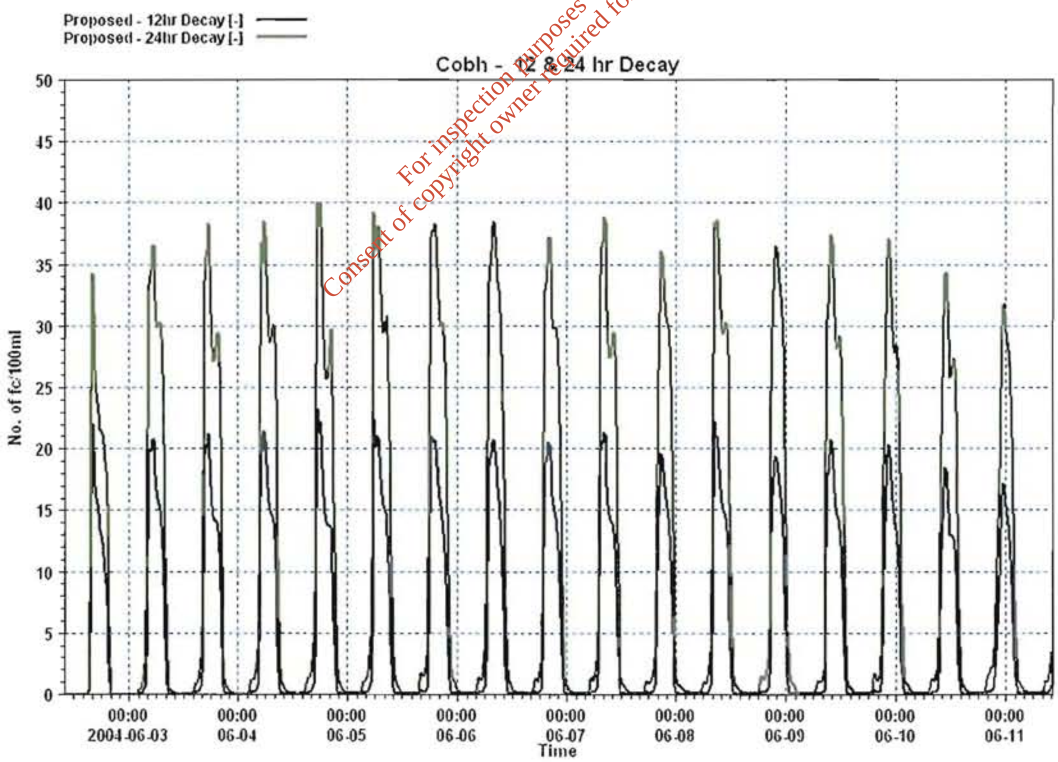

Fig. 4.55 Cobh - 24hr decay sensitivity

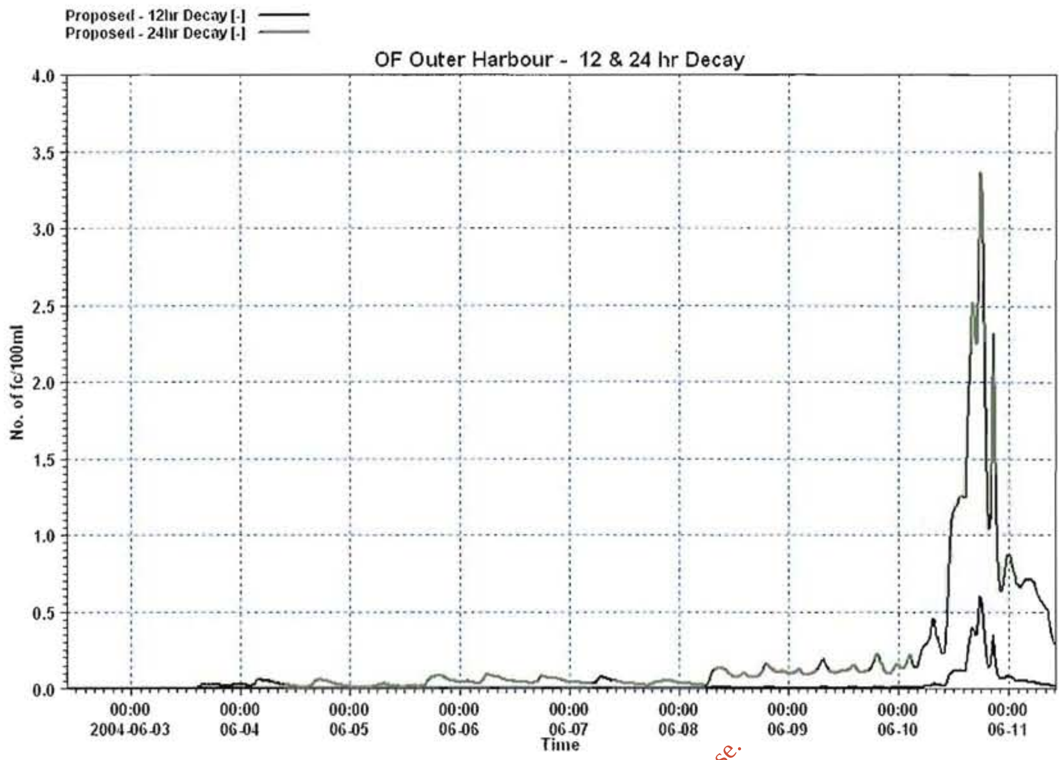

Fig. 4.56 OF Outer Harbour - 24hr decay sensitivity

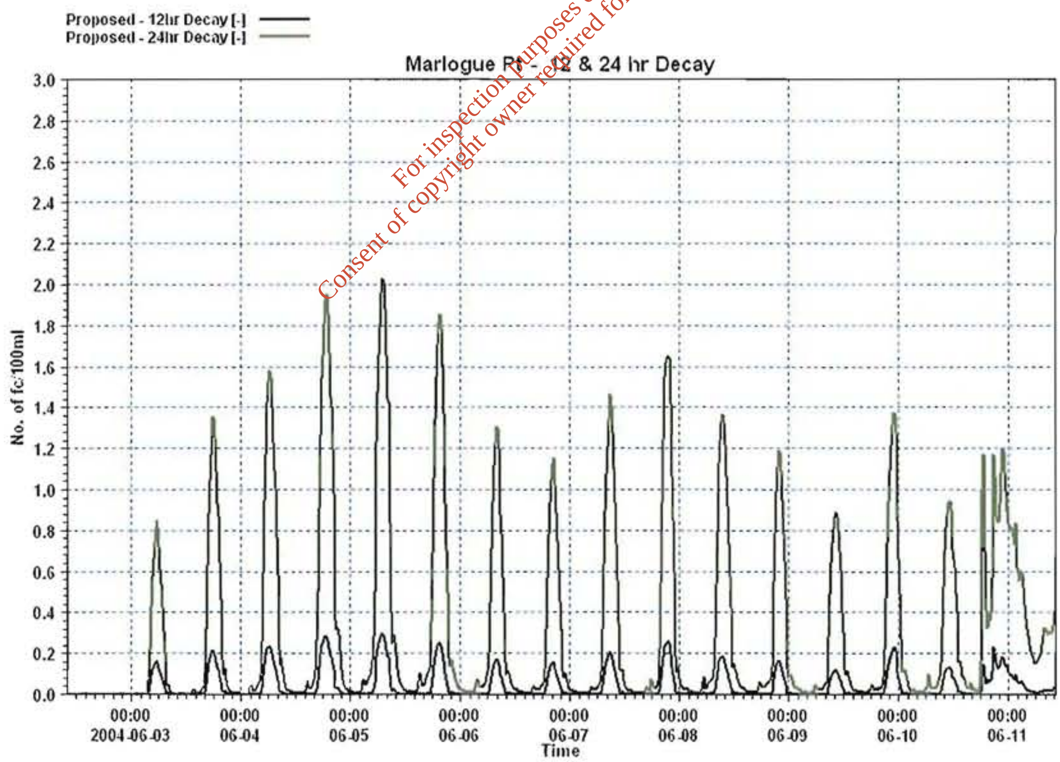

Fig. 4.57 Marlogue Pt - 24hr decay sensitivity

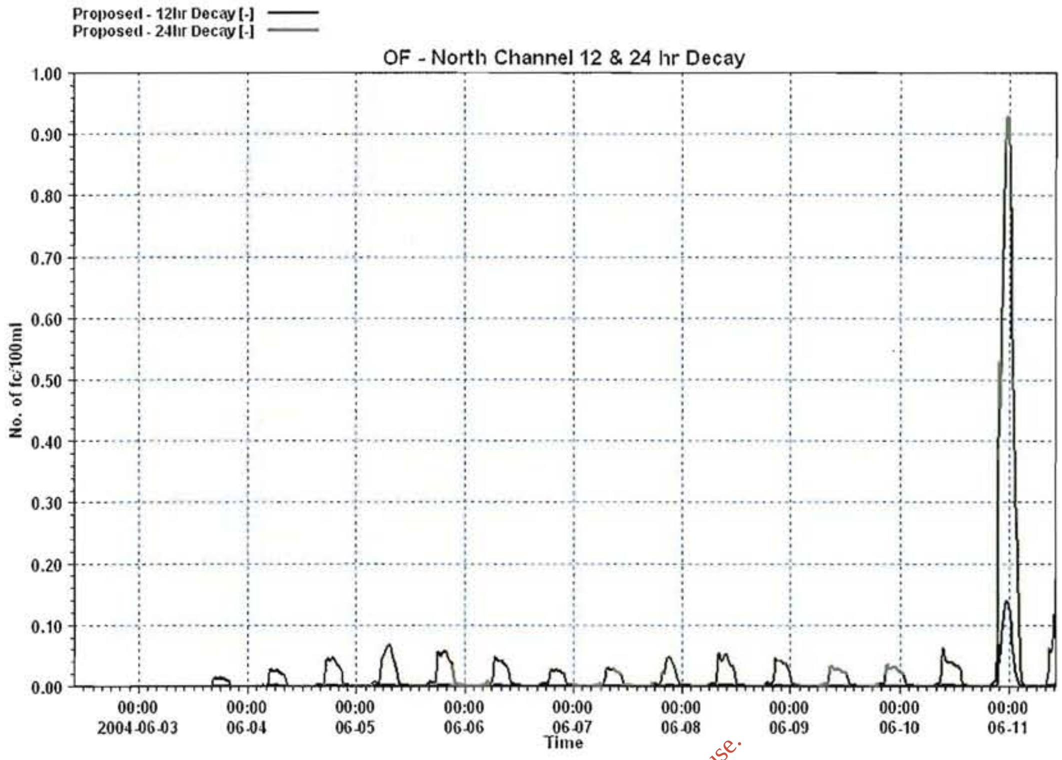

Fig. 4.58 OF North Channel - 24hr decay sensitivity

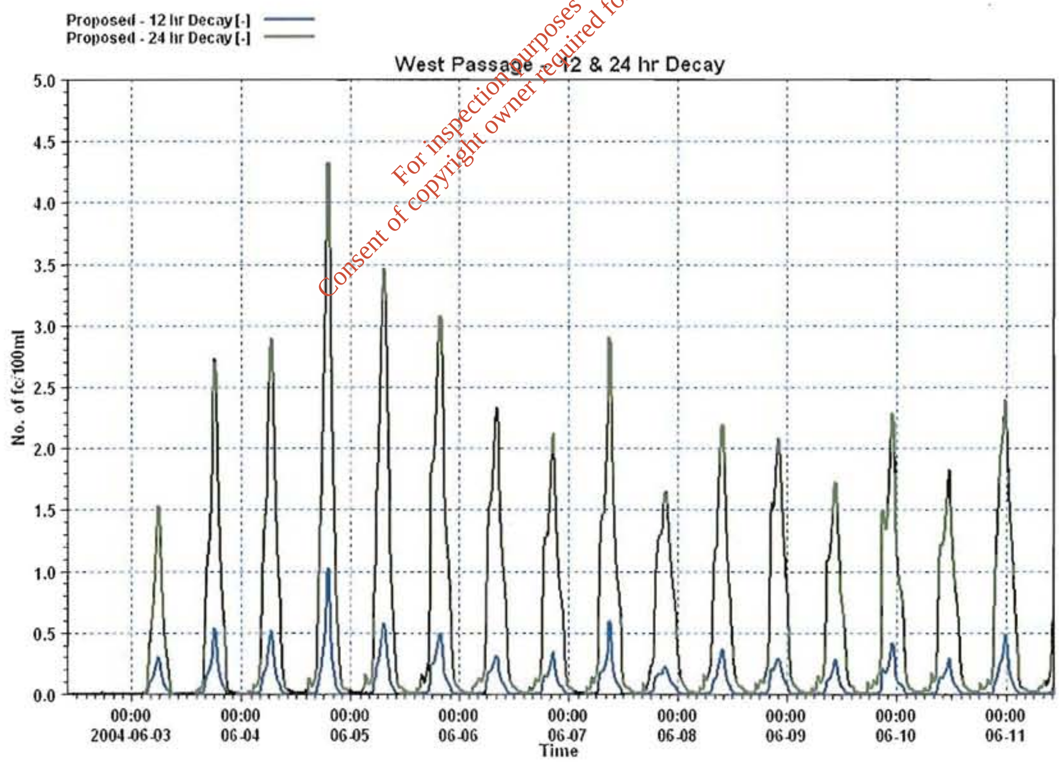

Fig. 4.59 West Passage - 24hr decay sensitivity

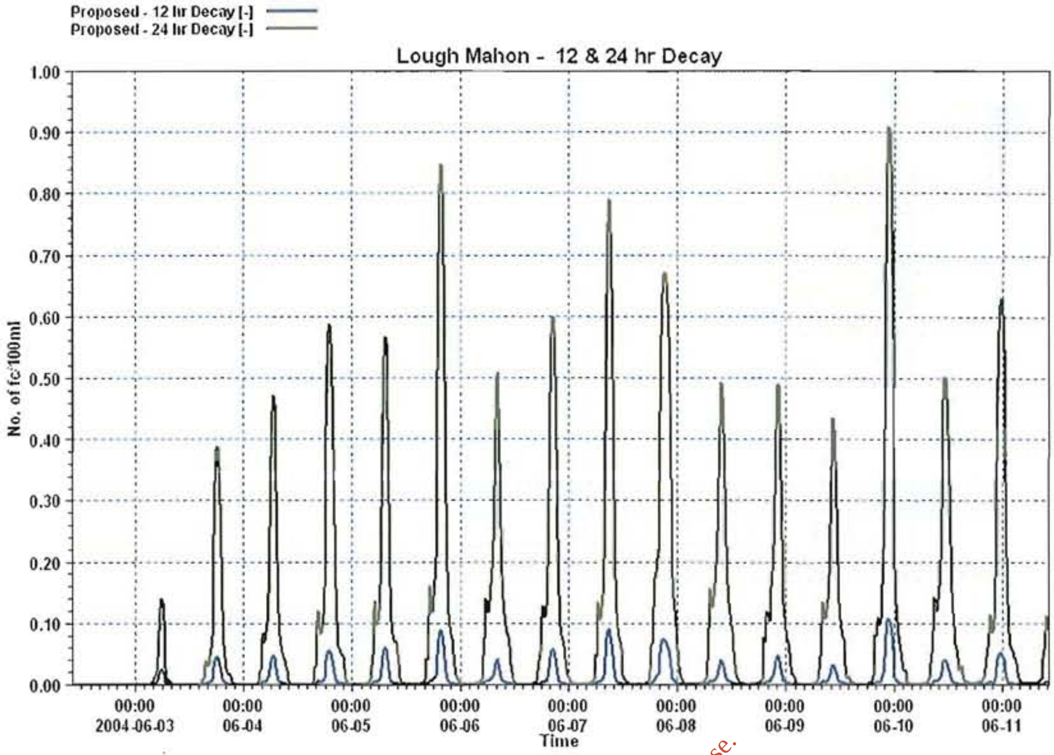

Fig. 4.60 Lough Mahon - 24hr decay sensitivity

4.5.2 Wind forcing sensitivity – repeating spring tides

The wind forcing sensitivity is now presented. For the repeating spring tides we have replaced the recorded wind with 4 different wind forcings each blowing from a different direction but with the same speed. This sensitivity involved 4 separate model runs each with one of the different wind forcings.

Each of the four wind sensitivity runs were simulated for 3 days.

Run No.	Wind Speed	Wind Direction
1	10m/s (constant)	From West (270 deg)
2	10m/s (constant)	From North (0 deg)
3	10m/s (constant)	From East (90 deg)
4	10m/s (constant)	From South (180 deg)

Table 4-8 List of wind sensitivity runs

The recorded wind forcing is presented in Fig. 4.61. The wind speed is plotted on the left hand axis (black line) while the direction is plotted using the blue arrows. The direction in which the blue arrow is pointing indicates the direction in which the wind is blowing from.

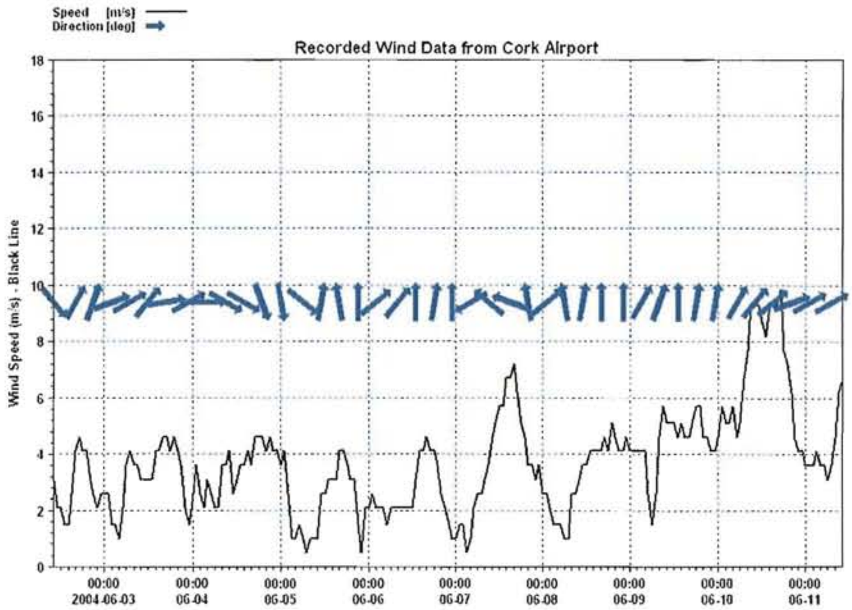

Fig. 4.61 Recorded Wind data

The results of the wind sensitivity are presented using spatially varying maps of maximum concentrations. In all 6 maps are presented:

1. Recorded wind simulation maximum concentrations. This plot was already presented in Fig. 4.3 using a different colour palette.
2. Constant 10m/s wind blowing from West
3. Constant 10m/s wind blowing from North
4. Constant 10m/s wind blowing from East
5. Constant 10m/s wind blowing from South
6. The maximum concentrations of the 4 separate wind sensitivity maximum concentration maps. This map presents the maximum value of the four separate wind sensitivity maximum values (i.e. at each grid point the highest of the 4 concentrations from the 4 wind sensitivity simulation runs is presented).

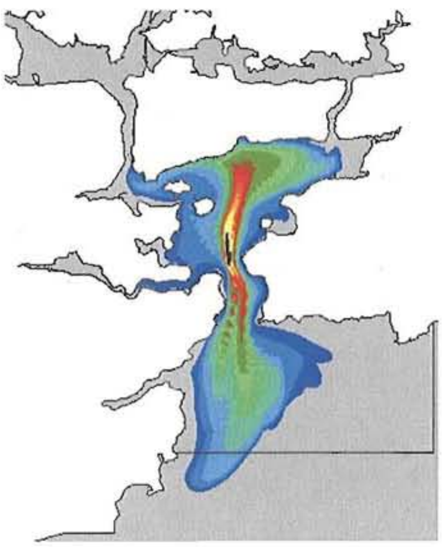

Fig. 4.62 Recorded wind – Base Case

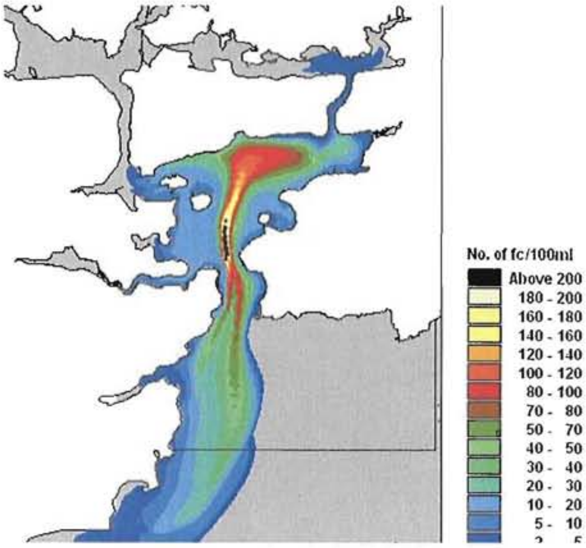

Fig. 4.65 Wind from East

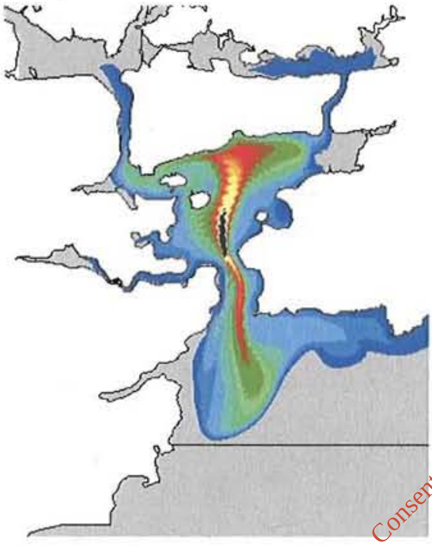

Fig. 4.63 Wind from West

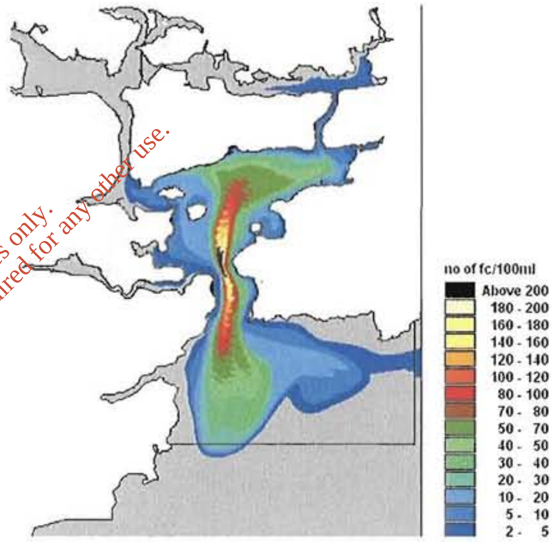

Fig. 4.66 Wind from South

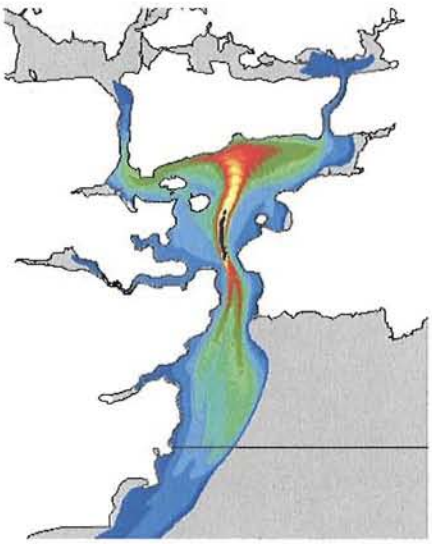

Fig. 4.64 Wind from North

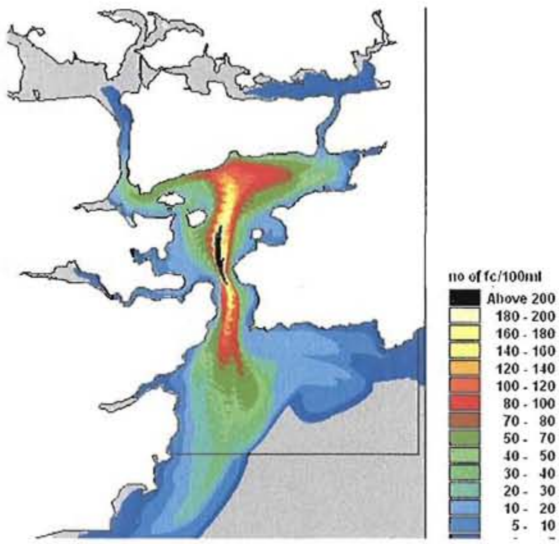

Fig. 4.67 Maximum of wind sensitivities

We can see from the figures that the extent of the plume is different for each of the 4 wind sensitivity simulation runs. In each case the plume extends into the North Channel and has an impact on the oyster farm but not in high concentrations (<10fc/100ml).

The concentrations in the outer harbour are increased with each of the wind sensitivities. We can see from the plots that these increases can be as much as 40-60 faecal coliforms per 100ml in certain areas.

A table presenting the maximum concentrations for each of the 15 points of interest for the combined maximum worse case wind sensitivities (Fig. 4.67) is shown below. The maximum concentrations for the recorded wind case (as presented in Table 4-4) are shown to aid the reader in making a comparison.

	2010	2010 – Wind sensitivity	2030	2030 – Wind sensitivity
	MAX	MAX	MAX	MAX
Fountainstown	0.2	3.5	0.3	5.0
Myrtleville	0.7	3.5	1.0	5.0
Roches Point	65.3	92.0	93.5	131.7
Crosshaven	3.8	11.3	5.4	16.1
Ringaskiddy Ferry	0.0	1.8	0.0	2.6
Monkstown Creek	0.0	0.5	0.0	0.7
Oyster F - NC	0.1	3.4	0.2	4.9
Marlogue Point	0.3	13.4	0.4	19.2
Oyster F - Outer	0.6	10.1	0.9	14.4
Cobh	23.2	67.7	33.2	96.9
Spike Island	9.1	38.1	13.1	54.5
Shoreline	2.2	8.9	3.2	12.7
Upstream of Outfall	333.7	346.4	477.6	495.7
West Passage	1.0	36.4	1.5	52.1
Lough Mahon	0.1	2.4	0.2	3.5

Table 4-9 Maximum concentrations for the combined maximum worse case wind sensitivities

4.6 Intestinal Enterococci concentrations

We have used the results of our faecal coliform modelling to predict the concentrations of intestinal enterococci in Cork Harbour when the treatment plant is in operation in 2010 and 2030. We have assumed that intestinal enterococci have a T90 of 24 hours and that there are $4.0*10^9$ enterococci in every cubic metre of raw sewage which is equivalent to $4.0*10^5$ enterococci in every 100ml[27]. We have assumed that the proposed waste water treatment plant will remove 90% of the organic matter so that there are $4.0*10^8$ enterococci in every cubic metre of treated effluent which is equivalent to $4.0*10^4$ enterococci per 100ml.

The faecal coliform results (with a T90 of 24 hours) may be used to predict the concentrations of intestinal enterococci owing to the linearity of the partial differential equation that describes the dynamic number-balance of the coliforms. The scaling property is a special case of the principle of superposition. It says the effect of multiplying, or scaling, any individual discharge by a constant positive number, x, is x times the concentration of coliforms in the Harbour due to that discharge before scaling *i.e.* when x is one.

We have assumed that there are $1*10^{11}$ faecal coliforms in every cubic metre of raw sewage and, as stated above, that there are $4.0*10^9$ intestinal enterococci per m^3. If we also assume that the removal efficiency of the treatment plant is the same for both we find that in order to rescale the faecal coliform results (T90 = 24hours) to the intestinal enterococci results we need to multiply the coliform concentrations by 0.04 (i.e. $1*10^{11} / 4.0*10^9 = 0.04$).

We are able to rescale in this way as the flow rates from the outfalls are the same for both bacteria. The decay rates (T90 = 24hours) and all other forcings in the model are also the same for both Bacteria. The maximum and average number of intestinal enterococci per 100ml for each of the 15 points of interest is presented in the following table.

27 World Health Organization. *WHO Guidelines for safe recreational water environments Volume 1 Coastal and Fresh waters*. Geneva: World Health Organization, 2003.

Year **Repeating Tide**	**2010** Spring MAX	 AVG	**2010** Neap MAX	 AVG	**2030** Spring MAX	 AVG	**2030** Neap MAX	 AVG
Fountainstown	0.05	0.02	0.05	0.01	0.07	0.02	0.08	0.02
Myrtleville	0.11	0.04	0.19	0.09	0.15	0.06	0.27	0.13
Roches Point	3.18	0.67	5.78	1.01	4.55	0.95	8.27	1.44
Crosshaven	0.45	0.14	0.37	0.06	0.64	0.21	0.52	0.09
Ringaskiddy	0.01	0.01	0.00	0.00	0.02	0.01	0.00	0.00
Monkstown Ck	0.02	0.01	0.00	0.00	0.02	0.01	0.00	0.00
Oyster F - NC	0.04	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Marlogue Point	0.08	0.01	0.04	0.00	0.12	0.02	0.05	0.00
Oyster F - Outer	0.13	0.00	0.20	0.00	0.19	0.00	0.29	0.00
Cobh	1.60	0.42	0.30	0.02	2.29	0.61	0.42	0.03
Spike Island	0.86	0.20	1.60	0.44	1.23	0.29	2.29	0.63
Shoreline	0.34	0.07	0.30	0.03	0.48	0.09	0.43	0.05
Upstream Outfall	14.28	1.03	19.18	2.91	20.44	1.47	27.44	4.17
West Passage	0.17	0.02	0.01	0.00	0.25	0.03	0.01	0.00
Lough Mahon	0.04	0.00	0.00	0.00	0.05	0.01	0.00	0.00

Table 4-10 Concentration of intestinal enterococci at locations of interest

We can see from the table that the concentrations are very small with the exception of the area around the proposed outfall.

4.7 *Escherichia coli* concentrations

The concentrations of *Escherichia coli* in Cork Harbour may be calculated using the same rescaling technique as for the intestinal enterococci. We have assumed that *E coli* have a T90 of 24 hours and that there are $1.0*10^{12}$ *E coli* in every cubic metre of raw sewage which is equivalent to $1.0*10^{8}$ *E coli* in every 100ml[28]. This is the same concentration as for the faecal coliforms concentrations in raw sewage that were modelled. The results for the coliforms are therefore equivalent to *E coli* concentrations and are not repeated in this section.

4.8 Discussion and Conclusion

The OH_2 model has been used to simulate the release and advection of faecal coliforms from the relevant outfalls in Cork Harbour. We assumed that there

[28] World Health Organization. Op. cit. ante.

were $1.0*10^7$ faecal coliforms in every 100ml of raw sewage. We also assumed that the proposed wastewater treatment plant will remove 90% of the organic matter, so that there are $1.0*10^6$ faecal coliforms in every 100ml of treated effluent.

A comparison between Case 2 (*no* treatment, 2010 population) and Case 3 (*with* treatment, 2010 population) was made for repeating spring and neap boundary conditions. It was shown that there was a substantial relative reduction in the number of faecal coliforms across the entire model area. This improvement in water quality was quantified by expressing the maximum concentrations for Case 3 (with treatment) as a percentage of the maximum concentrations for Case 2 (no treatment). It was found that the maximum concentrations with the treatment plant in place were less than 20% of the maximum concentrations with no treatment for the entire harbour area i.e. there is an 80% relative reduction in the number of indicator organisms. For the inner harbour and the East and West passages they were less than 5% i.e. there is a 95% relative reduction in the number of indicator organisms. This represents a significant improvement in water quality.

Time series of faecal coliform concentrations were presented for 15 points of special interest. The improvement in water quality was highlighted by plotting the time series for Case 2 and Case 3 on the same graph for the repeating spring and neap tides. The point with the highest concentrations was located just upstream of the outfall where the concentration of faecal coliforms per 100ml ranged from 50 -2300 fc/100ml for the case of no treatment, and 10 - 400 fc/100ml for the case with treatment applied. The points with the lowest concentrations were the centre of the oyster farm in the North Channel and Fountainstown. For both of these locations the number of faecal coliforms per 100ml was less than 1 with no treatment. When the treatment plant was in place it was found to be almost zero. With a strong wind (>10m/s) from the southwest the concentrations in the North Channel increased to over 7 fc/100ml.

A sensitivity analysis was carried out on the OH_2 model for Case 3 (with treatment, 2010 population). It was found that when the faecal coliforms were simulated with a T90 of 24 hours the concentration in the outer harbour increased in by as much as 40 fc/100ml in certain areas. When the model was simulated with adverse wind conditions it was found that the concentrations in the outer harbour increased by as much as 40 - 60 fc/100ml in certain areas. In the area adjacent to the outfall the concentrations increased in by as much as 60 - 90 fc/100ml.

Maximum and averaged concentrations for intestinal enterococci were calculated by rescaling the faecal coliform results for Case 2 and Case 3. It was found that the intestinal enterococci concentrations were very small with the exception of the area immediately around the proposed outfall.

Maximum and averaged concentrations for *E coli* were calculated by rescaling the faecal coliform results for Case 2 and Case 3. As must be the case the concentrations were equal since all inputs were identical in value.

Chapter 5 *Norovirus* Results

5.1 Background

This chapter presents the results of the *Norovirus* modelling. The *Norovirus* or "winter vomiting bug" is the primary pathogen in outbreaks of gastroenteritis following consumption of raw oysters.

The *Norovirus* is endemic in many countries. Outbreaks of "winter vomiting bug" may occur all year round and are often made public in Ireland by the closure of hospitals to visitors. Waters at al.[29] reported that "Since 2002, the burden of Norovirus (NoV) infection in Ireland has increased. Outbreaks in institutional settings are the most common causing widespread disruption to health service delivery". Kelly et al. (2006)[30] reported 226 outbreaks in Ireland during 2004 and concluded: "Results so far indicate that the majority of reported outbreaks in the island of Ireland are associated with hospitals and residential institutions." There is no comment on the probable number of non-reported outbreaks.

The virus is life-threatening to those with post-operative stress in hospital and to the very young and very old. In healthy adults it is not very dangerous.

The *Norovirus* is a colloidal particle 27-38nm in diameter. It is highly infectious especially in the case of projectile vomiting. The minimum infective dose is very low, between one and ten ingested particles. Incubation takes 24 to 48 hours.

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[29] Waters, A., et al. (2006) "Molecular epidemiology of *Norovirus* strains circulating in Ireland from 2003 to 2004" *Epidemiol. Infect.,* Page 1 of 9. Cambridge University Press. http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=420336#

[30] Kelly S., Foley B., Coughlan S., Dunford L., O'Neill H., Smyth B., McKeown P., Lynch M. "Epidemiology and molecular analysis of *Norovirus* outbreaks in Ireland" Abstract p1030

European Society of Clinical Microbiology and Infectious Diseases 16th European Congress of Clinical Microbiology and Infectious Diseases. Nice, France, April 1-4, 2006.

The average infected person may excrete[31] roughly 0.15 billion *Norovirus* particles per day to the sewer system. Roughly 3 to 6% of the population of a town or city may be infected during an outbreak. Asymptomatic excretion from infected persons may persist for a period of up to 2 to 3 months.[32]

The virus has a long survival time in coastal waters from 7 days (summer T90) to 30 days (winter T90)[33]. These T90 values are ten times those for the indicator bacteria, such as faecal coliforms, used in regulatory instruments for the protection of consumers of oysters and the quality of coastal waters where oysters are produced. Consequently, when the infective agent is viral, absence of indicator bacteria does not imply the absence of contamination and health risk. Protection against *Norovirus* may also protect against most other viral pathogens as well.

We have assumed that there are 50 million *Norovirus* in every cubic metre of raw sewage. This is a slightly more conservative value than was used in a study of the *Norovirus* by a team of microbiologists at IFREMER in France[34] where it was assumed that there are 20 million *Norovirus* in every cubic metre of raw sewage.[35] This concentration, multiplied by the flow rate for each town (as listed in Chapter 1) gives the loading for each outfall. Adopting such an approach

[31] Pommepuy, M. et al. "Sewage impact on shellfish microbial contamination". Water Science and Technology. Vol. 50, No. 1 pp 117-124. IWA publishing, 2004.

[32] Pommepuy, M. et al., 2004, Op. cit. ante.

[33] Pommepuy, M. et al. "Faecal contamination in coastal waters: An engineering approach" Book chapter (p331-359) in Oceans and Health: Pathogens in the Marine Environment. Springer 2006. http://www.springerlink.com, http://www.ifremer.fr/docelec. The T90 time is the time required for 90% decay.

[34] Pommepuy, M. et al., 2004, Op. cit. ante.

[35] No epidemiological data, or models, for the spread of winter vomiting due to *Norovirus* are available either nationally or internationally. Consequently, only relative concentrations are significant in our model *i.e.* the relative change in concentrations due to the new treatment plant and new outfall location. There are no standards for *Norovirus* in recreational or oyster producing waters.

assumes that each and every person living within the catchments experience an identical attack of *Norovirus* gastroenteritis and discharges the same number of *Norovirus* particles to the nearest sewer at a constant rate for the duration of the outbreak of *Norovirus*. We have assumed that an outbreak of *Norovirus* in the population lasts for 20 days[36]. The OH_2 model was therefore simulated for 25 days. In all the time series presented in section 5.3 we can see the concentration of *Norovirus* increase up to a maximum value occurring approximately at the end of the 20 day pulse. The concentrations decrease afterwards. We have therefore used a spring to neap tidal cycle as the boundary condition for the *Norovirus* modelling.

In this study we have assumed that the proposed waste water treatment plant will remove 90% of the organic matter. We have assumed an equivalent removal efficiency of *Norovirus* such that after treatment there are 5 million *Norovirus* in every cubic metre of treated effluent (i.e. 90% of 50 million is 45 million, hence 5 million are left).

In order to determine the worse case scenario in terms of concentration we have assumed that the T90 of the *Norovirus* is 30 days. This slow decay rate is representative of "winter conditions".

The presentation of the results in this chapter follows the same format as in the previous chapter. Spatially varying maps of maximum concentration are presented in the following section. Time series for the 13 points of interest to the study are then given. Unlike the previous chapter where all the concentrations were expressed in number of faecal coliforms per 100ml, all the concentrations in this chapter are expressed as ***Norovirus* per cubic metre.**

5.2 Spatially Varying maps of concentration

This section presents the spatially varying maps of maximum concentration over the entire area. Over the course of the model run the number of *Norovirus* at each grid point will, at some specific moment, reach a maximum value. These

[36] Pommepuy, M. et al., 2004, Op. cit. ante

maxima, at each and every grid point, may be extracted from the result files of a production run and plotted together on a single map. This diagram then illustrates the spatially varying maximum concentrations of the simulation period for Cork Harbour. The time at which the concentrations reach their peak is not considered.

As before the colour palette is the same for each plot in order to aid the reader in making a visual comparison between the different model runs.

The concentrations for Case 2 are presented in Fig. 5.1. We can see from the figure that the maximum concentrations are located in the vicinity of the outfalls. We can also observe that the viral plume extends much further into the Celtic sea than the bacterial plume presented in the previous chapter.

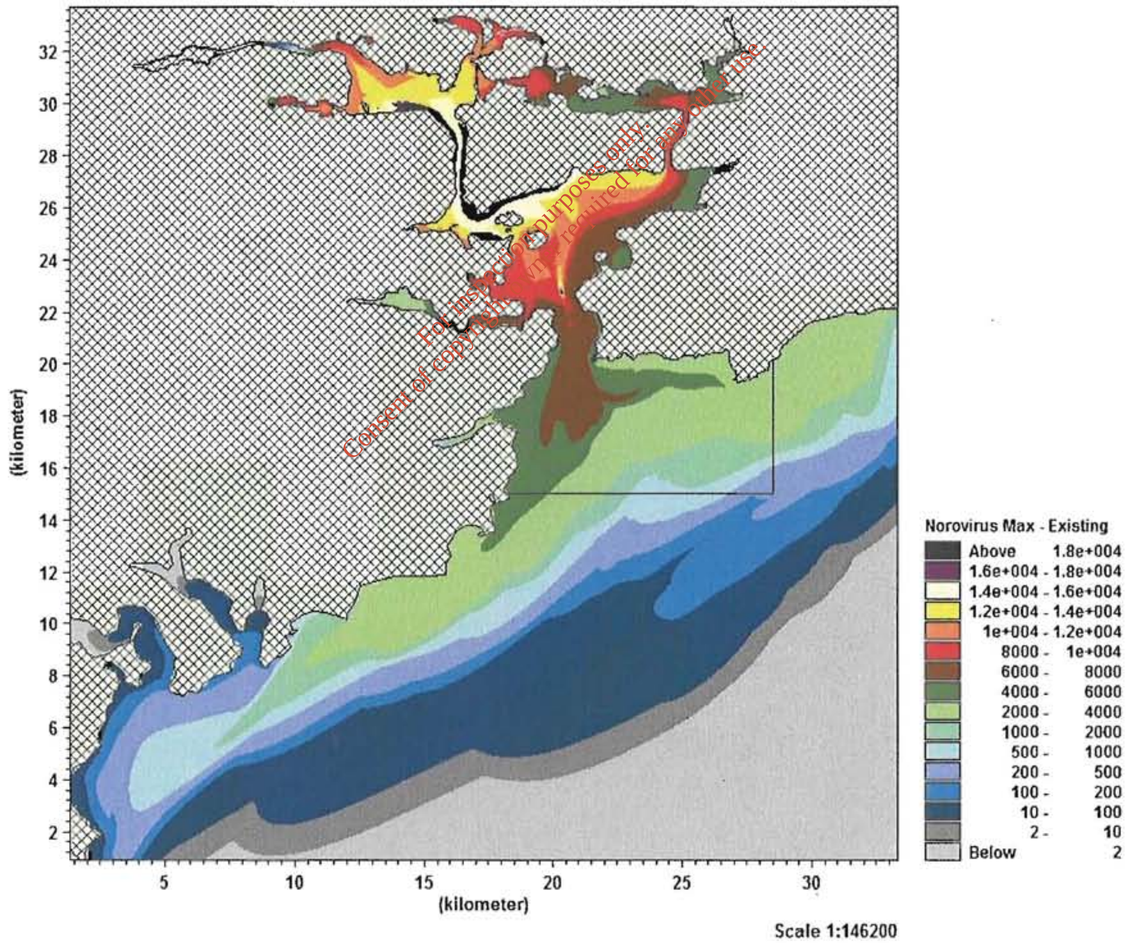

Fig. 5.1 Plot of maximum concentration for Case 2 (2010 – no treatment)

Case 3 is presented in Fig. 5.2. We can see from the figure that there has been a reduction in the number of *Norovirus* throughout the harbour. For Case 2 the *Norovirus* concentrations ranged from 2 to over 18,000 viral particles per cubic metre. For Case 3 this range is greatly reduced. We can see that the range is between 2 and 4000 particles per cubic metre if one ignores the very high concentrations in the immediate vicinity of the outfall.

In order to quantify this reduction in concentration we may express the maximum concentrations for Case 2 as a percentage of the maximum concentrations of Case 3 as we did in the previous chapter. This is plotted in Fig. 5.3. We can see from the figure that for Lough Mahon and the Belvelly Channel the concentrations with the treatment plant in operation are less than 5% of the concentrations when untreated waste is being discharged i.e. there is at least a 95% relative reduction in the number of *Norovirus*. For the rest of the Inner harbour they are less than 10% i.e. a 90% relative reduction. For the outer harbour they are less than 20% i.e. an 80% relative reduction.

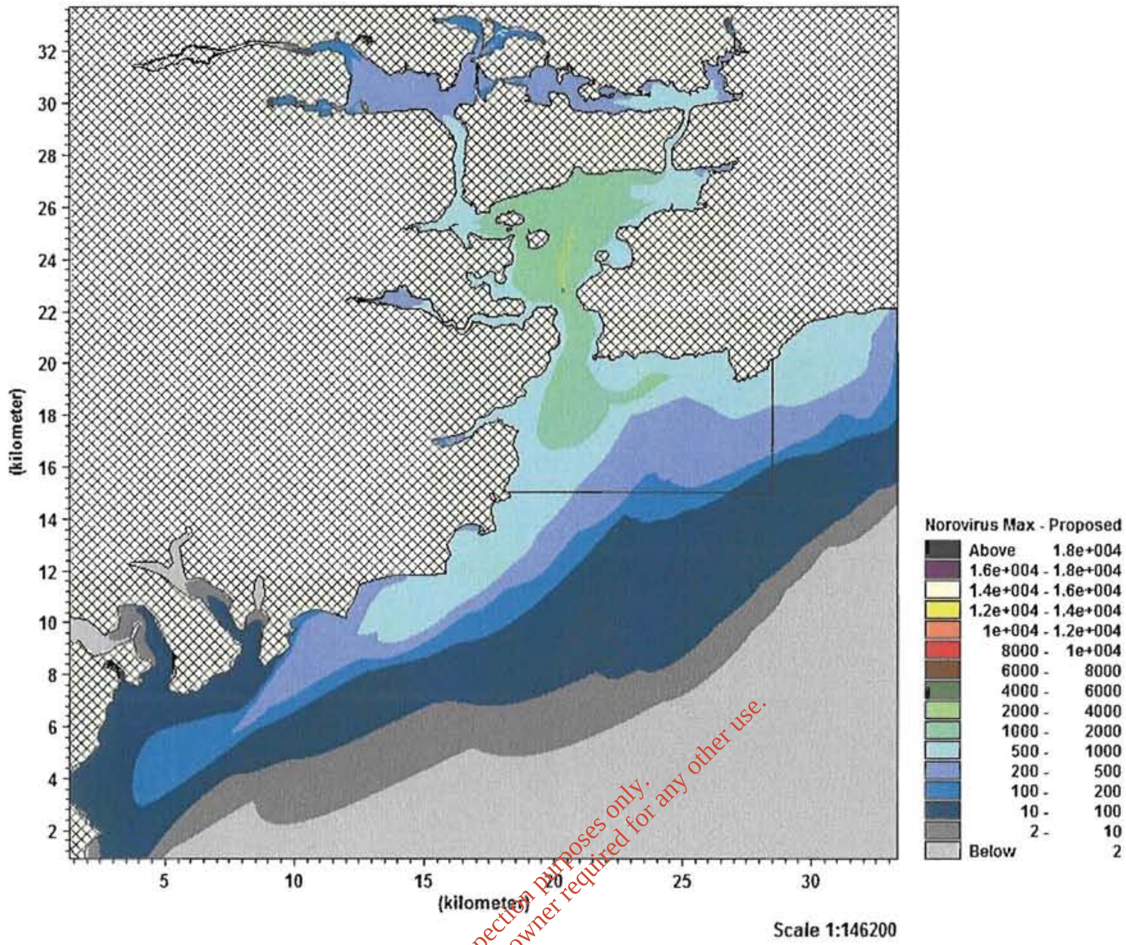

Fig. 5.2 Plot of maximum concentration for Case 3 (2010 – with treatment)

The exception to this is the area immediately upstream of the outfall where the concentrations for Case 3 are less than 25% of the concentrations for Case 2 i.e. a 75% relative reduction.

The pattern of relative reduction of *Norovirus* with the introduction of the proposed scheme is very similar to that of the faecal coliforms.

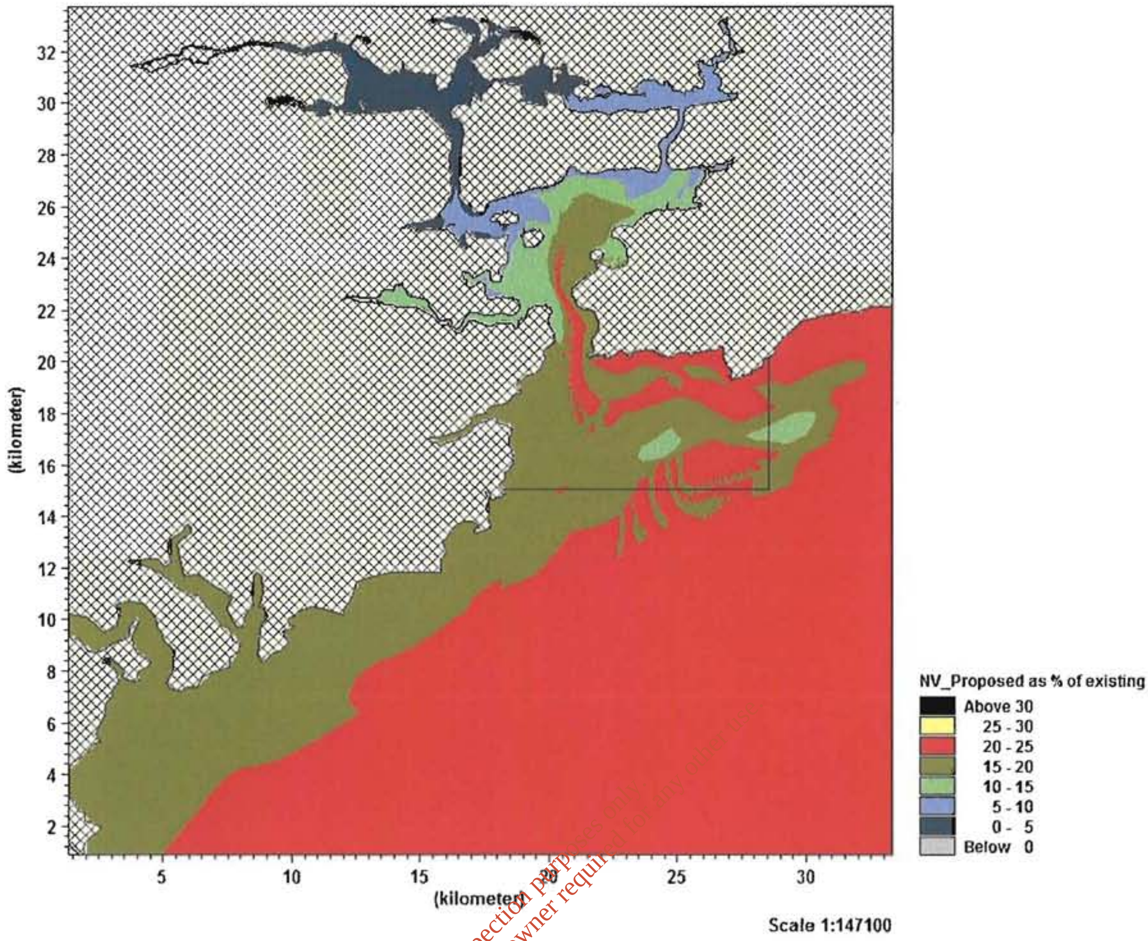

Fig. 5.3 The 2010 proposed concentrations as a percentage of the existing concentrations

5.3 Time series of concentration of *Norovirus*

The previous section presented spatially varying plots of concentration across the entire harbour area. In order to evaluate the benefit of the proposed scheme at a particular location we must extract the time series of concentration from the locations of interest in the model. For this Environmental Impact Statement 15 points of special interest have been identified and are listed in Table 5-1.

The maximum and averaged concentrations of *Norovirus* for these points of interest are presented in Table 5-2 and Table 5-3.

Point No	Location	E (UTM)	N (UTM)
1	Fountainstown	547588	5736208
2	Myrtleville	548700	5737121
3	Roches Point	550651	5738138
4	Crosshaven	548497	5739695
5	Ringaskiddy Ferry	546466	5742772
6	Monkstown Creek	545166	5743316
7	Oyster Farm - North Channel	552712	5748103
8	Marlogue Point	554291	5745574
9	Oyster Farm - Outer Harbour	555451	5744826
10	Cobh - Recreational Area	548617	5744396
11	Spike Island - Proposed Heritage Area	549349	5742451
12	Shoreline Closest to Existing Outfall	547959	5741601
13	200m Upstream of Existing Outfall	550203	5740759
14	West Passage	546223	5744496
15	Entrance to Lough Mahon	545505	5747784

Table 5-1 – Points of interest to the study

In order to make an assessment of the improvement in water quality resulting from the proposed wastewater treatment plant, Case 2 and Case 3 are plotted against with other in the following graphs. The plots for Case 4 (2030) are not presented. As before one may obtain the concentration for 2030 by simply multiplying the values for Case 3 by 1.431.

One graph is presented for each of the 15 locations. Case 2 is plotted with a black line and is referred to in the legend as "existing". Case 3 is plotted using blue and is referred to in the legend as "proposed".

The reader should be aware that the scale on the left-hand axis, which expresses the number of ***Norovirus* per cubic metre**, varies for each of 15 locations.

	2001 Untreated MAX	**2010** Untreated MAX	**2010** Treated MAX	**2030** Treated MAX
Fountainstown	2816	3886	695	994
Myrtleville	3291	4542	798	1142
Roches Point	4694	6478	1254	1795
Crosshaven	5754	7940	917	1312
Ringaskiddy	8507	11740	550	788
Monkstown Ck	8851	12214	556	795
Oyster F – NC	4254	5870	550	787
Marlogue Point	7806	10772	933	1335
Oyster F - Outer	3967	5475	545	780
Cobh	11704	16152	1374	1966
Spike Island	7281	10048	1203	1722
Shoreline	6498	8967	1028	1471
Upstream Outfall	10863	14991	3157	4518
West Passage	11100	15318	817	1169
Lough Mahon	10674	14730	471	675

All concentrations are expressed in no of Norovirus per m3

Table 5-2 Maximum Norovirus concentrations

	2001 Untreated AVERAGE	**2010** Untreated AVERAGE	**2010** Treated AVERAGE	**2030** Treated AVERAGE
Fountainstown	730	1008	195	278
Myrtleville	1091	1505	285	408
Roches Point	1921	2650	532	762
Crosshaven	1816	2507	368	527
Ringaskiddy	5379	7423	219	314
Monkstown Ck	5246	7239	186	266
Oyster F – NC	964	1331	89	127
Marlogue Point	2421	3341	252	361
Oyster F - Outer	1848	2550	219	313
Cobh	6124	8452	430	615
Spike Island	2904	4008	523	748
Shoreline	1601	3964	496	396
Upstream Outfall	2744	3787	701	1004
West Passage	6352	8766	205	293
Lough Mahon	5448	7518	98	140

All concentrations are expressed in no of *Norovirus* per m3

The average values are for the 20 day viral pulse

Table 5-3 Averaged Norovirus concentrations

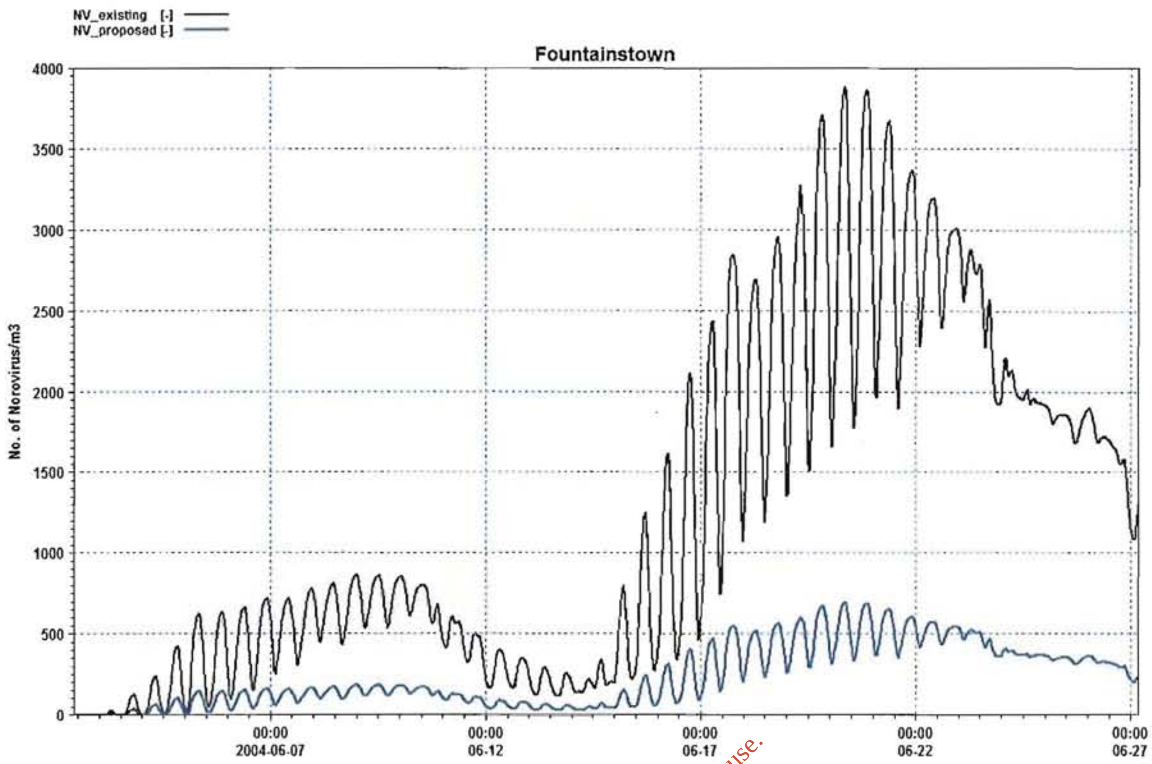

Fig. 5.4 Fountainstown – Norovirus Case 2 & Case 3 (2010)

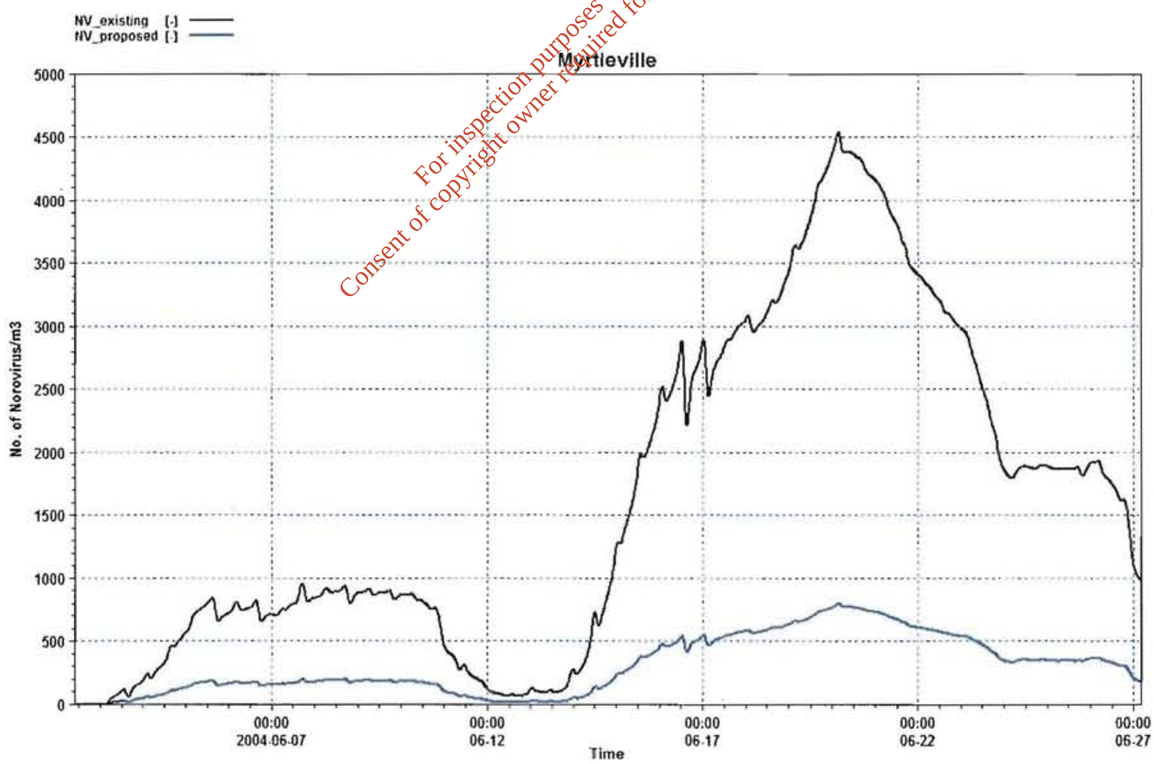

Fig. 5.5 Myrtleville – Norovirus Case 2 & Case 3 (2010)

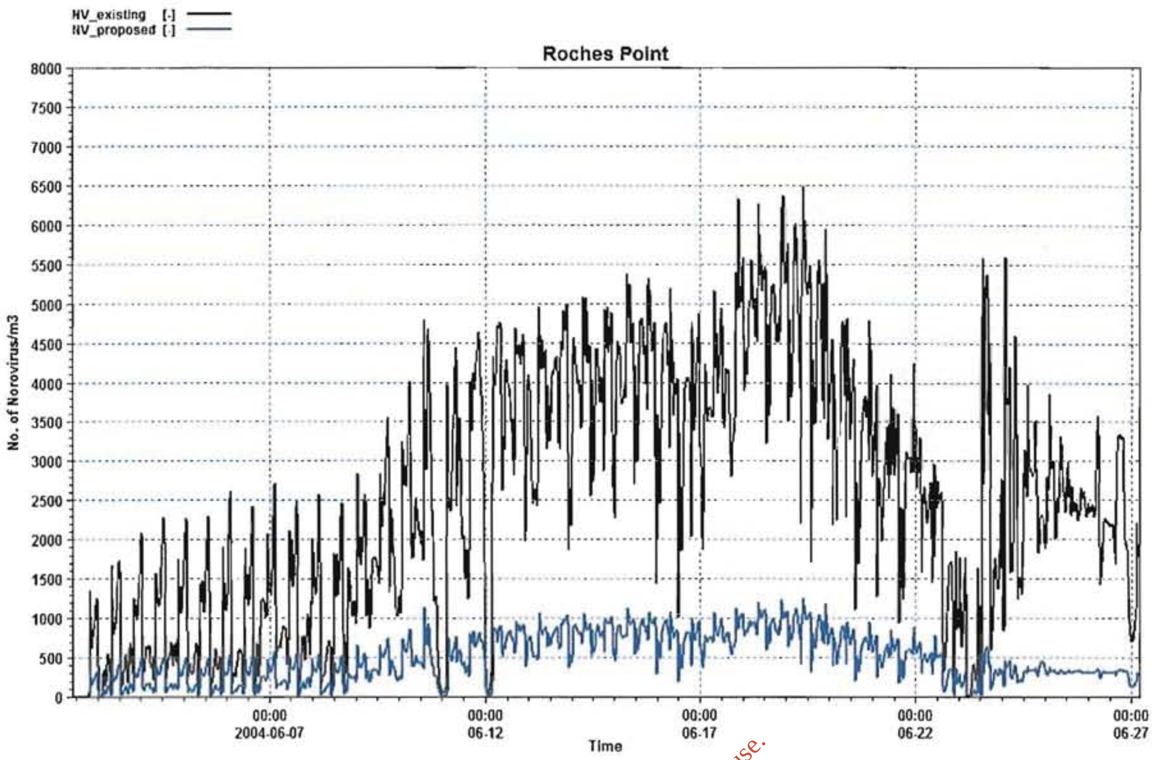

Fig. 5.6 Roches Point – Norovirus Case 2 & Case 3 (2010)

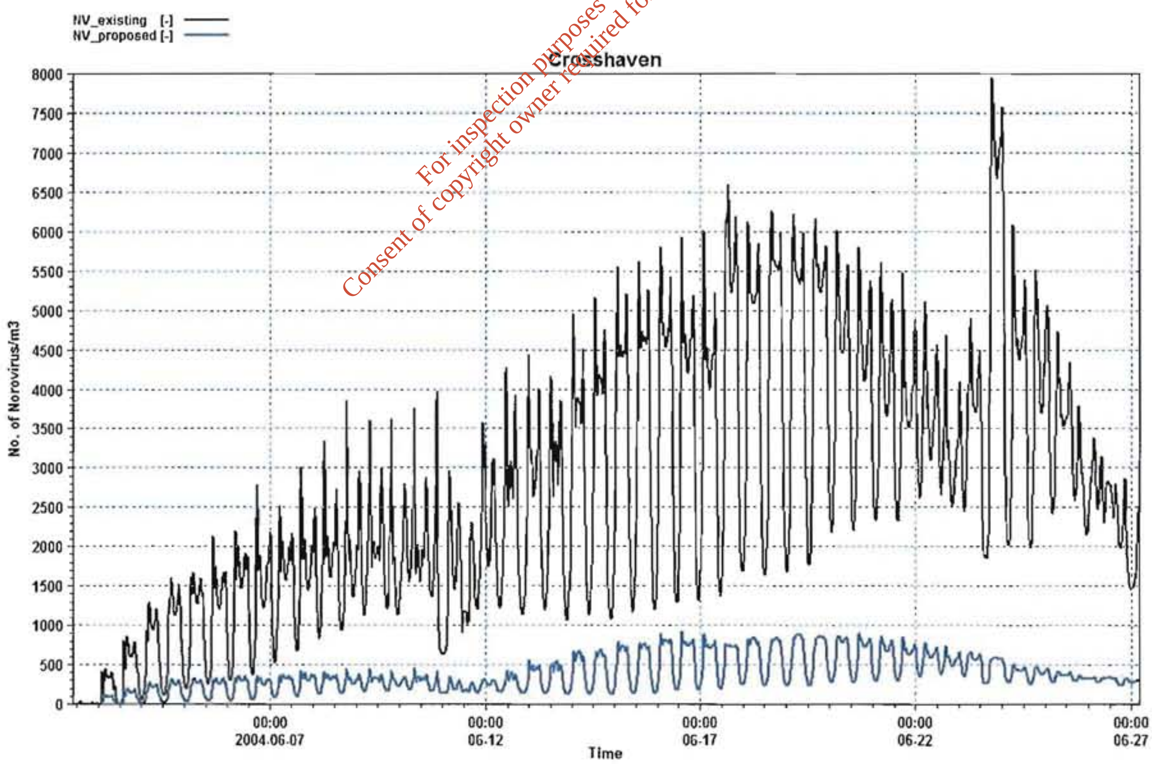

Fig. 5.7 Crosshaven – Norovirus Case 2 & Case 3 (2010)

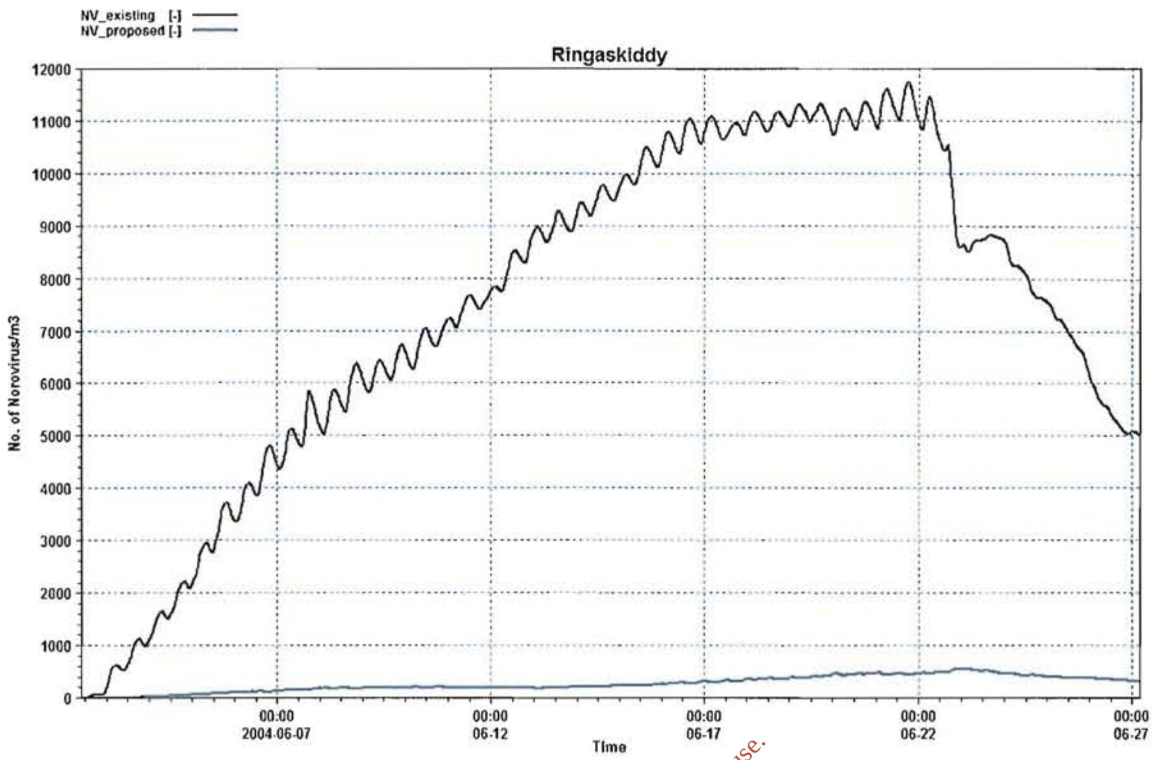

Fig. 5.8 Ringaskiddy – Norovirus Case 2 & Case 3 (2010)

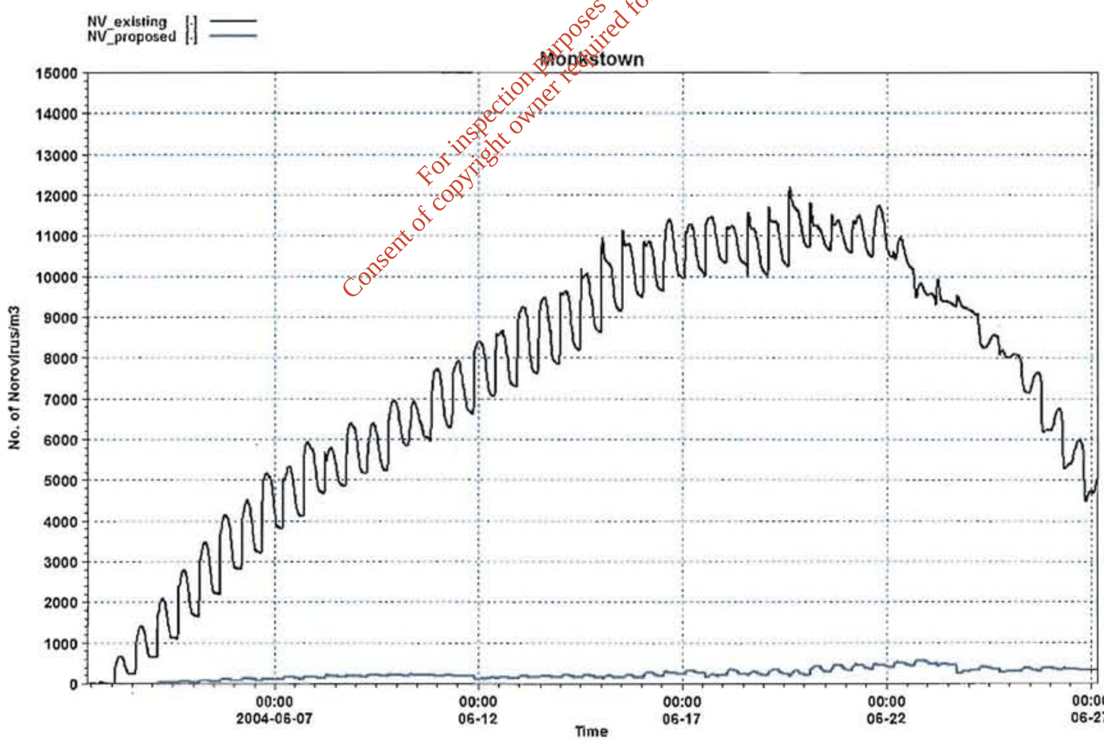

Fig. 5.9 Monkstown – Norovirus Case 2 & Case 3 (2010)

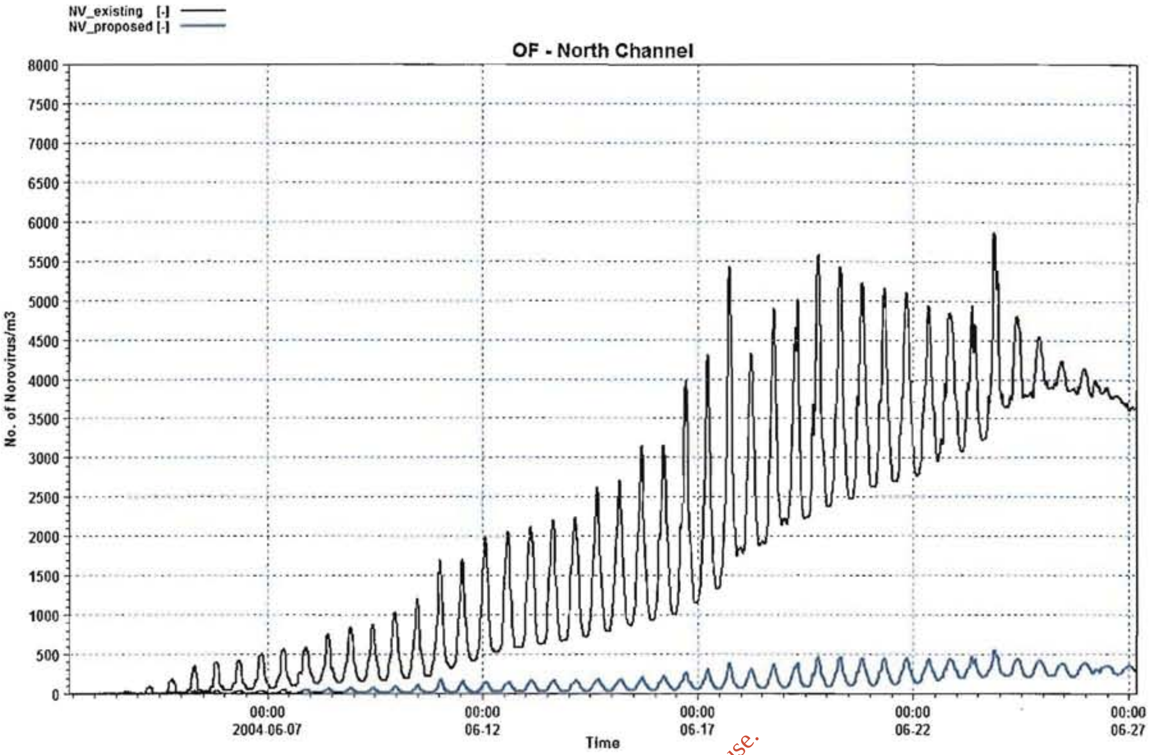

Fig. 5.10 OF - North Channel – Norovirus Case 2 & Case 3 (2010)

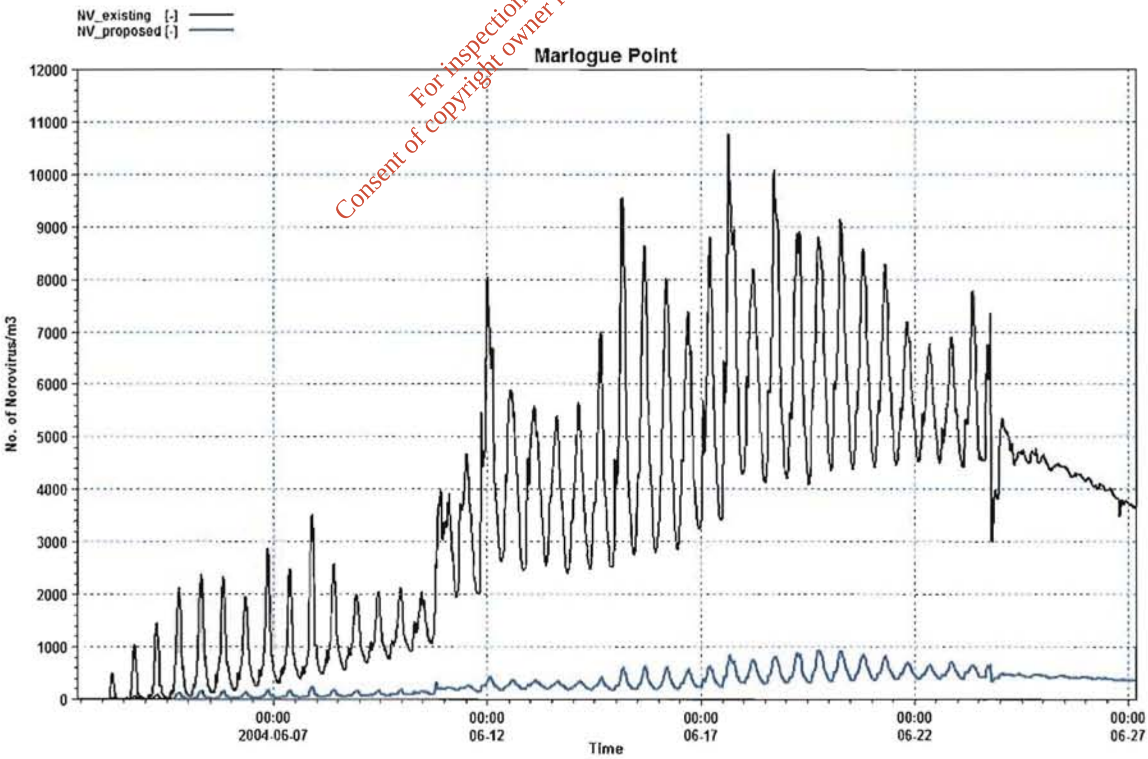

Fig. 5.11 Marlogue Point – Norovirus Case 2 & Case 3 (2010)

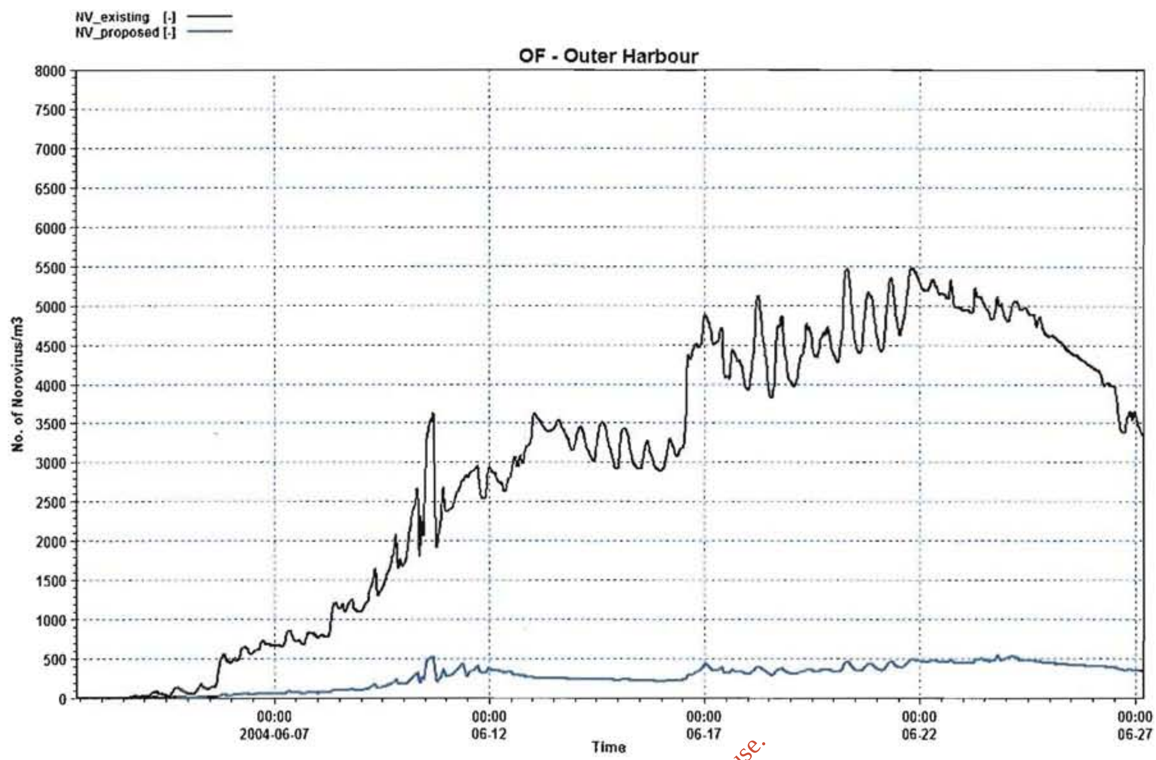

Fig. 5.12 OF – outer harbour – Norovirus Case 2 & Case 3 (2010)

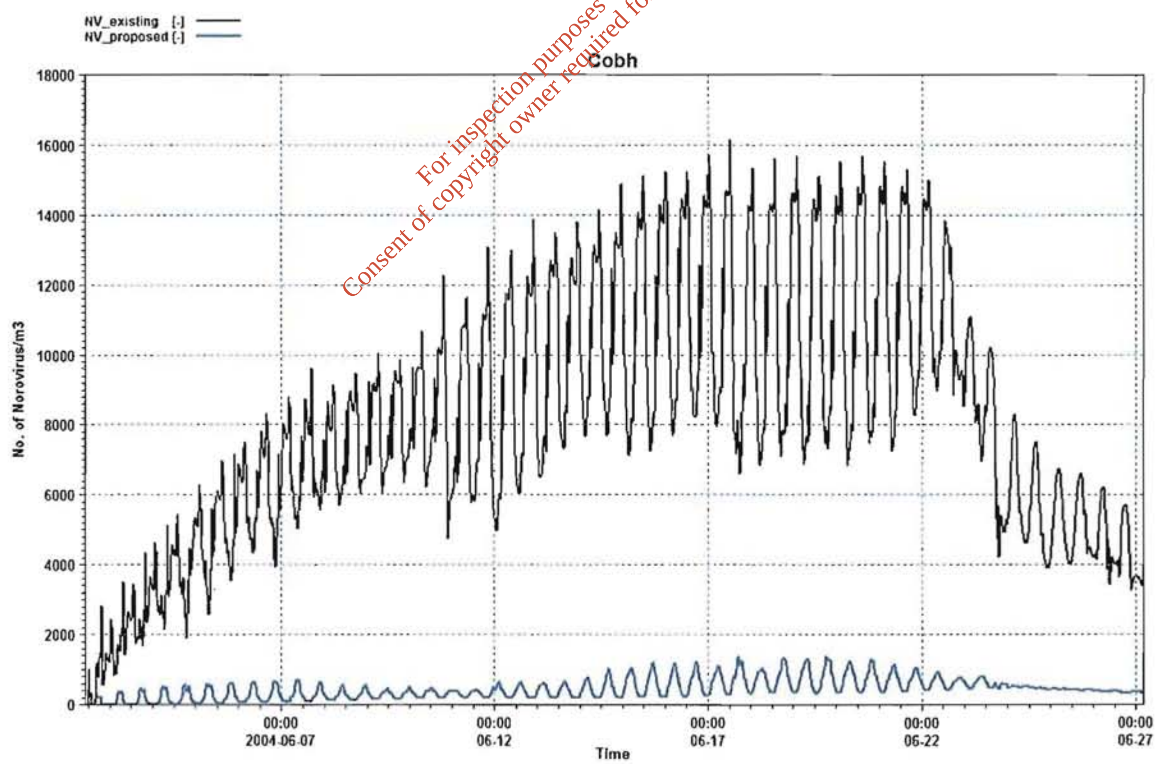

Fig. 5.13 Cobh recreational area – Norovirus Case 2 & Case 3 (2010)

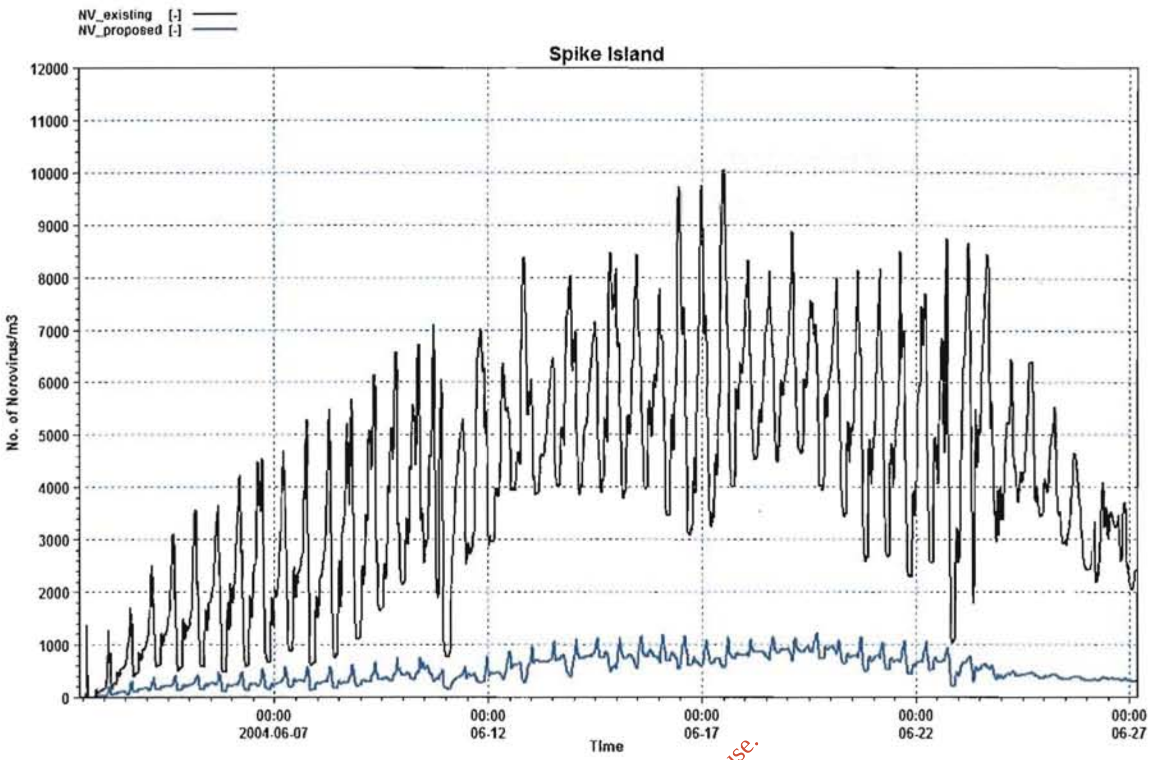

Fig. 5.14 Spike Island – Norovirus Case 2 & Case 3 (2010)

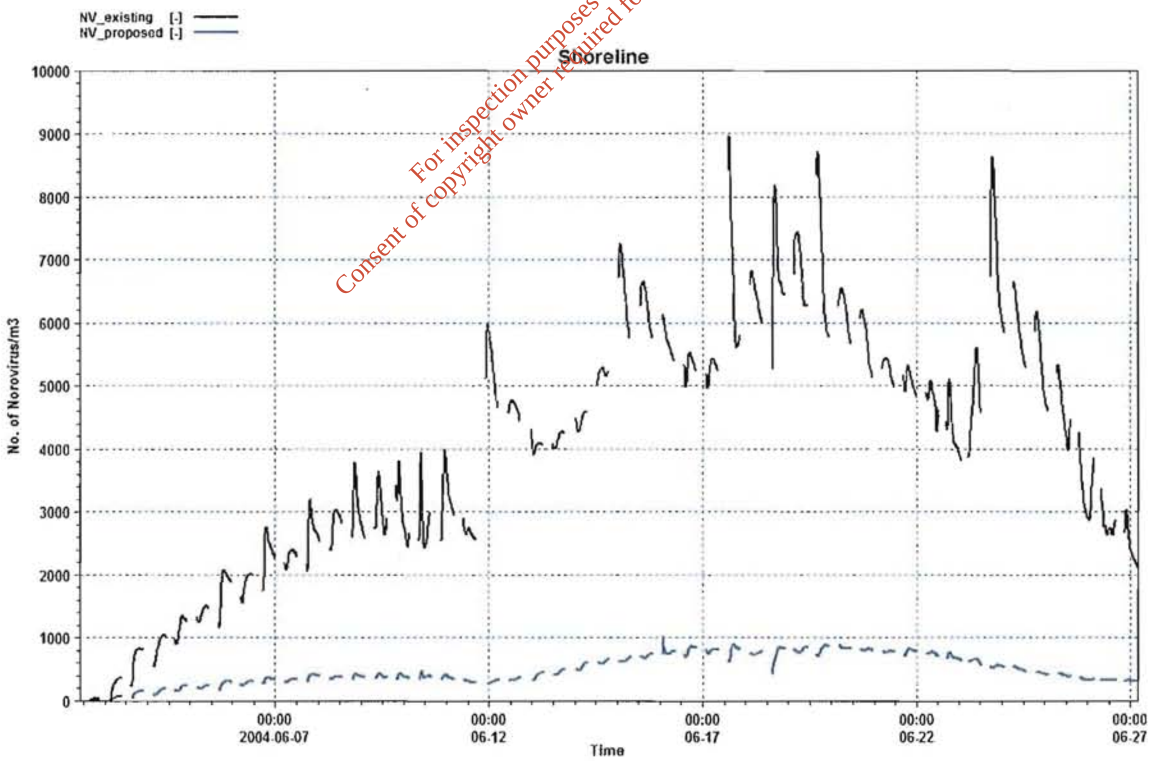

Fig. 5.15 Existing Shoreline closest to the outfall – Norovirus Case 2 & Case 3 (2010)

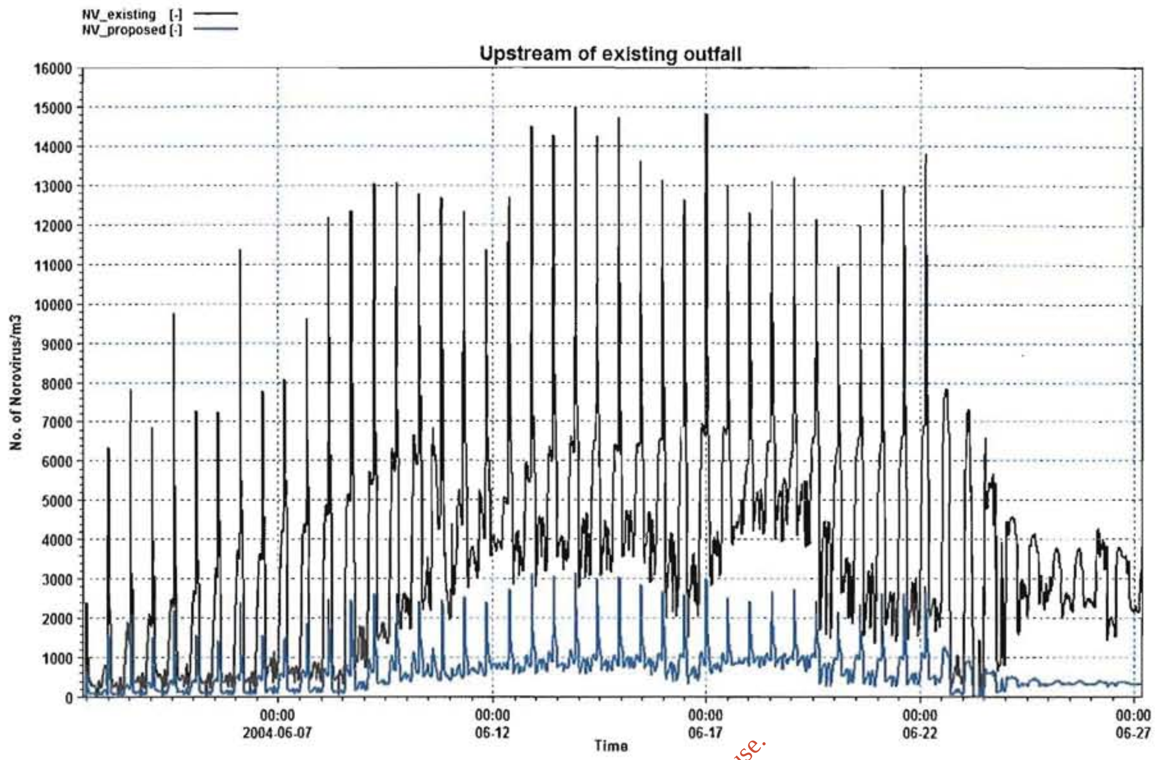

Fig. 5.16 200m upstream of the existing outfall – Norovirus Case 2 & Case 3 (2010)

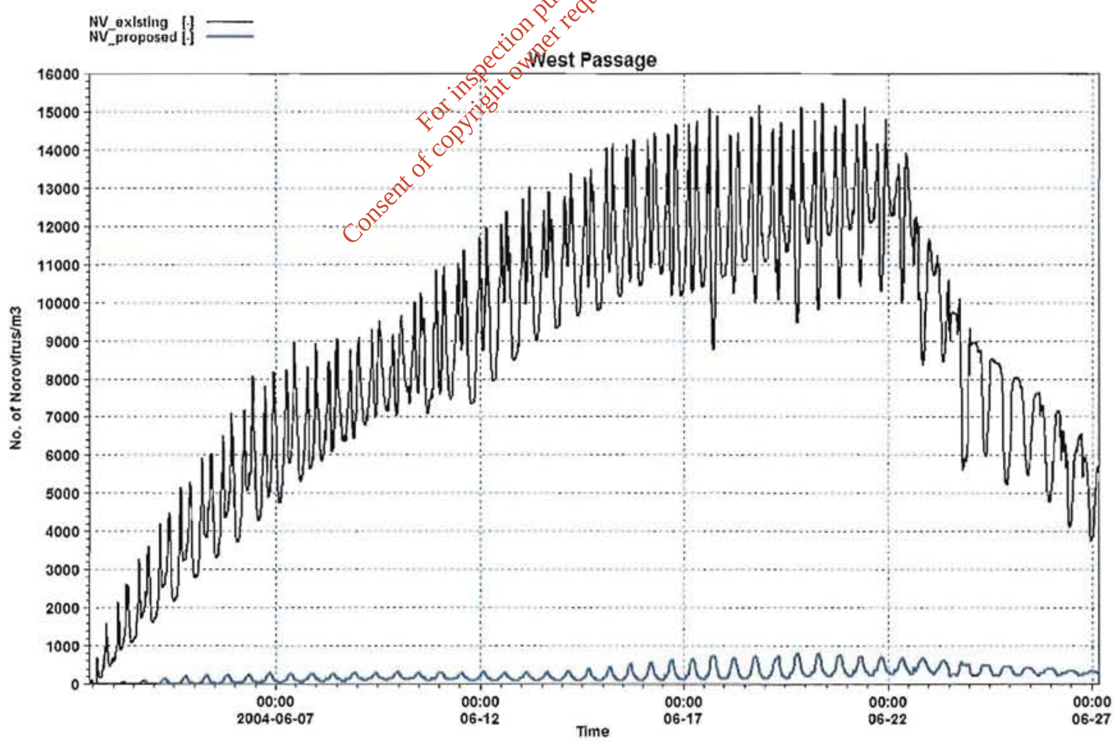

Fig. 5.17 West Passage – Norovirus Case 2 & Case 3 (2010)

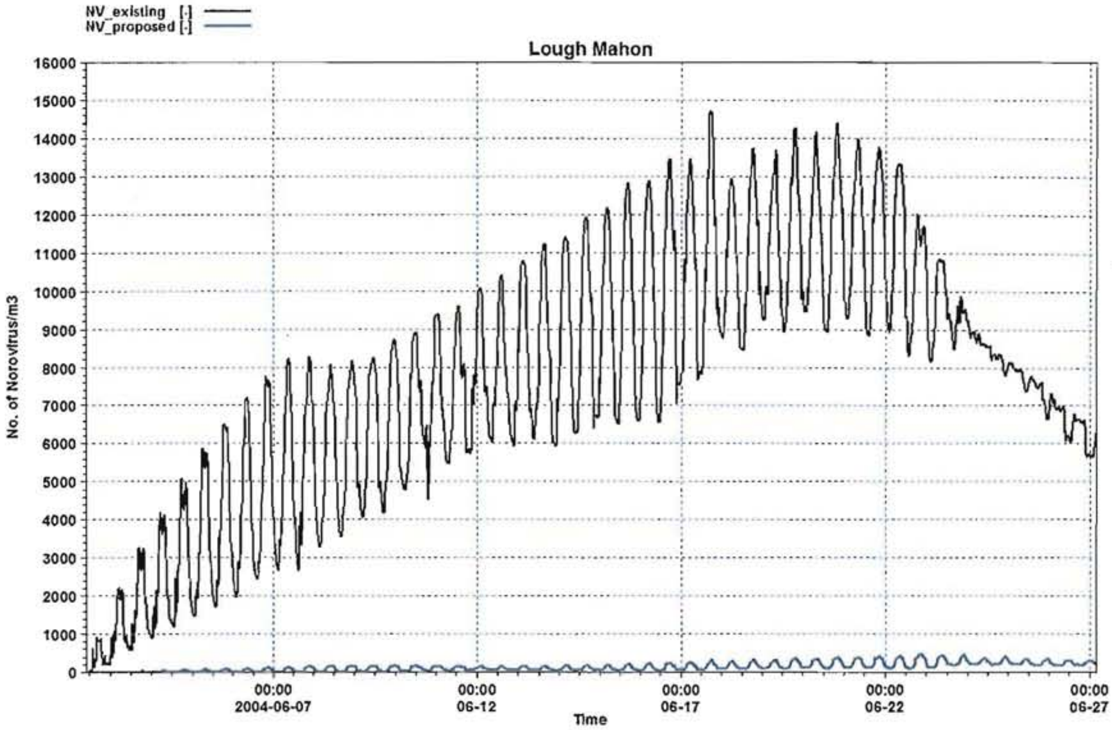

Fig. 5.18 Lough Mahon – Norovirus Case 2 & Case 3 (2010)

5.4 Discussion and Conclusion

The OH_2 model has been used to simulate the release and advection of *Norovirus* from the relevant outfalls in Cork Harbour. *Norovirus* was included in this Environmental Impact statement in order to assess the changes in concentration at the oyster farms and water-contact recreation areas present in the harbour.

We assumed that there was 50 million *Norovirus* in every cubic metre of raw sewage during a 20 day outbreak of "winter vomiting". We also assumed that the proposed wastewater treatment plant will remove 90% of the *Norovirus* so that there are 5 million *Norovirus* in every cubic metre of treated effluent for 20 days. We assumed a T90 of 30 days, a typical value for winter conditions leading to maximum concentrations in the harbour.

A comparison between Case 2 (*no* treatment, 2010 population) and Case 3 (*with* treatment, 2010 population) was made for a spring to neap to spring tidal cycle for a 25 day period. It was shown that there was a reduction in the number of *Norovirus* across the entire model area. This was quantified by expressing the maximum concentrations for Case 3 (with treatment) as a percentage of the maximum concentrations for Case 2 (no treatment). It was found that the maximum concentrations with the treatment plant in place were less than 20% (i.e. an 80 % relative reduction) of the maximum concentrations with no treatment for the entire harbour area with the exception of the area immediately adjacent to the outfall. For areas of the Inner harbour the improvement was much greater with the maximum concentrations for Case 3 being less than 5% of those for Case 2 (i.e. a 95 % relative reduction).

Time series of *Norovirus* concentrations were presented for 15 points of special interest. The improvement in water quality was highlighted by plotting the time series for Case 2 and Case 3 on the same graph.

From this we can conclude that the burden of *Norovirus* on Cork Harbour is reduced with the construction of the proposed wastewater treatment plant.

Chapter 6 Nitrogen Results

6.1 Introduction

Nitrogen in different forms is an important nutrient in the coastal zone. Changes in the speciation and distribution of nitrogen can increase or decrease primary production by phytoplankton and macrophytes rooted to the bed of an estuary or harbour. We have chosen to examine the impact of the proposed treatment plant on such forcing by using a linear cascade model containing three species of nitrogen: organic nitrogen, ammonia and nitrate. The model quantifies the relative effect of the scheme on the concentration of these three species throughout the harbour and adjacent coast over a test period of ten days[37]. The relative effect is with respect to an unaltered background concentration of each species of nitrogen.

6.2 The cascade model

Each species of nitrogen is conceptualised as a concentration in milligrams per litre of atomic nitrogen[38], namely, nitrogen in the form of organic nitrogen (N_org) in raw or treated sewage, or as nitrogen in the form of ammonia (N_NH4), or as nitrogen in the form of inorganic nitrate (N_NO3).

We assume that an adapted flora of microflora, such as *Nitrosomonas* and *Nitrobacter,* is present to mediate the transformation of organic nitrogen to ammonia and the subsequent nitrification of ammonia to inorganic nitrate. We then speak of a cascade of reactions. We further assume that the concentrations of the different species of nitrogen are sufficiently dilute so that these reactions

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[37] A ten day period is sufficiently long to determine the relative change resulting from the construction of the treatment plant.

[38] This makes all stoichiometric constants unity.