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

Attachment D1: WATER QUALITY MODELLING, ECOLOGICAL IMPACT ASSESSMENT, EIA SCREENING

– **Attachment D.1.a: Castletownbere Far Field Modelling Report**

Irish Water

Cork UTAS

Castletownbere Far Field Modelling

257589-00

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Executive Summary

Irish Water has identified 44 agglomerations in Ireland where untreated sewerage is discharged directly to receiving waters, either from sewer network outfalls or via septic tanks in which the level of treatment provided is negligible. In response, Irish Water are presently implementing upgrades to these agglomerations through the Untreated Agglomerations programme.

Arup has been commissioned by Irish Water to advance an Untreated Agglomerations project for Castletownbere in Bantry Bay. A Water Quality impact assessment is required as part of the study in order to determine the compliance of the effluent discharges from the proposed Wastewater Treatment Plant on the receiving waters in Bantry Bay with the Environmental Quality Standards as defined in the relevant European Union water quality regulations.

In order to undertake the assessment a high-resolution MIKE 21 Water Quality model of Bantry Bay was developed. A baseline (existing scenario) model was first developed which simulated existing concentrations of the six relevant state variables in the area of interest. The model was then reconfigured to simulate the proposed scenario. By comparing the results of the two scenarios the impact of the proposed Wastewater Treatment Plant can be determined.

The hydrodynamic element of the model has been calibrated and validated against recorded water level, current speeds and direction data at the site of interest. The model is reasonably well matched against the recorded data.

Our model results show that the 95%ile concentrations of both E. Coli and Intestinal Enterococci are significantly reduced in the inner harbour area of Castletownbere with the proposed scheme in place. Our model results also show that the 50%ile concentrations of Dissolved Inorganic Nitrogen, Molybdate Reactive Phosphorus, Total Ammonia and Unionised Ammonia are reduced across large areas of the harbour area.

Our results also indicate that the 95%ile concentrations of both E. Coli and Intestinal Enterococci as well as the 50%ile concentrations of the other modelled nutrients are increased in the vicinity of the proposed outfall location. The increases however do not lead to the Environmental Quality Standards at any of the designated Environmental Protection Agency Surface Water Regulation monitoring points outside the immediate mixing zone to be exceeded.

The proposed scheme therefore does not cause any of the Environmental Quality Standard thresholds in Castletownbere harbour to be exceeded and the discharges from the proposed Wastewater Treatment Plant for Castletownbere are in full compliance with the relevant European Union water regulations.

A number of sensitivity model runs have been undertaken which have examined changes to the coliform decay and wind forcing. Neither of these sensitivity runs result in the any of the Environmental Quality Standards thresholds from any of the European Union water regulation directives being exceeded.

Abbreviation Glossary

IW	Irish Water
UTAS	Untreated Agglomerations
WQ	Water Quality
WwTP	Wastewater Treatment Plant
EQS	Environmental Quality Standard
EU	European Union
PE	Population Equivalent
PS	Pump Station
FC	Faecal Coliforms
IE	Intestinal Enterococci
EC	Escherichia coli
SS	Suspended Solids
DIN	Dissolved Inorganic Nitrogen
MRP	Molybdate Reactive Phosphorus
TA	Total Ammonia
UiA	Unionised Ammonia
SFPA	Sea-Fisheries Protection Authority
WFD	Water Framework Directive
SAC	Special Area of Conservation
NHAs	National Heritage Areas
EPA	Environmental Protection Agency
DCSM	Dutch Continental Shelf Model
DWF	Dry Weather Flow
AER	Annual Environmental Report
SA	Sensitivity Analysis

1 Introduction

1.1 Background

Irish Water (IW) has identified 44 agglomerations in Ireland where untreated sewerage is discharged directly to receiving waters, either from sewer network outfalls or via septic tanks in which the level of treatment provided is negligible. In response, Irish Water are presently implementing upgrades to these agglomerations through the Untreated Agglomerations (UTAS) programme.

Arup has been commissioned by Irish Water to advance three separate UTAS projects in Co. Cork:

- Castletownbere in Bantry Bay;
- Whitegate/Aghada in Cork Harbour;
- Castletownshend in West Cork;

A Water Quality (WQ) impact assessment is required for each of these three UTAS projects in order to determine the compliance of the effluent discharges from the proposed Wastewater Treatment Plant (WwTP) with the Environmental Quality Standards (EQS) in the receiving waters as defined in the relevant European Union (EU) water quality regulations.

This report presents the WQ assessment for Castletownbere. This work is being undertaken in accordance with Irish Water's Technical Standards for Marine Modelling[1]. Following the guidance outlined in these standards, the work has been undertaken in two distinct phases:

Phase 1:

- Data gathering, data gap analysis and quality assurance;
- Screening assessment to determine which WQ parameters are relevant to each site by considering the relevant water quality legislation for that site;
- Near-field[2] dispersion modelling to calculate concentrations of the relevant WQ parameters in the immediate vicinity of the outfall where the buoyancy and momentum of the effluent discharge dominate the mixing process;
- Assess which WQ parameters are lower than the relevant EQS in the near field and hence are complaint with the relevant legislation;
- Make recommendations for the scope of Phase 2.

Phase 2:

- Where required, procure and manage a marine hydrographic survey which has been scoped as part of Phase 1;

[1] Technical Standards, Marine Modelling (Draft), Irish Water, July 2018.
[2] The near field relates to the initial mixing zone area immediately adjacent to the outfall where the buoyancy and momentum of the outfall discharge is dominant

- Where required, undertake far-field[3] dispersion modelling of the relevant WQ parameters at each site;
- Determine the compliance of the modelled WQ parameter with the EQS at monitoring points relevant to the site;
- For sites where the EQS's are exceeded, advise on what level of additional treatment and/or dilution is required in order to meet with the requirements.

This report details the findings of Phase Two of the study for the Castletownbere agglomeration. The findings of Phase One are reported on separately.

1.2 Guidance documents

The following guidance documents have been assessed as part of the study:

- Irish Water's Technical Standards for Marine Modelling (Draft) dated from June 2018;
- Cork UTAS Design Reports and Technical Notes for Castletownbere (AECOM/Jennings O'Donovan)
- Scottish Environment Protection Agency, Modelling Coastal and Transitional Discharges, Supporting Guidance (WAT-SG-11);
- Relevant Regulatory Framework documents:
  - Urban Waste Water Treatment Regulations 2001;
  - Surface Water Regulations 2009;
  - The Bathing Water Directive 2006/7/EC;
  - The Shellfish Directive 2006/113/EC.

1.3 Castletownbere UTAS project outline

Castletownbere is located in Co. Cork along the northern shoreline of Bantry Bay as indicted in Figure 1. At present, wastewater generated in the town discharges into Berehaven Harbour, or to adjacent percolation areas, with no treatment. The objective of the UTAS project is to provide primary treatment for the town and end the discharge of untreated waste into Bearhaven Harbour.

An overview of the existing wastewater infrastructure in Castletownbere is provided in Section 1.3.1. The proposed scheme is detailed in Section 1.3.2.

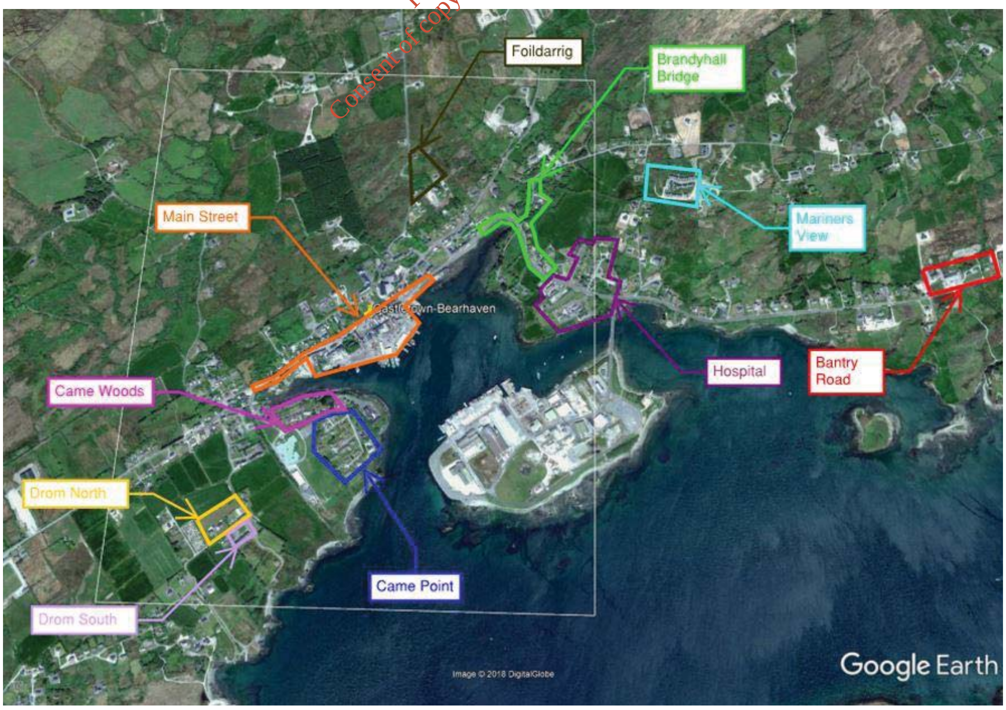
[3] The far field relates to the mixing zone outside the near field where the outfall discharge loses all its initial buoyancy and momentum and becomes passive

Figure 1: Castletownbere location

1.3.1 Existing wastewater infrastructure

The Castletownbere agglomeration is currently divided into ten drainage areas, or sub-catchments, as shown in Figure 2. A detailed description of these drainage areas can be found in the separate Castletownbere Jennings O'Donovan/AECOM Design Report.

Figure 2: Existing Drainage Areas (Arup/ByrneLooby Design Review Report 2019)



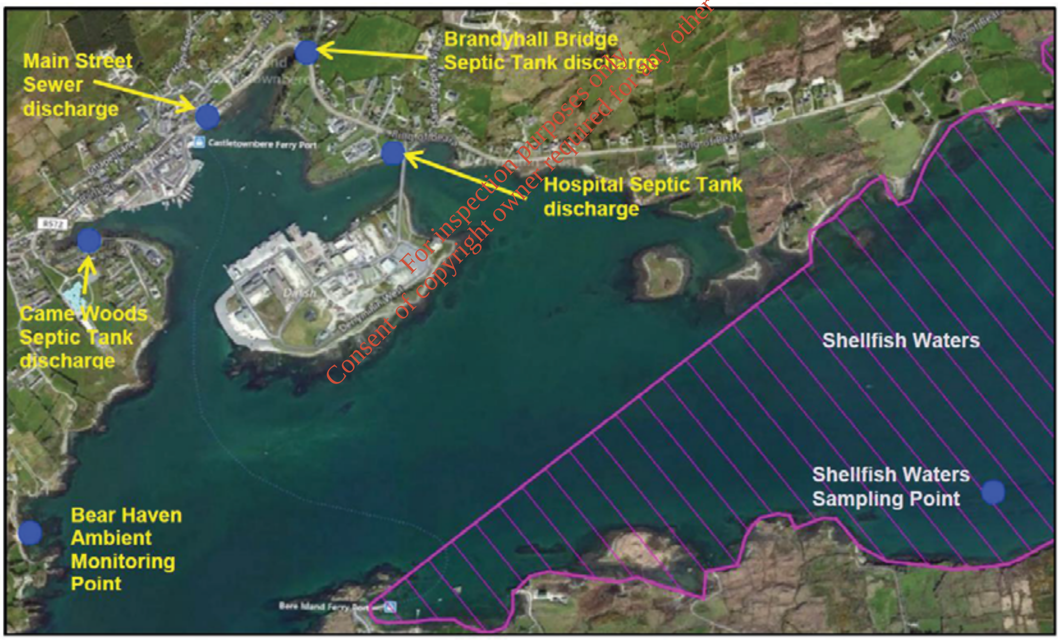
Wastewater from each of the ten drainage areas is presently conveyed to six septic tanks:

- Brandyhall Bridge Septic Tank
- Hospital Septic Tank
- Came Woods Septic Tank
- Came Point Septic Tank
- Drom North Septic Tank
- Foildarring Septic Tank

Each of the six septic tanks have an associated sewer outfall which discharges directly into Bearhaven Harbour as indicated in Figure 3. Following consultation with Irish Water it has been assumed in this study that these septic tanks do not provide any treatment in the existing scenario.

The flow rates used in the study for these outfalls are presented in Section 6.3.

Figure 3: Existing discharge locations (Jennings O'Donovan/AECOM Design Report 2015)



The existing infrastructure includes 3 package treatment plants two of which are in private ownership and one of which is public. They are located at the Drom South, Mariners View and Bantry Road drainage areas. The the public package treatment plant at Drom South is to be decommissioned as part of the proposed scheme.

The current population figures for Castletownbere have been taken from the Jennings O'Donovan/AECOM Design Report and are presented in Table 1.

Table 1: Current Population Estimate

Population Type	Winter PE	Summer PE
Domestic	1080	1581
Non-domestic	372	380
PE Total	**1452**	**1961**

The populations are based on 2011 census data as published by the Central Statistics Office. The population figures given in the census are considered to reflect winter occupancy. Summer population figures have been calculated by multiplying the number of dwellings in the agglomeration by an occupancy factor of 2.7 people per dwelling, thereby assuming a 100% occupancy rate.

It is noted that the proposed scheme is being designed with a 30-year population loading. Any uplift in the population that may have occurred between the 2011 and the present day is therefore accommodated in the proposed scheme.

1.3.2 Outline of Proposed scheme

The objective of the Castletownbere UTAS project is to provide a WwTP capable of primary treatment in compliance with the Urban Waste Water Treatment Directive. The proposed WwTP will comply with European and Irish legislation and meet the needs of the agglomeration up to 2040.

Figure 4 presents the site boundary for the proposed WwTP and outfall in the context of its surrounds. The figure presents an extract of a full drawing shown in Appendix B. The scheme will consist of:

- A new WwTP;
- 4 No. pumping stations;
- Circa 1,700m of proposed rising main;
- 600m of proposed gravity sewers and associated and ancillary infrastructure.

A detailed description of the key components provided by the scheme is given in the following section of this report.

Figure 4: The site boundary for the proposed WwTP and outfall

1.3.3 Components of the proposed scheme

Four new pumping stations (PS) are required as part of the scheme in order to convey wastewater to the WwTP. Each pumping station will incorporate stormwater storage tanks in order to minimise stormwater overflows to the estuary when the capacity of the pumps is exceeded. These pumping stations are detailed in Table 2.

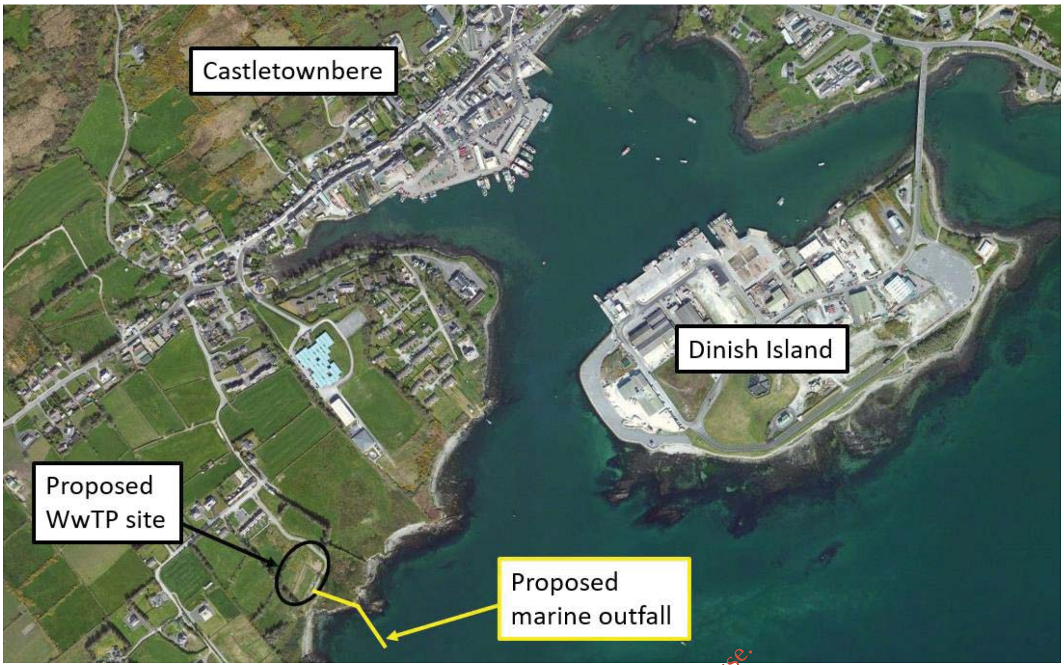
Table 2: Proposed pumping stations

Pumping Station	Details
Hospital Pumping Station	• 32m long diversion of the existing 150mm diameter gravity sewer; • Wastewater Pumping Station capable of passing forward Formula A (10 year) flow (6.7 l/s), incorporating 51.7m³ of stormwater storage and utilising the existing outfall as an overflow facility; • 260m long, 12mm OD rising main to convey pumped flows to a proposed discharge manhole on the R572; and • Decommissioning of the existing septic tank.
Brandyhall Bridge Pumping Station	• 10m long diversion of the existing 225mm diameter gravity sewer;

Pumping Station	**Details**
	• Wastewater Pumping Station capable of passing forward Formula A (10 year) flow (10.3 l/s), incorporating 50.5m³ of stormwater storage and utilising the existing outfall as an overflow facility; • 205m long, 160mm diameter rising main to convey pumped flows to a proposed discharge manhole on the R572; and • Decommissioning of the existing septic tank.
Came Woods	• 24m long diversion of the existing 150mm diameter gravity sewer; • Wastewater Pumping Station capable of passing forward Formula A (10 year) flow (4.8 l/s), incorporating 57.2m³ of stormwater storage and utilising the existing outfall as an overflow facility; • 210m long, 90mm diameter rising main to convey pumped flows to a proposed discharge manhole on the R572; and • Decommissioning of the existing septic tank.
Quays Pumping Station	• 385m of new 810mm diameter gravity sewer to convey flows to the Quays Pumping Station. • Wastewater Pumping Station capable of passing forward Formula A (10 year) flow (34.5 l/s), incorporating 135m³ of stormwater storage and utilising the existing outfall as an overflow facility; • 1,050m long, 250mm diameter rising main to convey pumped flows to a proposed discharge manhole on Tallon Heights; • 120m of gravity sewer from the discharge point for the rising main to the Wastewater Treatment Plant;

A new primary treatment WwTP with associated ancillary development works is proposed as part of the scheme. Construction of the plant will involve the decommissioning and removal of the existing package WwTP at that location. A new 85m gravity effluent pipe will connect the plant to the launch point of the new marine outfall. Figure 5 presents the location of the proposed WwTP and marine outfall in relation to Castletownbere. For more detail on the proposed network, please see the accompanying planning drawings.

Figure 5: Location of the proposed WwTP and outfall near Castletownbere



1.3.4 Justification for the scheme

At present, wastewater generated in Castletownbere is discharged into Berehaven Harbour or to adjacent percolation areas with little to no treatment. This practice of discharging untreated wastewater in not compliant with the obligations of the Urban Wastewater Treatment Directive (UWWTD) 91/271/EEC.

The proposed development of a WWTP will meet with the requirements of the UWWTD and will improve water quality in Bere Haven and bring benefits in terms of health, environmental integrity. It would also facilitate the economic and social development of Castletownbere.

The benefits of the proposed scheme can be summarised by:

- Secure the objectives of the Water Framework Directive by improving the water quality in Bere Haven Harbour;
- Support the development of additional dwelling units in Castletownbere;
- Support the development objectives set out by The Cork County Development Plan (CCDP);
- Support the wide objective for Castletownbere set out in the West Cork Municipal District Local Area Plan 2017;
- Support the development of tourism in Castletownbere.

The proposed scheme is therefore fully justified on this basis.

1.4 Phase 1 of the study

1.4.1 Screening Assessment

An initial screening assessment of WQ parameters was completed as part of Phase 1 of the study which identified the WQ legalisation enacted in Castletownbere and Bantry Bay. From this the WQ parameters that need to be assessed in order to demonstrate compliance with the relevant legislation was determined.

The relevant regulatory framework directives are as follows:

- Urban Wastewater Treatment Regulations 2001;
- Surface Water Regulations 2009;
- The Bathing Water Regulations 2008;
- The Shellfish Directive 2006/113/EC;

The WQ parameters to be considered, along with the corresponding EQS threshold levels are presented in Table 3. We note that although no salmonid waters are present in the vicinity of the site, ammonia and unionised ammonia were included as part of the assessment following consultation with Irish Water.

Table 3: EQS threshold levels for relevant WQ parameters

Parameter	WQ Directive	Target Level
Biochemical Oxygen Demand (mg/l O_2)	Surface Water Regulations 2009	4.0
Dissolved Oxygen	Surface Water Regulations 2009	95%ile > 80% saturation (35psu)
Suspended Solids (mg/l)	Shellfish Directive 2006	2.6
Dissolved Inorganic Nitrogen (mg/l)	Surface Water Regulations 2009	0.25
Molybdate Reactive Phosphorous (mg/l)	Surface Water Regulations 2009	0.04
Intestinal Entercocci (cfu/100ml)	Bathing Water Directive 2008	200
Escherichia Coli (cfu/100ml)	Bathing Water Directive 2008	500
Total Ammonia (mg/l)	Salmonid Waters Regulations 1988	1
Unionised Ammonia (mg/l)	Salmonid Waters Regulations 1988	0.02

1.4.2 Bathing Water Regulations

The bathing water directive governs the monitoring of water quality at 135 identified bathing waters across Ireland. The directive sets WQ standards in terms of ‘pollution’ by assessing the presence of Escherichia Coli (EC) and Intestinal Enterococci (IE) bacteria which present a risk to bather’s health. Bathing waters are classified into four categories, as outlined in Table 4, in accordance with the water quality standards specified in the 2008 regulations, with a classification of ‘sufficient’ to be achieved by 2015 for all bathing waters.

Table 4: Classification of bathing waters (Schedule 4 of S.I. No. 79/2008)

Water Type	Parameter	Excellent	Good	Sufficient
Coastal/ Transitional	Intestinal Enterococci	100 (*)	200 (*)	185 (**)
	E. Coli	250 (*)	500 (*)	500 (**)
Inland Waters	Intestinal Enterococci	200 (*)	400 (*)	330 (*)
	E. Coli	500 (*)	1000 (*)	900 (*)

(*) based on a 95-percentile evaluation (**) based on a 90-percentile evaluation

1.4.3 Surface Water Regulations

The surface water regulations set out a wide range of environmental standards for Irish surface waters, including guidelines on nutrients such as Dissolved Inorganic Nitrogen (DIN) and Molybdate Reactive Phosphorus (MRP). The limits for nutrient levels as set out in the regulations are given in Table 5

Table 5: Nutrient Conditions (Table 9, Part A, S.I. No.272/2009)

Nutrient conditions	River water body	Lake	Transitional water body (winter and summer)		Coastal water body (winter and summer)	
Total Ammonia (mg N/l)	High status ≤ 0.040 (mean) and ≤ 0.090 (95%ile) Good status ≤ 0.065 (mean) and ≤ 0.140 (95%ile)					
Dissolved Inorganic Nitrogen (mg N/l)					High status (0 psu (1)) ≤ 1.0 High status (34.5 psu(1)) ≤ 0.17	Good status (0 psu (1)) ≤ 2.6 Good status (34.5 psu(1)) ≤ 0.25
Molybdate Reactive Phosphorus (MRP) (mg P/l)	High status ≤ 0.025 (mean) and ≤ 0.045 (95%ile) Good status ≤ 0.035 (mean) and ≤ 0.075 (95%ile)		High Status (0-17 psu (1)) ≤ 0.030 (median) (>17-35psu(1)) ≤ 0.030-0.025 (median)	Good Status (0-17 psu (1)) ≤ 0.060 (median) (>17-35psu(1)) ≤ 0.060-0.040 (median)		
Total Phosphorus (mg P/l)		High status ≤ 0.010 (mean) Good status ≤ 0.025 (mean)				

(1) Linear interpolation to be used to establish the limit value for water bodies between these salinity levels based on the median salinity of the water body being assessed."

1.4.4 Shellfish Water Directive

The aim of the Shellfish Waters Directive is to protect or improve shellfish waters in order to support shellfish life and growth.

The Directive requires Member States to designate waters that need protection and sets physical, chemical and microbiological requirements that designated shellfish waters must comply with or endeavour to improve.

In regard to Suspended Solids (SS), the Shellfish Directive states that '*A discharge affecting shellfish water must not cause the suspended solids content of the waters to exceed by more than 30 per cent the suspended solids content of waters not so affected.*'

1.4.5 Near field study

A near field dispersion modelling study was undertaken for each of the identified WQ parameters as part of the screening assessment to calculate their concentrations in the near field after initial dilution. The findings are presented in the Phase 1 Dispersion Modelling Report and are summarised in this section of the report.

Where the results of the near filed modelling indicated that the concentration of a particular WQ parameter was below the EQS threshold in the near field it was concluded that this parameter was in compliance with the relevant EU legislation and no further assessment was therefore required.

The Phase 1 report for Castletownbere concluded that the concentration of two WQ parameters exceeded the EQS thresholds in the near field and were therefore required to be modelled in the far field. These parameters were:

- Intestinal Enterococci;
- Escherichia Coli/Faecal Coliforms.

We note that E. Coli is accepted as a surrogate for Faecal Coliforms in terms of behaviour in the marine environment and source concentrations. It is therefore only necessary to consider one of these parameters in order to determine the concentration of both. As E. Coli is the WQ parameter in the Bathing Water Regulations 2008, it will be adopted as part of this study.

Following consultation with Irish Water four additional WQ parameters are also assessed as part of the far field modelling assessment:

- DIN;
- MRP;
- Total Ammonia (TA);
- Unionised Ammonia (UiA)

Each of these six parameters have been assessed in detail in the far field using a high-resolution numerical model of Bantry Bay as described later in this report.

The water quality parameters assessed in each phase of the study are summarised in Table 6.

Table 6: Water Quality modelling parameters

Parameter	Near-Field	Far-Field
Biochemical Oxygen Demand	√	X
Dissolved Oxygen	√	X
SS	√	X
DIN	√	√
MRP	√	√
EC	√	√
IE	√	√
TA	X	√
UiA	X	√

For further details on the findings of the Phase 1 near-field study please refer to Appendix C.

1.5 Far field modelling

Far field dispersion modelling has been carried out to simulate the transport and decay of all the relevant WQ parameters presented in Section 1.4.5. The aim of the far field study is to assess compliance of these parameters with EQs threshold levels and adherence with the relevant EU water quality directives.

Two separate scenarios have been considered as part of the study:

- The Existing (baseline) Scenario: This represents the current situation with a number of outfalls discharging untreated sewage into Berehaven at Castletownbere.
- The Proposed Scenario: This represents the situation with the proposed WwTP in place, namely the untreated sewage outfalls being replaced by one new outfall discharging primary treated effluent into Berehaven.

By comparing the results of the baseline model with the proposed scenario model the impact of the WwTP can be determined.

1.6 Layout of the report

Table 7 below presents an overview of the report.

Table 7: Report chapters and descriptions

Chapter	Title	Description
1	Introduction	Details the project background and provides an overview of the study.
2	Bantry Bay characteristics	Identifies the key receptors, the status of the waterbodies and fluvial inflows into Bantry Bay.
3	Data acquisition	Provides a summary on the data used for the study: marine survey data; hindcast data and publicly available data from various sources.
4	Hydrodynamic model	Details the development and set up of the hydrodynamic model.
5	Hydrodynamic model calibration	Presents the calibration of the hydrodynamic model - Spring tide calibration, the Neap tide validation, drogue data validation as well as astronomical tide validation.
6	Water Quality Modelling	Presents the findings of the Water Quality modelling. It details the dispersion coefficient, outfall loadings and a series of plots from both the existing and proposed scenarios. The difference between the existing and proposed scenarios are presented using delta plots.
7	Model sensitivity analysis	Presents the sensitivity models runs undertaken as part of the study.
8	Discussion and conclusion	Provides an overall discussion of the results and presents the key conclusions of the study.

2 Bantry Bay Characteristics

2.1 Overview

Bantry Bay is a macro-tidal coastal bay that covers a large area as presented in Figure 6. The bay experiences a twice daily tidal variation in water level of circa 4m for Spring tides and circa 2m for neap tides. This vertical motion of the water is accompanied by a large horizontal oscillatory motion leading to a dynamic movement of the tide in the harbour with considerable temporal and spatial variation in velocities throughout the harbour.

Figure 6: Bantry Bay

2.2 Identification of key receptors

Table 8 presents an overview of the key receptors in the study area. Relevant key receptors are shown, along with any discharges/outfalls included in the model, in Appendix A

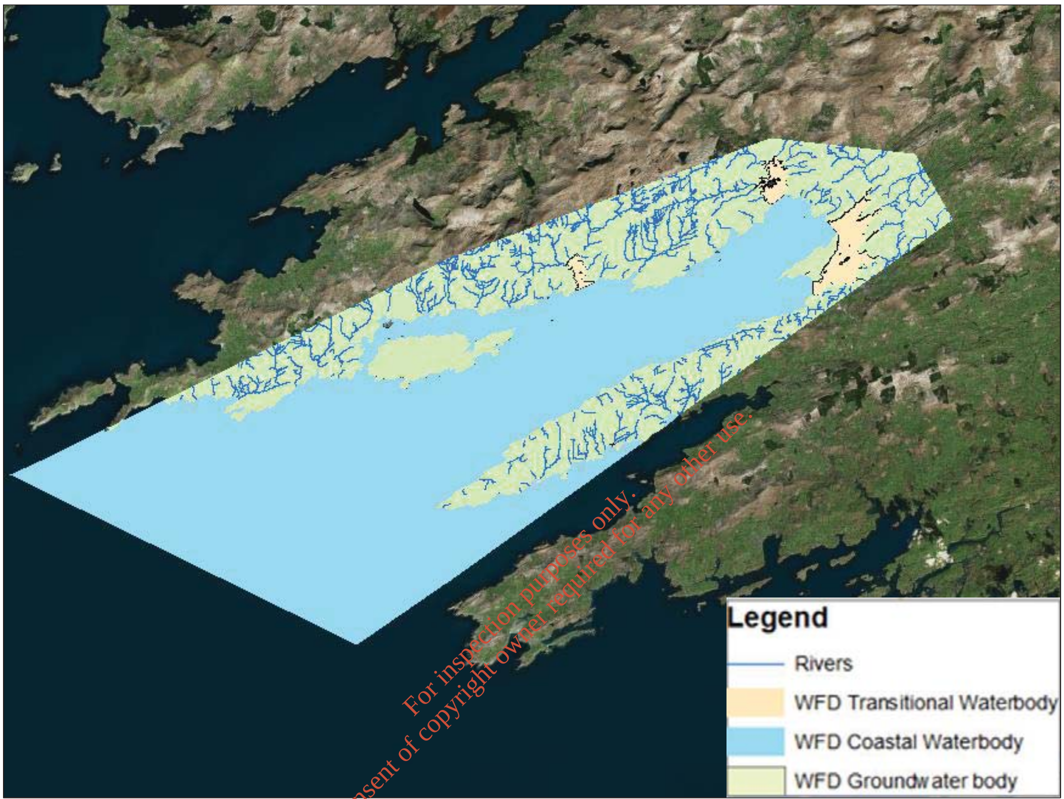
Table 8: Key receptors in study area

Key receptors in study area	Regulatory Framework Document/ Body
Special Area of Conservation	Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (Habitats Directive) European Communities (Natural Habitats) Regulations, 1997
National Heritage Area	National Parks and Wildlife Service
Shellfish Areas	The Shellfish Directive 2006/113/EC
WFD Transitional Waterbody	Water Framework Directive
WFD Coastal Waterbody	Water Framework Directive

2.2.1 Water Framework Directive waterbodies

Waterbodies within the study area have been identified by the Water Framework Directive (WFD) as coastal and transitional, with groundwater bodies in the surrounding land. These are shown as the blue, orange and green areas in Figure 7, respectively. Rivers in the study area are indicated by the dark blue lines.

Figure 7: WFD Waterbodies (Data Courtesy: EPA).



2.2.2 Shellfish Areas

Castletownbere is designated as a classified shellfish production area (Figure 8) under the Communities (Quality of Shellfish Waters) Regulations, 2006.

Figure 8: Shellfish Areas (Data Courtesy: EPA).

Shellfish production areas are classified according to the risk of contamination of shellfish with bacterial and viral pathogens (AER, 2016). The criteria for this classification is set out under Regulations (EC) No. 854/2004, regulation (EC) 853/2004 and Regulation (EC) 2073/2005. Details of the classified production areas in Castletownbere as identified by the Sea-Fisheries Protection Authority (SFPA) are presented in Table 9.

Table 9: List of Classified Bivalve Mollusc in Castletownbere (Data Courtesy: SFPA).

Production Area	Species	Class
Castletownbere	Mussels	A
Castletownbere	Oysters	B*
Castletownbere	Urchins	B*

Shellfish monitoring data for Castletownbere has been collated and compared in the shellfish production reduction programme report. The monitoring programmes assessed were:

- Marine Institute Shellfish Monitoring Programme
- Environmental Protection Agency (EPA) Marine Monitoring Programme
- WFD Monitoring Programme
- Shellfish Flesh Monitoring Programme

The results from this assessment determined that:

- *'The results of the WFD monitoring do not indicate any water quality issues within the shellfish area or in the waters discharging in the vicinity of this shellfish area'*
- *The dedicated shellfish samples available for this shellfish area were found to be non-compliant with the shellfish guideline values for FC in biota as outlined in Annex 1 of the shellfish waters directive (2006/113/EC) and Schedule 4 of the quality of shellfish waters regulations (S.I. No. 268 of 2006).*
- *Shellfish flesh classification indicates faecal contamination in the shellfish area*

2.2.3 Special Areas of Conservation

Castletownbere lies close to a designated Special Area of Conservation (SAC), site code 000102, as shown in Figure 9

Figure 9: Special Area of Conservation in Bantry Bay (Data Courtesy: EPA).

2.2.4 National Heritage Areas

National Heritage Areas (NHAs) have been determined by the National Parks and Wildlife Service as areas considered important for the habitats present or areas which contain species whose habitats require protection. Proposed NHAs have been identified in the study area, these are shown by the purple hatched areas in Figure 10. Proposed NHAs were published on a non-statutory basis in 1995, and whilst at present have not been statutorily designated as NHAs they are recognised as sites of significance for wildlife.

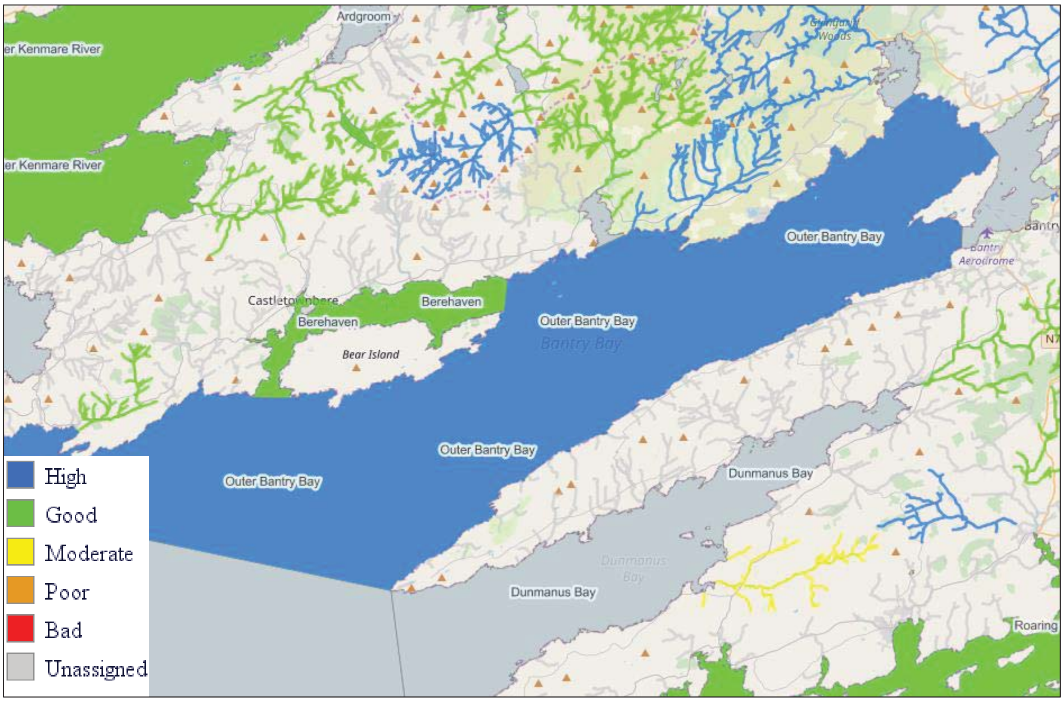
Figure 10: Proposed National Heritage Areas (Data Courtesy: EPA).

2.3 WFD waterbody status

2.3.1 Current WFD Status

The EU WFD has established a framework for the protection, improvement and management of surface waters (which include transitional and coastal waters) and ground waters. The WFD status of the waterbodies in Castletownbere is presented in Figure 11.

Figure 11: Waterbody status in study area (Data Courtesy: www.catchments.ie).



The status results are recorded in accordance with European Communities (Water Policy) Regulations 2003 (SI No. 722/2003). The regulation objectives include attaining ‘good’ or ‘high’ status in all waterbodies. Figure 11 indicates the coastal water body in the vicinity of Castletownbere having a ‘good’ water quality status, while the status in the outer Bantry Bay is ‘high’.

2.3.2 Current risk of failure to meet WFD Objectives

In order to realise the objectives of the WFD, ‘good’ quality status must be achieved in the waterbody which receives discharges from the WwTP. EPA maps have been assessed to determine the current risk of failing to meet the objectives (see Figure 12). It can be seen that the coastal waterbody in Bantry Bay is defined as ‘not at risk’ of failing to meet the directive’s objectives. The EPA therefore states that at present, these waterbodies require no additional investigative assessment or measurements to be applied, other than those measures already in place.

It can therefore be concluded that this waterbody, at present, is not close to failing the WFD objective.

Figure 12: WFD Waterbodies risk (Data Courtesy: EPA).

2.4 Existing wastewater outfalls

A number of urban agglomerations are located in the immediate vicinity of Castletownbere, each of which discharge wastewater into the bay. While a number of these agglomerations discharge into a septic tank before discharging to the bay, following consultation with Irish Water it has been assumed in this study that each of these discharges are untreated.

A list of the primary WwTP outfalls discharging into Bantry Bay is provided in Table 10. Figure 13 presents a plot of the individual outfalls that discharge from Castletownbere. We note that each of these individual outfalls have been considered as part of this study and are further discussed in Section 6.3.

Table 10: Primary outfalls for urban agglomerations in Bantry Bay

Urban Area	Location of the agglomeration's main outfall (ING)		Population Equivalent	Treatment Type	EPA licence number
	X	Y			
Glengarriff	93265	55916	1060	None	D0471-01
Bantry	96802	48205	4984	Tertiary	D0168-01
Castletownbere	68028	46138	1700	None	D0297-01

Figure 13: Plot of the primary outfalls for the urban agglomerations discharging from the Castletownbere agglomeration

2.5 Fluvial inflows

A number of watercourses discharge into Bantry Bay. The alignment of the watercourses as included in the EPA database are shown in Figure 15. The watercourses relevant to the hydrodynamics of the area of interest were included in the far-field modelling as sources of pollutant loadings. This is detailed later in Section 6.3.2 of this report.

Figure 14: Watercourses discharging into Bantry Bay

2.6 Geometry of Bantry Bay

The bathymetry and geometry of the Bantry Bay varies considerably as indicated in Figure 15. The Bay is circa 10km wide at its entrance to the bay while the distance between Bere Island and the mainland is only circa 350m. The deepest part of the bay is circa -100mOD at the western open sea boundary while some areas are intertidal and subject to flooding and drying with the movement of the tide.

Figure 15: Bantry Bay Bathymetry (metres Ordnance Datum Malin)

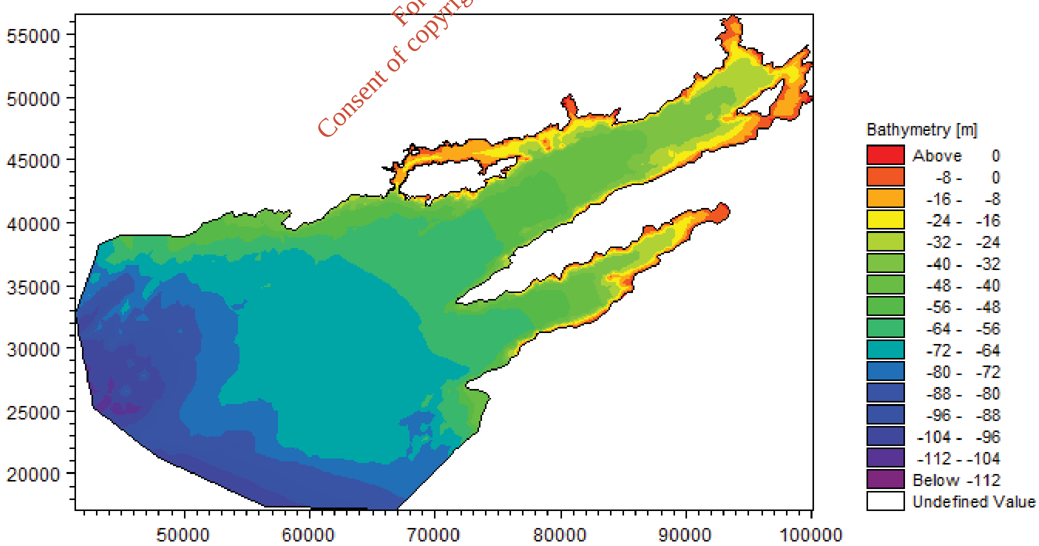
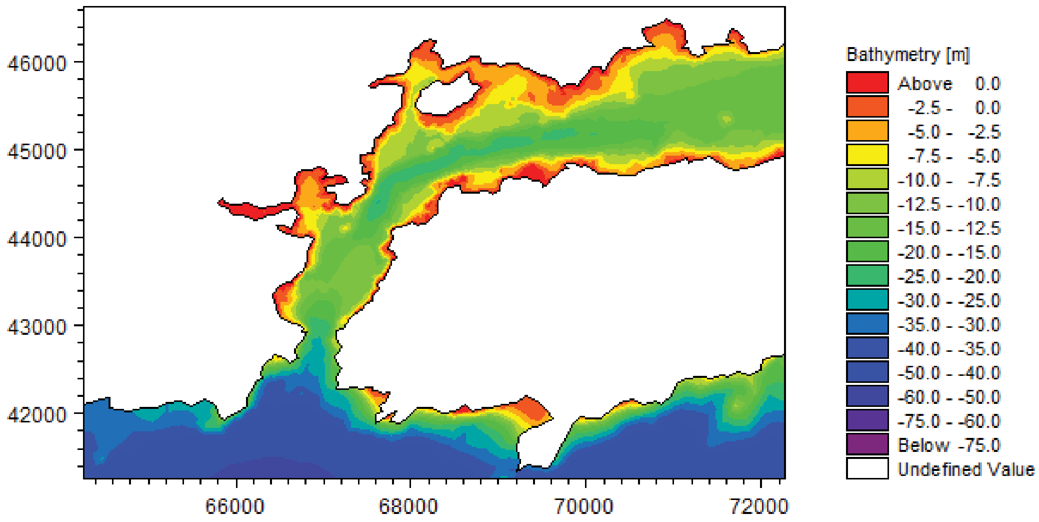


Figure 16 presents a close-up view of the bathymetry in the vicinity of the proposed outfall location. It can be seen from the figure that there is a notable difference in bed elevations between area between Bere Island and the mainland and the other area of the Bay.

Figure 16: Bathymetry in immediate vicinity of outfall



3 Data Acquisition

3.1 Introduction

A marine survey was commissioned as part of the study in order to provide data with which to calibrate and validate the Castletownbere model. A bathymetric survey of the estuary in the vicinity of the proposed outfall was also commissioned in order to provide accurate and up to date bed levels for the key area of interest. The survey was undertaken in the spring of 2018 by Irish Hydrodata Ltd and is detailed in this chapter.

Hindcast water level data for points in the Irish Sea was also purchased from Deltares as part of the study in order to provide an open sea boundary condition for the calibration runs of the model.

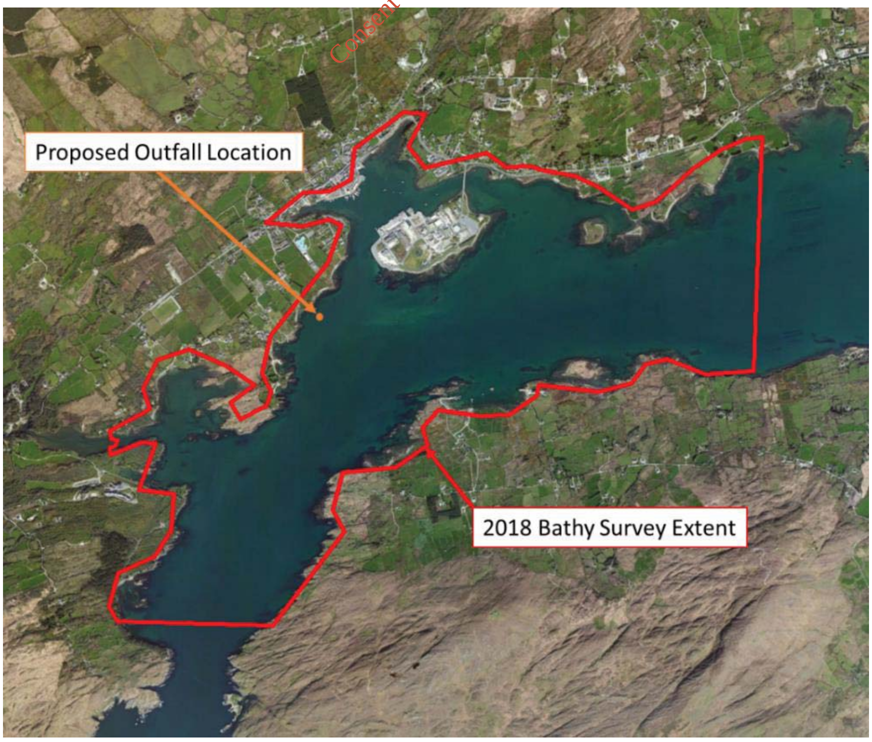
Arup have also utilized various publicly available datasets for this study including EPA datasets and monitoring data, INFOMAR bathymetric and coastline data, Cork Airport wind data, and Marine Institute tidal gauge data.

3.2 Marine survey 2018

3.2.1 Bathymetry Survey

A high-resolution bathymetric survey of the key area of interest in Castletownbere was collected by Irish Hydrodata in April 2018 in order to provide accurate and up to date data on bed elevations. Figure 17 presents the extent of the survey area.

Figure 17: 2018 bathy survey extent



Bathymetric data for the rest of the harbour was sourced from publicly available INFOMAR datasets. Each of the individual bathymetric datasets were then combined to form a single composite bathymetric dataset for the entire model domain. Figure 15 presents this composite bathymetry file.

3.2.2 Hydrographic data

As part of the 2018 marine survey, hydrographic data was collected from a number of locations. Water level, current speeds and current direction measurements were taken at the location of the proposed outfall (Figure 18). Data was collected at 30-minute intervals for two separate 12-hour periods:

- a neap tide – 24th May 2018
- a spring tide – 31st May 2018

Data was collected at three points in the water column to allow the variation in current in the vertical direction be assessed. Data was collected (1) near the surface, (2) mid depth, and (3) near the bed. This data is presented in Appendix D.

A tide gauge was also deployed at Beal Lough Pier (see Figure 18) for circa 8 days at five-minute intervals. The Beal Lough Pier water level data was used to calibrate the model (Appendix D).

Figure 18: Survey Locations

3.3 Drogue survey

A drogue tracking survey was undertaken for both a spring and neap tide. Spring data was collected on the 31st May 2018, while the neap data was collected on 24th May 2018.

A number of drogues were released at the outfall location (shown Figure 18) at various stages of the tide and subsequently tracked in order to track their motion as they were advected by the tidal hydrodynamics.

The drogue data was used to validate the hydrodynamic model. The surveyed tracks for the spring and neap tides drogues are presented in Appendix D.

Dye tracer studies were not undertaken as part of the marine survey due to environmental concerns relating to the release of a toxic substance into the environment.

3.4 Salinity data

The salinity data collected as part of the study indicates a near consistent salinity value across a spring tidal cycle (values vary from 33.9PSU to 34.3PSU) and neap tidal cycle (values vary from 33.8PSU to 34.0PSU).

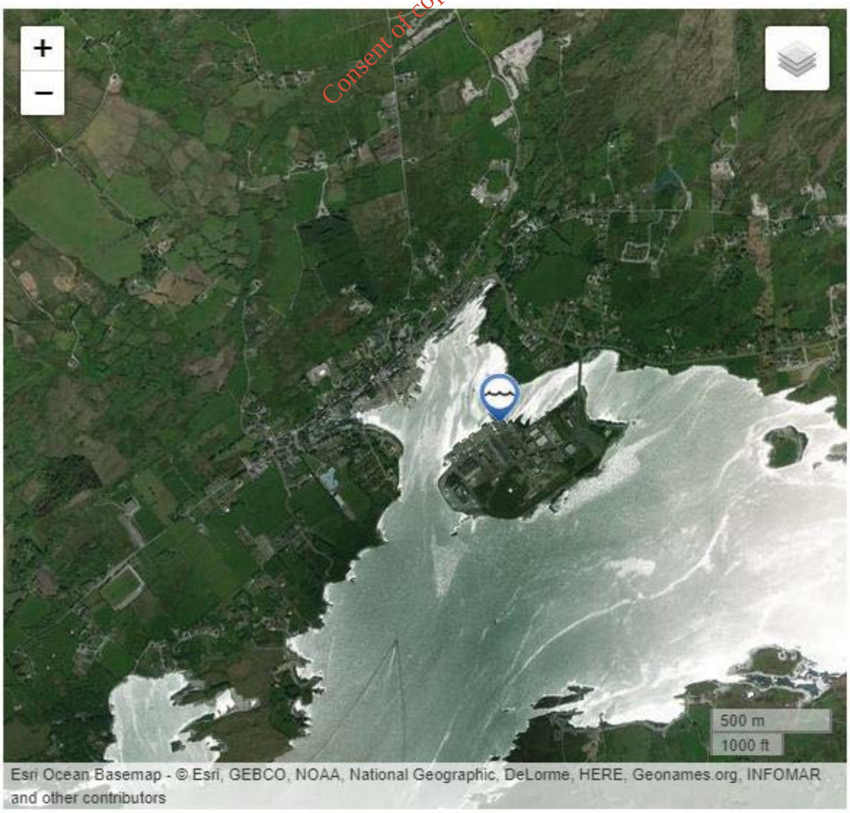
3.5 Water levels from Castletownbere Port

The Marine Institute maintain a water level gauge in Castletownbere Port (Figure 19). Data from the gauge is available on the Marine Institute website (Table 11). This data was collected for May 2018 at five-minute intervals and used as part of the model calibration and validation.

Table 11: Castletownbere Port Tide Gauge Details

Co-ordinates	Station ID	WL above LAT (m)	WL to OD Malin Head (mOD)
Lat: 51.6496, Long: -9.9034	Castletownbere Port	1.731	-0.7

Figure 19: Location of gauge in Castletownbere



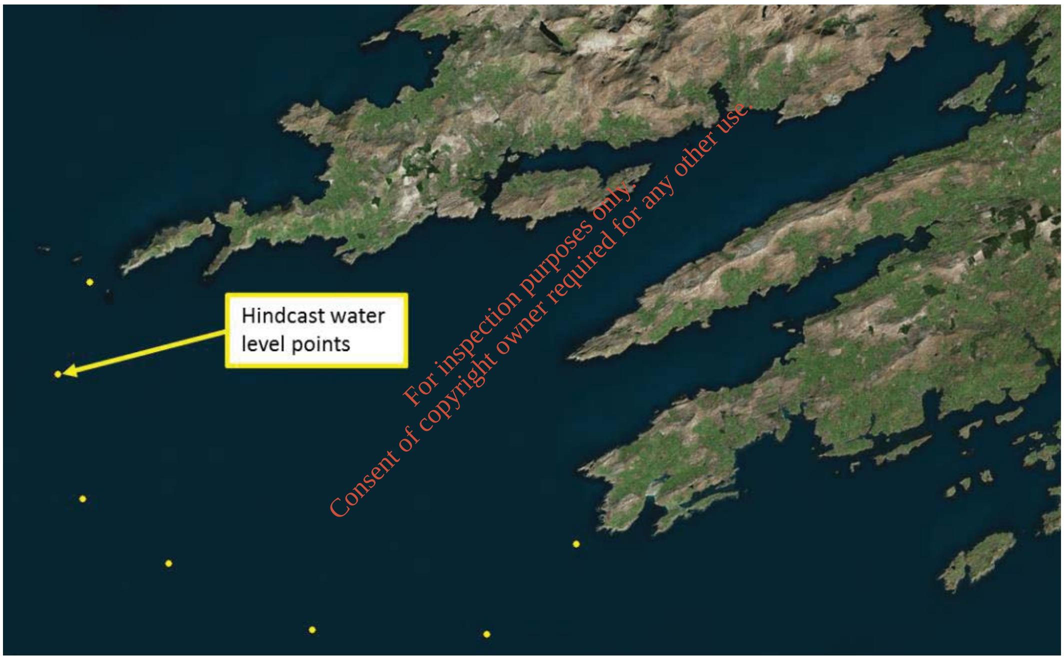
3.6 Hindcast data from Deltares

Hindcast water level data for the same period over which the marine survey was undertaken was procured from Deltares. This dataset provides a definition of the boundary conditions for the calibration model runs.

The data was extracted by Deltares from the 2D Dutch Continental Shelf Model (DCSM) model which is run by the Rijkswaterstaat of the Netherlands. The model is calibrated against tide gauges in various countries across Europe, including Ireland.

Water level at hourly intervals for seven points over a two-week period were purchased. The location of these points is presented in Figure 20. The open sea boundary of the WQ model was aligned to match the location of these points data points.

Figure 20: Hindcast water level data points



3.7 Summary of data acquired

A summary of the data acquired for the far-field modelled study is presented in Table 12.

Table 12: Hydrographic data acquired

Data	Location	Source	Used	How data is used
Bathymetric survey	Castletownbere	April 2018 survey	√	Used to inform bed elevations in area of interest
Bathymetric survey	Harbour	INFOMAR	√	Used to inform bed elevations in outer harbour
Water level	Outfall location, surface	May 2018 survey	X	Castletownbere gauge data used instead to calibrate model as it is of better quality
Water level	Beal Lough Pier	May 2018 survey	√	Used to calibrate model
Water level	Castletownbere Port	Marine Institute	√	Used to calibrate model
Water level	Outer Harbour	Deltares DCSM Model	√	Used to derive model boundary for calibration run
Water level	Outer Harbour	Astronomical tide (Mike 21 tool)	√	Used to derive model boundary for design runs
Current Speeds	Outfall location, surface	May 2018 survey		Use to inform calibration
Current Speeds	Outfall location, mid-depth	May 2018 survey	√	Used to calibrate model
Current Speeds	Outfall location, bed	May 2018 survey	√	Use to inform calibration
Current Directions	Outfall location, surface	May 2018 survey	√	Use to inform calibration
Current Directions	Outfall location, mid-depth	May 2018 survey	√	Used to calibrate model
Current Directions	Outfall location, bed	May 2018 survey	√	Use to inform calibration
Drogue tracking (Spring & Neap)	Released at outfall location	May 2018 survey	√	Used to validate model

4 Hydrodynamic Model

4.1 Introduction

A detailed high-resolution MIKE21 numerical model of Bantry Bay and the area of the Irish Sea adjacent to its entrance of the harbour has been developed as part of the study. The model consists of two separate parts which are dynamically coupled and run together as a single model:

- **Hydrodynamic model:** calculates the time varying water level, current velocities and water fluxes on an irregular grid of points throughout the model domain in response to the oscillation of the tide, river inflow and wind;
- **Water Quality (EcoLab) model:** calculates the spatially and time varying concentrations of the relevant water quality parameters on the same irregular grid of points as per the hydrodynamic model in response to the hydrodynamics, outfall loadings and dispersion characteristics of the harbour.

The model was first configured to represent the existing (baseline) scenario in the harbour i.e. with the existing discharges of untreated waste from Castletownbere. Once the baseline scenario model was established, a separate model was developed which simulated the proposed scenario i.e. the discharge of waste from the proposed outfall at Castletownbere. By comparing the results of the baseline scenario model against the proposed scenario model the impact of discharges of treated effluent from the proposed WwTP in Bantry Bay can be assessed.

This section described the development of the hydrodynamic model. Section 5 presents the hydrodynamic model calibration.

The development and results from the WQ model is described in Section 6.

4.2 Software and model approach

The model has been developed using the flexible mesh version of MIKE21 HD. MIKE21 is developed by the Danish Hydraulic Institute and is recognised internationally as being one of the leading software in the field of coastal and estuarine modelling.

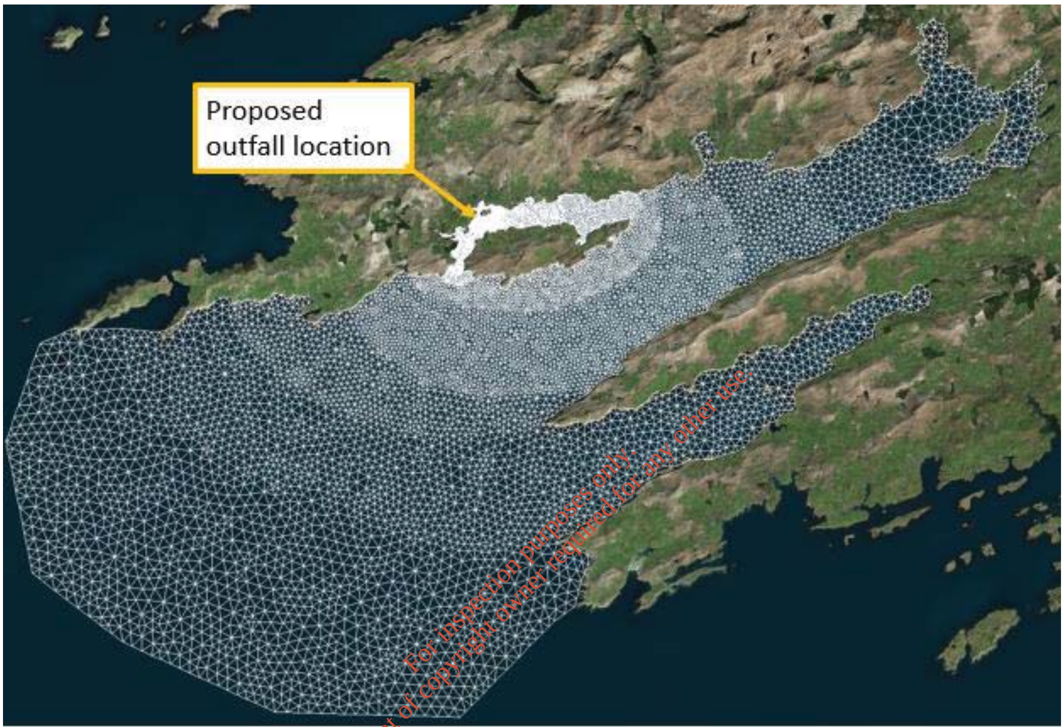
The model is a depth integrated two-dimensional model i.e. it assumes that the estuary can be represented as a single layer of fluid. Stratification of flow in the vertical dimension is therefore not included for as part of the model.

Given the relatively shallow depth of water in comparison to the width of the bay in the key area of interest, the body of water in the main area can be considered as a shallow lens of water. The primary mechanism by which the dispersion of contaminants occurs will therefore be the large horizontal oscillatory motion of the water which is driven by the vertical motion of the tide. This mechanism is simulated by our two-dimensional model and therefore captures the primary mechanisms by which pollutants are advected and dispersed. This modelling approach is therefore deemed valid and has been adopted for the study.

4.3 Model set up

The extent of the model domain is presented in Figure 21. The entire area of Bantry Bay and a section of the Irish Sea is included in the model domain. This extent is sufficient to ensure that any effects from the boundaries of the model do not influence the modelled hydrodynamics and water quality concentrations in the area of interest.

Figure 21: Computational mesh of model (shown in white).



4.3.1 Computational mesh

The 2D model resolution is set by the area of the triangular mesh elements of the 2D model grid. As the model is a flexible mesh model the resolution varies throughout the domain.

Defining the model resolution involves a trade-off between utilising a high-resolution mesh to accurately resolve the flow and the computational run time of the model which increases with increasing mesh resolution.

A number of varying computational mesh resolutions were tested during the model build phase of the work in order to find the optimal balance between resolution and model run time. A close-up view of the finalised mesh in the vicinity of the outfall is presented in Figure 22. The mesh cell size is smallest around the outfall (circa 30m^2) and largest near the model boundary (circa 150,000m^2). It can be seen from the figure a very high resolution has been set for the area in the vicinity of the proposed outfall.

Figure 22: Finalised computational mesh at proposed outfall location

We note that the mesh for the existing scenario model is identical to the mesh for the proposed scenario model to allow both scenarios to be directly compared without introducing interpolation errors into the comparison.

4.3.2 Model time step

An adaptive time step was used in the model. The maximum time step was selected as 5 seconds. The minimum time step was selected as 0.01 seconds. The actual time step used by the model throughout the simulation was determined by the model computations based on the requirements of the mesh.

4.3.3 Parameters

A number of additional parameters require definition in the hydrodynamic model. These are listed below along with the values selected for the model. It is noted that setting of model parameters is guided by both the model calibration process and also by our experience in numerical modelling. As detailed later in the report, a good match between the measured and modelled data had been achieved with the hydrodynamic model which confirms the realism and accuracy of the model. From this is can be concluded that the parameters of the study are suitable and appropriate.

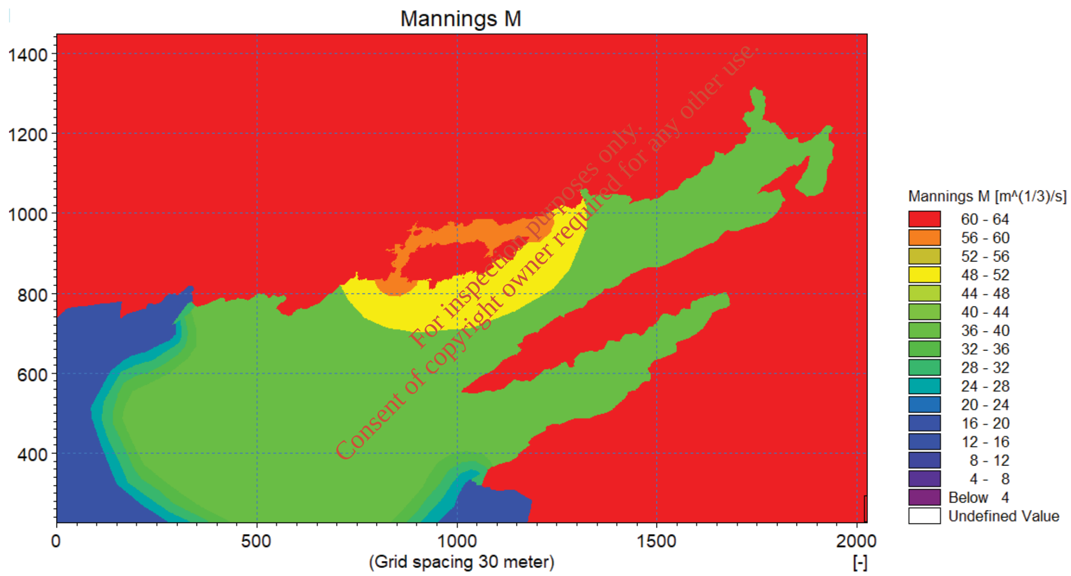
Table 13 presents some of the primary model parameters used for this study.

Table 13: Model parameters used in the study

Parameter	Value
Drying depth	0.005m
Flooding depth	0.05m
Wetting Depth	0.1m
Eddy Viscosity	Smagorinsky formulation
Bed resistance	Spatially varying Manning's M formulation.

Figure 23 below shows the spatially varying Manning's M values used to represent bed resistance for Bantry Bay as part of this study. The Manning's values were initially selected based on the composition of bed material in Bantry Bay. As part of the model calibration process however these values were fine tuned in order to derive a good match between the measured and modelled data. The values presented in Figure 23 are the finalised values.

Figure 23: Spatially varying Manning's M



Precipitation, evaporation, wave radiation and ice coverage were all ignored in the model as they were deemed insignificant to the hydrodynamics of Bantry Bay.

4.4 Boundary conditions

Boundary conditions are required for both the upstream and downstream end of the model:

- The upstream boundaries of the model are defined by both land boundaries and flow time series for the various fluvial inputs to the model (QT);
- The downstream open sea boundary of the model is defined by a time and spatially varying water level profile (HT) which replicates tidal oscillation.

Both boundary conditions are now discussed.

4.4.1 Upstream land boundary of the model

The land boundary of the hydrodynamic model is located at the extent of the tidal reach all across Bantry Bay. The various islands in the Bay are also defined as land boundaries.

Water cannot flow upstream of the land boundary on the flood tide and it is therefore sufficient to represent the upstream inflows from the various rivers in Bantry Bay as sources discharge points in the model. A list of the various inflows is detailed later in Section 6.3.

4.4.2 Source inflows into the model

Fluvial (river) flows from watercourses discharging into Bantry Bay have been included in the design model runs.

Flow discharges from the WwTP outfalls were also included.

4.4.3 Downstream boundary of the model

The downstream open sea boundary of the model is defined by a time and spatially varying water level profile that covers the entire extent of the open boundary. Separate methodologies were used for deriving the downstream boundary for the both the calibration model run and the design model run.

Calibration model run boundary condition

As discussed in Section 3, Hindcast data was deemed the most suitable to derive the calibration model open sea boundary. The boundary of the computational mesh therefore had to be aligned to the position of the hindcast data points in order to correctly apply the data to the model. The hindcast data also had to be interpolated to the individual grid cells of the mesh along the boundary.

A Flather boundary condition was specified for the open boundary in order to improve the performance of the model in the vicinity of the boundary.

Design model run boundary condition

An astronomical tide has been used as the design model run boundary condition. This enabled various model simulation times, including those longer than the period of recorded data. The boundary was derived using the MIKE21 Global Tide Model Prediction tool which allows for tidal prediction of water levels for time and spatially varying boundaries.

The Global Tide Model has a 0.125º x 0.125º resolution and accounts for 10 tidal constituents: Semidiurnal (M2, S2, K2, N2), diurnal (S1, K1, O1, P1, Q1) and – Shallow water (M4). This number of constituents is more than sufficient to accurately describe the variation on water level owing to the astronomical tidal forcing.

5 Hydrodynamic Model Calibration and Results

5.1 Overview

Model calibration involves comparing model results against recorded data in order to determine how good the model is at reproducing the time varying water levels and currents in the area of interest. The process of calibration allows for some of the model parameters to be fine-tuned to achieve the best match between the data and the model. These parameters include the bed resistance (Manning's M), the viscosity coefficient, and the model mesh itself.

Model validation involves running the calibrated model against a different set of recorded data to confirm the reliability of the model at reproducing the hydrodynamics of the estuary.

This model was calibrated using the spring tide data and validated against the neap tide data. The model included a suitable warm up time of 4 hours. The 2D hydrodynamic model was calibrated against the following measured parameters:

- Water levels
- Current speeds
- Current directions

Water levels for both spring and neap tides were calibrated/validated against measured data at the Castletownbere gauge (details of which are presented in Section 3.3). These findings are presented in Section 5.3.1 and 5.4.1.

Current speeds and directions were calibrated against measured data recorded as part of the 2018 survey for the calibration point located at the site of the proposed outfall near Castletownbere. Spring data was recorded from 06:30 to 19:00 on the 31/05/2018, a total period of 12.5 hours. Section 5.3 presents the findings of the calibration. Neap data was recorded from 06:30 to 19:00 on the 24/05/2018, at total of 12.5 hours. Section 5.4 presents the findings of the neap tide validation.

As both the calibration and validation are at a single point in space, they need to be considered in the context of overall hydrodynamics for the area of interest which is presented in Section 5.5. As the design runs were simulated with an astronomical tide for the boundary condition, a validation for the astronomical only tide was carried out and this is detailed in Section 5.6.

5.2 Irish Water calibration guidance

Following the guidance outlined in the draft IW Technical Standards for Marine Modelling, our calibration/validation has been undertaken in two ways:

- A visual interpretation of the goodness of fit of the modelled data to the recorded data;
- A statistical analysis of the modelled data against the recorded data.

The statistical analysis detailed in the draft technical guidance states that the hydrodynamic performance of a model should be validated for the following parameters and associated statistical performance targets:

- Water level: ±15% and ±20% of measured levels during Spring and Neap tides respectively. ±0.1m of measured levels as an absolute difference;
- Current velocity: ±10% of measured peak velocities at Mid tide, ±20% of measured velocities at high and low water. ±0.1m/s of measured velocities as an absolute difference;
- Current direction: ±20 degrees of measured directions;
- Timing of high water: ±15 minutes at estuary mouth; ±25 minutes at estuary head.

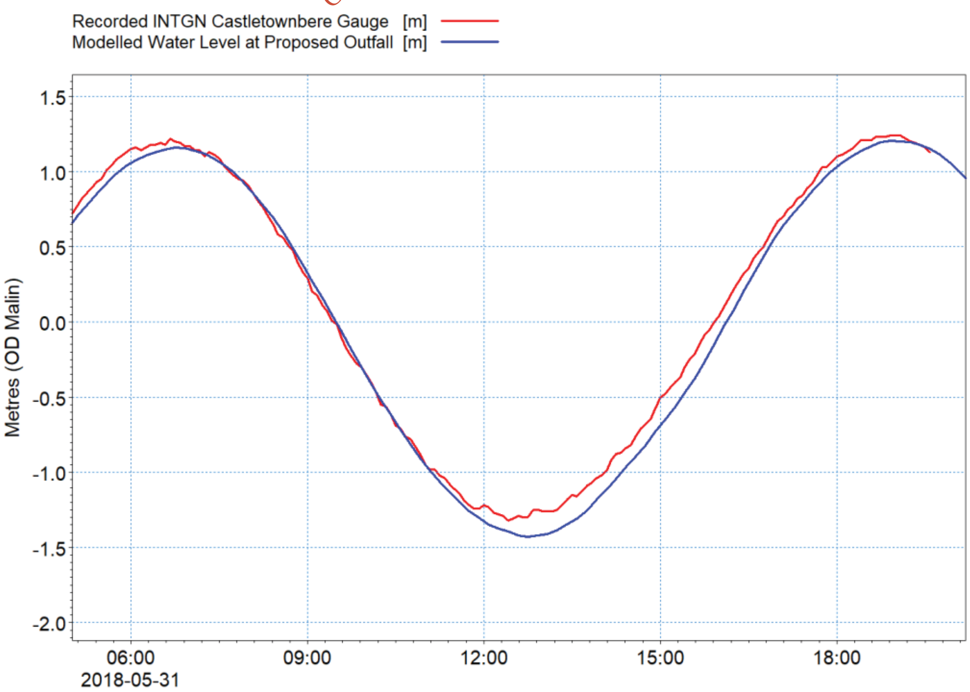
Statistical guidelines should not be used in isolation when assessing the performance and acceptability of a model and it is necessary for the experienced modeller to offer a critical assessment of model performance taking all of the available information and calibration data into account.

5.3 Spring tide calibration

5.3.1 Water level

The water level calibration is presented in Figure 24. It can be seen from the figure the modelled water level is a good match to the recorded water level. The differences between the model results and the recorded data for the maximum (high tide) water levels is very low while the model slightly underestimates the minimum water level at low tide.

Figure 24: Spring Tide Water Level Calibration – visual analysis



There is a difference of circa 5 minutes between the model and recorded data for time of occurrence of high water. The difference for the time of low water is also circa 5 minutes. The performance of the model for these criteria is therefore well within the target value as set by the Irish Water Technical standards.

The modelled tidal range is within 1% of the recorded tidal range which demonstrates the ability of the model to accurately replicate water levels at the site of interest.

The statistical analysis of the water level calibration is presented in Table 14. The cells highlighted in green are those than meet the statistical performance targets set out by the IW Technical Standards for Marine Modelling. It can be seen that the model is within the performance target circa 69% of the time for the absolute difference and 81% of the time for the relative percentage difference. In total, the model is within either an absolute or relative percentage difference criteria 88% of the time. These results represent a good statistical match.

Table 14: Statistical performance results for Spring Tide water level calibration

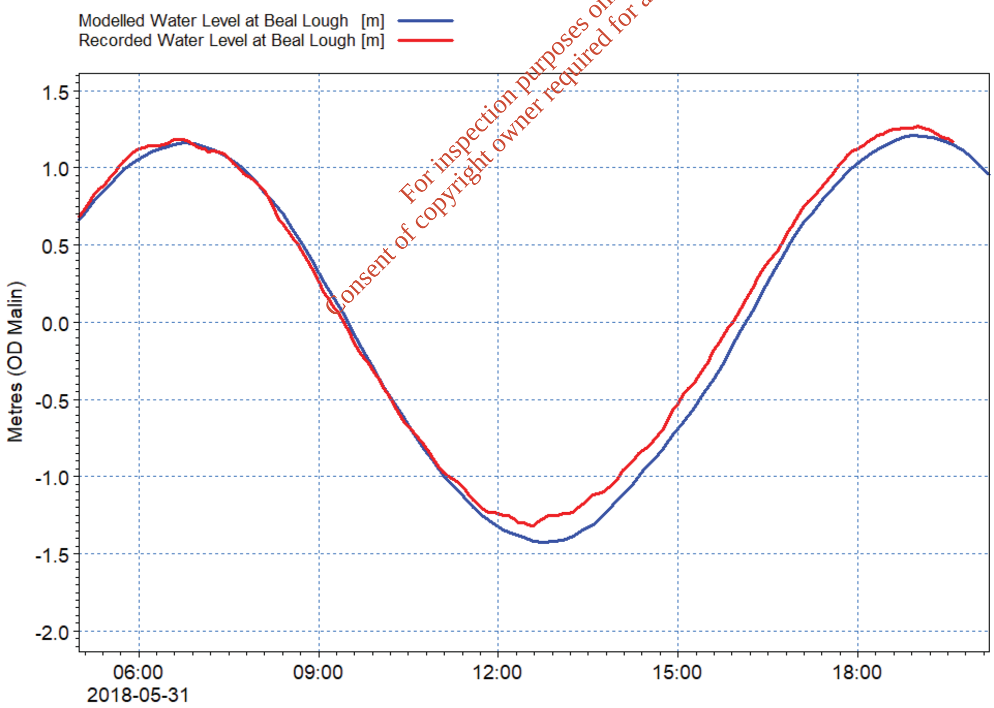
Time	Recorded Water Level (mOD)	Modelled Water Level (mOD)	Absolute difference between modelled and recorded (m)	Difference as a percentage of recorded values (%)
31-05-18 6:30	1.19	1.14	0.05	4%
31-05-18 7:00	1.17	1.15	0.02	2%
31-05-18 7:30	1.09	1.06	0.03	2%
31-05-18 8:00	0.9	0.89	0.01	1%
31-05-18 8:30	0.58	0.64	0.06	11%
31-05-18 9:05	0.29	0.27	0.02	8%
31-05-18 9:30	-0.02	-0.01	0.01	57%
31-05-18 10:00	-0.35	-0.36	0.01	3%
31-05-18 10:30	-0.69	-0.67	0.02	3%
31-05-18 11:00	-0.95	-0.95	0.00	0%
31-05-18 11:30	-1.11	-1.16	0.05	5%
31-05-18 12:00	-1.22	-1.33	0.11	9%
31-05-18 12:30	-1.31	-1.41	0.10	7%
31-05-18 13:00	-1.26	-1.42	0.16	12%
31-05-18 13:30	-1.15	-1.33	0.18	15%
31-05-18 14:00	-1.02	-1.15	0.13	13%
31-05-18 14:30	-0.82	-0.93	0.11	13%
31-05-18 15:00	-0.5	-0.69	0.19	38%
31-05-18 15:30	-0.25	-0.42	0.17	70%
31-05-18 16:00	0.041	-0.09	0.13	*314%
31-05-18 16:30	0.36	0.26	0.10	28%
31-05-18 17:00	0.67	0.59	0.08	12%

Time	Recorded Water Level (mOD)	Modelled Water Level (mOD)	Absolute difference between modelled and recorded (m)	Difference as a percentage of recorded values (%)
31-05-18 17:30	0.89	0.83	0.06	7%
31-05-18 18:00	1.1	1.03	0.07	6%
31-05-18 18:30	1.21	1.15	0.06	5%
31-05-18 19:00	1.24	1.20	0.04	3%

*We note that the results at 16:00 show a large percentage difference due to the methodology by which the percentages were calculated and are not the result of instabilities in the numerical model. When the denominator of a percentage is small (i.e. at 16:00 = -0.09mOD) and the numerator is larger (absolute difference in recorded and modelled), the resulting percentage derives a large value (314%).

Water level data was recorded as part of the marine survey for this study at Beal Lough (Figure 18). Figure 25 below shows the Spring Tide water level calibration for the model using this data. It can be seen that the modelled water level is a good match to the recorded water level and are very similar to the results for the water level calibration as presented in the previous section.

Figure 25: Spring Tide Beal Lough Water Level Calibration – Visual Analysis

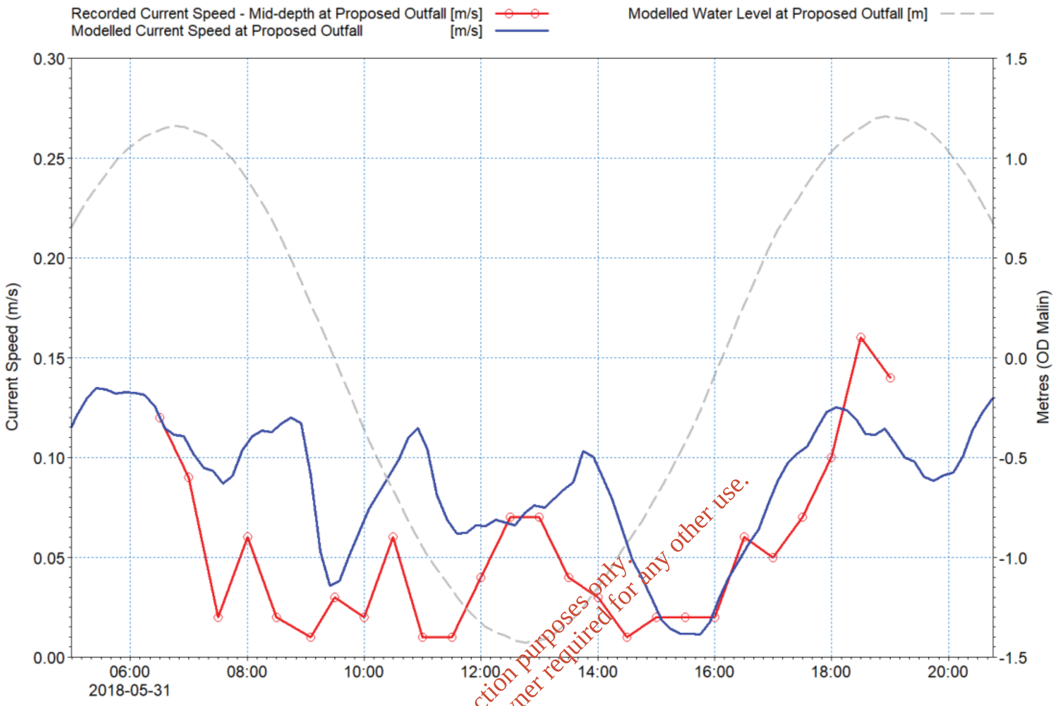


5.3.2 Current speed

The current speed calibration is presented in Figure 26. The recorded current speed presented on the plot corresponds to the speed recorded at mid depth in the water column.

This data represents the most appropriate current speed data collected as part of the survey[4] to calibrate the model against. The modelled water level is also presented in the plot in order to aid the reader in deciphering the stage of the tide at which the current speeds occur.

Figure 26: Current Speed Calibration – visual analysis



It can be seen from Figure 26 that the modelled current speed is reasonably well matched to the recorded data as the model captures the overall trend in current speed through the various stages of the tidal cycle. The low recorded current speeds however are not captured by the model. This however is understandable given that a numerical model is generally unable to simulate very low current speeds such as the values collected on site (<0.05m/s). The model slightly underestimates the peak current speed at circa 18.30hrs before high tide.

The statistical analysis of the current speed calibration is presented in Table 15. The cells highlighted in green are those that meet the statistical performance targets set out by the IW Technical Standards for Marine Modelling. It can be seen that the model is within the absolute difference performance criteria of 0.1m/s for each time step. The model however is only within the relative percentage difference for 40% of the time. This difference can be attributed to the use of very low denominators when calculating the relative percentages.

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[4] As noted earlier in the report, current speed and direction was collected from three points in the water column: (1) near the surface, (2) at mid depth, and (3) close to the bed. As our model is a 2D model it calculates the depth averaged current speed in the water column. The current speed recorded at mid depth is the best representation of this.

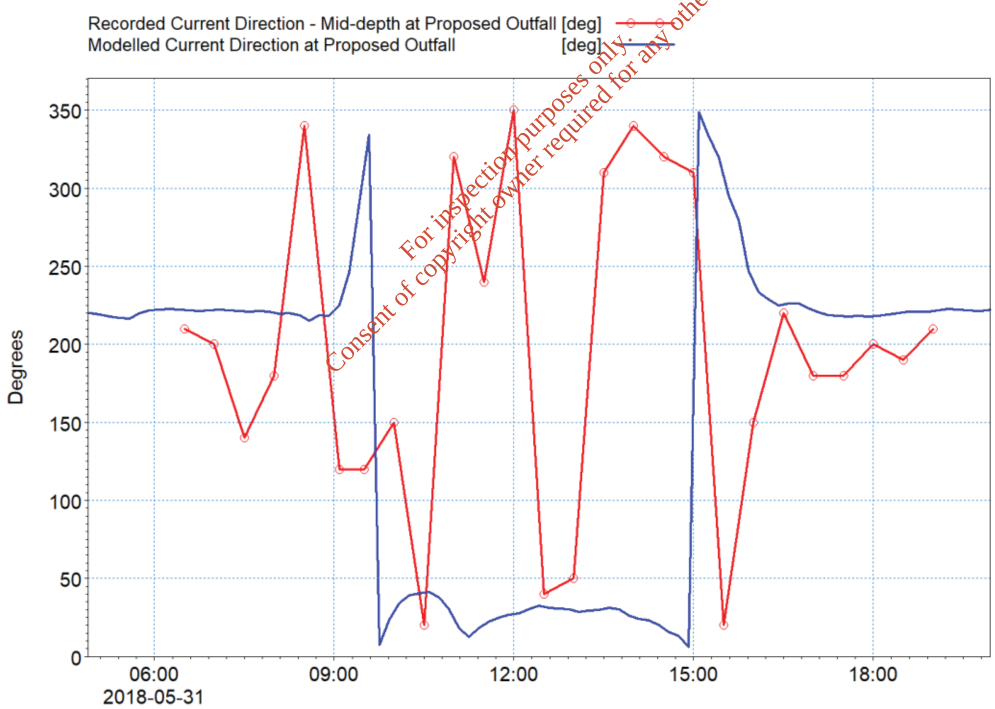
Table 15: Statistical performance results for Spring Tide current speed calibration

Time		Recorded Current Speed (m/s)	Modelled Current Speed (m/s)	Absolute difference between modelled and recorded (m/s)	Difference as a percentage of recorded values (%)
31-05-18 6:30	High Tide	0.12	0.12	0.00	0%
31-05-18 9:30	Mid-Tide	0.03	0.04	0.01	23%
31-05-18 12:30	Low Tide	0.07	0.07	0.00	5%
31-05-18 15:30	Mid-Tide	0.02	0.01	0.01	42%
31-05-18 19:00	High Tide	0.14	0.11	0.03	21%

5.3.3 Current direction

The current direction calibration is presented in Figure 27. It can be seen from the figure the modelled current direction is well matched to the recorded data. The model captures the direction of the tide on both the flood and ebb tide quite well. The model also well replicates the time at which the tide turns.

Figure 27: Current Direction Calibration – visual analysis



The statistical analysis of the current direction calibration is presented in Table 16. The analysis suggests that the model is preforming poorly as it is within the performance threshold 23% of the time for current direction. The statistical analysis however is sensitive to slight variations in the recorded current direction data that can arise from localised currents in the vicinity of where the data was captured. It is evident from the visual comparison that the model replicates the recorded current direction for both ebb and flood tides.

Table 16: Statistical performance results for Spring Tide current direction calibration

Time	Recorded Current Direction (Deg)	Modelled Current Direction (Deg)	Absolute difference between modelled and recorded (Deg)
31-05-18 6:30	210	222	12
31-05-18 7:00	200	222	22
31-05-18 7:30	140	221	81
31-05-18 8:00	180	220	40
31-05-18 8:30	340	217	123
31-05-18 9:05	120	225	105
31-05-18 9:30	120	313	193
31-05-18 10:00	150	29	121
31-05-18 10:30	20	41	21
31-05-18 11:00	320	24	296
31-05-18 11:30	240	20	220
31-05-18 12:00	350	27	323
31-05-18 12:30	40	32	8
31-05-18 13:00	50	30	20
31-05-18 13:30	310	31	279
31-05-18 14:00	340	25	315
31-05-18 14:30	320	18	302
31-05-18 15:00	310	177	133
31-05-18 15:30	20	308	288
31-05-18 16:00	150	240	90
31-05-18 16:30	220	226	6
31-05-18 17:00	180	222	42
31-05-18 17:30	180	218	38
31-05-18 18:00	200	218	18
31-05-18 18:30	190	220	30
31-05-18 19:00	210	221	11

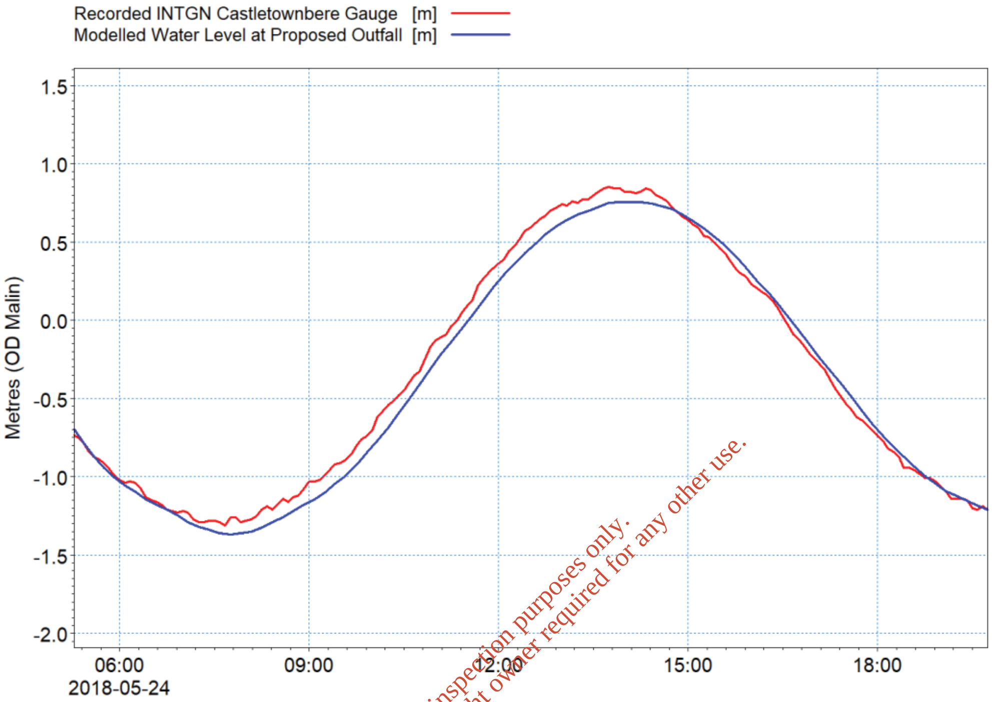
5.4 Neap tide validation

5.4.1 Water level

The water level validation is presented in Figure 28. It can be seen from the figure the modelled water level is a good match to recorded data. The model underestimates the peak water level by circa 100mm. The model overestimates the minimum water level by circa 60mm.

There is a difference between the modelled and recorded water level timing of approximately 5 minutes for low tide and approximately 10 - 15 minutes for high tide. In relation to tidal range, the modelled neap tide range is 99% of the recorded tidal range. Therefore, the model accurately replicates the timing and range of the neap tide.

Figure 28: Neap Tide Water Level Validation – visual analysis



The statistical analysis of the water level validation is presented in Table 17. It can be seen that the model performs very well against the recorded data. It can be seen that the model is within the performance target circa 69% of the time for the absolute difference and 73% of the time for the relative percentage difference. In total, the model is within either an absolute or relative percentage difference criteria 85% of the time. These results represent a good statistical match.

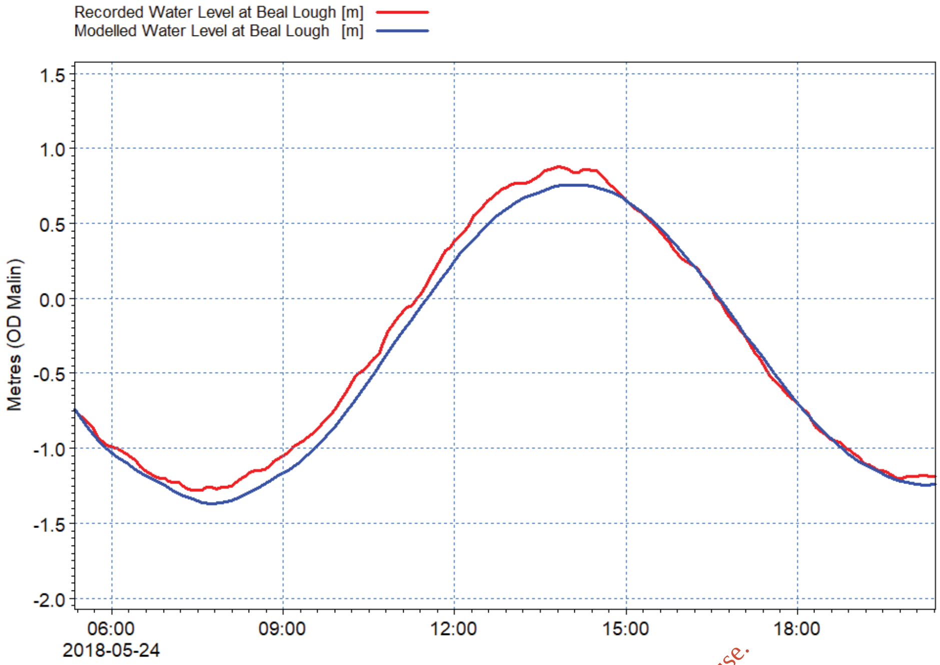
Table 17: Statistical performance results for Neap Tide water level validation

Time	Recorded Water Level (mOD)	Modelled Water Level (mOD)	Absolute difference between modelled and recorded (m)	Difference as a percentage of recorded values (%)
24-05-18 6:30	-1.15	-1.16	0.01	1%
24-05-18 7:00	-1.22	-1.27	0.05	4%
24-05-18 7:30	-1.28	-1.35	0.07	6%
24-05-18 8:00	-1.28	-1.36	0.08	6%
24-05-18 8:30	-1.18	-1.28	0.10	8%
24-05-18 9:00	-1.03	-1.16	0.13	13%
24-05-18 9:30	-0.91	-1.02	0.11	12%
24-05-18 9:50	-0.76	-0.89	0.13	16%
24-05-18 10:25	-0.48	-0.59	0.11	23%

Time	Recorded Water Level (mOD)	Modelled Water Level (mOD)	Absolute difference between modelled and recorded (m)	Difference as a percentage of recorded values (%)
24-05-18 11:00	-0.13	-0.27	0.14	105%
24-05-18 11:30	0.09	-0.01	0.10	111%
24-05-18 12:00	0.36	0.25	0.11	31%
24-05-18 12:30	0.59	0.46	0.13	22%
24-05-18 13:00	0.74	0.62	0.12	16%
24-05-18 13:30	0.8	0.71	0.09	11%
24-05-18 14:00	0.82	0.75	0.07	8%
24-05-18 14:30	0.8	0.74	0.06	8%
24-05-18 15:00	0.64	0.65	0.01	2%
24-05-18 15:35	0.43	0.47	0.04	10%
24-05-18 16:00	0.23	0.30	0.07	29%
24-05-18 16:30	0.02	0.07	0.05	228%
24-05-18 17:00	-0.24	-0.20	0.04	18%
24-05-18 17:30	-0.53	-0.45	0.08	16%
24-05-18 18:00	-0.74	-0.70	0.04	6%
24-05-18 18:30	-0.94	-0.90	0.04	4%
24-05-18 19:00	-1.06	-1.07	0.01	1%

Water level data was recorded as part of the marine survey for this study at Beal Lough, the location of which is shown in Figure 18. Figure 29 below shows the Neap Tide water level validation for the model using this data. It can be seen that the modelled water level is a good match to the recorded water level. The result looks very similar to the outfall validation above, therefore the statistical analysis would yield very similar results and because of this they won't be presented. This additional validation at Beal Lough provides more confidence that the model water levels are closely replicating reality.

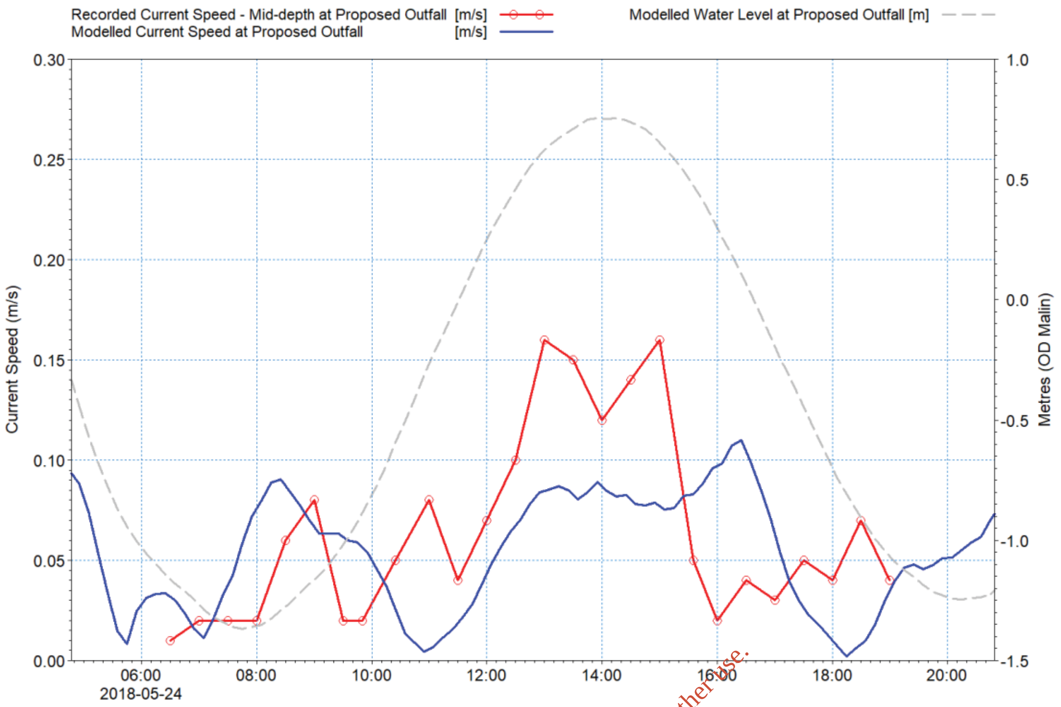
Figure 29: Beal Lough Neap Tide Water Level Validation – visual analysis



5.4.2 Current speed

The current speed validation is presented in Figure 30. It can be seen from the plot that the modelled current speed is a reasonable match to the recorded data. As with Spring tide conditions however, recorded current speeds at the site are low and it is difficult for a hydrodynamic model to simulate these conditions. In this context our model is seen to be a reasonable match to the recorded data.

Figure 30: Current Speed Validation – visual analysis



The statistical analysis of the current speed validation is presented in Table 18. It can be seen that the model is within the absolute difference performance criteria of 0.1m/s for each time step. The model appears to be performing poorly for the relative percentage difference targets (10% for mid-tide, 20% for high and low tide). This however is a result of using low denominators for the percentages. All in all, the current validation calibration is reasonably well matched.

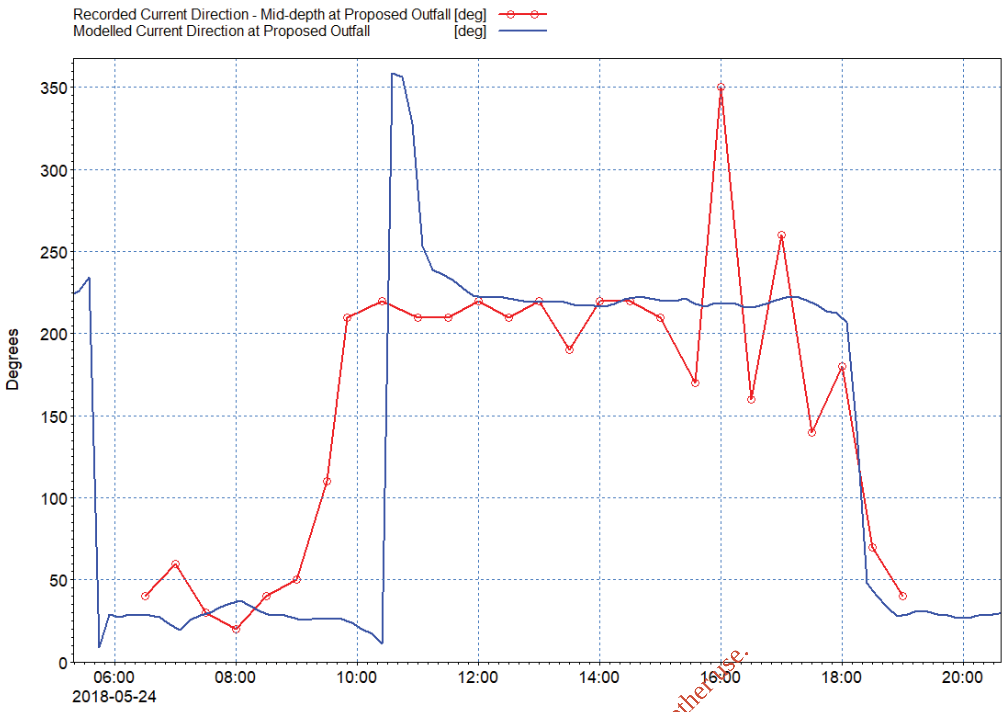
Table 18: Statistical performance results for Neap Tide current speed validation

Time		Recorded Current Speed (m/s)	Modelled Current Speed (m/s)	Absolute difference between modelled and recorded (m/s)	Difference as a percentage of recorded values (%)
24-05-18 7:30	Low Tide	0.02	0.04	0.02	88%
24-05-18 10:25	Mid-Tide	0.05	0.03	0.02	48%
24-05-18 14:00	High Tide	0.12	0.09	0.03	28%
24-05-18 17:00	Mid-Tide	0.03	0.06	0.03	110%

5.4.3 Current direction

The current direction validation is presented in Figure 31. It can be seen from the figure the modelled current direction is a good match to recorded data and captures the general direction of the recorded current on both the flood and ebb tide.

Figure 31: Current Direction Validation – visual analysis



The statistical analysis of the current direction validation is presented in Table 19. It can be seen that the model is within the performance target circa 42% of the time. While this may suggest a reasonably poor validation, it can be seen from the visual analysis that the model captures the recorded direction reasonable well.

Table 19: Statistical performance results for Neap Tide current direction validation

Time	Recorded Current Direction (Deg)	Modelled Current Direction (Deg)	Absolute difference between modelled and recorded (Deg)
24-05-18 6:30	40	28	12
24-05-18 7:00	60	21	39
24-05-18 7:30	30	29	1
24-05-18 8:00	20	37	17
24-05-18 8:30	40	29	11
24-05-18 9:00	50	26	24
24-05-18 9:30	110	26	84
24-05-18 9:50	210	25	185
24-05-18 10:25	220	11	209
24-05-18 11:00	210	291	81
24-05-18 11:30	210	234	24
24-05-18 12:00	220	223	3
24-05-18 12:30	210	221	11
24-05-18 13:00	220	219	1
24-05-18 13:30	190	218	28

Time	Recorded Current Direction (Deg)	Modelled Current Direction (Deg)	Absolute difference between modelled and recorded (Deg)
24-05-18 14:00	220	217	3
24-05-18 14:30	220	222	2
24-05-18 15:00	210	221	11
24-05-18 15:35	170	218	48
24-05-18 16:00	350	219	131
24-05-18 16:30	160	216	56
24-05-18 17:00	260	221	39
24-05-18 17:30	140	219	79
24-05-18 18:00	180	210	30
24-05-18 18:30	70	44	26
24-05-18 19:00	40	28	12

5.5 Results of the hydrodynamic model

5.5.1 Spring Tide

Spatially varying results plots of the current speeds and velocity vectors for particular moments in time from the Spring tide calibration model run are presented in this section of the report. These plots aid understanding of the hydrodynamics in the area of interest.

Figure 32 presents the velocity vector and current speed plots for low Spring tide. It can be seen that while the current speeds in the main channel are approaching zero with the turning of the tide, the current speeds in the vicinity of the proposed outfall are marginally higher given that a secondary circulation is flowing in a clockwise direction through that area.

Figure 32: Velocity vector and current speeds at low tide

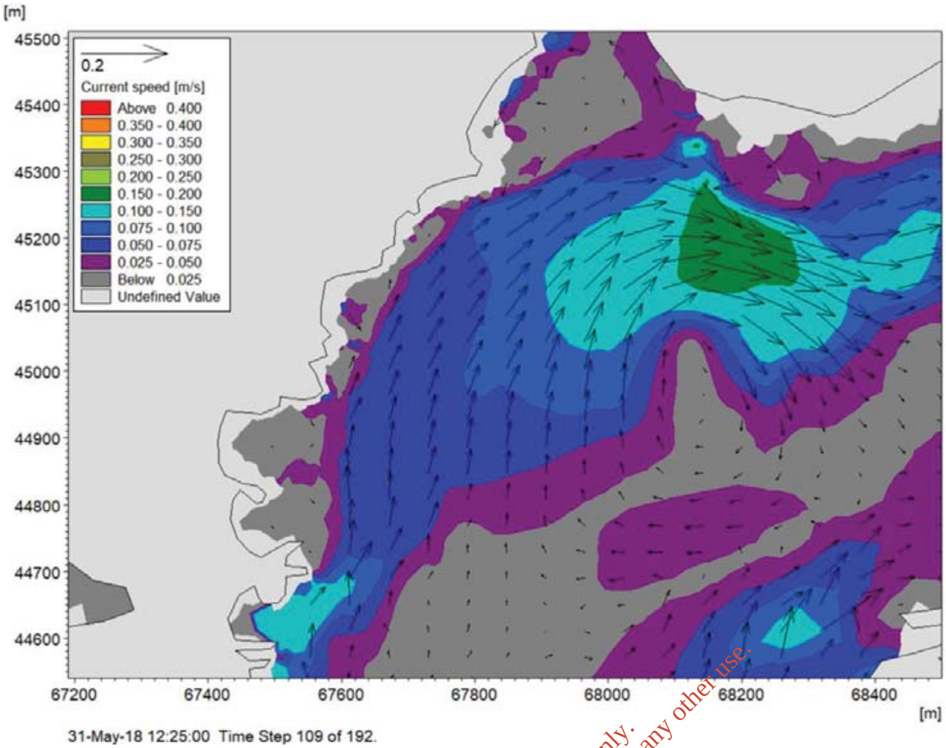


Figure 33 presents the velocity vector and current speed plots for mid flood tide on the Spring tide. It can be seen from the figure that while current speeds in the main channel are in excess of 0.3m/s and very evidently flowing in a North Easterly direction, in the immediate vicinity of the outfall they are very low and close to zero due to secondary circulations flowing in this area of the estuary.

Figure 33: Velocity vector and current speeds at mid-flood tide

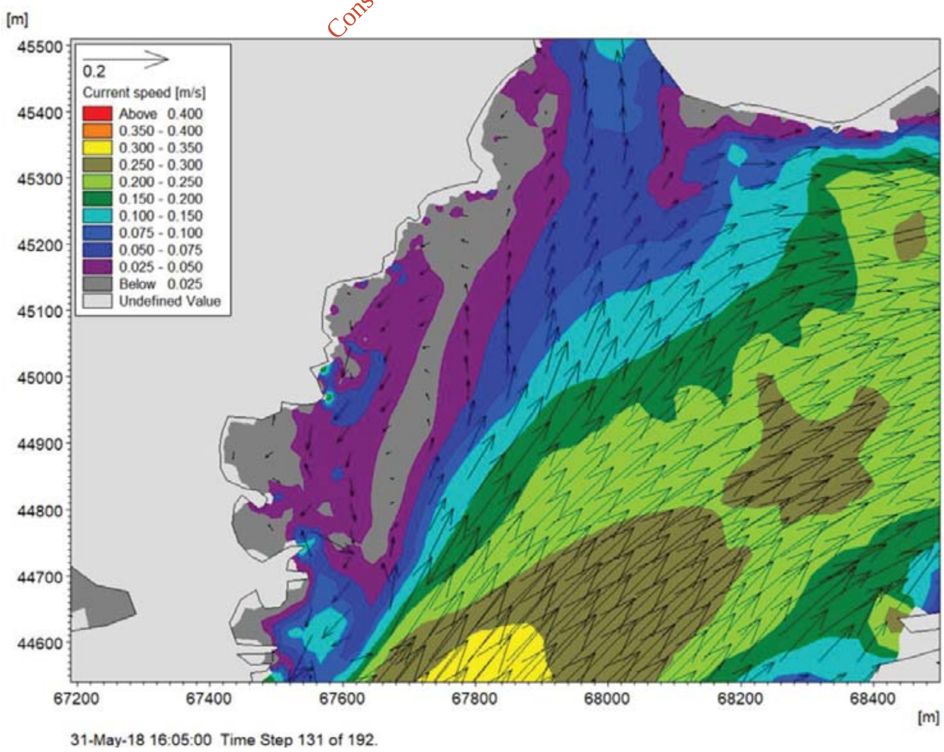


Figure 34 presents the current speeds and velocities at high tide. As with the hydrodynamics at low tide, there is a noticeable difference between the current speeds in the main channel and in the immediate vicinity of the location of the proposed outfall. An eddy has formed in the southern area presented in the plot and the maximum current speeds at this stage of the tide are to the East of the eddy.

Figure 34: Velocity vector and current speeds at high tide

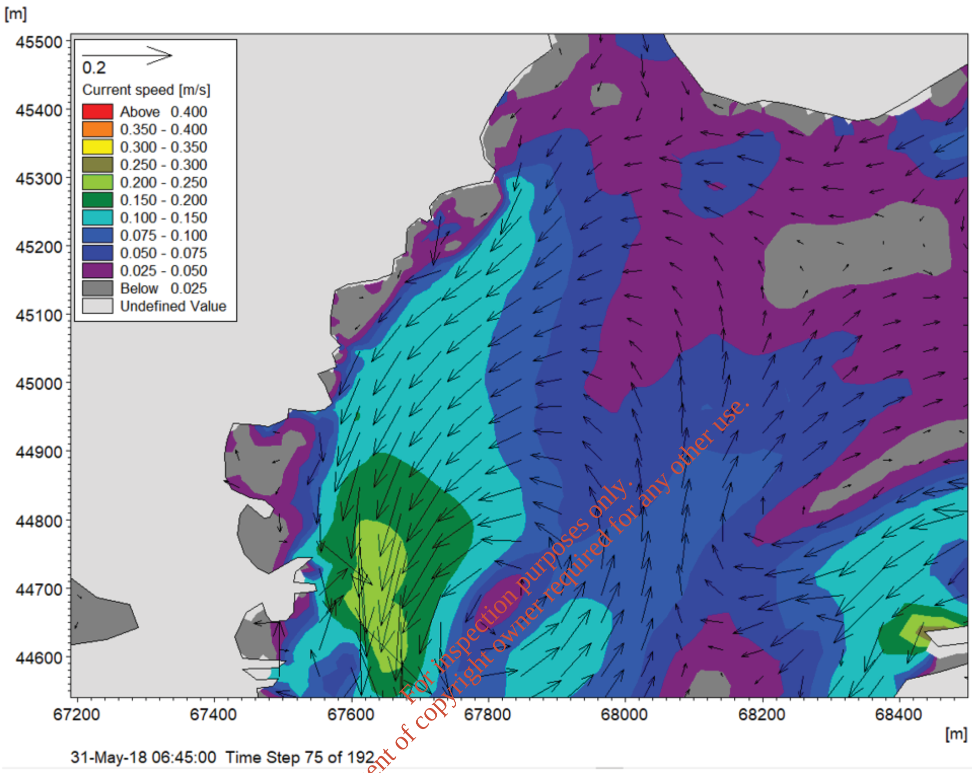
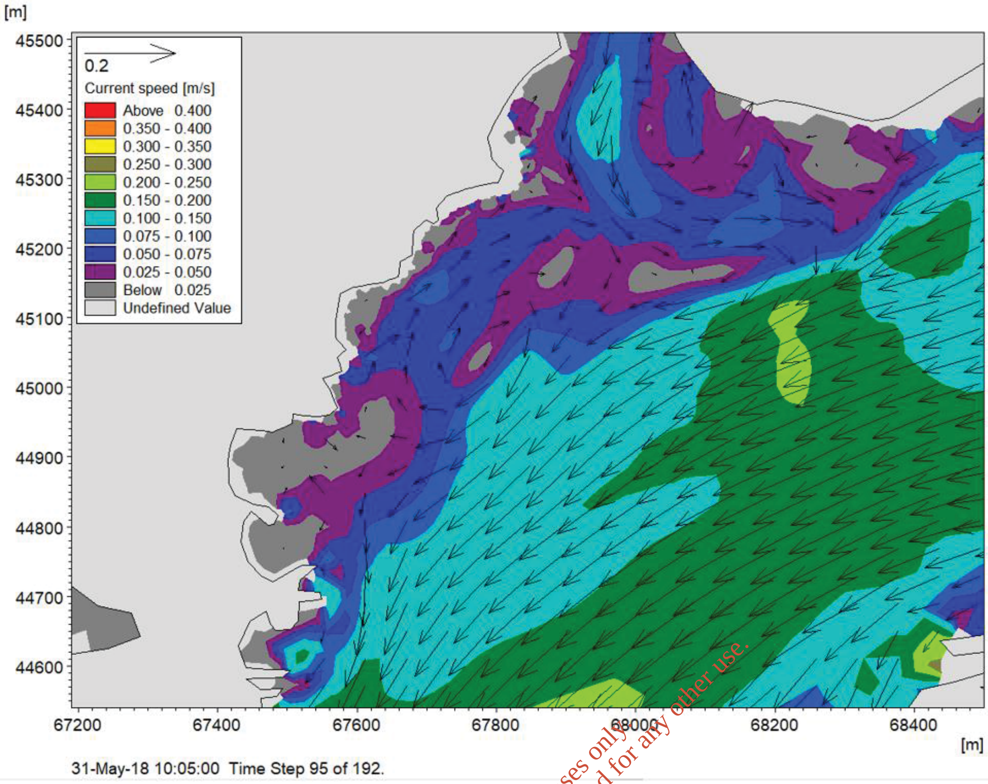


Figure 35 presents current speeds and velocities at mid ebb tide. As with mid flood tide conditions the hydrodynamics in the main channel are noticeable different to the hydrodynamics in the immediate vicinity of the location of the proposed outfall due to secondary circulations. A small eddy is circulating close to the outfall location while in the main channel the velocity vectors are following the main gradient of the estuary bed and the current speeds are in excess of 0.2m/s.

Figure 35: Velocity vector and current speeds at mid-ebb tide

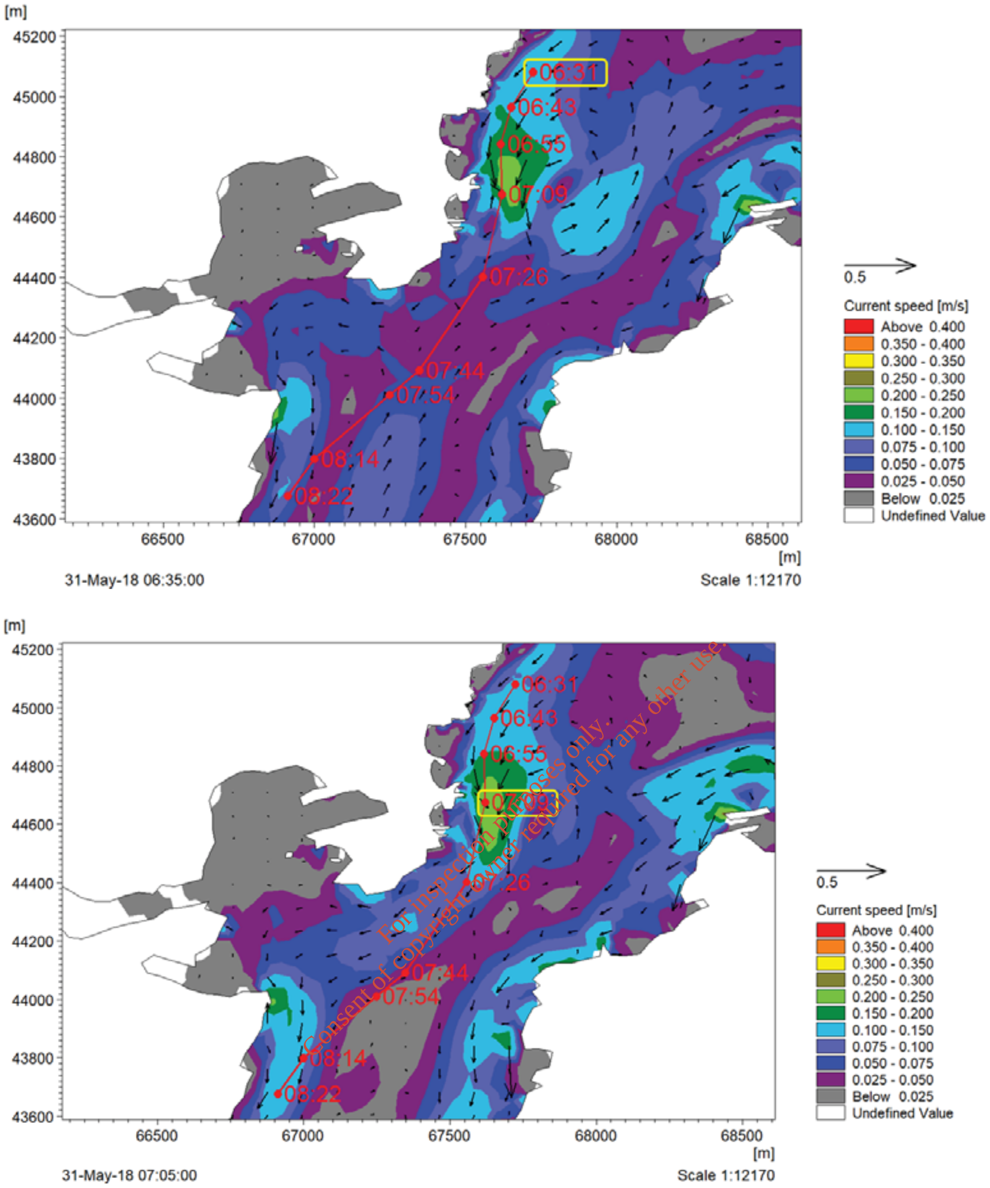


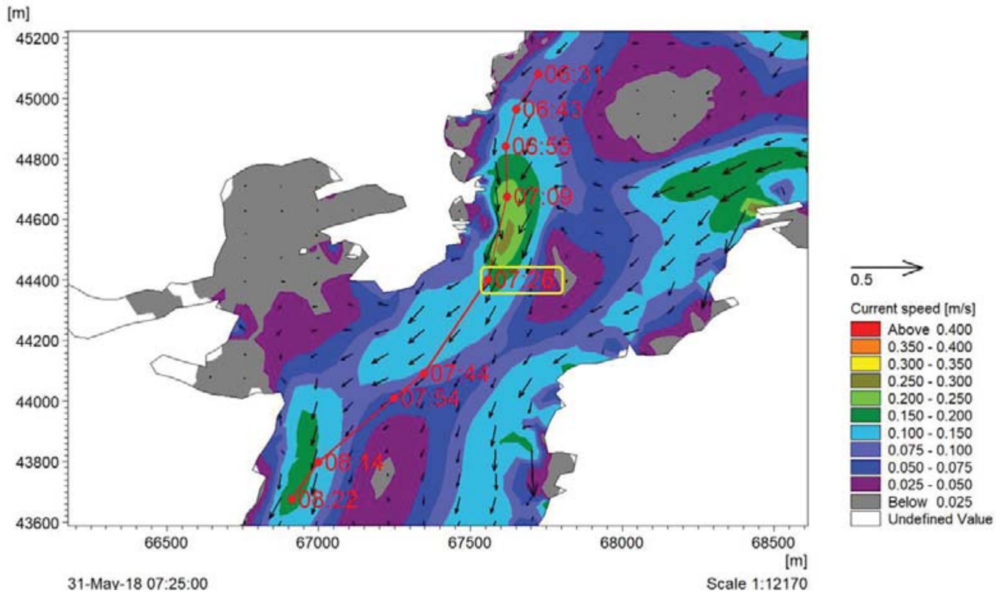
5.6 Drogue data validation

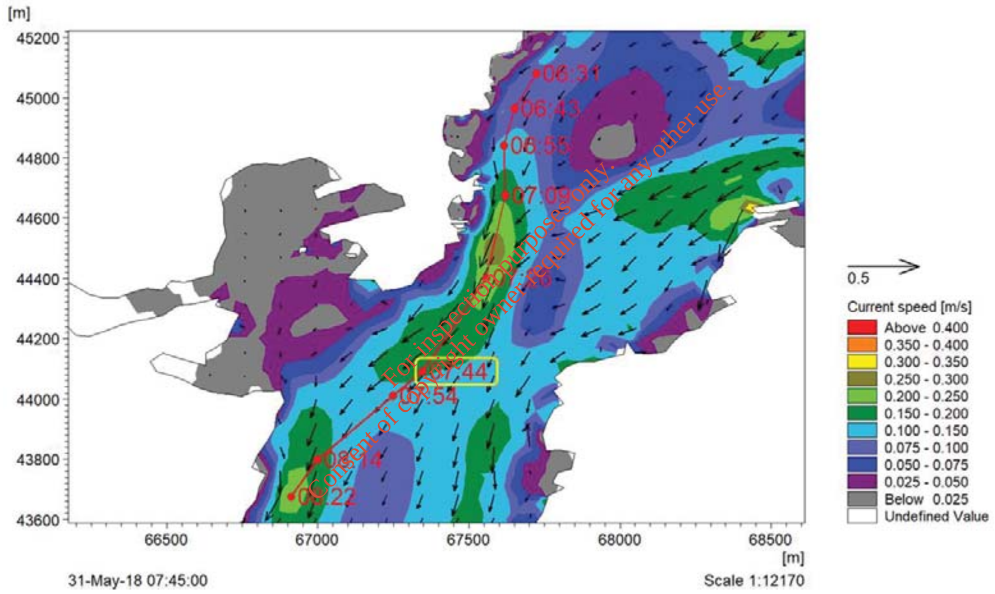
Drogue data was collected for a Spring and a Neap tidal cycle as part of the Marine Survey and has been used to offer further validation of the hydrodynamic model.

Figure 36 presents the current speed and velocity vectors plots for five stages of the ebb tide. The time and position of the drogue track throughout the duration of the ebb tide is superimposed with the red lines and its associated labels. The drogue time/location highlighted in yellow corresponds to the time at which the velocity vectors in the plot are taken from. It is evident from the plots that the modelled flow direction follows the track of the drogue very well – the drogue is being advected in the same direction as the modelled current throughout the ebb tide.

Figure 36: Spring ebb tide drogue validation




[m]
45200
45000
44800
44600
44400
44200
44000
43800
43600
66500
67000
67500
68000
68500
[m]
06:31
06:43
06:55
07:09
07:26
07:44
07:54
08:14
08:22
0.5
Current speed [m/s]
Above 0.400
0.350 - 0.400
0.300 - 0.350
0.250 - 0.300
0.200 - 0.250
0.150 - 0.200
0.100 - 0.150
0.075 - 0.100
0.050 - 0.075
0.025 - 0.050
Below 0.025
Undefined Value
31-May-18 07:25:00
Scale 1:12170


[m]
45200
45000
44800
44600
44400
44200
44000
43800
43600
66500
67000
67500
68000
68500
[m]
06:31
06:43
06:55
07:09
07:44
07:54
08:14
08:22
0.5
Current speed [m/s]
Above 0.400
0.350 - 0.400
0.300 - 0.350
0.250 - 0.300
0.200 - 0.250
0.150 - 0.200
0.100 - 0.150
0.075 - 0.100
0.050 - 0.075
0.025 - 0.050
Below 0.025
Undefined Value
31-May-18 07:45:00
Scale 1:12170

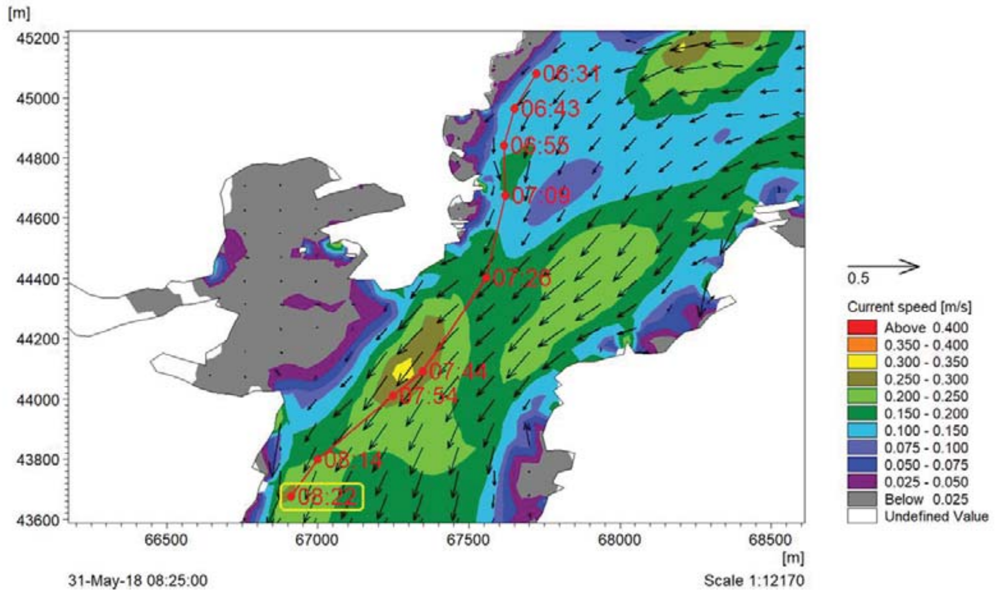
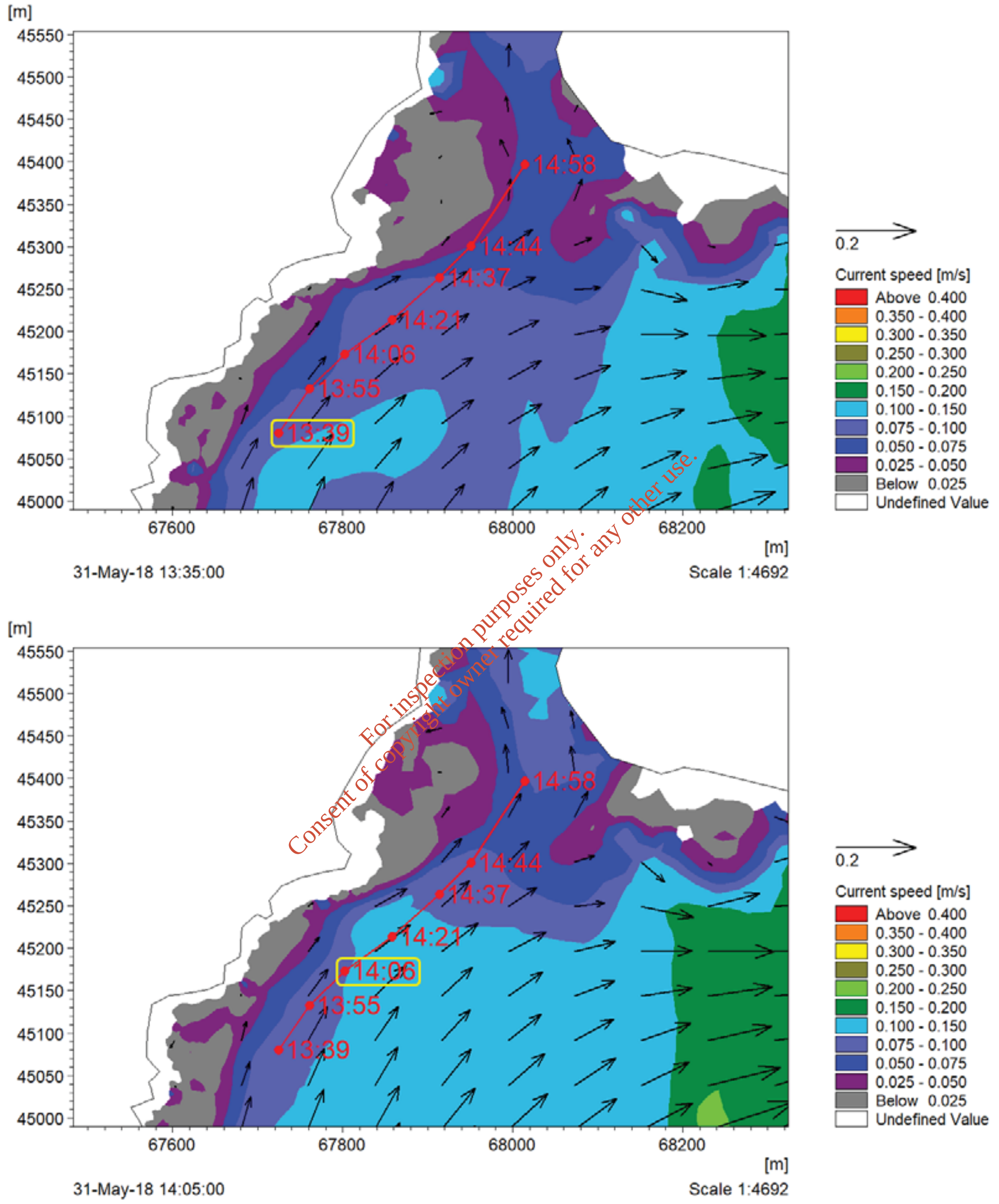
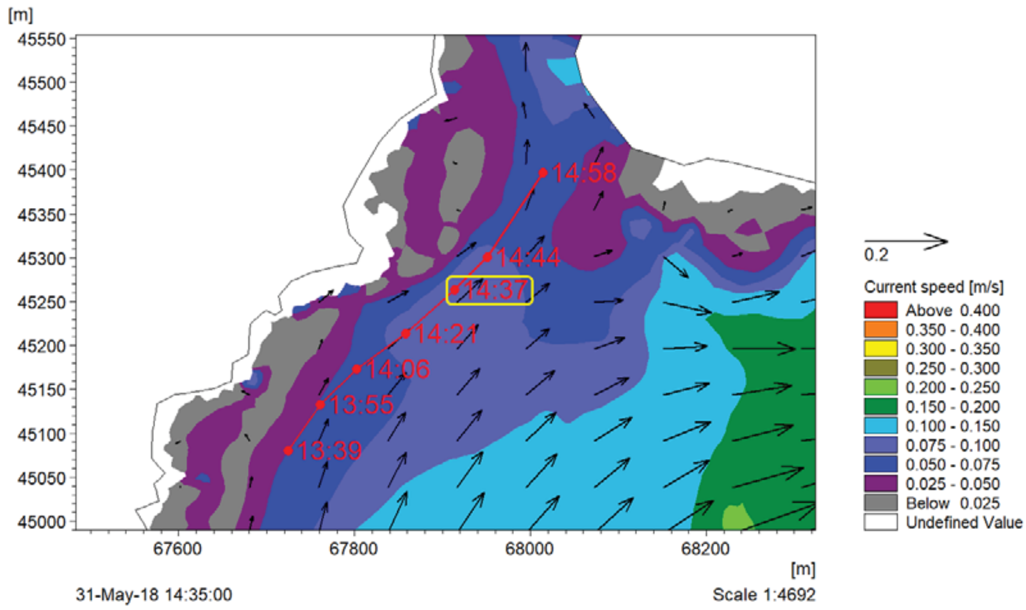
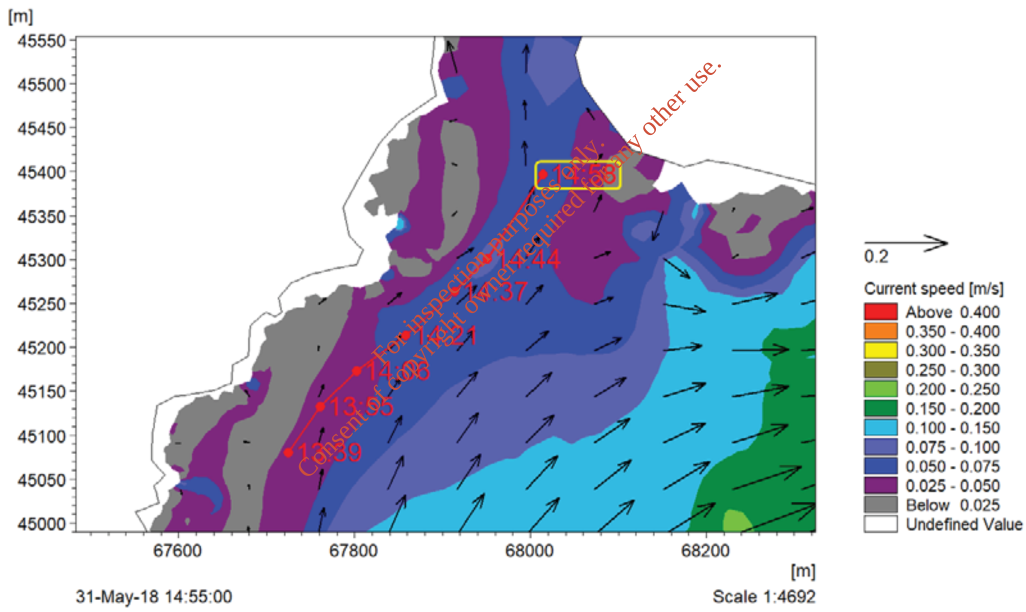

[m]
45200
45000
44800
44600
44400
44200
44000
43800
43600
66500
67000
67500
68000
68500
[m]
06:31
06:43
06:55
07:09
07:26
07:44
07:54
08:14
08:22
0.5
Current speed [m/s]
Above 0.400
0.350 - 0.400
0.300 - 0.350
0.250 - 0.300
0.200 - 0.250
0.150 - 0.200
0.100 - 0.150
0.075 - 0.100
0.050 - 0.075
0.025 - 0.050
Below 0.025
Undefined Value
31-May-18 08:25:00
Scale 1:12170

Figure 37 presents the current speed and velocity vectors drogue validation for the flood tide. It is evident from the plots that the drogue track data validates the hydrodynamic model – the track of the drogue is well captured by the model in terms of the direction of the current.

Figure 37: Spring Flood Tide Drogue Validation







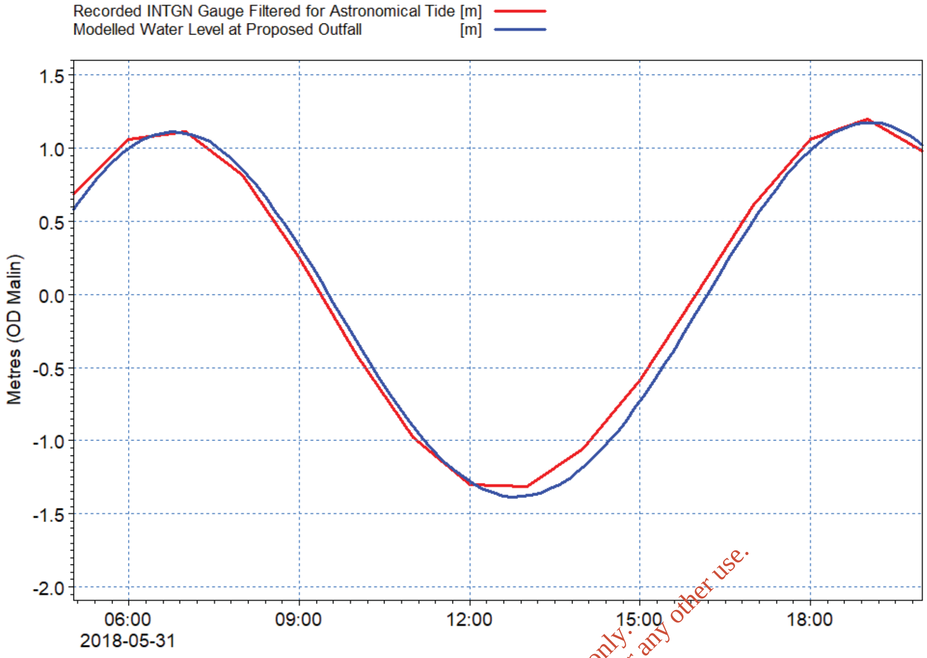
5.7 Astronomical tide validation

The hydrodynamic model was run with an astronomical tidal open sea boundary and validated against an astronomical tidal that was generated for the gauge in Castletownbere. The following methodology was adopted in undertaking this task:

- Data from the Castletownbere tidal gauge was filtered to produce an astronomical-only tidal signal for a 1-month period.
- Separately, an astronomical tidal signal for the open boundary condition was produced using the MIKE21 Tide Prediction of Heights tool.
- The model was run with the astronomical tidal boundary and compared against the derived astronomical tidal data from the gauge.

Figure 38 presents the astronomical spring tide validation tidal for the same period as presented in Section 5.3.

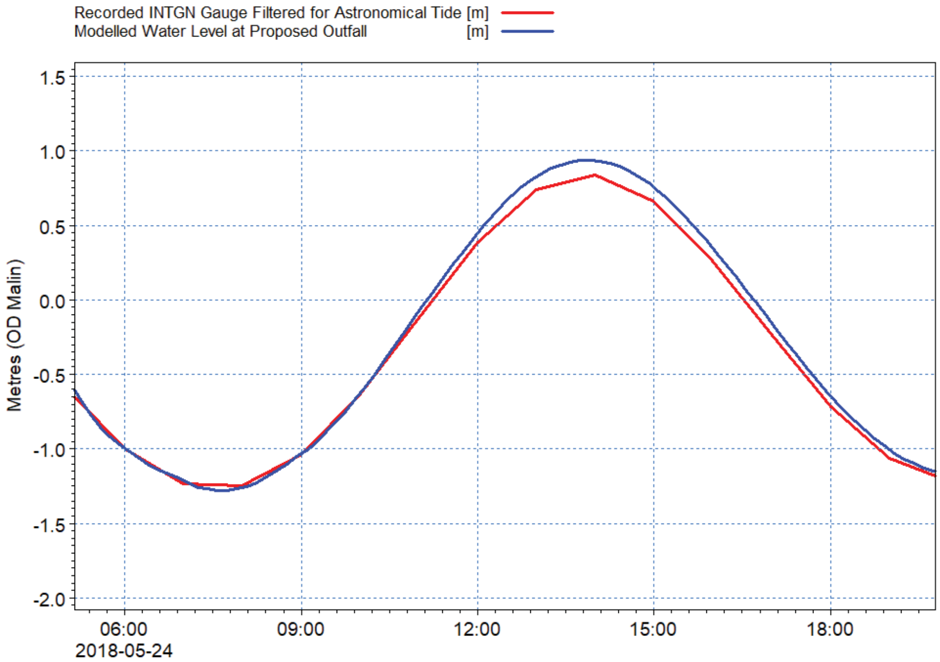
Figure 38: Astronomical spring tide water level calibration



It can be seen from the figure the modelled astronomical water level is a good match to the derived astronomical water level. The water level difference at high tide is very low, while the model slightly overestimates the minimum water level during the low tide and flood tide.

Figure 39 presents the result for the neap tide astronomical validation.

Figure 39: Astronomical neap tide water level calibration



It can be seen from the figure that for the neap tide, the modelled astronomical water level is well matched to the derived astronomical tidal water level. The model slightly overestimates the high tide water level.

The astronomical tidal validation provides greater confidence in the hydrodynamic model demonstrate the accuracy of the model in reproducing water levels for astronomical tides.

5.8 Discussion

The hydrodynamics at the location of the proposed outfall at Castletownbere are characterised by secondary circulations that have noticeably different current speeds and velocity vectors than flow conditions in the main channel. While current speeds in the main channel are generally low (<0.3m/s), they are very low in the vicinity of the outfall (<0.15m/s). Very low current speeds can be difficult to replicate with a depth integrated hydrodynamic model due to the limitations of the numerical formulations and the model calibration needs to be considered in this context.

The model is deemed to be reasonably well matched against the recorded water levels, current speed and current direction for both Spring and Neap tides. The model accurately reproduces observed water levels in the area of interest. While the very low current speeds observed at the site of interest are not reproduced by the model, the overall simulated current speeds are considered to be a reasonable match. The observed current directions are reasonably well captured by the model.

Further validation runs against drogue track data and astronomical tidal data provides greater confidence in the model to reproduce the hydrodynamics in the estuary.

Based on the results of both the model calibration and validation, the hydrodynamic model is deemed suitable for use in assessing the impact of the discharges from the proposed WwTP outfall for Castletownbere.

6 Water Quality Modelling

6.1 Overview

This chapter describes the development and running of the WQ Ecolab model which is coupled to the hydrodynamic model described in the previous chapter. The results of the baseline and proposed scenario model runs are also presented in this chapter.

6.2 Dispersion coefficient

The dispersion coefficient parameter is a key parameter of the WQ model and needs to be specified as part of the model build. It was not possible to calibrate the dispersion coefficient against salinity data due to very little variation in salinity across the tidal cycle – the recorded data indicated that over a spring tidal cycle the salinity varied from 33.9PSU top 34.3PSU. This range is insufficient to allow an accurate dispersion coefficient calibration be made. Data from a dye study can also be used to calibrate the dispersion coefficient. A dye study however was not undertaken as part of the project due to environmental concerns regarding the release of a fluorescent dye into the marine environment.

The specification of the dispersion coefficient in our model is therefore based on best practice within the industry and our experience in developing coastal dispersion models. The 'Scaled Eddy Viscosity' formulation has been used in the WQ model to define the dispersion coefficient. This parameter allows for the dispersion coefficient to vary in time and space and accounts for the varying cell size of the computational mesh. It is the most accurate specification of the dispersion coefficient within the MIKE system.

A scaling factor is specified in the model which can amplify or dampen the dispersion process. Our baseline models have used a scaling factor of 1. Different scaling factors however have been tested as part of a sensitivity analysis to assess the variation in WQ concentrations resulting from changes to the scaling factor. These are presented later in the report.

6.3 Discharges and background concentrations

The background concentrations of the modelled WQ parameters have been accounted for in the model by including coliform/nutrient discharges from three separate sources:

- All relevant WwTP outfalls in Bantry Bay;
- Primary rivers that flow into the Bantry Bay;
- Open sea boundary.

Each outfall and river source is characterised by two separate numbers:

- A flow rate in m^3/s;

- A concentration of the relevant WQ parameter in #/m3 or mg/L (i.e. coliforms, nutrients etc.).

The product of these two numbers gives the total flux of either coliform or nutrient from the outfall/river in #/s or g/m^3.

Discharges along the open sea boundary have been included by specifying a concentration at the boundary.

6.3.1 Outfall discharges

Six separate outfalls presently make up the existing discharge from the Castletownbere agglomeration to Bearhaven. We used the information presented in the Jennings O'Donovan/AECOM report to determine the PE for these outfalls. The flow rates were then estimated by multiplying the PE for each outfall by 225L/person/day[5].

We note that the flow rates derived using this method were circa 12% greater than the Dry Weather Flow (DWF) as presented in the Jennings O'Donovan/AECOM report. For the proposed scenario at Castletownbere the design flow was calculated as the DWF * 1.3. We note that this flow rate corresponds to what was used as part of our near field modelling. For the other outfalls in Bantry Bay which combined contribute to the background concentrations, we have used flow data from the relevant Annual Environmental Report (AER) to derive the outfall flow rate.

The concentrations of the various WQ parameters considered as part of the study for the different stages of treatment have been agreed with Irish Water and are based on their experience and standard values in literature. The outfall flows and concentrations are presented later in Table 20.

6.3.2 Fluvial discharges

As discussed in Section 2.5, a large number of rivers and streams discharge into the Bantry Bay. These discharges are relevant to the study in two ways:

- The rivers act as sources for the WQ parameters considered as part of the study;
- The rivers will increase the volume of water in the bay and therefore increase the dilution of a WQ parameter that is being advected in the Bay.

All the watercourses that impact on the area of interest in Bearhaven Harbour have been included in the model. Each watercourse acts as a source for the WQ parameters considered.

The 50%ile flow rate over the winter months has been used as the flow rate for each river in the model. As none of the rivers are gauged, it was not possible to use gauged data to estimate the 50%ile flow. The following methodology was therefore adopted:

[5] 225L/p/d is Irish Water's assumed rate per day per person

- The Office of Public Works' Flood Studies Update portal was used to identify a hydrologically similar catchment;
- Gauged data from the hydrologically similar catchment was analysed in order to estimate the 50%ile flow for both summer and winter conditions;
- The derived 50%ile flow values were used to estimate flow values for the relevant catchments discharging into Bantry Bay by scaling the flows based on catchment areas.

EPA WQ monitoring data was not available for any of the watercourses discharging into Bantry Bay. It was therefore not possible to estimate the source concentrations for each of the WQ parameters for the rivers.

Instead, values derived by Arup as part of the Whitegate/Aghada UTAS Dispersion Modelling study were used for the Castletownbere Study. For the Whitegate/Aghada study, EPA WQ monitoring data for 3 rivers were utilized to derive averaged values for each of the WQ parameters.

The flows and concentrations used in the model are presented in the following section of the report.

It is noted that the specification of the river concentrations only influences the background concentrations. The reduction in concentration of the relevant WQ parameter with the scheme in place (i.e. the delta value) is not impact as the source concentration is the same for both the baseline and proposed scenario.

6.3.3 Discharge information

The fluvial and outfall discharge points incorporated into the dispersion model in the vicinity of Bere Island are presented in Figure 40 and Figure 41 for the existing and proposed scenarios respectively.

Figure 40: Discharge points – existing scenario. The fluvial inflows are in green and the outfalls in red.

Figure 41: Discharge points – proposed scenario

Table 20 below presents the flow rates and concentrations for all discharges included in the model.

Table 20: Discharge Information

Source Type	Source Name	Flow Rate (m^3/s)	Easting (ING)	Northing (ING)	Treatment Type	WQ Parameter Concentration					
						E. Coli (cfu/100ml)	IE (cfu/100ml)	DIN (mg/l)	MRP (mg/l)	Ammonia (mg/L)	UnI Ammonia (mg/L)
River	Cloghane river	0.2921	58440	40724	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 1	0.0629	62600	41617	–	3000	13	3.05	0.026	0.053	0.0015
River	Inchinagat river	0.3771	63804	42200	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 2	0.0557	66760	44209	–	3000	13	3.05	0.026	0.053	0.0015
River	Creevoge Stream	0.3311	66676	44418	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 3	0.1397	68374	45900	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 4	0.0716	70655	46348	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 5	0.0835	70874	46444	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 6	0.0548	71064	46423	–	3000	13	3.05	0.026	0.053	0.0015
River	Owgariff river	0.1903	72813	46635	–	3000	13	3.05	0.026	0.053	0.0015
River	Rossmackowen river	0.2589	74035	46632	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 7	0.1095	76411	46751	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 8	0.3565	80190	49541	–	3000	13	3.05	0.026	0.053	0.0015
River	Ardrigole river	0.9313	80740	50168	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 9	0.0497	82259	48600	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 10	0.5734	84550	48900	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 11	1.4072	92970	56100	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 12	2.1860	99600	54000	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 13	2.6015	100001	52700	–	3000	13	3.05	0.026	0.053	0.0015
River	Unnamed watercourse 14	1.8457	100000	49850	–	3000	13	3.05	0.026	0.053	0.0015

Source Type	Source Name	Flow Rate (m^3/s)	Easting (ING)	Northing (ING)	Treatment Type	WQ Parameter Concentration E. Coli (cfu/100ml)	IE (cfu/100ml)	DIN (mg/l)	MRP (mg/l)	Ammonia (mg/L)	UnI Ammonia (mg/L)
Sea	Open Sea	-	Applied along downstream boundary		–	400	28	0.20	0.007	0.020	0.0006
Outfall	Glengarriff WwTP	0.0028	93265	55916	Primary Treatment	1000000	40000	54.00	12.000	50.000	0.8350
Outfall	Bantry WwTP	0.0269	96802	48205	Tertiary	10000	400	30.00	3.000	10.000	0.1670
Outfall	Castletownbere (Main Street)	0.0026	68028	46138	No Treatment	10000000	400000	60.00	14.000	55.000	0.9185
Outfall	Castletownbere (Brandyhall)	0.0005	68205	46220	No Treatment	10000000	400000	60.00	14.000	55.000	0.9185
Outfall	Castletownbere (Hospital)	0.0006	68615	45995	No Treatment	10000000	400000	60.00	14.000	55.000	0.9185
Outfall	Castletownbere (Came Woods)	0.0006	67660	45770	No Treatment	10000000	400000	60.00	14.000	55.000	0.9185
Outfall	Castletownbere (Bantry Road)	0.0004	69829	45628	No Treatment	10000000	400000	60.00	14.000	55.000	0.9185
Outfall	Castletownbere (Came Point)	0.0002	67912	45413	No Treatment	10000000	400000	60.00	14.000	55.000	0.9185
Outfall	Castletownbere Proposed Outfall	0.0063	67744	45118	Primary Treatment	1000000	40000	54.00	12.000	50.000	0.8350

6.4 Overview of design model runs

The design model run was simulated with the following parameters:

- Astronomical tidal conditions for the open boundary;
- Simulation period: from 18/05/2018 00:15 to 12/06/2018 22:00 to give a total duration period of circa 25.9 days.
- A warm up period of 6.5 hours.
- No wind forcing was used in the design runs;
- Coliform linear decay rate: T90 = 20 hours[6]
- Assume the cycling of nutrients in the harbour can be described using a liner decay function with T90 values of:
  - DIN T90 = 23 days[7]
  - MRP, TA and UIA T90 = 33 days

The T90 parameter is considered as part of the sensitivity analysis and is presented later in the report.

Spatially varying 95%ile (coliform) and 50%ile (nutrient) plots have been estimated and are presented in the following sections of the report for both the existing and proposed scenario. The difference between the existing and proposed (the 'delta' plot) is also presented.

95%ile (coliform) and 50%ile (nutrient) point concentrations at a number of EPA monitoring points are also presented and assessed. Both the spatially varying and point concentrations are used to assess compliance of the parameters with the EQS thresholds and adherence with the relevant EU water quality directives.

6.5 Design model results – 95%ile plots

Design model results are presented as spatially varying 95%ile (coliform) and 50%ile (nutrient) plots. The plots have been derived using the DatastatisticsFM.exe tool in MIKE 21 which allows percentile calculations to be undertaken on the result files of model simulations runs.

[6] The scientific literature outline a range of coliform T90 values. A T90 value of 20 hours has been selected for E. Coli following consultation with Irish Water. It is noted that this is a conservative estimate. The sensitivity of the T90 value is considered later in the report.

[7] The cycling of nutrients in the marine environment involved complex chemical and biological reactions. We have simplified the process by assuming that it can be represented using a linear decay function. We have conservatively used very slow decay rates in line with previous studies undertaken for Irish Water.

6.5.1 E. Coli

The spatially varying 95%ile plot for E. Coli for both the existing and proposed scenario is presented in Figure 42. The difference between the two plots (the 'delta' plot) is also presented in Figure 42.

From the results it can be seen that the 95%ile concentrations vary across the area of interest in Castletownbere for both scenarios. For the existing scenario concentrations are greater than 1,000 cfu/100ml in the inner harbour area and in the immediate location of the Bantry Road outfall. 95%ile concentrations in the immediate vicinity of where Rivers Derrymihin West, Knockaneroe and West Dom enter the bay are also in excess of 1,000 cfu/100ml due to the coliform loading from the rivers.

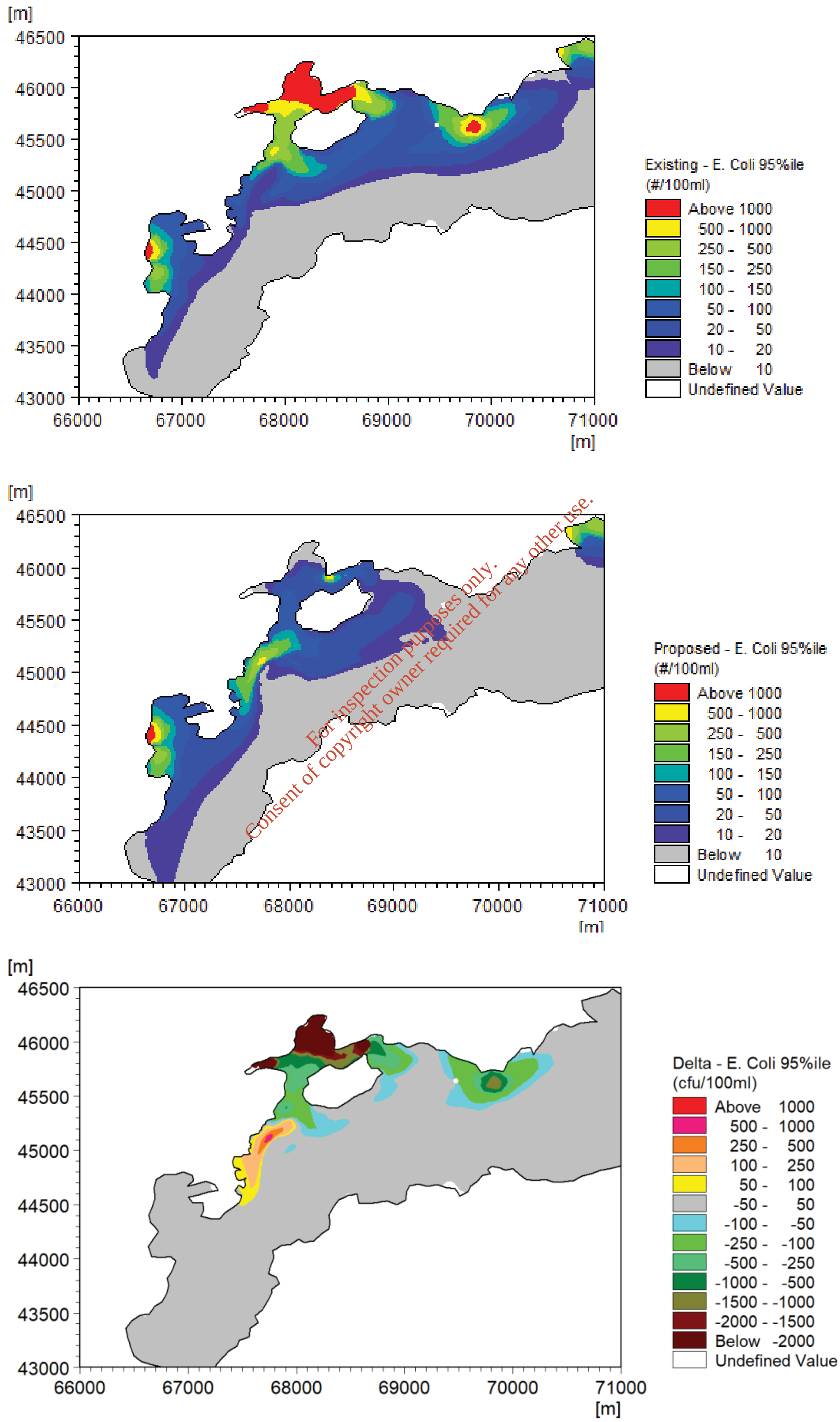
It can be seen from the figure that the concentrations reduce considerably along the North-South direction. 95%ile concentrations are less than 10 cfu/100ml half way line between the coastline at Castletownbere and Bere Island.

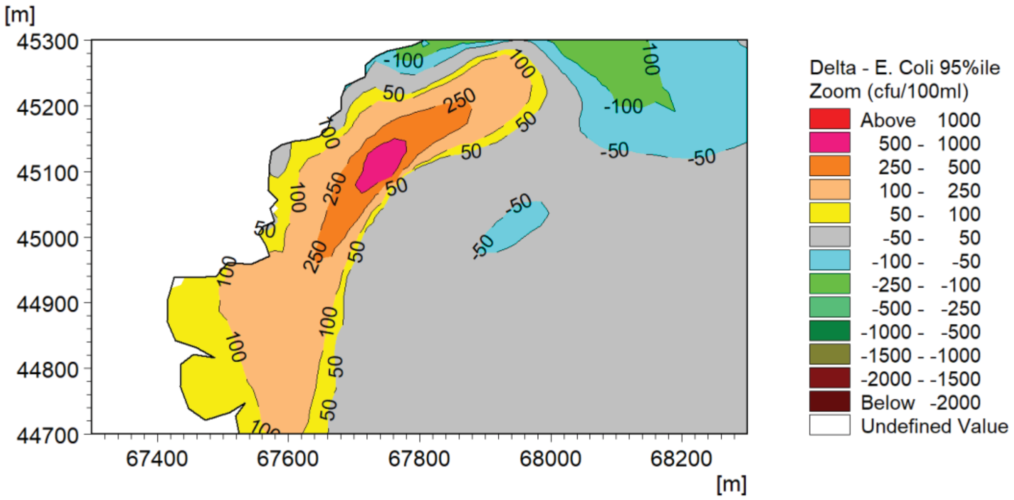
For the proposed scenario the 95%ile E. Coli concentrations are considerably reduced across the harbour area. In the inner harbour area concentrations are less than circa 50 cfu/100ml which represents a very significant reduction from the baseline (1,000 cfu/100ml). At the location of the existing Bantry Road outfall, the concentrations are also very significantly reduced – with the proposed scheme in place the 95%ile concentrations are reduced from greater than 1,000 cfu/100ml to less than 10 cfu/100ml.

The delta plot (Figure 42) illustrates the differences between the existing and proposed scenarios. As the existing scenario has been subtracted from the proposed scenario, the reduction in 95%ile concentrations are presented as negative values while the increase in concentrations are presented as positive values. From the plot it can be seen that the proposed scheme significantly reduces the 95%ile E. Coli concentrations across a large area of Castletownbere harbour and also to the immediate east of the harbour. The largest reduction is greater than circa 1000 cfu/100ml in the inner harbour area which represents a very significant reduction.

The proposed scheme results in an increase in concentration in the vicinity of the proposed outfall. It can be seen from the zoomed in delta plot that the increase varies spatially and is highest in the immediate vicinity of the outfall where it is greater than 500 cfu/100ml. Within circa 50m of the outfall however the increase in the 95%ile E. Coli concentration is much less and varies between 100 and 250 cfu/100ml.

Figure 42: E. Coli 95%ile concentration plots – existing scenario, proposed scenario and delta plot (including a close-up view)





Under the Bathing Water Quality Regulations 2008 (S.I. No. 79/2008), 95%ile E-coli concentrations of 250 cfu/100ml or less in coastal/ transitional waters are considered "Excellent" as indicated in Table 21.

Table 21: Bathing Water Classification

Water Type	Parameter	Excellent	Good	Sufficient
Coastal/Transitional	E-Coli cfu/100ml	250 (*)	500 (*)	500 (**)

(*) based on a 95-percentile evaluation; (**) based on a 90-percentile evaluation

It can be seen from the results presented in Figure 42 that the 250 cfu/100ml 95%ile concentration threshold is exceeded within in the mixing zone of the proposed outfall (i.e. in the immediate vicinity). The concentrations drop below the 250 cfu/100ml threshold within circa 50m from the outfall. It can therefore be concluded that the water is classified as "Excellent" as per the Bathing Water Quality Regulations 2008 (S.I. No. 79/2008) within circa 50m of the outfall.

6.5.2 Intestinal Enterococci 95%ile Plots

The spatially varying 95%ile concentration plot for Intestinal Enterococci for both the existing and proposed scenario is presented in Figure 43. The delta plot is also provided.

The results for Intestinal Enterococci broadly follow the same pattern of concentration and changes in concentration associated with the E. Coli results as presented in the previous section: the 95%ile concentrations of Intestinal Enterococci are significantly reduced across large areas of Castletownbere Harbour. The most significant reduction is at the location of the existing discharges at Castletownbere (see Figure 40) where the reduction is greater than 200 cfu/100ml.

There is an increase in 95%ile concentration of circa 50 cfu/100ml in the immediate vicinity of the proposed outfall. Within circa 120m of the outfall however the increase is less than 2 cfu/100ml which is considered to be very low.

Under the Bathing Water Quality Regulations 2008 (S.I. No. 79/2008), (outlined in Table 23) 95%ile Intestinal Enterococci concentrations of 100 cfu/100ml or less in coastal/ transitional waters is considered "Excellent".

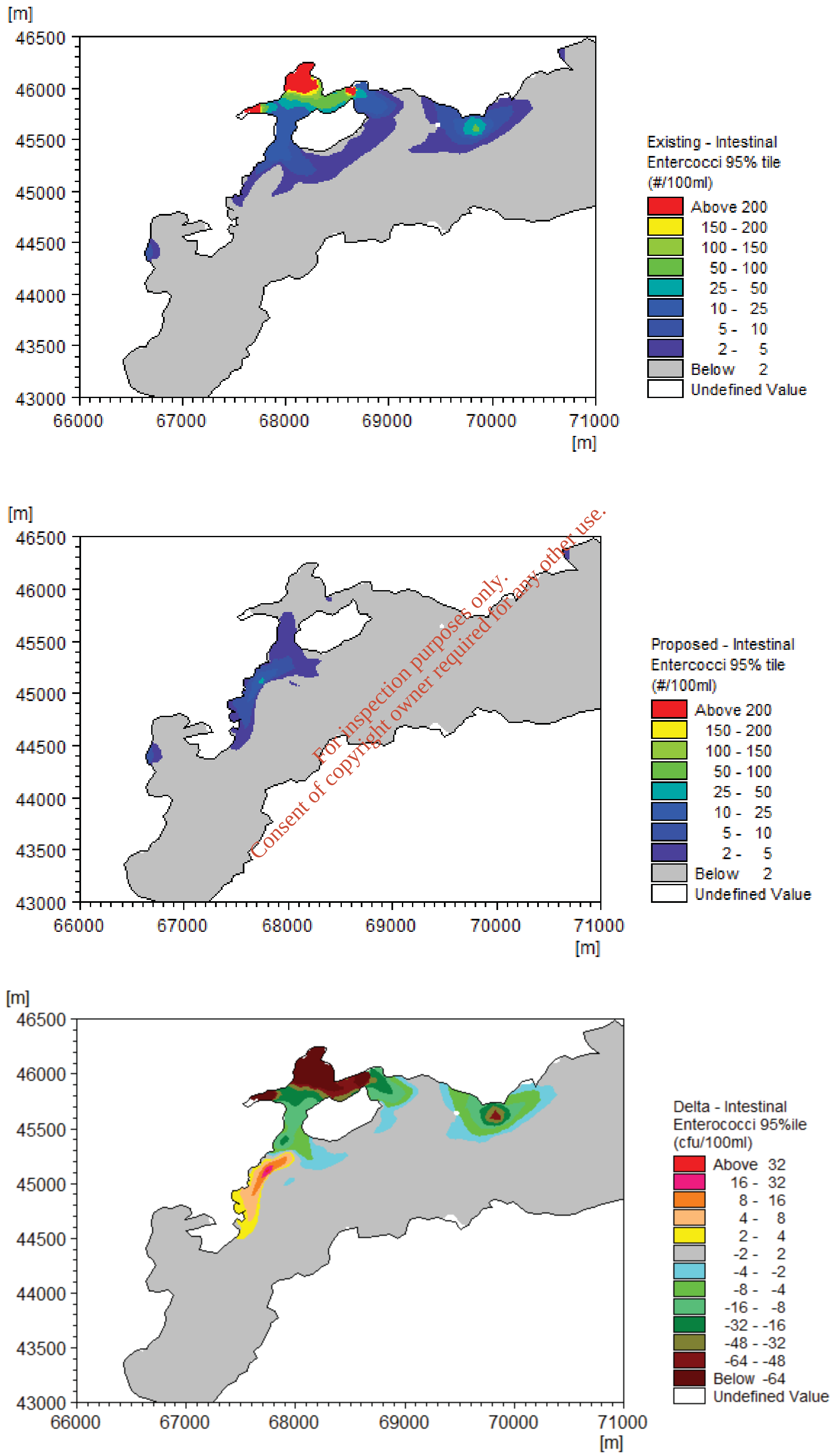
Table 22: Bathing Water Quality Regulations

Water Type	Parameter	Excellent	Good	Sufficient
Coastal / Transitional	Intestinal enterococci cfu/100ml	100 (*)	200 (*)	185 (**)

(*) based on a 95-percentile evaluation (**) based on a 90-percentile evaluation

For the proposed scenario the 95%ile concentration are less than 100 cfu/100ml at the outfall location and less than 25 cfu/100ml within circa 20m of the outfall. The proposed scheme therefore maintains "Excellent" status as per the Bathing Water Quality Regulations for Intestinal Enterococci across Bearhaven Harbour.

Figure 43: Intestinal Enterococci 95%ile concentration plots – existing scenario, proposed scenario and delta plot



6.5.3 DIN 50%ile Plots

The spatially varying 50%ile plot for DIN for both the existing and proposed scenario is presented in Figure 44. The delta plot is also presented in the figure.

From the results it can be seen that the 50%ile concentrations vary across the area of interest in Castletownbere for both scenarios. For the existing scenario concentrations exceed circa 0.1mg/l in the inner harbour area. These levels are notably reduced in the proposed scenario, with maximum values of circa 0.06mg/l observed in the inner harbour area.

In both cases peak concentrations of over 0.1mg/l occur at the location of the fluvial inflows i.e. at Knockaneroe and West Dom rivers. As the fluvial inflow loadings are unchanged in both scenarios the results are the same.

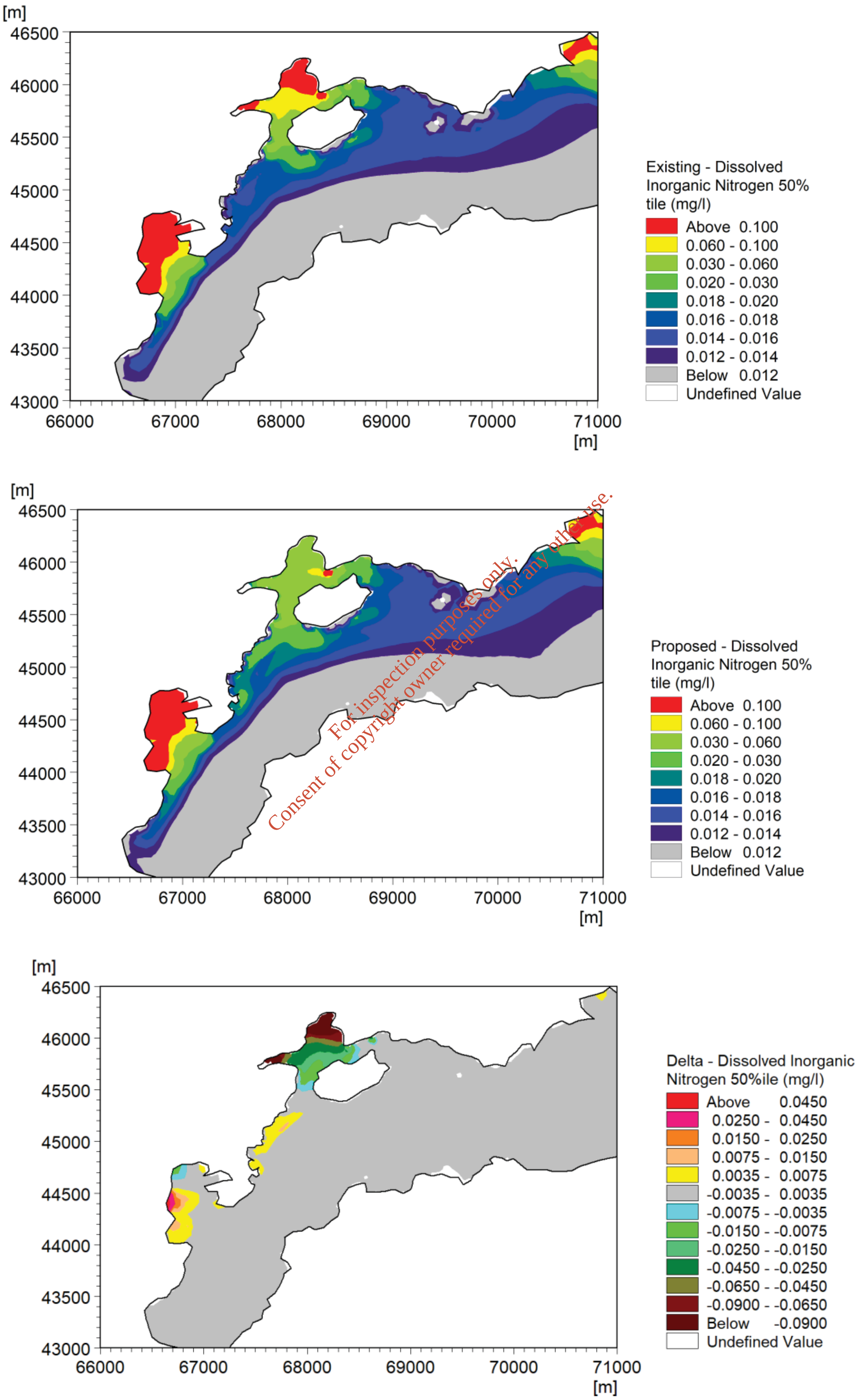
The 50%ile concentrations are very low on the Southern side of Bearhaven Harbour adjacent to Bere Island.

It can be seen from the delta plot that the proposed scheme reduces the 50%ile concentrations of DIN across the inner harbour. At the location of the existing outfalls in the inner harbour the reduction is greater than 0.03mg/l.

The proposed discharge increases the 50%ile concentrations of DIN in the immediate vicinity of the proposed outfall. It can be seen from Figure 44 that the concentrations are increased by circa 0.015mg/L at the outfall. The increase in concentration to the area west of the proposed outfall is less and varies between 0.005mg/l to 0.001mg/l.

In the context of the EQSs as defined in the Surface Water Regulations, the increase in DIN associated with the proposed outfall is very minor. As the target level of DIN is 0.25mg/l, our results show that the increase associated with the proposed scheme in place in the vicinity of the outfall is less than 5% of this limit. This increase is therefore deemed to be very minor.

Figure 44: DIN 50%ile concentration plots – existing scenario, proposed scenario and delta plot



6.5.4 MRP 50%ile Plots

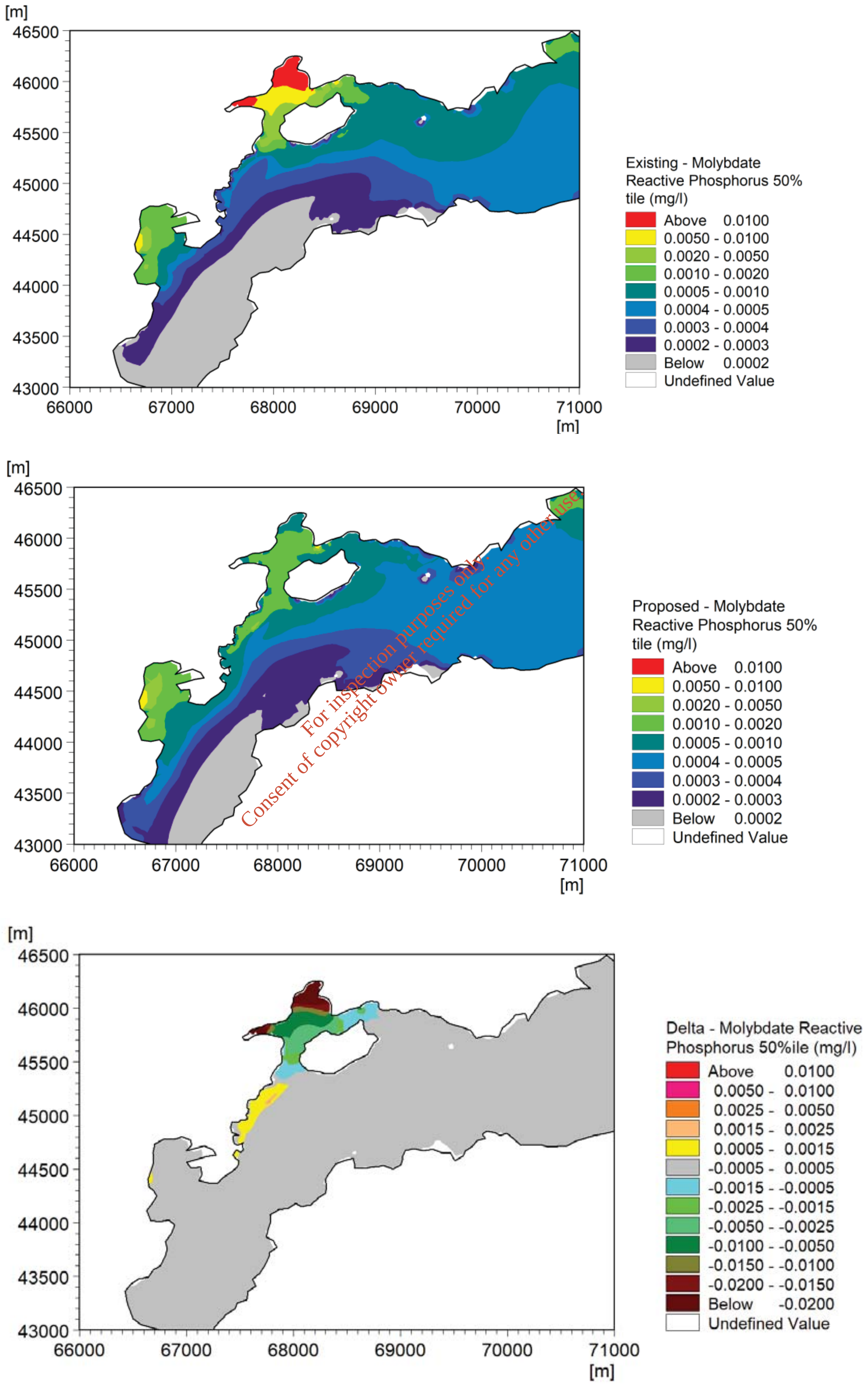
The results for MRP are presented in Figure 45. It can be seen that the general pattern of the 50%ile concentration and change in concentration associated with the proposed scheme for MRP is broadly similar to the results presented in the previous section for DIN.

The proposed scheme reduces the 50%ile concentration in the outer harbour but increases concentrations locally in the immediate vicinity of the outfall. In the inner harbour concentrations are reduced from circa 0.01mg/l in the existing scenario to circa 0.002mg/l in the proposed scenario. In the vicinity of the proposed outfall 50%ile concentrations are increased from circa 0.004mg/l to over 0.001mg/l.

For both scenarios the MRP 50%ile concentrations reduce in a North-south direction due to the hydrodynamics of the model limiting the advection of the plume into this area.

The increase in the 50%ile concentration of MRP local to the outfall represents a very small fraction of the target level of 0.04mg/l as specified by the Surface Water Regulations EQSs. Our results indicate that the increase is less than 3% of the target level which is deemed to be a very minor increase.

Figure 45: MRP 50%ile concentration plots – existing scenario, proposed scenario and delta plot



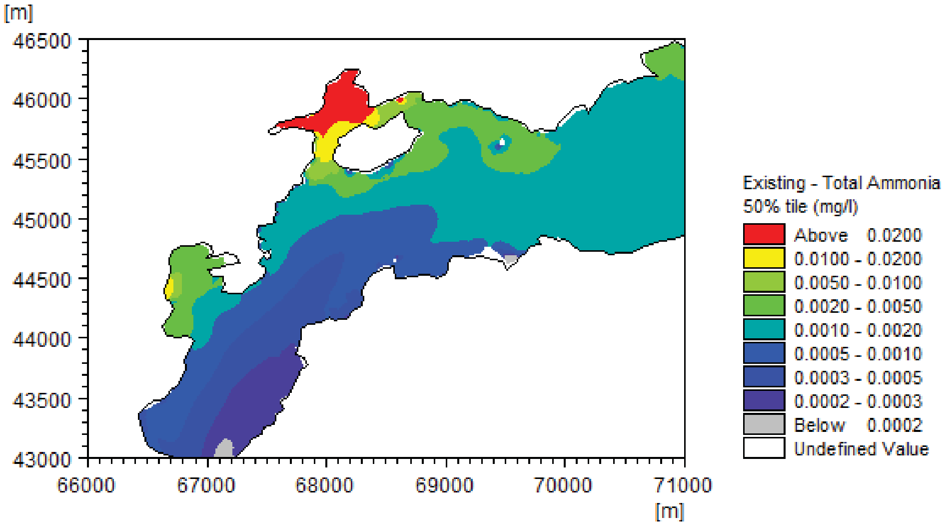
6.5.5 Total Ammonia 50%ile Plots

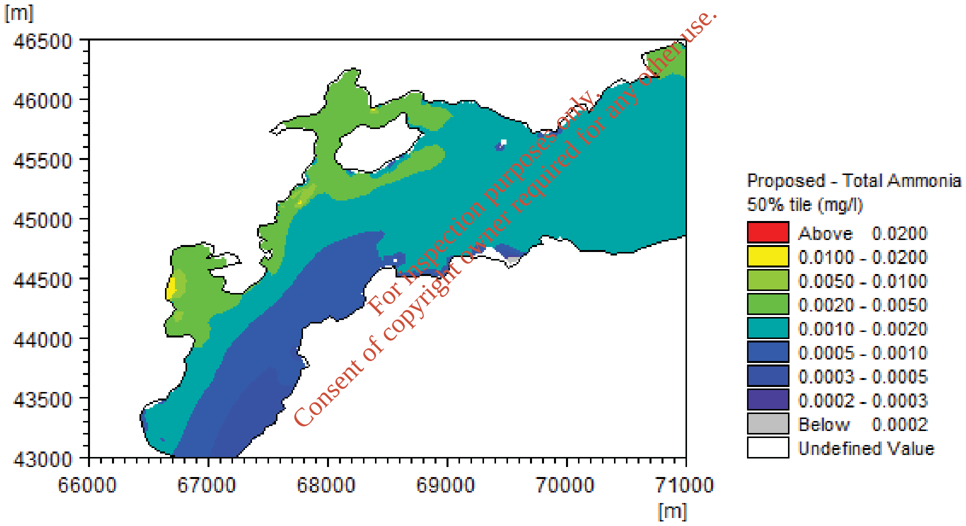
The results for TA are presented in Figure 46. Implementation of the proposed scheme is seen to reduce the TA in the vicinity of existing discharges, where concentrations are reduced from circa 0.02mg/l to circa 0.005mg/l. At the East Side of the inner harbour, 50%ile concentrations are reduced by circa 0.002 mg/l with the proposed scheme in place.

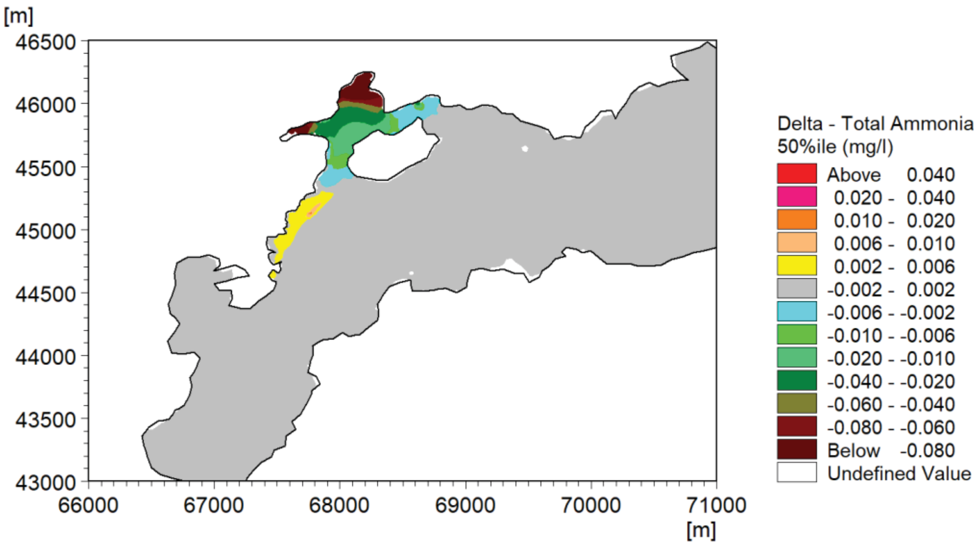
Concentrations are increased locally at the proposed outfall location with the scheme in place. For the existing scenario concentrations are circa 0.002mg/L while for the proposed scenario they are circa 0.02mg/l. This represents an increase of circa 0.02mg/l with the scheme in place.

The target level of TA as per the EQSs as defined in the Salmonid Water Regulations is 1mg/l. In this context the increase in TA associated with the proposed outfall is very minor.

Figure 46: TA 50%ile concentration plots – existing scenario, proposed scenario and delta plot







6.5.6 Unionised Ammonia 50%ile Plots

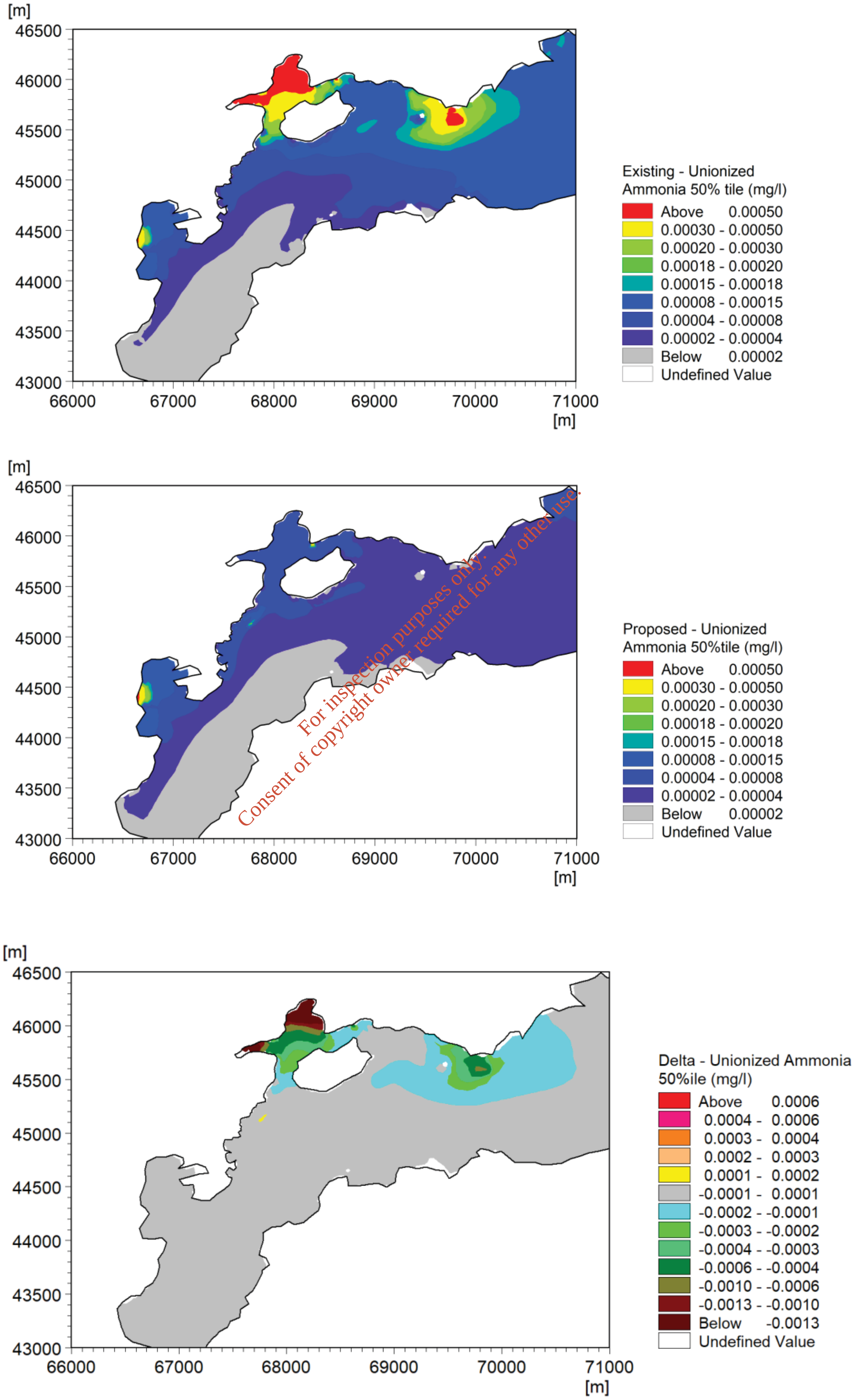
Model results for assessment of Unionised Ammonia are presented in Figure 47. It can be seen that the general pattern of the 50%ile concentration and change in concentration associated with the proposed scheme for UiA is broadly similar to the results presented in the previous section for TA – The proposed scheme significantly reduces the 50%ile concentration in the outer harbour but increases concentrations locally in the vicinity of the proposed outfall location.

For the existing scenario the 50%ile UiA concentrations in the inner harbour is circa 0.0005mg/l. For the proposed scenario concentrations in this location are reduced to circa 0.00008mg/l which is considered significant.

At the vicinity of the proposed outfall concentrations of circa 0.00008mg/l are observed for the existing scenario and increase to circa 0.003mg/l in the proposed scenario.

The UIA target level as specified by the Salmonid Water Regulations EQSs is 0.02mg/l. As the maximum increase in the 50%ile concentration of UiA local to the outfall is circa 0.002mg/l, it is considered to be represent a very minor increase.

Figure 47: UiA 50%ile concentration plots – existing scenario, proposed scenario and delta plot



6.6 Baseline Scenario Results – exceedance concentrations at monitoring points

The 95%ile and 50%ile concentrations for the water quality parameters considered in this study at each of the designated monitoring points in Castletownbere are presented in Table 23. These monitoring points are an amalgamation of points from the EPA's National Water Monitoring Stations as well as sampling points from the bathing water and shellfish water directives. The location of the points is presented in Figure 48.

Figure 48: Location of monitoring points

The difference between the 95%ile and 50%ile concentrations at each of the points is also presented in the delta columns of the table. The green shading in the delta column indicates a reduction in the concentration with the proposed scheme in place while the red shading indicates an increase.

It is evident from the table that the 95%ile concentrations of both E. Coli and Intestinal Enterococci are reduced at most points across the harbour with the exception of the area immediately adjacent to the location of the proposed outfall.

The 50%ile nutrient concentrations are also reduced at most of the points in the harbour, with only very minor increases in the vicinity of the proposed outfall location.

In the context of the EQS thresholds of the various parameters however, the increases in the percentile concentrations are considered to be low as discharges from the proposed outfall do not result in the EQS thresholds being exceeded. The exception to this is at the location of the proposed outfall which is within the mixing zone (refer to Section 6.7). The proposed outfall is therefore in full compliance with the relevant EU water quality directives.

Table 23: Coliform (95%ile) and Nutrient (50%ile) concentrations at monitoring points

Concentrations	95%ile						50%ile											
	Intestinal Enterococci (cfu/100ml)			Escherichia Coliforms (cfu/100ml)			Dissolved Inorganic Nitrogen (mg/l)			Molybdate Reactive Phosphorus (mg/l)			Total Ammonia (mg/l)			Unionised Ammonia (mg/l)		
Label	Existing	Proposed	Delta	Existing	Proposed	Delta	Existing	Proposed	Delta	Existing	Proposed	Delta	Existing	Proposed	Delta	Existing	Proposed	Delta
Piper's Point, Bullig Bay	0	0	0	3	9	6	7E-03	7E-03	6E-04	1E-04	2E-04	8E-05	3E-04	7E-04	4E-04	1E-05	1E-05	2E-06
RSL Dunboy Castle	0	1	0	56	56	0	4E-02	4E-02	8E-04	5E-04	7E-04	2E-04	1E-03	2E-03	1E-03	4E-05	5E-05	7E-06
Dunboy Castle	1	1	0	196	200	4	2E-01	2E-01	5E-03	2E-03	2E-03	2E-04	4E-03	5E-03	1E-03	1E-04	1E-04	1E-05
Walter Scott Rock Buoy	2	0	-2	61	11	-50	2E-02	2E-02	4E-04	4E-04	5E-04	9E-05	1E-03	2E-03	5E-04	4E-05	3E-05	-9E-06
Castletownbere Harbour	32	1	-32	821	28	-792	8E-02	5E-02	-2E-02	6E-03	1E-03	-5E-03	2E-02	3E-03	-2E-02	5E-04	7E-05	-4E-04
RSL Opp. Minane Island	1	0	-1	32	3	-29	2E-02	1E-02	-7E-04	7E-04	5E-04	-2E-04	3E-03	2E-03	-6E-04	1E-04	3E-05	-1E-04
Hornet Rock Buoy	0	0	0	8	7	-1	1E-02	1E-02	2E-04	5E-04	4E-04	-2E-05	2E-03	2E-03	-4E-05	1E-04	3E-05	-9E-05
Lawrence Cove	0	0	0	0	0	0	6E-03	6E-03	-5E-05	2E-04	2E-04	-2E-05	6E-04	6E-04	-5E-05	4E-05	1E-05	-3E-05
Rossmackowen	0	0	0	28	29	0	4E-02	4E-02	-2E-03	5E-04	5E-04	-3E-05	1E-03	1E-03	-4E-05	5E-05	3E-05	-2E-05
RSL Carraiglee Point	0	0	0	0	0	0	7E-03	7E-03	0.0	1E-04	1E-04	0.0	2E-04	2E-04	-2E-06	1E-05	6E-06	-7E-06
Mouth of Berehaven	0	0	0	0	0	0	2E-03	2E-03	-5E-05	3E-05	3E-05	4E-07	7E-05	7E-05	5E-06	3E-06	2E-06	-8E-07
Mouth of Bantry Bay	0	0	0	0	0	0	8E-04	1E-03	4E-04	1E-05	1E-05	4E-06	2E-05	3E-05	7E-06	7E-07	8E-07	5E-08
Roancarrigmore	0	0	0	0	0	0	2E-03	3E-03	6E-04	2E-05	3E-05	2E-06	5E-05	6E-05	4E-06	2E-06	2E-06	-2E-07
South of Mehal Head	0	0	0	0	0	0	2E-04	5E-04	2E-04	3E-06	5E-06	2E-06	6E-06	1E-05	4E-06	1E-07	3E-07	1E-07
Proposed Outfall	1	23	22	17	563	546	2E-02	2E-02	7E-03	4E-04	1E-03	9E-04	1E-03	5E-03	4E-03	5E-05	8E-05	4E-05
CTB Gauge	48	0	-48	1214	27	-1188	6E-02	4E-02	-2E-02	5E-03	9E-04	-4E-03	2E-02	3E-03	-2E-02	4E-04	6E-05	-3E-04
Castletownbere AER Monitoring Point	1	3	2	33	83	51	2E-02	2E-02	5E-03	4E-04	1E-03	1E-03	1E-03	6E-03	4E-03	5E-05	9E-05	4E-05

6.7 Mixing Zones

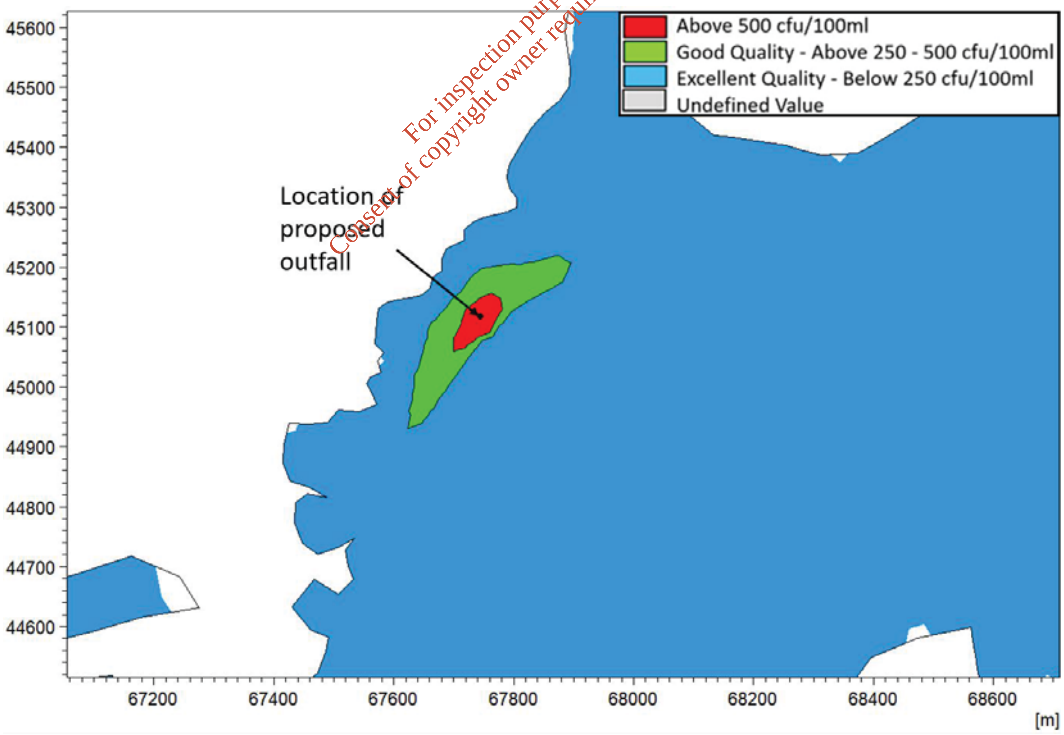
The mixing zone for the proposed outfall has been estimated as part of the study. Our methodology for calculating the mixing zone is:

- Run the proposed scenario model with zero background concentration (i.e. only simulate the proposed outfall in the model);
- Calculate the 95%ile of the model results;
- Present the 95%ile results with the colour palette set to the relevant target values of the relevant EU water directive.

The results for E. Coli are presented in Figure 49 with the target values set to the bathing water directive. We note that this parameter has been selected to delineate the mixing zone as it is the produces the most conservative estimate (i.e. largest) of the mixing zone.

It can be seen that the mixing zone is limited to the immediate vicinity of the outfall and is correlated with the direction in which the plume is advected away from the outfall. The zone that exceeds the 500 cfu/100ml threshold is approximately 3,800m^2. The zone that is of good quality is approximately 28,600m^2 in area.

Figure 49: Mixing Zone for outfall (outfall location indicated)



6.8 Discussion

The results of our model show that the 95%ile concentrations of both E. Coli and Intestinal Enterococci are significantly reduced within Castletownbere harbour with the proposed scheme in place. The scheme does however result in an increase in the coliform concentration in the vicinity of the proposed outfall.

The proposed scheme however does not however result in concentrations of E. Coli or Intestinal Enterococci exceeding their EQS thresholds at any location in the harbour (with the single exception of the location of the proposed outfall).

The results of the model also indicate that the 50%ile concentrations of both DIN, MRP, TA and UiA are reduced across large areas of Castletownbere Harbour but are increased in the vicinity of the location of the proposed outfall.

In the context of the EQS thresholds, the increases in the percentile concentrations are considered to be minor and do not lead to the thresholds being exceeded at any of the designated EPA Surface Water Regulation monitoring points. Discharges from the proposed WwTP for Castletownbere are therefore in full compliance with the EU water regulations.

7 Dispersion Model Sensitivity Analysis

7.1 Overview

Four separate sensitivity analysis (SA) simulations runs were undertaken as part of work. These are:

- SA1: Decay Sensitivity – The T90 value of both E. Coli and Intestinal Enterococci was increased from 20 hours to 40 hours.
- SA2: Wind Sensitivity – a Constant wind speed of 5.14m/s blowing from the South West (240 degrees). We note that this wind speed represents the 50%ile wind speed blowing from the predominate south westerly direction based on hourly data from Cork Airport from a single calendar year.
- SA3: Dispersion coefficient sensitivity – Model run with an increased Scaled Eddy Viscosity Formulation factor of 1.5.
- SA4: Dispersion coefficient sensitivity – Model run with a decreased Scaled Eddy Viscosity Formulation factor of 0.5.

7.2 Sensitivity analysis results

The findings of the analysis are presented in the following tables.

Table 24: Sensitivity Analysis – 95%ile Escherichia Coliform concentrations

	Escherichia Coliforms (95%ile)				
	Proposed	**S1 - Decay**		**S2 - Wind**	
	(cfu/100ml)	**(cfu /100ml)**	**Delta**	**(cfu/100ml)**	**Delta**
Piper's Point, Bullig Bay	9	15	6	7	-2
RSL Dunboy Castle	56	78	22	40	-16
Dunboy Castle	200	236	36	241	41
Walter Scott Rock Buoy	11	26	15	9	-2
Castletownbere Harbour	28	46	18	43	15
RSL Opp. Minane Island	3	10	7	9	6
Hornet Rock Buoy	7	13	6	3	-5
Lawrence Cove	0	0	0	0	0
Rossmackowen	29	35	6	27	-2
RSL Carraiglee Point	0	1	1	1	1
Mouth of Berehaven	0	1	1	0	0
Mouth of Bantry Bay	0	0	0	0	0
Roancarrigmore	0	0	0	0	0
South of Mehal Head	0	0	0	0	0
Proposed Outfall	563	595	32	875	312
CTB Gauge	27	43	16	47	20
Castletownbere AER Monitoring Point	83	112	29	79	-4

It can be seen from Table 24 that the 95%ile concentration of E. Coli are not sensitive to the more conservative decay values and neither are they sensitive to the inclusion of the wind forcing.

For a number of the points in the vicinity of the proposed outfall however there is a noticeable increase in the 95%ile concentration. In the context of the EQS thresholds however the increase is considered small.

Table 25: Sensitivity Analysis – 95%ile Escherichia Coliform concentrations

	Escherichia Coliforms (95%ile)				
	Proposed- Eddy Viscosity Scaling Factor of 1	S3 - Eddy Viscosity Scaling Factor of 1.5		S4 - Eddy Viscosity Scaling Factor of 0.5	
	(cfu/100ml)	(cfu/100ml)	Delta	(cfu/100ml)	Delta
Piper's Point, Bullig Bay	9	9	0	8	-1
RSL Dunboy Castle	56	48	-8	67	11
Dunboy Castle	200	186	-14	218	18
Walter Scott Rock Buoy	11	11	0	12	1
Castletownbere Harbour	28	27	-1	29	1
RSL Opp. Minane Island	3	3	0	3	0
Hornet Rock Buoy	7	6	-1	7	0
Lawrence Cove	0	0	0	0	0
Rossmackowen	29	26	-3	32	3
RSL Carraiglee Point	0	0	0	0	0
Mouth of Berehaven	0	0	0	0	0
Mouth of Bantry Bay	0	0	0	0	0
Roancarrigmore	0	0	0	0	0
South of Mehal Head	0	0	0	0	0
Proposed Outfall	563	559	-4	561	-2
CTB Gauge	27	29	2	24	-3
Castletownbere AER Monitoring Point	83	89	6	77	-6

It can be seen from Table 25 that the model's results are not sensitive to the changes in the scaling factor on the dispersion coefficient. In the immediate vicinity of the outfall the different scaling factors lead to only marginal changes.

Table 26: Sensitivity Analysis – 95%ile Intestinal Enterococci concentrations

	Intestinal Enterococci (95%ile)				
	Proposed	**S1 - Decay**		**S2 - Wind**	
	(cfu/100ml)	**(cfu/100ml)**	**Delta**	**(cfu/100ml)**	**Delta**
Piper's Point, Bullig Bay	0	1	1	0	0
RSL Dunboy Castle	1	1	0	1	0
Dunboy Castle	1	1	0	1	0
Walter Scott Rock Buoy	0	1	1	0	0
Castletownbere Harbour	1	1	0	2	1
RSL Opp. Minane Island	0	0	0	0	0
Hornet Rock Buoy	0	1	1	0	0
Lawrence Cove	0	0	0	0	0
Rossmackowen	0	0	0	0	0
RSL Carraiglee Point	0	0	0	0	0
Mouth of Berehaven	0	0	0	0	0
Mouth of Bantry Bay	0	0	0	0	0
Roancarrigmore	0	0	0	0	0
South of Mehal Head	0	0	0	0	0
Proposed Outfall	23	24	1	35	12
CTB Gauge	0	0	0	0	0
Castletownbere AER Monitoring Point	3	4	1	3	0

It can be seen from Table 26 that the 95%ile concentration are not sensitive to the slower decays rates as the changes in concentration at the monitoring points is very low. The change with inclusion of the wind forcing is also very minor.

Table 27: Sensitivity Analysis – 95%ile Intestinal Enterococci concentrations

	Intestinal Enterococci (95%ile)				
	Proposed- Eddy Viscosity Scaling Factor of 1	S3 - Eddy Viscosity Scaling Factor of 1.5		S4 - Eddy Viscosity Scaling Factor of 0.5	
	(cfu/100ml)	(cfu/100ml)	Delta	(cfu/100ml)	Delta
Piper's Point, Bullig Bay	0	0	0	0	0
RSL Dunboy Castle	1	1	0	1	0
Dunboy Castle	1	1	0	1	0
Walter Scott Rock Buoy	0	0	0	0	0
Castletownbere Harbour	1	1	0	1	0
RSL Opp. Minane Island	0	0	0	0	0
Hornet Rock Buoy	0	0	0	0	0
Lawrence Cove	0	0	0	0	0
Rossmackowen	0	0	0	0	0
RSL Carraiglee Point	0	0	0	0	0
Mouth of Berehaven	0	0	0	0	0
Mouth of Bantry Bay	0	0	0	0	0
Roancarrigmore	0	0	0	0	0
South of Mehal Head	0	0	0	0	0
Proposed Outfall	23	22	-1	22	-1
CTB Gauge	0	0	0	0	0
Castletownbere AER Monitoring Point	3	4	1	3	0

It can be seen from Table 27 that the results are not sensitive to the changes in the dispersion coefficient. In the immediate vicinity of the outfall the different scaling factors lead marginally lower concentrations.

7.3 Discussion

A number of sensitivity model runs have been undertaken which have examined changes to the decay rates, wind forcing and dispersion coefficient. The results for EC and IE have been presented and demonstrate that none of these sensitivity runs result in the any of the EQS thresholds from any of the EU Water regulation directives being exceeded. The other WQ parameters included in the sensitivity model runs but not presented as they have similar findings.

It can be concluded therefore that the model results are not sensitive to changes in decay rates, wind forcing or the dispersion coefficient.

8 Discussion and Conclusions

Arup has been commissioned by Irish Water to undertake a water quality impact assessment study for the proposed WwTP at Castletownbere as part of the Cork UTAS project.

This report presents the findings of Phase 2 of the study which considered the concentrations of E. Coli, Intestinal Enterococci, DIN, MRP, Ammonia and Unionised Ammonia in the far field.

In order to undertake the assessment a high-resolution MIKE 21 Water Quality model of Bantry Bay was developed. A baseline (existing scenario) model was first developed which simulated existing concentrations of the six relevant state variables in the area of interest. The model was then reconfigured to simulate the proposed scenario. By comparing the results of the two scenarios the impact of the proposed WwTP can be determined.

The hydrodynamic element of the model has been calibrated and validated against recorded water level, current speeds and direction data at the site of interest. The model is reasonably well matched against the recorded data.

Our model results show that the 95%ile concentrations of both E. Coli and Intestinal Enterococci are significantly reduced in the inner harbour area of Castletownbere with the proposed scheme in place. Our model results also show that the 50%ile concentrations of DIN, MRP, TA and UiA are reduced across large areas of the harbour area.

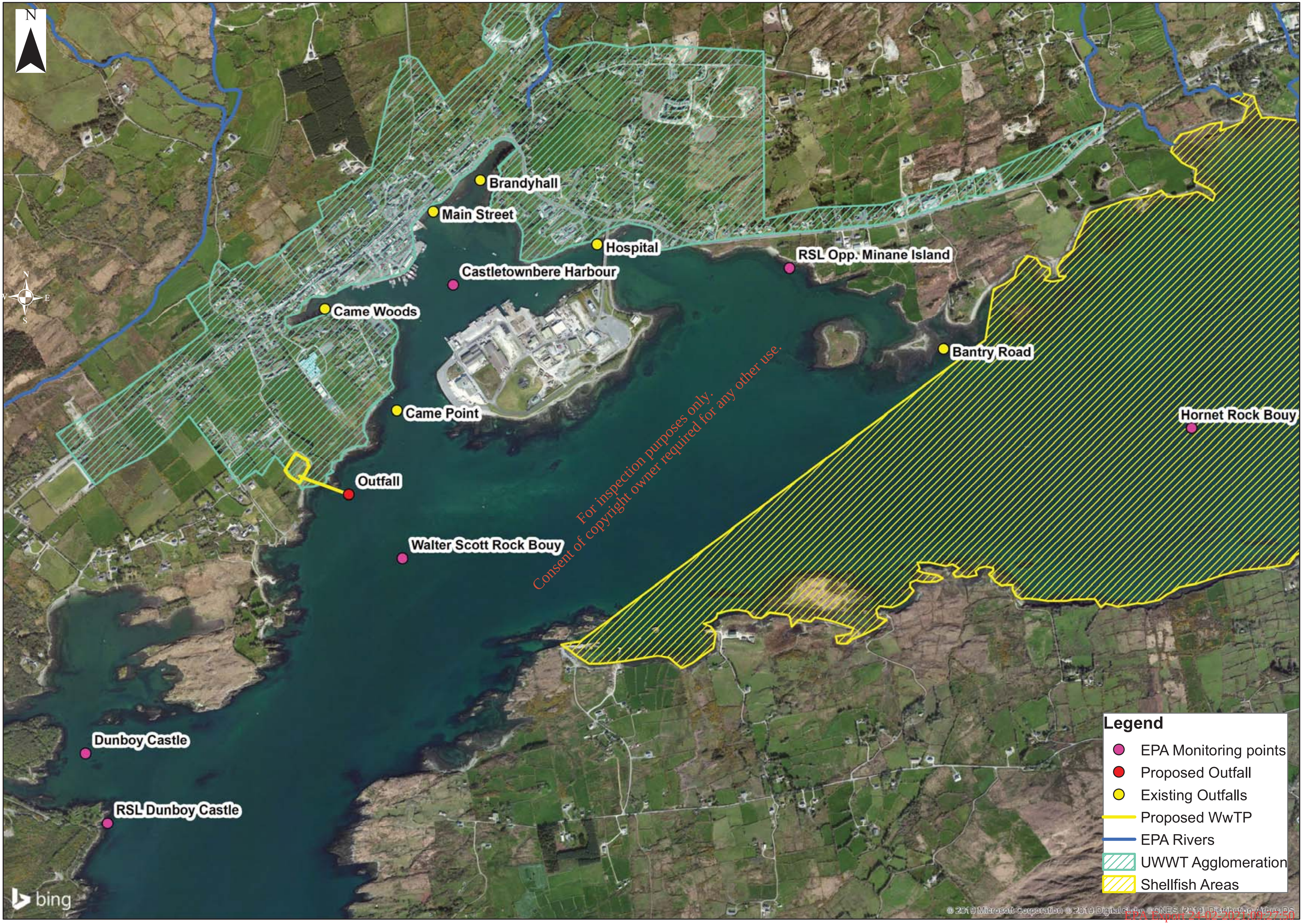
Our results also indicate that the 95%ile concentrations of both E. Coli and Intestinal Enterococci as well as the 50%ile concentrations of the other modelled nutrients are increased in the vicinity of the proposed outfall location. The increases however do not lead to the EQS at any of the designated EPA Surface Water Regulation monitoring points outside the immediate mixing zone to be exceeded.

The proposed scheme therefore does not cause any of the EQS thresholds in Castletownbere harbour to be exceeded and the discharges from the proposed WwTP for Castletownbere are in full compliance with the relevant EU water regulations.

A number of sensitivity model runs have been undertaken which have examined changes to the coliform decay and wind forcing. Neither of these sensitivity runs result in the any of the EQS thresholds from any of the EU Water regulation directives being exceeded.

Appendix A

Area of interest map


N
Brandyhall
Main Street
Hospital
Castletownbere Harbour
RSL Opp. Minane Island
Came Woods
Bantry Road
Came Point
Hornet Rock Bouy
Outfall
Walter Scott Rock Bouy
Dunboy Castle
RSL Dunboy Castle
Legend
EPA Monitoring points
Proposed Outfall
Existing Outfalls
Proposed WwTP
EPA Rivers
UWWT Agglomeration
Shellfish Areas
bing
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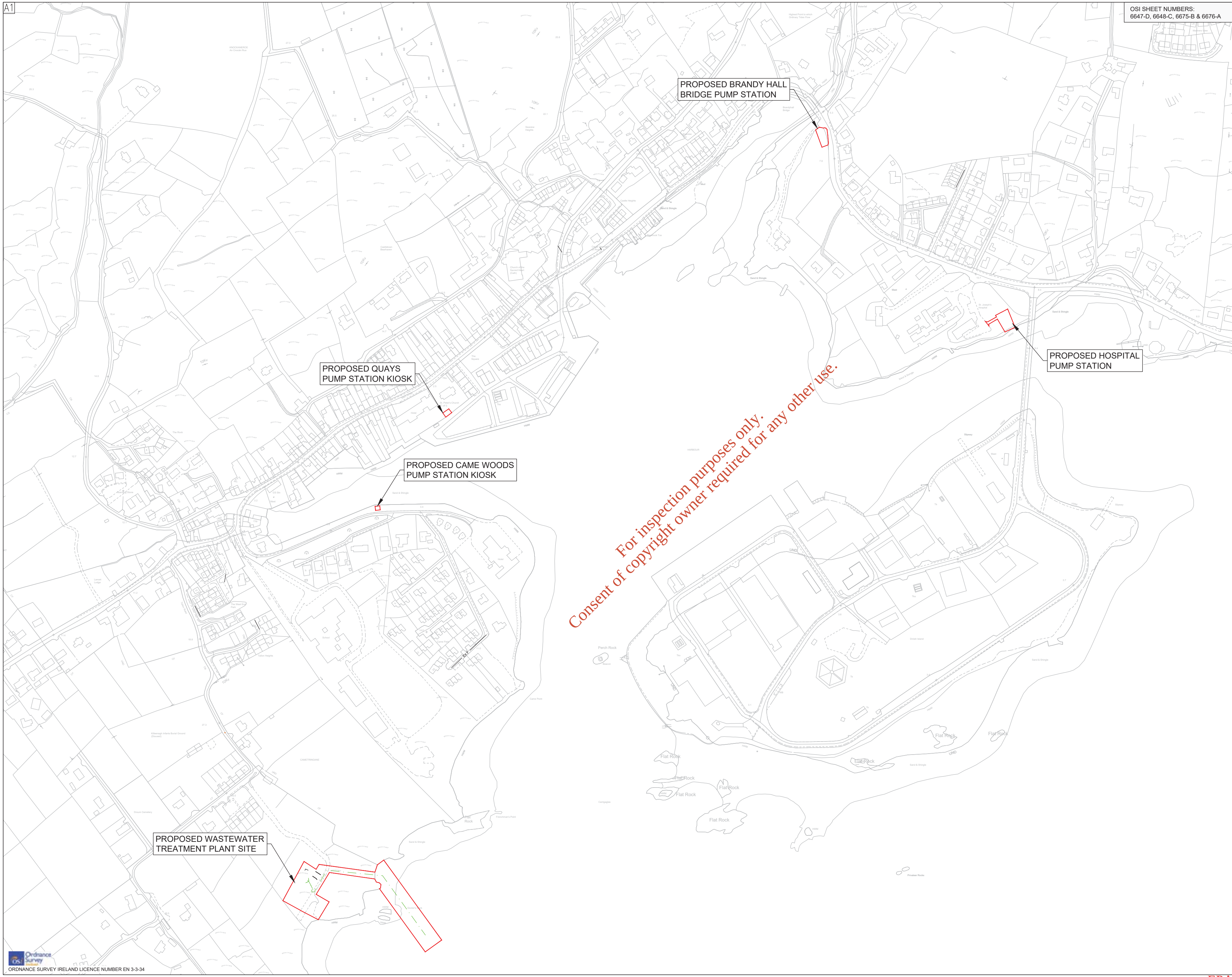
Appendix B

Proposed scheme



OSI SHEET NUMBERS:
6647-D, 6648-C, 6675-B & 6676-A

GENERAL NOTES

N W E S

LEGEND:

PROPOSED SITE BOUNDARY

PROPOSED OUTFALL

NOTES:

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PROJECT
CASTLETOWNBERE SEWERAGE SCHEME
UTAS - CORK BUNDLE

DRAWING TITLE
PROPOSED WASTE WATER TREATMENT PLANT, PUMP STATION & KIOSKS OVERALL SITE LAYOUT PLAN

STATUS
FOR PLANNING

Date: 17/12/19	Scale: 1:2500@A1 1:1250@A3	Drawn: TD	Chk: AM	App: KOS
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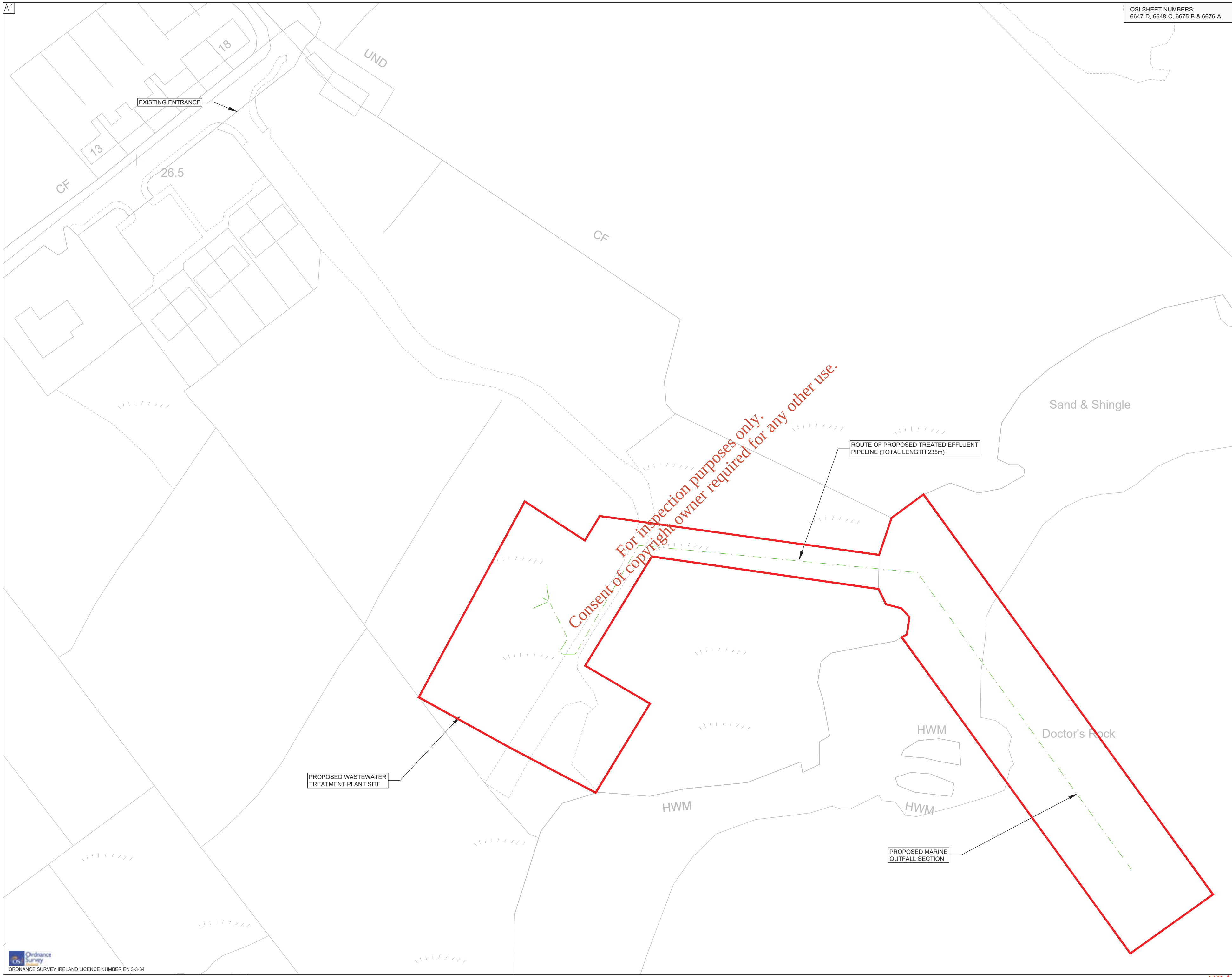

GENERAL NOTES

LEGEND:

PROPOSED SITE BOUNDARY

PROPOSED OUTFALL

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PROJECT
CASTLETOWNBERE SEWERAGE SCHEME
UTAS - CORK BUNDLE

DRAWING TITLE
LAYOUT PLAN
OF OUTFALL

STATUS
FOR PLANNING

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Appendix C

Phase 1 – Near field modelling report

Irish Water

Cork UTAS

Castletownbere Phase 1 Dispersion Modelling Report

Issue 1 | 16 December 2019

Job number 257589-00

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Issue Document Verification with Document ✓

Contents

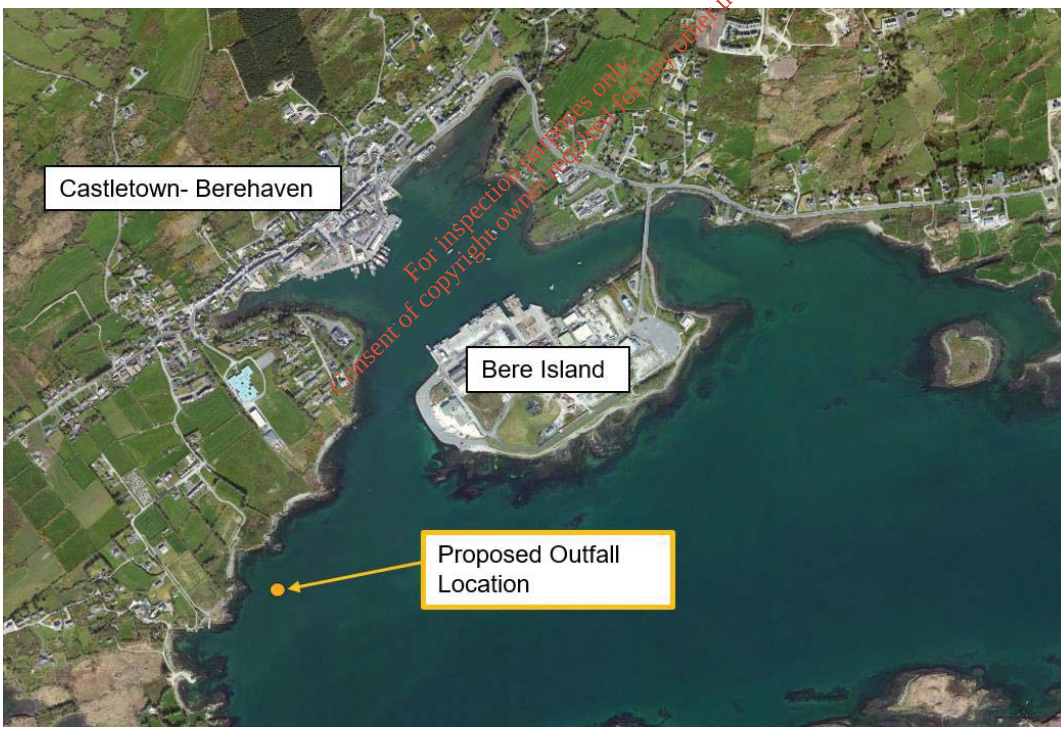
1 Introduction

1.1 Background

As part of the Cork UTAS project, Arup has been commissioned by Irish Water to undertake dispersion modelling for the proposed Castletownbere Wastewater Treatment Plant (WWTP) in order to assess the compliance of the effluent discharge from the site with the relevant water quality legislation. The site in consideration is located in Castletownbere in West Cork.

At present, sewage from Castletownbere is currently discharging untreated into Berehaven. It is proposed to build a new WWTP and network in Castletownbere to provide primary treatment for the effluent. The proposed WWTP will be located to the south-west of Castletownbere with treated effluent to be discharged via a proposed outfall pipeline to Berehaven in a south-easterly direction. The proposed outfall location is shown in Figure 1 below.

Figure 1: Location of proposed outfall



Following guidance from Irish Water, the dispersion modelling work is being undertaken in two distinct phases:

- **Phase 1:**
  - Data gathering and quality assurance;
  - Screening assessment to determine the relevant Water Quality (WQ) parameters at the site;

 - Near-field[1] dispersion modelling to calculate concentrations of the relevant WQ parameters in the immediate vicinity of the outfall where the buoyancy and momentum of the effluent discharge dominate the mixing process;
 - Make recommendations for the scope of Phase 2 (if required).

- **Phase 2:**
  - Where required, procure and manage a marine hydrographic survey which has been recommended and scoped as part of Phase 1;
  - Where required, undertake far-field[2] dispersion modelling of the relevant WQ parameters at the site;
  - Undertake a compliance assessment for the relevant minimum Environmental Quality Standards (EQS) at the site;
  - Where the EQS's are exceeded, advise on what level of additional treatment and/or dilution is required in order to meet with the requirements.

This report details the findings of Phase 1 of the study and provides recommendations on Phase 2. The findings of Phase 2 are presented in a separate far-field modelling report.

1.2 Guidance documents

The following guidance documents have been assessed as part of the study:

- DRAFT Irish Water Technical Standards for Marine Modelling;
- UTAS Design Reports and Technical Notes for the site (AECOM/Jennings O'Donovan);
- Scottish Environment Protection Agency, Modelling Coastal and Transitional Discharges, Supporting Guidance (WAT-SG-11);
- Relevant Regulatory Framework documents:
  - Urban Waste Water Treatment Regulations 2001;
  - Surface Water Regulations 2009;
  - The Bathing Water Directive 2006/7/EC;
  - The Shellfish Directive 2006/113/EC.

[1] The near field relates to the initial mixing zone area immediately adjacent to the outfall where the buoyancy and momentum of the outfall discharge is dominant
[2] The far field relates to the mixing zone outside the near field where the outfall discharge loses all its initial buoyancy and momentum and becomes passive

2 Water Quality Legislation

2.1 Irish Water Standards

The DRAFT Irish Water Technical Standards for Marine Modelling lists the parameters that are to be modelled as part of marine outfall compliance assessments to "demonstrate compliance with Surface Water, Bathing Water and Shellfish legislation".

These parameters are listed as:

- Temperature;
- Salinity;
- Biochemical Oxygen Demand (BOD);
- Dissolved Oxygen (DO);
- Escherichia Coli (EC);
- Intestinal Enterococci (IE);
- Norovirus;
- Molybdate-Reactive Phosphorus (MRP);
- Dissolved Inorganic Nitrogen (DIN);
- Nitrate;
- Nitrite;
- Ammonia;
- Chlorophyll-a.

Irish Water have noted to Arup that this list is not exhaustive and, if necessary, other water quality parameters that are not listed may also need to be assessed in order to demonstrate compliance.

2.2 Screening Assessment

A screening assessment has been undertaken to determine which Water Quality Legislation is enacted at the site. From this the WQ parameters that need to be assessed at the site to demonstrate compliance with the relevant legislation can be determined.

The findings of the screening assessment are presented in Table 1. The table is colour coded to aid the reader in determining which legislation is governing the inclusion of each of the water quality parameters.

We note that in addition to the legislative requirements, Arup have consulted with Irish Water on the list of water quality parameters that are to be assessed as part of the study.

Table 1: WQ modelling parameters

Castletownbere
Temperature
Salinity
BOD
DO
Suspended Solids
-
Intestinal Enterococci
DI Nitrogen
Faecal Coliforms and E Coli
Relevant Legislation
Surface Water Regulations 2009
Bathing Water Directive
Shellfish Directive

3 Near Field Dispersion

3.1 Background

The near-field concentrations of the WQ parameters listed in Table 1 have been calculated. The modelling has been undertaken using Visjet which is an industry standard software for undertaking near field modelling[3]. Visjet allows for the buoyancy and momentum of the effluent discharge, as well as the hydrodynamic conditions of receiving water, to be considered as part of the near-field modelling.

3.2 Data requirements

The data requirements and data sources for the near-field modelling are listed in Table 2.

Table 2: Near field data requirements

Site	Data	Sources
Castletownbere	Ambient background WQ conc.	EPA monitoring data and Irish Water Agglomeration Annual Environmental Report
	Tidal data and datums	2018 survey data and UK/Ireland Admiralty Tide Tables
	Outfall configuration	We have assumed a single horizontal diffuser port outfall with a diameter of 80mm
	Bed elevation at outfall/current speed	Bathymetric data from 2018 survey
	Current speed	Current speed data from 2018 survey
	Effluent loadings and concentrations	Calculated by Arup design team and instruction from Irish Water
	Target levels	Relevant WQ regulations

The temporal resolution of the EPA water quality dataset is relatively coarse and peak concentrations in the water column may therefore not be captured by the dataset.

[3] The Springer Handbook of Ocean Engineering 2016 lists Visjet (which is also known as Jetlag) as an industry standard near-field software on page 15 (Section C).

As part of this report we have not assessed the implications of this and how as a consequence the background concentrations of the WQ parameters may vary throughout the year.

Further we note that background concentrations of suspended solids in Castletownbere were not available from the EPA database. In order to address this, we have used our engineering judgement to assign background concentration values. Suspended solids for Castletownbere has been set equal to 2mg/l. This reasonably low value is justified given that the site of the proposed outfall is salinity dominated and receives little fresh water inflow. There will therefore be a low fluvial sediment loading discharging into the site. We note that this value of 2mg/l is equal to the measured background concentration at Whitebay, Cork Harbour, used as part of a separate UTAS project.

3.2.1 Marine Survey

A marine survey was commissioned as part of this study to provide the data required for the near-field dispersion modelling. The survey was undertaken in the Summer of 2018 by Irish Hydrodata Ltd.

Water level, current speed, and current direction, temperature and salinity measurements were taken at the location of the proposed outfall in Castletownbere. Data was collected at half-hour intervals for a spring tide at three points in the water column: (1) near the surface, (2) mid depth, and (3) near the bed.

3.3 Loadings from the outfall

The design flow and parameter concentrations for primary treatment have been supplied by Irish Water and are based on their experience and standard values in literature. Table 3 presents the loadings from the proposed outfall.

Table 3: Effluent concentrations (with primary treatment)

Parameter	Castletownbere
Mean Flow (m^3/s)	0.006307
BOD (mg/l O2)	280
DO (mg/l)	0
SS (mg/l)	200
DIN (mg/l)	41
MR Phosphorous (mg/l)	-
Intest. Enterococci (cfu/100ml)	4x104
EC and FC (cfu/100ml	1x106

3.4 Diffuser port configuration assessment

As part of this study, a high-level assessment of the diffuser port configuration was undertaken in order to assess the sensitivity of different port configurations on the near field dilutions and exit velocities from the ports.

The Springer Book of Ocean Engineering[4] notes that there is a risk of seawater intrusion into sewage outfalls as the effluent density is less than the density of seawater.

To mitigate this risk a Froude number greater than 1.6 is recommended for port discharges to ensure the exit velocity from the ports are high enough to prevent intrusion. Wood et al[5] also recommend a minimum port diameter of 65mm for a port diffuser.

A single port diffuser of 80mm diameter is recommend as the preferred configuration for the outfall at the site. This approach is justified:

- Given the relatively low design effluent flow the scope for including a number of port diffusers at the outfall is limited as additional ports will result in the reduction of the port exit velocity and therefore increase the risk of seawater intrusion.
- The 80mm diameter exceeds the minimum recommended by Wood.

The outfall arrangement will need to be confirmed as part of the detailed design of the outfall.

3.5 Near-field dispersion modelling results

3.5.1 Overview of initial dilution

The dilution at the water surface was calculated at hourly intervals for both Spring and Ebb tidal cycles. The 95%ile and 50%ile exceedance values were then calculated from these dilutions. The findings of the analysis are presented in Table 4 below.

Table 4: Number of dilutions at water surface

Scenario	Castletownbere
95%ile scenario	95
50%ile scenario	220

For compliance with SEPA guidelines, an initial dilution of 100 is recommended for primary treated effluents in the near-field.

[4] The Springer Handbook of Ocean Engineering 2016
[5] I.R. Wood, R.G. Bell, D.L. Wilkinson, Ocean Disposal of Waste (World Scientific, Singapore 1993)

It is evident from the results that the Castletownbere outfall has a 95%ile scenario dilution value of 95 which is marginally below the SEPA guideline.

3.5.2 Castletownbere near field concentrations

The near field modelling results for Castletownbere are presented in

Table **5** (95%ile) and Table 6 (50%ile).

It can be seen from Table 7 that concentrations of BOD and DO are below the EQS target levels for the 95%ile scenario in the near field. Discharges of BOD and DO from the proposed outfall at Castletownbere are therefore in full compliance with all the relevant legislation in the near field. No further assessment of their impact in the far field is therefore required.

It can also be seen that 95%ile concentrations of SS is marginally above the EQS threshold. It is reasonable to assume that the EQS for this parameter will be met in the far field given that it is so close to the threshold in the near field.

The 95%ile concentrations of IE and EColi/FC are above their EQS threshold.

Table 5: 95%ile scenario: Initial Dilution of 95

Parameter	Treated Eff. Conc	Background Conc.	Conc. After I.D.	Target Level	Additional Far Field Dilution Required
BOD (mg/l O2)	280	0.6	3.5	4.0	0
DO (%Saturation)	0	104	102.4	80-120	0
DIN (mg/l N)	41	0.06	0.48	0.25	1
SS (mg/l)	200	2	4.1	2.6	1
Intest. Entercocci (cfu/100ml)	40,000	3	423	100	4
E-Coli and FC (cfu/100ml)	1,000,000	6	10497	250	41

It can be seen from Table 6 that the 50%ile concentration of DIN is marginally within its EQS threshold.

Table 6: 50%ile scenario: Initial Dilution of 220

Parameter	Treated Eff. Conc	Background Conc.	Conc. After I.D.	Target Level	Additional Far Field Dilution Required
BOD (mg/l O2)	280	0.6	1.9	4.0	0
DO (%Saturation)	0	104	103.0	80-120	0
DIN (mg/l N)	40.5	0.06	0.24	0.25	0
SS (mg/l)	200	2.0	2.9	2.6	1
Intest. Entercocci (cfu/100ml)	40,000	3	185	100	1
E-Coli and FC (cfu/100ml)	1,000,000	6	4545	250	18

As the concentrations of IE and E Coli/FC at the Castletownbere outfall exceed their respective EQS target values in the near field it is necessary to assess their impact in the far field as they have an adverse impact on sensitive receptors. This work will be undertaken as part of Phase 2 of the project as discussed in Section 5.

4 Recommendations

The findings of our near-field dispersion modelling indicate that a number of the WQ parameters considered as part of the study exceed their respective EQS thresholds in the near field at the site. There is therefore a risk that the transport of these parameters in the far field may have an adverse impact on the sensitive receptors in the far field and a Phase 2 study is therefore required. Recommendations for Phase 2 are presented in the following section.

An assessment of the impact of the following WQ parameters in the far field of Castletownbere is required in order to assess the compliance of the discharge from the outfall on sensitive receptors:

- Intestinal Enterococci;
- Escherichia coli/Faecal Coliforms.

Following advice from Irish Water, Molybdate Reactive Phosphorus and Dissolved Inorganic Nitrogen are also to be assessed in the far field as part of Phase 2 of the study.

5 Far field Dispersion Modelling

5.1 Proposed models

We propose to construct a far field dispersion model for Castletownbere in order to simulate the transport and decay of the WQ parameters listed in the previous section. The models will be developed in MIKE 21 and consist of two separate components:

- **Hydrodynamic (HD) module –** simulates the depth-averaged time-varying water level, current speed and direction for the model domain under varying tidal, wind and river flow forcing. The salinity and temperate gradient will also be included in the HD model.
- **Ecolab (EL) module –** simulates the release, transport and decay of the relevant WQ parameters in response the hydrodynamics and dispersion characterise of the site of interest.

Both modules will be fully coupled and run together as a single integrated model. As detailed in the following section, the hydrodynamic model will be calibrated and validated against recorded data before being utilised to simulate a range of design scenarios.

5.2 Data requirements

Far-field dispersion models require extensive datasets in order to develop, calibrate, validate and run the models. We have undertaken a detailed review of all the available datasets for the site and the findings of our analysis is presented in Table 7.

Table 7: Available datasets

Bathymetry	Hydrographic (water level, current speed & direction, temperature & salinity)	Drogue/Dye release data	WQ parameter background concentration data
Castletownbere			
2009 dataset collected to facilitate Marcon study is deemed unsuitable due to dredging works that have been undertaken in the interim. A 2011 bathymetric dataset collected by Hydrographic surveys is also deemed unsuitable. A new survey is therefore required which will be integrated with existing Infomar data to form a composite dataset.	2009 dataset deemed unsuitable. New survey data therefore required.	2009 dataset deemed unsuitable. New survey data therefore required.	EPA WQ dataset is deemed suitable. As noted above, the temporal resolution of the dataset however is limited.

5.3 New Marine Surveys

We propose to appoint a hydrographic surveyor to collate the required data. Once Irish Water have approved the scope of the surveys, Arup will confirm the fees and programme for undertaking the works.

5.3.1 Castletownbere

- **HD model development –** Single beam bathymetric survey at the site of interest. Line spacing to vary relative to distance from outfall.
- **HD calibration data –** Measurement of water level at surface, current speed & direction at different locations in the water column at a high temporal frequency at the site of interest. The data will be collected for two separate 12hr periods: a spring tide period and a neap tide period. We note that this data will be collected from a boat.
- **HD boundary condition data –** Measurement of water level at surface for the same periods as noted above at a distance from the site of interest.
- **WQ calibration data –** Drogue release survey for spring tide conditions and neap tide conditions (i.e. two separate surveys). Drogues to be released at the location of the outfall at the surface and below water surface.

The indicative fee for this survey is circa €10,200 ex. VAT.

5.4 Hindcast data

We note that Arup may utilise hindcast data (i.e. Deltares ISM model, Proundman CS3 model etc.) as part of the study in order to derive design water level and/or flux boundary conditions of the various models.

5.5 Scope of the far field modelling

Our proposed methodology for undertaking the far-field modelling for Castletownbere has been developed following consultation with Irish Water and referring to the DRAFT Irish Water Technical Standards for Marine Modelling.

Our scope for the work is summarised as:

- Develop a hydrodynamic model for the site of interest with sufficient spatial resolution to accurately resolve the hydrodynamics. Our model will be developed using a flexible mesh.
- The boundary condition of the model will be located at a sufficient distance from the key area of interest in order to ensure boundary effects do not influence the performance of the model in the area of interest and that no concentrations are lost through the open boundary.
- The hydrodynamic model will be calibrated against the spring tide water level, current speeds and current direction data. The model will be validated against the equivalent neap tide data.

- The water quality dispersion model will be calibrated against both the salinity data and the findings of the drogue spring tide release survey. The water quality model will be validated against the neap tide datasets.
- Once calibrated and validated a number of design runs will be undertaken which will consider various forcing's of tide, wind, river flow and different decay rates of the water quality parameters.
- Undertaking a compliance assessment at the key areas of interest to determine if the effluent discharge is in exceedance of the minimum EQS for the WQ parameters considered as part of the far-field modelling.
- Consult with the design team and, if required, advise on the need for greater removal efficiency in the WWTP and/or relocation of the marine outfall. Alterative configurations of the outfall diffuser will also be considered.
- A final report will be produced which will detail all aspects of the model development and calibration and the findings of the Water Quality modelling.