ATTACHMENT NO: D.1

DISPERSION MODELLING-FAR FIELD/ NEAR FIELD MODELLING ASSESSMENTS

Irish Water

Cork UTAS

Whitegate Aghada Far Field Modelling

257589-00

Issue 3 | 12 October 2020

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 257589-00

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Executive Summary

Irish Water has identified 36 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 Whitegate/Aghada in Cork Harbour. A Water Quality impact assessment is required as part of the study to determine the compliance of the effluent discharges from the proposed Wastewater Treatment Plant on the receiving waters in Cork Harbour 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 Cork Harbour has been 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 well matched against the recorded data.

The results of the model show that the 95%ile concentrations of both E. Coli and Intestinal Enterococci are significantly reduced in the outer area of Cork Harbour with the proposed scheme in place. The results also show that the 50%ile concentrations of Dissolved Inorganic Nitrogen, Molybdate Reactive Phosphorus, Total Ammonia and Unionised Ammonia are reduced in the outer harbour area.

The model 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 to be exceeded outside the immediate mixing zone.

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

A number of sensitivity runs have been undertaken and have assessed what changes to the coliform decay rate, wind forcing and dispersion coefficient have on the results. Two future scenario model runs were also undertaken to assess the cumulative and long-term impact of the scheme. The results of our model indicate that none of these scenarios result in the Environmental Quality Standard thresholds for coliforms being exceeded at the relevant monitoring points.

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
POC	Port of Cork
DCSM	Dutch Continental Shelf Model
SCE	Scaled Eddy Viscosity

1 Introduction

1.1 Background

Irish Water have identified 36 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 to this, Irish Water (IW) 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 assess the compliance of the effluent discharges from the proposed Wastewater Treatment Plant (WwTP) with the Environmental Quality Standards (EQSs) in the receiving waters as defined in the relevant European Union (EU) water quality regulations.

This report presents the WQ assessment for Whitegate/Aghada. 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[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;
- Assess which WQ parameters are lower than the relevant EQS in the near field and hence are compliant 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] 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[2] 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 Whitegate/Aghada agglomeration. The findings of Phase One are reported on separately and have also been included as Appendix C to this report.

1.2 Guidance Documents

The following guidance documents have been used to inform the study:

- Irish Water's Technical Standards for Marine Modelling (2018) [1];
- Cork UTAS Design Reports and Technical Notes for Whitegate/Aghada (AECOM/Jennings O'Donovan, 2016) [2];
- Scottish Environment Protection Agency, Modelling Coastal and Transitional Discharges, Supporting Guidance WAT-SG-11 (2013) [3];
- Relevant Regulatory Framework documents:
  - Urban Waste Water Treatment Regulations 2001 [4];
  - Surface Water (Amendment) Regulations 2019 [5];
  - The Bathing Water Directive 2006/7/EC [6];
  - The Shellfish Directive 2006/113/EC [7].

1.3 Whitegate/Aghada UTAS Project Outline

Whitegate, Aghada and Rostellan villages are located in Co Cork, approximately 18km east of Cork City, and together form one of the untreated agglomerations. At present, wastewater emerging from the agglomeration is collected in separate collection systems, all of which discharge untreated wastewater to the receiving waters. The three catchments have inadequate or no treatment of sewage. The objective of the UTAS project is to provide preliminary and primary treatment for this agglomeration.

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

[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

Figure 1: The locations of Whitegate, Aghada and Rostellan villages

1.3.1 Existing wastewater infrastructure

The Whitegate/Aghada agglomeration has an estimated current population equivalent of 2,238 and is currently divided into four drainage areas, or sub-catchments, as shown in Figure 2. For more detail on the existing wastewater infrastructure please see the accompanying Natura Impact Statement report.

Figure 2: Existing Drainage Areas (Jennings O'Donovan/AECOM Design Report 2015)

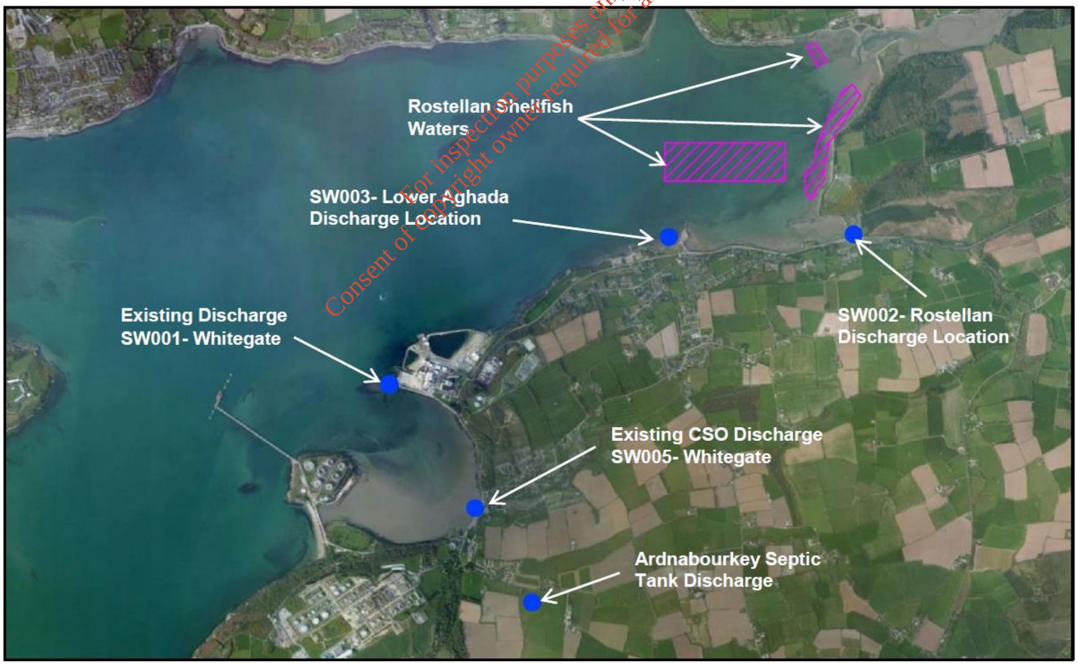
Wastewater from each of the four drainage areas is discharged into the receiving waters at five outfall locations as shown in Figure 3. These include:

- SW001 - Whitegate
- SW002 – Rostellan
- SW003 – Lower Aghada
- GW004 – Ardnabourkey
- SW005 – Whitegate CSO

The existing discharge locations are shown in Figure 3 below. Following consultation with Irish Water it has been assumed in this study that no treatment is provided to the effluent discharging at these locations for the existing scenario. Outfall GW004 discharges into an inland percolation area and as such was not included in the WQ model. Outfall SW005 is a combined sewer overflow and not a constant discharge, therefore it was not included in the WQ model.

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

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



The current population figures for Whitegate/Aghada have been taken from the Jennings O'Donovan/AECOM Design Report [2] and are presented in Table 1.

Table 1: Current Population Estimate

Population Type	Rostellan and Lower Aghada	Whitegate and Upper Aghada	Total Agglomeration
Domestic	435	1653	2088
Non-domestic	0	150	150
PE Total	**435**	**1803**	**2238**

The populations are based on 2011 census data as published by the Central Statistics Office. The numbers shown above are Summer population figures.

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 2011 and the present day is therefore accounted for in the proposed scheme.

1.3.2 Outline of the proposed scheme

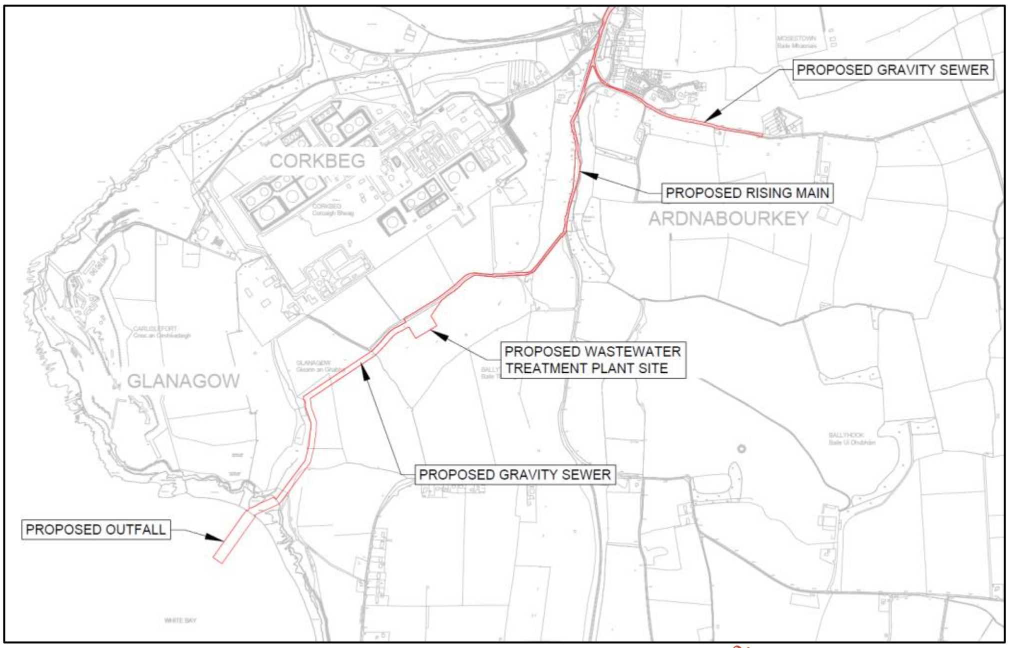
The objective of the Whitegate/Aghada UTAS project is to provide a WwTP capable of providing primary treatment in compliance with the Urban Waste Water Treatment Directive. The proposed WwTP will comply with European and Irish legislation and meet the needs of the agglomeration up to 2040.

Figure 4 presents the layout of the proposed scheme in the vicinity of Whitegate. The figure presents an extract of a full engineering drawing of the scheme which is presented in Appendix B. The scheme will consist of:

- A new WwTP;
- 3 No. pumping stations;
- Circa 3,800m of proposed rising main;
- Circa 1,000m of proposed gravity sewers and associated ancillary infrastructure.

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

Figure 4: Layout of proposed scheme at Whitegate



1.3.3 Components of the proposed scheme

Three 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.

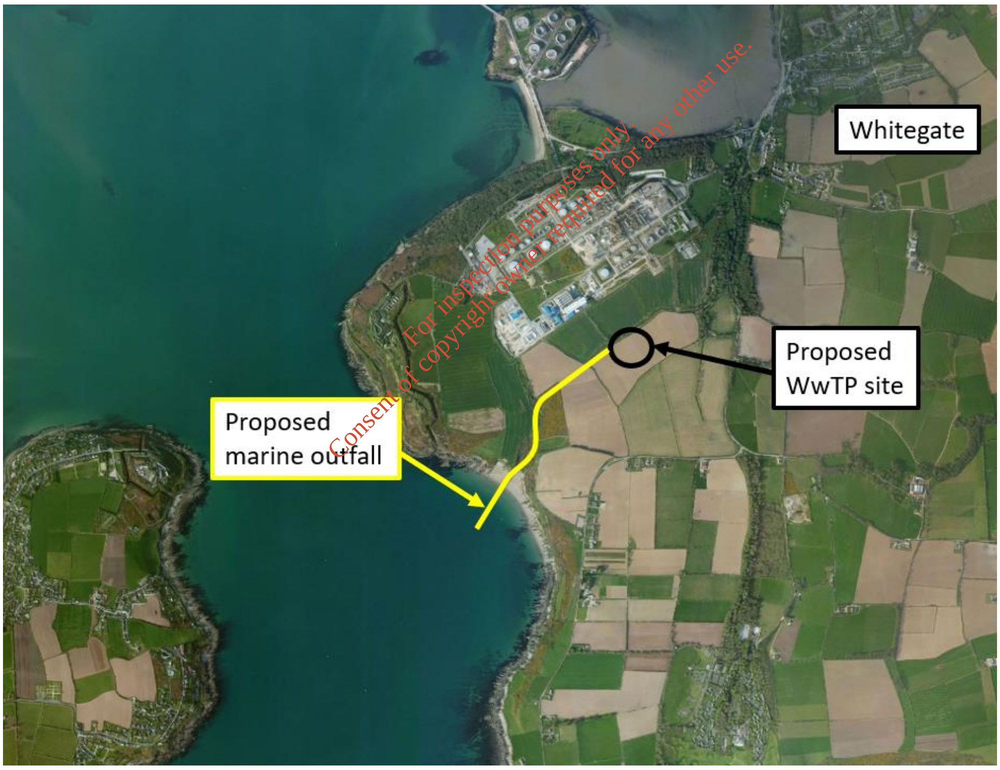
Table 2: Proposed pumping stations

Pumping Station	Details
Rostellan Pumping Station	• 65m long diversion of the existing 225mm diameter gravity sewer; • Wastewater pumping station capable of passing forward Formula A (8.1 l/s), incorporating 52.9m^3 of stormwater storage and utilising the existing outfall as an overflow facility; • 1,426m long, 110mm diameter rising main to convey pumped flows to the proposed pumping station in the Lower Aghada network.
Lower Aghada Pumping Station	• 50m long diversion of the existing 225mm diameter gravity sewer; • Wastewater Pumping Station capable of passing forward Formula A (21.5l/s), incorporating 140.6m^3 of stormwater storage and utilising the existing outfall as an overflow facility; • 660m long, 160mm diameter rising main to convey combined Rostellan and Lower Aghada pumped flows to the proposed pumping station in the Upper Aghada – Whitegate network; • Decommissioning of the existing package treatment plant.
Whitegate Pumping Station	• 55m long diversion of the existing 300mm diameter gravity sewer;

Pumping Station	Details
	• Terminal Wastewater Pumping Station capable of passing forward Formula A (65.7l/s), incorporating 239.3m^3 of stormwater storage and utilising the existing outfall as an overflow facility; • 1,750m rising main to convey all Formula A flows to the proposed new Wastewater Treatment Plant.

A new primary treatment WwTP with associated ancillary development works is proposed as part of the scheme. Construction of the plan will involve the decommissioning and removal of the existing package WwTP at that location. A 835m 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 approximate alignment of the new marine outfall that is to be provided as part of the scheme. The reader is referred to the accompanying planning drawings for more detailed information on the proposed network.

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



1.3.4 Justification for the scheme

At present, wastewater generated in Whitegate/Aghada is discharged into Cork Harbour with effectively no treatment. The 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 Cork Harbour and bring benefits in terms of health and environmental integrity. It would also facilitate the economic and social development of Whitegate/Aghada.

The great benefits of the proposed scheme can be summarised by:

- Secure the objectives of the Water Framework Directive by improving the water quality in Cork Harbour;
- Support the development of additional dwelling units in Whitegate/Aghada;
- Support the development objectives set out by The Cork County Development Plan (CCDP);
- Support the development of tourism in Whitegate/Aghada.

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 EU legislation enacted in Cork Harbour. 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 [4];
- Surface Water (Amendment) Regulations 2019 [5];
- The Bathing Water Directive 2006 [6];
- The Shellfish Directive 2006/113/EC [7];

The WQ parameters to be considered, along with the corresponding EQS threshold levels are presented in Table 3.

It is noted 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 (Amendment) Regulations 2019	4.0
Dissolved Oxygen	Surface Water (Amendment) Regulations 2019	95%ile > 80% saturation (35psu)
Suspended Solids (mg/l)	Shellfish Directive 2006	2.6
Dissolved Inorganic Nitrogen (mg/l)	Surface Water (Amendment) Regulations 2019	0.25
Molybdate Reactive Phosphorous (mg/l)	Surface Water (Amendment) Regulations 2009	0.04
Intestinal Enterococci (cfu/100ml)	Bathing Water Directive 2006	200

Parameter	WQ Directive	Target Level
Escherichia Coli (cfu/100ml)	Bathing Water Directive 2006	500
Total Ammonia (mg/l)	Salmonid Water Regulations 1988	1
Unionised Ammonia (mg/l)	Salmonid Water Regulations 1988	0.02

1.4.2 Bathing Water Directive 2006

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 2006 directive, with a classification of 'sufficient' to be achieved by 2015 for all bathing waters.

Table 4: Classification of bathing waters (Annex I of Directive 2006/7/EC)

Water Type	Parameter	Excellent	Good	Sufficient
Coastal/Transitional	Intestinal Enterococci (cfu/100ml)	100 (*)	200 (*)	185 (**)
	E. Coli (cfu/100ml)	250 (*)	500 (*)	500 (**)
Inland Waters	Intestinal Enterococci (cfu/100ml)	200 (*)	400 (*)	330 (*)
	E. Coli (cfu/100ml)	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 State 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 and in Appendix C.

Where the results of the near field 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 Whitegate/Aghada [8] 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.

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 Directive 2006, 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:

- Dissolved Inorganic Nitrogen;
- Molybdate Reactive Phosphorus;
- 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 Cork Harbour 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	√	√
MR Phosphorous (mg/l)	√	√
IE	√	√
EC	√	√
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 Cork Harbour.
- **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 Cork Harbour.

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 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	Cork Harbour characteristics	Identifies the key receptors, the status of the waterbodies and fluvial inflows into Cork Harbour.
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 Cork Harbour Characteristics

2.1 Overview

Cork Harbour is a macro-tidal estuary that covers a large area from Roches point to Cork City (in the North West) and Midleton (in the North East). The harbour 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 considerable temporal and spatial variation in velocities and water levels throughout the harbour.

The harbour can be considered as consisting of two separate sections:

- The upper harbour consisting of the Lough Mahon and the upper Lee estuary;
- The lower harbour which covers our area of interest at Whitegate/Aghada.

Given the proximity of the area of interest in Whitebay to the mouth of the harbour at Roches Point, our model extends beyond the harbour mouth at Roches Point into the Celtic sea.

Figure 3: Cork Harbour

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.

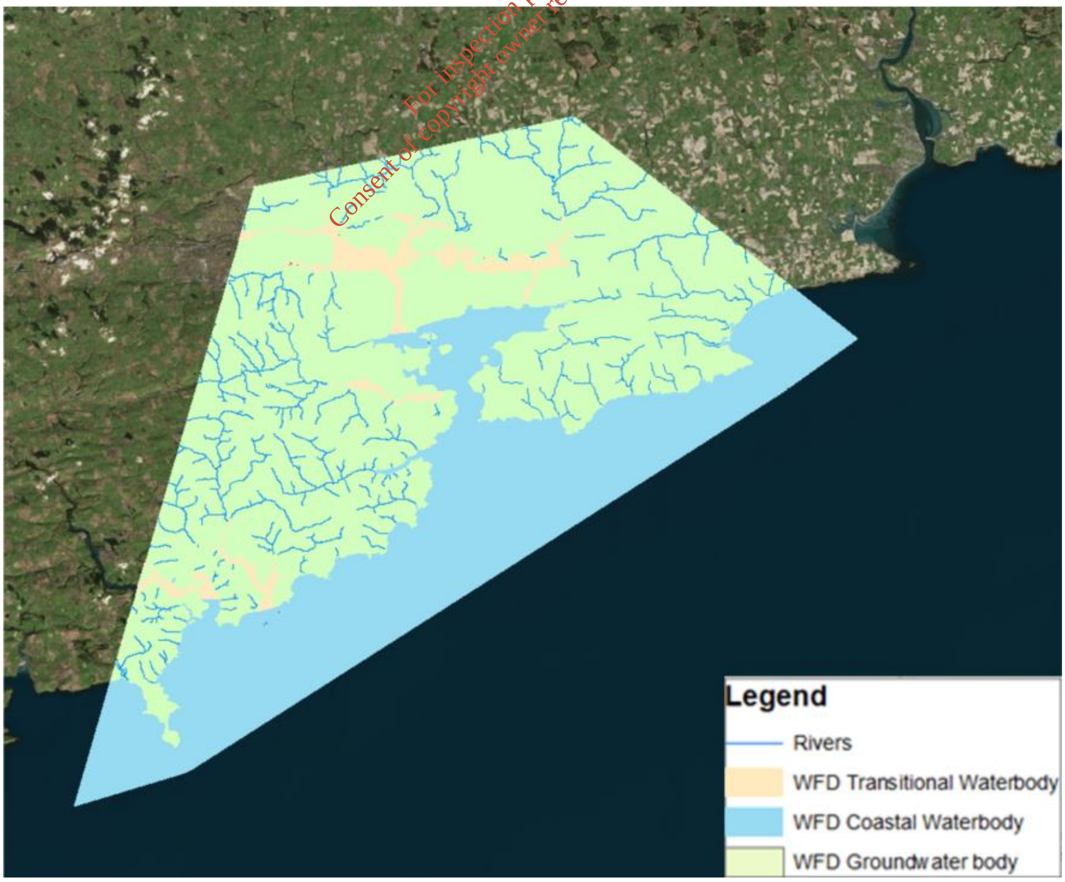
Table 8: Key receptors in the study area

Key receptors in study area	**Regulatory Framework Document/Body**
Special Area of Conservation (SAC)	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 (NHA)	National Parks and Wildlife Service
Shellfish Areas	The Shellfish Directive 2006/113/EC
Bathing Waters	The Bathing Water Directive (2006/7/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 6, respectively. Rivers in the study area are indicated by the blue lines.

Figure 6: WFD Waterbodies (Data Courtesy: EPA).



2.2.2 Shellfish areas

Waters in the Rostellan area and in the North Channel of Cork harbour are designated as classified shellfish production areas (Figure 7) under the Communities (Quality of Shellfish Waters) Regulations, 2006.

Figure 7: Shellfish Areas (Data Courtesy: EPA)

Shellfish production areas are classified according to the risk of contamination of shellfish with bacterial and viral pathogens. 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 Cork Harbour as identified by the Sea-Fisheries Protection Authority (SFPA) are presented in Table 9

Table 9: List of Classified Bivalve Mollusc in Cork Harbour (Data Courtesy: SFPA)

Production Area	**Species**	**Class**
North Channel West	Oysters	B
North Channel East	Oysters	B
Rostellan*	Oysters	B*

*Dormant Fishery

Shellfish monitoring data has been collated and compared in the shellfish production reduction programme reports for the Cork Harbour North Channel and Rostellan North, South and West. 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:

1. For the North Channel:
    - *'The results of monitoring undertaken for the proposes of the Shellfish Waters Directive (2006/113/EC) and schedules 2 and 4 of the Quality of Shellfish Waters Regulations (S.I. No. 268 of 2006) do not indicate any water quality issues within / in the vicinity of this shellfish area'*
    - *'The results of WFD monitoring indicate water quality issues with the levels of dissolved oxygen and dissolved inorganic nitrogen within / in the vicinity of this shellfish area.'*
    - *'The monitoring of shellfish flesh for food hygiene purposes indicates faecal contamination in this shellfish area.'*
2. For Rostellan North, South and West:
    - *'The results of monitoring (2009) undertaken for the proposes of the Shellfish Waters Directive (2006/113/EC) and schedules 2 and 4 of the Quality of Shellfish Waters Regulations (S.I. No. 268 of 2006) indicated faecal contamination within / in the vicinity of this shellfish area'*
    - *'the most up to date results of monitoring (2012) indicated that this area is in compliance with the Guide Value of 300 faecal coliforms / 100ml. However, due to the previous indication it is prudent to continue with the actions outlined in this Pollution Reduction Programme'*
    - *'The results of the Shellfish Water monitoring do not indicate any water quality issues within / in the vicinity of this shellfish area. However due to previous water quality issues with DIN and mercury within / in the vicinity of this shellfish area in this Pollution Reduction Programme'*
    - *'The monitoring of shellfish flesh for food hygiene purposes indicates faecal contamination in this shellfish area. However, the available shellfish monitoring at this site is in compliance with the shellfish guideline value for faecal coliforms as indicated above.'*

2.2.3 Special areas of conservation

Cork Harbour's North Channel is a designated Special Area of Conservation (SAC), site code 001058, as shown in Figure 8.

Figure 8: Special Area of Conservation (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. There are no designated NHAs in the study area. Proposed NHAs however have been identified in the study area, these are shown by the purple areas in Figure 9. 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 9: Proposed National Heritage Areas (Data Courtesy: EPA).

2.2.5 Bathing waters

A bathing water location has been identified at Fountainstown (shown in Figure 10). The water quality at this bathing location has been classified as 'Excellent' under the Bathing Water Directive (2006/7/EC).

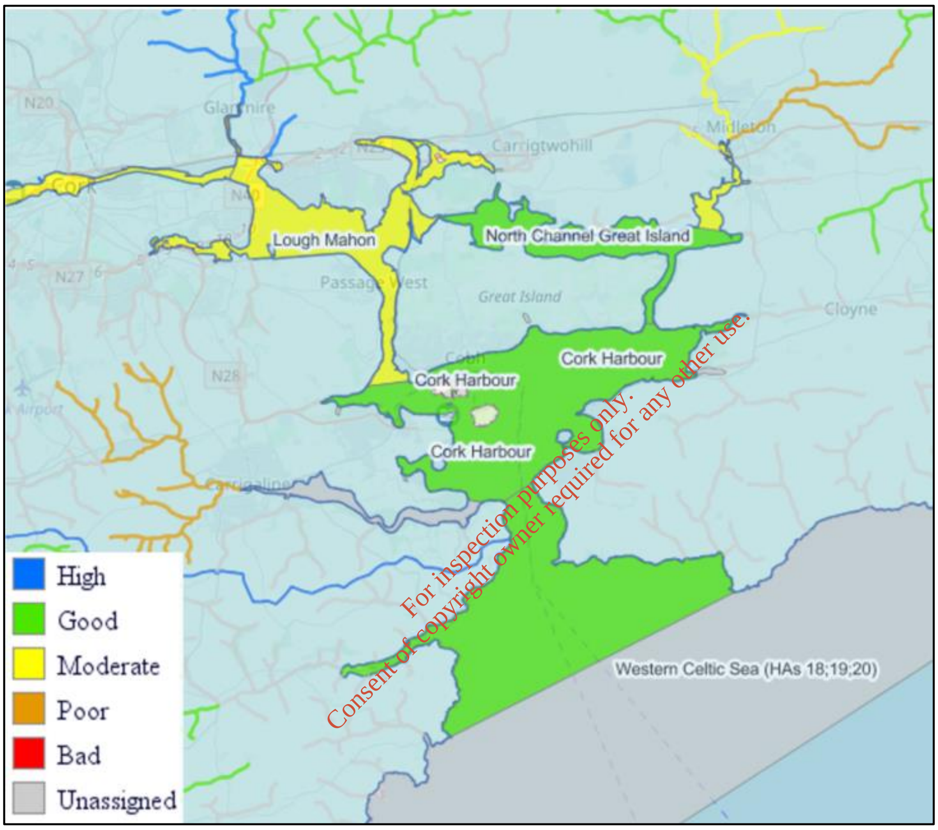
Figure 10: Bathing water locations (Data Courtesy: EPA).

2.3 WFD Waterbody Status

2.3.1 Current WFD status

The EU Water Framework Directive 200/60/EC (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 Cork Harbour is presented in Figure 11.

Figure 11: Waterbody status in the 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 Lower Cork Harbour of having a ‘good’ water quality status, while the status in the transitional waters of the North Channel and Lough Mahon ae ‘good’ and ‘moderate’, respectively.

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 the Celtic Sea is defined as ‘not at risk’ of failing to meet the directive’s objectives.

The coastal waterbody in Cork Harbour and transitional waters in the North Channel however are classified as 'under review'. Lough Mahon transitional waters are identified as 'at risk'.

Water bodies 'under review' have insufficient information to determine the risk or have had measures implemented but some additional monitoring is required to confirm that the expected improvements have been achieved. Water bodies 'at risk' have either not achieved their objective by 2015 or have achieved their objectives but the trend data indicates that they are deteriorating, and that further action is required.

It can therefore be concluded that transitional waters in the study area, along with coastal waters in the harbour, are potentially close to failing the WFD objective.

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

2.4 Existing Wastewater and Industrial Outfalls

A number of urban agglomerations are located in the immediate vicinity of Cork Harbour, each of which discharge wastewater into the harbour. These discharges have a range of treatment levels from 'no treatment' to 'tertiary' treatment. A number of industrial outfalls also discharge into Cork Harbour.

The outfalls included in this assessment have been agreed following consultation with Irish Water. The WwTP outfalls included in this study are listed in Table 10 all the outfalls are plotted in Figure 13.

These source discharges are further discussed in Section 6.3.

Table 10: WwTP outfalls for urban agglomerations in Cork Harbour

Urban Area	Location of the agglomeration primary outfall (ING)		Population Equivalent	Treatment Type	EPA licence number
	X	Y			
Carrigrennan	176683	69726	291,207	Secondary	D0033-01
IDA/Shanbally	181358	62521	22,032	Secondary	D0057-01
Midleton/ID	186177	69506	17,713	Tertiary	D0056-01
Cobh	178243	65558	14,437	None	D0054-01
Carrigtwohill 1	179911	72583	13,828	Tertiary	D0044-01
Carrigtwohill 2	180594	72283	13,828	Tertiary	D0044-02
Whitegate/Aghada	183337	64664	2,266	None	D0423-01
North Cobh	177535	67632	966	Secondary	D0140-01
Saleen Village	187700	67360	187	None	A0432-01

Table 11: Industrial outfalls in Cork Harbour

Industrial Outfall	Location of the outfall (ING)		Licence number
	X	Y	
SKB	178885	62710	P0004-05
ESB	183266	65316	P0561-05b
P66WR	182596	63221	P0266-02
BGE	182410	63165	P0830-02
M Chem	177310	69720	P0034-03

As part of the ongoing Cork Lower Harbour Main Drainage Project, some of the agglomerations discharging untreated effluent into the harbour are being diverted to the Shanbally WwTP. Following consultation with Irish Water it has been assumed that for the existing and proposed scenarios, the untreated loads from Passage/Monkstown and Ringaskiddy Village are considered to be connected to Shanbally. The loadings from these agglomerations have therefore been added to the Shanbally outfall. We note that the Cobh outfall has not yet been diverted to Shanbally.

It is noted that the industrial discharge from the Irish Development Agency (IDA) site is combined with the Shanbally WwTP outfall. Similarly, the industrial discharge from the Irish Distilleries site is combined with the Midleton WwTP outfall.

A number of the urban agglomerations presented in Table 10 have secondary discharge points (i.e. at Cobh). These secondary discharge points have not included in our modelling given that their primary function is to facilitate storm water overflow discharges which have not been considered as part of the study.

Figure 13: Plot of the primary outfalls for the urban agglomerations discharging into Cork harbour

2.5 Fluvial Inflows

A number of watercourses discharge into Cork harbour. The alignment of the watercourses as included in the EPA database are shown in Figure 14. These watercourses were accounted for in the model and are detailed later in Section 6.3.2 of the report.

Figure 14: Watercourses discharging into Cork Harbour

2.6 Geometry of Cork Harbour

The bathymetry and geometry of the harbour area varies considerably in terms of bed elevations and the width of the different areas of the harbour, as indicated in Figure 15. The outer harbour is circa 10.5km wide while the flow through the North Channel at its narrowest point is circa 200m wide.

The dominant geometric feature is a relatively narrow deep channel that extends from Roche's Point at the entrance to the harbour, through the outer harbour and West Passage and into Lough Mahon in the inner harbour. This deep channel is surrounded by shallow mudflats that are subject to flooding and drying by the rising and falling of the tide.

Figure 15: Cork Harbour Bathymetry (metres Ordnance Datum Malin)

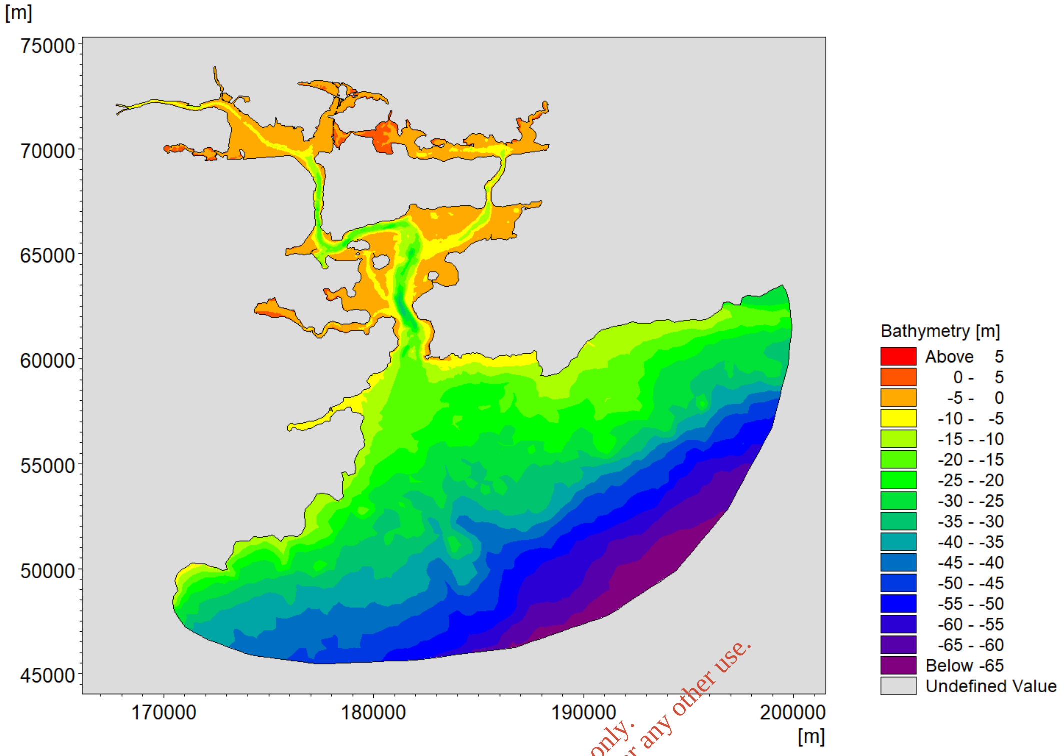
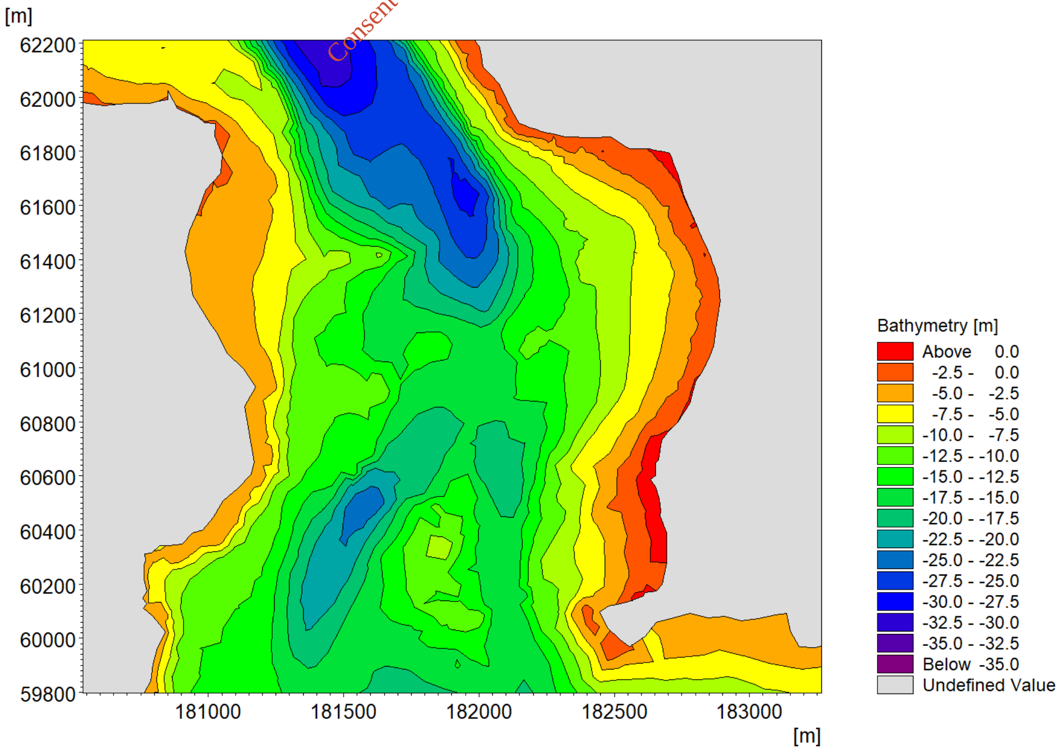


Figure 16 presents a close-up view of the bathymetry in the vicinity of the proposed outfall location. It can be seen from the figure that there is a considerable variation in bed elevation across the width of the harbour at this location.

Figure 16: Bathymetry at Whitebay (metres Ordnance Datum Malin)



3 Data Acquisition

3.1 Introduction

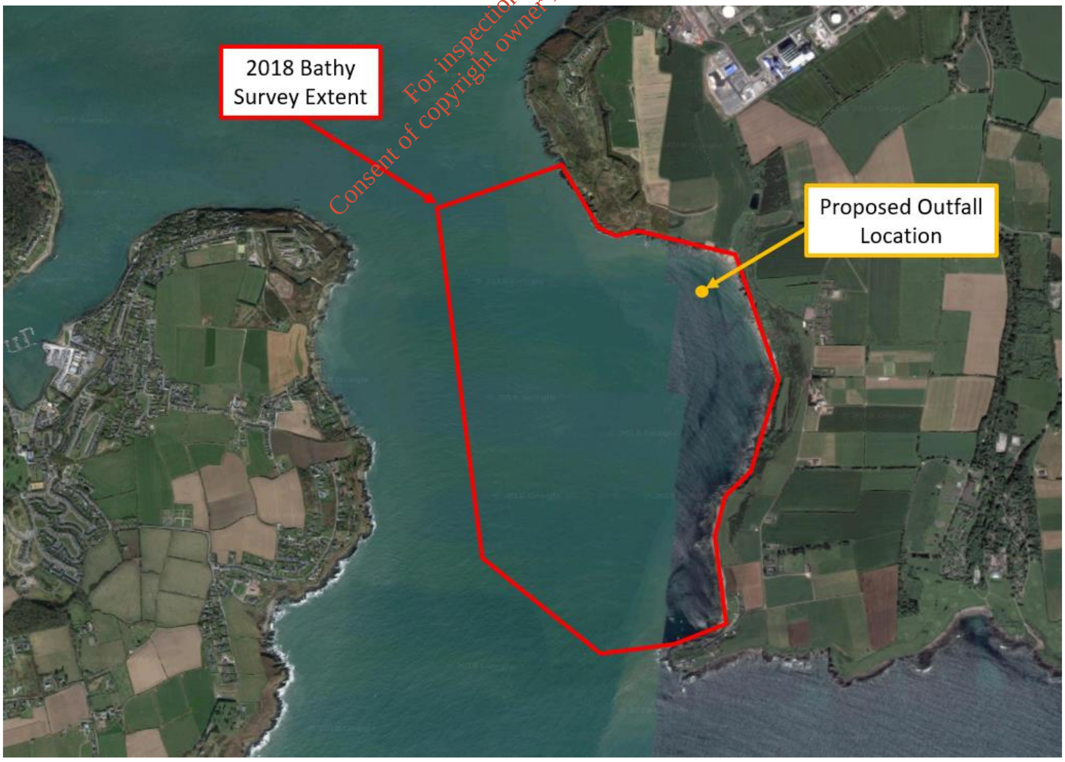
A marine survey was commissioned as part of the study to provide data with which to calibrate and validate the Cork Harbour model. A bathymetric survey of the harbour in the vicinity of the proposed outfall was also commissioned in order to provide accurate and up-to-date bed levels for the key area of interest. The survey was undertaken in the Spring of 2018 by Irish Hydrodata Ltd and is detailed in this chapter. Arup have also utilised various publicly available datasets as part of the study. These are EPA datasets and monitoring data, INFOMAR bathymetric and coastline data, Cork Airport wind data, and Marine Institute and Port of Cork tidal gauge data all of which are detailed in this chapter.

3.2 Marine Survey 2018

3.2.1 Bathymetry survey

A high-resolution bathymetric survey of the key area of interest in Cork Harbour was collected by Irish Hydrodata in March 2018 to provide accurate and up-to-date 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 both Port of Cork and 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 speed and current direction measurements were taken at the location of the proposed outfall in Whitebay (Figure 18). Data was collected at 30-minute intervals for two separate 12-hour periods:

- A neap tide – 8^{th} April 2018
- A spring tide – 29^{th} April 2018

Data was collected at three points in the water column to allow the variation in current in the vertical direction to 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 Kinsale Head (see Figure 18) for two weeks at five-minute intervals. The Kinsale Head water level was used as a boundary condition to calibrate the model. The reader is referred to Appendix D for plots of the raw survey data.

Figure 18: Survey Locations

3.3 Drogue Survey

A drogue tracking survey was undertaken as part of the survey for both a spring and neap tide. Spring data was collected on 29th April 2018, while the neap data was collected on 8th April 2018. Up to 5 drogues were released at the outfall location (shown in Figure 18) at various stages of the tide and subsequently tracked in order to trace their motion as they were advected by the tide. The findings of the drogue study were used to validate the hydrodynamic model. The surveyed tracks for the spring and neap tide drogues are presented in Appendix D.

3.4 Water Levels from Ringaskiddy and Tivoli

The Port of Cork maintain a water level gauge at Tivoli, the location of which is shown in Figure 19. Data from the gauge was obtained from the Port of Cork for April 2018 at six-minute intervals. A water level gauge at Ringaskiddy, also shown in Figure 19, is maintained by the Marine Institute. Data from his gauge was obtained from waterlevel.ie for all of 2018 at 15-minute intervals. Both of these datasets were used as part of the model calibration and validation.

Table 12: Tivoli and Ringaskiddy Tide Gauge Details

Gauge	Co-ordinates	Station ID
Tivoli	Lat: 51.90089, Long: -8.4104	Tivoli - 19067
Ringaskiddy	Lat: 51.84, Long: -8.304	Ringaskiddy -19069

Figure 19: Location of Tivoli and Ringaskiddy Gauges

3.5 Hindcast Data from Deltares

Hindcast water level data for the same period over which the marine survey in Whitebay was undertaken was procured from Deltares. This dataset provided a second version 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 from Deltares. 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 data points.

Figure 20: Hindcast water level data points outside Cork Harbour

The hindcast data was not utilised as part of the study as the recorded datasets provided a more accurate model boundary condition to the model. The hindcast data is therefore not considered further in this report.

3.6 Summary of Data Acquired

A summary of the data acquired for the far field modelled study is presented in Table 13.

Table 13: Hydrographic data acquired

Data	Location	Source	Used	How data is used
Bathymetric Survey	Whitegate Bay area	Spring 2018 survey	√	Used to inform bed elevations in area of interest
Bathymetric Survey	Cork Harbour	INFOMAR	√	Used to inform bed elevations in harbour
Bathymetric Survey	Cork Harbour	Port of Cork	√	Used to inform bed elevations in harbour
Water Level	Outfall location, surface	April 2018 survey	√	Used to calibrate model
Water Level	Kinsale Head	April 2018 survey	√	Used to derive model boundary for calibration run
Water Level	Tivoli	Port of Cork	√	Used to calibrate model
Water Level	Ringaskiddy	Marine Institute	√	Used to calibrate model
Water Level	Outer Harbour	Deltares DCSM Model	√	Used to validate model boundary condition for calibration runs
Water Level	Outer Harbour	Astronomical Tide (Mike 21 tool)	√	Used to derive model boundary for design runs
Current Speeds	Outfall location, surface	April 2018 survey	√	Used to calibrate model
Current Speeds	Outfall location, mid-depth	April 2018 survey	√	Used to calibrate model
Current Speeds	Outfall location, bed	April 2018 survey	√	Used to calibrate model
Current Direction	Outfall location, surface	April 2018 survey	√	Used to calibrate model
Current Direction	Outfall location, mid-depth	April 2018 survey	√	Used to calibrate model
Current Direction	Outfall location, bed	April 2018 survey	√	Used to calibrate model
Drogue tracking (Spring & Neap)	Released at outfall location	April 2018 survey	√	Used to validate model

4 Hydrodynamic Model

4.1 Introduction

A detailed high-resolution MIKE 21 numerical model of Cork Harbour and the area of the Celtic Sea adjacent to the entrance of the harbour at Roches Point 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 Whitegate and Aghada. Once the baseline scenario model was established, a separate model was developed which simulated the proposed scenario i.e. the discharge of wastewater from the proposed outfall at Whitebay. 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 the harbour 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 Water Quality model is described in Section 6.

4.2 Software and Modelling Approach

The model has been developed using the flexible mesh (FM) version of MIKE 21 HD. MIKE 21 is developed by the Danish Hydraulic Institute (DHI) 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 harbour can be represented as a single layer of fluid. Stratification of flow in the vertical dimension is therefore not accounted for in the model.

Given the relatively shallow depth of water in comparison to the width of the estuary 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 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.

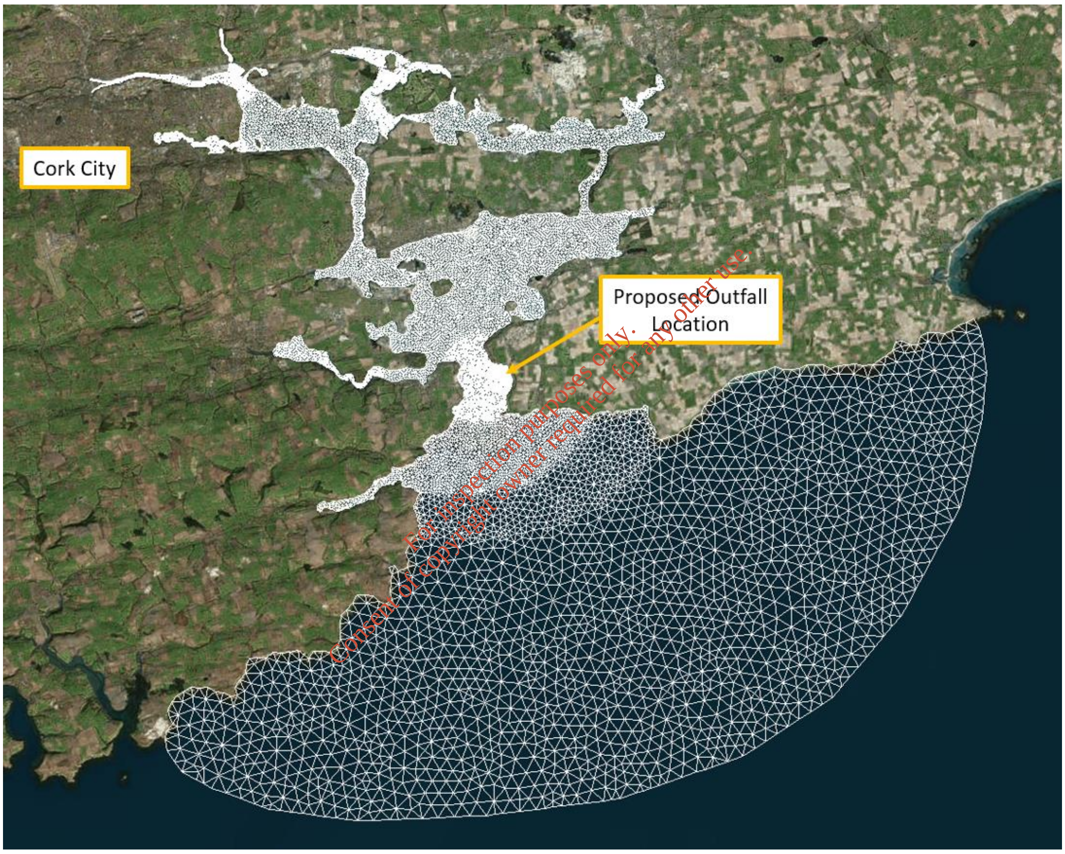
This mechanism is simulated by the two-dimensional model and therefore captures the primary mechanisms by which pollutants are advected and dispersed.

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 extent of the estuary is included in the model domain as well as an area of the Celtic Sea adjacent to Roches Point. 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. The finalised mesh for the calibration and design run model is presented in Figure 21.

A close-up 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 200m²) and largest near the model boundary (circa 150,000m²). 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 Whitebay

We note that the mesh for the existing scenario model is identical to the mesh for the proposed scenario model in order 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 it can be concluded that the parameters of the study are appropriate.

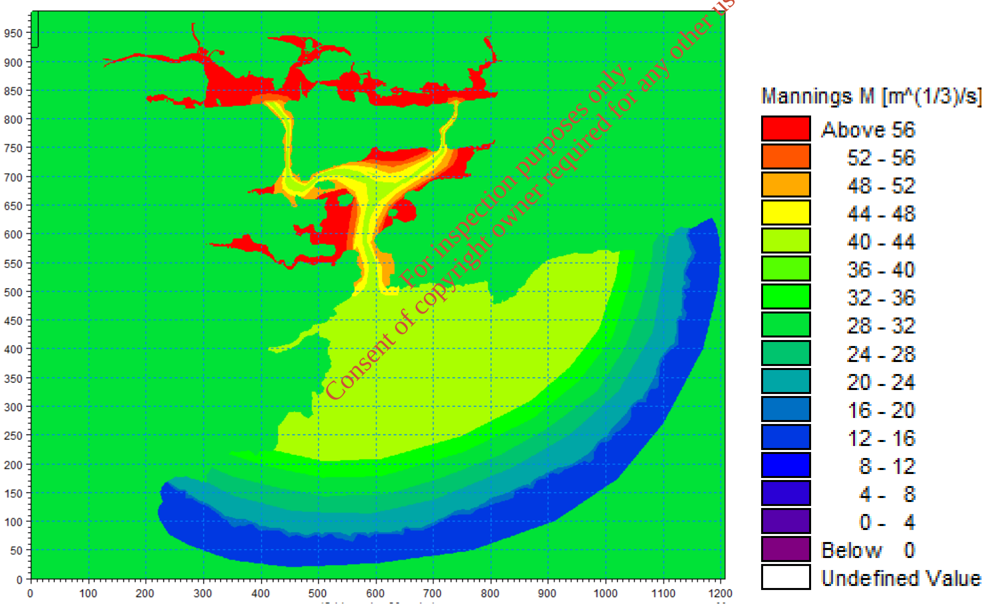
Table 14 presents some of the primary model parameters used for this study.

Table 14: 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 Cork Harbour as part of this study. The Manning's values were initially selected based on the composition of bed material in Cork Harbour. As part of the model calibration process 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 Cork Harbour.

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 upstream land boundary of the hydrodynamic model is located at the extent of the harbour. The various islands in the Harbour 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 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 Cork Harbour have been included in the design model runs. Flow discharges from WwTPs and industrial outfalls have also been included.

4.4.3 Downstream boundary of the model

The downstream boundary of the model is defined by a time varying and spatially 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

The boundary condition for the calibration run was constructed using data recorded close to the Old Head of Kinsale from the 2018 marine survey undertaken by Irish Hydrodata. The methodology used in our study was:

- Derive the astronomical tide at the location where the data was recorded and at every grid cell along the open boundary;
- Calculate the difference in level between the astronomical tide at the location where the data was recorded and at each grid cell along the open boundary;
- Using the differences in levels, project the recorded data to each grid cell along the open boundary of the model to form the spatially and time varying water level across 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 0.125° x 0.125° 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 hydrodynamics in the area of interest. The process of calibration allows for some of the model parameters to be adjusted to achieve the best match between the data and the model. These parameters include the spatial resolution of the mesh, bed resistance (Manning's M) and the viscosity coefficient.

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 harbour.

This model was calibrated using the spring tide data and validated against the neap tide data for the following measured parameters:

- Water levels
- Current speeds
- Current directions.

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 in Whitebay. Spring data was recorded from 07:45 to 20:00 on the 29/04/2018, a total period of 12.25 hours. Section 5.3 presents the findings of the calibration. Neap data was recorded from 07:30 to 20:00 on the 08/04/2018, 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 boundary condition, a validation for the astronomical only tide was carried out and this is detailed in Section 5.7.

5.2 Irish Water Calibration Guidance

The 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 performance targets for this study have been taken from the IW Marine Modelling Technical Standards [1], and supplemented with additional targets from a later version of the guidelines [9]. The Technical Standards state that the hydrodynamic performance of a model should be validated for the following parameters and associated statistical performance targets:

- Water level: ±0.1m of measured levels as an absolute difference. A Root Mean Squared Error of below 0.1m. A modelled tidal range within ±10% of recorded spring tides and ±15% of recorded neap tides;
- Current velocity: ±0.1m/s of measured velocities as an absolute difference for coastal water;
- Current direction: ±20 degrees of measured directions;
- Timing of high water: ±15 minutes at estuary mouth; ±25 minutes at estuary head.

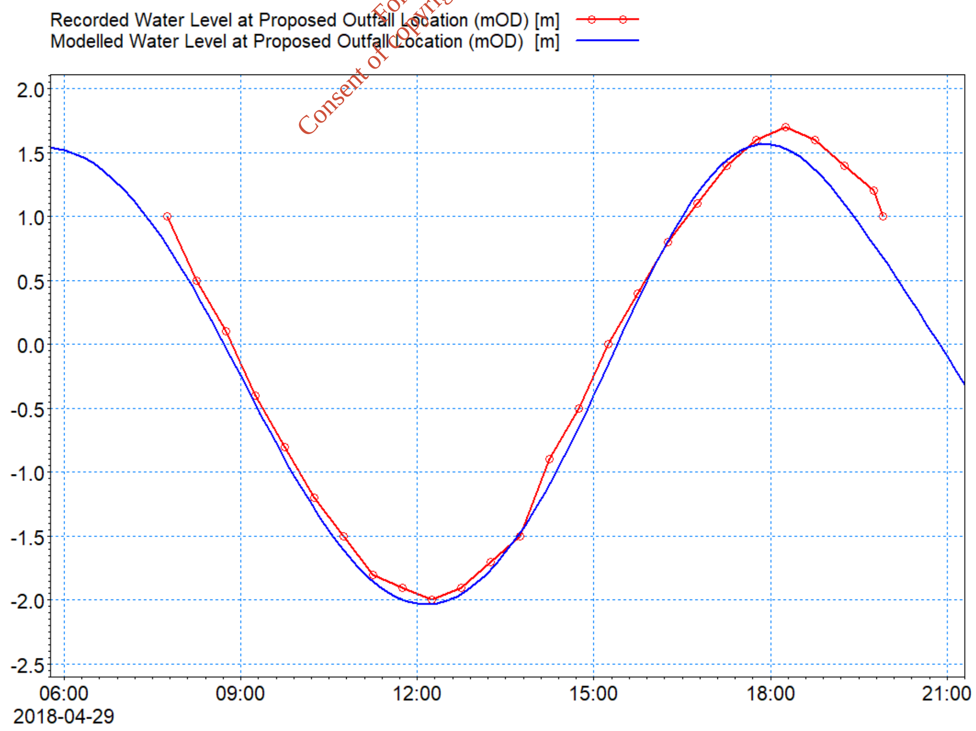
Statistical guidelines should not be used in isolation when assessing the performance and acceptability of a model and it is necessary for the experienced modeller to offer a critical assessment of model performance taking all of the available information and calibration data into account.

5.3 Spring Tide Calibration

5.3.1 Water level

The water level calibration at the outfall location is presented in Figure 39. It can be seen from the figure the modelled water level is a good match to recorded water level. The differences between the model results and the recorded data for the minimum (low tide) water levels is insignificant. The model is slightly underestimating the maximum water level at high tide.

Figure 24: Water level calibration at the proposed outfall location



There is a difference of circa 5 minutes between the model and recorded data for time of occurrence at low tide. The difference for the time of high tide is circa 15 minutes. The performance for these criteria is within the target value as set by the IW Marine Modelling Technical Standards.

The modelled tidal range is within 3% 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 15. The cells highlighted in green are those that meet the statistical performance targets set out in the standards. The absolute levels at low water (29/04/2018 12:15) are within the ±0.1m tolerances, while the absolute levels at high water (29/04/2018 18:15) are marginally above this limit i.e. 0.17m. Over the full spring tidal cycle, the model is within the absolute tolerances 65% of the time. The RMSE value of the observed and modelled water level throughout the spring tidal cycle is 0.1747m, which marginally exceeds the tolerance specified in the guidelines.

Table 15: 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)
29/04/2018 07:45	1.00	0.77	0.23
29/04/2018 08:15	0.50	0.39	0.11
29/04/2018 08:45	0.10	-0.03	0.13
29/04/2018 09:15	-0.40	-0.03	0.37
29/04/2018 09:45	-0.80	-0.90	0.10
29/04/2018 10:15	-1.20	-1.28	0.08
29/04/2018 10:45	-1.50	-1.61	0.11
29/04/2018 11:15	-1.80	-1.85	0.05
29/04/2018 11:45	-1.90	-2.00	0.10
29/04/2018 12:15	-2.00	-2.03	0.03
29/04/2018 12:45	-1.90	-1.95	0.05
29/04/2018 13:15	-1.70	-1.76	0.06
29/04/2018 13:45	-1.50	-1.47	0.03
29/04/2018 14:15	-0.90	-1.09	0.19
29/04/2018 14:45	-0.50	-0.64	0.14
29/04/2018 15:15	-0.05	-0.15	0.10
29/04/2018 15:45	0.40	0.35	0.05
29/04/2018 16:15	0.80	0.80	0.00
29/04/2018 16:45	1.10	1.18	0.08
29/04/2018 17:15	1.40	1.44	0.04
29/04/2018 17:45	1.60	1.56	0.04
29/04/2018 18:15	1.70	1.53	0.17
29/04/2018 18:45	1.60	1.37	0.23
29/04/2018 19:15	1.40	1.10	0.30
29/04/2018 19:45	1.20	0.78	0.42
29/04/2018 19:55	1.00	0.67	0.33

It has been seen from the water level validation plot that the model reproduces the observed tide but is marginally below the recorded data for most of the tidal cycle duration.

This causes the statistical analysis to marginally exceed the tolerance specified in the guidelines. When the visual and statistical analysis are compared together it can however be concluded that the model can reproduce water levels at the site of interest to a level of accuracy sufficient for the study.

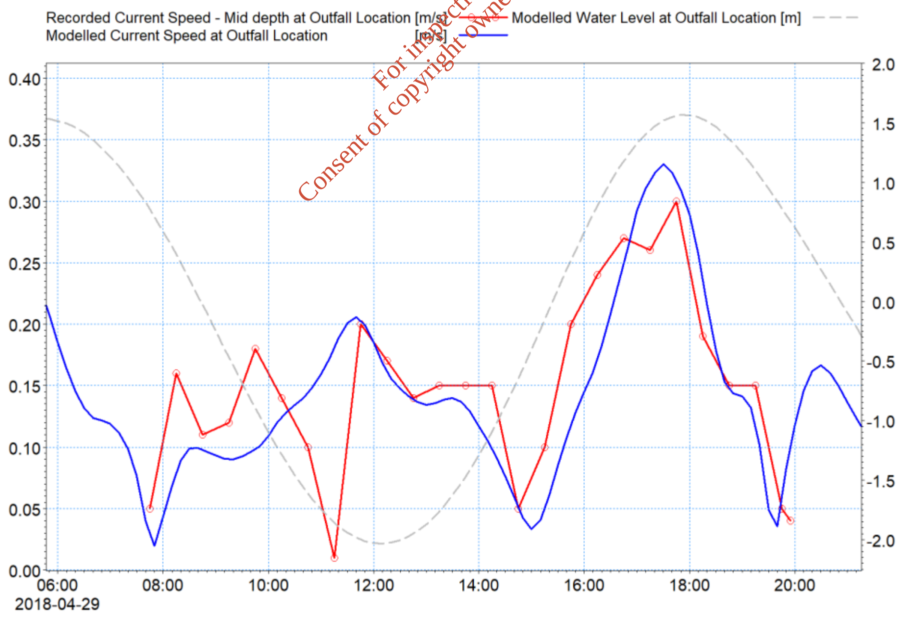
5.3.2 Current speed

The current speed calibration is presented in Figure 25. We note that the recorded current speed presented on the plot corresponds to the speed recorded at mid depth in the water column.[3] 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.

It can be seen from the figure that the modelled current speed is well matched to the recorded data. The model captures the overall trend in current speed through the various stages of the tidal cycle very well.

The model slightly underestimates the peak current speed at circa 17.00hrs before high tide. The model however does not capture the minimum current speed at circa 11.00hrs before low water.

Figure 25: Current Speed Calibration – visual analysis



The statistical analysis of the current speed calibration is presented in Table 16. It can be seen that the modelled current speed at the outfall location is within the

[3] It is noted that the recorded spring tide current speeds and direction from the three points in the water column are very similar which indicates a uniform distribution of currents throughout the water column. It was therefore not deemed necessary to average the recorded Spring tide data from the three points in the water column in order to create a water column average. The mid depth speeds and directions were instead used to validate the model.

absolute difference performance criteria of 0.1m/s through 96% of the tidal cycle. The model is therefore well calibrated against the recorded current speeds.

From Table 16 it can also be seen that the highest current speeds occur at high and low tide. This is due to the localised hydrodynamic conditions within Whitebay which is discussed further in Section 5.5.

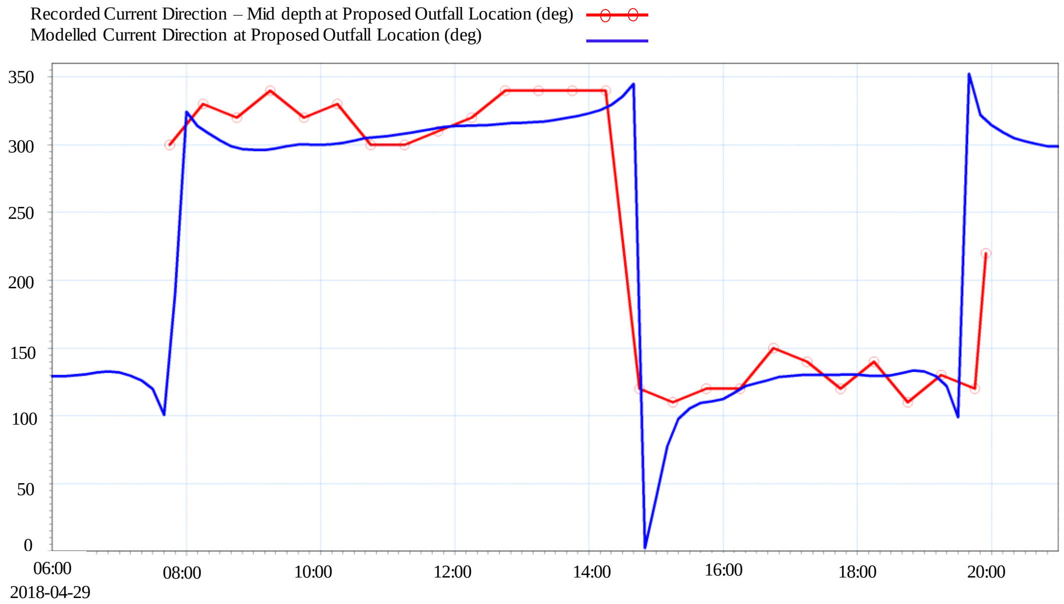
Table 16: Statistical performance results for Spring Tide current speed calibration

Time	Recorded Current Speed (m/s)	Modelled Current Speed (m/s)	Absolute difference between modelled and recorded (m/s)
29/04/2018 07:45	0.05	0.03	0.02
29/04/2018 08:15	0.16	0.08	0.08
29/04/2018 08:45	0.11	0.10	0.01
29/04/2018 09:15	0.12	0.10	0.02
29/04/2018 09:45	0.18	0.10	0.08
29/04/2018 10:15	0.14	0.12	0.02
29/04/2018 10:45	0.10	0.14	0.04
29/04/2018 11:15	0.01	0.18	0.17
29/04/2018 11:45	0.20	0.20	0.00
29/04/2018 12:15	0.17	0.16	0.01
29/04/2018 12:45	0.14	0.14	0.00
29/04/2018 13:15	0.15	0.14	0.01
29/04/2018 13:45	0.15	0.13	0.02
29/04/2018 14:15	0.15	0.10	0.05
29/04/2018 14:45	0.05	0.05	0.00
29/04/2018 15:15	0.10	0.05	0.05
29/04/2018 15:45	0.20	0.13	0.07
29/04/2018 16:15	0.24	0.17	0.07
29/04/2018 16:45	0.27	0.25	0.02
29/04/2018 17:15	0.26	0.32	0.06
29/04/2018 17:45	0.30	0.32	0.02
29/04/2018 18:15	0.19	0.24	0.05
29/04/2018 18:45	0.15	0.15	0.00
29/04/2018 19:15	0.15	0.12	0.03
29/04/2018 19:45	0.05	0.06	0.01
29/04/2018 19:55	0.04	0.10	0.06

5.3.3 Current direction

The current direction calibration is presented in Figure 26. It can be seen from the figure the modelled current direction is well matched to the recorded data. The model captures the predominant direction of the tide on both the flood and ebb tide quite well. It also captures the time at which the tide turns with only a minor difference of circa 20 minutes evident from the plot.

Figure 26: Current Direction Calibration – visual analysis



The statistical analysis of the current direction calibration is presented in Table 17. It appears from the analysis that the model is preforming poorly as it is within the performance threshold 42% of the time. It is evident from the visual comparison however that this is not the case and the model is well calibrated against current direction.

Table 17: 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)
4/29/18 7:45	300	146	154
4/29/18 8:15	330	311	19
4/29/18 8:45	320	298	22
4/29/18 9:15	340	298	42
4/29/18 9:45	320	300	20
4/29/18 10:15	330	301	29
4/29/18 10:45	300	305	5
4/29/18 11:15	300	308	8
4/29/18 11:45	310	312	2
4/29/18 12:15	320	314	6
4/29/18 12:45	340	316	24
4/29/18 13:15	340	317	23
4/29/18 13:45	340	320	20
4/29/18 14:15	340	328	12
4/29/18 14:45	120	174	54
4/29/18 15:15	110	88	22

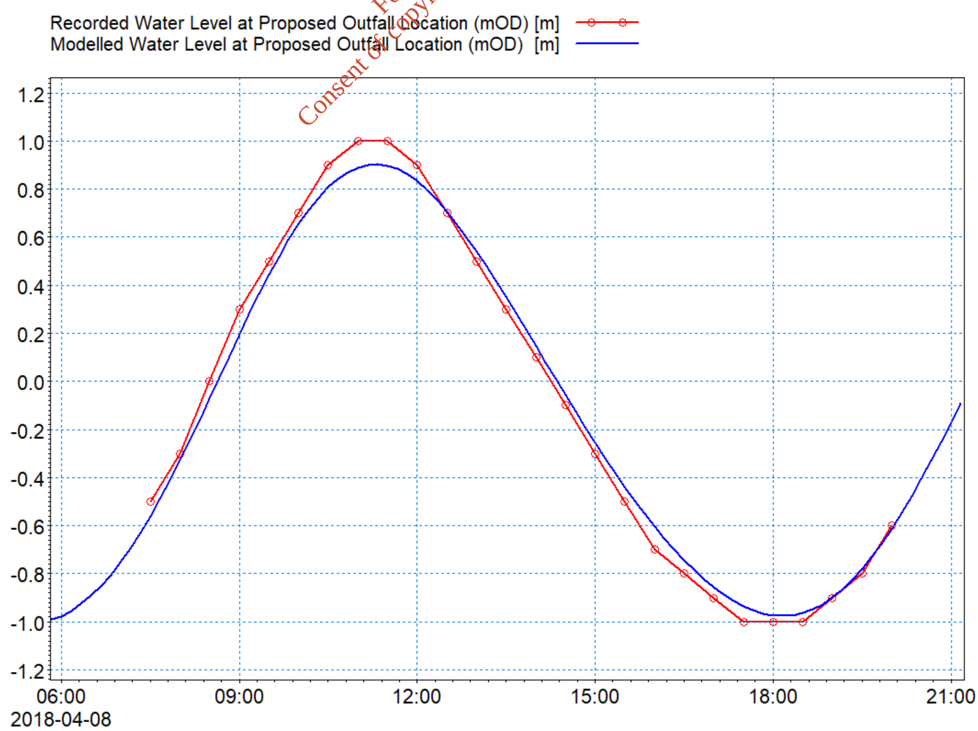
Time	Recorded Current Direction (Deg)	Modelled Current Direction (Deg)	Absolute difference between modelled and recorded (Deg)
4/29/18 15:45	120	302	182
4/29/18 16:15	120	119	1
4/29/18 16:45	150	128	22
4/29/18 17:15	140	130	10
4/29/18 17:45	120	130	10
4/29/18 18:15	140	129	11
4/29/18 18:45	110	132	22
4/29/18 19:15	130	126	4
4/29/18 19:45	120	337	217
4/29/18 19:55	220	318	98

5.4 Neap Tide Validation

5.4.1 Water level

The water level calibration is presented in Figure 27. 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 20mm.

Figure 27: Water level validation at the proposed outfall location



The difference between the modelled and recorded time of high tide is approximately 5 minutes and approximately 10 minutes for low tide.

In relation to tidal range, the modelled neap tide range is 94% of the recorded tidal range. Therefore, the model accurately replicates the timing and range of the neap tide.

The statistical analysis of the water level calibration is presented in Table 18. It can be seen that the model performs very well against the recorded data. The absolute levels at high (08/04/2018 11:30) and low (08/04/2018 18:00) water are within the ±0.1m tolerances. The water level is within the absolute tolerances for 92% of the tidal cycle and is only marginally exceeded at two time-steps. The RSME value for the neap tidal cycle is 0.0597m, which is below the IW tolerance of 0.1m. The model is therefore very well matched statistically to the neap tide water level.

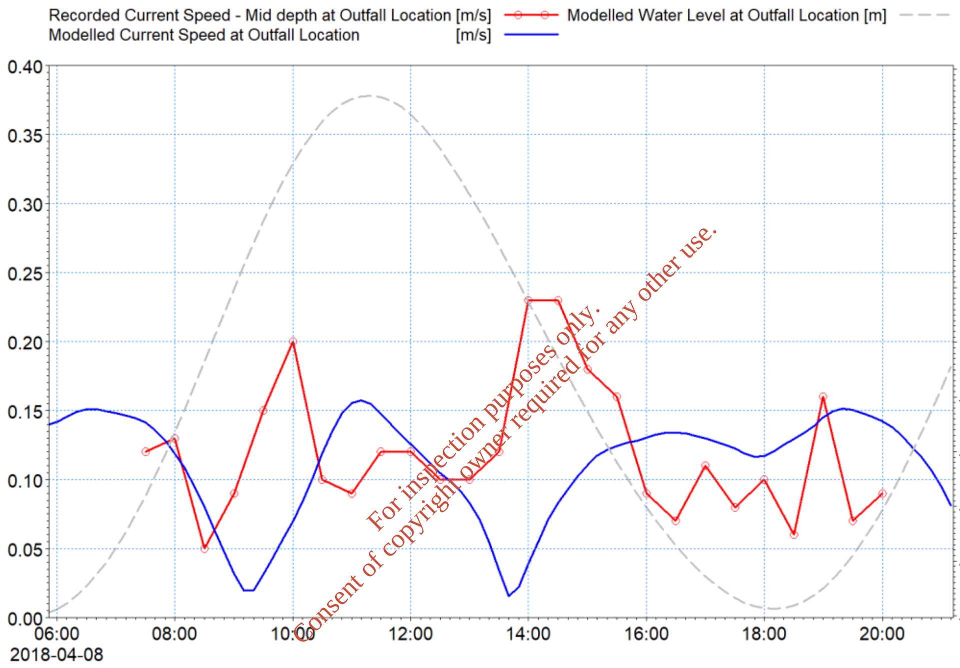
Table 18: Statistical performance results for the Neap Tide water level validation

Time	Recorded Water Level (mOD)	Modelled Water Level (mOD)	Absolute difference between modelled and recorded (m)
08/04/2018 07:30	-0.50	-0.56	0.06
08/04/2018 08:00	-0.30	-0.33	0.03
08/04/2018 08:30	-0.05	-0.07	0.02
08/04/2018 09:00	0.30	0.19	0.11
08/04/2018 09:30	0.50	0.44	0.06
08/04/2018 10:00	0.70	0.65	0.05
08/04/2018 10:30	0.90	0.81	0.09
08/04/2018 11:00	1.00	0.89	0.11
08/04/2018 11:30	1.00	0.90	0.10
08/04/2018 12:00	0.90	0.83	0.07
08/04/2018 12:30	0.70	0.71	0.01
08/04/2018 13:00	0.50	0.54	0.04
08/04/2018 13:30	0.30	0.35	0.05
08/04/2018 14:00	0.10	0.15	0.05
08/04/2018 14:30	-0.10	-0.06	0.04
08/04/2018 15:00	-0.30	-0.26	0.04
08/04/2018 15:30	-0.50	-0.44	0.06
08/04/2018 16:00	-0.70	-0.60	0.10
08/04/2018 16:30	-0.80	-0.74	0.06
08/04/2018 17:00	-0.90	-0.86	0.04
08/04/2018 17:30	-1.00	-0.94	0.06
08/04/2018 18:00	-1.00	-0.97	0.03
08/04/2018 18:30	-1.00	-0.96	0.04
08/04/2018 19:00	-0.90	-0.90	0.00
08/04/2018 19:30	-0.80	-0.78	0.02
08/04/2018 20:00	-0.60	-0.61	0.01

5.4.2 Current speed

The current speed validation is presented in Figure 28.[4] Overall the modelled current speeds are within 0.05m/s of the recorded current speeds with the exception of circa 09.00hrs and circa 14.00hrs when the model and recorded data diverge: the model predicts a reduction in current speed while the recorded data suggests the current speed increases at these times. The difference between the model and measured data is due to the model predicting the formation of an eddy in the northern area of Whitebay at both of those moments in time. The eddy reduces the current speed locally at the monitoring point and hence a divergence with the recorded data occurs.

Figure 28: Current Speed Validation – visual analysis



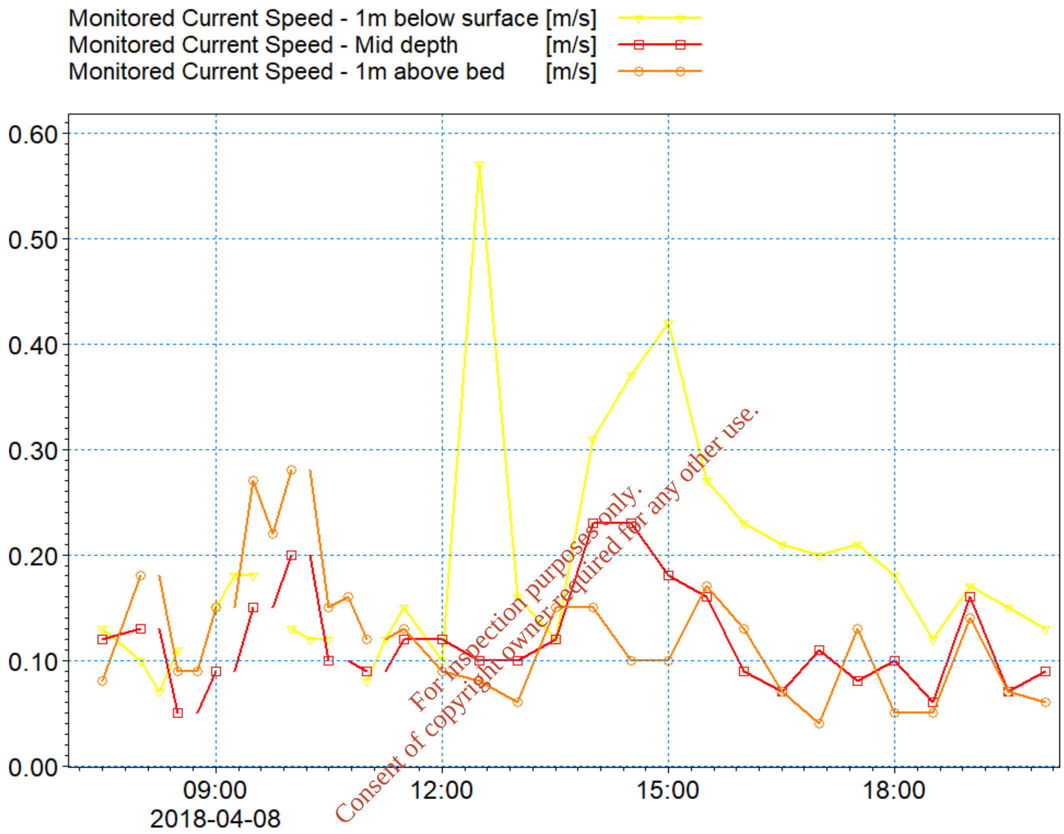
The recorded current speed from the surface during the period of the neap tide data acquisition show very large spikes at circa 13.00hrs and 15.00hrs on the ebb tide (Figure 29). These large spikes occur over a very short duration and only at the surface i.e. they are not occurring through the water column. As they were visually observed by the surveyor while the survey was being undertaken, they are deemed to be real and are not the result of errors in the data. It is noted that the surveyor did not observe any localised wind forcing that may have caused the spike in current speed.

It is therefore evident that very strong localised and temporal currents occur at the surface in the vicinity of the outfall during neap tide conditions.

[4] It is noted that the recorded neap tide current speeds and direction from the mid depth and near the bed points in the water column are very similar which indicates a uniform distribution of currents throughout a significant depth of the water column. As highlighted in the report, the surface neap current speed and direction data however shows notable differences with the mid depth and near the bed data. It was therefore deemed inappropriate to average the recorded Spring tide data from the three points in the water column in order to create a water column average. The mid depth speeds and directions have instead used to validate the model.

They may also occur at other tides, but we do not have a sufficiently long dataset to be able to confirm this. It is not possible for a depth integrated hydrodynamic model to simulate these conditions as they are very localised and temporal and only occur at the surface. The goodness of fit of our neap tide validation therefore needs to be considered in light of this.

Figure 29: Recorded current speeds for three points in the water column over the neap tide



The statistical analysis of the neap tide current speed validation is presented in Table 19. It can be seen that the modelled current speed at the outfall location is within the absolute difference performance criteria of 0.1m/s through 85% of the tidal cycle. The statistical analysis therefore shows a good validation between modelled and recorded neap current speed data at the outfall location.

It can therefore be concluded that overall the neap tide current direction is well validated against the recorded data.

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

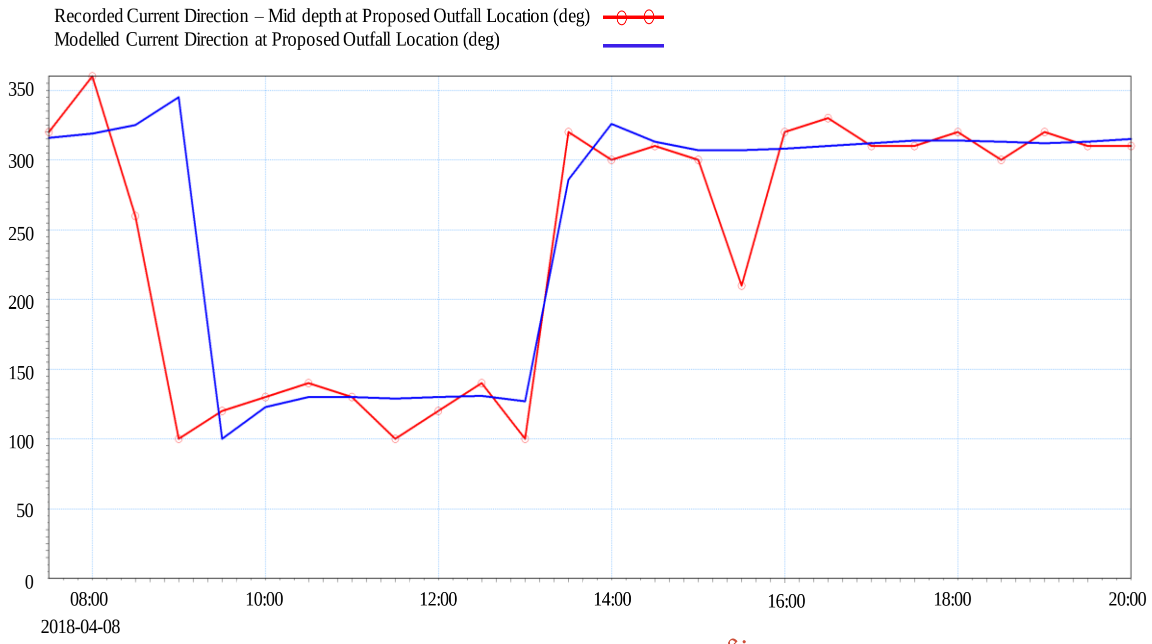
Time	Recorded Current Speed (m/s)	Modelled Current Speed (m/s)	Absolute difference between modelled and recorded (m)
08/04/2018 07:30	0.12	0.14	0.02
08/04/2018 08:00	0.13	0.12	0.01
08/04/2018 08:30	0.05	0.08	0.03
08/04/2018 09:00	0.09	0.03	0.06

Time	Recorded Current Speed (m/s)	Modelled Current Speed (m/s)	Absolute difference between modelled and recorded (m)
08/04/2018 09:30	0.15	0.03	0.12
08/04/2018 10:00	0.20	0.07	0.13
08/04/2018 10:30	0.10	0.12	0.02
08/04/2018 11:00	0.09	0.16	0.07
08/04/2018 11:30	0.12	0.15	0.03
08/04/2018 12:00	0.12	0.13	0.01
08/04/2018 12:30	0.10	0.10	0.00
08/04/2018 13:00	0.10	0.08	0.02
08/04/2018 13:30	0.12	0.03	0.09
08/04/2018 14:00	0.23	0.04	0.19
08/04/2018 14:30	0.23	0.08	0.15
08/04/2018 15:00	0.18	0.11	0.07
08/04/2018 15:30	0.16	0.12	0.04
08/04/2018 16:00	0.09	0.13	0.04
08/04/2018 16:30	0.07	0.13	0.06
08/04/2018 17:00	0.11	0.13	0.02
08/04/2018 17:30	0.08	0.12	0.04
08/04/2018 18:00	0.10	0.12	0.02
08/04/2018 18:30	0.06	0.13	0.07
08/04/2018 19:00	0.16	0.14	0.02
08/04/2018 19:30	0.07	0.15	0.08
08/04/2018 20:00	0.09	0.14	0.05

5.4.3 Current direction

The Neap Tide current direction validation at the outfall location is presented in Figure 30. It can be seen from the figure the modelled current direction is a reasonable match to recorded data and captures the predominant direction of the recorded current on both the flood and ebb tide. The turning of the tide at high water is well captured by the model while the turning and low water is slightly out of phase from the recorded data.

Figure 30: Current Direction Validation – visual analysis



The statistical analysis of the current direction calibration is presented in Table 20. It can be seen that the model is within the performance target circa 70% of the time. Overall the model is therefore a good match to the recorded neap tide current direction dataset.

Table 20: 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)
4/8/18 7:30	320	316	4
4/8/18 8:00	360	319	41
4/8/18 8:30	260	325	65
4/8/18 9:00	100	345	245
4/8/18 9:30	120	100	20
4/8/18 10:00	130	123	7
4/8/18 10:30	140	130	10
4/8/18 11:00	130	130	0
4/8/18 11:30	100	129	29
4/8/18 12:00	120	130	10
4/8/18 12:30	140	131	9
4/8/18 13:00	100	127	27
4/8/18 13:30	320	286	34
4/8/18 14:00	300	326	26
4/8/18 14:30	310	313	3
4/8/18 15:00	300	307	7
4/8/18 15:30	210	307	97
4/8/18 16:00	320	308	12

Time	Recorded Current Direction (Deg)	Modelled Current Direction (Deg)	Absolute difference between modelled and recorded (Deg)
4/8/18 16:30	330	310	20
4/8/18 17:00	310	312	2
4/8/18 17:30	310	314	4
4/8/18 18:00	320	314	6
4/8/18 18:30	300	313	13
4/8/18 19:00	320	312	8
4/8/18 19:30	310	313	3
4/8/18 20:00	310	315	5

5.5 Results of the Hydrodynamic Model

5.5.1 Spring tide

Spatial plots of the current speeds and velocity vectors for particular moments in time from the Spring tide are presented in this section of the report. We note that this section is to be read in conjunction with the calibration and validation plots presented earlier in the chapter.

Figure 31 presents the velocity vector and current speed plots for low tide. It can be seen that while the water in the main channel is slack and on the point of turning, water in the shallower area of Whitebay has already turned and is flowing upstream with a peak current speed greater than 0.4m/s.

Figure 31: Velocity vector and current speeds at low tide

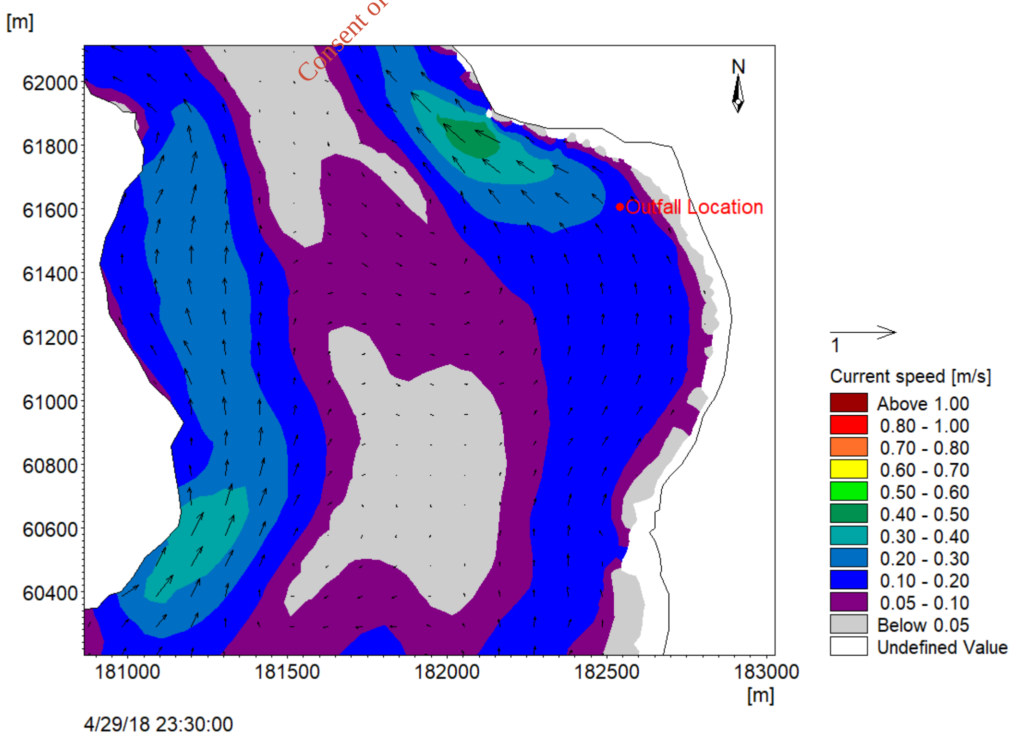


Figure 32 presents the velocity vector and current speed plots for mid flood tide on the Spring tide. It can be seen from the figure that the hydrodynamics in the main navigational channel and in Whitebay are very different to each other. In the main channel the tide is flowing into the harbour with peak current speeds in excess of 1m/s. An eddy however has formed in Whitebay leading to secondary circulations. Water at the eastern end of the bay is flowing in a southerly direction with current speeds of between 0.1m/s to 0.2m/s. The area of slack water in the centre of the eddy is evident in the plot.

Figure 32: Velocity vector and current speeds at mid-flood tide

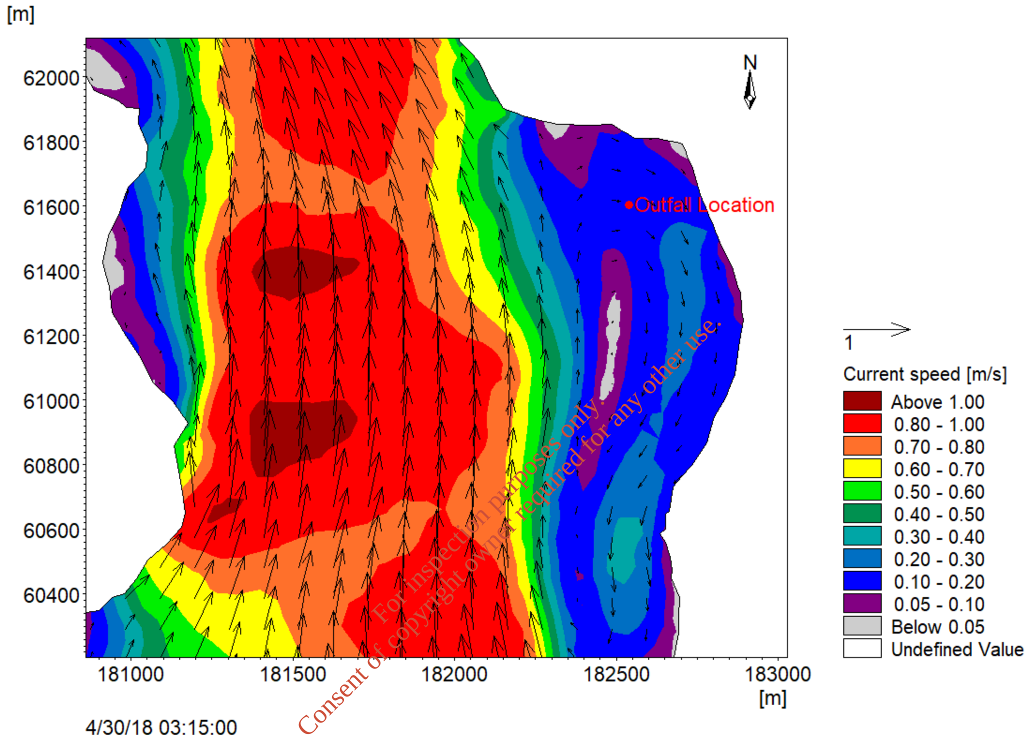


Figure 33 presents the current speeds and velocities at high tide. As with the hydrodynamic conditions at low tide, while the tide is turning in the deeper channel, it has already turned in Whitebay and is flowing in a southerly direction with maximum current speeds greater than 0.6m/s.

Figure 33: Velocity vector and current speeds at high tide

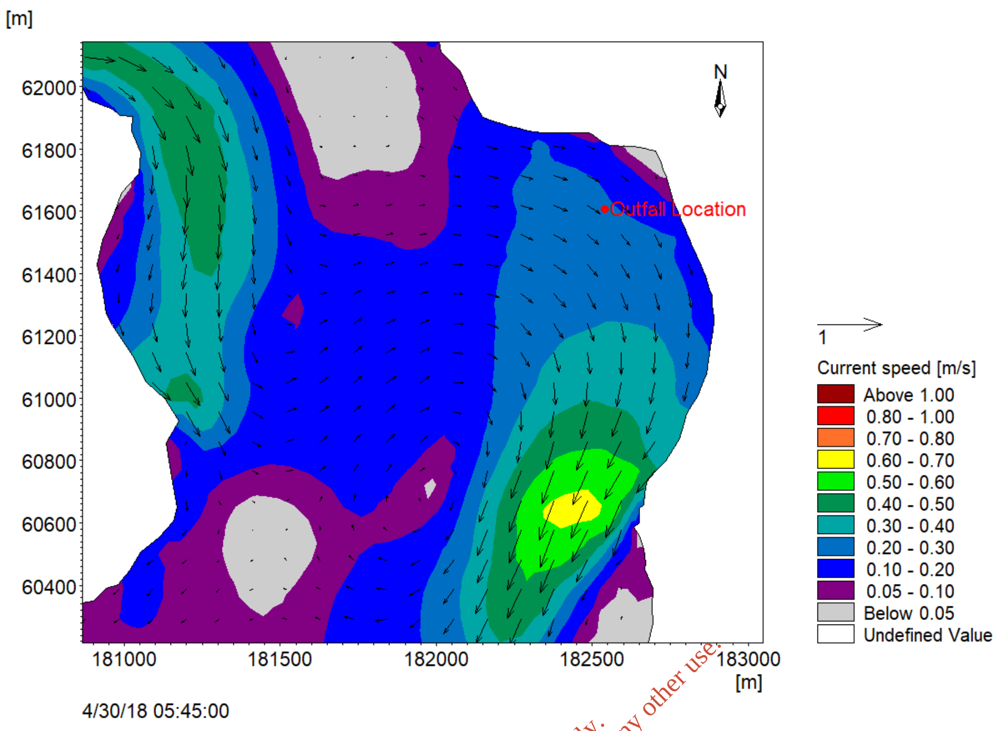
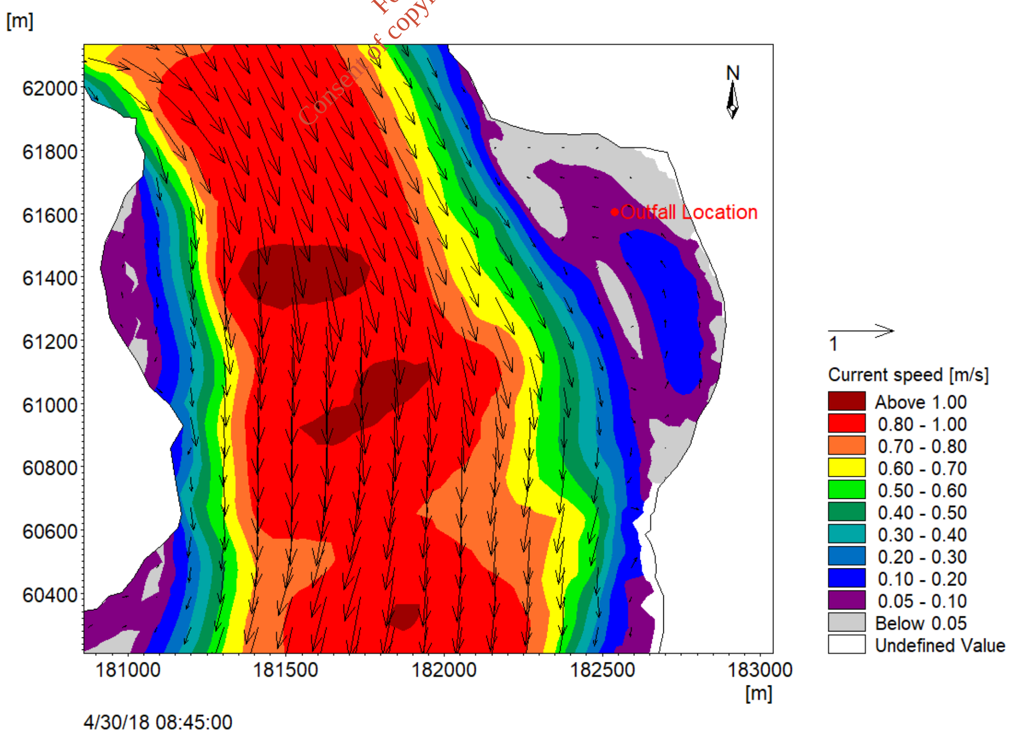


Figure 34 presents current speeds and velocities at mid ebb tide. As with flood tide conditions, a secondary circulation is leading to very different hydrodynamic conditions in Whitebay and in the main channel.

Figure 34: Velocity vector and current speeds at mid-ebb tide



5.5.2 Neap tide

Figure 35 presents the current speed and velocity vector plot for the moment in time from our neap tide validation in which the modelled data and recorded data diverge on the flood tide as described in Section 5.4.2 and presented in Figure 28.

It can be seen from the plot that the low simulated current speed at the monitoring point is due to the development of a secondary circulation in the northern section of Whitebay. As noted previously, a strong localised and temporal current at the surface was observed to occur at this location on the ebb tide. It is not possible for a depth integrated model to simulate such a phenomenon.

Figure 35: Velocity vector and current speeds – flood tide for neap conditions

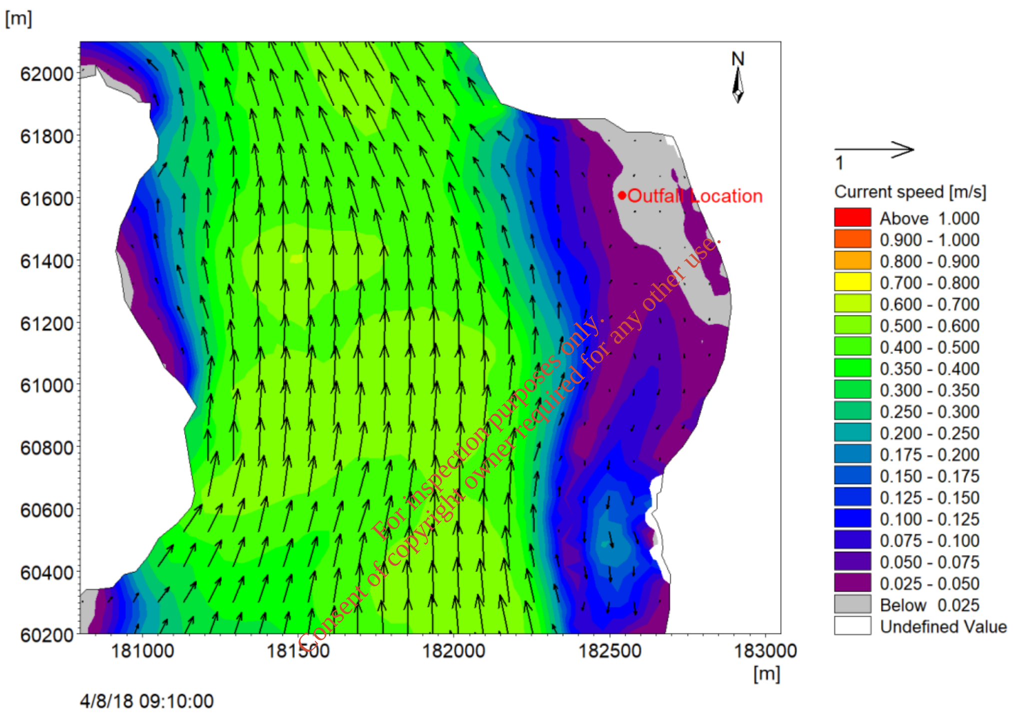
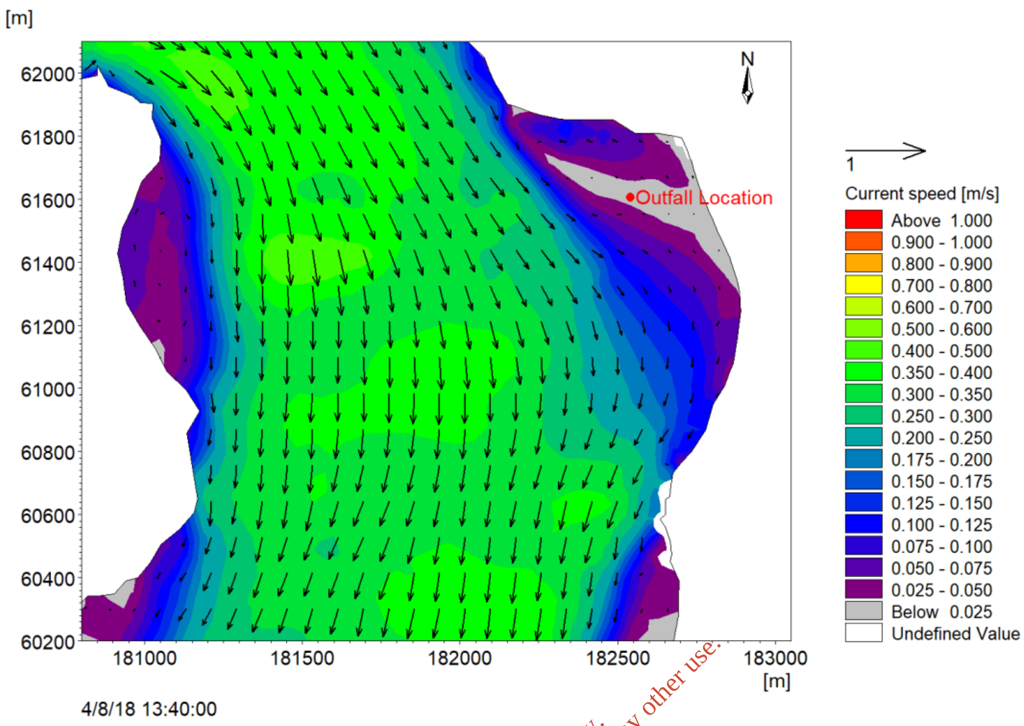


Figure 36 presents the current speed and velocity vector plots for the point on the ebb tide in which our modelled data and recorded data diverge as described in Section 5.4.2 and presented in Figure 28. As with the flood tide conditions presented in the previous section, a secondary circulation has formed in the area to the North of Whitebay and is leading to a drop in current speed at the location of interest.

Figure 36: Velocity vector and current speeds – ebb neap tide



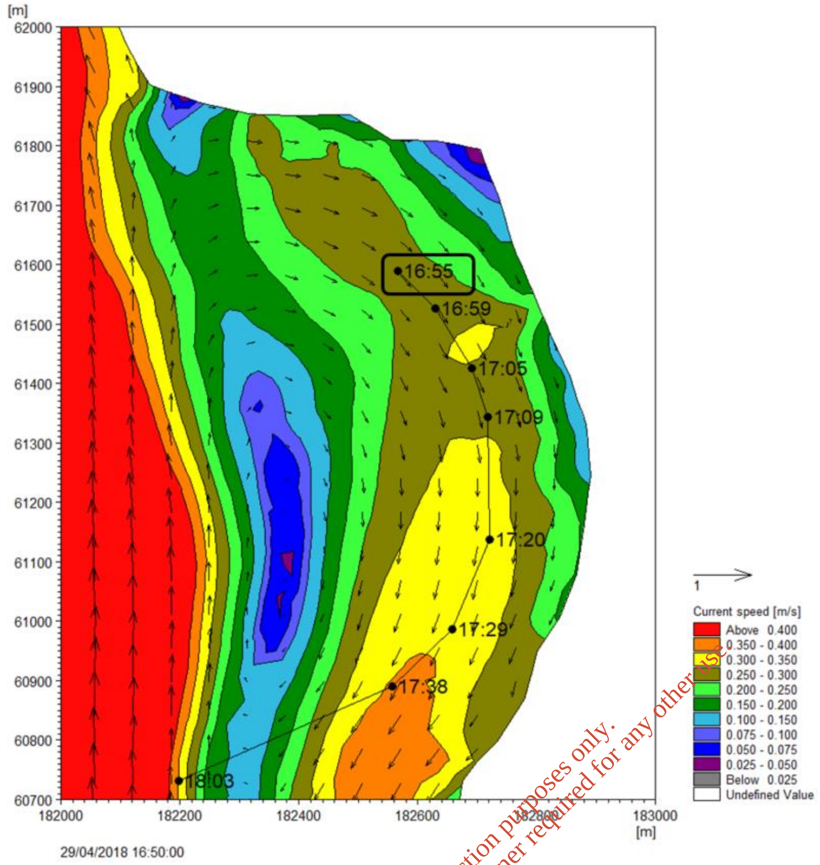
5.6 Drogue Data – Current Direction Validation

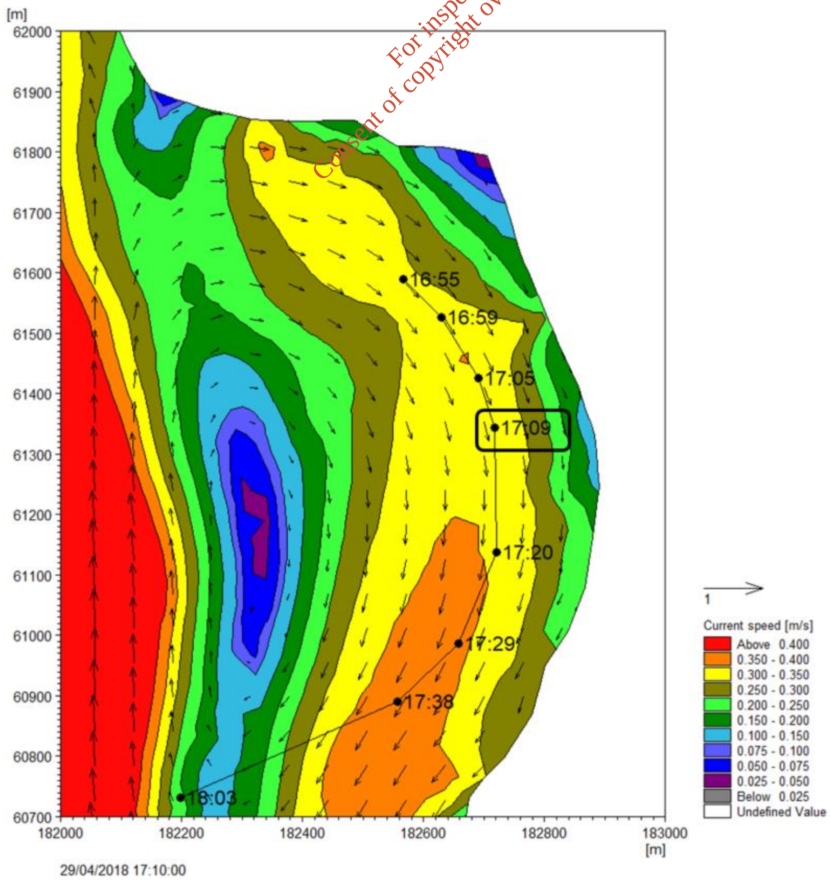
Drogue data was collected for a spring and neap tidal cycle as part of the marine survey and has been used to provide further validation of the modelled current direction.

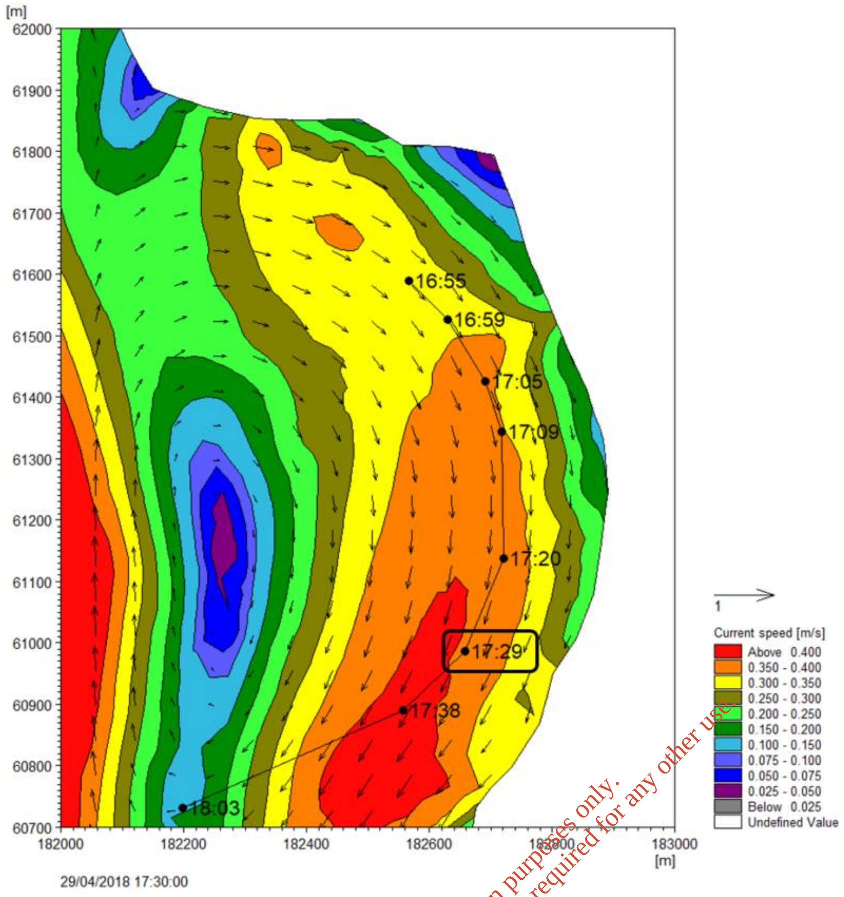
As the area of interest is within the estuary and bounded by the geometry of the harbour (i.e. it is not in the open sea which would be very sensitive to wind and wave action) the drogue track data is deemed to be representative of the surface currents. It needs to be considered however that as the model simulates depth averaged currents and not the surface currents, comparing the model with the drogue data is not a direct like for like comparison.

Figure 37 presents the current speed and velocity vector plots for four stages of the ebb tide. The time and position of the drogue track throughout the duration of the ebb tide is superimposed in black. The drogue time/location highlighted in black corresponds to the same time at which the velocity vectors are taken from. It is evident from the plots that the modelled current direction is well matched to the directional track of the drogue throughout the ebb tide.

Figure 37: Spring ebb tide drogue validation






[m]
62000
61900
61800
61700
61600
61500
61400
61300
61200
61100
61000
60900
60800
60700
182000
182200
182400
182600
182800
183000
[m]
16:55
16:59
17:05
17:09
17:20
17:29
17:38
18:03
1
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
29/04/2018 17:30:00

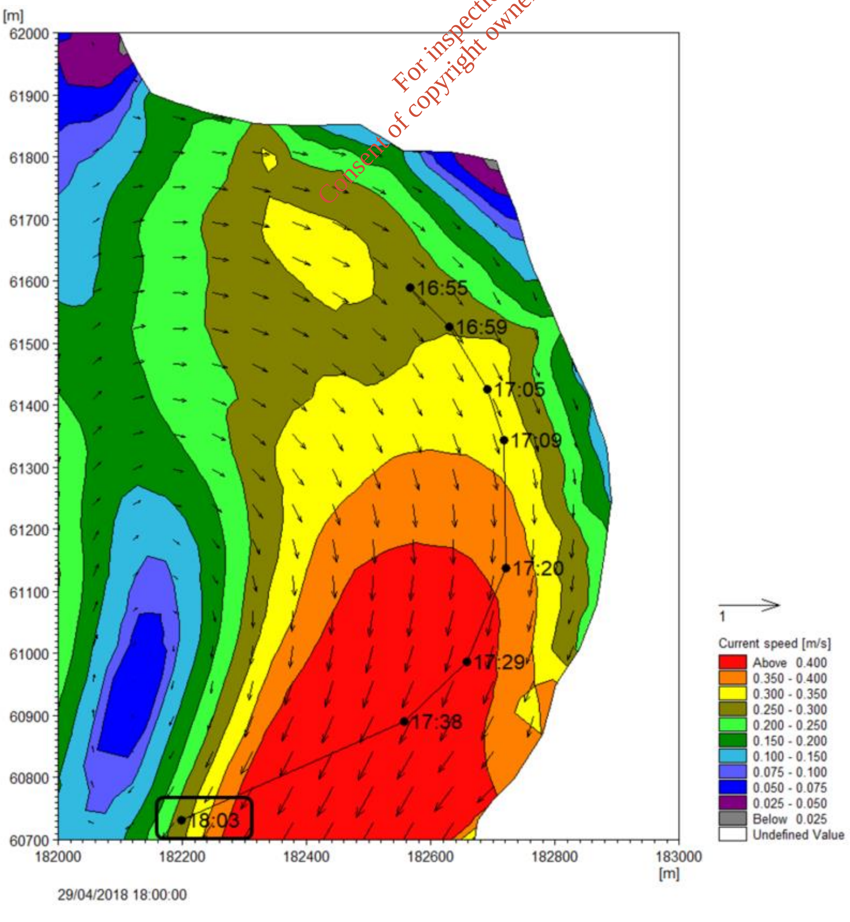
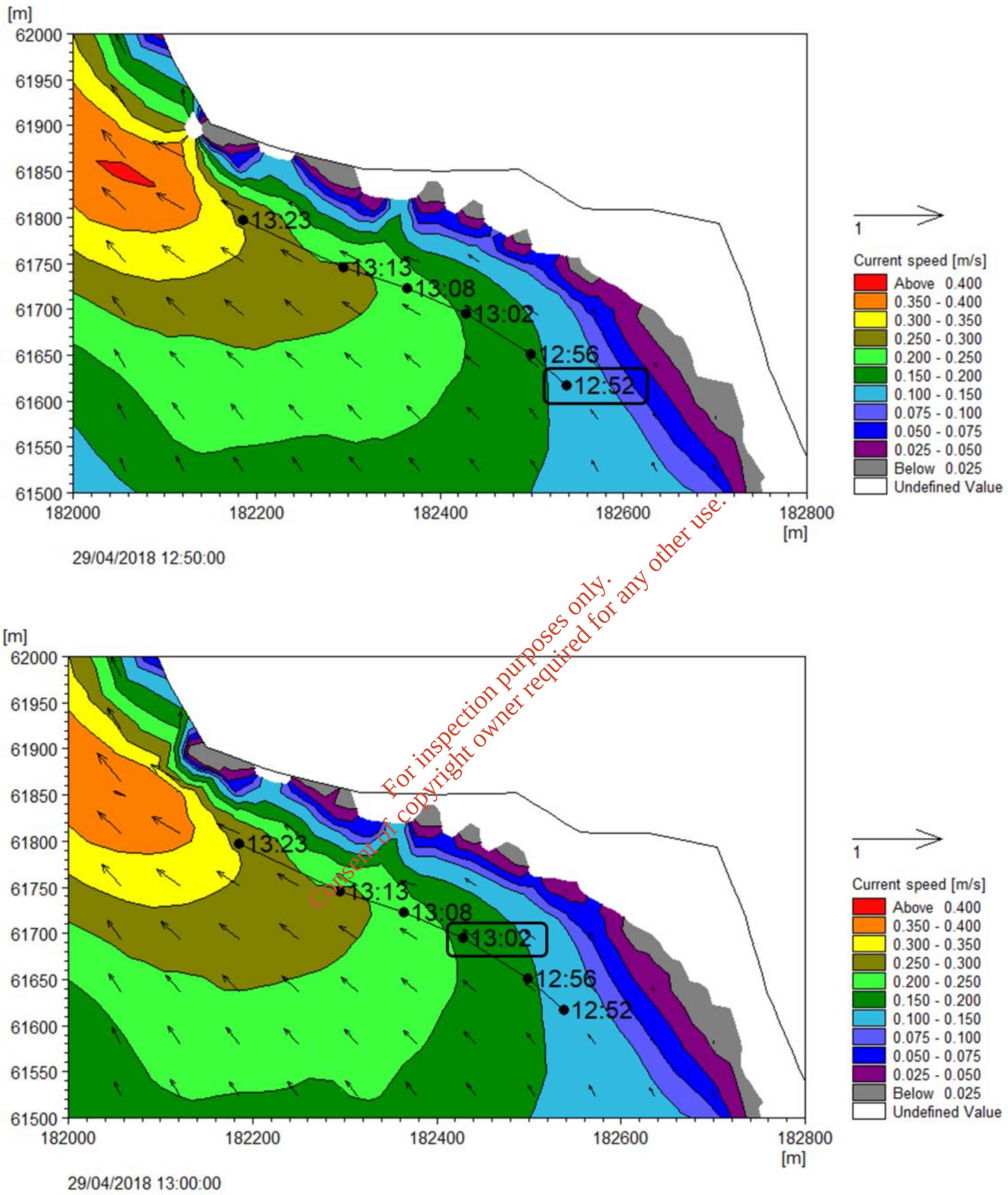
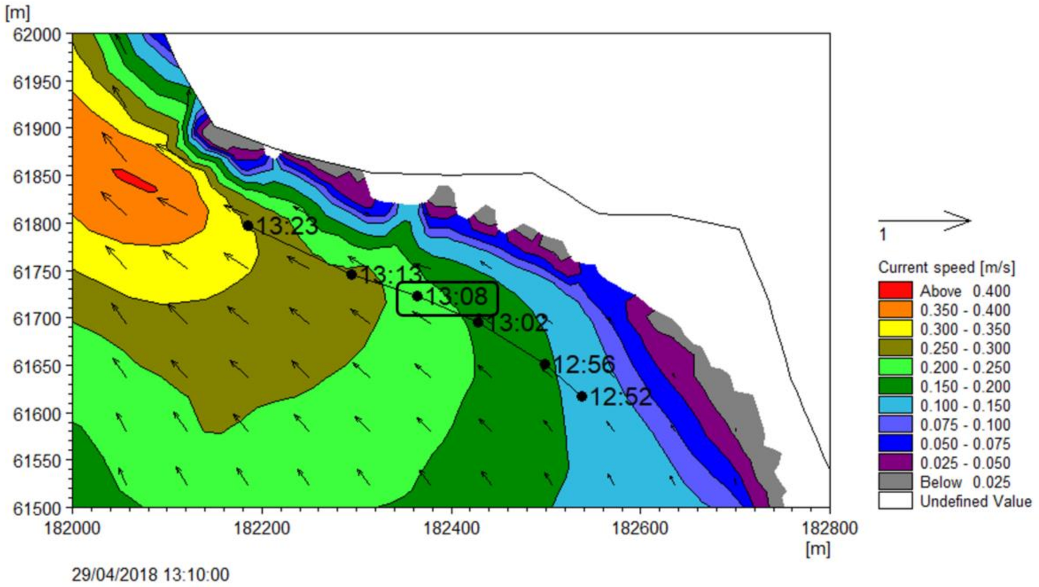
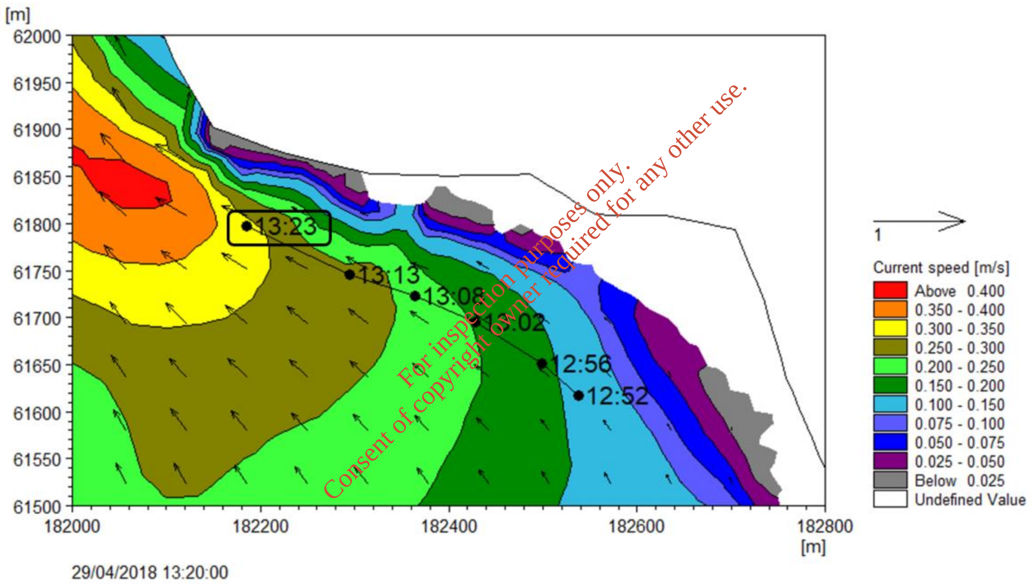

[m]
62000
61900
61800
61700
61600
61500
61400
61300
61200
61100
61000
60900
60800
60700
182000
182200
182400
182600
182800
183000
[m]
16:55
16:59
17:05
17:09
17:20
17:29
17:38
18:03
1
Current speed [m/s]
Above 0.400
0.350 - 0.400
0.300 - 0.350
0.250 - 0.300
0.200 - 0.250
0.150 - 0.200
0.100 - 0.150
0.075 - 0.100
0.050 - 0.075
0.025 - 0.050
Below 0.025
Undefined Value
29/04/2018 18:00:00

Figure 38 presents the current speed and velocity vector drogue validation for the flood tide. It is evident from the plots that the modelled current direction is well validated by the directional track of the drogue data.

Figure 38: Spring flood tide drogue validation







5.7 Additional Water Level Validation

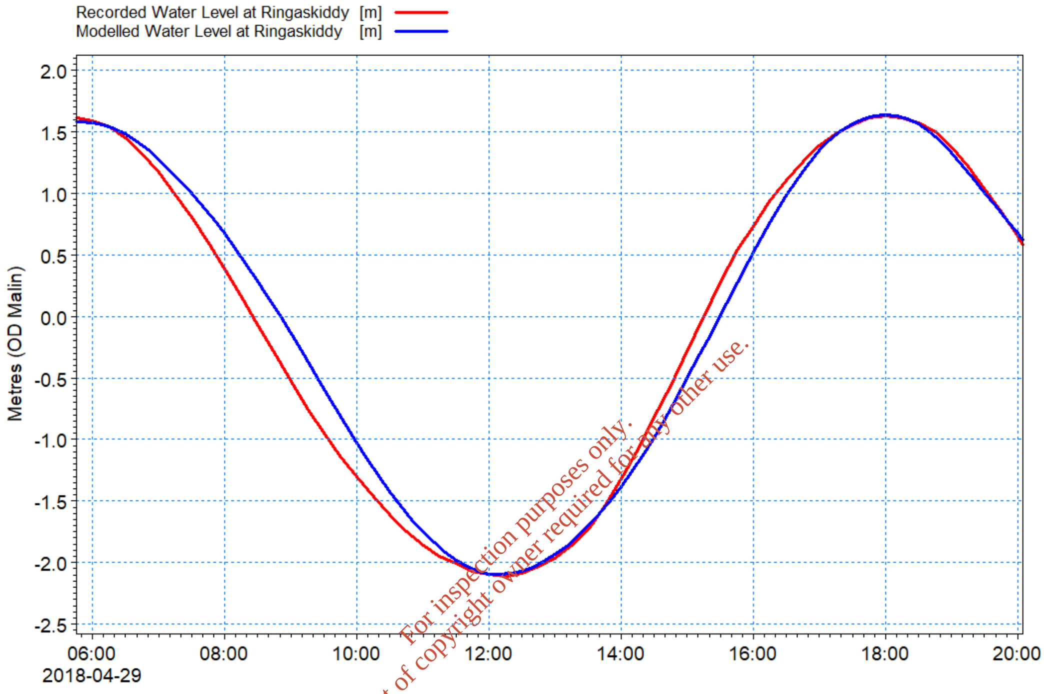
5.7.1 Spring tide water level

Further validation of the model was undertaken for water levels recorded at the Ringaskiddy and Tivoli gauges in Cork Harbour which are located some distance from the primary area of interest in Whitebay. As outlined in Section 4, due to the need to find a compromise between mesh resolution and the computational time of the model, the cell sizes of the mesh in areas located away from the key area of interest in Whitebay are coarser than the cell sizes used in Whitebay. While this ensures high precision in the model for the main area of interest, the model is less accurate in other further away areas such as in the vicinity of Ringaskiddy and Tivoli. This needs to be considered when assessing the validation for both of these locations.

The spring tide water level validation at Ringaskiddy is presented in Figure 39 for the same time period as the outfall location recorded data.

It can be seen from the figure that the modelled water level is well matched to the recorded maximum and minimum water levels at both high and low tides respectively. The model is also well matched to the time at which high and low water occurs. During the ebb tide the model overestimates water levels while on the flood tide the reverse occurs and the model slightly underestimates levels.

Figure 39: Ringaskiddy Water Level Validation – visual analysis



The statistical analysis for the spring tide water level calibration at Ringaskiddy is presented in Table 21.

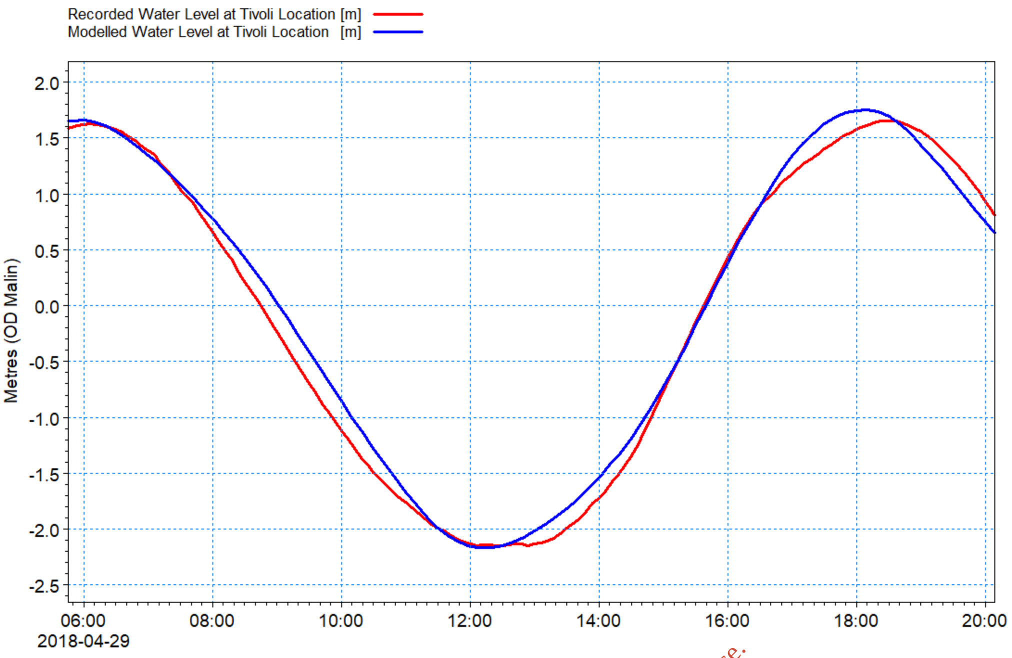
The absolute levels at high water (29/04/2018 18:15) and low water (29/04/2018 12:15) are within the ±0.1m tolerances specified in the IW guidelines. However, over the full spring tidal cycle, the model is within the absolute tolerances only 54% of the time. The RMSE value of the observed and modelled water level throughout the spring tidal cycle is 0.1826m, which exceeds the tolerance specified in the guidelines. This statistical analysis indicates a moderate model validation against the recorded water levels which is in keeping with the results presented in the visual analysis in Figure 39.

Table 21: Statistical performance results for Spring Tide water level calibration at Ringaskiddy

Time	Recorded Water Level (mOD)	Modelled Water Level (mOD)	Absolute difference between modelled and recorded (m)
29/04/2018 07:45	0.60	0.84	0.24
29/04/2018 08:15	0.16	0.48	0.32
29/04/2018 08:45	-0.30	0.08	0.37
29/04/2018 09:15	-0.75	-0.36	0.39
29/04/2018 09:45	-1.13	-0.81	0.32
29/04/2018 10:15	-1.47	-1.23	0.24
29/04/2018 10:45	-1.75	-1.59	0.15
29/04/2018 11:15	-1.95	-1.88	0.07
29/04/2018 11:45	-2.07	-2.05	0.02
29/04/2018 12:15	-2.11	-2.09	0.01
29/04/2018 12:45	-2.03	-2.02	0.02
29/04/2018 13:15	-1.86	-1.83	0.03
29/04/2018 13:45	-1.55	-1.55	0.00
29/04/2018 14:15	-1.08	-1.19	0.11
29/04/2018 14:45	-0.56	-0.75	0.20
29/04/2018 15:15	0.00	-0.25	0.25
29/04/2018 15:45	0.53	0.27	0.26
29/04/2018 16:15	0.94	0.76	0.17
29/04/2018 16:45	1.26	1.18	0.08
29/04/2018 17:15	1.48	1.47	0.01
29/04/2018 17:45	1.61	1.62	0.01
29/04/2018 18:15	1.62	1.62	0.00
29/04/2018 18:45	1.50	1.46	0.04
29/04/2018 19:15	1.22	1.17	0.05
29/04/2018 19:45	0.85	0.84	0.01
29/04/2018 20:15	0.43	0.50	0.07

The water level validation at Tivoli is presented in Figure 40. It can be seen from the figure that the model is well matched to the recorded data as regards both the timing and the maximum and minimum water levels at high and low tide respectively. As with the validation at Ringaskiddy, the model overestimates waters levels on the ebb tide. It also overestimates water levels for the first circa two hours of the flood tide but is then well matched to it for the remainder of the flood tide.

Figure 40: Tivoli Water Level Validation – visual analysis



The statistical analysis for the spring tide water level validation at Tivoli is presented in Table 22.

The absolute levels at low water (29/04/2018 12:15) are within the ±0.1m tolerances specified in the IW guidelines, while absolute tolerances at high water (29/04/2018 18:15) are slightly exceeded. Over the full spring tidal cycle, the model is within the absolute tolerances 39% of the time. The RMSE value of the observed and modelled water level throughout the spring tidal cycle is 0.1572m, which exceeds the tolerance specified in the guidelines.

Table 22: Statistical performance results for Spring Tide water level validation at Tivoli

Time	Recorded Water Level (mOD)	Modelled Water Level (mOD)	Absolute difference between modelled and recorded (m)
29/04/2018 07:45	0.87	0.94	0.07
29/04/2018 08:15	0.44	0.61	0.17
29/04/2018 08:45	0.00	0.23	0.23
29/04/2018 09:15	-0.47	-0.19	0.28
29/04/2018 09:45	-0.92	-0.63	0.28
29/04/2018 10:15	-1.32	-1.07	0.25
29/04/2018 10:45	-1.63	-1.47	0.15
29/04/2018 11:15	-1.88	-1.84	0.04
29/04/2018 11:45	-2.08	-2.09	0.01
29/04/2018 12:15	-2.14	-2.17	0.03
29/04/2018 12:45	-2.13	-2.09	0.04
29/04/2018 13:15	-2.10	-1.93	0.17
29/04/2018 13:45	-1.88	-1.69	0.19
29/04/2018 14:15	-1.54	-1.37	0.17

Time	Recorded Water Level (mOD)	Modelled Water Level (mOD)	Absolute difference between modelled and recorded (m)
29/04/2018 14:45	-1.08	-0.97	0.11
29/04/2018 15:15	-0.47	-0.46	0.00
29/04/2018 15:45	0.14	0.11	0.03
29/04/2018 16:15	0.69	0.65	0.04
29/04/2018 16:45	1.04	1.13	0.09
29/04/2018 17:15	1.29	1.50	0.20
29/04/2018 17:45	1.50	1.71	0.20
29/04/2018 18:15	1.63	1.74	0.11
29/04/2018 18:45	1.62	1.59	0.04
29/04/2018 19:15	1.45	1.28	0.17
29/04/2018 19:45	1.14	0.92	0.21
29/04/2018 20:15	0.71	0.58	0.13

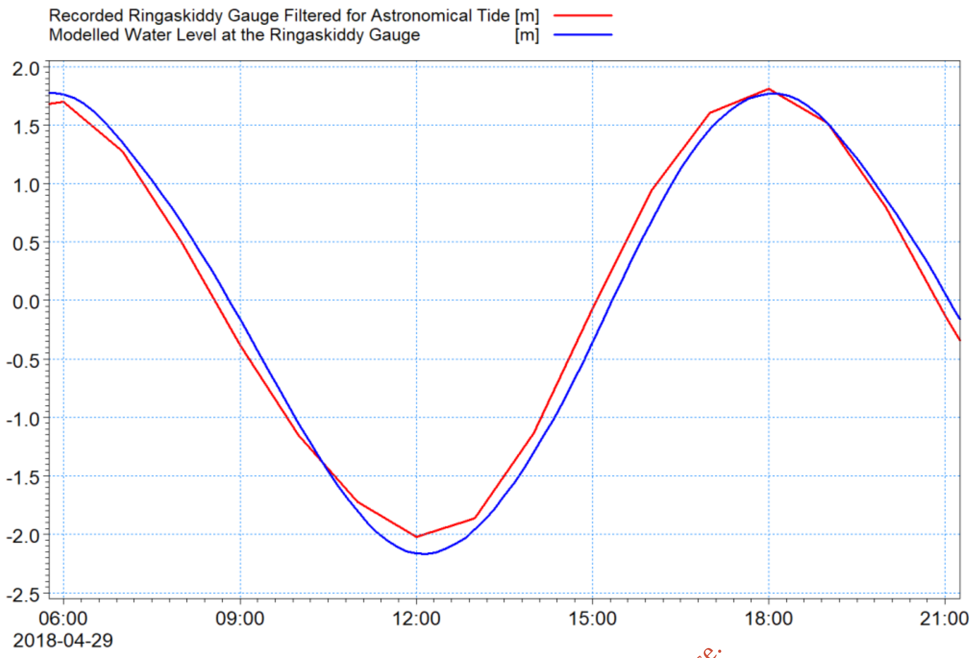
5.7.2 Astronomical tide validation

The model was also validated for astronomical tidal data using the following approach:

- Data from the Ringaskiddy gauge was filtered using data analysis techniques 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 for the same period;
- The model was run with the astronomical tidal boundary and compared against the derived astronomical tidal data from the gauge.

Figure 41 presents the astronomical spring tide validation for the same period as that presented in Section 5.3.

Figure 41: Astronomical spring tide water level validation



It can be seen from the figure that the match between the modelled astronomical water level and the derived astronomical water level is moderate: both tidal signals are in phase but there are differences in the water levels of circa 20-30mm through the tidal cycle. The model correctly predicts high tide water level and slightly underestimates the minimum water level during at low tide.

5.8 Discussion

The hydrodynamic model has been calibrated and validated against recorded data at the key site of interest in Whitebay. The model is well matched against recorded water level and current direction for both Spring and Neap tides. The model is also well matched against recorded Spring tide current speeds.

The neap tide current speed calibration is well matched for certain stages of the tide. The model however shows a divergence from the recorded data at two different points in time due to the formation of an eddy in the northern area of Whitebay. Strong localised currents were observed to occur on the surface at the site of interest which cannot be simulated with a depth integrated hydrodynamic model and this accounts for the divergence between the modelled and recorded data.

Further water level validation of the model was undertaken with data from the Ringaskiddy and Tivoli gauges. Given that these points are located away from the key area of interest in Whitebay they are resolved with a lower grid mesh resolution in the model and hence the modelled hydrodynamics in these areas is not as detailed as in Whitebay. Setting up the model in this way ensures a balance is achieved between its run time and its accuracy in the key areas. Given that Ringaskiddy and Tivoli are both located outside the tidal excursion of Whitebay, the ability of the model to accurately assess the impact of discharges from the proposed outfall is not in any way compromised.

The results of the water level validation demonstrate that the modelled water levels at these gauges is well matched against the recorded maximum and minimum water levels at high and low water. The modelled tide is also in phase with the recorded data. There are however differences in water level on both the ebb and flood tides caused by the localised grid resolution. Given that Ringaskiddy and Tivoli are outside the key area of interest, these differences are not deemed to have any significant impact on the ability of the model to assess the impact of discharge from the proposed outfall in Whitebay.

The accuracy of the model in simulating the hydrodynamics of the harbour have therefore been demonstrated and it can be concluded that the model is suitable for use in assessing the impact of the discharges from the proposed WwTP for Whitegate/Aghada.

6 Water Quality Modelling

6.1 Overview

This chapter describes the development and running of the Water Quality 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 can be calibrated using salinity data or a dye study. However, neither salinity nor dye study data was collected as part of the marine survey. It was concluded that the salinity range at the outfall location would be insufficient to allow an accurate dispersion coefficient calibration to be made. A dye study was not undertaken as it was deemed by Arup that a dye study at the site would not have provided a sufficiently accurate dataset with which to calibrate the model. The specification of the dispersion coefficient in the model is instead based on best practice within the industry and our extensive experience in developing coastal dispersion models. A sensitivity analysis has also been undertaken to assess if the findings of the model change when the dispersion coefficient is varied.

The Scaled Eddy Viscosity (SEV) formulation has been used to define the dispersion coefficient in the WQ model. This formulation allows for the dispersion coefficient to vary in time and space and also accounts for the varying cell size of the computational mesh. It is the most accurate specification of the dispersion coefficient within the MIKE system.

The SEV requires a scaling factor to be defined which amplifies or dampens the dispersion process. Different scaling constants have been tested against the recorded drogue data tracks to assess the variation in WQ concentrations resulting from changes to the scaling factor using the following methodology:

- An instantaneous release of a conservative pollutant was simulated by the model. The time and location of the release corresponds directly to the time and location of the drogue release;
- The track of the conservative pollutant's plume has been determined by extracting the maximum concentrations from the model run over the period for which the drogue was deployed;
- By plotting the maximum concentrations against the recorded drogue track they can be compared with each other.

The results are presented in Figure 42 to Figure 45. Four separate cases are presented: one flood and one ebb tide simulation for both Spring and Neap tide conditions. The recorded drogue track is presented with the black points and lines in each of the figures.

The numbers correspond to the time at which the location of the drogue was recorded by the surveyor. The format of the time stamp is hour-minute-second. The colour palette for the conservative pollutant has not been included in the figures as the actual modelled concentrations are somewhat arbitrary given that the purpose of the exercise is to present the track of the plume.

It can be seen that in each of the cases the track of the modelled plume is very similar to the recorded drogue track. The only noticeable difference is towards the end of the Spring tide ebb release where the drogue track and modelled track diverge slightly. It is also evident from the plots that the model is not sensitive to changes in the specification of the scaling factor of the SEV as the plume is very similar for each of the four values assessed. We have therefore used a scaling factor of 1.0 in the model for the baseline model simulations.[5]

[5] As it is a scaling factor, the number is dimensionless.

Figure 42: Neap tide conditions – ebb tide release

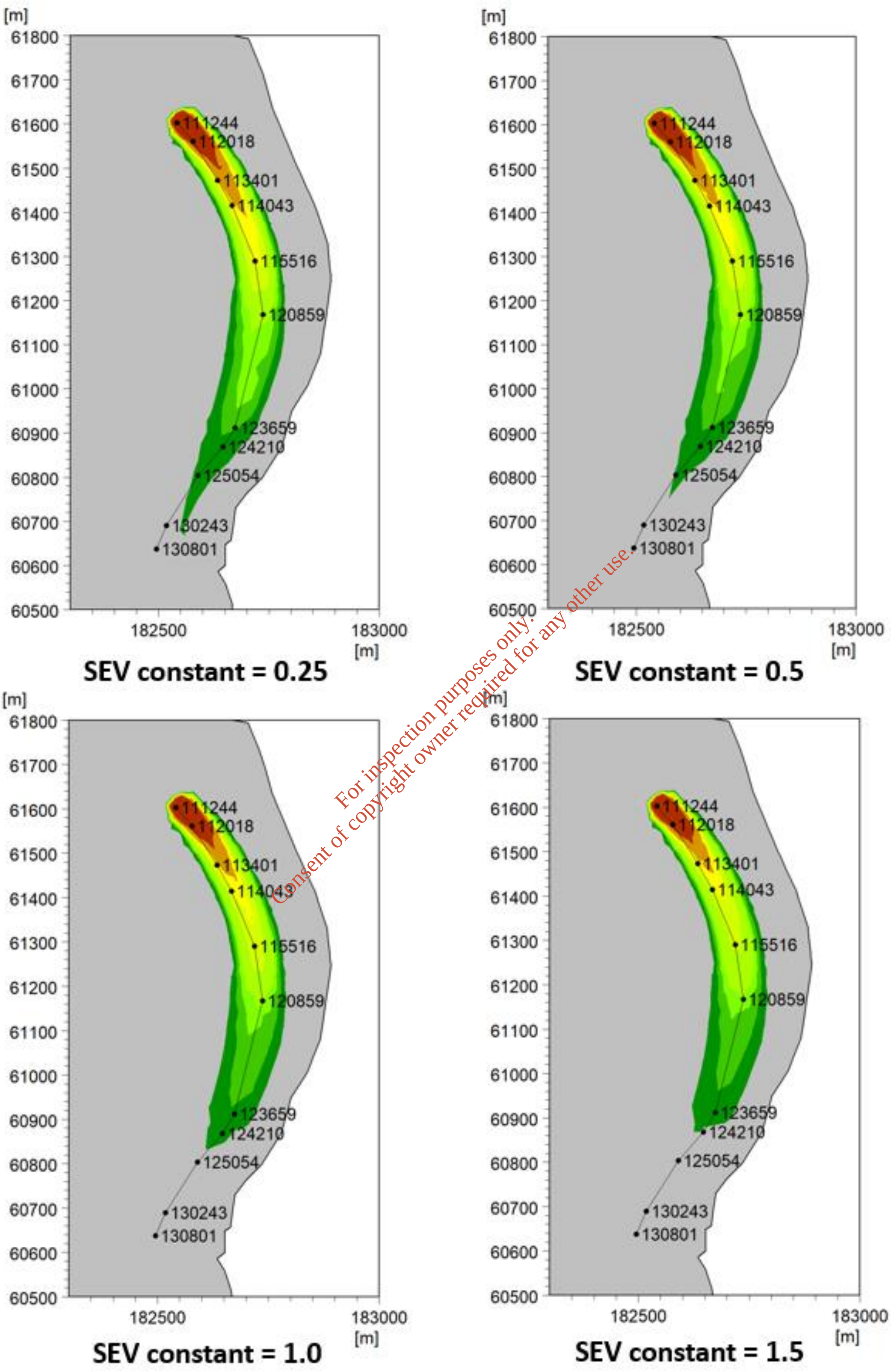


Figure 43: Neap tide conditions – flood tide release

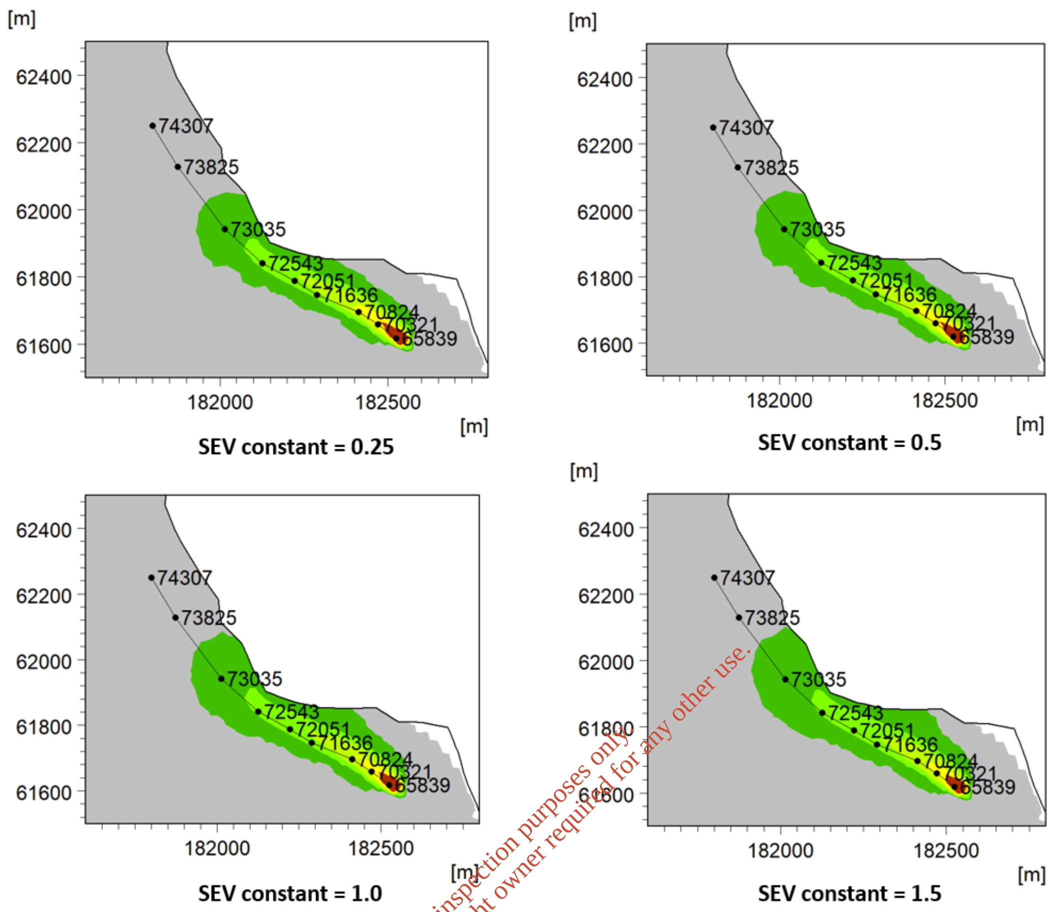


Figure 44: Spring tide conditions – ebb tide release

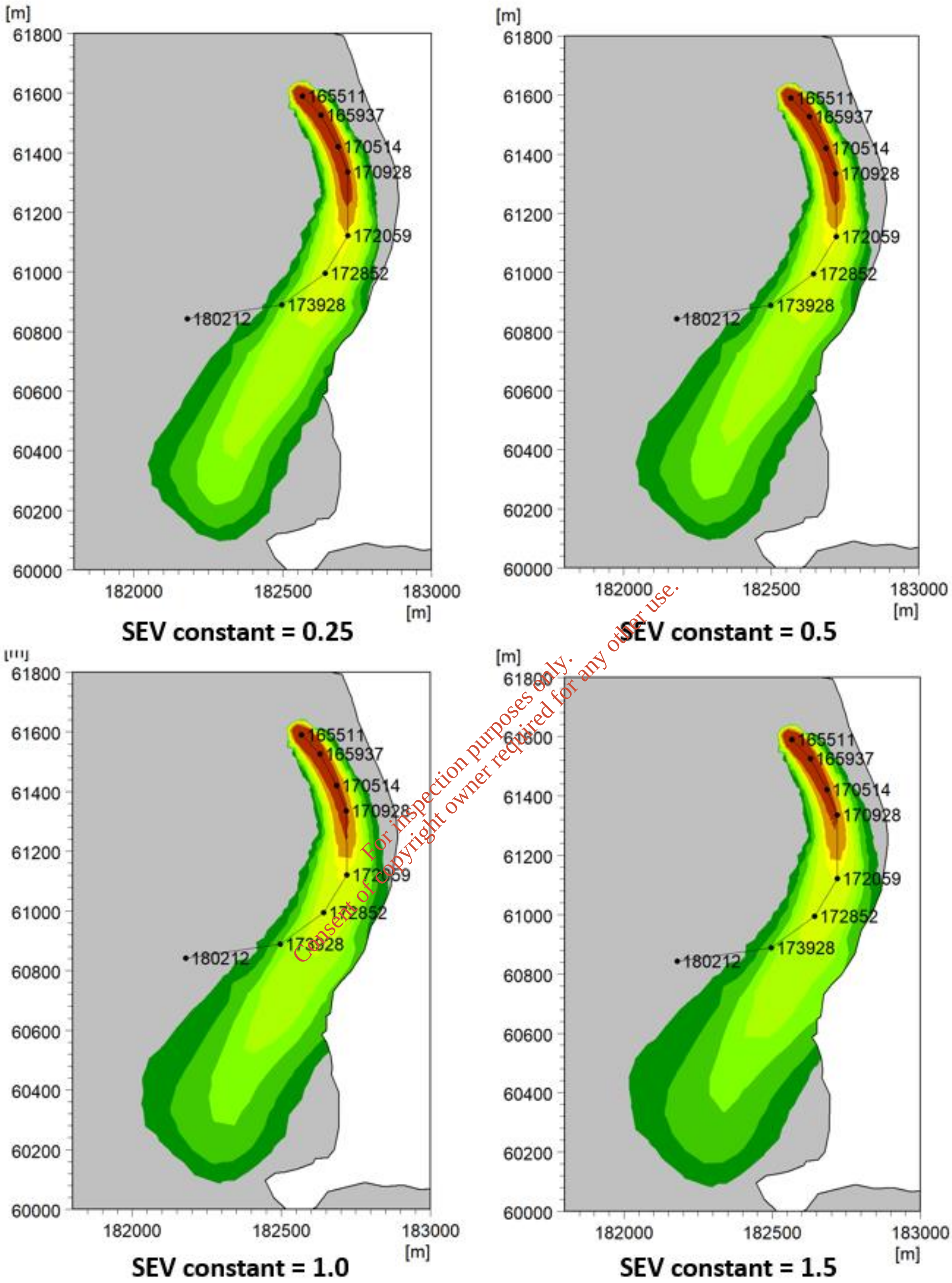
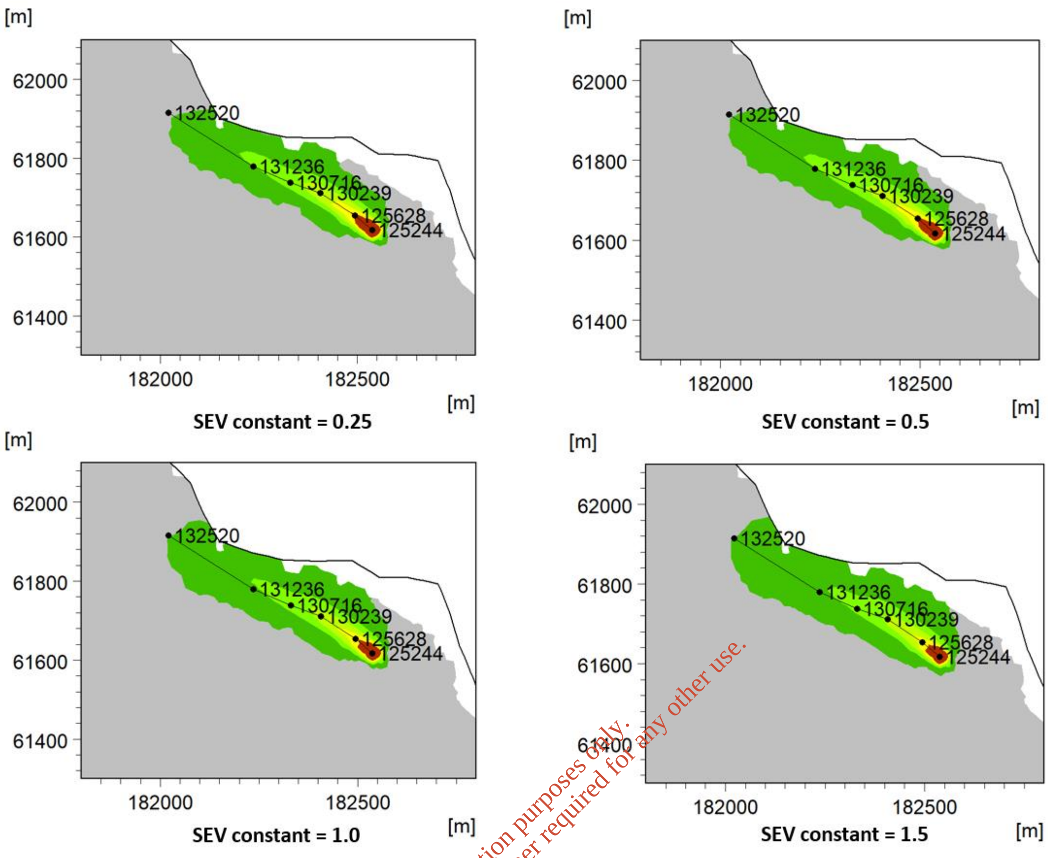


Figure 45: Spring tide conditions – flood tide release



6.3 Discharges and Background Information

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 and industrial outfalls in Cork Harbour;
- Primary rivers that flow into the Cork Harbour;
- 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 cfu/m^3 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 cfu/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

Three outfalls presently make up the existing Whitegate/Aghada discharge to Cork Harbour. We used the information presented in the Jennings/AECOM report to determine the PE for these three outfalls. The flow rates were then estimated by multiplying the PE for each outfall by 225L/person/day[6].

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/AECOM report [2]. For the proposed scenario at Whitegate/Aghada 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.

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 23.

6.3.2 Fluvial discharges

As discussed in Section 2.5, a large number of rivers and streams discharge into Cork Harbour. These 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 harbour.

All the watercourses that impact on the area of interest have been included in the model. Our methodology for specifying the input flow rates for the rivers is given as:

- For gauged catchments, the 50%ile flow rate for the winter months was calculated from the gauge's flow record and used in the model. Where required, adjustments were made to the flow to account for differences in the catchment area at the gauge and the catchment area of the river where it meets with the harbour;
- For ungauged catchments, flow rates were derived from the 50% winter flow calculated for the Ballea gauge which is located on the River Owenboy upstream of Carrigaline based on differences in catchment areas;

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 of the model and not the existing and proposed WWtP scenarios for Whitegate/Aghada. The reduction in concentration of the relevant WQ parameter with the scheme in place (i.e. the delta value) is not impacted as

[6] 225L/p/d is Irish Water's assumed rate per day per person

the background concentration is the same for both the baseline and proposed scenario.

6.3.3 Discharge locations

The fluvial and outfall discharge points in the vicinity of Whitegate/Aghada are presented in Figure 46 and Figure 47 for the existing and proposed scenarios respectively. It can be seen that a number of the fluvial discharges are located a short distance from the land boundary. This approach was adopted to avoid numerical instability in the model associated with positioning discharge points in grid cells subject to flooding and drying.

Figure 46: Existing discharges (fluvial inflows in green, outfalls in red)

Figure 47: Proposed discharges (fluvial inflows in green, outfalls in red)

Table 23 below presents the flow rates and concentrations for all discharges included in the model.

Table 23: 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	Lee	29.3037	168380	71950	–	3000	13	1.8	0.023	0.07	0.0009
River	Glashaboy	3.3673	172720	72370	–	3000	13	3.0	0.026	0.05	0.0015
River	Douglas	0.6654	172900	69720	–	3000	13	3.0	0.026	0.05	0.0015
River	Owenacurra	3.9580	187500	71300	–	3000	13	1.4	0.017	0.04	0.0016
River	Aghada	0.3906	186650	65840	–	3000	13	1.4	0.017	0.04	0.0016
River	Owenboy	3.0258	179000	61500	–	3000	13	1.4	0.017	0.04	0.0016
River	Ardnabourkey	0.0743	183600	63700	–	3000	13	1.4	0.017	0.04	0.0016
River	Knocknamadderee	0.1467	187800	67360	–	3000	13	1.4	0.017	0.04	0.0016
River	Carrigtwohill	0.5951	180400	72420	–	3000	13	1.4	0.017	0.04	0.0016
River	Glounatouig	0.2200	175900	65100	–	3000	13	1.4	0.017	0.04	0.0016
Sea	Open Sea	-	Applied at downstream boundary		-	400	28	0.2	0.007	0.02	0.0006
Outfall	Saleen Village	0.0003	187700	67360	None	10,000,000	400,000	60.0	14	55	0.9185
Outfall	Cobh	0.0260	178243	65558	None	10,000,000	400,000	50.0	8	34	0.5678
Outfall	Whitegate/Aghada Existing	0.0052	183337	64664	None	10,000,000	400,000	25.0	4	5	0.0835
Outfall	Whitegate/Aghada Proposed	0.0085	182521	61580	Primary	1,000,000	40,000	54.0	12	50	0.8350
Outfall	North Cobh	0.0064	177535	67632	Secondary	100,000	4,000	12.6	1.38	4.3	0.07
Outfall	Carrigrennan	1.3954	176683	69726	Secondary	100,000	4,000	20.7	1.72	17.5	0.29
Outfall	Shanbally IDA	0.1622	181358	62521	Secondary	52,200	4,000	132.7	42.5	29.1	0.4860
Outfall	Midleton ID	0.0911	186177	69506	Tertiary	8,574	343	4.1	0.41	0.65	0.011
Outfall	Carrigtwohill 1	0.0271	179911	72583	Tertiary	10,000	400	7.2	0.407	1.3	0.022

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)
Outfall	Carrigtwohill 2	0.0271	180594	72283	Tertiary	10,000	400	7.2	0.407	1.3	0.022
Outfall	SKB	0.0151	178885	62710	-	0	0	25.0	2	10	0.1670
Outfall	ESB	0.0058	183266	65316	-	0	0	10.0	0	10	0.1670
Outfall	P66WR	0.1389	182596	63221	-	0	0	25.0	2	15	0.2505
Outfall	BGE	0.0069	182410	63165	-	0	0	5.0	5	5	0.0835
Outfall	M Chem	0.0035	177310	69720	-	0	0	15.0	0	10	0.1670

6.4 Overview of Design Model Runs

The design model runs were simulated with the following parameters:

- Astronomical tidal conditions for the open boundary;
- Simulation period: from 27/04/2018 09:45 to 19/05/2018 17:30 to give a total duration period of circa 23 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[7]
- Assume the cycling of nutrients in the harbour can be described using a linear decay function with T90 values of:
  - DIN T90 = 23 days[8]
  - 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

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

[7] The scientific literature outlines a range of coliform T90 values. A T90 value of 20 hours has been selected for coliforms 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.
[8] 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 48. The difference between the two plots (the 'delta' plot) is also presented.

From the results it can be seen that the 95%ile concentrations vary across the outer harbour and in the area of interest in Whitebay for both scenarios. For the existing scenario concentrations are greater than 150 cfu/100ml in the vicinity of Haulbowline Island, while in the area of interest in Whitebay they are generally less than 50 cfu/100ml. It can be seen from the figure that concentrations reduce considerable along the north-south direction. 95%ile concentrations are less than 10 cfu/100ml south of Whitebay towards the coastline.

For the proposed scenario the 95%ile concentrations appear broadly similar to the existing scenario plot with the only noticeable visual difference being a very significant reduction in the concentrations at the location of the existing outfalls in Whitegate/Aghada and an increase in concentrations local to the proposed outfall. With the proposed scheme in place the 95%ile concentrations are reduced from greater than 1,000 cfu/100ml to less 10 cfu/100ml at the existing Whitegate/Aghada outfalls, and concentrations at the proposed outfall are increased from below 50 cfu/100ml to over 500 cfu/100ml.

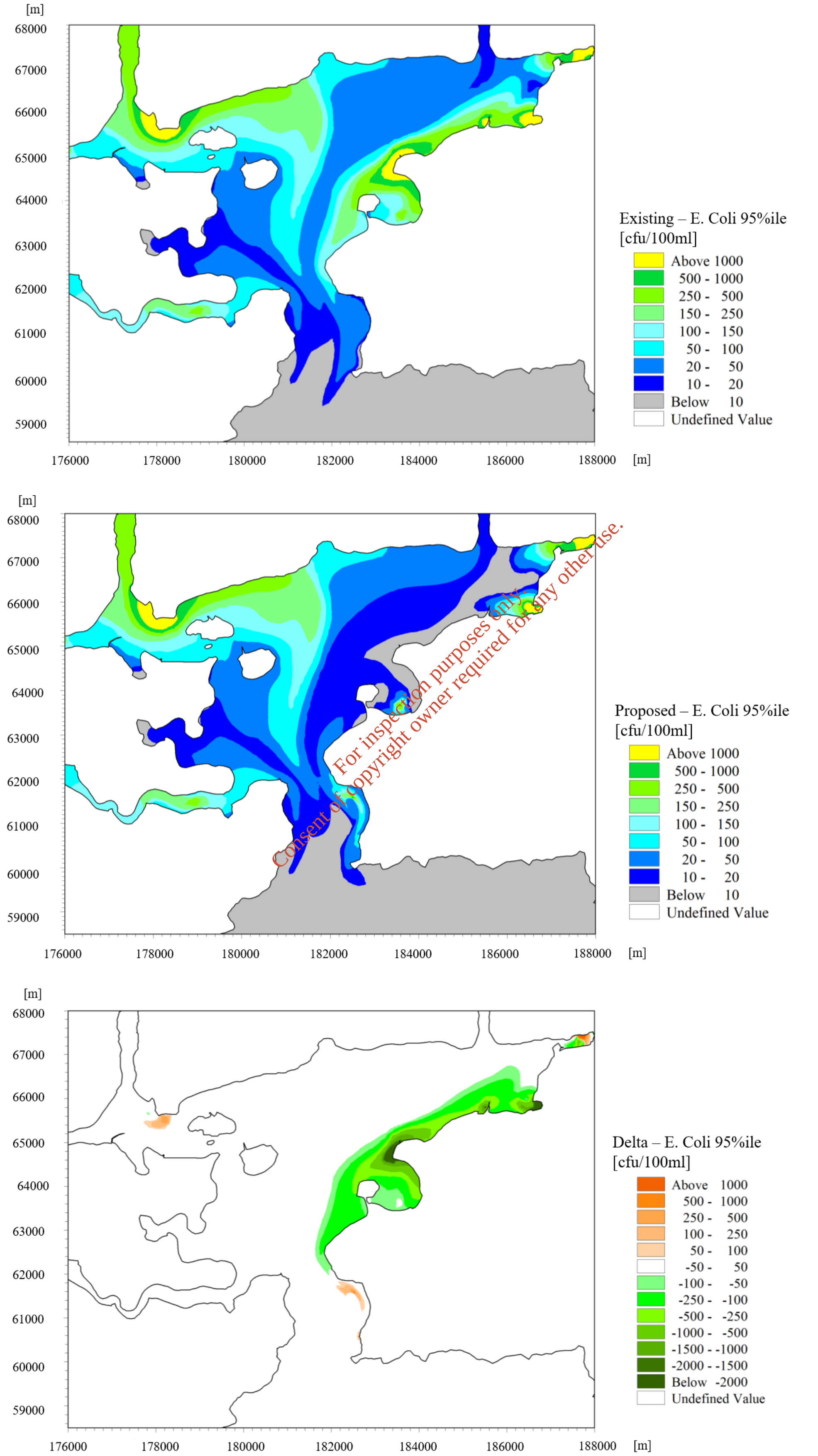
The delta plot illustrates the differences between the existing and proposed scenarios. As the existing scenario has been subtracted from the proposed scenario, reductions in 95%tile concentrations are presented as negative values, while increases in concentrations are presented as positive values. From the plot it can be seen that the proposed scheme reduces the 95%ile E. Coli concentrations across a large area of the eastern outer harbour area. For some areas of the outer harbour these reductions are in excess of 1,000 cfu/100ml which is considered very significant. 95%ile concentrations in the immediate vicinity of where the Knocknamadderee and Aghada rivers enter the harbour are however in excess of 1,000 cfu/100ml due to the coliform loading from the rivers.

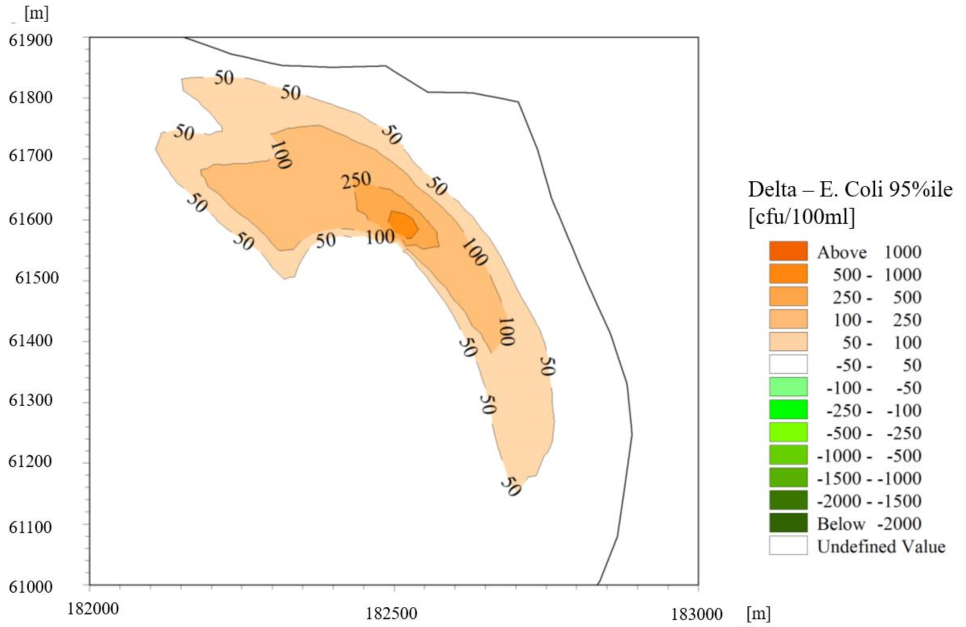
For the area around Cobh and up into West Passage the difference is minimal as these areas are not influenced by discharges from the existing Whitegate/Aghada outfall i.e. plumes from the existing outfall are not advected by the currents into these areas.

It can be seen from Figure 48 that there are small areas close to the Cobh outfall that suggest minor differences in the 95%ile concentrations for the different scenarios. These small pockets of concentrations however are not associated with changes due to the existing and proposed scenarios but are instead caused by minor errors in the model associated with the flooding and drying of grid cells in the immediate vicinity of source discharge points.

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 100m of the outfall however the increase in the 95%ile E. Coli concentration is less than 250 cfu/100ml and within circa 300m the increase is less than 100 cfu/100ml.

Figure 48: E. Coli 95%ile concentration plots – existing, proposed and delta plots (including a close-up view)





Whitebay is not a designated EU bathing water area. It is however used for recreation and we have therefore considered the results in the context of the Bathing Water Regulations.

Under the Bathing Water Quality Directive (2006/7/EC), 95%ile E. Coli concentrations of 250cfu/100ml or less in coastal/transitional waters are considered "Excellent" as indicated in Table 24.

Table 24: Bathing Water Classification (Annex I of Directive 2006/7/EC)

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 48 that the 250 cfu/100ml 95%ile concentration threshold is exceeded within 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 Directive (2006/7/EC) within circa 50m of the outfall.

6.5.2 Intestinal enterococci 95%ile plots

The spatially varying 95%ile plot for Intestinal Enterococci for both the existing and proposed scenario is presented in Figure 49. 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 the outer harbour but are increased locally in Whitebay.

The most significant reduction in the 95%ile concentrations is at the location of the existing discharges at Whitegate/Aghada where the reduction in coliform count is greater than 100 cfu/100ml in places. There is an increase in the 95%ile concentration of circa 32 cfu/100ml in the immediate vicinity of the proposed outfall. Within circa 400m of the outfall however the increase is less than 2 cfu/100ml which is considered to be very low.

Under the Bathing Water Quality Directive (2006/7/EC) (outlined in Table 25) 95%ile Intestinal Enterococci concentrations of 100 cfu/100ml or less in coastal/transitional waters are considered “Excellent”.

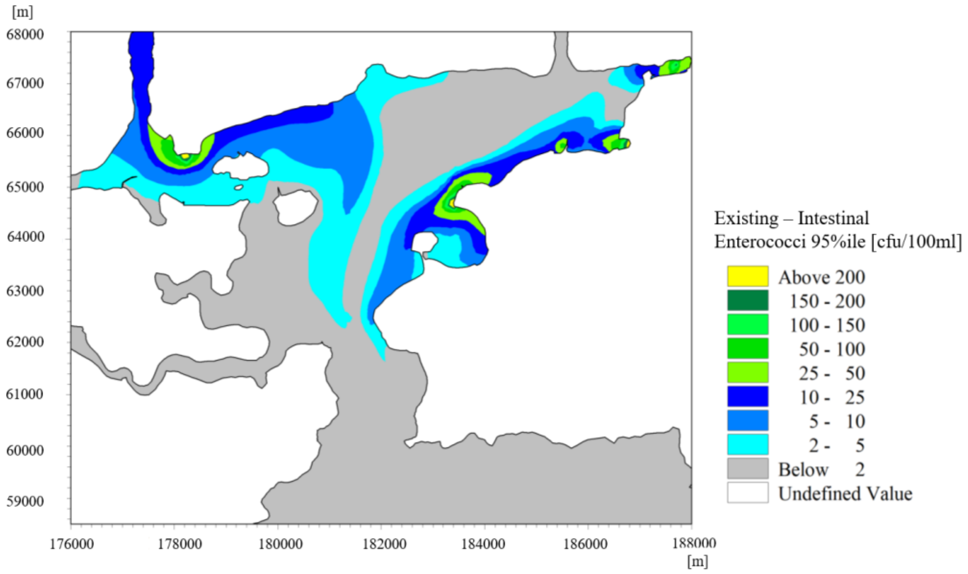
Table 25: Bathing Water Quality Directive (Annex I of Directive 2006/7/EC)

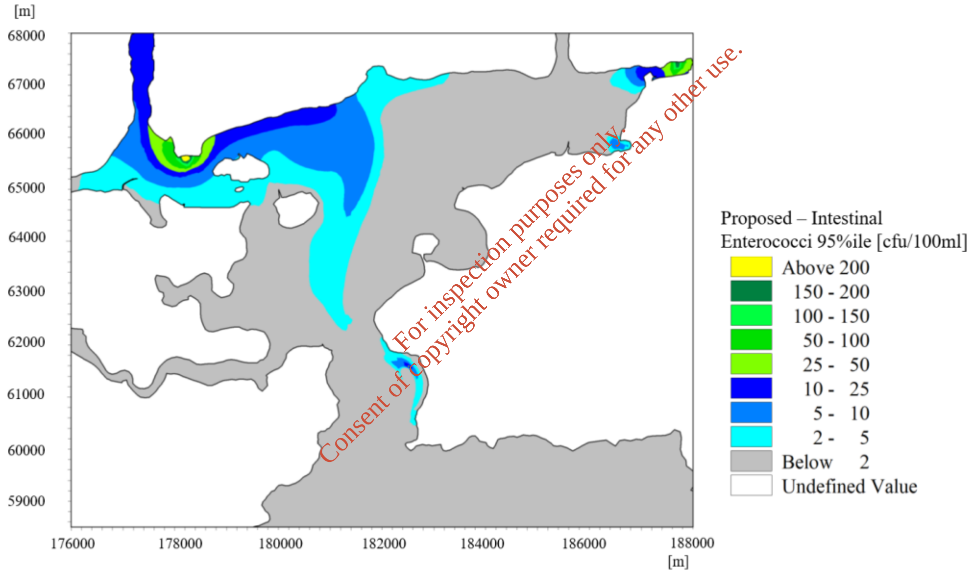
Water Type	Parameter	Excellent	Good	Sufficient
Coastal / Transitional	Intestinal enterococci cfu/100ml	100 (*)	200 (*)	185 (**)

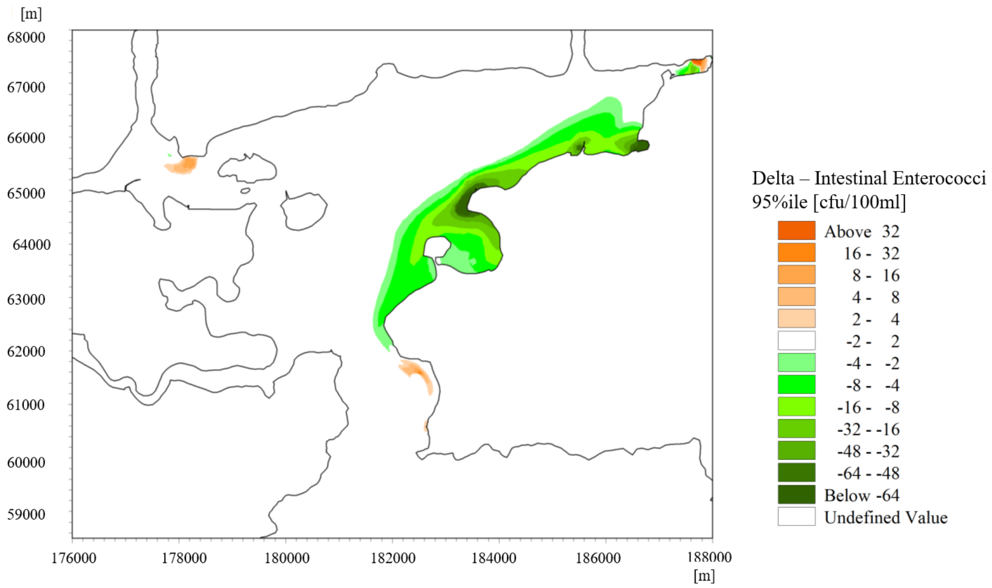
(*) based on a 95-percentile evaluation (**) based on a 90-percentile evaluation

For the proposed scenario the 95%ile concentration are less than 50 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 Directive for Intestinal Enterococci across the harbour.

Figure 49: IE 95%ile concentration plots – existing, proposed and delta plots.







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 50. The delta plot is also presented in the figure.

From the results it can be seen that the 50%ile concentrations vary across the outer harbour and in the area of interest in Whitebay for both scenarios, with concentrations reducing in a southerly direction towards the coastline.

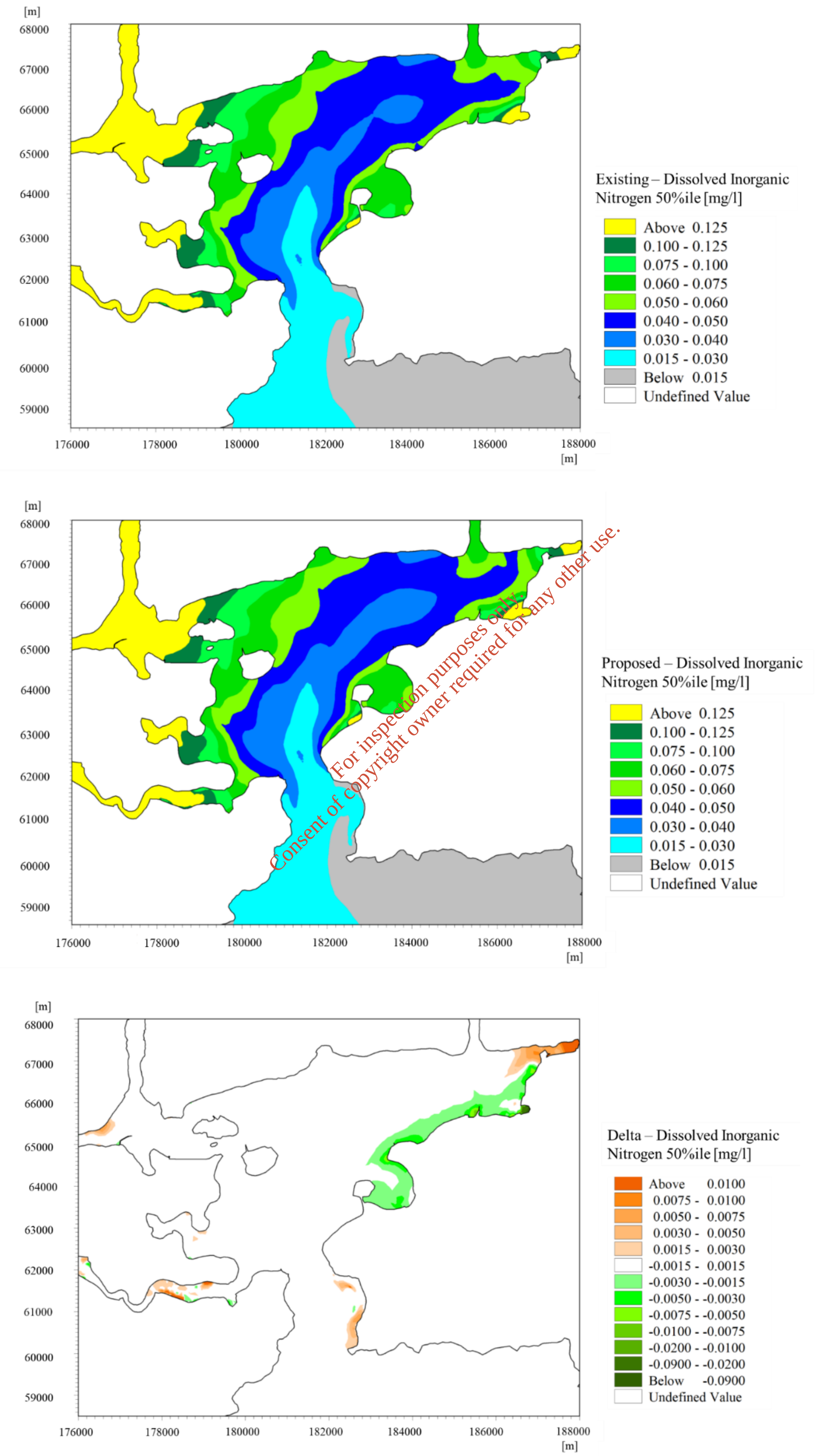
For the existing scenario concentrations exceed circa 0.03mg/l in the outer harbour area. For the proposed scenario the 50%ile concentrations appear broadly similar to the existing scenario plot. In both cases peak concentrations of over 0.125mg/l occur at the location of the river inflows. As the fluvial inflow loadings are unchanged in both scenarios the resulting concentrations in the water volume in the model are the same.

It can be seen from the delta plot that the proposed scheme reduces the 50%ile concentrations of DIN across the eastern side of the outer harbour where the existing Whitegate/Aghada discharges are. At the location of the existing Whitegate/Aghada outfalls the reduction is greater than 0.003mg/l.

The proposed outfall discharge increases the 50%ile DIN concentrations local to the outfall in Whitebay. It can be seen from the delta plot that the concentrations local to the outfall are increased by circa 0.0015 – 0.0075mg/l with the scheme in place.

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. The target level of DIN is 0.25mg/l. The model results show that the increase associated with the proposed scheme in place in the vicinity of the outfall is considerably less that this target level. This increase in concentration is therefore deemed to be very minor.

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



6.5.4 MRP 50%ile plots

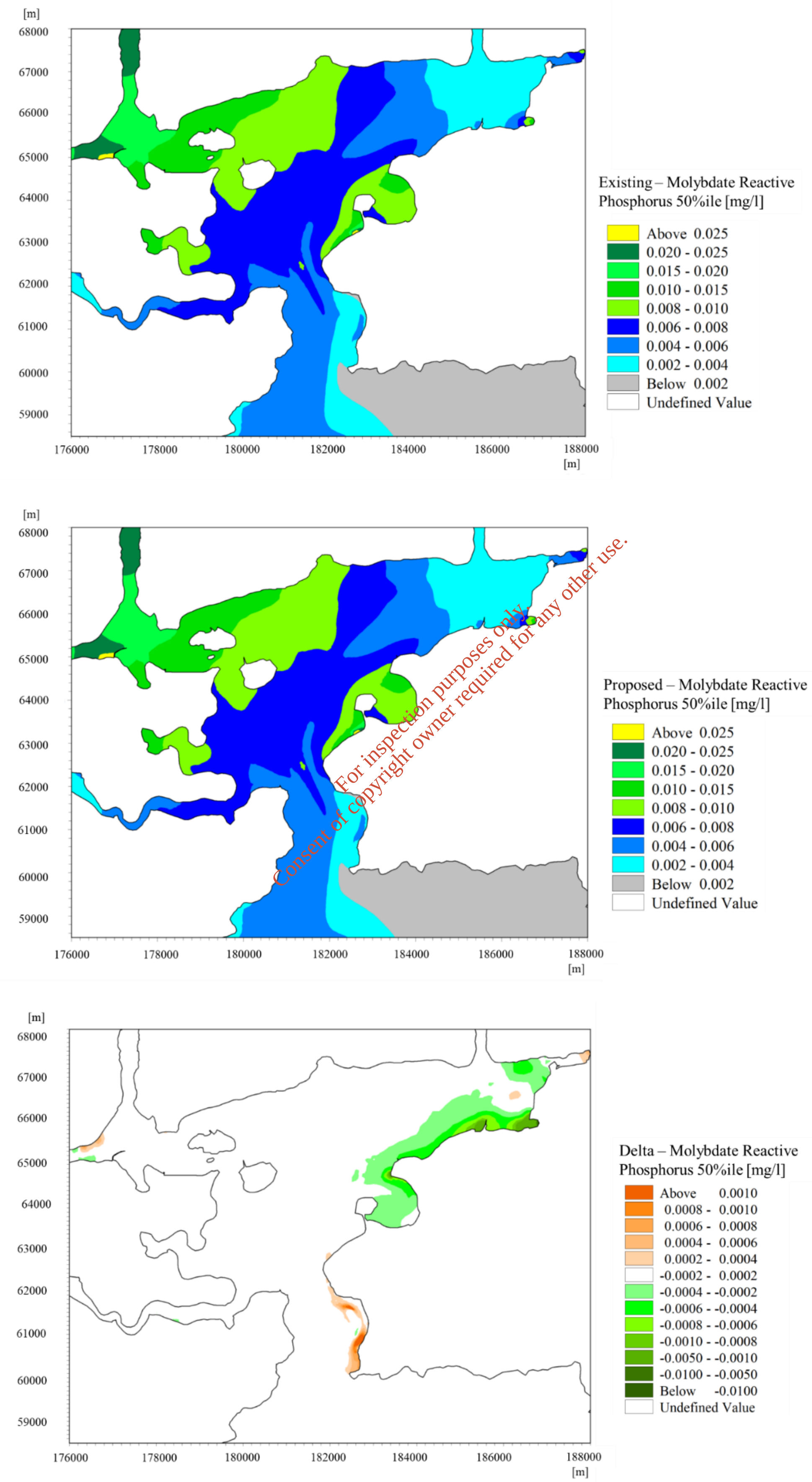
The results for MRP are presented in Figure 51. It can be seen that the general pattern of the 50%ile concentration and change in concentration associated with the proposed scheme for MRP is broadly similar to the results presented in the previous section for DIN. From the figures it is evident that there is little impact on the existing MRP levels in the outer harbour as a result of the proposed scheme.

The delta plot however shows the minor differences in MRP as a result of the scheme. The proposed scheme reduces the 50%ile concentration in the outer harbour but increases concentrations locally in the vicinity of the outfall. In the eastern side of the outer harbour concentrations are reduced by circa 0.0002 – 0.001 mg/l in the proposed scenario. In the vicinity of the proposed outfall 50%ile concentrations are increased by circa 0.0002 – 0.001 mg/l in the proposed scenario.

For both scenarios the MRP 50%ile concentrations reduce in a north-south direction due to the hydrodynamics of the harbour limiting the advection of the plume past Roches point.

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. The results of the model indicate that the increase is less than 3% of the target level which is deemed to be very minor.

Figure 51: MRP 50%ile concentration plots – existing, proposed and delta plots

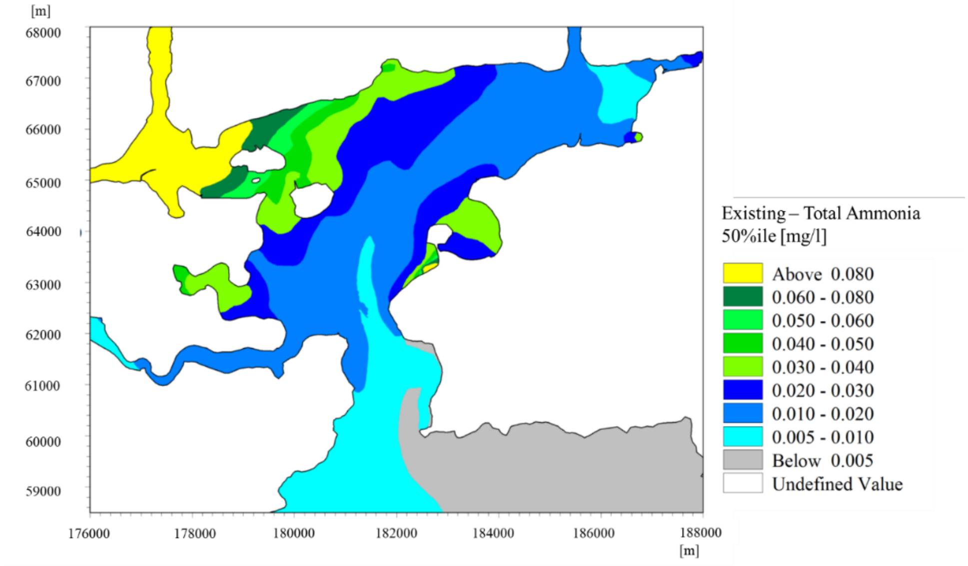


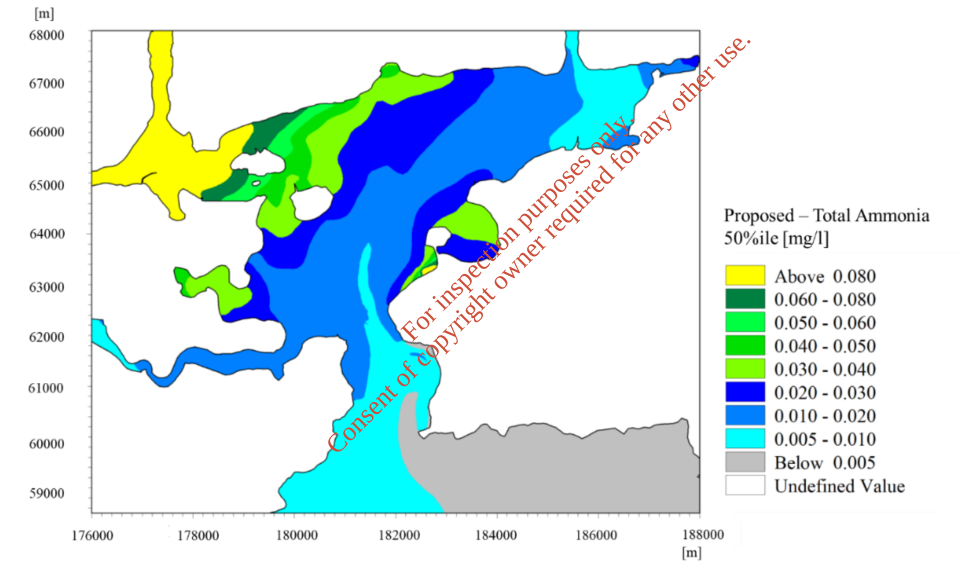
6.5.5 Total ammonia 50%ile plots

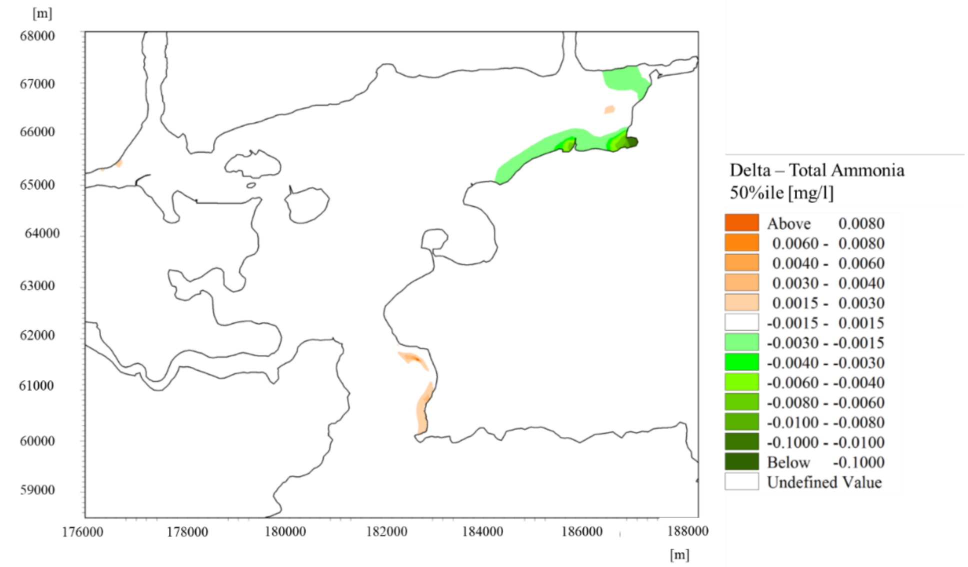
The results for Total Ammonia (TA) are presented in Figure 52. Results are similar to those for DIN and MRP, with the proposed scheme having very minor impact on the 50%ile concentrations. Implementation of the proposed scheme is seen to reduce the TA in the vicinity of existing outfalls on the eastern side of the outer harbour, where reductions of up to 0.006mg/l are observed. Increases in concentrations of up to 0.006mg/l are seen locally at the proposed outfall.

The target level of TA as per the EQSs as defined in the Salmonid Water Regulations is 1mg/l. 50%iles concentrations of TA are relatively low across the outer harbour, below the EQS threshold. In this context the increase in TA associated with the proposed outfall is deemed to be very minor.

Figure 52: TA 50%ile concentration plots – existing, proposed and delta plots





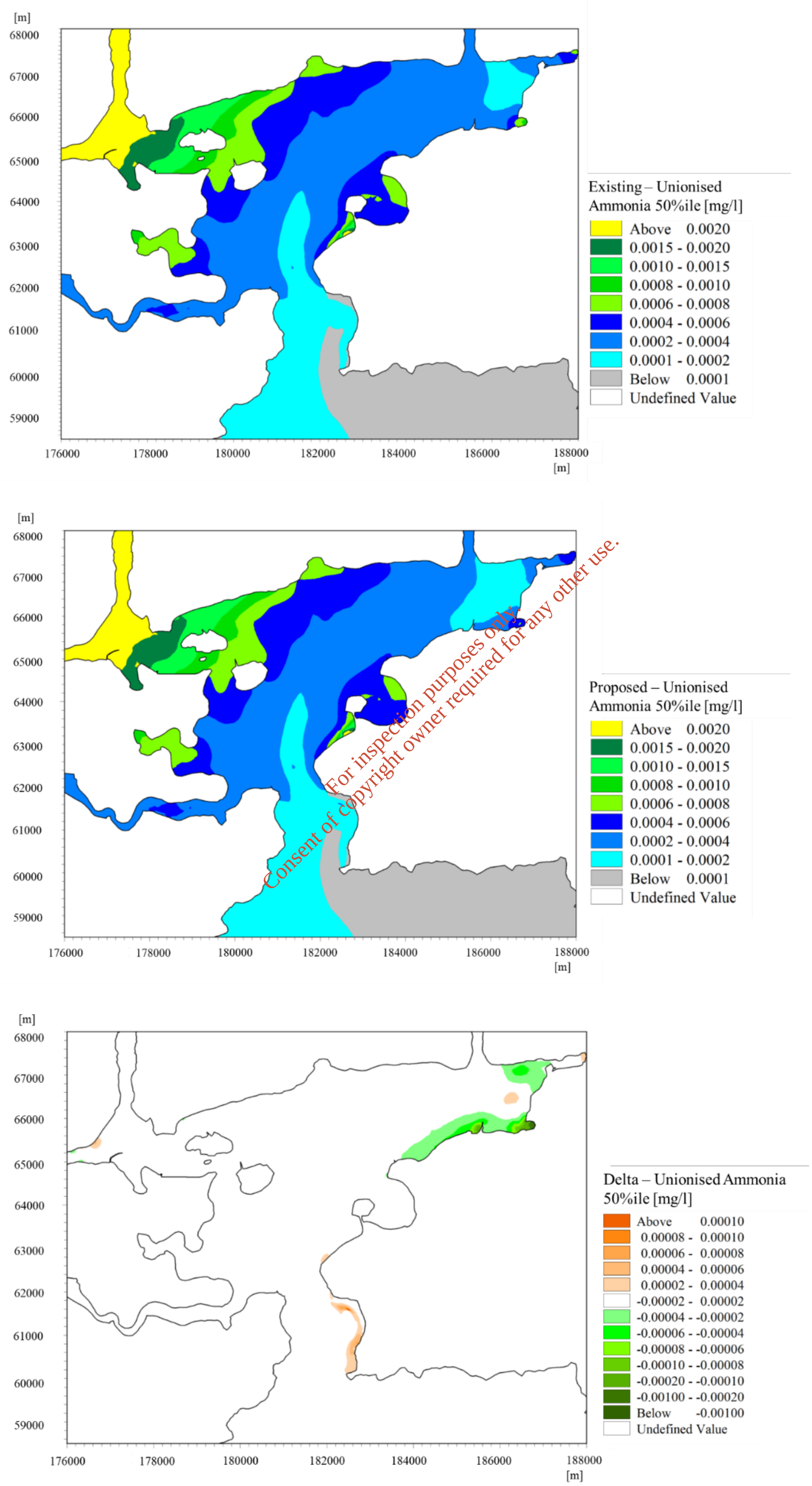


6.5.6 Unionised ammonia 50%ile plots

Model results for the assessment of Unionised Ammonia are presented in Figure 53. 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, with very low UiA concentrations observed throughout the outer harbour area. The proposed scheme has a very minor impact on concentrations at the proposed outfall locations, resulting in a marginal increase of circa 0.00002 - 0.0001mg/l.

The UIA target level as specified by the Salmonid Water Regulations EQSs is 0.02mg/l. In both the existing and proposed cases UiA levels are substantially lower than this limit.

Figure 53: UiA 50%ile concentration plots – existing, proposed and delta plots



6.6 WQ Concentrations at Monitoring Points

The 95%ile and 50%ile concentrations for the six WQ parameters considered in this study at each of the designated monitoring points in Cork Harbour are presented in Table 26. We note that 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. Arup have also deemed certain points to be of interest (i.e. the bathing area at Myrtleville beach) and have included these. The location of the points is presented in Figure 54. The 95%ile and 50%ile concentrations for the six WQ parameters are also assessed for four locations within the designated shellfish waters, as shown in Figure 55.

Figure 54: Location of monitoring points

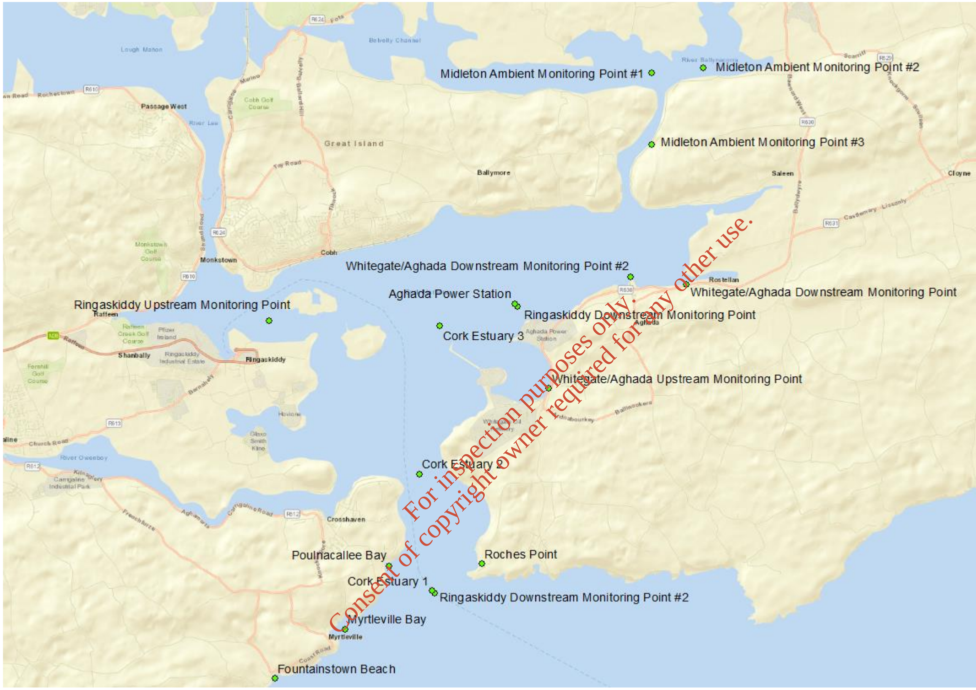


Figure 55: Location of monitoring points within shellfish waters

The difference between the existing and proposed scenario concentrations at each of the points is also presented in the delta columns of the table.

It is evident from the table that the 95%ile concentrations of both E. Coli and Intestinal Enterococci are reduced at nearly all the points across the harbour. A reduction is observed at each point within the shellfish waters, with the exception of shellfish point 1, where there is a slight increase. This increase does not however lead to EQS thresholds being exceeded at this point. The only noticeable increase is at Roches Point which is considered a comparatively minor increase with regard to the EQS threshold for E. Coli.

The differences in the 50%ile concentrations of the various nutrients at the various monitoring points are also considered minor.

Only two concentrations presented in the table (highlighted in yellow) exceed their EQS for the proposed scenario: the E. Coli and DIN concentrations at the Whitegate Aghada Downstream Monitoring Point 1. The concentrations of both of these parameters are above their relevant EQS thresholds of 500cfu/100ml and 0.25mg/l respectfully.

The Whitegate Aghada Downstream Monitoring Point 1 is located adjacent to the River Aghada's source discharge in the model and is therefore very sensitive to discharges from the river, which elevate concentrations locally. The proposed scheme however still results in a significant improvement in water quality at this monitoring point due to the removal of the untreated discharge from Rostellan. This improvement is demonstrated by the reduction in the E. Coli 95%ile concentration at this point from 3182 to 883cfu/100ml. The exceedance of the EQS threshold is therefore on account of the background concentration in the model and is not as a result of the impact of the proposed scheme.

From the results it appears as if the proposed scheme results in a reduction in the DIN 50%ile concentration at this same monitoring point (-0.02mg/l).

The model predicts that discharges from the proposed WwTP for Whitegate/Aghada are therefore in compliance with the relevant EU regulations.

Table 26: Coliform (95%ile) and nutrient (50%ile) concentrations at monitoring points

Label	95%ile						50%ile											
	E. Coli (cfu/100ml)			Intestinal Enterococci (cfu/100ml)			Dissolved Inorganic Nitrogen (mg/l)			Molybdate Reactive Phosphorus (mg/l)			Total Ammonia (mg/l)			Unionised Ammonia (mg/l)		
	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta
Roches Point	6	27	21	0	1	1	1E-02	9E-03	-5E-03	3E-03	2E-03	-9E-04	5E-03	4E-03	-1E-03	1E-04	7E-05	-3E-05
Cork Estuary 1	7	5	-2	0	0	0	2E-02	2E-02	3E-04	5E-03	5E-03	4E-05	7E-03	7E-03	2E-04	1E-04	1E-04	3E-06
Cork Estuary 2	36	36	0	1	1	0	3E-02	3E-02	1E-04	6E-03	6E-03	6E-05	1E-02	1E-02	3E-04	2E-04	2E-04	4E-06
Cork Estuary 3	45	44	-1	2	2	0	4E-02	4E-02	1E-04	8E-03	8E-03	3E-05	2E-02	2E-02	4E-04	3E-04	3E-04	8E-06
Aghada Power Station	39	12	-28	2	1	-1	4E-02	4E-02	-1E-03	6E-03	5E-03	-1E-04	2E-02	2E-02	-8E-04	3E-04	3E-04	-2E-05
Poulnacallee Bay	6	5	0	0	0	0	2E-02	2E-02	2E-04	5E-03	5E-03	4E-05	9E-03	9E-03	3E-04	2E-04	2E-04	5E-06
Fountainstown Beach	0	0	0	0	0	0	7E-03	7E-03	9E-05	2E-03	2E-03	2E-05	3E-03	3E-03	1E-04	5E-05	5E-05	2E-06
Myrtleville Bay	1	1	0	0	0	0	2E-02	2E-02	1E-04	4E-03	4E-03	4E-05	7E-03	7E-03	3E-04	1E-04	1E-04	4E-06
Ambient Monitoring Pt 1	18	18	0	0	0	0	9E-02	9E-02	-7E-04	3E-03	3E-03	-8E-05	9E-03	9E-03	-2E-04	2E-04	2E-04	-5E-06
Ambient Monitoring Pt 2	234	230	-4	1	1	0	2E-01	2E-01	-8E-04	5E-03	5E-03	-6E-05	1E-02	1E-02	-2E-04	4E-04	4E-04	-4E-06
Ambient Monitoring Pt 3	23	23	0	1	0	0	8E-02	8E-02	-8E-04	3E-03	3E-03	-8E-05	1E-02	1E-02	-3E-04	2E-04	2E-04	-5E-06
Ringaskiddy Upstream Monitoring Pt	116	116	0	5	5	0	1E-01	1E-01	2E-04	1E-02	1E-02	3E-05	9E-02	9E-02	1E-04	1E-03	1E-03	3E-06
Ringaskiddy Downstream Monitoring Point 1	53	11	-42	2	1	-2	4E-02	4E-02	-1E-03	6E-03	6E-03	-2E-04	2E-02	2E-02	-8E-04	3E-04	3E-04	-1E-05
Ringaskiddy Downstream Monitoring Pt 2	8	5	-3	0	0	0	2E-02	2E-02	2E-04	5E-03	5E-03	4E-05	7E-03	7E-03	2E-04	1E-04	1E-04	3E-06

Label	95%ile						50%ile											
	E. Coli (cfu/100ml)			Intestinal Enterococci (cfu/100ml)			Dissolved Inorganic Nitrogen (mg/l)			Molybdate Reactive Phosphorus (mg/l)			Total Ammonia (mg/l)			Unionised Ammonia (mg/l)		
	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta	Existing Scenario	Proposed Scenario	Delta
Whitegate/ Aghada Upstream Monitoring Pt	275	2	-272	11	0	-11	6E-02	6E-02	-5E-03	9E-03	8E-03	-8E-04	3E-02	3E-02	-2E-03	6E-04	6E-04	-3E-05
Whitegate/ Aghada Downstream Monitoring Pt 1	3182	883	-2298	95	4	-91	3E-01	3E-01	-2E-02	8E-03	6E-03	-2E-03	2E-02	2E-02	-7E-03	6E-04	5E-04	-1E-04
Whitegate/ Aghada Downstream Monitoring Pt 2	648	27	-620	25	0	-25	7E-02	7E-02	-4E-03	4E-03	3E-03	-9E-04	1E-02	9E-03	-3E-03	2E-04	2E-04	-6E-05
Shellfish point 1	89	93	4	3	4	0	6E-02	5E-02	-7E-03	3E-03	3E-03	-2E-04	1E-02	9E-03	-9E-04	2E-04	2E-04	-2E-05
Shellfish point 2	10	10	0	0	0	0	7E-02	7E-02	-6E-04	2E-03	2E-03	-2E-05	6E-03	6E-03	-2E-05	1E-04	1E-04	-1E-06
Shellfish point 3	77	33	-44	2	0	-2	7E-02	7E-02	-3E-04	3E-03	3E-03	-2E-04	1E-02	9E-03	-4E-04	2E-04	2E-04	-5E-06
Shellfish point 4	111	4	-107	4	0	-4	5E-02	4E-02	-8E-04	3E-03	3E-03	-2E-04	1E-02	1E-02	-8E-04	2E-04	2E-04	-1E-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 all background concentrations included (i.e. the normal proposed conditions) for the entire simulation period;
- Calculate the 95%ile of the relevant WQ parameter;
- Present the 95%ile results with the colour palette set to the relevant target values of the relevant EU water directive.

As per Section 11.3 of the IW technical guidelines for marine modelling [1], mixing zones have been delineated for all water quality parameters considered in this study. The mixing zone for each WQ parameter has been defined based on the relevant EQS threshold, where the mixing zone is the area at which the percentile standard exceeds the EQS threshold for that parameter.

The results are presented in Figure 56 - Figure 61 with the target values set to those defined in the relevant EU directives.

For E.Coli, it can be seen that the mixing zone is limited to the immediate vicinity of the outfall and that the Whitebay shoreline maintains excellent water quality. The zone that exceeds the 500 cfu/100ml threshold is approximately 2,500m^2 in size.

For IE, DIN, MRP, TA and UIA, no mixing zone envelope is shown, indicating that the EQS threshold levels are not exceeded at the outfall location for any of these WQ parameters.

The mixing zone for each WQ parameter is in compliance with the targets outlined in Table 11-3 of the IW guidelines [1]. It can be concluded that the proposed scenario excellent water quality is maintained at the outfall location.

Figure 56: E. Coli Mixing Zone for outfall (outfall location indicated)

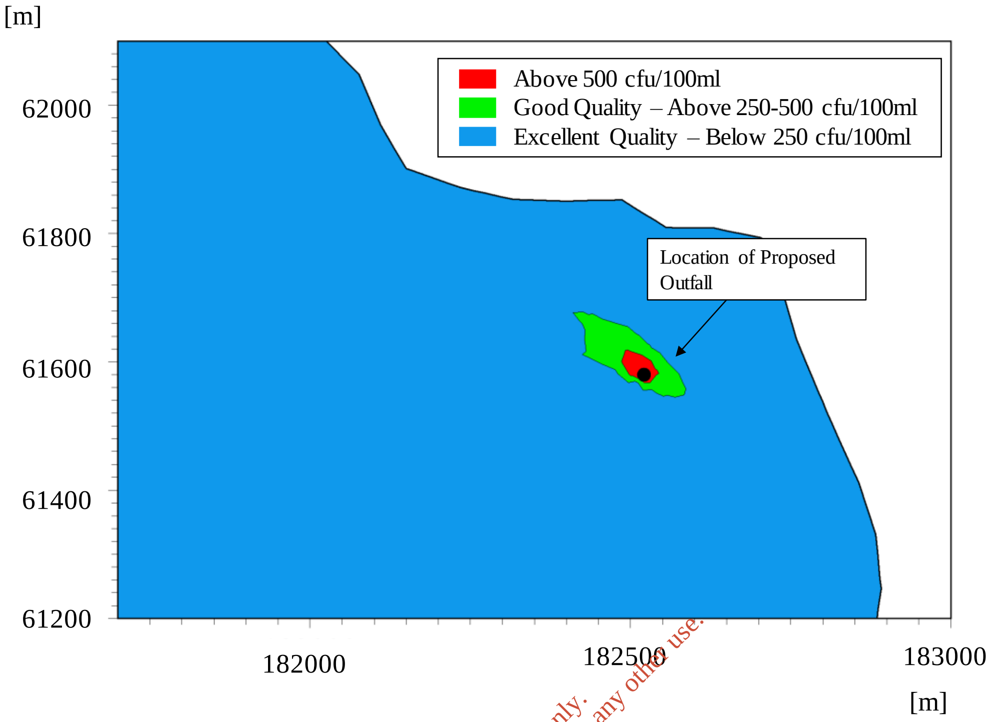


Figure 57: IE Mixing Zone for outfall (outfall location indicated)

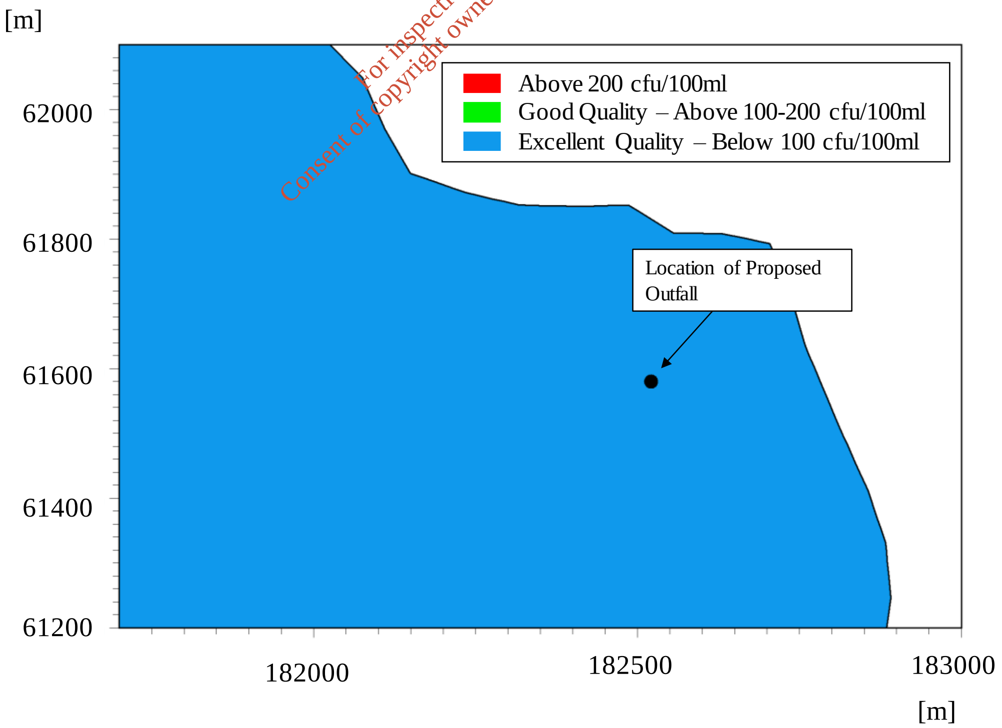


Figure 58: DIN Mixing Zone for outfall (outfall location indicated)

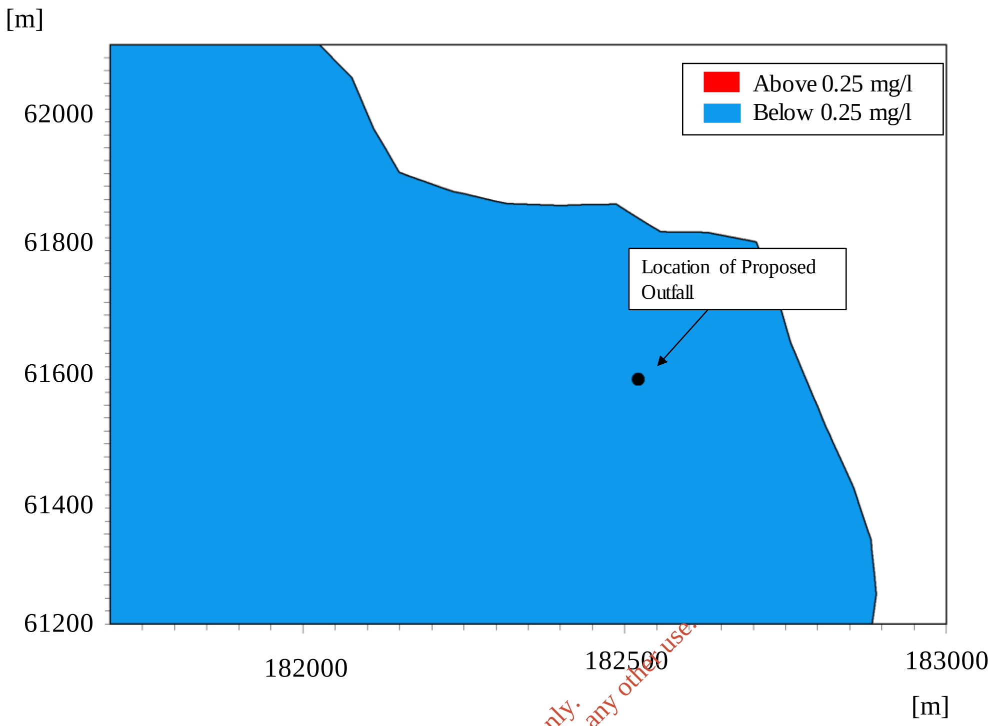


Figure 59: MRP Mixing Zone for outfall (outfall location indicated)

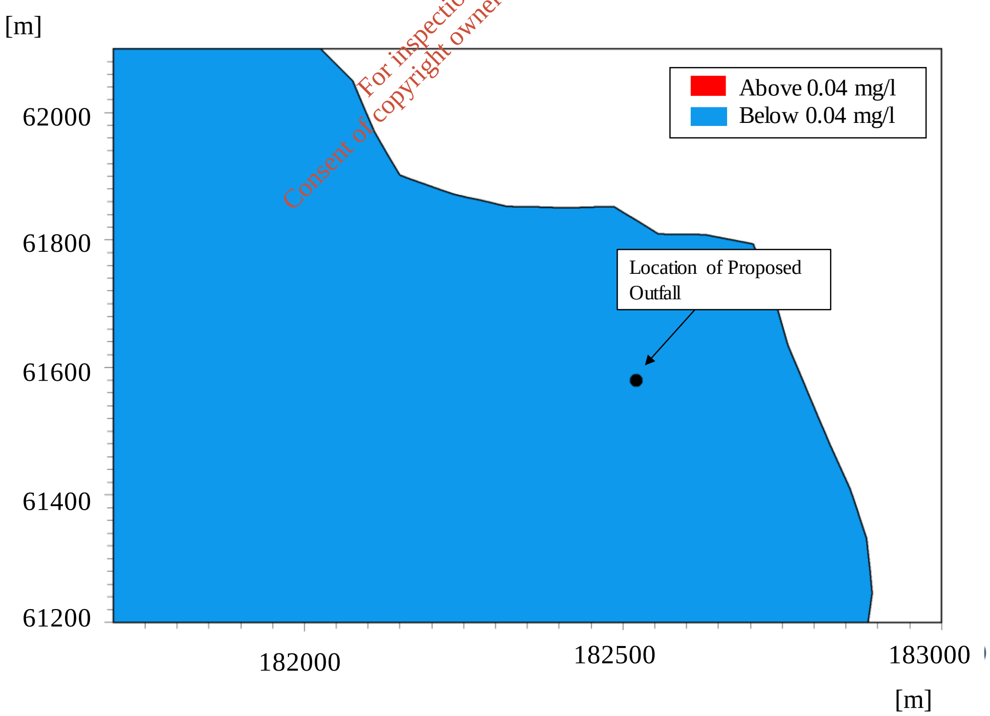


Figure 60: TA Mixing Zone for outfall (outfall location indicated)

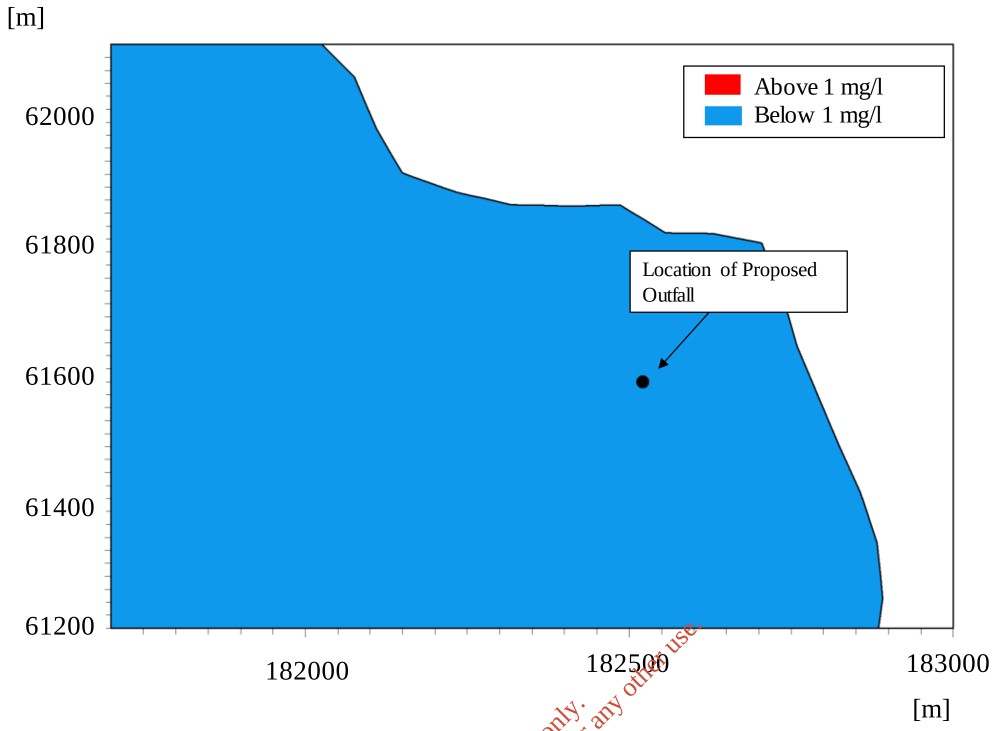
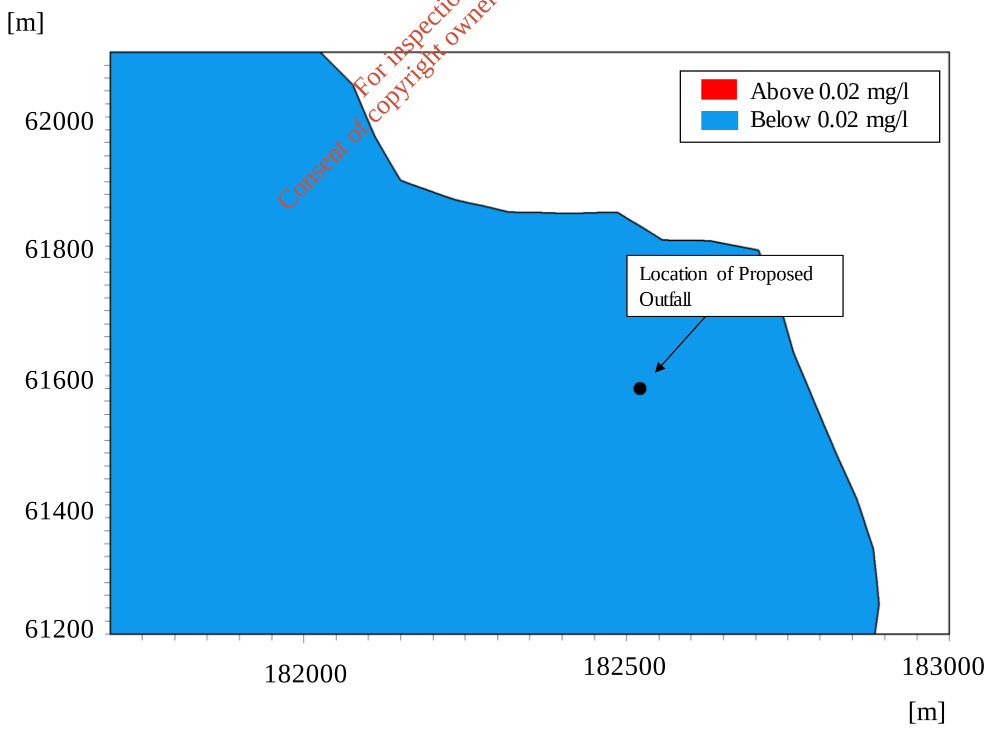


Figure 61: UIA Mixing Zone for outfall (outfall location indicated)



6.8 Discussion

The results of the model show that the 95%ile concentrations of both E. Coli and Intestinal Enterococci are significantly reduced in the outer harbour as a result of the scheme but are increased local to the outfall in Whitebay.

While Whitebay is not a designated EU Bathing Water area, we have considered our results in the context of the EQSs specified in the Bathing Water Directive in order to inform on the water quality. In the context of the EQS's, the increase in both E. Coli and Intestinal Enterococci are considered minor and excellent water quality will be achieved in Whitebay with the proposed scheme in place. The model results also indicate that the proposed scheme reduces the 95%ile concentrations of E. Coli and Intestinal Enterococci within the designated shellfish waters in Cork Harbour. The Bathing Water EQS thresholds are also are also not exceeded within these Shellfish areas.

The results of the model also show that the proposed scheme has a very minor impact on the existing 50%ile concentrations of DIN, MRP, TA and UiA in Cork Harbour. The results indicate a minor reduction in existing nutrient concentrations at the location of the existing untreated Whitegate/Aghada discharges in the outer harbour. There is also a minor increase in the 50%ile nutrient concentrations local to the outfall.

In context of the regulations, the results demonstrate that the proposed scheme does not cause any of the EQS thresholds in the harbour to be exceeded and the discharges from the proposed WwTP for Whitegate/Aghada are 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 to assess the impact of the proposed scheme. These are:

- SA1: Decay Sensitivity –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 5.1m/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 wind 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 27: Sensitivity Analysis – 95%ile Escherichia Coliform concentrations

	Escherichia Coliforms (95%ile)				
	Proposed Scenario	**SA1 - Decay**		**SA2 - Wind**	
	(cfu/100ml)	**(cfu /100ml)**	**Delta**	**(cfu/100ml)**	**Delta**
Roches Point	28	32	4	24	-4
Cork Estuary 1	5	10	5	5	0
Cork Estuary 2	36	68	32	35	-1
Cork Estuary 3	44	95	51	45	1
Aghada Power Station	12	33	21	12	0
Poulnacallee Bay	5	13	8	4	-1
Fountainstown Beach	0	1	1	0	0
Myrtleville Bay	1	3	2	1	0
Midleton Monitoring Pt. 1	18	40	22	19	0
Midleton Monitoring Pt. 2	230	424	194	227	-3
Midleton Monitoring Pt. 3	23	45	23	23	0
Ringaskiddy Upstream Monitoring Point	116	264	148	117	1
Ringaskiddy Downstream Monitoring Pt. 1	11	31	20	12	0
Ringaskiddy Downstream Monitoring Pt. 2	5	10	5	5	0
Whitegate/Aghada Upstream Monitoring Point	2	9	6	18	15
Whitegate/Aghada Downstream Monitoring Pt. 1	883	1097	214	555	-328
Whitegate/Aghada Downstream Monitoring Pt. 2	27	52	25	6	-21

It can be seen from Table 27 that there is an increase in E. Coli concentrations at all monitoring points as a result of the slower T90 decay rate. In the context of the EQS thresholds, the increases in concentration do not result in the E. Coli threshold of 500cfu/100ml to be exceeded at any of the monitoring locations.

The 95%ile concentrations are not sensitive to the inclusion of wind forcing with the exception of the Whitegate/Aghada Downstream Monitoring Pt. 1. At this location the inclusion of the wind forcing reduces the E. Coli concentration.

Table 28: Sensitivity Analysis – 95%ile Escherichia Coliform concentrations

	Escherichia Coliforms (95%ile)				
	Proposed Scheme - Eddy Viscosity Scaling Factor of 1	**SA3 - Eddy Viscosity Scaling Factor of 1.5**		**SA4 - Eddy Viscosity Scaling Factor of 0.5**	
	(cfu/100ml)	**(cfu/100ml)**	**Delta**	**(cfu/100ml)**	**Delta**
Roches Point	28	27	0	24	-4
Cork Estuary 1	5	5	0	5	0
Cork Estuary 2	36	35	-1	35	-1
Cork Estuary 3	44	42	-2	48	5
Aghada Power Station	12	12	1	11	-1
Poulnacallee Bay	5	5	0	5	0
Fountainstown Beach	0	0	0	0	0
Myrtleville Bay	1	1	0	1	0
Midleton Monitoring Pt. 1	18	19	1	17	-1
Midleton Monitoring Pt. 2	230	239	9	220	-10
Midleton Monitoring Pt. 3	23	23	0	23	1
Ringaskiddy Upstream Monitoring Point	116	121	5	107	-9
Ringaskiddy Downstream Monitoring Pt. 1	11	12	1	10	-1
Ringaskiddy Downstream Monitoring Pt. 2	5	5	0	6	0
Whitegate/Aghada Upstream Monitoring Point	2	3	1	2	0
Whitegate/Aghada Downstream Monitoring Pt. 1	883	854	-30	976	92
Whitegate/Aghada Downstream Monitoring Pt. 2	27	26	-1	28	0

It can be seen that the model's results are not sensitive to the changes in the scaling factor on the dispersion coefficient, with the exception of the Whitegate/Aghada Downstream Monitoring Point 1 where there are minor changes in the modelled concentrations.

Table 29: Sensitivity Analysis – 95%ile Intestinal Enterococci concentrations

	Intestinal Enterococci (95%ile)				
	Proposed	**SA1 - Decay**		**SA2 - Wind**	
	(cfu/100ml)	**(cfu/100ml)**	**Delta**	**(cfu/100ml)**	**Delta**
Roches Point	1	1	0	1	0
Cork Estuary 1	0	1	0	0	0
Cork Estuary 2	1	3	1	1	0
Cork Estuary 3	2	4	2	2	0
Aghada Power Station	1	1	1	1	0
Poulnacallee Bay	0	0	0	0	0
Fountainstown Beach	0	0	0	0	0
Myrtleville Bay	0	0	0	0	0
Midleton Monitoring Pt. 1	0	1	0	0	0
Midleton Monitoring Pt. 2	1	2	1	1	0
Midleton Monitoring Pt. 3	0	1	1	0	0
Ringaskiddy Upstream Monitoring Point	5	11	6	5	0
Ringaskiddy Downstream Monitoring Pt. 1	1	1	1	1	0
Ringaskiddy Downstream Monitoring Pt. 2	0	1	0	0	0
Whitegate/Aghada Upstream Monitoring Point	0	0	0	0	0
Whitegate/Aghada Downstream Monitoring Pt. 1	4	5	1	2	-1
Whitegate/Aghada Downstream Monitoring Pt. 2	0	0	0	0	0

It can be seen from Table 29 that the slower decay rate for SA1 results in some minor increases in IE concentrations. The change with inclusion of the wind forcing is negligible. In the context of the EQS threshold, these increases do not result in the exceedance of the IE threshold of 200cfu/100ml at any of the monitoring locations.

Table 30: Sensitivity Analysis – 95%ile Intestinal Enterococci concentrations

	Intestinal Enterococci (95%ile)				
	Proposed- Eddy Viscosity Scaling Factor of 1	**SA3 - Eddy Viscosity Scaling Factor of 1.5**		**SA4 - Eddy Viscosity Scaling Factor of 0.5**	
	(cfu/100ml)	**(cfu/100ml)**	**Delta**	**(cfu/100ml)**	**Delta**
Roches Point	1	1	0	1	0
Cork Estuary 1	0	0	0	0	0
Cork Estuary 2	1	1	0	1	0
Cork Estuary 3	2	2	0	2	0
Aghada Power Station	1	1	0	1	0
Poulnacallee Bay	0	0	0	0	0
Fountainstown Beach	0	0	0	0	0
Myrtleville Bay	0	0	0	0	0
Midleton Monitoring Pt. 1	0	0	0	0	0
Midleton Monitoring Pt. 2	1	1	0	1	0
Midleton Monitoring Pt. 3	0	0	0	0	0
Ringaskiddy Upstream Monitoring Point	5	5	0	4	0
Ringaskiddy Downstream Monitoring Pt. 1	1	1	0	1	0
Ringaskiddy Downstream Monitoring Pt. 2	0	0	0	0	0
Whitegate/Aghada Upstream Monitoring Point	0	0	0	0	0
Whitegate/Aghada Downstream Monitoring Pt. 1	4	4	0	4	0
Whitegate/Aghada Downstream Monitoring Pt. 2	0	0	0	0	0

It can be seen from Table 30 that the results are not sensitive to the changes in the dispersion coefficient.

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 E. Coli and Intestinal Enterococci have been presented and demonstrate that none of the sensitivity runs would result in changes to the outcome of this modelling study. In the context of the regulations, the differences in concentrations as a result of the sensitivity runs do not lead to an exceedance of the relevant EQS thresholds at any of the monitoring points. The other WQ parameters were included in the sensitivity model runs but are not presented as they have similar findings.

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

8 Cumulative Impact Scenario

With the Lower Harbour Main Drainage Scheme project in place, untreated wastewater from Cobh will be collected and treated at the Shanbally WwTP. This scenario has been considered as part of the study and incorporated in two separate future scenarios:

- 10-year future scenario;
- 30-year future scenario.

The WwTP discharges for these future scenarios were estimated based on Irish Water's predicted growth rates for each of the agglomerations. Only the Midleton WwTP is projected to exceed its design capacity (as given by the most recent AER). It has been assumed as part of these future scenarios that additional capacity will be added to the plant. These flow rates for the future scenarios are presented in Table 31.

Table 31: Future estimated WwTP discharges

WwTP Outfall	Proposed scenario discharges (m^3/s)	Projected 2030 future scenario discharges (m^3/s)	Projected 2050 future scenario discharges (m^3/s)
Saleen Village	0.0003	0.00033	0.00039
Proposed outfall	0.0085	0.0101	0.0133
North Cobh	0.0064	0.0080	0.0115
Carrigrennan (Cork City)	1.395	1.7303	2.6356
Shanbally/IDA	0.1622	0.2160	0.2780
Midleton/ID	0.28	0.3820	0.5740
Carrigtwohill 1	0.0271	0.038	0.064
Carrigtwohill 2	0.0271	0.038	0.064

The fluvial river inflows and industrial outfall source discharges are unchanged for the future scenario model runs. The concentrations of the various WQ parameters for both the treated effluent and river inflows were left unchanged for these future scenarios.

The exception to the above are the Shanbally/IDA and Midleton/ID outfalls, which are a combination of WwTP and industrial flows. The future flows and WQ parameter concentrations for these discharges were provided by Irish Water.

Table 32 and Table 33 below present the 95%ile concentrations for E. Coli and Intestinal Enterococci for the future scenarios. The differences between the future scenario and the proposed scenario are also displayed. It can be seen that there are decreases in the 95%ile concentration at the monitoring points closer to Cobh which can be attributed to the removal of untreated waste being discharged at Cobh. There are also however some increases in the 95%ile concentration in the vicinity of the Shanbally outfall due to the increased loading from the outfall.

Table 32: E. Coli 95%ile concentrations at monitoring points for the future scenarios

	E. Coli				
	Proposed	2030		2050	
	(cfu/100ml)	(cfu/100ml)	Diff	(cfu/100ml)	Diff
Roches Point	28	33	5	44	16
Cork Estuary 1	5	7	2	10	5
Cork Estuary 2	36	7	-29	10	-26
Cork Estuary 3	44	13	-31	18	-26
Aghada Power Station	12	9	-3	12	1
Poulnacallee Bay	5	4	-1	5	-1
Fountainstown Beach	0	0	0	0	0
Myrtleville Bay	1	1	0	1	0
Midleton Monitoring Pt. 1	18	19	1	22	3
Midleton Monitoring Pt. 2	230	230	0	230	0
Midleton Monitoring Pt. 3	23	24	1	27	4
Ringaskiddy Upstream Monitoring Point	116	78	-38	119	3
Ringaskiddy Downstream Monitoring Pt. 1	11	9	-3	12	1
Ringaskiddy Downstream Monitoring Pt. 2	5	7	2	10	5
Whitegate/Aghada Upstream Monitoring Point	2	2	0	2	0
Whitegate/Aghada Downstream Monitoring Pt. 1	883	883	-1	881	-3
Whitegate/Aghada Downstream Monitoring Pt. 2	27	27	0	28	0

There are minor changes to the 95% Intestinal Enterococci concentrations (Table 33) which are minor and not deemed significant. In the context of the EU water quality regulations, the predicted increase of WwTP hydraulic loads for these future scenarios do not lead to an exceedance of the relevant EQS thresholds at any of the monitoring points.

Table 33: Intestinal Enterococci 95%ile concentrations at monitoring points for the future scenarios

	Intestinal Enterococci				
	Proposed	**2030**		**2050**	
	(cfu/100ml)	**(cfu/100ml)**	**Diff**	**(cfu/100ml)**	**Diff**
Roches Point	1	1	0	2	1
Cork Estuary 1	0	1	0	1	0
Cork Estuary 2	1	1	-1	1	-1
Cork Estuary 3	2	1	-1	1	-1
Aghada Power Station	1	1	0	1	0
Poulnacallee Bay	0	0	0	0	0
Fountainstown Beach	0	0	0	0	0
Myrtleville Bay	0	0	0	0	0
Midleton Monitoring Pt. 1	0	0	0	0	0
Midleton Monitoring Pt. 2	1	1	0	1	0
Midleton Monitoring Pt. 3	0	0	0	0	0
Ringaskiddy Upstream Monitoring Point	5	3	-2	5	0
Ringaskiddy Downstream Monitoring Pt. 1	1	1	0	1	0
Ringaskiddy Downstream Monitoring Pt. 2	0	1	0	1	0
Whitegate/ Aghada Upstream Monitoring Point	0	0	0	0	0
Whitegate/ Aghada Downstream Monitoring Pt. 1	4	4	0	4	0
Whitegate/ Aghada Downstream Monitoring Pt. 2	0	0	0	0	0

9 Discussion and Conclusions

A high-resolution MIKE 21 Water Quality model of Cork Harbour has been developed as part of the study to assess the concentrations of E. Coli, Intestinal Enterococci, DIN, MRP, Ammonia and Unionised Ammonia in the harbour with the proposed WwTP at Whitegate/Aghada in place.

The results of the model show that the 95%ile concentrations of both E. Coli and Intestinal Enterococci are significantly reduced in the eastern part of the Outer Harbour with the proposed scheme in place. The results also show that the 50%ile concentrations of DIN, MRP, TA and UiA are also considerably reduced.

The 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 to be exceeded and the Whitebay shoreline still retains excellent water quality with the proposed outfall in place.

The proposed scheme therefore does not cause any of the EQS thresholds in Cork harbour to be exceeded and the discharges from the proposed WwTP for Whitegate 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 decay rate, wind forcing, and dispersion coefficient. None of the sensitivity runs cause any of the EQS thresholds to be exceeded at any of the monitoring points.

Two future scenarios were also assessed as part of the project for 2030 and 2050. These model runs increased the outfall flow rates at all the relevant outfalls in Cork Harbour based on projected population growth rates. Neither of these future scenarios resulted in the coliform EQS thresholds being exceeded at the monitoring points within the harbour.

It can therefore be concluded that the proposed WwTP at Whitegate/Aghada is fully compliant with all the relevant Water Quality legislation.

References

[1] Irish Water, “Technical Standards - Marine Modelling Rev 1.0,” IW, 2018.

[2] AECOM & Jennings O'Donovan, “Cork UTAS Design Reports and Technical Notes for Whitegate/Aghada,” 2016.

[3] Scottish Environment Protection Agency (SEPA), “Supporting Guidance (WAt-SG-11) Modelling Coastal and Transitional Discharges, Version V3.0,” 2013.

[4] Statutory Instruments No. 254 of 2001, “Irish Statutory Requirements, 2001. S.I. No. 254/2001 - Urban Waste Water Treatment Regulations,” SI, 14 June 2001.

[5] European Union, “Environmental Objectives (Surface Waters) (Amendment) Regulations. S.I. No. 77 of 2019,” EU, 2019.

[6] European Union, “Directive 2006/7/EC of the European Parliment and of the Council of 15 Fenruary 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC,” EU, 2006.

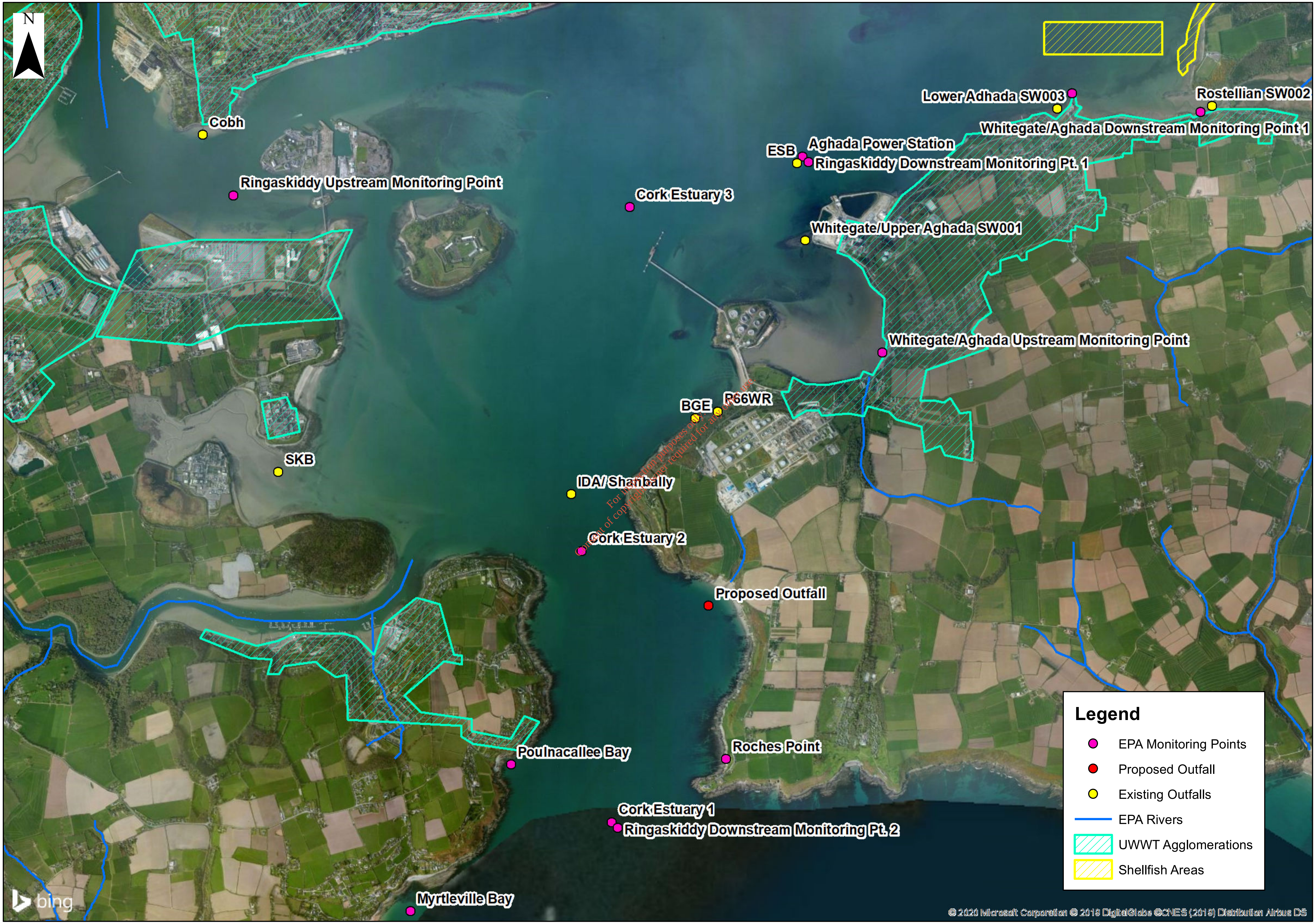
[7] Irish Statutory Requirements No 79 of 2008, “Irish Statutory Instruments, 2006 European Communities (Quality of Shellfish Waters) Regulations,” SI, 22nd May 2006.

[8] Arup, “Cork UTAS, Whitegate/Aghada Phase 1 Dispersion Modelling Report,” 16th December 2019.

[9] Irish Water, “Technical Standards - Marine Modelling, Revision 1.86,” IW, 2019.

Appendix A

Area of Interest Map


N
Cobh
Ringaskiddy Upstream Monitoring Point
Cork Estuary 3
ESB
Aghada Power Station
Ringaskiddy Downstream Monitoring Pt. 1
Lower Adhada SW003
Rostellian SW002
Whitegate/Aghada Downstream Monitoring Point 1
Whitegate/Upper Aghada SW001
Whitegate/Aghada Upstream Monitoring Point
BGE
R66WR
SKB
IDA/ Shanbally
Cork Estuary 2
Proposed Outfall
Poulnacallee Bay
Roches Point
Cork Estuary 1
Ringaskiddy Downstream Monitoring Pt. 2
Myrtleville Bay
Legend
EPA Monitoring Points
Proposed Outfall
Existing Outfalls
EPA Rivers
UWWT Agglomerations
Shellfish Areas
bing
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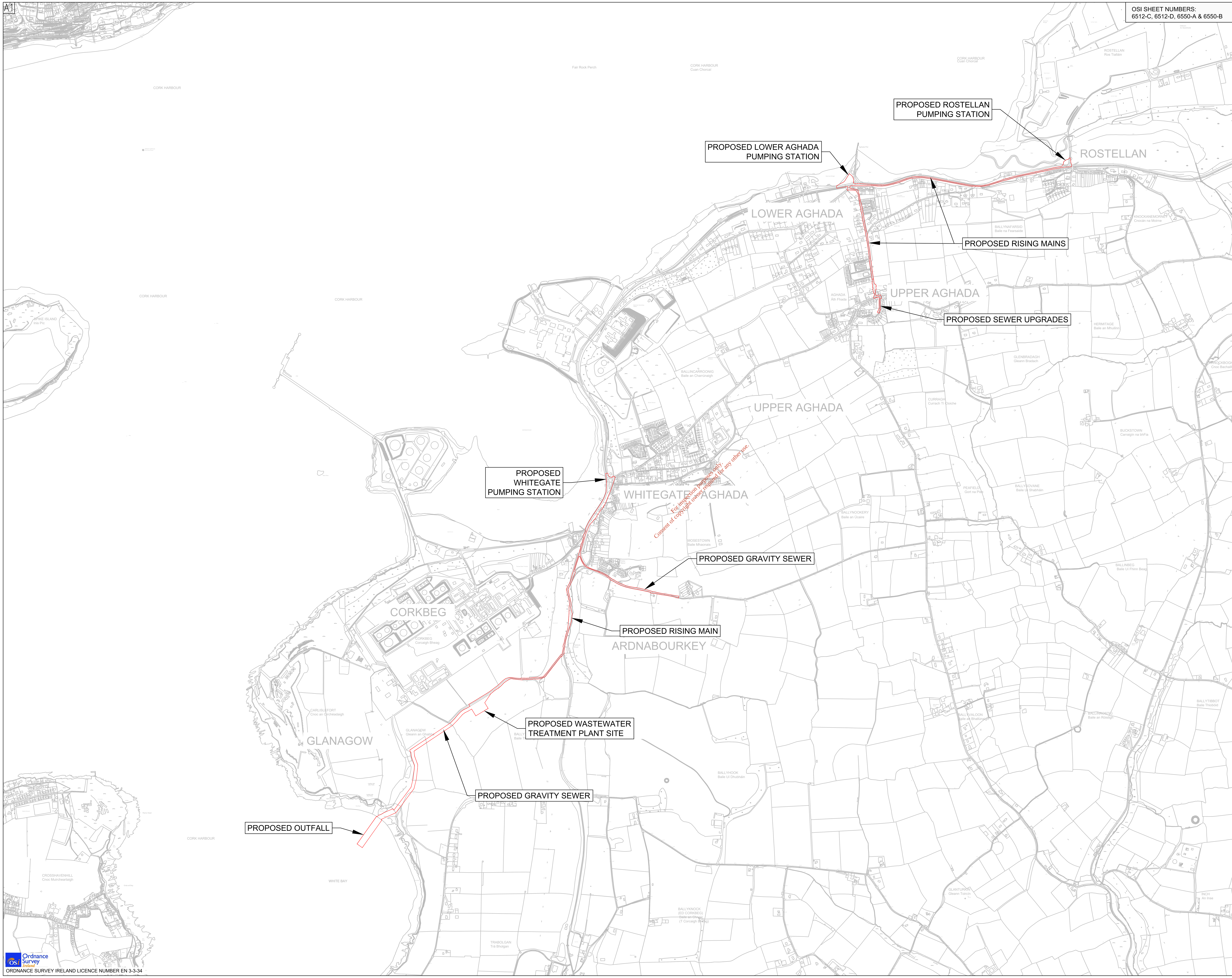
Appendix B

Proposed Scheme

A1



GENERAL NOTES

LEGEND:

PROPOSED SITE BOUNDARY

NOTES:

1. THIS DRAWING TO BE READ IN CONJUNCTION WITH ALL OTHER RELEVANT DRAWINGS AND SPECIFICATIONS.
2. ANY QUERIES OR DISCREPANCIES ARE TO BE REFERRED TO THE EMPLOYER'S REPRESENTATIVE IMMEDIATELY.

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Rev	Date	Description	By	Chk	App
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PROJECT

WHITEGATE - AGHADA SEWERAGE SCHEME
UTAS - CORK BUNDLE

DRAWING TITLE

LOCATION MAP

STATUS

FOR PLANNING

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Project No: 257589-00	Drg. No: IW-10015229-03-01-001			Rev: P1

Appendix C

Phase 1 - Near Field Modelling Report

Irish Water

Cork UTAS

Whitegate/Aghada 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 Whitegate/Aghada 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 Whitebay in Cork Harbour.

At present, sewage from Whitegate/Aghada is currently discharging untreated into Cork Harbour. It is proposed to build a new WWTP and network in to provide primary treatment for the effluent. The proposed WWTP will be located to the south of Whitegate with treated effluent to be discharged via a proposed outfall pipeline to the mouth of Cork Harbour in a south-westerly direction. The proposed outfall location near the mouth of Cork Harbour is shown in Figure 1 below.

Figure 1: Location of proposed outfall

Following guidance from Irish Water, the 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.

- **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

Whitegate
Temperature
Salinity
BOD
DO
-
MR Phosphorus
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
Whitegate/Aghada	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	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 MRP in Whitegate/Aghada are not available from the EPA database. The background concentration of MRP for Whitegate Aghada has therefore been set equal to zero for the near field dispersion modelling. It will however be considered in greater detail as part of the Phase 2 of the study.

3.3 Loadings from the outfall

Table 3 presents the loadings from the proposed outfall.

Table 3: Effluent concentrations (with primary treatment)

Parameter	Whitegate/Aghada
Mean Flow (m^3/s)	0.00845
BOD (mg/l O2)	280
DO (mg/l)	0
SS (mg/l)	-
DIN (mg/l)	41
MR Phosphorous (mg/l)	9
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.

[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)

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	Whitegate/Aghada
95%ile scenario	119
50%ile scenario	533

For compliance with SEPA guidelines, an initial dilution of 100 is recommended for primary treated effluents in the near-field. It is evident from the results that the Whitegate/Aghada outfall has achieved this guideline for the 95%ile scenario with a dilution value of 119.

3.5.2 Whitegate/Aghada near field concentrations

The near-field concentration results for Whitegate/Aghada are presented in Table 5 (95%ile scenario) and Table 6 (50%ile scenario). The concentrations have been calculated by dividing the effluent concentration by the number of dilutions and subsequently adding the background concentration values. The highlighted parameters in each percentile table are the parameters whose EQS relates to the that particular percentile.

It can be seen from Table 5 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 Whitegate/Aghada outfall 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 concentrations of IE and EC/FC are above their EQS target levels.

Table 5: 95%ile scenario: Initial Dilution of 119

Parameter	Treated Eff. Conc.	Background Conc.	Conc. After I.D.	Target Level	Additional Far Field Dilution Required
BOD (mg/l O2)	280	0.5	2.8	4.0	0
DO (%Saturation)	0	105	104.1	80-120	0
DIN (mg/l)	41	0.10	0.44	0.25	1
MR Phosphorus (mg/l)	9	0	0.08	0.04	1
Intest. Entercocci (cfu/100ml)	40,000	349	682	100	6
E-Coli and FC (cfu/100ml)	1,000,000	943	9324	250	37

Table 6: 50%ile scenario: Initial Dilution of 533

Parameter	Treated Eff. Conc	Background Conc.	Conc. After I.D.	Target Level	Additional Far Field Dilution Required
BOD (mg/l O2)	280	0.5	1.0	4.0	0
DO (%Saturation)	0	105	104.8	80-120	0
DIN (mg/l)	41	0.10	0.18	0.25	0
MR Phosphorus (mg/l)	9	0	0.02	0.04	0
Intest. Entercocci (cfu/100ml)	40,000	349	423	100	4
E-Coli and FC (cfu/100ml)	1,000,000	943	2817	250	11

It can be seen from **Table 6** that concentrations of DIN and MRP are below the 50%ile EQS target levels and are therefore in full compliance with all the relevant legislation in the near field. No further assessment of their concentrations in the far field is therefore required.

As the concentrations of IE and EC/FC for the Whitegate/Aghada 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. 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 sections.

An assessment of the impact of the following WQ parameters in the far field of Cork Harbour 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 far field dispersion models for Whitegate/Aghada in order to simulate the transport and decay of the WQ parameters listed the previous section. The model 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 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
Whitegate/Aghada			
Port of Cork surveyed the site of interest in 2017 and the dataset is deemed suitable for use in the study. The data will be integrated with additional survey and Infomar data to form a complete composite bathymetric dataset for the harbour and area outside Roches Point.	No suitable data available for the site of interest. New survey data therefore required.	No suitable data available for the site of interest. New survey data therefore required.	EPA WQ dataset is deemed suitable. We note however that the temporal resolution of the dataset is relatively coarse. Peak concentrations in the water column may therefore not be captured by the dataset.

5.3 New Marine Surveys

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

5.3.1 Whitegate/Aghada Marine Survey

We propose collecting:

- **HD model development –** Single beam bathymetric survey at the site of interest.
- **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 €8,900 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 Whitegate/Aghada has been developed following consultation with Irish Water and referring to the DRAFT Irish Water Technical Standards for Marine Modelling.

Our scope of 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 area 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.

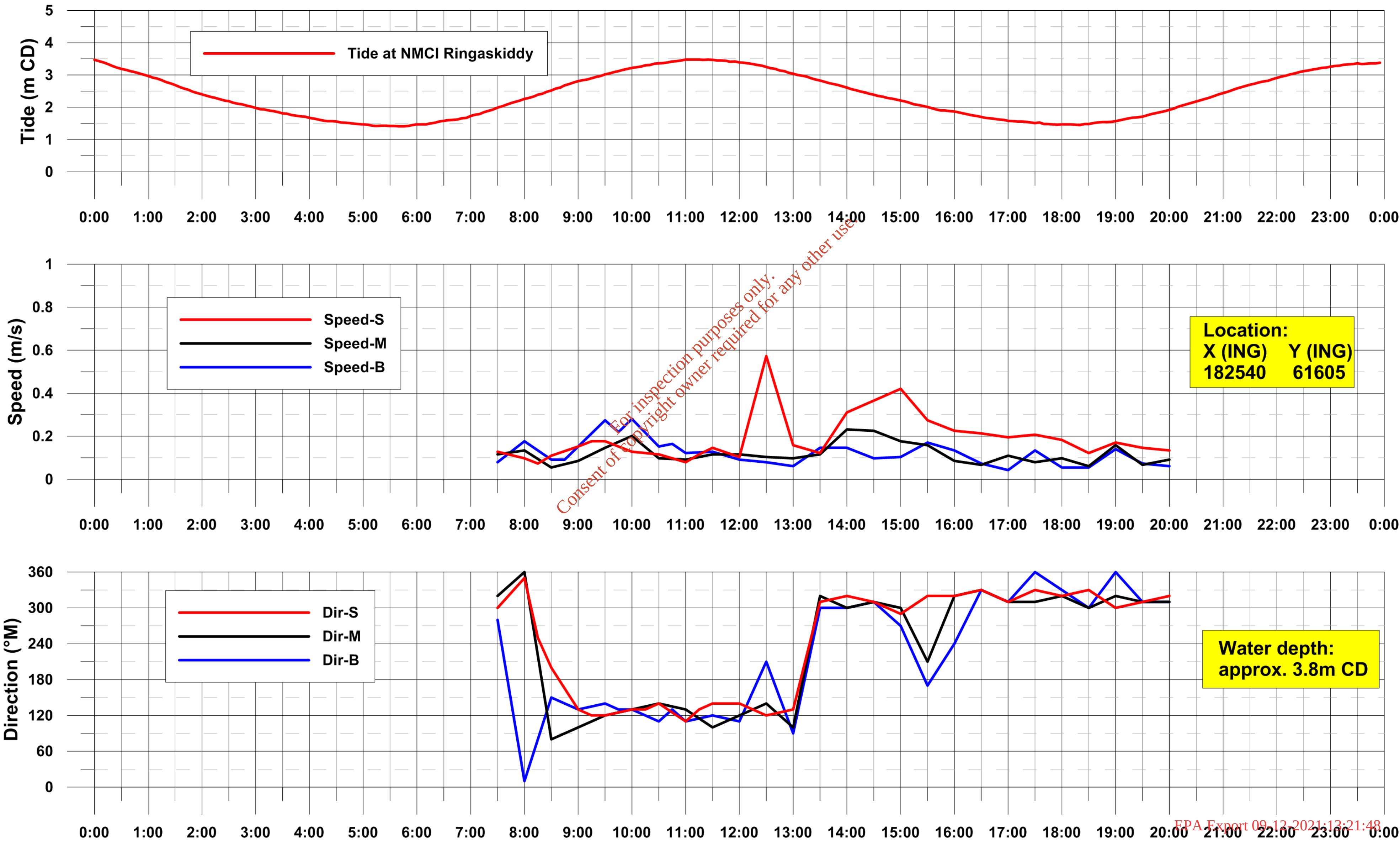
Appendix D

Marine Survey Data

UTAS Surveys for Arup & Irish Water

Cork Harbour - White Bay

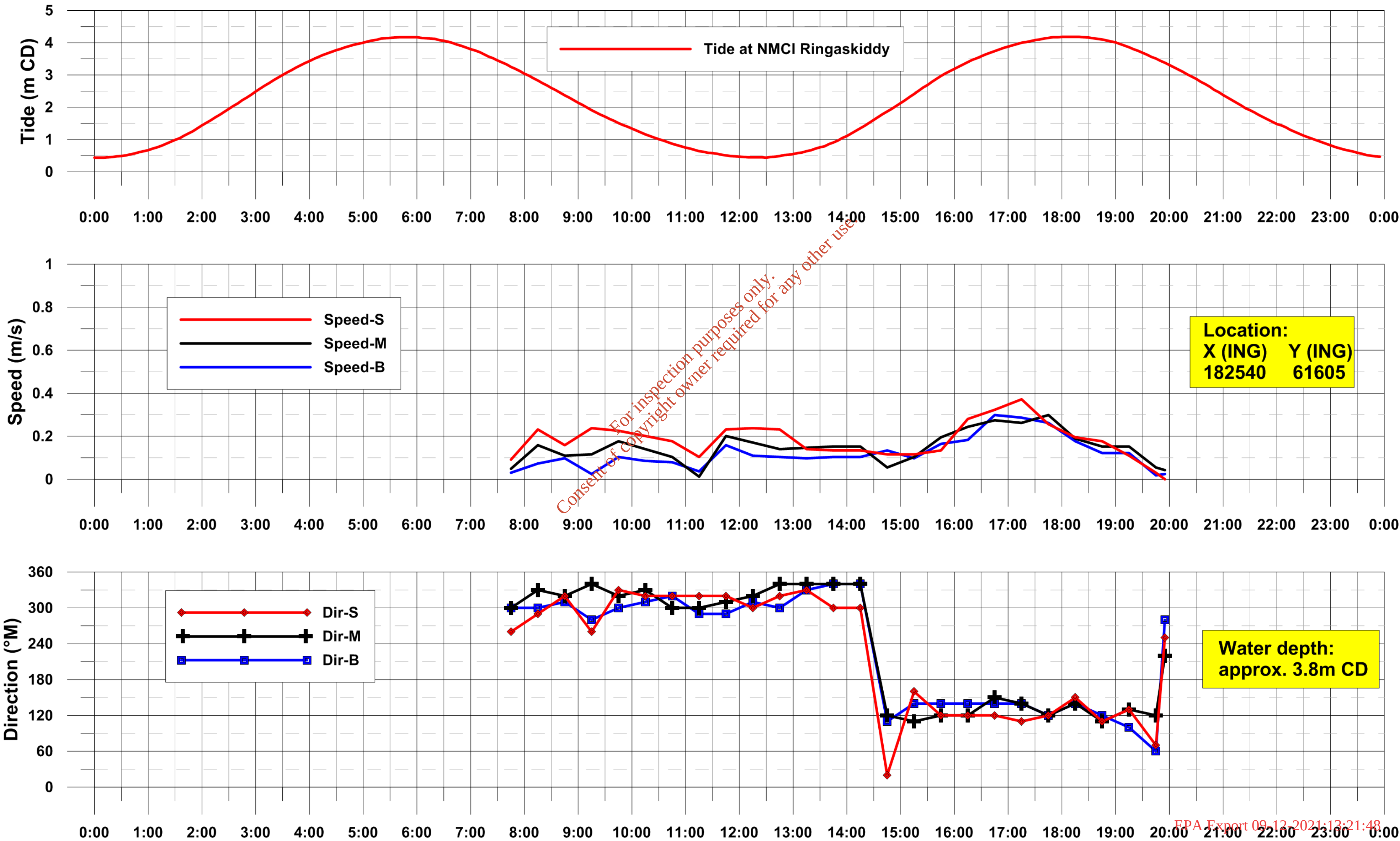
Fixed Station Current Speed and Direction - April 8th 2018

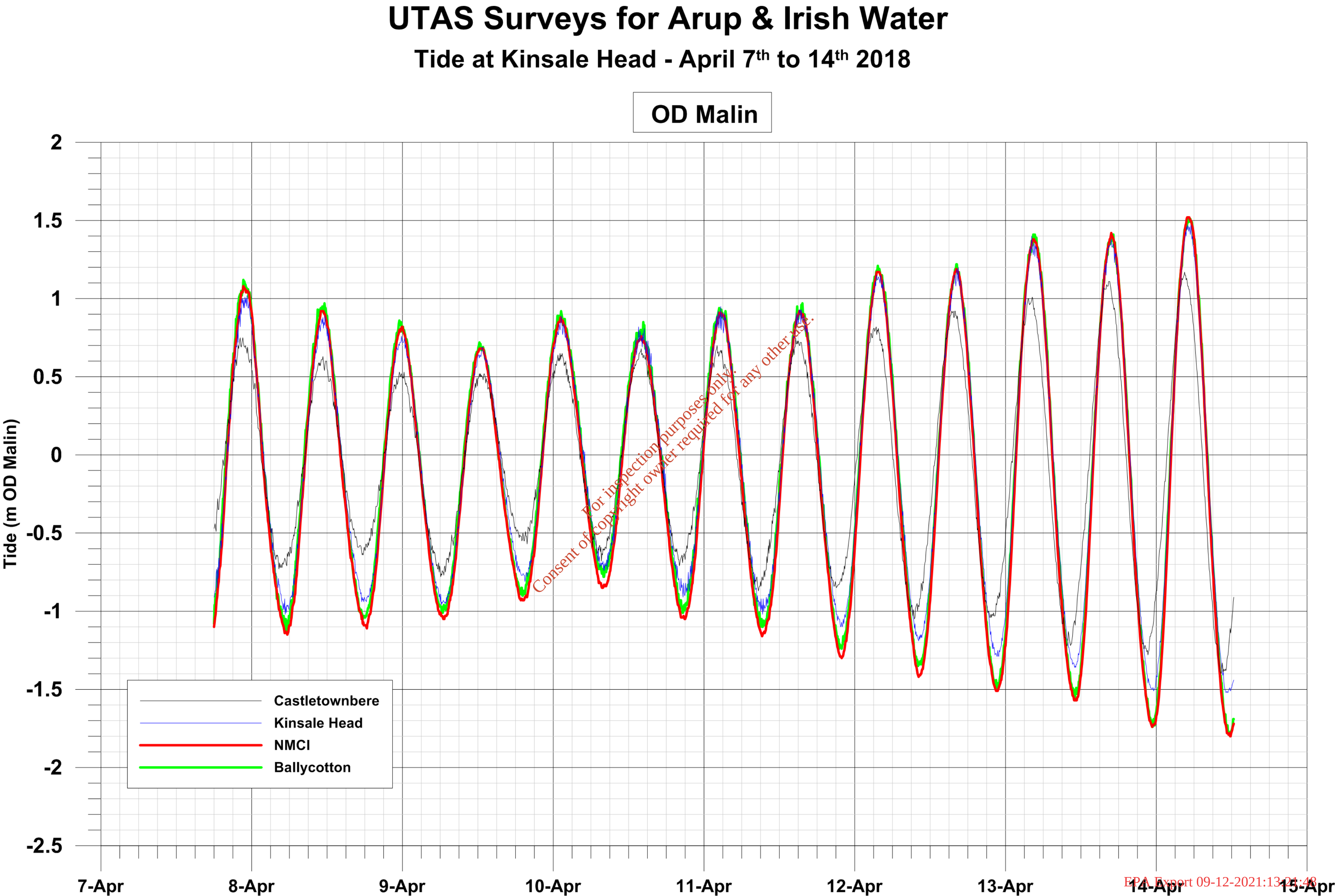


UTAS Surveys for Arup & Irish Water

Cork Harbour - White Bay

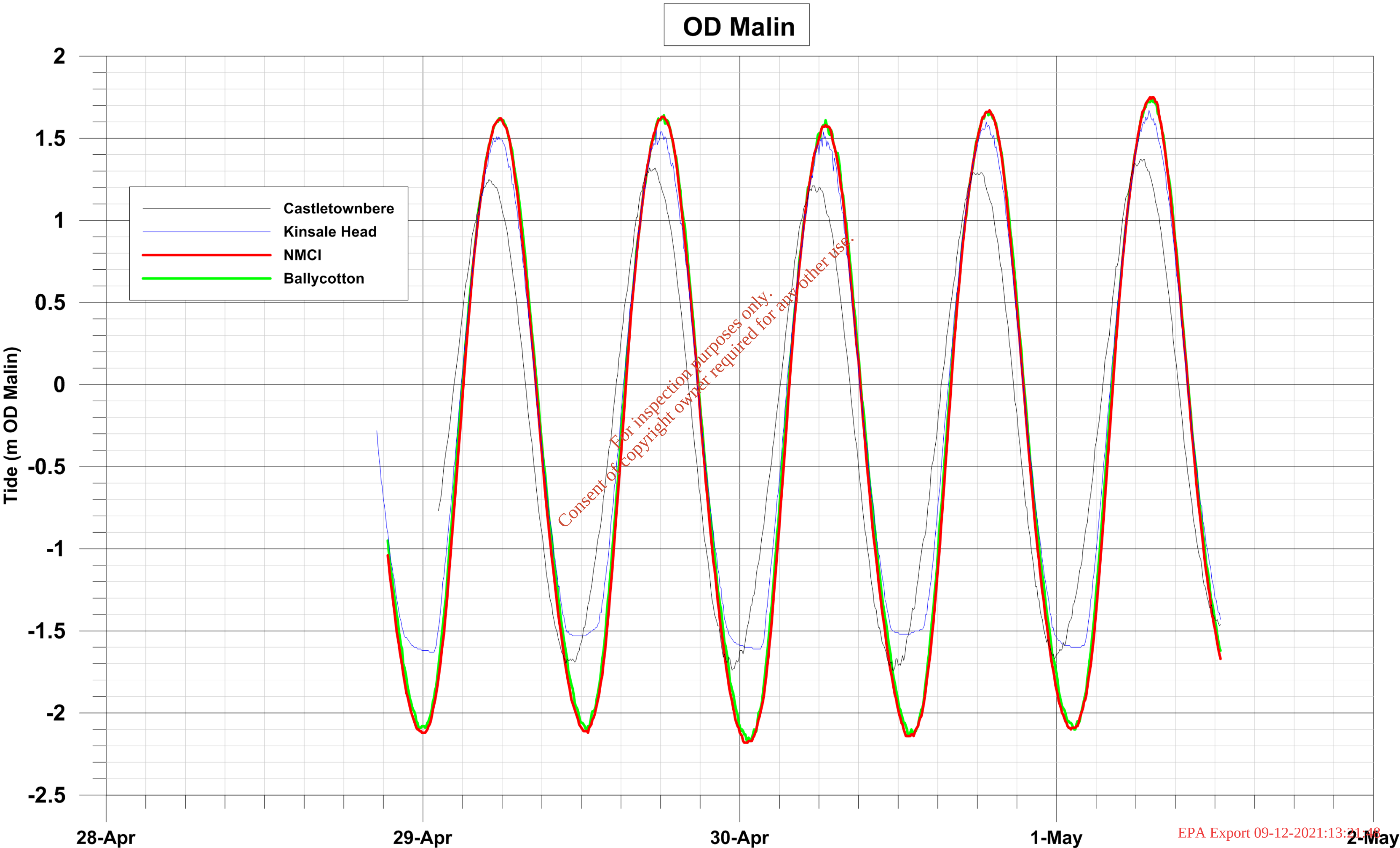
Fixed Station Current Speed and Direction - April 29th 2018

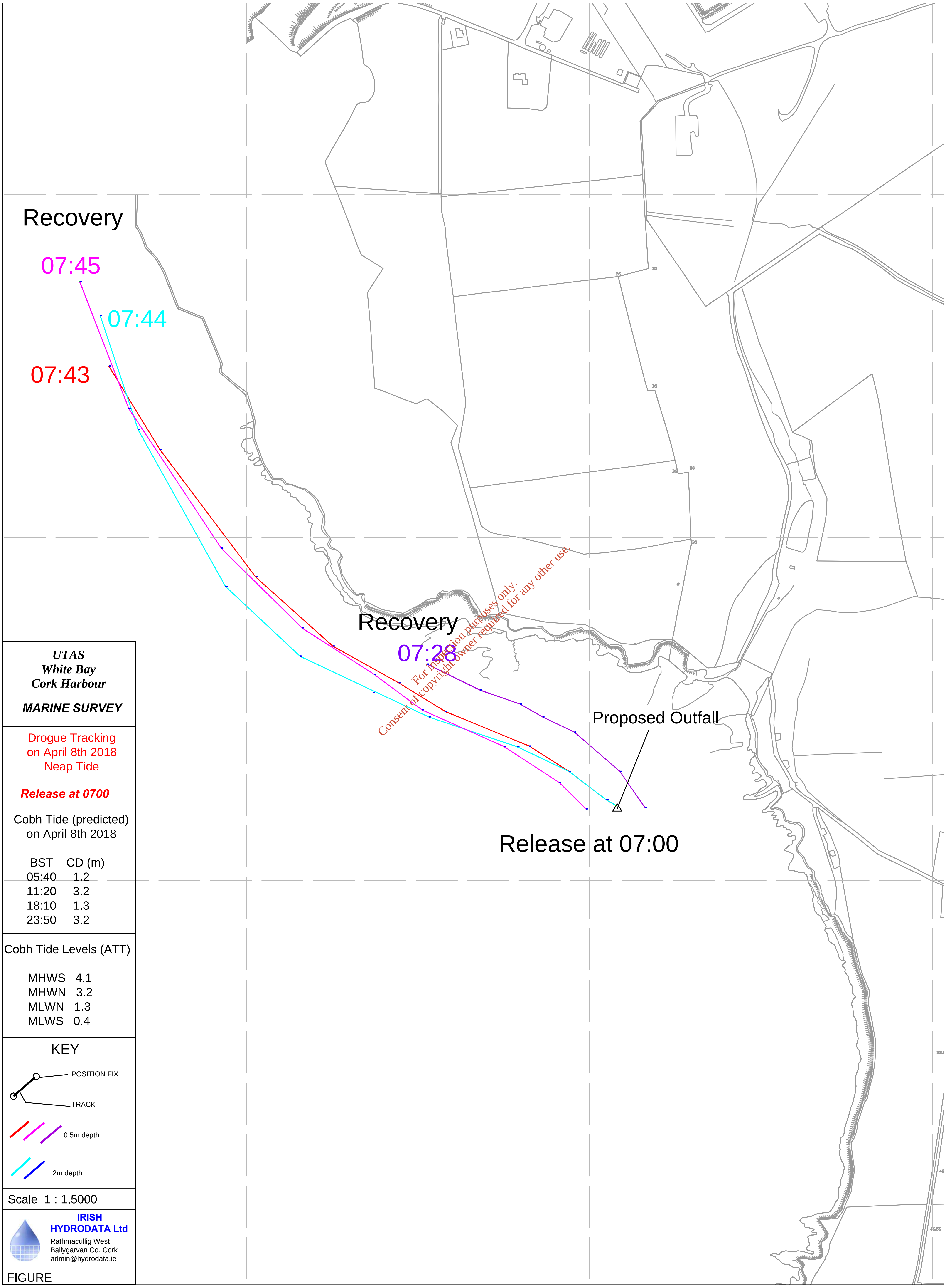


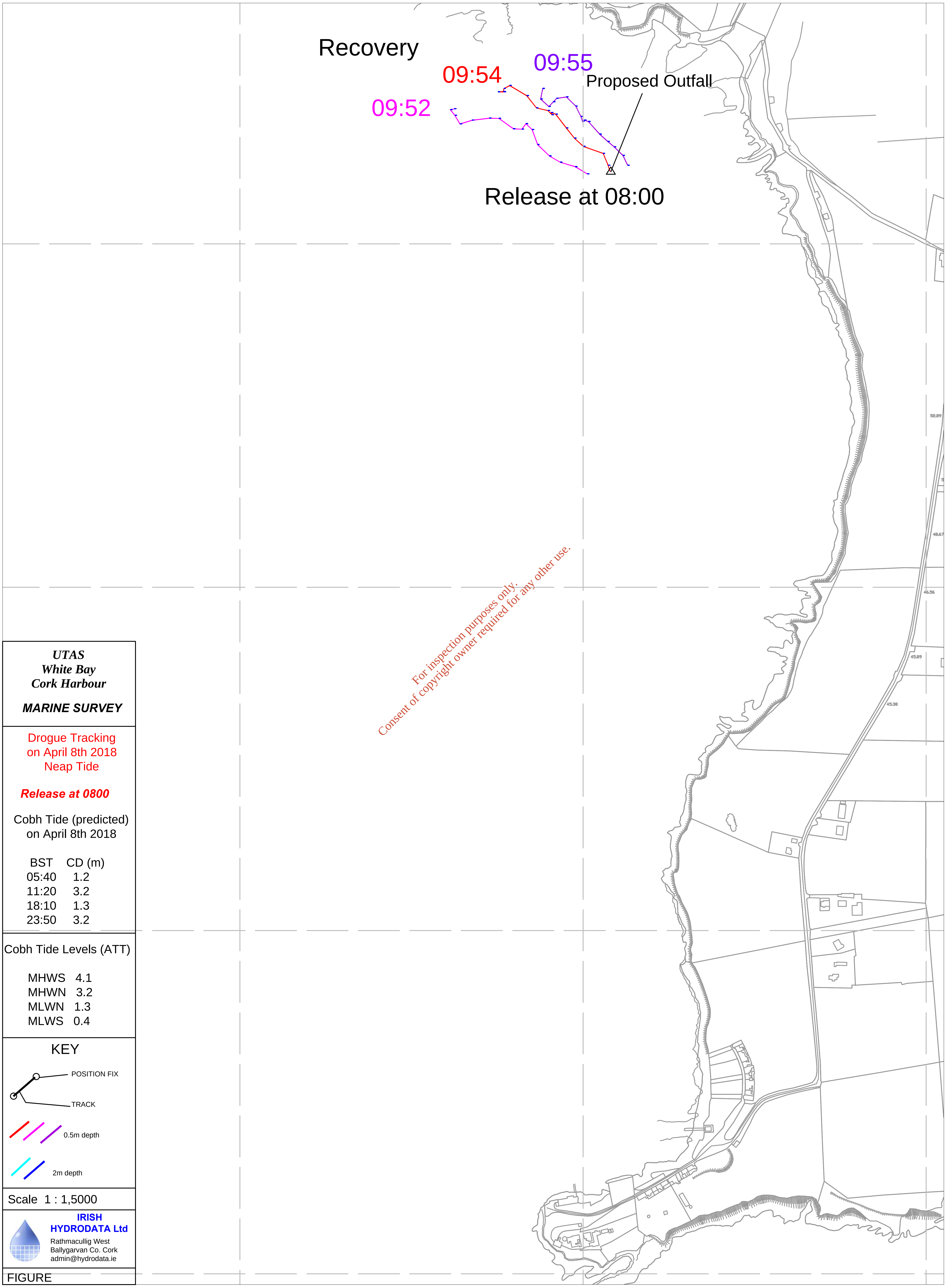

UTAS Surveys for Arup & Irish Water
Tide at Kinsale Head - April 7th to 14th 2018
OD Malin
Tide (m OD Malin)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
7-Apr
8-Apr
9-Apr
10-Apr
11-Apr
12-Apr
13-Apr
14-Apr
15-Apr
Castletownbere
Kinsale Head
NMCI
Ballycotton

UTAS Surveys for Arup & Irish Water

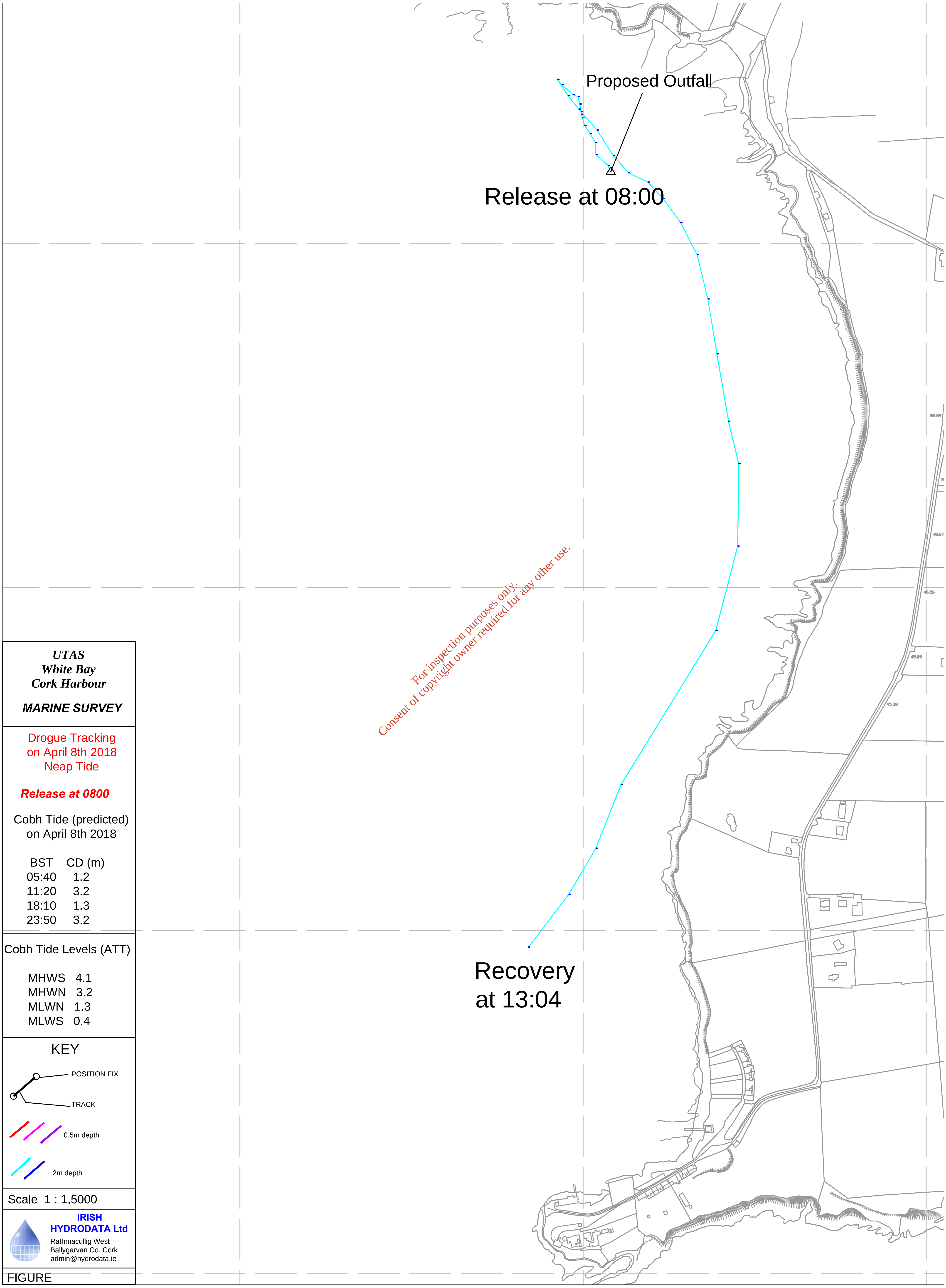
Tide at Kinsale Head - April 28th to May 1st 2018

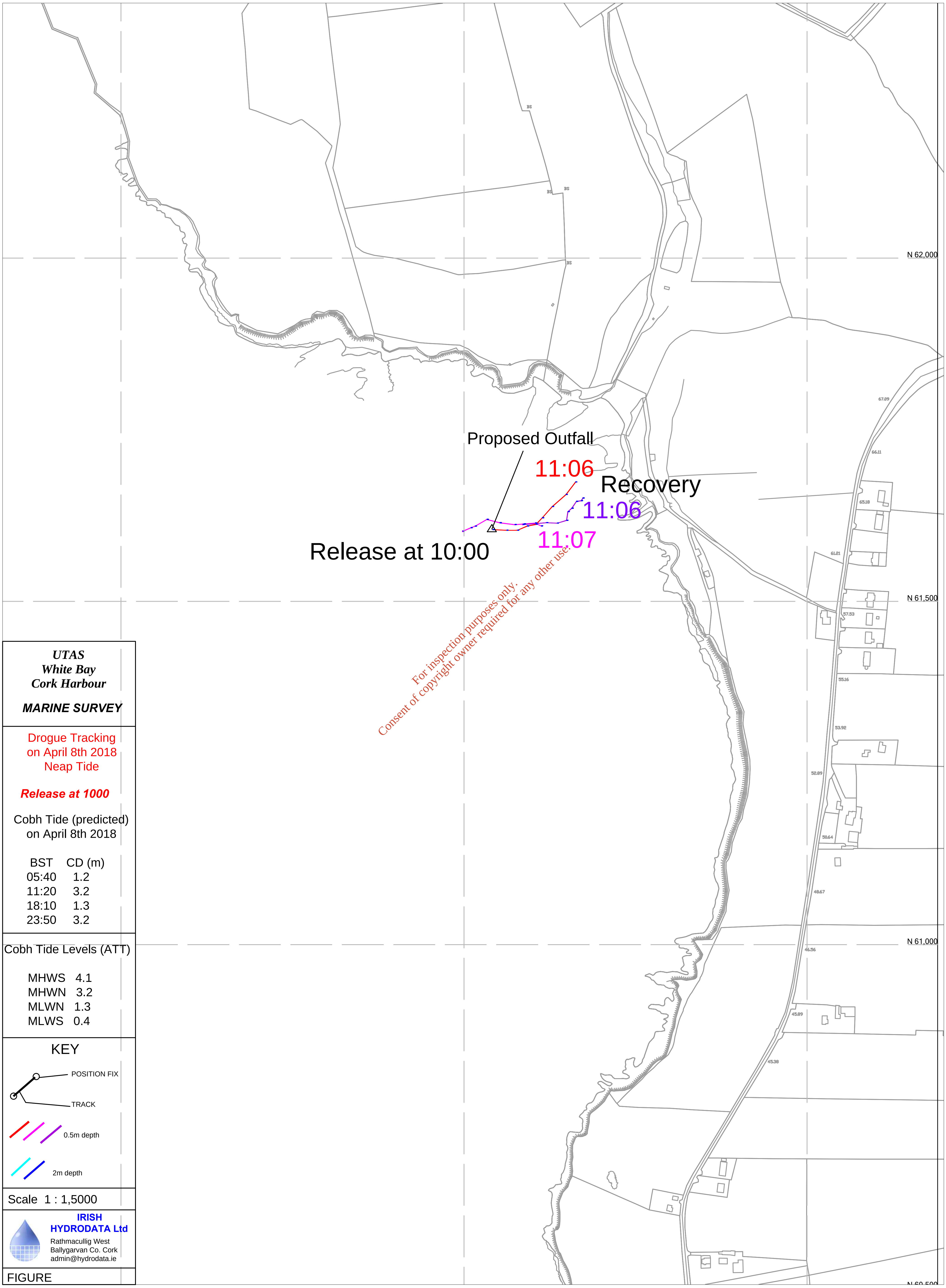



Recovery
07:45
07:44
07:43
Recovery
07:28
Proposed Outfall
Release at 07:00
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 8th 2018
Neap Tide
Release at 0700
Cobh Tide (predicted)
on April 8th 2018
BST CD (m)
05:40 1.2
11:20 3.2
18:10 1.3
23:50 3.2
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE



Recovery
09:54
09:55
09:52
Proposed Outfall
Release at 08:00
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 8th 2018
Neap Tide
Release at 0800
Cobh Tide (predicted)
on April 8th 2018
BST CD (m)
05:40 1.2
11:20 3.2
18:10 1.3
23:50 3.2
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE


Proposed Outfall
Release at 08:00
Recovery at 13:04
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 8th 2018
Neap Tide
Release at 0800
Cobh Tide (predicted)
on April 8th 2018
BST CD (m)
05:40 1.2
11:20 3.2
18:10 1.3
23:50 3.2
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE



UTAS
White Bay
Cork Harbour

MARINE SURVEY

Drogue Tracking
on April 8th 2018
Neap Tide

Release at 1000

Cobh Tide (predicted)
on April 8th 2018

BST	CD (m)
05:40	1.2
11:20	3.2
18:10	1.3
23:50	3.2

Cobh Tide Levels (ATT)

MHWS	4.1
MHWN	3.2
MLWN	1.3
MLWS	0.4

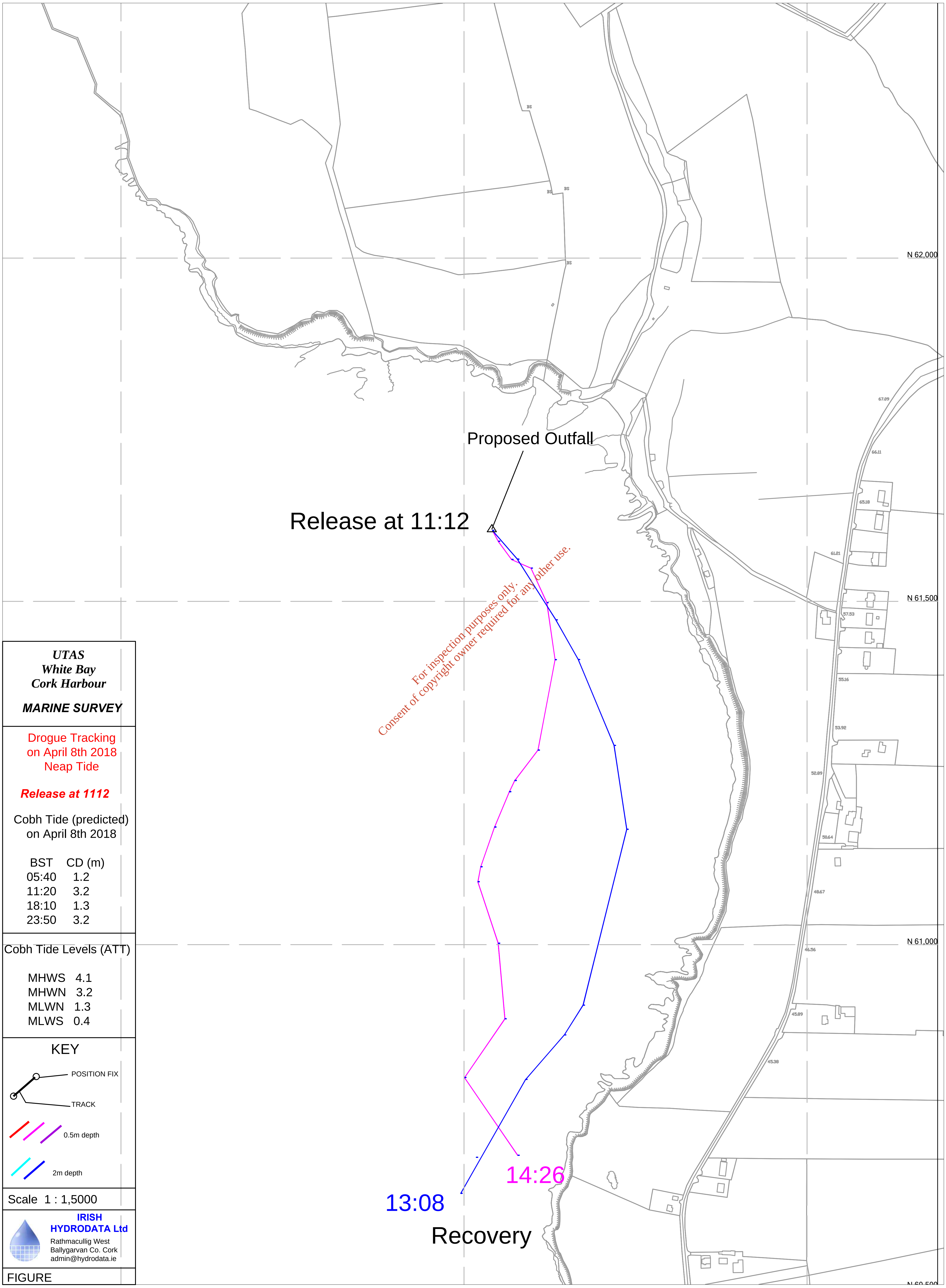
KEY

POSITION FIX
TRACK
0.5m depth
2m depth

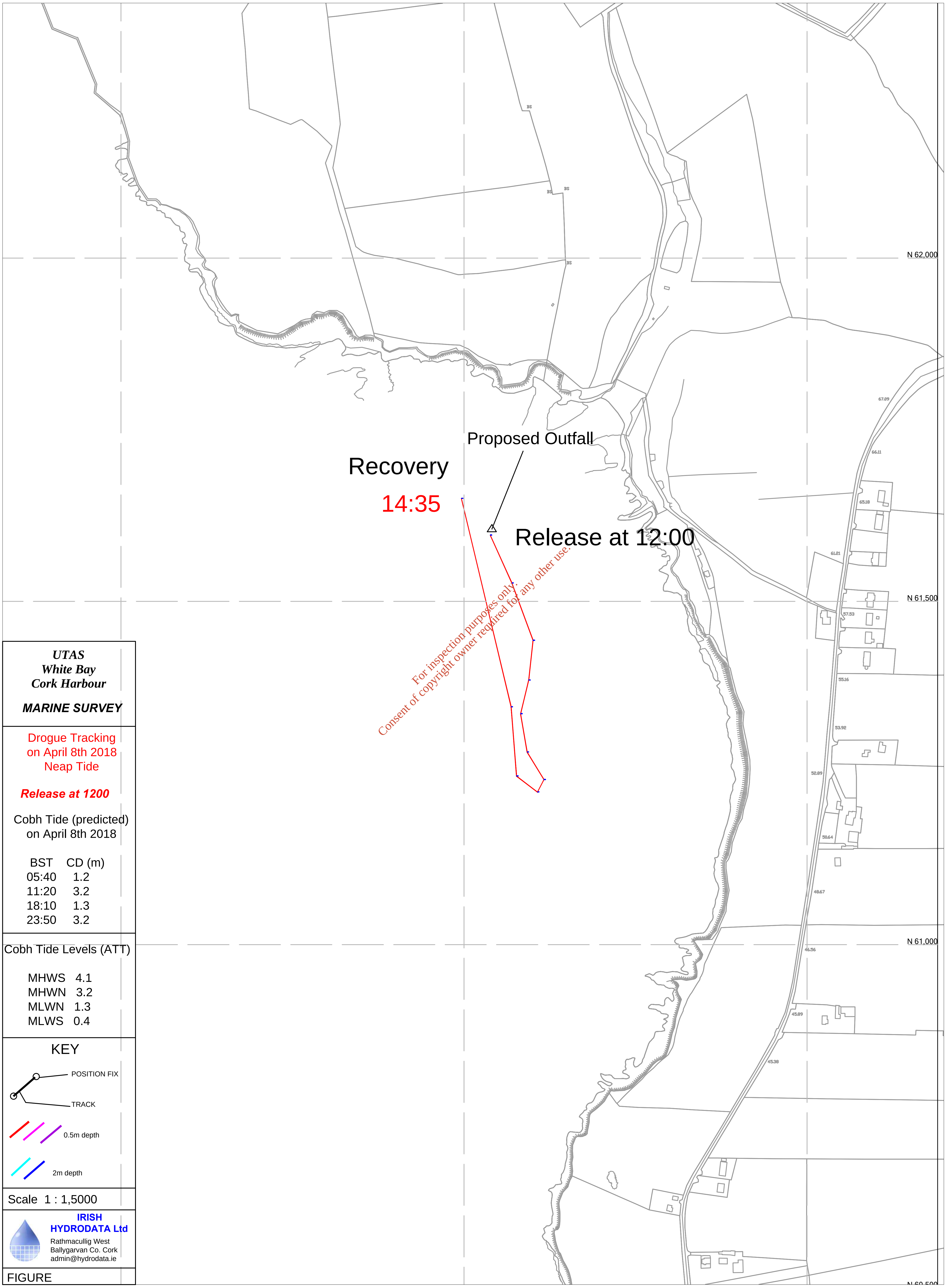
Scale 1 : 1,5000

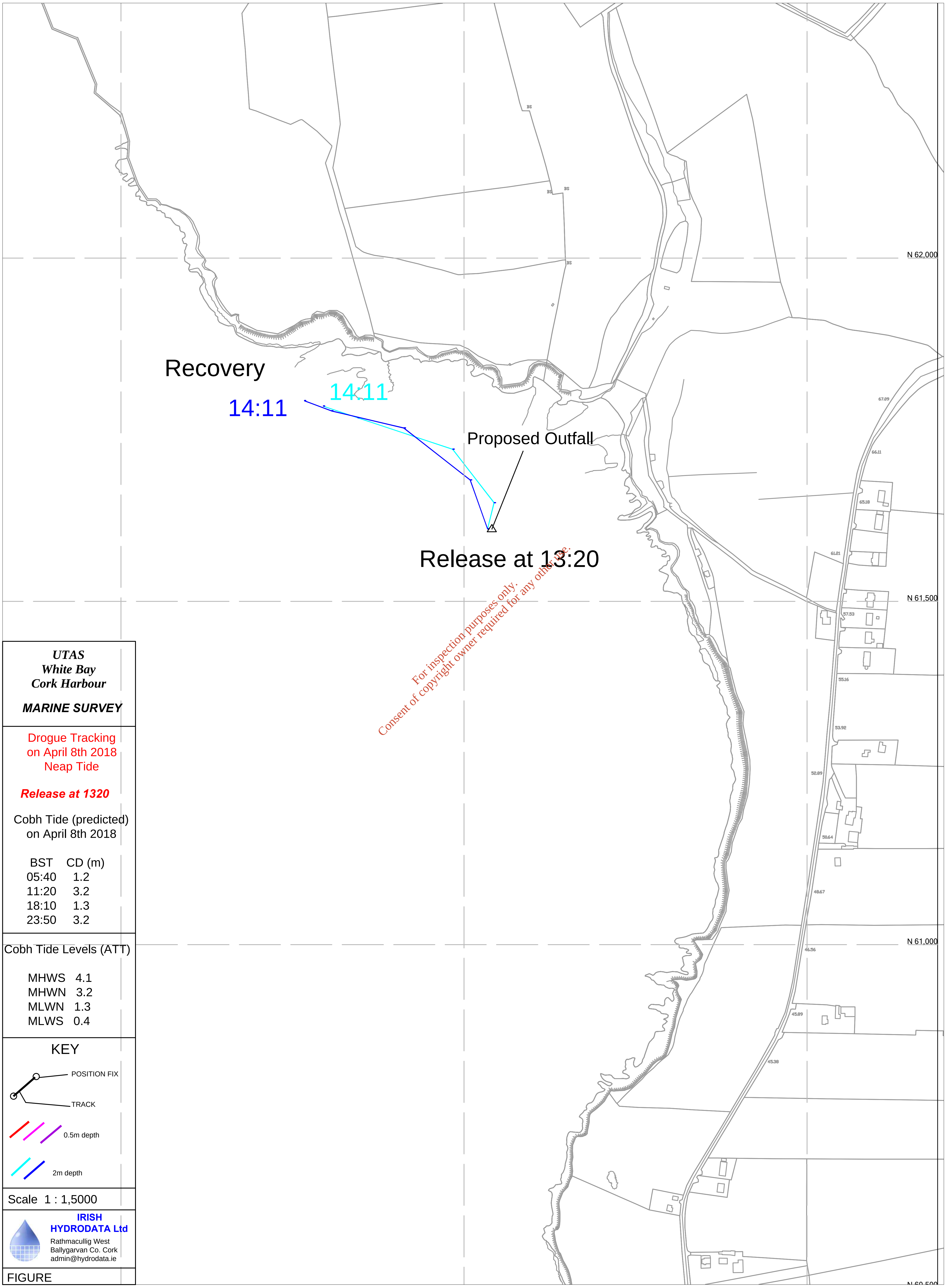
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie

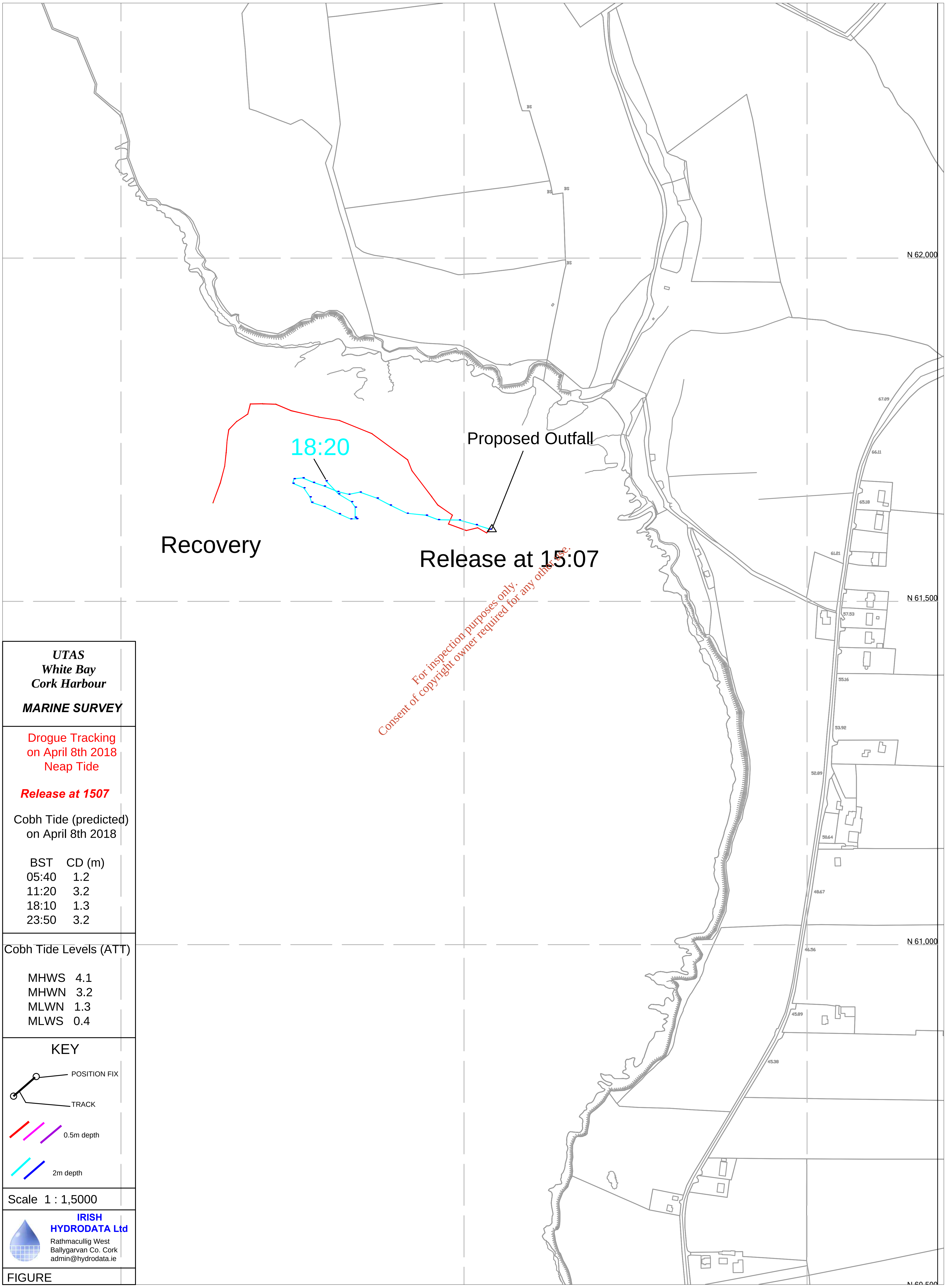
FIGURE



Proposed Outfall
Release at 11:12
14:26
13:08
Recovery
N 62,000
N 61,500
N 61,000
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 8th 2018
Neap Tide
Release at 1112
Cobh Tide (predicted)
on April 8th 2018
BST CD (m)
05:40 1.2
11:20 3.2
18:10 1.3
23:50 3.2
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE


Proposed Outfall
Recovery
14:35
Release at 12:00
N 62,000
N 61,500
N 61,000
N 60,500
For inspection purposes only.
Consent of copyright owner required for any other use.
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 8th 2018
Neap Tide
Release at 1200
Cobh Tide (predicted)
on April 8th 2018
BST CD (m)
05:40 1.2
11:20 3.2
18:10 1.3
23:50 3.2
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE


Recovery
14:11
14:11
Proposed Outfall
Release at 13:20
N 62,000
N 61,500
N 61,000
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 8th 2018
Neap Tide
Release at 1320
Cobh Tide (predicted)
on April 8th 2018
BST CD (m)
05:40 1.2
11:20 3.2
18:10 1.3
23:50 3.2
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE



UTAS
White Bay
Cork Harbour

MARINE SURVEY

Drogue Tracking
on April 8th 2018
Neap Tide

Release at 1507

Cobh Tide (predicted)
on April 8th 2018

BST	CD (m)
05:40	1.2
11:20	3.2
18:10	1.3
23:50	3.2

Cobh Tide Levels (ATT)

MHWS	4.1
MHWN	3.2
MLWN	1.3
MLWS	0.4

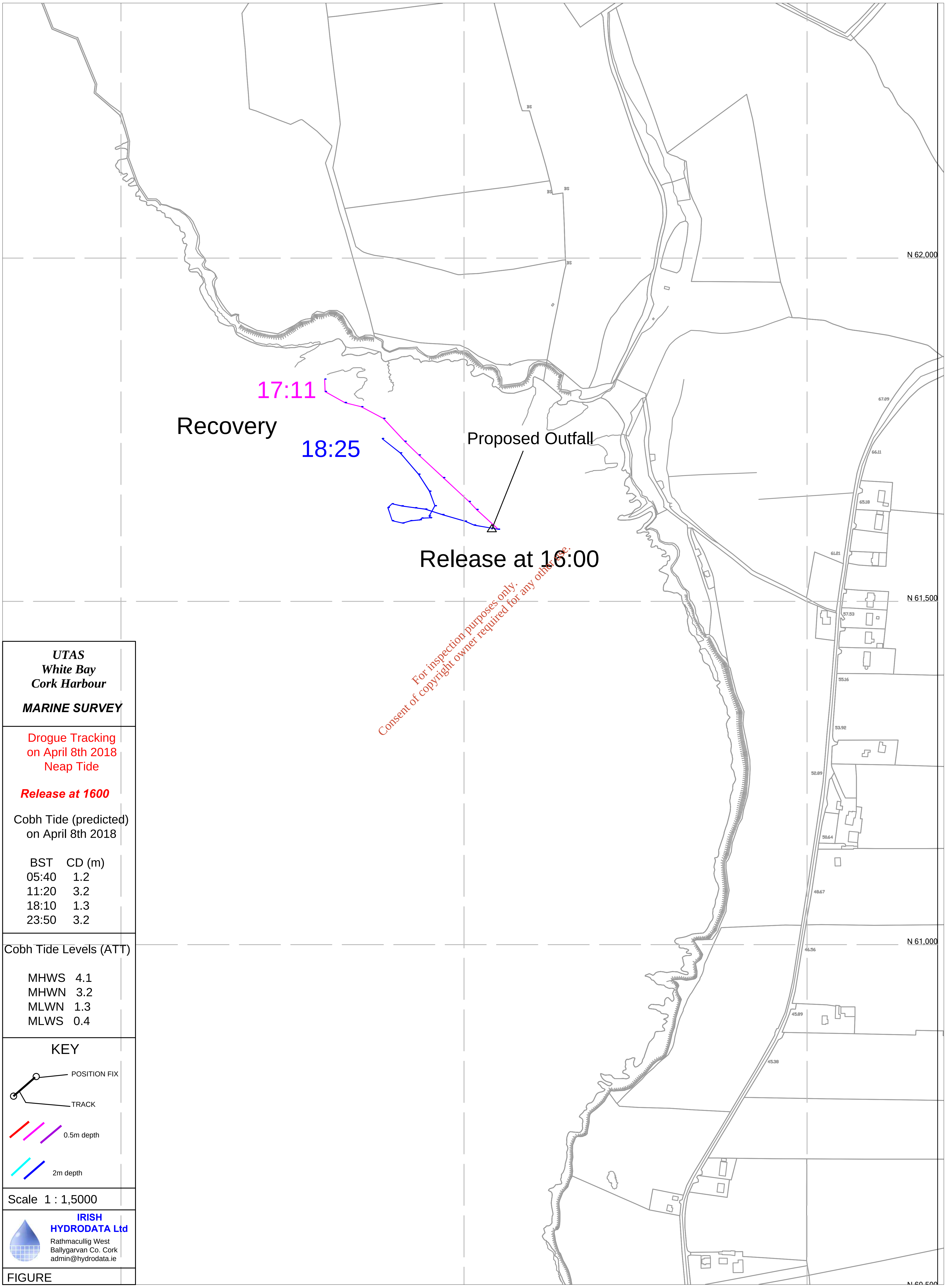
KEY

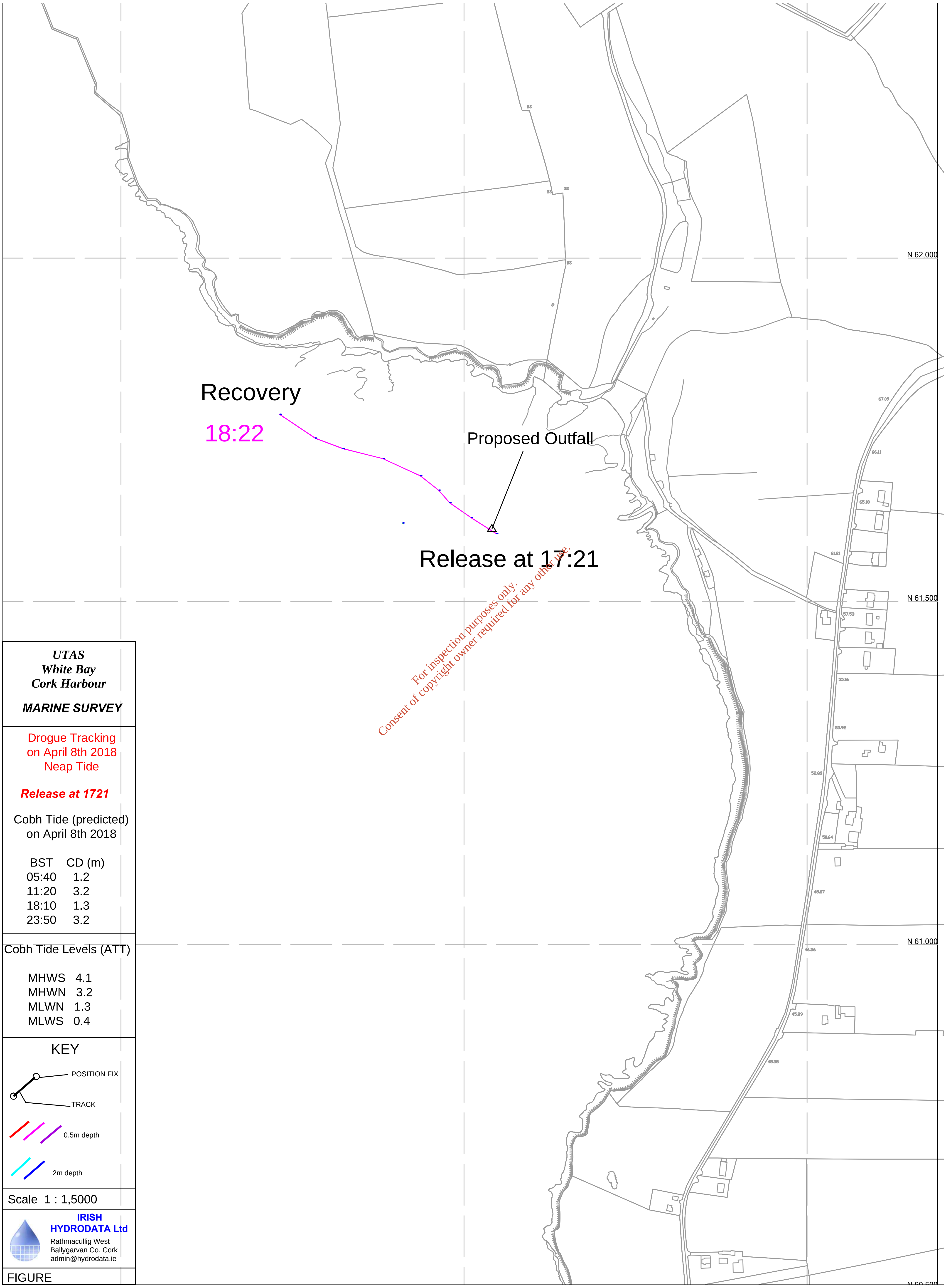
POSITION FIX
TRACK
0.5m depth
2m depth

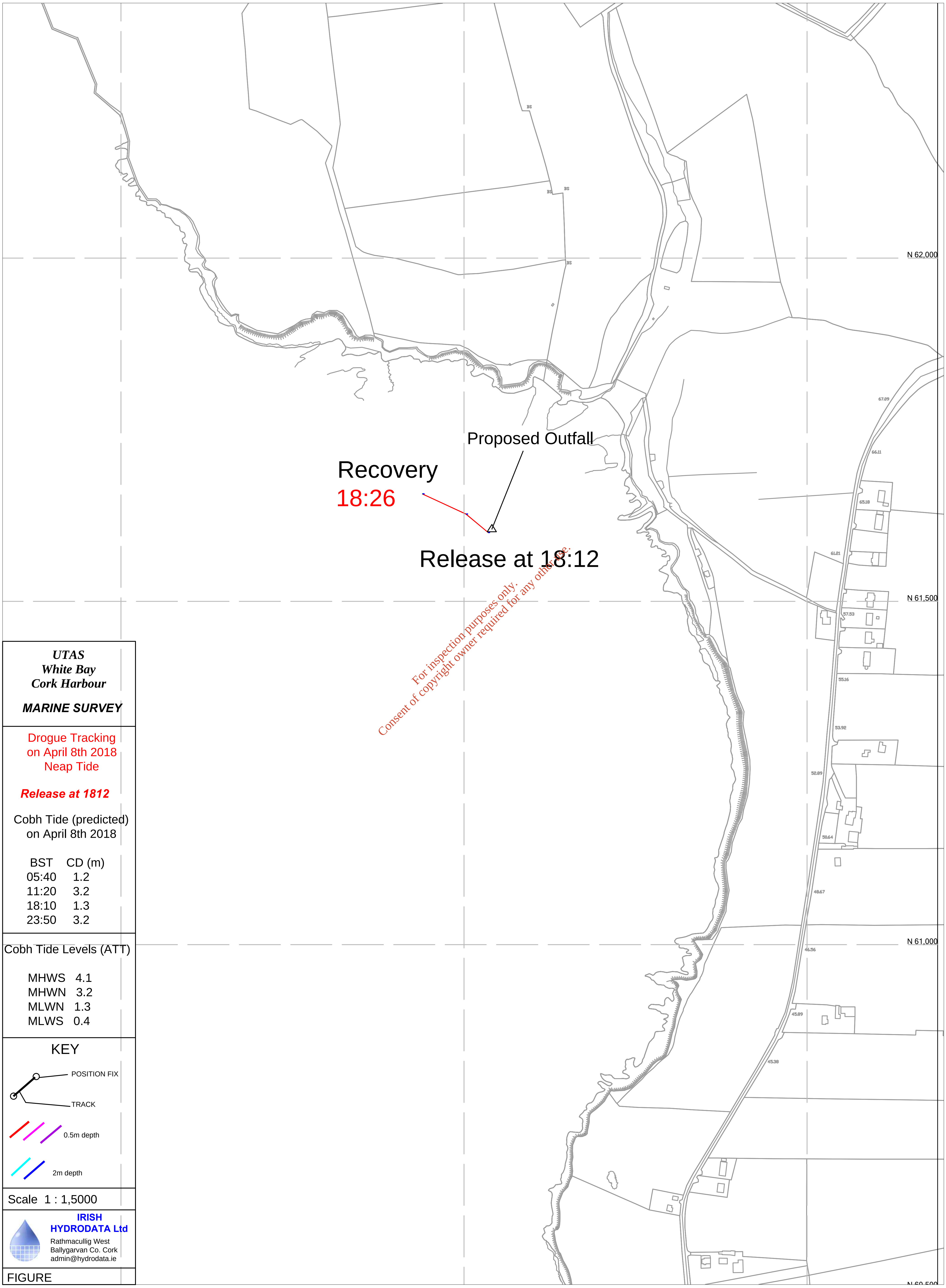
Scale 1 : 1,5000

IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie

FIGURE


17:11
Recovery
18:25
Proposed Outfall
Release at 16:00
N 62,000
N 61,500
N 61,000
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 8th 2018
Neap Tide
Release at 1600
Cobh Tide (predicted)
on April 8th 2018
BST CD (m)
05:40 1.2
11:20 3.2
18:10 1.3
23:50 3.2
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE


Recovery
18:22
Proposed Outfall
Release at 17:21
N 62,000
N 61,500
N 61,000
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 8th 2018
Neap Tide
Release at 1721
Cobh Tide (predicted)
on April 8th 2018
BST CD (m)
05:40 1.2
11:20 3.2
18:10 1.3
23:50 3.2
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE



UTAS
White Bay
Cork Harbour

MARINE SURVEY

Drogue Tracking
on April 8th 2018
Neap Tide

Release at 1812

Cobh Tide (predicted)
on April 8th 2018

BST	CD (m)
05:40	1.2
11:20	3.2
18:10	1.3
23:50	3.2

Cobh Tide Levels (ATT)

MHWS	4.1
MHWN	3.2
MLWN	1.3
MLWS	0.4

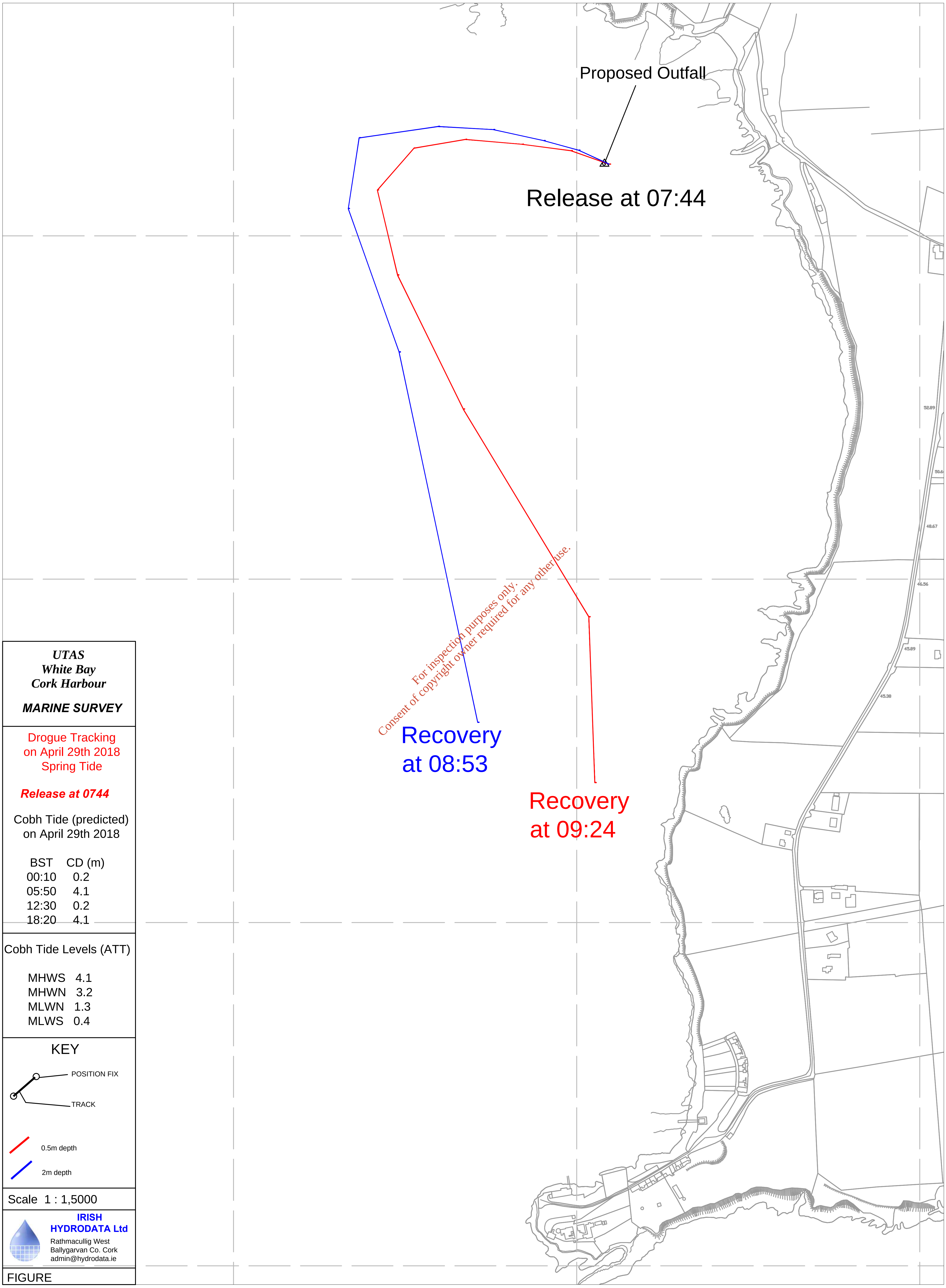
KEY

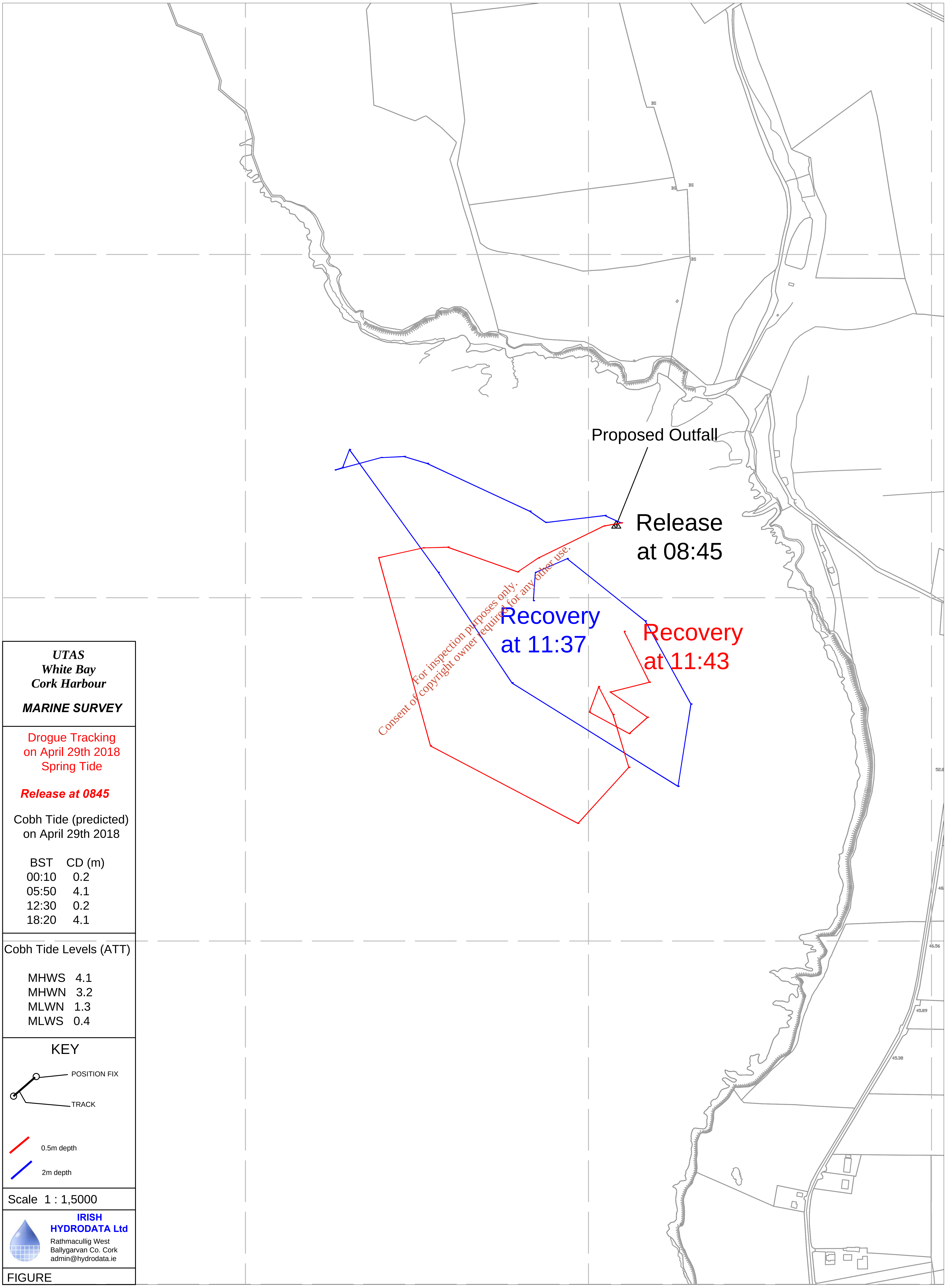
POSITION FIX
TRACK
0.5m depth
2m depth

Scale 1 : 1,5000

IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie

FIGURE


Proposed Outfall
Release at 07:44
Recovery at 08:53
Recovery at 09:24
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 29th 2018
Spring Tide
Release at 0744
Cobh Tide (predicted)
on April 29th 2018
BST CD (m)
00:10 0.2
05:50 4.1
12:30 0.2
18:20 4.1
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE



UTAS
White Bay
Cork Harbour

MARINE SURVEY

Drogue Tracking
on April 29th 2018
Spring Tide

Release at 0845

Cobh Tide (predicted)
on April 29th 2018

BST	CD (m)
00:10	0.2
05:50	4.1
12:30	0.2
18:20	4.1

Cobh Tide Levels (ATT)

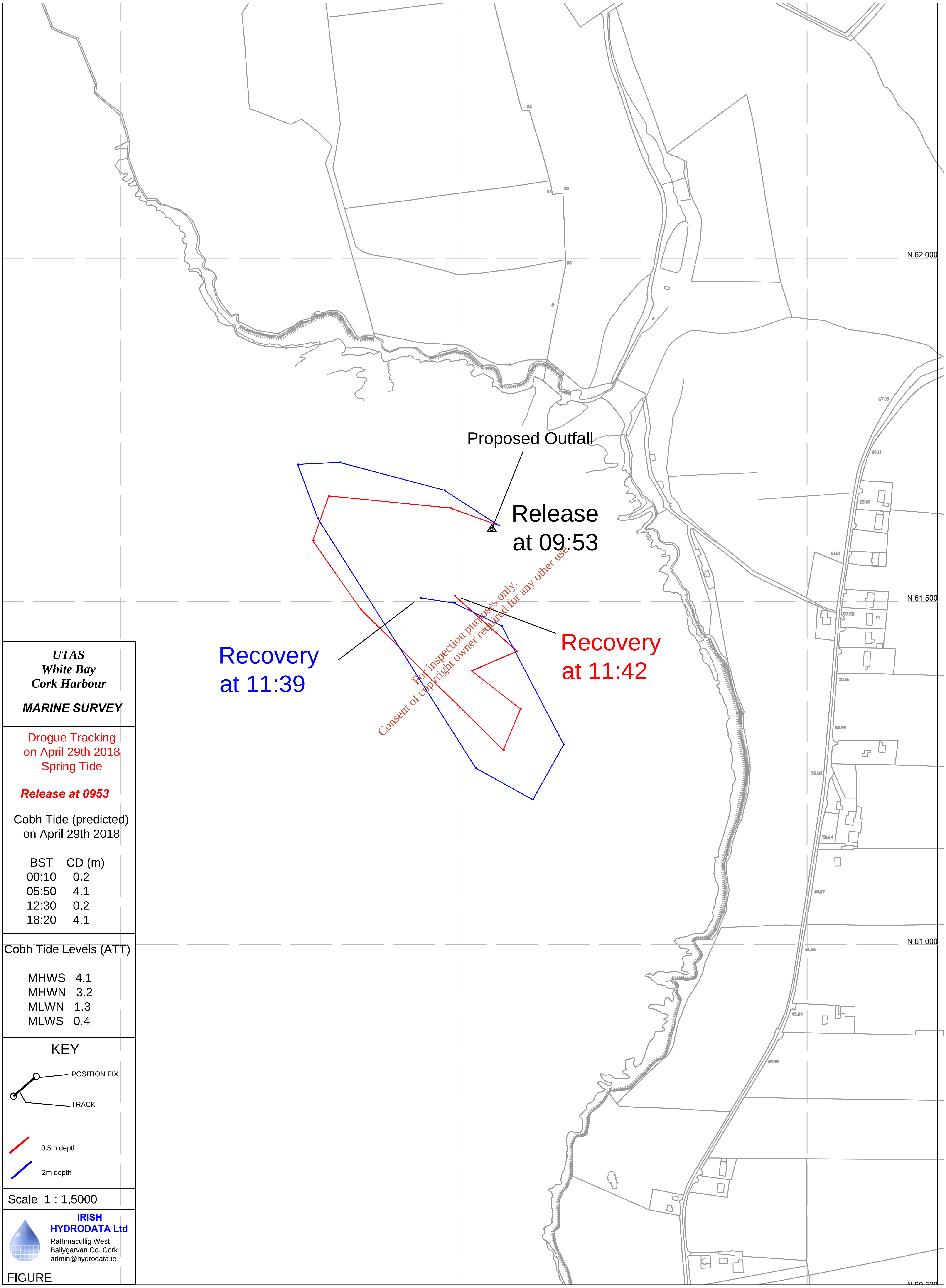
MHWS	4.1
MHWN	3.2
MLWN	1.3
MLWS	0.4

KEY

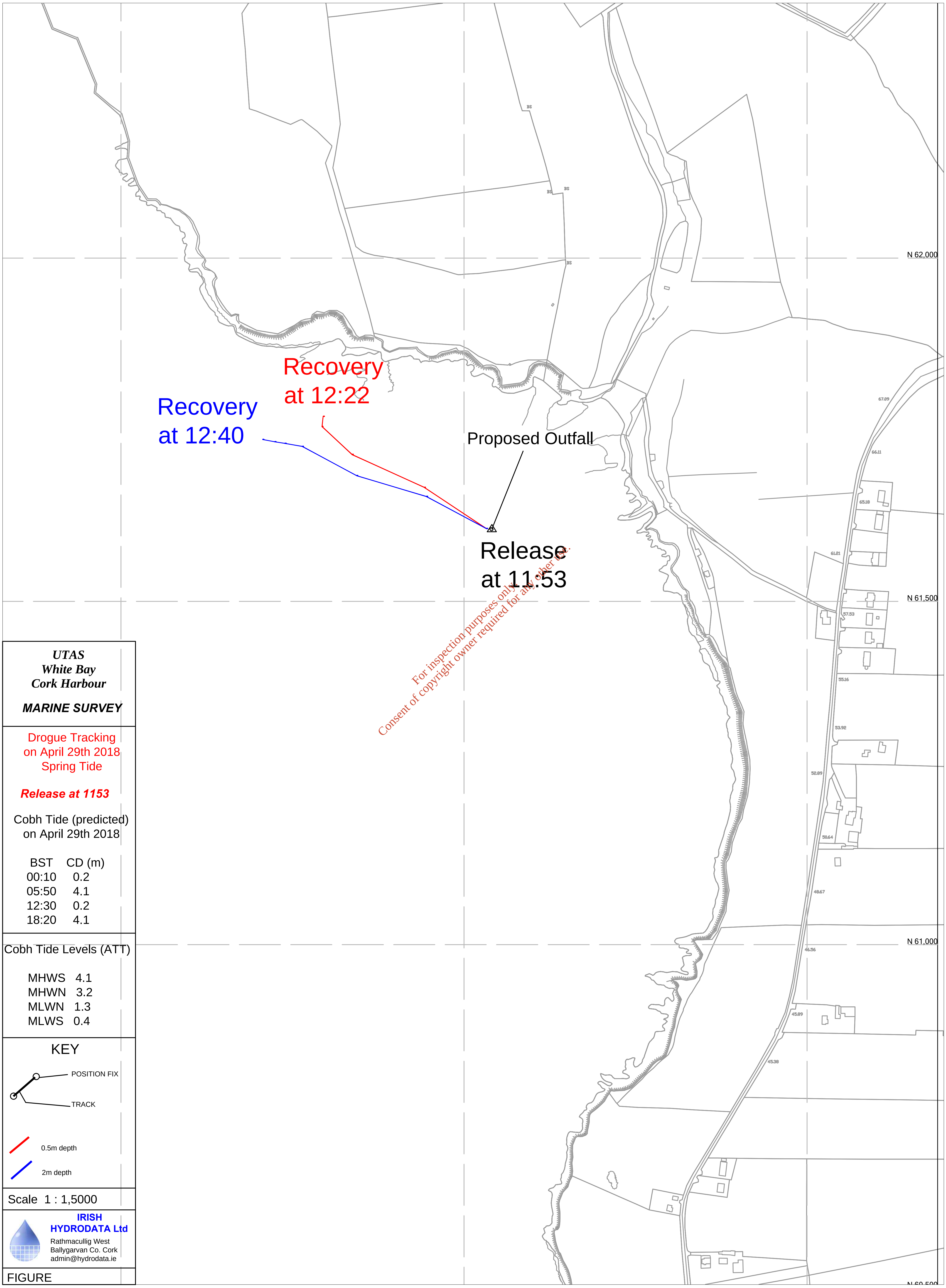
Scale 1 : 1,5000

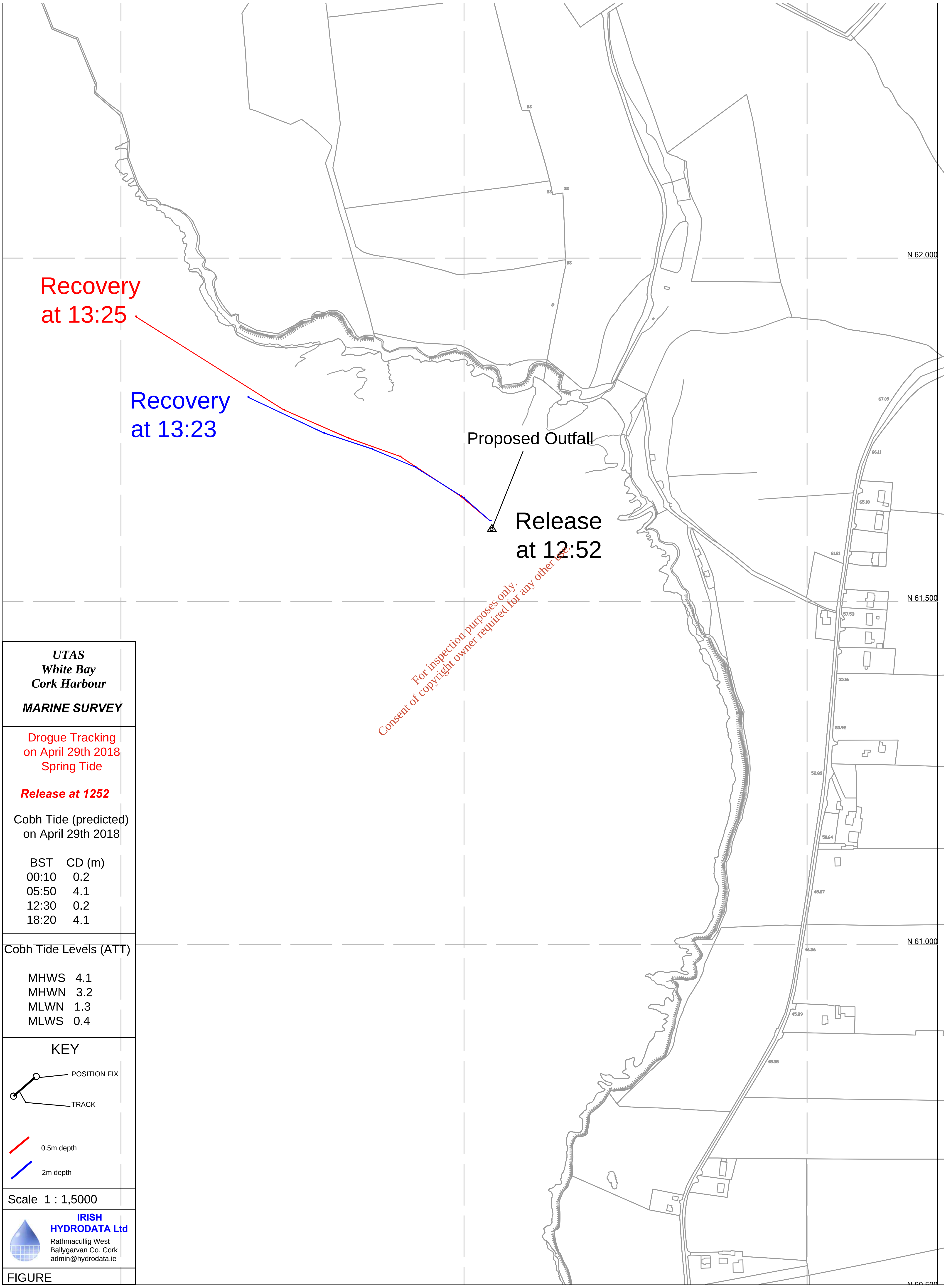
IRISH HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie

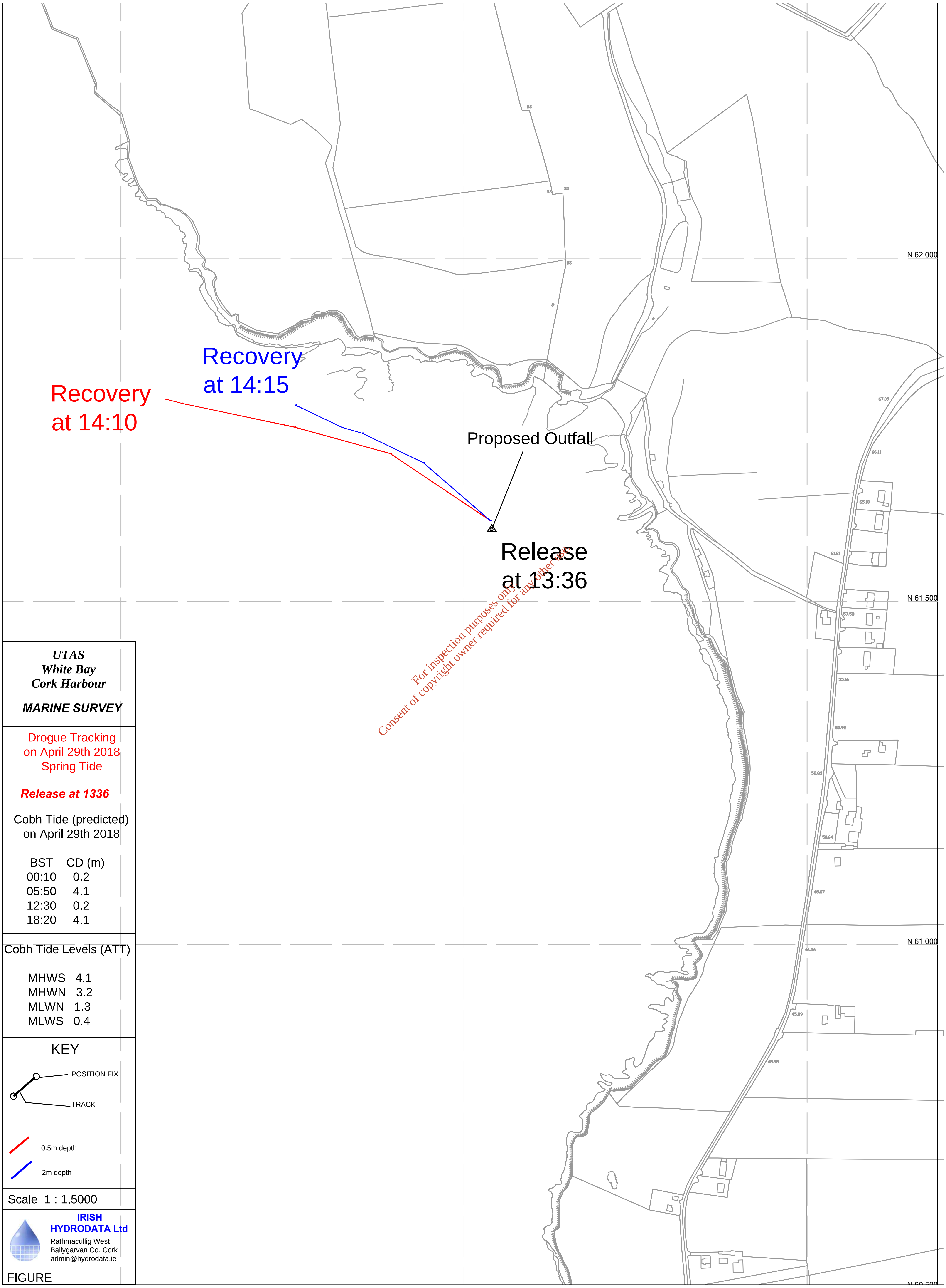
FIGURE



N 62,000
N 61,500
N 61,000
N 60,500
Proposed Outfall
Release
at 09:53
Recovery
at 11:39
Recovery
at 11:42
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 29th 2018
Spring Tide
Release at 0953
Cobh Tide (predicted)
on April 29th 2018
BST CD (m)
00:10 0.2
05:50 4.1
12:30 0.2
18:20 4.1
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE


Recovery at 12:22
Recovery at 12:40
Proposed Outfall
Release at 11:53
N 62,000
N 61,500
N 61,000
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 29th 2018
Spring Tide
Release at 1153
Cobh Tide (predicted)
on April 29th 2018
BST CD (m)
00:10 0.2
05:50 4.1
12:30 0.2
18:20 4.1
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE


Recovery
at 13:25
Recovery
at 13:23
Proposed Outfall
Release
at 12:52
N 62,000
N 61,500
N 61,000
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 29th 2018
Spring Tide
Release at 1252
Cobh Tide (predicted)
on April 29th 2018
BST CD (m)
00:10 0.2
05:50 4.1
12:30 0.2
18:20 4.1
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE



UTAS
White Bay
Cork Harbour

MARINE SURVEY

Drogue Tracking
on April 29th 2018
Spring Tide

Release at 1336

Cobh Tide (predicted)
on April 29th 2018

BST	CD (m)
00:10	0.2
05:50	4.1
12:30	0.2
18:20	4.1

Cobh Tide Levels (ATT)

MHWS	4.1
MHWN	3.2
MLWN	1.3
MLWS	0.4

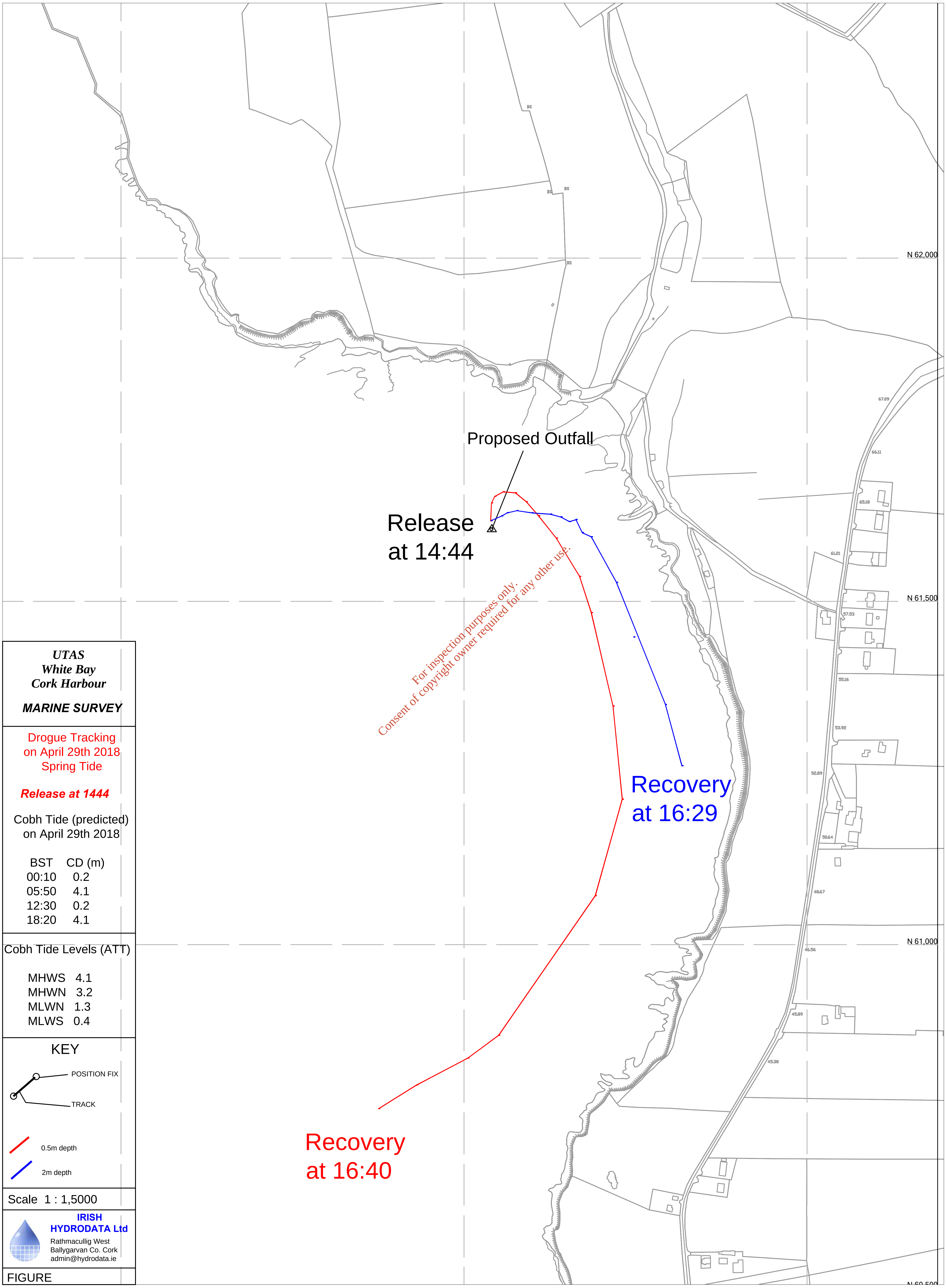
KEY

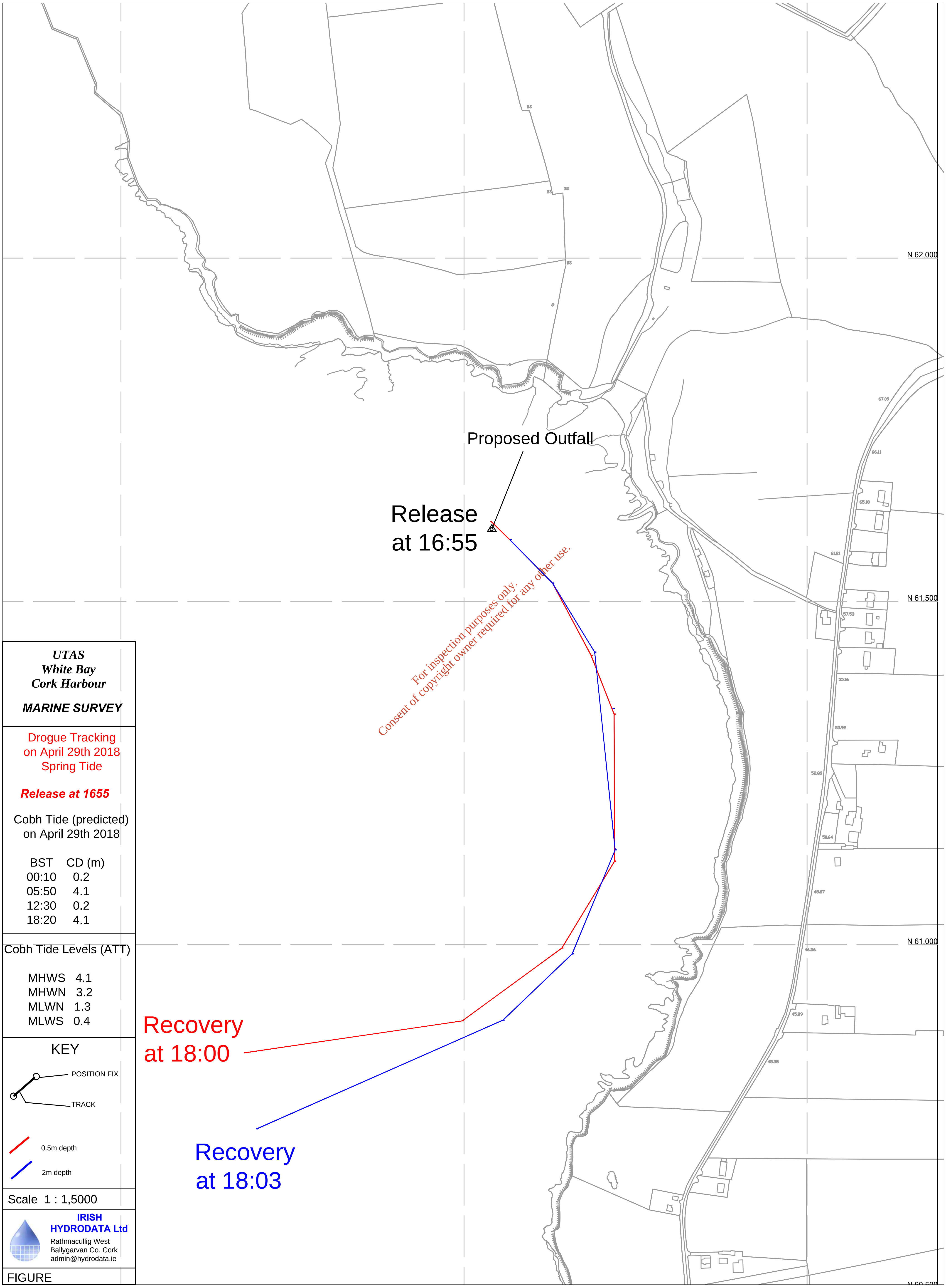
POSITION FIX
TRACK
0.5m depth
2m depth

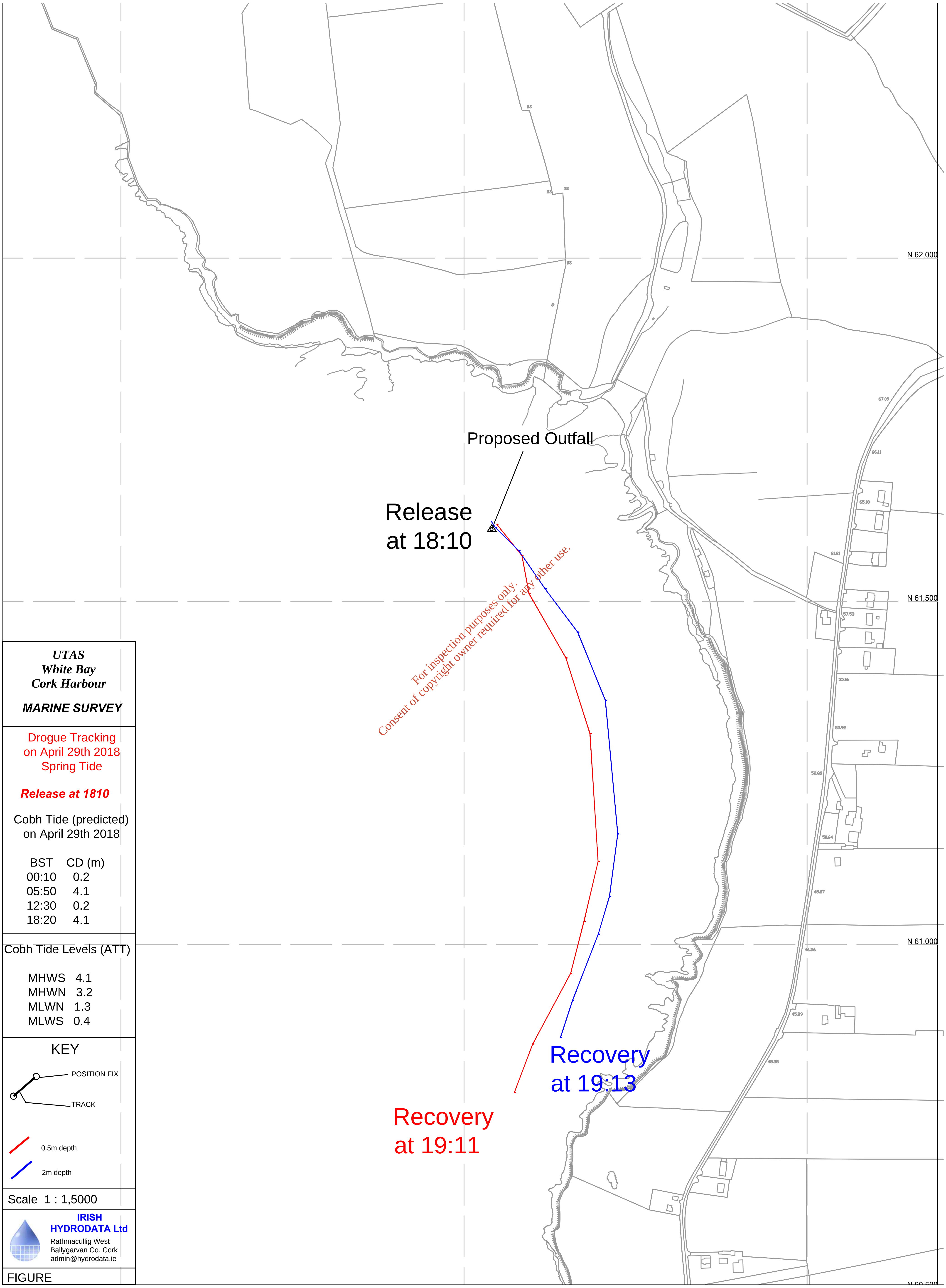
Scale 1 : 1,5000

IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie

FIGURE


UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 29th 2018
Spring Tide
Release at 1444
Cobh Tide (predicted)
on April 29th 2018
BST CD (m)
00:10 0.2
05:50 4.1
12:30 0.2
18:20 4.1
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE
Proposed Outfall
Release
at 14:44
Recovery
at 16:29
Recovery
at 16:40
N 62,000
N 61,500
N 61,000


N 62,000
N 61,500
N 61,000
Proposed Outfall
Release
at 16:55
For inspection purposes only.
Consent of copyright owner required for any other use.
Recovery
at 18:00
Recovery
at 18:03
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 29th 2018
Spring Tide
Release at 1655
Cobh Tide (predicted)
on April 29th 2018
BST CD (m)
00:10 0.2
05:50 4.1
12:30 0.2
18:20 4.1
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
Rathmacullig West
Ballygarvan Co. Cork
admin@hydrodata.ie
FIGURE



N 62,000
N 61,500
N 61,000
N 60,500
Proposed Outfall
Release
at 18:10
Recovery
at 19:13
Recovery
at 19:11
UTAS
White Bay
Cork Harbour
MARINE SURVEY
Drogue Tracking
on April 29th 2018
Spring Tide
Release at 1810
Cobh Tide (predicted)
on April 29th 2018
BST CD (m)
00:10 0.2
05:50 4.1
12:30 0.2
18:20 4.1
Cobh Tide Levels (ATT)
MHWS 4.1
MHWN 3.2
MLWN 1.3
MLWS 0.4
KEY
POSITION FIX
TRACK
0.5m depth
2m depth
Scale 1 : 1,5000
IRISH
HYDRODATA Ltd
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Ballygarvan Co. Cork
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FIGURE