Appendix 15.2

Outfall Study

Document Ref. No. 1207/5/17F

Final Report

Arklow WWTP
Investigation of the Impact of Treated Wastewater Discharges to the Irish Sea

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Revision History	Note	Date
1207/1/15D	Draft issued to BL-PHMcC for comment	5/4/15
1207/2/15P	Preliminary report issued	15/4/15
1207/3/17D	Draft report for marine outfall	15/2/17
1207/4/17D	Revised draft report for marine outfall	30/11/17
1207/5/18F	Final report for marine outfall	20/08/18

Glossary

ADF	Average Daily Flow
ATT	Admiralty Tide Tables
BOD	Biochemical Oxygen Demand
cfu	Bacterial Colony Forming Unit
DIN	Dissolved Inorganic Nitrogen (as N)
DWF	Dry Weather Flow
DO	Dissolved Oxygen
EC	E.Coli
ELV	Emission Limit Value
EPA	Environmental Protection Agency
EQS	Environmental Quality Standards
GSI	Geological Survey of Ireland
HW	High Water
IE	Intestinal Enterococci
IHD	Irish Hydrodata Ltd
IW	Irish Water
LW	Low Water
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
NHA	National Heritage Area
NPWS	National Parks and Wildlife Service
OPW	Office of Public Works
PE	Population Equivalent
PO4	Molybdate reactive phosphorus (P)
SAC	Special Area of Conservation
SS	Suspended Solids
T_{90}	Decay time
TA	Total Ammonia (as N)
TON	Total Oxidised Nitrogen (as N)
UWWTR	Urban Wastewater Treatment Regulations
WFD	Water Framework Directive
WQ	Water Quality
WWTP	Wastewater Treatment Plant

1. Introduction

1.1 Background Information

Arklow is a significant urban centre on the east coast. It is served by drainage system from which untreated municipal wastewaters discharge directly into the Avoca river. A treatment plant has been in planning for a number of years and various detailed designs including marine outfall studies have been completed. Recent investigative studies by consulting engineers Arup have identified a suitable treatment plant site on the seafront which would facilitate a marine outfall (Figure 1.1). This study seeks to examine the possible impacts of discharges to the nearby waterbodies.

There are three waterbodies in the locality identified under the Water Framework Directive (WFD). These are listed in Table 1.1 and illustrated in Figure 1.2. The results of the WFD monitoring programme indicate that there are some water quality issues with the Lower Avoca river and the Avoca estuary. These relate to historic leakages from upstream mines and untreated municipal wastewater discharges to the estuary. The Arklow environs have numerous sandy beaches, all of which are used extensively during the summer months. The beaches at Brittas Bay and Clogga (Figure 1.3) are designated bathing waters.

There are two marine SAC's in the vicinity; these are the Wicklow Head Reef and the Blackwater Bank (Figure 1.4). The Arklow town marsh, located on the northern bank of the Avoca river, is a proposed NHA (Figure 1.5).

1.2 Study Brief

The purpose of the study was to:

- make an assessment of the effects of treated wastewater discharges to the Arklow coastal area;
- establish suitable effluent discharge standards;
- ensure compliance with all EC and national regulations;

The brief called for various scenarios to be focused on. These included spring and neap tides and calm and windy conditions. Under the Urban Wastewater Treatment Regulations 2001 secondary treatment of effluent is mandatory. This will significantly reduce the biological impacts of wastewater discharges on the receiving waters. The main concerns regarding the proposed discharges are the impacts on nutrient levels and on bacterial concentrations in nearby bathing waters.

1.3 Regulatory Framework

The main regulatory constraints that apply to the discharges are:

* Urban Wastewater Treatment Regulations 2001 (SI 254/2001);
* European Communities (Water Policy) Regulations (SI 722/2003);
* European Communities Environmental Objectives (Surface Waters) Regs 2009 (SI 272/2009);
* European Communities (Birds and Natural Habitats) Regs(SI 477/2011);
* Bathing Water Quality Regulations 2008 (SI 79/2008);
* European Communities (Quality of Salmonid Waters) Regulations 1988 (SI 293/1988).

1.4 Summary of Study Works

The study included of a review of available data and previous reports. Irish Hydrodata Ltd (IHD) has previously conducted outfall investigations for the Arklow WWTP in 1985, 1991 and 2005. Subsequently, hydrodynamic & water quality models were constructed to simulate the impacts of the proposed discharges allowing comparisons to be made and suitable discharge standards to be set.

Waterbody	Risk Scores	WFD Status 2010-2015	Status 2012[1]
Avoca Lower (River)	At risk of not achieving Good	Unassigned	Moderate
Avoca Estuary (Transitional)	At risk of not achieving Good Status	Moderate	Intermediate
Brittas Bay HA10 (Coastal)	Expected to achieve Good Status	Unassigned	Unpolluted

Table 1.1 - Local WFD waterbodies

Figure 1.1 - Potential outfall corridor to coastal waterbody

[1] Values for the estuary and coastal water bodies are 'Trophic Status' for 2010-2012 as described under the EPA's 'Trophic Status Assessment Scheme'

Figure 1.2 - Local WFD waterbodies:

Avoca Estuary: Transitional (yellow)
Brittas Bay (HA10): Coastal (Blue)

Figure 1.3 - Designated bathing waters

Figure 1.4 - Local SAC's Wicklow Head (2274), & Blackwater Bank (2953), Brittas Dunes (729), Kilpatrick (1742)

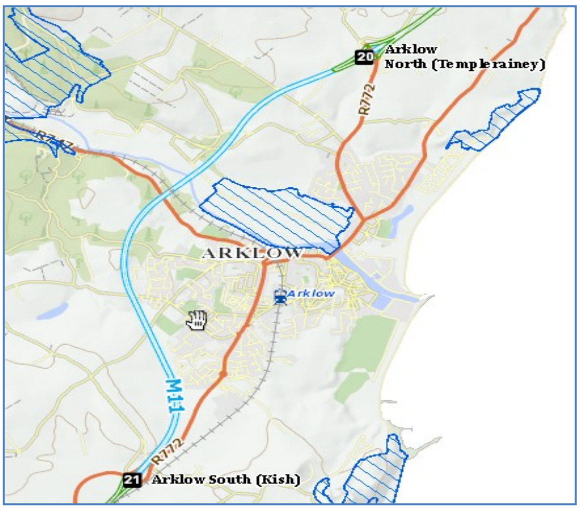


Figure 1.5 - Proposed coastal NHA sites, Arklow Rock –Askintinny (1745), Arklow Sand Dunes (1746)

2. Area Characteristics

2.1 Coastal Bathymetry

The general bathymetry for the Arklow area is available on the Admiralty chart of the area (ref:1) and is presented in Figure 2.1a. The nearshore coastal area was surveyed in 2016 by the Geological Survey of Ireland under the Infomar program (ref:2). Figure 2.1b shows a contoured extract from this data. There are no major differences between the older Admiralty and more recent Infomar datasets in the vicinity of the outfall. However, some erosion has taken place locally adjacent to the shoreline where depths have increased by 1m when compared with data from an IHD survey of 1986. This can be seen in a profile along the proposed outfall line presented later in Section 4 of the report.

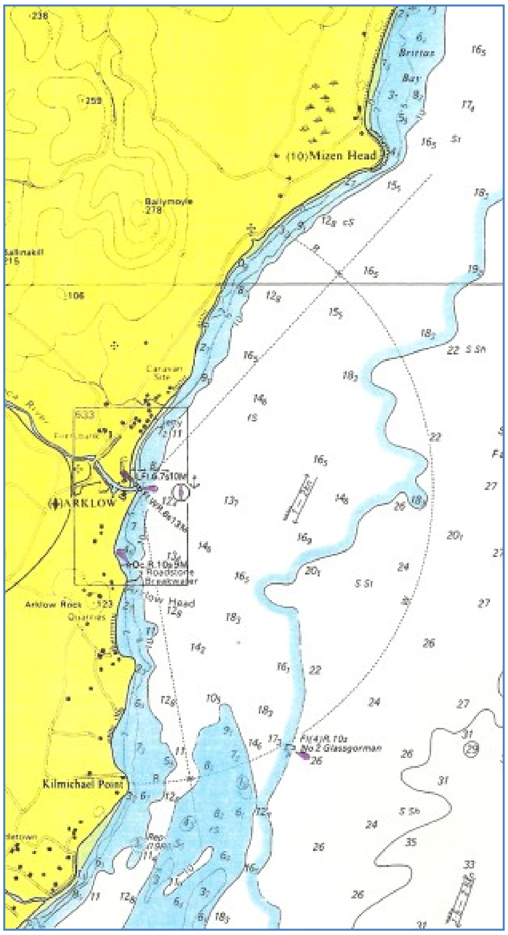


Figure 2.1a - Coastal bathymetry from Admiralty chart (no 1787)

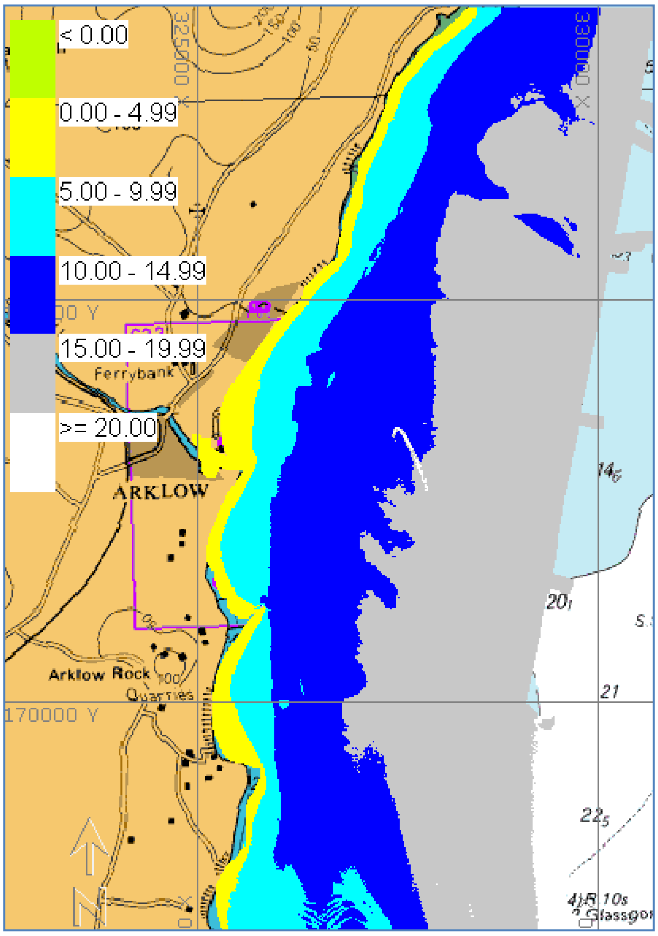


Figure 2.1b - Coastal bathymetry from Infomar data (2016)

2.2 Tidal Levels

Tidal patterns in the locality are semi-diurnal. Ranges are small and the tidal elevation curves are somewhat complex due to the proximity of a degenerate amphidrome near Courtown (ref:3). The Admiralty Tide Tables (ATT) publication NP-201-17 (ref:4) provides summary tidal level information for Arklow based on historic information. This data is presented in Table 2.1. In 1985 IHD conducted detailed studies in the area as part of earlier outfall investigations (ref:5). Digital tidal data was collected for 30 days and harmonically analysed. Derived statistics are also included in Table 2.1. A comparison of the IHD data with that based on the ATT is shown in Figure 2.2.

Figure 2.3 shows a prediction of water levels at Arklow for a representative year of 2015 relative to Malin Head datum. The associated tidal height percentage exceedance plot is shown in Figure 2.4. The highest predicted tide level over the year was 0.58m OD Malin while the lowest level was -0.85m Malin. Other years would produce similar ranges with a small variation over the 18.6 year cycle associated with lunar declination.

Tide	Tide	Admiralty Tide Table Level CD (m)	Admiralty Tide Table Level OD Malin	Irish Hydrodata Ltd Level OD Malin
MHWS	Mean high water springs	1.4	0.27	0.42
MHWN	Mean high water neaps	1.2	0.07	0.12
ML	Mean level	1.03	-0.1	
MLWN	Mean low water neaps	0.9	-0.22	-0.14
MLWS	Mean low water springs	0.6	-0.53	-0.44

Table 2.1 - Summary tidal statistics for Arklow

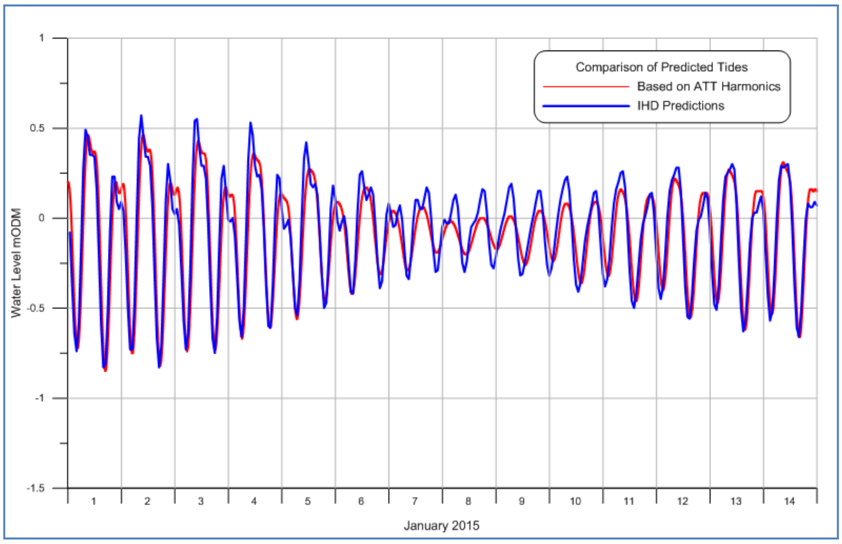


Figure 2.2 - Comparison of predicted tides over 2 week period

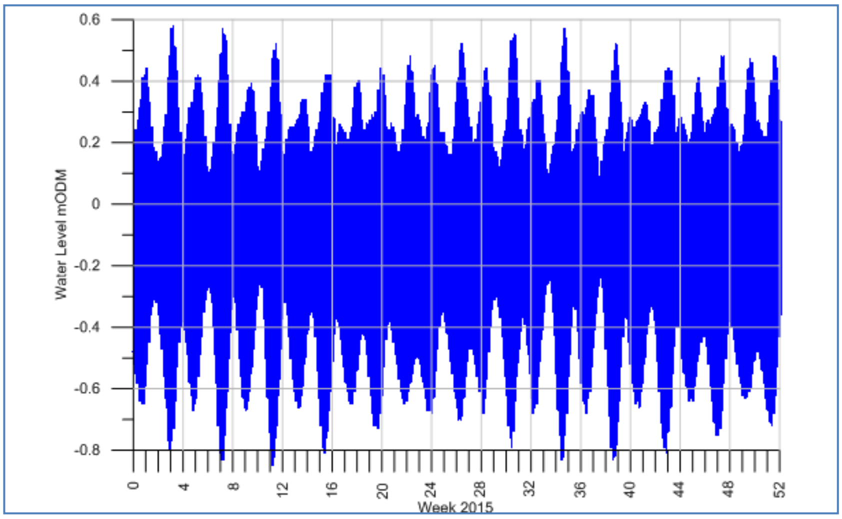


Figure 2.3 - Hourly tidal prediction for representative year of 2015 Malin datum

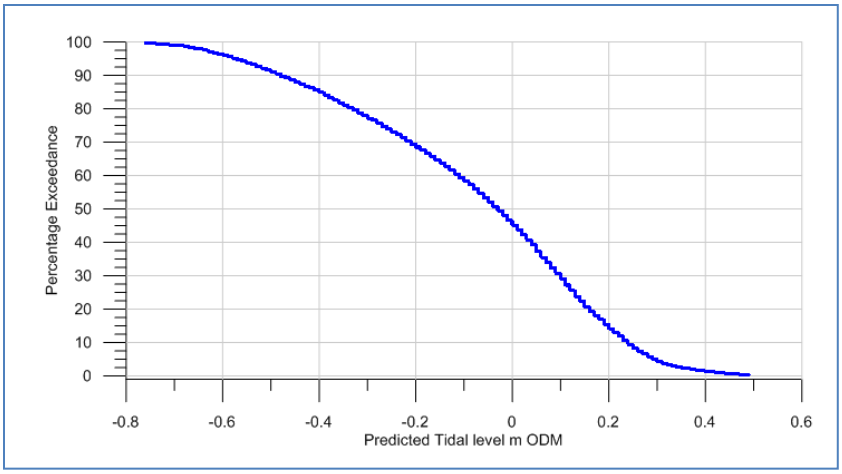


Figure 2.4 - Percentage exceedance of tidal level for 2015

2.3 Coastal Oceanography

Previously IHD conducted detailed studies at Arklow for various marine long sea outfalls and a possible river discharge. These studies were conducted between 1985 and 2005 (refs:5,6,7). The information on physical characteristics of the coastal waterbody obtained for those investigations has been used in this study. Example data are presented in Figures 2.5 to 2.11. The oceanography can be described as energetic with strong tidal currents, brief slack waters, large tidal excursions and good dispersive characteristics. Table 2.2 summarises depth averaged current speed and drogue trajectory data derived during the 1985 study.

In order to confirm the validity of older data a drogue release was conducted from a potential outfall location identified in preliminary evaluations during September 2017. A day was chosen with calm winds and average tides. Three floating drogues (sails at 0-1m, 1-2m and 5-6m) were released at the proposed outfall location on both a flooding and ebbing tide. They were tracked and the position noted at regular intervals. The trajectories followed the patterns observed in

1985 and are shown overlain on that data in Figure 2.6. The surface drogue tracked further offshore while the deeper one moved parallel to the coast. At the change in tide the two shallower drogues turned offshore while the deeper one reversed its course.

A recording current meter was also deployed for 30 days during the 1985 survey. This was located approximately 1000m east-northeast from the harbour mouth on the then proposed outfall line (Figure 2.10). It was positioned at a height of 1.5m above the seabed. The 95%'ile exceedance speed recorded at the current meter location was 0.05m/s (Figure 2.11). This indicates that the durations of slack water at the site are limited.

	Current Speeds m/s		Drogue Excursions	
Tide	**Flood**	**Ebb**	**Flood**	**Ebb**
Spring	0.66	0.59	15km	15km
Neap	0.42	0.35	11km	6km

Table 2.2 - Summary depth averaged oceanographic information

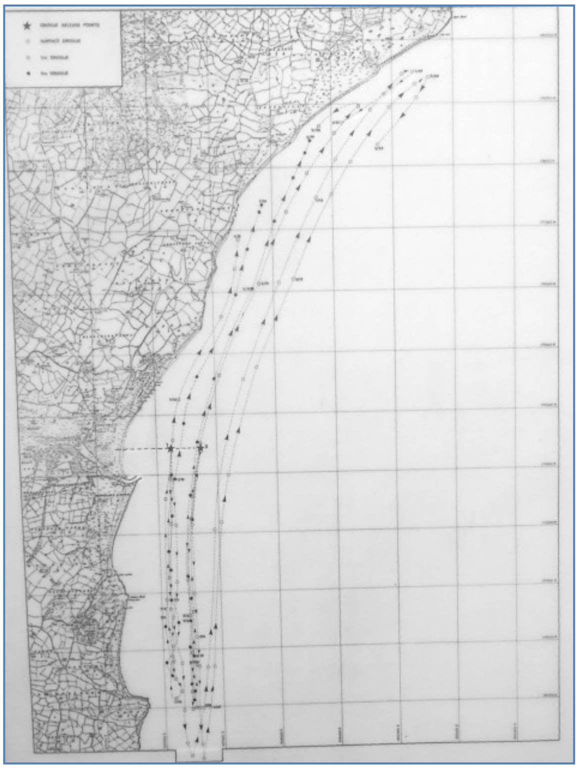


Figure 2.5 - Spring Tide Drogue Release
(1985 data)

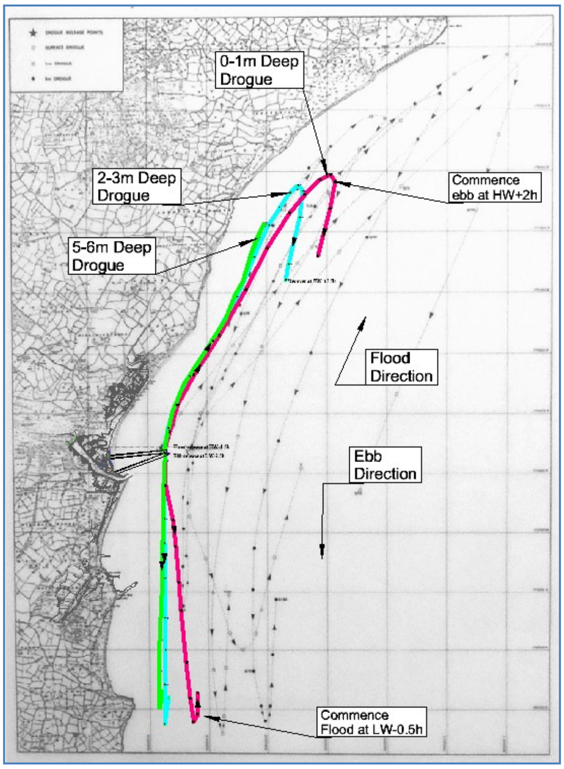


Figure 2.6 - Spring Tide Drogue Release
Data from drogue release at proposed outfall location (Sept 2017) overlain on data from 1985

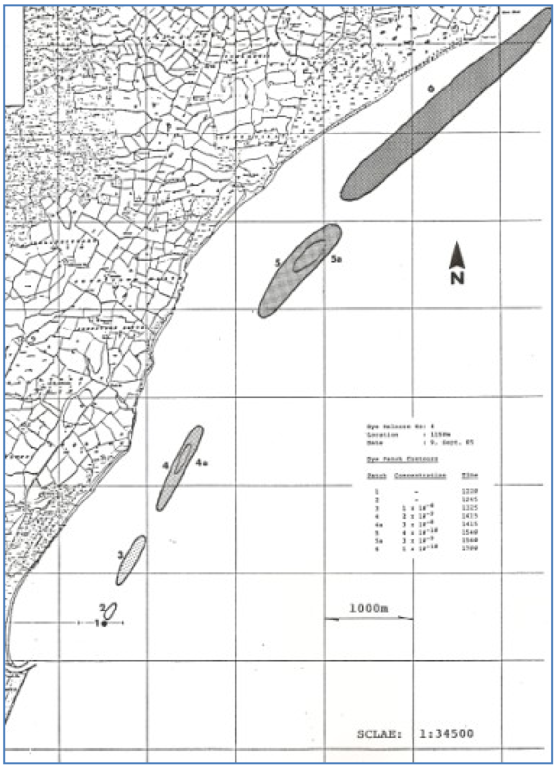


Figure 2.7 Spring Flood Tide Dye Release

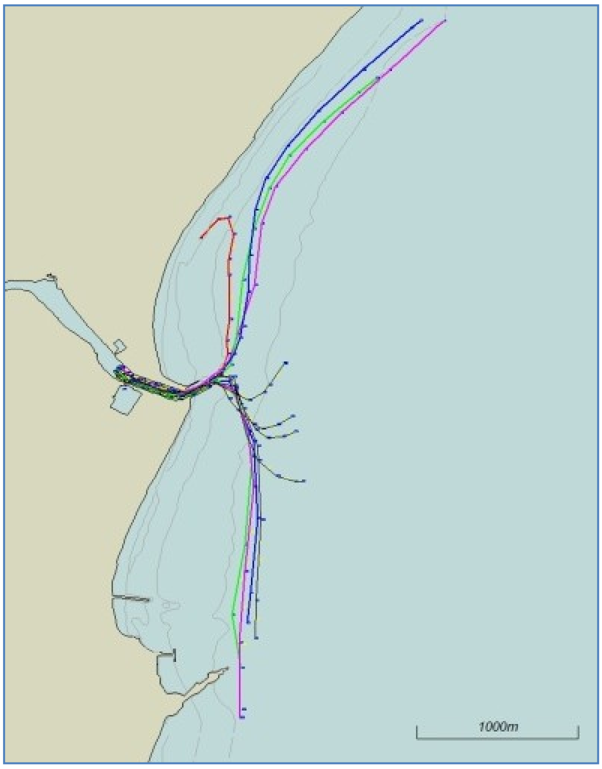


Figure 2.8 – Harbour Drogue Release
Data from Jan 2005, river flow = $21m^3/s$

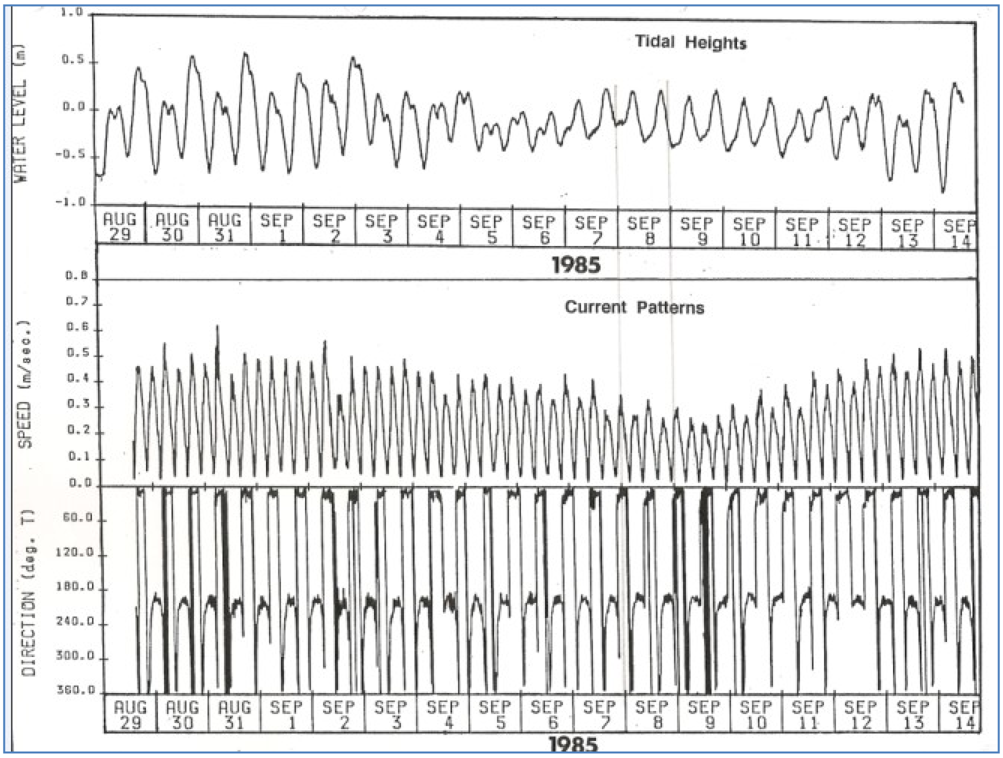


Figure 2.9 - Current meter data from previous study (ref:4)

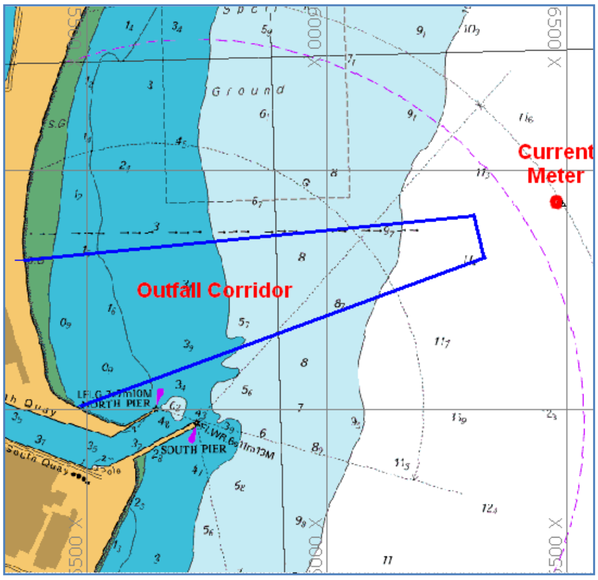


Figure 2.10 - Recording current meter location and proposed outfall corridor

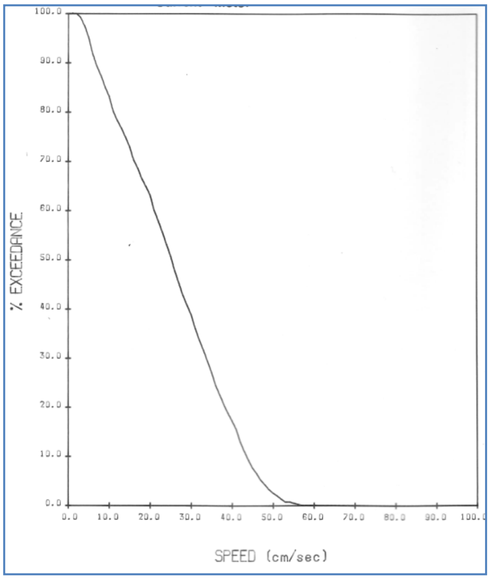


Figure 2.11 - Current speed exceedence plot

2.4 Avoca River

The Avoca river is a substantial waterbody with a primarily upland catchment of some 650km^2. The Avoca flow characteristics based on the EPA Hydrometric data system are: DWF = 0.8 m^3/s, 95%'ile = 3.1 m^3/s and 50%'ile = 15 m^3/s. The average flows are significant, thus a surface plume will generally develop at the harbour mouth.

3. Analysis Approach

3.1 Methods

The potential impacts of the proposed discharges on the marine waters were assessed using various calculations and hydraulic modelling methods. These included:

1. Initial dilution simulations of the outfall diffuser;
2. Water circulation modelling;
3. Contaminant dispersion modelling.

A jet type model was used to simulate the effluent stream issuing from the diffuser and to estimate the near-field dilutions at the immediate discharge location. Water movements in the wider area were simulated with a 2D-hydrodynamic model driven by tidal forcing. A contaminant simulation model, driven by hydrodynamics was used to evaluate the location-specific impacts of discharges within the mid- and far-field areas.

3.2 Applicable Water Quality Standards

The proposed PE for the plant is greater than 10,000 therefore secondary treatment is required in accordance with the UWWT regulations, SI 254/2001. None of the local waterbodies has been designated 'Sensitive' and therefore minimum design parameters for the plant are as listed in Table 3.1.

Parameters	Final Effluent Concentration	Minimum Percentage Reduction on Source Effluent
BOD_5	25mg/l O_2	70-90
COD	125mg/l O_2	75
SS	35 mg/l	90

Table 3.1 - Urban Wastewater Treatment Regulations requirements

The discharge has the potential to impact only the coastal waterbody. It cannot directly impact the Avoca river and an impact on the estuary is unlikely due to the distance offshore of the discharge point. The target water quality standards for various environments are listed in Tables 3.2 and 3.3. The parameters that are most relevant to the proposed outfall are e.coli, intestinal enterococci (IE), dissolved inorganic nitrogen (DIN) and biochemical oxygen demand (BOD). Concentrations for other parameters such as orthophosphate (PO4) and total ammonia (TA) are not specified for coastal waters but are included here for completeness.

Under the Surface Water regulations, SI 272/2009, the DIN target must be achieved at the edge of the mixing zone. A regulatory method for determining the extent of the mixing zone is not defined. It is required to be restricted to the proximity of the discharge and be proportionate. Various non binding guidelines for the assessment of discharges have been developed under the EC Common Implementation Strategy for the Water Framework Directive. The general approaches for identifying mixing zones (ref: 8) are followed here. The design objective of 'High Status' is used to delineate the mixing zone extent.

E.coli and IE target concentrations are set by the Bathing Water Quality Regulations, SI 79/2008. The nearest designated bathing waters are at Clogga Beach which is located some 3km to the south of the harbour. Brittas Bay beach is over 9km to the north-east. For the purposes of this study the bathing water regulations are considered to apply to all coastal beaches immediately to the north and south of the harbour mouth as these are actively used for recreational activities. The design objective is to achieve the 'Excellent Quality' for these locations (Table 3.3).

Parameter	Transitional Waters	Coastal Waters
BOD (mg O_2/l)	<4.0 (Good Status, 95%ile)	*Not Specified*
Dissolved Oxygen (DO) (% sat)	Summer (95%ile) 80%<DO<120% (35psu) 70%<DO<130% (0psu)	Summer (95%ile) 80%<DO<120% (35psu)
Suspended Solids (SS) (mg/l)	*Not Specified*	*Not Specified*
Total Ammonia (mg N/l)	*Not Specified*	*Not Specified*
PO4 (mg P/l)	0.06mg/l (0-17psu) median 0.04mg/l (34psu) median	*Not Specified*
Dissolved Inorganic Nitrogen DIN (mg N/l)		Good Status <2.6mg/l(0psu) median Good Status <0.25mg/l(34.5psu) median High Status <0.17mg/l(34.5psu) median

Table 3.2 - Target water quality standards (EQS) for surface waters (SI 272/2009, SI 386/2015)

	Bathing Waters Target	Regulation/Code
E.coli	<250 cfu/100ml (Excellent Quality)	Bathing Waters: SI 79/2008, 2006/7/EC Based on 95%ile evaluation
Intestinal enterococci (IE)	<100 cfu/100ml (Excellent Quality)	

Table 3.3 - Target bacterial water quality standards for bathing waters

3.3 Background Coastal Water Quality

Background water quality for the Arklow coastal area was derived from EPA and Marine Institute monitoring data sets (ref:9, 10). There are approx 20 sampling sites located in the area between the coastline and the Arklow bank (Figures 3.1 & 3.2). The available datasets cover the period 2007 to 2016. Not all of the sites are sampled at the same frequency. The median background values for the coastal locations AV110 to AV160 (Table 3.4) are: DIN = 0.154mg/l N, TA = 0.017mg/l N. Corresponding values for the estuary location AV010 (Table 3.5) are DIN = 1.74mg/l N, TA = 0.1mg/l N. The median DIN in the Marine Institute data for the sites shoreward of the Arklow Bank is 0.156mg/l N.

Bacterial sampling data is available for both Clogga beach to the south and Brittas Bay beach to the north. Data for the bathing seasons in 2016 and 2017 are listed in Table 3.6. Both beaches are assigned Excellent Status in terms of SI 79/2008 (e.coli <250 cfu/100ml, IE <100 cfu/100ml). The calculated 95%ile values based on the last 4 years of sampling data for Clogga are e.coli =

185cfu/100ml and IE = 79 cfu/100ml and for Brittas e.coli = 173 cfu/100ml and IE = 68 cfu/100ml respectively. There is some appreciable overall variation in this data and the results may be impacted either by the existing Arklow town discharges or also possible contamination from more local S4 licenced outfalls (Figure 3.3).

Figure 3.1 - EPA coastal and transitional waters sampling stations

Figure 3.2 - Marine Institute water sampling stations in Arklow area

StationNo	Sample Depth	Salinity	TON mg/l N	NH3 mg/l N	DIN mg/l N	BOD mg/l	Season
AV110	0.0	33.22	0.16	0.014	0.174	1.0	Winter
AV110	9.7	33.25	0.15	0.022	0.172	1.0	Winter
AV110	0.0	34.14	0.01	0.016	0.026	1.0	Summer
AV110	9.7	34.17	0.01	0.021	0.031	1.0	Summer
AV120	0.0	28.87	0.21	0.122	0.332	1.0	Summer
AV120	9.8	34.15	0.01	0.023	0.033	1.0	Summer
AV130	0.0	32.93	0.19	0.016	0.206	1.0	Winter
AV130	10.1	33.20	0.15	0.018	0.168	1.0	Winter
AV130	0.0	30.78	0.02	0.017	0.037	1.0	Summer
AV130	6.4	34.12	0.02	0.050	0.07	1.0	Summer
AV150	0.0	33.38	0.14	0.014	0.154	1.0	Winter
AV150	18.0	33.39	0.14	0.022	0.162	1.0	Winter
AV150	0.0	34.14	0.02	0.014	0.034		Summer
AV150	15.0	34.19	0.02	0.012	0.032		Summer
AV160	0.0	33.25	0.14	0.022	0.162		Winter
AV160	13.5	33.36	0.14	0.014	0.154		Winter
Average			**0.10**	**0.026**	**0.122**	**1.0**	
Median		**33.37**	**0.14**	**0.017**	**0.154**	**1.0**	

Table 3.4 - Coastal background water quality data (2007-2016)

Sample Depth	‰	TON mg/l N	NH3 mg/l N	B.O.D. mg/l O2	DIN mg/l N	PO4 µg/l P
0	0.03	2.50	0.05	1.0	2.55	25
0	0.04	2.60	0.03	3.0	2.63	12
0	0.25	2.60	0.03	3.0	2.63	12
0	0.02	0.99	0.05	1.0	1.04	33
0	0.02	1.20	0.08	1.0	1.28	2.5
0	0.03	1.30	0.08	1.0	1.38	6
0	0.03	1.30	0.08	1.0	1.38	6
0	0.04	1.90	0.10	1.0	2	24
0	0.07	2.80	0.14	1.0	2.94	5
0	0.18	2.20	0.20	2.0	2.4	8.4
3	1.28	2.10	0.12		2.22	6.1
3	0.04	1.70	0.14	1.0	1.84	12
0	0.04	1.82	0.055	0.5	1.875	2.5
0	0.03	1.02	0.095	0.5	1.115	5
0	0.06	1.5	0.132	0.5	1.632	7
2.6	0.11	1.49	0.129	0.5	1.619	5
0	2.03	1.43	0.196	1.2	1.626	10
0	2.16	1.36	0.245	1.4	1.605	11
Average	**0.36**	**1.77**	**0.11**	**1.21**	**1.87**	**10.69**
Median	**0.04**	**1.60**	**0.10**	**1.00**	**1.74**	**7.70**

Table 3.5 - Avoca Estuary background water quality data (Station Av010) (2007-2016)

Clogga Beach			Brittas Bay South		
Date	e.coli/100ml	IE/100ml	Date	e.coli/100ml	IE/100ml
04/09/2017	98	35	04/09/2017	243	25
21/08/2017	160	92	21/08/2017	51	<10
14/08/2017	110	<10	14/08/2017	52	<10
31/07/2017	52	53	31/07/2017	10	10
17/07/2017	<10	<10	17/07/2017	41	<10
03/07/2017	10	<10	03/07/2017	10	<10
19/06/2017	10	<10	26/06/2017	63	13
12/06/2017	20	23	19/06/2017	<10	<10
22/05/2017	<10	10	12/06/2017	20	<10
05/09/2016	605	240	22/05/2017	<10	<10
22/08/2016	10	68	05/09/2016	20	<10
08/08/2016	187	20	22/08/2016	10	12
25/07/2016	122	20	08/08/2016	51	14
11/07/2016	122	73	25/07/2016	10	<10
04/07/2016	<10	<10	11/07/2016	183	53
27/06/2016	<10	<10	04/07/2016	20	<10
13/06/2016	20	<10	27/06/2016	<10	<10
30/05/2016	31	<10	20/06/2016	20	11

Table 3.6 - Clogga Beach and Brittas Bay South bacterial water quality data 2016-2017

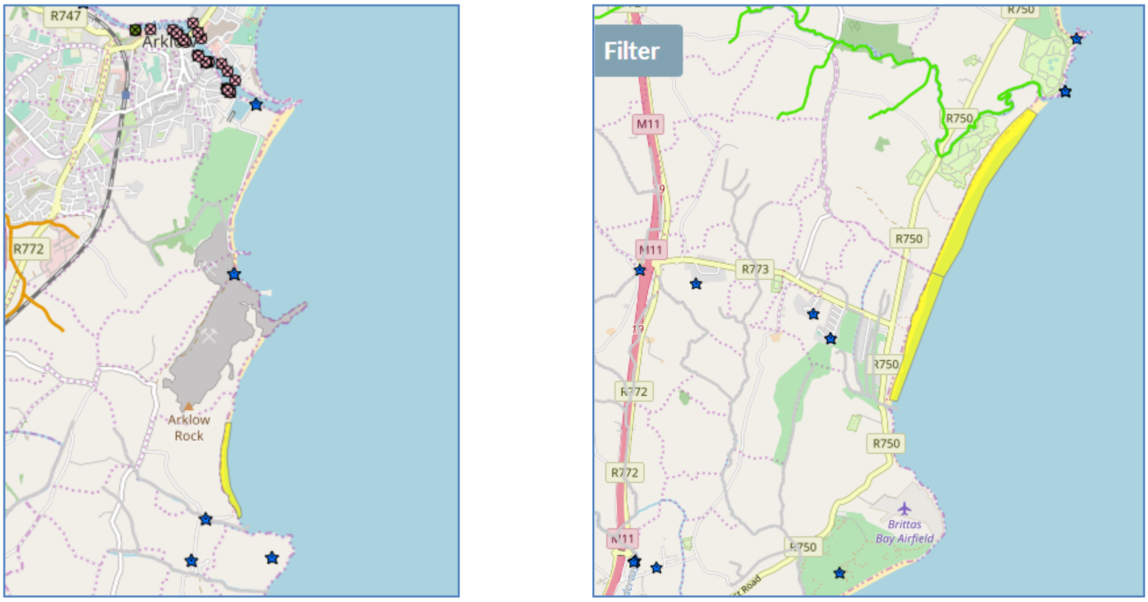


Figure 3.3 - Section 4 waste discharge locations (*) adjacent to Clogga and Brittas beaches

3.4 Proposed Outfall Location

Three potential offshore discharge locations were examined in the preliminary report, with associated outfall lengths of 400m, 650m and 900m. Only the furthest offshore discharge location (900m outfall) met all compliance requirements and is examined in this document. The discharge centre point coordinate is presented in Table 3.7. The proposed route is shown in Figure 3.4. The outfall length is measured from the low water mark and may change slightly as the starting point has not yet been established. A typical seabed profile through the area is shown in Figure 3.5. This compares depths from the 2016 GSI Infomar survey with those from the 1985 survey. There is an apparent increase in depth near the shoreline and a shoaling further offshore. These differences may be the result of a changing coastline or normal seasonal variations in bed profile.

The proposed storm overflow is located at the shoreline to the north of the proposed outfall route and is also indicated in Figure 3.4.

Pipe Length	ING Easting (m)	ING Northing (m)	Water Depth (m) OD Malin [2016 data]
900	326270	173350	10.6
SWO	325355	173240	Shoreline

Table 3.7 - Outfall discharge point coordinates

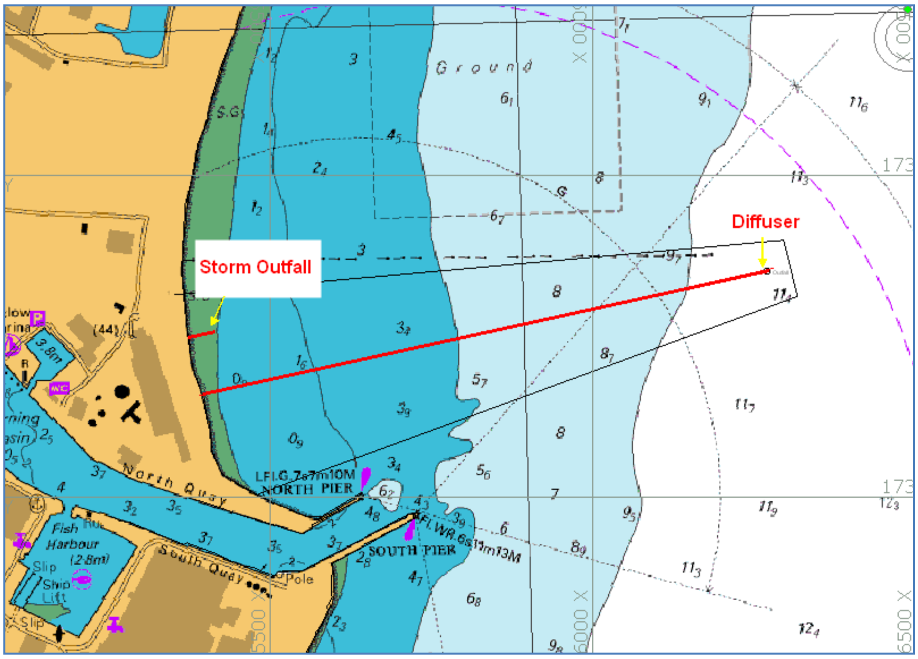


Figure 3.4 - Proposed outfall location at 900m offshore,

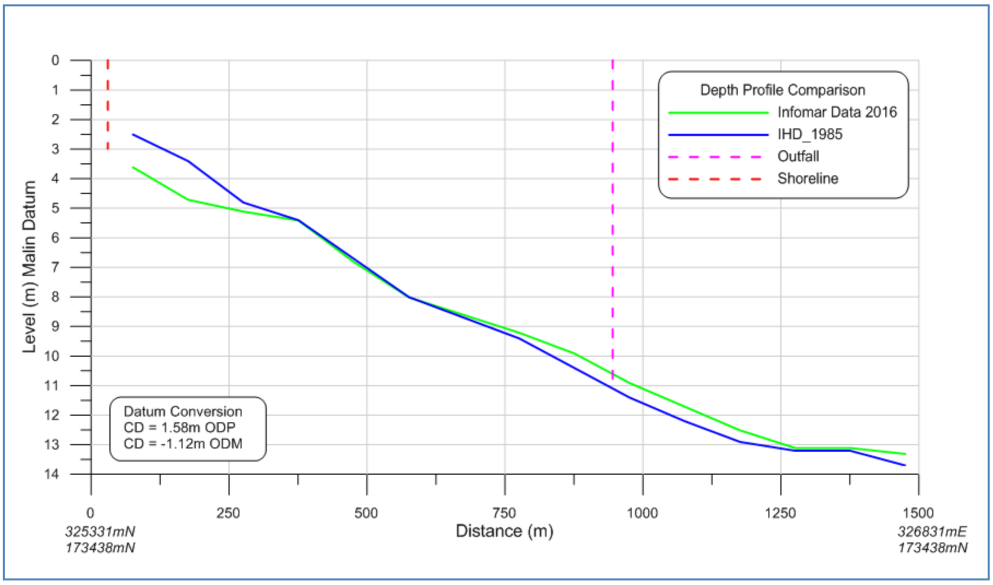


Figure 3.5 - Typical seabed profile through outfall corridor

3.5 WWTP Discharge Characteristics

The proposed WWTP will be constructed in two phases. Phase 1 has a design population equivalent (PE) of 18,000 while for Phase 2 it doubles to 36,000. The longer term PE is used in this study. The associated discharge dry weather flow (DWF) is 0.101m^3/s and the average daily flow is 0.127m^3/s.

The WWTP will provide secondary treatment as required under the Urban Wastewater Treatment Regulations 2001. Table 3.8 lists water quality standards that will be achieved in the final effluent. The design maximum values for the various parameters are conservatively set much higher than those typically expected from the plant during normal operation. The storm water outfall design standards are listed in Table 3.9.

Parameter	Abbreviation	Design Value Maximum
Population Equivalent	PE	36000
Dry Weather Flow	DWF	0.101 m^3/s
Average Daily Flow	ADF	0.127 m^3/s
Discharge Standards		
Biochemical Oxygen Demand	BOD	25mg/l
Chemical Oxygen Demand	COD	125mg/l
Suspended Solids	SS	35mg/l
Total Ammonia (as N)	TA	55mg/l
Total Oxidised Nitrogen (as N)	TON	5mg/l
Dissolved Inorganic Nitrogen (as N)	DIN	60mg/l
E.Coli	EC	1 x 10^6 cfu/100ml
Intestinal Enterococci	IE	2 x 10^5 cfu/100ml

Table 3.8 - Modelled flow rates and concentrations used in the impact assessment

Parameter	Design Value Maximum
Existing (1 hour event, 1 year return period)	1.13 m^3/s
Future (1 hour event, 1 year return period)	1.77 m^3/s
E.Coli concentration in storm waters	5 x 10^6 cfu/100ml

Table 3.9 - Modelled flow storm water discharge in the impact assessment

Target water quality values for coastal waters on the basis of various regulations were outlined in Table 3.2. Only three of these are of particular significance for the marine outfall. These are e.coli, IE and DIN. The relatively high levels of bacterial contamination in the treated effluent mean that e.coli and IE are usually the most critical parameters in outfall evaluation when bathing areas are located nearby. There are no standardised decay times for these two parameters as they vary substantially with environmental stress factors including ambient solar radiation, season and water clarity. Typically a conservative e.coli decay time of 12 hours and an IE decay time of 24 hours are used in the industry.

4. Marine Outfall Evaluation

4.1 Initial Dilutions at Outfall Discharge Location

An effluent plume discharging from a pipe near the seabed rises to the surface at a rate dependent on the momentum and buoyancy forces. Subsequently it goes through various stages until spreading by advection/diffusion processes are established. In the case of multiple plumes from a diffuser the individual plumes may interact and merge depending on the diffuser port spacing. Analyses of this initial mixing process and subsequent near-field dilutions were made with the IJP model (ref:11).

Calculations were based on a 6-port diffuser configuration (10m port spacing) and a range of current speeds. The speed data is based on the current meter exceedance profile shown previously in Figure 2.11. Table 4.1 presents the calculated dilutions and associated displacement of the surfaced plume centroid from the discharge location. The calculations are made for representative speeds and the associated water depths. In the real world scenario these speeds and all in-between will occur twice each tidal cycle, on the flood and on the ebb. The calculations show that the 900m long outfall will comfortably meet the minimum 95%'ile initial dilution target of 50 considered necessary to eliminate any localised surface sheens, slicks or odours (ref:12).

Current Speed	Dilution at plume surfacing location	Water depth (m) at diffuser	Surfaced plume displacement (m) from diffuser
Slack Water = 0.0 m/s	50	MLWS = 10.1m	0
95%'ile = 0.05 m/s	88	10.1m	8
50%'ile = 0.26 m/s	290	10.4m	40
10%'ile = 0.43 m/s	440	Mid Tide = 10.6m	70

Table 4.1 - Predicted initial dilutions and plume displacements (ADF = 127 l/s, 6 ports, port diameter = 0.16m, port spacing = 10m).

The predicted initial dilution estimates have been used to calculate the near-field concentration of the parameters BOD, COD, SS, TA, DIN, e.coli and IE. The background coastal water concentrations where available have been taken from the EPA data presented in Table 3.2. The results for the three representative moving water conditions are presented in Tables 4.2 to 4.4. The low speed 95%ile results are shown in Table 4.2 and indicate that for DIN a relatively small amount of additional mid-field dilution will bring these parameters below the target water quality levels outlined in Table 3.4. The e.coli and IE concentrations are higher and additional significant dilutions will be required to reach the Bathing Water targets in Table 3.5. The BOD, COD and SS concentrations will be close to background levels.

At the higher speeds, Tables 4.3 & 4.4, with greater dilutions available model predictions show that less far-field dilution is required.

Parameter	Treated Effluent Concentration	Background Concentration	Concentration in surfaced plume after initial dilution	Target Level
BOD (mg/l O2)	25	1.0	1.27	-
COD (mg/l O2)	125	2**	3.49	-
SS (mg/l)	35	2**	2.37	-
Total Ammonia (mg/l N)	55	0.017	0.635	-
DIN (mg/l N)	60	0.154	0.826	0.17
E.Coli cfu/100ml	1×10^6	25	11261	250
IE cfu/100ml	2×10^5	15	2262	100

Table 4.2 - Surfacing plume contaminant concentrations for 95%'ile current = 0.05m/s and initial dilution = 88, ** assumed value, no data or limited data

Parameter	Treated Effluent Concentration	Background Concentration	Concentration in surfaced plume after initial dilution	Target Level
BOD (mg/l O2)	25	1.0	1.08	-
COD (mg/l O2)	135	2**	2.46	-
SS (mg/l)	35	2**	2.11	-
Total Ammonia (mg/l N)	55	0.017	0.206	-
DIN (mg/l N)	60	0.154	0.360	0.17
E.Coli cfu/100ml	1×10^6	25	3461	250
IE cfu/100ml	2×10^5	15	702	100

Table 4.3 - Surfacing plume contaminant concentrations for 50%'ile current = 0.26m/s and initial dilution = 290

Parameter	Treated Effluent Concentration	Background Concentration	Concentration in surfaced plume after initial dilution	Target Level
BOD (mg/l O2)	25	1.0	1.05	-
COD (mg/l O2)	135	2**	2.30	-
SS (mg/l)	35	2**	2.07	-
Total Ammonia (mg/l N)	55	0.017	0.142	-
DIN (mg/l N)	60	0.154	0.290	0.17
E.Coli cfu/100ml	1×10^6	25	2293	250
IE cfu/100ml	2×10^5	15	468	100

Table 4.4 - Surfacing plume contaminant concentrations for 10%'ile current = 0.43m/s and initial dilution = 440

4.2 Water Circulation Modelling

Preparation

Tidal circulation in the coastal waters off Arklow was investigated with a 2-dimensional numerical model M2D (ref:13). The model is a general purpose modelling package for simulating flow and transport in surface water systems. The model has been used in various forms for previous studies on the Arklow outfall (ref:6,7).

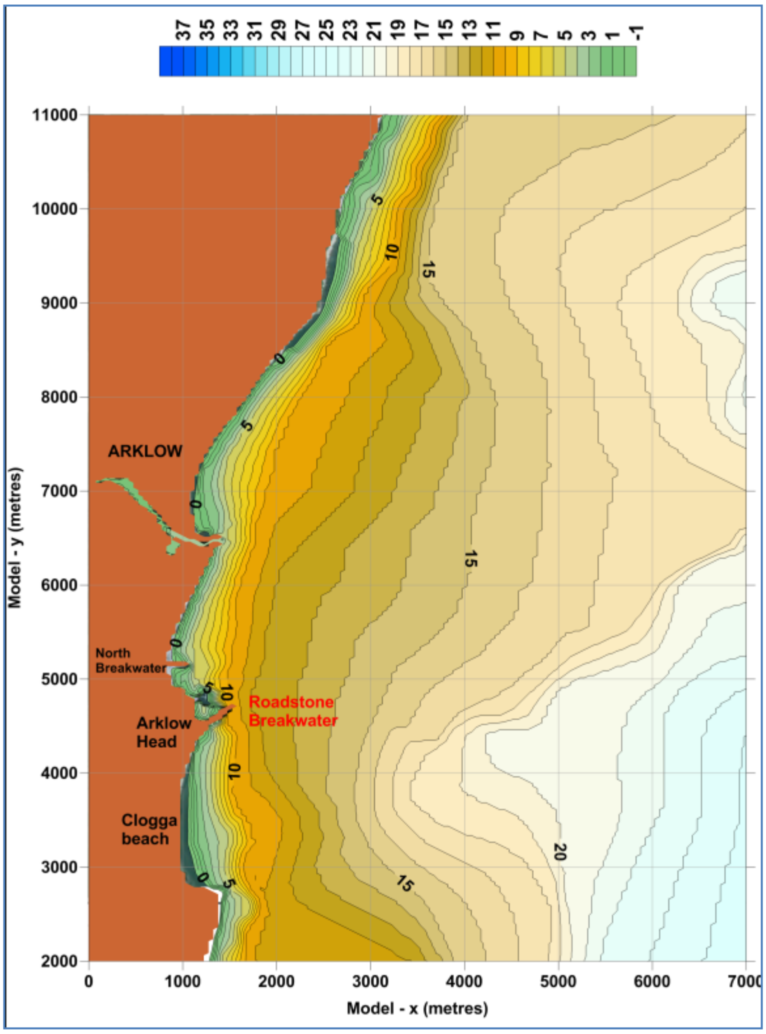


Figure 4.1 - Central part of model spatial grid (overall extent 17km N-S, 8km E-W)

The circulation model employed a 50 x 25m rectangular cell grid centred on Arklow. Bathymetry was derived from various sources including GSI Infomar data, local echo-sounding surveys and was augmented by Admiralty Chart data as required (Chart No. 1787, Figure 2.1a).

The central part of the spatial grid is shown in Figure 4.1. The full grid extends 17km north-south and 7km offshore. The model was used to simulate water movements during the typical spring-neap tidal cycle for the ranges outlined in Table 2.1.

Calibration and Verification

The model was calibrated with tidal elevation, current meter, drogue and dye track data taken from the surveys in 1985, 1996, 2005 and 2017 (ref:5,6,7). Model runs with typical coefficient settings were found to reproduce the observed tidal elevations to an acceptable level. Simulated current speeds and drogue tracks closely resembled measured data. The flow patterns are predominately driven by the bathymetry and vectors are parallel to the shoreline. Example plots are shown in Figures 4.2 and 4.3.

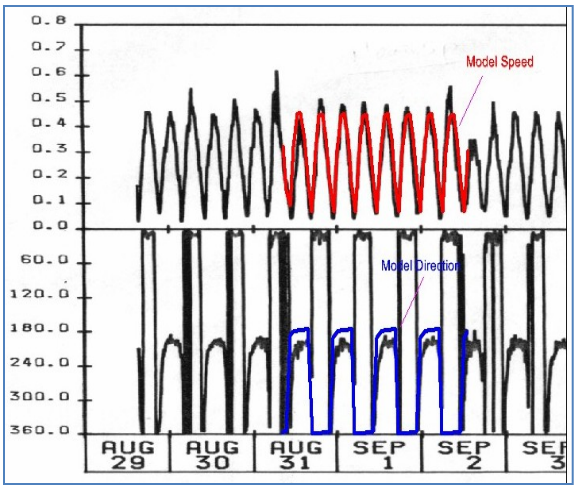


Figure 4.2 - Comparison of modelled and measured currents.

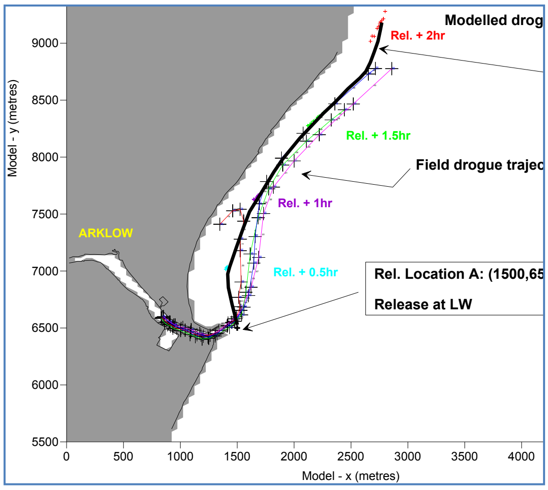


Figure 4.3 - Comparison of modelled and measured drogue trajectories

4.3 Contaminant Dispersion Simulations

The contaminant dispersion model LAG (ref:14) was used to simulate the mid and far-field dispersion of outfall discharges. This model is driven by the flow fields generated by M2D.

Four scenarios were examined with the model. These were:

a. *The existing scenario with untreated discharges to Avoca estuary;*
b. *The proposed 900m outfall;*
c. *The proposed storm water overflow.*

The outfall contaminants of particular interest are e.coli and IE due to the proximity of the Bathing Waters and DIN as the outfall is located in Coastal Waters. Dissolved oxygen is not modelled but the level of oxygenation in the waterbody is reflected by BOD simulations. Model output was generated in a variety of formats including plume and tabular data for specified regions in the model area to facilitate before (existing) and after (new 900m outfall) comparisons.

The specific requirements of the various regulations listed in Tables 3.2 & 3.3 frame compliance in terms of occurrences at either the 95%ile or 50%ile level. The required percentile plots were generated by simulating a full spring-neap tidal cycle and computing percentile occurrences at each model cell. These were computed for the calm weather scenario which would produce the most concentrated plume.

a. Simulation of the Existing Discharge Scenario

The existing outfalls discharge at multiple locations within the estuary. Simulations of the four main discharge points, shown in Figure 4.4, indicate that all harbour areas are bacterially contaminated. Wastewaters are buoyant and thus rise to the surface where they are carried by the river waters out of the harbour. For the main coastal analysis the discharges are therefore assumed to be located at the harbour mouth. Additionally the Avoca flow is assumed to be relatively low so that there is no beneficial momentum from the river plume which would carry the wastewaters further offshore. The parameters used in the simulation are listed in Table 4.5. The bacterial contaminant concentrations used are typical conservative values for untreated effluent. Flow data, BOD and DIN concentration values are taken from the 2017 flow and load survey (ref: 15).

Examples of the modelled neap tide e.coli and IE plumes are shown in Figure 4.5 and 4.6. The plume travels to the north on the flood and to the south on the ebb. The plots show that the existing discharges can significantly impact the bathing areas to the north and south of the harbour mouth and can also reach Clogga beach to the south. The corresponding spring tides produce larger excursions and hence lower local concentrations.

Assessment of the overall existing situation in terms of 95%ile compliance with the Bathing Water regulations is presented in Figure 4.7. This indicates that apart from the region very close to the shoreline the bacterial concentrations are above the guideline targets. The predicted 95%ile concentration in the main bathing areas at the locations shown in Figure 4.8 are summarised in Table 4.6.

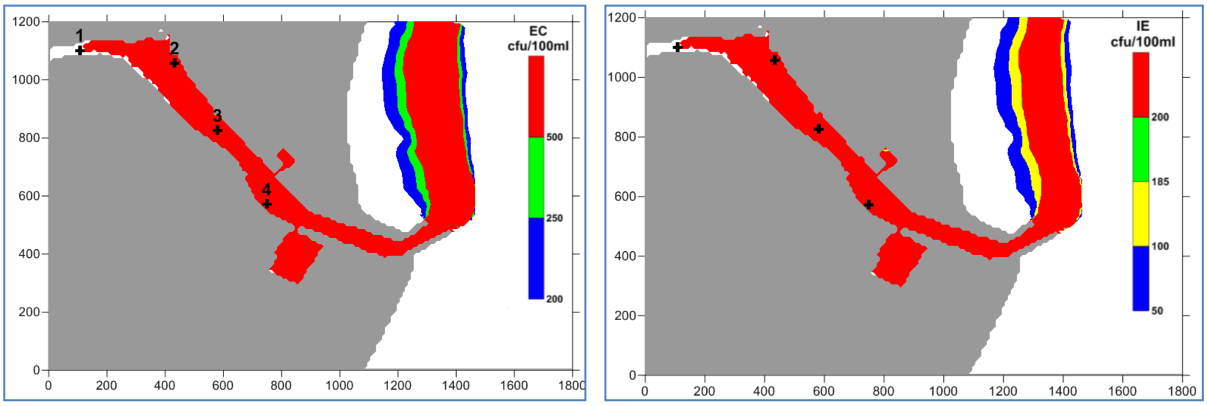
Simulations of DIN and BOD are presented in Figures 4.9a-b both with and without the contributions from the Avoca. A river discharge of $9m^3/s$, was used as representative of typical conditions. The simulations show that existing discharges raise the local nearshore DIN levels to the north and south of the harbour mouth, Figure 4.9a. The river is a significant source of DIN and the combined concentrations are significantly higher, Figure 4.9b. The BOD levels are not significantly altered and remain below 2mg/l everywhere.

Parameter	Wastewater Imput	River Input	Coastal Background
Flow	$0.03m^3/s$	$9\ m^3/s$	
E.Coli	1×10^7 cfu/100ml	0	0
Intestinal Enterococci	2×10^6 cfu/100ml	0	0
BOD	150	1.5 mg/l	1.0 mg/l
DIN	70	1.5 mg/l N	0.154 mg/l N

Table 4.5 - Discharge parameters used in the existing scenario assessment

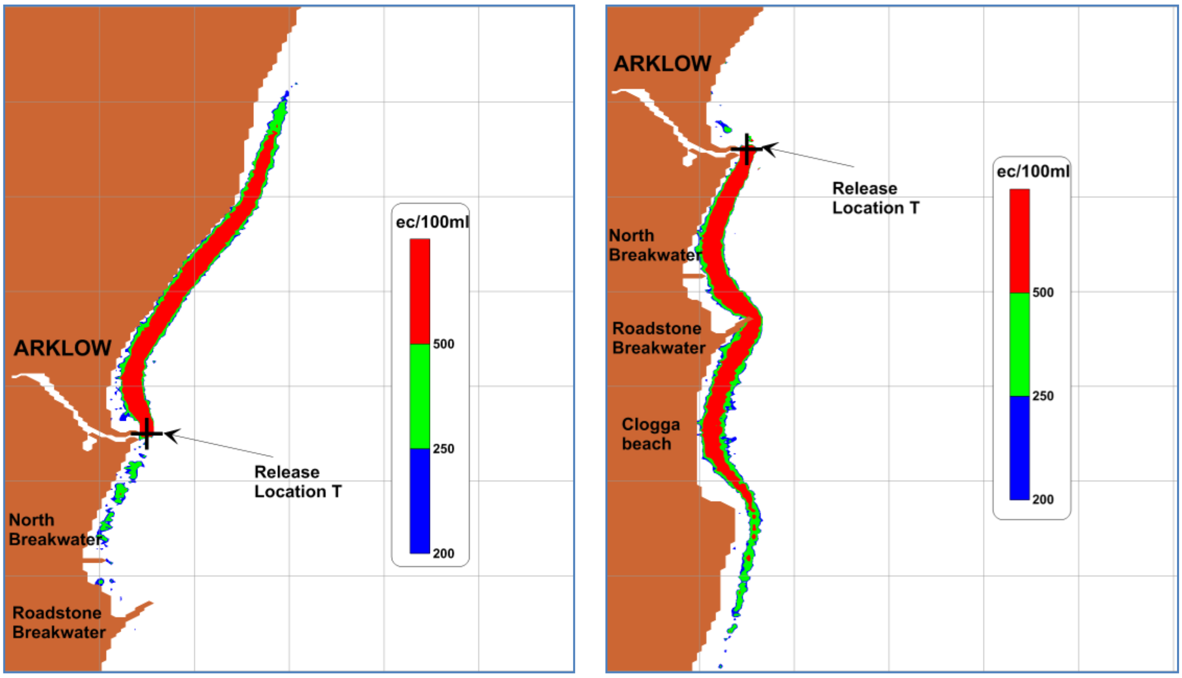
	Model Location				
	Clogga Beach	South Beach	North Beach 1	North Beach 2	Brittas South
	E.coli (cfu/100ml)				
Calm	350	900	320	280	<5
	Intestinal Enterococci (cfu/100ml)				
Calm	130	360	160	160	<5

Table 4.6 - Predicted 95%ile bacterial concentrations at bathing areas



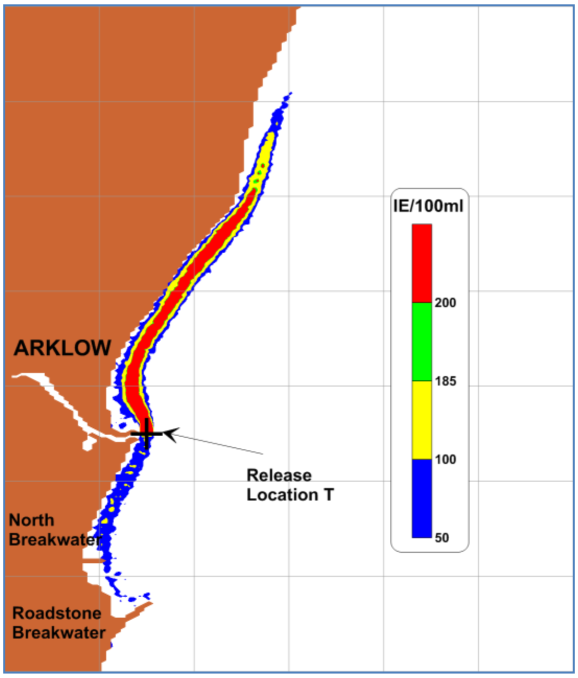
E.coli IE

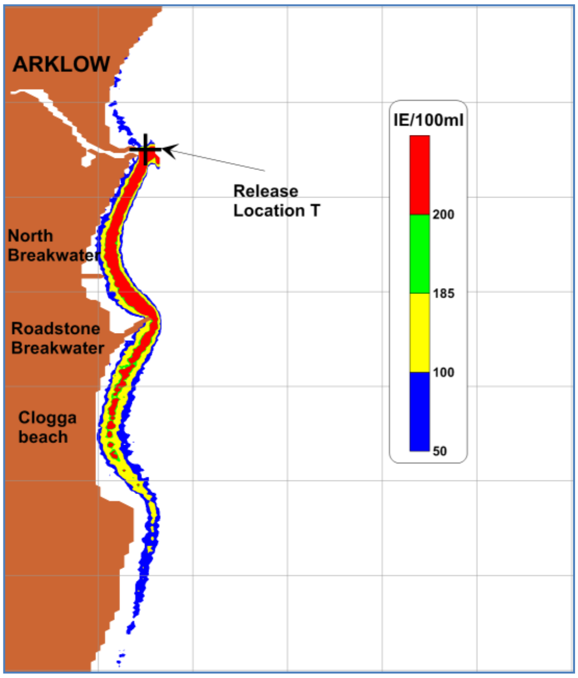
Figure 4.4 - Existing Scenario - simulated harbour concentrations



Max Flood Max Ebb

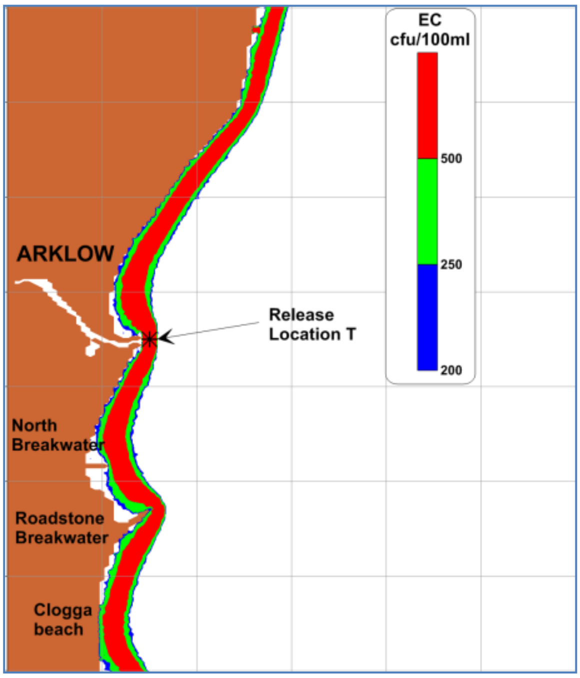
Figure 4.5 - Existing Scenario - simulated E.Coli plume concentrations during neap tides





Max Flood **Max Ebb**

Figure 4.6 - Existing Scenario - simulated IE concentrations during neap tides

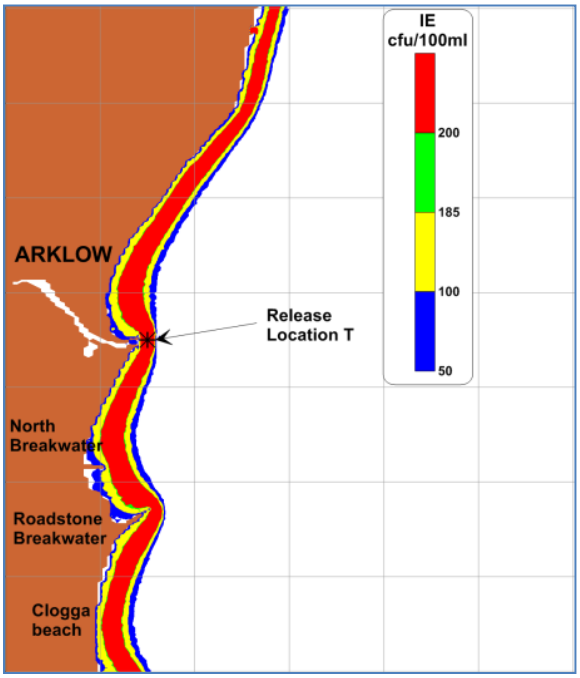


95%ile e.coli

Colour bands represent Bathing Water regulation categories of:

Excellent Quality<250 cfu/100ml (95%ile) &

Good Quality<500 cfu/100ml (95%ile)



95%ile I.E.

Colour bands represent Bathing Water regulation categories of:

Excellent Quality<100 cfu/100ml (95%ile).

Good Quality<200 cfu/100ml (95%ile)

Sufficient Quality <185 cfu/100ml (90%ile)

Figure 4.7 - Simulated 95%ile bacterial concentration for discharges from the existing outfall locations

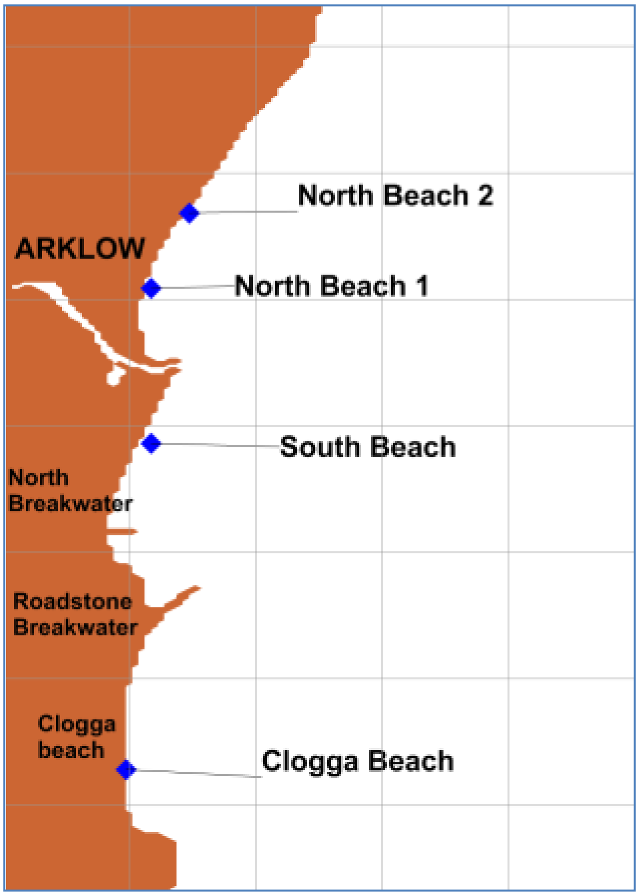
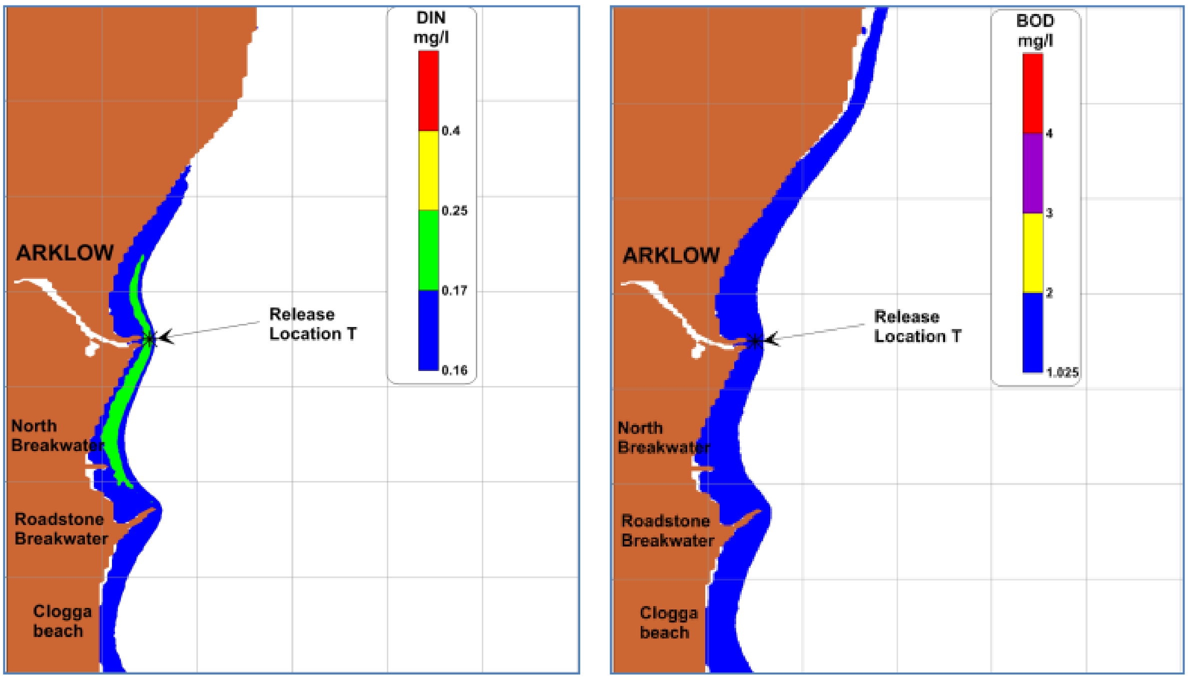
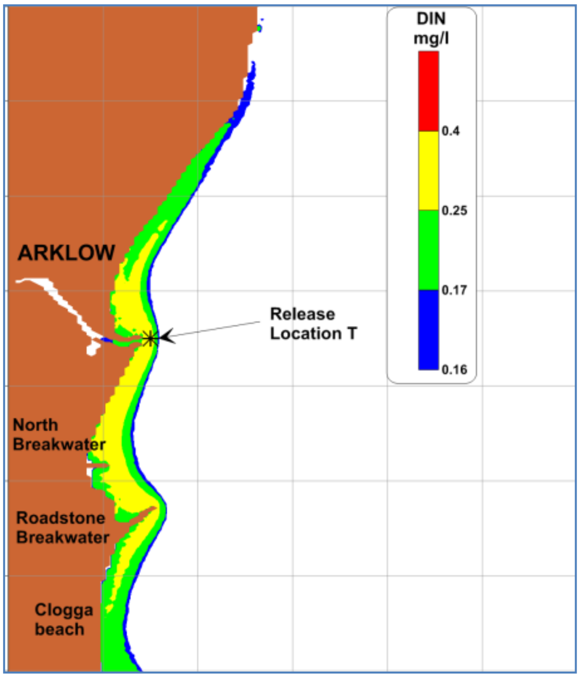


Figure 4.8 - Location of 95%ile model data presented in Table 4.6

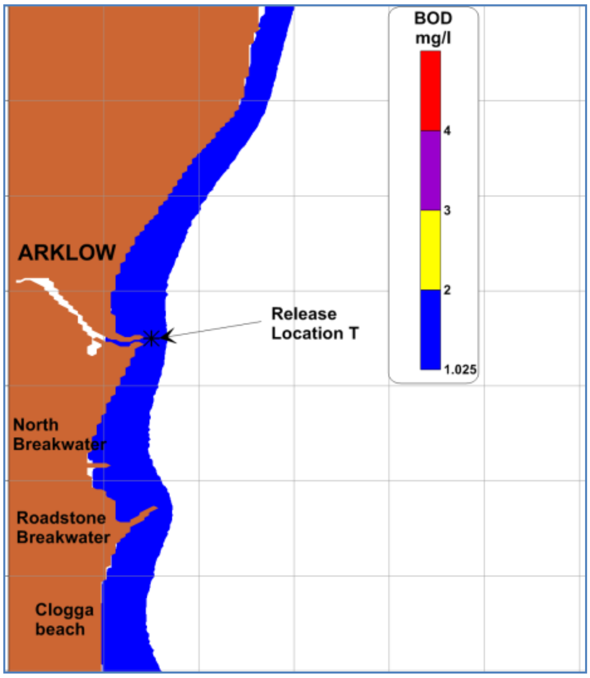


50%ile DIN 95%ile BOD

Figure 4.9a - Simulated percentile concentration for discharges from the existing outfall locations showing wastewater sources only



50%ile DIN



95%ile BOD

Figure 4.9b - Simulated percentile concentration for discharges from the existing outfall locations showing wastewater and Avoca river contributions

b. Simulation of the proposed 900m outfall

Model simulations of the proposed 900m outfall were conducted for a range of conditions. These included both spring and neap tides for calm and windy conditions and for a full spring-neap cycle. Concentration plots were generated to show the trajectory of the plume and its extent at various stages of the tide. Bacterial plots are the most illustrative due to the high concentrations of e.coli and IE in the discharge.

During spring tide calm conditions the e.coli plume remains narrow and travels north and south parallel to the shoreline as shown by Figure 4.10. The trajectories are similar to the drogue and dye data presented previously in Section 2. Areas of highest concentration are generally observed closest to the outfall. The neap tide plume, Figure 4.11, is more concentrated and travels less as a result of the weaker current speeds. An area of high concentration at the maximum excursion of the neap tide plume (Figure 4.11) is the result of a localised build-up that occurs immediately above the outfall diffuser around slack water. Introducing the effects of wind into the simulation by means of enhanced mixing (Figure 4.12 & 4.13) produces a more dispersed plume.

Concentration plots for the IE plumes during calm conditions are shown in Figures 4.14 & 4.15. They follow the same trajectories as those of the e.coli due to the same underlying hydrodynamics. Differences are due to a longer decay time and lower source concentrations. The plume is narrower and less pronounced than the corresponding e.coli plots. During windy conditions (Figure 4.16 & 4.17) the plume is more dispersed.

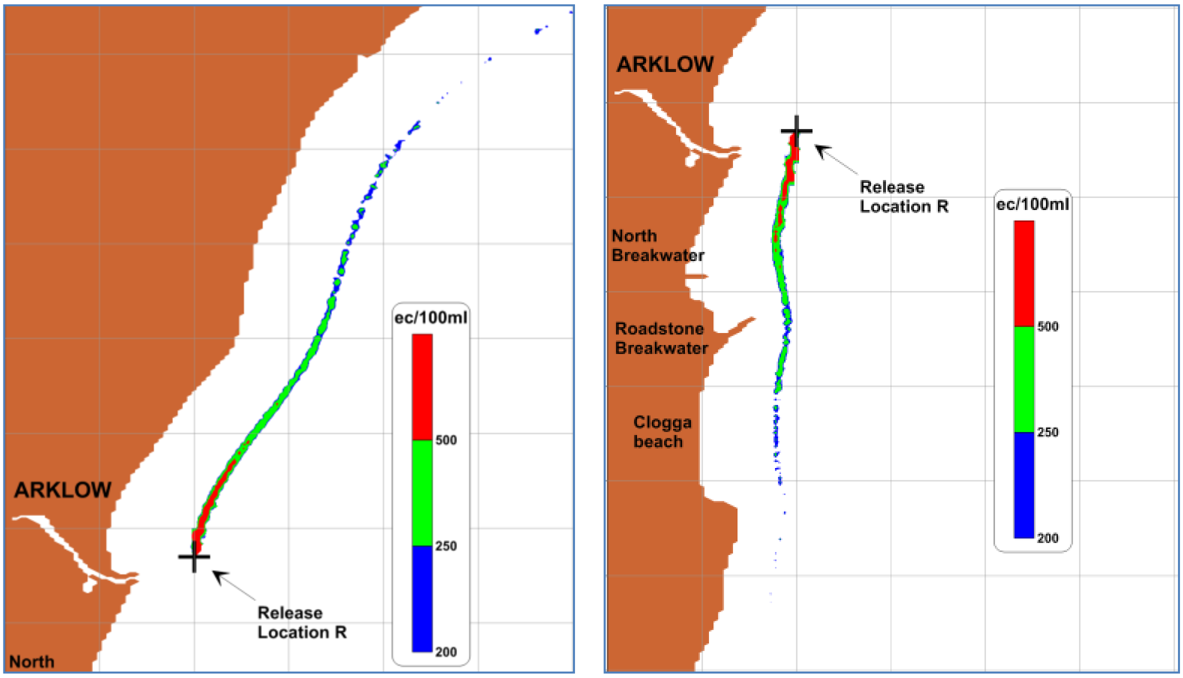
Assessment of the overall existing situation in terms of 95%ile compliance with the bathing water regulations is presented in Figure 4.18. The region of consistently elevated concentrations follows the axis of the plume and remains well offshore. The bacterial concentrations at all of the identified bathing areas listed in Table 4.7 are below the model resolution of 5cfu/100ml and well within the target 'Excellent' e.coli category limit of 250 cfu/100ml and the IE limit of 100 cfu/100ml.

The DIN and BOD plumes from the outfall follow the same trajectories as indicated for e.coli in Figure 4.10. The associated concentrations are very low as once the plume has surfaced from the diffuser only a small amount of additional dilution is required to reduce levels to near background. The impact of these parameters is summarised in the percentile plots presented in Figure 4.19. The DIN mixing zone envelope (High Status, 0.17mg/l) is calculated to extend 200m to the north of the proposed outfall on the flood tide and about 100m to the south on the ebb. It will have an overall width of about 40m. This envelope represents the potential zone of influence of the plume for all stages of the tide.

The predicted BOD levels in the vicinity of the outfall are small and remain very close to the background.

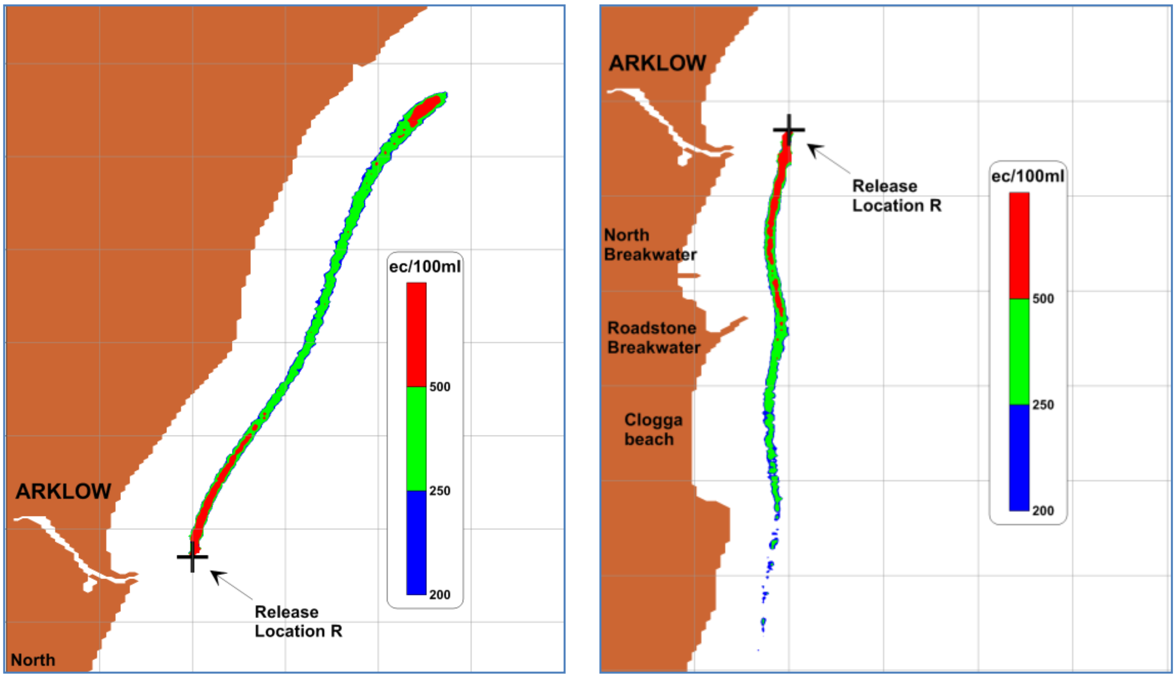
	Model Location				
	Clogga Beach	South Beach	North Beach 1	North Beach 2	Brittas South
	E.coli (cfu/100ml)				
Calm	<5	<5	<5	<5	<5
	Intestinal Enterococci (cfu/100ml)				
Calm	<5	<5	<5	<5	<5

Table 4.7 - Predicted 95%ile bacterial concentrations arising from the 900m outfall



Max Flood Max Ebb

Figure 4.10 - Simulated e.coli plume during SPRING tides and CALM conditions



Max Flood Max Ebb

Figure 4.11 - Simulated e.coli plume during NEAP tides and CALM conditions

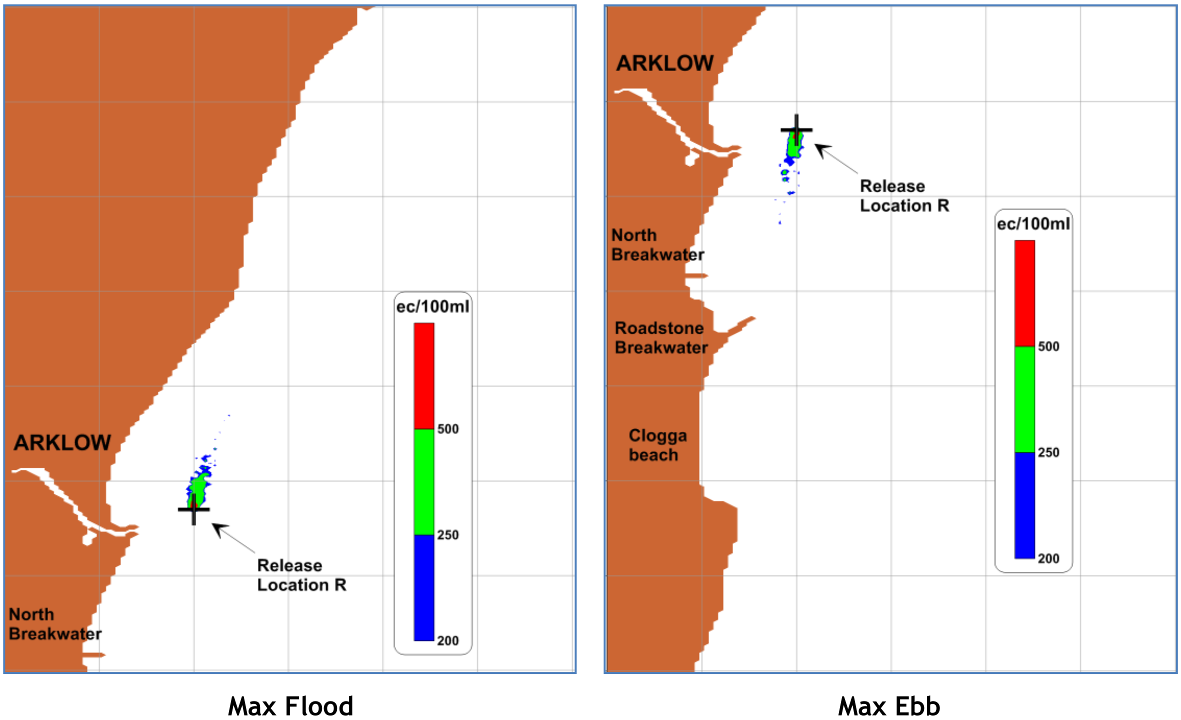


Figure 4.12 - Simulated e.coli plume during SPRING tides and WINDY conditions.

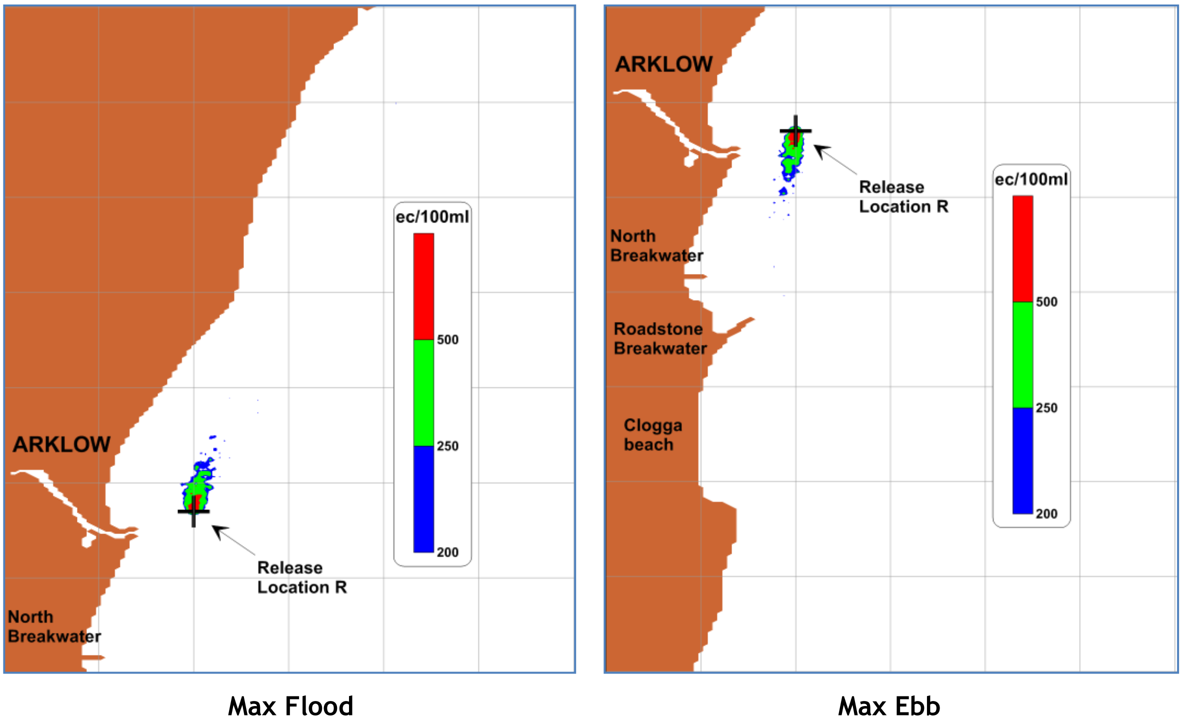
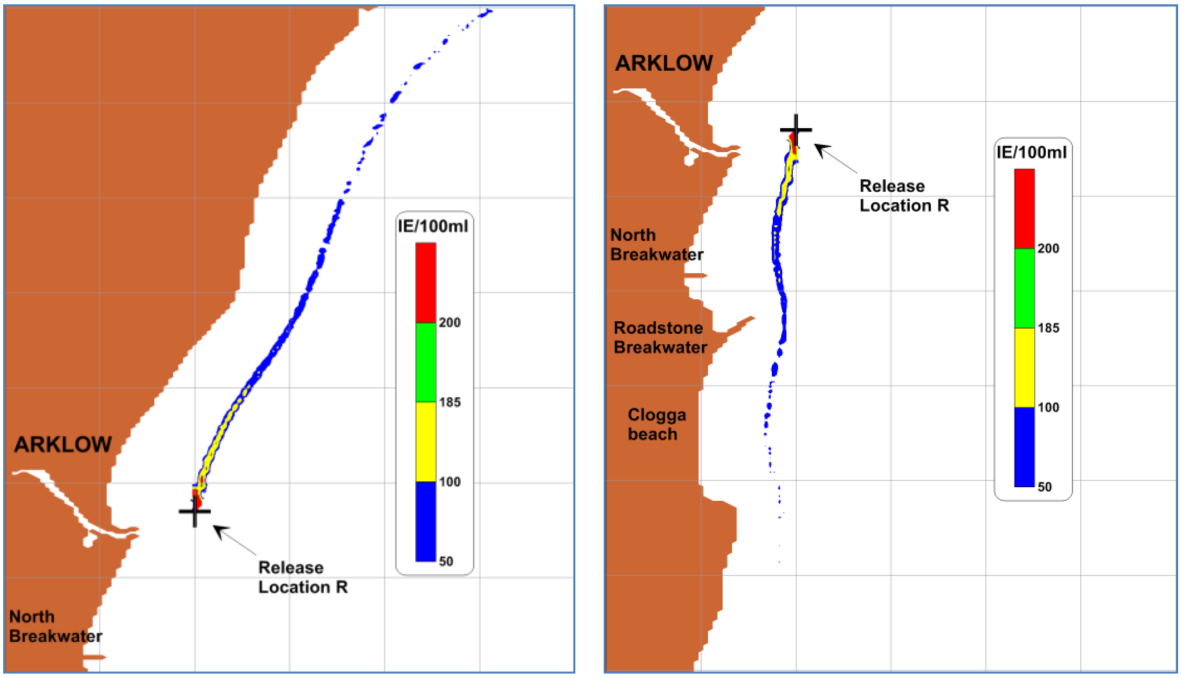
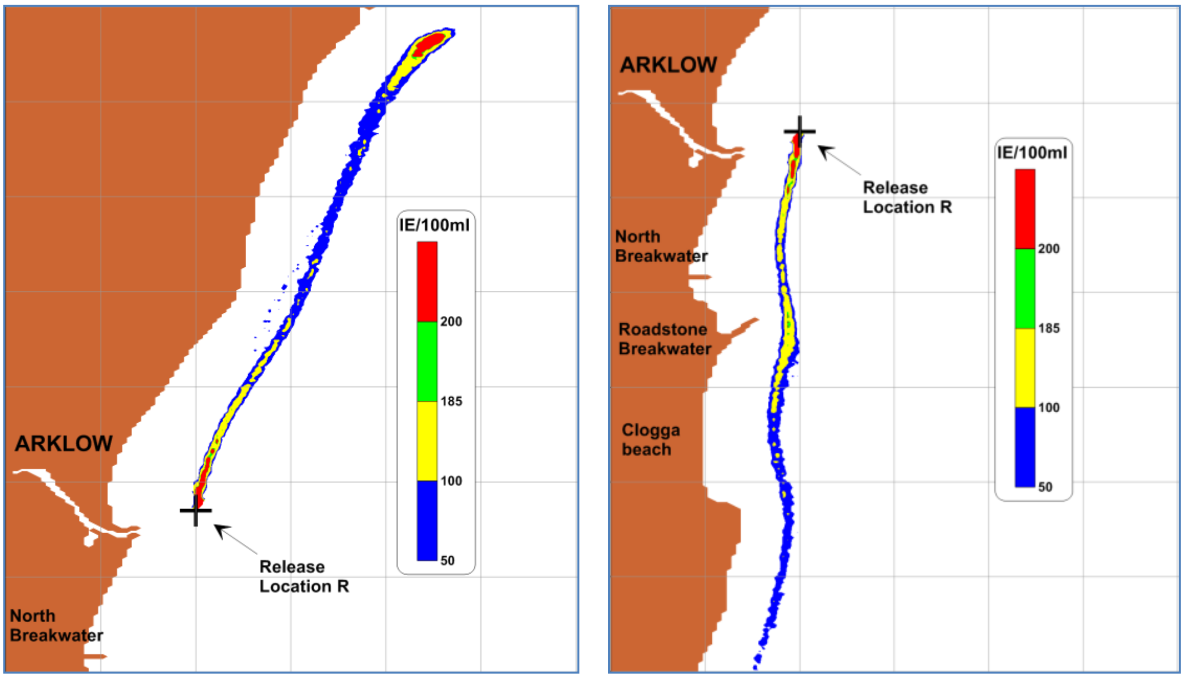


Figure 4.13 - Simulated e.coli plume during NEAP tides and WINDY conditions.



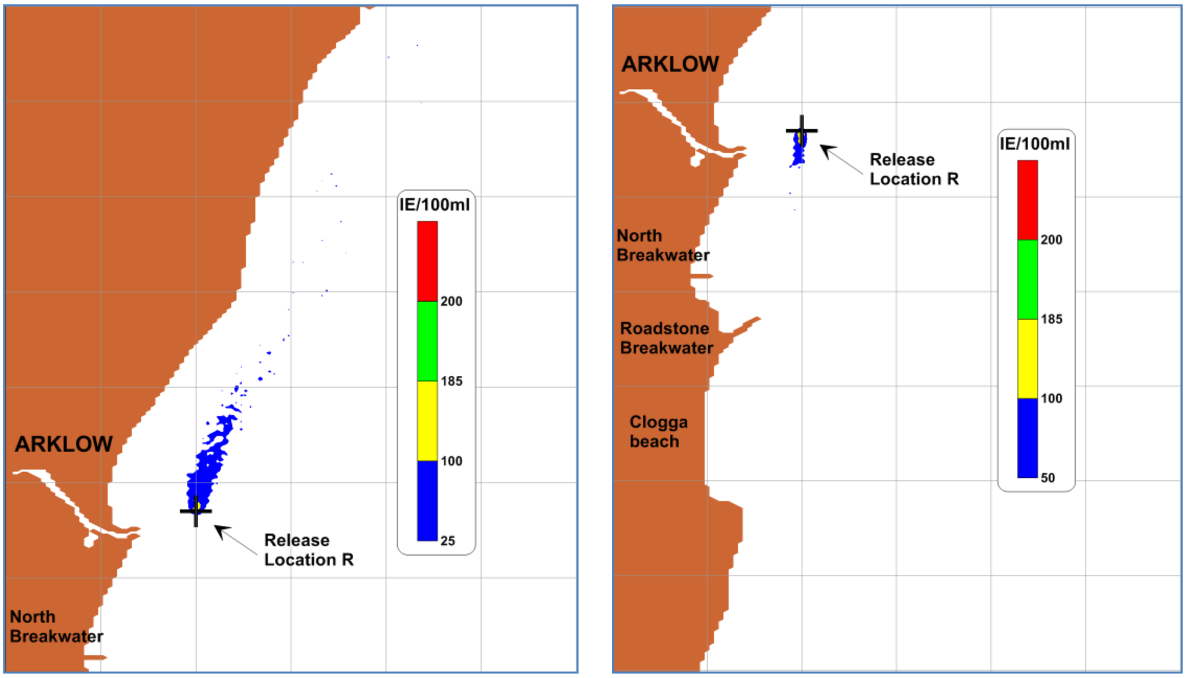
Max Flood Max Ebb

Figure 4.14 - Simulated IE plume during spring tides and calm conditions



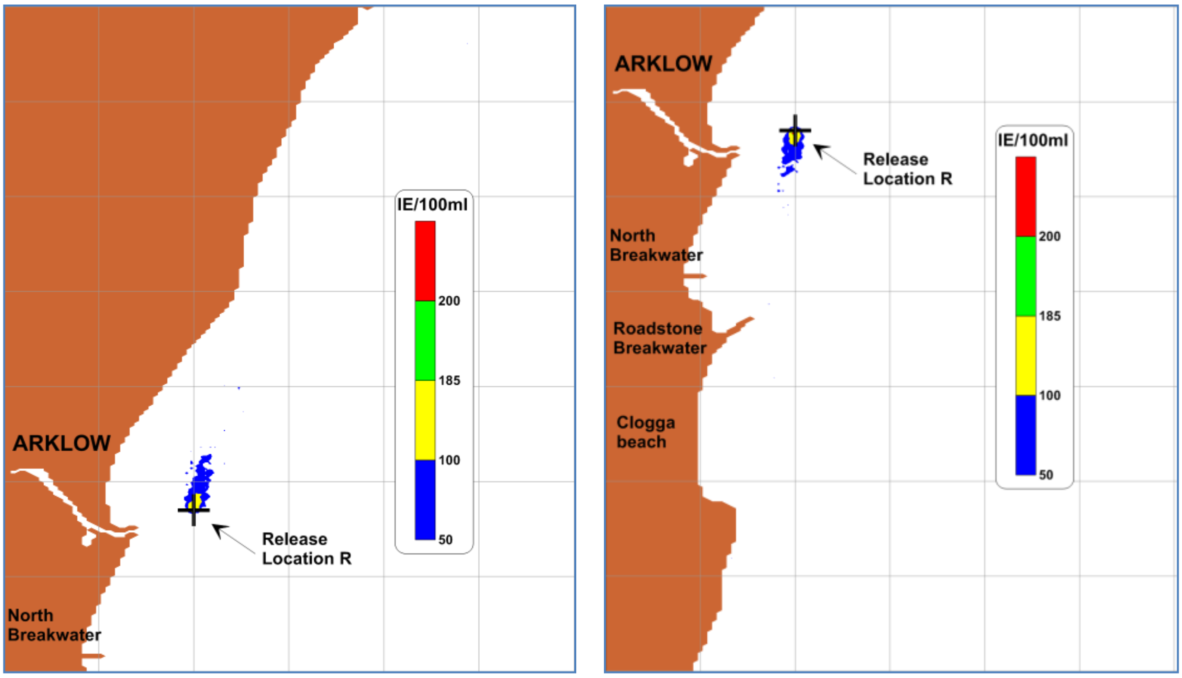
Max Flood Max Ebb

Figure 4.15 - Simulated IE plume during neap tides and calm conditions



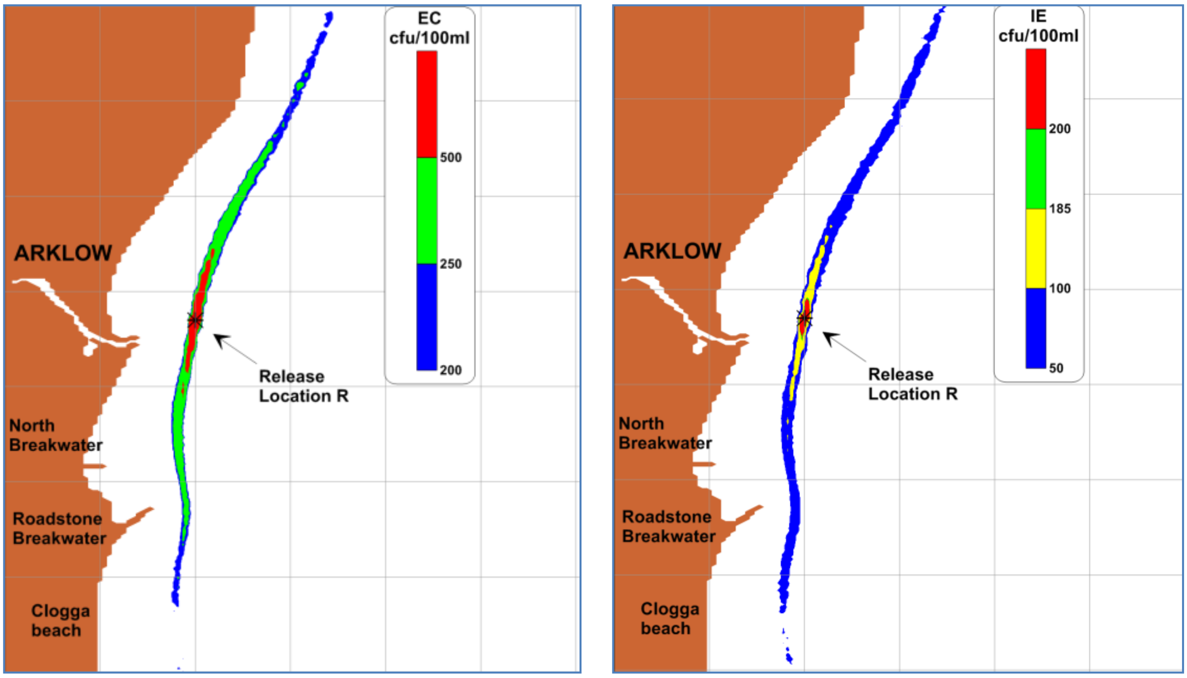
Max Flood Max Ebb

Figure 4.16 - Simulated IE plume during spring tides and windy conditions.



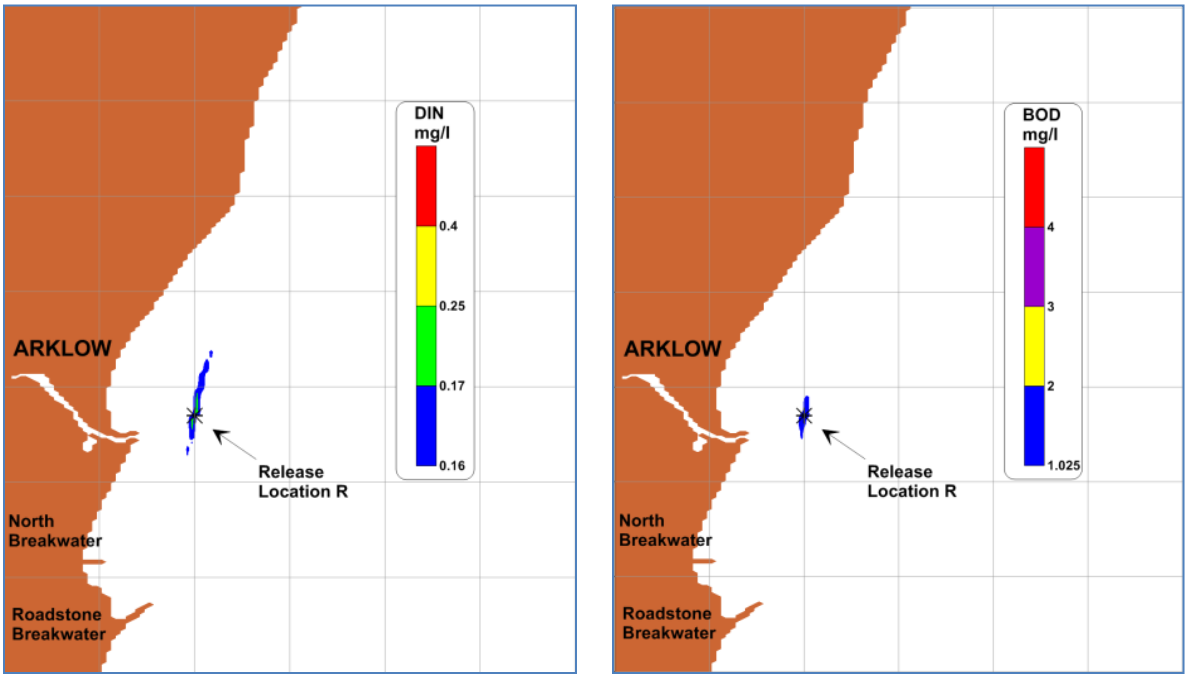
Max Flood Max Ebb

Figure 4.17 - Simulated IE plume during neap tides and windy conditions.



95%ile e.coli 95%ile I.E.

Figure 4.18 - Simulated 95%ile concentration for discharges from the 900m outfall location



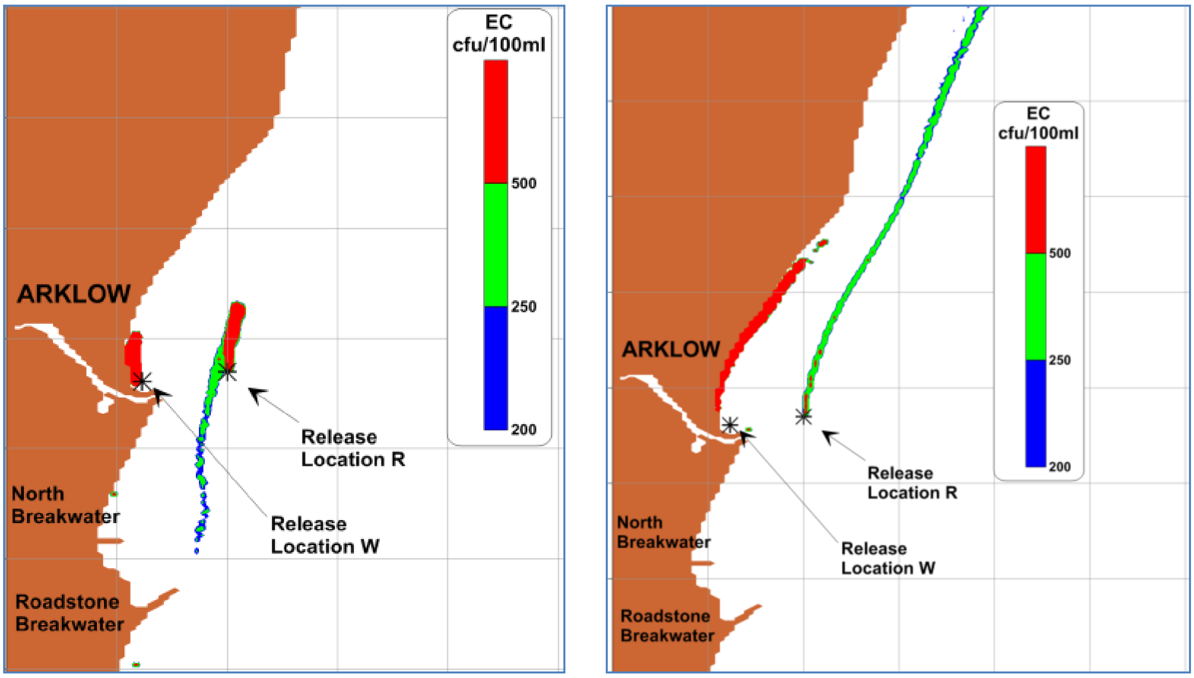
50%ile DIN 95%ile BOD

Figure 4.19 - Simulated percentile concentration for discharges from the 900m outfall

c. Storm water discharges

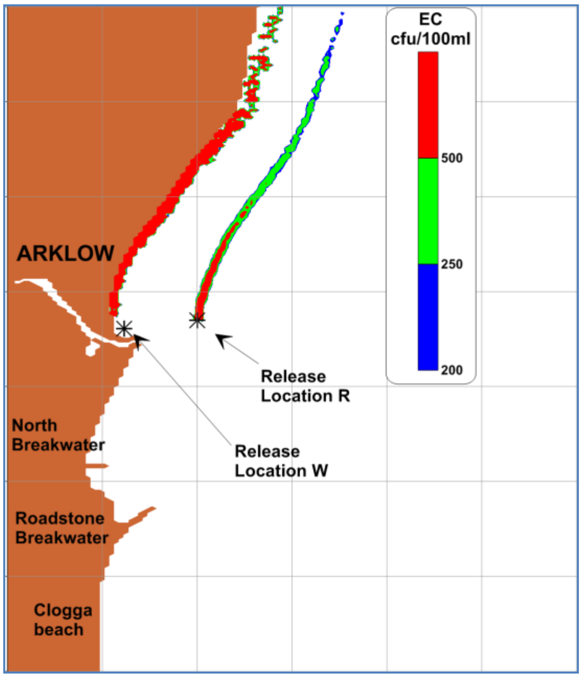
The proposed storm water outfall (SWO) is to be located to the north of the proposed outfall (Figure 3.4). Overflow discharges will only occur during exceptional rainfall events.

Model simulations of a short-term discharge (1 hour) with flows corresponding to the 1-year event were conducted for e.coli. The predictions are presented in Figure 4.20a-f and show the progress of the storm water plume as it disperses over time. The main outfall plume is also included. The overflow release was timed to coincide with the flooding tide and is illustrative of the many other possible times over the tidal cycle. The simulations show high levels of bacterial concentration in the shoreline area for over 15 hours. The e.coli levels on Clogga beach and the bathing area to the north and south of the harbour will be impacted and be above the bathing water targets for a period of up to about 24 hours after the event.

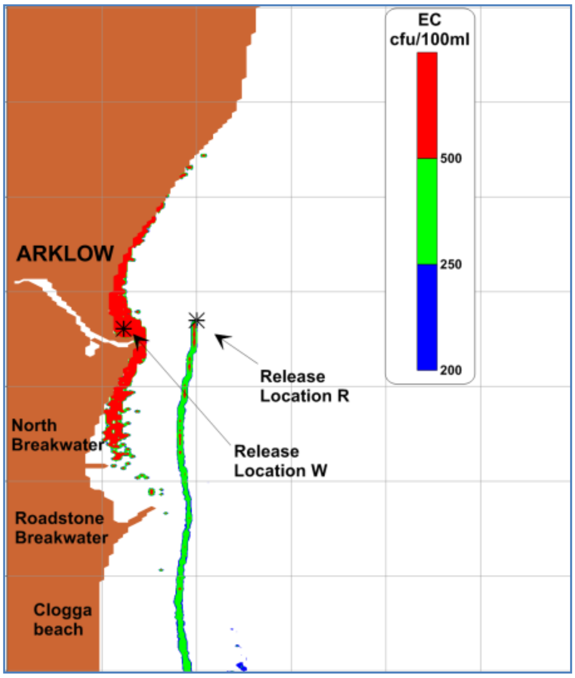


a. e.coli plume HW+1h b. e.coli plume HW+3h

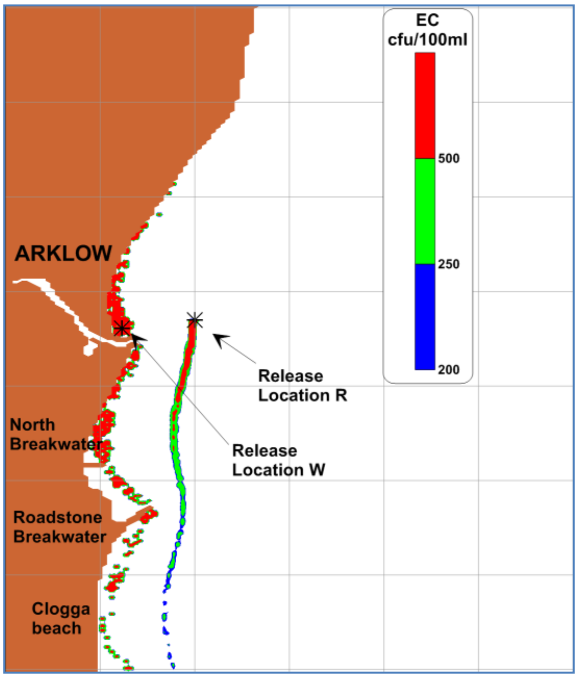
Figure 4.20a-b - Storm water outfall simulation



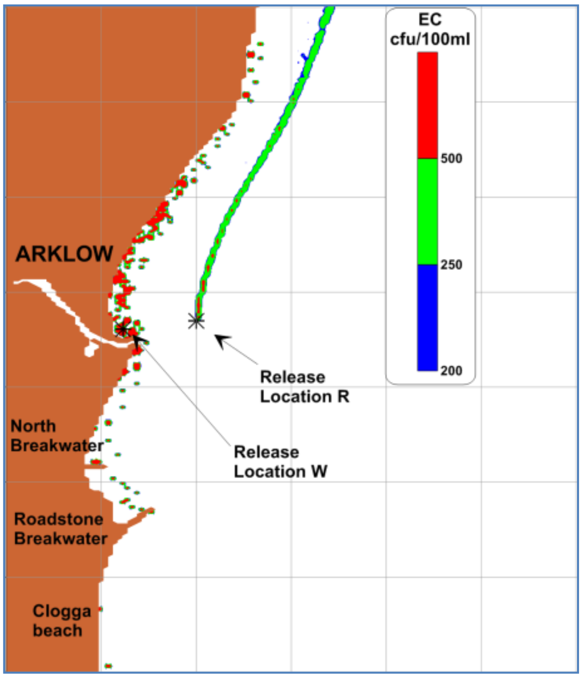
c. e.coli plume HW+6h



d. e.coli plume HW+9h



e. e.coli plume HW+12



f. e.coli plume HW+15

Figure 4.20c-f - Storm Water Overflows

5. Conclusions

An assessment of the impact of wastewater discharges from the proposed Arklow outfall has been conducted. The study was based on numerical modelling supported by field measurements. The proposed outfall discharge point is located 900m off the North Beach and to the north east of the harbour mouth. The outfall will comprise a diffuser section incorporating six ports each 10m apart.

A well defined local current regime and favourable water depths ensure that the 95%'ile initial dilution available at the outfall location will exceed a factor of 88. This is well above the minimum value of 50 recommended to eliminate local surface slicks and odours. The DIN, BOD, COD, SS and TA concentrations will all be reduced to near background levels in the immediate vicinity of the outfall. Analysis of the wider coastal area with a 2-dimensional numerical model shows that significant additional dilutions are available away from the immediate discharge location.

The proposed outfall discharges into a Coastal waterbody as defined under the Water Framework Directive. Therefore a key objective as per the Surface Water Regulations (SI 272/2009) is to establish a mixing zone. The relevant controlling parameter for coastal waters is the dissolved inorganic nitrogen (DIN) nutrient concentration. The proposed discharge has a maximum design DIN concentration of 60mg/l N and the mixing zone envelope (High Status, 0.17mg/l) is calculated to extend 200m to the north from the proposed outfall on the flood tide and about 100m to the south on the ebb. It will have an overall width of about 40m. This envelope represents the potential zone of influence of the plume for all stages of the tide.

The beaches to the north and south of the harbour mouth are popular bathing areas. The nearest designated bathing waters are at Clogga Beach, 3km to the south of the harbour and Brittas Bay 9km to the north. The design objective is to ensure that all the local beaches will meet the bacterial standards for e.coli and intestinal enterococci (IE) as set out in the Bathing Water directive (SI 79/2008). The maximum outfall discharge concentrations for these parameters have been chosen to be conservatively high (e.coli = $1x10^6$ cfu/100ml and IE = $2x10^5$ cfu/100ml). The model data shows that even with these high values any bacterial contamination of bathing areas arising from the proposed outfall will be well below the limits specified in the regulations.

The proposed storm water outfall is to be located at the shoreline to the north of the main outfall route. This will only discharge during exceptional rainfall events. Model simulation of a short term discharge (1 hour) with flows corresponding to the 1-year event show that the e.coli levels on Clogga beach and the bathing area to the north and south of the harbour will be impacted for a period of up to about 24 hours after the event.

The proposed 900m outfall and storm water outfall replace approximately 19 existing outfalls and overflows all of which discharge into the harbour. There will thus be a significant improvement in water quality both in the harbour and on the bathing areas.

The study confirms that the wastewater treatment levels adopted for the proposed outfall are appropriate and it will have no negative impact on the environment.

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