# Environmental and Hydrographic Survey of the Marine Environment, Belmullet, Co. Mayo

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# 1 INTRODUCTION

Aqua-Fact International Services Ltd. was commissioned by Mayo County Council to carry out a survey of the marine environment surrounding Belmullet town, as part of a plan to construct a new wastewater treatment works for Belmullet, Co. Mayo. This survey was required to establish the quality of the marine environment in Blacksod Bay and Inner Broadhaven Bay and to determine the assimilative and dispersive ability of the marine environment in relation to the discharge of effluent from the proposed treatment works. Initially, the study focused on Inner Broadhaven Bay. However, following completion of the field element of the survey in this bay, it was felt that the study should be expanded and include detailed information on the dispersive properties of Blacksod Bay. The surveys within each bay included an oceanographic survey, a water quality survey, a biological survey, a mathematical model, analysis and report of all fieldwork undertaken and a site investigation along the optimum outfall pipeline route.



Aqua-Fact has previously carried out survey work in Blacksod and Inner Broadhaven Bays on a variety of projects including aquaculture, water quality, marine biological projects and gas-field surveys. The study site includes a number of aquaculture production sites for both mussels and salmon, and is contained entirely within two candidate Special Areas of Conservation (cSAC), namely Inner Broadhaven Bay and the Mullet/Blacksod Bay Complex. There are a number of other cSACs close to the study area, namely Erris Head, Inishkea Islands and Duvillaun Islands cSACs.

## 1.1. Outline Description

The marine survey was designed to establish the characteristics and quality of the marine environment in Inner Broadhaven Bay and inner Blacksod Bay, the tidal range of coastal waters, together with tidal streams and currents over the full cycle of spring and neap tides. For the purpose of this survey two stations were selected in Inner Broadhaven Bay as potential outfall locations. Station 1 being the existing site of the wastewater outfall and Station 2 being the proposed outfall location (see Figure 1.1.1). A further station, Station 3 close to Inishderry Island on the south side of Inner

Broadhaven Bay, was included for evaluation. Two stations were also selected for Blacksod Bay, at 70908.56N, 330350.41W (Station 1) and 70462.78N, 329860.5W (Station 2) (see Section B, Figure 1.1.1). A general survey was also carried out to determine the capacity of the marine environment in the Belmullet region to assimilate and disperse discharge of effluent from a proposed wastewater treatment plant. In addition, a biological assessment of existing pollution loads was carried out along with the establishment and calibration of numerical predictive models to determine the baseline characteristics of the survey area.

The work included oceanographic surveys including bathymetric surveys, drogue tracking, dye studies, fixed station current profiling and the collection of tidal, meteorological and water chemistry data. A mathematical model was developed to examine the extent of dilution and dispersion of effluent flow and sediment transport and to predict coliform numbers and other parameters, under varying conditions, at beaches and fish farms in the area.



## 1.2. Purpose of the marine investigation and analysis of data

The purpose of the marine investigation and analysis of the data recorded were as follows:

a) To establish the existing condition of the marine ecosystem under present conditions with discharge from existing waste water treatment works and discharges from freshwater flows and from existing development within within Inner Broadhaven Bay and in proximity to Belmullet town and also inner Blacksod Bay and in proximity to Belmullet town. To examine nutrient levels under existing conditions and likely levels after provision of the proposed sewerage scheme.
b) To monitor coastal and estuary waters over tidal cycles at spring and neap tides as a means of establishing their circulative, dispersive and physical properties.
c) To examine the impact of treated effluent discharge from the proposed treatment works and storm water overflows from the proposed pumping station and to assess the capabilities of the coastal and estuary waters to assimilate them.

d) To establish the suitability of the proposed outfall points, or the existence of a better position, and to propose suitable outfall lengths and alignment, given the restrictions relating to access to the landfall points.

e) To assess compliance of the proposed treatment facilities with Article 7 of EC Directive 91/271/EC, which requires "appropriate treatment" for urban wastewater to coastal waters, defined as "any process and/or disposal system, which after discharge allows the receiving waters to meet the relevant quality objectives and relevant provisions of this and other Community Directives".

f) To predict coliform count numbers at beaches within the survey area using a numerical model calibrated to take account of hydrographic and meteorological parameters measured during the contract.

This report is being submitted to the Engineer on completion of the hydrographic model and all required fieldwork including biological and water quality testing. This will provide baseline data for decisions on the requirement for geophysical data and further investigative work if required for the design and construction of the outfall pipeline.

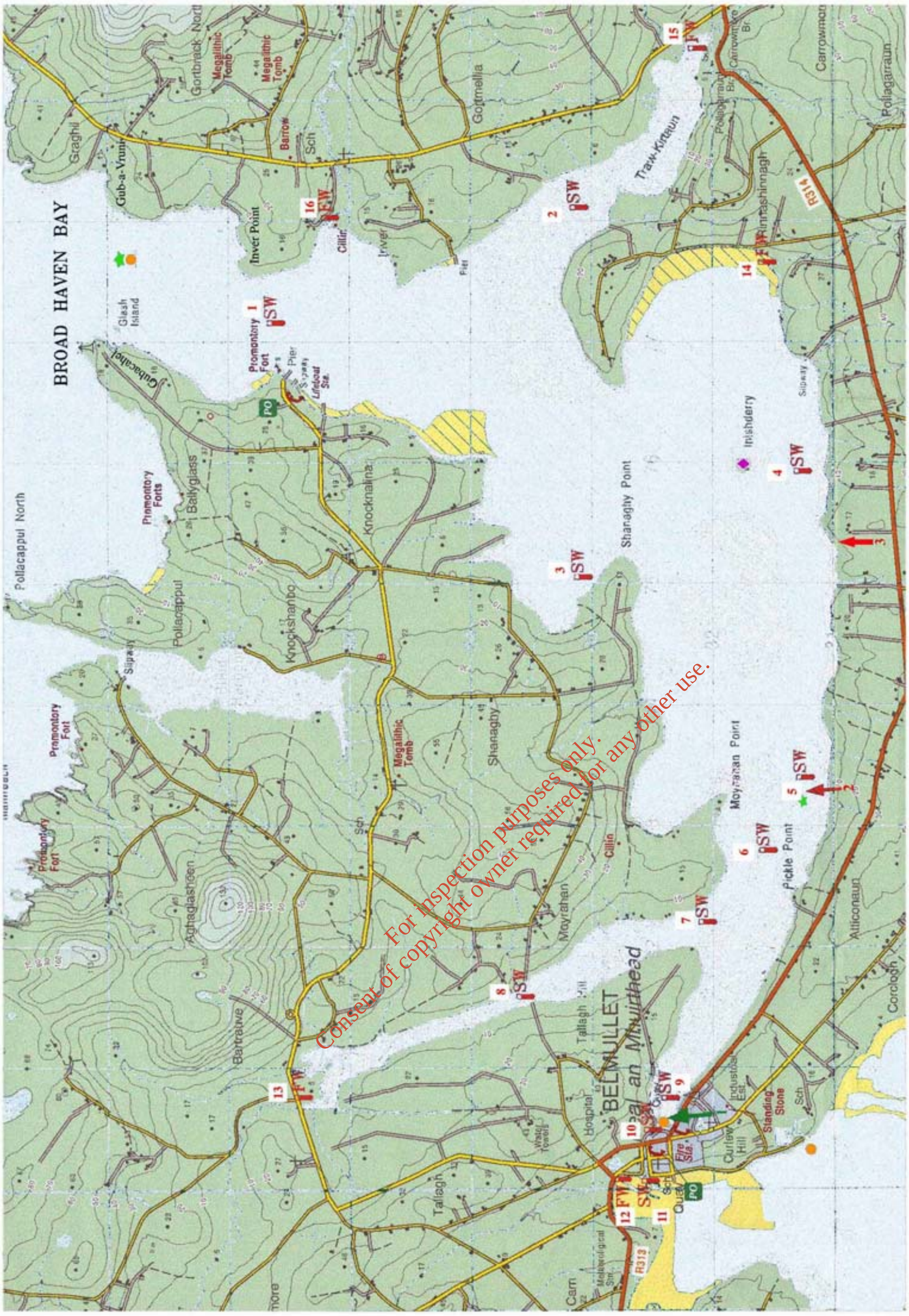



**Figure 1.1.1: Map showing Belmullet and Broadhaven Bay. Stations 1-3, the water sampling locations, the meterological station, tidal gauges, current meters and water sampling stations are all marked.**

# 2. RESULTS

## SECTION A INNER BROADHAVEN BAY SURVEY

The results of the Inner Broadhaven survey are presented in the following sections:

**2.1 Benchmarking**
**2.2. Bathymetric survey and positioning**
**2.3. Meteorological data**
**2.4. Tidal gauge data**
**2.5. Current meter data**
**2.6. Dye studies**
**2.7. Drogue studies**
**2.8 Water and sediment quality studies**
**2.9 Benthic sampling**
**2.10 Modelling**



## 2.1 BENCHMARKING

Benchmarks were established by engineers from Ryan Hanley Consulting Engineers around the Belmullet area, these were levelled to Malin Head O.D. One of these benchmarks was located on the bridge in Belmullet town at 70369.0418 East, 332579.7776 North and at a height of 5.990 m O.D. All depth contours relating to the marine survey were tied into this point.

## 2.2 BATHYMETRY & POSITIONING

A bathymetric survey was carried out over five days, from the 21st to the 25th of October 2003. The survey covered a 50m grid of Inner Broadhaven Bay (east of Moyrahan point), a 100m grid of outer hydrographic area (west of Moyrahan point) and a survey of the canal in Belmullet.

Dynamic horizontal positioning for the survey boat was achieved by means of Differential Global Positioning system (DGPS), which delivered precise, homogenous and continuous navigational output over the entire study area. Regular checks were made against suitable control points to ensure integrity and cross-calibration between terrestrial and sounding data. A continuous real-time record of the survey track was made in conjunction with depth data output from the echo sounder. Continuous recording echo sounding was carried out at the prescribed line intervals and calibration of the echo sounder using the bar-check method was undertaken prior to and upon completion of each survey period. The records of position and depth were time tagged to enable subsequent correction for tidal height with continuously recorded tidal data.

**Bathymetric equipment**

*PRECISION SONARLITE ECHO SOUNDER*- **A COMPLETE ECHO SOUNDER SYSTEM DESIGNED FOR SHALLOW WATER SURVEYING**.

| | |
|---|---|
| **Transducer Frequency:** | 200KHz Active Transducer |
| **Beam Spread:** | 8 to 10 degrees |
| **Depth Range:** | 0.30 to 80 m |
| **Accuracy:** | +/- 0.025 m |
| **Sound Velocity Range:** | 1400 to 1600 m/sec |
| **Pulse Frequency:** | 1Hz |
| **Data Output:** | ASCII, NMEA, Navitronic, Odom, Atlas, Elac, Geotronics |



**Differential Global Positioning System (DGPS)**

The General Lighthouse Authorities (GLAs) public marine Differential Global Positioning System transmit a signal from their reference station at Loop Head 52°33'N, 9°55'W that has a nominal range of 277 km. This signal is transmitted at a frequency of 293 kHz and its integrity can be monitored either live or post operation. This signal was received by the Trimble NT300D which provides real-time sub-meter (typically 30cm) position data when operating within the broadcast area of a reference station conforming to the International Association of Lighthouse Authorities Standards, to position all surveying equipment. In addition, the Trimble NT300D was checked against an additional reference station, its co-ordinates supplied by the Ordnance Survey of Ireland

**Positioning Equipment**

Trimble NT300D

The NT300D combines a GPS receiver and a Beacon receiver into one unit, packaged in a rugged housing. The NT300D is designed to interface with other marine equipment and systems as well as being used alone as a precise navigator. Computers, autopilots, and radars are examples of instruments the NT300D interfaces with. The NT300D utilizes Trimble's advanced low-power, low noise, high accuracy Maxwell chip technology to achieve sub-meter (typically 30cm) level position accuracy. The unit contains a 12 channel GPS receiver and a dual-channel, all-digital, fully automatic radio beacon receiver.

**Results**

Figure 2.2.1 shows the track of the boat over the area covered during the bathymetric survey. Depth limitations or obstructions such as oyster trestles restricted movement in a number of areas e.g. north-east of Moyrahan Point. However, in general the survey consisted of 100 m spaced transects of the area east of Moyrahan Point out to Gubacashel and 50 m spaced transects from Moyrahan Point to the west side of the Belmullet Canal. Figure 2.2.2 is a plot of depth contours generated from the bathymetric data collected. For ease of viewing, depth contours were drawn at 1 m intervals and all depths relate to Malin Head Ordinance Datum (Malin Head OD is approximately 2.1 m above the local Admiralty Chart Datum). It is noted from the survey that the existing outfall location, Station 1, lies in a narrow channel that runs through the mud flats towards the canal that connects Inner Broadhaven Bay with Blacksod Bay. These mud flats lie above chart datum and dry out at low water on all tides. The bottom type outside of Moyrahan Point consists predominantly of fine to medium sand and a relatively deep narrow channel runs from the outer area of Inner Broadhaven Bay to the inner Bay.

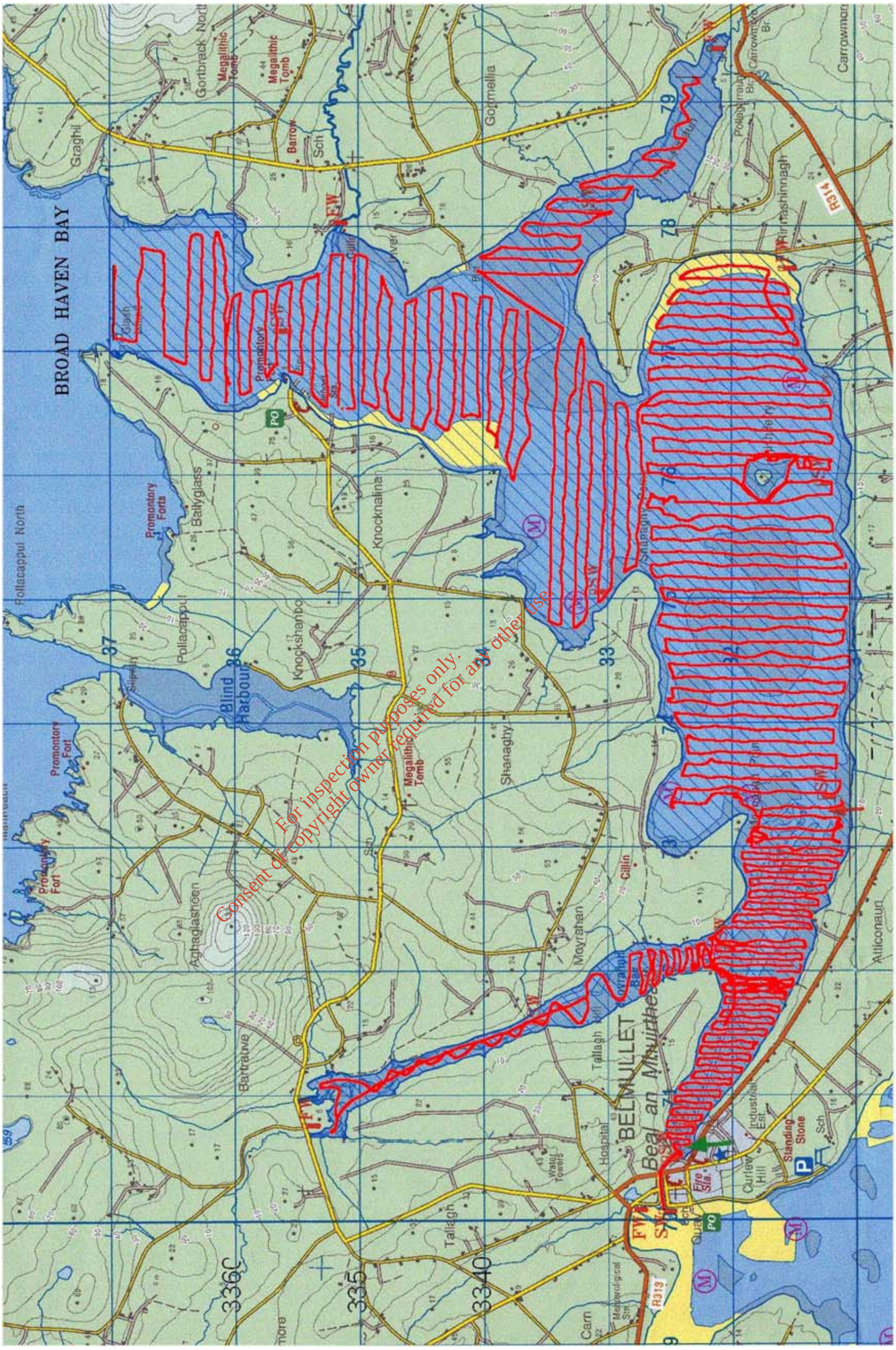





**Figure 2.2.1. Track of the boat during the bathymetry survey of Broadhaven Bay.**

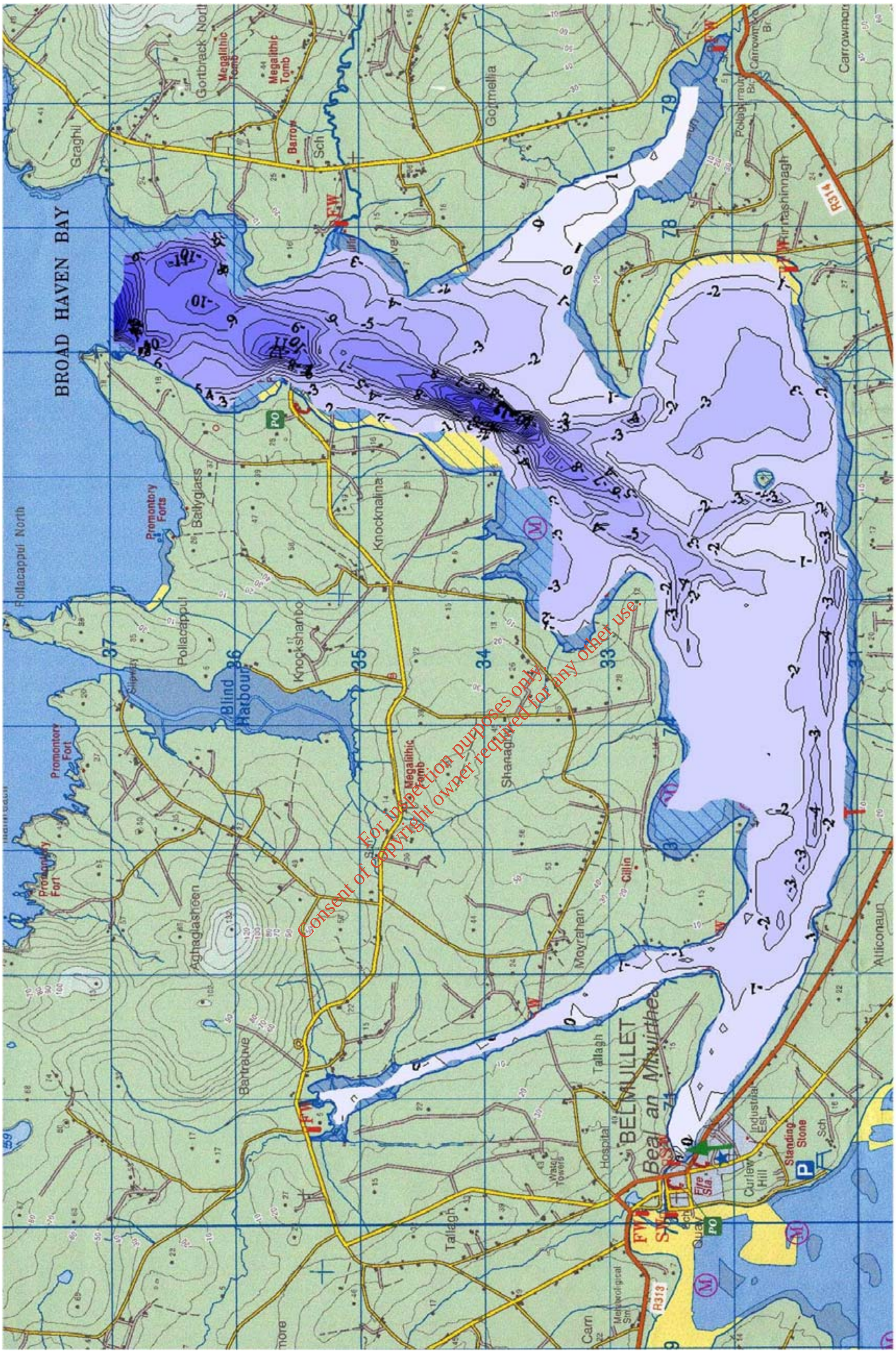



Figure 2.2.2. Depth contours within Broadhaven Bay (all depths reduced to Malin Head O.D.)

## 2.3 METEOROLOGICAL DATA

Wind speed and direction were automatically recorded every 10 seconds by a WindSonic ultrasonic wind speed and direction sensor and data logger that was established on the island of Inishderry (see Figure 1.1.1) where its position was not sheltered from the wind in any direction and where data generated best approximate wind speeds near sea level within the survey area.

**Results**

Figures 2.3.1 presents the meteorological data collected during the course of the fieldwork. From this figure it can be seen that the predominant wind was along a north-east south-west axis reaching strengths of over 15m/s (see percent occurrence table) although, during the course of the study, the meter recorded wind flow from all directions for significant periods of time.

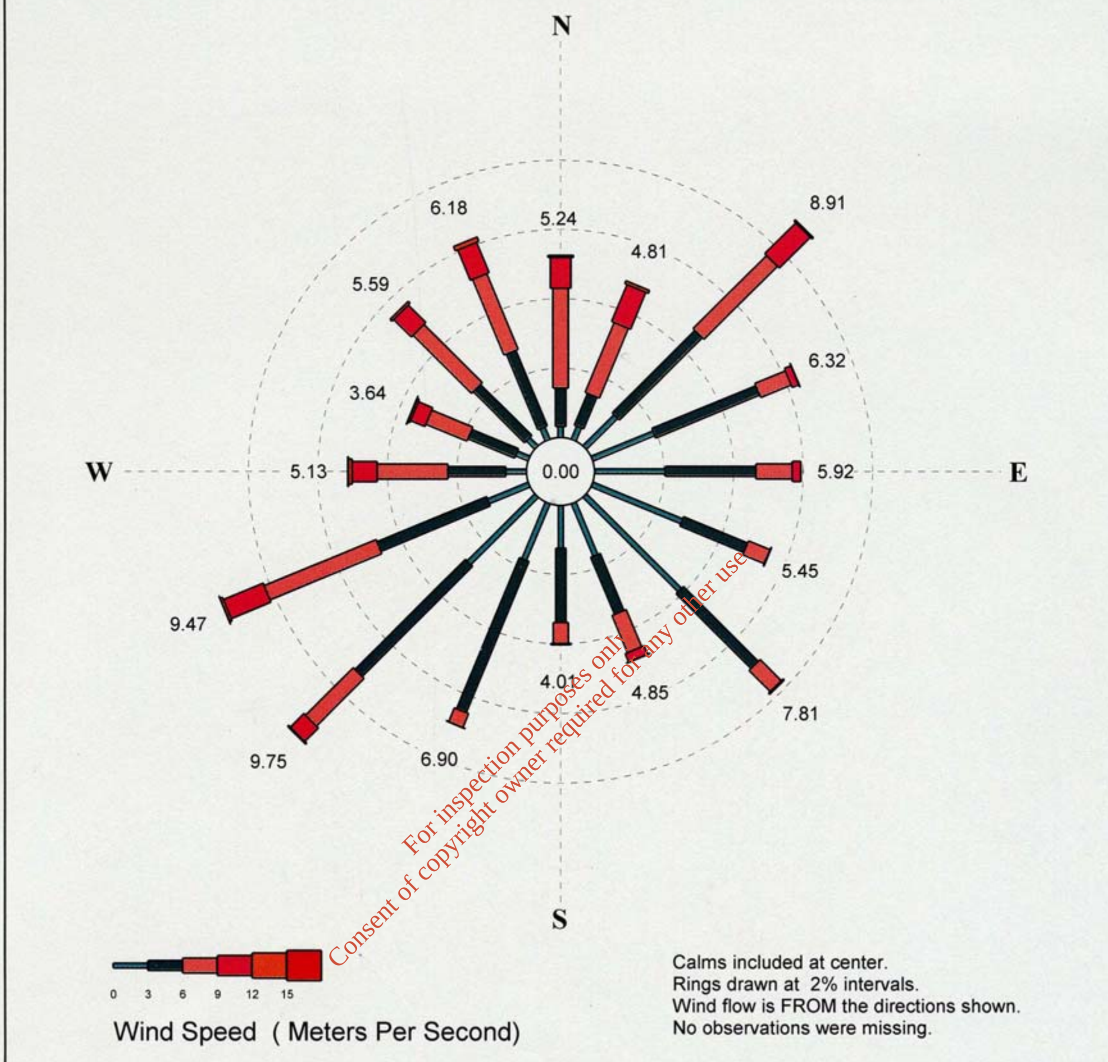


## 2.4 TIDAL GAUGE DATA

**Continuous recording tidal measurements**

Three Enviromon CTD-Divers were deployed to automatically record tidal elevations for the study period. These units were levelled to Malin Head Ordnance Datum. Two of the tidal gauges were deployed on the 15$^{th}$ of October 2003, one on the east side of the canal bridge in Belmullet with the second positioned with a current meter at the outer location (north east of Ballyglass) 54º 16.013, 9º 52.757 as shown in Figure 1.1.1. The third gauge was located on the west side of the canal on the 26$^{th}$ October.

**Figure 2.3.1. Broadhaven Wind Data 15/10/03 - 11/12/03**






PERCENT OCCURRENCE: Wind Speed ( Meters Per Second)
LOWER BOUND OF CATEGORY

| DIR | 0 | 3 | 6 | 9 | 12 | 15 |
|---|---|---|---|---|---|---|
| N | 0.31 | 1.12 | 2.87 | 0.89 | 0.06 | 0.00 |
| NNE | 0.41 | 0.99 | 2.17 | 1.14 | 0.09 | 0.00 |
| NE | 1.26 | 3.36 | 2.98 | 1.26 | 0.05 | 0.00 |
| ENE | 1.92 | 3.24 | 0.95 | 0.20 | 0.01 | 0.00 |
| E | 2.02 | 2.60 | 1.04 | 0.25 | 0.00 | 0.00 |
| ESE | 2.78 | 1.99 | 0.66 | 0.02 | 0.00 | 0.00 |
| SE | 3.86 | 3.04 | 0.86 | 0.05 | 0.00 | 0.00 |
| SSE | 1.64 | 1.79 | 1.15 | 0.26 | 0.01 | 0.00 |

TOTAL OBS = 263598 MISSING OBS = 0

PERCENT OCCURRENCE: Wind Speed ( Meters Per Second)
LOWER BOUND OF CATEGORY

| DIR | 0 | 3 | 6 | 9 | 12 | 15 |
|---|---|---|---|---|---|---|
| S | 1.23 | 2.15 | 0.60 | 0.04 | 0.00 | 0.00 |
| SSW | 1.77 | 4.70 | 0.42 | 0.00 | 0.00 | 0.00 |
| SW | 2.74 | 4.49 | 1.94 | 0.55 | 0.04 | 0.00 |
| WSW | 1.27 | 3.41 | 3.48 | 1.24 | 0.08 | 0.01 |
| W | 0.60 | 1.66 | 2.03 | 0.72 | 0.10 | 0.02 |
| WNW | 0.39 | 1.45 | 1.28 | 0.45 | 0.06 | 0.01 |
| NW | 0.34 | 2.08 | 2.37 | 0.71 | 0.08 | 0.00 |
| NNW | 0.38 | 2.36 | 2.35 | 0.95 | 0.13 | 0.00 |

CALM OBS = 4 PERCENT CALM = 0.00

## Tidal pole measurements

Tidal pole measurements were carried out in conjunction with direct reading current measurements from the canal bridge in Belmullet town on 21st of October (neap tide) and on the 28th of October 2003 (spring tide).

## Equipment

EnviroMon CTD-Diver gauges are small stainless steel sensors with a ceramic pressure sensor.

## Specifications

Range: 30m

Long Term stability: +/- 3cm

Accuracy: +/- 0.1%

Resolution: 0.6cm

Measuring principle: Resistor Bridge



## Results

Figure 2.4.1 presents the raw tidal data recorded by the three meters located within the survey area. The meter located close to Ballyglass was retrieved on 20th November 2003 while the remaining meters were retrieved on 11th December 2003. However, analysis of the data revealed that the meter located east of the bridge was removed from the water on 22nd November and although returned to the canal was relocated incorrectly and data recorded by the meter from this data was not included. Figure 2.4.2 compares the tidal data recorded east and west of the Belmullet canal from the 26th of October to the 22nd of November 2003. Both sets of data have been reduced to Malin O.D. Although timing of high and low water were similar, the tidal ranges recorded by the two meters were significantly different with a greater range (approximately 3.5 m spring tide, 1.5 m neap tide) being recorded west of the canal compared to the east on spring tides (approx. 3.0 m spring tide, 1.5 m neap).

Figure 2.4.3. presents the difference in elevation east and west of the canal at each 10-minute recording interval from 26th October 2003 to 22nd November 2003. Negative values indicate a higher elevation on the Eastern side of the canal and it was found that for 73% of the records water elevation was higher on the east side.

Figure 2.4.4. compares tidal elevations recorded by a tide pole located at the canal bridge in Belmullet town (70369.0418 E, 332579.7776 W) with the automatic recorder located on the east side of the canal during a neap tide on 21st October 2003. The tidal curve is similar with the slight difference in elevation due to the sensitivity differences between the two recording methods. The restriction at the entrance of the canal will cause a slight build up of water when water flow is moving east to west and this is particularly evident during the ebb tide with a higher elevation being recorded by the meter when water velocity was strong in the canal as recorded by the direct reading current meter (see section 2.5.).



Figure 2.4.5. presents tidal data from the meters located east and west of the canal and the tide pole located at the bridge during a spring tide on 28th October 2003. The difference in elevations recorded east and west are in general agreement with Figure 2.4.3. Water flow (when there is sufficient water to flow), as recorded by the direct reading current meter, flowing to the lower elevation as recorded by the tide gauges.

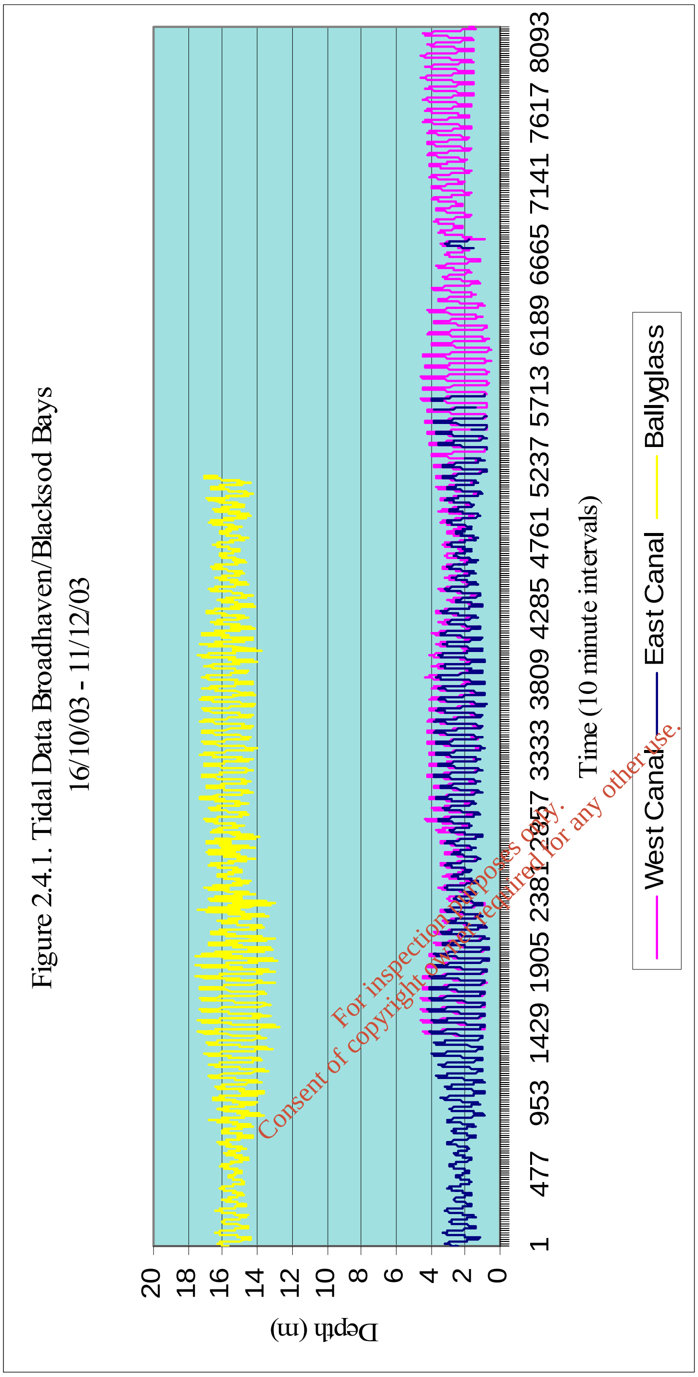


Figure 2.4.1. Tidal Data Broadhaven/Blacksod Bays
16/10/03 - 11/12/03
Depth (m)
20
18
16
14
12
10
8
6
4
2
0
1 477 953 1429 1905 2381 2857 3333 3809 4285 4761 5237 5713 6189 6665 7141 7617 8093
Time (10 minute intervals)
West Canal
East Canal
Ballyglass

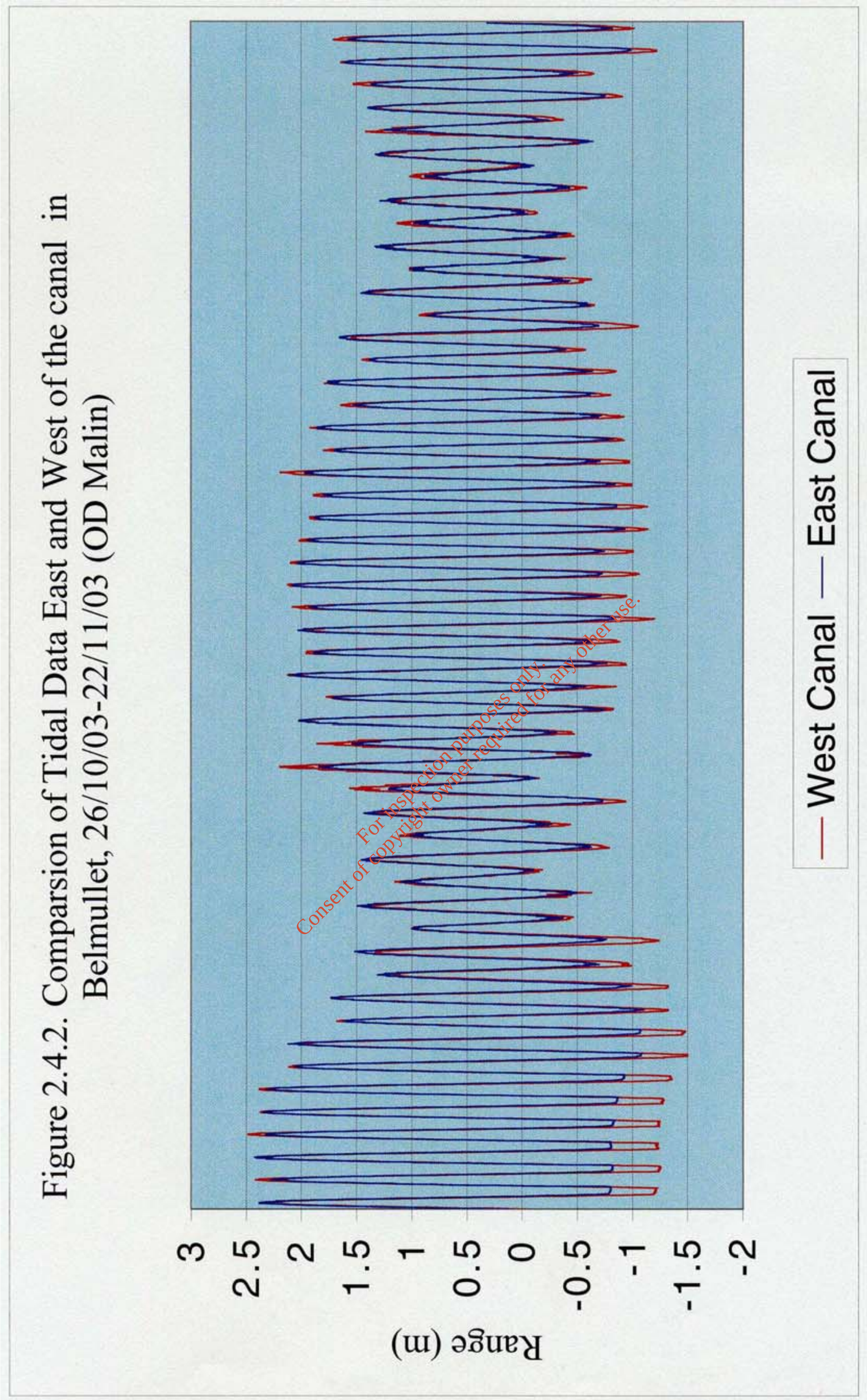



Figure 2.4.2. Comparsion of Tidal Data East and West of the canal in Belmullet, 26/10/03-22/11/03 (OD Malin)

Figure 2.4.3. Comparsion of tidal elevations East and West of the canal in Belmullet, 26/10/03 - 22/11/03 (negative value indicates higher elevation on East)

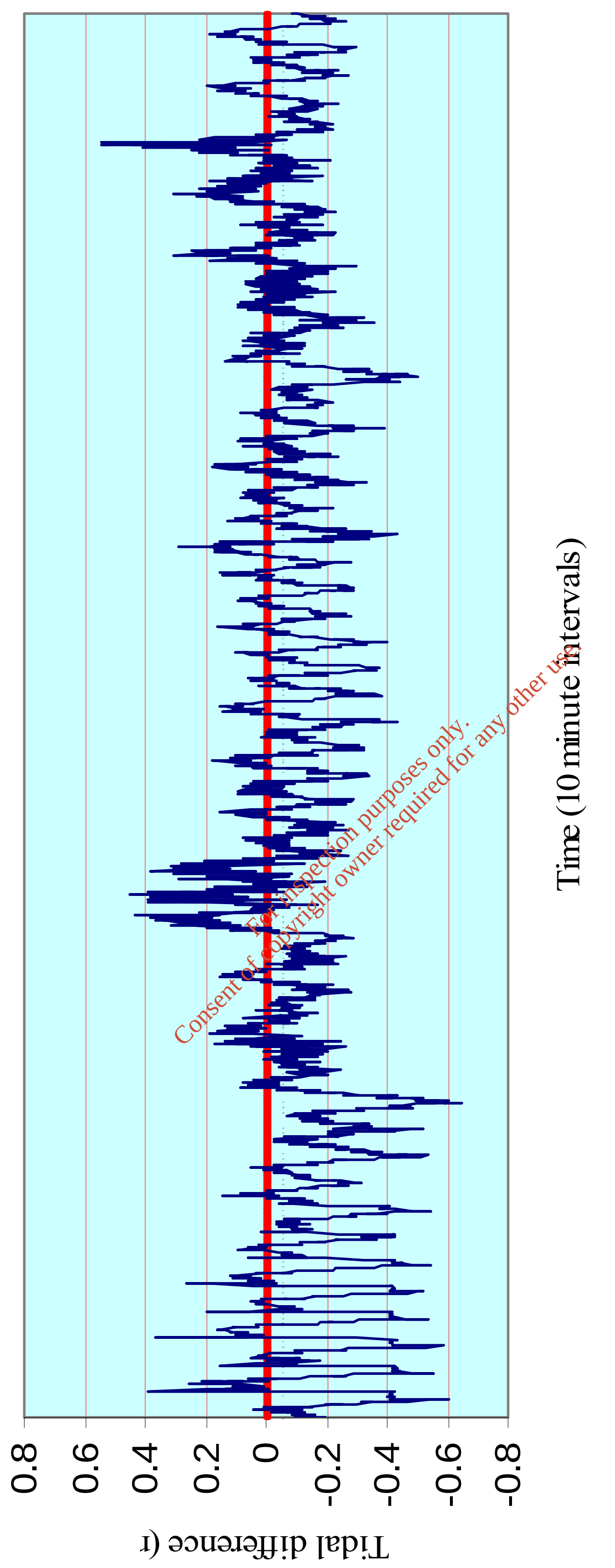
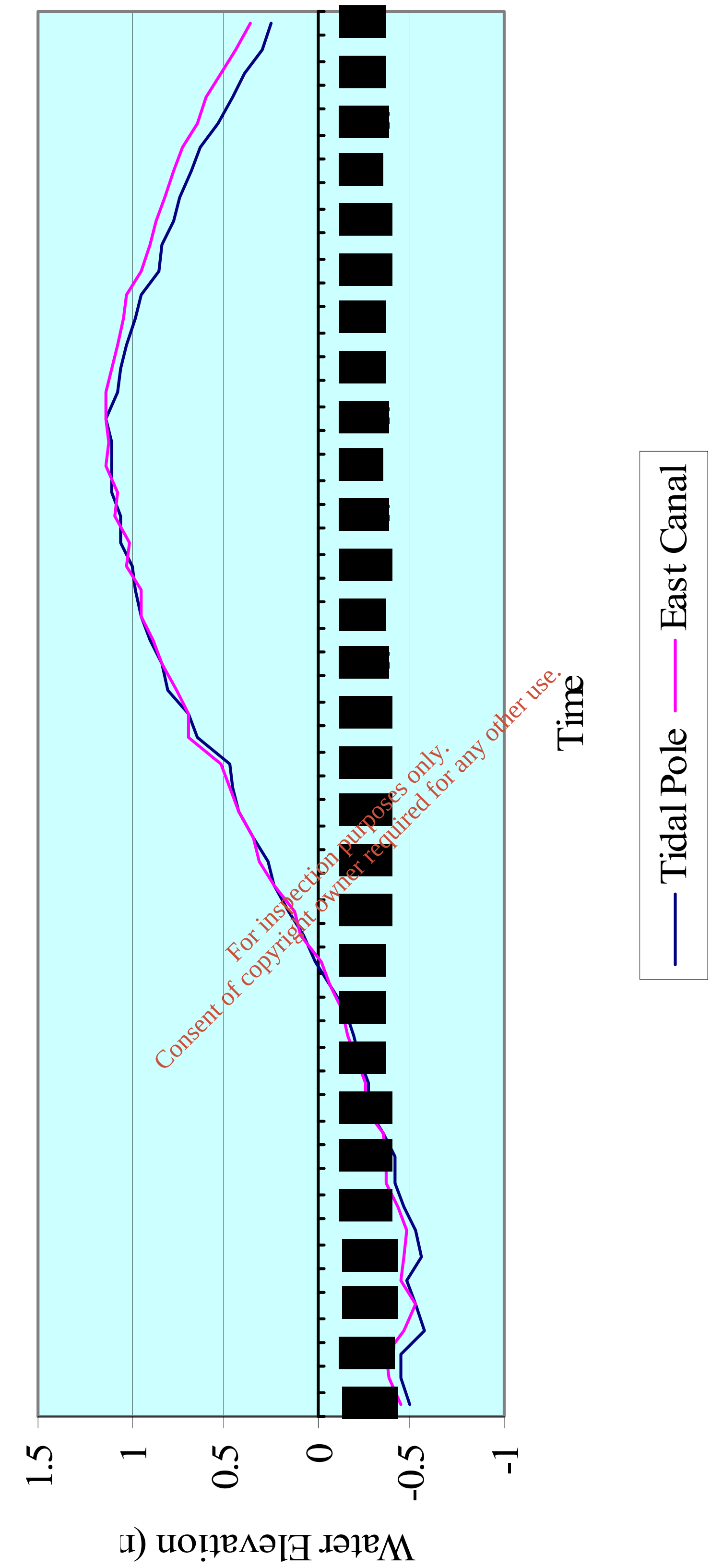


Figure 2.4.4. Tidal data recorded by Tidal Pole at Belmullet Canal and Automatic Recorder East of the Canal on 21/10/03 (Neap Tide)



## 2.5 CURRENT METER

### Continuous recording meters

Two continuous recording current meters were deployed on 15th October 2003. The first was located at the outer location, northeast of Ballyglass (54º 16.013, 9º 52.757), at a depth of 15m and the other (RCM7) was positioned at the proposed outfall location east of Pickle Point (54º 12.907, 9º 56.400), at a depth of 5m. The outer meter was retrieved on the 7th of November 2003 and the inner meter was retrieved on the 2nd of December 2003.

### Belmullet Bridge direct current measurements

A further current meter survey using a Valeport Braystroke (BFM 008 MK3) direct reading current meter was carried out from the canal bridge in Belmullet town on 21st of October 2003 (neap tide) and on the 28th of October 2003 (spring tide). Readings were taken every 10 minutes for a 12 hour period on each occasion.

### Neap and Spring tide direct current measurements



Vertical profile current velocity and direction was measured with a Valeport Braystroke (BFM 008 MK3) direct reading current meter at each of the two identified outfall points over a full tidal cycle neap and spring tides, on the 22nd and 29th of October 2003, respectively. When possible, observations were taken at 0.5 m below the surface, 25% depth, 50% depth, and 75% depth and at 0.5 m above seabed at 30-minute intervals. Vertical profiles at various stations throughout the study area were also measured during the field survey work. The positions of the meter were fixed by DGPS.

## Equipment

### Direct reading current meter

Valeport Braystroke (BFM 008 MK3)

| | Velocity | Direction |
|---|---|---|
| Range | 0.03 to 6.0 $ms^{-1}$ | 0 to 360 degrees |
| Accuracy | Better than 1.5% of measured velocity | +/- 5 degrees |

### Continuous Recording current meters

Aanderaa RCM 8/7's

| | Velocity | Direction |
|---|---|---|
| Range | 2 to 295 $cms^{-1}$ | 0 to 360 degrees |
| Accuracy | +/- 1cm or 2% whichever is greater | +/- 5 degrees |

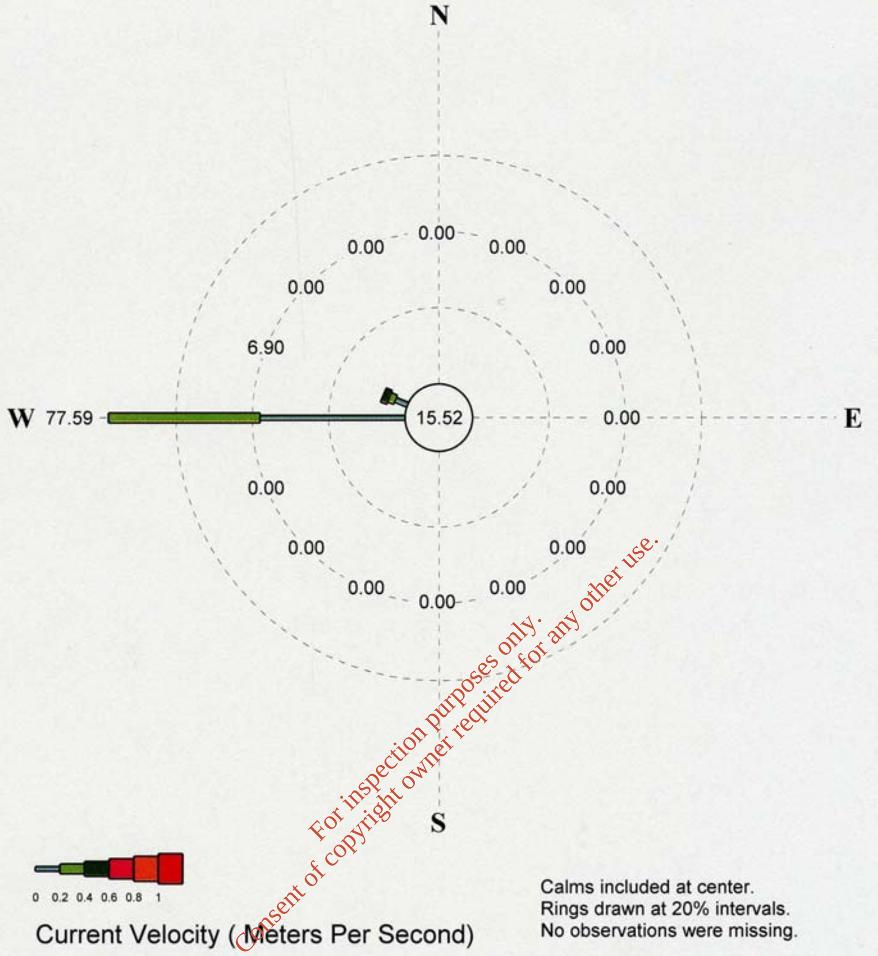
## Results



The results of the direct reading current meter for the bridge in Belmullet are presented in Figures 2.5.1 and 2.5.2. for a neap tide (21/10/03) and spring tide (28/10/03), respectively. Neap tide currents were consistently recorded flowing in a westerly direction along the canal into Blacksod Bay from Inner Broadhaven Bay with the predominant current being less than 0.4 m/s. This situation changed during the spring tide study with strong currents (>0.8 m/s) being recorded flowing in an easterly direction into Inner Broadhaven Bay from Blacksod Bay. In fact, it was found that water flowed easterly for 36.6% of the time compared with 26.98% of the time in the opposite direction during the spring tide study. No flow, predominantly due to low water level, made up the remaining time.

The results of the direct reading current meter for Stations 1 and 2 in Inner Broadhaven Bay are represented in Figure 2.5.3 to 2.5.6. and the data is included in Appendix I. Water flow was predominantly in a north-west direction. However, the frequency rose diagrams use the combined data from each depth and together, with depth limitations at the stations and access difficulties due to the mud flats, it is difficult to interpret flow patterns from these single point data.

**Figure 2.5.1. Belmullet Canal Neap Current Speed and Direction Frequency**
**21/10/03, 08:00 - 19:00 (10 minute intervals)**
**(flow is TO direction shown)**






PERCENT OCCURRENCE: Current Velocity ( Meters Per Second)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
|---|---|---|---|---|---|---|
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

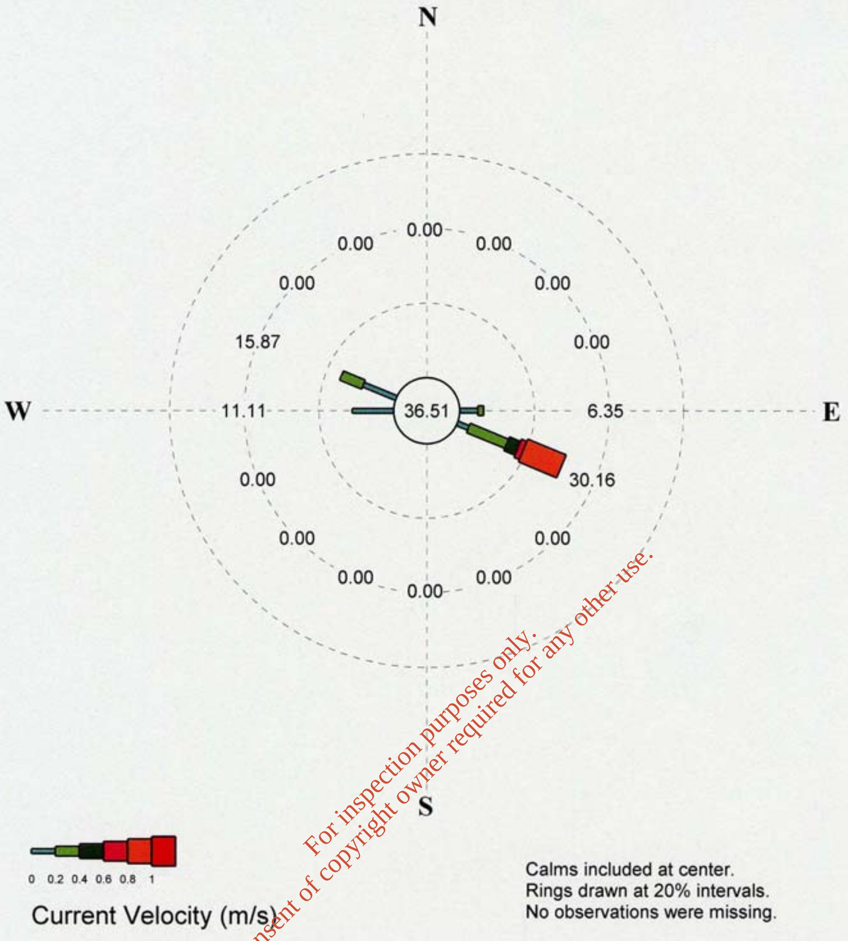
TOTAL OBS = 58 MISSING OBS = 0

PERCENT OCCURRENCE: Current Velocity ( Meters Per Second)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
|---|---|---|---|---|---|---|
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| W | 37.93 | 39.66 | 0.00 | 0.00 | 0.00 | 0.00 |
| WNW | 3.45 | 1.72 | 1.72 | 0.00 | 0.00 | 0.00 |
| NW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

CALM OBS = 9 PERCENT CALM = 15.52

**Figure 2.5.2. Belmullet Canal Spring Current Speed and Direction Frequency 28/10/03, 08:00 - 20:00 (10 minute intervals) (flow is TO direction shown)**






PERCENT OCCURRENCE: Current Velocity (m/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
|---|---|---|---|---|---|---|
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E | 4.76 | 1.59 | 0.00 | 0.00 | 0.00 | 0.00 |
| ESE | 3.17 | 11.11 | 3.17 | 1.59 | 11.11 | 0.00 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

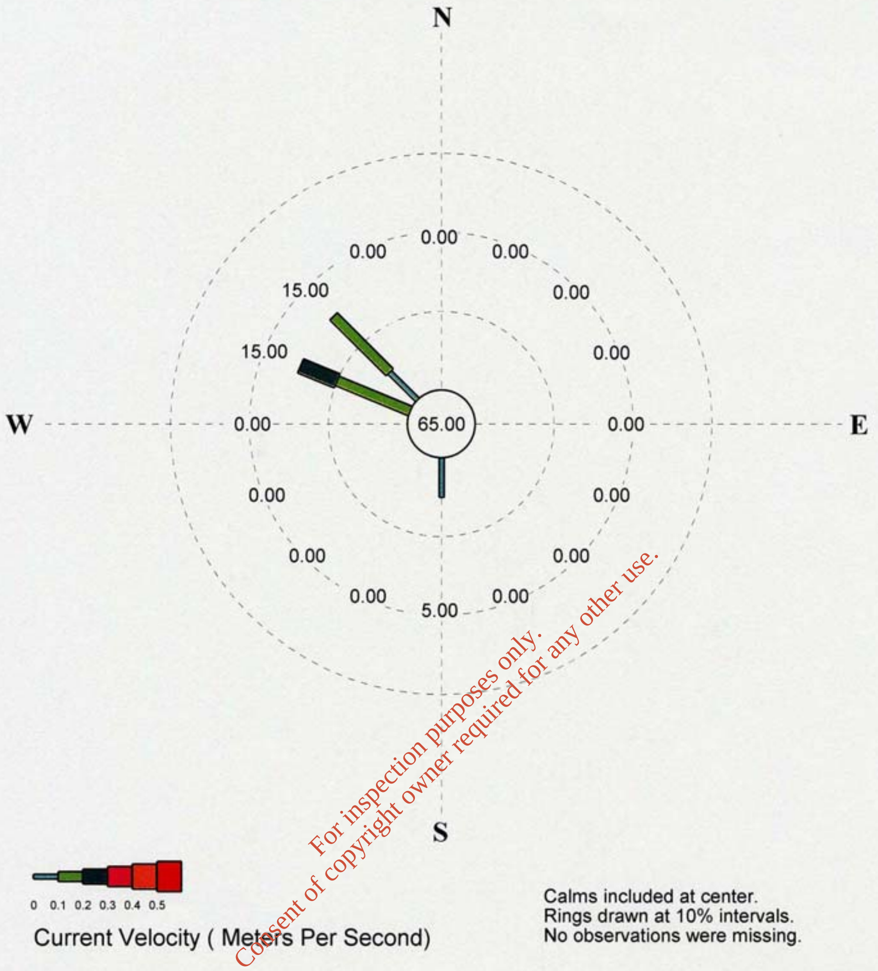
TOTAL OBS = 63 MISSING OBS = 0

PERCENT OCCURRENCE: Current Velocity (m/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
|---|---|---|---|---|---|---|
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| W | 11.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WNW | 9.52 | 6.35 | 0.00 | 0.00 | 0.00 | 0.00 |
| NW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

CALM OBS = 23 PERCENT CALM = 36.51

**Figure 2.5.3. Belmullet Station 1, 22/10/03**
**Neap Tide HW 16:10, LW 9:48**
**(water flow is to direction shown)**






PERCENT OCCURRENCE: Current Velocity ( Meters Per Second)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

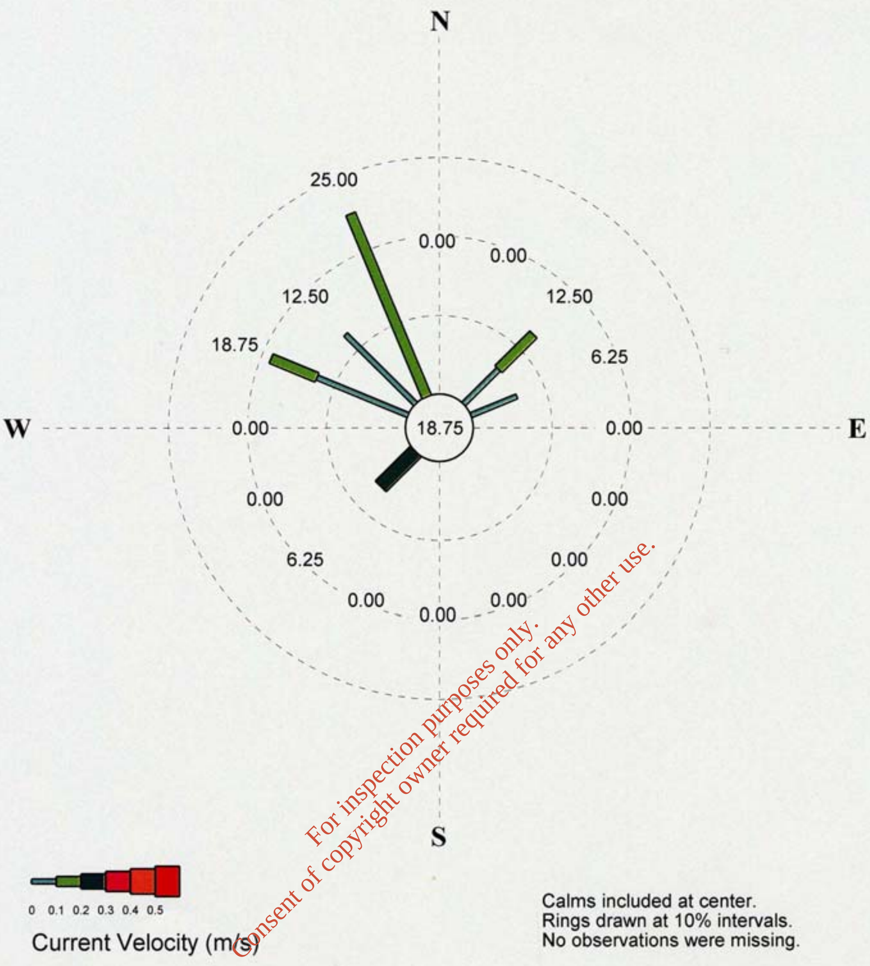
TOTAL OBS = 20 MISSING OBS = 0

PERCENT OCCURRENCE: Current Velocity ( Meters Per Second)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|
| S | 5.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| W | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WNW | 0.00 | 10.00 | 5.00 | 0.00 | 0.00 | 0.00 |
| NW | 5.00 | 10.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

CALM OBS = 13 PERCENT CALM = 65.00

**Figure 2.5.4. Belmullet Station 2, 22/10/03**
**Neap Tide HW 16:10, LW 9:48**
**(water flow is to direction shown)**






PERCENT OCCURRENCE: Current Velocity (m/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NE | 6.25 | 6.25 | 0.00 | 0.00 | 0.00 | 0.00 |
| ENE | 6.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

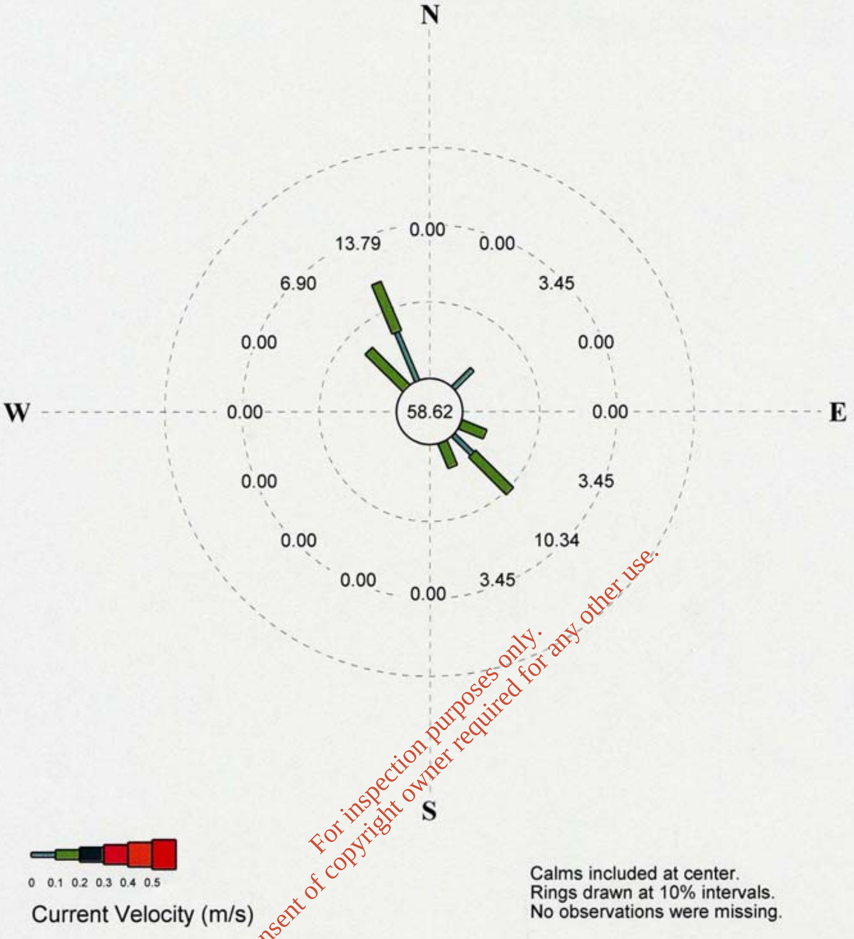
TOTAL OBS = 16 MISSING OBS = 0

PERCENT OCCURRENCE: Current Velocity (m/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SW | 0.00 | 0.00 | 6.25 | 0.00 | 0.00 | 0.00 |
| WSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| W | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WNW | 12.50 | 6.25 | 0.00 | 0.00 | 0.00 | 0.00 |
| NW | 12.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNW | 0.00 | 25.00 | 0.00 | 0.00 | 0.00 | 0.00 |

CALM OBS = 3 PERCENT CALM = 18.75

**Figure 2.5.5. Belmullet Station 1, 29/10/03**
**Spring Tide HW 07:52, LW 13:58**
**(water flow is to direction shown)**






PERCENT OCCURRENCE: Current Velocity (m/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NE | 3.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ESE | 0.00 | 3.45 | 0.00 | 0.00 | 0.00 | 0.00 |
| SE | 3.45 | 6.90 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSE | 0.00 | 3.45 | 0.00 | 0.00 | 0.00 | 0.00 |

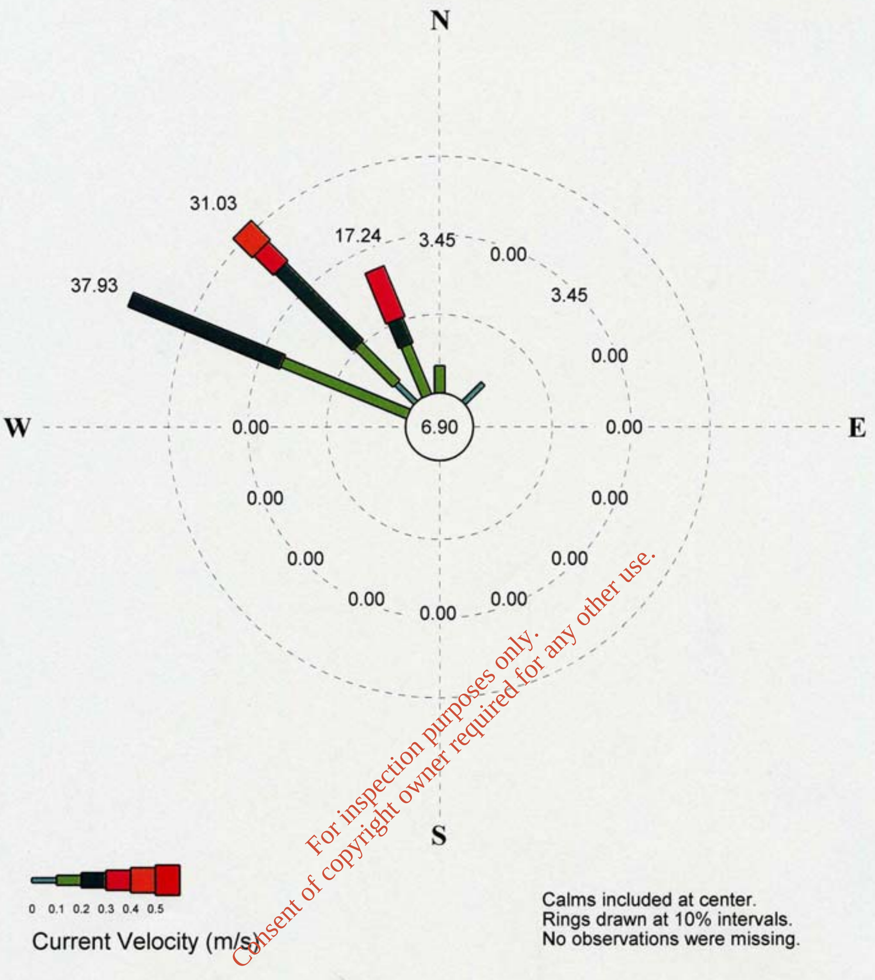
TOTAL OBS = 29 MISSING OBS = 0

PERCENT OCCURRENCE: Current Velocity (m/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| W | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NW | 0.00 | 6.90 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNW | 6.90 | 6.90 | 0.00 | 0.00 | 0.00 | 0.00 |

CALM OBS = 17 PERCENT CALM = 58.62

**Figure 2.5.6. Belmullet Station 2, 29/10/03**
**Spring Tide HW 7:52, LW 13:58**
**(water flow is to direction shown)**






PERCENT OCCURRENCE: Current Velocity (m/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|
| N | 0.00 | 3.45 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NE | 3.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

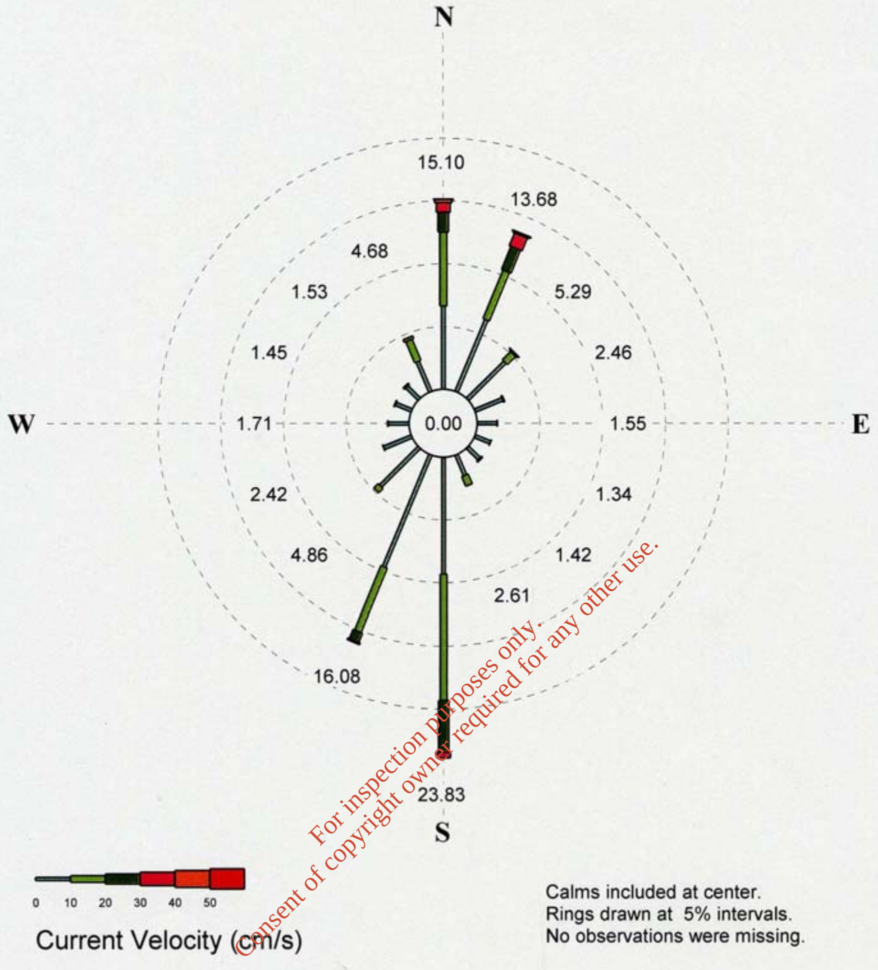
TOTAL OBS = 29 MISSING OBS = 0

PERCENT OCCURRENCE: Current Velocity (m/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|---|
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| W | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WNW | 0.00 | 17.24 | 20.69 | 0.00 | 0.00 | 0.00 |
| NW | 3.45 | 6.90 | 13.79 | 3.45 | 3.45 | 0.00 |
| NNW | 0.00 | 6.90 | 3.45 | 6.90 | 0.00 | 0.00 |

CALM OBS = 2 PERCENT CALM = 6.90

**Figure 2.5.7. Frequency of currents recorded by the automatic current meter located close to Ballyglass from 15th October to 7th November 2003.**






PERCENT OCCURRENCE: Current Velocity (cm/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|
| N | 6.62 | 5.86 | 1.57 | 0.75 | 0.28 | 0.02 |
| NNE | 6.23 | 4.17 | 1.99 | 1.10 | 0.12 | 0.08 |
| NE | 4.23 | 0.90 | 0.14 | 0.02 | 0.00 | 0.00 |
| ENE | 2.34 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 |
| E | 1.53 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| ESE | 1.32 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| SE | 1.30 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSE | 1.77 | 0.85 | 0.00 | 0.00 | 0.00 | 0.00 |

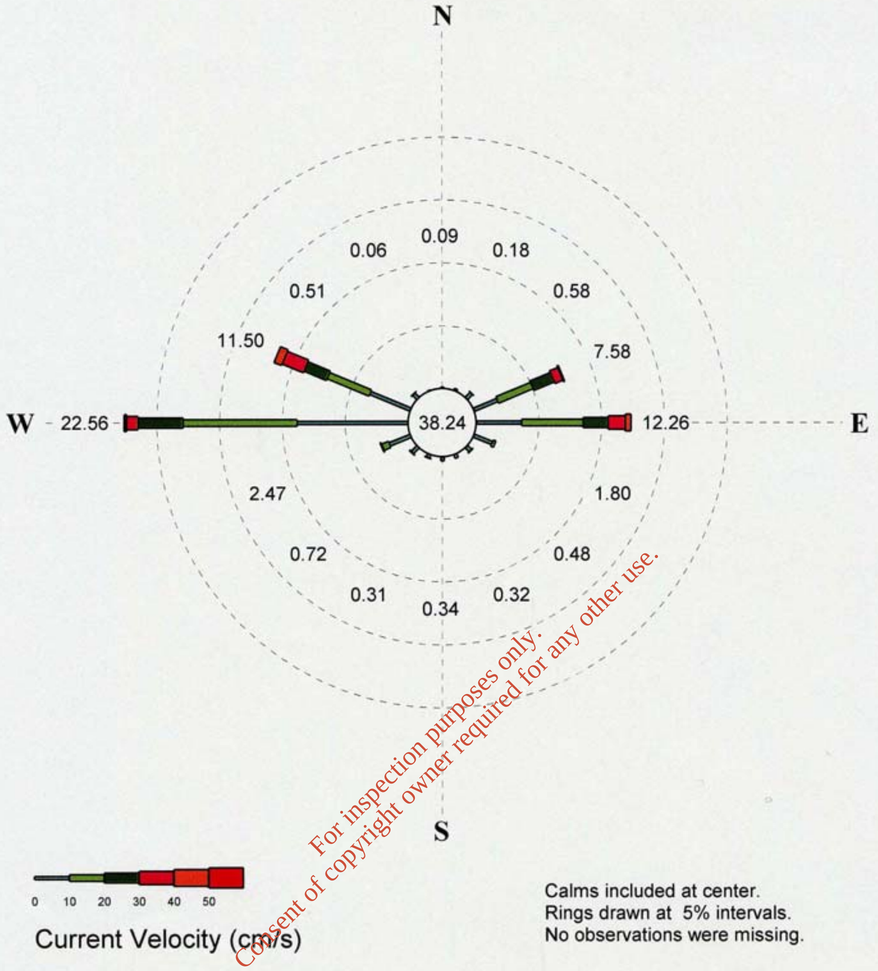
TOTAL OBS = 5087 MISSING OBS = 0

PERCENT OCCURRENCE: Current Velocity (cm/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|
| S | 9.30 | 9.97 | 4.11 | 0.45 | 0.00 | 0.00 |
| SSW | 9.65 | 5.48 | 0.81 | 0.14 | 0.00 | 0.00 |
| SW | 4.36 | 0.49 | 0.00 | 0.00 | 0.00 | 0.00 |
| WSW | 2.40 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| W | 1.69 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| WNW | 1.40 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |
| NW | 1.38 | 0.16 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNW | 2.65 | 1.83 | 0.20 | 0.00 | 0.00 | 0.00 |

CALM OBS = 0 PERCENT CALM = 0.00

**Figure 2.5.8. Frequency of currents recorded by the automatic current meter located close to Pickle Point from 15th October to 2nd December 2003.**






PERCENT OCCURRENCE: Current Velocity (cm/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|
| N | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNE | 0.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NE | 0.57 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| ENE | 2.03 | 2.98 | 1.77 | 0.69 | 0.12 | 0.00 |
| E | 3.58 | 4.88 | 1.99 | 1.36 | 0.45 | 0.00 |
| ESE | 1.56 | 0.23 | 0.00 | 0.00 | 0.00 | 0.00 |
| SE | 0.45 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSE | 0.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

TOTAL OBS = 6843 MISSING OBS = 0

PERCENT OCCURRENCE: Current Velocity (cm/s)
LOWER BOUND OF CATEGORY

| DIR | 0 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|
| S | 0.34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SSW | 0.29 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| SW | 0.66 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |
| WSW | 1.83 | 0.58 | 0.06 | 0.00 | 0.00 | 0.00 |
| W | 8.83 | 9.06 | 3.58 | 0.91 | 0.19 | 0.00 |
| WNW | 3.51 | 3.58 | 1.93 | 1.84 | 0.64 | 0.00 |
| NW | 0.50 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNW | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

CALM OBS = 2617 PERCENT CALM = 38.24

Figure 2.5.7 and 2.5.8. present the results of the current data collected by the continuous recording meters located near Ballyglass and Pickle Point, respectively. As expected, current flow at Ballyglass is in a predominantly North-South axis with flow to the south occurring for a longer period of time (42.5% compared to 33.46% to the north) Maximum current velocity (just over 0.5 m/s or 1 knot) was recorded in a northerly direction on the ebbing tide. Water flow off Pickle Point was in an east-west axis with water flow occurring for 36.5% of the time in a westerly direction compared to 21.6% in an easterly direction. The current speeds at the Ballyglass location are consistent with the Tidal Diamond, as shown on the Admiralty Chart for Inner Broadhaven Bay, located at the centre of the channel. This shows current speeds reaching 1.3 knots at highest Spring tide.

## 2.6 DYE STUDIES

Dye dispersion studies were carried out at the proposed outfall locations on the south side of Inner Broadhaven Bay. The studies were carried out for neap tides at Station 2 and for both neap and spring tides at Station 3 (see Figure 1.1.1). Due to the restricted nature of the existing outfall location, it was agreed with the consulting engineers that dye releases would not be carried out at this location. Rhodamine WT was the fluorescent dye used and batches of dye were mixed with methanol and freshwater prior to release to achieve a density similar to that of treated sewage effluent.



Prior to release, the fluorimeter was calibrated against the tracer, in the ambient seawater into which the tracer was released. This was done using a standard concentration solution. After the tracer was released, its dispersal was monitored visually, with its movement and expansion plotted through recording of positions with the DGPS unit. Once it had dispersed sufficiently to monitor with the fluorimeter, regular transects were made through the plume to record its progress. In addition to horizontal transects, vertical profiles through the tracer were also taken. When the tracer plume was no longer visible and fluorimeter readings had returned to background levels, the study was terminated.

## Equipment

### *Chelsea Instruments Minitracka II R In-situ Fluorimeter*

| | |
|---|---|
| **Fluorimeter:** | Chelsea Instruments Minitracka II R In-situ Fluorimeter |
| **Concentration Range:** | 0.03-100µg/l Rhodamine-WT |
| **Resolution:** | 0.01 µg/l Rhodamine-WT |
| **Excitation wavelength:** | 470/30 nm |
| **Emission wavelength:** | 590/45 nm |
| **Deck Unit:** AQUA^sition data logging interface unit | |
| **Data Processor:** Panasonic Toughbook with Pico software | |

## Results

Figures 2.6.1 to 2.6.3 present the results of the dye studies carried out at the proposed outfall locations in Inner Broadhaven Bay.



High water (neap tide) on the 1st December 2003 occurred at approximately 11:35. The dye was released into the water just after 12:35 close to Pickle Point at 72854.509 E, 331241.519 N. The sky was overcast and a gusty northerly wind (Beaufort force 3-4) was blowing that continued throughout the study. There was little movement of the dye patch in the following half hour and the patch expanded slowly from a central point. The first transect through the patch was carried out at 13:14 and the concentrations recorded across this transect and further transects together with the progress of the patch along the Bay are presented in Figure 2.6.1. The dye had progressed approximately 30 m NE of the drop point at this time with a maximum concentration of 180 µg/l recorded close to the transect start point. A vertical profile of the patch carried out at 13:30 at 73037 E, 331218 N revealed that the dye was mainly concentrated in the upper half of the water column although dye was recorded through the column (see Table 2.6.1.).

| Depth (m) | Concentration (µg/l) |
|---|---|
| 0 | 72 |
| 0.5 | 72 |
| 1.0 | 53 |
| 1.5 | 35 |
| 2.0 | 15 |
| 2.5 | 5 |

**Table 2.6.1.** Dye concentrations relative to depth recorded during a vertical profile of the dye patch on 1/12/03 at 13:30.

The dye patch continued moving slowly east following a path parallel to the shore with concentrations reducing with time (see concentration graphs Figure 2.6.1.). By 15:25 only traces of dye were recorded in the water column although the dye patch had only progressed approximately 1.5 km from its release point. Apart from the transects through the dye patch, spot checks and additional runs were made with the fluorimeter outside and surrounding the dye patch without picking up traces of dye. In addition to dye dispersion, t was felt that the reduction in dye concentration with time was due in part to absorption of dye to suspended solids in the water column as the water was quite turbid on this side of the bay at the time of the study.



On the 2nd December predicted high water occurred at 12:48 and dye was released into the water column at 13:39 at a new proposed location (74858.645 E, 331246.011 N), south west of Inishderry Island, within the channel that runs parallel to the shore. Weather conditions were good with a predominant light north north-east wind. The dye patch expanded laterally in an east-west direction over the following half hour, the extents of the patch being outlined in Figure 2.6.2. The first runs through the patch were carried out at 14:22 and the concentrations are presented as graphs in Figure 2.6.2. together with the concentrations recorded during further runs and movement of the patch as outlined by the path of the boat during the transects. In general, there was slow movement of the dye over time with the dye patch progressing approximately 1.3 km in a north-east direction by 17:00 when the study was terminated due to low light conditions. Although the patch followed the channel for most of its progress, it veered south-west close to Inishderry Island heading towards the large basin located west of the island (see Figure 2.2.2.). Dye concentrations progressively reduced with time as detailed in the concentration graphs (Figure 2.6.2.) recorded on each run through the patch. Vertical profiles of the patch (Table 2.6.2.) taken at 14:33 (74939 E, 331318 N) and 15:14 (75114 E, 331406 N) indicate that the dye also dispersed through the water column with the higher concentration found in the top half of the column.

| Depth (m) | Concentration (µg/l) | |
|---|---|---|
| | 14:33 | 15:14 |
| 0 | 327 | 324 |
| 0.5 | 166 | 340 |
| 1.0 | 18 | 335 |
| 1.5 | 5 | 106 |
| 2.0 | 0 | 25 |
| 2.5 | | 2 |

**Table 2.6.2.** Dye concentrations relative to depth recorded during vertical profiles of the dye patch on 2/12/03.



Predicted high water (spring tide) on the 11th December occurred at 7:00 and dye was released into the water column at 8:48 at the new proposed location (75060 E, 331213 N) located south west of Inishderry. Weather conditions were good with a predominant moderate north-east wind Force 2-3. The dye patch immediately moved in a north-east direction with the patch limits shown in Figure 2.6.3. The first transect was run at 9:28 and although the dye was visible in the water column recorded concentrations were low. As described above, it is probable that suspended solids in the water column affected the recorded values, as the water was very turbid. However, although recorded concentrations were low, it was possible to follow the progress of the patch over time as detailed in Figure 2.6.3. Vertical profiles of the patch showed that it was dispersed through the water column. The dye patch followed a similar route to that described above for neap conditions moving in a north-east direction until, close to Inishderry Island, it veered south-east around the southern side of the island into the large basin to the east of the island. Additional transects were carried out to the north and west of the island with no trace of dye being located. By 11:30, no further trace of dye could be discerned in the water column as it dispersed within the area east of Inishderry Island.

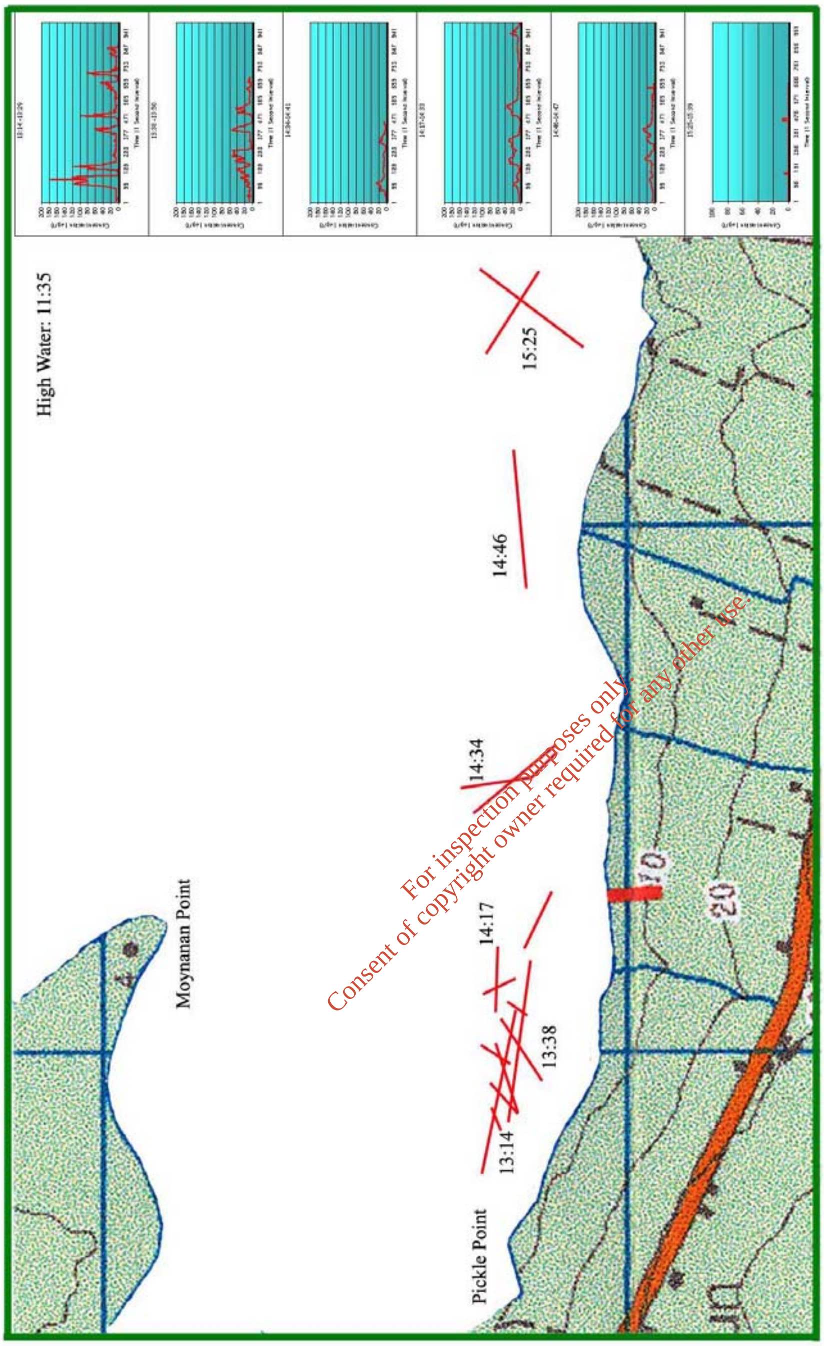



Figure 2.6.1. Dye concentration and progress following a release at Station 2 shortly after high water on a neap tide on 1/12/03

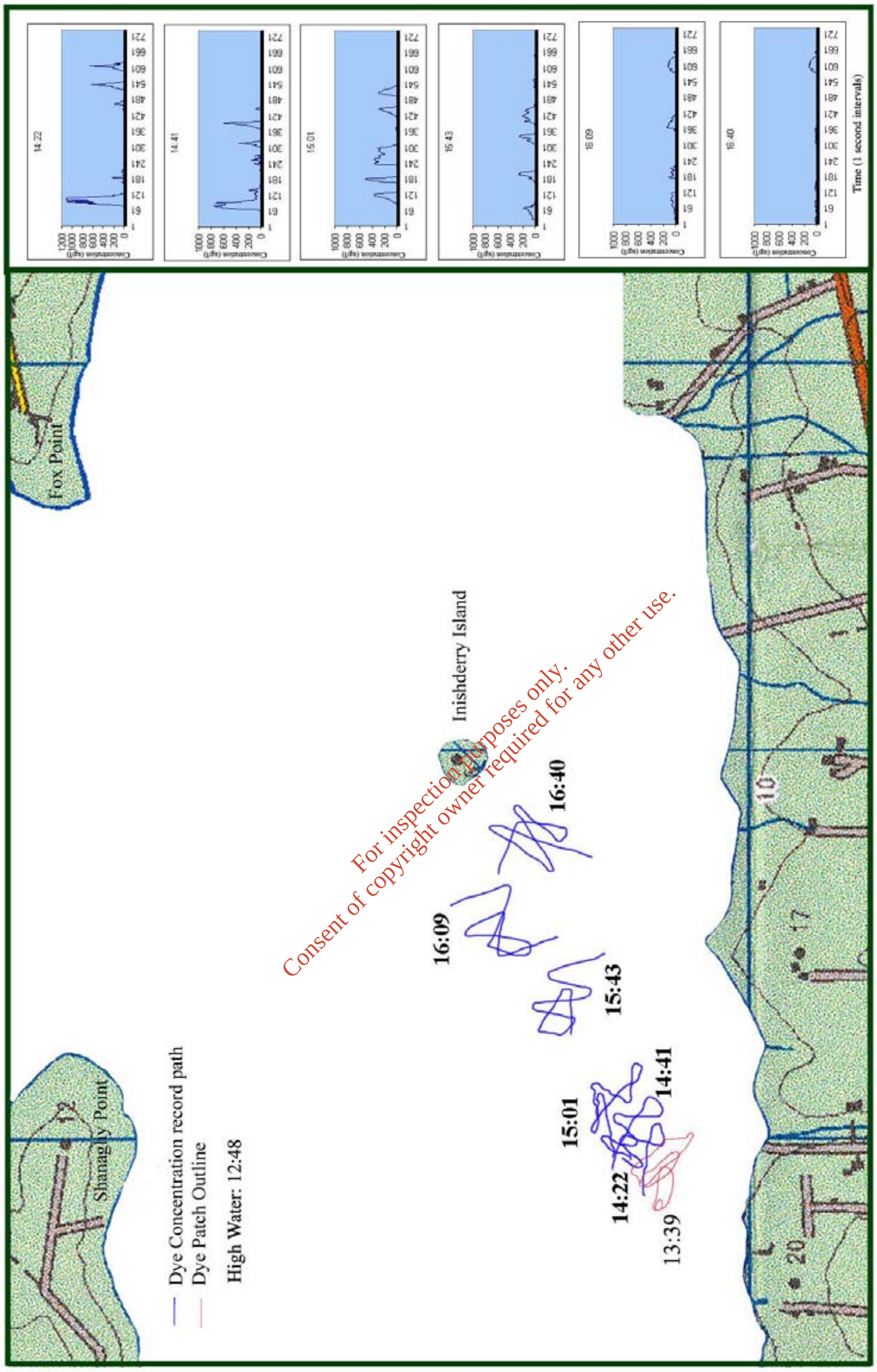



Figure 2.6.2. Dye concentration and progress following a release at Station 3 shortly after high water on a neap tide on 2/12/03

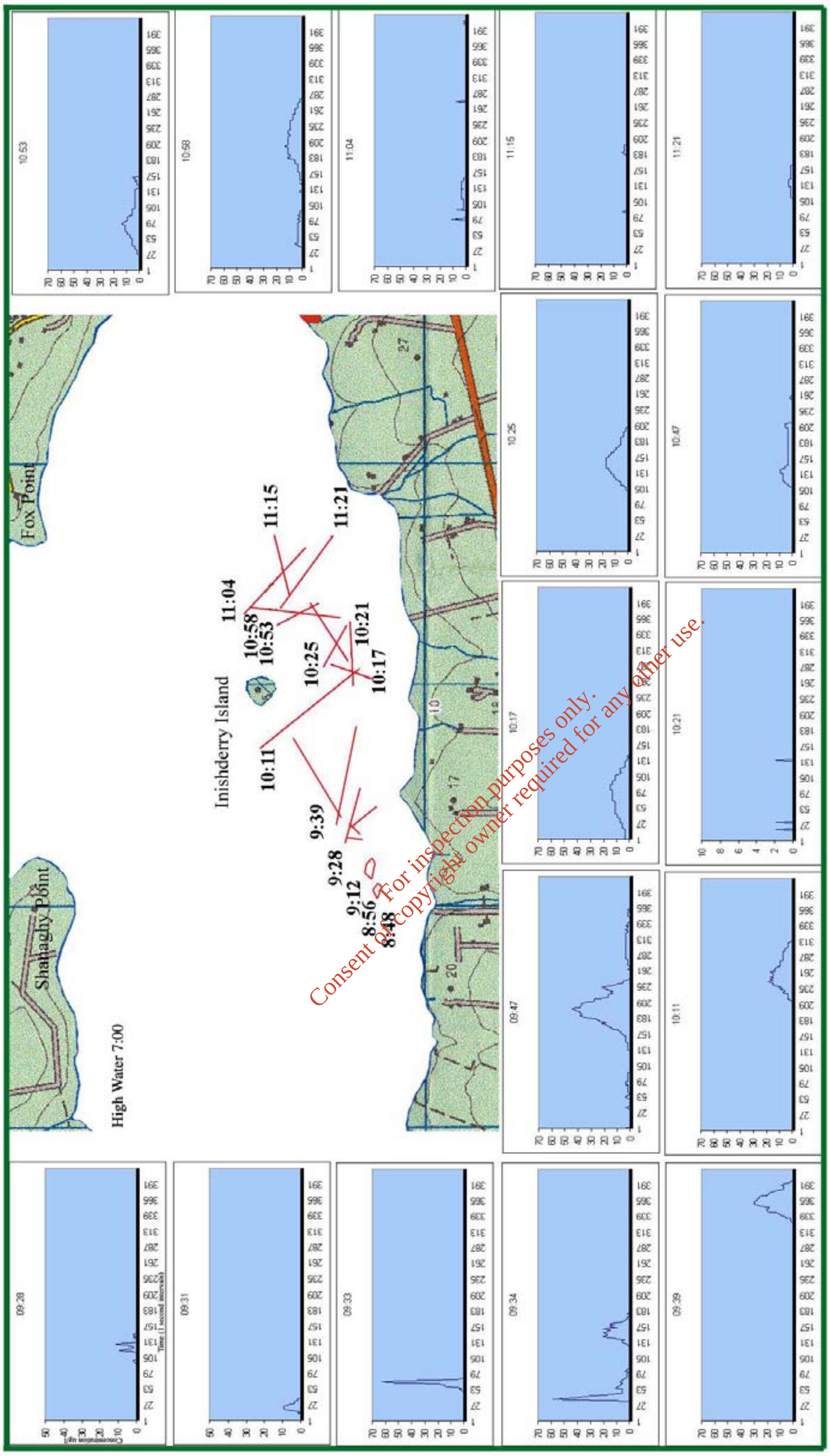



Figure 2.6.3. Dye concentration and progress following a release at Station 3 shortly after high water on a spring tide on 11/12/03

## 2.7 DROGUE STUDIES

Window-blind type drogues designed to track currents were placed at the surface, mid-water, and off-bottom where depths allowed. A R.W. MUNRO digital, hand held anemometer was used to record wind speed and direction. Drogue studies were undertaken over both a neap and spring tidal cycle. It was initially planned that three groups of current tracking drogues, released at the surface, mid-water and off-bottom, would be deployed at high water, three hours after high water, low water, and again three hours after low water at each of the proposed outfall points. However, due to the very shallow depths of water particularly at the inner site only surface drogues were deployed. The survey vessel tracked these drogues over a twelve and half hour period and fix their positions at 30-minute intervals. Wind speed and direction were recorded simultaneously from the survey vessel.

Tracks of the drogues at each station are presented in Figures 2.7.1 – 2.7.5.



Figures 2.7.1 and 2.7.2 show drogue tracks on Neap and Spring tides released at Station 1 (existing outfall) at High water, High water +3 hours, Low water, and Low water +3 hours. The Neap tide survey was carried out on the 21st October 2003; low water was at 08:52Hrs and high water at 15:16Hrs. The Spring tide survey was carried out on the 28th October 2003, high water was at 07:07 and low water at 13:10.

At Low water during the Neap tide, the water depth at Station 1 was initially too low (< 0.5m) to deploy a window-blind drogue thus surface floats were used instead. These headed east toward Inner Broadhaven Bay before becoming grounded. Three hours after Low water the water depth at Station 1 was sufficient to deploy a window-blind drogue that, along with the surface floats, moved westward through the canal into Blacksod Bay. On the ebbing tide the High Water drogue also headed west into Blacksod Bay. Three hours following high water the final drogue moved east toward Inner Broadhaven Bay while the two drogues that passed through the canal headed toward the eastern side of Blacksod Bay. During the Spring tide it was too shallow to deploy drogues at Station 1 for roughly two hours either side of Low water. The drogue deployed at High water moved into Inner Broadhaven Bay on the ebbing tide.

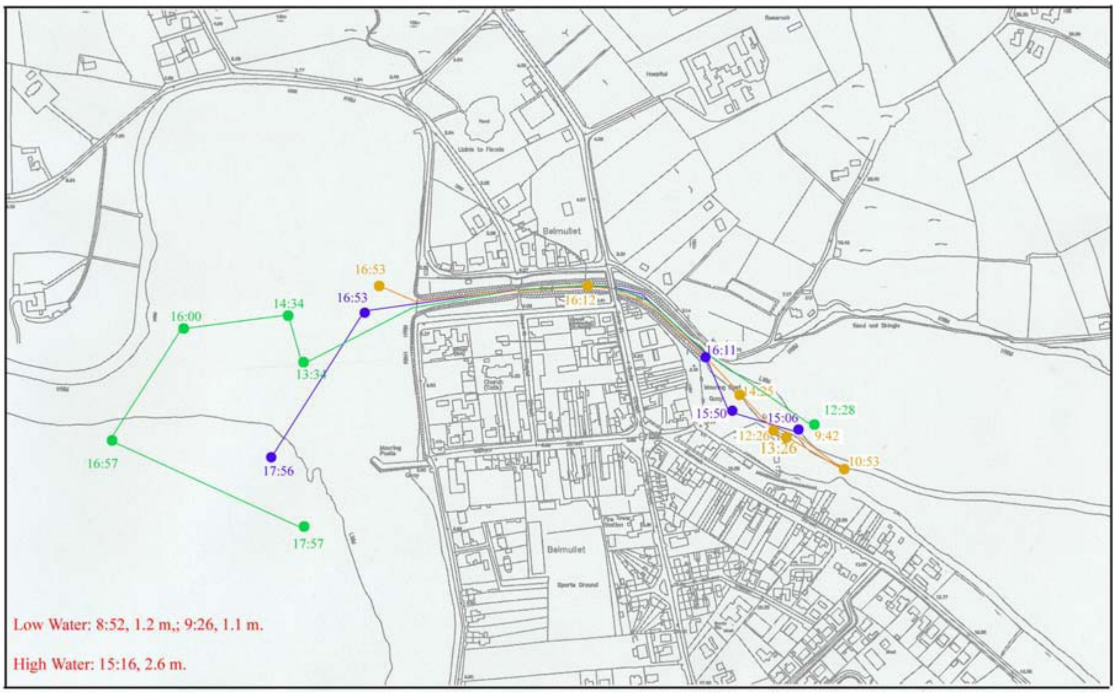



Figure 2.7.1. Drogue survey, Station 1 neap tide, Belmullet, Co. Mayo, 21/10/03.



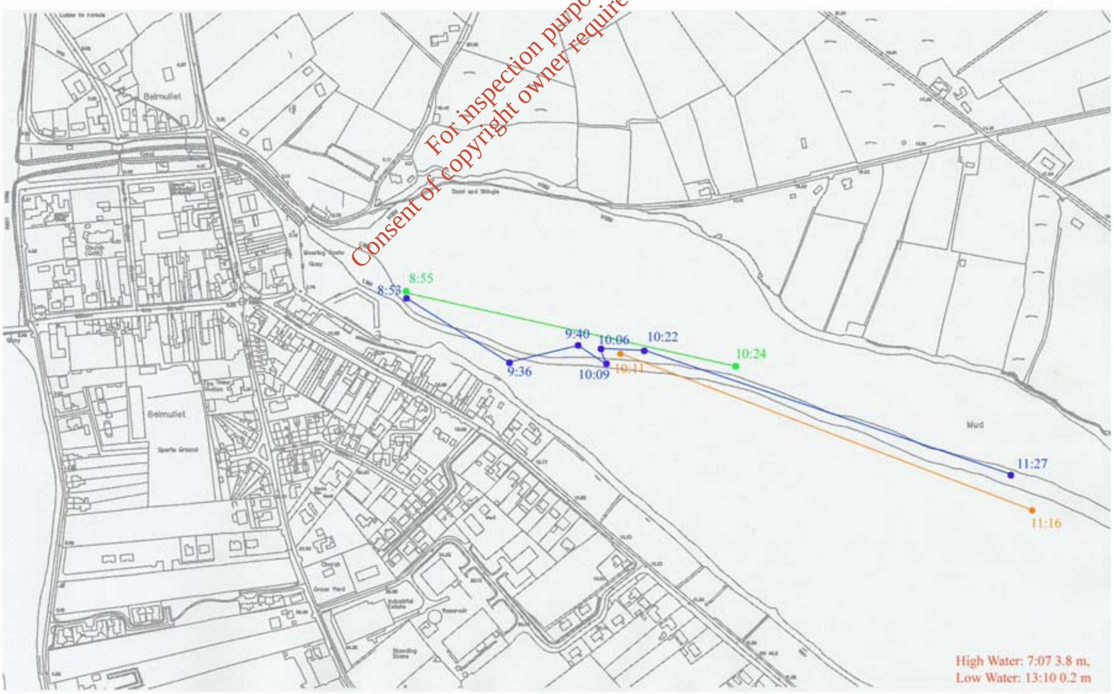



Figure 2.7.2. Drogue survey, Station 1 spring tide, Belmullet, Co. Mayo 28/10/03

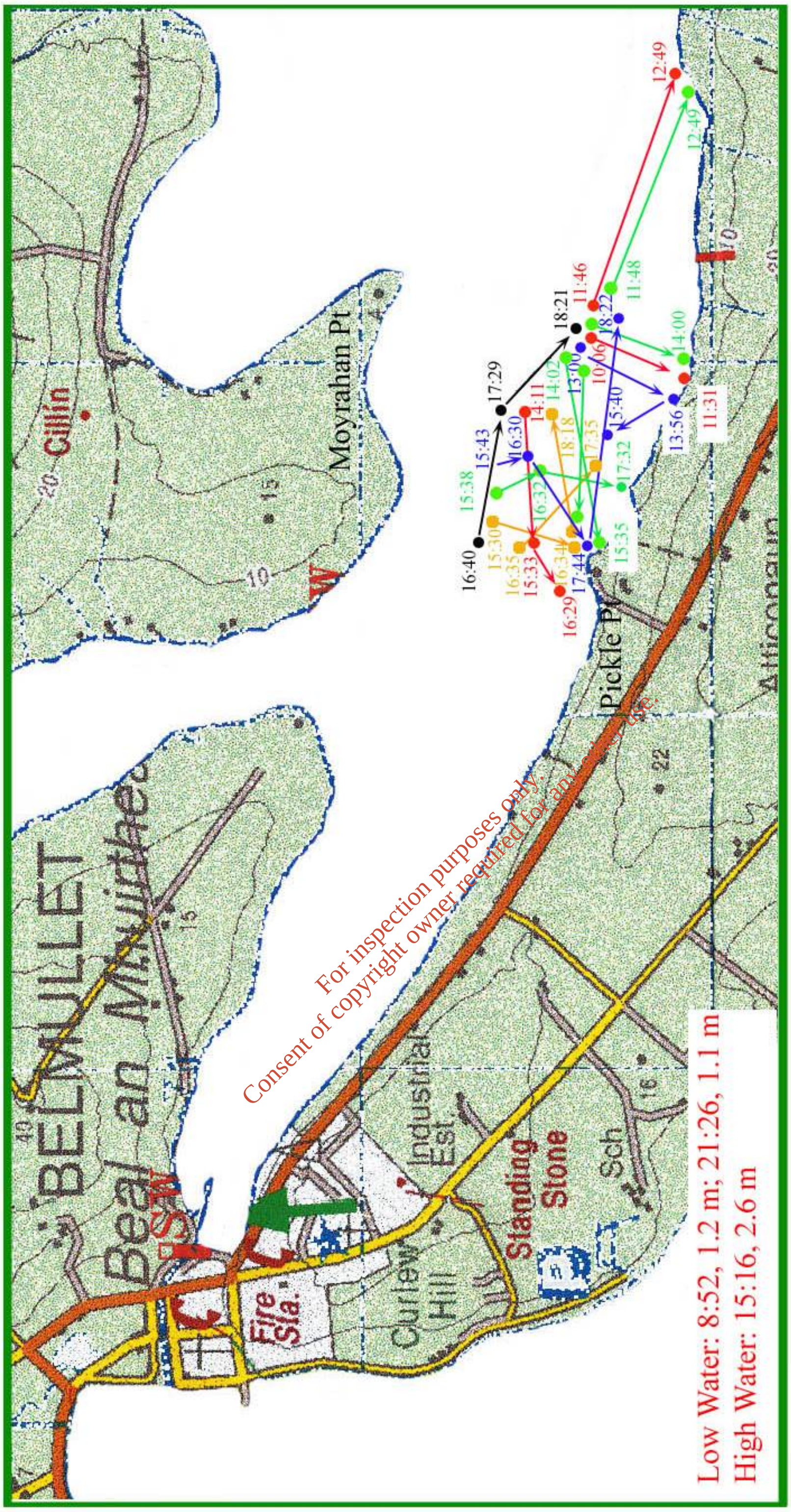





Figure 2.7.3. Drogue survey, Station 2 neap tide, Belmullet, Co. Mayo, 21/10/03.

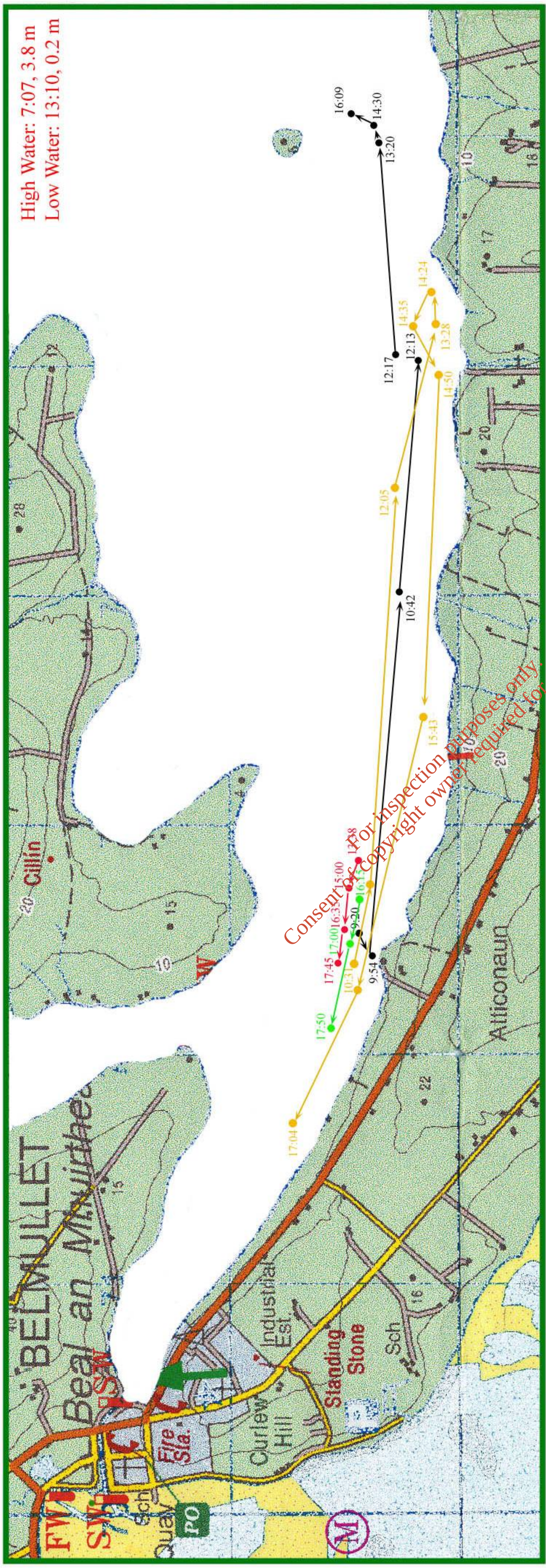



Figure 2.7.4. Drogue survey, Station 2 spring tide, Belmullet, Co. Mayo, 28/10/03.

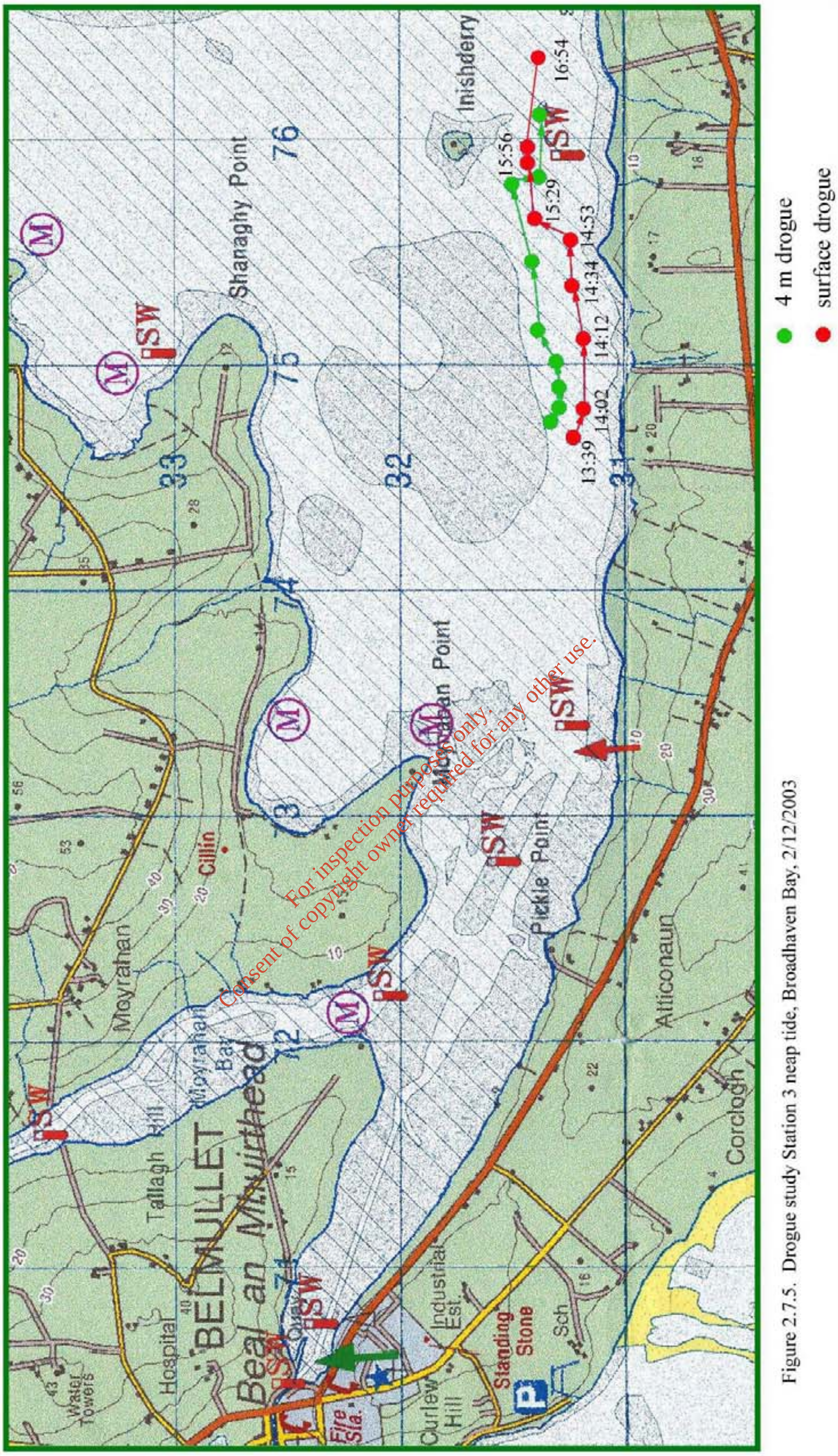





Figure 2.7.5. Drogue study Station 3 neap tide, Broadhaven Bay, 2/12/2003

Figures 2.7.3 and 2.7.4 show the drogue tracks on Neap and Spring tides respectively, at Station 2 (proposed outfall) at High water, High water +3 hours, Low water, and Low water +3 hours. During the flooding Neap tide, little drogue movement was recorded at Station 2. The drogues headed west toward the inner bay but were repeatedly pushed onto shore by the wind. On the ebbing tide, the drogues moved east, again being pushed toward the shore by the wind. After high water on the Spring tide the drogues deployed at Station 2 headed east along the shore. However, the drogue deployed three hours after High water having initially moved eastwards changed direction and headed west, back in toward Pickle Point where it was originally deployed. This is most likely due to the change in water movement from the ebb to the flood. The drogues released at Low water and Low water +3 hours headed west with the flooding tide toward the inner bay.

Figure 2.7.5 shows the track of two wind-blind surface drogues over the course of a neap tide cycle, carried out at the same time as the dye study of December 2nd 2003. One drogue was designed to follow surface currents with the second designed to follow currents at a depth of 4 metres. As can be seen from the figure both drogues moved in the same eastward direction and kept to a similar track over the course of the study.



## 2.8 WATER AND SEDIMENT QUALITY DATA

Freshwater, seawater and sediment grab samples were collected at the locations identified as per the tender document. The positions of the stations (see Figure 1.1.1) were fixed by DGPS and numbered from 1-16. Complete Laboratory Solutions, an accredited laboratory in Rosmuc, was used for analysis of the samples. It was recommended in the tender document that the spore forming *Clostridium perfringens* be used as a marker in the marine sediments as *E.coli* and other non-spore forming bacteria quickly die in aerobic conditions, while *Clostridium* is able to withstand such conditions by forming a spore. As such it reflects the long-term effects of sewage on the seabed. Aqua-Fact was directed to include for this additional analysis.

Sampling was carried out for all water quality stations on three dates in October the 15th, 22nd and 29th. Seawater samples were collected at Stations 1 to 9, over a full tidal cycle at spring and neap tides. Freshwater samples were collected from Stations 12 to 16 during low flow and high run off periods. Stations 10 and 11 were located at either end of the canal in Belmullet.

Parameters measured included *E.coli*, total coliforms, salinity, temperature, dissolved oxygen, B.O.D., suspended solids, orthophosphate, ammonium and nitrate. Marine samples were taken at 0.5 m below the surface. The results of the analyses are presented in Figures 2.8.1 to 2.8.8. The results tables are contained in Appendix II.

Marine water samples, taken at the proposed outfall locations (Stations 1 and 2) in Inner Broadhaven Bay during neap and spring tides, were analysed for nitrate levels (as $NO_3$). These samples were taken during the direct reading current meter surveys, at intervals of 30 minutes when possible. The samples were kept cool before being sent for analysis. The first suite of samples was taken on the 22nd of October 2003 (Neap tide) and the second on the 29th of October 2003 (Spring tide). The results of the nitrate analysis from the proposed outfall locations are presented in Appendix II as Table 2.8.1. Relatively little of the nitrate found in natural waters is of mineral origin, most coming from organic and inorganic sources, the former including waste discharges and the latter comprising chiefly artificial fertilisers. Surface water regulations for Nitrate measured as mg/l $NO_3$ is 50. All recorded values are well below the regulation level.



Profiles for temperature, salinity and dissolved oxygen were taken using a Temperature/Salinity meter and an oxymeter at the two proposed outfall locations on the same dates as above. The results obtained are presented in Appendix II as Tables 2.8.2 – 2.8.5. Recorded values for temperature and salinity were normal for a costal location for this time of year. Dissolved oxygen levels are slightly lower than normal coastal levels (100% saturated) and reflect the retentive nature of the area that receives an organic input. This is particularly evident from the bottom records for the existing outfall location where dissolved oxygen values were generally below 90% saturation levels.

Figure 2.8.1 presents the results of the analysis for suspended solids and BOD in seawater while Figure 2.8.2 details the results of the analysis for suspended solids and BOD at the freshwater locations on the three sampling dates. The level of suspended solids in a water body is a reflection of the turbidity of the water and is significant in that the solids may consist of algal growths and hence be indicative of the level of eutrophication of the water body; they may indicate the discharge of washings form *e.g.*, construction; they will reduce light penetration in surface waters and interfere with aquatic plant life; they will damage fishery waters and may affect fish life; they may form deposits on the bed of rivers and estuaries which will in turn give rise to septic and offensive conditions; and they may indicate the presence of unsatisfactory sewage effluent conditions. The levels recorded in Inner Broadhaven Bay are variable between sampling stations and also between sampling dates. This reflects differences in station locations and also weather conditions where increased rainfall and wind prior to sampling will have increased suspended solids in the water column. It was notable during the study that water visibility on the north side of the bay was significantly clearer than the south side, a fact that is highlighted by the suspended solid record for the 22/10/03 (Figure 2.8.2.) where the level recorded at station 3 (3.5 mg/l) located on the north shore is significantly lower than the stations located on the south shore. The EU maximum admissible concentration for salmonid waters is ≤25mg/l and aside from the samples taken on the 22/10/03, the majority of samples taken on the 15th and 28th October 2003 are below this limit.



The (five-day) BOD of water is the amount of dissolved oxygen taken up by bacteria in degrading oxidisable matter in the sample, measured after five days incubation in the dark at 20°C. The BOD is simply the amount by which the DO level has dropped during the incubation period. According to Flanagan (1992), waters with a BOD falling within the range of 0 - 4mg/l are of satisfactory quality for salmonid fish and thus for other beneficial uses. The EU criteria for salmonid waters sets a maximum admissible concentration of ≤5mg/l. The BOD measurements made in the vicinity of Belmullet were variable with a number of samples, particularly the inner stations on the 15/10/03, recording values above these guideline levels (see Figure 2.8.1. and Tables 2.8.6. to 2.8.8.)

Figures 2.8.3 and 2.8.4 present the results of phosphate, nitrate and ammonia levels recorded from the samples taken at the seawater and freshwater locations, respectively, on the 15th, 22nd and 28th October 2003. Recorded levels of phosphate and nitrate are generally within surface water regulations for A1 waters of 0.22 mg/l P for phosphate and 50 mg/l $NO_3$ for nitrate. However, the majority of ammonia records are above the surface water regulations for A1 waters of 0.2 mg/l $NH_4$. Ammonia is generally present in natural waters, though in very small amounts, as a result of microbiological activity which causes the reduction of nitrogen-containing compounds. The form of ammonia – whether it is free, as $NH_3$, or saline, as $NH_4$, depends on the pH and these forms are not distinguished from one another during analysis.

Results for *E. coli* and total coliforms are presented in Figures 2.8.5 and 2.8.6 for the marine and freshwater samples (includes Belmullet canal), respectively. Figure 2.8.7 represents the results of the analysis for faecal streptococci levels in the freshwater (and canal) samples. The results of the analyses are also presented in Appendix II as Tables 2.8.6 to 2.8.8.

In the bacteriological analysis of water, the universal indicator organisms are the coliforms, especially *Escherichia coli*. These bacteria are of definite faecal origin (human and animal) and they are excreted in vast numbers. Their presence in a water supply is proof that faecal contamination has occurred and is a definite indication that the risk that pathogens may be present. The absence of these faecal coliforms [specifically *E. coli* Type 1 (classified on the basis of test responses)] indicates strongly the probability that pathogens are absent. Because not all coliform organisms (or organisms which show the same test behavior as coliforms) are of faecal origin, some type being able to grow in soil, a second analysis is carried out for the presence of total coliforms, giving an indication of the general level of microbiological contamination of a water. The latter is a confirmatory test. The interpretation of the results of analysis may be summarised as follows.



Where *E. coli* are present in large numbers the inference is that heavy, recent pollution by human or animal wastes has occurred; is the *E. coli* numbers are low it is inferred that pollution from the same source(s) is either less recent or less severe. If coliforms not including *E. coli* are observed the indication is that either the pollution is non-faecal in origin or of remote, faecal origin such that the intestinal coliforms have not survived. However, if any coliforms at all are found in a treated drinking water supply, following chlorination, it should be concluded that inadequate treatment is being applied or else the contamination has been introduced during distribution of the water, or in the sampling or handling of the sample(s). Any indication at all of contamination, however apparently mild, must be regarded as a matter of gravity and the circumstances investigated promptly.

Bacteriological results can be measured against the Bathing Waters Directive, the Drinking Water Directive, the Surface Waters Directive and in the case of faecal coliforms, the Shellfish Waters Directive. The Shellfish Waters Directive usually applies to faecal coliform levels in shellfish flesh, but can also be applied to the waters in which 'shellfish directly edible by man' are farmed, this is pending further legislation. The limits of these Directives are presented below as Table 2.8.10.

The seawater sites, Stations 1-9, did not exceed the limits of the Bathing Water or Surface Water Directives for total coliforms (Figure 2.8.5). However, faecal coliform (as *E. coli*) limits for the Shellfish Directive were exceeded at Station 6 on the 22nd of October and at Station 8 on the 29th of October. Figure 2.8.6 indicates that total coliform limits were exceeded at Stations 10 and 16 on the 15th of October, at Stations 10, 15 and 16 on the 22nd of October and at Stations 12, 14 and 15 on the 29th of October. Faecal coliform levels were also exceeded at Stations 10, 11, and 15 on the 15th, 10, 15 and 16 on the 22nd and at Stations 12, 13, 14 and 15 on the 29th of October. It must be noted from Figure 2.8.6 that the limits were exceeded by three orders of magnitude at some stations. As can be seen from Figure 2.8.7 all stations were within the limits for faecal streptococci except for Station 10 on the 22nd of October. This was probably due to a release of sewage into the canal at the time of the survey.



| | Faecal Streptococci | Faecal Coliforms | Total Coliforms | *Clostridium perfringens* |
|---|---|---|---|---|
| **Bathing Waters Directive** | ≤300 | <1000 guideline | ≤5000 | |
| **Shellfish Waters Directive** | | ≤300 (pending new directive – 'shellfish directly edible by man') | | |
| **Surface Water Directive** | 200 | 1000 | 5000 | |
| **Drinking Water Directive** | 0 | 0 | 0 | 0 |

**Table 2.8.10:** Water quality limits as determined by relevant EU Directives.

Caution is required in interpreting the outcome of bacterial analyses when all that is available is a once-off measurement of what is naturally a very variable parameter depending on a variety of conditions. Ideally, to achieve a sound baseline of bacterial conditions and some understanding of the conditions that regulate their occurrence, determinations should be carried out on a routine basis. Some of the more important factors which affect bacteria levels detected in the field include the nature and quantity of recent additions, presence of persistent material, other-source contamination (e.g. bird faeces, land-runoff) and the particular environmental conditions occurring at and prior to sampling.

Eight sediment samples were taken from inner Inner Broadhaven Bay (see Figure 2.9.1 for locations) using a small Van Veen Grab and analysed for *Clostridium perfringens* levels. The results are displayed as Figure 2.8.8 and in Appendix II as Table 2.8.9.



In addition to conditions that can affect numbers of bacteria as outlined above, *Clostridium perfringens*, which is an anaerobic bacterium, the nature of the oxygen conditions will influence the actual numbers encountered. The presence of *Clostridium perfringens* in a natural water or sediment is an indication of some degree of faecal contamination either recently or previously. *C. perfringens* forms resistant spores which survive for much longer periods than the vegetative organisms of the coliform group and which also usually resist chlorination procedures. Areas not experiencing faecal contamination will not show the presence of *C. perfringens*.

While a positive confirmation of *Clostridium* in the sedimentary environment is indicative of sewage contamination, the actual distribution of *Clostridium* CFU's (colony forming units) may be influenced by a number of factors. For instance, a very strong association between sediment fine particle content and sediment *Clostridium* distributions has been demonstrated for other areas. Thus, the number of *Clostridium* units detected per gram of sediment (plotted on a logarithmic scale) has been shown to increase in a more or less an exponential relationship as sediment silt-clay content increases. This relationship is not surprising as high levels of silt-clay are indicative of sink areas or areas of accumulation of fine particulate material. Conversely, low levels of silt-clay suggest areas subject to either non-deposition or scour transport of fine material. Seeing that *Clostridium* CFU's are of a similar order of magnitude as clay

Figure 2.8.1: Suspended solids - seawater. 15th/22nd/29th October 03. Belmullet water samples

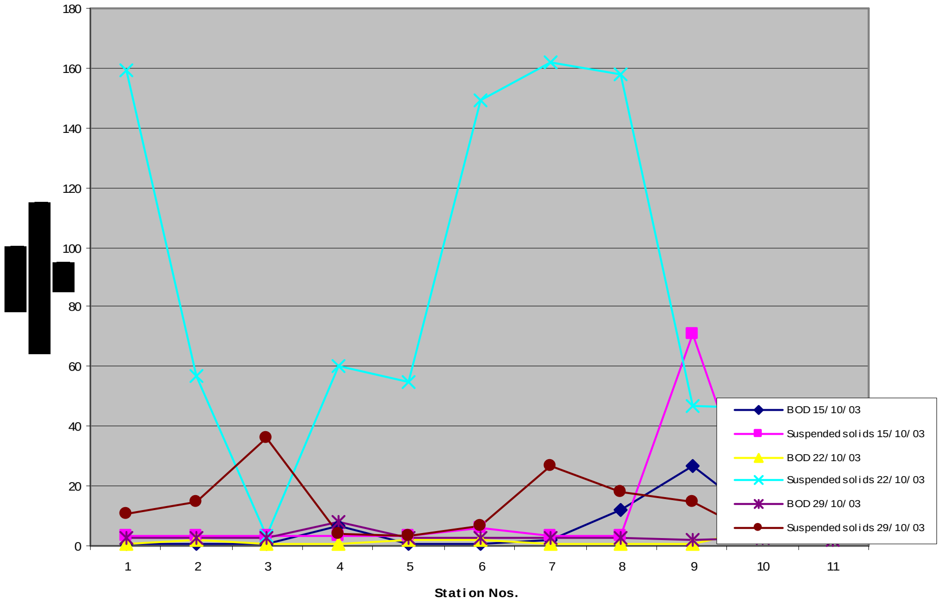





Figure 2.8.2: BOD/Suspended Solids - Freshwater. 15th/ 22nd/ 29th October 03 Belmullet Water Sampling

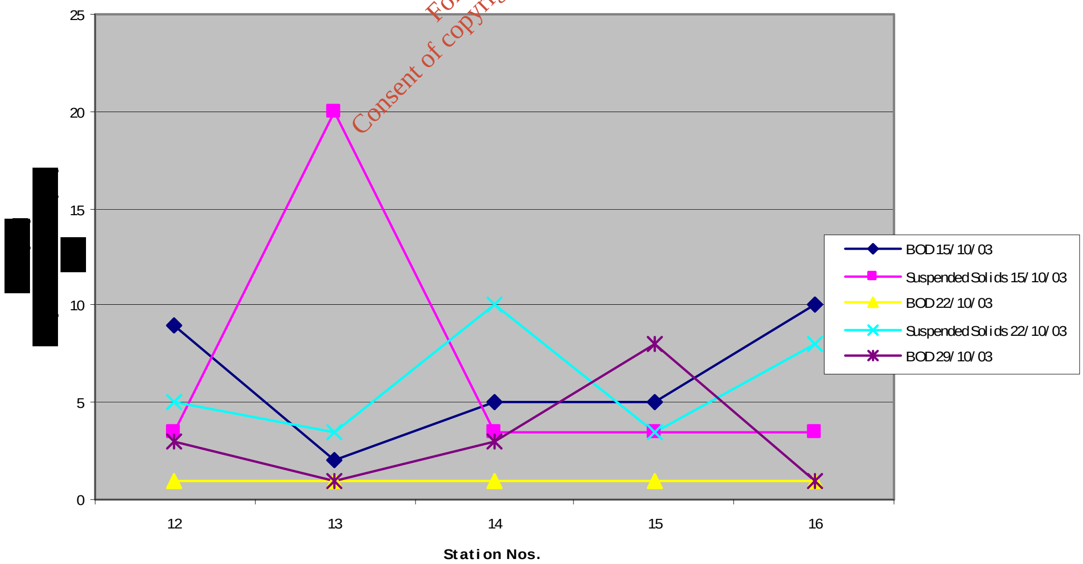


Figure 2.8.3: Phosphate, Nitrate and Ammonia levels in seawater samples
15th/22nd/29th October 03 Belmullet water sampling

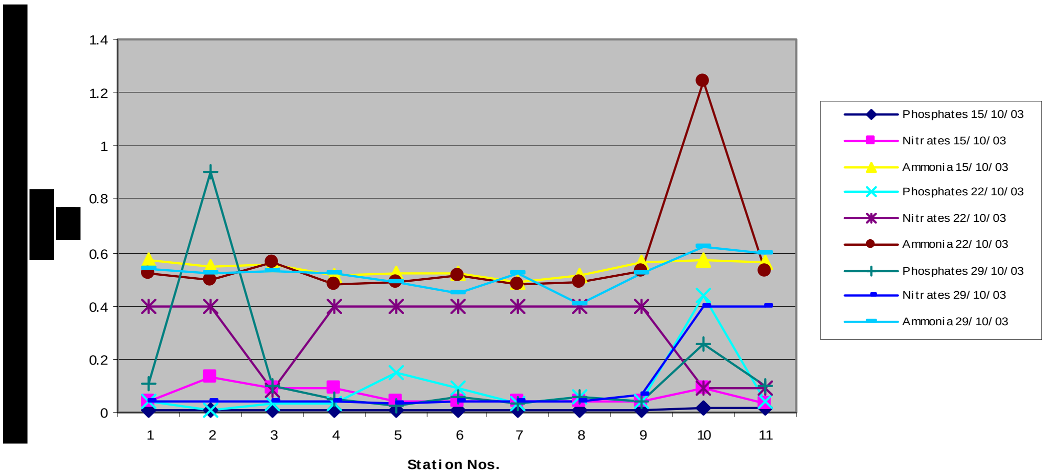





Figure 2.8.4: Phosphate, Nitrate and Ammonia levels in freshwater samples
15th/22nd/29th October 03 Belmullet water sampling

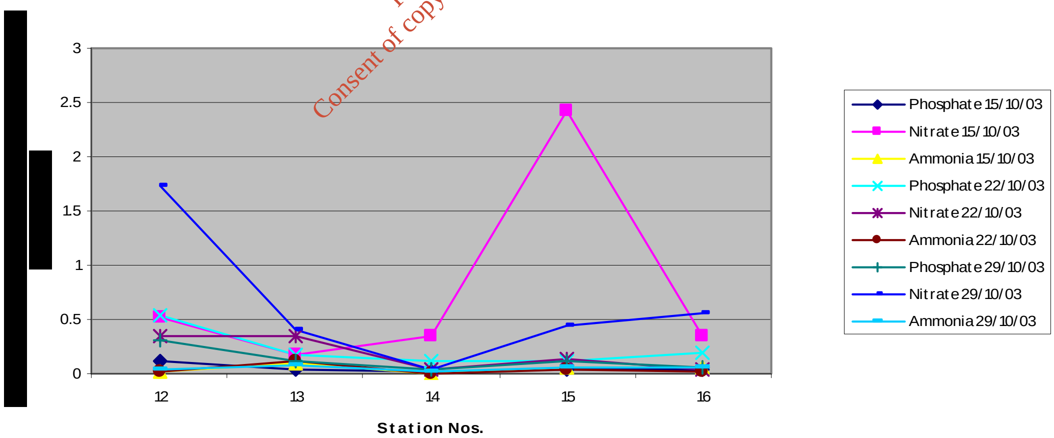


Figure 2.8.5: E. coli and total coliforms levels in seawater samples 15th/22nd/29th October 03 Belmullet water sampling

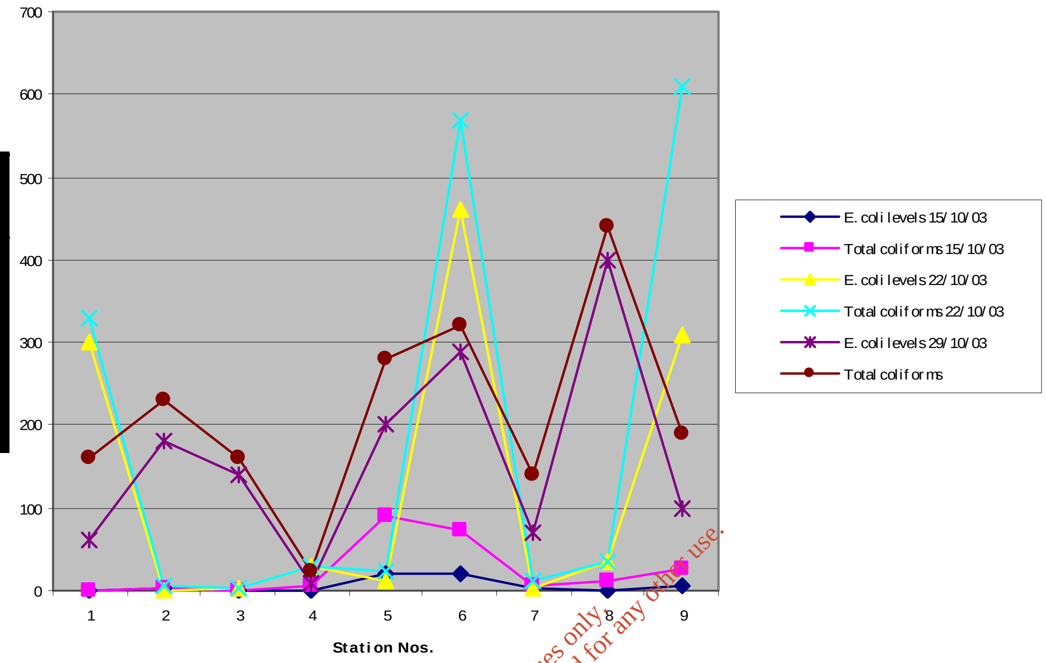





Figure 2.8.6: E.coli and total coliforms levels in canal/freshwater samples 15th/22nd/29th October 03 Belmullet water sampling

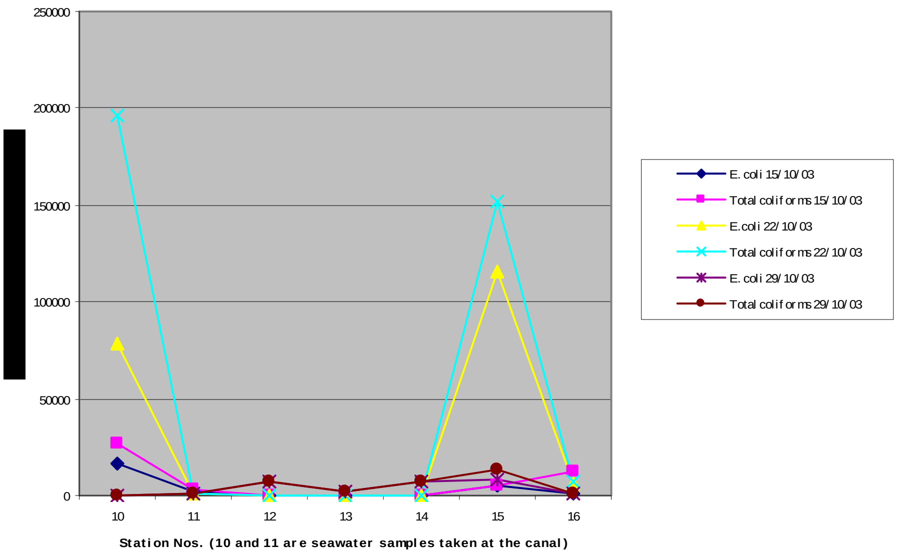


Figure 2.8.7: Faecal streptococci levels in canal/freshwater samples 15th/22nd/29th October 03Belmullet water sampling

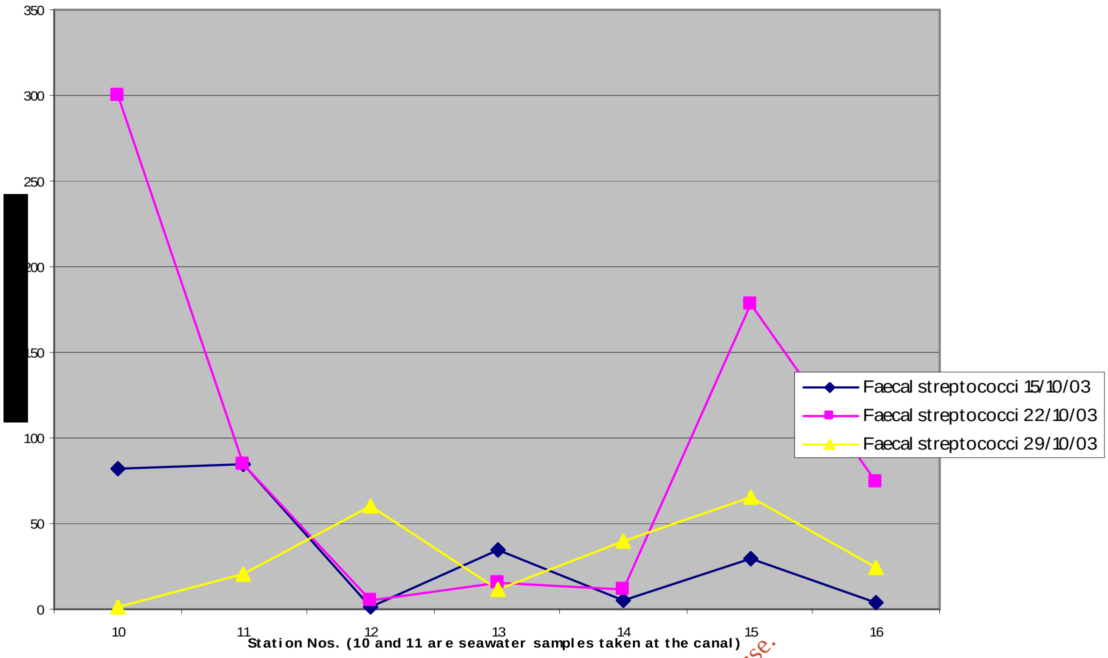
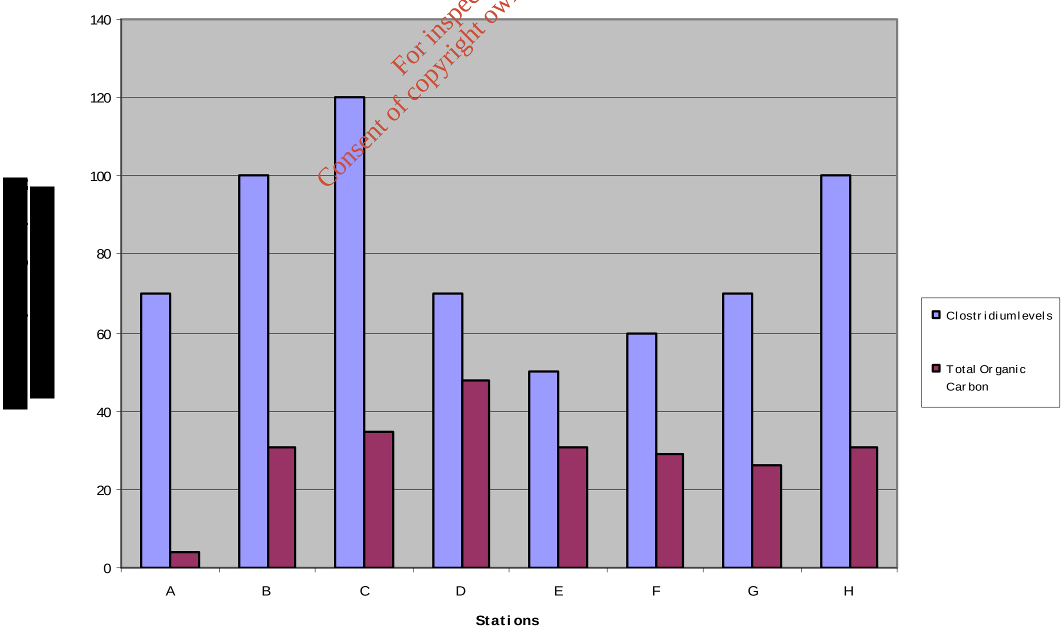





Figure 2.8.8: Belmullet Marine Survey Sediment samples results



particles, one would expect them to have a similar distribution to sediment fine particles.

The general indications of this study are that the locations sampled are under the influence of some sewage contamination, i.e. in the absence of faecal material *Clostridium* should not be encountered. Whilst this could indicate either a recent low level of contamination or else contamination from a distant source it may also reflect the local hydrographic and sedimentary environment, which seems to characterise the Inner Broadhaven Bay area. In other words, the locations sampled during the course of the present investigation occur in areas where the substrate type is basically a muddy fine sand. The nature of the substrate encountered indicates a depositional environment so that settlement or accumulations of particulate material is likely to be significant. There are no EU criteria for levels of *Clostridia* in sea water while mandatory levels for drinking waters are set at ≤1 (MPN). In general, the higher the level of CFU counts, the greater the degree of contamination. The highest counts in the present survey were recorded at stations B, C and H and probably indicate the presence of outfall points at these locations. However, with levels ranging from 50 to 120 cfu/g. there is no major difference between stations given the distribution characteristics of this organism as explained above.



## 2.9 BENTHIC SAMPLING

A benthic survey was carried out on the 22nd of October 2003. Grab samples were collected at eight sites (A-H) between the proposed outfall location at Pickle Point, westwards towards the eastern mouth of the canal (Fig. 2.9.1). The co-ordinates for these eight sampling sites are given in Table 2.9.1.

These grab samples were taken to determine the baseline diversity of fauna, the presence and importance of indicator species found, and the effects of any perceived organic pollution within the area. A sub-sample of each grab was taken for particle size, organic carbon, and clostridium analysis; the remainder was preserved in 4% formalin solution for taxonomic identification and enumeration. The faunal samples were sieved through a 1mm sieve and identified to species level where possible.

| Station | N | W |
|---|---|---|
| A | 54 12.92 | 09 57.22 |
| B | 54 13.06 | 09 57.45 |
| C | 54 13.16 | 09 57.24 |
| D | 54 13.26 | 09 58.14 |
| E | 54 13.33 | 09 58.30 |
| F | 54 13.38 | 09 58.57 |
| G | 54 13.40 | 09 58.91 |
| H | 54 13.48 | 09 59.17 |

**Table 2.9.1: Co-ordinates of the eight grab sampling sites.**

***Note:** These are the same locations as the marine sediment samples.

A total of 49 species were recorded from the eight stations sampled. Of the total number of species identified there were 24 Polychaetes, 2 Oligochaetes, 13 Crustacea, 9 Molluscs, and 1 Echinoderm. No unusual or rare species were found. A full species list is included as Appendix III.



The sediments at each station consisted mainly of blackened mud to muddy sand indicating oxygen-stressed conditions. Stations G and H returned the least number of species. However, these stations had the highest densities of *Capitellidae* sp. (27 and 166, respectively). *Capitellidae* sp. are direct deposit feeding worms that inhabit muddy sands and muds ingesting sediment as they burrow through it. *Capitella capitata* is an opportunistic species, typical of an environment with an unexploited source of organic material and is tolerant of oxygen-stressed conditions. According to the Marine Nature Conservation Review (1997) the most suitable classification for this type of habitat would be estuarine sublittoral muds (IMU.EstMu), which include shallow sublittoral muds, extending from the extreme lower shore to about 15m depths in estuarine conditions. Such habitats typically support communities of oligochaetes and polychaetes. Some of the characterising species of this habitat type include the polychaete *Nepthys hombergii*, found at all stations except station A, the polychaete *Pygospio elegans* found at five stations, and the polychaete *Capitella capitata* found at station H. *Tubificida* sp. (oligochaetes) are also commonly found in this habitat type with high numbers being recorded at stations D (47) and E (43).

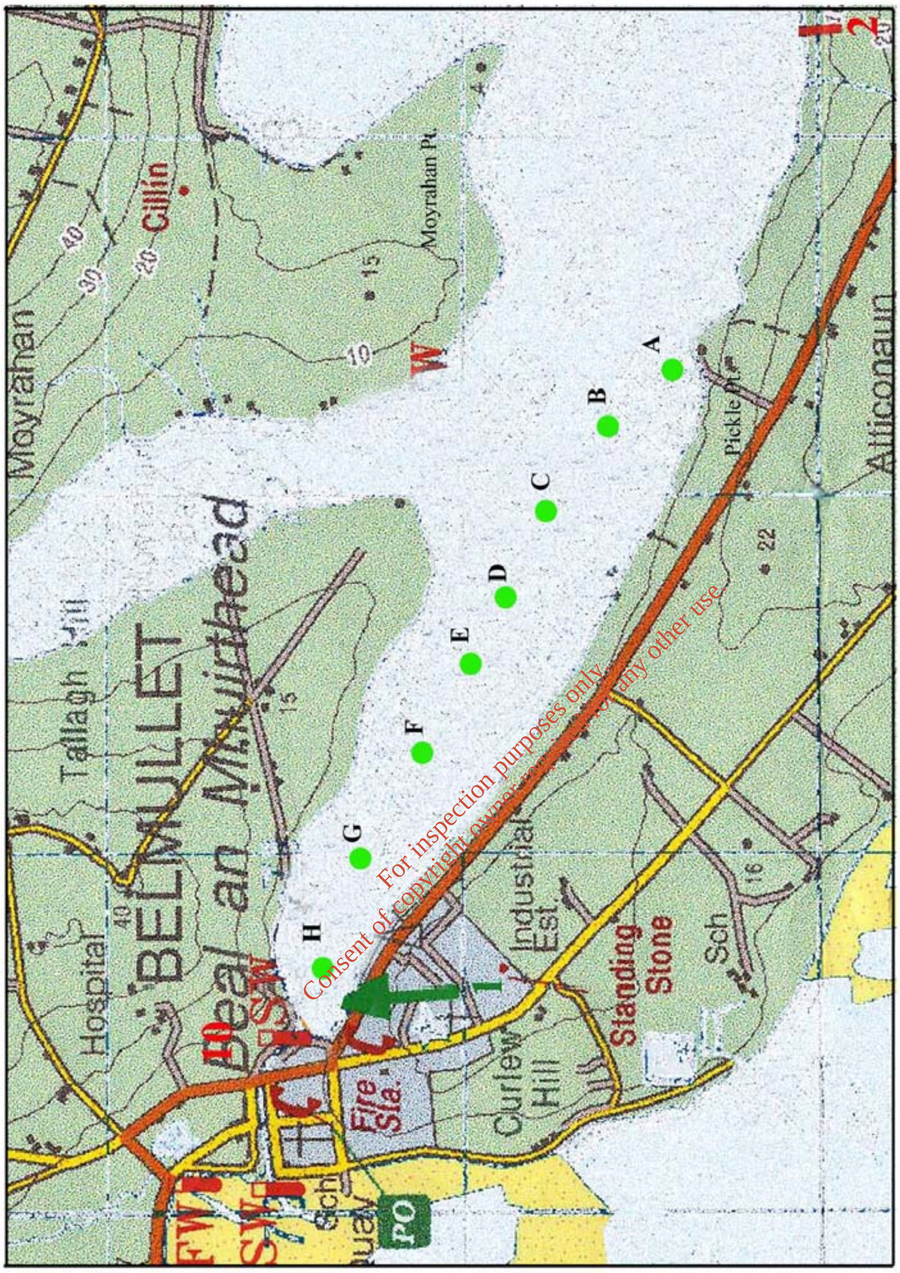



Figure 2.9.1. Benthic and *Clostridium* sampling locations, Belmullet Co. Mayo, 22/10/03.

The species of Mollusca found are all indicative of oxygen-stressed muddy sediments. Crustaceans were found in low numbers at Station A, Station B, Station C and Station E.

Species found at Station A are common and usually found in mud or muddy sands, such as the amphipods *Corophium crassicorne* (a burrower in muddy sands) and *Ampelisca brevicornis*. The Tanaid *Tanaopsis graciloides* is a common species from sandy mud.

Station B had the highest diversity of them all, with eight different species including *Liocarcinus arcuatus* (a sandy bottom decapod) and the amphipods *Erichtonius punctatus* (a tube builder often found in salt marshes), *Microdeutopus* sp. and *Corophium crassicorne* (both amphipod species from muddy substrata).

Only two crustaceans were found at Station C, the amphipod *Ampelisca brevicornis* and the isopod *Gnathia formica* (praniza larval stage). Both are species of intertidal and sublittoral muddy bottoms. Eight individuals of the amphipod *Gammarus locusta* were found at Station E, being this a common species among algae and debris.



## 2.10 HYDROGRAPHIC MODEL

### Model Background

The type of model used in this study, DIVAST, is amongst the best tools available for the modelling of hydrodynamic conditions within a coastal environment. The mathematical formulation of the model is based on the well-validated Navier-Stokes equations that describe variations in current speeds and directions at discrete intervals of time. These equations have been well validated on many hydraulic engineering studies and are widely used for the type of problem considered in this study. DIVAST uses an implicit finite difference scheme to solve the Navier-Stokes equations for unsteady flow conditions. The finite difference technique is the most common method employed to solve these equations and is ideally suited for total water quality management of a water body as well as evaluating individual problems.

The computer model DIVAST was used to carry out a hydrodynamic study of Inner Broadhaven Bay. The purpose of this study was to examine flow patterns and current velocities in order to determine whether the hydrodynamic characteristics of the area were suitable for coping with discharge from outfall pipes in specific locations.

The model DIVAST was developed at the University of Bradford about 17 years ago and is extended and upgraded on an ongoing basis. The model is widely used in Ireland and the U.K. for many different types of hydro-environmental studies in coastal waters such as sewage effluent discharges, oil spill modelling, aquaculture assessment and water quality management planning. The model has been used to date on more than 200 such studies throughout Ireland and the U.K. and has proven it to be a reliable tool for such analyses. DIVAST is an industry standard package for water quality model studies.

**Model Development**



The first stage consisted of developing a water circulation model of Inner Broadhaven Bay to compute the hydrodynamic patterns and tidal elevations within the estuary for prescribed environmental conditions. The second stage in the study was the calibration of this hydrodynamic model against field data.

A finite difference model of Inner Broadhaven Bay was developed using data obtained from a detailed bathymetric survey. The data was interpolated and a grid was created, using the commercially available software SURFER, to produce the finite difference grid. The grid had equal spacing of 30m x 30m in two orthogonal directions. A total of 57,950 grid points were used to define the model. At each grid point the water depth at that location is identified to the model using the bathymetric data. A three-dimensional surface plot of the bathymetry of the bay is shown in Figure 2.10.1

The topography of the area is defined by specifying land boundaries, which delineate the extent of the water body. At the northern limit of the model a water elevation boundary is specified. This boundary condition is the main forcing function that induces circulation in the water body.

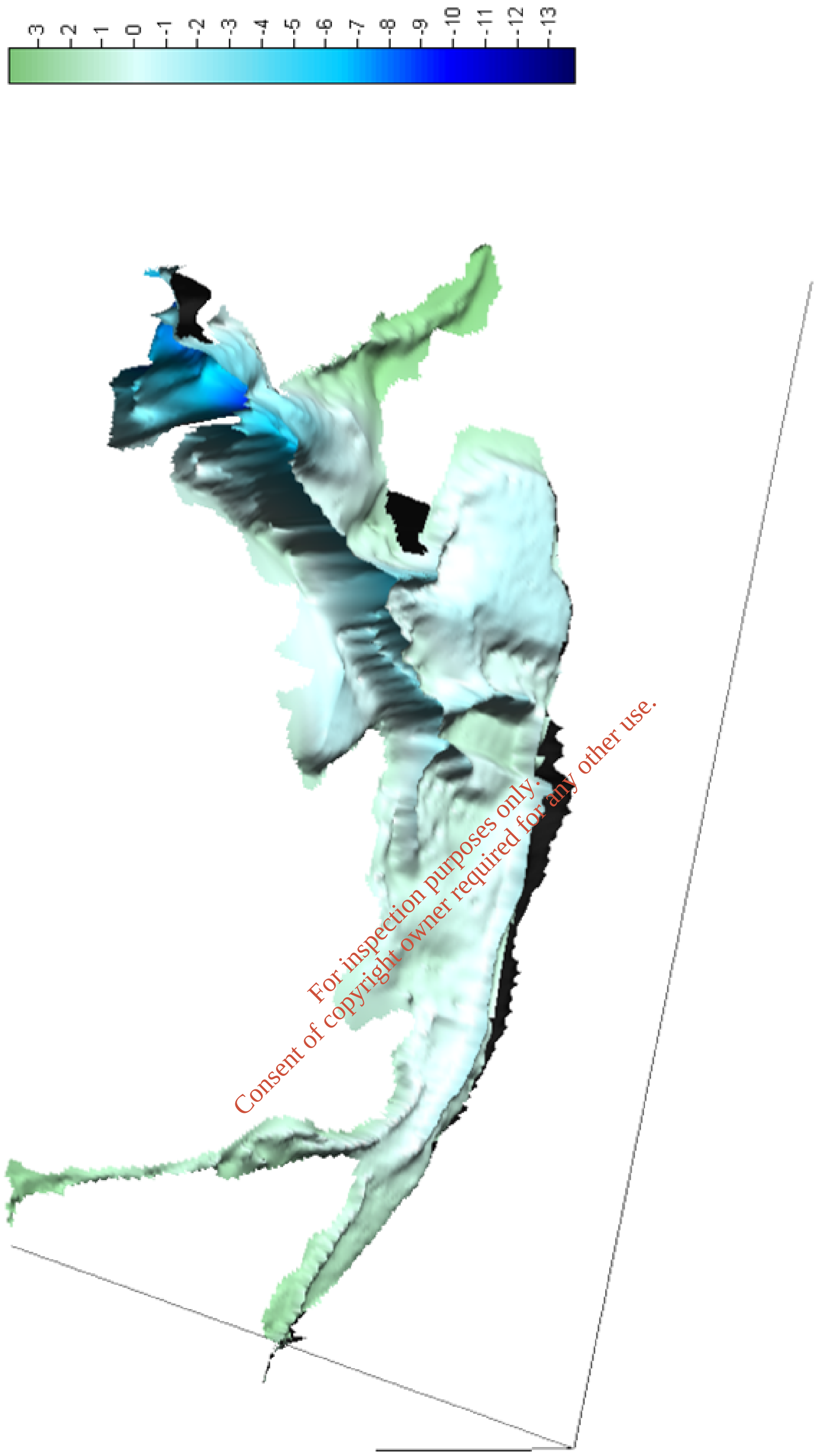





Figure 2.10.1 – 3D bathymtric plot of inner Broadhaven bay (m)

The water currents that are observed in coastal waters are induced by many different forces. In the model employed for this study the following significant forcing functions were incorporated into all simulation runs of the hydrodynamic model:

- Tide elevations
- Coriolis effect

The Coriolis force induces water currents due to the fact that the water body is on the surface of a rotating globe. The force is a function of the latitude of the water body and the rotational velocity of the earth, in this case considered to be 54.23° and 400 m/s respectively.

**Hydrodynamic Model Calibration**

The calibration of computer models is an important aspect of any water quality study. Only when a model is calibrated will confidence be gained in model results and can decisions be made on them. Details of this calibration exercise are now presented.



The hydrodynamic model was calibrated by comparing model predictions against field measurements of current speeds and water surface elevations for given environmental conditions. When running the model, tidal elevations were specified at the northern open sea boundary for spring and neap tides. These elevations corresponded with measured tidal dynamics. For the calibration simulations, the tidal elevations as measured on the day when the hydrographic survey was carried out, were specified to the model.

**Calibration Results**

The hydrodynamic model was calibrated by comparing current velocities and water surface elevations as calculated by the model against field measurements recorded by the current meters and tide gauges as detailed in Figure 1.1.1. The hydrodynamic model was run for a full spring-neap tidal cycle to ensure a comprehensive set of data was available for comparison. The current velocities and water surface elevations as calculated by the calibrated model and those measured in the field are presented in Figures 2.10.2 – 2.10.5.

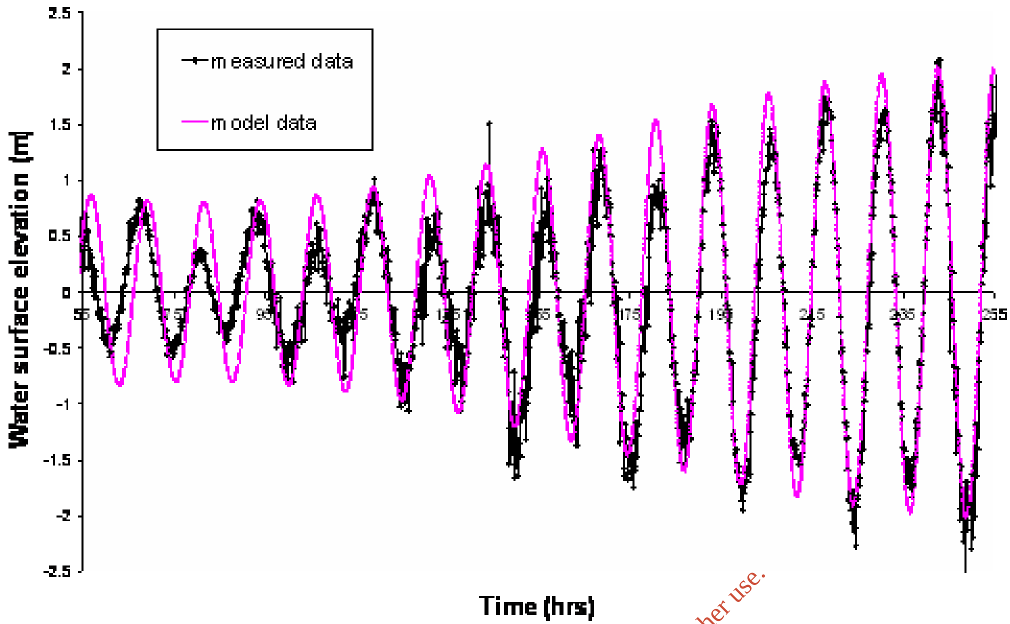



Figure 2.10.2: Comparison of water surface elevations at Ballyglass



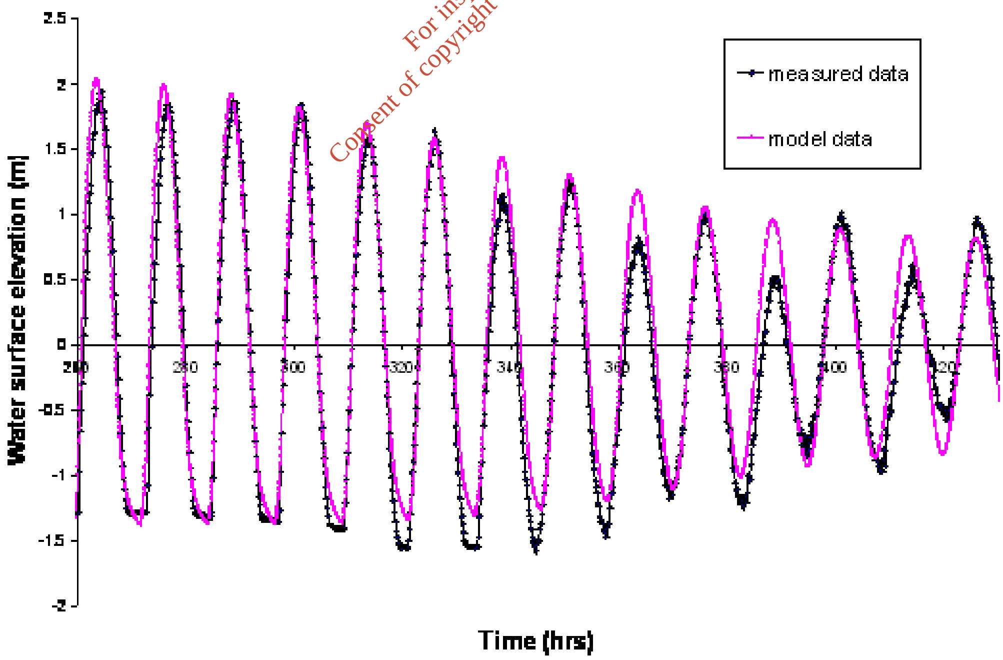



Figure 2.10.3: Comparison of water surface elevations at Pickle Point.

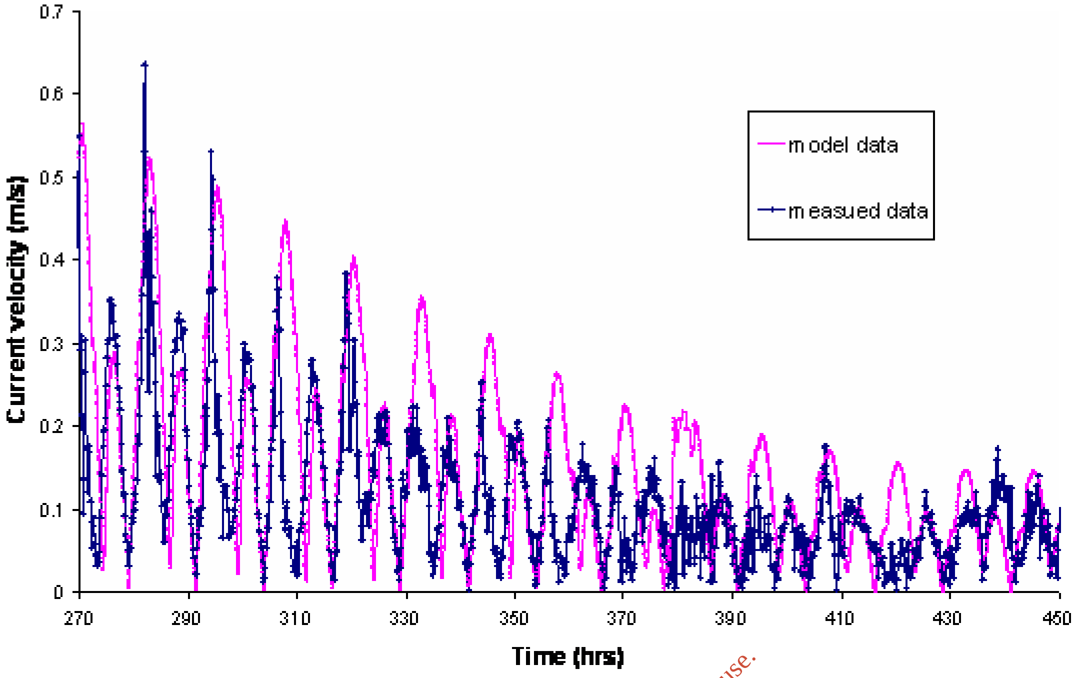



Figure 2.10.4: Comparison of current velocities at Ballyglass.



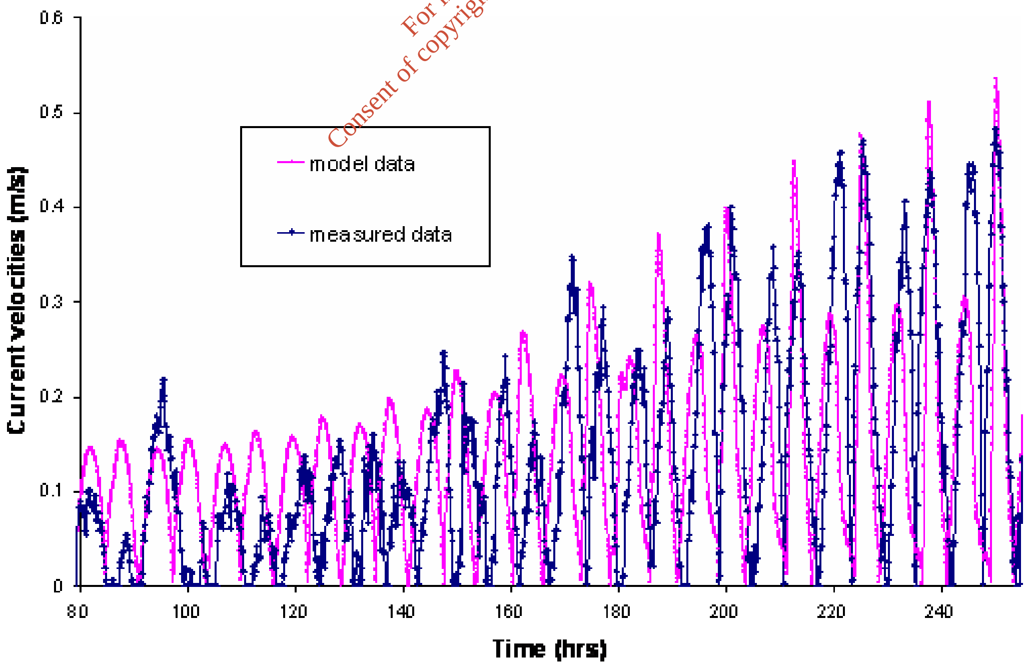



Figure 2.10.5: Comparison of current velocities at the East Canal.

The results presented in these Figures are a good verification that the model is accurately predicting the hydrodynamic conditions of Inner Broadhaven Bay

**Hydrodynamic Simulation Results**

The hydrodynamic model was run for a full spring-neap tidal cycle to examine the water circulation patterns and the variation of current velocities throughout the bay. The results from the hydrodynamic model simulations are presented in Figures 2.10.6 to 2.10.9 as snapshots in time of velocity vectors at model grid points. The output is presented at four different times during the course of a spring tidal cycle: mid-flood, high water, mid-ebb and low water.

Some of the pertinent points illustrated by these diagrams are:

- At mid-ebb the velocity vectors indicate that currents around Pickle point (one of the proposed locations for an outfall pipe) are quite small and hence may not produce the desired transport of effluent away from the surrounding coastal area.
- At low water there are large areas of stagnant water which would lead to the build up of discharged effluent from an outfall pipe during this tidal period.
- In contrast to the mid ebb situation, there is relatively strong current running in an east – west direction at mid-flood, which would transport discharged effluent in the direction of the canal.

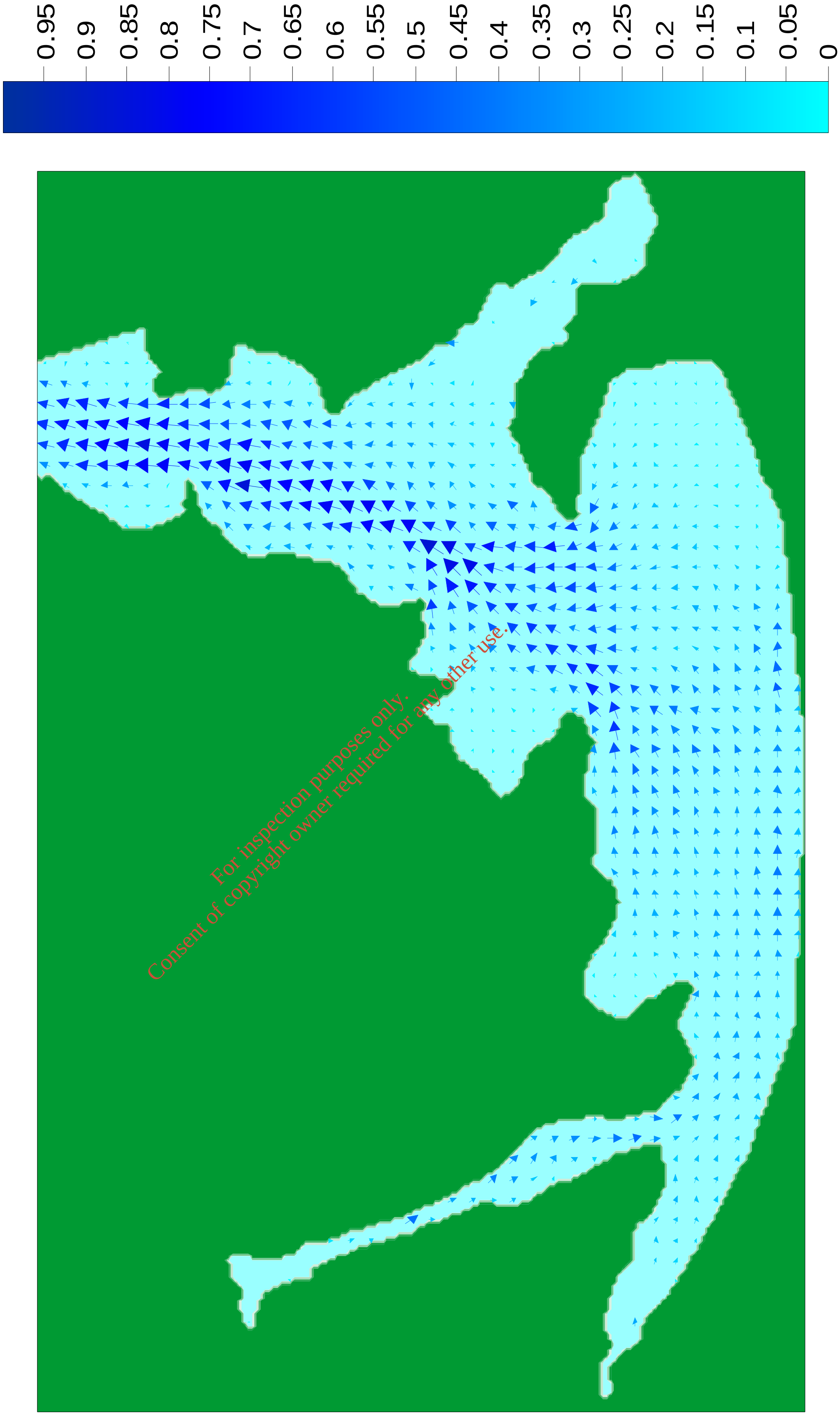





Figure 2.10.6 – Current velocity vectors (m/sec) calculated at mid-ebb on a spring tide.

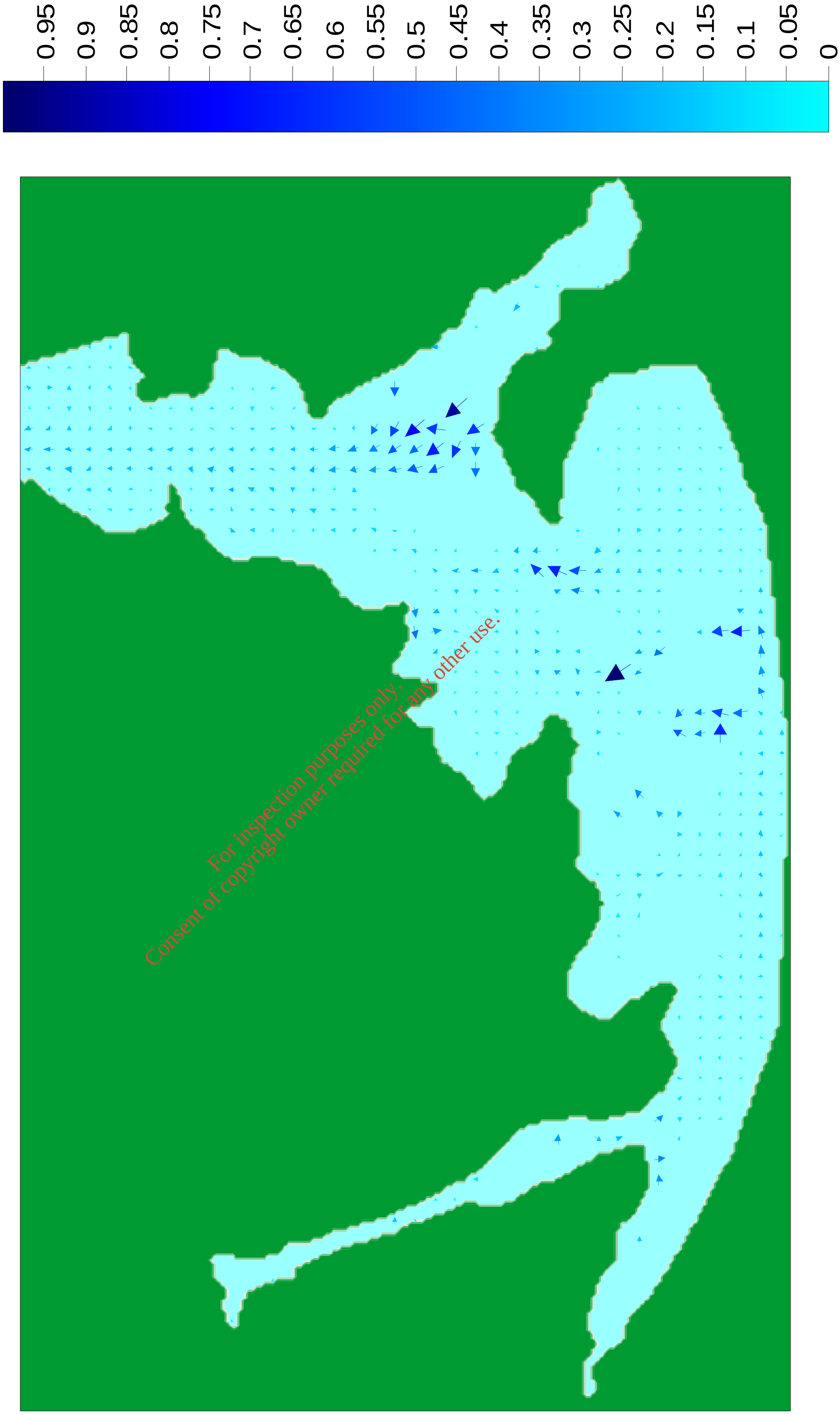





Figure 2.10.7 – Current velocity vectors (m/sec) calculated at low water on a spring tide.

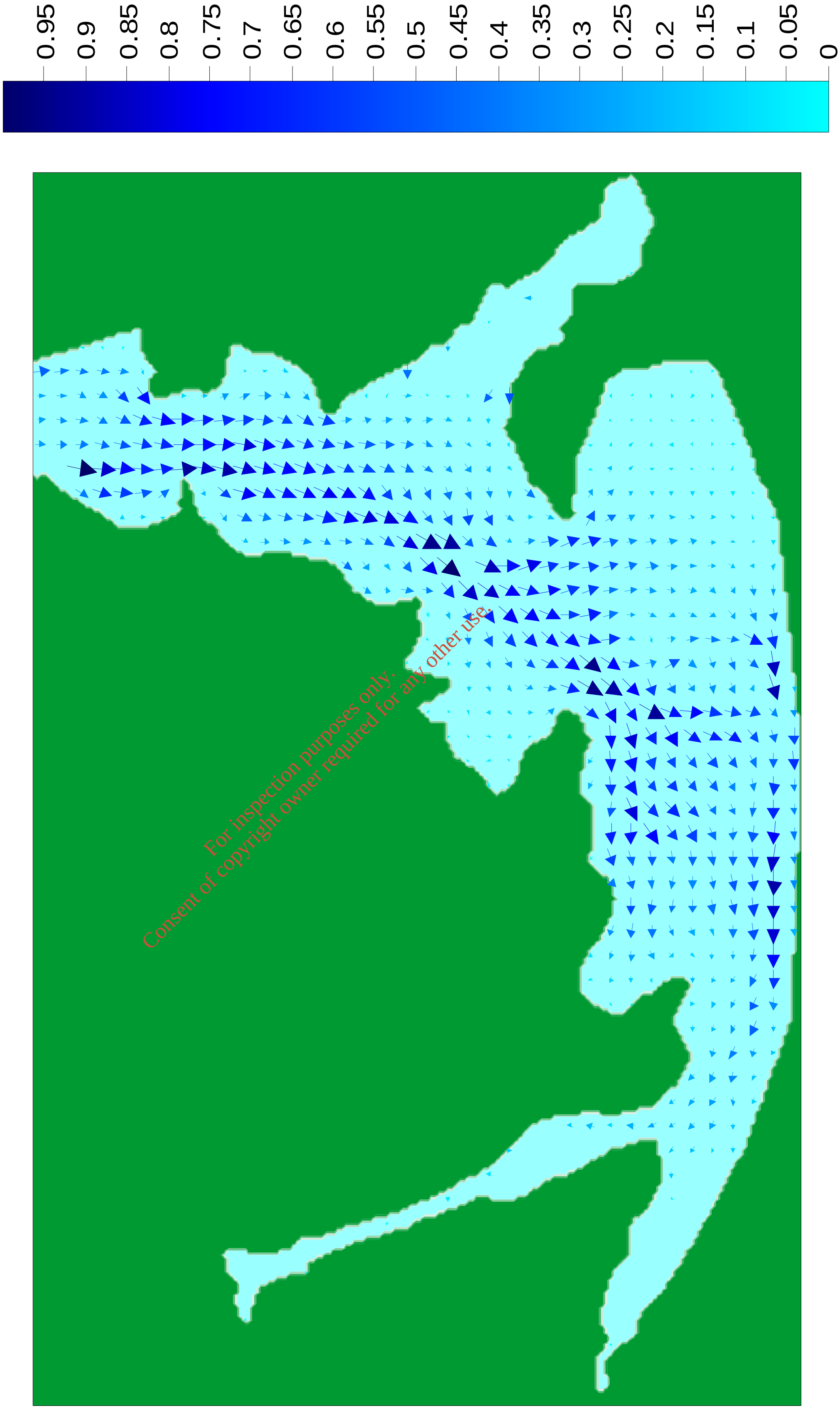





Figure 2.10.8 – Current velocity vectors (m/sec) calculated at mid-flood on a spring tide.

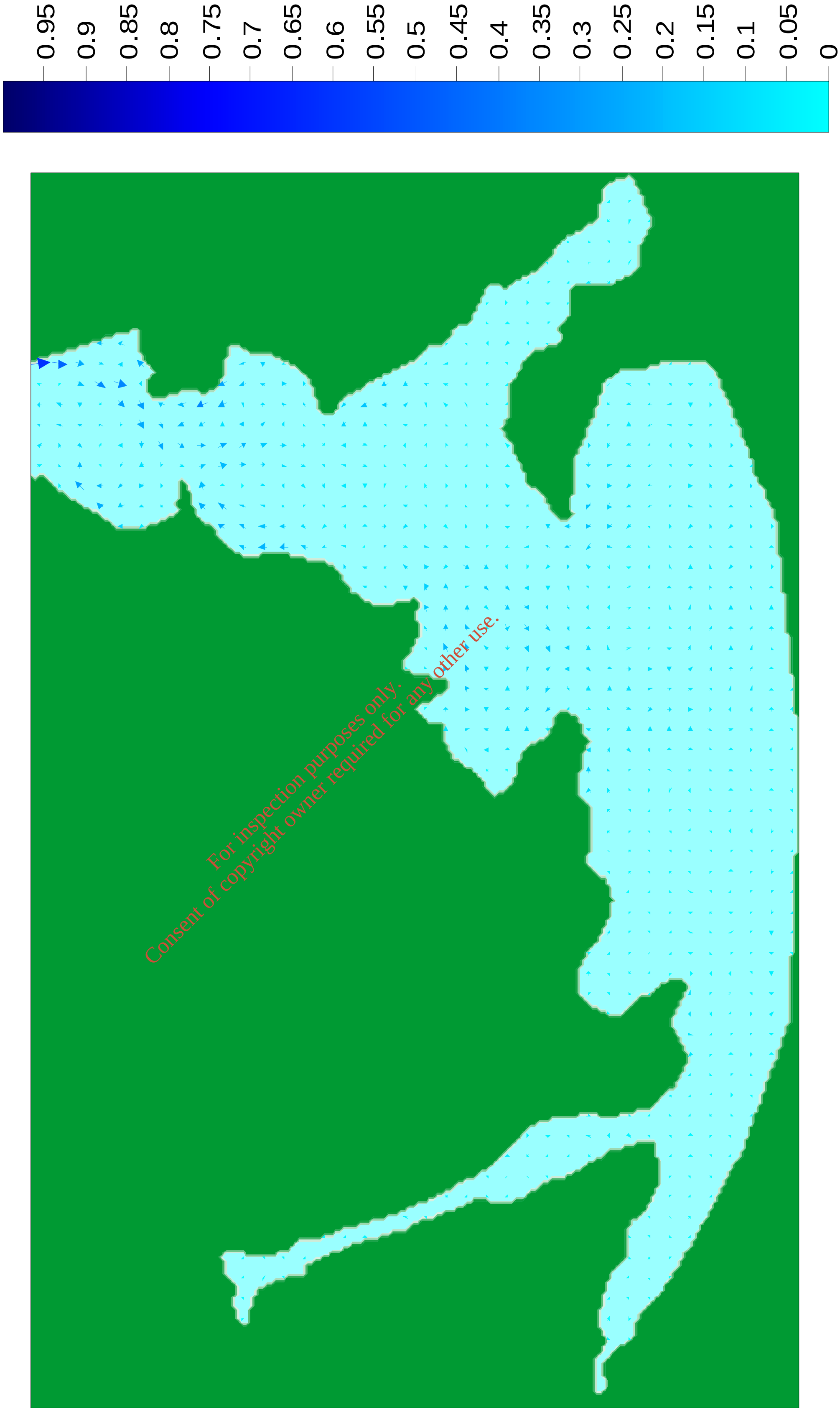





Figure 2.10.9 – Current velocity vectors (m/sec) calculated at high water on a spring tide.

## 2.11 DISCUSSION OF RESULTS

In general the water quality, the benthos and hydrographic conditions, as indicated by tidal measurements, current meter measurements, drogue studies and hydrographic model simulations, indicate that the Inner Broadhaven Bay area, east of Belmullet town is retentive with poor water exchange to the open sea.

The detailed bathymetric work shows that much of the inner bay is very shallow in nature where large sections of the sea floor dry out or are very shallow at low water. In addition the relatively restrictive nature of the approach channel and the shallow nature of the inner bay results in the restriction and dissipation of the incoming tide over the mud flats resulting in low current speeds. Similarly, the restrictive nature of the approaches to the inner bay results in low current speeds and retention during the ebbing tides.



These findings are further confirmed when comparing tidal meter measurements from west of the canal, east of the canal and at the entrance to Inner Broadhaven Bay. Tidal elevation data have shown that tidal amplitude is much greater at both the west of the canal (Blacksod Bay) and outer Broadhaven Bay areas when compared to the east canal site close to Belmullet. In addition, the retentive nature of Inner Broadhaven is further demonstrated when looking at water flows in the canal over spring and neap tides. Water elevations were higher on the eastern side of the canal for 73% of the duration of the present study suggesting the majority of the water flow in the canal is from Inner Broadhaven to Blacksod Bay. This is confirmed by current measurements taken on the bridge in Belmullet during a spring and neap tide and by drogues released on the eastern side of the bridge.

The poor flows and retentive nature of Inner Broadhaven Bay were further demonstrated during the drogue and dye studies in Inner Broadhaven. Drogues released on flooding neap tides at the current outfall site raced through the canal and into Blacksod Bay. Drogues released at the ebbing tide at this outfall point and during the spring and neap tide ebb and flood period from Pickle point and due south of Inishderry Island all provided further evidence of the retentive nature of the bay. In fact, drogues released on an ebbing tide from Pickle Point were retained in the bay and moved back further west than their original release point towards Belmullet town.

The model vector plots showing current speed and direction provide further data on the low energy nature of Inner Broadhaven Bay. The water velocities provided in the final report are probably over estimates as the plots do not take account of the flows out of the bay at the canal in Belmullet.

In conclusion, the results from the present study show that the 3 locations (Station 1 existing outfall pipe, Station 2 Pickle Point and Station 3 south of Inishderry) considered for a new proposed sewerage pipe all discharge into low energy, retentive hydrographic environments.

# SECTION B INNER BLACKSOD BAY SURVEY

The second survey for the proposed water treatment works for Belmullet town was carried out within inner Blacksod Bay. The proposed Station locations and equipment deployment locations are illustrated in Figure 1.1.1.

The results of the Blacksod Bay survey are presented in the following sections:

**2.1 Benchmarking**
**2.2. Bathymetric survey and positioning**
**2.3. Meteorological data**
**2.4. Tidal gauge data**
**2.5. Current meter data**
**2.6. Dye studies**
**2.7. Drogue studies**
**2.8. Water and sediment quality studies**
**2.9. Benthic sampling**
**2.10 Modelling**



## 2.1 BENCHMARKING

Benchmarks, levelled to Malin Head O.D., were established by engineers from Ryan Hanley Consulting Engineers around the Belmullet area. One of these benchmarks was located on the bridge in Belmullet town at 70369.0418 East, 332579.7776 North and at a height of 5.990 m O.D. All depth contours relating to the marine survey were tied into this point.

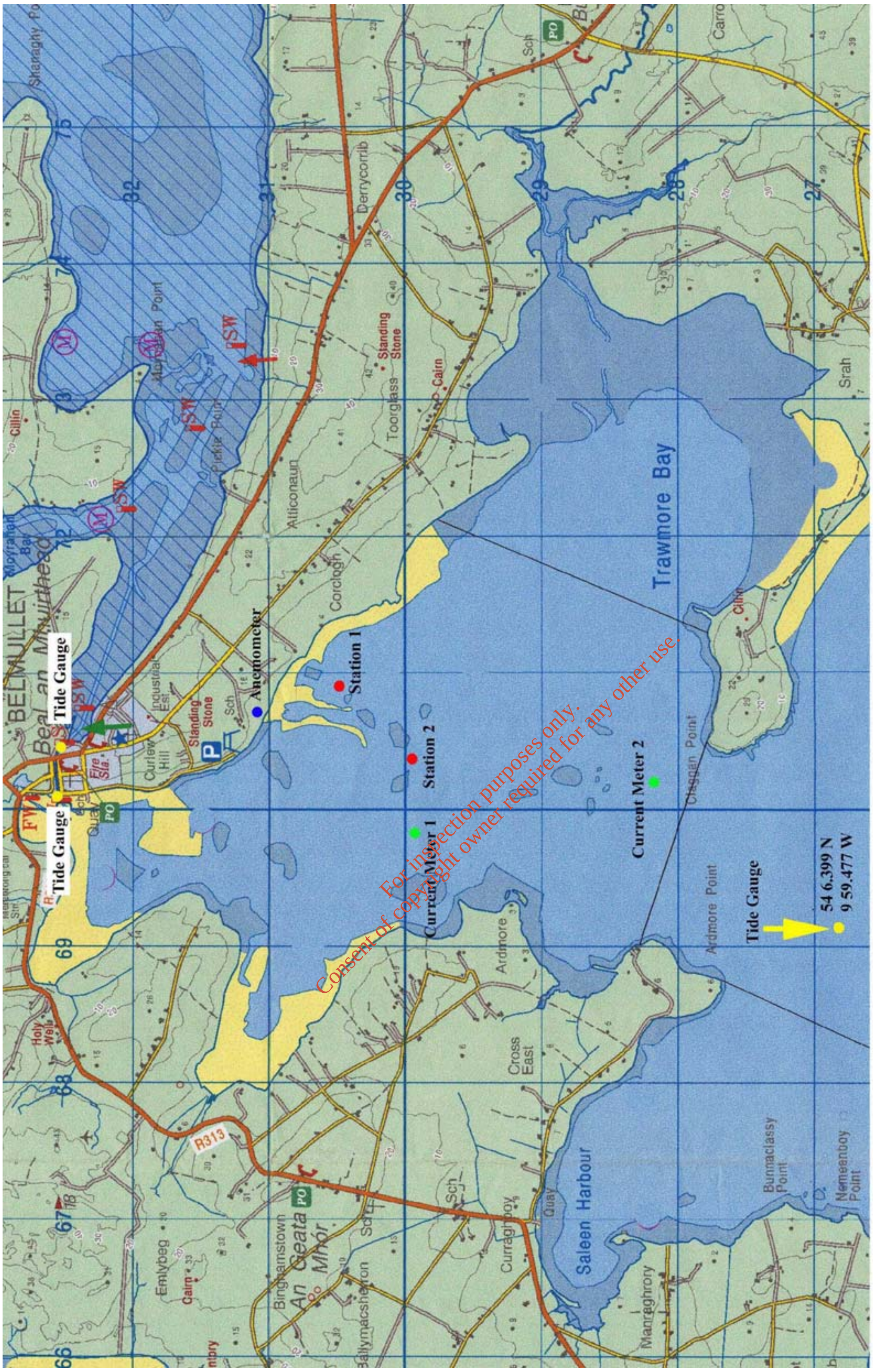



**Figure 1.1.1:** Locations of equipment deployed from 28/4/04 - 27/5/04 in Blacksod Bay, Co. Mayo.

## 2.2 BATHYMETRY & POSITIONING

A bathymetric survey was carried out over three days, from the 12th to the 14th of May 2004. The survey covered the area to the north of Ardmore Point to Claggan Point (see Figure 1.1.1.).

Dynamic horizontal positioning for the survey boat was achieved by means of Differential Global Positioning system (DGPS), which delivered precise, homogenous and continuous navigational output over the entire study area. Regular checks were made against suitable control points to ensure integrity and cross-calibration between terrestrial and sounding data. A continuous real-time record of the survey track was made in conjunction with depth data output from the echo sounder. Continuous recording echo sounding was carried out at the prescribed line intervals and calibration of the echo sounder using the bar-check method was undertaken prior to and upon completion of each survey period. The records of position and depth were time tagged to enable subsequent correction for tidal height with continuously recorded tidal data.



Figure 2.2.1 shows the track of the boat over the area covered during the bathymetric survey. Depth limitations restricted movement in a number of areas e.g. east side of Trawmore Bay. Figure 2.2.2 is a plot of depth contours generated from the bathymetric data collected. Depth contours were drawn at 0.5 m intervals and all depths relate to Malin Head Ordinance Datum (Malin Head OD is approximately 2.1 m above the local Admiralty Chart Datum). It is noted from the survey that both the proposed outfall locations lie to the northeast of a narrow channel that runs to the outer Blacksod Bay area, Station 2 being the closer to the channel.

## 2.3 METEOROLOGICAL DATA

Wind speed and direction were automatically recorded during the course of the fieldwork and the results presented in Figures 2.3.1. The predominant wind during this period was from a northerly direction although, during the course of the study, the meter recorded wind flow from all directions for significant periods of time.

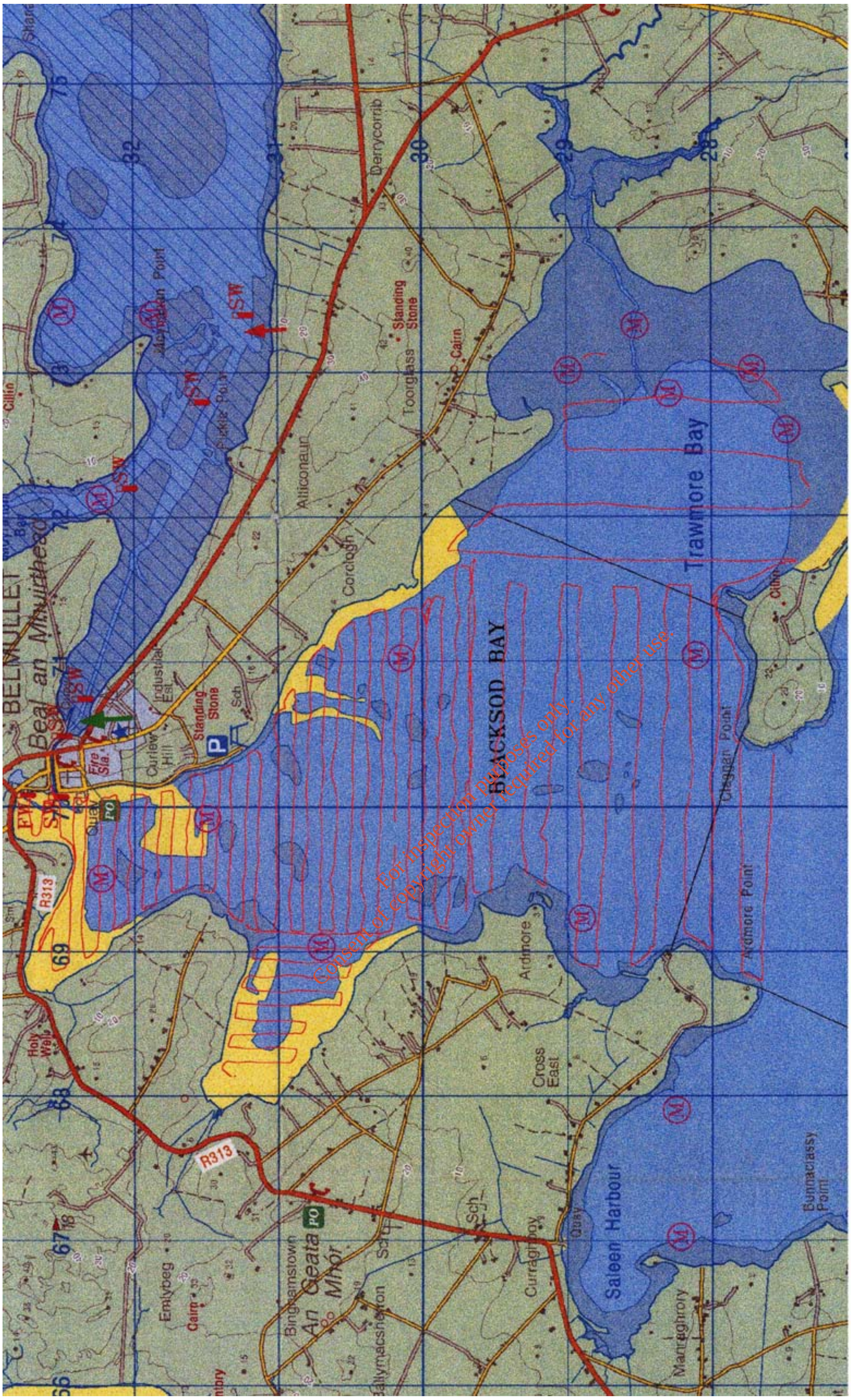



**Figure 2.2.1:** Track of the boat during the bathymetric survey, May 2004.

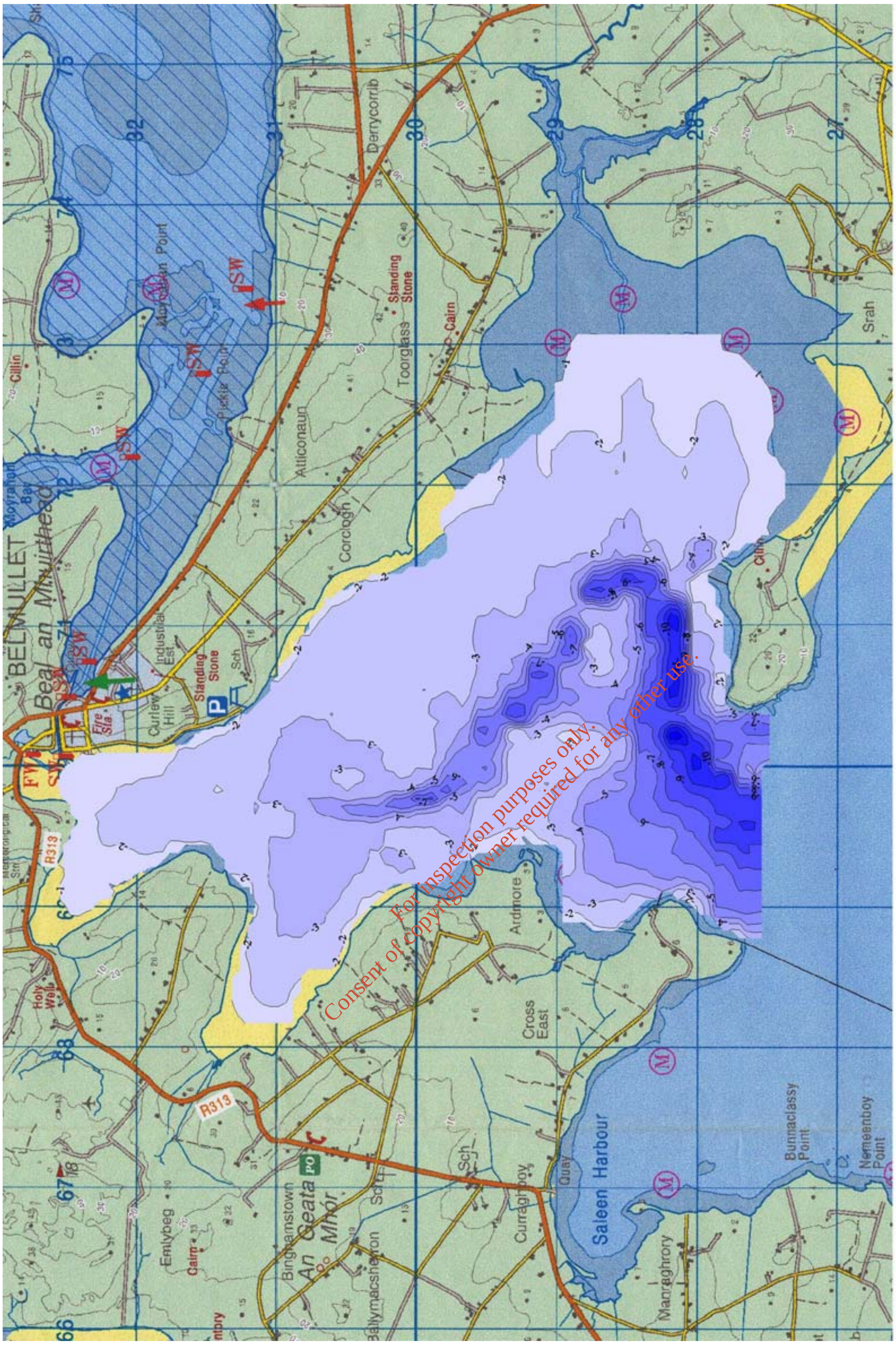



**Figure 2.2.2:** Plot of depth contours taken from the bathymetric survey, May 2004.

## 2.4 TIDAL GAUGE DATA

Three Enviromon CTD-Divers were deployed on the 28th April to automatically record tidal elevations for the study period. These units were levelled to Malin Head Ordnance Datum. A tidal gauges was located either side of the canal connecting Inner Broadhaven and Blacksod Bays while the third was positioned in outer Blacksod Bay at 54° 6.399 N, 9° 59.477 W.

Figure 2.4.1 presents the tidal data recorded by the three meters located within the survey area. This data is used to calibrate the predictive model and the difference in tidal range between spring and neap tides is obvious. Tidal range recorded during spring tides was approximately 4 m while neap tides produce a range of less than 2 m.

Differences in elevation east and west of Belmullet canal at each 10-minute recording interval from 28th of April to 20th May 2004 are presented in Figure 2.4.2. Negative values indicate a higher elevation on the Eastern side of the canal and it was found that water elevation was higher on the east side for the majority of the time indicating a predominant flow from east to west. Visual observations during the recording period confirmed the flow direction as indicated by the elevation differences.



## 2.5 CURRENT METER DATA

**Continuous Recording Current Measurements**

Two continuous recording current meters were deployed on 28th May 2004 in Blacksod Bay. The first was located at the apex of the channel running out the Bay (54º 12.136, 9º 59.787), at a depth of 7m and the other (RCM7) was positioned close to Claggan Point (54º 11.184, 9º 59.259), at a depth of 12m (Figure 1.1.1.). Both meters were retrieved on the 27th May.

Figures 2.5.1 and Figure 2.5.2 present the current velocity and direction recorded at the two stations over the course of their deployment. Current direction at both stations was in keeping with the orientation of the channel in which they were located i.e. current flow at Station 1 is predominantly North-south while Station 2

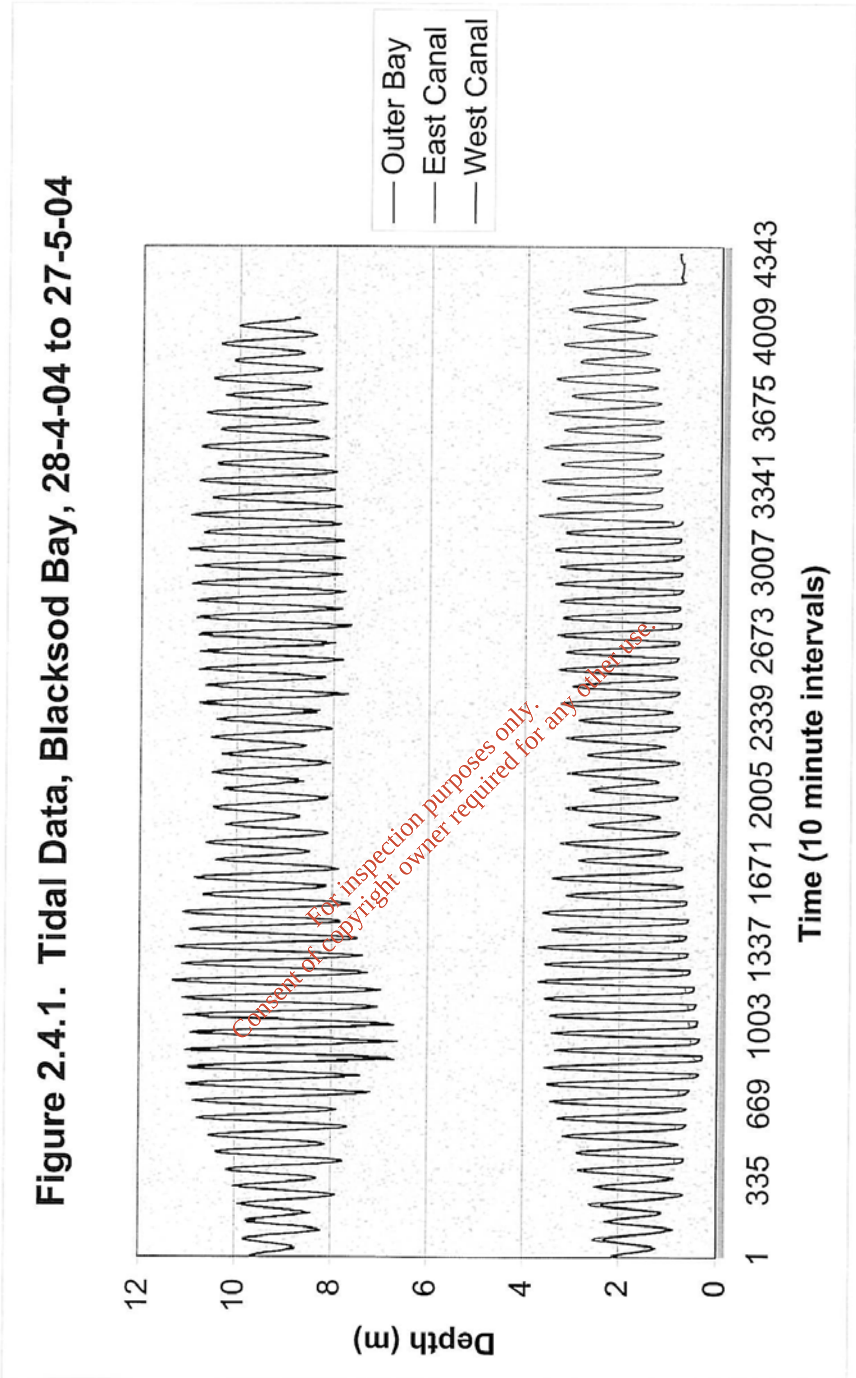


Figure 2.4.1. Tidal Data, Blacksod Bay, 28-4-04 to 27-5-04

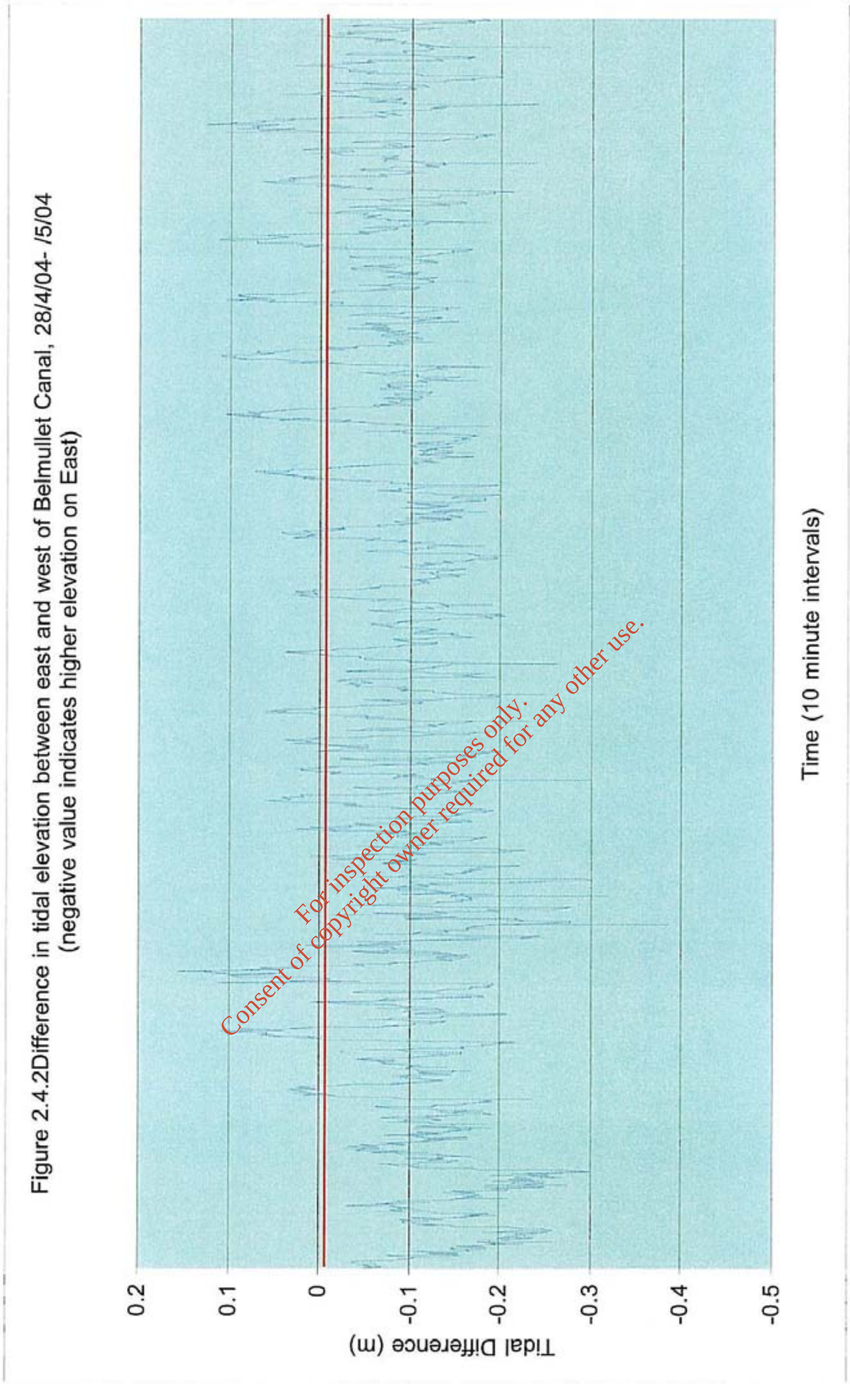


Figure 2.4.2Difference in tidal elevation between east and west of Belmullet Canal, 28/4/04- /5/04
(negative value indicates higher elevation on East)
Tidal Difference (m)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Time (10 minute intervals)

current is predominantly east-west (see bathymetric contours). Maximum velocity recorded at both meters was just under 0.5 m/s (1 knot) although current velocities were significantly lower than this for the majority of the deployment.

**Neap and Spring tide direct current measurements**

Vertical profile current velocity and direction was measured with a Valeport Braystroke (BFM 008 MK3) direct reading current meter at each of the two identified outfall points over a full tidal cycle neap tide, on the 12$^{th}$ of May 2004. Given that both proposed outfall locations are situated in relatively shallow locations, observations were taken at 0.5 m below the surface, 50% depth, and at 0.5 m above seabed at 30-minute intervals when possible. Vertical profiles at various stations throughout the study area were also measured during the field survey work. The positions of the meter were fixed by DGPS.

The data recorded from the direct reading current meter for Stations 1 and 2 over the neap tidal cycle in Blacksod Bay are presented in Appendix IV. Water flow was predominantly along a north-south axis.



## 2.6 DYE STUDIES

Dye dispersion studies were carried out at the two proposed outfall locations on both neap and spring tides (see Figure 1.1.1). Rhodamine WT was the fluorescent dye used and batches of dye were mixed with methanol and freshwater prior to release to achieve a density similar to that of treated sewage effluent.

Prior to release, the fluorimeter was calibrated against the tracer, in the ambient seawater into which the tracer was released. This was done using a standard concentration solution. After the tracer was released, its dispersal was monitored visually, with its movement and expansion plotted through recording of positions with the DGPS unit. Once it had dispersed sufficiently to monitor with the fluorimeter, regular transects were made through the plume to record its progress. In addition to horizontal transects, vertical profiles through the tracer were also taken. When the tracer plume was no longer visible and fluorimeter readings had returned to background levels, the study was terminated.

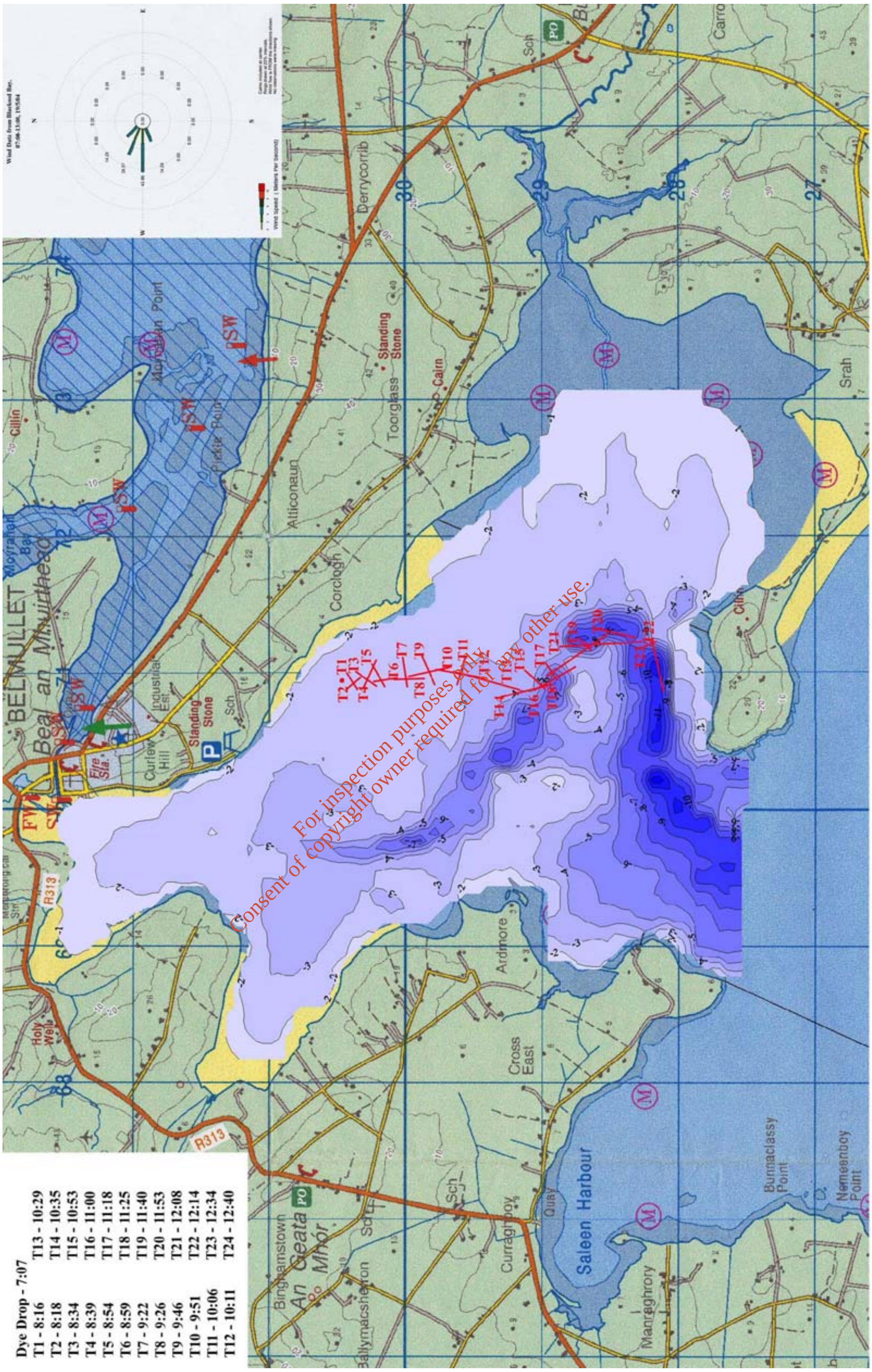





**Figure 2.6.1. Progress of the dye plume and transect locations following a dye release at Station 1 on a spring tide, 19/5/04**

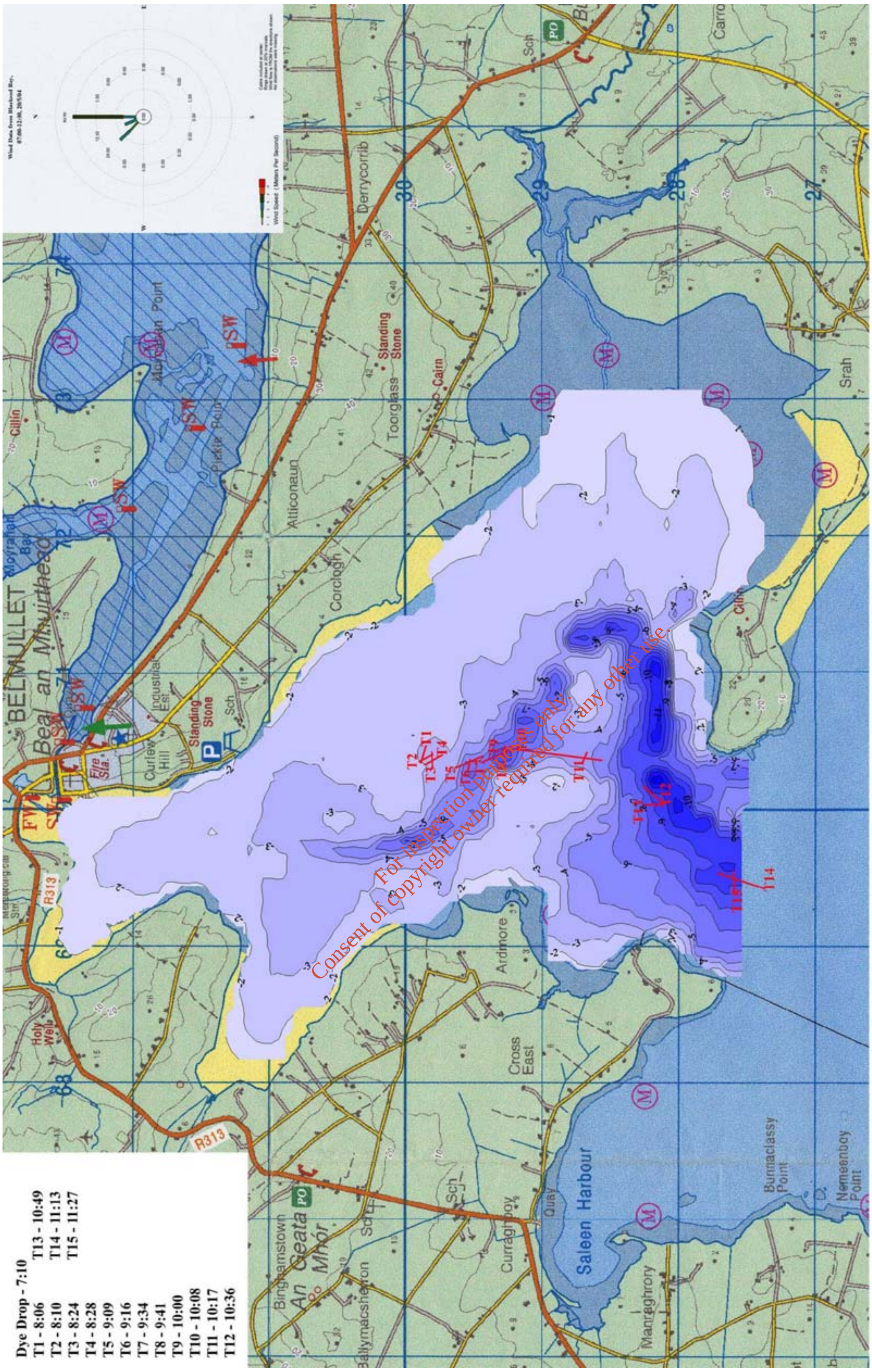



Figure 2.6.2. Progress of the dye plume and transect locations following a dye release at Station 2 on a spring tide, 20/5/04

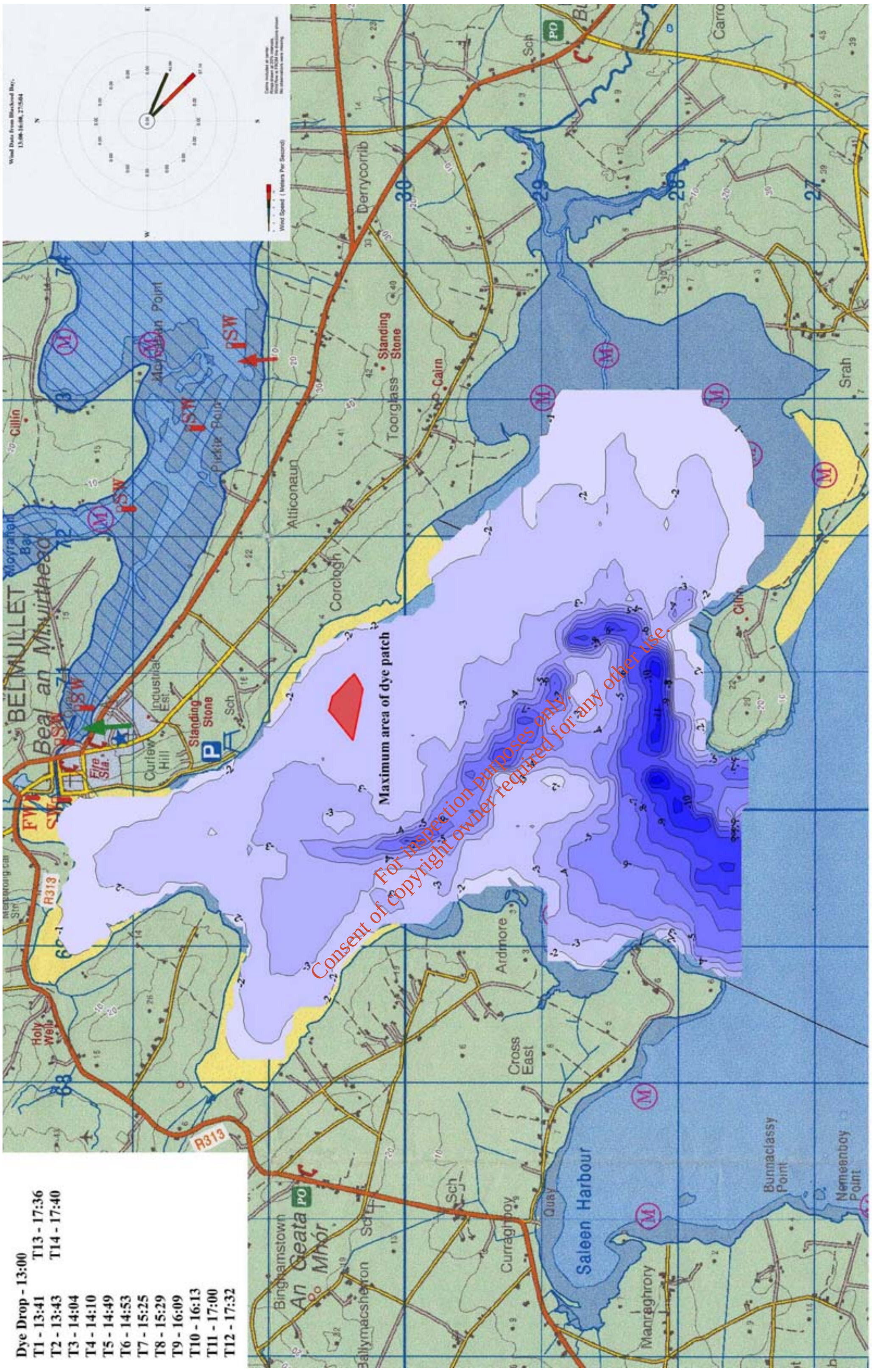



Figure 2.6.3. Progress of the dye plume and transect locations following a dye release at Station 1 on a neap tide, 27/5/04

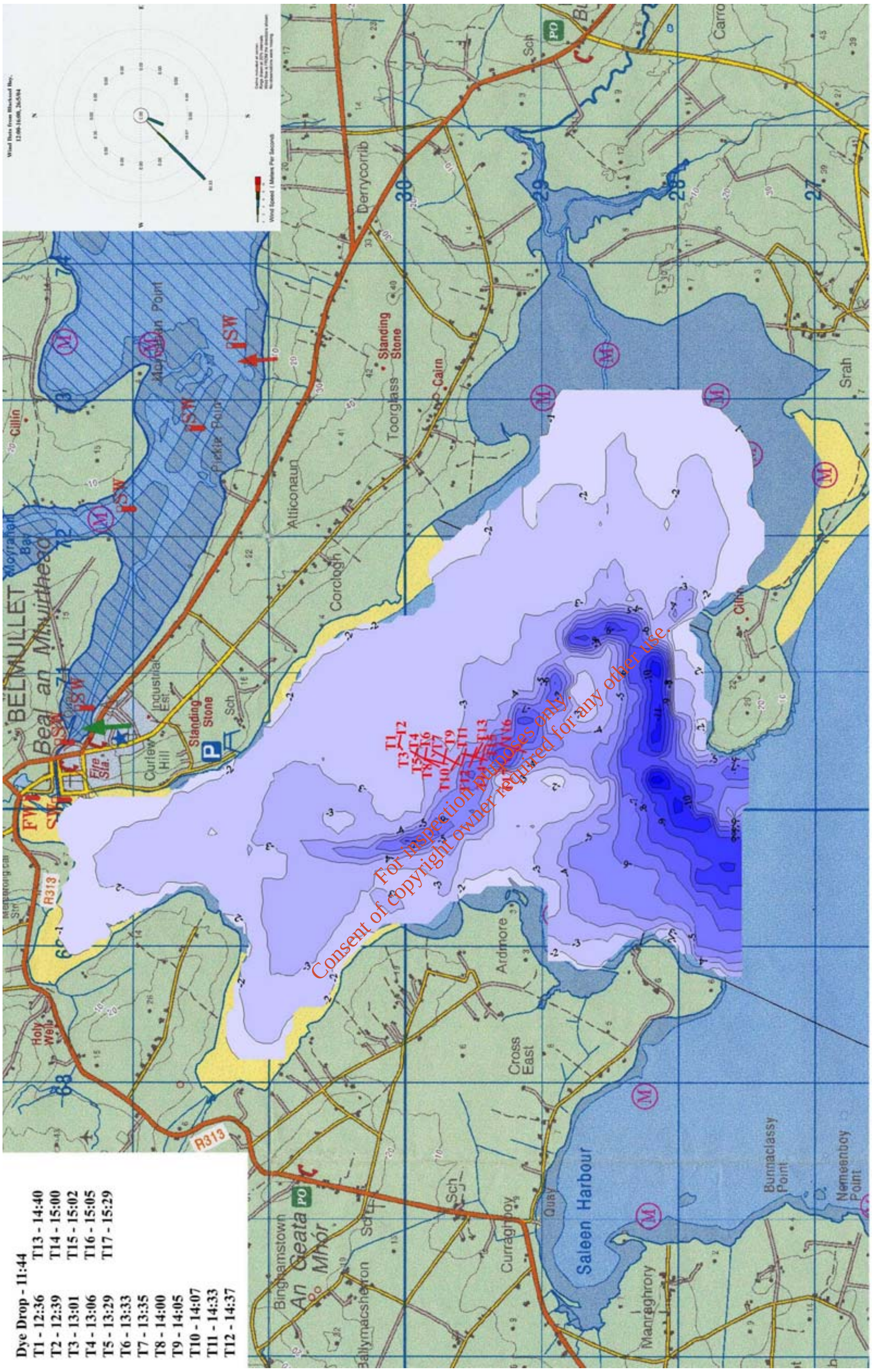



**Figure 2.6.4. Progress of the dye plume and transect locations following a dye release at Station 2 on a neap tide, 26/5/04**

Figures 2.6.1 to 2.6.4 present the results of the dye studies carried out at the proposed outfall locations in Blacksod Bay.

In general, it was found that dye dispersion and movement on the spring tide (19th and 20th May 2004) was good at both locations with the dye patch moving into and along the relatively deep channel where it dispersed to undetectable levels (see Figures 2.6.1 and 2.6.2).

Dye movement recorded during the neap tide (26th and 27th May 2004) was significantly different between the two locations. Dye was released shortly after high water at the outer location on the 26th May and it followed a similar path to that recorded during the spring tide (Figure 2.6.4). When the dye had progressed as far as the middle of the channel it quickly dispersed to untraceable levels. On the 27th May, dye was released at the inner location shortly after high water. However, little movement of the dye patch was recorded over the following six hours with the dye dispersing horizontally and vertically from a central position with little movement of the patch (Figure 2.6.3). It is probable that lack of tidal currents, due to the relatively strong south-easterly wind (see dye Figure 27/5/04) combined with neap tidal conditions on the day of the release, was the main reason for this lack of movement of the dye patch.



## 2.7 DROGUE STUDIES

Drogues studies were carried out over both a neap and spring tidal cycle. The Neap tide survey was carried out on the 11th of May 2004; high water was at 12:30 Hrs and low water at 18:10 Hrs. The Spring tide survey was carried out on the19th of May 2004; low water was at 14:20 Hrs and high water was at 18:40 Hrs.

The drogues used were of the window-blind type and they were placed at surface, mid-water and off-bottom where depths allowed. A hand held anemometer was used to record wind speed and direction. It was initially planned that three groups of current tracking drogues, released at the surface, mid-water and off-bottom, would be deployed during the twelve hours tidal cycle. Only surface and mid-water drogues could be deployed due to the shallow depths of water. These drogues were tracked using an inflatable boat over a twelve-hour period and their position fixed at 30-minute intervals using a handheld DGPS.

The results of the drogue studies are presented in Figures 2.7.1- 2.7.4. Figures 2.7.1 and 2.7.2 show drogues tracks on Neap and Spring tides released at Station 1 (inner proposed outfall location) at Mid-Water (Flooding), High Water, Mid-Water (Ebbing) and Low Water.

The Neap tide drogue tracking commenced at Mid-water (Flooding) when a surface drogue was released in Station 1 (Inner proposed outfall location). No mid-water drogue was released because there was not enough water depth to do so. Two more drogues were released in Station 1 at high water, one at the surface and another one at mid-depth. Finally, only surface drogues were deployed both at mid-water (Ebbing) and low water. All drogues headed in a southwest direction, the surface drogue released at high water being the one that travelled the furthest (it finally became stranded at low water in the rocky area west of the channel).



During the Spring tide, two drogues were released at surface and mid-depth on the ebbing tide. These drogues headed in a southwest direction, the mid-depth one became stranded at low water and was retrieved. The surface drogue travelled as far as the channel in front of Claggan Point before moving towards Trawmore Bay on the flooding tide.

Only a surface drogue could be released at low water at Station 1. This one headed north towards the shore before becoming grounded.

The surface drogue released on the flooding tide and the two drogues (surface and mid-depth) released at high tide headed north before being retrieved three hours after high water.

Figures 2.7.3 and 2.7.4 represent the drogues tracks on Neap and Spring tides at Station 2 (Outer proposed outfall location). The first drogues were released on the flooding tide, one at the surface and another one at mid-depth. The drogues headed in a north-west direction before moving southwards on the ebbing tide. The mid-depth drogue became stranded on the rocky area in front of Ardmore while the surface drogue went as far as Ardmore point before it was retrieved at low water.

Two drogues were deployed at high water, the surface drogue moved southwards, passing the rocky area west of the channel and changing direction to the southeast on the ebbing tide before it became grounded at low water. The mid-depth drogue also travelled southwards before slowly started to move eastwards on the ebbing tide when it was retrieved.

Only surface drogues were deployed on the ebbing tide and at low water due to lack of water depth for a mid-depth drogues. The mid-water drogue moved southwards before becoming stuck in the rocky area west of the channel. The low water drogue first moved southwards before changing to a northeast direction on the flooding tide. Similar movement patterns were observed during the Spring tide drogue survey.

Surface and mid-depth drogues were deployed at Station 2 at mid-water on the ebbing tide. The drogues moved south before changing direction on the flooding tide, heading east into Trawmore being, where they were retrieved at the end of the survey. The mid-depth drogue became grounded in the rocks south of the channel. After observing the track followed by the surface drogue the mid-depth was redeployed south of the rocks from where it followed an eastwards direction into Trawmore Bay.



The drogues released at Station 2 at Low water and three hours after Low water headed north on the flooding tide.

Finally three drogues (surface, mid-water and off-bottom) were deployed at High water but little movement was recorded as they all stayed in close-by Station 2 until they were picked-up back to the boat an hour later.

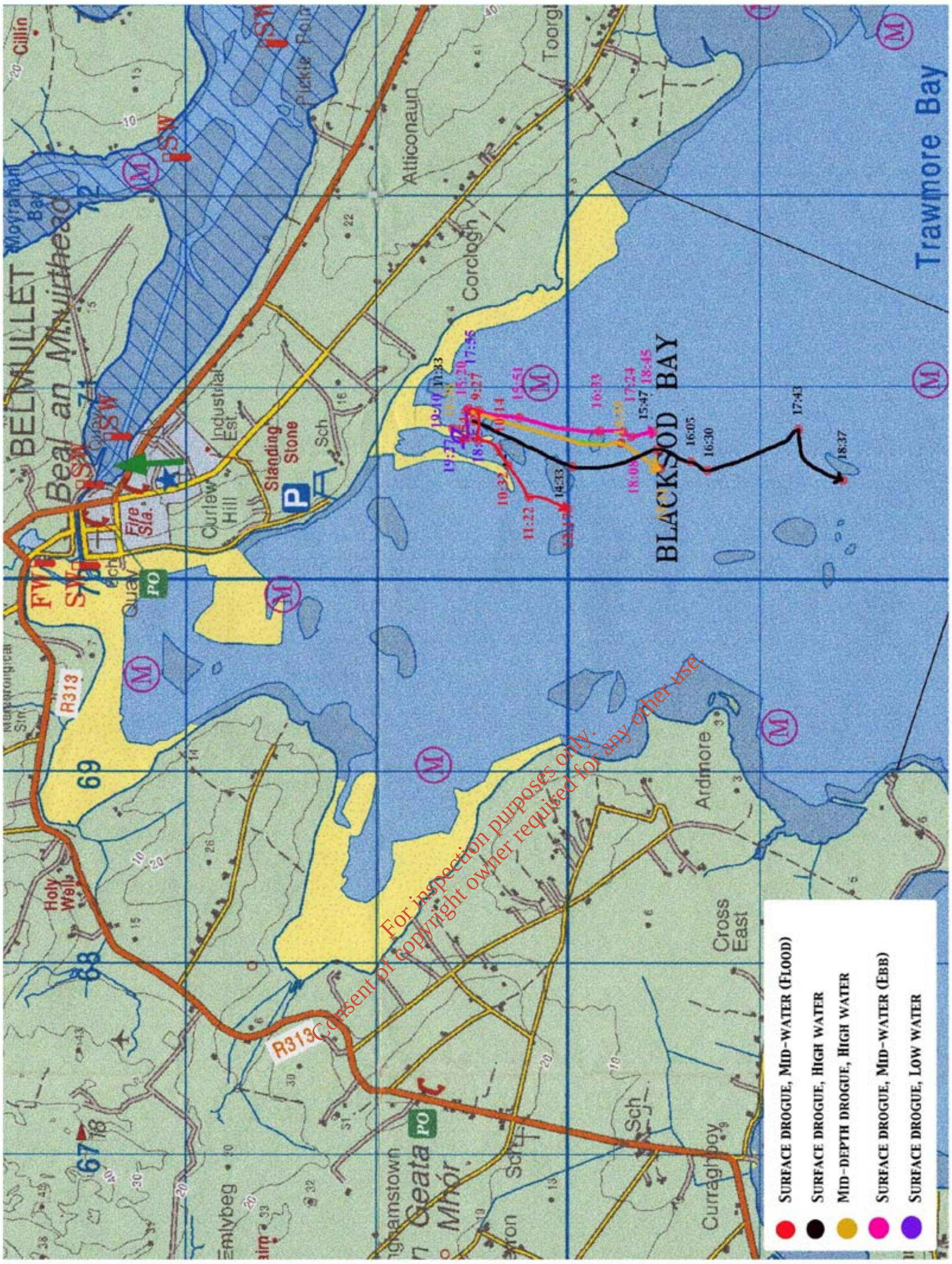



**Figure 2.7.1:** Station 1 drogue tracks for Neap tide, May 2004.

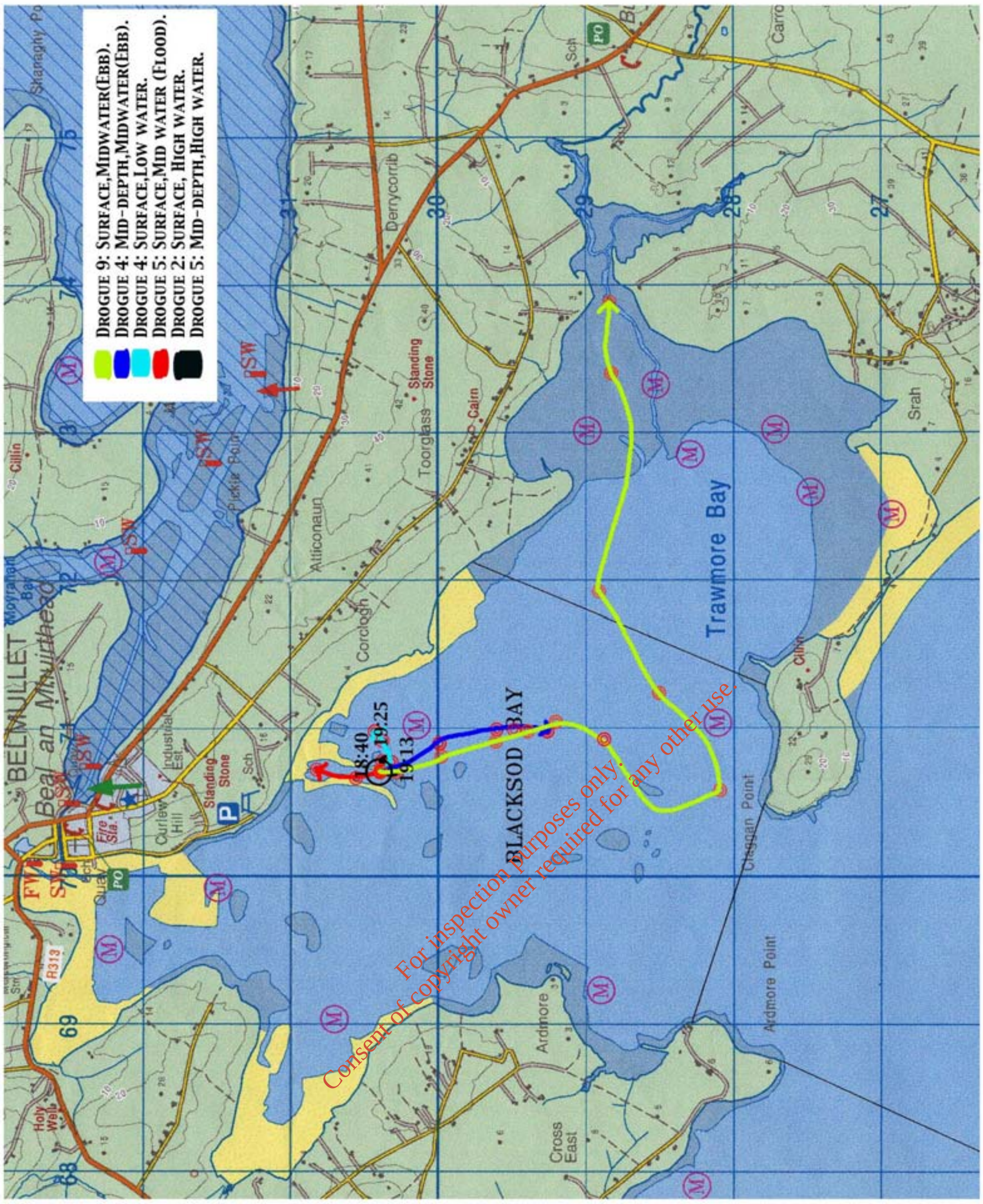





**Figure 2.7.2:** Station 1 drogue tracks for Spring tide, May 2004

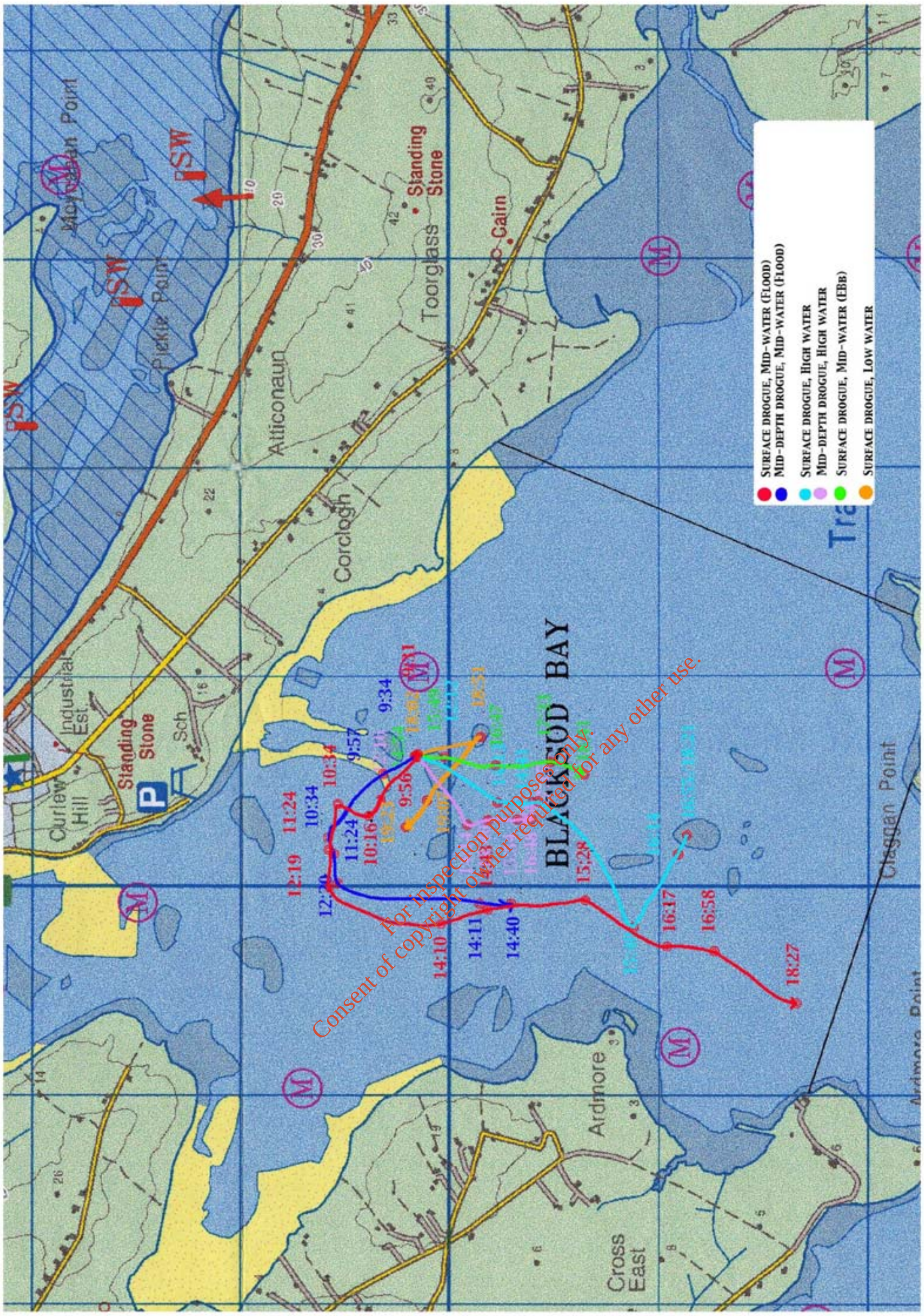



**Figure 2.7.3:** Station 2 drogue tracks for Neap tide, May 2004.

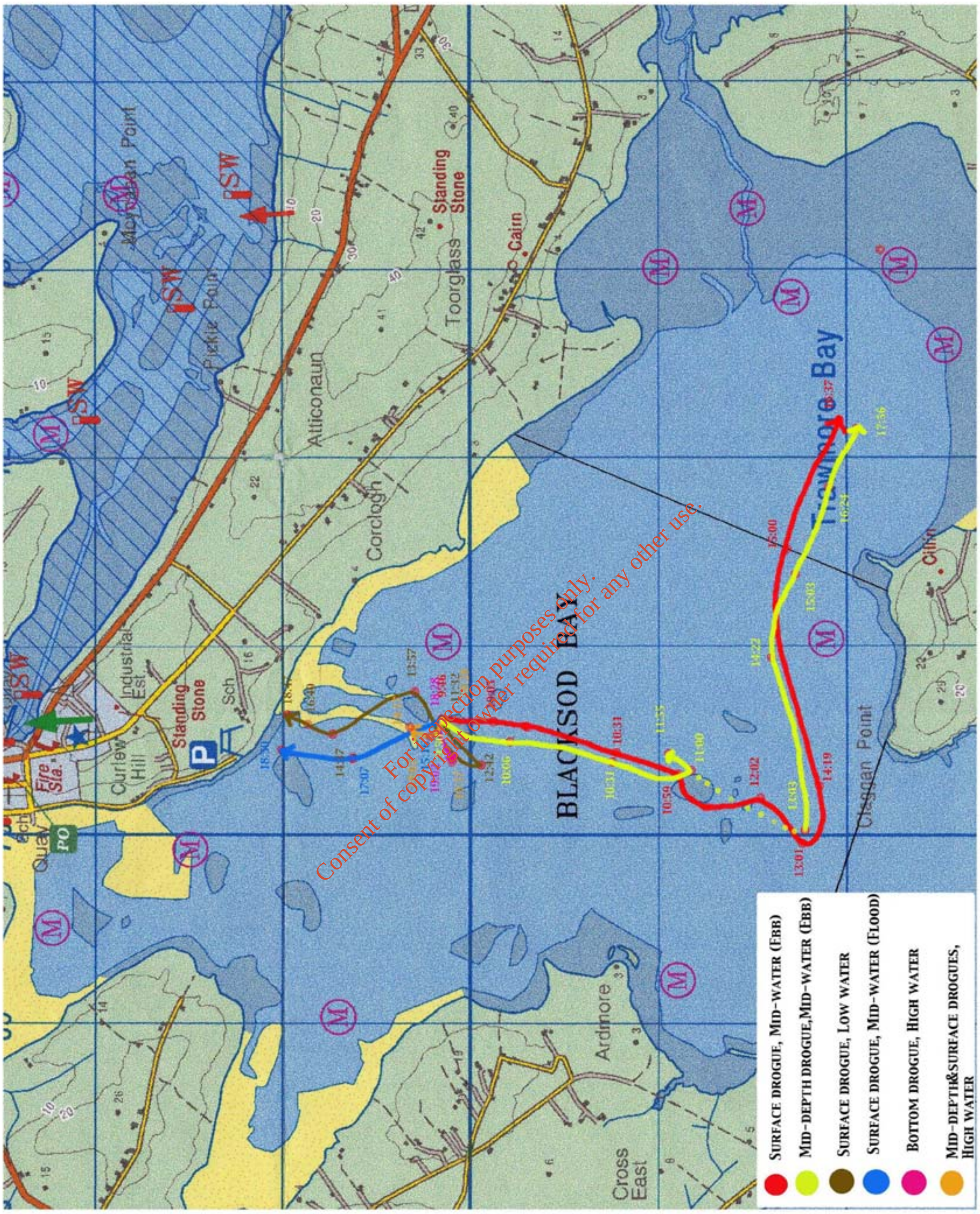



**Figure 2.7.4:** Station 2 drogue track for Spring tide, May 2004.

## 2.8 WATER AND SEDIMENT QUALITY DATA

Freshwater, seawater and sediment samples were collected at the locations shown in Figure 2.8.1a. The positions of the stations were fixed by DGPS and the samples were sent to an accredited laboratory for analysis.

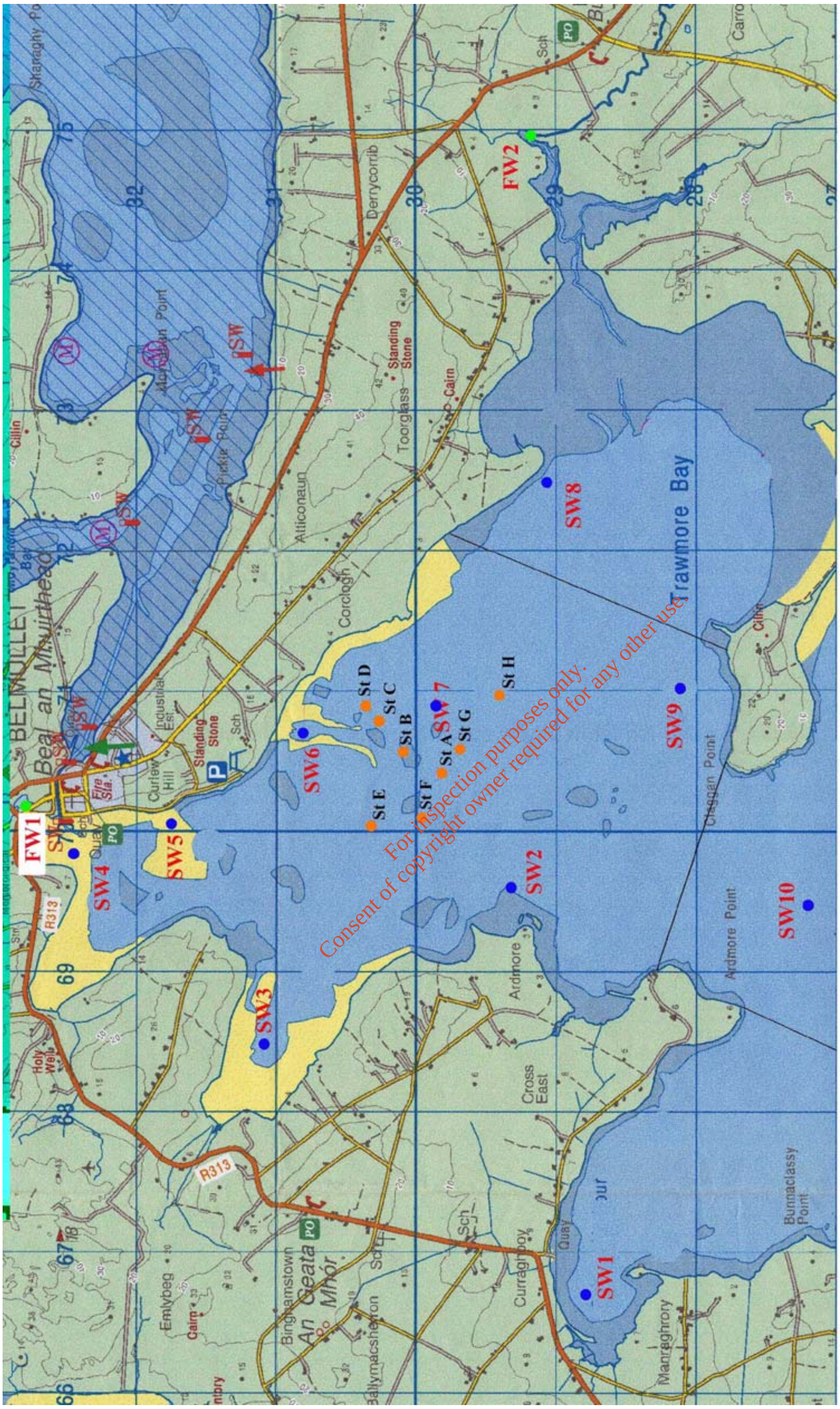
Sampling was carried out for all water quality stations on three dates in May the 10th, 18th and 26th. Seawater samples were collected at Stations SW1 to SW10, over a full tidal cycle at spring and neap tides. Freshwater samples were collected from Stations FW1 and FW2.

Parameters measured included total coliforms, BOD, suspended solids, phosphate, nitrate and ammonia for seawater samples. Freshwater samples were analysed for *E. coli*, total coliforms, faecal *Streptococcus*, BOD, suspended solids, ammonia, phosphate and nitrate. The results of the analyses are presented in Figures 2.8.1 to 2.8.10 and in Appendix V (Tables 2.8.1 to 2.8.6).



Marine water samples were taken at the proposed outfall locations (Stations 1 and 2) in Blacksod Bay during neap and spring tides. The samples were kept cool before being sent for analysis. These samples were taken during the direct reading current meter surveys (12/5/04 and 20/5/04) at low, mid and high water over a full tidal cycle.

Profiles for temperature, salinity and dissolved oxygen were taken using a Temperature/Salinity meter and an oxymeter at the two proposed outfall locations on the 12th and 20th May 2004. The results obtained are shown in Appendix II as Table 2.8.1 (neap tide) and Table 2.8.2 (spring tide). Recorded values for temperature and salinity were normal for a coastal location for this time of the year. Dissolved oxygen levels are normal for the shallow coastal location where the proposed outfall locations are to be placed, ranging between 90% and 100% saturation levels. Analysis for nitrate levels (as $NO_3$) was also carried out. Relatively little of the nitrate found in natural waters is of mineral origin, most coming from organic and inorganic sources, the former including waste discharges and the latter comprisingchiefly artificial fertilisers. Surface water Regulations for Nitrate is 50mg/l (measured as mg/l $NO_3$). All recorded values are well below the regulation level. See Table 2.8.3, Appendix II.




= Sediment and Faunal Station
= Sea Water Station
= Fresh Water Station

**Figure 2.8.1a. Water, sediment and faunal station locations in Blacksod Bay.**

The Biochemical Oxygen Demand (BOD) of water is the amount of dissolved oxygen taken up by bacteria in degrading oxidable matter in the sample, measured after five days incubation in the dark at 20 °C. According to Flanagan (1992), waters with a BOD falling within the range of 0-4 mg/l are of satisfactory quality for salmonid fish and thus for other beneficial uses. The levels recorded in Blacksod Bay are all well below the EU maximum admissible concentration of 5 mg/l set in the Surface Waters Regulations, even the ones obtained in the innermost stations.

Results from the analysis for BOD and suspended solids in seawater are shown in Figure 2.8.1 and Figure 2.8.2 respectively, while the results for the same parameters in freshwater locations are displayed in Figures 2.8.7 (Station 1) and 2.8.9 (Station 2).

The level of suspended solids in a water body is a reflection of the turbidity of the water and is significant in that the solids may consist of algal growths and hence be indicative of the level of eutrophication of the water body; they may indicate the discharge of washings from e.g. construction; they will reduce light penetration in surface waters and interfere with aquatic plant life; they will damage fishery waters and may affect fish life; they may form deposits on the bed of rivers and estuaries which will in turn give rise to septic and offensive conditions; and they may indicate the presence of unsatisfactory sewage effluent conditions. The EU maximum admissible concentration for salmonid waters is set at 25 mg/l. Most results obtained show values below that limit with the exception of Station 6 (First Run, 12/5/04) and Station 4 (Second Run, 18/5/04). The results obtained in the freshwater samples are all very low and below the EU limit for salmonid waters. This limit is the most restrictive limit established by a EU Regulation. In the Surface Water Regulations the limit is 50 mg/l, considerably higher than any result obtained with the exception of Station 4 (54 mg/l). Station 4 is the innermost of all the stations sampled during the survey and it is located close to the canal that connects Inner Broadhaven Bay and Blacksod Bay. Suspended particles are carried in the water from Belmullet Quay area and this is reflected in the relatively high values obtained.

**Figure 2.8.1: BOD Results**
**Blacksod Bay Survey**
**May 2004**

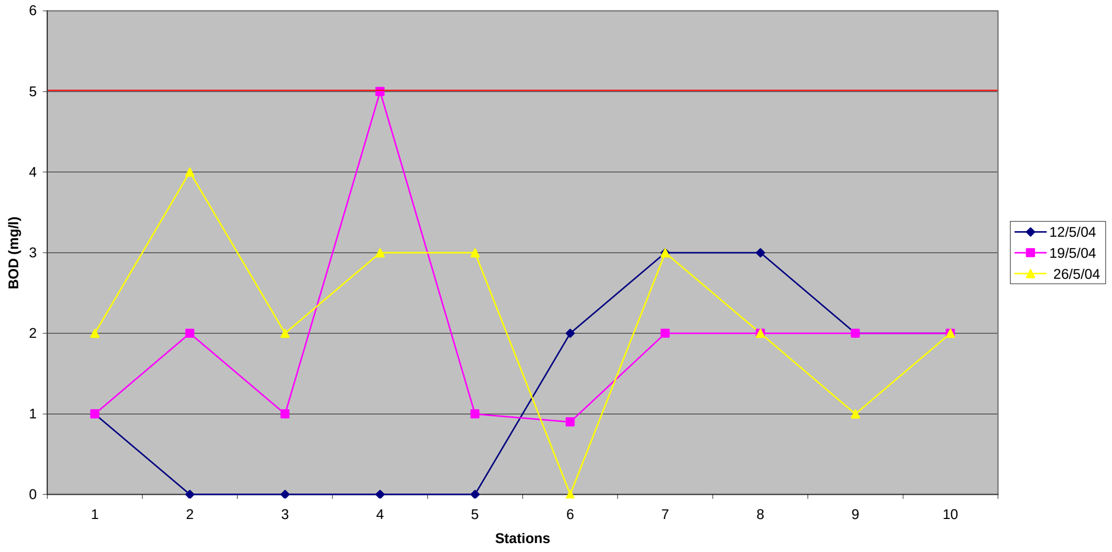



**Figure 2.8.2: Suspended Solids Results**
**Blacksod Bay Survey**
**May 2004**

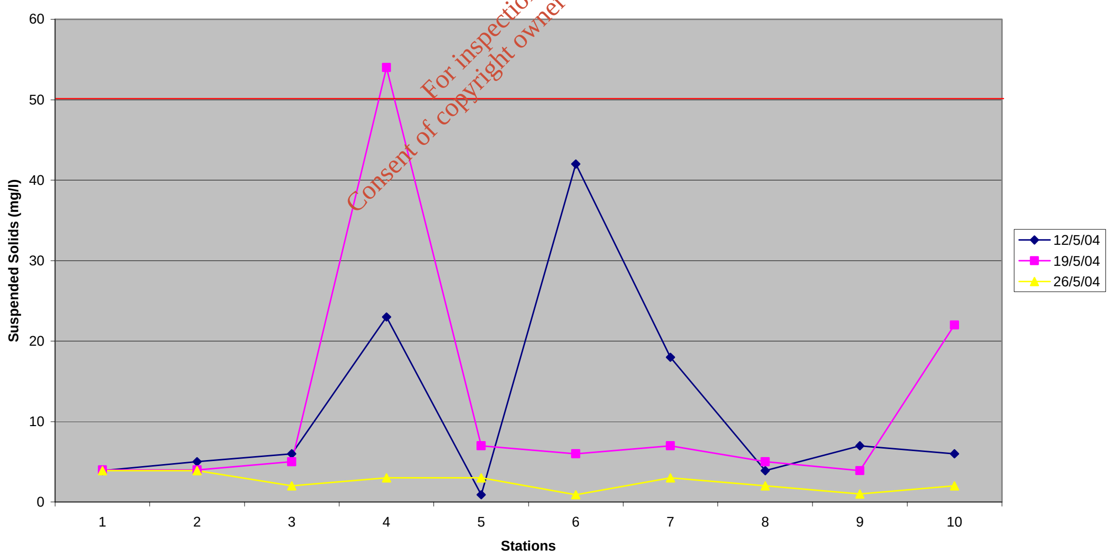


**Figure 2.8.3: Phosphate Results**
**Balcksod Bay Survey**
**May 2004**

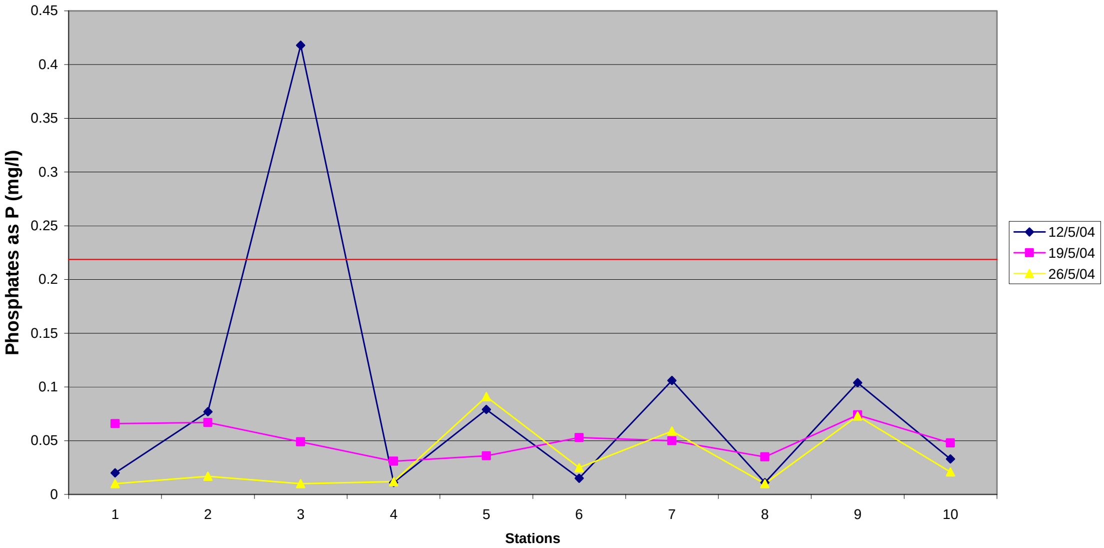



**Figure 2.8.4: Nitrate Results**
**Balcksod Bay Survey**
**May 2004**

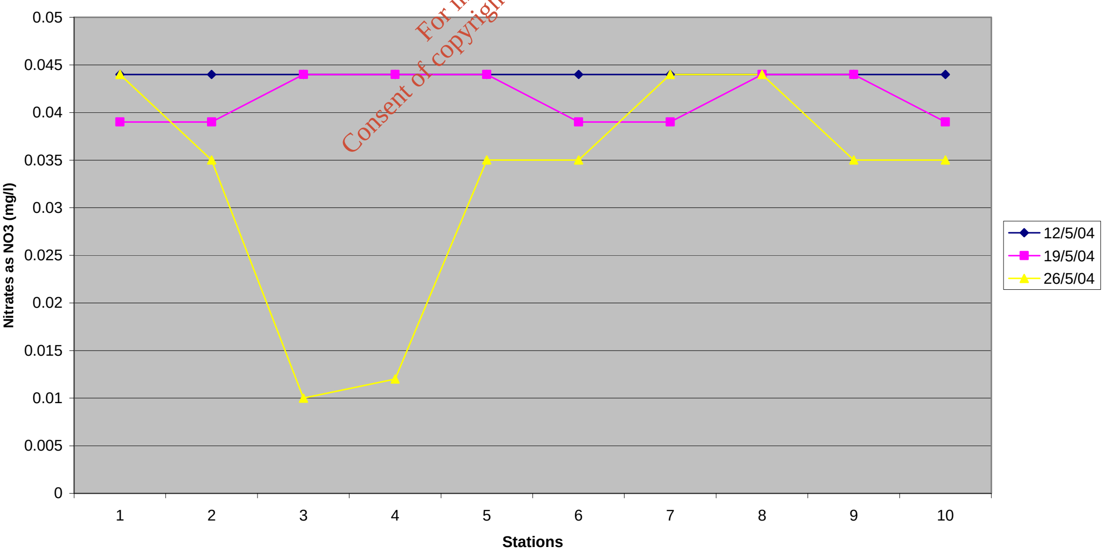


**Figure 2.8.5: Ammonia Results**
**Blacksod Bay Survey**
**May 2004**

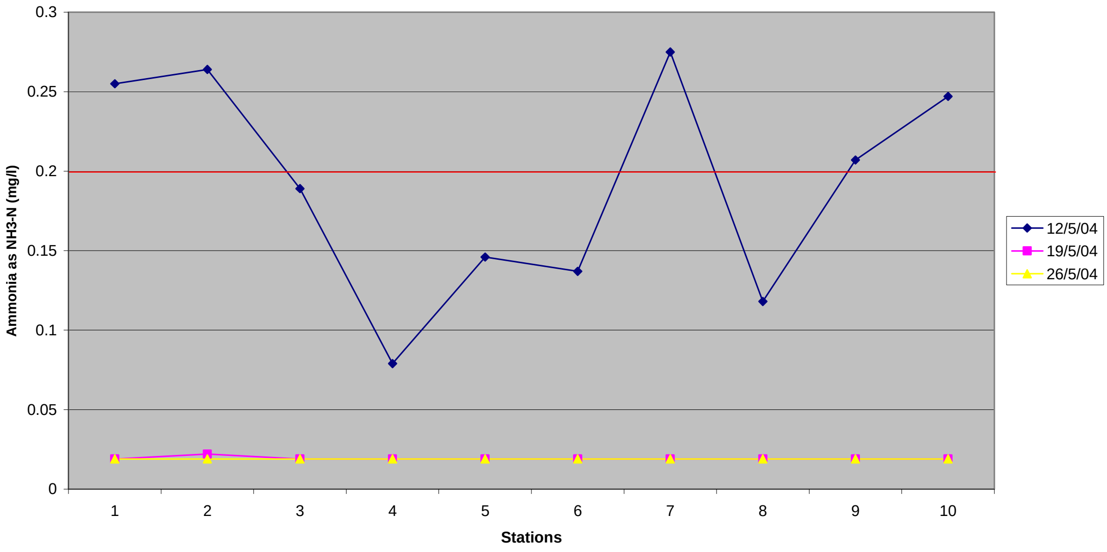





**Figure 2.8.6: Total Coliforms Results**
**Blacksod Bay Survey**
**May 2004**

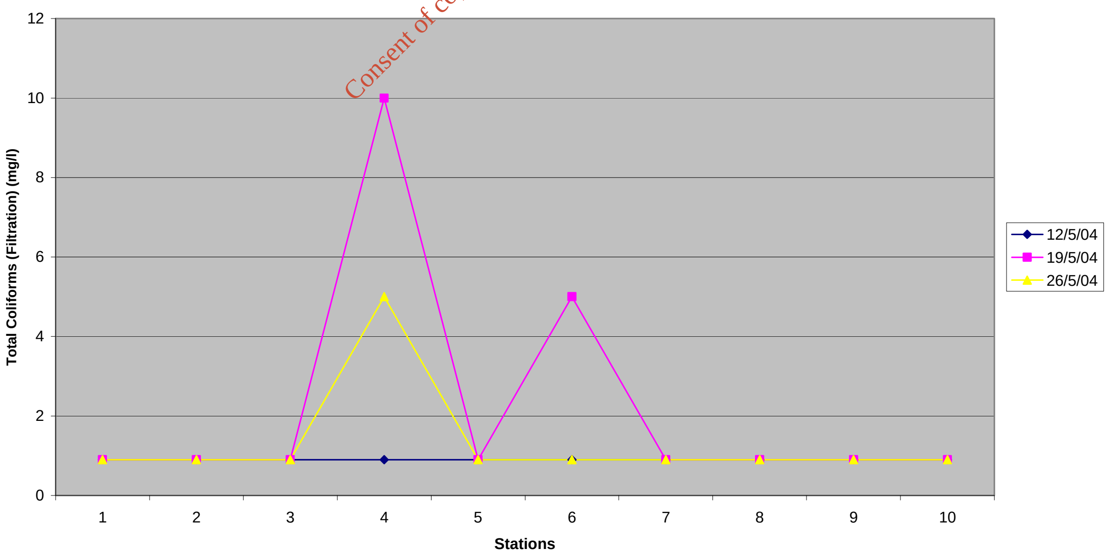


**Figure 2.8.7**
**Blacksod Bay Survey May 2004**
**Freshwater Analysis Results**
**Station 1**

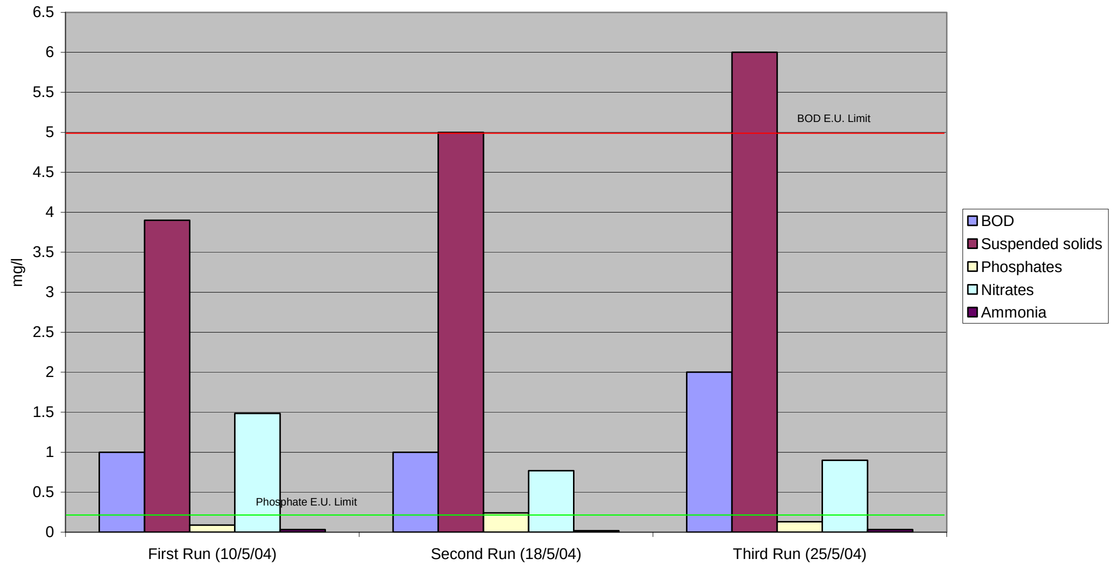





**Figure 2.8.8**
**Blacksod Bay Survey May 2004**
**Freshwater Microbiological Analysis Results**
**Station 1**

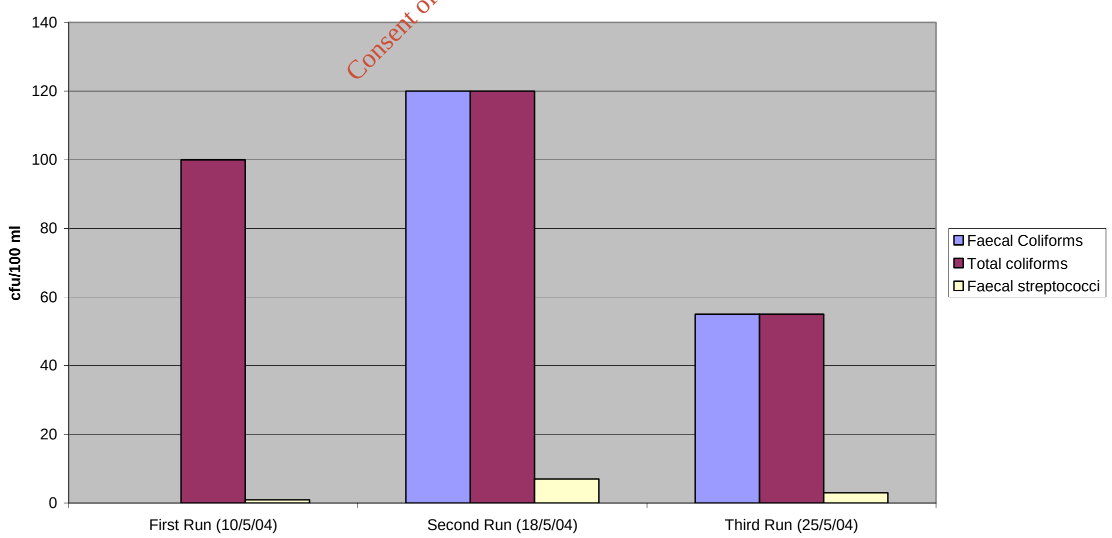


**Figure 2.8.9**
**Blacksod Bay Survey May 2004**
**Freshwater Analysis Results**
**Station 2**

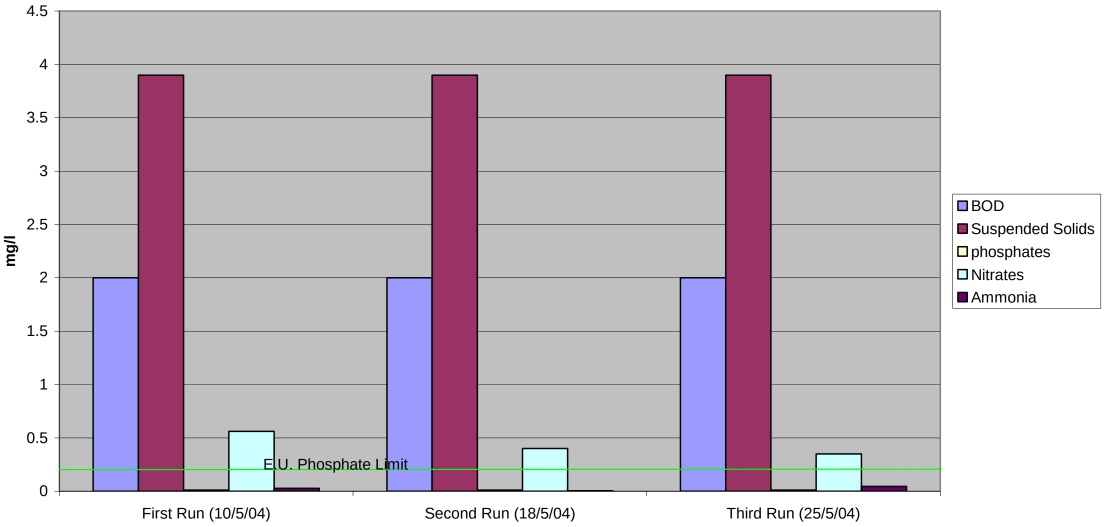
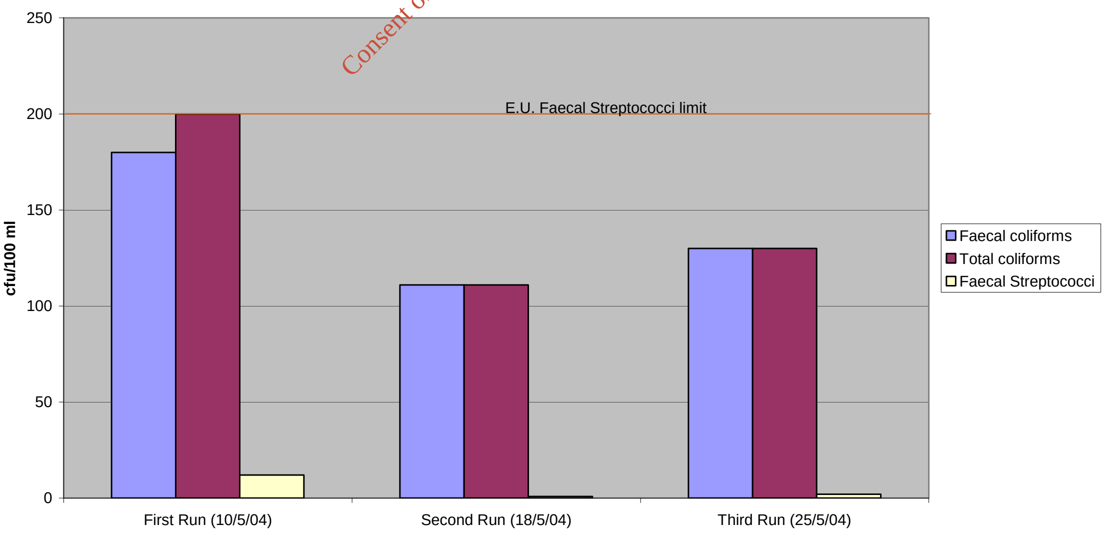





**Figure 2.8.10**
**Blacksod Bay Survey May 2004**
**Freshwater Microbiological Analysis Results**
**Station 2**



Recorded levels of phosphate (Figure 2.8.3) and nitrate (Figure 2.8.4) are within the limits set by the Surface Water Regulations for A1 waters (0.22 mg/l for phosphate and 50 mg/l for nitrate). The same surface water regulations establish a 0.2 mg/l limit for A1 waters. Ammonia levels recorded during the first run (12/5/04) exceeded the limit at Stations 1,2,7,9 and 10 (see Figure 2.8.5). The remaining records are all well below the limit. All the results obtained from the freshwater samples are below the limits established by the EU. Ammonia is present in natural waters, though in very small amounts, as a result of microbiological activity, which causes the reduction of nitrogen-containing compounds. The form of ammonia, either free ($NH_3$) or saline ($NH_4$), depends on the pH and these forms are not distinguished from one another during analysis. The results of the above analyses are presented in Figures 2.8.7 (Station 1) and 2.8.9 (Station 2).

Bacteriological results can be measured against the Bathing Waters Directive, the Drinking Water Directive and the Surface Waters Directive and in the case of faecal coliforms, the Shellfish Waters Directive. The Shellfish Waters Directive usually applies to faecal coliform levels in shellfish flesh, but can also be applied to waters in which 'shellfish directly edible by man' are farmed, this is pending further legislation. The limits of these Directives are presented as Table 2.8.10. Total coliform levels at the seawater sites did not exceed the limits of either the Bathing Water or Surface Water Directives (Figure 2.8.6). Freshwater records also show values well below the limits for total and faecal coliforms and faecal *Streptococci*, as presented in Figure 2.8.8 (Station 1) and Figure 2.8.10 (Station 2). Sediment sampling took place on 11th of May along two transects with four stations per transect. Four stations were selected evenly over a line connecting the two proposed outfall locations and the remaining four stations created a perpendicular transect intersecting the first, see Figure 2.8.1a. A Van Veen Grab was used from an inflatable boat and the samples were analysed for *Clostridium perfringens* levels. The results are displayed as Table 2.8.7 below.

| **Station** | **Latitude** | **Longitude** | ***C. perfringens*** (cfu/ml) |
|---|---|---|---|
| A | 54 12.06 | 9 58.18 | <10 |
| B | 54 12.21 | 9 59.05 | <10 |
| C | 54 12.30 | 9 58.89 | <10 |
| D | 54 12.35 | 9 58.75 | 30 |
| E | 54 12.32 | 9 59.54 | 100 |
| F | 54 12.13 | 9 59.48 | <10 |
| G | 54 11.99 | 9 59.02 | <10 |
| H | 54 11.85 | 9 58.66 | <10 |

**Table 2.8.7: Results of the grab sample *Clostridium* analysis taken on the 11/5/04, Blacksod Bay, Co. Mayo**

***Note:** These are the same sampling locations as for the benthic grab samples.

While a positive confirmation of *Clostridium* in the sedimentary environment is indicative of sewage contamination, the actual distribution of *Clostridium* CFU's (colony forming units) may be influence by a number of factors. There are no EU criteria for levels of *Clostridium* in seawater while mandatory levels for drinking waters are set at ≤1 (MPN). As a general rule the higher the level of *Clostridium*, the greater the degree of contamination. The highest counts were obtained from samples taken at Station A in Transect 1 (30 cfu/g) and Station E (100 cfu/g) in Transect 2. Although these values are low they indicate that faecal contamination has occurred recently, either locally or from a distant source (i.e. the canal). The records obtained at the remaining stations are all very low (less than 10 cfu/g).



## 2.9 BENTHIC SAMPLING

A benthic survey was carried out on the 11th of May 2004. Grab samples were collected at eight sites (A-H) in the vicinity of the two proposed outfall locations as described in the above section (Fig. 2.8.1a).

These grab samples were taken to determine the baseline diversity of fauna, the presence and importance of indicator species found, and the effects of any perceived organic pollution within the area. A sub-sample of each grab was taken for particle size, organic carbon, and clostridium analysis (as described in Section 2.8 above); the remainder was preserved in 4% formalin solution for taxonomic identification and enumeration. The faunal samples were sieved through a 1mm sieve and identified to species level where possible.

### 2.9.1 Granulometery

The sediments at each station consisted mainly of very fine sand through to gravel fractions. The highest fraction of material found at the majority of sampling sites, with the exception of stations F and G, consisted of very fine sand. Stations F and G along Transect 2, however, contained slightly higher fractions of fine sand. Station G also contained the largest fraction of coarse material, returning the highest percentages for medium sand (13.70%), coarse sand (6.74%) and very coarse sand (5.17%). Gravel material (2-4mm) was only recorded from station B, G, and H, while all eight stations contained <1% of silt (<0.063mm). The percentage of each sediment fraction is presented in Appendix VI.



### 2.9.2 Macrofaunal analysis

A total number of 75 species were recorded from the eight macrofaunal samples, consisting of 40 Polychaeta, 24 Crustacea, 8 Mollusca, 1 Chelicerata, 1 Oligochaete, and 1 species of sea anemone, *Actinia* sp. No unusual or rare species were recorded. A list of the species recorded can be found in Appendix VII.

According to the Marine Nature Conservation Review (1997) the most suitable classification for this type of habitat would be a shallow sand faunal community (IGS.FaS), which includes clean sands occurring in shallow water, either on the open coast of in tide-swept channels of marine inlets. Such habitats typically lack a significant seaweed component and are usually characterised by robust fauna, particularly venerid bivalves, amphipods and robust polychaetes. Polychaetes such as the Nepthyidae, *Spiophanes bombyx*, and *Chaetozone setosa* are characteristic of shallow sand communities, along with the bivalves *Chamelea gallina* and *Spisula elliptica* and the amphipod *Bathyporeia* sp.

Both venerid bivalves were recorded from five of the eight stations sampled, thus the biotope '*Spisula elliptica* and venerid bivalves in infralittoral clean sand or shell gravel' (IGS.Sell) from the Marine Nature Conservation Review (1997) gives the closest description of the habitat under investigation in Blacksod Bay. It consists of coarse, loose sands subject to moderately strong water movement, containing *Chamelea gallina* and is characterised by a prevalence of *Spisula elliptica*. This biotope may give way to others with characterising species such as the bivalve *Donax vittatus*, and the polychaete *Nepthys caeca* on exposed lower shore sands (LGS.AP Pon) (Jones,1950).

According to Fossit (2000) this habitat falls under 'infralittoral gravels and sands SS1'. In shallow water, coarse clean gravels and sands are generally colonised by a robust fauna of venerid bivalve molluscs, polychaetes and amphipods (Fossit, 2000). This category of habitat may contain examples of 'sandbanks slightly covered by sea water all the time (1110)' and thus falls under the EU Annex I habitats list (Fossit, 2000).

## 2.10 RESULTS OF MODEL CALIBRATION AND VALIDATION



### Introduction

The type of model used in this study, it's background, and the general model development process have already been described in Section A of this report when discussing the model of Inner Broadhaven Bay. The model of Blacksod Bay presented in this section was developed using basically the same procedure, except that the grid size in this model is 50m x 50m since the modelled area was much larger. The total number of grid points is 43290 and the water elevation boundary is specified at the southern limit of the model.

### Hydrodynamic Model Calibration

The hydrodynamic model was calibrated by comparing model predictions against field measurements of current speeds and water surface elevations for given environmental conditions. When running the model, tidal elevations were specified at the southern open sea boundary for spring and neap tides. These elevations corresponded with measured tidal dynamics. For the calibration simulations, the tidal elevations recorded while doing the hydrographic survey were used as inputs for the model.

**Calibration Results**

The hydrodynamic model was calibrated by comparing current velocities and water surface elevations as calculated by the model against field measurements recorded by the current meters and tide gauges as detailed in Figure 1.1.1., in Section B of this report. The hydrodynamic model was run for a full spring-neap tidal cycle to ensure a comprehensive set of data was available for comparison.

Figure 2.10.1 illustrates a comparison of the water elevation recorded over a period of two weeks (a spring-neap tidal cycle) in outer Blacksod Bay and the tidal elevations predicted by the model for the same location. From this figure, it is apparent that the tidal phase measured in Blacksod Bay is simulated accurately by the model for the entire spring-neap tidal cycle. It is also evident that the amplitude of the tidal constituents predicted by the model and measured using the tidal gauges, exhibit excellent agreement at spring and neap tide.



Comparisons of the current velocities simulated by the model and the values recorded using the current meters at the locations shown in Figure 1.1.1 were also conducted. The results are shown in Figures 2.10.2(a) and (b). From these figures, it is clear that the magnitude of the measured current velocity (current meters 1 and 2) exhibit good agreement with model predicted data. As expected, the recorded data is generally less regular than the simulated results; this is due to prevailing wind conditions.

The results presented in these diagrams above are a good verification that the model is predicting the hydrodynamic conditions of Blacksod Bay with sufficient accuracy.

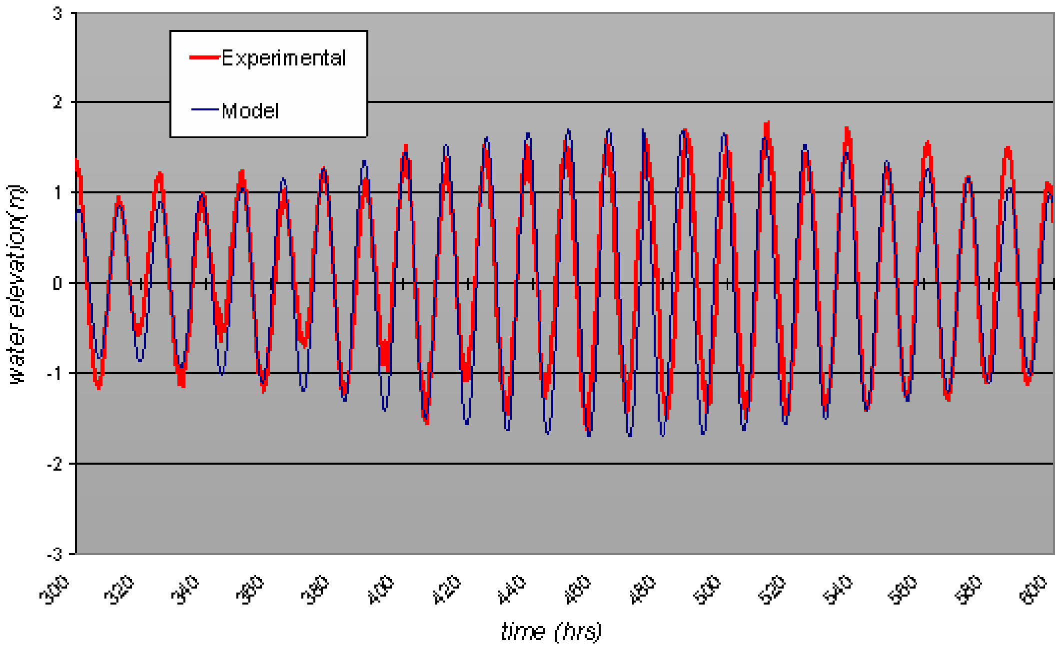



*Figure 2.10.1 Comparison of simulated and measured water surface elevation over a spring-neap tidal cycle in outer Blacksod Bay*



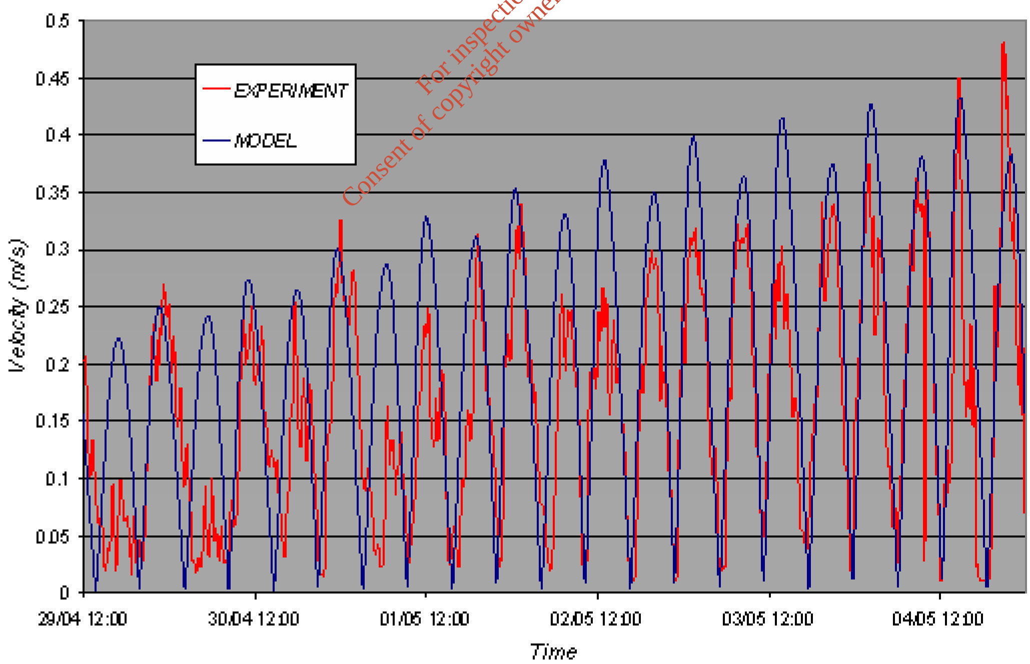



*Figure 2.10.2 (a) Comparison of simulated and measured current velocities over a spring-neap tidal cycle at location of current meter 1.*

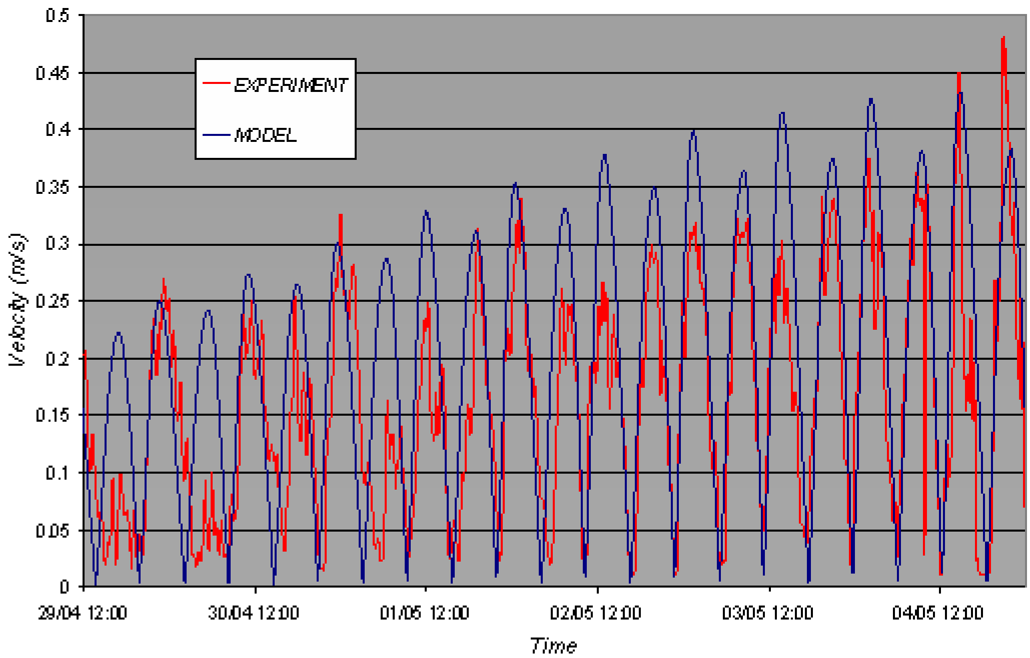



***Figure 2.10.2 (b) Comparison of simulated and measured current velocities over a spring-neap tidal cycle at location of current meter 2.***



**Hydrodynamic Simulation Results**

The hydrodynamic model was run for a full spring-neap tidal cycle to examine the water circulation patterns and the variation of current velocities throughout the bay. The results from the hydrodynamic model simulations are presented at four different times during the course of a spring tidal cycle: mid-flood, high water, mid-ebb and low water (Figures 2.10.3 – 2.10.10).

The current velocities calculated during the spring tidal cycle at mid-ebb and mid-flood are much greater than the corresponding flows during the neap tidal cycle. The mean maximum neap tide velocity is 0.2 m/s whereas the mean maximum spring tide velocity approximately 0.5m/s, although the velocities can be as high as 0.75m/s in specific locations. Hence the dilution factor should be much greater during a spring tide. The annual mean spring and neap tidal ranges are 3.6 m and 1.8 m respectively.

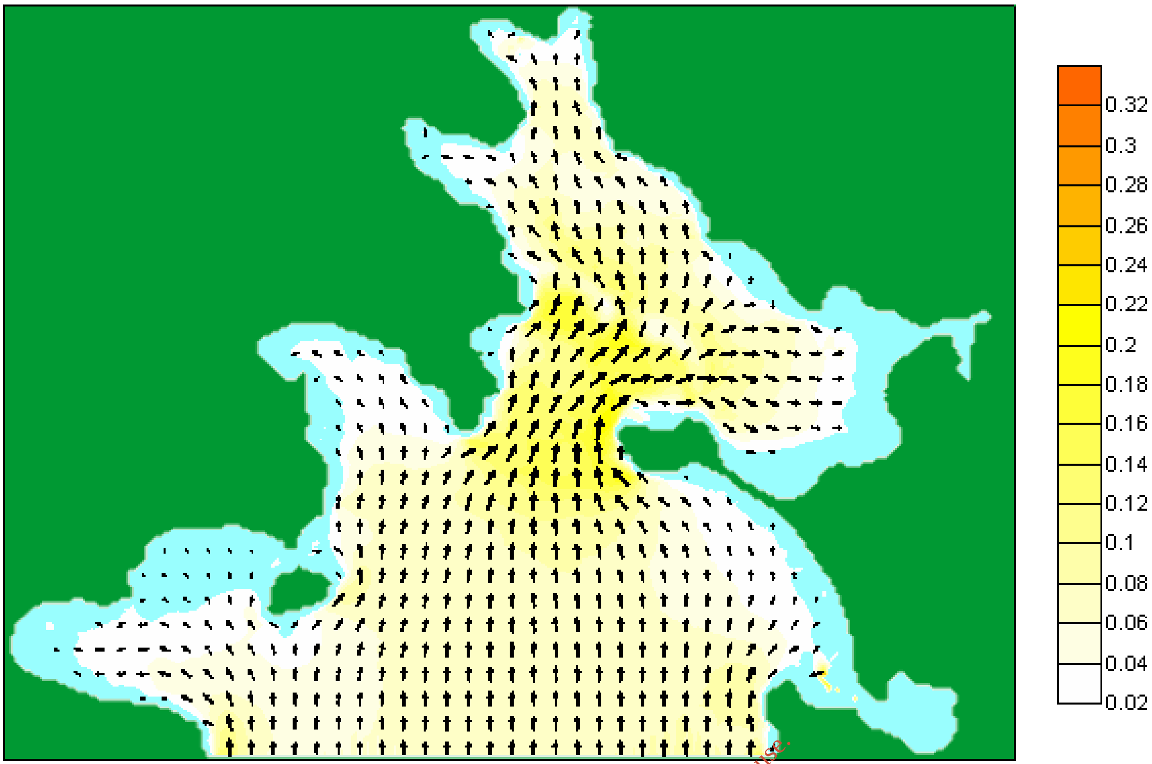



Figure 2.10.3 – Current velocity vectors (m/sec) calculated at mid-flood on a neap tide.



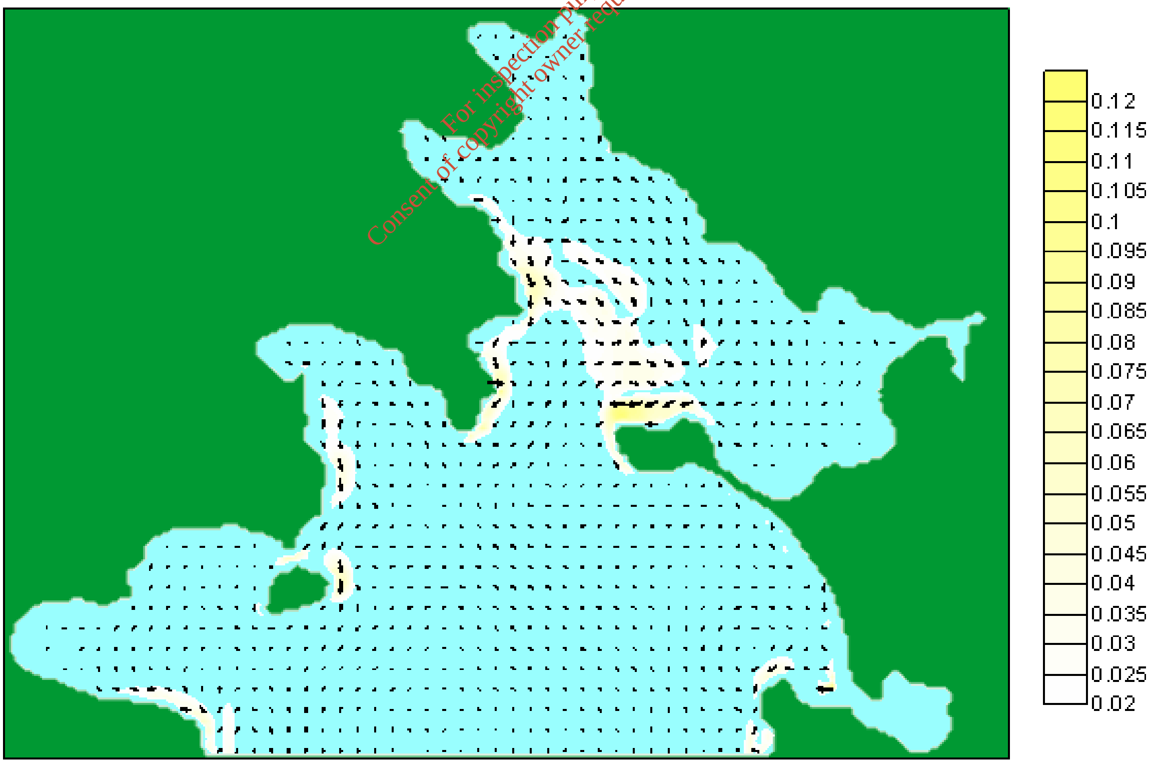



Figure 2.10.4 – Current velocity vectors (m/sec) calculated at high water on a neap tide.

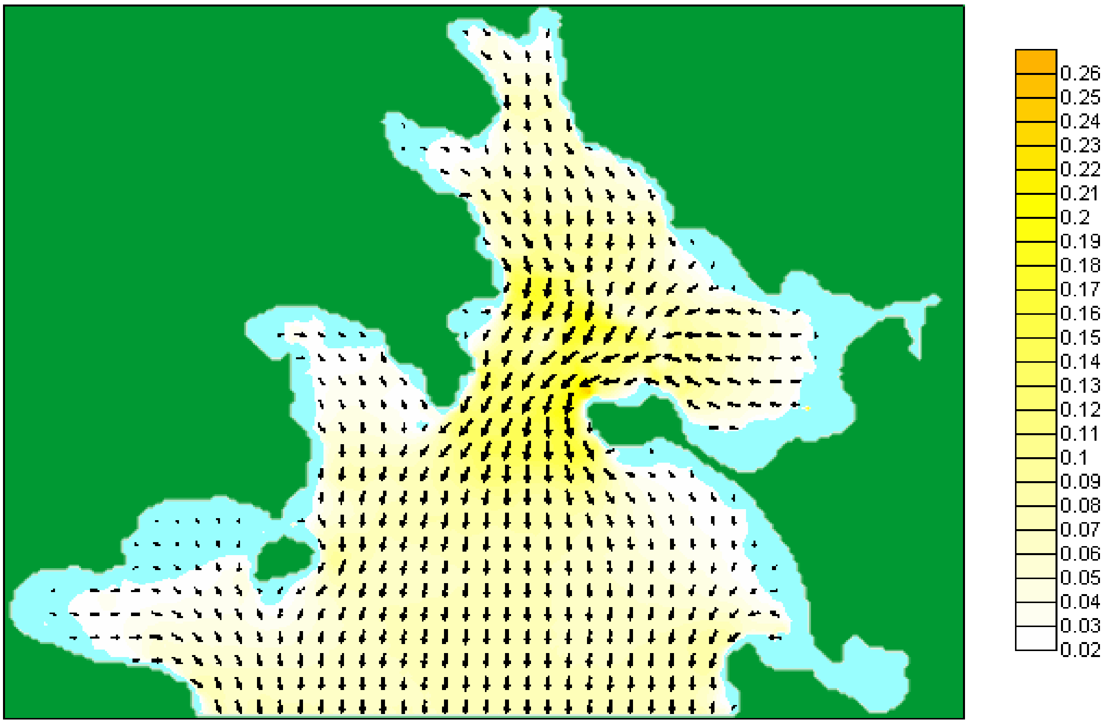



Figure 2.10.5 – Current velocity vectors (m/sec) calculated at mid-ebb on a neap tide.



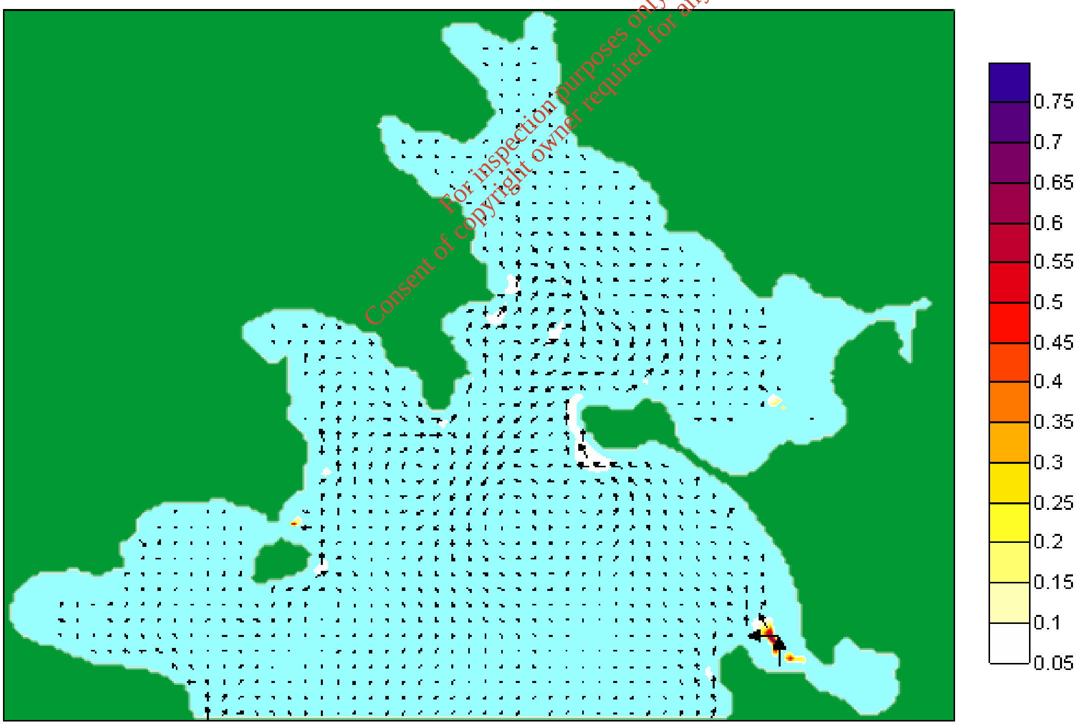



Figure 2.10.6 – Current velocity vectors (m/sec) calculated at low water on a neap tide.

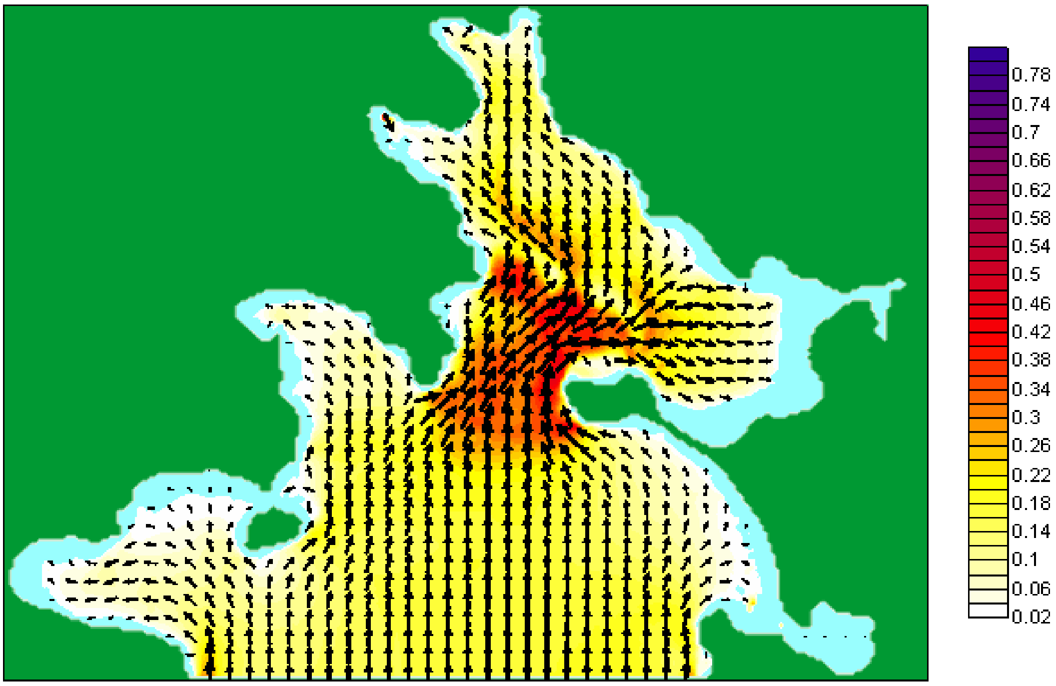



Figure 2.10.7 – Current velocity vectors (m/sec) calculated at mid-flood on a spring tide.

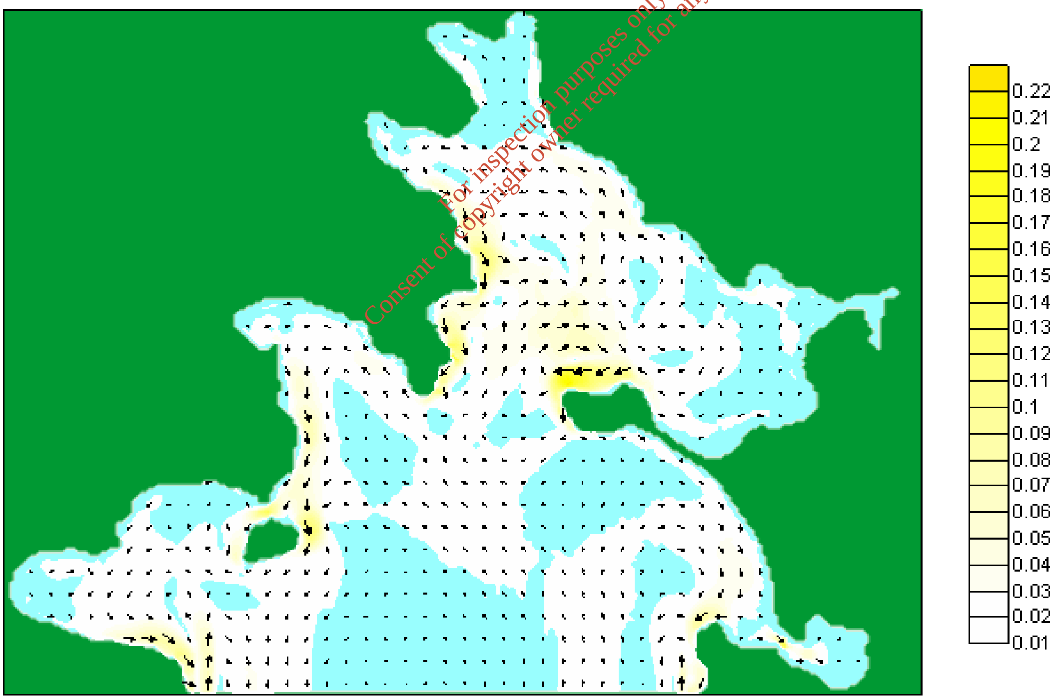



Figure 2.10.8 – Current velocity vectors (m/sec) calculated at high water on a spring tide.

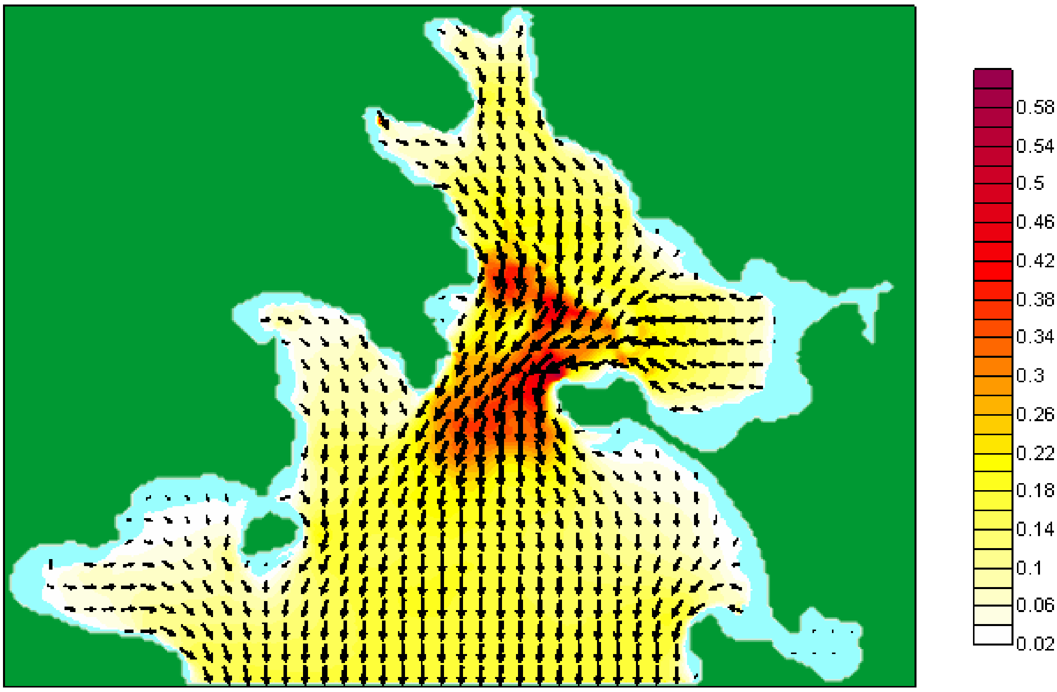



Figure 2.10.9 – Current velocity vectors (m/sec) calculated at mid-ebb on a spring tide.



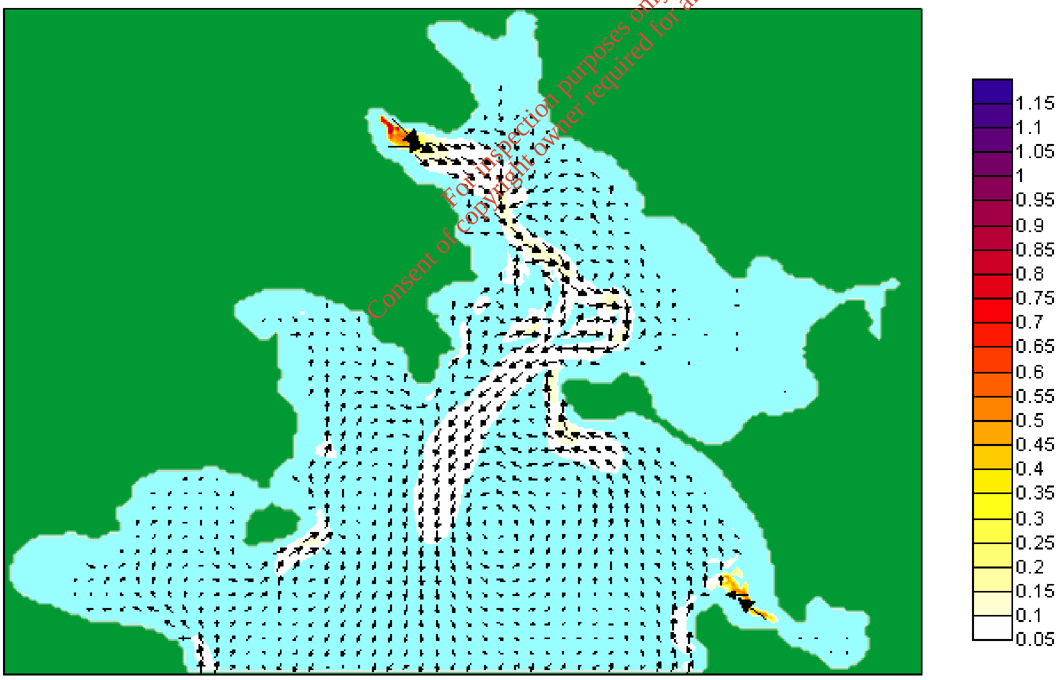



Figure 2.10.10 – Current velocity vectors (m/sec) calculated at low water on a spring tide.

**Solute Model Validation Results**

Validation of the solute model was carried out by comparing solute plumes generated by the model against plumes observed during the dye study as outlined in subsection 2.6. The model simulated the release of dye at high water on a spring tide at a location identical to that used during the dye study. The wind conditions that prevailed at that time were also included in the model. The lateral and longitudinal dispersion coefficients were adjusted in the model to ensure the best possible agreement with the measured data was observed. The results of the simulations were plotted at half hour intervals and are shown in Figures 2.10.11 to 2.10.18

In comparing the predicted spread of the dye patch in these figures with that observed in Figure 2.6.2, it can be seen that in both cases the dye patch behaves in a very similar manner. After initial release it spread slowly in a southerly direction while increasing its size due to diffusion. It then starts to elongate considerably as the current velocities increase due to the ebbing tide and it reaches the channel where the faster flowing current rapidly disperses the plume. The time taken for this to occur is approximately the same in each instance, i.e. approximately 3½ hrs.



**Conclusions**

From the calibration and validation exercises carried out above it is considered that the model developed can accurately simulate the hydrodynamics within Blacksod Bay and the transport and dispersion of solutes. Thus, the model can be used to make predictions of concentrations of various water quality parameters due to the discharge of effluent into the bay.

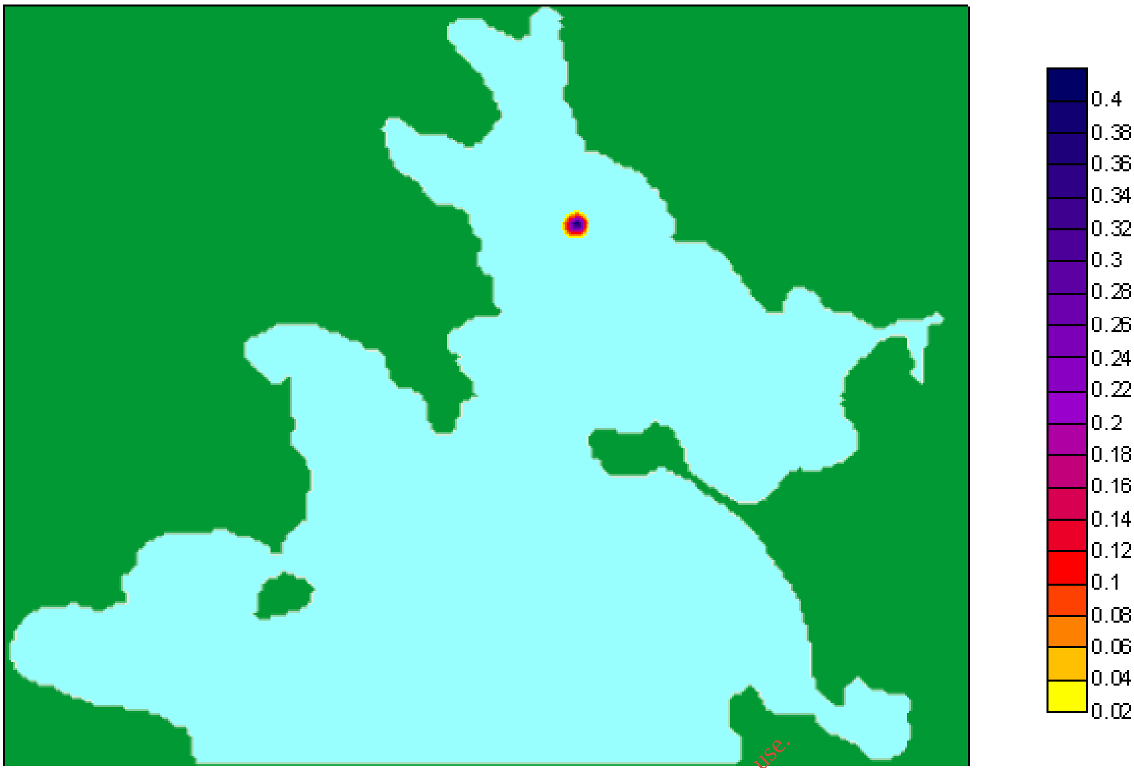



**Figure 2.10.11 – Dye Dispersion at high water on a spring tide**



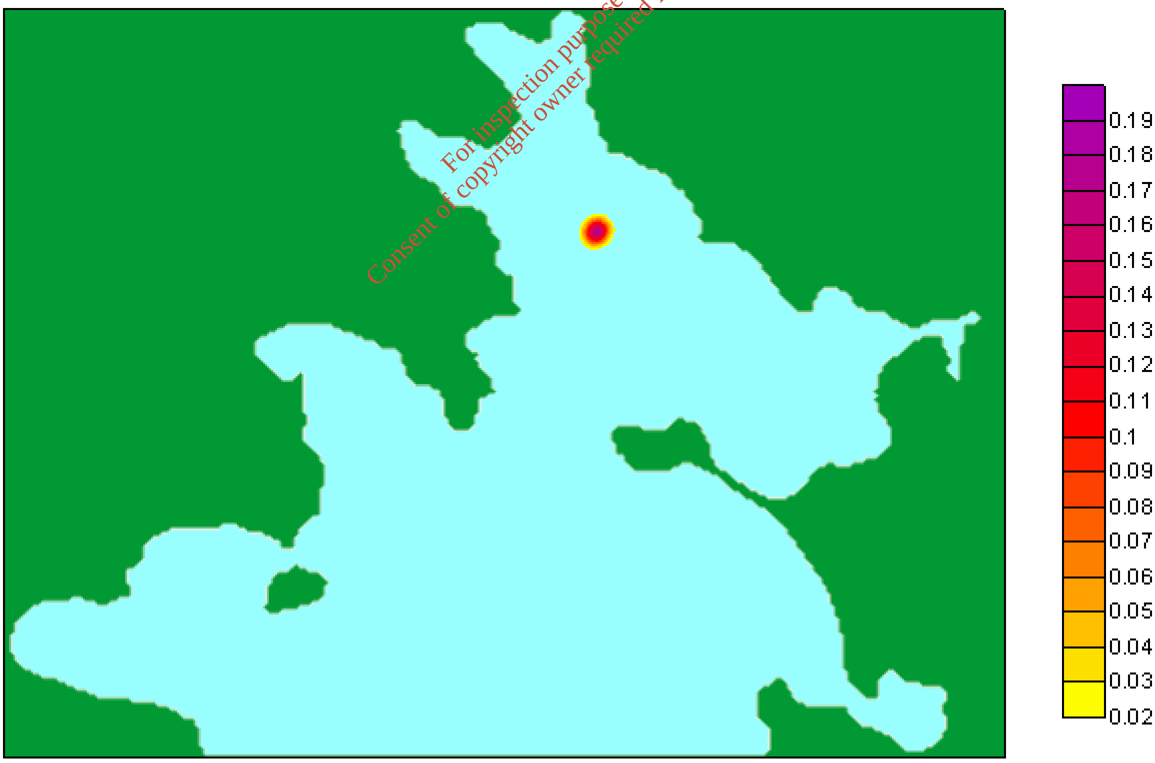



**Figure 2.10.12 – Dye Dispersion at high water + ½ hr**

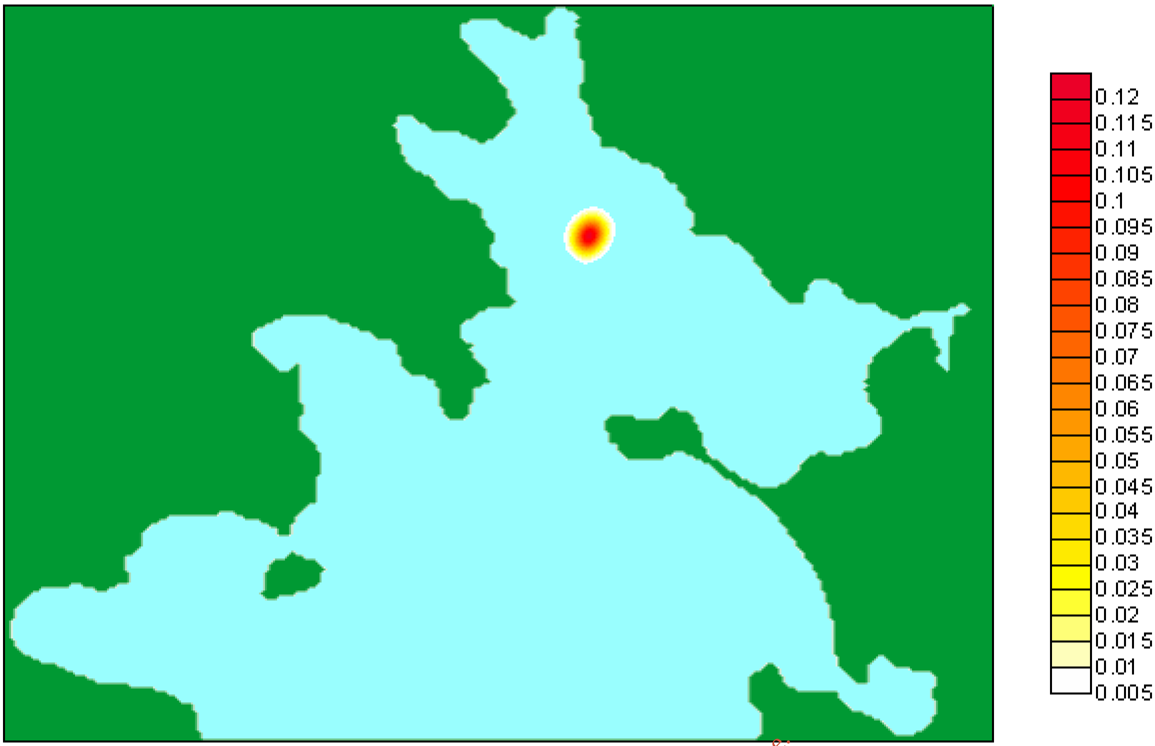



**Figure 2.10.13 – Dye Dispersion at high water + 1 hr**



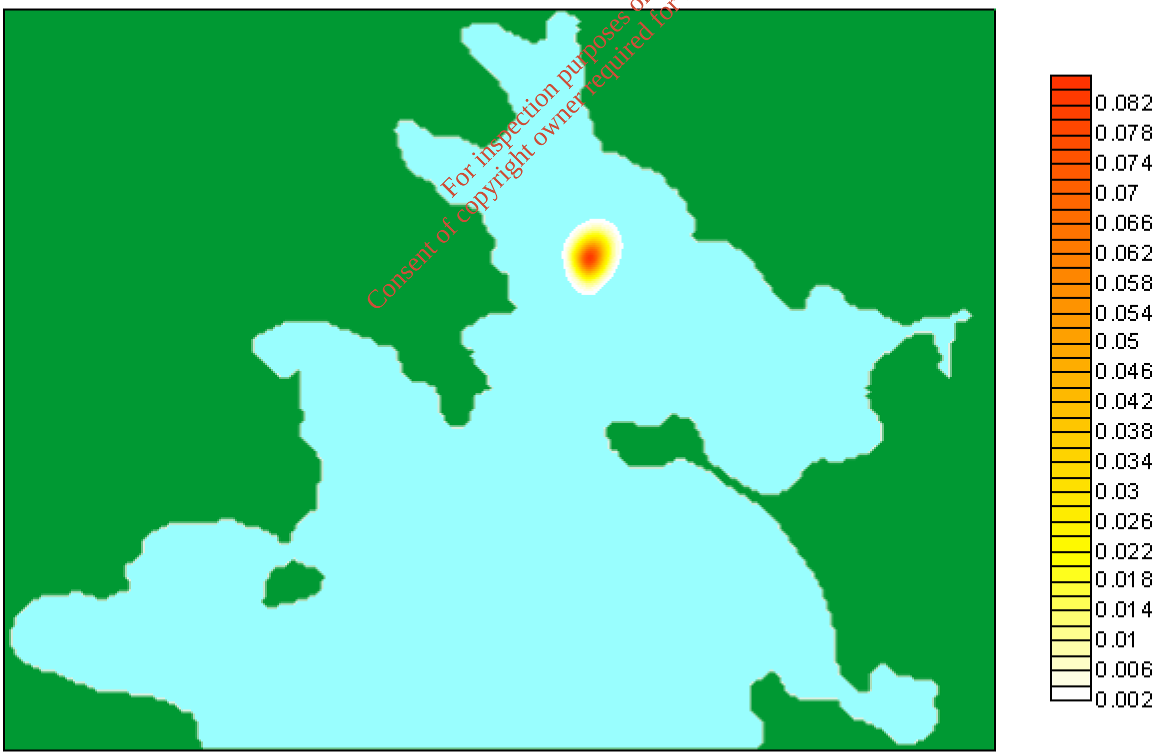



**Figure 2.10.14 – Dye Dispersion at high water + 1½ hr**

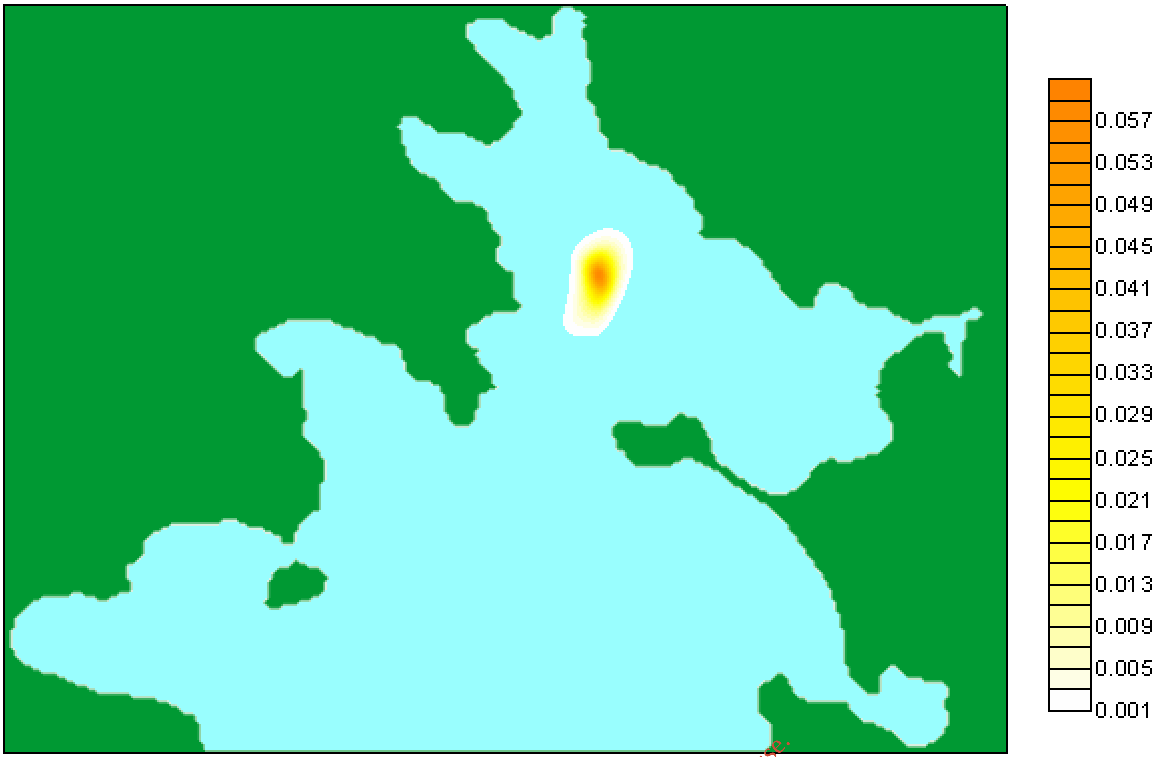



**Figure 2.10.15 – Dye Dispersion at high water +2 hr**




**Figure 2.10.16 – Dye Dispersion at high water + 2½ hr**


**Figure 2.10.17 – Dye Dispersion at high water +3 hr**




**Figure 2.10.18 – Dye Dispersion at high water + 3½ hr**

## 2.11 RESULTS OF MODEL ANALYSIS

### Introduction

In this study a solute transport model was developed using DIVAST, as detailed in section 2.10. The model was then used to assess the impact of urban waste water discharged from an outfall pipe, by simulating the spread and fate of faecal-coliforms throughout the bay. As mentioned earlier in this report Blacksod Bay contains a number of aquaculture sites for mussels and salmon. When dealing with shellfish waters, it is generally considered that the local operational standards set for the faecal coliform parameter are likely to be the most important consideration in determining the action required at sewage treatment works to achieve the necessary water quality standards. The modelling approach adopted in this study is typical of the model studies undertaken when assessing impacts of effluent from sewage treatment outfalls in Ireland and Europe.



Initially the suitability of two different locations for the outfall site was investigated. At each site three different concentration levels of faecal coliforms in the effluent were considered; $1x10^6$ number/100ml, $2x10^5$ number/100ml, and $1x10^3$ number/100ml. Based on the results from the subsequent simulations it was decided that the outer site was much more suitable in terms of dilution characteristics and so it was chosen as the preferred location for the proposed outfall. For this site further simulations were carried out to include three different wind directions and two different wind speeds (i.e. maximum and average) using a faecal coliform concentration of $1x10^3$ number/100ml in the effluent. This lower concentration was agreed upon to ensure minimal impact on the surrounding marine environment. The predicted rate of discharge at this site is 14.6l/sec.

A set of all the outputs from these simulations are presented in the appendix. In the this section of the report section however, only results pertaining to the outer site using a concentration of $1x10^3$ number/100ml and a zero wind condition will be presented. The influence of wind on the transport of the effluent will be discussed in section 2.12.

## Simulations and Results

Using the above discharge the DIVAST model was used to estimate the faecal coliform concentration of the effluent throughout the study area during the course of a spring-neap tidal cycle. The faecal coliform loading was specified as continuous discharge after one tidal cycle of the hydrodynamic model had been run, which ensured that hydrodynamic cold start effects had dissipated. The model simulations were performed a over a spring-neap tidal cycle (350 hours) using a time intervals of 10 seconds. The duration of the each simulation was sufficiently long enough to allow steady state conditions to be attained. This ensured that the maximum levels of contaminant which would be reached throughout the water body would be observed.

In order to analyse the model results, snapshots of the effluent plumes within the study area were output by the model at four different stages of the tide, namely, high water, mid-ebb, low water and mid-flood, for both neap and spring tide conditions. The neap solute plumes were output by the model at approximately 175 hours into the simulation while the spring plumes were output after approximately 350 hours of the simulation. These solute plumes are illustrated in Figures 2.11.1 – 2.11.8.



Table 2.11.1 summarises the maximum concentrations of the effluent predicted at the proposed outfall location at eight different stages in the tidal cycle:

| Tidal stage | Faecal coliform conc. [number/100 ml] |
|---|---|
| Neap mid flood | 0.87 |
| Neap high water | 1.15 |
| Neap mid ebb | 0.90 |
| Neap low water | 1.96 |
| Spring mid flood | 0.43 |
| Spring high water | 0.69 |
| Spring mid ebb | 0.45 |
| Spring low water | 3.22 |

***Table 2.11.1:*** *Maximum faecal coliform concentration (number/100ml) at different periods in the tidal cycle*

## 2.12 Discussion of Results

In general the water quality, the benthos and hydrographic conditions, as indicated by tidal measurements, current meter measurements, dye and drogue studies and hydrographic model simulations, indicate that the inner Blacksod Bay area, south of Belmullet town has relatively good dispersive properties with good water exchange to the open sea through a narrow opening defined by Ardmore and Claggan Points.

Although much of the bay is relatively shallow where large sections of the sea floor dry out or are very shallow at low water, there is a good exchange of sea water on each tide from the more open outer Blacksod Bay. However, as was recorded during the neap dye survey, the influence of the wind has an important part to play in this tidal exchange. Under certain conditions as displayed on the 27th May 2004, strong winds from a southerly direction will push the water up the bay and given the relatively shallow nature of this area, tidal currents will be limited.



The model vector plots showing current speed and direction agree with the drogue and dye studies carried out in low wind conditions. As expected, a relatively strong current is observed flowing through the mouth formed by Ardmore Point and Claggan Point on both the flood and ebb tide. The direction of the flow is consistent with the orientation of the channel located in this area.

### Discussion of Model Results

Upon examination of Figures 2.11.1 – 2.11.8 it is evident that, in general, higher solute concentrations occur during the neap tidal cycle due to a smaller volume of water entering or leaving the bay. This is due to the reduced water depth and associated low current velocity values which tend to inhibit rapid dilution of the effluent during this period. Conversely, dilution of the effluent plumes is greatest on the spring tide at periods of relatively high current velocity i.e. at mid-ebb and mid-flood tide, when the volume of water entering or leaving the bay is at a maximum.

Figures 2.11.1 – 2.11.4 show faecal coliform concentrations for the different stages of the neap tide. It is evident that the maximum levels of faecal coliforms are experienced in the immediate vicinity of the outfall, as expected. At the four stages of the neap tide faecal coliform levels within this area vary between 0.87 and 1.96 no./100ml. Away from the immediate vicinity of the outfall the concentration of faecal coliforms can be seen to decrease to values of less than 0.05 number/100ml. The maximum value of faecal coliforms during the neap tidal cycle (1.96 number/100ml) occurs at low water, which is to be expected, since the water depth will provide less dilution than at other stages of the tide. Looking at the current velocity vectors in figure 2.10.6 it can be seen that the current is very weak during this low water period which also contributes to the build up of faecal coliforms in the area.

Faecal coliform concentrations for the different stages of the spring tide are shown in Figures 2.11.5 – 2.11.8. These, in general, are less than those of the neap tide (approximately 0.4 – 0.7 number/100ml) except for a couple of hours around low water when the concentration reaches a maximum of 3.22 number/100ml. This occurs because the water depth and currents are smallest at this point and prohibit effective dilution of the effluent. However, this relatively high concentration is confined to within approximately 25m of the outfall pipe and is quickly diluted with the return of the flooding tide.



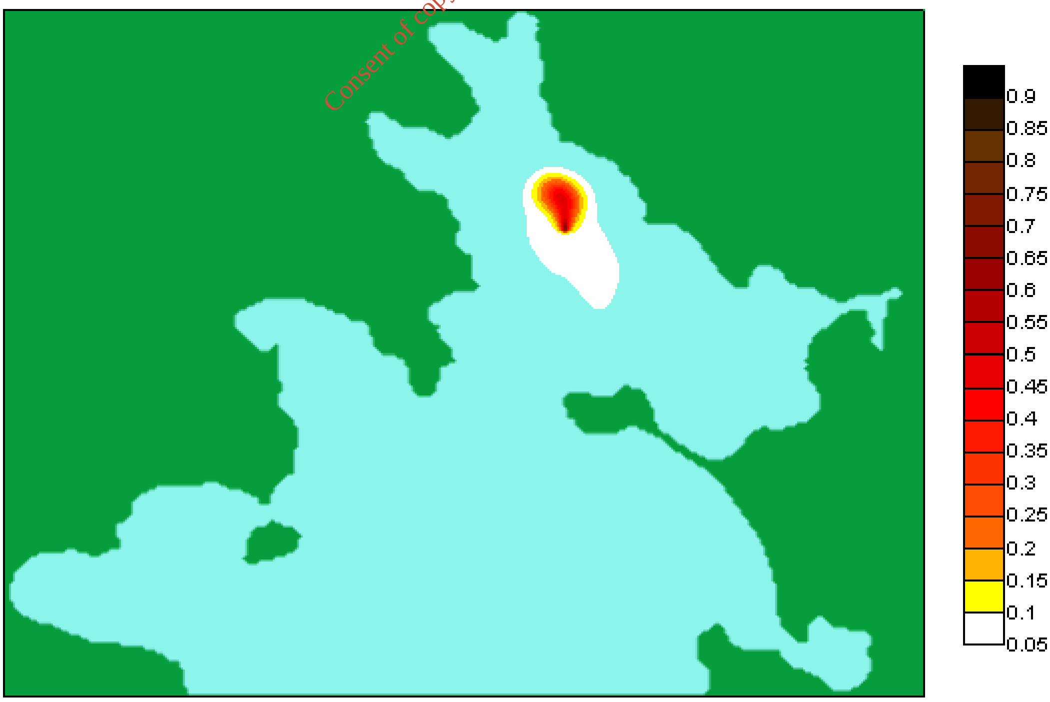



**Figure 2.11.1 - Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (No wind – outer site)**

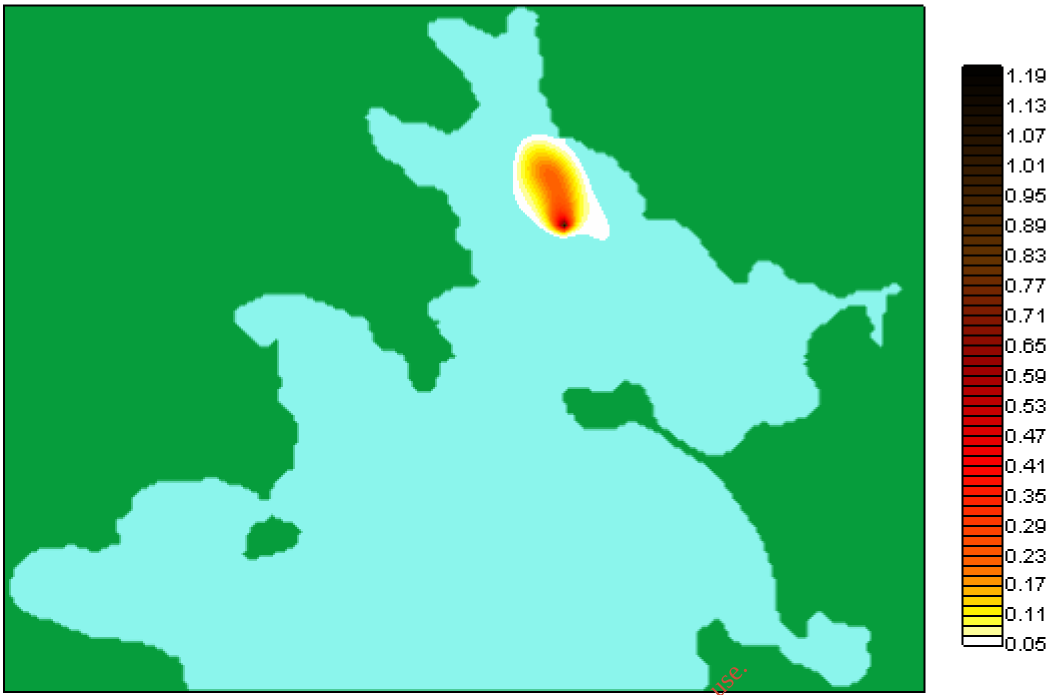



**Figure 2.11.2 - Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (No wind – outer site)**



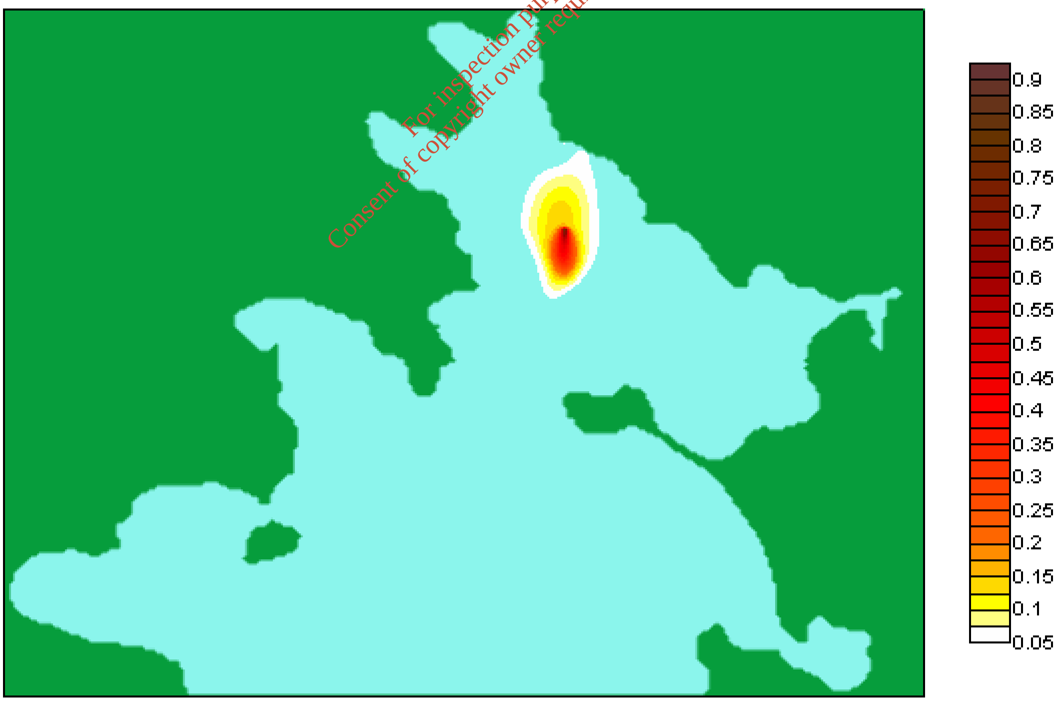



**Figure 2.11.3 - Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (No wind – outer site)**

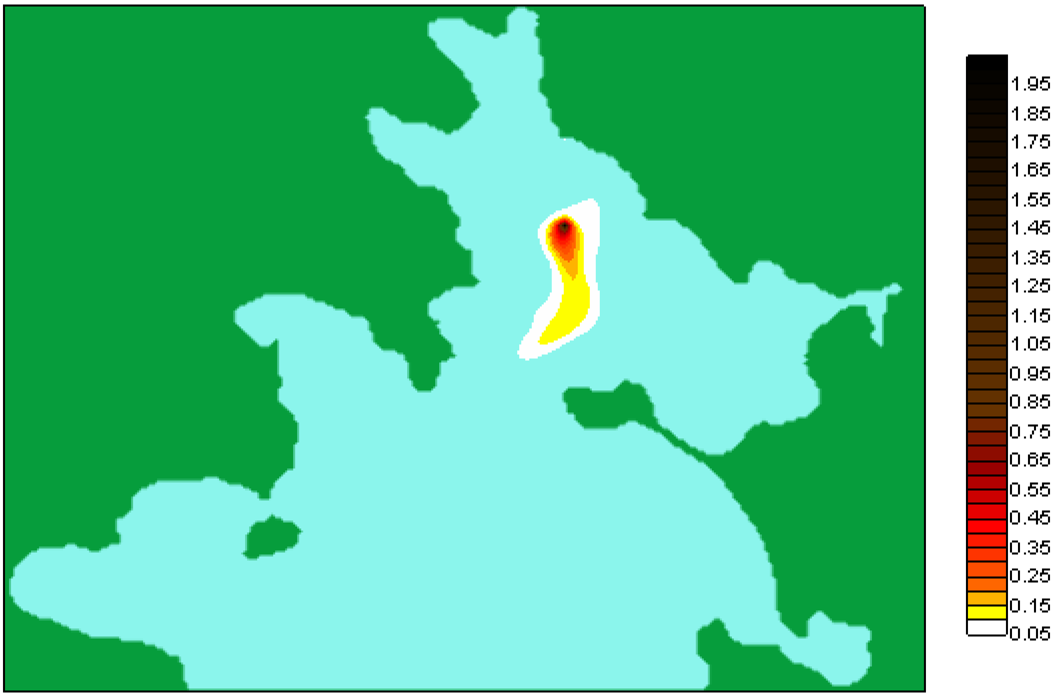



**Figure 2.11.4 - Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (No wind – outer site)**



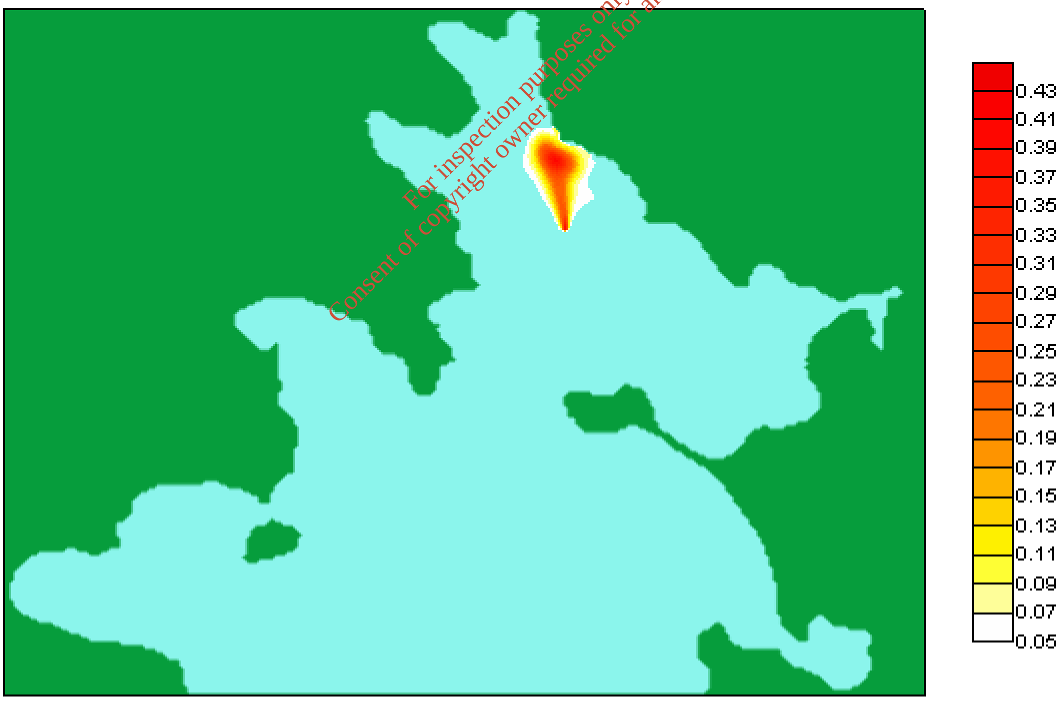



**Figure 2.11.5 - Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (No wind – outer site)**


**Figure 2.11.6 - Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (No wind – outer site)**




**Figure 2.11.7 - Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (No wind – outer site)**

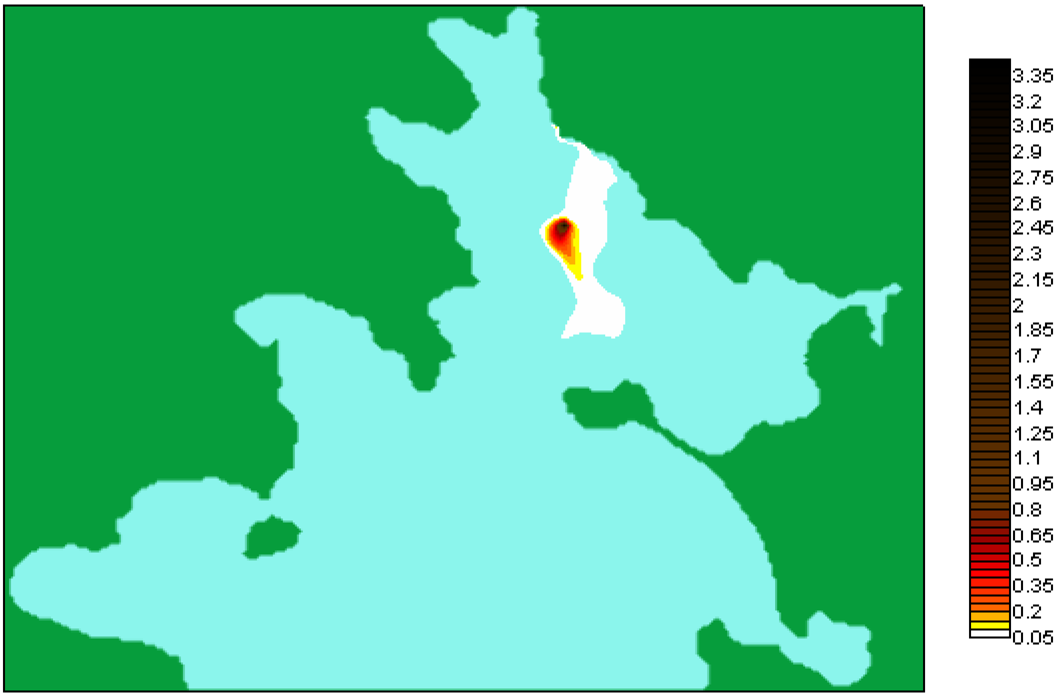



**Figure 2.11.8 - Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (No wind – outer site)**



The influence that the wind has on the transport of effluent in Blacksod Bay can be seen in Figures A.17 – A.64 of appendix VIII. In general the wind causes a greater dispersion of the effluent resulting in an elongated plume with lower concentrations. The greater the wind speed, the more pronounced this dispersion is. It is particularly noticeable at low water on a spring tide where the maximum concentration of faecal coliforms is less than half of the corresponding concentration without wind (i.e. figures A.16 and A.32). The reason for this is that the wind induced currents dominate at this stage since the current velocity due to the tide is practically zero. Overall, the wind improves the mixing process and any effluent transported far from outfall contains a very low concentration of faecal coliforms, which will have no impact on the marine environment.

**Water Quality Standards**

The Shellfish Water Directive (79/923/EEC) states that a mandatory value of <300 faecal coliforms/100ml applies "in the shellfish flesh and intervalvular fluid". As a footnote it also adds that – "however, pending the adoption of another Directive, on the protection of the consumers of shellfish products, it is essential that this value (i.e. 300 faecal coliforms/100ml) be observed in the waters in which live shell fish directly edible by man." A further EC Directive 'laying down the health conditions for the production and the placing on the market of live bivalve molluscs' (CEC,1991c) reiterated the water quality parameters of the earlier Directive as well as additional guidelines for harvesting, transportation, and purification centers.

The Department of the Marine and Natural Resources (DMNR) is the competent authority in Ireland for classifying shellfish production areas and Regulations (S.I. No. 147 of 1996) implementing the directives were made by the Minister in 1996. The scheme of classification has three categories, corresponding with the criteria laid down in the directive, which can be summarised in Table 2.12.1.



| Classification | Faecal coliforms/*E.coli* per 100g of shellfish flesh[1] | Requirements |
|---|---|---|
| A | Less than 300 faecal coliforms or 230 *E.coli* consumption permitted | None - sale for direct human |
| B | Less than 6000 faecal coliforms or 4600 *E.coli* in 90% of samples | Purification in an approved plant for 48 hours prior to sale for human consumption |
| C | Less than 60000 faecal coliforms | Relaying for a period of at least two months in clean seawater prior to sale for human consumption |

[1]five-tube, three-dilution MPN test

***Table 2.12.1* : *Summary of scheme of classification of shellfish production areas operated by the Department of the Marine under Directive 91/492/EEC.***

Therefore, based on the 79/923/EEC Directive, a shellfish area which is classified as 'A', should have less than 300 faecal coliforms/100ml in the surrounding waters. In fact, this standard for the water quality has also been adapted by the UK government [1] as "a national minimum which meets the Directive's requirement to endeavour to observe the guide value". (i.e 300 faecal coliforms/100ml in the shellfish flesh).

International standards are even stricter however, with the World Health Organisation and the United Nations Environmental Programme [2] requiring that the faecal coliform median or geometric mean must not to exceed 14 MPN/100 ml, and that not more than 10 percent may exceed 43 MPN/100 ml (MPN = Most Probable Number)[3]. These standards have also been adopted by the National Shellfish Sanitation Program (NSSP) in the US.

In comparing the above national and international standards for the production of shellfish with the results from the model, it is clear that discharging the given quantities of faecal coliforms from the proposed outfall in Blacksod Bay will have little or no impact on the surrounding water quality with regard to shellfish production. As mentioned in the previous section, the highest concentration of faecal coliforms predicted by the model was 3.22 number/100ml at the outfall site. This value is well below the strictest requirements for faecal coliforms considered above.



When considering the impact of the proposed discharge on the quality of bathing waters in the area, bacteriological results are measured against the Bathing Water Directive (76/160/EEC) and the Surface Water Directive (75/440/EEC). The most restrictive limits established by these Directives are 1000 cfu/100ml (Faecal Coliforms), 5000 cfu/100ml (Total Coliforms) and 200 cfu/100ml (Faecal Streptococci). The highest predicted value of faecal coliforms anywhere in the bay at any time during the tidal cycle was 3.22 number/100ml, as mentioned above. This value is several orders of magnitude lower than the guideline value stipulated in the directives and hence there should be absolutely no adverse impact on the quality of the local bathing waters.

# 3.0 OVERALL CONCLUSIONS

**Inner Broadhaven Bay**

- 3 potential outfall sites were assessed in Inner Broadhaven Bay

- Detailed bathymetric studies in Inner Broadhaven confirm that much of the inner bay is shallow in nature where large sections of the sea floor dry out or are extremely shallow at low water.

- Tidal measurements, drogue studies and current meter measurements in the canal area in Belmullet indicate that majority of the water flow runs from Inner Broadhaven to the Blacksod Bay.

- The retentive and restrictive nature of Inner Broadhaven Bay is responsible for the predominant flows from Inner Broadhaven to Blacksod Bays. This is particularly the case during the neap tide period. However, during the spring tide period the elevation of water tends to be higher in Blacksod Bay for the high tide period and reverses the trend with water flowing predominantly into Inner Broadhaven Bay during this phase of the moon.



- Hydrographic models, drogues and dye studies indicate that, in general, Inner Broadhaven Bay is retentive in nature with poor water exchange in the inner reaches of the bay.

- The benthic animal communities and sediments in Inner Broadhaven Bay are also indicative of low energy environments.

- The results form the present study show that the 3 study locations proposed considered for a new proposed sewerage pipe all discharge into a low energy, retentive hydrographic environment.

**Blacksod Bay**

- 2 potential outfall sites were assessed in Blacksod Bay

- Additional studies during the Blacksod Study further confirmed the flow patterns identified at the canal in Belmullet during the Inner Broadhaven study

- Water quality, the benthos and hydrographic conditions as indicated by tidal measurements, current meter measurements, dye and drogue studies and hydrographic model simulations indicate that the Blacksod Bay area, south of Belmullet town has relatively good dispersive properties with good water exchange to the open sea through a narrow opening defined by Ardmore and Claggan Point

- Initially the suitability of two different locations for the outfall site was investigated. The hydrographic model, dye dispersions and current measurements have indicated that the outer proposed outfall location has higher dispersive characteristics than the inner location.



- At each site three different concentration levels of faecal coliforms in the effluent were considered; $1x10^6$ number/100ml, $2x10^5$ number/100ml, and $1x10^3$ number/100ml. Based on the results from the subsequent simulations it was decided that the outer site was much more suitable in terms of dilution characteristics and so it was chosen as the preferred location for the proposed outfall.

- For this site further simulations were carried out to include three different wind directions and two different wind speeds (i.e. maximum and average) using a faecal coliform concentration of $1x10^3$ number/100ml in the effluent. This lower concentration was agreed upon to ensure minimal impact on the surrounding marine environment. The predicted rate of discharge at this site is 14.6l/sec.

- The maximum allowable level of faecal coliforms permitted by national and international standards for shellfish waters was not exceeded at any location in the bay at any time during the model study. The maximum concentration observed was in fact five times lower than the strictest guideline value and hence should not have any adverse effects on the quality of the shellfish being harvested.

- The highest predicted value of faecal coliforms anywhere in the bay was several orders of magnitude lower than the guideline value specified in the Bathing and Surface Water Directives and hence will not impact on the surrounding bathing areas.

- The predominant wind from a south/south west direction has a significant effect of the dispersions in Blacksod Bay. In general the wind causes greater dispersion of the effluent resulting in an elongated plume with lower concentrations

## REFERENCES


[1] Dept. of Env., UK, 1998. "Implementation of the Shellfish Waters Directive (79/923/EEC)", Consultation Document, June 1998.

[2] WHO, 2000. Monitoring Bathing Waters: A Practical Guide to the Design and Implementation of Assessments and Monitoring Programmes".

[3] E.P.A., 1996. "Water Quality Survey Results".

**Appendix I** Direct Reading Current Meter Data for Station 1 and 2, Inner Broadhaven Bay

| St. 1 - Existing Outfall Site (Neap tide) | | | | | | |
|---|---|---|---|---|---|---|
| Date 22/10/03 | revs/sec | | Position | Time | Velocity | Direction |
| | 0.66 | 0.01 | Middle | 9:40 | ** | 333 |
| | 2.50 | 0.05 | Middle | 10:29 | ** | 171 |
| | 3.00 | 0.06 | Middle | 11:11 | ** | 330 |
| | 31.00 | 0.62 | Middle | 11:48 | 0.174 | 303 |
| | 41.00 | 0.82 | Middle | 12:38 | 0.229 | 293 |
| | 31.33 | 0.63 | Bottom | 14:10 | 0.176 | 307 |
| | 29.33 | 0.59 | Middle | 14:15 | 0.166 | 313 |
| | 26.00 | 0.52 | Surface | 14:18 | 0.146 | 297 |
| | 3.00 | 0.06 | Bottom | 15:39 | ** | 240 |
| | 1.33 | 0.03 | Middle | 15:43 | ** | 247 |
| | 4.66 | 0.09 | Surface | 15:45 | 0.035 | 187 |
| | 1.33 | 0.03 | Bottom | 17:10 | ** | 277 |
| | 2.33 | 0.05 | Middle | 17:15 | ** | 307 |
| | 4.00 | 0.08 | Surface | 17:18 | 0.033 | 310 |
| | | | | | | |

| St. 2 - Proposed Outfall Site | | | | | | |
|---|---|---|---|---|---|---|
| | revs/sec | | Position | Time | Velocity | Direction |
| | 5.00 | 0.10 | Middle | 10:20 | 0.030 | 320 |
| | 7.00 | 0.14 | Middle | 10:50 | 0.048 | 290 |
| | 24.00 | 0.48 | Middle | 11:29 | 0.136 | 300 |
| | 16.00 | 0.32 | Middle | 12:13 | 0.095 | 310 |
| | 26.33 | 0.53 | Bottom | 13:31 | 0.149 | 327 |
| | 26.00 | 0.52 | Middle | 13:34 | 0.146 | 340 |
| | 40.33 | 0.81 | Surface | 13:38 | 0.227 | 233 |
| | 11.66 | 0.23 | Bottom | 14:42 | 0.071 | 303 |
| | 28.33 | 0.57 | Middle | 14:46 | 0.160 | 348 |
| | 33.00 | 0.66 | Surface | 14:49 | 0.185 | 348 |
| | 4.33 | 0.09 | Bottom | 16:07 | 0.035 | 70 |
| | 16.66 | 0.33 | Middle | 16:11 | 0.097 | 47 |
| | 22.33 | 0.45 | Surface | 16:14 | 0.128 | 46 |

**St. 1 - Existing Outfall Site (Spring tide)**

| Date 29/10/03 | revs/sec | | Position | Time | Velocity | Direction |
|---|---|---|---|---|---|---|
| | 3.66 | 0.07 | Bottom | 9:00 | 0.030 | 43 |
| | 22.33 | 0.45 | Middle | 9:05 | 0.115 | 140 |
| | 20.00 | 0.40 | Surface | 9:08 | 0.128 | 147 |
| | 10.00 | 0.20 | Bottom | 10:19 | 0.064 | 340 |
| | 22.33 | 0.45 | Middle | 10:21 | 0.066 | 333 |
| | 10.66 | 0.21 | Surface | 10:23 | 0.128 | 337 |
| | 33.66 | 0.67 | Surface | 11:36 | 0.188 | 120 |
| | 9.66 | 0.19 | Bottom | 12:39 | 0.061 | 130 |
| | 34.66 | 0.69 | Surface | 12:43 | 0.193 | 137 |
| | 30.00 | 0.60 | Bottom | 17:11 | 0.113 | 313 |
| | 19.33 | 0.39 | Middle | 17:15 | 0.171 | 313 |
| | 30.33 | 0.61 | Surface | 17:18 | 0.168 | 327 |
| | | | | | | |

**St. 2 - Proposed Outfall Site**

| | revs/sec | | Position | Time | Velocity | Direction |
|---|---|---|---|---|---|---|
| | 62.66 | 1.25 | Bottom | 9:47 | 0.349 | 323 |
| | 53.33 | 1.07 | Middle | 9:50 | 0.299 | 333 |
| | 67.66 | 1.35 | Surface | 9:53 | 0.376 | 343 |
| | 20.66 | 0.41 | Bottom | 11:00 | 0.118 | 300 |
| | 33.33 | 0.67 | Middle | 11:03 | 0.188 | 333 |
| | 48.66 | 0.97 | Surface | 11:06 | 0.271 | 320 |
| | 37.33 | 0.75 | Bottom | 12:00 | 0.210 | 323 |
| | 11.66 | 0.23 | Middle | 12:03 | 0.071 | 320 |
| | 58.00 | 1.16 | Surface | 12:06 | 0.324 | 333 |
| | 25.00 | 0.50 | Bottom | 13:01 | 0.141 | 337 |
| | 18.00 | 0.36 | Middle | 13:04 | 0.105 | 360 |
| | 15.00 | 0.30 | Surface | 13:07 | 0.090 | 50 |
| | 38.66 | 0.77 | Bottom | 13:45 | 0.216 | 320 |
| | 88.33 | 1.77 | Middle | 13:48 | 0.493 | 310 |
| | 36.00 | 0.72 | Surface | 13:51 | 0.202 | 313 |
| | 30.00 | 0.60 | Bottom | 14:50 | 0.168 | 317 |
| | 39.66 | 0.79 | Middle | 14:53 | 0.221 | 300 |
| | 49.33 | 0.99 | Surface | 14:56 | 0.277 | 297 |
| | 32.33 | 0.65 | Bottom | 15:15 | 0.182 | 303 |
| | 45.66 | 0.91 | Middle | 15:18 | 0.254 | 303 |
| | 50.33 | 1.01 | Surface | 15:21 | 0.282 | 297 |
| | 34.00 | 0.68 | Bottom | 15:54 | 0.191 | 297 |
| | 45.33 | 0.91 | Middle | 15:57 | 0.254 | 303 |
| | 32.66 | 0.65 | Surface | 16:00 | 0.182 | 307 |
| | 26.33 | 0.53 | Bottom | 16:35 | 0.149 | 293 |
| | 27.66 | 0.55 | Middle | 16:38 | 0.155 | 300 |
| | 41.33 | 0.83 | Surface | 16:41 | 0.232 | 293 |

**Appendix II** Water Quality Data, Inner Broadhaven Bay

**Belmullet Water Sampling survey**

| | **Existing outfall Station 1** | | | | **Proposed outfall (Pickle Point) Station 2** | | | |
|---|---|---|---|---|---|---|---|---|
| | Nitrates mg/l | | | | Nitrates mg/l | | | |
| Date | Low Water | Mid-Water (Flooding) | High Water | Mid-Water (Ebbing) | Low Water | Mid-Water (Flooding) | High Water | Mid-Water (Ebbing) |
| **22/10/03 Neaps** | 0.09 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | |
| **28/10/03 Springs** | | <0.44 | <0.44 | <0.44 | <0.44 | <0.44 | <0.44 | <0.44 |

Table 2.8.1: Nitrate levels obtained from existing and proposed outfall locations, Belmullet, Co. Mayo.

| **Station 1 (existing outfall)** | | | | |
|---|---|---|---|---|
| Time | Depth | Temperature © | Salinity (ppt) | Dissolved Oxygen (%sat) |
| 9:31 | B | 8.5 | 33.5 | 85 |
| 9:31 | S | 8.6 | 33.5 | 86 |
| 10:27 | M | 8.5 | 33.2 | 85 |
| 11:05 | B | 8.2 | 33.2 | 86 |
| 11:05 | S | 8.2 | 33.3 | 87 |
| 11:45 | B | 8.1 | 33.3 | 88 |
| 11:45 | S | 8.1 | 33.1 | 88 |
| 12:35 | B | 8.1 | 33.4 | 91 |
| 12:35 | S | 8.2 | 32.8 | 91 |
| 14:07 | B | 8.6 | 33.5 | 95 |
| 14:07 | M | 8.6 | 33.5 | 96 |
| 14:07 | S | 8.6 | 33.5 | 96 |
| 15:36 | B | 8.5 | 33.3 | 97 |
| 15:36 | M | 8.5 | 33.3 | 98 |
| 15:36 | S | 8.5 | 33.2 | 97 |
| 17:08 | B | 8.4 | 33.3 | 84 |
| 17:08 | M | 8.4 | 33.2 | 90 |
| 17:08 | S | 8.4 | 33 | 88 |



**Table 2.8.2: Neap tide temperature, salinity and dissolved oxygen results taken on the 22/10/03, Belmullet, Co. Mayo.**

| Station 2 (Pickle point - Proposed outfall) | | | | |
|---|---|---|---|---|
| Time | Depth | Temperature © | Salinity (ppt) | Dissolved Oxygen (%sat) |
| 10:12 | M | 7.6 | 33.4 | 87 |
| 10:41 | B | 7.5 | 33.2 | 89 |
| 10:41 | S | 7.4 | 33.2 | 88 |
| 11:26 | B | 7.8 | 33.5 | 90 |
| 11:26 | S | 7.8 | 33.5 | 90 |
| 12:09 | B | 8 | 33.4 | 92 |
| 12:09 | S | 8 | 33.5 | 93 |
| 13:16 | B | 8.5 | 33.7 | 94 |
| 13:16 | M | 8.5 | 33.7 | 95 |
| 13:16 | S | 8.6 | 33.7 | 95 |
| 14:39 | B | 8.9 | 33.9 | 96 |
| 14:39 | M | 8.9 | 33.9 | 97 |
| 14:39 | S | 9 | 33.9 | 97 |
| 16:03 | B | 9.3 | 34 | 98 |
| 16:03 | M | 9.3 | 34 | 99 |
| 16:03 | S | 9.3 | 34 | 99 |

Table 2.8.3: Neap tide temperature, salinity and dissolved oxygen results taken on the 22/10/03, Belmullet, Co. Mayo.



| Station 1 (existing outfall) | | | | |
|---|---|---|---|---|
| Time | Depth | Temperature © | Salinity (ppt) | Dissolved Oxygen (%sat) |
| 8:56 | B | 10 | 33.3 | 86 |
| | M | 10.1 | 33.3 | 88 |
| | S | 10.1 | 33.2 | 91 |
| 10:14 | B | 10 | 33.3 | 88 |
| | M | 10 | 33.3 | 87 |
| | S | 10 | 33.3 | 87 |
| 11:53 | B | | | |
| | M | | | |
| | S | 10 | 32.8 | 88 |
| 12:24 | B | 10.1 | 32.8 | 86 |
| | M | | | |
| | S | 10.1 | 32.8 | 86 |
| 17:09 | | 9.9 | 31.6 | 89 |
| | | 10 | 31.5 | 89 |
| | | 10 | 31.5 | 88 |

**Table 2.8.4: Spring tide temperature, salinity and dissolved oxygen results taken on the 28/10/03, Belmullet, Co. Mayo**

| Station 2 (Pickle point - Proposed outfall) | | | | |
|---|---|---|---|---|
| Time | Depth | Temperature © | Salinity (ppt) | Dissolved Oxygen (%sat) |
| 9:43 | B | 10.7 | 33.6 | 86 |
| | M | 10.7 | 33.5 | 95 |
| | S | 10.8 | 33.5 | 92 |
| 10:56 | B | 10 | 33.9 | 86 |
| | M | 10 | 33.8 | 86 |
| | S | 10 | 33.8 | 91 |
| 12:00 | B | 10.8 | 33.5 | 88 |
| | M | 10.6 | 33.2 | 86 |
| | S | 10.4 | 32.4 | 87 |
| 12:59 | B | 10.7 | 21.7 | 88 |
| | M | 10.4 | 33 | 86 |
| | S | 10.2 | 30.8 | 86 |
| 13:40 | B | 10.3 | 32.8 | 88 |
| | M | 10.2 | 32.4 | 86 |
| | S | 10.1 | 30.2 | 86 |
| 14:45 | B | 10.4 | 32.4 | 86 |
| | M | 10.3 | 32.2 | 88 |
| | S | 10.2 | 31.2 | 86 |
| 15:15 | B | 10.4 | 32.5 | 86 |
| | M | 10.3 | 31.8 | 86 |
| | S | 10.3 | 31.8 | 86 |
| 15:51 | B | 10.3 | 32 | 88 |
| | M | 10.2 | 31 | 87 |
| | S | 10.2 | 30.7 | 87 |
| 16:33 | B | 10.4 | 32.6 | 87 |
| | M | 10.4 | 32.6 | 87 |
| | S | 10.4 | 32.6 | 86 |



Table 2.8.5: Spring tide temperature, salinity and dissolved oxygen results taken on the 28/10/03, Belmullet, Co. Mayo.

The following tables 2.8.6 to 2.8.8 are the results of the marine and freshwater (also canal) analysis. Stations 1-9 are marine samples, 10 &11 are from the canal and 12-16 are freshwater

| Station | BOD | Suspended solids | Phosphates | Nitrates | Ammonia | Faecal coliforms | Total coliforms | Faecal streptococci |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 3.5 | 0.009 | 0.044 | 0.57 | 0.9 | 0.9 | |
| 2 | 0.9 | 3.5 | 0.01 | 0.132 | 0.545 | 2 | 2 | |
| 3 | 0.9 | 3.5 | 0.009 | 0.088 | 0.558 | 0.9 | 0.9 | |
| 4 | 7 | 3.5 | 0.009 | 0.088 | 0.515 | 1 | 5 | |
| 5 | 1 | 3.5 | 0.01 | 0.044 | 0.524 | 20 | 89 | |
| 6 | 0.9 | 6 | 0.01 | 0.044 | 0.522 | 20 | 73 | |
| 7 | 2 | 3.5 | 0.01 | 0.044 | 0.49 | 3 | 5 | |
| 8 | 12 | 3.5 | 0.01 | 0.044 | 0.51 | 0.9 | 12 | |
| 9 | 27 | 71 | 0.01 | 0.044 | 0.56 | 5 | 27 | |
| 10 | 9 | 3.5 | 0.02 | 0.088 | 0.57 | 16200 | 27000 | 82 |
| 11 | 4 | 3.5 | 0.02 | 0.035 | 0.56 | 1840 | 2640 | 85 |
| 12 | 9 | 3.5 | 0.12 | 0.516 | 0.02 | 21 | 35 | 0.9 |
| 13 | 2 | 20 | 0.04 | 0.176 | 0.1 | 110 | 120 | 35 |
| 14 | 5 | 3.5 | 0.01 | 0.35 | 0.009 | 330 | 330 | 5 |
| 15 | 5 | 3.5 | 0.04 | 2.42 | 0.05 | 4800 | 4800 | 30 |
| 16 | 10 | 3.5 | 0.03 | 0.35 | 0.06 | 820 | 12200 | 4 |

Table 2.8.6: Results of the analysis of samples taken on the 15/10/03, Belmullet, Co. Mayo.



| Station | BOD | Suspended solids | Phosphates | Nitrates | Ammonia | Faecal coliforms | Total coliforms | Faecal streptococci |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.9 | 159 | 0.04 | 0.4 | 0.52 | 300 | 330 | |
| 2 | 2 | 57 | 0.009 | 0.4 | 0.5 | 1 | 5 | |
| 3 | 0.9 | 3.5 | 0.029 | 0.079 | 0.561 | 2 | 3 | |
| 4 | 1 | 60 | 0.029 | 0.4 | 0.48 | 30 | 30 | |
| 5 | 2 | 55 | 0.15 | 0.4 | 0.49 | 13 | 22 | |
| 6 | 2 | 149 | 0.09 | 0.4 | 0.51 | 460 | 570 | |
| 7 | 0.9 | 162 | 0.03 | 0.4 | 0.48 | 2 | 13 | |
| 8 | 1 | 158 | 0.06 | 0.4 | 0.49 | 34 | 34 | |
| 9 | 1 | 47 | 0.04 | 0.4 | 0.53 | 310 | 610 | |
| 10 | 6 | 46 | 0.44 | 0.088 | 1.24 | 78400 | 196000 | 300 |
| 11 | 6 | 31 | 0.04 | 0.088 | 0.53 | 710 | 1010 | 84 |
| 12 | 0.9 | 5 | 0.53 | 0.352 | 0.01 | 70 | 70 | 5 |
| 13 | 0.9 | 3.5 | 0.17 | 0.352 | 0.11 | 140 | 160 | 16 |
| 14 | 0.9 | 10 | 0.11 | 0.035 | 0.009 | 360 | 360 | 11 |
| 15 | 0.9 | 3.5 | 0.11 | 0.132 | 0.04 | 116000 | 152000 | 178 |
| 16 | 0.9 | 8 | 0.197 | 0.035 | 0.015 | 5760 | 7200 | 74 |

Table 2.8.7: Results of the analysis of samples taken on the 22/10/03, Belmullet, Co. Mayo.

| Station | BOD | Suspended solids | Phosphates | Nitrates | Ammonia | Faecal coliforms | Total coliforms | Faecal streptococc |
|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 11 | 0.11 | 0.04 | 0.54 | 60 | 160 | |
| 2 | 3 | 15 | 0.9 | 0.04 | 0.52 | 180 | 230 | |
| 3 | 3 | 36 | 0.1 | 0.04 | 0.53 | 140 | 160 | |
| 4 | 8 | 4 | 0.05 | 0.04 | 0.52 | 10 | 24 | |
| 5 | 3 | 3.5 | 0.025 | 0.035 | 0.49 | 200 | 280 | |
| 6 | 3 | 7 | 0.06 | 0.04 | 0.45 | 290 | 320 | |
| 7 | 3 | 27 | 0.03 | 0.04 | 0.52 | 70 | 140 | |
| 8 | 3 | 18 | 0.06 | 0.04 | 0.41 | 400 | 440 | |
| 9 | 2 | 15 | 0.044 | 0.07 | 0.52 | 100 | 190 | |
| 10 | 3 | 3 | 0.26 | 0.4 | 0.62 | 140 | 140 | 1 |
| 11 | 2 | 25 | 0.1 | 0.4 | 0.6 | 910 | 1120 | 20 |
| 12 | 3 | **** | 0.3 | 1.73 | 0.04 | 7400 | 7400 | 60 |
| 13 | 1 | **** | 0.11 | 0.4 | 0.07 | 2000 | 2100 | 12 |
| 14 | 3 | **** | 0.04 | 0.04 | 0.02 | 7200 | 7200 | 40 |
| 15 | 8 | **** | 0.12 | 0.45 | 0.05 | 13500 | 13500 | 65 |
| 16 | 0.9 | **** | 0.06 | 0.56 | 0.06 | 700 | 1170 | 25 |

Table 2.8.8: Results of the analysis of samples taken on the 29/10/03, Belmullet, Co. Mayo.



| Station | Latitude | Longitude | *Clostridium perfringens* levels (cfu/g) | Total Organic Carbon (g/kg) |
|---|---|---|---|---|
| **A** | 54 12.92 | 9 57.22 | 70 | 4 |
| **B** | 54 13.06 | 9 57.45 | 100 | 31 |
| **C** | 54 13.06 | 9 57.44 | 120 | 35 |
| **D** | 54 13.26 | 9 58.14 | 70 | 48 |
| **E** | 54 13.33 | 9 58.3 | 50 | 31 |
| **F** | 54 13.38 | 9 58.57 | 60 | 29 |
| **G** | 54 13.4 | 9 58.91 | 70 | 26 |
| **H** | 54 13.48 | 9 59.17 | 100 | 31 |

Table 2.8.9: Results of the grab sample sediment analysis taken 22/10/03, Belmullet, Co. Mayo.

Note: Sediment grab sample locations are the same as those for the benthic samples.

**Appendix III** Species List, Inner Broadhaven Bay

**JN624 Species List, Belmullet, Co. Mayo.**

| | | | St. A | St. B | St. C | St. D | St. E | St. F | St. G | St. H |
|---|---|---|---|---|---|---|---|---|---|---|
| **ANNELIDA** | | | | | | | | | | |
| PHYLLODOCIDA | | | | | | | | | | |
| Harmothoe sp. | P | 50 | | 1 | | | | | | |
| Pholoe synophthalmica | P | 94 | | 4 | | | | | | |
| Sigalion squamosus | P | 105 | 1 | | | | | | | |
| Eteone longa | P | 118 | | | | | 2 | | | |
| Mysta picta | P | 127 | 1 | | | | | | | |
| Anaitides mucosa | P | 145 | | | | 1 | | | | |
| Kefersteinia cirrata | P | 305 | | 1 | | | | | | |
| Exogone hebes | P | 421 | 9 | | | | | | | |
| Nephtys hombergii | P | 499 | | 4 | 13 | 12 | 7 | 5 | 1 | 1 |
| ORBINIIDA | | | | | | | | | | |
| Scoloplos armiger | P | 672 | 3 | | 5 | | | | | |
| SPIONIDA | | | | | | | | | | |
| Minuspio cirrifera | P | 747 | | 2 | | | | | | |
| Pygospio elegans | P | 776 | 1 | | 17 | 9 | 12 | 1 | | |
| CAPITELLIDA | | | | | | | | | | |
| Capitella capitata | P | 907 | | | | | | | | 29 |
| Capitellides giardi | P | 910 | | | | | | | 23 | 128 |
| Capitomastus minimus | P | 912 | 1 | | | | 6 | | 24 | 9 |
| Heteromastus filiformis | P | 917 | 1 | | | | | | | |
| Notomastus latericeus | P | 921 | 1 | | | | | | | |
| Maldanidae sp. | P | 938 | 2 | | | | | | | |
| TEREBELLIDA | | | | | | | | | | |
| Melinna palmata | P | 1124 | | | 5 | | | 1 | 1 | |
| Lanice conchilega | P | 1195 | | 2 | | | | | | |
| Polycirrus norvegicus | P | 1243 | 5 | | | | | | | |
| Thelepus cincinnatus | P | 1254 | | 1 | | | | | | |
| SABELLIDA | | | | | | | | | | |
| Fabricia sp. | P | 1282 | | | | | 1 | | | |
| Laonome kroyeri | P | 1292 | | 1 | | | | | | |
| OLIGOCHAETA | | | | | | | | | | |
| TUBIFICIDA | | | | | | | | | | |
| Tubificidae | P | 1425 | | | | 47 | | | | |
| Enchytraeidae sp. | P | 1501 | | | 3 | | 43 | | | |
| **CRUSTACEA** | | | | | | | | | | |
| AMPHIPODA | S | 97 | | | | | | | | |
| Apherusa bispinosa | S | 102 | | 1 | | | | | | |
| Urothoe marina | S | 249 | 1 | | | | | | | |
| Ampelisca brevicornis | S | 427 | 1 | | 1 | | | | | |
| Gammarus locusta | S | 478 | | | | | 8 | | | |
| Ericthonius punctatus | S | 564 | | 7 | | | | | | |
| Microdeutopus sp. | S | 592 | | 9 | | | | | | |
| Corophium crassicorne | S | 611 | 1 | 1 | | | | | | |
| | | | **St. A** | **St. B** | **St. C** | **St. D** | **St. E** | **St. F** | **St. G** | **St. H** |
| Caprellidae sp. | S | 639 | | 1 | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phtisica marina | S | 657 | 1 | 1 | | | | | | |
| Pseudoprotella phasma | S | 659 | | 1 | | | | | | |
| ISOPODA | S | 790 | | | | | | | | |
| Paragnathia formica | S | 799 | | | 1 | | | | | |
| TANAIDACEA | S | 1099 | | | | | | | | |
| Tanaopsis graciloides | S | 1142 | 2 | | | | | | | |
| DECAPODA | S | 1276 | | | | | | | | |
| Liocarcinus arcuatus | S | 1578 | | 3 | | | | | | |
| **MOLLUSCA** | | | | | | | | | | |
| POLYPLACOPHORA | W | 46 | | | | | | | | |
| MESOGASTROPODA | | | | | | | | | | |
| Lacuna parva | W | 290 | 1 | | | | | | | |
| CEPHALASPIDEA | | | | | | | | | | |
| Philine aperta | W | 1038 | | | 28 | | | | | |
| ANASPIDEA | | | | | | | | | | |
| Akera bullata | W | 1142 | 2 | | 14 | 8 | 7 | 4 | | |
| NUCULOIDA | | | | | | | | | | |
| Nucula nitidosa | W | 1569 | | | | | | | | 1 |
| VENEROIDA | | | | | | | | | | |
| Parvicardium exiguum | W | 1949 | | 2 | | | | | | |
| Parvicardium minimum | W | 1950 | | | | | | | 5 | |
| Cerastoderma glaucum | W | 1962 | | | | | 6 | | | |
| Abra nitida | W | 2061 | | | | | 1 | | | |
| Angulus tenuis | W | 2012 | | 1 | | | | | 2 | |
| **ECHINODERMATA** | | | | | | | | | | |
| OPHIUROIDEA | ZB | 105 | | | | | | | | |
| OPHIURIDA | | | | | | | | | | |
| Amphiura juvenile | ZB | 149 | 1 | | | | | | | |

**Appendix IV** Current Velocity Data, Blacksod Bay

**Appendix V** Water Quality Data, Blacksod Bay

| | Station 1 | | | | | Station 2 | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Position** | **Time** | **Temperature** | **Salinity** | **Oxygen** | **Position** | **Time** | **Temperature** | **Salinity** | **Oxygen** |
| Surface | 09:42 | 12.2 | 33.1 | 95 | Surface | 10:05 | 12.0 | 33.9 | 96 |
| Middle | | | | | Middle | | 12.0 | 33.9 | 90 |
| Bottom | | 12.2 | 33.1 | 96 | Bottom | | 12.0 | 33.9 | 97 |
| Surface | 10:21 | 12.2 | 33.9 | 89 | Surface | 10:45 | 12.0 | 34.0 | 90 |
| Middle | | 12.2 | 33.9 | 88 | Middle | | 12.0 | 34.0 | 88 |
| Bottom | | 12.2 | 33.9 | 97 | Bottom | | 12.0 | 34.0 | 94 |
| Surface | 11:22 | 12.0 | 34.0 | 90 | Surface | 12:16 | 11.9 | 34.1 | 98 |
| Middle | | 12.0 | 34.0 | 92 | Middle | | 11.8 | 34.1 | 92 |
| Bottom | | 12.0 | 34.0 | 97 | Bottom | | 11.9 | 34.1 | 92 |
| Surface | 11:50 | 12.1 | 34.0 | 92 | Surface | 13:08 | 12.0 | 34.1 | 94 |
| Middle | | 12.1 | 34.0 | 92 | Middle | | 11.9 | 34.1 | 95 |
| Bottom | | 12.1 | 34.0 | 93 | Bottom | | 11.9 | 34.1 | 95 |
| Surface | 12:40 | 12.1 | 34.0 | 99 | Surface | 14:28 | 12.1 | 34.1 | 99 |
| Middle | | 12.1 | 34.0 | 95 | Middle | | 12.1 | 34.1 | 97 |
| Bottom | | 12.0 | 34.0 | 92 | Bottom | | 12.0 | 34.1 | 99 |
| Surface | 13:25 | 12.2 | 34.1 | 96 | Surface | 15:25 | 12.4 | 34.0 | 93 |
| Middle | | 12.2 | 34.1 | 95 | Middle | | 12.4 | 34.1 | 96 |
| Bottom | | 12.2 | 34.1 | 94 | Bottom | | 12.3 | 34.1 | 96 |
| Surface | 15:01 | 12.4 | 34.1 | 96 | Surface | 16:48 | 12.6 | 34.1 | 96 |
| Middle | | 12.4 | 34.1 | 95 | Middle | | 12.6 | 34.1 | 97 |
| Bottom | | 12.3 | 34.1 | 95 | Bottom | | 12.6 | 34.1 | 97 |
| Surface | 16:26 | 12.7 | 34.0 | 95 | Surface | 17:30 | 12.8 | 34.1 | 95 |
| Middle | | 12.7 | 34.0 | 95 | Middle | | 12.8 | 34.1 | 98 |
| Bottom | | 12.7 | 34.0 | 95 | Bottom | | 12.7 | 4.1 | 96 |
| Surface | 17:09 | 12.8 | 34.1 | 95 | Surface | 18:08 | 12.8 | 34.1 | 95 |
| Middle | | 12.8 | 34.0 | 95 | Middle | | 12.8 | 34.1 | 95 |
| Bottom | | 12.8 | 34.0 | 95 | Bottom | | 12.8 | 34.1 | 96 |
| Surface | 17:51 | 13.0 | 34.1 | 95 | | | | | |
| Middle | | 13.0 | 34.1 | 95 | | | | | |
| Bottom | | 13.0 | 34.1 | 96 | | | | | |
| Surface | 18:25 | 13.0 | 34.1 | 95 | | | | | |
| Middle | | 13.0 | 34.0 | 95 | | | | | |
| Bottom | | 13.0 | 34.0 | 95 | | | | | |

**Table 2.8.1:** Neap tide temperature, salinity and dissolved oxygen results taken on the 12/5/04 at two proposed outfall locations, Blacksod Bay, Co. Mayo.

| | Station 1 | | | | Station 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Position** | **Time** | **Temperature (ºC)** | **Salinity (ppt)** | **Oxygen (% Sat)** | **Position** | **Time** | **Temperature (ºC)** | **Salinity (ppt)** | **Oxygen (% Sat)** |
| | | | | | | | | | |
| Surface | 10:30 | 14.9 | 33.9 | 92 | Surface | 10:50 | 14.9 | 33.8 | 96 |
| Middle | | 14.8 | 33.9 | 93 | Middle | | 14.8 | 33.5 | 96 |
| Bottom | | 14.8 | 34.1 | 92 | Bottom | | 14.8 | 33.8 | 96 |
| Surface | 11:05 | 14.8 | 34 | 93 | Surface | 11:22 | 14.8 | 33.9 | 98 |
| Middle | | 14.9 | 34.1 | 92 | Middle | | 14.9 | 33.9 | 98 |
| Bottom | | 14.8 | 34.1 | 92 | Bottom | | 14.8 | 33.9 | 98 |
| Surface | 11:43 | 15.1 | 34.2 | 95 | Surface | 11:51 | 14.9 | 34 | 99 |
| Middle | | 15.1 | 34.3 | 99 | Middle | | 14.5 | 34.1 | 99 |
| Bottom | | 15.2 | 34.2 | 99 | Bottom | | 14.6 | 34 | 100 |
| Surface | 12:10 | 15.3 | 33.2 | 98 | Surface | 12:25 | 14.9 | 34.1 | 98 |
| Middle | | 15.2 | 34.5 | 97 | Middle | | 14.9 | 34.1 | 98 |
| Bottom | | 15.2 | 34.5 | 97 | Bottom | | 14.9 | 34.1 | 98 |
| Surface | 12:45 | 15.1 | 34.1 | 98 | Surface | 13:00 | 15 | 34.1 | 98 |
| Middle | | 15.1 | 34.2 | 98 | Middle | | 15.1 | 34.1 | 98 |
| Bottom | | 15.1 | 34.2 | 98 | Bottom | | 15.1 | 34.1 | 99 |
| Surface | 13:17 | 15.2 | 34.2 | 99 | Surface | 13:33 | 15.1 | 34.1 | 98 |
| Middle | | 15.1 | 34.1 | 97 | Middle | | 15.1 | 34.1 | 99 |
| Bottom | | 15.1 | 34 | 99 | Bottom | | 15.1 | 34.1 | 99 |
| Surface | 14:00 | 15.2 | 34 | 98 | Surface | 14:25 | 15.2 | 34.1 | 99 |
| Middle | | 15.1 | 34.3 | 96 | Middle | | 15.1 | 34.1 | 98 |
| Bottom | | 15.2 | 34.3 | 97 | Bottom | | 15.1 | 34.2 | 98 |
| Surface | 14:43 | 15.3 | 34.3 | 96 | Surface | 15:08 | 15.2 | 34.2 | 97 |
| Middle | | 15.2 | 34.2 | 95 | Middle | | 15.2 | 34.1 | 97 |
| Bottom | | 15.2 | 34 | 95 | Bottom | | 15.2 | 34.1 | 97 |
| Surface | 15:25 | 15.2 | 34.1 | 96 | Surface | 15:42 | 15.2 | 34.2 | 97 |
| Middle | | 15.3 | 34 | 93 | Middle | | 15.1 | 34.2 | 97 |
| Bottom | | 15.2 | 34.1 | 95 | Bottom | | 15.1 | 34.2 | 96 |
| Surface | 16:00 | 15.3 | 34.1 | 98 | Surface | 16:17 | 15.1 | 34.1 | 98 |
| Middle | | 15.3 | 34.2 | 99 | Middle | | 15.1 | 34.1 | 98 |
| Bottom | | 15.3 | 34.2 | 99 | Bottom | | 15.1 | 34.1 | 94 |
| Surface | 16:33 | 15.4 | 34.1 | 98 | Surface | 16:52 | 15.2 | 34.3 | 97 |
| Middle | | 15.2 | 34.1 | 98 | Middle | | 15.2 | 34.2 | 97 |
| Bottom | | 15.3 | 34.1 | 98 | Bottom | | 15.1 | 34.2 | 98 |
| Surface | 17:11 | 15 | 34.1 | 98 | Surface | 17:30 | 15.2 | 34.2 | 97 |
| Middle | | 15.2 | 34.1 | 98 | Middle | | 15.2 | 34.2 | 95 |
| Bottom | | 15.1 | 34.2 | 98 | Bottom | | 15.2 | 34.1 | 95 |
| Surface | 17:48 | 15.2 | 34.2 | 97 | Surface | 18:09 | 15.2 | 34.1 | 96 |
| Middle | | 15.2 | 34.2 | 98 | Middle | | 15.3 | 34.1 | 96 |
| Bottom | | 15.3 | 34.1 | 98 | Bottom | | 15.3 | 34.1 | 94 |
| Surface | 18:22 | 15.2 | 34.2 | 97 | Surface | 18:38 | 15.2 | 34.1 | 98 |
| Middle | | 15.2 | 34.2 | 95 | Middle | | 15.3 | 34 | 95 |
| Bottom | | 15.2 | 34.2 | 95 | Bottom | | 15.3 | 34.1 | 98 |



**Figure 2.8.2:** Spring tide temperature, salinity and dissolved oxygen results taken on the 20/5/04 at two proposed outfall locations, Blacksod Bay, Co. Mayo

**Appendix VI** Sediment Fraction Percentages, Blacksod Bay

**Blacksod Bay Percentage of sediment fraction at each sampling site, 15/05/2004.**

| Stations | Gravel (4.0-2.0mm) | Very Coarse Sand (1.0-2.0mm) | Coarse Sand (0.5–1.0mm) | Medium Sand (0.25-.5mm) | Fine Sand (0.125-0.25mm) | Very Fine Sand (0.063-0.125mm) | Silt (≤ 0.063mm) |
|---|---|---|---|---|---|---|---|
| **A** | - | 2.98 | 1.43 | 1.63 | 6.37 | 87.19 | 0.40 |
| **B** | 1.72 | 3.67 | 0.77 | 0.82 | 13.89 | 78.21 | 0.92 |
| **C** | - | 4.47 | 1.75 | 1.53 | 13.84 | 78.21 | 0.20 |
| **D** | - | 2.01 | 1.20 | 1.10 | 2.32 | 92.99 | 0.37 |
| **E** | - | 4.06 | 4.66 | 9.90 | 26.41 | 54.70 | 0.27 |
| **F** | - | 2.61 | 1.66 | 4.81 | 49.15 | 40.90 | 0.87 |
| **G** | 1.53 | 5.17 | 6.74 | 13.70 | 36.83 | 35.91 | 0.12 |
| **H** | 1.07 | 2.72 | 2.79 | 5.25 | 38.67 | 49.35 | 0.15 |

# **Appendix VII** Species List, Blacksod Bay

## Blacksod Bay – Full Species List

| | | | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINIARIA** | | | | | | | | | | |
| *Actinia* sp. | D | 674 | | | | | 1 | | 3 | 2 |
| **ANNELIDA** | | | | | | | | | | |
| PHYLLODOCIDA | | | | | | | | | | |
| *Harmothoe* sp. | P | 50 | | | | | | | | 1 |
| *Harmothoe castanea* | P | 55 | | | | | | | | 1 |
| *Pholoe synophthalmica* | P | 94 | | | | | | | | 6 |
| *Anaitides mucosa* | P | 145 | | 1 | | | 3 | | | |
| *Eumida bahusiensis* | P | 164 | | | | 1 | | | 1 | 1 |
| *Glycera* sp. | P | 255 | | | | | | | 1 | |
| **Glycinde nordmanni** | P | 268 | | 1 | | | | | | |
| *Kefersteinia cirrata* | P | 305 | | | | | | | | 1 |
| *Ehlersia cornuta* | P | 349 | | | | | 1 | 1 | 1 | |
| *Odontosyllis gibba* | P | 388 | | | | | | | | 1 |
| *Streptosyllis bidentata* | P | 403 | | | 2 | | | 2 | | |
| *Streptosyllis websteri* | P | 405 | 1 | 2 | | 2 | | | 1 | |
| *Exogone hebes* | P | 421 | | | | | 1 | 2 | 1 | |
| *Exogone naidina* | P | 422 | | | 2 | | | | 1 | |
| *Sphaerosyllis tetralix* | P | 431 | | | | | | | 1 | |
| *Platynereis dumerilii* | P | 484 | 1 | | | | 1 | | | 4 |
| *Aglaophamus malmgreni* | P | 492 | | | | | 2 | 1 | | 1 |
| *Nephtys caeca* | P | 496 | 2 | | | | | | 1 | |
| *Nepthys kersivalensis* | P | 502 | | 1 | | | | | | |
| ORBINIIDA | | | | | | | | | | |
| **Scoloplos armiger** | P | 672 | | | | 1 | | | | |
| SPIONIDA | | | | | | | | | | |
| **Minuspio cirrifera** | P | 747 | | | | | 6 | | 5 | |
| *Prionospio* sp. | P | 763 | | | | 3 | | | | 1 |
| **Prionospio fallax** | P | 765 | 6 | 6 | 2 | | 10 | 7 | | 6 |
| *Prionospio plumosa* | P | 767 | | | | 1 | | | | |
| *Prionospio ehlersi* | P | 769 | | | 1 | 1 | 4 | | 2 | |
| *Spio* sp. | P | 787 | 1 | | | | 2 | | | |
| **Spio decorata** | P | 789 | 2 | | | 6 | 7 | 9 | 5 | 2 |
| *Spio filicornis* | P | 790 | 1 | | 1 | | 3 | 2 | | |
| *Spiophanes bombyx* | P | 794 | | 1 | | | | | | |
| *Magelona minuta* | P | 806 | | | | 1 | | | | |
| *Aphelochaeta* sp. | P | 823 | 1 | | | | | | | |
| *Chaetozone* sp. | P | 832 | | | | 2 | | | | |
| **Chaetozone setosa** | P | 834 | | | | 1 | | | | |

| | | | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|---|
| CAPITELLIDA | | | | | | | | | | |
| **Euclymene oerstedii** | P | 964 | 2 | | | | 4 | | | |
| OPHELIIDA | | | | | | | | | | |
| **Ophelina acuminata** | P | 1014 | 2 | | | | 2 | 1 | 5 | 16 |
| *Scalibregma inflatum* | P | 1027 | | | | | 1 | | | |
| TEREBELLIDA | | | | | | | | | | |
| Terebellidae sp. | P | 1099 | | 1 | | | | 1 | | |
| **Ampharete lindstroemi** | P | 1139 | | | | | 1 | | | |
| SABELLIDA | | | | | | | | | | |
| **Pomatoceros lamarcki** | P | 1340 | | | | | | | | 3 |
| *Serpula vermicularis* | P | 1343 | | | 2 | | | | | |
| OLIGOCHAETA | | | | | | | | | | |
| TUBIFICIDA | | | | | | | | | | |
| Enchytraeidea sp. | P | 1501 | 2 | | | | | | | |
| **CHELICERATA** | | | | | | | | | | |
| PYCNOGONIDA | | | | | | | | | | |
| **Nymphon gracile** | Q | 7 | | 1 | | | | | | |
| **CRUSTACEA** | | | | | | | | | | |
| OSTRACODA | | | | | | | | | | |
| Ostracoda sp. | R | 2412 | | | | 1 | 1 | 1 | | |
| AMPHIPODA | | | | | | | | | | |
| *Perioculodes longimanus* | S | 130 | 2 | | | | | 1 | | |
| *Pontocrates altamarinus* | S | 133 | | | | 4 | | | | |
| *Urothoe elegans* | S | 248 | 1 | | | | 4 | | | |
| *Urothoe marina* | S | 249 | | | | | 2 | | | |
| *Ampelisca* sp. | S | 423 | | | | 1 | | | | |
| *Ampelisca brevicornis* | S | 427 | 1 | | | | 1 | | 2 | |
| *Bathyporeia guilliamsoniana* | S | 454 | 7 | 1 | | 8 | | 1 | | |
| *Bathyporeia nana* | S | 455 | | | | | 6 | | | |
| *Gammarus* sp. | S | 471 | 1 | | | | | | | |
| *Cheirocratus intermedius* | S | 505 | 1 | 1 | | | | | | |
| *Microdeutopus* sp. | S | 592 | | | | | 1 | | | |
| Microdeutopus anomalus | S | 593 | 1 | | 2 | | | | | |
| *Corophium* sp. (juvenile) | S | 605 | | 1 | | | | | | |
| *Corophium crassicorne* | S | 611 | 38 | 12 | 1 | | 27 | 27 | 7 | |
| *Corophium volutator* | S | 616 | | | | 8 | | | | |
| *Pariambus typicus* | S | 651 | | | | 1 | | | | |
| *Phtisica marina* | S | 657 | 1 | | 1 | | 2 | 1 | | |

| | | | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|---|
| TANAIDAE | | | | | | | | | | |
| Tanaidae sp. | S | 1102 | | | | | 1 | | | |
| **Pseudoparatanais batei** | S | 1140 | | | | | | | | 1 |
| CUMACEA | | | | | | | | | | |
| Cumacea sp. | S | 1183 | | | | | 1 | 1 | | |
| **Bodotria scorpioides** | S | 1197 | | | | | | | | 3 |
| DECAPODA | | | | | | | | | | |
| **Hippolyte varians** | S | 1350 | 1 | | | | | | | |
| *Carcinus maenas* | S | 1594 | | | | | | 1 | | |
| **MOLLUSCA** | | | | | | | | | | |
| POLYPLACOPHORA | | | | | | | | | | |
| NEOLORICATA | | | | | | | | | | |
| Neoloricata sp. (juvenile) | W | 47 | | | | | | 1 | | |
| CEPHALASPIDEA | | | | | | | | | | |
| **Philine aperta** | W | 1038 | | | | 1 | | | | |
| MYTILOIDA | | | | | | | | | | |
| Mytilacea sp. (juvenile) | W | 1690 | | | | | | | | 1 |
| VENEROIDA | | | | | | | | | | |
| **Spisula elliptica** | W | 1975 | 2 | | | | 4 | 1 | 2 | 2 |
| *Donax vittatus* | W | 2041 | | | | 1 | | | | |
| *Gari fervensis* | W | 2051 | | | | | | 1 | | |
| *Chamelea gallina* | W | 2098 | 2 | 2 | 1 | 2 | 1 | | | |
| PHOLADOMYOIDA | | | | | | | | | | |
| **Thracia phaseolina** | W | 2231 | | | | 1 | 2 | 2 | 3 | 2 |

## **Appendix VIII** Model Output Data, Blacksod Bay

# Section A

## Faecal coliform concentration in effluent = $1x10^3$ number/100ml

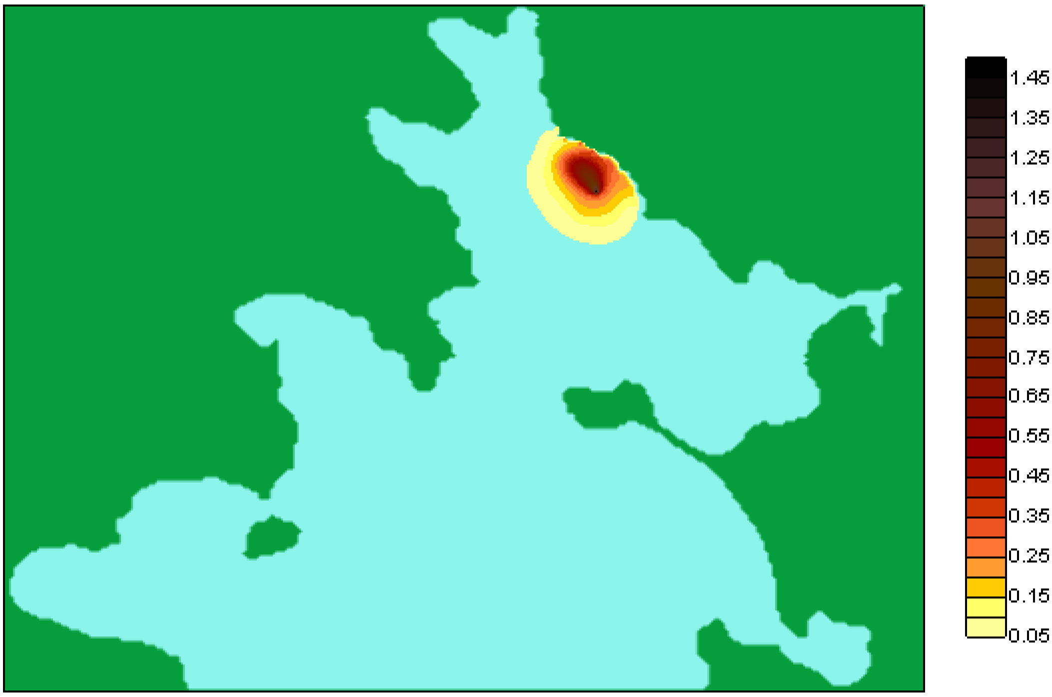



**Figure A.1- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (No wind – inner site)**



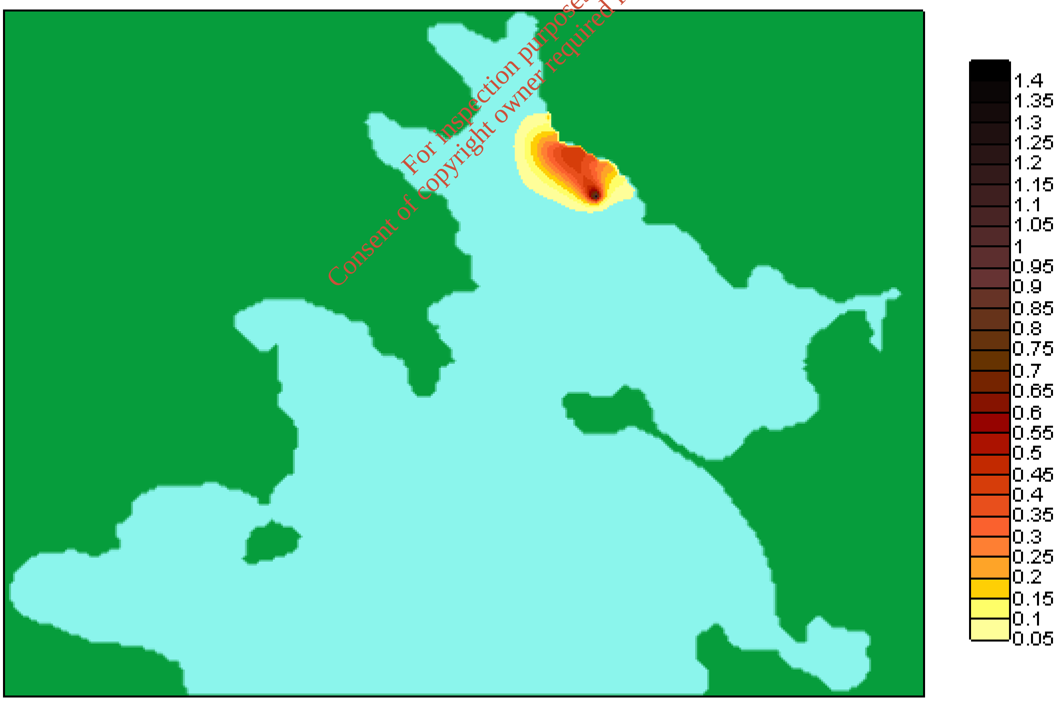



**Figure A.2- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (No wind – inner site)**

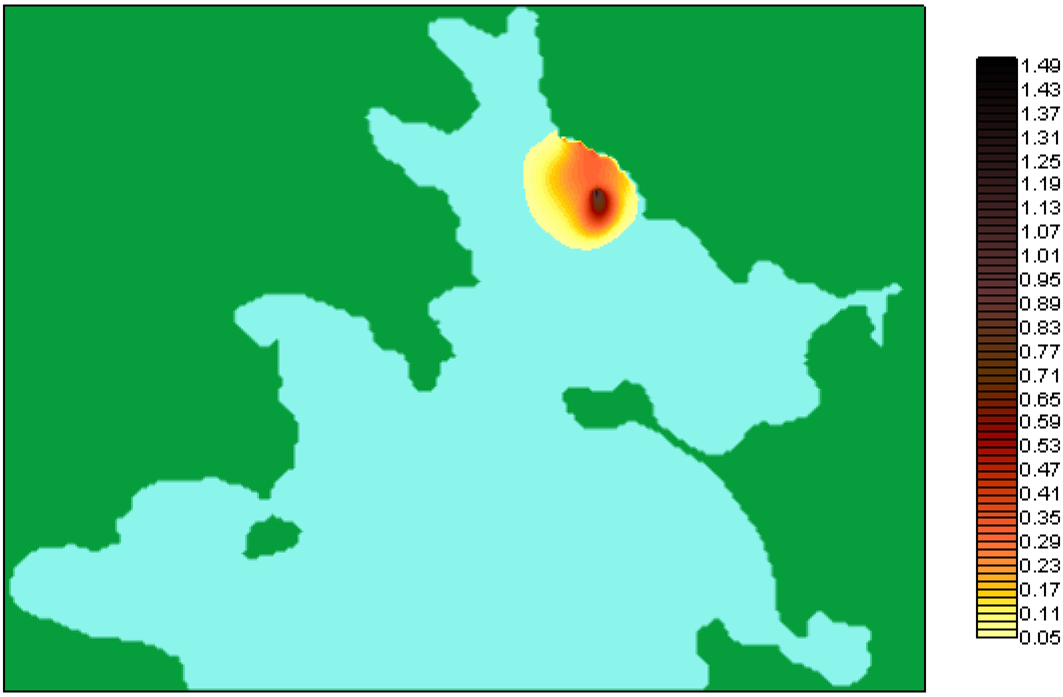



**Figure A.3- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (No wind – inner site)**



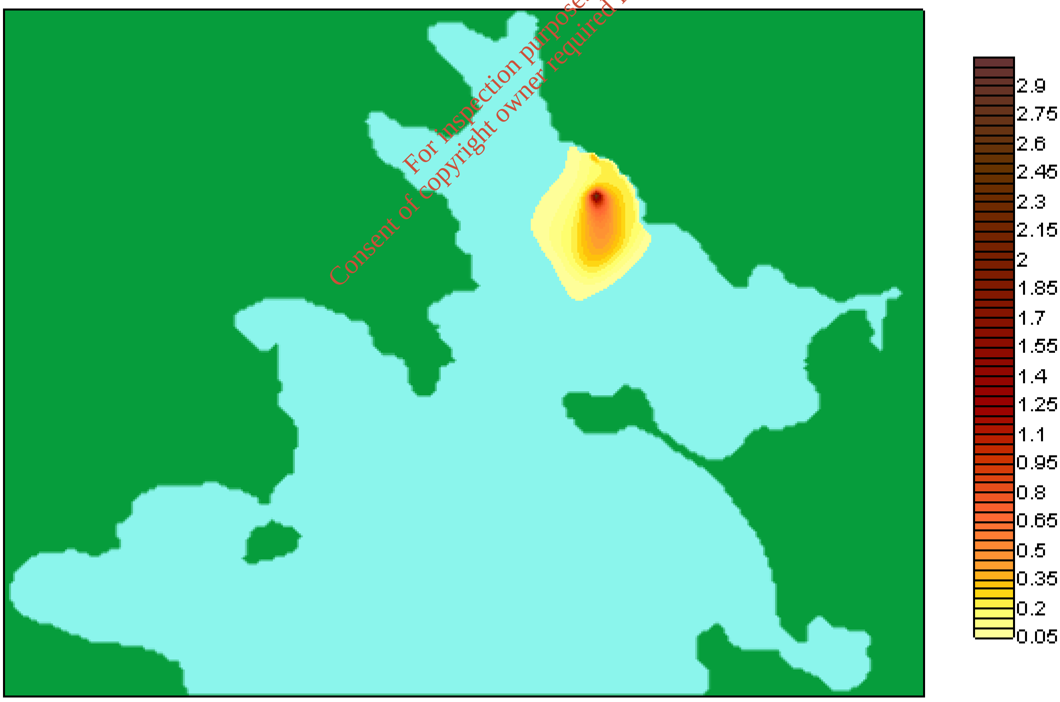



**Figure A.4- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (No wind – inner site)**

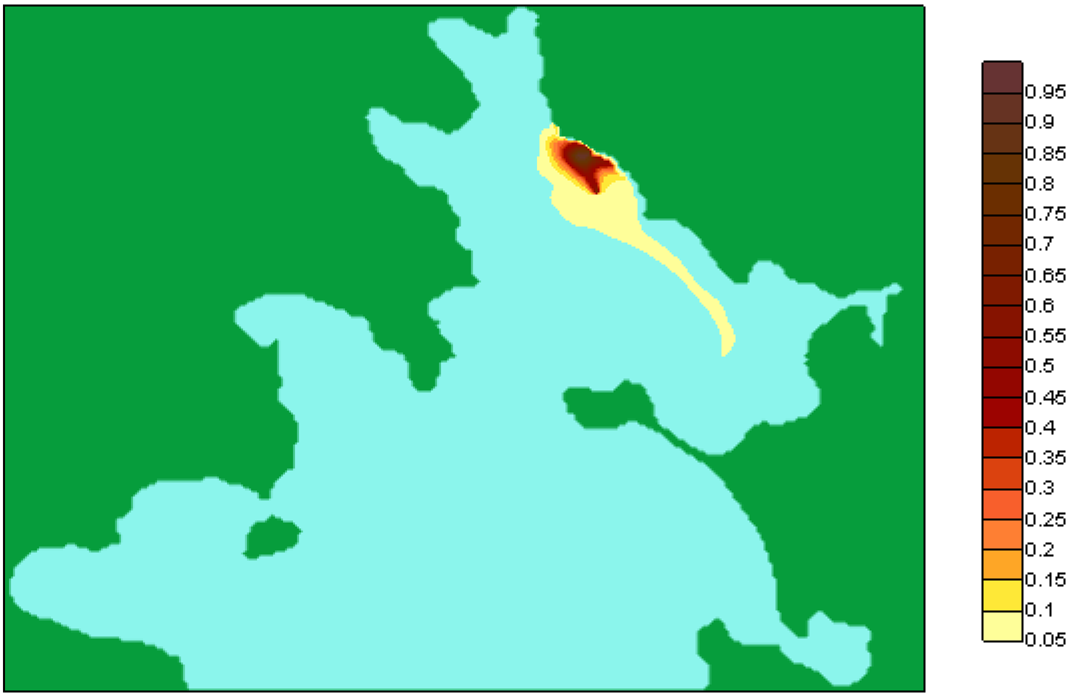



**Figure A.5- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (No wind – inner site)**



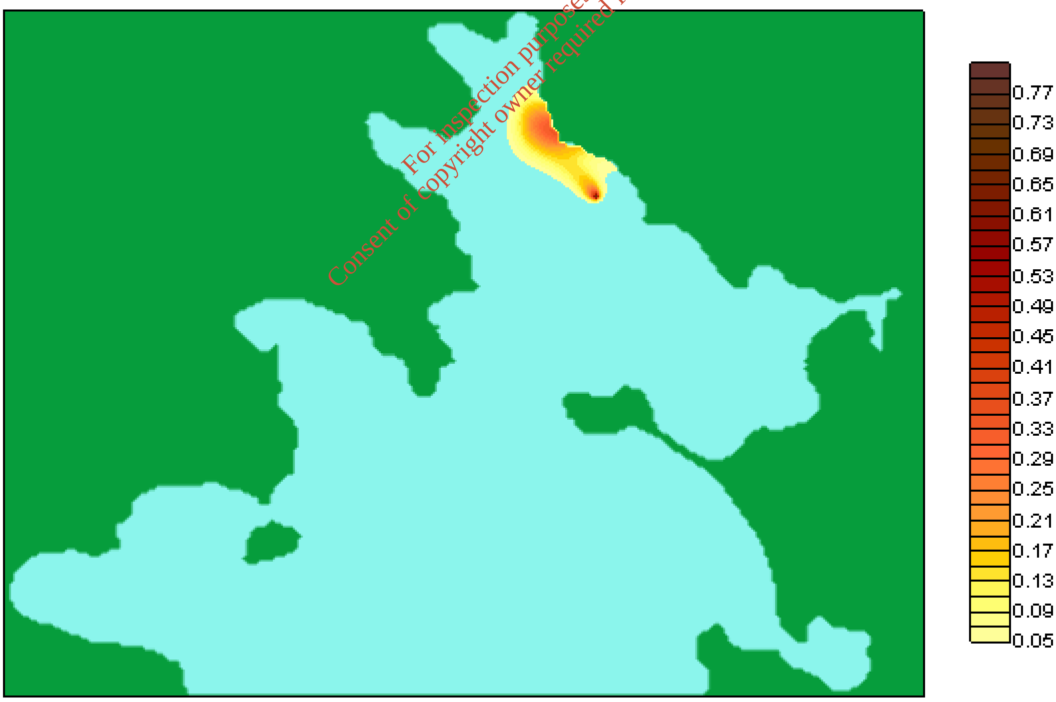



**Figure A.6- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (No wind – inner site)**

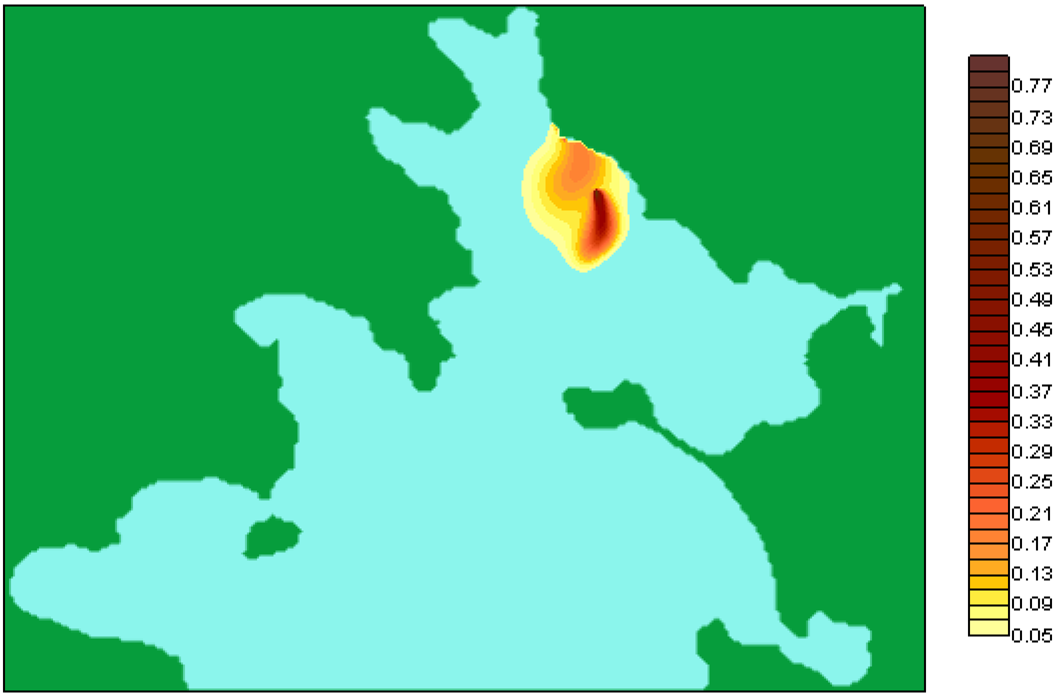



**Figure A.7- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (No wind – inner site)**



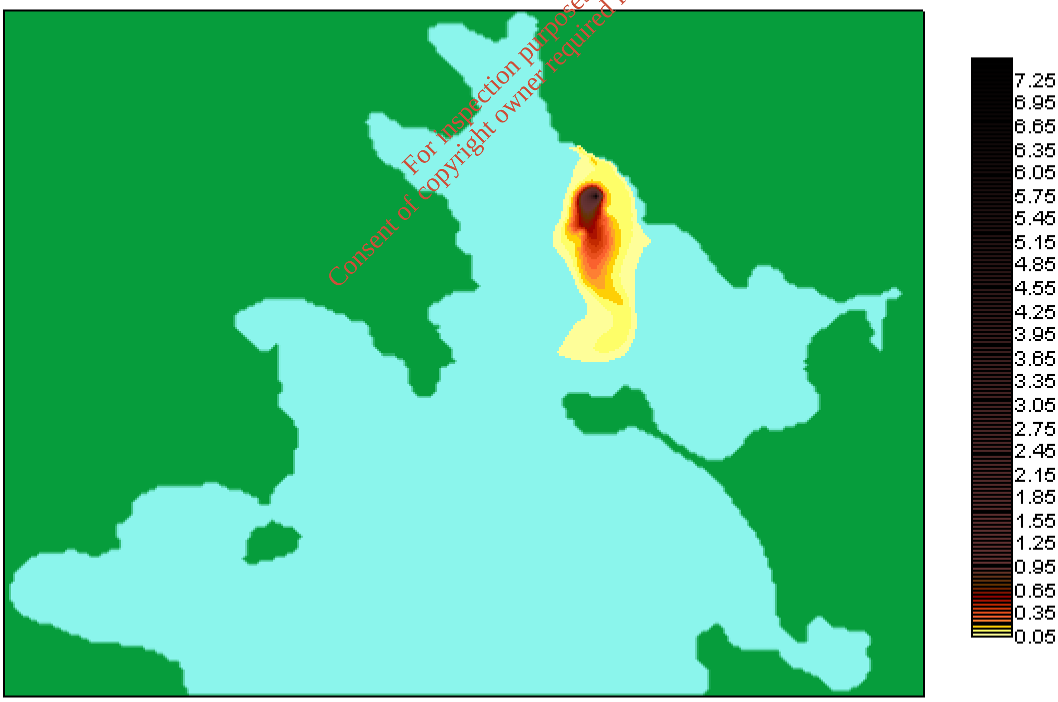



**Figure A.8- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (No wind – inner site)**

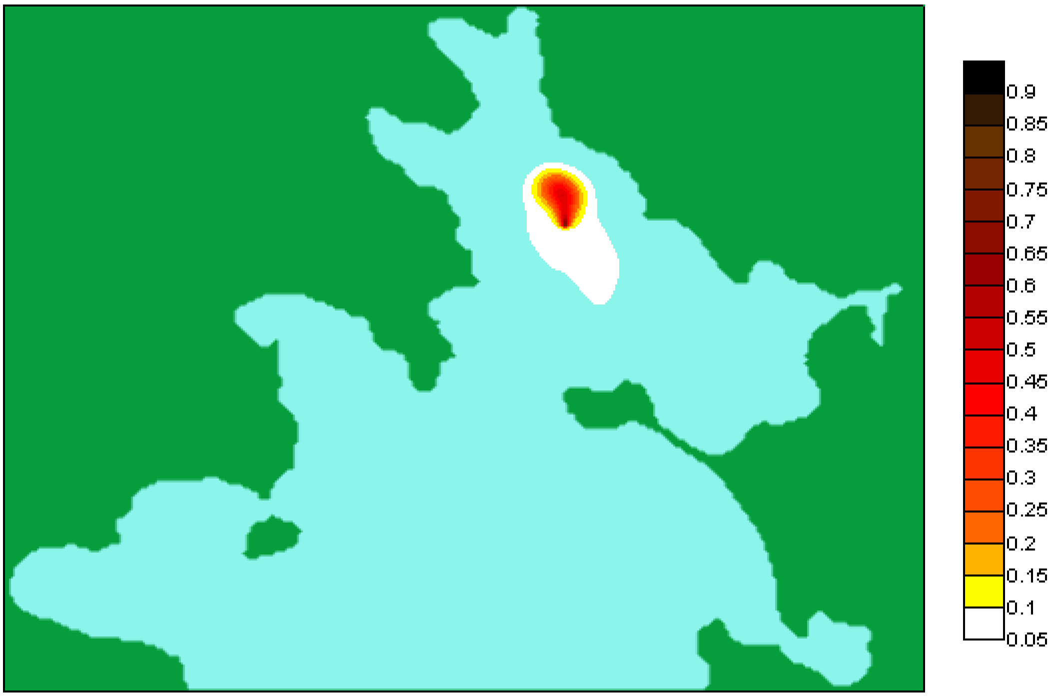



**Figure A.9- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (No wind – outer site)**



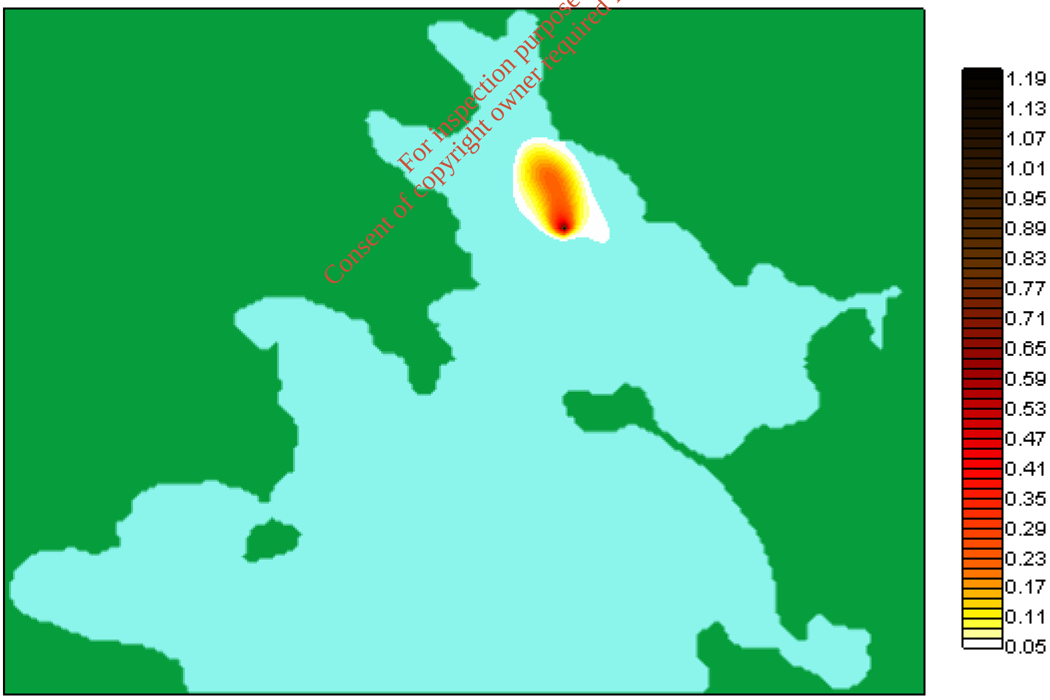



**Figure A.10- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (No wind – outer site)**

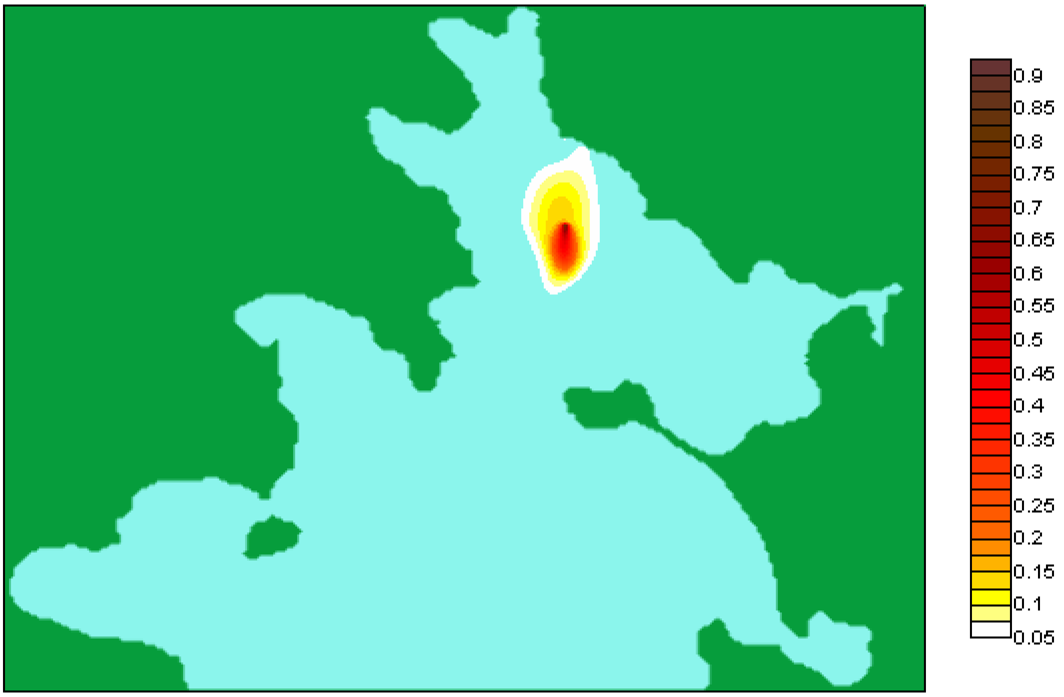



**Figure A.11- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (No wind – outer site)**



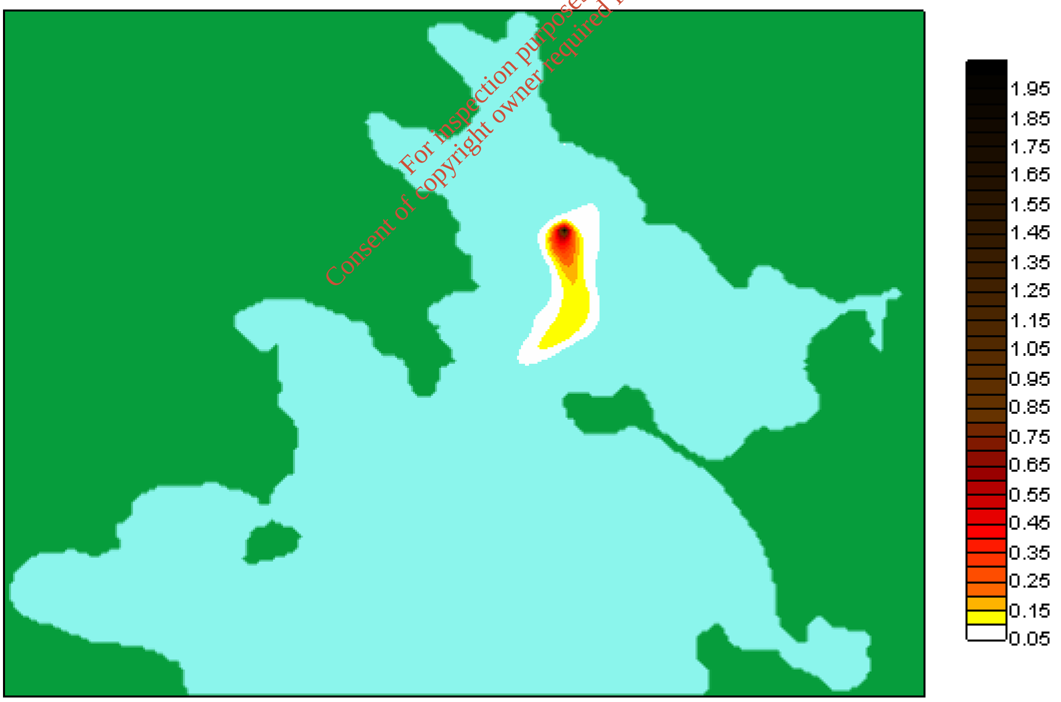



**Figure A.12- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (No wind – outer site)**


**Figure A.13- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (No wind – outer site)**




**Figure A.14- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (No wind – outer site)**

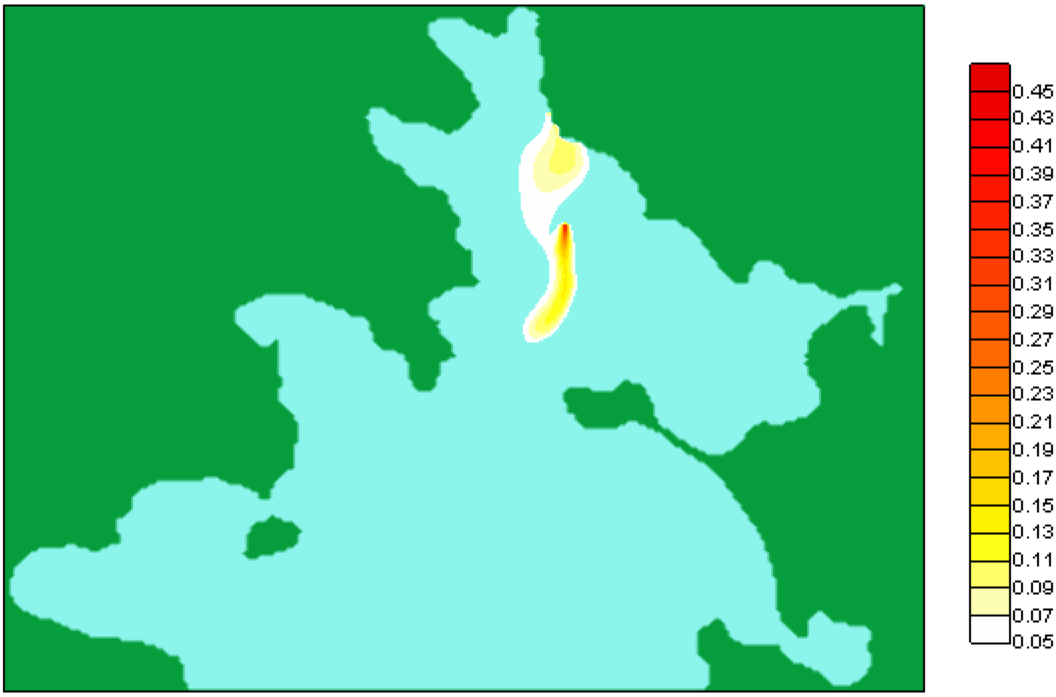



**Figure A.15- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (No wind – outer site)**




**Figure A.16- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (No wind – outer site)**

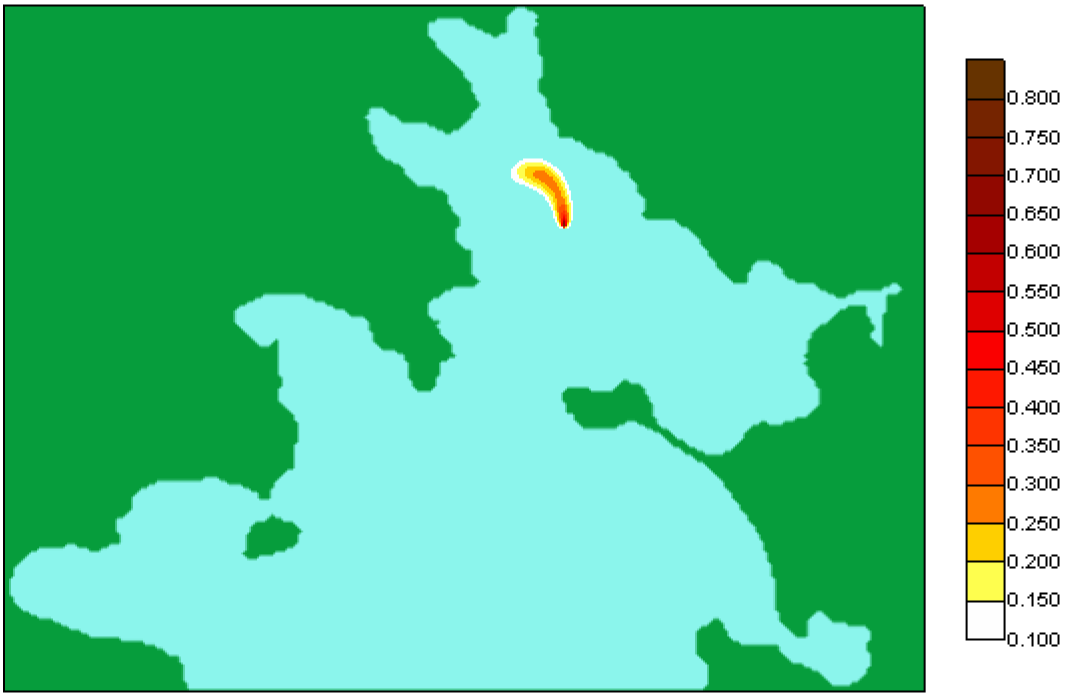



**Figure A.17- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 180 deg, speed 8.5m/s)**



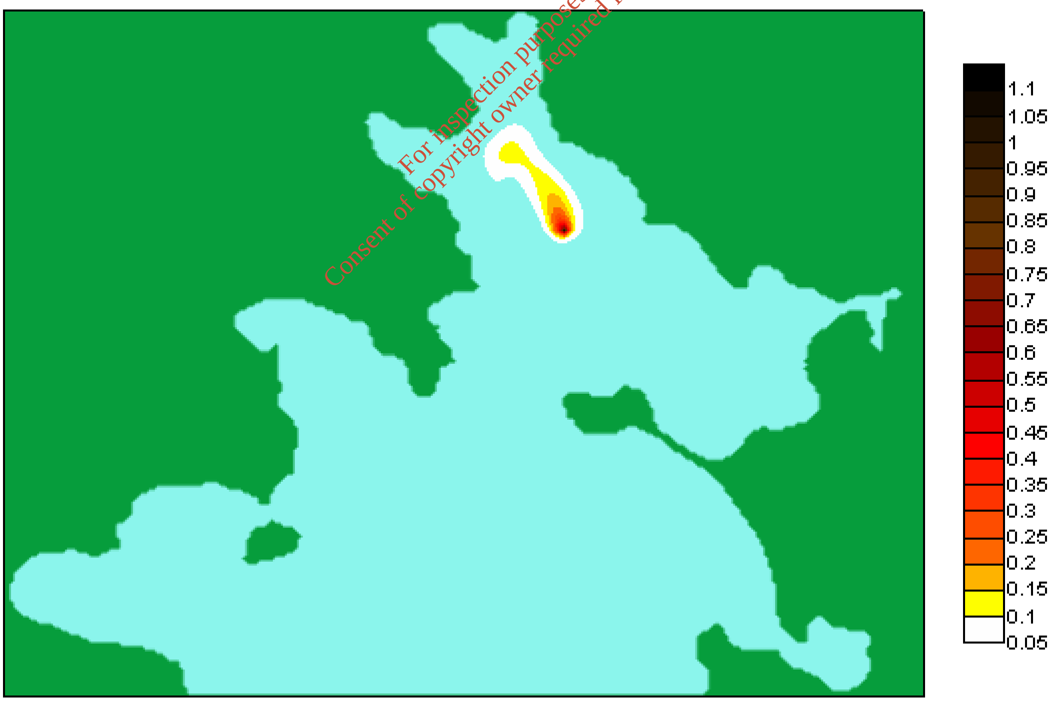



**Figure A.18- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 180 deg, speed 8.5m/s)**


**Figure A.19- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 180 deg, speed 8.5m/s)**




**Figure A.20- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 180 deg, speed 8.5m/s)**


**Figure A.21- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 180 deg, speed 8.5m/s)**




**Figure A.22- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 180 deg, speed 8.5m/s)**

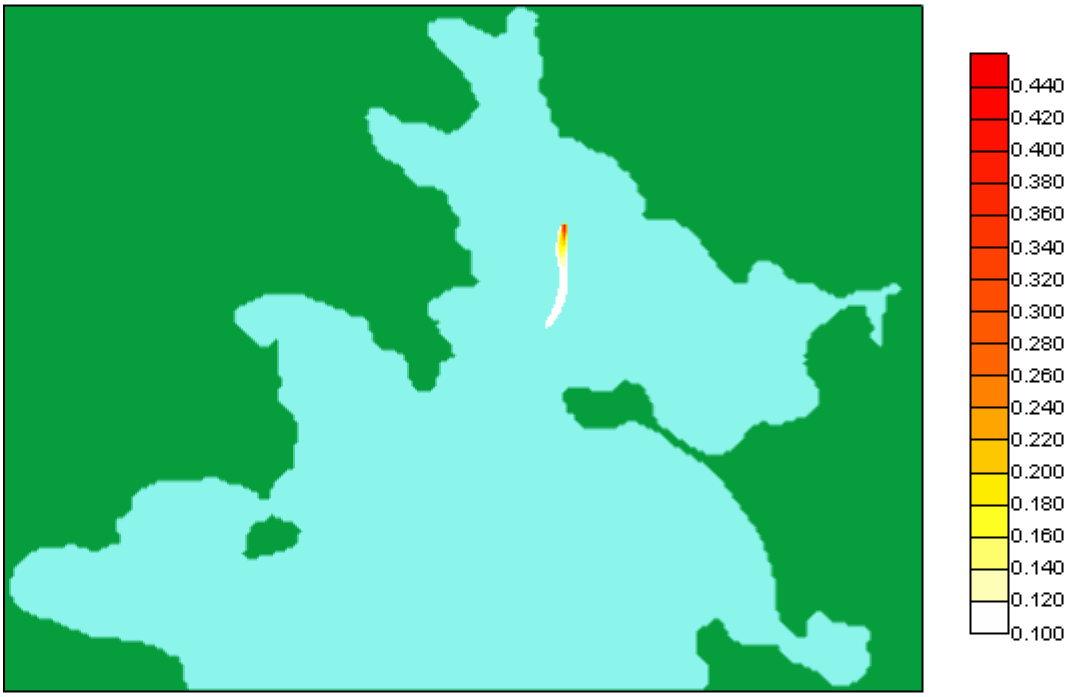



**Figure A.23- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 180 deg, speed 8.5m/s)**




**Figure A.24- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 180 deg, speed 8.5m/s)**

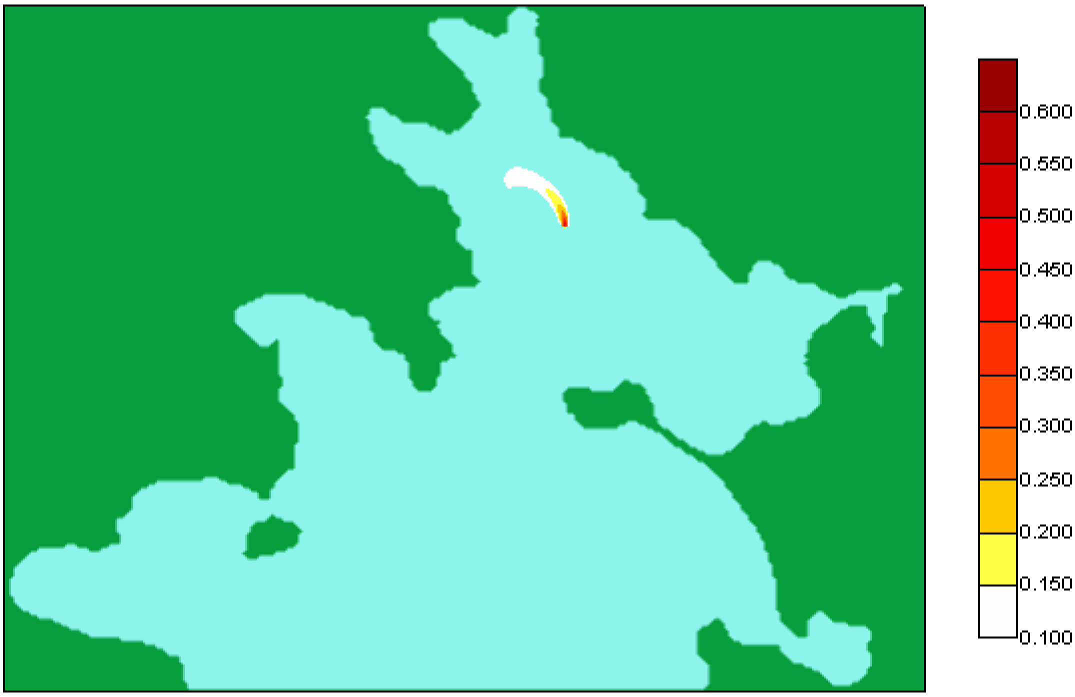



**Figure A.25- Faecal Coliforms Concentration (counts/100 ml) at Mid flood on a Neap Tide (Wind direction 180 deg, speed 18.5m/s)**




**Figure A.26- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 180 deg, speed 18.5m/s)**

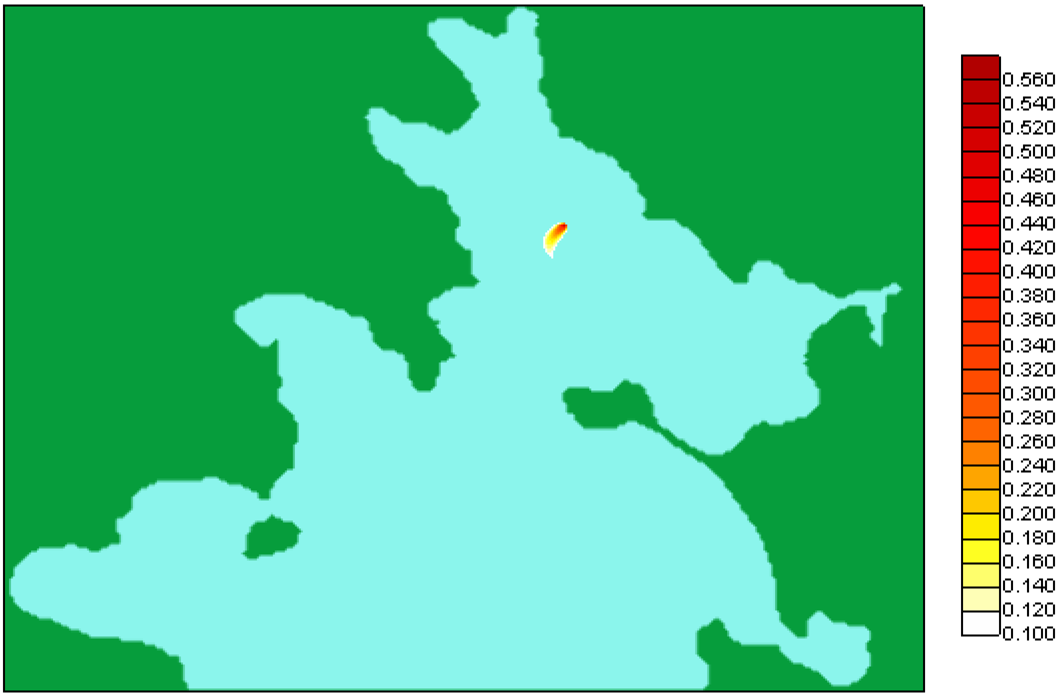



**Figure A.27- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 180 deg, speed 18.5m/s)**




**Figure A.28- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 180 deg, speed 18.5m/s)**

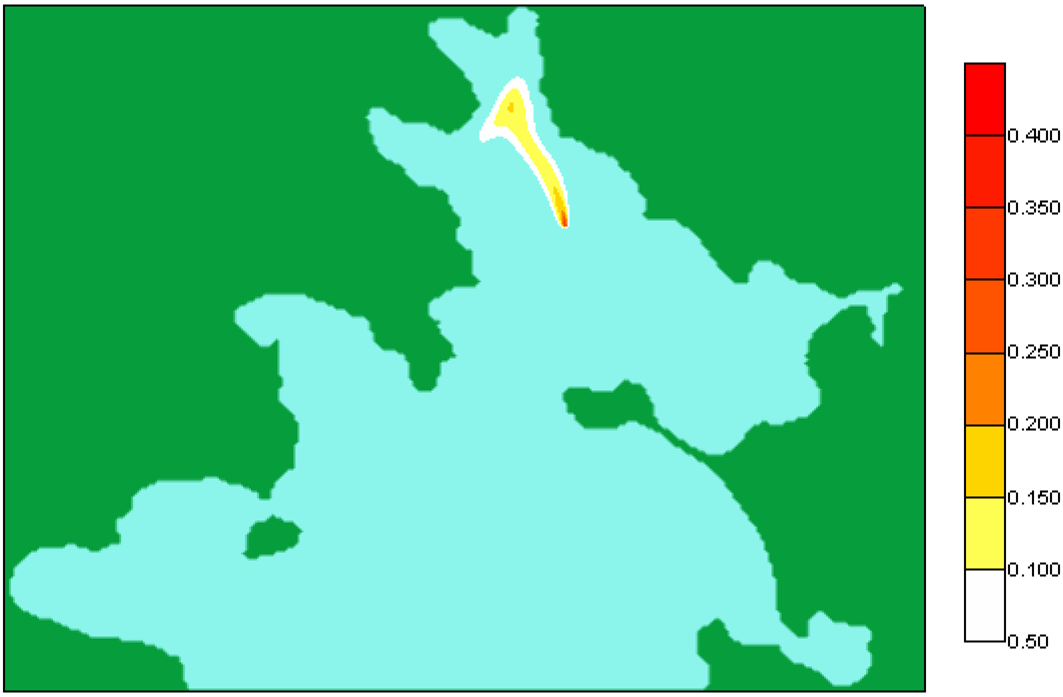



**Figure A.29- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 180 deg, speed 18.5m/s)**




**Figure A.30- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 180 deg, speed 18.5m/s)**

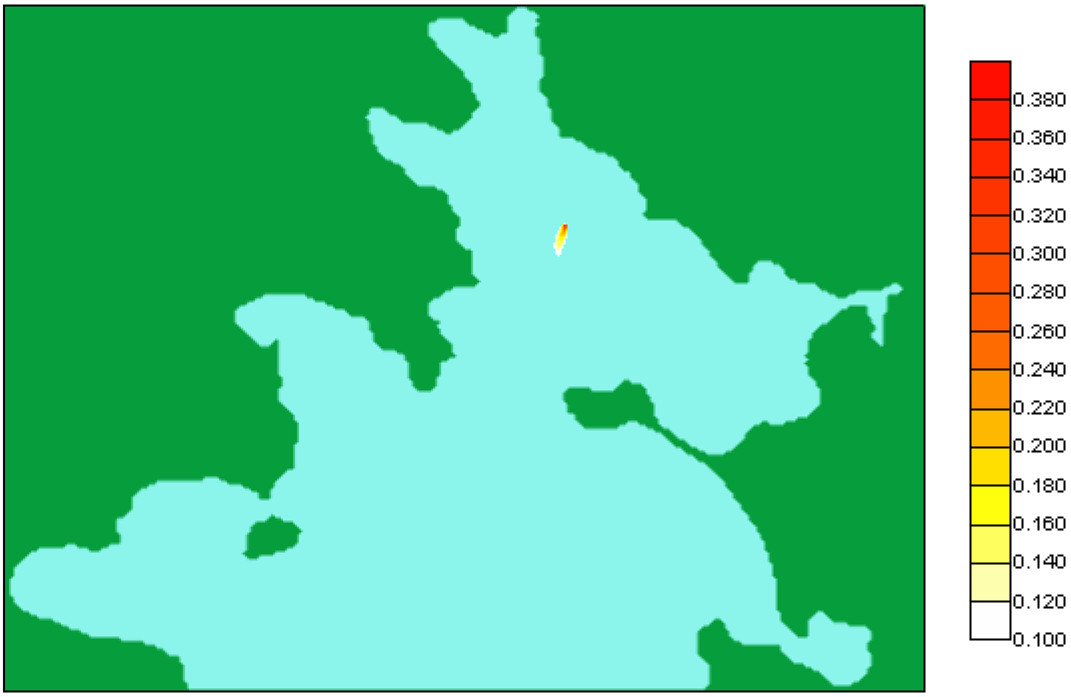



**Figure A.31- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 180 deg, speed 18.5m/s)**




**Figure A.32- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 180 deg, speed 18.5m/s)**

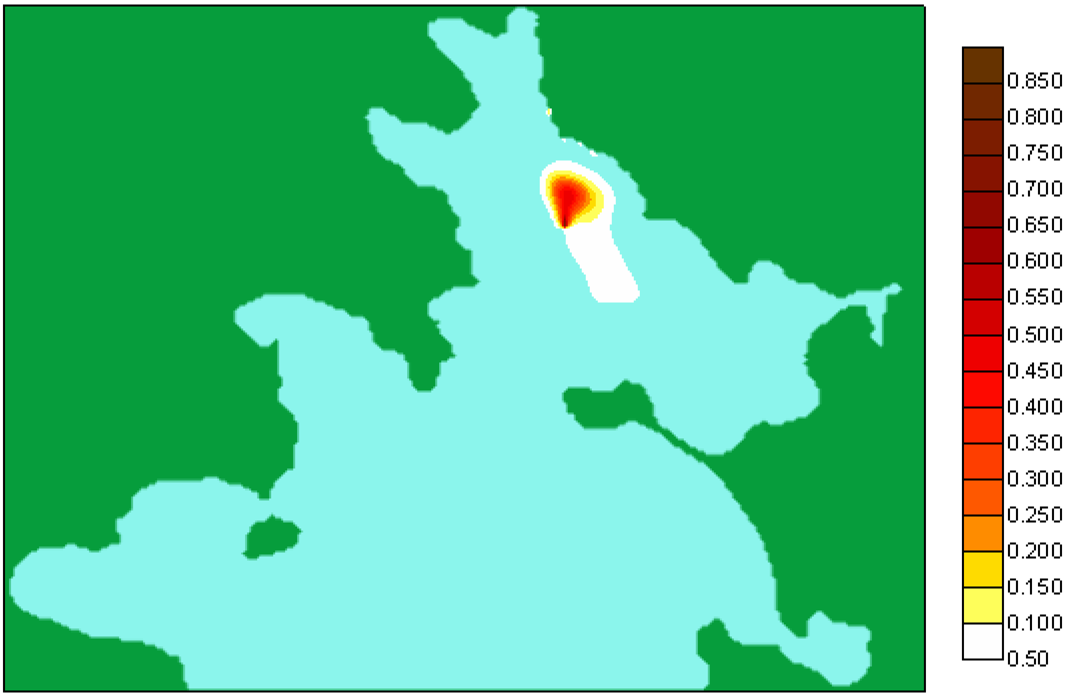



**Figure A.33- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 225 deg, speed 8.3m/s)**



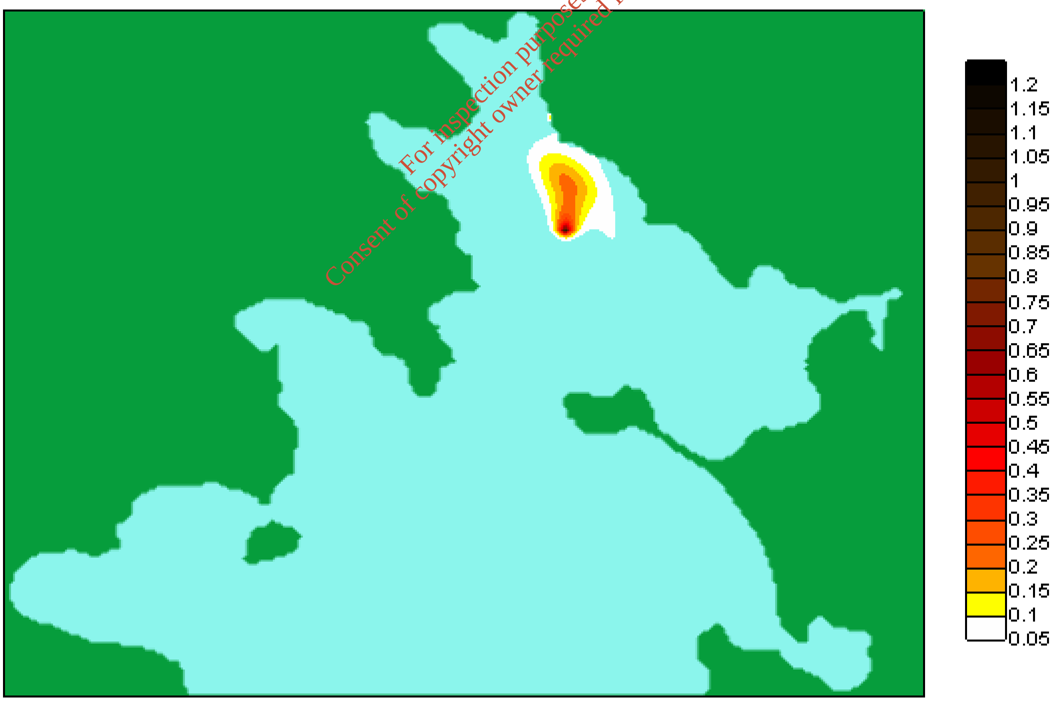



**Figure A.34- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 225 deg, speed 8.3m/s)**


**Figure A.35- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 225 deg, speed 8.3m/s)**




**Figure A.36- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 225 deg, speed 8.3m/s)**


**Figure A.37- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 225 deg, speed 8.3m/s)**




**Figure A.38- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 225 deg, speed 8.3m/s)**

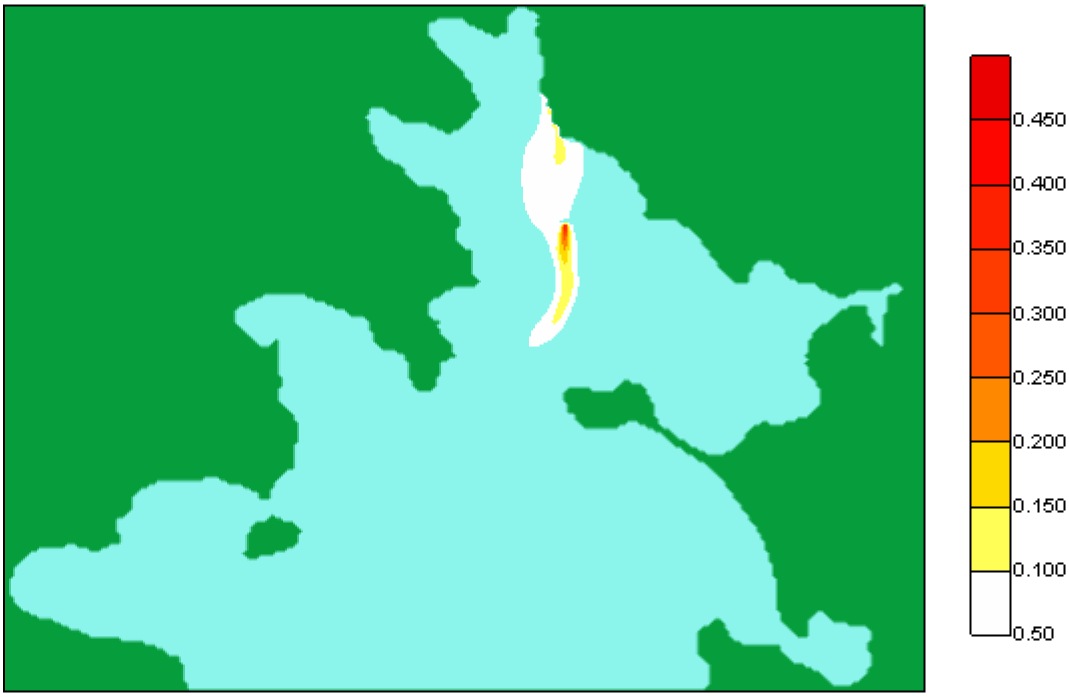



**Figure A.39- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 225 deg, speed 8.3m/s)**




**Figure A.40- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 225 deg, speed 8.3m/s)**

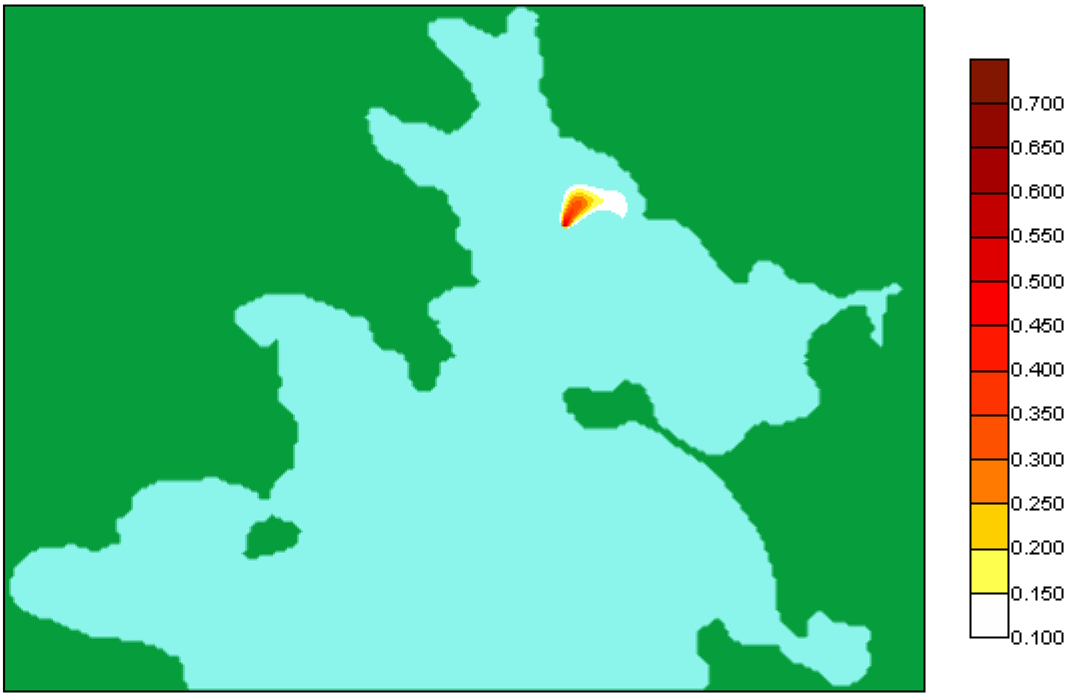



**Figure A.41- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 225 deg, speed 18.5m/s)**




**Figure A.42- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 225 deg, speed 18.5m/s)**

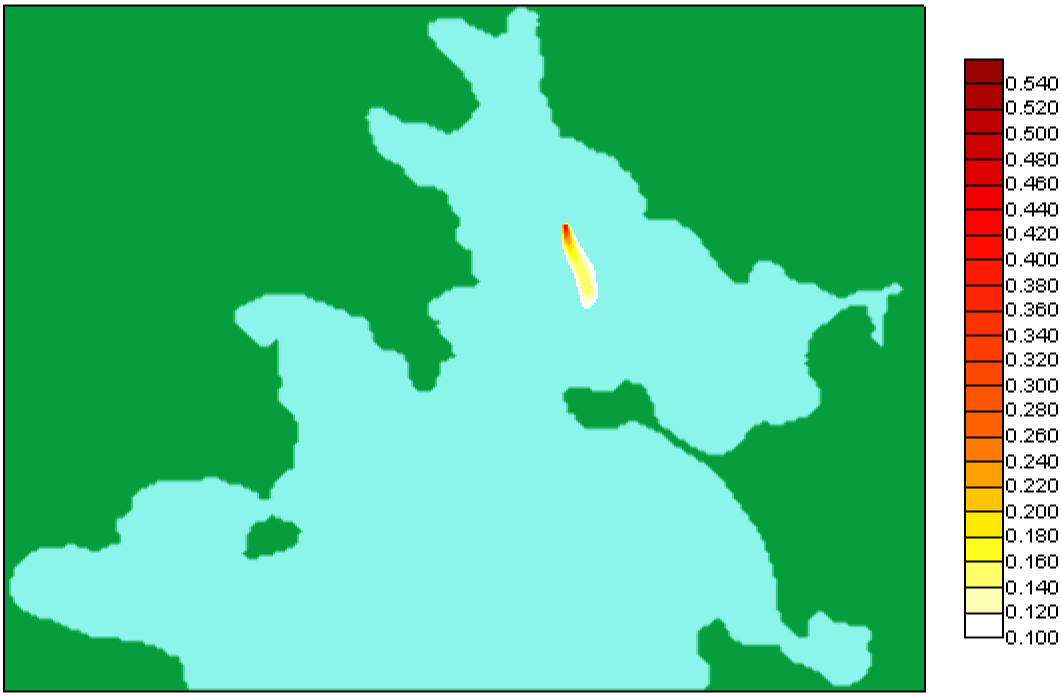



**Figure A.43- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 225 deg, speed 18.5m/s)**




**Figure A.44- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 225 deg, speed 18.5m/s)**

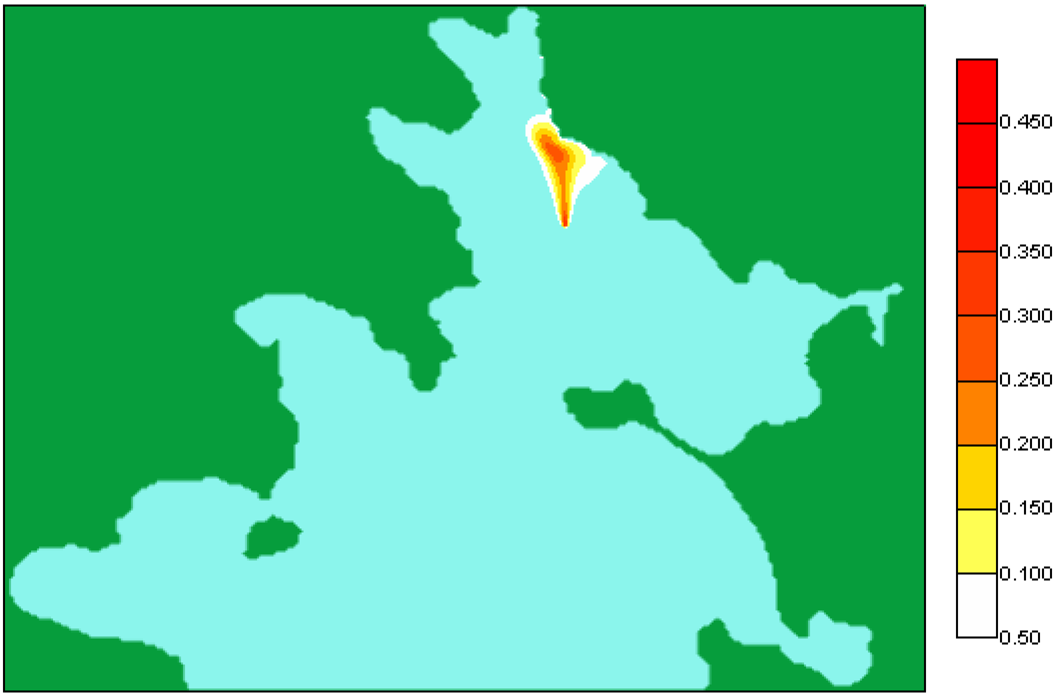



**Figure A.45- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 225 deg, speed 18.5m/s)**




**Figure A.46- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 225 deg, speed 18.5m/s)**

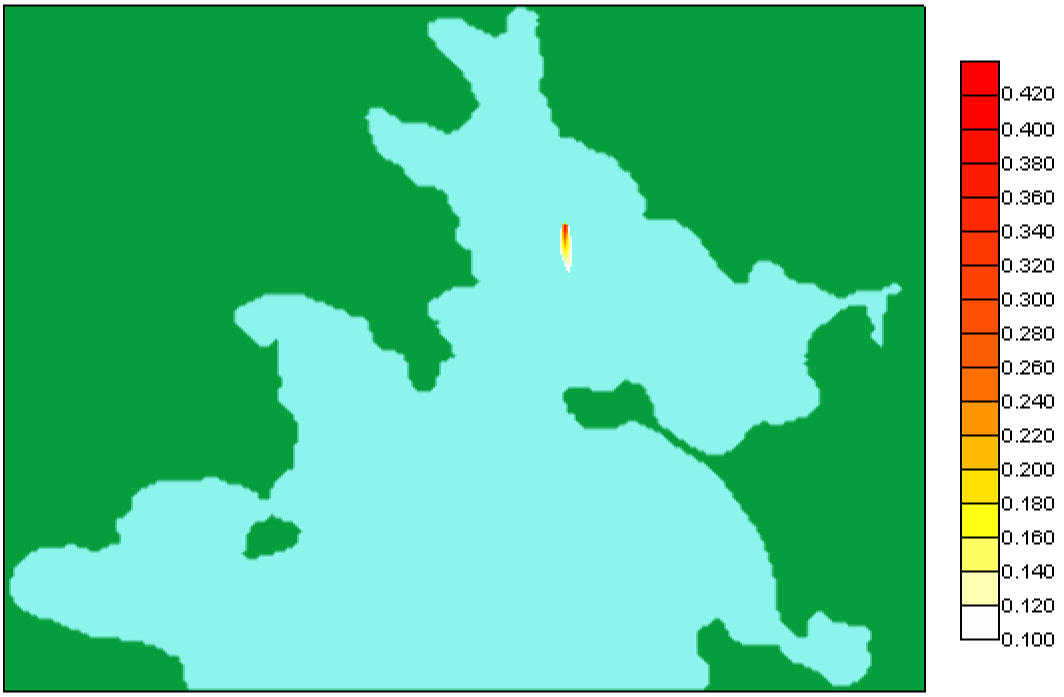



**Figure A.47- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 225 deg, speed 18.5m/s)**




**Figure A.48- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 225 deg, speed 18.5m/s)**


**Figure A.49- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 270 deg, speed 7.5m/s)**



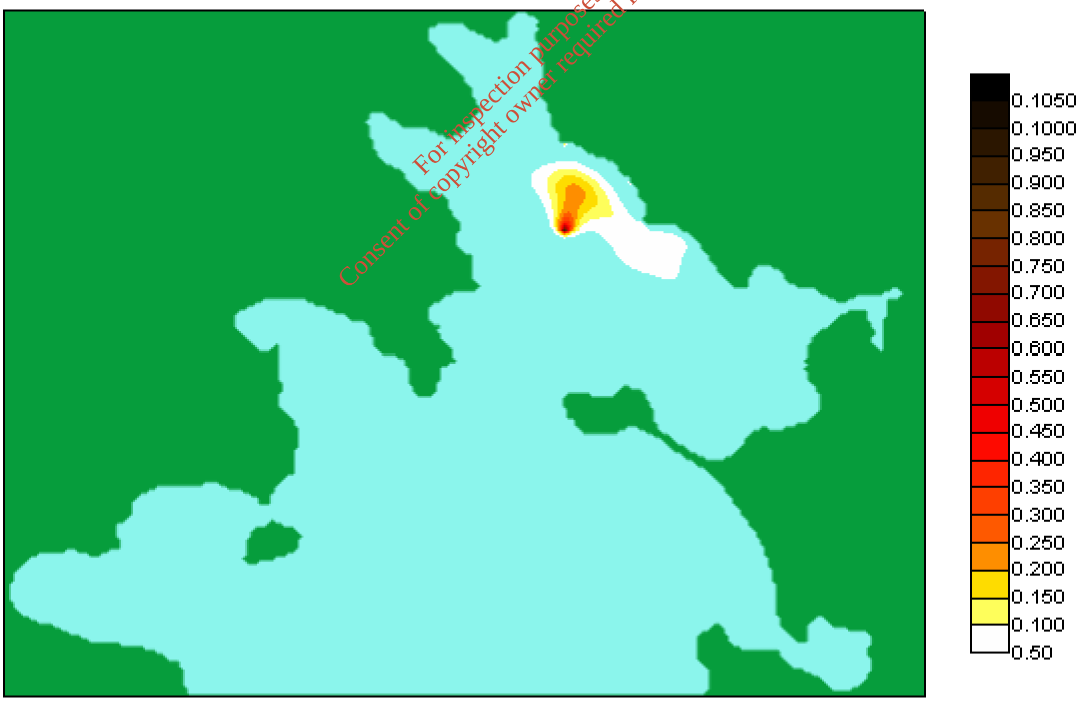



**Figure A.50- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 270 deg, speed 7.5m/s)**

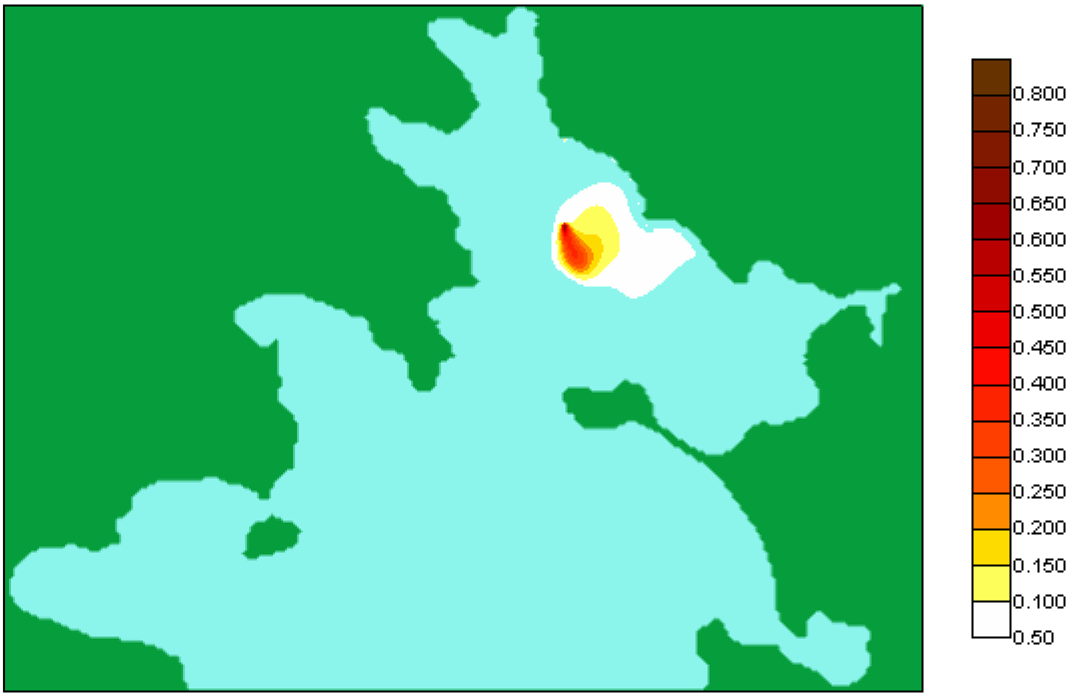



**Figure A.51- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 270 deg, speed 7.5m/s)**




**Figure A.52- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 270 deg, speed 7.5m/s)**

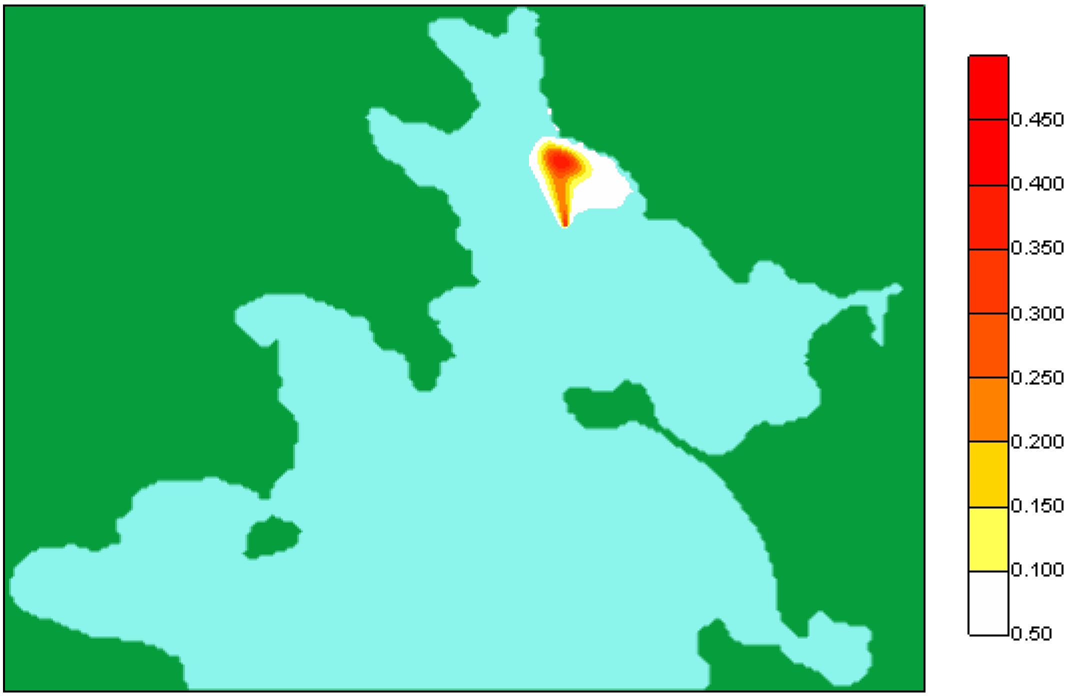



**Figure A.53- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 270 deg, speed 7.5m/s)**




**Figure A.54- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 270 deg, speed 7.5m/s)**

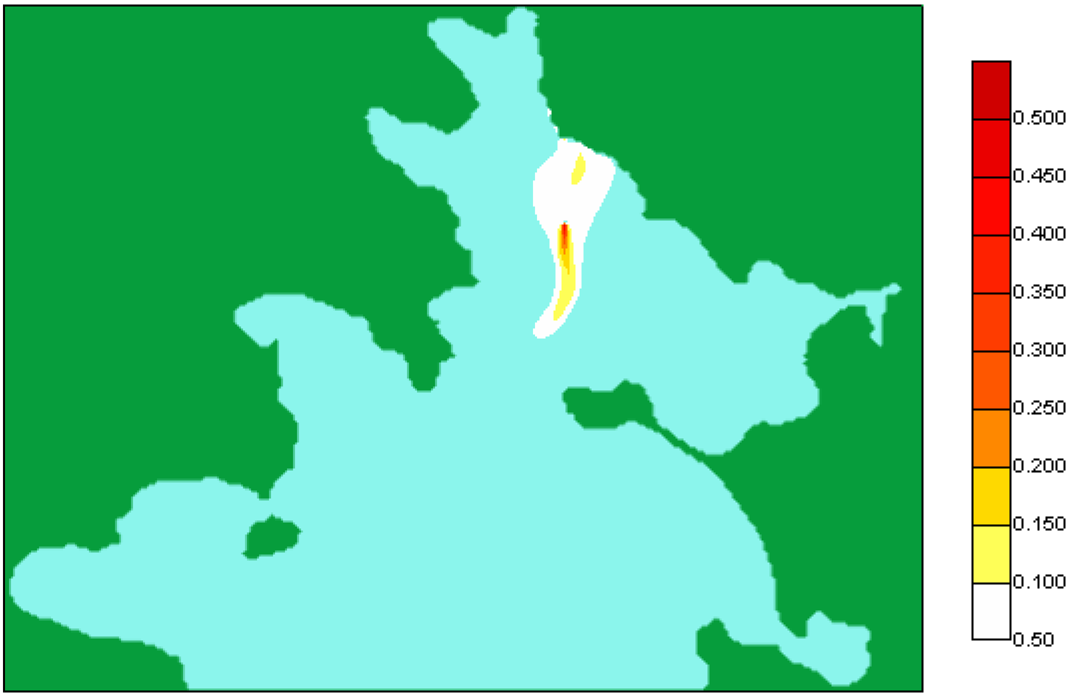



**Figure A.55- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 270 deg, speed 7.5m/s)**




**Figure A.56- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 270 deg, speed 7.5m/s)**


**Figure A.57- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 270 deg, speed 15.5m/s)**




**Figure A.58- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 270 deg, speed 15.5m/s)**

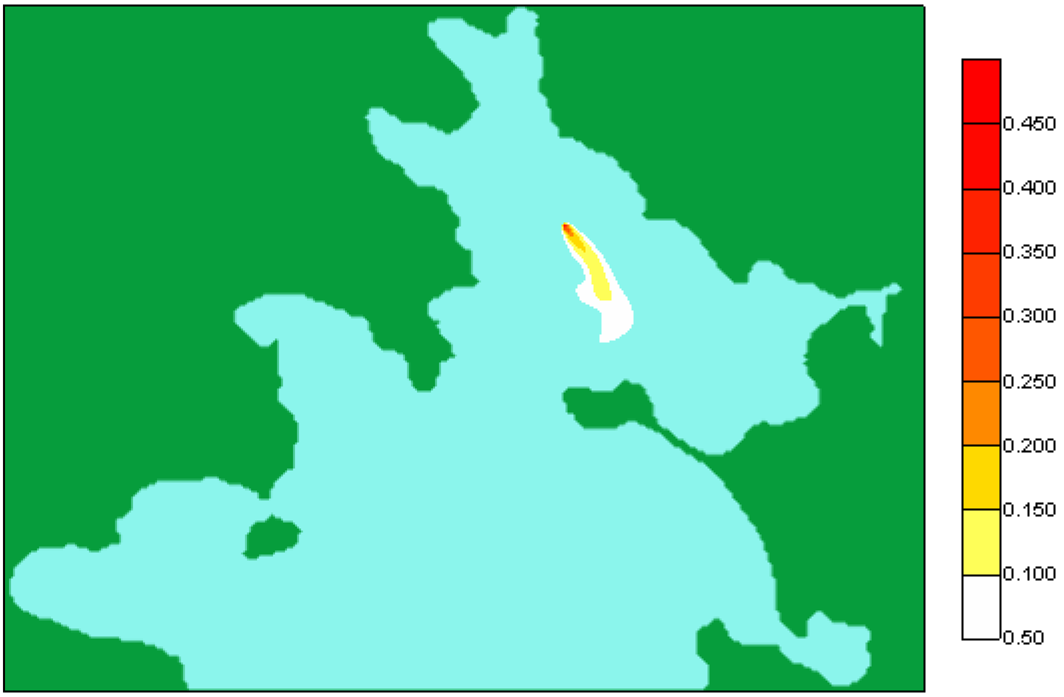



**Figure A.59- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 270 deg, speed 15.5m/s)**




**Figure A.60- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 270 deg, speed 15.5m/s)**


**Figure A.61- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 270 deg, speed 15.5m/s)**




**Figure A.62- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 270 deg, speed 15.5m/s)**

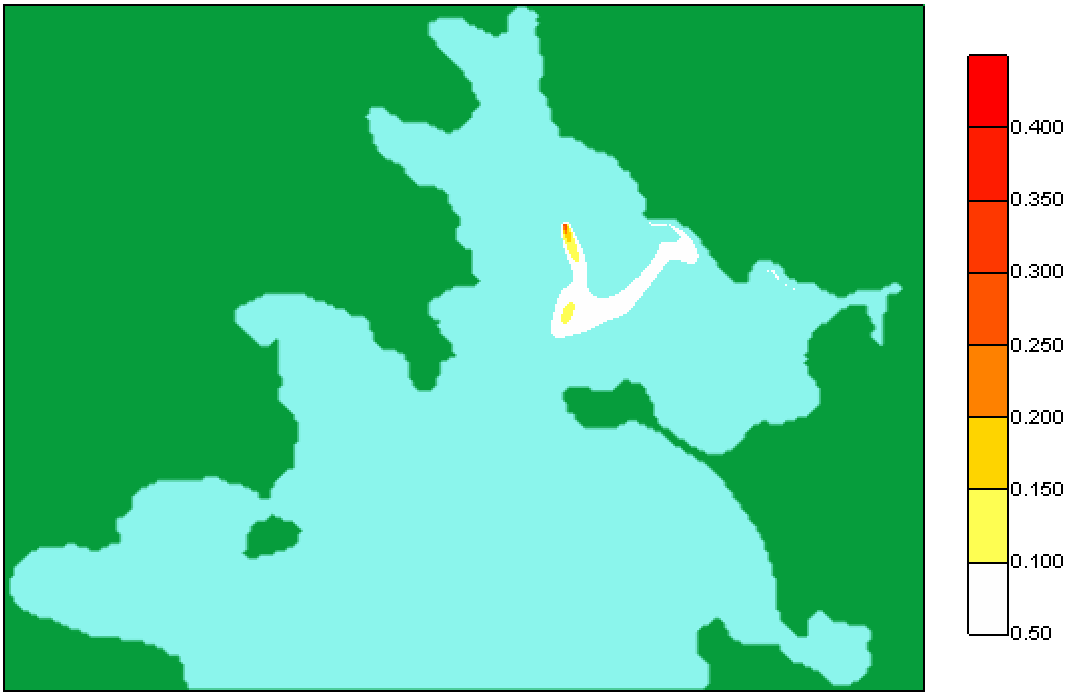



**Figure A.63- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 270 deg, speed 15.5m/s)**




**Figure A.64- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 270 deg, speed 15.5m/s)**

# Section B

## Faecal coliform concentration in effluent = $1x10^6$ number/100ml

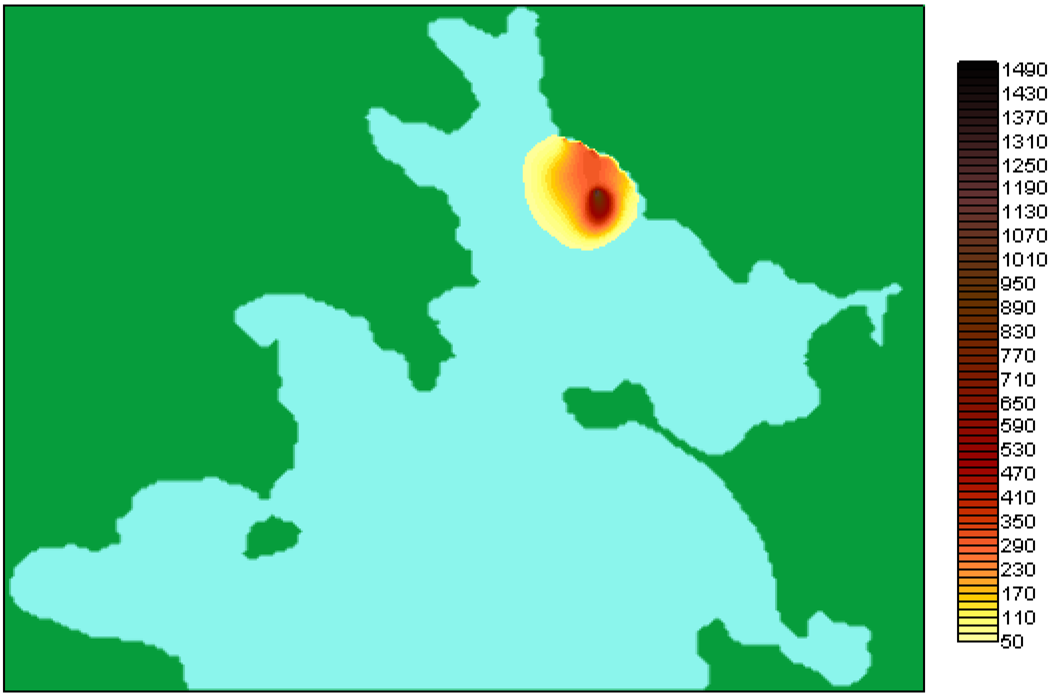



**Figure B.1- Faecal Coliforms Concentration (counts/100ml) at Mid Flood on a Neap Tide ( No Wind – inner site)**



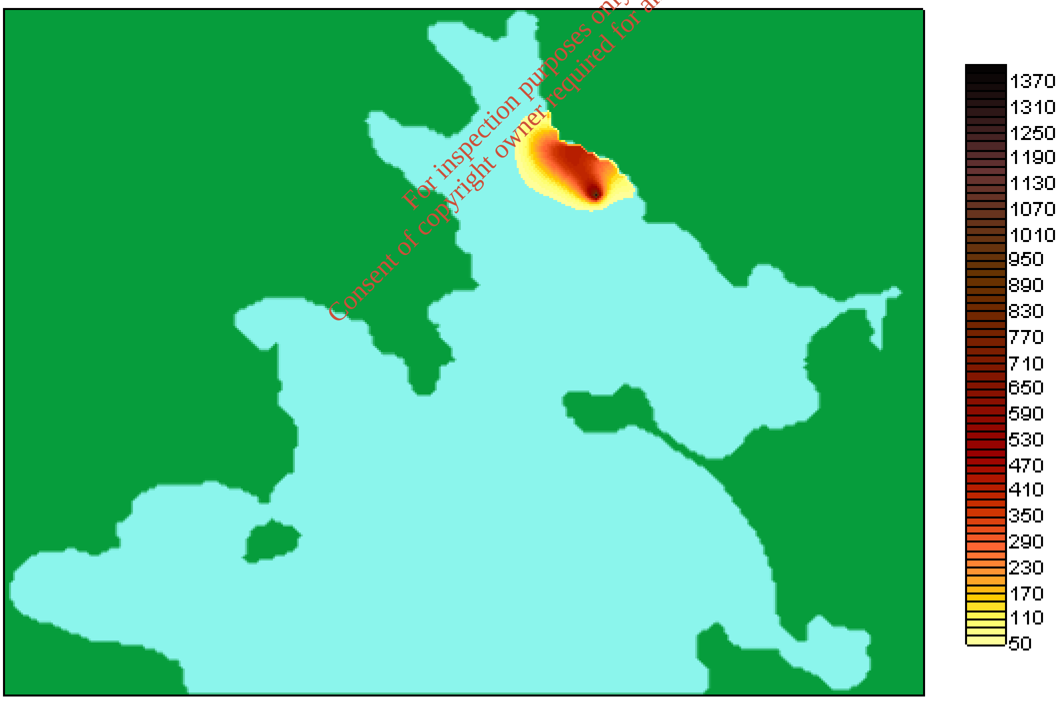



**Figure B.2- Faecal Coliforms Concentration (counts/100ml) at High Water on a Neap Tide ( No Wind – inner site)**

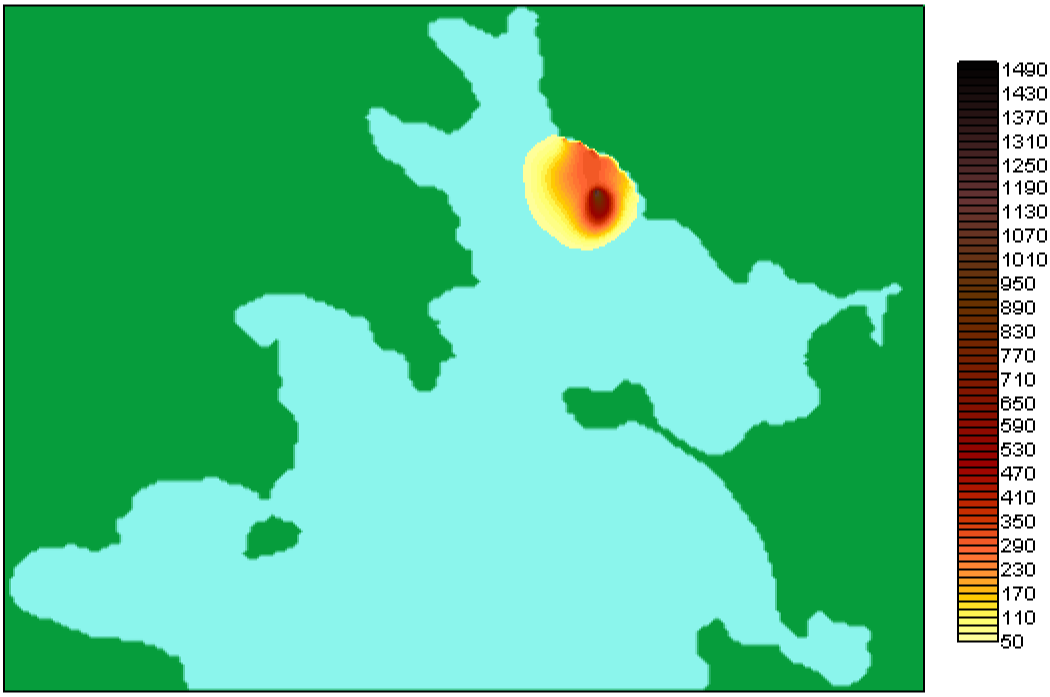



**Figure B.3- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (No wind – inner site)**



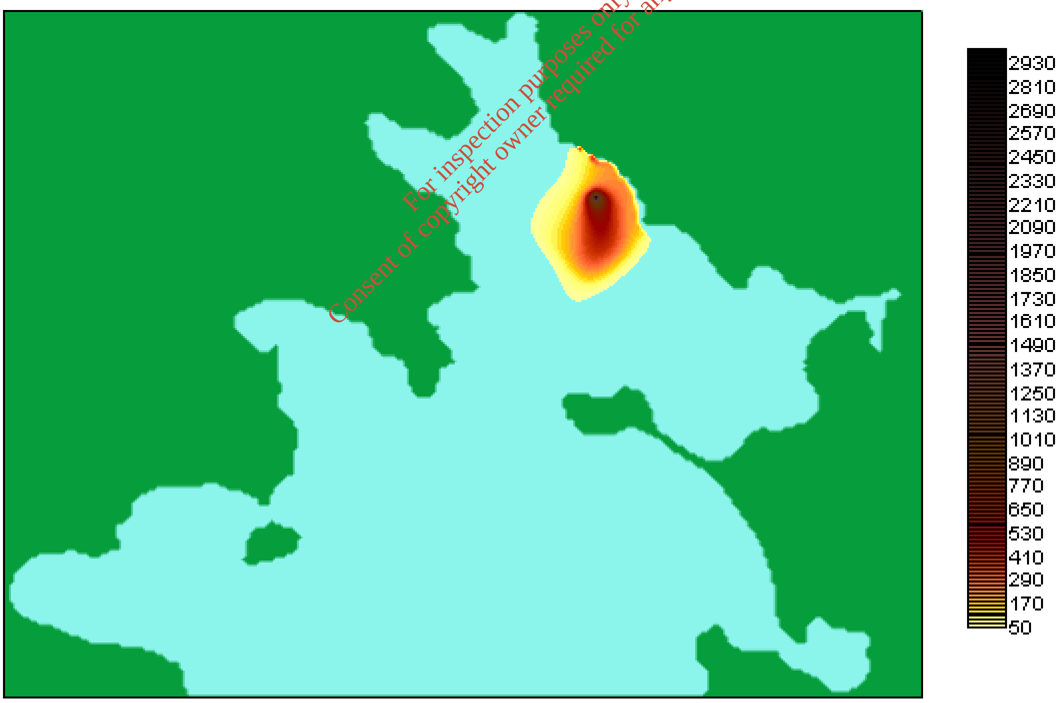



**Figure B.4- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (No wind – inner site)**


**Figure B.5- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (No wind – inner site)**



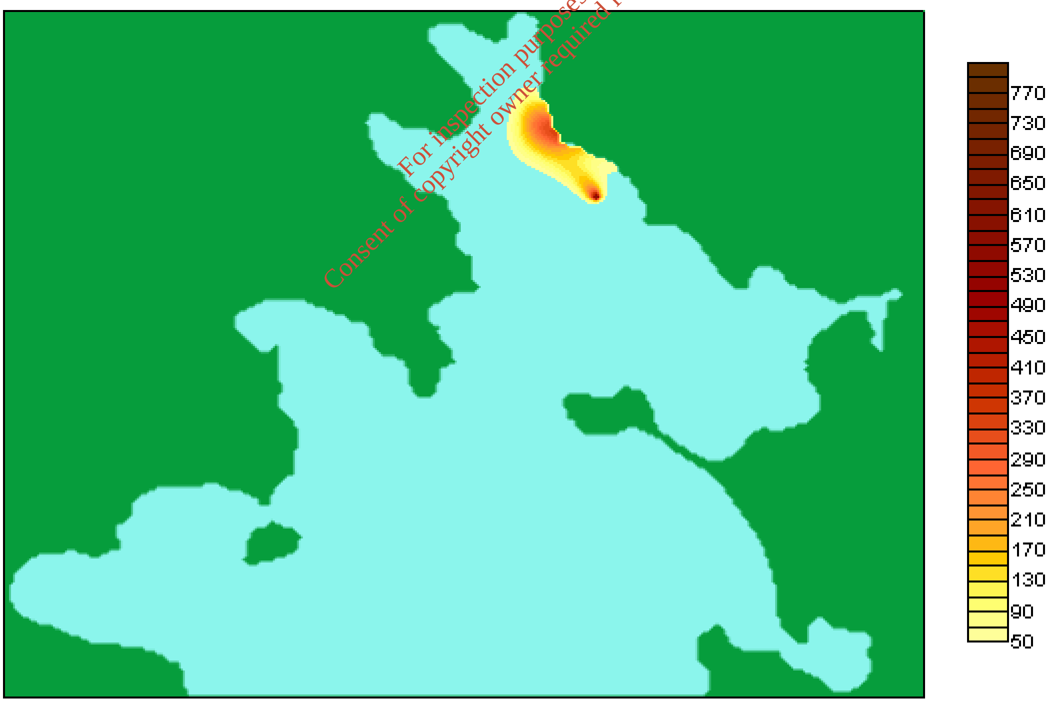



**Figure B.6- Faecal Coliforms Concentration (counts/100 ml) at High water on a Spring Tide (No wind – inner site)**

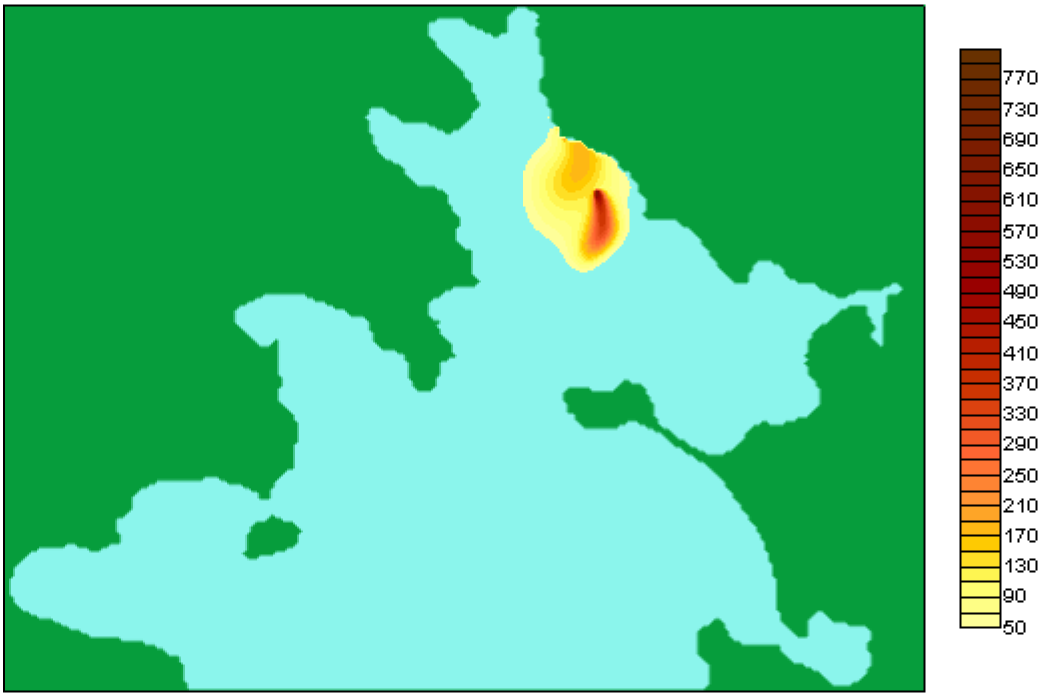



**Figure B.7- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (No wind – inner site)**



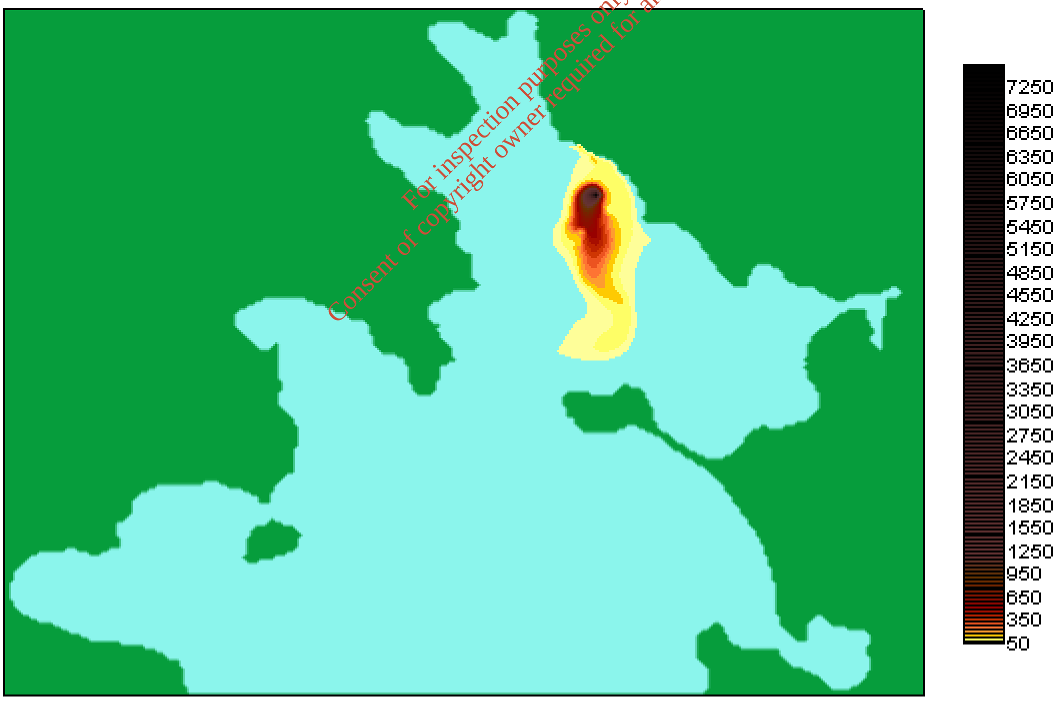



**Figure B.8- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (No wind – inner site)**

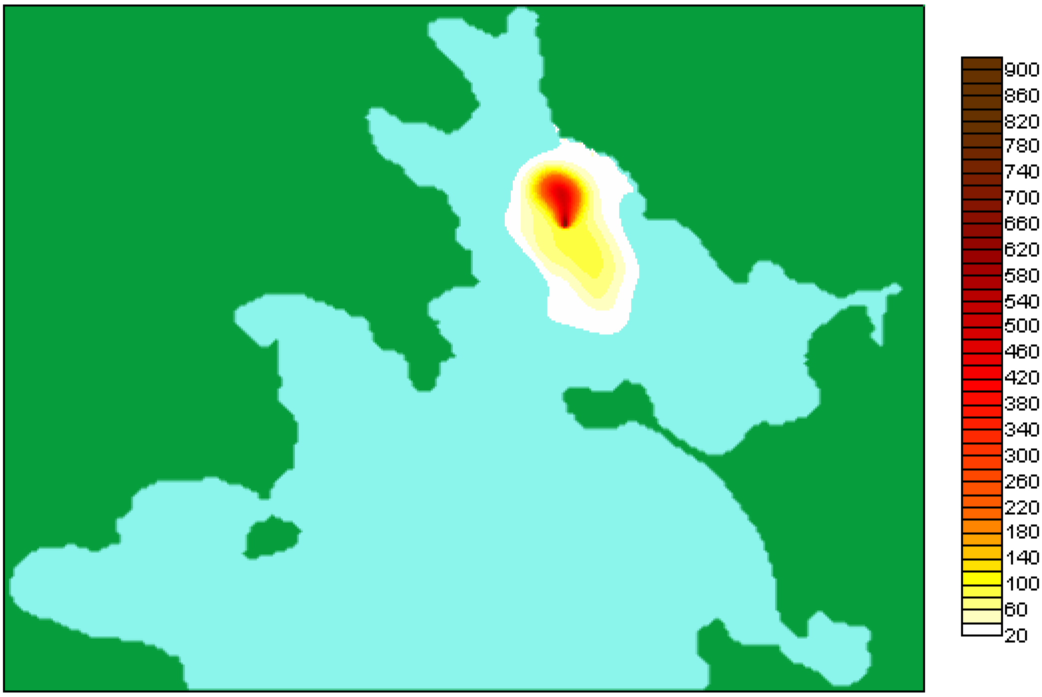



**Figure B.9- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (No wind – outer site)**



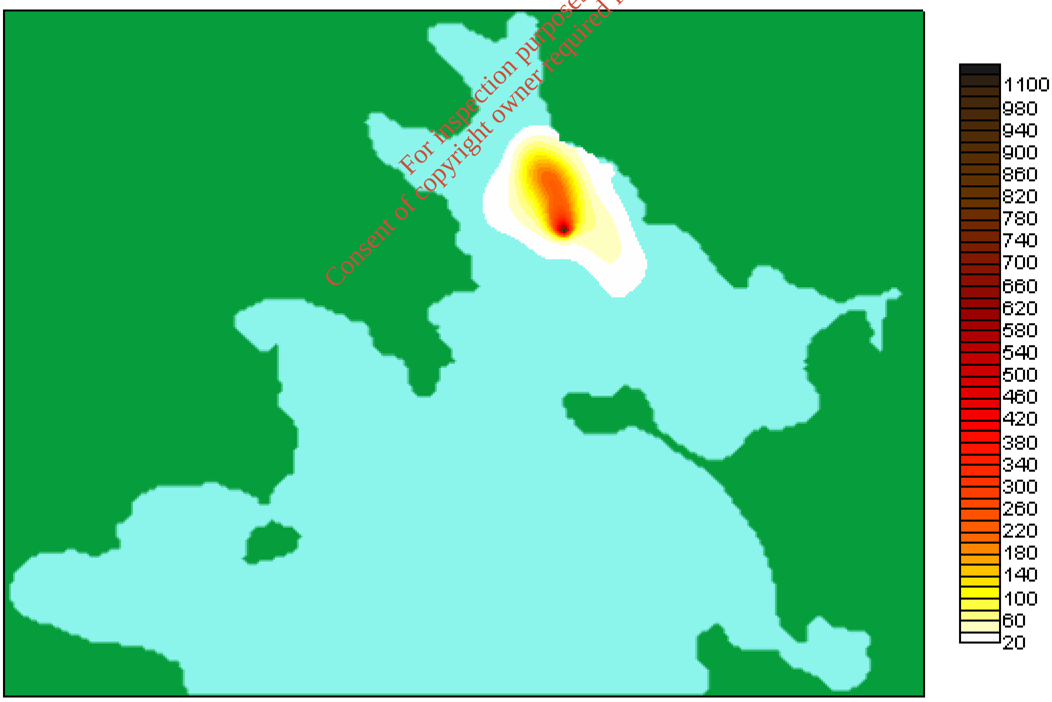



**Figure B.10- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (No wind – outer site)**

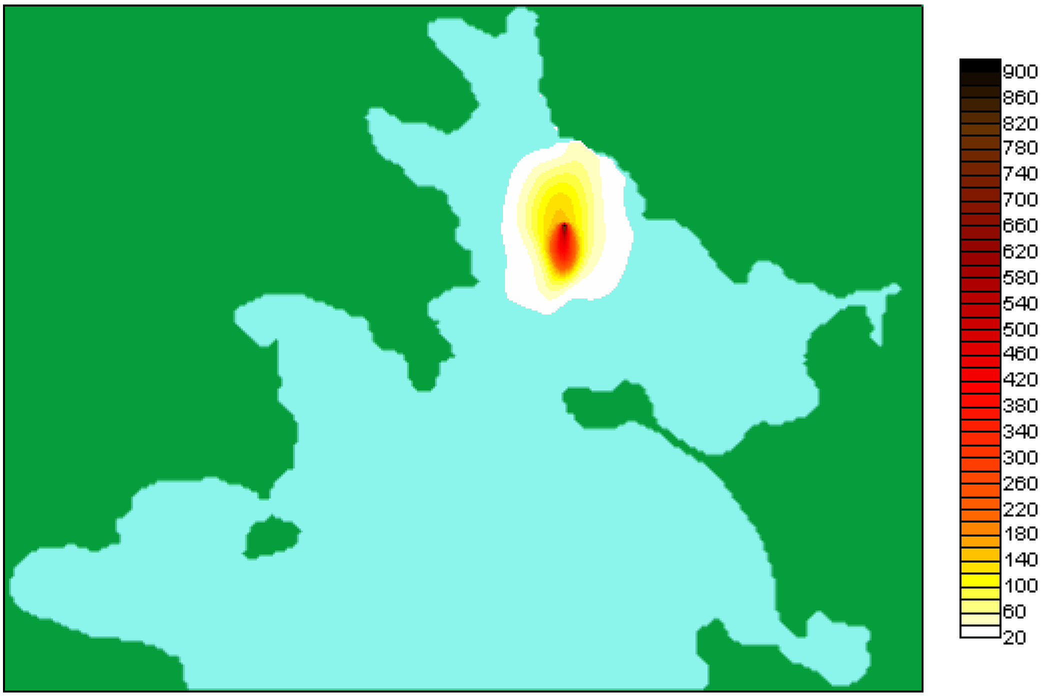



**Figure B.11- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (No wind – outer site)**



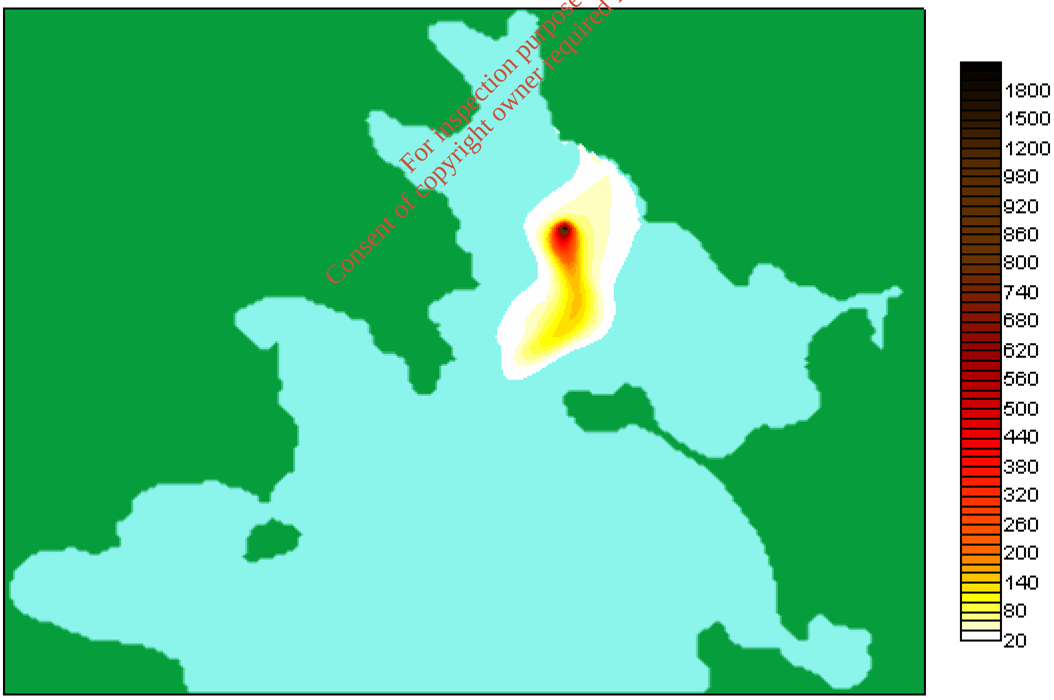



**Figure B.12- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (No wind – outer site)**


**Figure B.13- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (No wind – outer site)**



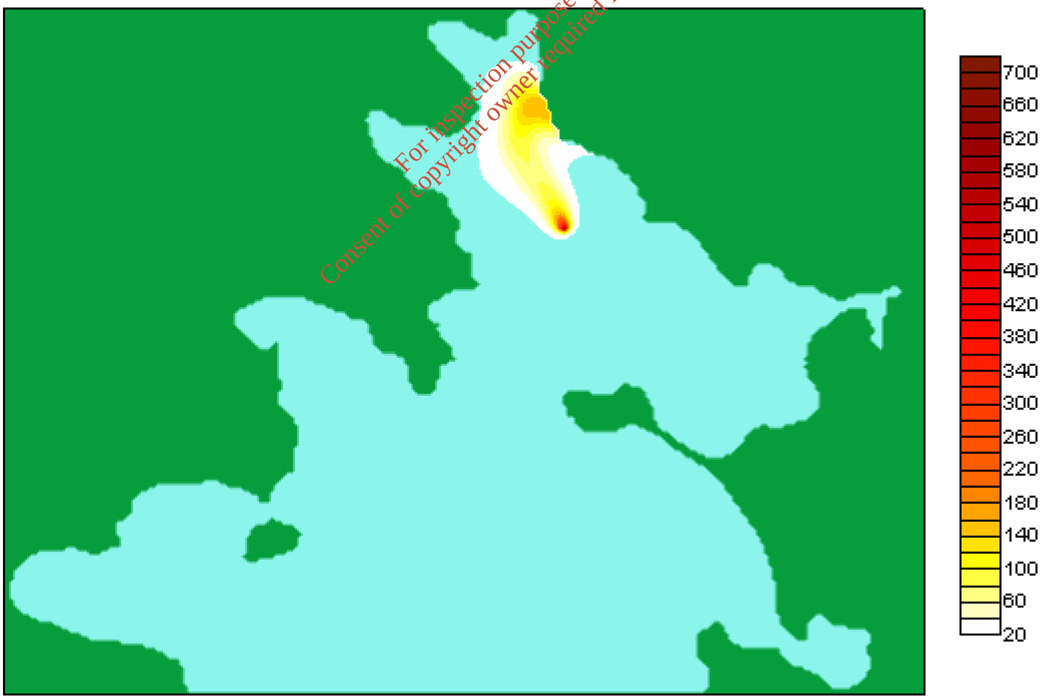



**Figure B.14- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (No wind – outer site)**


**Figure B.15- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (No wind – outer site)**

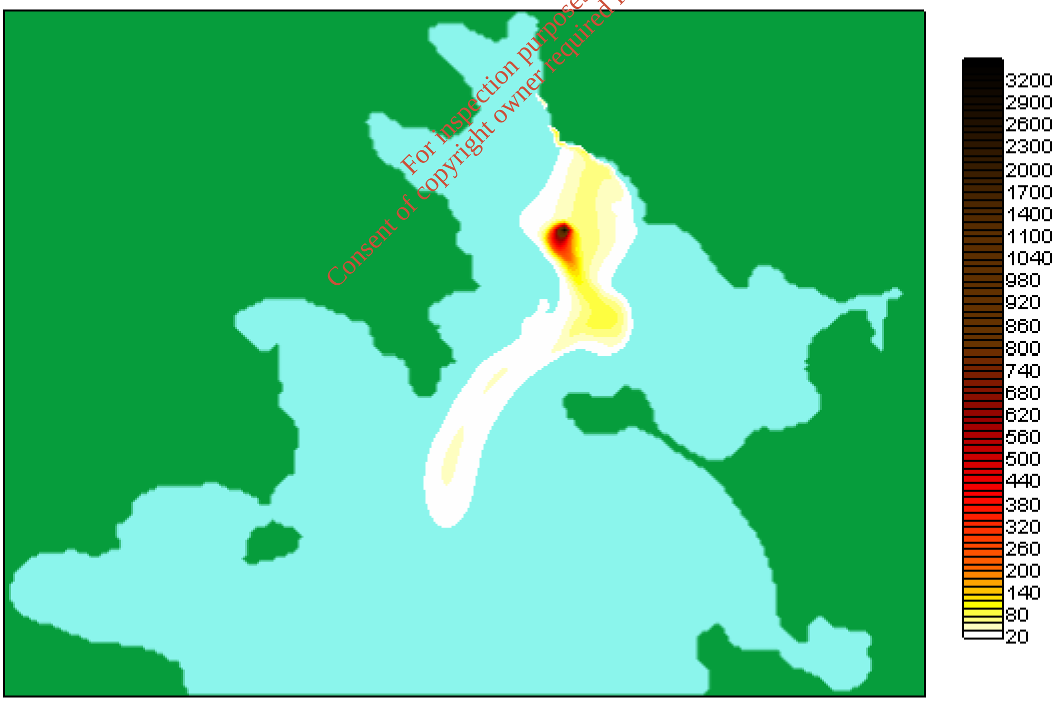



**Figure B.16- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (No wind – outer site)**

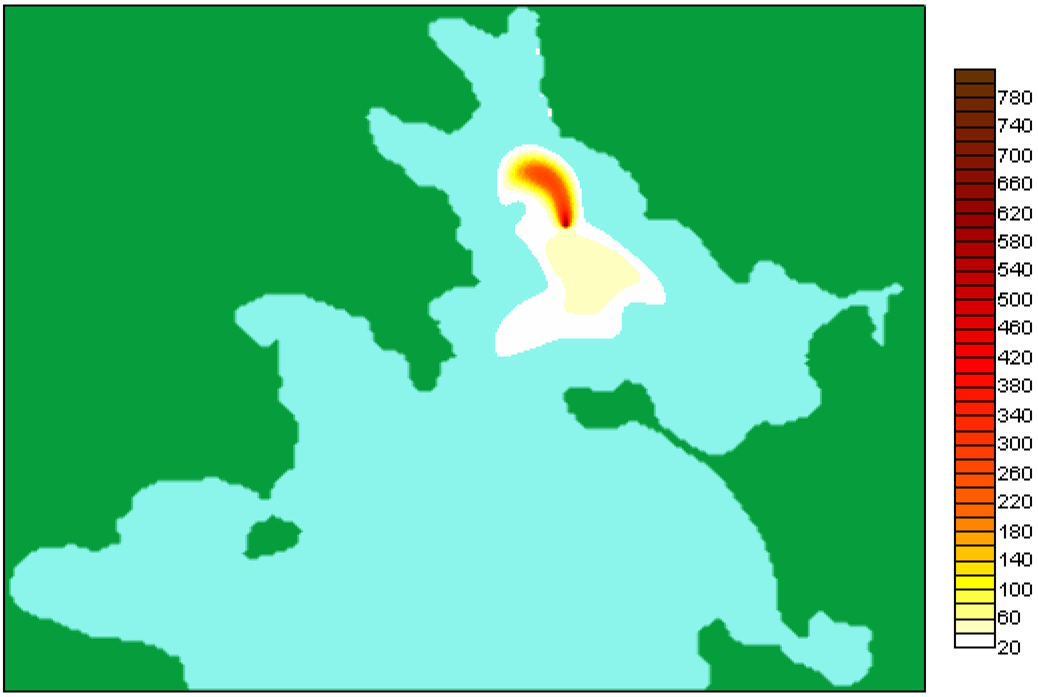



**Figure B.17- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 180 deg, speed 8.5m/s)**



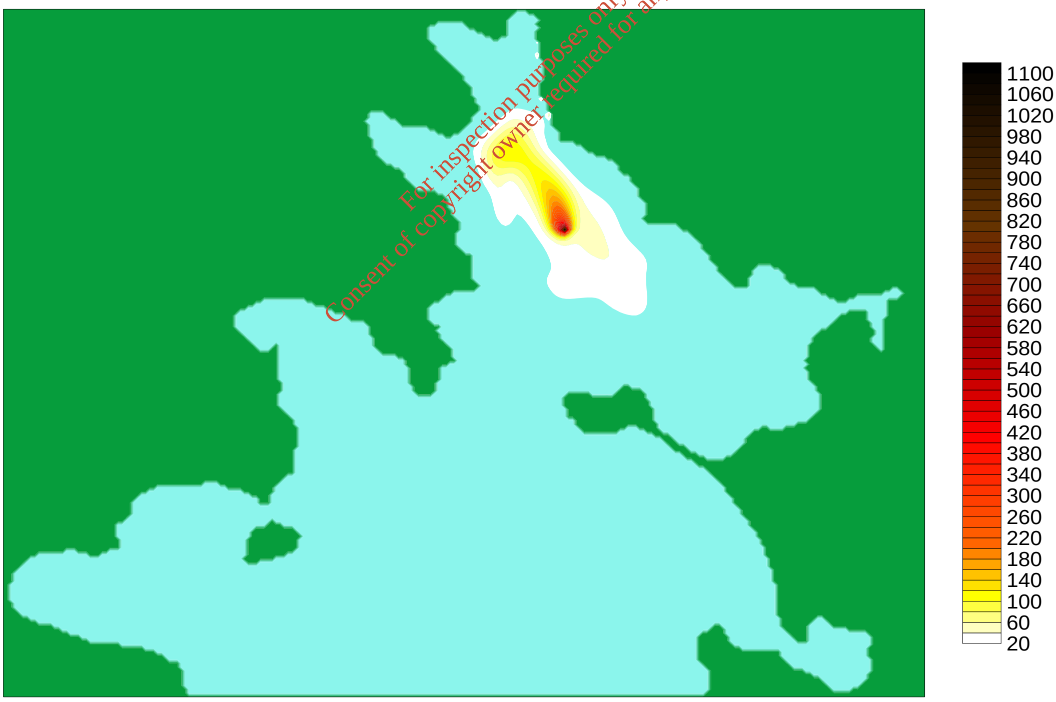



**Figure B.18- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 180 deg, speed 8.5m/s)**

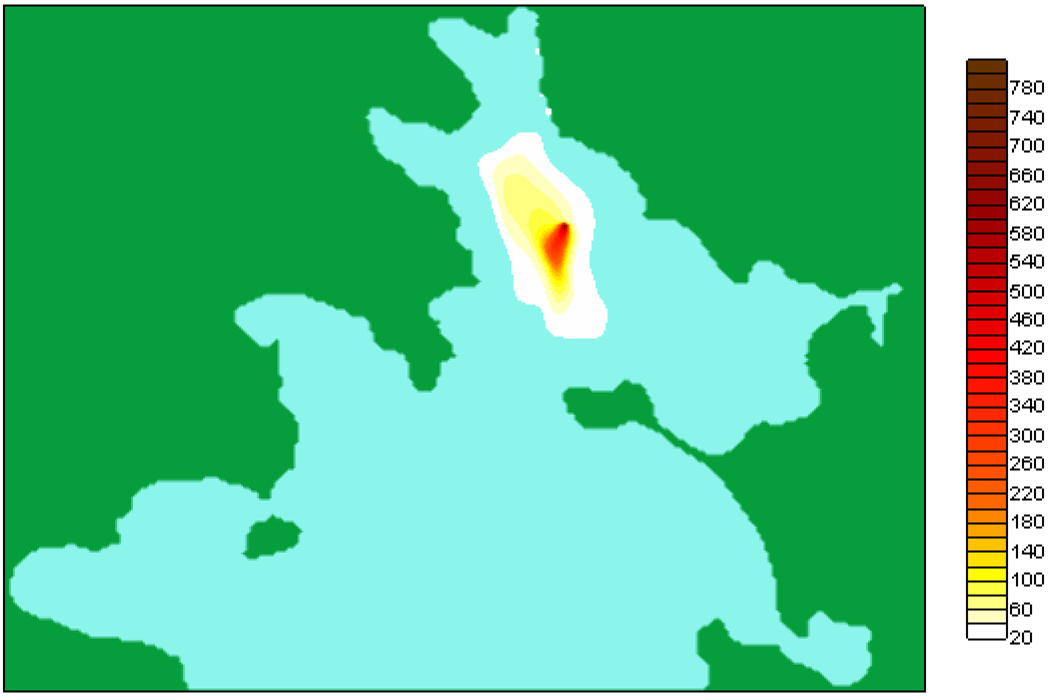



**Figure B.19- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 180 deg, speed 8.5m/s)**



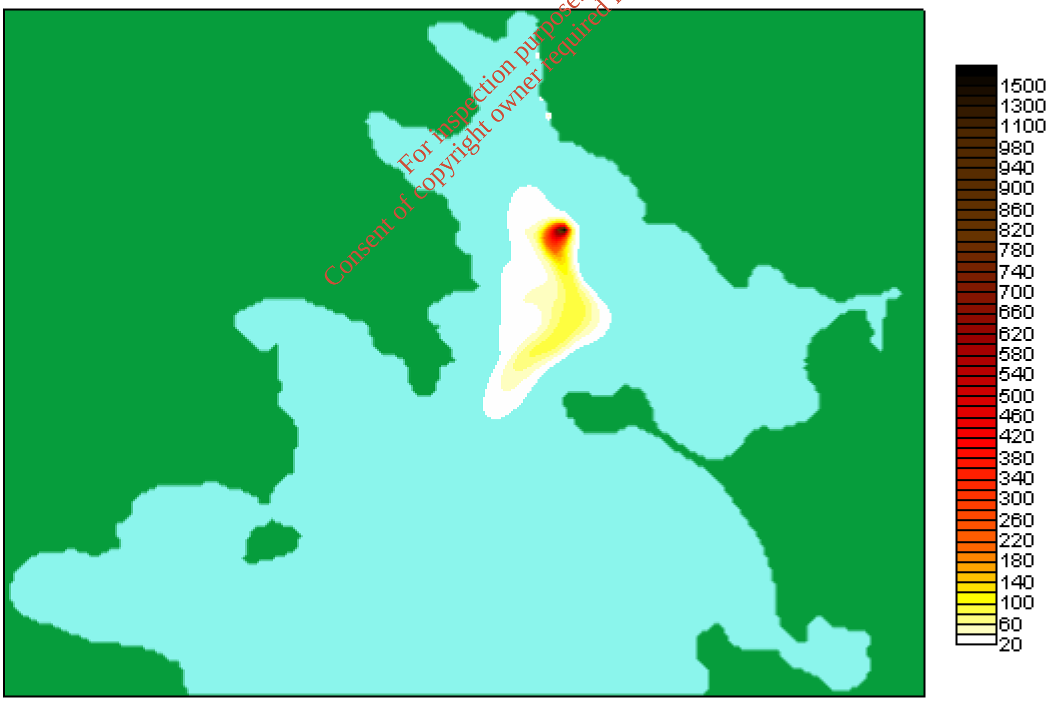



**Figure B.20- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 180 deg, speed 8.5m/s)**

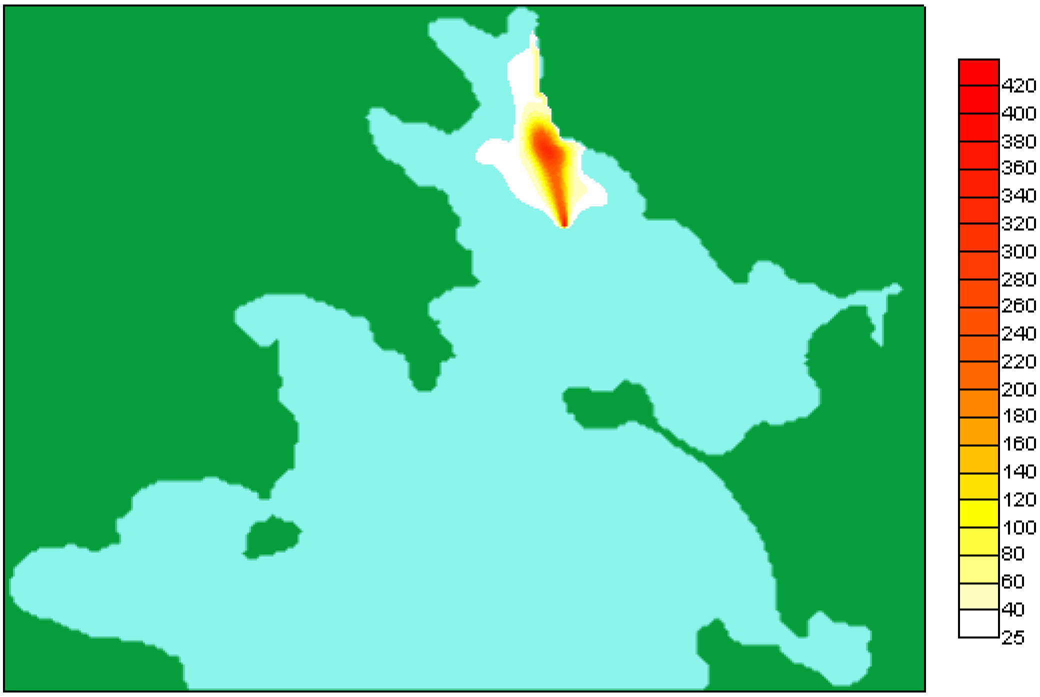



**Figure B.21- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 180 deg, speed 8.5m/s)**




**Figure B.22- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 180 deg, speed 8.5m/s)**

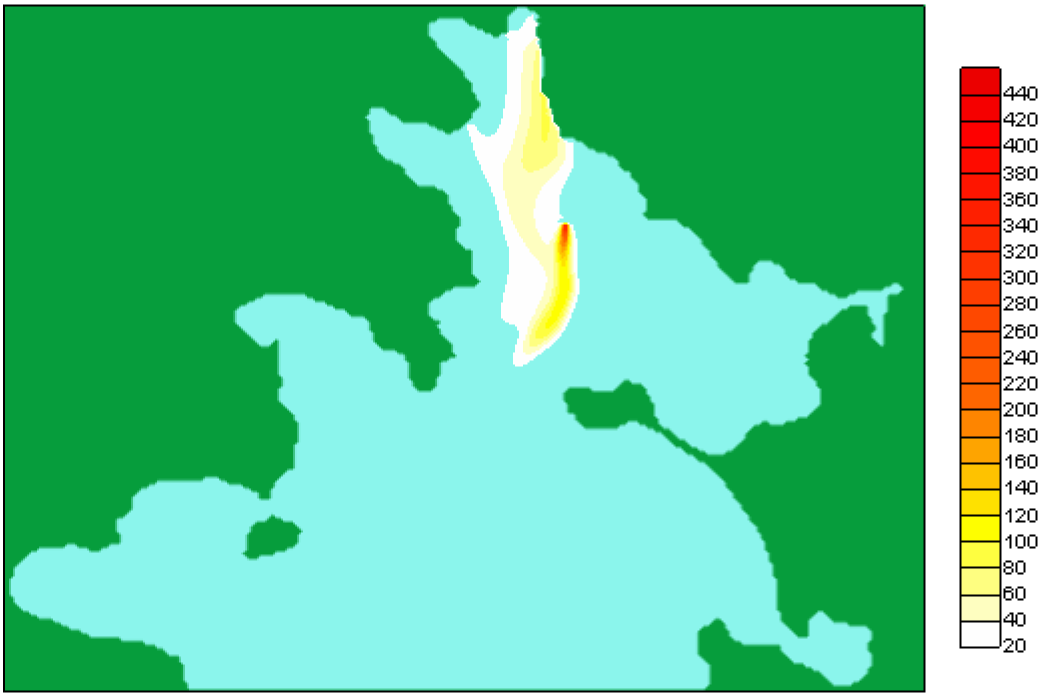



**Figure B.23- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 180 deg, speed 8.5m/s)**



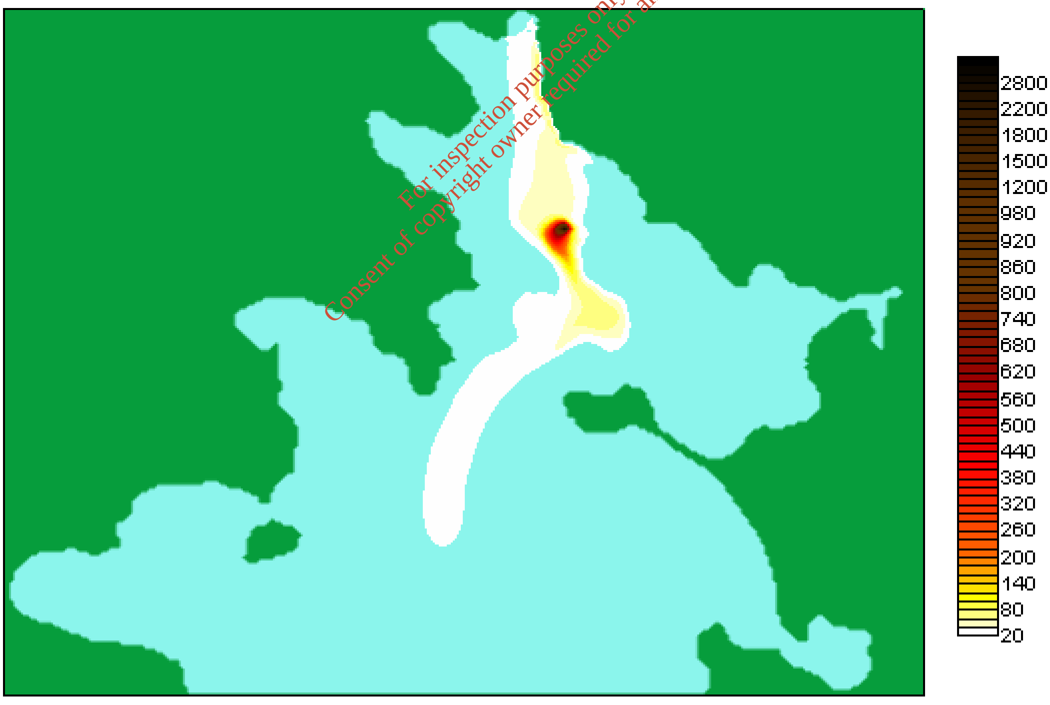



**Figure B.24- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 180 deg, speed 8.5m/s)**


**Figure B.25- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 180 deg, speed 18.5m/s)**



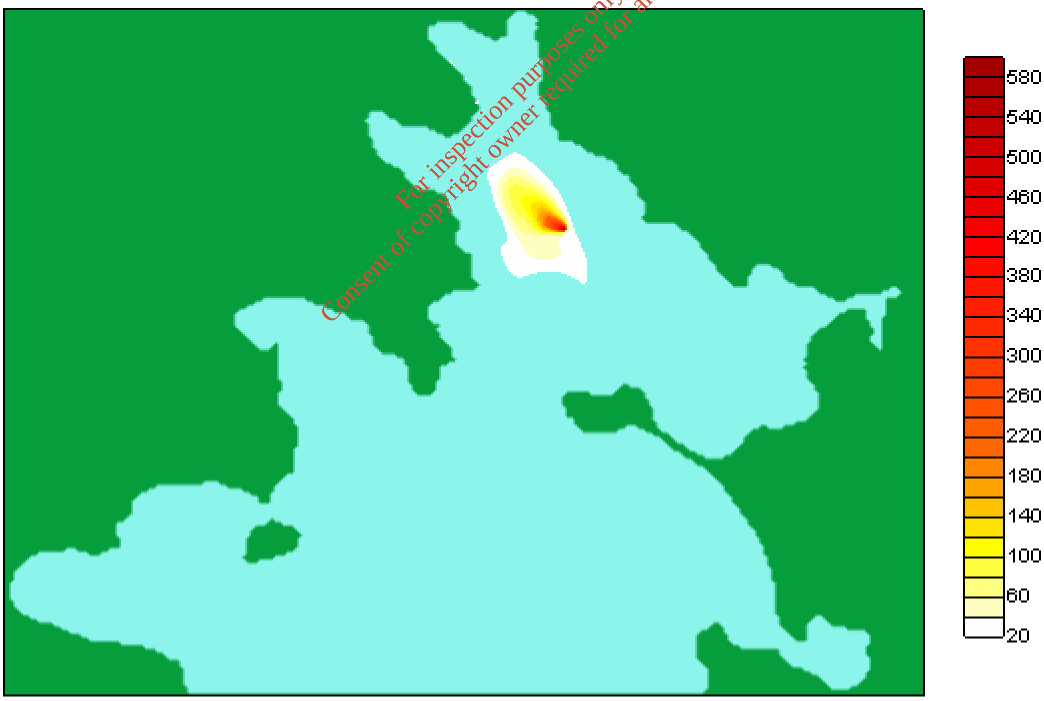



**Figure B.26- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 180 deg, speed 18.5m/s)**


**Figure B.27- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 180 deg, speed 18.5m/s)**



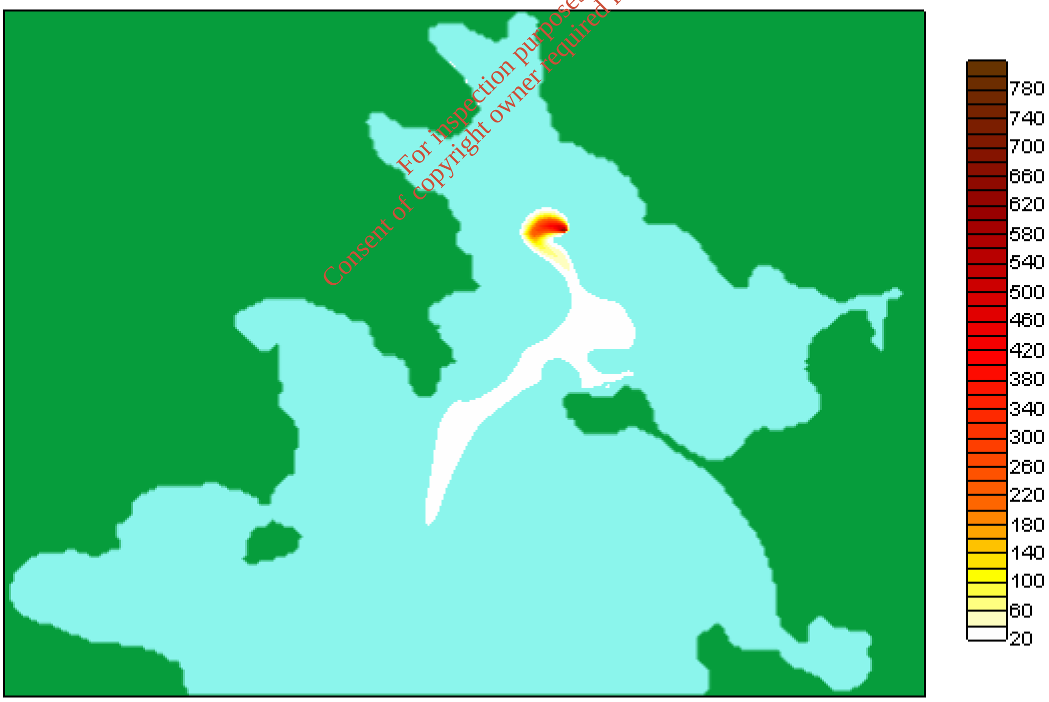



**Figure B.28- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 180 deg, speed 18.5m/s)**


**Figure B.29- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 180 deg, speed 18.5m/s)**



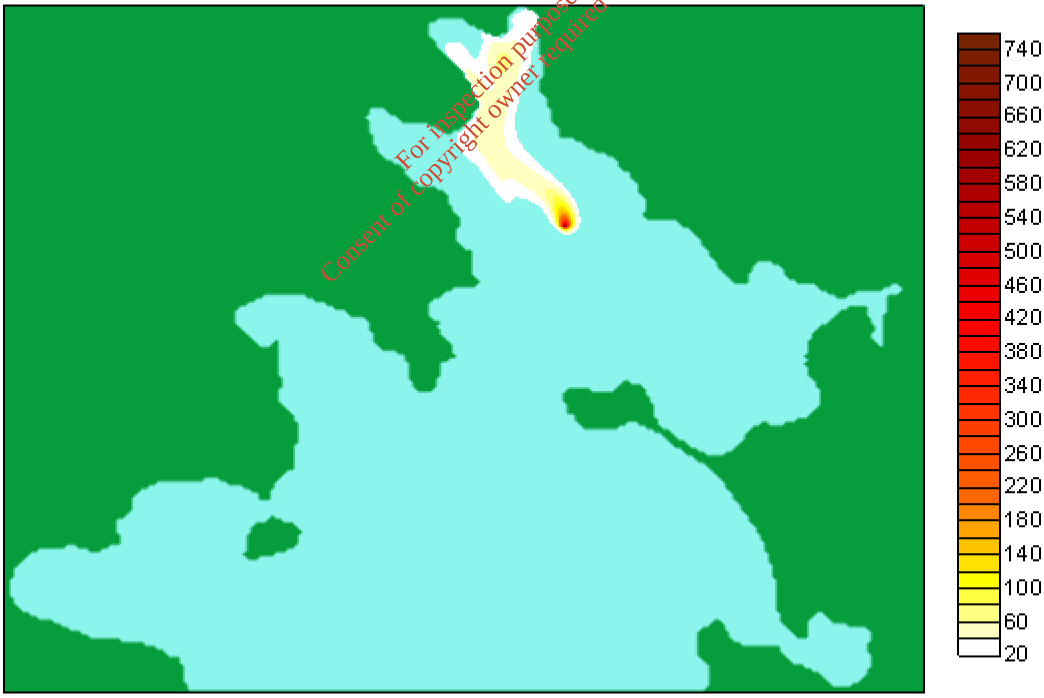



**Figure B.30- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 180 deg, speed 18.5m/s)**


**Figure B.31- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 180 deg, speed 18.5m/s)**




**Figure B.32- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 180 deg, speed 18.5m/s)**

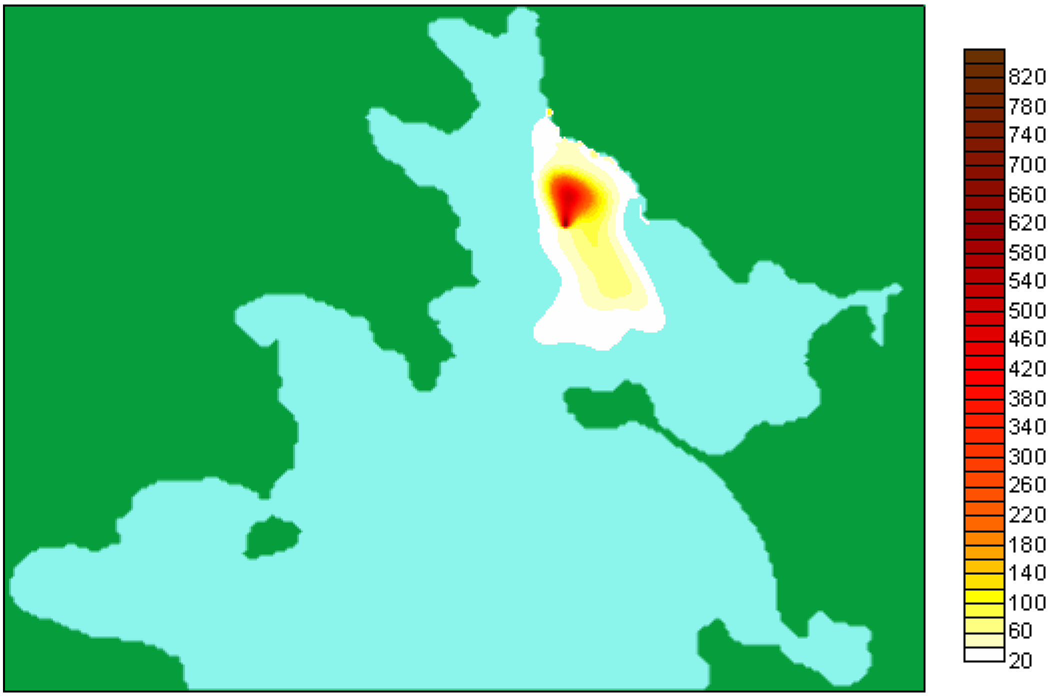



**Figure B.33- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 225 deg, speed 8.3m/s)**



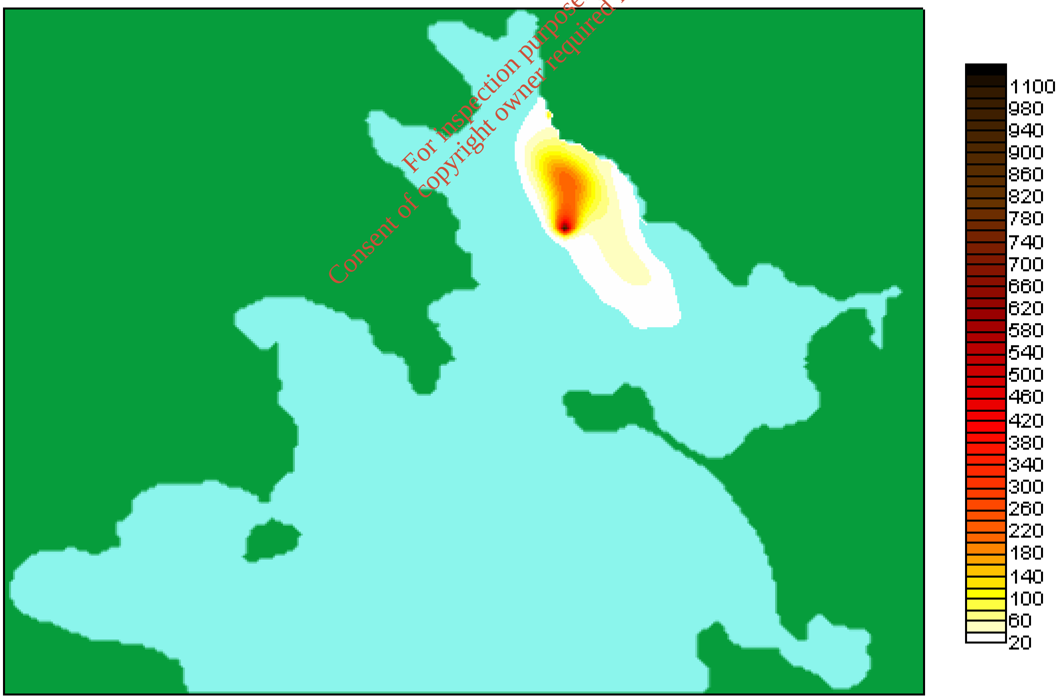



**Figure B.34- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 225 deg, speed 8.3m/s)**

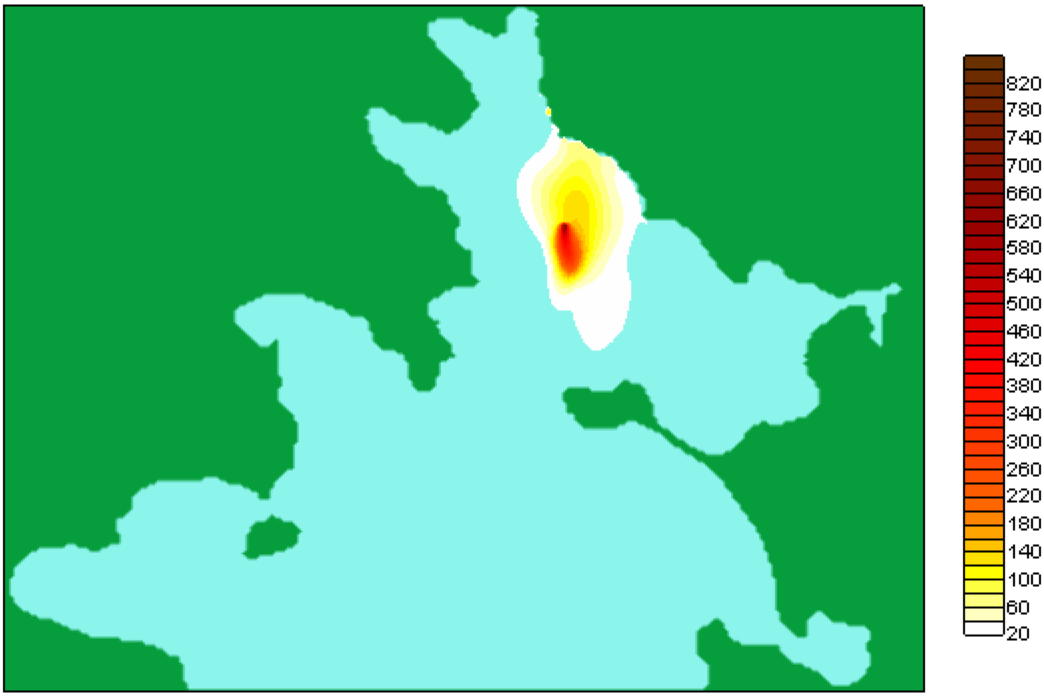



**Figure B.35- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 225 deg, speed 8.3m/s)**



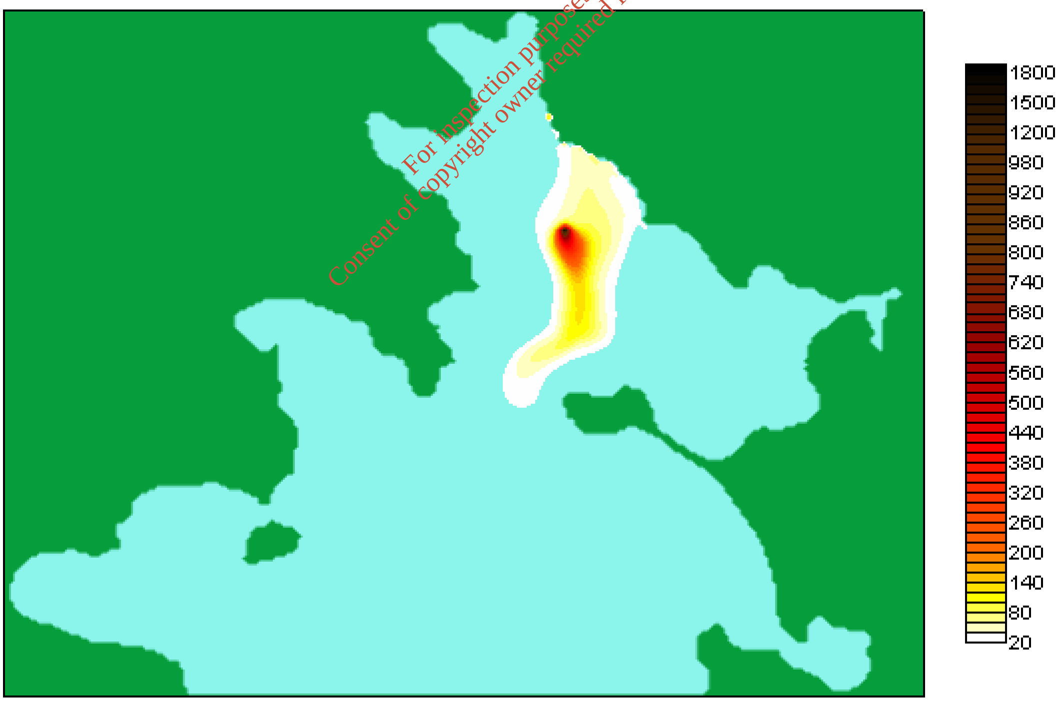



**Figure B.36- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 225 deg, speed 8.3m/s)**

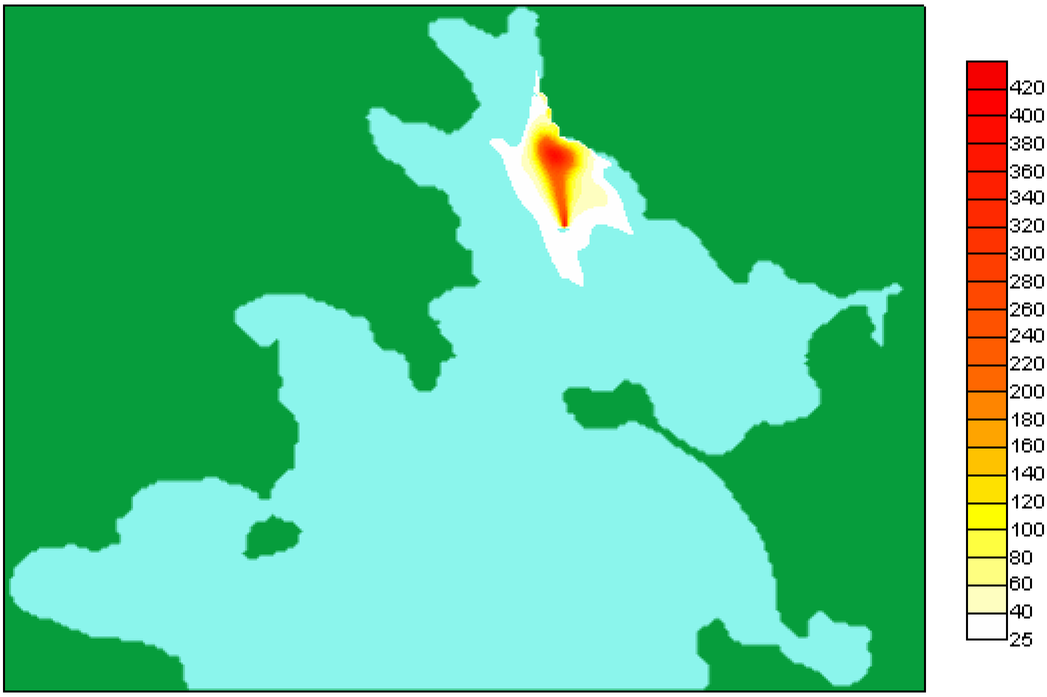



**Figure B.37- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 225 deg, speed 8.3m/s)**



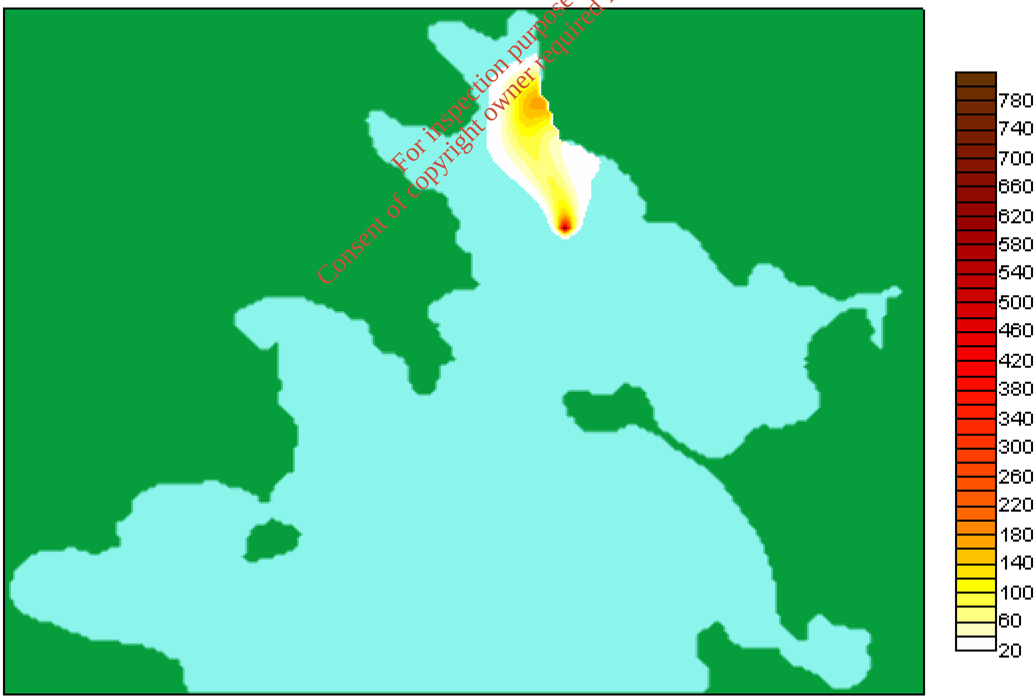



**Figure B.38- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 225 deg, speed 8.3m/s)**


**Figure B.39- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 225 deg, speed 8.3m/s)**



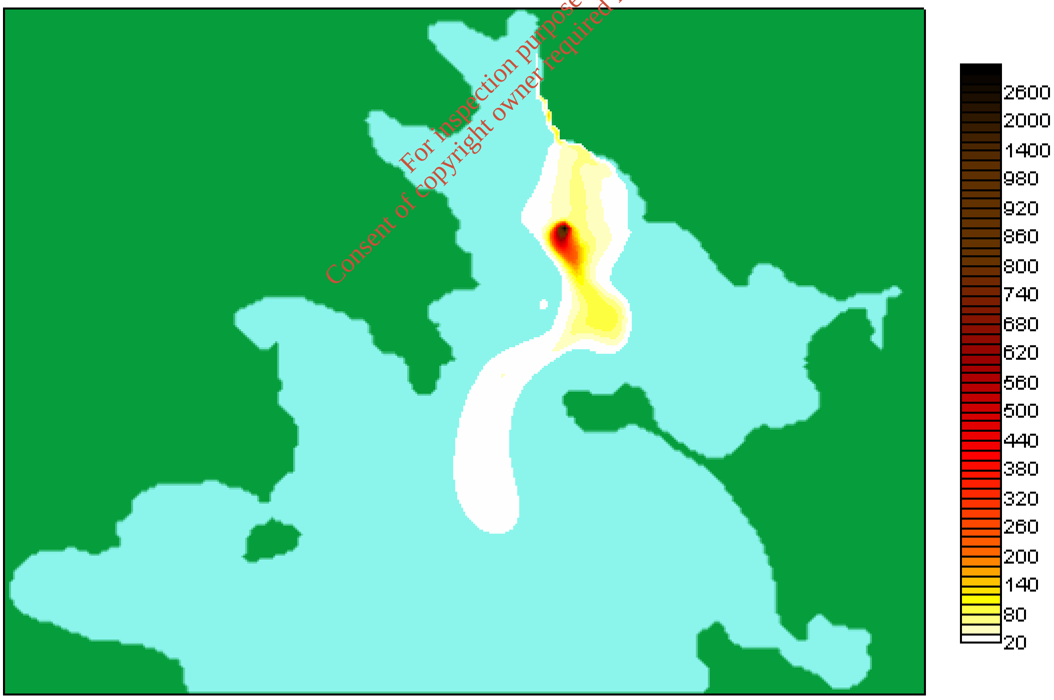



**Figure B.40- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 225 deg, speed 8.3m/s)**


**Figure B.41- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 225 deg, speed 18.5m/s)**



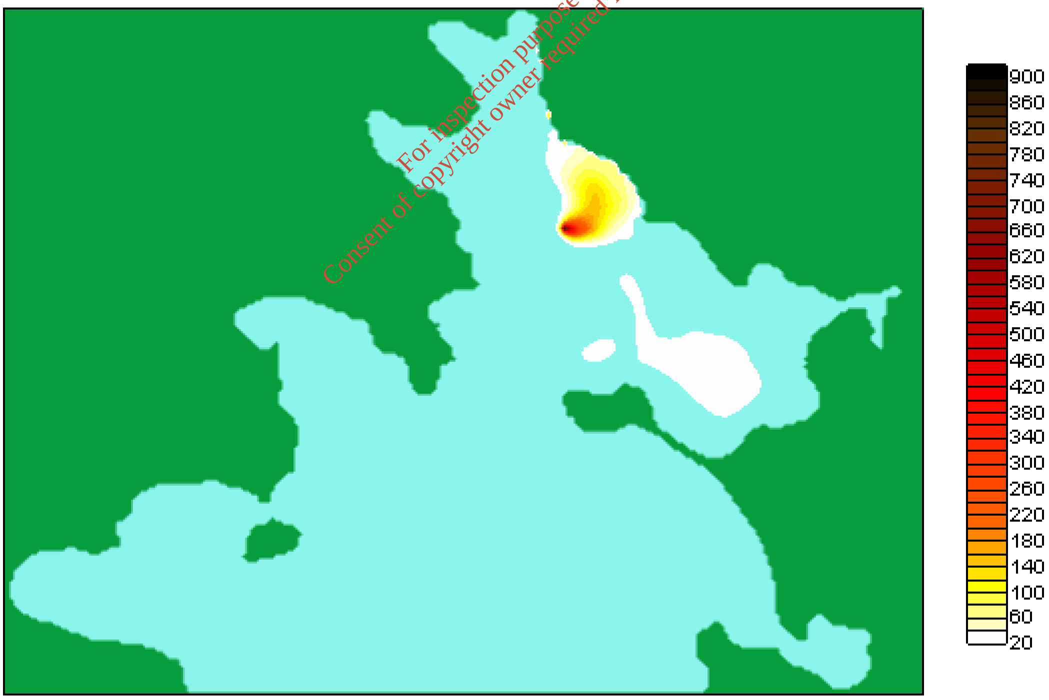



**Figure B.42- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 225 deg, speed 18.5m/s)**


**Figure B.43- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 225 deg, speed 18.5m/s)**



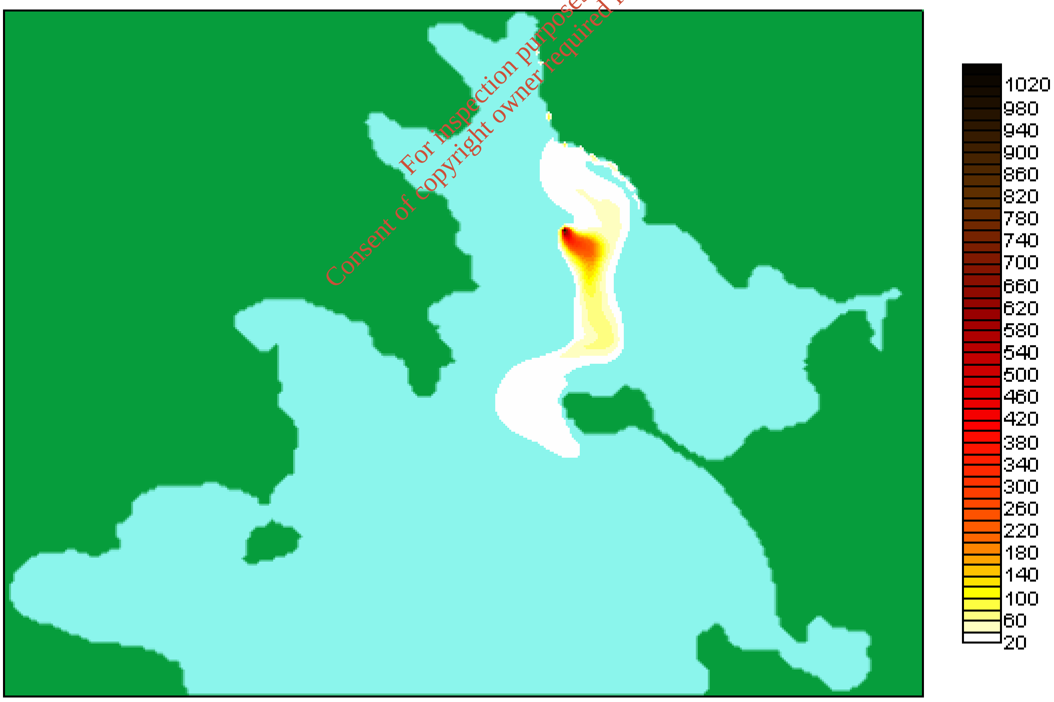



**Figure B.44- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 225 deg, speed 18.5m/s)**

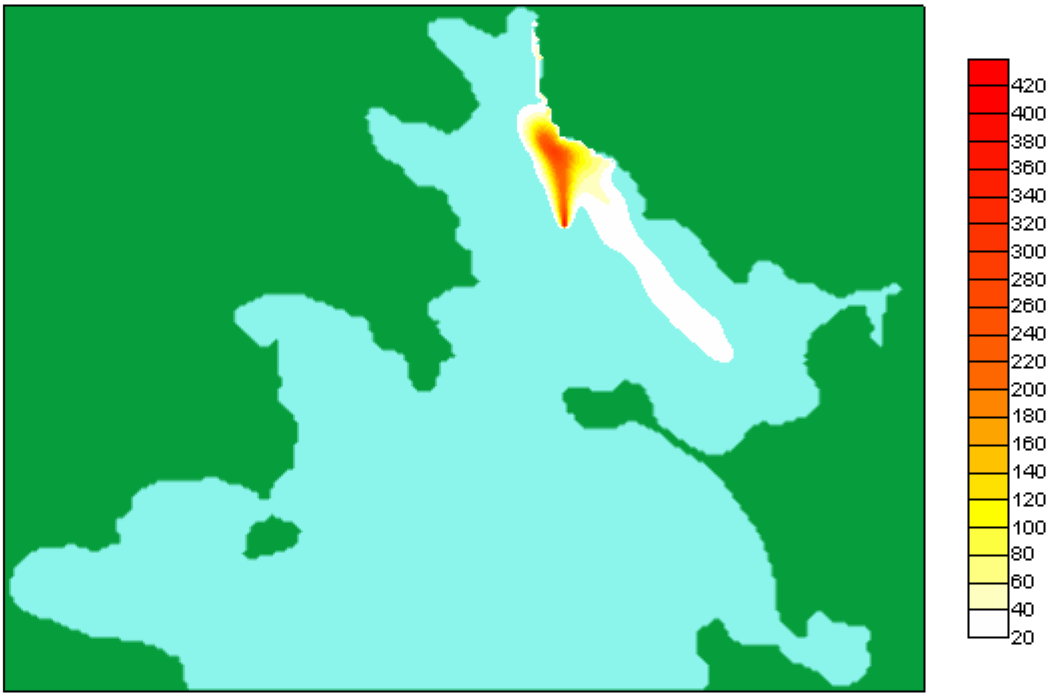



**Figure B.45- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 225 deg, speed 18.5m/s)**




**Figure B.46- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 225 deg, speed 18.5m/s)**

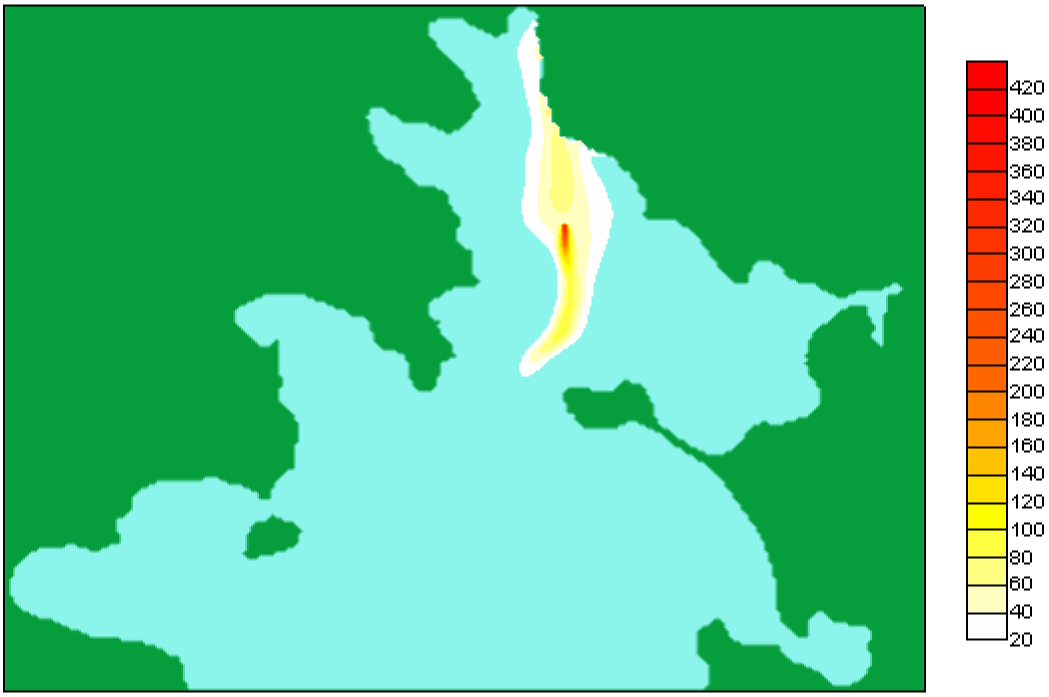



**Figure B.47- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 225 deg, speed 18.5 m/s)**



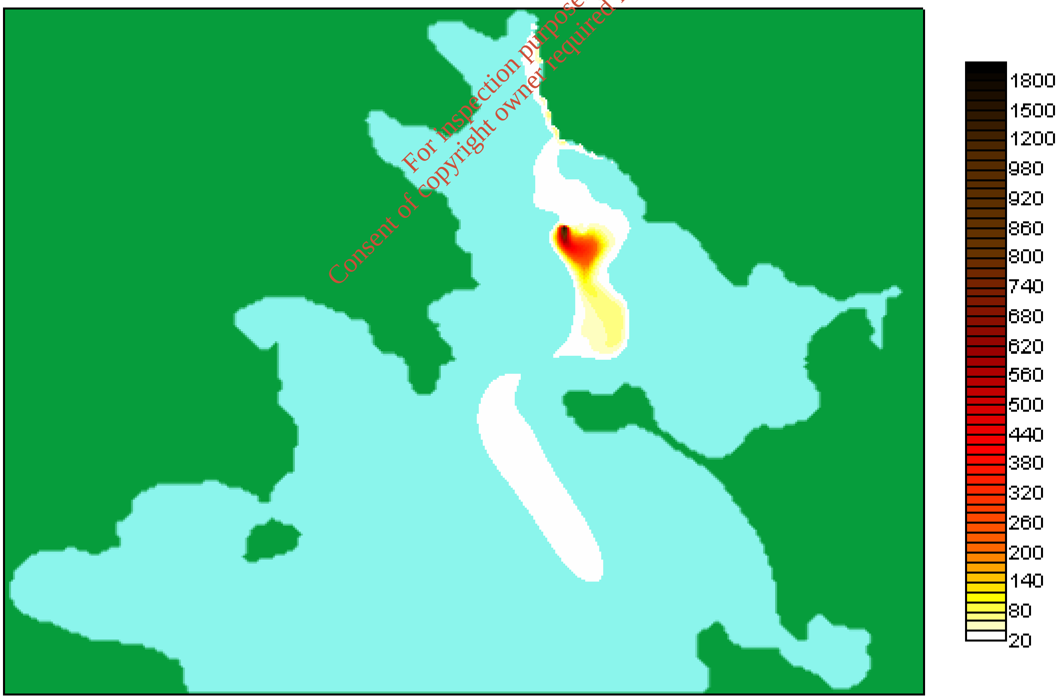



**Figure B.48- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 225 deg, speed 18.5m/s)**

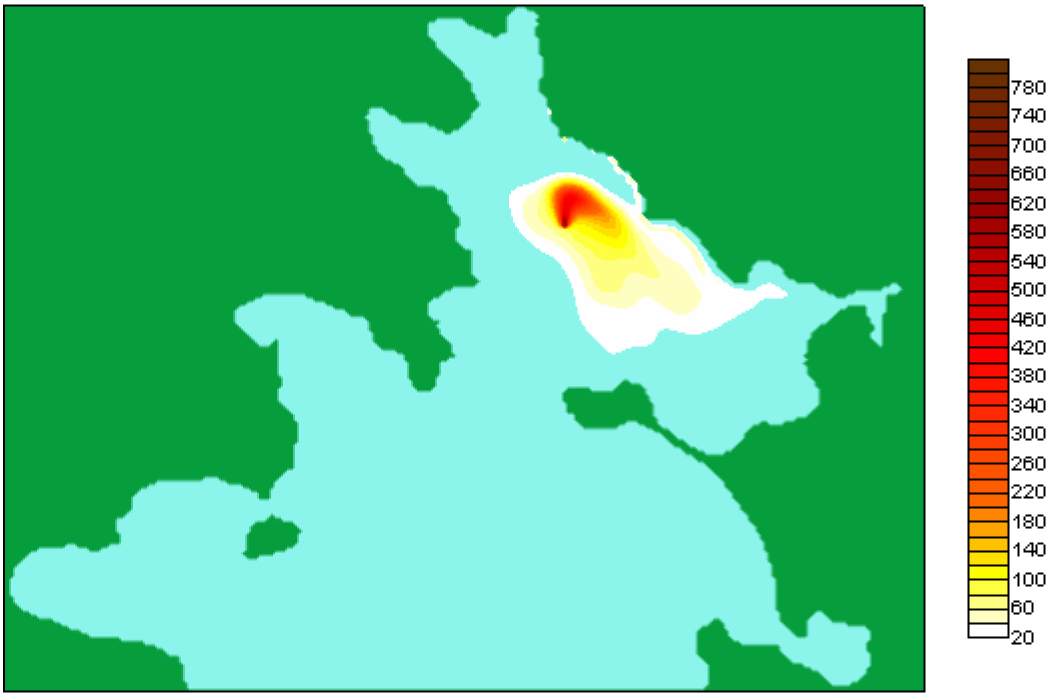



**Figure B.49- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 270 deg, speed 7.5m/s)**



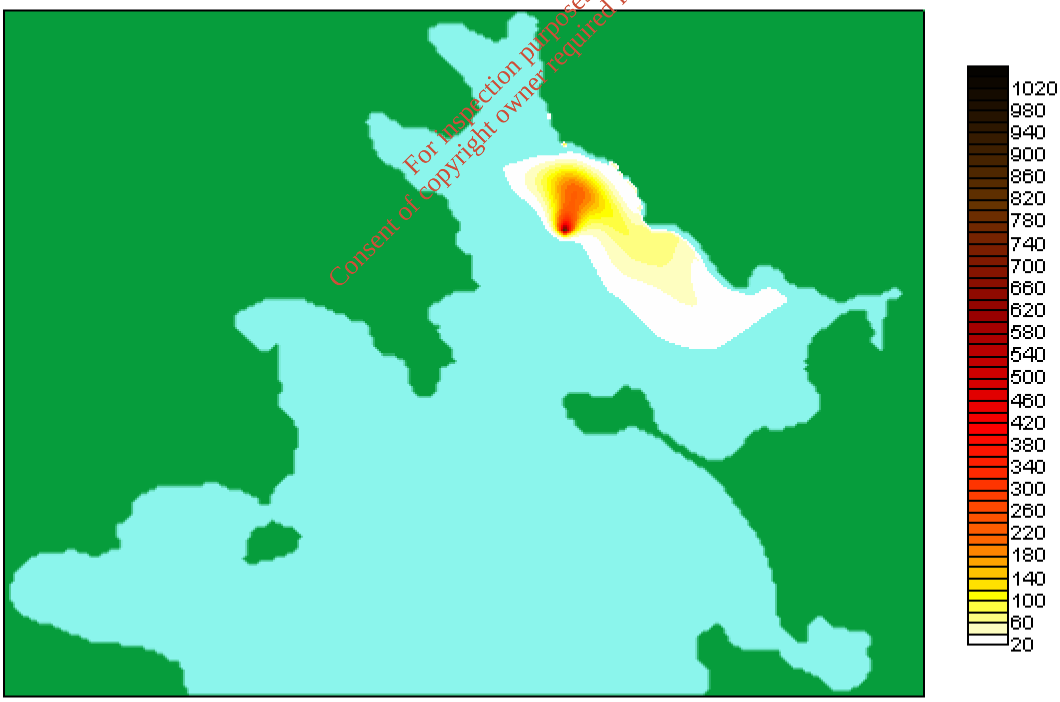



**Figure B.50- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 270 deg, speed 7.5m/s)**

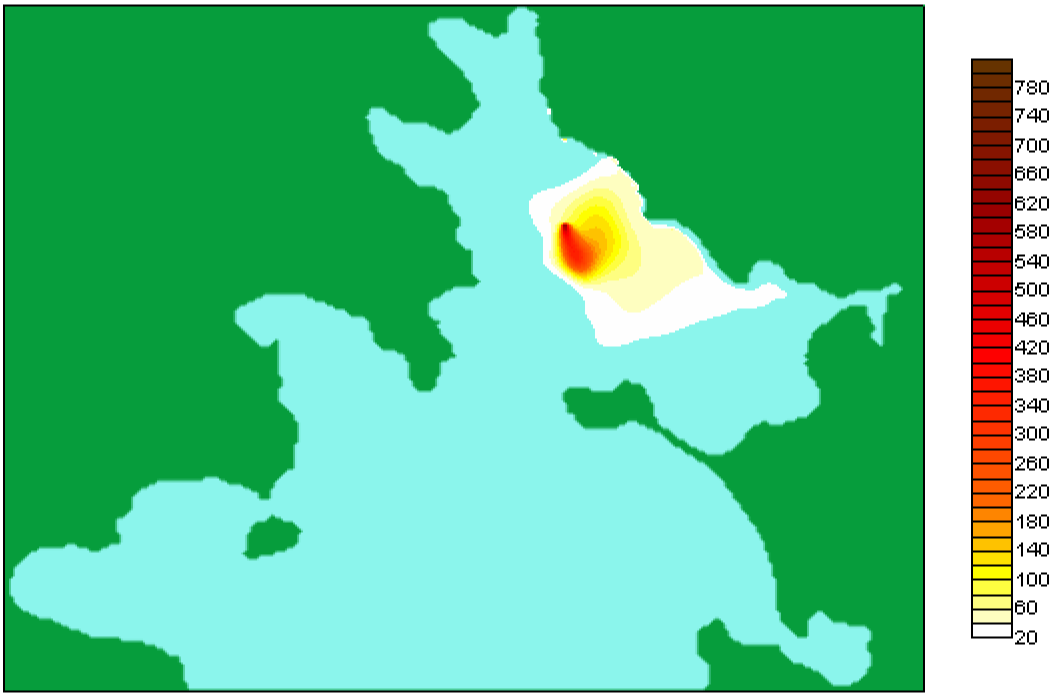



**Figure B.51- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 270 deg, speed 7.5m/s)**



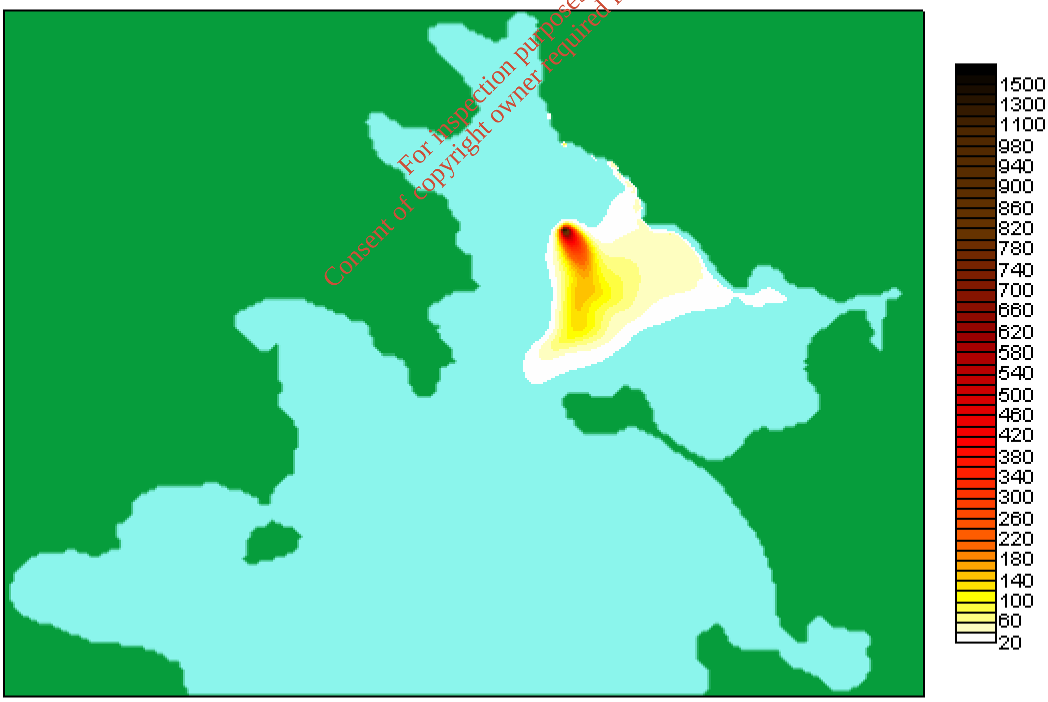



**Figure B.52- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 270 deg, speed 7.5m/s)**

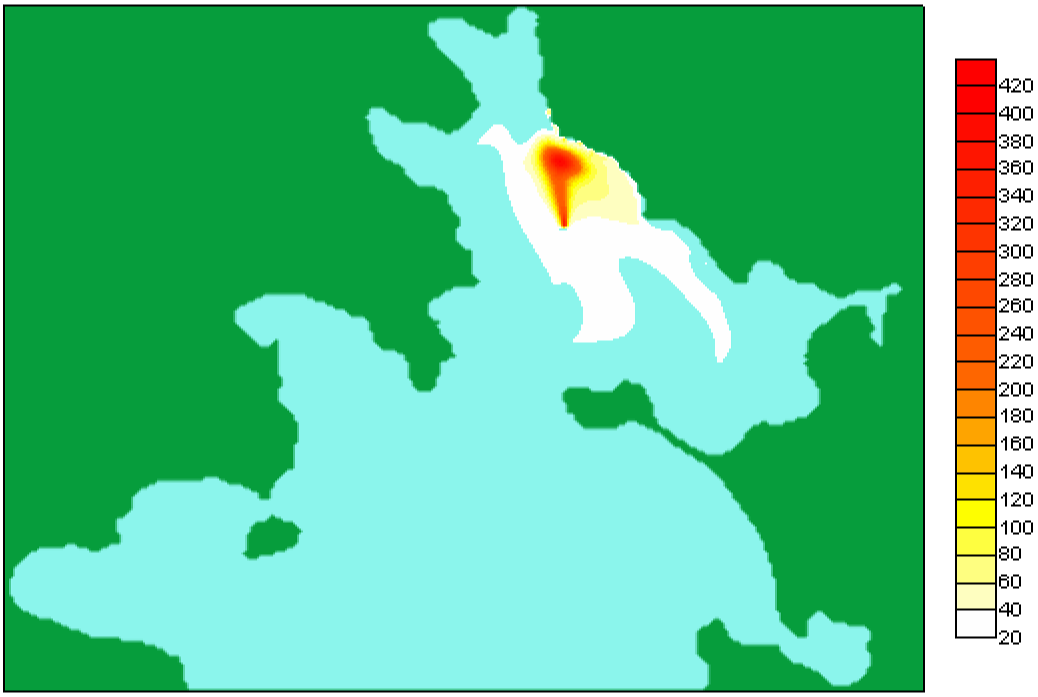



**Figure B.53- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 270 deg, speed 7.5m/s)**



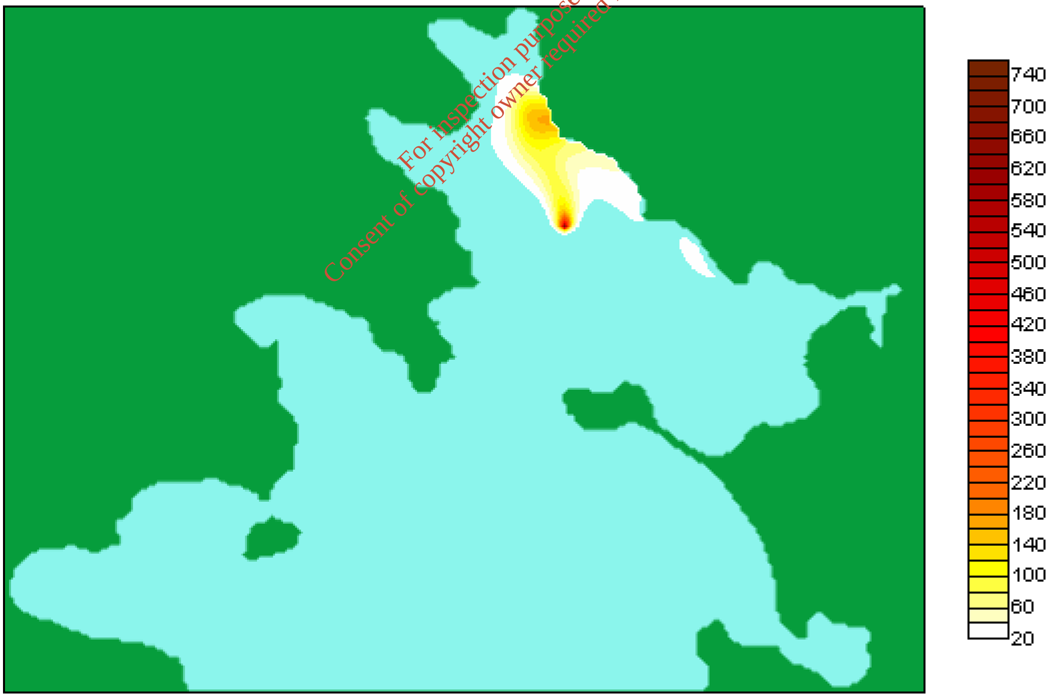



**Figure B.54- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 270 deg, speed 7.5m/s)**


**Figure B.55- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 270 deg, speed 7.5m/s)**



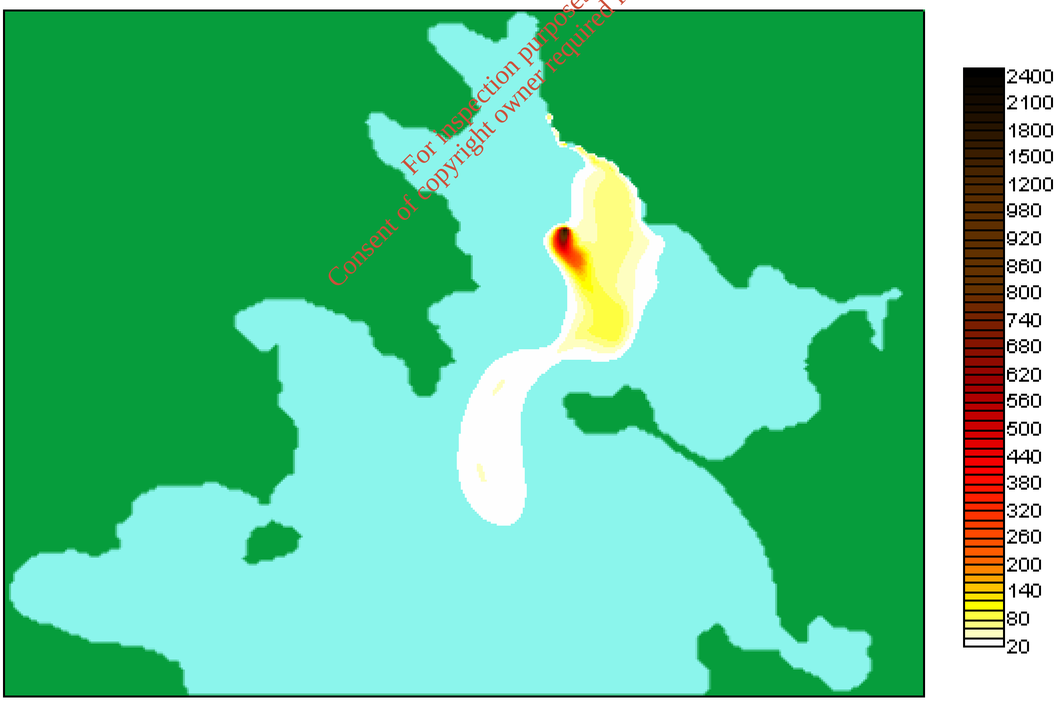



**Figure B.56- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 270 deg, speed 7.5m/s)**


**Figure B.57- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (Wind direction 270 deg, speed 15.5m/s)**



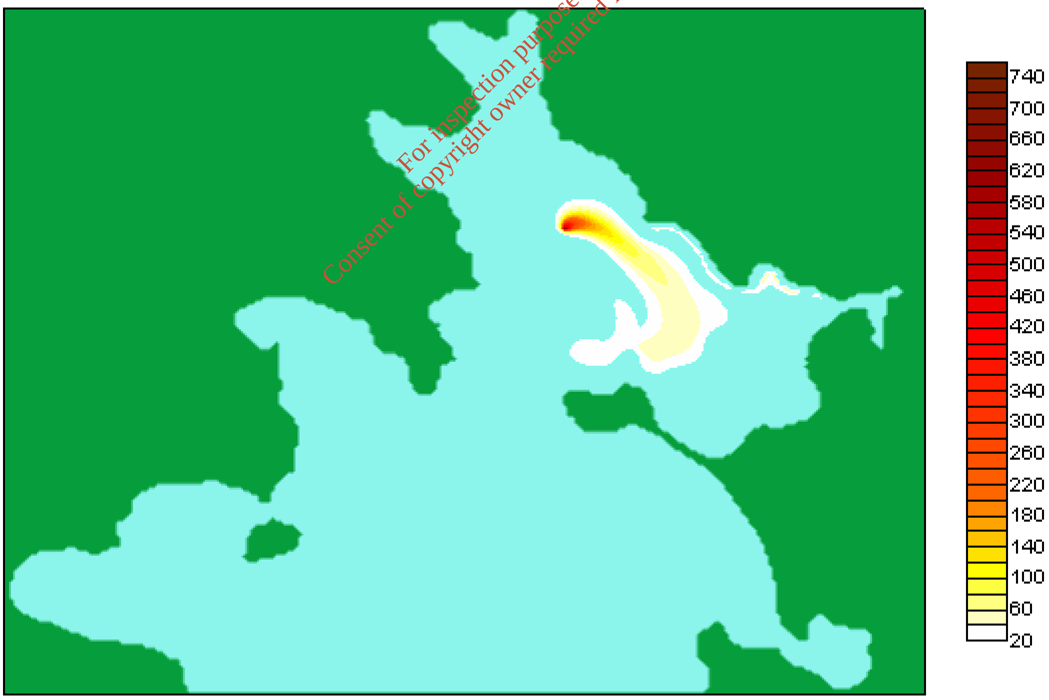



**Figure B.58- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (Wind direction 270 deg, speed 15.5m/s)**


**Figure B.59- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (Wind direction 270 deg, speed 15.5m/s)**




**Figure B.60- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (Wind direction 270 deg, speed 15.5m/s)**

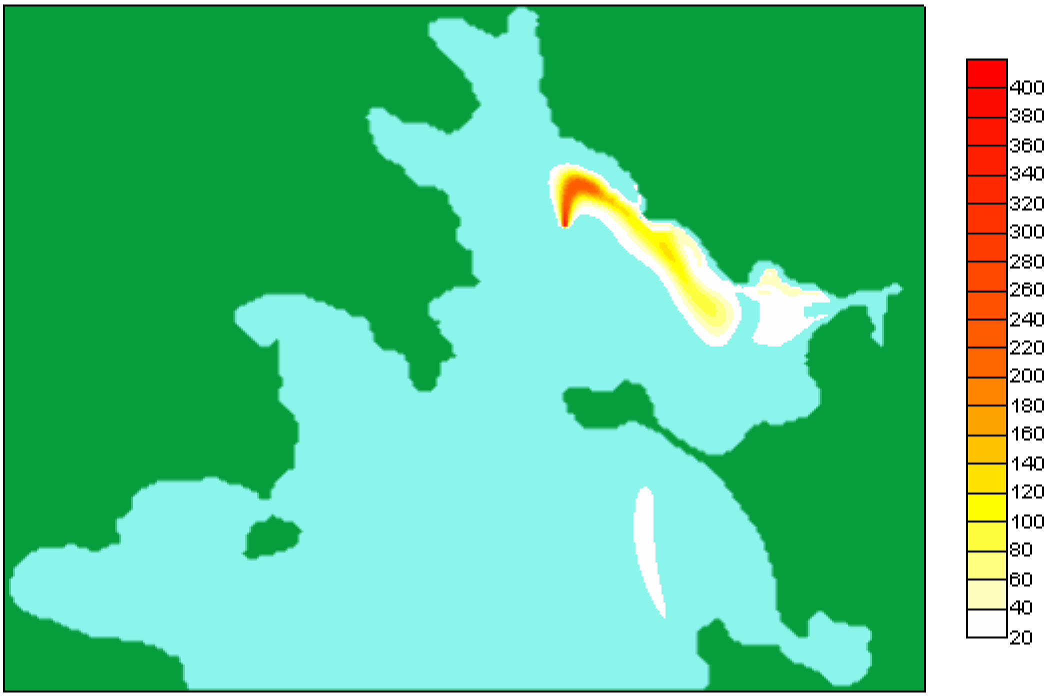



**Figure B.61- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (Wind direction 270 deg, speed 15.5m/s)**




**Figure B.62- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (Wind direction 270 deg, speed 15.5m/s)**

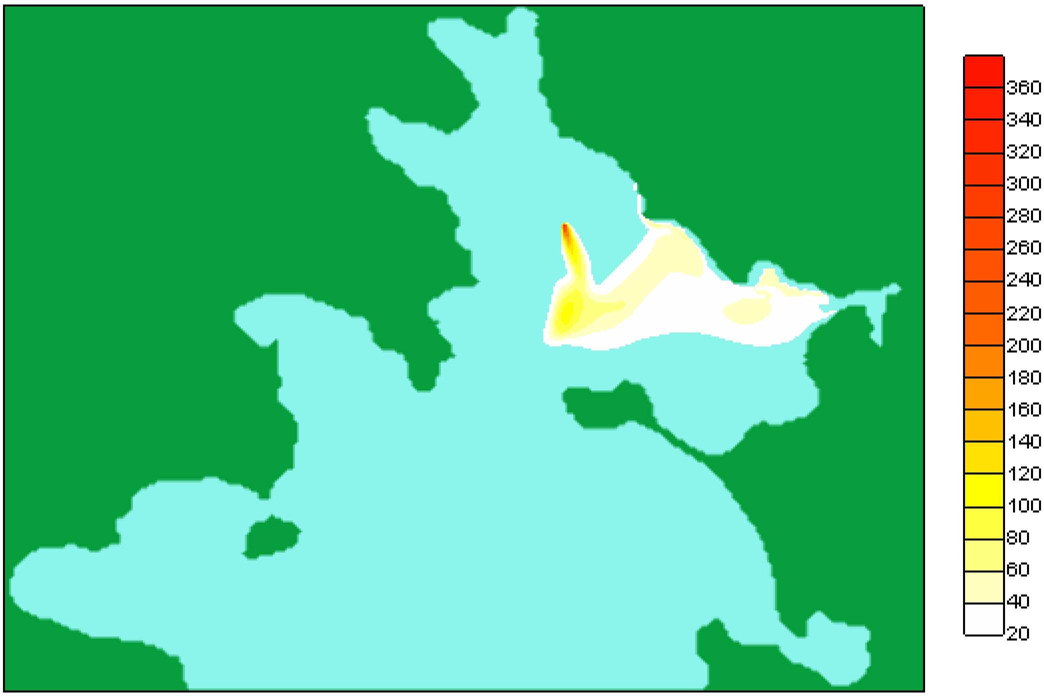



**Figure B.63- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (Wind direction 270 deg, speed 15.5m/s)**



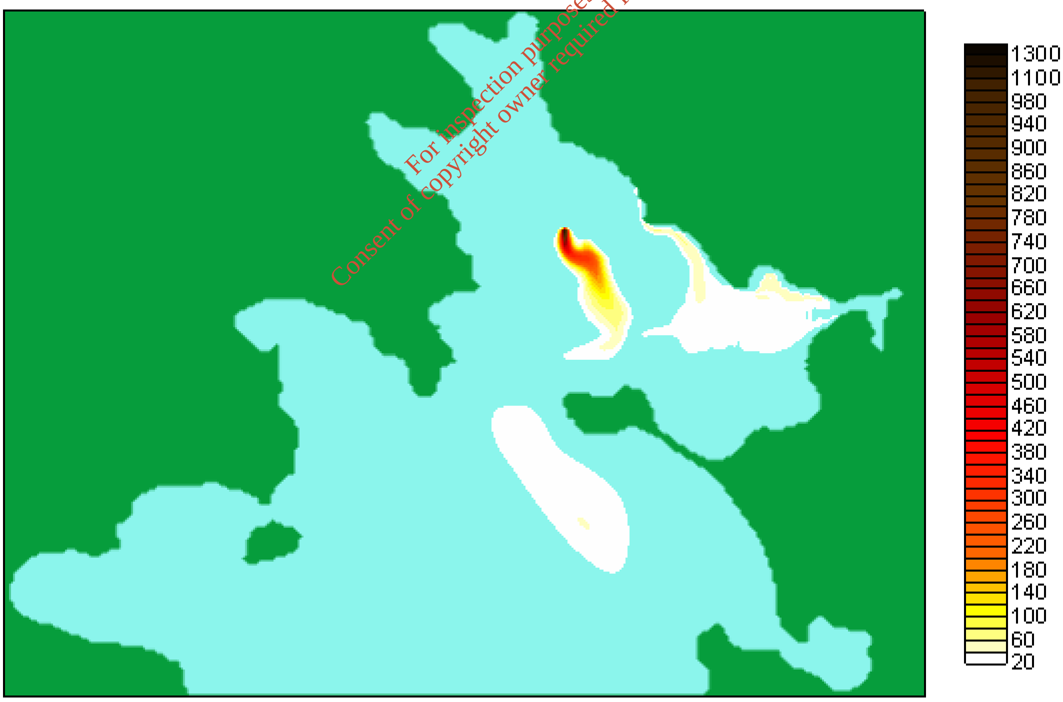



**Figure B.64- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (Wind direction 270 deg, speed 15.5m/s)**

# Section C

## Faecal coliform concentration in effluent = $2x10^5$ number/100ml

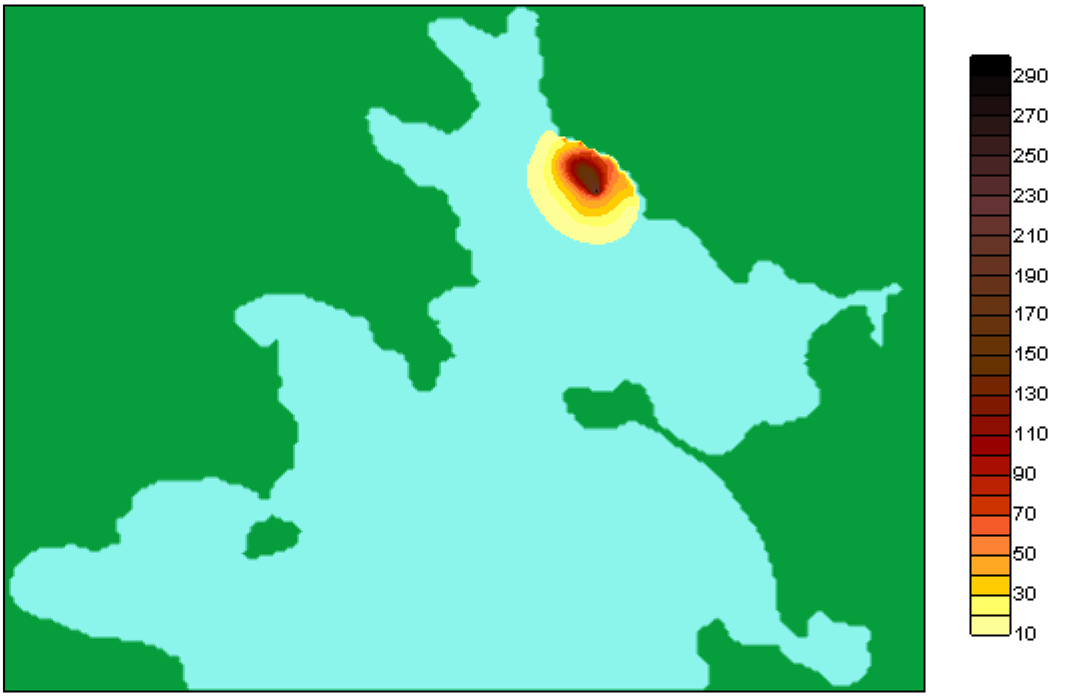



**Figure C.1- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (No wind – inner site)**



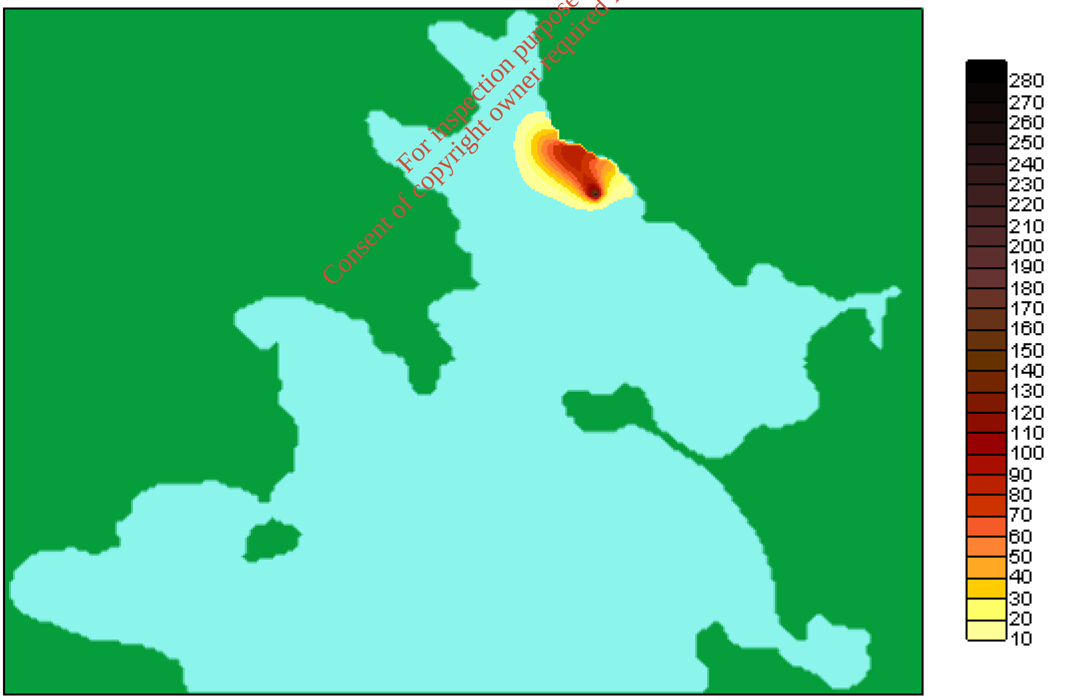



**Figure C.2- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (No wind – inner site)**

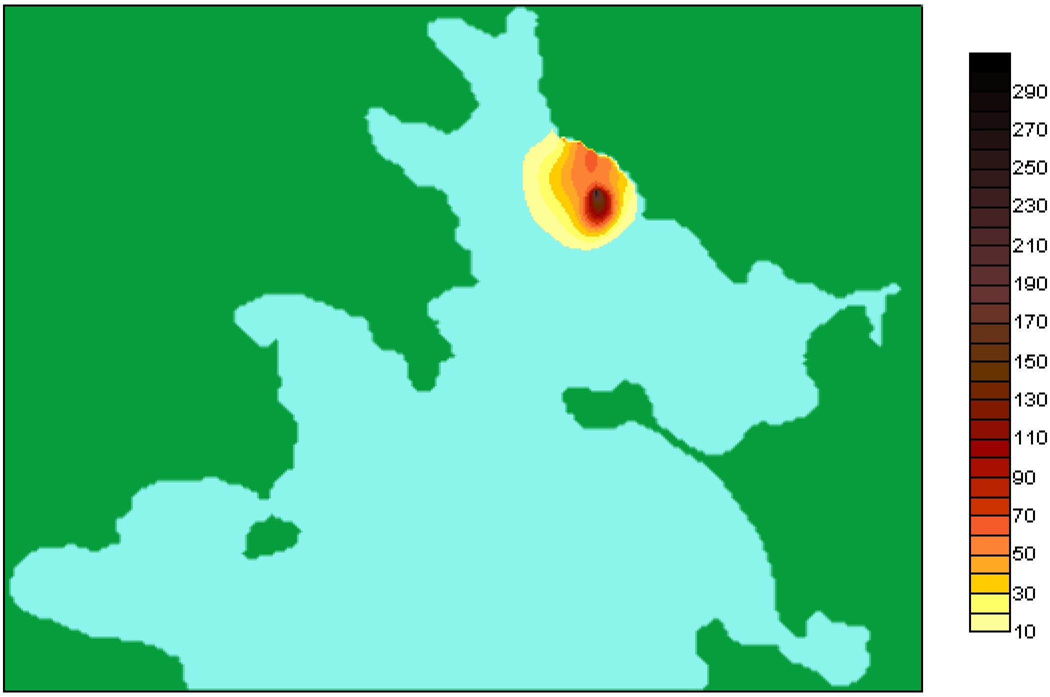



**Figure C.3- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (No wind – inner site)**



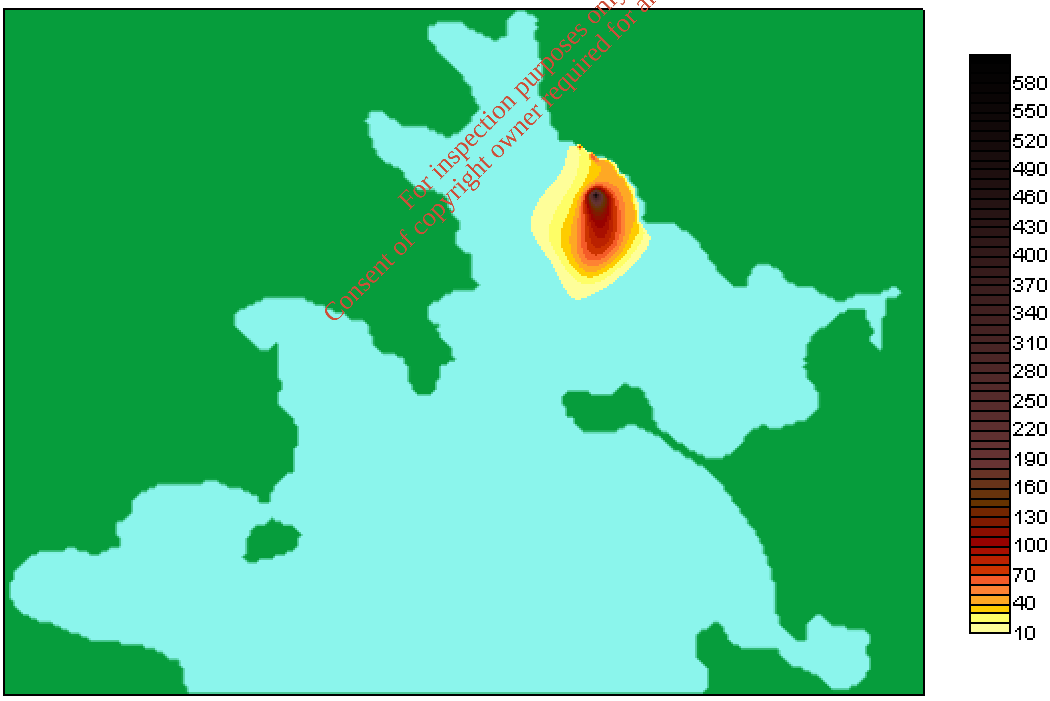



**Figure C.4- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (No wind – inner site)**

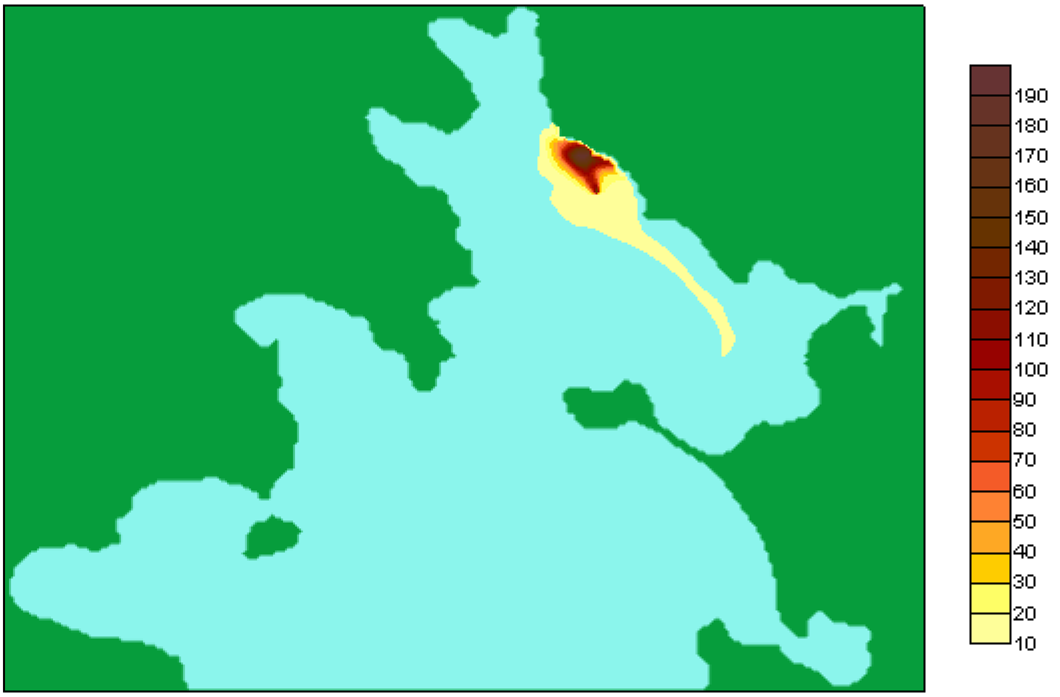



**Figure C.5- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (No wind – inner site)**


**Figure C.6- Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (No wind – inner site)**


**Figure C.7- Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (No wind – inner site)**



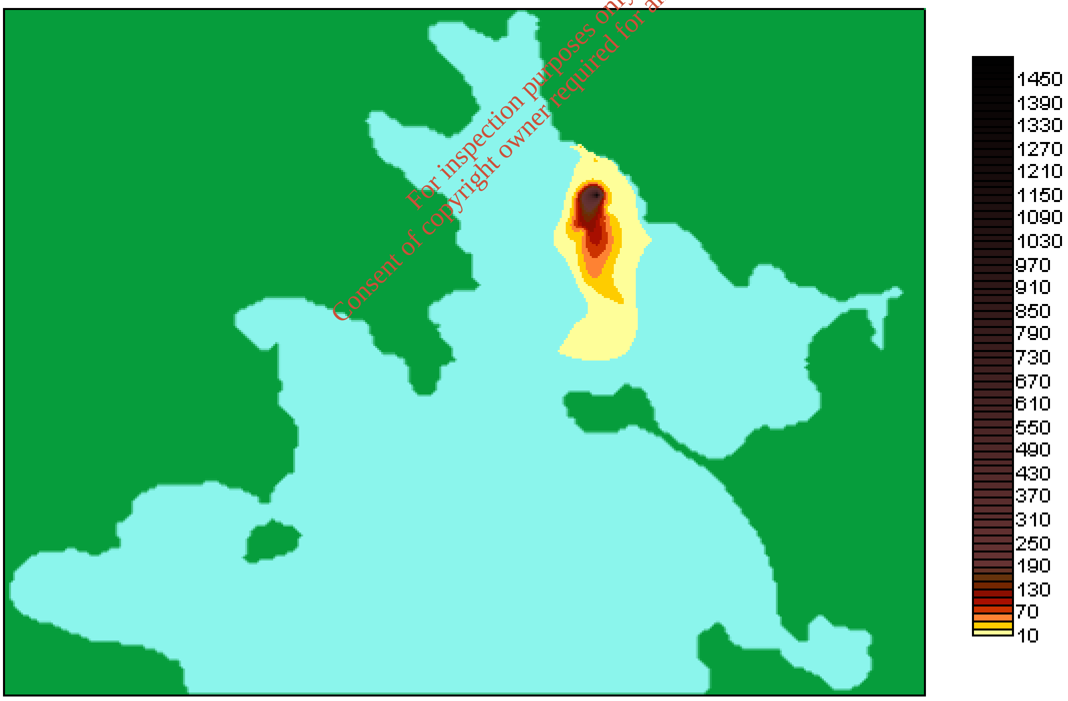



**Figure C.8- Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (No wind – inner site)**

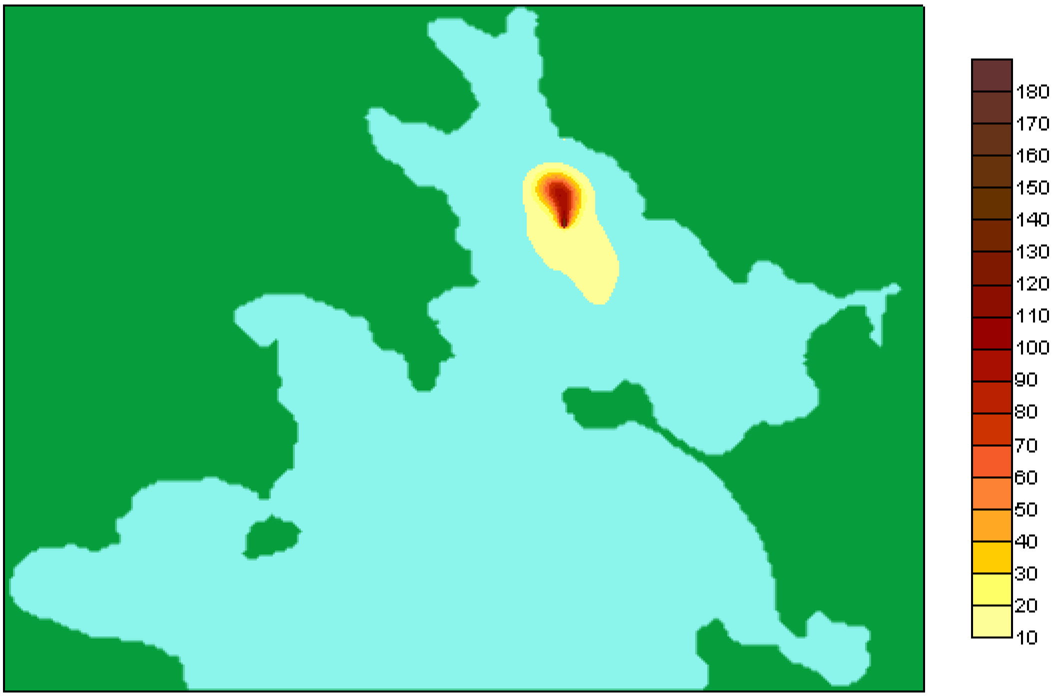



**Figure C.9- Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Neap Tide (No wind – outer site)**



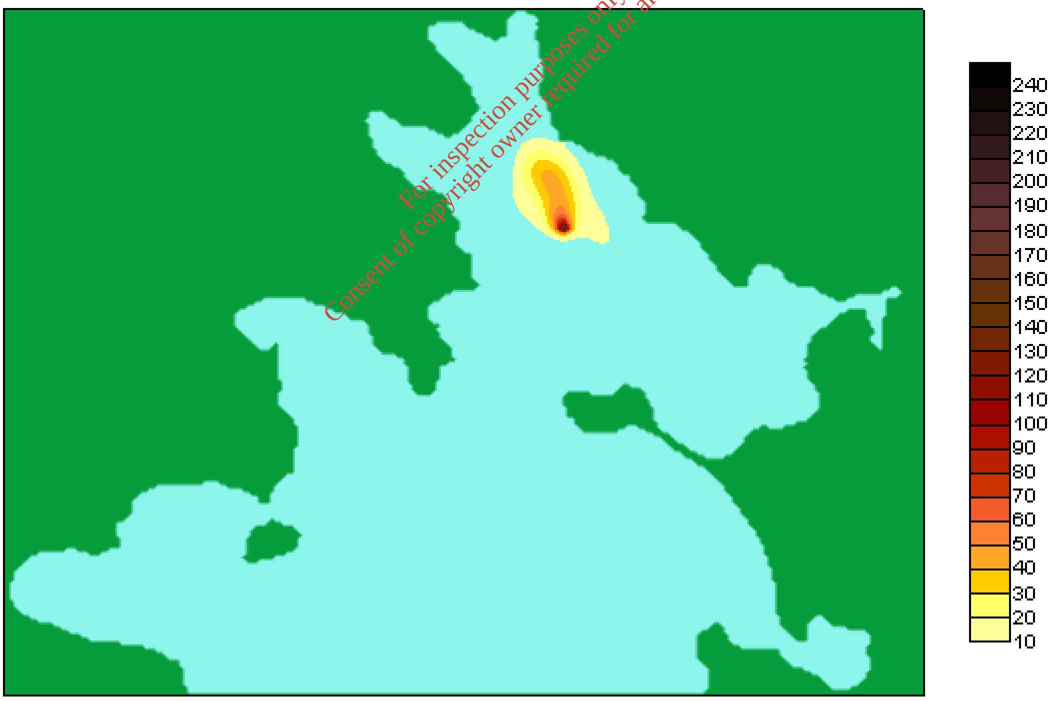



**Figure C.10 - Faecal Coliforms Concentration (counts/100 ml) at High Water on a Neap Tide (No wind – outer site)**


**Figure C.11 - Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Neap Tide (No wind – outer site)**




**Figure C.12 - Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Neap Tide (No wind – outer site)**


**Figure C.13 - Faecal Coliforms Concentration (counts/100 ml) at Mid Flood on a Spring Tide (No wind – outer site)**




**Figure C.14 - Faecal Coliforms Concentration (counts/100 ml) at High Water on a Spring Tide (No wind – outer site)**

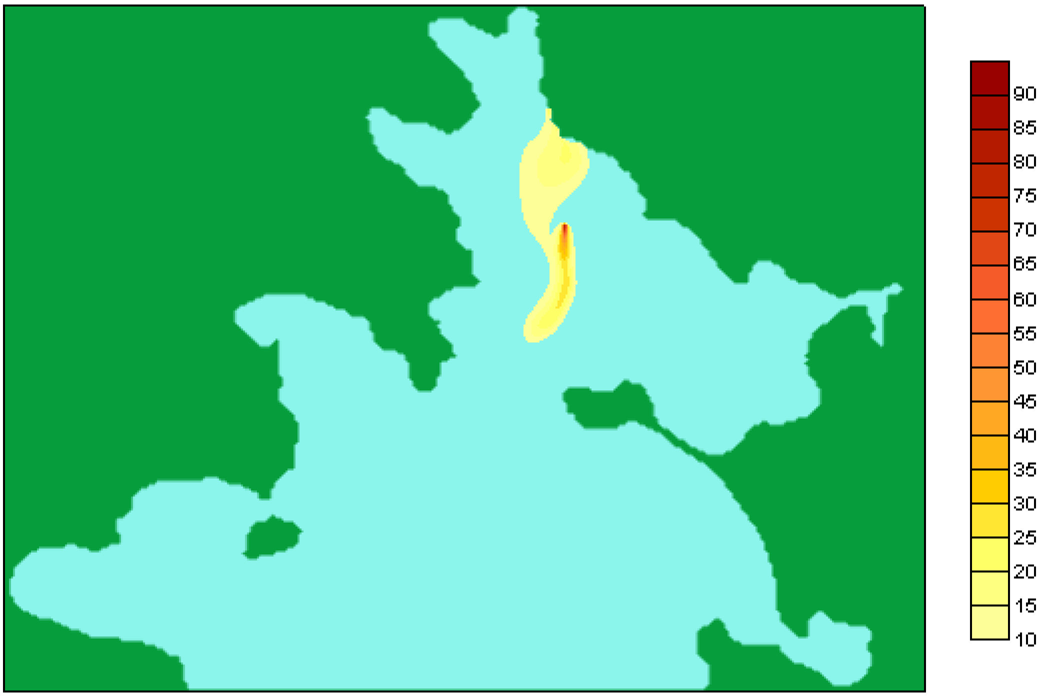



**Figure C.15 - Faecal Coliforms Concentration (counts/100 ml) at Mid Ebb on a Spring Tide (No wind – outer site)**

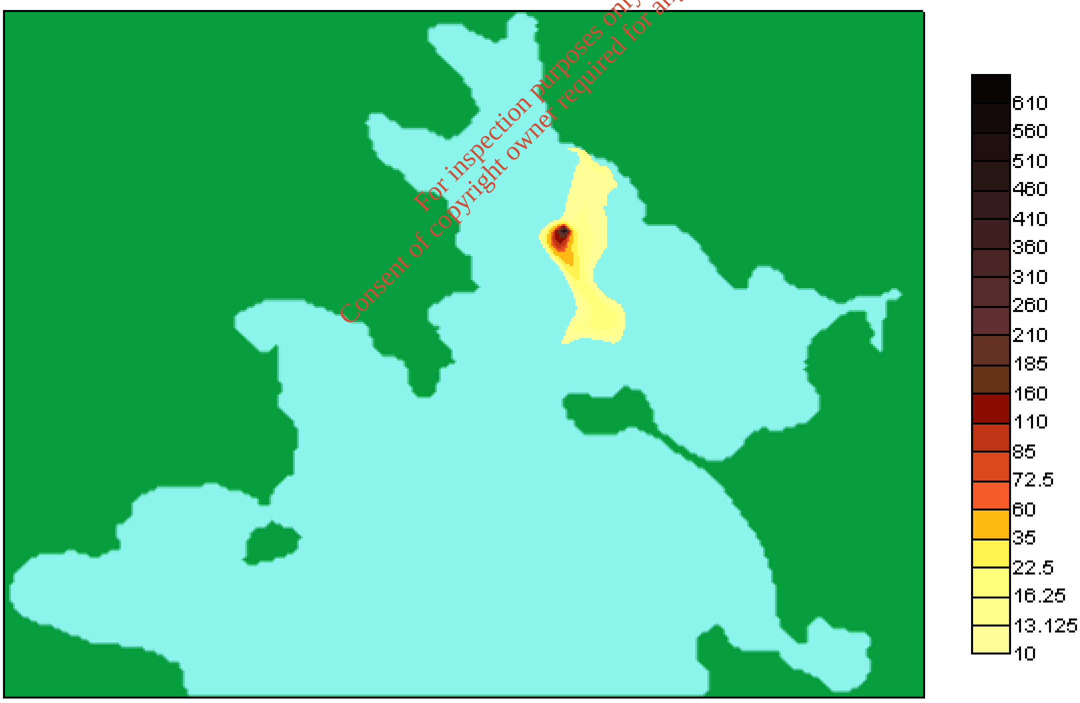



**Figure C.16 - Faecal Coliforms Concentration (counts/100 ml) at Low Water on a Spring Tide (No wind – outer site)**