WATER QUALITY STUDY

SEPTEMBER, 2004

NEWPORT SEWAGE OUTFALL
NEWPORT BAY
CO. MAYO

For: E.G. Pettit & Company,
Shelbourne House,
Shelbourne Rd.,
Dublin 4.
www.egpettit.ie

By: Aqua-Fact International Services Ltd.,
12 Kilkerrin Park,
Liosbaun,
Galway.
www.aquafact.ie

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CHAPTER 1
INTRODUCTION

1.1 Background

Aqua-Fact International Services Ltd. were commissioned by E.G. Pettit & Company to undertake a detailed environmental impact assessment of the likely effects of discharging effluent from an outfall on the local environment. This assessment was to be carried out with particular reference to possible adverse effects on the water quality of Lough Furnace, the Pearl Mussel (Margaritifera) beds in the Newport River and Oyster beds located east of Mallaranny. It is intended to release the effluent through a proposed outfall pipe located in the Newport Bay area, as shown in Figure 1.1.

As part of this study, a computer based hydrodynamic and water quality model called DIVAST, was used to illustrate the changes in water quality in Newport Bay due to cadmium, copper, faecal coliform, and ammonia discharges from the plant. Copper and cadmium were modelled as conservative substances (i.e. non biodegradable). Therefore, the concentrations of any other conservative elements in the receiving waters can be predicted based on the dilutions calculated for these substances.

In addition to using DIVAST, the U.S. E.P.A.'s Cornell Mixing Zone Expert System (CORMIX) was also used to carry out the environmental analysis. CORMIX enables the local characteristics of effluent plumes to be simulated based on the outfall diffuser configuration. It provides valuable information relating to plume dispersion, plume dilution and regulatory mixing zone requirements which, when used in conjunction with DIVAST simulations, provides a more comprehensive description of the fate of the effluent discharge.

The purpose of the model simulations, the results of which are presented in this report, is to examine the dispersion pattern and concentration of the various effluent discharges from the outfall and to determine if they satisfy regulatory requirements specified by EU legislation for estuarine and coastal waters [1,2] and also water quality standards stipulated in the Shellfish Waters Directive (79/923/EEC).

A description of the numerical model used to carry out the current study and the process of model calibration, are presented in Chapters 2 and 3. The results of the faecal-coliform, cadmium, copper, and ammonia solute transport models are presented in Chapter 4. These results are discussed in relation to relevant water quality standards in Chapter 5.

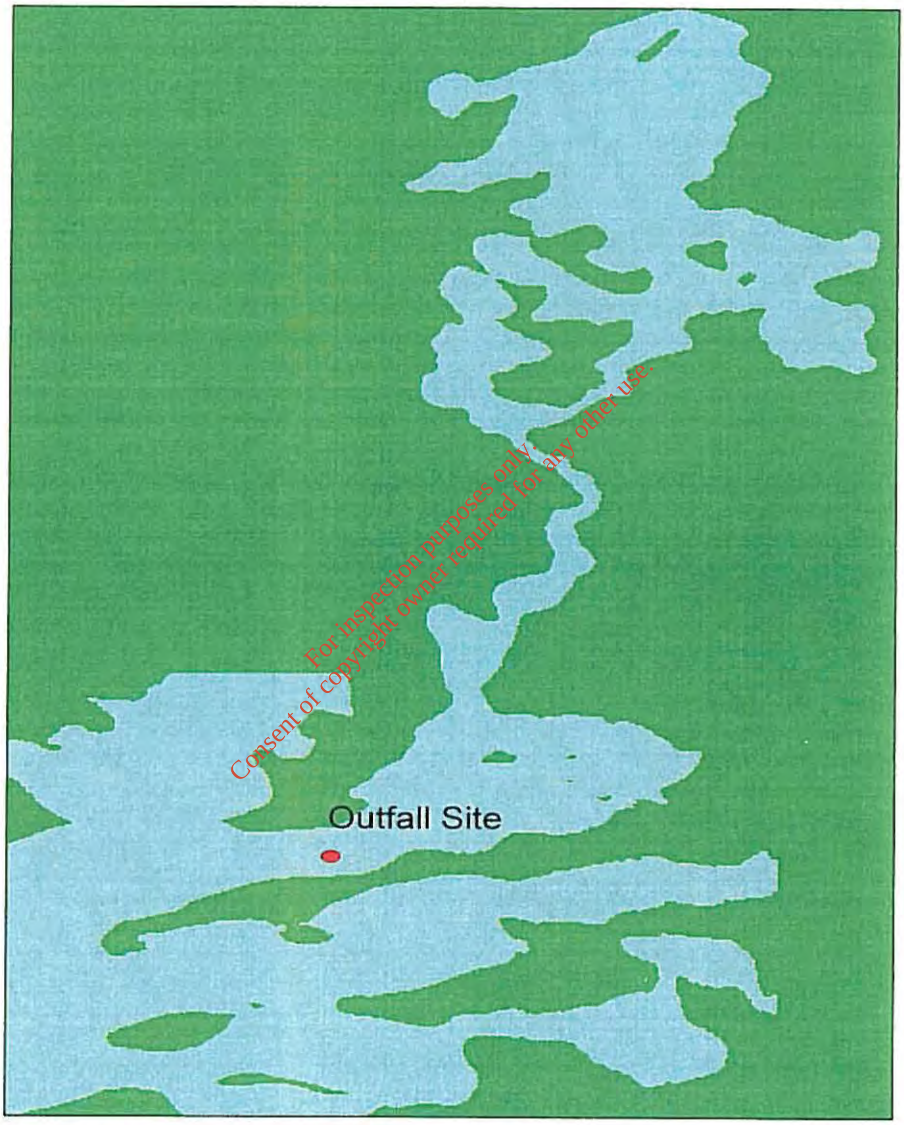

Figure 1.1: Plan view of Newport Bay study area showing the location of the proposed outfall (E95670, N294210)

CHAPTER 2
MODEL STUDY

2.1 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 water quality study of the Newport Bay/Lough Furnace area, Co. Mayo. The purpose of this study was to examine the hydrodynamic patterns of the area, to investigate the dispersion and diffusion of faecal coliform, cadmium, copper, and ammonia discharges from a proposed outfall and to determine the effects, if any, of these discharges on the local environment. The model DIVAST was developed by Professor Roger Falconer at the University of Bradford about 20 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.

2.2 Model Development

This water quality study was carried out by developing a model to simulate water circulation and the relevant aspects of the proposed outfall discharges. This was performed, as typical in all such model studies, in three interactive stages.

The first stage consisted of developing a water circulation model of the Newport Bay area 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.

The third stage of the study consisted of the development of a solute transport model capable of computing concentrations of a contaminant throughout the water body. The spread and fate of a solute in water is strongly dependent on the local water circulation patterns. The solute transport model developed in this study uses the output from the hydrodynamic model to compute concentrations of faecal coliforms, cadmium, copper, and ammonia in the water.

The finite difference model of Newport Bay and Lough Furnace was developed by using information obtained from the Geological Survey of Ireland (GIS). The GIS commissioned the services of the Tenix LADS (Laser Airborne Depth Sounder) Corporation to conduct a survey of this area using LIDAR technology. The resulting information provided a bathymetric survey of the area with a resolution of 1m. This represented a significant improvement in accuracy on the 50m resolution data previously obtained from Admiralty Charts. The LIDAR data was then interpolated and a finite difference grid was produced using the commercially available software SURFER. It was decided to use a grid with equal spacing of 10m x 10m in two orthogonal directions which was the smallest grid spacing available for model simulations. A total of 188,834 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 two-dimensional surface plot of the bathymetry of the bay is shown in Figure 2.1

The topography of the area is defined by specifying land boundaries, which delineate the extent of the water body. At the western 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.

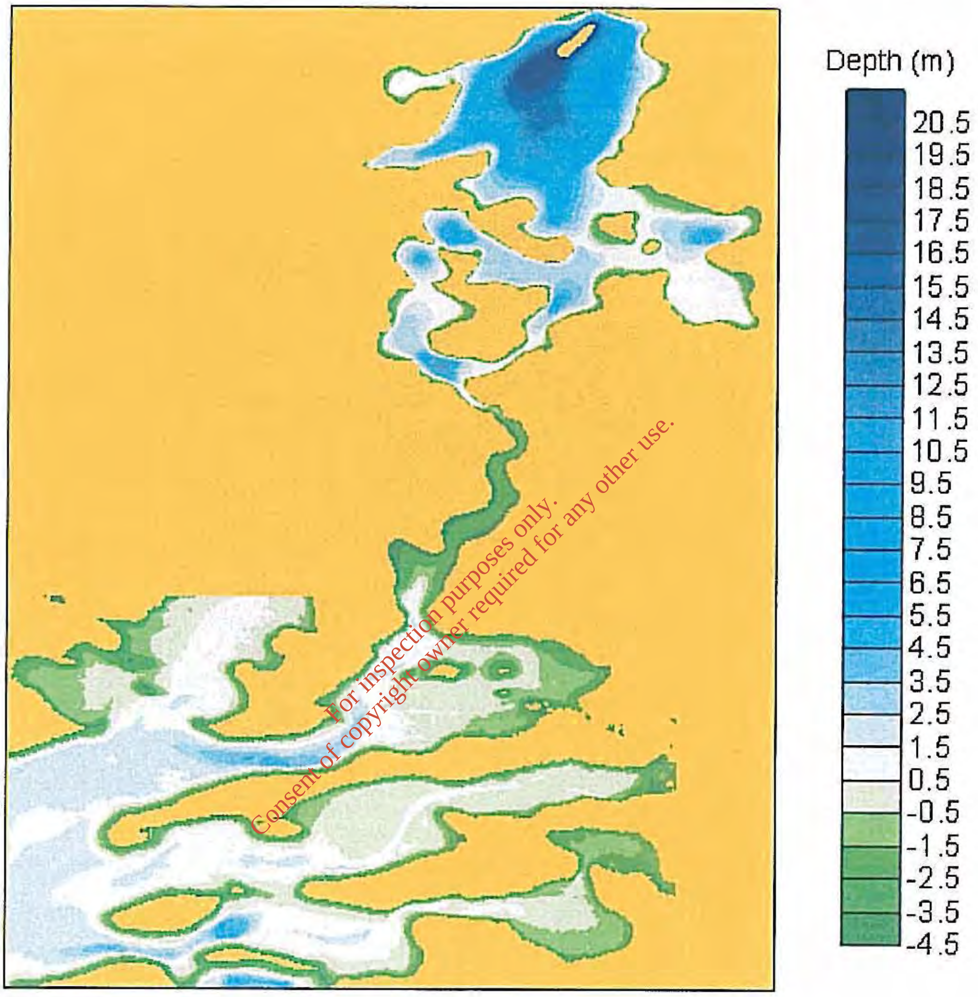

Figure 2.1: Two-dimensional bathymetrical plot of Newport Bay and Lough Furnace.

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 53.85° and 400 m/s respectively.

2.3 Additional Model Development

In a complimentary investigation, the local characteristics of the effluent plume in the immediate vicinity of the outfall were also examined using a computer model called CORMIX (Cornell Mixing Zone Expert System). This software system is used for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. It was developed by Cornell University under funding from the U.S. EPA during the period 1985 – 1995 and is a recommended tool in key guideline documents on the permitting of industrial, municipal, thermal and other point source discharges to receiving waters [3].

The major emphasis of the system is on the geometry and dilution characteristics of the initial mixing zone so that compliance with water quality regulatory constraints may be judged. However, the system also predicts the behaviour of the discharge plume at distances further from the point source.

Output from the CORMIX simulations consists of: the location of the plume centreline (x, y, z), hydrodynamic average dilution, average pollutant concentration, plume top-hat thickness (measured vertically from the sea bed), plume top-hat half-width (measured horizontally from the shoreline) and cumulative time of travel for the different mixing zones and for the specified region of interest or until the time of tidal reversal whichever has the least time of travel.

As a detailed analysis of the Newport outfall configuration and the resulting effluent plume dispersion/concentration had been previously conducted by Hydro-Environmental Ltd. [4] using CORMIX, only a limited number of additional simulations were conducted in the current investigation. These were conducted for the purposes of comparison with the DIVAST model.

2.4 Model input data for CORMIX

2.4.1 Bathymetry

CORMIX requires that the actual cross-section of an ambient water body be described by a rectangular channel that may be bounded laterally or unbounded. Using the LADS survey data a cross-section of the bay coinciding with the location of the diffuser was examined and the average depth calculated. The channel was classified as bounded with a width of 140m at mid-water. The discharge is located close to the left bank (approximately 40m) An average depth of 5m was used for the rectangular channel, whereas the discharge point was located at depth of 6m.

2.4.2 Ambient Conditions At Outfall Site

The an ambient density profile was specified as uniform at 1025 kg/m^3 throughout its depth and the effluent density was taken as 1000 kg/m^3. Current velocities at the proposed site, as predicted by DIVAST, act in a predominantly rectilinear direction (i.e. parallel to the coastline). The ebb tide is stronger than the flood. The mean maximum neap tide velocity is 0.13 m/s and the mean maximum spring tide velocity is 0.32 m/s. The annual mean spring and neap tidal ranges as calculated from Admiralty Charts are 4.0 m and 1.6 m respectively. The average water depth along the diffuser line is approximately 5m (at mid water).

2.4.3 Diffuser Type and Configuration

The diffuser manifold is identical to that described in [4] (Configuration B) and is shown in Figure 2.2. It is arranged normal to the ambient flow direction. The horizontal and vertical orientations of the diffuser ports are parallel to the manifold. The manifold is buried beneath the sea bed having a 500 mm covering along its length and having the same fall as the bed slope. The port centrelines are located 750 mm above the bed. The start of the diffuser line is located approximately 40m from the western shoreline (at mid water) and the total length of the diffuser is 18m. The riser port diameters are equal to 0.110m.

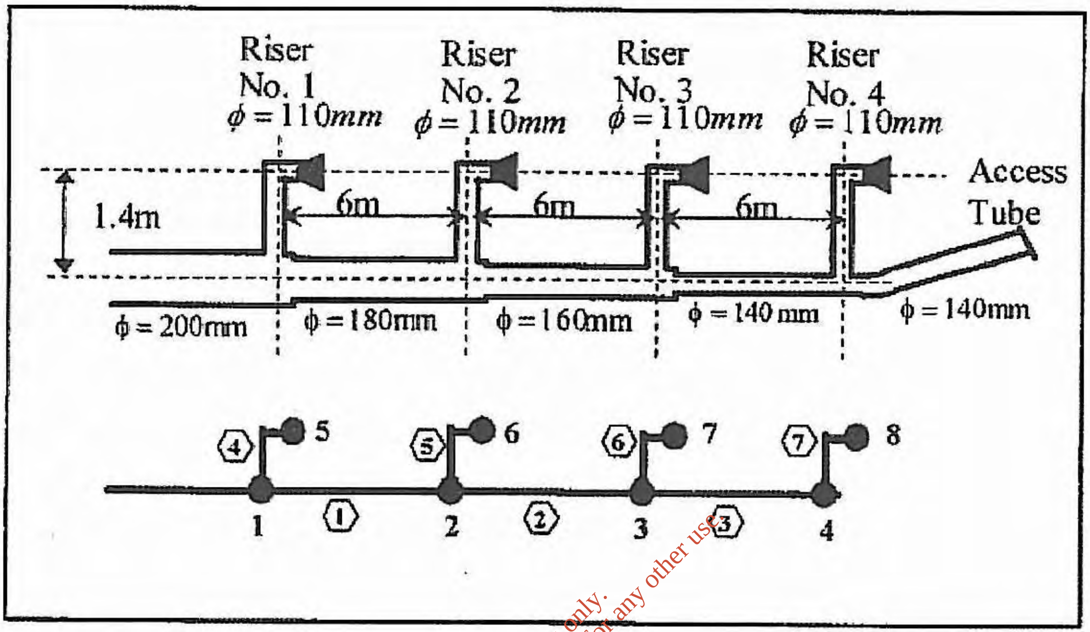

Figure 2.2: Diffuser configuration with four risers fitted with 100mm Tideflex valves

CHAPTER 3

HYDRODYNAMIC MODEL CALIBRATION

3.1 Introduction

Calibration involves the adjustment of the model parameters and forcing functions within the bounds of modelling uncertainties, to obtain the best possible approximation of the physical phenomena being simulated.

3.2 Calibration procedure

In the current study, the model was calibrated from physically measured field data, recorded using an Acoustic Doppler Current Profiler (ADCP) which had been used for a previous study [5]. The ADCP was deployed in the north inner area of Clew bay, the location of which is shown in Table 1.1. It recorded measurements of current speed, current direction and water elevation for a period of one month (a full spring-neap cycle). Although this location is in fact outside the model domain area, the recorded surface elevation will be practically identical to that within the Newport Bay area since the tide will not vary significantly over such a short distance.

However, the recorded current velocities from the previous study cannot be used to calibrate this model since these measurements are site specific, depending on the local water depth and surrounding topography. Nevertheless experience shows that once the tides are accurately predicted for a given model, adjusting other parameters such as sea bed roughness, vertical velocity distribution coefficients, and eddy viscosity coefficients does not have a major effect on the current velocities produced. Previous studies around the Irish coast have shown that these factors affect the predicted velocities by 2-3% at most.

Instrument	Location	Latitude	Longitude
ADCP	North Inner Bay	53° 51.409	9° 44.459

Table 1.1 ADCP recording position in Clew Bay

3.3 Results of Model Calibration

Figure 3.1 illustrates a comparison of the water elevation recorded over a period of two weeks (a spring-neap tidal cycle) at the location mentioned above. From this figure it is apparent that the tidal phase measured in Clew Bay is simulated accurately by the model for the entire spring-neap tidal cycle. It is also evident that the overall amplitude of the tidal constituents predicted by the model, and measured using the ADCP's, exhibit excellent agreement at the spring and neap tides. The variation between the amplitude of individual waves is due to the fact that DIVAST only models two tidal constituents in order to produce a *mean* spring-neap tidal cycle. In reality however, the presence of many more tidal constituents means that the maximum wave heights will vary slightly from one spring-neap cycle to the next.

The comparison presented in the diagram above is a good verification that the model is predicting the hydrodynamic conditions of Newport Bay with sufficient accuracy.

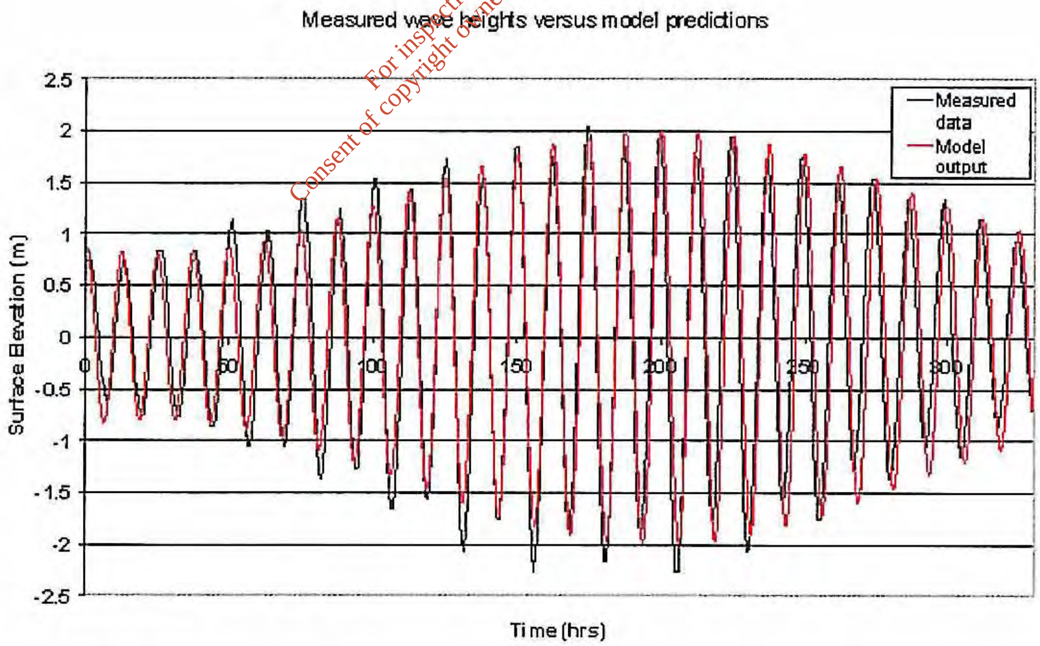

Figure 3.1: Comparison of simulated and measured water surface elevation over a spring-neap tidal cycle

3.4 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 3.2 to 3.9 as snapshots in time of velocity vectors at model grid points. The output is presented at four different times during the course of a neap tidal cycle: mid-flood, high water, mid-ebb and low water, and also during a spring tidal cycle

Current velocities near the proposed site, as predicted by DIVAST, act in a predominantly rectilinear direction (i.e. parallel to the coastline). 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 current velocities are also greater on the ebbing tide. The mean maximum neap tide velocity is 0.13m/s and the mean maximum spring tide velocity is 0.32m/s on the ebbing tide whereas the corresponding velocities are 0.1m/s and 0.25m/s on the flood tide. The annual mean spring and neap tidal ranges are 4.0 m and 1.6 m respectively.

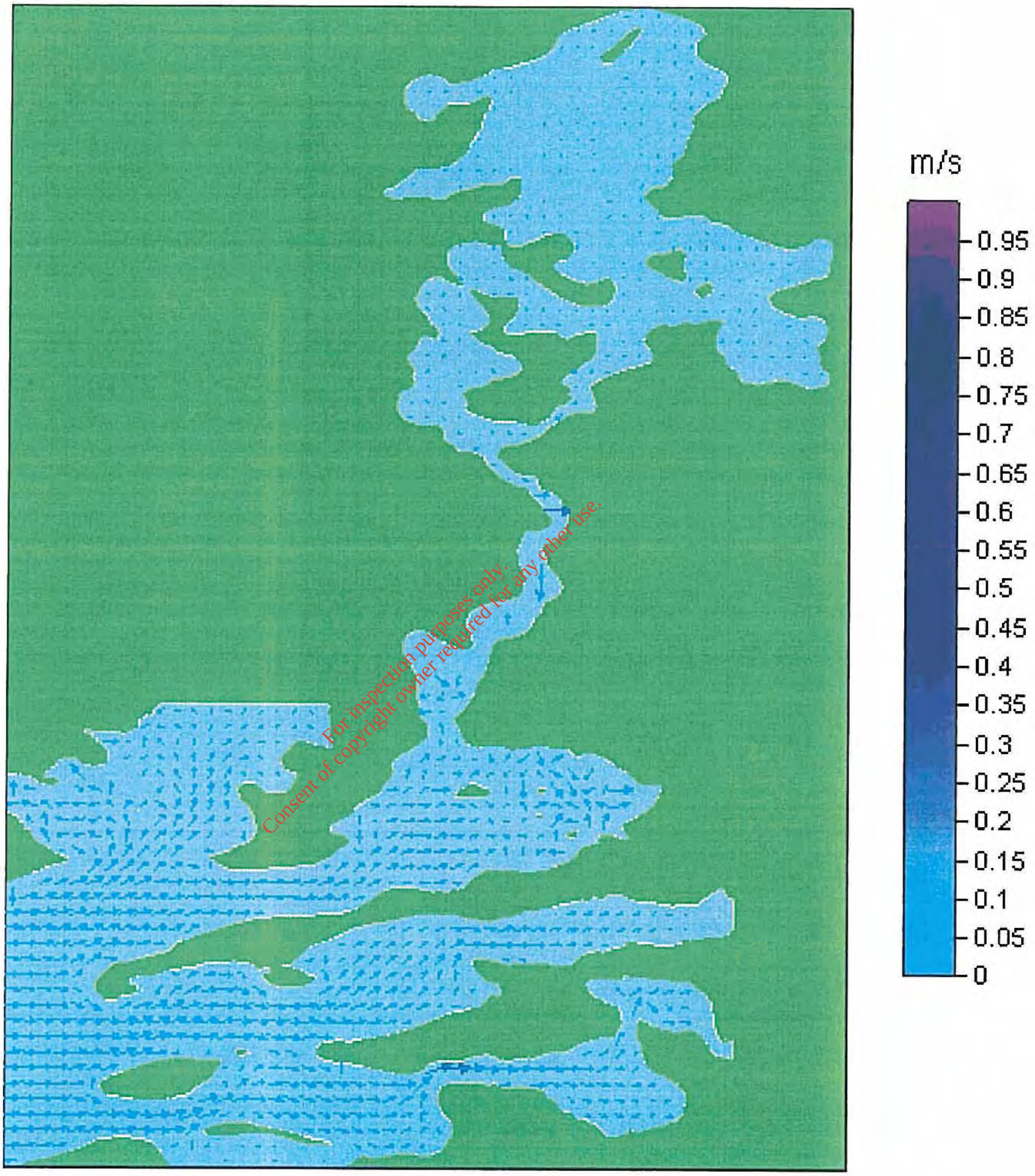

Figure 3.2 – Current velocity vectors (m/sec) calculated at mid-flood on a neap tide.

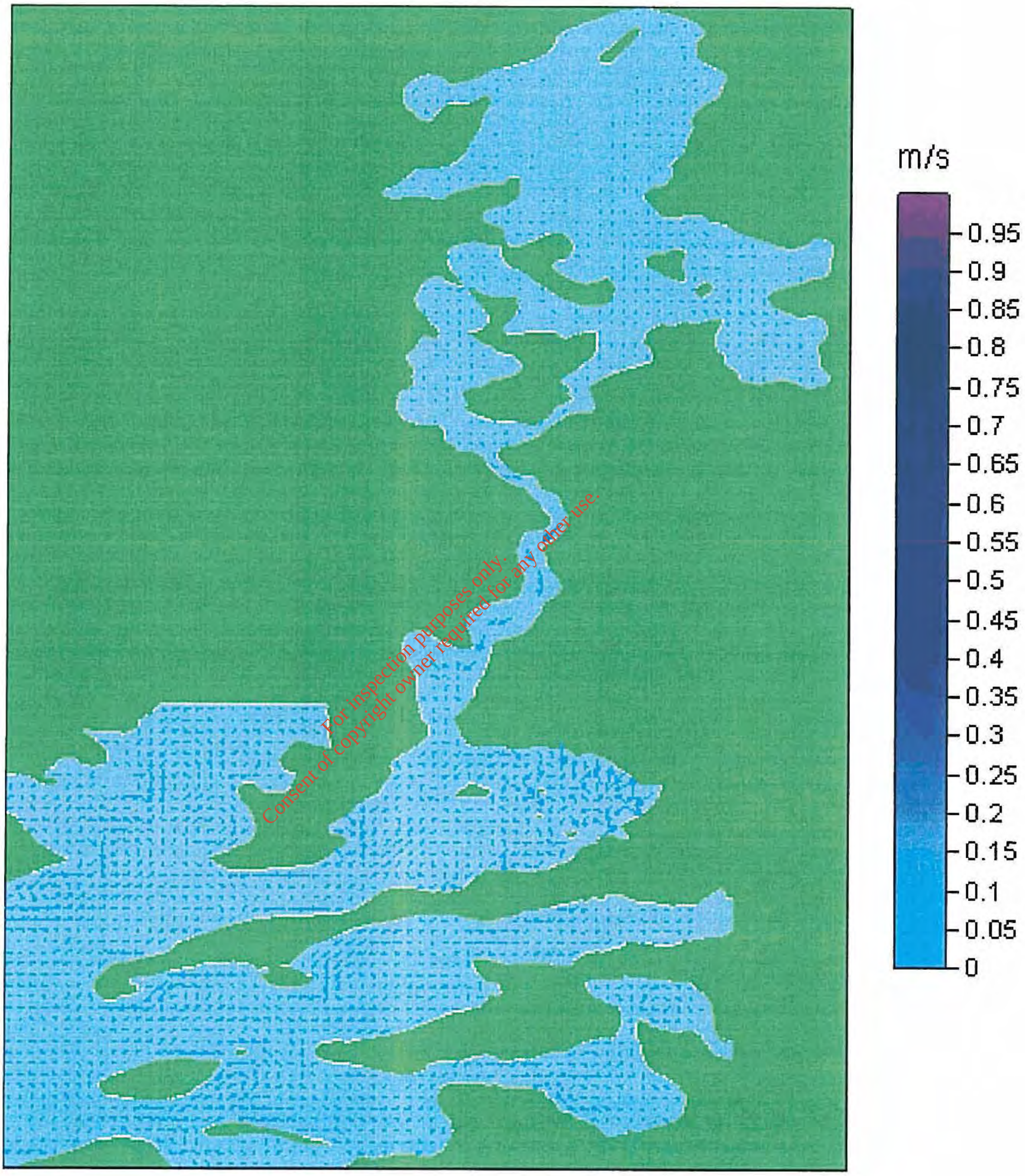

Figure 3.3 – Current velocity vectors (m/sec) calculated at high water on a neap tide.

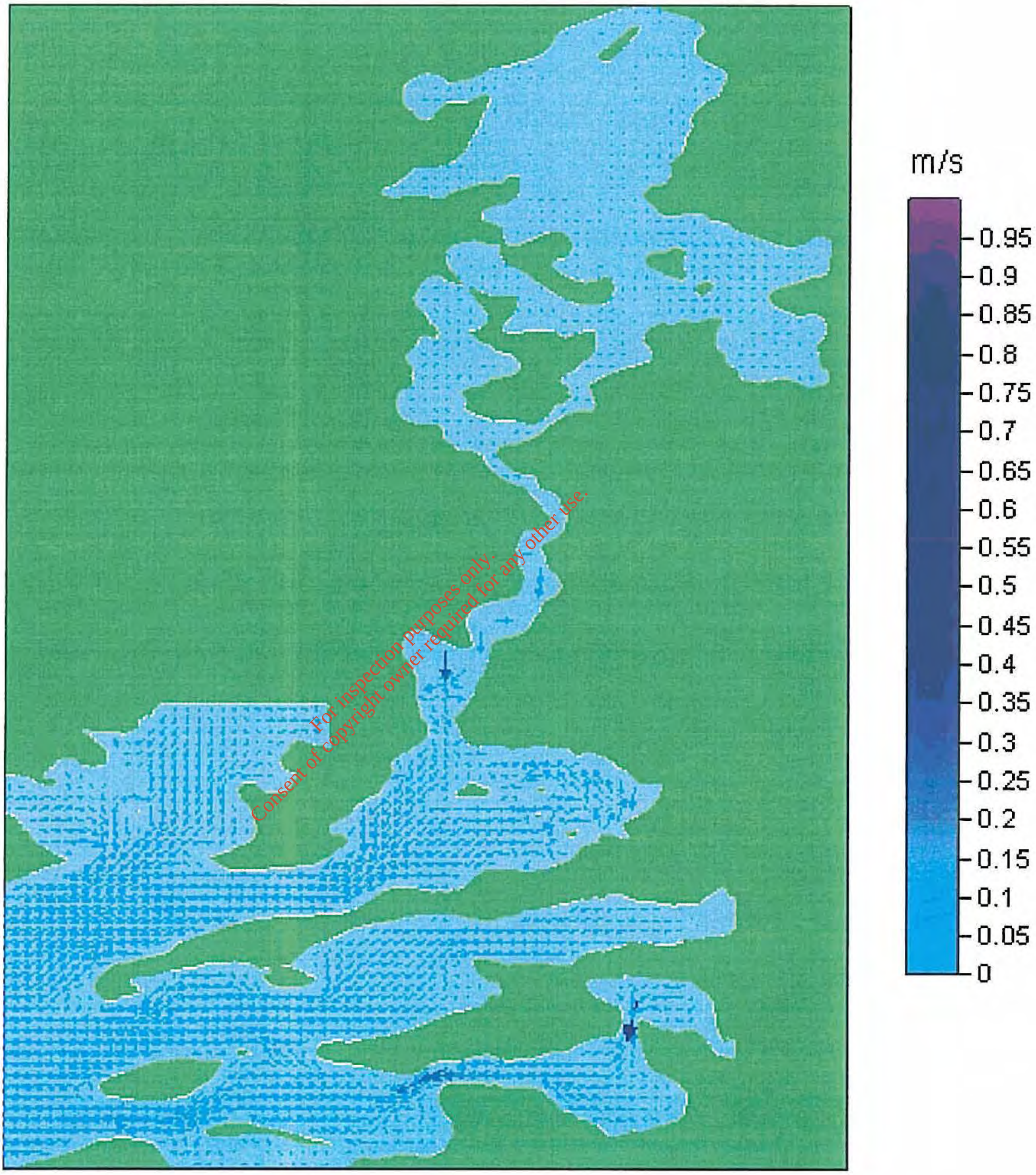

Figure 3.4 – Current velocity vectors (m/sec) calculated at mid-ebb on a neap tide.

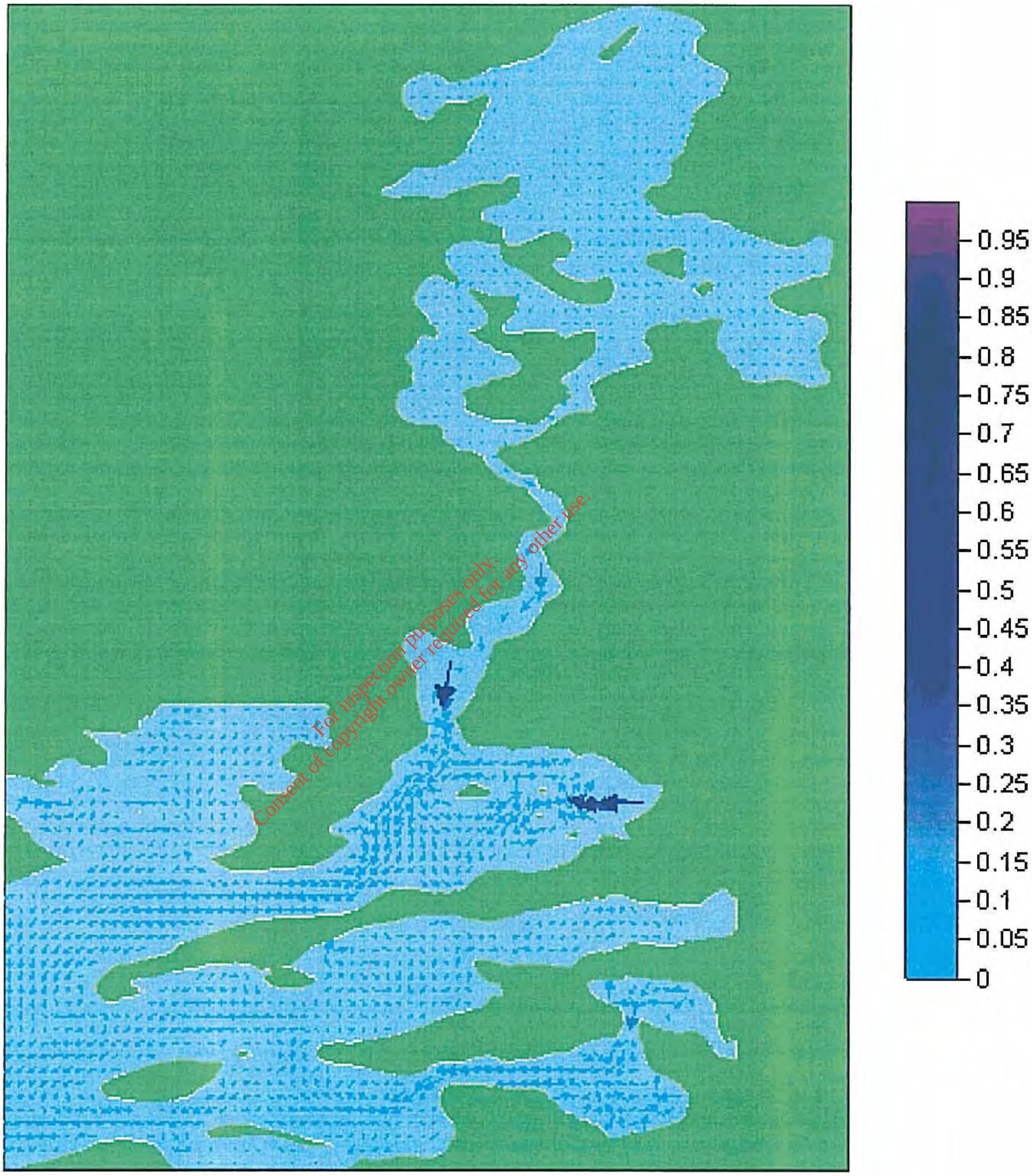

Figure 3.5 – Current velocity vectors (m/sec) calculated at low water on a neap tide.

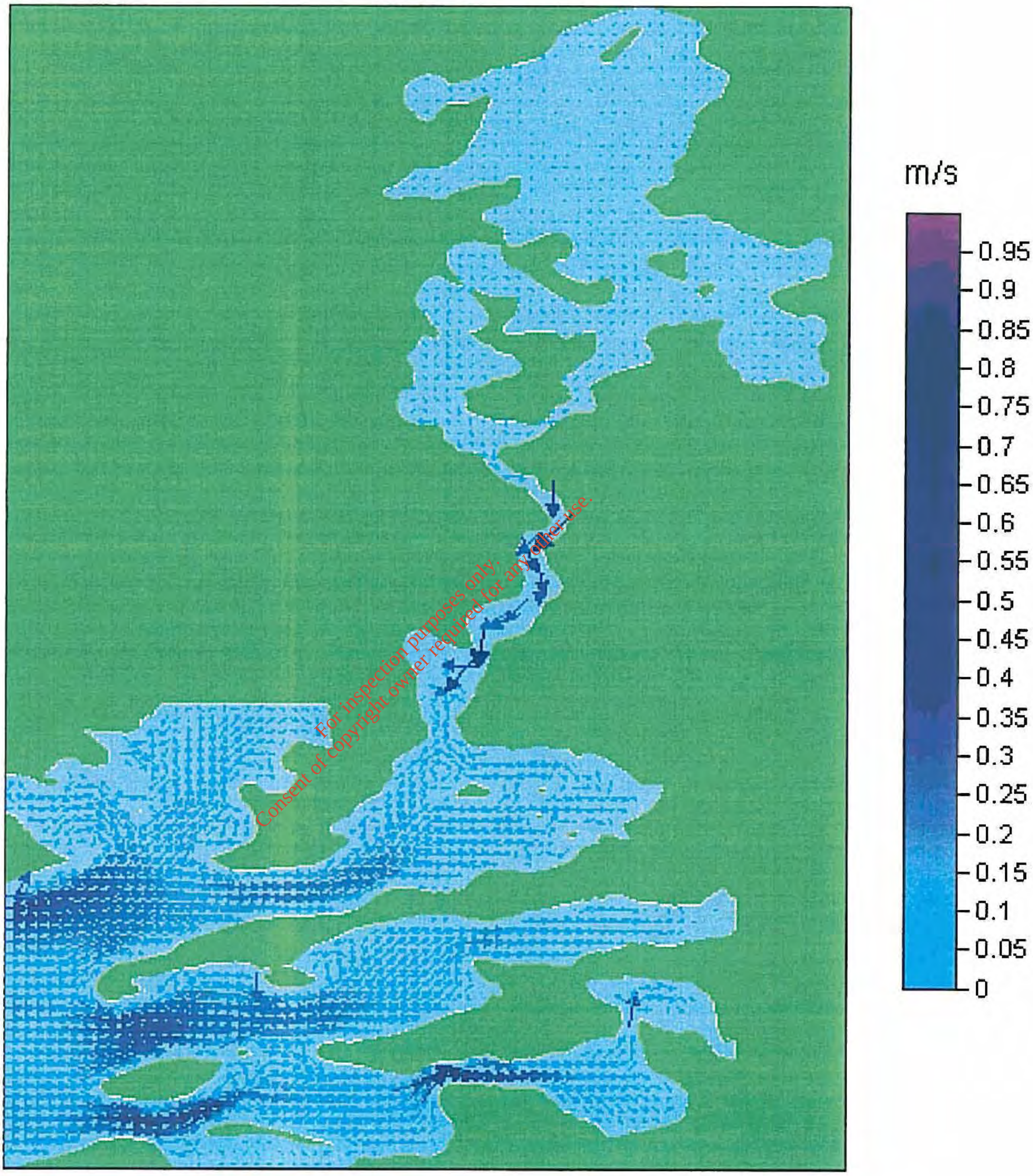

Figure 3.6 – Current velocity vectors (m/sec) calculated at mid-flood on a spring tide.

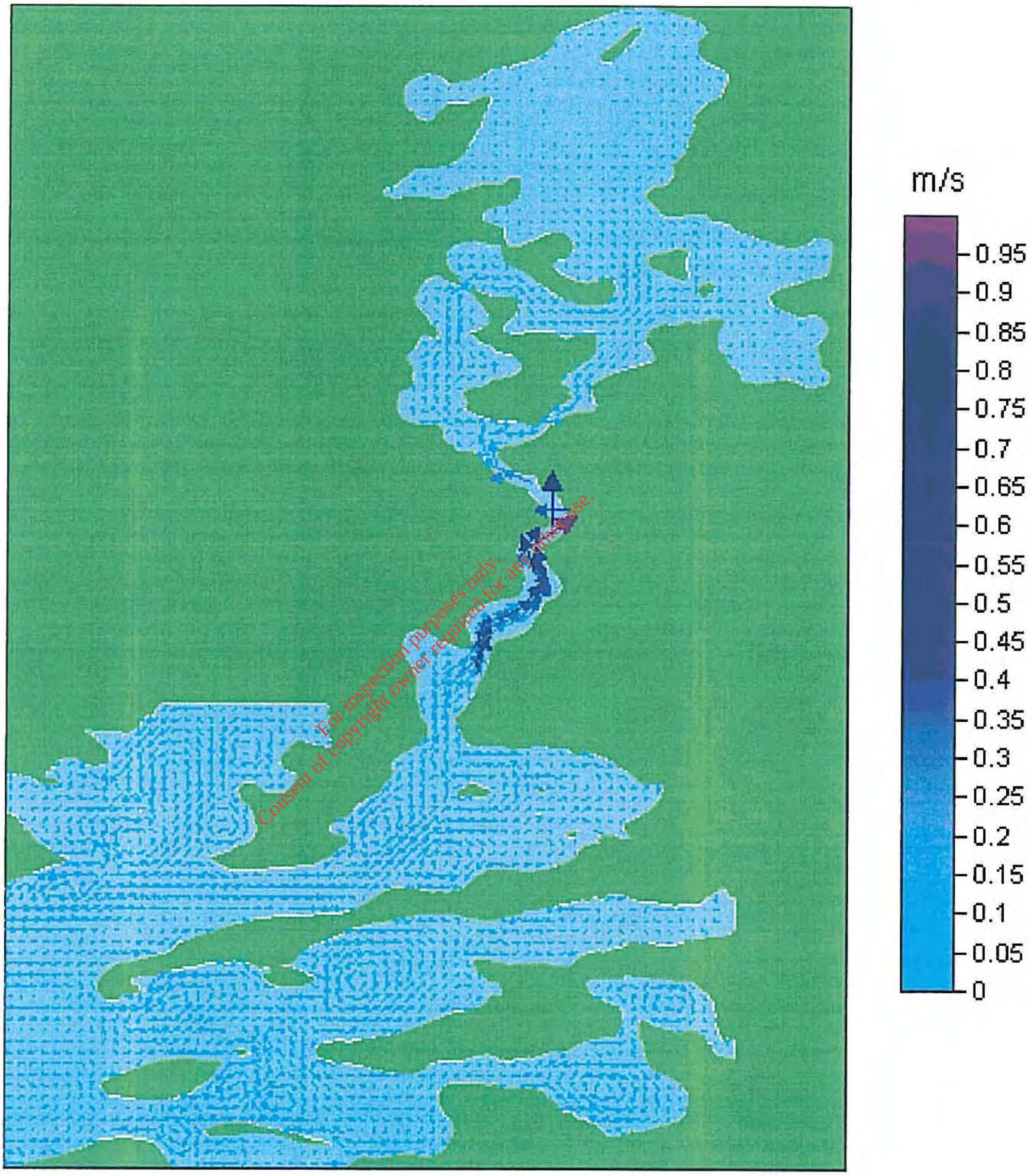

Figure 3.7 – Current velocity vectors (m/sec) calculated at high water on a spring tide.

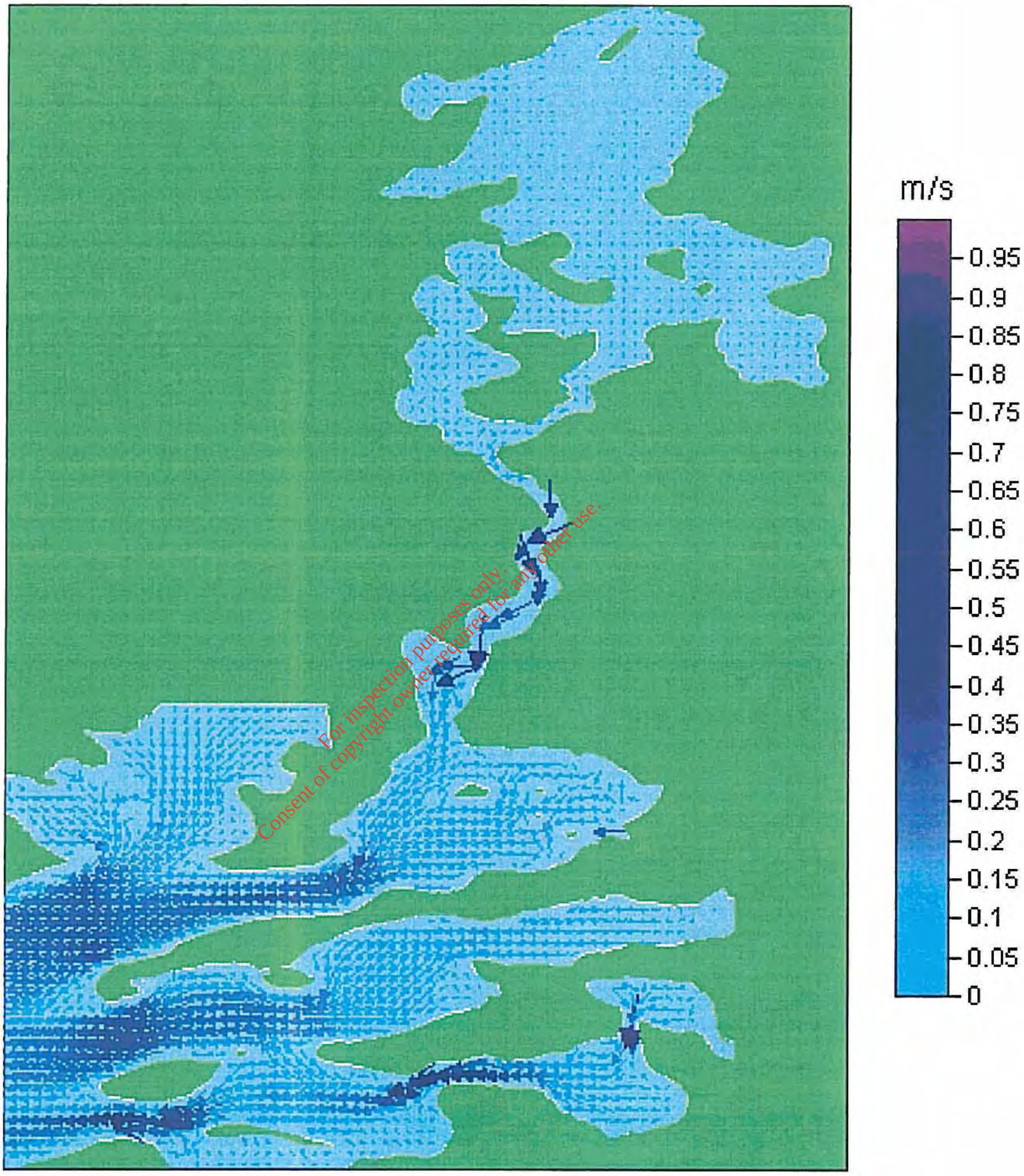

Figure 3.8 – Current velocity vectors (m/sec) calculated at mid-ebb on a spring tide.

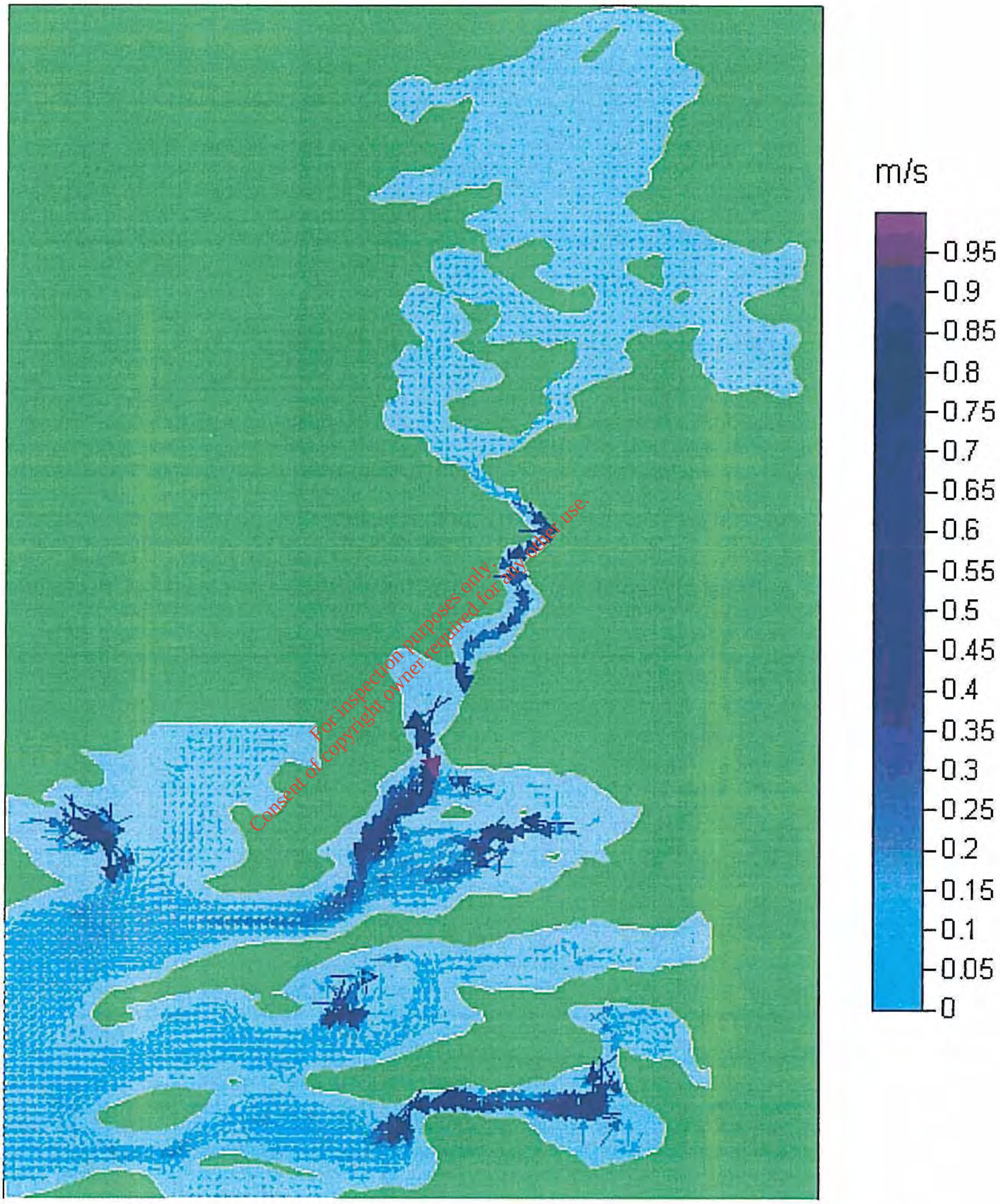

Figure 3.9 – Current velocity vectors (m/sec) calculated at low water on a spring tide.

CHAPTER 4

RESULTS OF ANALYSIS

4.1 Introduction

In this study a solute transport model was developed using DIVAST, as detailed in Chapters 2 and 3. The model was then used to assess the impact of a nutrient load discharged from an outfall pipe, by simulating the spread and fate of faecal-coliforms, cadmium, and copper and throughout the bay. Additional simulations were carried out using an extended model of inner Clewbay, which was used to examine the spread of ammonia. Details of these simulations are presented in section 4.2.3.

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. In cases of industrial or mining pollution a most important group of pollutants which must be analysed are metals: iron, manganese, copper, lead, zinc, cadmium, chromium, nickel, etc. All are undesirable and some, e.g., cadmium and copper are very toxic to fish. Cadmium is strongly adsorbed on mud, humus and organic matter, leading to the possibility of entry to the food chain via fish and fish food and subsequent accumulation in tissue. 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. [1]

The characteristics of the proposed effluent to be discharged from the outfall are shown in Table 4.1. The total rate of discharge of the effluent is 12.3l/s.

Rate of discharge (l/s)	Maximum concentration of faecal coliforms (number/100ml)	Maximum concentration of copper (mg/l)	Maximum concentration of cadmium (mg/l)
12.3	2000	0.08	0.001

Table 4.1: Characteristics and flow rate of effluent from outfall pipe

4.2 Simulations and Results

Using the above discharges the DIVAST model was used to estimate the concentrations of various effluents throughout the study area during the course of a spring-neap tidal cycle. The faecal coliform, cadmium and copper loadings were specified as continuous discharges 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 2.5 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 faecal coliform, cadmium and copper which would be reached throughout the water body would be observed. For the purpose of the present analysis, two different flows into Lough Furnace due to river discharges and precipitation were examined. As a 'worst case scenario' it was decided to model the area without any flow into Lough Furnace which would simulate a very dry period where the maximum concentration of effluent into the lake could be examined without dilution effects. In the second scenario a mean flow into the lake of 5m^3/s was considered, which is also considerably lower than the actual river discharges (max 50m^3/s, average 25m^3/s – note: figures obtained from Environmental protection Agency). A south-westerly wind with a speed of 7.5m/s was also specified in the model inputs as it was found during model simulations that this represented the weather condition which most favoured the transport of the effluent towards Lough Furnace.

4.2.1 Concentration Snapshots

In order to analyse the model results, snapshots of the faecal coliform, cadmium and copper 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 tide is the tide that occurs when the difference between high and low tide is least. Neap tide comes twice a month, in the first and third quarters of the moon. Conversely the maximum range of tide in an area, the spring tide, occurs twice a month when the moon is new or full.

The spring solute plumes were output by the model at approximately 350 hours into the simulation while the neap plumes were output after approximately 525 hours of the simulation. These solute plumes are illustrated in Figures 4.1 – 4.24. The flow into Lough Furnace (from river discharge and land runoff) during this simulation was zero, so the results presented are conservative. Due to the small amounts of metals discharged from the outfall (i.e. 0.08mg/l copper and 0.001mg/l cadmium) the maximum concentrations at any point in the study area are very low and are measured in ng/l. (ng = nanogram = 10^{-9} grams).

Table 4.2 summarises the maximum concentrations of each effluent predicted at the proposed outfall location at eight different stages in the tidal cycle. These values relate to the concentrations predicted in a 10m x 10m grid square and so they can be considered in reality to be the concentrations expected at a distance of 5m from the actual outfall pipe.

Tidal stage	Copper conc. [ng/litre]	Cadmium conc. [ng/litre]	FC conc. [number/100 ml]
Neap mid flood	74.713	0.934	1.538
Neap high water	87.542	1.094	1.821
Neap mid ebb	81.693	1.023	1.547
Neap low water	81.693	1.023	1.547
Spring mid flood	41.507	0.519	0.815
Spring high water	30.942	0.377	0.860
Spring mid ebb	26.791	0.334	0.711
Spring low water	36.413	0.455	0.749

Table 4.2: Maximum faecal coliform, cadmium and copper concentrations at different periods in the tidal cycle

4.2.2 Time-trace Results

In this section, the variations in faecal coliform, cadmium and copper concentrations with time at a number of locations are presented. Figure 4.25 shows the location of four observation sites with the time-traces presented in figures 4.26 to 4.43. These four locations where chosen to examine the following:

1. The effluent concentrations reaching the sensitive Lough Furnace area

2. The effluent concentrations in Newport channel which could impact on the pearl mussel beds
3. The effluent concentrations at the boundary of the model from which the maximum concentrations entering outer Newport Bay could be examined.

The two different flow scenarios mentioned above were used to examine the potential build up of toxic substances in Lough Furnace and how this is affected by the volume of water due to river discharges and precipitation entering the lake. The difference between the concentration of the effluent at sites C and D for the different flow rates was negligible since these sites were not affected by the amount water entering Lough Furnace, and therefore only one set of time-traces is shown for each of these sites. Figures 4.26 – 4.31 show time-traces recorded for sites A and B when the flow into the lake was zero, figures 4.32 – 4.37 show the equivalent time-traces for a mean flow of 5m^3/s, and figures 4.38 – 4.43 show the time-traces recorded at sites C and D. The first simulation where the flow into the lake was zero was run for a period of 700hrs, or two spring-neap tidal cycles, whereas the second simulation was run for 1100hrs or three spring-neap tidal cycles.

It can be seen from the graphs that the concentration at a point is highly dependent on the stage of the tide; high concentrations are computed at low tide due to less dilution available and low concentrations are computed at high tide due to greater dilution. Obviously, it is important to consider the maximum concentration levels at various locations in the bay. Thus specific values from time-traces are summarised in Table 4.3 and 4.4, which tabulate the maximum concentration attained at each of the observation sites A to D during both simulations.

Location	Copper conc. [ng/litre]	Cadmium conc. [ng/litre]	FC conc. [number/100 ml]
Point A	14.339	0.181	0.064
Point B	16.603	0.218	0.104
Point C	27.734	0.341	0.425
Point D	8.867	0.113	0.032

Table 4.3: Maximum faecal coliform, cadmium and copper concentrations calculated at time-trace locations during simulation 1.

Location	Copper conc. [ng/litre]	Cadmium conc. [ng/litre]	FC conc. [number/100 ml]
Point A	0.425	0.006	0.005
Point B	1.057	0.013	0.012
Point C	27.734	0.341	0.425
Point D	8.867	0.113	0.032

Table 4.4: Maximum faecal coliform, cadmium and copper concentrations calculated at time-trace locations during simulation 2.

4.2.3 – Additional DIVAST Simulations.

As presented in the addendum to this report, an extended model of the inner Clewbay area was also created to examine an alternative site to the one proposed above. Using this model the discharge of ammonia from the *current* site was also examined to give a better understanding of how far west of the outfall pipe the effluent could travel rather than looking at the impact on Lough Furnace which was the primary aim of the first model. A concentration level of 5mg/l of ammonia in the effluent was considered. Simulations were carried out which included the effects of diffusion due to a moderate southerly breeze, (i.e. 7.5m/s) and also for a zero wind condition. The predicted rate of discharge was 12.3l/sec. These solute plumes are illustrated in Figures 4.44 – 4.59. Table 4.5 summarises the maximum concentrations of the effluent at eight different stages in the tidal cycle for the different wind conditions.

Tidal stage	Ammonia Conc. (mg/l) site 1 – no wind	Ammonia Conc. (mg/l) site 1 – wind
Neap mid flood	0.0094	0.0038
Neap high water	0.0194	0.0048
Neap mid ebb	0.0074	0.0038
Neap low water	0.0170	0.0038
Spring mid flood	0.0040	0.0019
Spring high water	0.0110	0.0030
Spring mid ebb	0.0029	0.0019
Spring low water	0.0036	0.0018

Table 4.5: Maximum ammonia concentration (mg/l) at different periods in the tidal cycle