2007

Water Quality Modelling in Dublin from Bray to Balbriggan GDSDS/75407/130

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Drainage Division,
Floor 2 Block 1
22-12-08

FAO:- Mr P Byrne
Inspector

Re: Application for Discharge Licence Ref No D0034-01,
Request for Additional Information

I refer to yours of 27-11-08 requesting further information in support of our application for a waste water discharge licence for the Ringsend agglomeration.

Please find attached both hard and soft copy of our response to the various issues raised.

We have not amended the non-technical summary due to the fact that there are no material differences to the main body of information contained in these responses.

Should you have any queries on this matter please contact Mr. Gerry Doherty, telephone number 01-2222930.

M. Ryan
Divisional Engineer

Requirement 2.

B.9 (i) Population Equivalent of Agglomeration

TABLE B.9.1 POPULATION EQUIVALENT OF AGGLOMERATION

The population equivalent (p.e.) of the agglomeration to be, or being, served by the waste water works should be provided and the period in which the population equivalent data was compiled should be indicated.

Population Equivalent (measured)	**2.54 million**
Data Compiled (Year)	**2006 EPA Return**
Method	**Maximum weekly average (UWW Regulations, 2001 Methodology)**

Historical Trends

Measured Population Equivalent values reported to the EPA since 1998 were as follows :

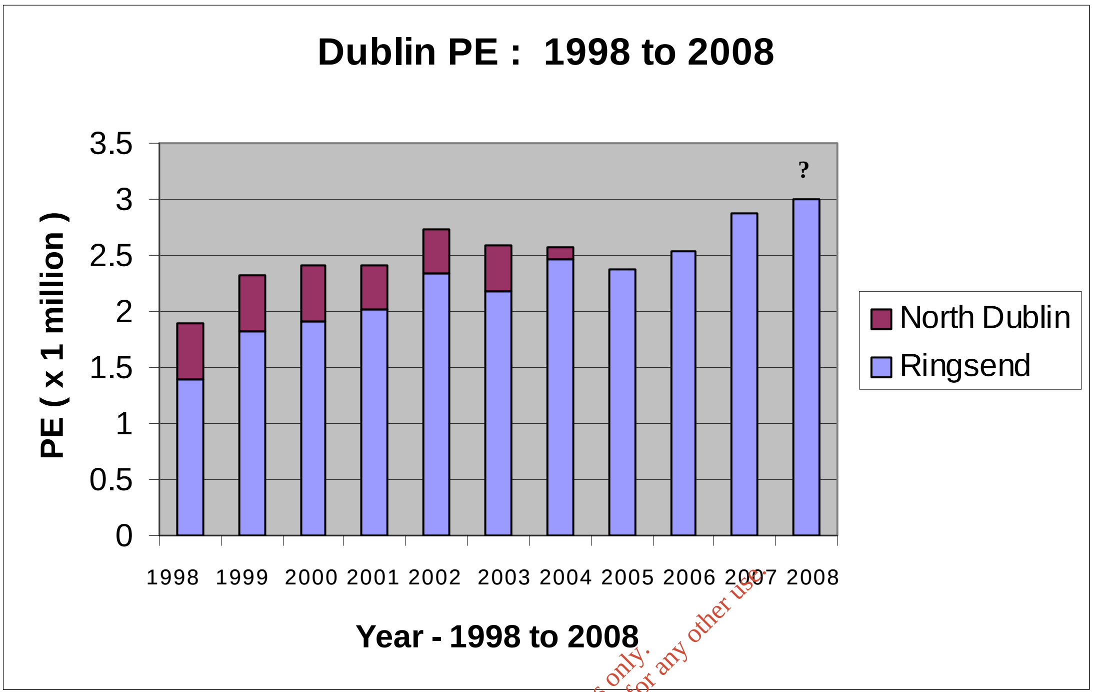
Year	**Population Equivalent Ringsend** million (measured)	**Population Equivalent North Dublin** million (estimated)
1998	1.398	0.5
1999	1.819	0.5
2000	1.903	0.5
2001	2.01	0.4
2002	2.34	0.4
2003	2.187	0.4
2004	2.47	0.1
2005	2.38	N/A
2006	2.54	

Historical trends show a fairly consistent growth in the Dublin PE (which was the sum of the Ringsend and North Dublin Agglomerations until 2003) when the Sutton Pumping Station was connected to Ringsend. The 9 year period to the end of 2006 covered the domestic, industrial and commercial growth and development period of the celtic tiger.

Future Predictions

Year	**Population Equivalent Ringsend** million (measured)
2007	2.87
2008	>3.00 (incomplete)

The 2007 PE maintained the increasing trends of previous years. Indications from 2008 to date (end November) appear to extend this trend. See plot below.



It is impossible in the current economic climate to predict the future PE growth in the Dublin area.

Requirement 3 – Impacts on Bathing Waters

A number of transitional and coastal water bodies are impacted by tidal excursions of the Ringsend WWTW discharge plume in the far field mixing zone. The perimeters of the Liffey Estuary (Upper and Lower), the Tolka Estuary, Dublin Bay, and the North and South Bull Lagoons are richly resourced with bathing waters whose bathing water quality and ecosystems are extensively monitored under the Bathing Water Regulations. There are 5 EU designated bathing waters in the Dublin area -

- Dollymount Strand (Bathing Zone)
- Sandymount Strand
- Merrion Strand
- Seapoint
- Killiney

6 non-designated bathing waters are monitored at –

- Bull Wall
- Half Moon
- Blackrock
- Sandycove
- Coliemore Harbour
- Corbawn Lane

These are intensively monitored during each bathing season (20 to 25 dates) and less intensively monitored all year by Dublin City Council and Dun Laoire Rathdown County Council. The frequency of monitoring is determined by the legislation, the number of designated and non-designated sites, and the range of parameters required. Monitoring of bathing waters is scheduled annually by both local authorities. Results are returned for the designated bathing sites, for the bathing season, on an annual basis to the EPA.
A Blue Flag is successfully maintained at Dollymount bathing zone.

Evaluation and Assessment

In terms of acute impacts on bathing water quality, microbiological parameters are the most critical effecting human health. During the bathing season, secondary treated effluent at the Ringsend plant receives supplementary treatment with UV light. Under the new Bathing Water Quality Regulations 2008 (SI No.79 of 2008) the key parameters are intestinal enterococci and eschericia coli. These regulations were issued on 20/03/2008 to transpose the EU Bathing Water Directive, 2006. A transitional period is provided with 1992 Regulations revoked from 31/12/2014.

In terms of chronic impacts on bathing water bodies, eutrophication is most frequently reported in nutrient enriched waters. The Liffey Estuary -from Islandbridge weir to Poolbeg Lighthouse, including the River Tolka basin and the South Bull Lagoon were designated as sensitive areas under Urban Waste Water Treatment Regulations, 2001 (S.I.No.254/2001). Standards of 1 mg/l for Total Phosphorus and 10 mg/l for Total Nitrogen were set to apply on 31st.May 2008. One or both parameters were to apply depending on the local situation.

Bathing Water Assessment - 2002 to 2006

A comprehensive report (Interim Report on Retrospective Compliance of Irish Designated Bathing Areas with the EU Bathing Water Directive (2006/7/EC) by Bartholomew Masterson was released in October, 2007. An assessment was made of two 4 year rolling microbiological datasets in the period 2002 – 2006.

Parameters assessed were faecal coliform (interpreted as 100% eschericia coli) and faecal streptococci (interpreted as 100% intestinal enterococci). This provides a conservative estimate of microbiological water quality.

A summary of the 5 Dublin designated bathing waters, abstracted from this report, is tabulated below. A copy of Table 6 for Dublin City Council and Dun Laoire Rathdown County Council is attached. Preliminary indications show Dollymount Bathing Zone maintaining good quality, Sandymount Strand improving from poor to sufficient quality, Merrion Strand maintaining good quality, Seapoint Strand achieving excellent quality and Killiney improving from good to excellent quality over the 2 retrospective periods.

Table 5.

Designated Waters Assessment. Dublin City Council.

2002 to 2006 Monitoring Period (without discounting)

Bathing Area	**Period 2002-2005**	**Period 2003- 2006**	**Water Quality Score**
Dollymount Bathing Zone	Good	Good	140
Sandymount Strand	Poor	Sufficient	2
Merrion Strand	Sufficient	Sufficient	3

Designated Waters Assessment. Dun Laoire Rathdown County Council.

2002 to 2006 Monitoring Period (without discounting)

Bathing Area	**Period 2002-2005**	**Period 2003- 2006**	**Water Quality Score**
Seapoint	Excellent	Excellent	500
Killiney	Excellent	Excellent	230

The scores 0 for Poor Quality, 1 for Sufficient Quality, 10 for Good Quality and 100 for Excellent Quality, given for each period, were added to give the Water Quality (WQ) score.

Interim Report

Retrospective Compliance of Irish Designated Bathing Areas with the EU Bathing Water Directive (2006/7/EC)

by

Bartholomew Masterson

October 2007

Table 6: Irish designated bathing-areas classified according to the EU Bathing Water Directive (2006/7/EC), and derived from faecal coliforms (FC) and faecal streptococci (FS) emumerations for the two two-year assessment periods during the 2002-2006 bathing seasons (sorted by geographical location). The numbers of samples taken in each bathing season are shown, and where discounting has been applied, the numbers and pecentages of samples discounted in each assessment period are shown.

Local Authority	Coastal bathing area		Discounting status			4 yr/2003-2006 Classification	4 yr/2002-2005 Classification
Dublin City	DOLLYMOUNT STRAND		Discounting applied.			Excellent	Excellent
	Bathing season	No. samples	No. seasons	No. samples	No.(%) discounted		
	2002	26	4 (2003-2006)	89	5 (6%)		
	2003	23	4 (2002-2005)	96	4 (4%)		
	2004	21					
	2005	30					
	2006	20					
			Without discounting.			Good	Good
Dublin City	SANDYMOUNT STRAND		Discounting applied.			Good	Sufficient
	Bathing season	No. samples	No. seasons	No. samples	No.(%) discounted		
	2002	24	4 (2003-2006)	75	10 (12%)		
	2003	20	4 (2002-2005)	68	12 (15%)		
	2004	21					
	2005	23					
	2006	21					
			Without discounting.			Sufficient	Poor
Dublin City	MERRION STRAND		Discounting applied.			Good	Good
	Bathing season	No. samples	No. seasons	No. samples	No.(%) discounted		
	2002	24	4 (2003-2006)	76	10 (12%)		
	2003	20	4 (2002-2005)	68	11 (14%)		
	2004	22					
	2005	23					
	2006	21					
			Without discounting.			Sufficient	Sufficient

Table 6: Irish designated bathing-areas classified according to the EU Bathing Water Directive (2006/7/EC), and derived from faecal coliforms (FC) and faecal streptococci (FS) emumerations for the two two-year assessment periods during the 2002-2006 bathing seasons (sorted by geographical location). The numbers of samples taken in each bathing season are shown, and where discounting has been applied, the numbers and pecentages of samples discounted in each assessment period are shown.

Local Authority	Coastal bathing area		Discounting status			4 yr/2003-2006 Classification	4 yr/2002-2005 Classification
DunLaoghaire-Rathdown CC	SEAPOINT		No discounting applied.			Excellent	Excellent
	Bathing season	No. samples					
	2002	24					
	2003	22					
	2004	23					
	2005	24					
	2006	21					
DunLaoghaire-Rathdown CC	KILLINEY		Discounting applied.			Excellent	Excellent
	Bathing season	No. samples	No. seasons	No. samples	No.(%) discounted		
	2002	24	4 (2003-2006)	88	2 (3%)		
	2003	22	4 (2002-2005)	86	2 (3%)		
	2004	23					
	2005	24					
	2006	21					
			Without discounting.			Excellent	Good

Requirement 4 - Impact of Existing and Proposed Primary Discharge; Planning and EIS Requirements

The response to Item 6 outlines why it is felt there are no significant impacts from existing discharges. That response identifies cross compliance with various other regulatory requirements, in addition to using the methodology outlined in Circular L8/08, to support that conclusion.

In the particular case of the primary discharge referred to in this item, the results obtained from the bathing water monitoring carried out at the designated bathing waters on Bull Island are of particular interest insofar as this beach is the nearest to the primary discharge, being approximately 1500 metres away.
These bathing waters have achieved Blue Flag status for two of the past three years which supports our view of there being no significant impact.

Both planning permission and an environmental impact assessment will be required for the extension to the works.

Requirement 5 - Summary of Discharge Modelling

We attach a draft report of a modelling study commissioned by Dublin City Council from the Centre for Water Resources Research, Civil Engineering Department, UCD. This report is in draft form only and any conclusions/recommendations should be treated cautiously insofar as there are several major limitations highlighted within the report itself.

However it is useful as a guidance tool that has the potential to be further developed in the future.

The objective of the report was to investigate the movement of the effluent discharge plume from Ringsend Treatment Works and how it interacts with the tidal/river movements. Various scenarios were modelled to reflect varying concentrations of coliforms within the effluent stream. However, of necessity, some major assumptions had to be made in regard to the background parameters used in the model as the desired level of detailed information was not available.

This report has remained in draft format only. The next step would be to further sensitise some of the global inputs to it so that the output would be more accurate. It was carried out as a two dimensional modelling exercise and would, in the interests of more accurately reflecting real conditions, now require upgrading to develop a three dimensional model.

Some additional modelling may be carried out as part of the studies required in the proposed extension to Ringsend Treatment Works.

Draft Report2 on Water Quality Modelling

for
Dublin City Council Drainage Department

by

Aodh Dowley and Zeinab Bedri
Centre for Water Resources Research (CWRR)
Civil Engineering Department, UCD

April 30, 2007

4 Water Quality Models

The Water Quality of Dublin Bay is modelled in the CWRR using two different approaches: the commonly used "Mass-Balance" approach and the "Random Walk" (or Particle Tracking) Method.

The concept of the mass-balance method is based on the assumption that the mass of a solute is conserved so that the rate at which the volume gains (or loses) mass depends on the difference between the rate at which the mass of substance enters the volume and the rate at which it leaves it.

Mass-balance water quality models can, in general, adequately represent the physico-chemical processes of water quality determinands. They take into account: advection, diffusion, decay, interaction, sources and sinks. Two mass-balance models have been applied to Dublin Bay to estimate coliforms and nitrogen compounds. These are WQFLOW-2D (HR Wallingford UK) and SUBIEF-2D (EDF France). Both models are based on Telemac2d hydrodynamics.

The water quality (or mass transport model) also has an initial condition requiring an initial background concentration if such exists and boundary condition concentrations at open boundaries to maintain the background level. The model then starts at time $t = 0$ with a step change in concentration corresponding to an outfall with a constant load W. At a point in the flow field the concentration will increase from C_0 to $C(t)$ when contaminant reaches that point, and will continue to increase until the processes of mass transport and decay result in a quasi-steady state concentration (quasi because it exhibits an oscillation). This process may take a considerable time. One should continue until successive mean tidal cycle values differ by an insignificant amount (e.g. $1\mu g/l$). This requires 18 tidal cycles in the case of nitrate in the WQFLOW-2D model of Dublin Bay [?].

5 Mass-Balance Model: WQFLOW-2D

This is a finite element depth-averaged water quality model developed and maintained by HR Wallingford [?]. It simulates transport and mixing processes, biochemical interaction of water quality variables, oxygen and nutrient balance, and algal growth. The governing mass-balance equation is the advection-diffusion equation which is solved separately for each pollutant.

$$\frac{\partial(hC)}{\partial t} + \frac{\partial(huC)}{\partial x} + \frac{\partial(hvC)}{\partial y} = \frac{\partial(hD_s\frac{\partial C}{\partial s})}{\partial s} + \frac{\partial(hD_n\frac{\partial C}{\partial n})}{\partial n} - khC - F_c - \frac{L_c}{\Delta_s^2} + \frac{S}{\Delta_s^2} \quad (1)$$

where the symbols represent the following variables;

C	the depth-averaged concentration of a solute kg/m^3
u, v	the depth-averaged components of velocity m/s
D_s	the longitudinal *shearflow* dispersion coefficient m^2/s
D_n	the lateral *turbulent* diffusion coefficient m^2/s
x, y	are Cartesian coordinates in the horizontal plane m
s, n	are intrinsic coordinates parallel and normal to the mean flow, respectively m
t	the time s
h	the water depth m
Δs	the model grid size m
k	a first order decay rate s^{-1}
F_c	the flux of solute between water column and the bed $kg/m^2/s$
L_c	the loading of solute kg/s
S	a source/sink term kg/s

$C(x, y)$ is the unknown.

Extra source/sink terms are included as necessary to describe the interactions between solutes, losses or gains of material due to biochemical reactions, biological activity and physical processes (such as sedimentation).
The model also allows for the addition of ten user defined pollutants. Temperature is not a simulated variable but it is used to calculate coefficient rates and oxygen solubility. The processes of WQFLOW-2D are described in detail below.

5.1 Advection

WQFLOW-2D uses the hydrodynamics of TELEMAC-2D which provides the description of time-varying velocities and water depths. Tracers can be advected using two options: the standard method of characteristics or a hybrid characteristics and centred scheme. With the method of characteristics, a diffusion step is optional, i.e. it can be switched off to study only the advection of the tracer with the current. However, the hybrid characteristics and centred scheme, must include a diffusion step. For the advection of tracers in the current Dublin Bay model, the hybrid characteristics and centred scheme was selected.

5.2 Diffusion

The process of diffusion can be dealt with in three different ways in WQFLOW-2D:

1. It can be entirely neglected, though not usually in practice.
2. It can be calculated isotropically, with a single coefficient that is uniform in time and space.
3. It can be separated into longitudinal (in the direction of current flow) and transverse (at right angles to the flow direction) components.

The actual diffusion coefficients in terms of the x and y axes are calculated from the longitudinal and transverse coefficients as follows:

$$D_x = \frac{(K_{long}u^2 + K_{trans}v^2)}{\sqrt{u^2 + v^2}} \tag{2}$$

$$D_y = \frac{(K_{long}v^2 + K_{trans}u^2)}{\sqrt{u^2 + v^2}} \tag{3}$$

where K_{long}, K_{trans} are the longitudinal and transverse coefficients respectively, h is the water depth in metres, and u, v are the components of the depth-averaged velocity components m/s.

For each water quality variable the diffusion step is calculated separately using an iterative method (the pre-conditioned conjugate gradient approach). For the diffusion of tracers in the water quality model, an isotropic diffusion coefficient was adopted.

5.3 Decay

The decay of organic materials and the nitrification of ammoniacal-nitrogen are all expressed by first order kinetics. The rate of change of a substance due to decay is given by:

$$\frac{dC}{dt} = -kC \tag{4}$$

where k is the reaction rate coefficient. In general, the reaction rate coefficient is expressed as a function of temperature. The usual form is derived from the Arrhenius equation that relates the energy required to initiate a reaction, the temperature and the rate constant. This equation has been reduced to the form:

$$k_\theta = k_{20}\left(1 + \frac{\alpha}{100}\right)^{\theta-20} \tag{5}$$

where k_θ is the reaction rate coefficient at $\theta°C$, k_{20} is the rate constant at $20°C$ and α is the term that controls the rate coefficient's dependence on temperature.

5.4 Representation of Coliforms in WQFLOW-2D

In WQFLOW-2D, colifoms are represented as conservative substance that can decay according to first order kinetics but do not interact with any other substances. The only parameter required to model them is a constant mortality rate expressed as a T_{90} i.e. the time taken for a population to reduce to 10% of its original density. Alternatively a decay rate may be specified. The conversion from a first order decay rate constant $k_{cf}(day^{-1})$ to $T_{90}(inhours)$ is;

$$T_{90} = 24\frac{-ln(0.1)}{k_{cf}} \tag{6}$$

The equation used to calculate coliform concentrations is:

$$\frac{\partial(hCF)}{\partial t} + \frac{\partial(huCF)}{\partial x} + \frac{\partial(hvCF)}{\partial y} = \frac{\partial(hD_s\frac{\partial CF}{\partial s})}{\partial s} + \frac{\partial(hD_n\frac{\partial CF}{\partial n})}{\partial n} - k_{cf}CF - \frac{L_{CF}}{\Delta_s^2} + \frac{S}{\Delta_s^2} \tag{7}$$

where CF = concentration of coliforms in units of $1000cfu/100ml$.

5.5 Point Sources

Water quality loads are input into the model through a loadings file as point sources of discharge. The loads can vary temporally, and can be defined relative to an absolute time (in seconds from the start of the run), relative to a defined datum, or relative to a state of the tide (i.e. high water). When the loads are defined relative to the state of the tide an ASCII file "HWtimes" containing a list with the times of HW should be included.

In the loading file, the location of the discharge points, the effluent discharge and the pollutant loads must be specified. It is also necessary to include a "bearing" for the discharge point normal to the beach waterline. The bearing is used in cases where the element becomes dry due to tidal recession. In such cases, the loads are redirected along the defined bearing until a wet cell is encountered where it is relocated. This treatment insures that the source point of discharge remains continuously in the domain. However, if a source point was placed on a beach (with a bearing other than 90°), it might be constantly relocated down the beach in search of a wet cell. Depending on the distance by which the discharge point is relocated and the computation timestep, accuracy and quality of results might be affected. Therefore it is important to carefully locate the source point in question, based on the time-varying water depths produced by TELEMAC-2D.

5.6 Initial Conditions

Values of initial initial conditions can be directly specified in WQFLOW-2D. All concentrations of water quality variables are set to zero by default with the exception of salinity which is set to $30.0ppt$. For the water quality model of Dublin Bay, the initial conditions for the water quality variables concerned were set to the following values:
INITIAL COLIFORMS: $0.0thousands/100ml$,

5.7 Boundary Conditions

Similar to the initial conditions of the water quality variables, values of boundary conditions can also be directly specified in WQFLOW-2D. Again all boundary concentrations are set to zero by default (except salinity which is set to $30.0ppt$). Boundary condition concentrations of the water quality variables were the same as those of the initial conditions. This has proven to be essential in order to gain stability in the solution and to accelerate convergence to the quasi-steady state. The boundary conditions for the water quality variables concerned were:
BOUNDARY COLIFORMS $0.0thousands/100ml$,

5.8 Inputs and Outputs to WQFLOW-2D

WQFLOW-2D is used in conjunction with the TELEMAC-2D flow modelling system and takes as one of its inputs the description of time-varying flow velocities and water depths which are produced by TELEMAC-2D. Similar to TELEMAC-2D, WQFLOW-2D works on the unstructured triangular grid (provided by the hydrodynamic results file) and the equations are solved using a finite element method.

WQFLOW-2D uses the boundary conditions file and the hydrodynamics result file from TELEMAC-2D. Therefore, it can only produce water quality results in the same domain as that used by TELEMAC-2D.

5.9 Other Features and Limitations of WQFLOW-2D

An important feature of WQFLOW-2D is that it has the possibility of speeding up computation by providing the choice not to take into account a certain set of processes. There are four main processes in WQFLOW-2D :"COLIFORMS" which specifies whether coliforms are simulated, "ECOSYSTEM" which specifies whether the water quality processes related to algae and detritus are calculated, "REACTIONS" which specifies whether the oxygen balance processes are calculated, and "SETTLING" specifies whether particulate matter is permitted to deposit on or be eroded from the bed.

Some optional files in WQLFOW-2D include:

1. a file containing the names of the files that specify the initial conditions for the water quality parameters.

2. a file containing a list of values relating to the light attenuation of the water column at each node in the mesh.

3. a previous computation file if the current simulation is a continuation of a previous run.

4. an ASCII format file which lists the times of all high waters occurring within the TELEMAC-2D simulation period.

The output file is a binary file in the TELEMAC-2D SERAPHIN format. The output file can then be viewed by the RUBENS graphical interface post-processor.

Some of the limitations of WQFLOW-2D are:

1. It cannot be used to model pollutants entering the domain through inflow boundaries.

2. It has a number of features that are hard-coded in the programme and cannot be modified by the user e.g. the minimum water *depth* = $0.01m$.

3. elements with water depth less than this value are considered dry and outfalls in dry elements are relocated along prescribed bearing.

4. It cannot account for diurnal variation in coliforms decay rates.

5. The user has no control over the model processes i.e. access to the code is absolutely denied.

In order to make predictions of water quality, the model must first be calibrated using measured field data. The general approach is to use a historical data set consisting of an imposed load and the response to that load as seen in the field observations of the concentration. The following data sets were collected by/made available to the authors.

1. Measurements of effluent flow and water quality at the Ringsend Treatment Plant (January 2004-December 2005) taken by Celtic Anglian Water (CAW) Ltd. and provided to the authors by Dublin City Council.

2. A water quality sampling programme carried out by the authors along with staff in the Departments of Civil Engineering and Biochemistry in UCD. The measurements were made in Dublin Bay, on days with mean spring and neap tides in 2004 and 2005. Coliform Bacteria, nitrates and phosphates were analysed for the water samples taken every 20 minutes (Chapter [??]).

3. Some data was compiled by University College of North Wales during the period 1972–1976 [?] in a survey of the environmental conditions of Dublin Bay and the Liffey Estuary.

4. Further data was collected by the Environmental Research Unit(1992) for the Dublin Bay Water Quality Management Plan [?, 9, ?].

5. Further data was compiled from a study conducted by Brennan M.T. et al (1994) [?] involving the modelling of particulate nutrients in Dublin Bay by Dowley, A. and Hussey, M.

6. Flow and nutrient inputs from nine rivers discharging into the Port area (and ultimately into Dublin Bay) were presented by Wilson J.(2003) [?].

5.10 Data for the Coliform Model

5.10.1 Loads

The effluent from Ringsend STW is the major source of coliforms to Dublin Bay. Another source of coliforms is the riverine pollution from the Liffey catchment. However examination of the coliform concentrations in the estuary shows that this contribution is less than 1% of the total load to the Bay and therefore riverine input of coliform bacteria was ignored. Therefore only Item 1 of the data list above was used to provide the load to the Dublin Bay coliform model.

From the provided measurements (Item 1), the concentration of Faecal Coliforms was $231,300cfu/100ml$ on 28^{th} September, 2004 and $66,000cfu/100ml$ on the 14^{th} July, 2005.

From the daily flow data (Item 1), the flows corresponding to the concentrations on those dates were extracted. From the flow and the coliform bacteria concentrations, coliform loads were estimated and used as input to the model, taking into account the dilution with the cooling water in the effluent channel.

5.10.2 Responses

Item 2 of the data list was used in the calibration to provide the response to the water quality input loads. The sampling programme consisted of six excursions in which water samples from the Bay and Estuary were taken during spring and neap tidal conditions.

In order to calibrate the spring and neap tide Coliform models, measurements of E.Coli taken on 28^{th} of September, 2004 (Spring tide) and 14^{th} July, 2005 (Neap tide) were used.

Water quality samples on 28^{th} September 2004 were taken from a boat every $20min$ at a point approximately $600m$ north east of the North Bull Lighthouse (Point S in Figure 1).

For the neap tide model, measurements on the 14^{th} July 2005 were taken at two points which lie parallel to the North Bull Island (Points N1 and N2 in Figure 1). The sampling frequency at each point was $40min$.

At the Ringsend Treatment Works, the only coliform class measured in the sewage effluent is faecal coliform whereas E.Coli was the measured bacteriological class at the sampling points in Item 2.

Due to the scarcity of data for the two new microbial classes, the authors adopted some scientifically acceptable approximations in the computation of inputs loads to Dublin Bay. It was assumed that a conversion factor 1.0 applies between Faecal coliform and E.Coli, that is Faecal coliform concentrations can be used for E.Coli [?, ?, ?].

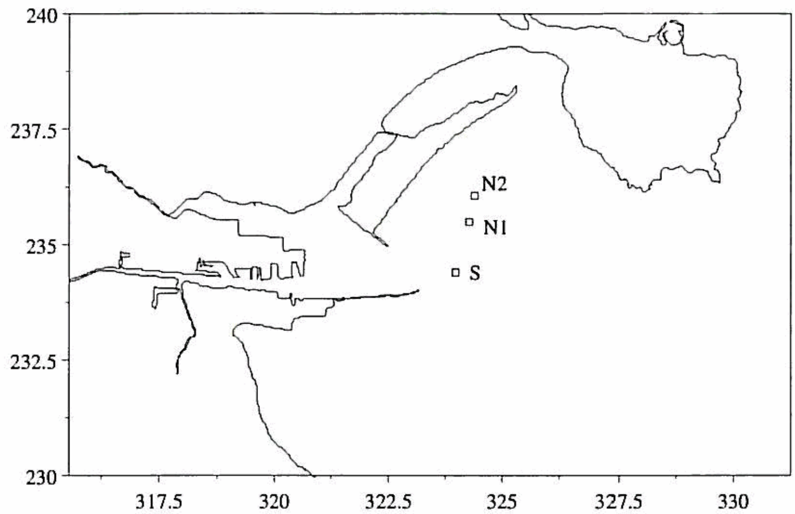


Figure 1: Location of Measurement Points in Dublin Bay used in the calibration of the Water Quality Model.

5.11 Calibration Results

The process of parameter estimation involved running the model using its default values of parameters in order to develop a crude a priori estimate of parameters. Then based on literature a refined range of controlling parameters was estimated. Finally the water quality model was used to simulate the input-output response of the system using carefully selected representative parameter sets. The model output was then compared to water quality measurements and the combinations of parameters that present the best fit were adopted. In those calibration simulations, model runs were extended until a quasi-steady state (repeated pattern) was reached. Model runs revealed that the Coliforms Model reached a quasi- steady state after 9 tidal cycles whereas the Nitrogen Model required 18 cycles to reach an *almost* repeated pattern. The Nitrogen Model was run until the peak values of successive tidal cycles varied by about ($1.5\mu g/l$). It took a significantly longer time than the Coliform Model to reach a quasi steady state because of the interactions between nitrogen compounds in the model.

5.11.1 Coliform Model

Before attempting to calibrate the water quality model, it was necessary to identify the model effective/controlling parameters. The controlling parameter of the coliform model was the decay rate [?, ?, ?]. Decay or die-off rates are physical parameters that ideally need not be calibrated. The determination of die-off rates of bacteria can be carried out in-situ or in the laboratory, see [?, ?] but in both cases it involves a difficult procedure that involves considerable uncertainty (rates measured in the laboratory may be very different from those determined in the field). Furthermore, there are uncertainties associated with the measurements of concentration in single sample. As a result, the decay rate of coliforms is commonly treated as a parameter that requires adjustment.

A second parameter that requires calibration in the coliform model is the diffusion coefficient of coliform bacteria.

Spring Tide Model The sensitivity of the water quality model to the diffusion coefficient was tested by performing a number of runs on the spring tide coliform model in which the isotropic diffusion coefficient (from which the actual diffusion coefficient is computed according to equations 2 and 3) was varied. In those runs, the decay rate of coliform bacteria was kept constant at a T_{90} of $24hrs$ and values of 5, 10 and 20 for the isotropic coefficient were used. For each of the three cases, the spring tide model was run for 9 tidal cycles to ensure that a quasi-steady state was reached.

In order to compare the effect of varying the diffusion coefficient on the coliform concentration, the time variation of coliform concentration was plotted for the sampling point S located north east of the North Bull lighthouse (figure 1). Figure 2 demonstrates

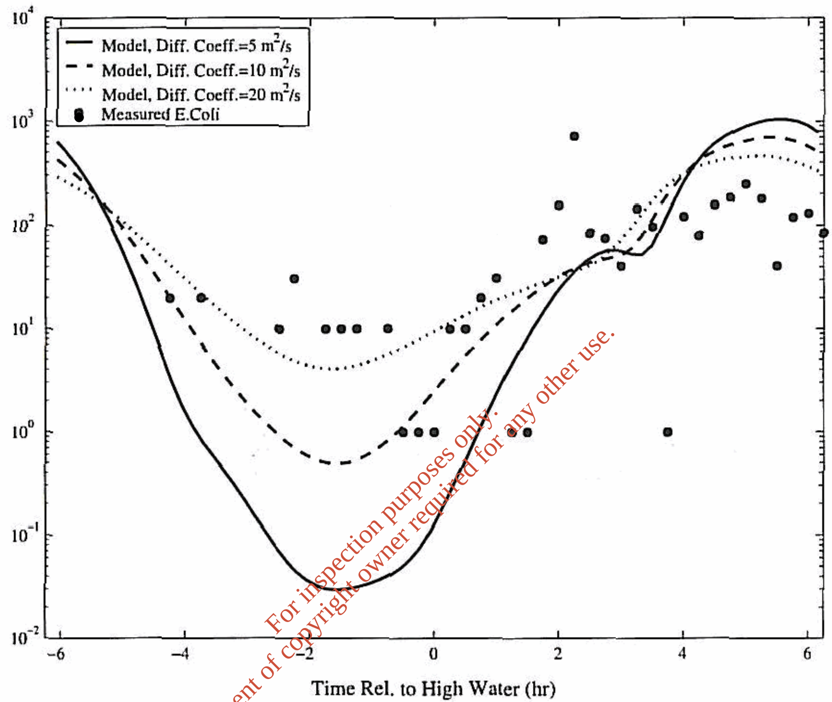


Figure 2: Calibration of Spring Tide Coliform Model: Varying diffusion coefficient

a decreasing E.Coli concentration during the flood tide reaching minimum concentration around the time of high water and then increases again with the ebbing tide to peak around time of low water. Comparison of diffusion coefficients clearly displays an inverse relationship between the diffusion coefficient and concentrations of E.Coli. Note that the simulation using a diffusion coefficient = $20m^2/s$ presents the best fit to observations at sampling point S.

The first order decay process of coliform decay is controlled in the model by the T_{90} parameter defined in Equation 6 above. To enable the choice of a suitable decay rate, the model was run using several values of T_{90}: 18, 24, 30 and $36hrs$. In each case, the model was run for 9 tidal cycles to ensure that a repeated pattern was reached.

In order to compare the effect of varying the decay rate on the coliform concentration, the time variation of coliform concentration (figure 3) was plotted at the sampling point S located north east of the North Bull lighthouse (figure1).

Figure 3 demonstrates a decreasing E.Coli concentration during the flood tide reaching minimum concentration around the time of high water and then increases again with

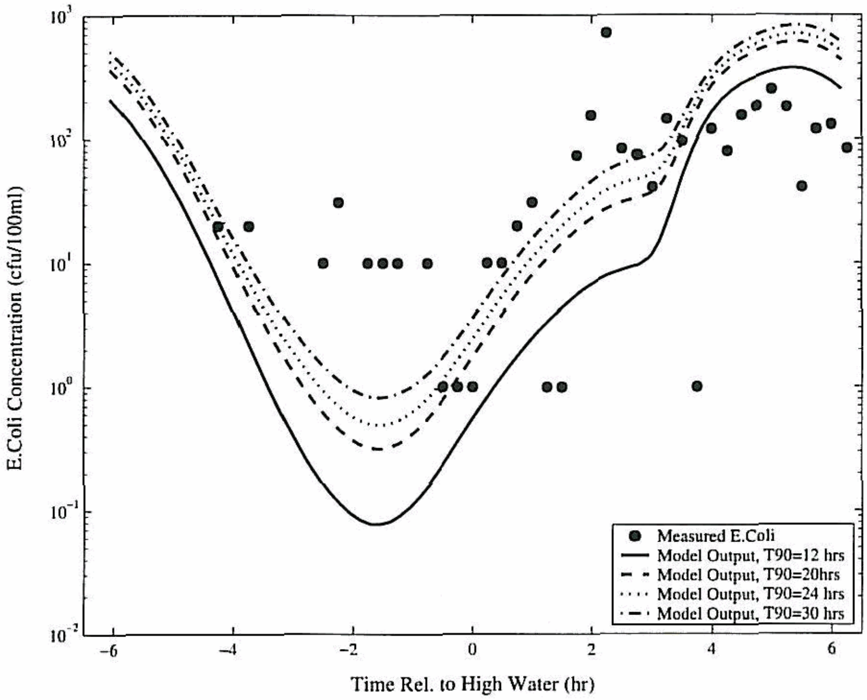


Figure 3: Calibration of Spring Tide Coliform Model: Varying decay rate

the ebbing tide and peaks around time of low water. Comparison of decay rates clearly demonstrates that the concentration of E.Coli increases with the increase of T_{90}, i.e. the concentration increases with the decrease of coliform decay rate. The best results were displayed when using a T_{90} of $30hrs$. Based on the results of the analysis shown above, an isotropic diffusion coefficient of $20m^2/s$ and a T_{90} of $30hrs$ were chosen.

6 Ecoli Distributions corresponding to 4 Loads from Ringsend Effluent Treatment Plant

Numerical Model Estimates of the Distributions of Ecoli were obtained for 4 separate Ringsend effluent loadings, using Telemac2D Hydrodynamics and Water Quality Model WQ2D presented for 4 Scenarios. The distinguishing feature between the four cases is concentration of coliform bacteria in the Ringsend outfall effluent , which has the following four values:

1. $100,000cfu/100ml$
2. $20,000cfu/100ml$
3. $10,000cfu/100ml$
4. $5,000cfu/100ml$

The values of the variables common to all four cases are as follows:

- Low river flow in the Liffey estuary $4.0m^3/s$

- Ringsend effluent flow $500,000m^3/day$, or $5.79m^3/s$
- ESB warm cooling water dilution flow $4.5m^3/s$
- Hydrodynamics corresponding to Mean Spring Tide for all 4 cases
- Calm weather, i.e. no wind
- Isotropic diffusion coefficient $20m^2/s$
- T_{90} ecoli of $30hrs$

See 4 separate files for the results of these simulations figsone.pdf - figsfour.pdf

6.1 Necessity for a Three-Dimensional Model

For problems with insignificant stratification in the near-field, two-dimensional depth averaged calculation methods are usually suitable. With some diffusion methods, it is possible to calculate the spreading of pollutants fairly reliably in the far-field where mean flow and turbulence are no longer influenced by the discharge (Rodi,1993)[?].

In the near-field of a buoyant discharge outlet, the vertical mixing is not strong enough to force the vertical homogeneity of water. Then a three-dimensional numerical model or a physical model is needed in order to represent the buoyancy effects in the fluid (Darras, et al)[?].

In the vicinity of the ESB outfall, a strong temperature and concentration field develops which means that hydrodynamic and water quality simulations using two-dimensional depth-averaged models are unsuitable. Therefore in such a case, a three-dimensional model is essential in order to adequately model the hydrodynamic and water quality processes.

The hydrodynamic model TELEMAC-3D was thus used to simulate the hydrodynamics of the Liffey Estuary where the ESB thermal generating station at Poolbeg abstracts cooling water from the Liffey Estuary, raises its temperature and discharges it to an open channel where it is joined by the effluent from Ringsend Wastewater Treatment Works and is discharged at the Poolbeg outfall to the estuary. This results in a buoyant (warm) layer of effluent on the surface of the estuary. It is an active tracer in two senses as it interferes with the hydrodynamics because of its density which is different from the ambient water in the estuary by reason of its higher temperature and lower salinity. The flow is stratified to a greater or lesser degree depending on the state of the tide, weather conditions.

SUBIEF-3D may be used to model faecal indicator organisms in these conditions. The coliforms behave as a passive tracer in the effluent, i.e. they are transported over the stratified layers and therefore a 2D depth averaged model cannot not properly simulate their transport.

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Modelling of Ringsend Discharge

Effluent Concentration $5,000cfu/100ml$

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Contents

List of Figures

1 Ecoli Distributions corresponding to 4 Loads from Ringsend Effluent Treatment Plant

Numerical Model Estimates of the Distributions of Ecoli were obtained for 4 separate Ringsend effluent loadings, using Telemac2D Hydrodynamics and Water Quality Model WQ2D presented for 4 Scenarios. The distinguishing feature between the four cases is concentration of coliform bacteria in the Ringsend outfall effluent , which has the following four values:

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- Hydrodynamics corresponding to Mean Spring Tide for all 4 cases
- Calm weather, i.e. no wind
- Isotropic diffusion coefficient $20 m^2/s$
- T_{90} ecoli of $30 hrs$

1.1 EColi Distributions/Effluent Conc. 5000cfu/100ml

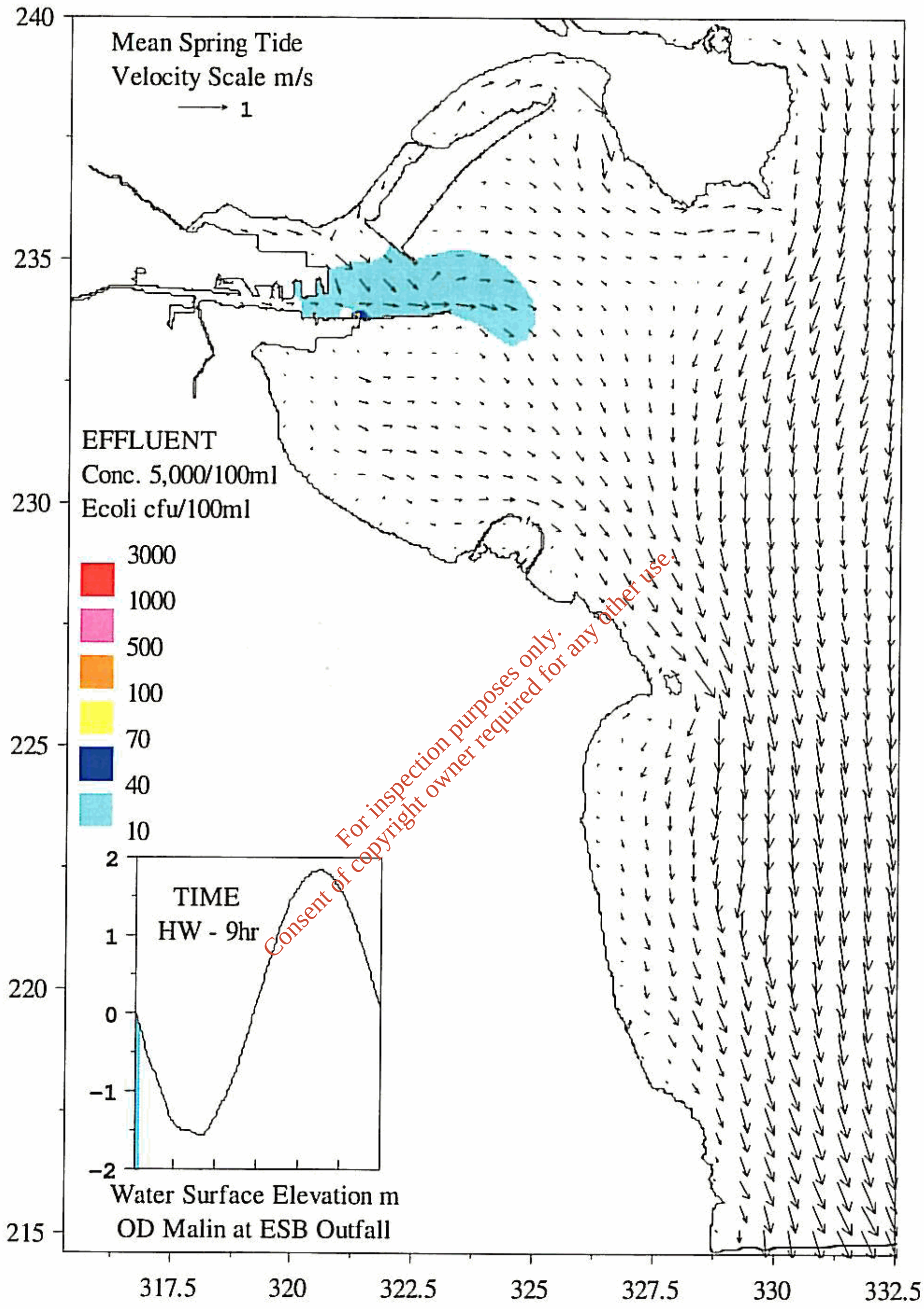

Figure 1: 9 Hours before High Water of Mean Spring Tide

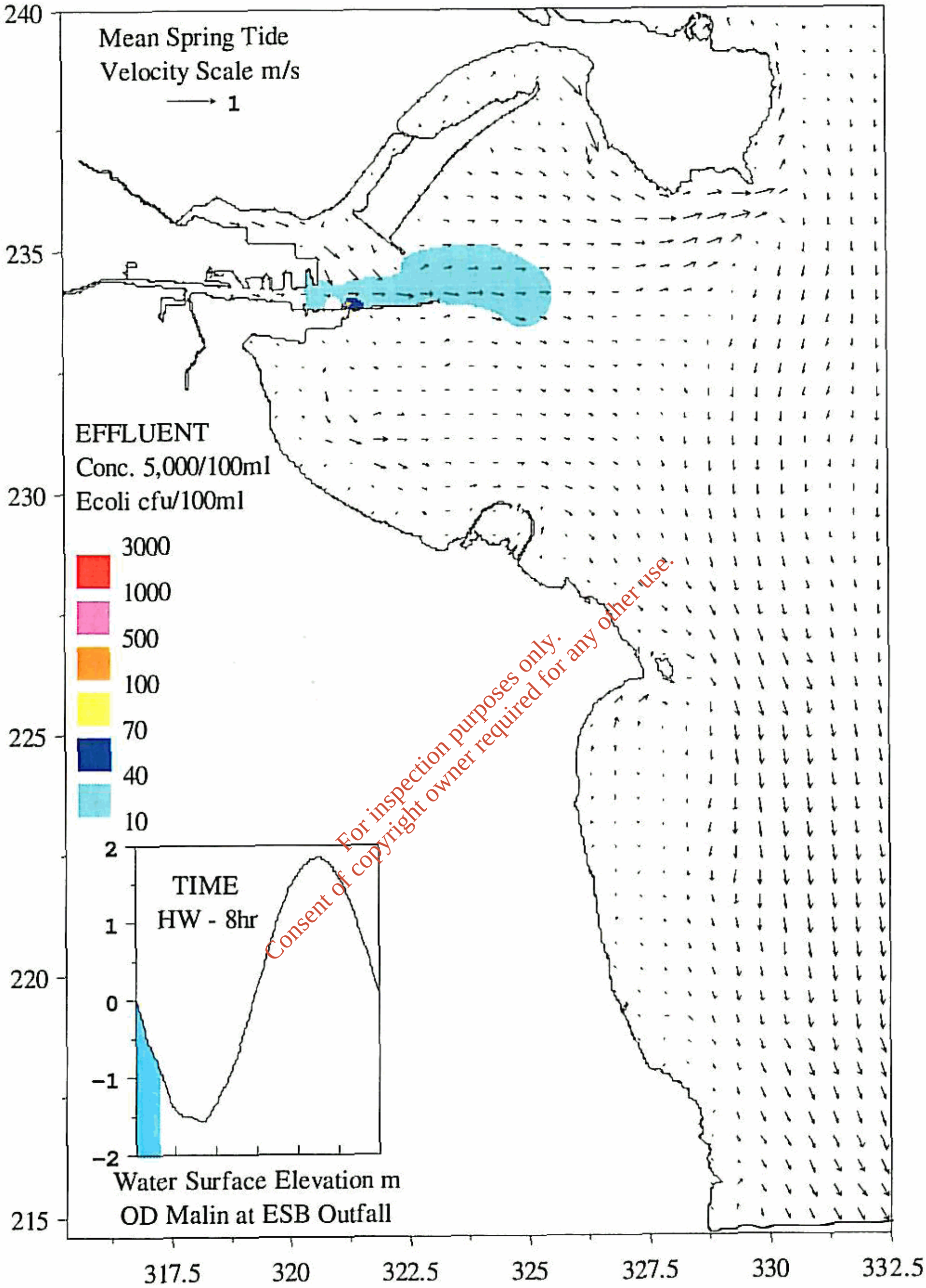

Figure 2: 8 Hours before High Water of Mean Spring Tide

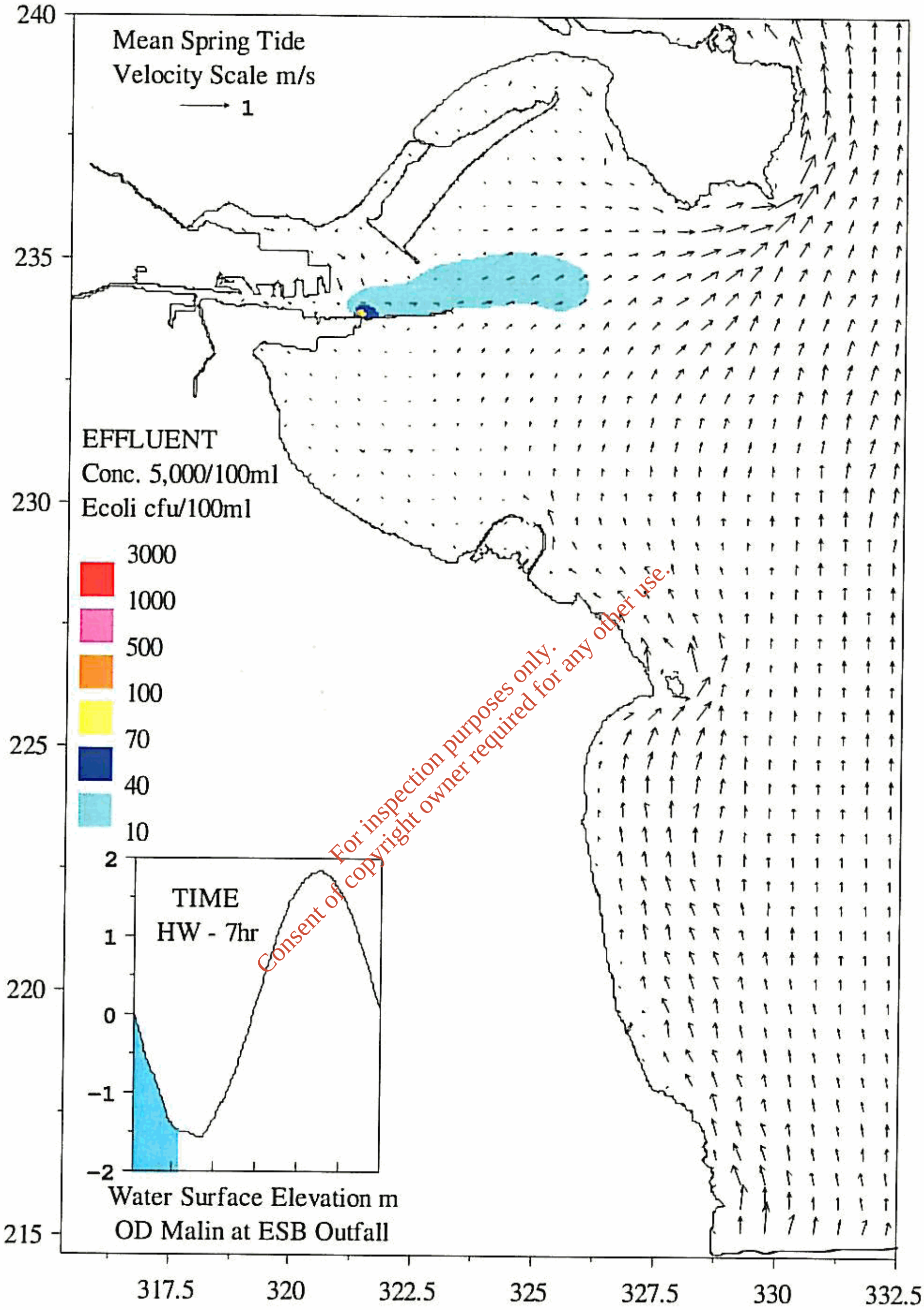

Figure 3: 7 Hours before High Water of Mean Spring Tide

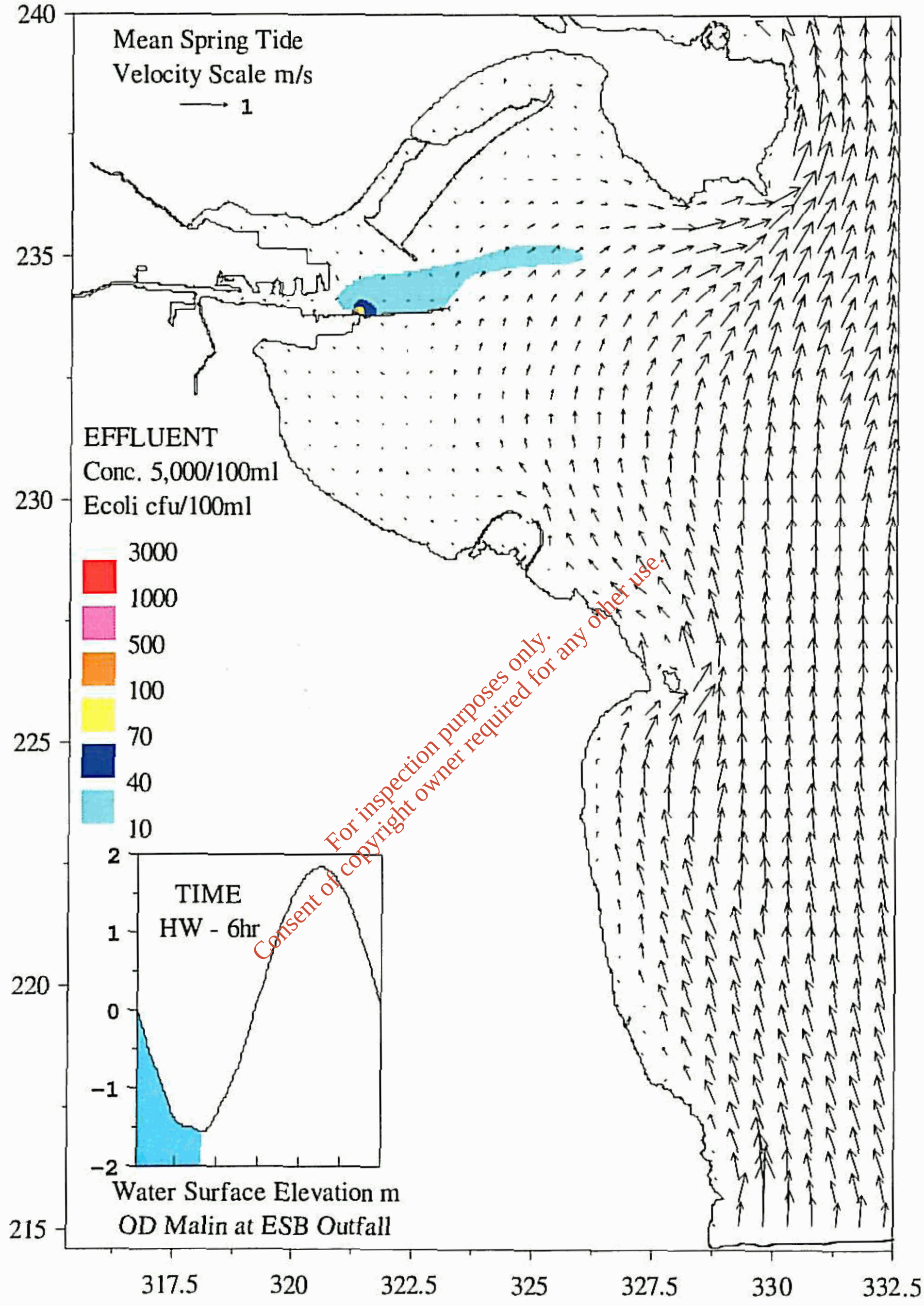

Figure 4: 6 Hours before High Water of Mean Spring Tide

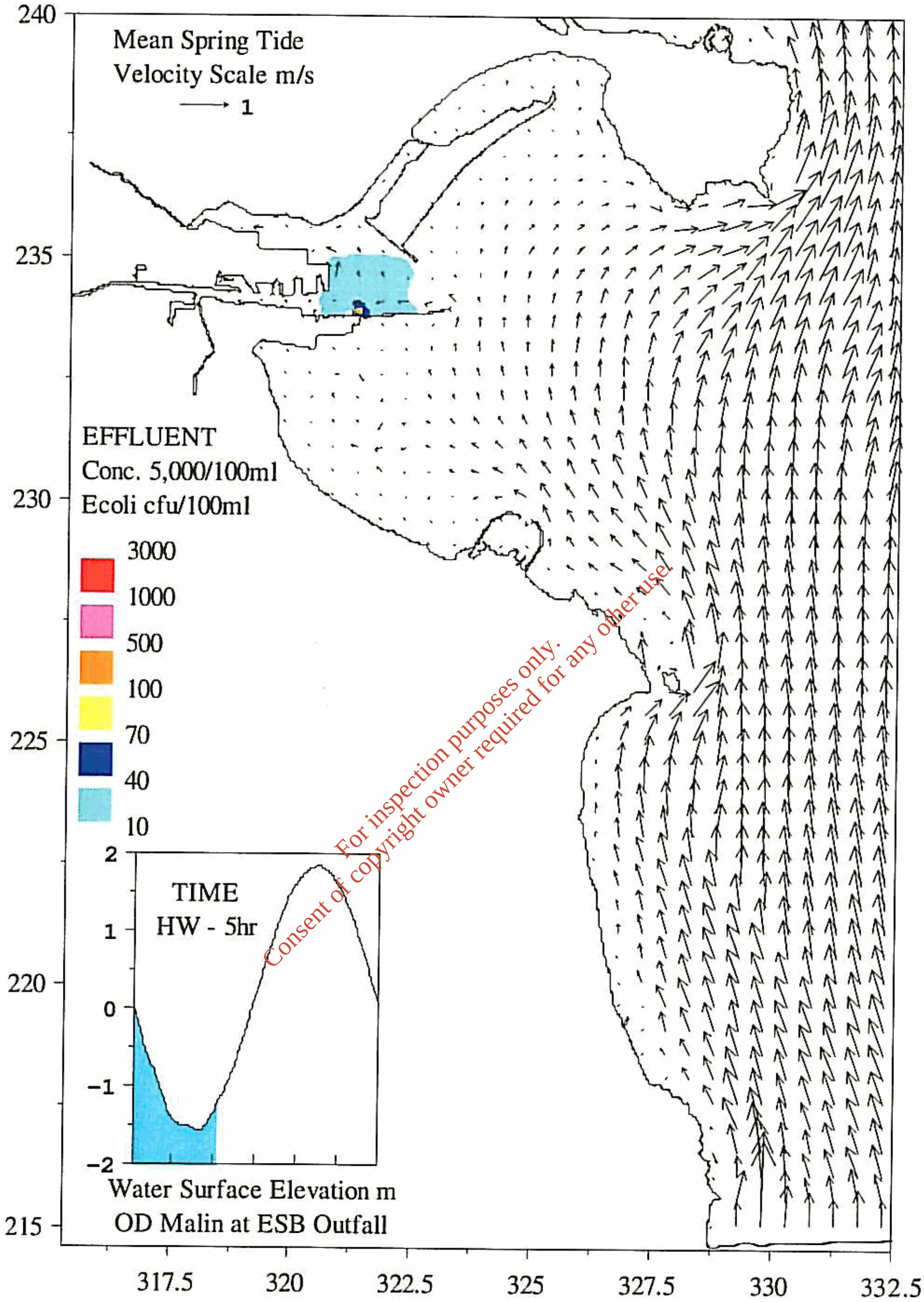

Figure 5: 5 Hours before High Water of Mean Spring Tide

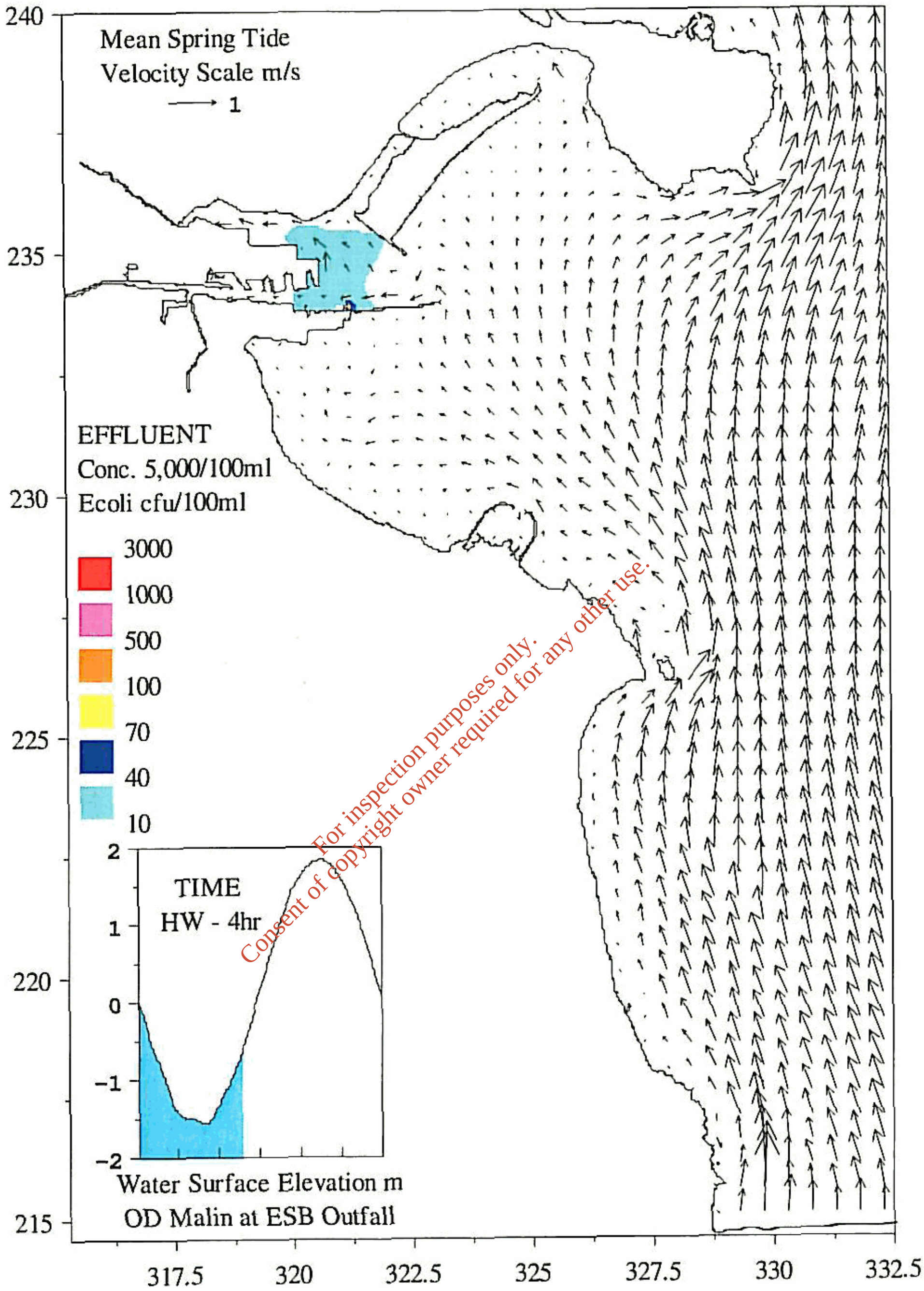

Figure 6: 4 Hours before High Water of Mean Spring Tide

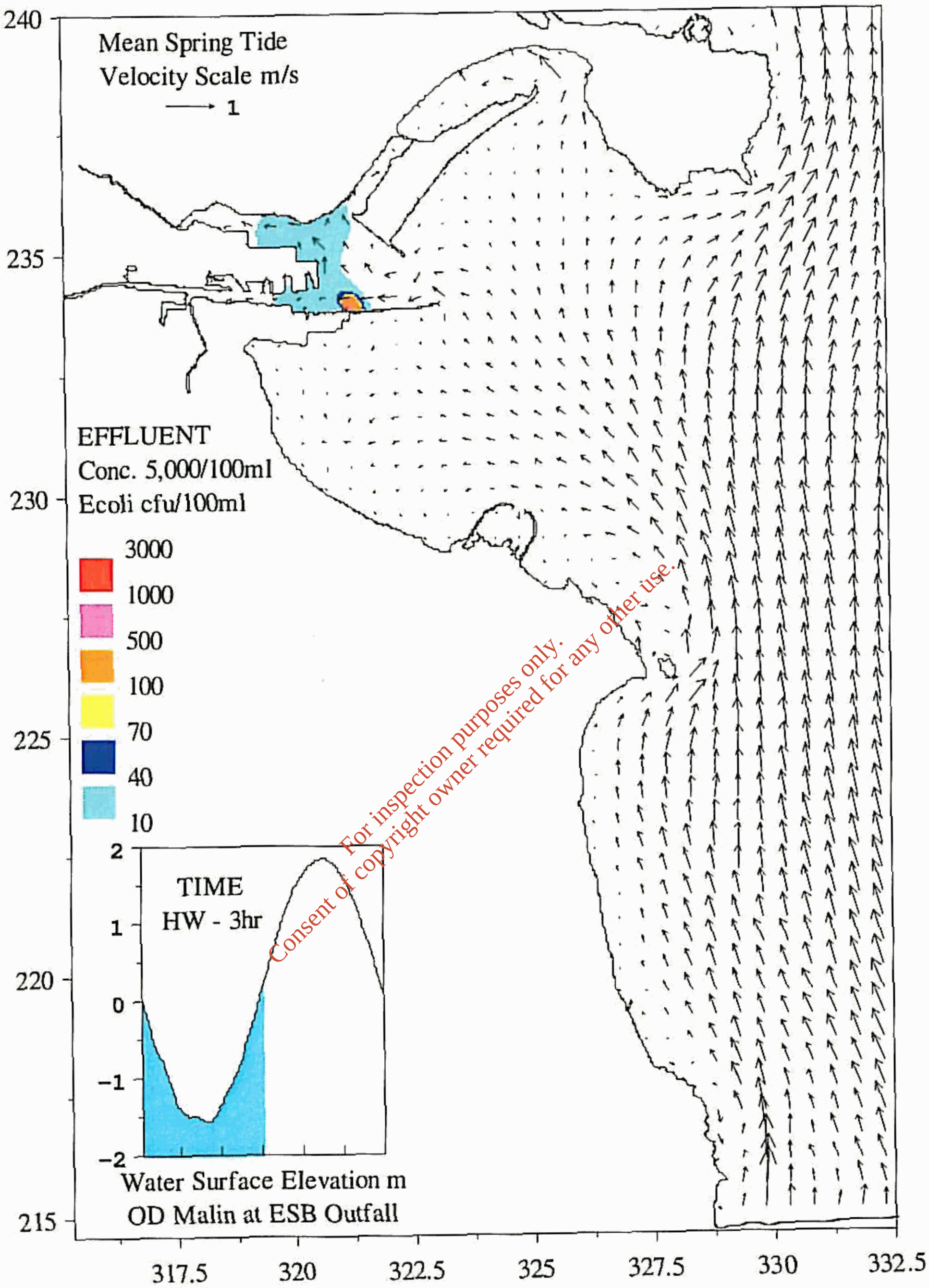

Figure 7: 3 Hours before High Water of Mean Spring Tide

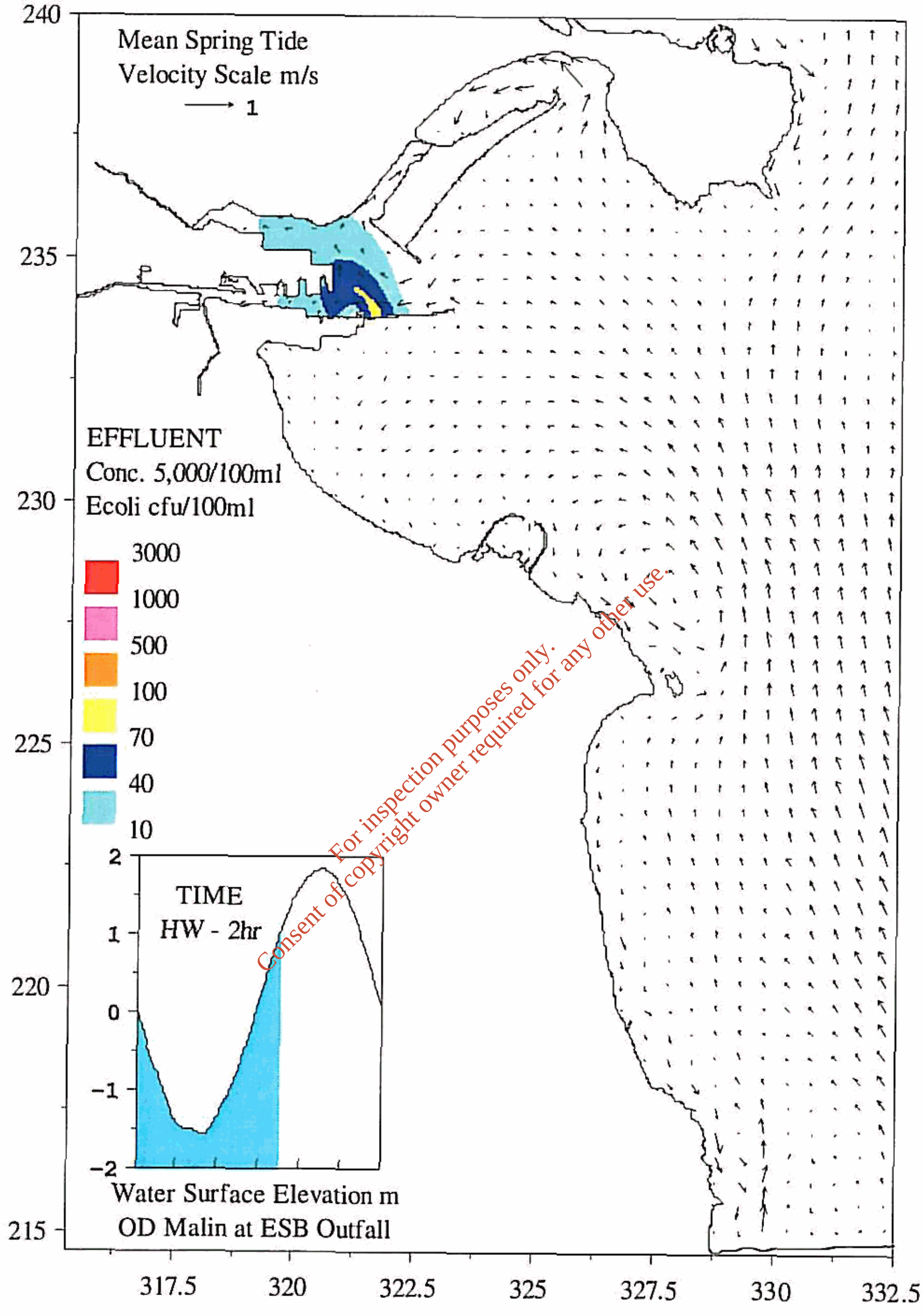

Figure 8: 2 Hours before High Water of Mean Spring Tide

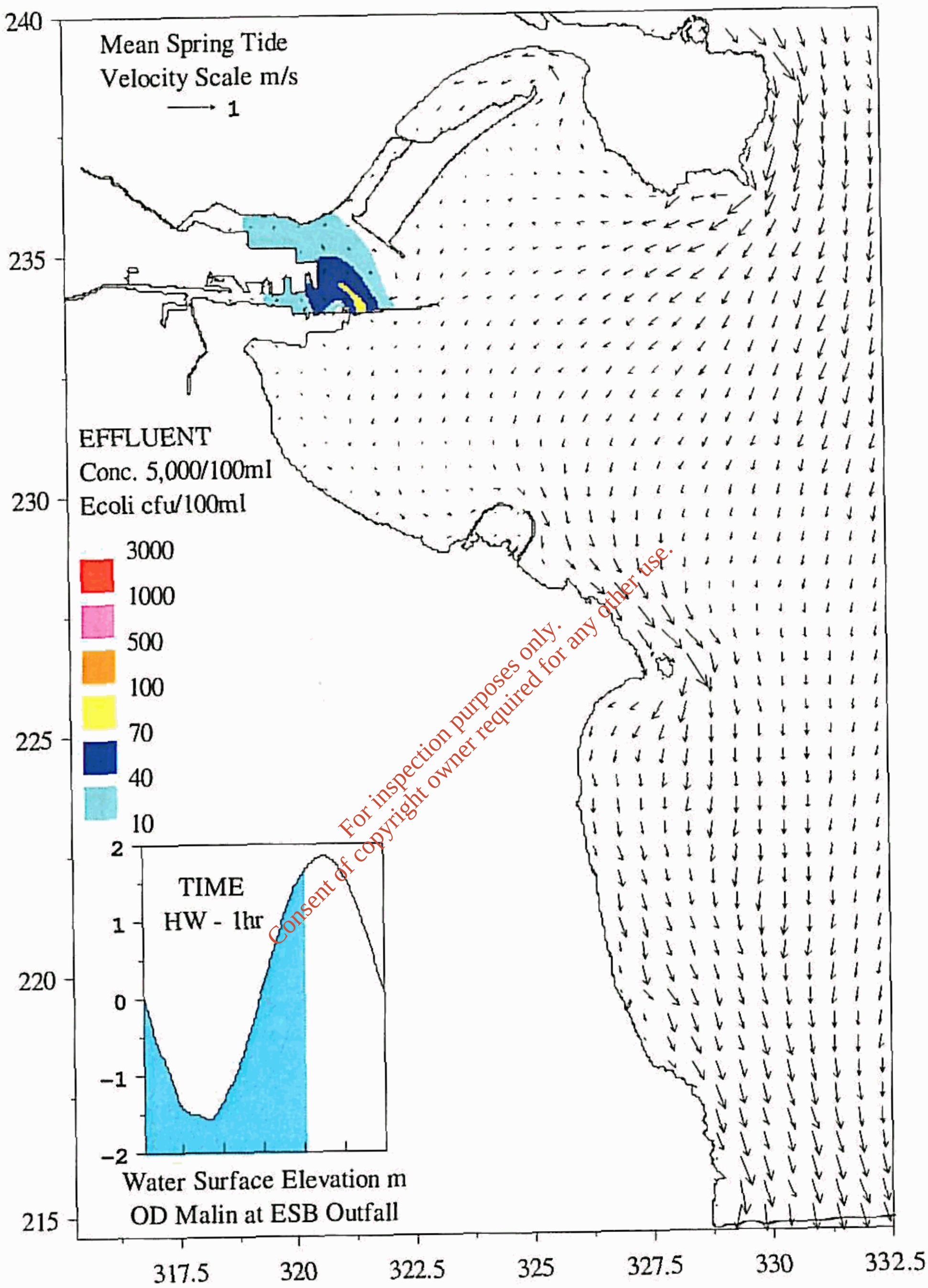

Figure 9: 1 Hour before High Water of Mean Spring Tide

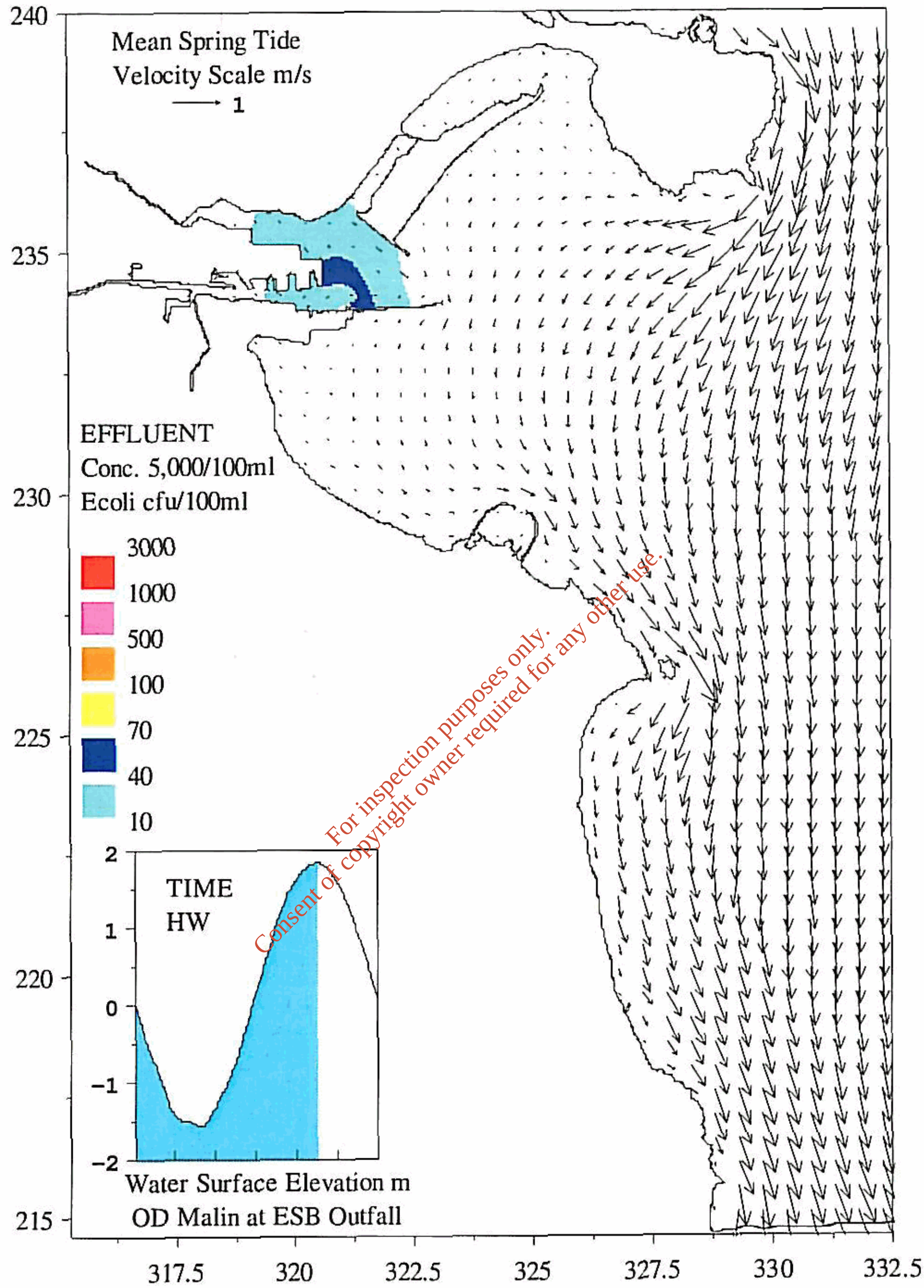

Figure 10: High Water of Mean Spring Tide

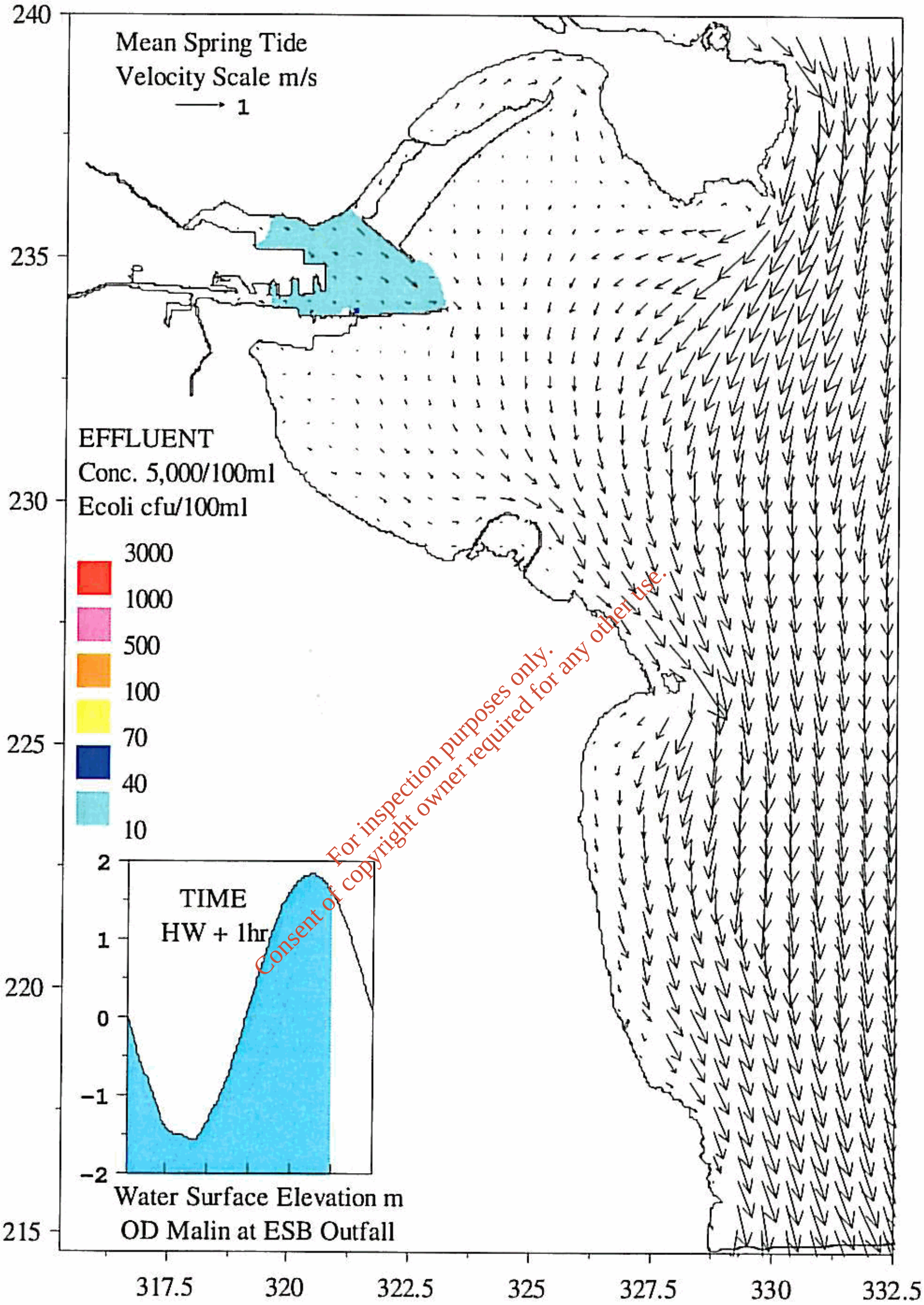

Figure 11: 1 Hour after High Water of Mean Spring Tide

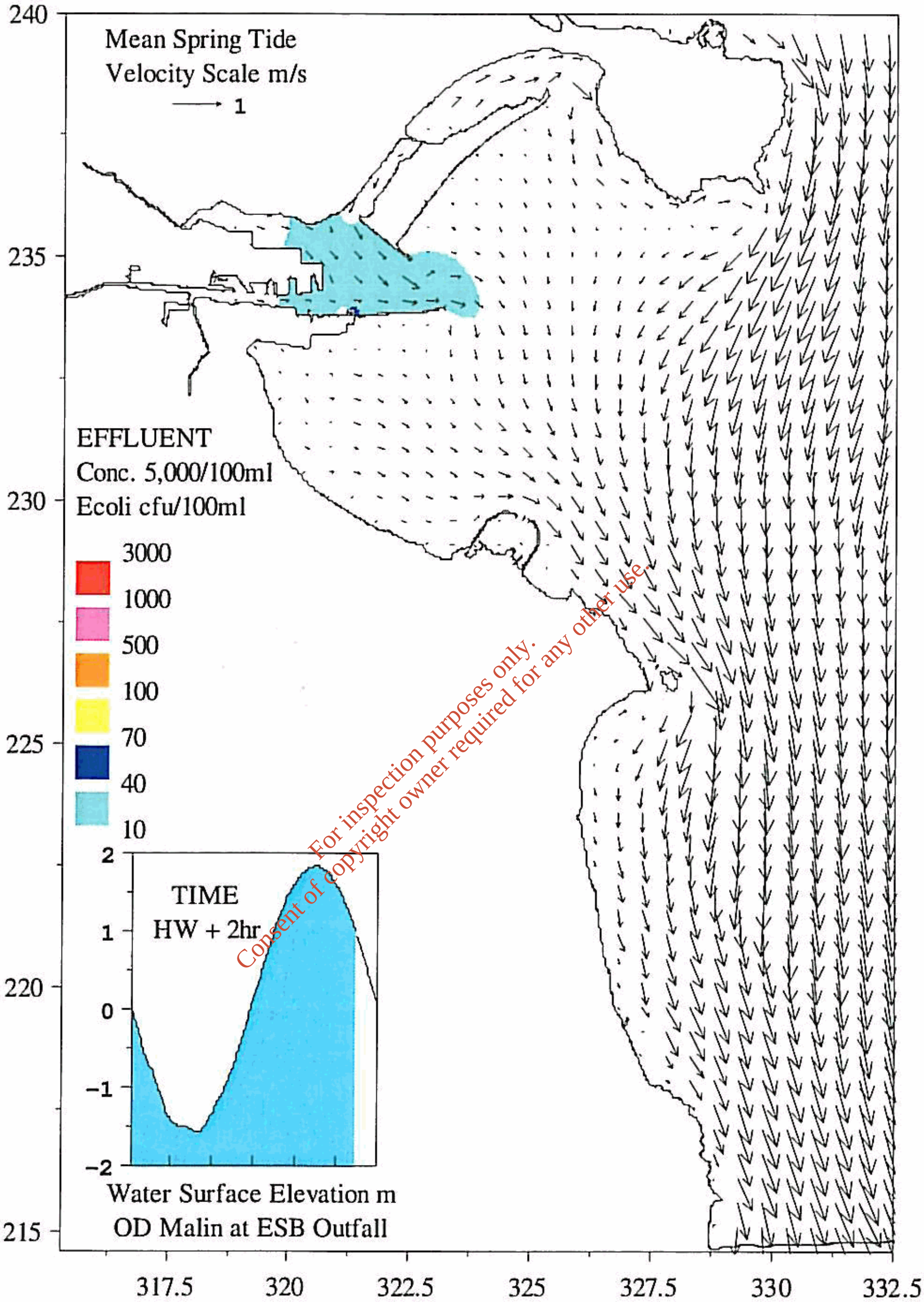

Figure 12: 2 Hours after High Water of Mean Spring Tide

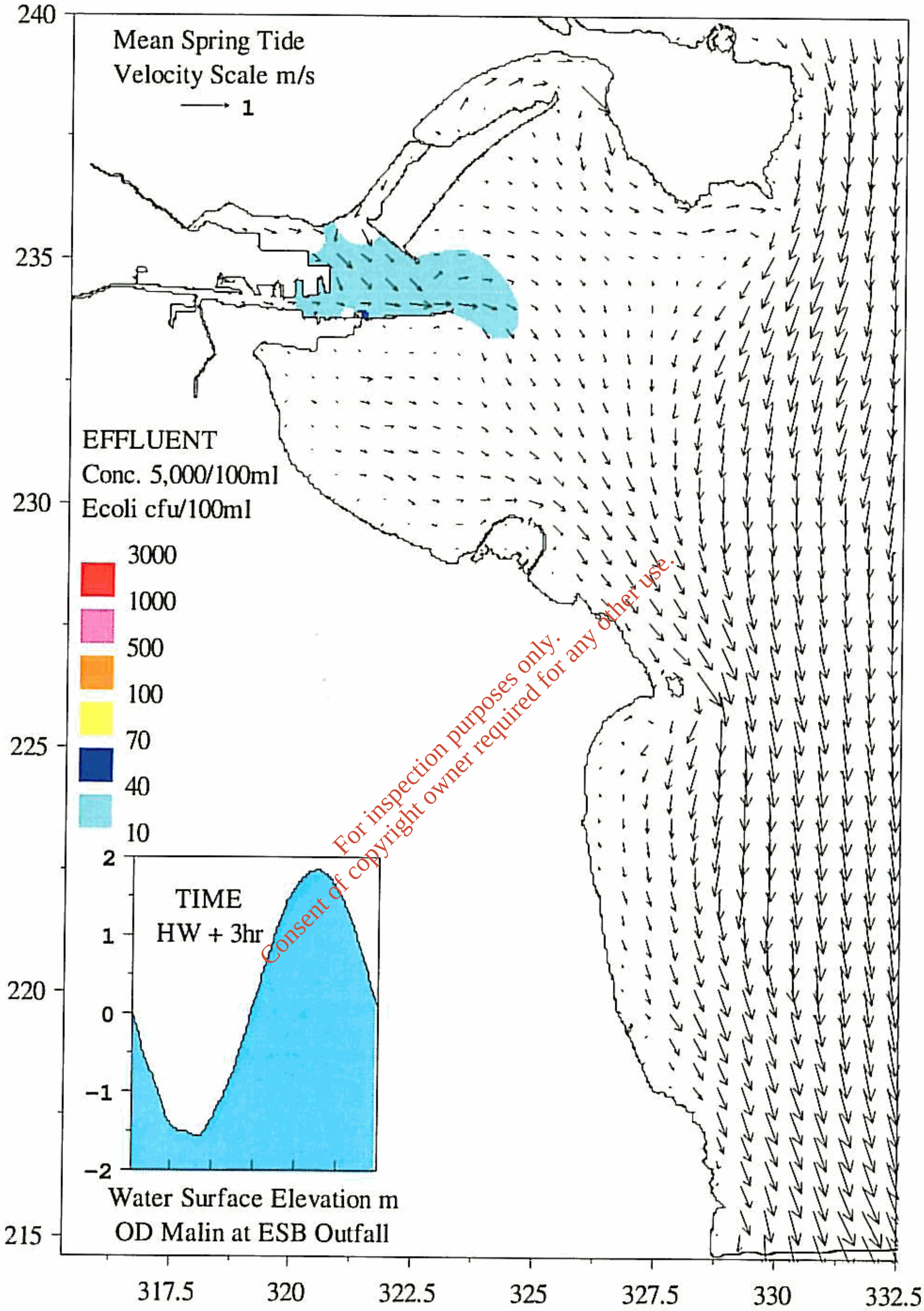

Figure 13: 3 Hours after High Water of Mean Spring Tide