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Fate and transport of particles in estuaries

Numerical modelling for bathing water enterococci estimation in the Severn estuary

Science report: SC000002/SR4

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Steve Killeen

Head of Science

Report Context

The overall aim of this project is to assess the impact of distant sources of faecal indicator organisms, specifically enterococci species of bacteria, on bathing beach compliance sites within a highly turbid and high energy estuarine environment. The final experimental design emerged after discussion with Agency personnel and a project steering group that included water company and Scottish Environment Protection Agency (SEPA) personnel, as well as Environment Agency staff. The total project effort can be split into three principal tasks that almost form stand alone studies.

1. Estimating bacterial inputs to the estuary from rivers (*n*=29) and marine sources (*n*=34) using a modelling approach grounded in past Centre for Research into Environmental and Health (CREH) empirical studies, which involved 'ground truth' data on enterococci concentrations and land use from 100 subcatchments;

2. Defining decay rates of enterococci under highly turbid conditions by conducting some 40 microcosm experiments on water derived from characteristic sampling points in the Seven estuary. These experiments were conducted under both simulated daylight and in the dark. In addition, investigating sediment characteristics by conducting settlement experiments.

3. Developing a hydrodynamic water quality model using data derived from 1 and 2 as inputs. The model incorporates both variable inputs and real-time decay rates for enterococci at key locations in the estuary and was validated with empirical field data that was acquired in the summer of 2001.

Overall, the study presents the first attempt at estimating bacterial 'inputs' to a major estuary at a regional level, the first attempt to define and quantify the environmental controls on enterococci survival in estuarine waters and the first attempt to develop a coastal hydrodynamic water quality model that incorporates a dynamic 'real-time' T_{90} value.

The overall approach offesr the potential for regional scale 'profiling' of recreational waters as suggested by the World Health Organization (WHO, 2003) and the Council of the European Communities (CEC, 2002). It also allows for 'real time' prediction of water quality as a beach management tool, as suggested by the WHO (2003) and by the Department for Food, Environment and Rural Affairs in recent negotiations regarding the revision of EU Directive 76/160/EEC.

This volume (Volume IV) presents in detail the results of the third task (numerical modelling). Volume I addresses the overall objectives by presenting an overview, summary of results and conclusions from the entire project. Volume II presents the results of the first task (estimating the enterococci inputs) and Volume III presents the results of the second task (laboratory experiments).

This was an ambitious project from the outset and many lessons have been learned in its execution. These lessons, as well as identified research gaps, are presented in Volume I.

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1. Introduction

This volume presents the numerical modelling of enterococci concentrations in the Severn estuary and at the identified bathing water compliance locations. It details the methods developed for describing the fate of enterococci organisms and describes the hydrodynamic and sedimentation processes that are the principal transport mechanisms for these organisms. The modelling utilises the enterococci input data and the empirical formulae obtained from the field and analytical studies described in Volumes II and III of this report.

The concentration of faecal indicator organisms in the coastal environment is influenced by many physical, chemical and biological factors, including sediments in the water column and on the seabed. However, there is currently a lack of understanding about the relationships between the concentration of faecal indicator bacteria and the transported sediment. Therefore, one of the main objectives of this study was to develop a methodology for describing these quantitative relationships in order to derive numerical models that are better able to predict the enterococci concentrations at compliance locations.

In this study, an integrated one-dimensional (1-D) and two-dimensional (2-D) model has been refined to predict the hydrodynamic processes, sediment concentration distributions and enterococci concentrations in coastal and estuarine waters. Firstly, the model computes the ‘sediment-attached’ enterococci loss due to deposition and the enterococci increase due to re-suspension in separate sub-models. The total enterococci disappearance rate includes both the mortality rate and the deposition rate. Secondly, the model assumes that the enterococci decay rate (T_{90}) varies with sunlight irradiance and the concentration of suspended solids (SS), with the received dose of light radiation reduced by any increase in the SS concentration. The SS concentration in this model therefore affects the bacterial concentration through two processes: (i) sedimentation/re-suspension and (ii) protection from bactericidal irradiance.

2. Background to model development

2.1 Existence of faecal indicator organisms in natural waters

Bacteria in natural waters can be considered to exist in two forms, either as free-living (‘free swimming’), or planktonic, bacteria within the water column or attached to suspended particles. The free-living bacteria are transported by currents, whilst the attached bacteria are transported with the suspended particles. The attached bacteria can settle out when the suspended particles deposit, whilst increased turbulence can re-suspend the particles into the overlying water column with the bacteria attached.

In natural waters, it has been suggested that 70–99 per cent of the bacteria exist attached to sediments, with the remaining proportion (1–30 per cent) being planktonic. Thus it is possible that the concentration of faecal indicator bacteria on bed sediments may be 100–2,000 times greater than that within the water column, particularly in environments dominated by depositional processes.

Past research has indicated that, in turbid waters, most of the bacterial organisms are attached to suspended solids. Marshall (1978) indicated that bacteria readily absorb onto different kinds of interfaces, such as liquid-solid, liquid-liquid and liquid-gas, and that most of the bacteria were attached to these surfaces. Marshall (1978) also quoted the results from other authors who found that only 0.02 per cent of the microbial population in the Nile river were planktonic, with the vast majority attached to mineral particles. In an aquifer contaminated by treated sewage, 96.8–100 per cent of the faecal indicator bacteria were found to be particulate bound when recorded by direct counting (acridine orange direct counting, AODC) (Harvey *et al.*, 1984). Albrechtsen (1994) also demonstrated that only 0.01 per cent of the total bacterial population were free-living in the pore-water.

These observations are supported by the empirical experiments carried out using water taken from the Severn estuary that are described in Volume III. Results of settling experiments showed that bacterial concentrations decreased as suspended sediments settled out of the water.

2.2 Survival of faecal indicator organisms in natural waters

The survival of faecal indicator organisms in natural waters has been the subject of substantial research. Many environmental factors have been investigated in previous studies, including: solar radiation, turbidity, sedimentation, salinity and nutrient levels, as well as other physical, chemical and biological factors. Previous survival studies (for example: Kittrell and Furfari, 1963; Hanes and Fragala, 1967; Klock, 1971; Canale *et al*., 1973; Thomann and Mueller, 1987; Salomon and Pommepuy, 1990; Bell *et al*., 1992; Canale *et al*., 1993; Alkan *et al*., 1995; Guillaud *et al*., 1997) have shown that in natural waters the decay of faecal indicator organisms can generally be approximated by a first order decay assumption, known as Chick's Law (1910) (see Volume II of this report).

The typical form of a first order decay model is given as:

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

(2.2.1)

where: k = decay coefficient, generally expressed as day^{-1}; t = time; and C = enterococci concentration ($\text{cfu } 100\text{ml}^{-1}$).

For engineering studies, the decay rate is usually expressed in the form of a T_{90} value, which is the time taken for 90 per cent of the bacteria to die (or become inactive). The relationship between T_{90} and k is given as:

$$T_{90} = 24 \ln 10/k.$$

(2.2.2)

where T_{90} is in hours.

Survival studies show a wide range of T_{90} values between 0.5 hours and several days (or even several weeks and months) depending on environmental conditions (Chamberlin and Mitchell, 1978; Solic and Krstulovic, 1992; Pommepuy *et al*. 1992; Guillaud *et al*. 1997; and Wait and Sobsey, 2001) (see also Section 2 of Volume III of this report). In this study, a time-variable T_{90} formulation, determined by turbidity and sunlight intensity, has been developed using the information derived from the microcosm experiments described in Volume III. This T_{90} formulation was applied in the water quality modelling described below.

2.3 Conceptual model of faecal indicator organism transport in natural waters

Faecal indicator organisms in coastal waters derive from the following sources (see Figure 2.1 and Volume II of this project report).

1. The disposal of treated sewage effluent via sea outfalls from wastewater treatment works (WwTWs). Related sources will include untreated sewage effluent discharges from storm sewer overflows (SSOs) and combined sewer overflows (CSOs).

2. Diffuse pollution, derived from livestock sources, delivered via river systems, which may also contain human-derived inputs from inland settlements.

3. Direct or indirect defecation from wildlife populations.

4. Re-suspension of organisms attached to suspended solids, which can also be considered as a bacterial source.

5. Inappropriate disposal of sanitary wastes from recreational and commercial shipping.

The fourth source can be important in bathing water compliance. For example, Obiri-Danso and Jones (2000) found that re-suspension of indicator bacteria from bed sediments was significant during high wind velocities. Similarly, Valiela *et al*. (1991) reported that re-suspension was a contributory factor to non-compliance of bathing waters with the criteria specified in EU Directive 76/160/EEC.

Many studies (Milne *et al*., 1986; Burton *et al.,* 1987; Davies *et al*., 1995; Crabill *et al*., 1999; and Obiri-Danso and Jones, 2000) have focused on bed sediments as a bacterial reservoir, although, to date, no quantitative relationships have been established between faecal indicator concentrations and re-suspended sediments.

Figure 2.1 shows that the reduction of bacteria in natural waters is influenced by two processes: bacterial death (or inactivation) and deposition. The mortality rate approximates a first order decay process (see equation 2.2.1 above and Volume III). The deposition rate (that is, disappearance of bacteria due to sedimentation) is a function of the settling process for the suspended solids.

The principal objective of this element of the project was to develop a mathematical approximation of bacterial removal, based on:

1. deposition of the suspended sediment (SS);

2. the increase in concentration associated with the re-suspension of bed sediments;

3. the mortality rate determined by Chick’s law, as influenced by sedimentary attenuation and the diurnal (daytime) pattern of irradiance.

2.4 Sediment transport in natural waters

Sediment transport in natural waters is governed by sediment characteristics and hydrodynamics (velocity or flow field). Once suspended into the water column, sediments are transported with the flow field and will tend to re-settle on the bed due to gravity. The settled bottom sediments may also be moved by increased turbulence, producing re-suspension.

2.4.1 Cohesive sediment transport equations

It is common to consider cohesive sediments for sediment transport modelling along coastal waters since effluent inputs, discharged from WwTW outfalls, normally contain flocculated particles. Many previous studies have focused on the deposition and re-suspension rates of cohesive sediments (Krone, 1962; Parthenaides, 1965; Lick, 1986; Ziegler and Lick, 1988; Sanford *et al*, 1991; Sanford and Halka, 1993; and Sanford and Maa, 2001).

A key parameter in the quantitative numerical modelling of sediment transport is the sediment flux q_s at the sediment-water interface. The cohesive sediment net flux q_s can be written as:

$$q_s = E - D \tag{2.4.1}$$

where: E is the independent re-suspension rate; and D is the independent deposition rate.

In equation 2.4.1 an assumption has been made that transport and deposition are independent processes, such that E is the sediment flux when no suspended sediment deposition occurs and D is the sediment flux in the absence of transport. For steady state flow ($q_s = 0$), the above equation indicates that there is a dynamic equilibrium at the sediment-water interface between transport and deposition.

2.4.1.1 Cohesive sediment resuspension rate E

The linear mathematical formulation of the re-suspension rate E (in equation 2.4.1) has been widely deployed in many studies (Kandiah, 1974; Mclean, 1985; Odd, 1988; Kuijper *et al.*, 1989; Lang *et al.*, 1989; Perillo and Sequeira, 1989; Uncles and Stephens, 1989; Sanford *et al.*, 1991; Hawley and Lesht, 1992; Sanford and Halka, 1993; and Mei *et al.*, 1997), and has also been adopted in this study:

$$E = \begin{cases} M\left(\frac{\tau_b}{\tau_c} - 1\right), & \tau_b > \tau_c \\ 0, & \tau_b \le \tau_c \end{cases} \tag{2.4.2}$$

where: E is the erosion rate (kg m^{-2} s^{-1}); τ_b is the effective bottom shear stress in (N m^{-2}); and τ_c is the critical shear stress for the initiation of sediment re-suspension from the bed in (N m^{-2}). Jing and Ridd (1996) found that τ_c was about 2.0 N m^{-2} for Cleveland Bay, Australia. M is an empirical constant with appropriate units that, for this study, were kg m^{-2} s^{-1}, (with $M = \tau_c \times$ the slope of the plot of E vs. τ_b). Sanford *et al*. (1991) used $M \approx 1.4 \times 10^{-6}$ kg m^{-2} s^{-1} and $\tau_c = 0.016$ Pa ($r^2 = 0.84$) in a study for the northern Chesapeake Bay, USA.

By defining ΔS_r as the increase in the SS concentration caused by re-suspension, within a computed time interval Δt, the re-suspension rate can be expressed as $\Delta S_r/\Delta t$. When the total amount of entrainment (transport), E, per unit bed area is considered to be uniformly distributed over the water depth H, then the instantaneous re-suspension rate is given as:

$$\frac{dS_r}{dt} = \frac{E}{H} = \frac{M}{H}\left(\frac{\tau_b}{\tau_c} - 1\right) \quad \Big|_{\tau_b > \tau_c}$$

(2.4.3)

There is general agreement that the bottom shear stress exerted on a unit area of the bed by waves and currents are the dominant forces causing re-suspension (or erosion). There is a critical shear stress (τ_c) associated with the initiation of sediment re-suspension, whose value depends upon the bed material characteristics (such as mineral composition, organic material, salinity, density) and the bed structure (water content of the bed sediments). When the effective shear stress (τ_b) exceeds the critical shear stress (τ_c) then the bed sediments are re-suspended into the water column.

The effective bed shear stress due to currents is given by Soulsby (1997) and may be expressed as:

$$\tau_b = \rho C_D \overline{U}^2$$

(2.4.4)

where: $\overline{U}$ = depth-averaged current speed (m s^{-1}); C_D = drag coefficient applicable to depth-averaged current; and ρ = density of seawater, typically 1027 kg m^{-3}.

2.4.1.2 Cohesive sediment deposition rate D

In equation 2.4.1, the deposition rate D can be written as (Sanford and Halka, 1993):

$$D = p \cdot w_d \cdot S_b$$

(2.4.5)

where: p = probability that a sediment particle will remain on the bed; S_b = near-bed sediment concentration; and w_d = deposition velocity, which is distinguished from the sediment fall velocity w_s, as defined by Stoke's Law.

For very small particles, w_d may be larger than w_s because of Brownian motion or diffusion (Lick, 1986; Sheng, 1986). However, for particle diameters greater than about 1μm, it is common to approximate $w_d = w_s$ (Lick, 1982). The probability of deposition is usually written (Einstein and Krone, 1962; Dyer, 1986; Mehta, 1989; Self *et al.*, 1989) in the form:

$$p = 1 - \frac{\tau_b}{\tau_d} \qquad \tau_b < \tau_d$$
$$p = 0 \qquad \tau_b \geq \tau_d$$
(2.4.6)

where: τ_d is the critical shear stress for deposition. Integrating these expressions into equation 2.4.5, gives:

$$D = \begin{cases} w_s S_b \left(1 - \frac{\tau_b}{\tau_d} \right) & \tau_b < \tau_d \\ 0 & \tau_b \geq \tau_d \end{cases}$$
(2.4.7)

where: D = deposition rate (kg $m^{-2}s^{-1}$); w_s = apparent sediment settling velocity (m s^{-1}); S_b = near-bed cohesive sediment concentration (kg m^{-3}); τ_b = effective bottom shear stress (N m^{-2}); and τ_d = critical shear stress beyond which there is no further deposition (N m^{-2}).

As a uniform distribution is applied to the SS concentration in a depth-averaged 2D model, then the rate of loss of the SS concentration due to cohesive sediment deposition is given as:

$$\frac{dS_d}{dt} = \frac{D}{H} = \frac{w_s S_b}{H} \left(1 - \frac{\tau_b}{\tau_d} \right) \quad \Bigg|_{\tau_b < \tau_d}$$
(2.4.8)

where: H is the depth of the water column in metres.

Lick (1986) indicated that, in the fine-grained sediment found in lakes or oceanic waters, particle sizes and, hence, velocities varied over several orders of magnitude. He also calculated that the deposition rate in equation 2.4.14 could be approximated by $D = \Sigma p \cdot w_d \cdot S_b$, where the sediments are separated into different components, each with its own average particle size, settling velocity and relative deposition velocity.

2.4.2 Non-cohesive sediment transport equations

The central tenet of cohesive sediment transport modelling is that erosion and deposition are mutually exclusive. In support of this, many laboratory studies have shown that there is a stress (or velocity) threshold below which erosion does not occur and a lower threshold above which deposition does not occur. In contrast, a deposition threshold is not included in non-cohesive sediment transport models, which allow erosion and deposition to occur simultaneously (Smith, 1977; Dyer, 1986; Glenn and Grant, 1987).

Under this scenario, sediments are transported initially as bedload, which implies a continual exchange between deposited and moving particles. This bedload layer, which is considered to be always in equilibrium with the bottom shear stress, serves as the source layer for suspended sediments when the shear stress, governed by the local hydrodynamic conditions, is sufficiently large. Net erosion and net deposition occur as the suspended load increases or decreases, depending upon the bedload concentration.

Mathematically, this approach amounts to specifying a boundary condition in the form of a concentration at some reference height '*a*', near the top of the bedload layer (Smith, 1977; Glenn and Grant, 1987), to give:

$$\begin{cases} S_a = \dfrac{S_b \gamma_o \left(\dfrac{\tau_b}{\tau_c} - 1 \right)}{1 + \gamma_o \left(\dfrac{\tau_b}{\tau_c} - 1 \right)} & \tau_b \geq \tau_c \\ S_a = 0 & \tau_b < \tau_c \end{cases}$$

(2.4.9)

where: S_a is the sediment concentration at reference height '*a*'; S_b is the sediment concentration in the bed layer; and γ_o is an empirical constant.

When the particles have varying grain sizes, this boundary condition may generally be calculated for a range of sediment classes, each with its own set of values for S_b and τ_c. The total distribution of suspended sediments is then expressed as the sum of all of the classes (Sanford and Halka, 1993).

Implementing these concepts for non-cohesive sediment transport modelling in this study has involved applying the formulae attributed to van Rijn (1984a, b), and outlined below.

The non-cohesive sediment net erosion or deposition rate E_{non} can be expressed as (Garcia and Parker, 1991; Lin and Falconer, 1995):

$$E_{non} = w_s(S_{ae} - S_a)$$

(2.4.10)

where: w_s is particle settling velocity; S_a is sediment concentration at reference level 'a'; S_{ae} is equilibrium sediment concentration at the reference level '*a*' ('*a*' is assumed to be equal to the equivalent roughness height (k_s), with a minimum value being given by: $a = 0.01H$). For the sediment concentration reference levels the following relationships are commonly used for the various cases:

1. $S_{ae} < S_a$, $E < 0$, deposition,

2. $S_{ae} > S_a$, $E > 0$, erosion,

3. $S_{ae} = S_a$, $E = 0$, the equilibrium re-suspension.

The expression for S_{ae}, as given by van Rijn (1984a), was:

$$S_{ae} = 0.015 \frac{D_{50} T^{1.5}}{a D_*^{0.3}}$$
(2.4.11)

where: D_{50} is the sediment particle diameter compared to which 50 per cent of the bed material is finer; T is transport stage parameter (van Rijn,1984a) and D_* is the particle parameter.

In a depth-integrated 2-D model, only the depth mean sediment concentration S is available. Hence, the value of the reference concentration S_a must be related to the depth mean concentration S, with this relationship being assumed to be of the form (Falconer and Owens, 1990):

$$S_a/S = S_{ae}/S_e$$
(2.4.12)

where: S_e is depth mean equilibrium concentration. Substituting equation 2.4.12 into 2.4.10 gives:

$$E_{non} = W_s \frac{S_{ae}}{S_e}(S_e - S)$$
(2.4.13)

The depth mean equilibrium concentration S_e can be calculated from the ratio (Lin and Falconer, 1995):

$$S_e = \alpha \frac{q_s}{q}$$
(2.4.14)

in which α is a profile factor, and assumed to be 1.13 after Celik and Rodi (1991); q is the fluid flux; and q_s is the suspended sediment flux (van Rijn, 1984b).

In summary, in a depth-averaged 2-D model, the net change of SS concentration caused by the non-cohesive sediment net erosion or deposition can be expressed as:

$$\frac{dS}{dt} = \frac{E_{non}}{H} = \frac{W_s}{H}\frac{S_{ae}}{S_e}(S_e - S)$$
(2.4.15)

When $S_e>S$, net re-suspension will occur and $dS_r/dt = dS/dt$; likewise when $S_e<S$, net deposition will occur and $dS_d/dt = dS/dt$.

2.4.3 Governing equation for sediment transport processes

2.4.3.1 Cohesive sediment

The standard 2-D depth-integrated governing equation for representing cohesive sediment transport processes can be written as:

$$\frac{\partial SH}{\partial t}+\frac{\partial SUH}{\partial x}+\frac{\partial SVH}{\partial y}-\frac{\partial}{\partial x}\left(HD_x\frac{\partial S}{\partial x}\right)-\frac{\partial}{\partial y}\left(HD_y\frac{\partial S}{\partial y}\right)=E-D$$

(2.4.16)

Likewise, the standard 1-D cross-sectional integrated governing equation for cohesive sediment transport processes can be written as:

$$\frac{\partial SA}{\partial t}+\frac{\partial SUA}{\partial x}-\frac{\partial}{\partial x}\left(AD_x\frac{\partial S}{\partial x}\right)=E-D$$

(2.4.17)

2.4.3.2 Non-cohesive sediment

The standard 2-D depth-integrated governing equation for non-cohesive sediment transport processes can be written as:

$$\frac{\partial SH}{\partial t}+\frac{\partial SUH}{\partial x}+\frac{\partial SVH}{\partial y}-\frac{\partial}{\partial x}\left(HD_x\frac{\partial S}{\partial x}\right)-\frac{\partial}{\partial y}\left(HD_y\frac{\partial S}{\partial y}\right)=E_{non}$$

(2.4.18)

Similarly, the standard 1-D cross-sectional integrated governing equation for non-cohesive sediment transport processes can be written as:

$$\frac{\partial SA}{\partial t}+\frac{\partial SUA}{\partial x}-\frac{\partial}{\partial x}\left(AD_x\frac{\partial S}{\partial x}\right)=E_{non}$$

(2.4.19)

2.5 Enterococci transport modelling associated with sediment transport

2.5.1 Concentration of enterococci and suspended solids deposition

In order to develop new formulations for the link between enterococci concentrations and suspended sediment concentrations in natural waters, the following assumptions have been adopted.

1. The adsorption of enterococci to suspended solids takes place immediately.

2. There are enough SS surfaces in the water column to provide attachment sites for enterococci.

3. Within the water column, the distribution of SS concentrations and enterococci concentrations are uniform through the water depth. Therefore, the enterococci concentrations adsorbed onto the SS surfaces are the same as that for each unit of SS concentration.

Under these assumptions, the bacterial disappearance process caused by the SS settling out can be described by the following expression, in which *N/S* is the uniform distribution concentration of bacteria:

$$dN = \frac{N}{S} dS_d$$

(2.5.1)

where: N = number of enterococci in counts; S = SS concentration (kg m^{-3}); and dS_d = amount of change of SS concentration caused by the settling process during a small time step dt (kg m^{-3} s^{-1}).

If a constant percentage of attached enterococci is applied, then equation 2.5.1 reduces to:

$$dN = \alpha_s \frac{N}{S} dS_d$$

(2.5.2)

where: α_s is the ratio of attached enterococci to total enterococci in the water column. For turbid natural waters α_s can be regarded as unity.

Changing the unit of bacterial population to a concentration, equation 2.5.2 becomes:

$$\frac{dC_d}{dt} = \alpha_s \frac{C}{S} \frac{dS_d}{dt}$$

(2.5.3)

where: C = enterococci concentration in water column (cfu 100ml^{-1}); and dC_d = loss of bacteria concentration due to the deposition of SS during the time interval dt.

2.5.2 Concentration of enterococci and suspended solids resuspension

In coastal waters, re-suspension of the bed sediments tends to occur periodically due to tidal and wave action. The increase of enterococci caused by this resuspension can be expressed as:

$$dC_r = 0.1 C_b \, dS_r$$

(2.5.4)

where: C_b = enterococci concentration on bed sediments in cfu g^{-1}; dS_r = the SS concentration re-suspended into the water column measured in kg m^{-3}; dC_r = the enterococci concentration increase due to sediment re-suspension in cfu 100ml^{-1}; and 0.1 is the constant that accounts for the unit change between C_b and C_r.

Dividing by the time interval dt on both sides of equation 2.5.4, we obtain:

$$\frac{dC_r}{dt} = 0.1 C_b \frac{dS_r}{dt}$$

(2.5.5)

where:

$$C_b = C_{b0} \cdot e^{-k_b t}$$

(2.5.6)

C_{b0} = enterococci concentration in bed sediments at the start time (cfu g^{-1}); and k_b = decay rate of bacteria in bed sediments (s^{-1}).

2.5.3 Two-dimensional enterococci transport governing equation

The depth-integrated 2-D governing equation used to describe enterococci transport, including the advective and diffusion processes, can be written as:

$$\frac{\partial C}{\partial t} + \frac{\partial CU}{\partial x} + \frac{\partial CV}{\partial y} - \frac{\partial}{\partial x}\left[D_x \frac{\partial C}{\partial x}\right] - \frac{\partial}{\partial y}\left[D_y \frac{\partial C}{\partial y}\right] = \sum \Phi_s$$

(2.5.7)

and

$$\sum \Phi_s = -kC - \frac{dC_d}{dt} + \frac{dC_r}{dt} + \sum_{n=1}^{n} \frac{Q_o C_o}{A_o H}$$

(2.5.8)

where: C = depth averaged enterococci concentration (cfu 100ml^{-1}); $\Sigma\Phi_s$ = source or sink terms, including enterococci decay, deposition disappearance, entrainment from bed and riverine/sewage inputs; Q_o = outfall discharge rate (m^3 s^{-1}); C_o = outfall discharge enterococci concentration (cfu 100ml^{-1}); A_o = horizontal discharge area (m^2); H = water depth at the discharge location (m); and n = number of riverine/sewage inputs.

2.5.4 One-dimensional bacterial transport governing equation

The general cross-sectional integrated 1-D governing equation used to describe the bacterial transport processes in rivers can be written as:

$$\frac{\partial C}{\partial t} + \frac{\partial CU}{\partial x} - \frac{\partial}{\partial x}\left[D_x \frac{\partial C}{\partial x}\right] = \sum \Phi_s \qquad (2.5.9)$$

where: C is the cross-sectional averaged bacteria concentration in cfu 100ml^{-1}; and $\Sigma\Phi_s$ is the source or sink terms, as given in equation 2.5.8.

2.5.5 Mathematical expression for source or sink terms

2.5.5.1 2-D governing equation

The 2-D enterococci source or sink terms associated with cohesive sediments can be expressed as follows: firstly, combining equations 2.5.3 and 2.4.8, gives:

$$\frac{dC_d}{dt} = -\alpha_s \frac{w_s}{H} \cdot \frac{S_b}{S} \cdot C \cdot \left(1 - \frac{\tau_b}{\tau_d}\right), \qquad \tau_b < \tau_d$$

(2.5.10)

secondly, combining equations 2.5.5 and 2.4.3 gives:

$$\frac{dC_r}{dt} = 0.1C_{b0} \cdot \frac{e^{-k_b t}}{H} \cdot M\left(\frac{\tau_b}{\tau_c} - 1\right), \qquad \tau_b > \tau_c$$

(2.5.11)

Substituting equations 2.5.10 and 2.5.11 into equation 2.5.8, the enterococci source or sink terms associated with the cohesive sediment transport level can be written as:

$$\sum \Phi_s = -kC - \alpha_s \frac{w_s}{H} \cdot \frac{S_b}{S} \cdot C \cdot \left(1 - \frac{\tau_b}{\tau_d}\right) \Bigg|_{\tau_b < \tau_d} + 0.1C_{b0} \cdot \frac{e^{-k_b t}}{H} \cdot M\left(\frac{\tau_b}{\tau_c} - 1\right) \Bigg|_{\tau_b > \tau_c} + \sum_{n=1}^{n} \frac{Q_o C_o}{A_o H}$$

(2.5.12)

For the 2-D enterococci sources or sinks associated with non-cohesive sediments, combining equations 2.4.15 and 2.5.3 gives:

$$\frac{dC_d}{dt} = \alpha_s \frac{W_s}{H} \frac{S_{ae}}{S_e} \frac{C}{S} (S_e - S) \quad , \qquad S_e < S$$

(2.5.13)

Likewise, combining equations 2.4.15 and 2.5.5 gives:

$$\frac{dC_r}{dt} = 0.1C_{b0} \cdot \frac{e^{-k_b t}}{H} \cdot \frac{W_s S_{ae}}{S_e} (S_e - S) \quad , \qquad S_e > S$$

(2.5.14)

Substituting equations 2.5.13 and 2.5.14 into 2.5.8, the enterococci source or sink term associated with the non-cohesive sediment transport level can be written as:

$$\sum \Phi_s = -kC + \alpha_s \frac{C}{SH} \frac{W_s S_{ae}}{S_e} (S_e - S) \Bigg|_{S_e < S} + 0.1C_{b0} \cdot \frac{e^{-k_b t}}{H} \cdot \frac{W_s S_{ae}}{S_e} (S_e - S) \Bigg|_{S_e > S} + \sum_{n=1}^{n} \frac{Q_o C_o}{A_o H}$$

(2.5.15)

Expressions 2.5.12 and 2.5.15 are the source and sink terms used in the general depth-averaged governing equations to represent the enterococci transport modelling associated with sediment transport fluxes in natural waters. These expressions not only include the enterococci mortality rate, but also the removal of enterococci by SS deposition and entrainment via sediment re-suspension.

2.5.5.2 1-D governing equation

For the cross-sectional integrated 1-D governing transport equation, the source or sink terms can be shown to be of the following form.

For the 1-D enterococci sources or sinks associated with cohesive sediments, the formulation is given as:

$$\sum \Phi_s = -kC - \alpha_s \frac{w_s}{A} \cdot \frac{S_b}{S} \cdot C \cdot \left(1 - \frac{\tau_b}{\tau_d}\right)\Bigg|_{\tau_b < \tau_d} + 0.1C_{b0} \cdot \frac{e^{-k_b t}}{A} \cdot M\left(\frac{\tau_b}{\tau_c} - 1\right)\Bigg|_{\tau_b > \tau_c} + \sum_{n=1}^{n} \frac{Q_o C_o}{A_o H}$$

(2.5.16)

Likewise, for the 1-D enterococci sources or sinks associated with non-cohesive sediments, the formulation can be written as:

$$\sum \Phi_s = -kC + \alpha_s \frac{C}{SA} \frac{W_s S_{ae}}{S_e}\left(S_e - S\right)\Bigg|_{S_e < S} + 0.1C_{b0} \cdot \frac{e^{-k_b t}}{A} \cdot \frac{W_s S_{ae}}{S_e}\left(S_e - S\right)\Bigg|_{S_e > S} + \sum_{n=1}^{n} \frac{Q_o C_o}{A_o H}$$

(2.5.17)

2.5.5.3 Combined expression for source and sink terms

In an integrated modelling tool, such as Divast (Depth Integrated Velocities And Solute Transport) and Faster (Flow And Solute Transport in Estuaries and Rivers), multiple sub-models for different modelling processes are included and these sub-models cater for both cohesive and non-cohesive sediment processes. In such modelling tools, the sediment sub-model computational results can be used directly to estimate bacterial transport. Therefore, the combined expression for the source or sink terms, as derived above for both cohesive and non-cohesive sediment fluxes, can be further combined to give:

$$\sum \Phi_s = -KC - \alpha_s \frac{Q_{dep}}{S} C + 0.1 * Q_{ero} C_b + \sum_{n=1}^{n} \frac{Q_o C_o}{A_o H}$$

(2.5.18)

where: Q_{dep} = computed total deposited SS rate including both non-cohesive and cohesive sediments (kg m^{-3} s^{-1}); Q_{ero} = computed total suspended sediments from bed including both non-cohesive and cohesive sediments (kg m^{-3} s^{-1}); S = suspended solid concentration for both coarse and fine particles (kg m^{-3}); Q_o = outfall discharge (m^3 s^{-1}); C_o = outfall enterococci concentration (cfu 100ml^{-1}); A_o = horizontal discharge area (the grid cell area) (m^2); H = water depth at the discharge location (m); n = number of outfalls; C = enterococci concentration in the water column (cfu 100ml^{-1}); C_b = enterococci concentration on bed sediments (cfu g^{-1}); and 0.1 = coefficient for the unit change.

3. Site description

3.1 Bathing water compliance locations

The bathing water compliance locations covered in this study are summarised in Table 3.1 and shown in Figure 3.1. Table 3.1 and Figure 3.1 also indicate where compliance locations were included within the same model grid cell due to the proximity of some monitoring points, and detail the model site reference number used throughout this report.

3.2 River input and WwTW outfall locations

River input locations have been defined in both the 1-D and 2-D model areas. Due to some rivers discharging within the same model cell, there are 17 riverine inputs located in the 2-D model area, comprising 25 rivers (Table 3.2 and Figure 3.1). The river inputs located in the 1-D model area are the rivers Wye, Severn, Frome and the little Avon (Table 3.3).

In total, there are 34 WwTW outfalls distributed within the model domain (Figure 3.2). These were grouped for modelling purposes into six outfall inputs in the 1-D area and 19 outfall inputs in the 2-D area (Tables 3.4 and 3.5 respectively).

4. Model set up

A dynamically-linked 1-D and 2-D model has been set up for the whole of the Bristol Channel and the Severn estuary, covering an area from an imaginary line drawn between Hartland Point and Stackpole Head to the tidal limit of the River Severn (Figure 4.1).

4.1 Model domain

The study area extends from the seaward boundary of the outer Bristol Channel to the tidal limit of the River Severn at Haw Bridge and is divided into two modelling domains. The 2-D modelling domain primarily covers the Bristol Channel and the 1-D modelling domain includes the Severn estuary up to the tidal limit of the River Severn at Haw Bridge.

The 1-D and 2-D domains overlap in the area between the M4 Severn Bridge (the new Severn bridge) and the M48 Bridge (the old Severn bridge) (Figure 4.1).

4.1.1 1-D model area

The 1-D model area was specified as being from the M4 (new) Severn bridge (the downstream boundary) to Haw Bridge (the upstream boundary). There were four reaches distributed along the domain, including a total of 351 nodes (computed cross-sections), with an average distance between cross-sections of 240m.

Flow discharges and enterococci flux data were included as the upper boundary condition. Water elevations and enterococci concentrations were predicted from the 2-D model and used in the 1-D model to provide the lower boundary conditions. The bathymetric data at each node were provided by Jeremy Benn Associates, obtained through the Environment Agency.

4.1.2 2-D model area

The 2-D model domain covered the Bristol Channel (14,636.2 km^2). The domain was divided into a mesh of 242×168 grid squares, with a fixed size of 600m×600m. There were two main boundaries in the 2-D domain, which were:

1. the downstream boundary, which extended from Hartland Point (51˚ 01.5´ N, 4˚ 31.4´ W) to Stackpole Head (51˚ 37.8´ N, 4˚ 53.0´ W) – a distance of 74 km;

2. the upstream boundary, along the line of the M48 (old) Severn bridge – a distance of 2.8 km between (OS grid UTM metres) Easting 356300, Northing 190000, and Easting 352250, Northing 190700.

The downstream boundary was specified as a tidal water elevation boundary, whilst the upstream boundary was specified in the form of a velocity boundary. The downstream boundary water level was obtained from the Proudman Oceanographic Laboratory (POL) Irish Sea model. The upstream boundary condition included the velocities as computed from the 1-D model, with these velocities transferred between the 1-D and 2-D modelling suites to generate predictions of the enterococci parameter data.

4.2 Simulation time

The model simulation time was for a period of 300 hours, commencing at 5.30pm on 20 July 2001 and finishing at 5.30am on 2 August 2001. This period was chosen to cover the four model calibration field surveys that were undertaken on 24 July 2001, 26 July 2001, 30 July 2001 and 1 August 2001 (see Section 4.6 of this volume for further details of the field surveys).

4.3 Sediment parameters

In order to provide instantaneous sediment concentrations, predictions of the sediment fluxes were calculated first. Details of the coefficients and initial values used in this element of the study are given below. These were derived from the microcosm and settlement experiments described in Volume III of this report and from the literature sources cited above.

1. The initial value of the non-cohesive sediment concentration across the whole domain was 2 mg l^{-1}.

2. The initial value of the cohesive sediment concentration across the whole domain was 2 mg l^{-1}.

3. The D_{16}, D_{50}, D_{84} and D_{90} particle diameters (in mm) for the coarse sediments were calculated using the samples taken at four sites. Mean values of 0.026mm, 0.058mm, 0.126mm and 0.15mm were obtained for the corresponding D_{16}, D_{50}, D_{84} and D_{90} values respectively.

4. The average size of the cohesive flocs was 0.010–0.063mm.

5. The critical shear stress for the deposition of cohesive particles was 0.100N m^{-2}.

6. The critical shear stress for the erosion of cohesive particles was 2.000N m^{-2}.

4.4 Enterococci parameters

The initial values for the modelling processes are detailed below:

1. The initial value of enterococci on the bed sediments was assumed to be 1000 cfu g^{-1}. A sensitivity analysis was undertaken by choosing different enterococci values on the bed sediments (see Section 8.4).

2. The ratio of attached enterococci to total enterococci was set at 80 per cent and this was regarded as a constant value during the simulation time. A sensitivity analysis was undertaken by choosing different ratios (see Section 8.5).

3. The initial value of enterococci in the water column was assumed to be zero cfu 100ml^{-1}.

4. The T_{90} value in the water column was assumed to be time variable, with the value obtained from the empirical regression equations described in Section 4.4.3 below.

5. The decay rate within the bed sediments was assumed to be zero.

4.4.1 Survival time of faecal indicator organisms in bed sediment

Survival times of faecal indicator organisms in sediments can vary from several days to several weeks, and even months (Marino and Gannon, 1991; Pommepuy *et al.*, 1992). Furthermore, some authors have suggested that faecal indicator organisms can grow in bottom sediments (Laliberte and Grimes (1982), Marino and Gannon (1991), and Davies *et al.* (1995)).

Van Donsel and Geldreich (1971) reported a T_{90} value for both faecal coliforms (FC) and *Salmonella* spp. of seven days in various sediments. Gerba and McLoed (1976) observed that the survival of *Escherichia coli* (*E. coli*) increased rapidly when either autoclaved or fresh estuarine sediments were added to estuarine water. Hood and Ness (1982) found that *E. coli* could survive longer in non-sterile (fresh) estuarine sediments than in estuarine waters (whether sterile or non-sterile). Burton *et al*. (1987) found that bacteria survived for longer in sediments than in water and concluded that the sediment reservoir allowed enteric and pathogenic bacteria to survive, possibly for several months. The authors therefore argued that re-suspension and human ingestion in primary-contact waters was a real possibility, representing a potential health hazard. Marino and Gannon (1991) found that faecal coliforms and faecal streptococci (enterococci) in the sediments remained stable for up to six days at 10^4–10^5 cfu 100ml^{-1} in their Creek field studies.

Thus, in the present study the decay rate within the bed sediments was assumed to be zero.

4.4.2 Bacterial concentration in bed sediment

In an analysis of over 200 samples, Buckley *et al.* (1998) found that the total coliform concentrations in streambed sediments were on average about 1,000 times greater than in the overlying water column, with a 95 per cent confidence interval for the sediment concentration of 760–1,560 cfu $100ml^{-1}$. The mean total coliform concentration in streambed sediments was 0.5×10^{6} cfu $100ml^{-1}$ during the dry season and 1.2×10^{6} cfu $100ml^{-1}$ during the wet season.

van Donsel and Geldreich (1971) and Stepheson and Rychert (1982) found the ratio between coliform concentrations in sediments and waters was within the range of 760-1,000. Ashbolt *et al*. (1993) found that sediments contained 100-1,000 times as many faecal indicator bacteria as the overlying water. Tunnicliff and Brickler (1984) examined sediments from the Colorado River and tributaries and found that average faecal coliform (FC) densities were 10 to 100 times those in the overlying waters, with the water concentration being $\leq$20 cfu $100ml^{-1}$.

Doyle *et al*. (1992) studied FC concentration distributions in water and associated beach sediments. Results showed that both water and sediment FC concentrations were highly variable over time and indicated that the ratio of sediment FC to water FC was in the range 10–100:1. The mean sediments FC density was about 10^{3} cfu $100ml^{-1}$, calculated by the most probable number technique.

Obiri-Danso and Jones (1999, 2000) sampled inter-tidal sediments in Morecambe Bay, UK, to determine the concentration of faecal indicator organisms in bed sediments underlying bathing water compliance monitoring points. The results showed that concentrations of faecal indicator organisms in sediments were at least an order of magnitude higher than in the overlying water column.

In another study, conduced by Crabill *et al*. (1999), very high FC concentrations were identified in bed sediments at Oak Creek, with the average being 2,200 times the FC concentration in the water column. The overall mean sediment FC concentration was 1.5×10^{5} cfu $100ml^{-1}$, whilst summer and winter concentrations were 7.8×10^{3} cfu $100ml^{-1}$ and 1.0×10^{5} respectively.

4.4.3 River inputs

Input data for 29 riverine sources were available to calibrate the model. The data included estimated hourly discharge (based on Environment Agency gauging station and catchment area data) and microbial concentration values modelled using catchment land cover data (see Volume II). The numerical model uses dynamically-variable inputs during simulations, derived from the flux modelling described in Volume II of this report.

4.4.4 Wastewater treatment works discharges

The WwTW discharges (flow rates and enterococci concentrations) were considered as constant during the model simulation period, with the exception of the Minehead WwTW outfall. The discharge at Minehead WwTW was tidally controlled, discharging from four hours after high water to two hours before high water, during which period the outfall discharge was assumed to be constant. There was no discharge for the remaining time.

4.4.5 Decay rates in water

The decay rates used in this study were based on the empirical regression equations obtained from the laboratory experiments described in Volume III. Significant relationships were reported between T_{90} and turbidity, whilst the suspended sediment (SS) concentration was also related to turbidity. The experiments used an artificial light source designed to reproduce the correct solar spectrum and intensity observed in the period 10.00am and 2.00pm between the beginning of July and the end of August at a latitude of 52° North. The irradiance values used for the experiments were: visible light: 260 $\pm$14 Wm^{-2}; UV-A: 5.2 $\pm$0.4 Wm^{-2}; UV-B: 1.1 $\pm$0.02 Wm^{-2}.

The corresponding relationships used were:

Light excluding outliers: $\text{Log } T_{90} = 0.0047 \times \text{Turbidity} + 0.677 \pm 0.2070$
(4.4.1)

Dark excluding outliers: $\text{Log } T_{90} = 0.0019 \times \text{Turbidity} + 1.237 \pm 0.199$
(4.4.2)

$\text{Turbidity} = 139.479 \times \text{Log SS} - 244.736 \pm 32.678$
(4.4.3)

where: T_{90} is in hours; turbidity is expressed as nepthalotropic turbidity units (NTU); and the SS concentration is in mg l^{-1}.

To characterise the appropriate adjustment for diurnal variability in irradiance, a further literature review was undertaken. Bellair *et al*. (1977) suggested that faecal coliform mortlity rates were inversely related to irradiance intensity as follows:

$T_{90} = 3.4\, I^{-0.42}$
(4.4.4)

where: T_{90} is in hours; and I is the hourly solar radiation (MJ m^{-2}).

Pommepuy *et al.* (1992) reported a close relationship between light intensity and the faecal coliform T_{90} value, of the form;

$$T_{90} = 1.2\times10^{4}\, I_n^{-0.56} \qquad (4.4.5)$$

where: T_{90} is in hours; and I_n is the light energy received by bacteria (μE m^{-2} hr^{-1}), which is a function of the turbidity and water depth.

Alkan *et al*. (1995) reported that T_{90} values decreased with light intensity, except when the sewage content exceeded 3.0 per cent, when no decrease was observed in the *E. coli* concentration for light intensity levels of up to 500 W m^{-2}. Above this value, a linear relationship between the mortality rate and light intensity was evident, even for high sewage contents. Taking into account a combined coefficient, the relationship could be presented as:

$$K_{EC} = A_{EC} + 1.3\times10^{-5}\, I_L \qquad (4.4.6)$$

$$K_E = A_E + 1.1\times10^{-5}\, I_L \qquad (4.4.7)$$

where: K_{EC}, K_E are the die-off rates for *E. coli* and enterococci respectively (min^{-1}); A_{EC}, A_E are the combined coefficients for *E. coli* and enterococci, which are related to three other factors – turbidity, sewage content and mixing effects; and I_L is the surface light intensity (W m^{-2}).

Guilland *et al*. (1997) studied the survival of *E. coli* in the laboratory and under sunlight illumination to investigate the impact of sewage content and SS concentration. The author found that the relationship between light intensity and T_{90} could be represented by the following formula:

$$T_{90} = 53683\, I_m^{-0.666} \qquad (4.4.8)$$

where: T_{90} is in hours; and I_m is the mean light intensity in the water column (μE m^{-2} hr^{-1}), which in this case is a function related to the surface light intensity, water depth and SS concentration.

In order to take account of both the sunlight intensity, which varies with time, and the impact of turbidity on the penetration of light through the water column, the following equation was used to represent T_{90}:

$$T_{90} = T_{90}^{2} + (T_{90}^{1} - T_{90*}^{1}) \qquad (4.4.9)$$

where: T_{90}^{1} is the enterococci mortality rate depending on surface sunlight (I): $T_{90}^{1} = \ln10/(1.1\times10^{-5}\, I)/60 = 3.5\times10^{3}\, I^{-1}$; $T_{90*}^{1} = \ln10/(1.1\times10^{-5}\, I^*)/60$, in which I^* is the fixed irradiance for the T_{90} vs. turbidity experiments (Wm^{-2}); and T_{90}^{2} is the enterococci
mortality rate obtained from the laboratory experiments (Equation 4.4.1): $Log T_{90}{}^{2} = 0.0047 \times turbidity + 0.677 \;\Big|_{I=I^*}$.

The time-varying T_{90}[1] value was calculated based on the diurnal irradiance data collected at Swansea Guildhall by the City and County of Swansea Council (shown in Figure 4.2).

The above empirical T_{90} equations were primarily obtained from experiments using saline and brackish water samples. From experience gained from a recent study of faecal coliforms in the Ribble estuary, it was decided that for fresh water the T_{90} equations should be multiplied by a factor of two in the 1-D model domain. Therefore, it was assumed during the computations that the T_{90} values in the 1-D domain were twice those values used in the 2-D domain, otherwise the same representations were applied in both models.

4.5 Hydrodynamic parameters

4.5.1 Bathymetry data

The bathymetric data used in the 1-D region were provided by Jeremy Benn Associates. The 2-D bathymetric data were digitised from the Admiralty Charts (1179, 1166, 1165 and 1152) and the bed elevations were obtained through interpolation using the Surfer software package.

4.5.2 Boundary input data

The water elevation data used to specify the downstream model boundary conditions were provided by the Proudman Oceanographic Laboratory (see Figure 4.3). At the upstream boundary of the River Severn, a flow rate varying from 60 $m^3 s^{-1}$ to 106 $m^3 s^{-1}$ was used. The inflows for the rivers Wye, Frome and Little Avon, located in the 1-D model domain, were treated as lateral inflows. More details on how the riverine inputs were estimated are given in Volume II of this study.

4.5.3 Survey data

Four sets of survey data (Surveys 1 and 2: South Wales on 24 July 2001 and 26 July 2001; Surveys 3 and 4: Somerset on 30 July 2001 and 1 August 2001) were used for calibrating the hydrodynamic and enterococci parameters. Results from eight sampling points were used for model calibration, comprising two offshore survey points and two bathing water compliance monitoring points from each survey location (see Table 4.1 (Porthcawl/Southerndown) and Table 4.2 (Minehead/Blue Anchor Bay and Figure 4.4)). Full details of the calibration field surveys are provided in Section 4.6.

4.6 Model calibration field surveys

The objective of the field surveys was to provide ground truth data to calibrate the hydrodynamic model of the Severn estuary. Meteorological, hydrodynamic and water quality data were collected from two strategic locations in the Severn estuary/Bristol Channel: (i) Porthcawl/Southerndown, S. Wales; and (ii) Minehead/Blue Anchor Bay, Somerset (Figure 4.4).

4.6.1 Survey Protocol

Two surveys over a single tidal cycle were conducted at each location. Each survey comprised hourly samples (half-hourly at one offshore site), which were tested for:

- enterococci concentration (cfu 00ml^{-1});
- turbidity, suspended solids concentration and particle size;
- conductivity, practical salinity and total dissolved solids.

At both offshore sites, in addition to the water quality parameters, current velocity and direction were measured. Solar irradiation, downwelling radiation, wind velocity and direction were then measured at one site. The survey also included:

- two bathing water compliance sites;
- local riverine inputs;
- local WwTW inputs.

Offshore samples were collected using the EA coastal survey vessel (csv) *Water Guardian* and its associated rib. Samples were ferried back to shore for transport to the mobile laboratory facility using the CREH survey vessel. The sampling protocol and parameters measured were different for each vessel.

From the *Water Guardian,* hourly water samples were collected using a displacement sampler from 1m below the surface and 60 per cent depth (measured from the water surface, using the ship-board sensor). The water was decanted into sterile containers and immediately stored in a dark cool box containing several frozen ice packs. A further sample was collected for sediment analysis. The *Water Guardian* was fitted with a downward facing acoustic doppler current profiler (ADCP), which continuously monitored current velocity and direction through the water column. Current velocity and direction profiles were measured hourly, using a Valeport BFM108 current meter. Measurements were taken at 1m below the water surface, at 0.2, 0.4, 0.6 and 0.8 depth, and 1m above the sea bed. An Aanderra 2770 solar radiation sensor linked to a data storage unit was also fitted to the survey vessel and this provided continuous data on solar radiation. Downwelling radiation was also measured hourly, at 0.5m intervals to a maximum depth of 4m, using a Skye Quantum sensor, which measures photosynthetically available radiation (PAR) in the range 400–700nm. Wind velocity and direction were measured using a hand-held anemometer.

Water samples were collected at half-hourly intervals from the rib, again using a displacement sampler, at a depth of 1m below the surface. Current velocity and direction profiles were measured hourly, using a Valeport BFM108 current meter. Again, measurements were taken at 1m below the water surface, at 0.2, 0.4, 0.6 and 0.8 depth, and 1m above the sea bed. Water depth was measured using a hand-held depth meter.

Water samples from the bathing water compliance locations were sampled hourly, 30cm below the surface in 1m depth of water. Samples from riverine and WwTW inputs were also sampled hourly. In the case of the Bridgend/Porthcawl sample area, sampling of the inputs commenced six hours before the start of the offshore and bathing water compliance sampling. At the Minehead/Blue Anchor Bay sampling area, it was decided not to commence sampling early due to the relatively small size of the riverine inputs, and the tidally-phased discharge at the Minehead WwTW.

4.6.2 Sample analysis

Bacteriological samples were transported to the CREH *Analytical* mobile laboratory facility, located close to the sampling area. Quality accreditation of temporary, mobile laboratory facilities is not possible, although all analyses were undertaken to UKAS standards.

Enterococci were isolated on Slanetz and Bartley agar by membrane filtration using gridded cellulose ester membranes with a 47mm diameter and a pore size of 0.45μm. The membranes were incubated at 37 ± 1˚C for four hours followed by 44 ± 0.5˚C for 44 hours ± 4 hours, and colonies of all sizes and shades of pink through to maroon were counted as presumptive enterococci (Environment Agency, 2000). Plates that were positive for enterococci were tested for aesculin hydrolysis (ISO 7899 – 2) by transferring the entire membrane using kanamycin aesculin azide agar (KAAA) incubated at 44 ± 1.0 ˚C for four hours. Colonies that turned brown to black as evidence of aesculin hydrolysis were counted as confirmed enterococci. Full analytical quality control (AQC), to United Kingdom Accreditation Service (UKAS) standards, was undertaken as part of the microbiological analyses.

Samples were analysed for conductivity (μS cm^{-1} or mS cm^{-1}) using a Denver Instruments model 220 pH/Conductivity meter. Conductivity values were also expressed as total dissolved solid (mg l^{-1}) and practical salinity (unitless)[1], with the concentration of total dissolved solids in selected samples verified by evaporation and gravimetry (BS 1377-3:1990, ; Greenberg *et al.*, 1992, pp 2-43 to 2-45). Turbidity (NTU) was measured using a HACH model 2100A Turbidimeter (optical scattering, with formazine primary and gelex secondary standards) (Greenberg *et al.*, 1992, pp 2-8 to 2-11). Suspended solids concentration (mg l^{-1}) was determined using evaporation and gravimetry based on Whatman 47mm GFC filters (average pore size 1.2μm) (Greenberg *et al.*, 1992, pp 2-53 to 2-54). Particle size distribution

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[1] practical salinity: a scale relative to a standard KCl solution – a seawater with conductivity at 15˚C equal to that of a KCl solution containing a mass of 32.4356g in a mass of 1kg of solution is defined as having a practical salinity of 35

was analysed using a laser diffraction particle size analyser (Beckman-Coulter LS230 with variable speed fluidics module).

4.6.3 Site descriptions

4.6.3.1 Porthcawl/Southerndown.

Situated approximately between Cardiff and Swansea on the South Wales coast, Porthcawl and Southerndown lie on the northern shore of the Bristol Channel (Figure 4.4a). Three designated bathing beaches are situated close to Porthcawl – Rest Bay, Sandy Bay and Trecco Bay – and the latter was chosen for monitoring (site four). Southerndown bathing water, approximately 6km to the southeast of Trecco Bay, was chosen as the second bathing water (site five). The two monitored bathing waters are situated approximately 3km either side of the mouth of the Afon (River) Ogwr, which is the main riverine input into the area. The tidal limit of the Afon Ogwr is approximately at its confluence with the Afon Ewenni and it was therefore necessary to monitor both rivers to ensure samples were collected upstream of tidal influence (sites 6 (Ogwr) and 7 (Ewenni)). One large WwTW, Pen-y-Bont, discharges to the tidal Afon Ogwr close to the tidal limit, and its activated sludge-secondary-treated final effluent was monitored (site 8). Further details of the monitoring sites are given in Table 4.1. The offshore sampling points were situated approximately 2km offshore, to the south west of the two compliance monitoring points (Figure 4.4a). The offshore site sampled by the *Water Guardian* was numbered as site one for the sample collected from 1m depth and site two for the sample collected from 60 per cent depth. The rib sample point was identified as site three.

4.6.3.2 Minehead/Blue Anchor Bay

The Minehead/Blue Anchor Bay survey area is situated on the Somerset coastline, which forms the southern shore of the Bristol Channel. Again, two bathing water compliance points were monitored at Minehead Terminus, within the Minehead embayment, and Dunster North West, within Blue Anchor Bay (Figure 4.4b). Two small streams discharge onto the beach at Minehead: Park/Puritan streams (site six), which discharge via an outfall situated above high water, close to the bathing water compliance point; and Butlins stream (site seven), which discharges through an outfall situated at approximately mid-tide to the south of the embayment. Both inputs were sampled at their respective outfalls. The river Avil discharges into Blue Anchor Bay close to the Dunster North West bathing water compliance sample point and was sampled close to where it flows onto the beach (site nine). One sewage input is discharged into the area, from Minehead WwTWs. The ultra-violet-treated final effluent from this works is discharged between four hours after high water to two hours before high water, and was therefore only sampled when operating (site eight). The offshore sampling points were situated approximately 3km northeast of the Dunster North West compliance point (*Water Guardian*: sites one and two) and 1km northeast of the Minehead Terminus compliance site (rib: site three) (Figure 4.4b). The offshore site sampled by the *Water Guardian* was again numbered as site one for the sample collected from 1m depth, and site two for the sample collected from 60 per cent depth. Further details of the monitoring sites are given in Table 4.2.

4.6.4 Results

The data collected during the field surveys are presented in full in Appendix I of this volume. During both surveys, depth profiles of current velocity and direction were attempted. However, the high current velocities that were encountered dragged the current meter away from the vertical despite the use of additional ballast up to safe working limits. Hence, the data collected was considered unreliable, and is not discussed in this report. These data are presented in Appendix I. Similar problems were encountered while attempting to collect water quality samples from 60 per cent depth, and it was only possible therefore to collect samples during periods of slack water.

4.6.4.1 Porthcawl/Southerndown

The surveys at Porthcawl/Southerndown were undertaken on 24 July 2001 (survey one) and 26 July 2001 (survey two). The weather conditions were hot and sunny with some light cloud cover on both days. The riverine and WwTW inputs (sites six, seven and eight) were sampled between midnight and 6.00pm (BST), whilst the bathing water compliance points and offshore sites (sites one, two, three, four and five) were sampled between 6.00am and 6.00pm BST.

Enterococci concentrations for surveys one and two are presented in Figure 4.5, whilst geometric mean concentrations for each site are included in Table 4.3 (survey one, 24 July 2001) and Table 4.4 (survey two, 26 July 2001). A clear hierarchy of enterococci concentrations between sites is evident in Figure 4.5. The lowest concentrations were observed at the offshore sites, where concentrations were either close to, or at, the limit of detection (<1 cfu 100ml^{-1}), with the maximum concentration during either survey being 3cfu 100ml^{-1}. Concentrations at 60 per cent depth (site two) were similar to those at the surface (site one). Enterococci concentrations at the bathing water compliance points (site four and five) were slighter higher than those offshore, ranging between 1 cfu 100ml^{-}1 and 57 cfu 100ml^{-1}. Concentrations at the two riverine sites (sites six and seven) ranged between 30 cfu 100ml^{-}1 and 401 cfu 100ml^{-1}. During both surveys, the Afon Ewenni (site seven) displayed slightly greater geometric mean (GM) concentrations than the Afon Ogwr (site six) (Table 4.3). The highest concentrations were observed in the Pen-y-Bont WwTW final effluent (site 8), which ranged between 5,000 cfu 100ml^{-1} and 81,000 cfu 100ml^{-1}. With the exception of the WwTW final effluent, most sites displayed an overall decline in enterococci concentrations during daylight hours, possibly as a result of solar radiation-induced bacterial mortality.

Current velocities, during both surveys, measured at 1m depth, varied between 1 cm s^{-1} and 121 cm s^{-1} at site one and between 10 cm s^{-1} and 130 cm s^{-1} at site three (Figure 4.6). Peak velocities occurred at mid-tide with minimum velocities around high and low water. Major changes in current direction were also observed around high and low water (Figure 4.6). This pattern of velocity and direction is typical of 'open' coastal conditions. Wind velocity ranged between 13 m s^{-1} and 24 m s^{-1}, predominantly from a south-westerly direction, during survey one, and between 2 m s^{-1} and 16 m s^{-1}, predominantly from a westerly direction, during survey two.

Problems associated with the battery for the Aanderra solar radiation sensor resulted in the loss of data after 8.42am during survey one and between 1.13pm and 6.17pm during survey two. The available data are shown in Figure 4.7, together with data for Cardiff Bay (supplied by Cardiff Bay Harbour Authority) to provide an indication of the irradiance intensity during the period for which data are missing. Figure 4.7 also shows the downwelling radiation at 0.5m depth intervals. Broadly, the downwelling radiation follows a similar pattern to the incoming solar radiation, with intensity decreasing with depth. Maximum solar irradiance measured at the *Water Guardian* during survey one before the instrument failed was 466 W m^{-2}. Maximum irradiation at Cardiff Bay was 1070 W m^{-2} at 1.15pm, although it is possible that cloudier conditions prevailed at the survey site given the relatively low irradiance measured between 11.15am and 3.00pm using the Skye quantum sensor (Figure 4.7a; lower graph). Maximum irradiance measured during survey two was 1163 W m^{-2} at 12.02pm, which was slightly greater than the maximum measured at Cardiff Bay (1070 W m^{-2} measured at 12.20pm (Figure 4.7b)). During survey two, solar irradiance increased over the morning period before declining during the afternoon. This pattern was reflected in the downwelling irradiation results (Figure 4.7b).

Summaries of the suspended sediment particle size descriptive statistics are provided in Table 4.5 for survey one and Table 4.6 for survey two. During both surveys, the finest particle sizes in suspension were associated with the offshore and bathing water sites, while the suspended sediments in the rivers and WwTW final effluent (FE) were coarser. This is reflected in the particle size distributions for the two surveys, shown in Table 4.7a and b.

4.6.4.2 Minehead/Blue Anchor Bay

The surveys at Minehead/Blue Anchor Bay were undertaken on 30 July 2001 (survey three) and 1 August 2001 (survey four). The weather conditions were cool and overcast, becoming clearer and warmer in the afternoons on both days. All sites were sampled between 6.30am and 6.30pm BST. It was not possible to collect samples from site seven (Butlins Stream) at higher stages of the tide due to the outfall being submerged.

Enterococci concentrations for surveys three and four are presented in Figure 4.8, whilst geometric mean concentrations for each site are included in Table 4.8 (survey three, 30 July 2001) and Table 4.9 (survey four, 1 August 2001). A hierarchy of enterococci concentrations between sites, similar to that displayed at Porthcawl/Southerndown (see Section 4.6.4.1) is again evident (Figure 4.8). The lowest concentrations were again observed at the offshore sites, where concentrations were either close to, or at, the limit of detection (<1 cfu $100ml^{-1}$), with the maximum concentration during either survey being 8 cfu $100ml^{-1}$. Concentrations at 60 per cent depth (site two) were similar to those at the surface (site one). Enterococci concentrations at the bathing water compliance points (site four and five) were higher than those offshore, with the bathing water sites at Trecco Bay and Southerndown – ranging between 3 and 281 cfu $100ml^{-1}$ – at times exceeding the enterococci *Guide* standard in the Bathing Waters Directive 76/160/EEC (100 cfu $100ml^{-1}$) (Council of the European Communities (CEC), 1976). During survey three (30 July 2001), Minehead WwTW FE (site eight) displayed the lowest GM concentration of the inputs (56 cfu $100ml^{-1}$), whilst the Park/Puritan streams outfall (site six) displayed the highest GM concentration (3,779 cfu $100ml^{-1}$). However, during survey four (1 August 2001), the lowest GM concentration of the inputs was observed at the river Avil (site nine) (369 cfu $100ml^{-1}$), although the highest was again the Park/Puritan streams outfall (site six). Enterococci concentrations at the two bathing water sites during survey three showed a distinct relationship with tide height (Figure 4.9a), although this relationship was not evident during survey four (Figure 4.9b).

Current velocities, during both surveys and measured at 1m depth, varied between 6 cm s^{-1} and 120 cm s^{-1} at site one and between 3 cm s^{-1} and 179 cm s^{-1} at site three (Figure 4.10). Again, the velocity and direction pattern is typical of ‘open’ coastal conditions. Peak velocities occurred at mid-tide with minimum velocities around high and low water. Major changes in current direction were also observed around high and low water (Figure 4.10). Wind velocity ranged between 2 m s^{-1} and 8 m s^{-1}, predominantly from a north-westerly direction, during survey three, and between 1 m s^{-1} and 4 m s^{-1}, predominantly from a south-easterly direction, during survey four.

During survey three, the solar radiation gradually increased throughout the morning before displaying a period of variability between 12.15pm and 13.30pm. A period of lower irradiance followed until approximately 3.00pm, when values increased as the cloud cover declined, then decreased over the later afternoon (Figure 4.11a; upper graph). Peak irradiance was 1384 W m^{-2} at 12.57pm. The pattern of downwelling irradiation was similar, with the signal becoming increasingly subdued with depth (Figure 4.11; lower graph). During survey four, a heavy cloud cover resulted in relatively low irradiances until the clouds cleared at around 3.00pm (Figure 4.11b; upper graph). Peak irradiance of 980 W m^{-2} was measured at 3.03pm with the irradiance declining as the afternoon progressed. Again, the irradiation pattern was reflected in the pattern of downwelling irradiation, with a commensurate increase in downwelling irradiation occurring at most depths around 3.00pm (Figure 4.11b; lower graph).

The summaries of suspended solids descriptive statistics in Table 4.10 (survey three) and Table 4.11 (survey four) show the finest sediments to be associated with the offshore and bathing water sites. The coarsest sediments were associated with Park/Puritan streams outfall (site six) and the River Avil (site nine). Again, this is reflected in the particle size distributions for the two surveys shown in Tables 4.12a and b.

5. Hydrodynamic Modelling

5.1 Modelling procedure

The hydrodynamic modelling is based on the standard 1-D and 2-D governing equations, which consist of the momentum and the continuity equations. These were used to compute the tidal water elevation and the tidal and riverine currents (both speed and direction) in the 2-D and 1-D model domains. These hydrodynamic results, when presented graphically, can provide contours of water elevations and current fields, both for the 2-D and 1-D domains. As the survey data are given in the form of water depths, the outputs for the tidal water elevations are deducted from the bed elevations to give the water depth outputs for the modelling results. Predicted water level and velocity distributions at four stages of a tidal cycle are shown in Figures 5.1–5.4 for a spring tide and Figures 5.5–5.8 for a neap tide.

5.2 Hydrodynamic calibration

Calibration of the water surface elevations, and current speeds and directions, was carried out for each of the four surveys, using the field survey data described in Section 4.6. Figures 5.9 to 5.20 illustrate the calibration results. The hydrodynamic calibration showed that the correlation between the predicted and measured data was very good for tidal phasing for all four surveys. The predictions of the water depths and current directions closely agreed with the site survey data. The current speed predictions showed good agreement with the measured data, except at the South Wales site where the model slightly (and consistently) underestimated the magnitude of fluid speed during the ebb tide. The order of accuracy of this model calibration was similar to that for other studies of the Bristol Channel (Lin and Falconer, 2001).

6. Sediment Transport Modelling

In this study, the enterococci concentration was assumed to be associated with the SS concentration. The enterococci concentration would decrease when the sediment was settling and increase when the sediment was re-suspending. This means that sediment transport processes play an important role in predicting the enterococci concentrations. Therefore, the existing sediment transport modules within the original 2-D and 1-D models were carefully reviewed and refined before being applied.

The enterococci T_{90} values were also dependent upon the instantaneous SS concentrations. The sediment transport rate was based on the periodicity of the tidal flow, with the increased velocities occurring around mean water level causing increased transport of the local bed sediments into the water column. These processes supplemented and interacted with the dynamic inputs of enterococci from the multiple riverine and sewage sources outlined in Volume II.

In the sediment transport model, both non-cohesive and cohesive sediments were included, with the total suspended solids (SS) concentration being the sum of non-cohesive and cohesive sediment concentrations.

Table 6.1 summarises the arithmetic mean values of the sediment concentrations at the bathing water compliance monitoring points. The predicted non-cohesive sediment concentration at selected bathing water compliance monitoring points – Whitmore Bay and Jacksons Bay (model site 14); Sandy Bay and Trecco Bay, Porthcawl (model site 16); and Southerndown (model site 17)) – are shown in Figure 6.1. The sediment concentrations were found to be relatively high for the first 150 hours but decreased thereafter. A similar pattern for the predicted sediment concentration distributions was found to occur at all of the selected locations, with only the numerical values differing. This pattern was closely linked to that of the tidal currents, as shown in Figure 4.3. The tidal range over the first 150 hours was about twice the value predicted for the second 150 hours. Therefore during the first 150 hours sediment re-suspension of the bed material was the predominant process, driven by the relatively large tidal currents.

For the second 150-hour period of simulation, sediment settling was the predominant process due to the lower tidal currents, which led to a greater proportion of the sediments being deposited back onto the bed. As the sediment load was advected (or transported) by tidal flow, the sediment concentration at each of the bathing water sites varied in a cyclical manner, which correlated with each tide.

Sediment types were described by Posford Duvivier and ABP Research (2000) as ‘mud’ and ‘sandy mud’ in the areas around Minehead and ‘fine sand’ and ‘medium sand’ along the South Wales coast. The cohesive sediment predictions were therefore based on two different average floc sizes: 0.010mm and 0.063mm. At the Minehead and Dunster North West sites, an average floc size of 0.010mm was used, since the median particle diameter was found to be between 0.0085mm and

0.0125mm (see Section 4.6 of this volume and Volume III of this study). Modelled tidal currents were also smaller at these sites. At the South Wales sites, an average floc size of 0.063mm was used. The predicted results for the locations described above (model sites 14, 16 and 17) are shown in Figure 6.2.

The total suspended solids concentration includes both non-cohesive and cohesive particles and, hence, the non-cohesive and cohesive sediment concentrations were summed to establish the total SS concentration. The total SS concentrations at model sites 14, 16 and 17 are presented in Figure 6.3, which again illustrates a similar cyclical pattern to that observed in Figures 6.1 and 6.2.

7. Water Quality Simulation

7.1 Model Calibration

Data from the four calibration field surveys (24 July 2001, 26 July 2001, 30July 2001 and 1 August 2001 (see Section 4.6)) were used to calibrate the enterococci parameter, for the sites described in Section 4.5.3. The calibration results are shown in Figures 7.1–7.8.

The enterococci concentrations at the four offshore locations (sampled at 1m depth) were generally very low. At these locations, the bed sediment size is generally quite large (Posford Duvivier and ABP Research, 2000) and it was assumed that enterococci concentrations within the bed sediments were effectively zero. As can be seen from Figures 7.3, 7.4, 7.7 and 7.8, the enterococci predictions were in good agreement with the survey data.

At the bathing water compliance monitoring points, calibrations were carried out using the combined ‘decay and SS’ model predictions, with the predicted results from the ‘decay only’ model also plotted. In Figures 7.1, 7.5 and 7.6, the predictions from the ‘decay and SS’ model matched the measured survey data with good agreement. However, in Figure 7.2 for the Southerndown site, the calibration for survey one (on 24 July 2001) was poorer. This was thought to be due to the Southerndown survey site being relatively close to riverine/effluent inputs. This means that localised features (such as the shape of the input plume) may not be captured with sufficient accuracy in a model based on a relatively coarse 600m by 600m grid. In terms of bacterial indicator modelling, the calibration results were considered to be satisfactory.

7.2 Simulation results and discussions

Considering the above calibration predictions and sensitivity analysis (see Section 8), the coefficients for the water quality estimation modelling were finally chosen as: 80 per cent ratio of attached enterococci to total enterococci; and an enterococci concentration of 1,000 cfu g^{-1} in the bed sediments.

7.2.1 Water quality at different bathing water sites

The predicted results for enterococci concentration at the bathing water compliance monitoring locations closest to the inner estuary (model sites one to four) and at the outer limit of the Bristol Channel (model site five), are shown in Figure 7.9. Figure 7.10 shows predicted enterococci concentrations for the bathing water compliance monitoring points included in the model calibration field surveys (model sites six, 10, 16 and 17). From these figures it can be seen that:

1. the enterococci concentration varies with the periodicity of the tidal currents, which flush the micro-organisms in and out of the basin;

2. the peak values at the compliance locations were determined by the distances from the pollutant input sites;

3. the time at which the peak concentration occurred within the tidal cycle was unique for each site.

The water quality derived from the predicted arithmetic mean enterococci concentrations, shown in Table 7.1, can be categorised as follows:

- those affected by both riverine inputs /sewage outfalls and entrainment (Type I);

- those affected by either riverine inputs /sewage outfalls or entrainment (Type II);

- those not affected by riverine inputs /sewage outfalls or entrainment (Type III).

7.2.2 Type I sites

There are seven bathing water compliance monitoring points, situated within five model grid cells, where the water quality is affected by riverine inputs/sewage outfalls and strong tidal currents, producing high levels of sediment transport (Table 7.1). Thus, these locations were affected by both the close proximity of enterococci inputs and sediment re-suspension.

7.2.3 Type II sites

These sites are affected either by sediment re-suspension or by riverine inputs/sewage outfalls. Eleven bathing water compliance monitoring points, situated within eight model cells, fall within this category (Table 7.1). For example, at model site 16 (Porthcawl, Trecco Bay/Sand Bay), enterococci loading comes only from the nearby inputs but not from sediment re-suspension, since sediment fluxes at this site are dominated by sediment deposition (Section 8).

7.2.4 Type III sites

Eleven bathing water compliance monitoring locations, situated within seven model cells, fall into this category (Table 7.1). These sites are relatively distant from the riverine inputs and/or sewage outfalls, exhibited very low SS concentrations and very low enterococci concentrations. In particular, model sites 13, 19 and 20 were found to have low enterococci concentrations, with maximum concentrations of 7 cfu $100ml^{-1}$, 32 cfu $100ml^{-1}$ and 38 cfu $100ml^{-1}$ respectively (Table 7.1).

The predicted mean values of the sediment concentrations at the bathing water compliance sites are shown in Table 6.1. By comparing the predicted results in Table 7.1 with those in Table 6.1 it can be seen that the predicted sediment concentrations at the Type III sites were relatively low. In particular, at model site 13 the suspended solid concentration was less than 1 mg l^{-1} (Table 6.1), whilst the mean enterococci concentration predicted at this site was virtually zero (Table 7.1).

8. Sensitivity analysis

8.1 Dilution effect

The Bristol Channel and Severn estuary constitute an estuarine basin with a large flow-through, primarily driven by the very high tidal range, typically up to 14m. It was therefore considered appropriate to assess the predicted dilution effects produced by these large tidal currents and then assess the sensitivity of bacterial disappearance to variations in several parameters. Parameters tested include: (i) the mortality rate; and (ii) the suspended sediment concentration. The dilution test was carried out using the same governing equations, but assuming no bacterial decay, which means that the transport of bacteria was governed by advection and dispersion only.

Two runs were conducted in order to investigate the impact of sediment transport when decay was not considered. The first run assumed that the bacteria were transported by the flow only, which was termed a ‘dilution only’ run. The second run assumed that the bacteria were transported by both the flow and the sediment transport flux. The second run included both flow dilution effects and attachment to sediments in the deposition and re-suspension phases. This process of dilution with sediment transport was termed ‘dilution and SS’.

The modelling results for all of the bathing water sites are listed in Table 8.1, with each site showing enterococci contamination, except model site five (Tunnels Beach and Capstone, Ilfracombe), which has a zero value when the ‘dilution only’ model is used. This site shows higher enterococci concentrations when the ‘dilution and SS’ model is used.

The predicted enterococci concentrations for the ‘dilution only’ model are shown in Figure 8.1 for the bathing water compliance locations closest to the inner estuary (model sites one to four) and at the outer limit of the Bristol channel (model site five). Figure 8.2 shows the bathing water compliance monitoring points included in the model calibration field surveys (model sites six, 10, 16 and 17). Figures 8.3 and 8.4 show a comparison between the ‘dilution only’ and the ‘dilution and SS’ simulations for Minehead Terminus (model site 10) (Figure 8.3) and Berrow North of Unity Farm and Brean bathing water compliance monitoring points (model site three) (Figure 8.4). Comparing the results shows that the re-suspended sediment increased enterococci concentrations in the water column.

In Figures 8.1 and 8.2, it can be seen that for all model sites with the exception of site five, the enterococci concentration rises during the simulation time due to the accumulation of inputs from the riverine/sewage sources. This indicated that, for most compliance locations, the degree of enterococci loading from the sewage and riverine inputs would continue to increase under the dilution only assumption (no decay), even though the advection effects were large due to the high tidal range. It can therefore be concluded that the dilution effect alone is not sufficient to predict the enterococci concentrations along the coastal reaches of the Severn estuary.

This is because many rivers and sewage sources produce relatively large net loadings of faecal indicator organisms into the estuary.

Further details on the dilution effects are illustrated in the contour drawings shown in Figures 8.5a–d. These illustrate the enterococci distribution across the whole 2-D model domain for the dilution only model for the four stages of the tidal cycle at the end of the simulation period. In assessing the degree of diluted enterococci, the Bristol Channel can be divided into three sections. The first, located in the outer part of the Bristol Channel and extending from the seaward boundary to Swansea and the Gower beaches on the Welsh coast to Hurlstone Point on the English coast, displayed enterococci concentrations close to zero. The second reach, located in the area of the Bristol Channel between Swansea Bay on the Welsh coast to Bridgewater Bay on the English coast, exhibited enterococci concentrations typically less than 50 cfu 100ml^{-1}. The third reach, including the inner Bristol Channel (northeast of Bridgewater Bay) and the Severn estuary, displayed enterococci concentrations typically exceeding 100 cfu 100ml^{-1} (above the *Guideline* level used for compliance assessment for faecal streptococci in EU Directive 76/160/EEC).

8.2 Re-entrainment of enterococci

There is a marked difference in the enterococci concentrations predicted by the model depending on whether sediment transport processes are included or excluded (Figures 8.3 and 8.4). For example, in Figure 8.3 the enterococci concentration increased significantly over the simulation period when the dilution model included suspended solids (the ‘dilution and SS’ model). These increased concentrations are caused by the re-entrainment of the sediments from the bed into the water column. These results therefore highlight the necessity of including sediment transport processes in representing the fate and transport of bacterial indicator organisms in highly turbid waters.

In the remainder of this section a number of simulation scenarios are referred to and these are defined below.

> The ‘decay only’ scenario refers to the first order decay model, which only takes account of the enterococci concentration in the water column that exisits as free-living bacteria that are subject to related decay processes. It does not include the addition of bacteria from re-suspension of the bed sediments.
>
> The ‘decay with SS’ scenario refers to the total enterococci concentration, including both the free-living bacteria in the water column and the addition of bacteria released into the water column from the re-entrainment of bed sediments and the partitioning of the bacteria into the water column. During this process, the enterococci will move with the sediments and also be subject to decay processes.

A number of simulations were carried out to compare the difference between the predicted enterococci concentration, both with and without the SS fluxes. When the bacteria predictions with SS were included, the enterococci concentrations associated with the sediments were set at 1,000 cfu g^{-1}.

The decay model predictions for the bathing water compliance monitoring sites are listed in Table 8.2. This shows that the predicted arithmetic mean enterococci concentration for all sites, with the exception of model site 12 (Swansea Bay), were higher when the SS effects were included in the model. It is likely that the velocity at Swansea Bay is generally low and that sediment deposition is the dominant process. Figures 8.6 to 8.8 show a comparison between the ‘decay only’ and ‘decay with SS’ model predictions for bathing water compliance monitoring points at model site three (Berrow North of Unity Farm and Brean; Figure 8.6), model site 12 (Swansea Bay; Figure 8.7) and model site four (Clevedon Beach; Figure 8.8).

In Figure 8.6, at model site three (Berrow North of Unity Farm and Brean), it can be seen that the predicted results wthout SS are almost zero, whereas when the SS inputs are included the predicted values are typically up to 300 cfu $100ml^{-1}$. This suggests that the faecal indicator concentrations at this site are primarily determined by sediment transport processes. Also, the decay processes are sufficient to reduce the enterococci concentration derived from the riverine/sewage inputs, since the predicted enterococci concentrations are almost zero when the SS fluxes are not included. This observation is supported by the data in Tables 8.1 and 8.2. In Table 8.1, the ‘dilution only’ results showed an arithmetic mean enterococci concentration of 58 cfu $100ml^{-1}$ at model site three. Likewise, from Table 8.2 it can be seen that the effects of kinetic first order decay caused the arithmetic mean enterococci concentration for model site three to fall to approximately 2 cfu $100ml^{-1}$, with the decay kinetics being sufficient to reduce the bacteria to negligible concentrations. In contrast, when the effects of the suspended sediments were included in the model the arithmetic mean enterococci concentration was to 57 cfu $100ml^{-1}$. Thus, the model results again indicate that re-suspended bed sediments elevate the predicted enterococci concentration concentrations in the water column. These results are further highlighted in Figure 8.6.

Figure 8.7 shows the results for the compliance site in Swansea Bay (model site 12). In contrast with Figure 8.6, the predicted bacterial concentrations shown for the simulations using the ‘decay only’ model are generally only slightly lower than those predicted using the ‘decay with SS’ model. This indicates that the enterococci concentrations at this site are governed more by the riverine/sewage discharges.

Figure 8.8 illustrates the predicted results at Clevedon Beach (model site four), where higher bacteria concentrations are predicted after SS inputs are included within the model. This again indicates that the enterococci concentrations at this site arise from both inputs associated with the bed sediments and inputs from nearby effluent outfalls and/or river inputs. Therefore, at this site, the predicted enterococci concentrations are associated jointly with the suspended sediment and terrestrial fluxes.

Enterococci concentration predictions at spring tide mid-ebb (relative to the seaward boundary) for the ‘decay only’ model are shown in Figure 8.9 and in Figure 8.10 for the ‘decay with SS’ model. These suggest that the bed sediment contribution to the enterococci concentrations in the water column affect a much larger area than terrestrially-derived (riverine and sewage) inputs alone.

8.3 Sensitivity of the decay rate

The model results will only be reliable when the model has reached a quasi-steady state averaged over a tidal cycle and this only occurs after about two tides (see Section 4.4.3.5). It is therefore essential to establish the impact of the initial conditions on the predicted results.

Two simulations were undertaken to establish how the initial conditions affected the model predictions. First, for 'dynamic initial decay', the decay rate was assumed to be dynamic from the outset, with the T_{90} value being variable from the start of simulations. Second, for 'constant initial decay', the T_{90} value was assumed to be constant for the first 24 hrs and thereafter a 'real time' (dynamic) decay rate was applied.

The predicted results for bathing water compliance monitoring sites at Weston-Super-Mare Sand Bay (model site one), Clevedon Beach (model site four), Swansea Bay (model site 12) and Southerndown (model site 17) are shown in Figures 8.11 to 8.14 respectively. In these figures, the navy blue line shows the predictions for the 'dynamic initial decay model' and the red line shows the predictions for the 'constant initial decay' model. From these predictions it can be seen that when different T_{90} values were used during the first 24 hours of the simulation different results were only obtained for the first 40 hours of the simulation. After approximately 40 hours, the predicted enterococci concentrations were the same, irrespective of the initial representation of the decay rate. It was therefore concluded that for continuous riverine and WwTW inputs to the model domain, the form of the kinetic decay rate in the initial period did not affect the predictions after about three tidal cycles.

At Weston-Super-Mare Sand Bay (model site one; Figure 8.11), a time lag of approximately three hours exists, which can be interpreted as the time required for the enterococci concentration in the water column to build up from an initial value of zero. This can be explained by the fact that this site is not particularly close to a riverine/sewage input and hence the initial zero enterococci concentration prevails until the effluent from the nearest source has been transported to the compliance monitoring point.

8.4 Sensitivity of bed boundary condition

A boundary concentration (C_b) for the enterococci concentration on bed sediments needed to be specified in the model in units of cfu g^{-1}. This sediment enterococci concentration can be converted to a water column concentration (C), normally expressed in cfu $100ml^{-1}$, by the following relationship: $C = 0.1 \times C_b \times S$, where S is the re-suspended sediment concentration in the water column in g l^{-1}.

The results discussed in section 8.1.2 indicate that the re-entrainment of sediment from the bed is a key factor in determining the enterococci concentrations in the water column. It was therefore necessary to consider the sensitivity of the predictions, using the model to establish the effect of different enterococci concentration in the bed sediment s.

Three bed concentrations were considered: 10 cfu g^{-1}, 100 cfu g^{-1} and 1,000 cfu g^{-1}. The predicted enterococci concentrations in the water column arising from these different bed sediment concentrations, and for predictions excluding SS, are shown in Figure 8.15 for Weston-Super-Mare Sand Bay (model site one) and in Figure 8.16 for Swansea Bay (model site 12).

The predictions for Weston-Super-Mare Sand Bay (Figure 8.15) show that predicted enterococci concentrations in the water column for a 1,000 cfu g^{-1} bed sediment enterococci concentration are significantly higher than the corresponding results for the 10 cfu g^{-1} or 100 cfu g^{-1} bed sediment concentrations. This suggests that sediment re-suspension may be a dominant process around this site.

In contrast, at Swansea Bay (Figure 8.16) the different bed concentrations produce similar concentrations within the water column, with only the prediction that excludes SS showing an appreciable difference. This indicates that in the vicinity of Swansea Bay the sediment transport processes were dominated by deposition, with a significant loss of enterococci from the water column when compared to the concentrations obtained from the prediction excluding suspended sediments.

8.5 Sensitivity of the ratio of sediment attached and 'free swimming' enterococci

In order to test the sensitivity of the model to the proportion of sediment attached bacteria, three different proportions were modelled: 80 per cent, 50 per cent and 20 per cent of the total enterococci concentration attached to sediment. For all of these cases the bed concentration was assumed to be 1000 cfu g^{-1}. Figures 8.17 and 8.18 show the corresponding model predictions for the different proportions at Weston-Super-Mare Sand Bay (model site one) and Swansea Bay (model site 12).

At Weston-Super-Mare Sand Bay (Figure 8.17) the predictions without SS (the light blue line) gave much lower enterococci concentrations than the corresponding predictions including SS, even for the relatively small ratio of only 20 per cent. This suggests that re-suspension of the bed sediments at this site significantly affects the concentration of enterococci entering the water column. Again, these results indicate that this site is dominated by re-suspension processes.

When re-suspension is the dominant process, the bed concentration becomes the governing source, rather than the ratio between enterococci attached to sediment and planktonic enterococci. Figure 8.17 shows that there is a relatively small difference between the predicted results for ratios of 50 per cent and 80 per cent, with the largest difference that occurred between the ratios of 20 per cent (navy blue line) and 80 per cent (orange line) being 375:320 (17 per cent).

In contrast, for Swansea Bay (see Figure 8.18), the predictions associated with the simulation without SS gave the highest bacterial concentrations (light blue line), with all of the predicted results associated with the inclusion of SS giving lower concentrations. This difference is explained by the settling process being dominant at this site. The results show that the higher the attached proportion, the higher the bacterial load settling out on the bed.

When the settling process dominates, the effect of the proportion of sediment-attached bacteria becomes very significant. It can be seen in Figure 8.18 that the largest difference that occurred between the ratios of 20 per cent (navy blue line) and 80 per cent (orange line) is 40:19 (over 100 per cent).

9. Discussion

This volume describes a hydro-environmental numerical model developed to predict the fate of enterococci organisms in estuarine and coastal waters. In this model, the reduction/increase of enterococci within the water column has been assumed to be caused by both bacterial deactivation (mortality) and sediment deposition/entrainment. The enterococci disappearance rate was linked to sediment deposition, whilst concentration increases were related to the sediment re-suspension. The model also assumed that the enterococci mortality rate varied with received irradiance, as determined by sunlight intensity, and suspended solids concentration. Therefore suspended solids affected the enterococci concentration through two processes: (i) sedimentation/re-suspension and (ii) protection from sunlight.

The dynamically-linked 1-D and 2-D hydro-environmental model was successfully applied to the Bristol Channel and Severn estuary. The model incorporated 29 riverine inputs and 34 sewage effluent discharges from WwTWs with variable microbial concentrations and flow volumes. The study area covered receiving waters from an integrated catchment area of up to 15,000 km^2, including a number of bays, rivers and the main estuary.

The numerical modelling tool highlighted close links between enterococci concentration and both bacterial mortality and sediment transport processes, with enterococci disappearance evident when the sediments were depositing. The T_{90} value that was used significantly affected the predicted enterococci concentrations. Dynamically-variable T_{90} values were used to reflect more accurately the variation in this parameter with the diurnal pattern of sunlight intensity. These T_{90} values were predicted from empirically-derived regression equations (see Volume III), which varied with the time-dependent and grid-dependent suspended solids concentrations.

As a result of the interactions between various processes, the enterococci concentrations varied in a cyclical manner in phase with the tidal oscillations and derived, at many locations, principally from bed sediments. When sediment re-suspension dominated the sediment transport processes, the ratio of the concentration of ‘attached enterococci’ to ‘total enterococci’ did not influence the model predictions to a major extent. However, in contrast, this ratio affected the predicted results noticeably when deposition (or settling) was the dominant sediment transport process.

Calibration data were collected from surveys of bathing water compliance monitoring points and offshore sites at Porthcawl and Southerndown (South Wales) and Minehead and Blue Anchor bays (Somerset). These surveys were designed to produce suitable data for the calibration of the numerical models. The ‘dynamic decay’ model results were in good agreement with the measured data at the four offshore survey sites, whilst the ‘dynamic decay and suspended solids’ model gave satisfactory agreement with the near-shore bathing water compliance monitoring points. These findings suggest that the suspended solids concentration generally had more impact on the predicted enterococci concentrations in the near-shore waters and less effect in the deeper offshore waters. This is in agreement with observations of increased re-suspension of sediments by wave action in the near-shore zone.

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Notation used in equations

a	near bed sediment concentration reference height
A_o	horizontal discharge area
C	depth averaged bacteria concentration
C_b	bacterial concentration on bed sediments
C_D	drag coefficient
C_o	outfall discharge’s concentration
D	deposition rate
dt	time interval
E	re-suspension rate
H	water depth at the discharge location
I	hourly solar radiation
k	decay coefficient
N	number of bacteria in counts
p	probability that a sediment particle will remain on the bed
q_s	sediment flux
Q_o	outfall discharge rate
S_a	sediment concentration at reference level
S_{ae}	equilibrium sediment concentration at the reference level
S_e	depth mean equilibrium concentration
SS	suspended solids concentration
T_{90}	time taken for 90 per cent of bacteria to die
T_{90}^1	enterococci mortality rate depending on surface sunlight (I)
T_{90}^2	enterococci mortality rate obtained from the laboratory experiments
$\overline{U}$	depth-averaged current speed
w_d	deposition velocity
w_s	sediment fall velocity
α_s	ratio between enterococci attached to sediments and total enterococci
ρ	density of water
τ_b	effective bottom shear stress
τ_c	critical shear stress for the initiation of sediment from bed
$\Sigma\Phi_s$	source or sink terms

Tables

Table 3.1 Bathing water compliance monitoring locations and associated model grid cell

Site No	Model grid cell		Location		OS grid (metres)		Co-ordinate	
	I	J	ID	Beach	Easting	Northing	Longitude	Latitude
1	190	34	35900	Weston-s-Mare Sand Bay	333000	163500	2˚58’40″	51˚22’00″
2	184	30	35800	Weston Main	331600	160700	3˚00’10″	51˚20'20″
2	184	30	35700	Weston-s-Mare Uphill Slip	331200	158800	3˚00’10″	51˚20'20″
3	175	21	35500	Berrow N.of Unity Farm	329300	154500	3˚02’20″	51˚18’00″
3	175	21	35600	Brean	329600	158500	3˚02’20″	51˚18’00″
4	205	40	36000	Clevedon Beach	339800	171200	2˚52’20″	51˚26’20″
5	44	70	34450	Ilfracombe Tunnels Beach	251450	147800	4˚08’10″	51˚12’10″
5	44	70	34500	Ilfracombe Capstone	251820	147900	4˚08’10″	51˚12’10″
6	59	52	34600	Ilfracombe Hele	253550	147920	4˚06’00″	51˚12’20″
6	59	52	34700	Combe Martin	257720	147320	4˚06’00″	51˚12’20″
7	140	19	35200	Blue Anchor West	302300	143500	3˚24’00″	51˚11’30″
7	140	19	35100	Dunster North West	299700	145500	3˚24’00″	51˚11’30″
8	92	43	34800	Lynmouth	272500	149750	3˚49’40″	51˚14’30″
9	112	33	34900	Porlock Weir	286400	147900	3˚37’40″	51˚13’30″
10	129	27	35000	Minehead Terminus	297300	146500	3˚29’00″	51˚13’00″
11	91	104	37200	Langland Bay	260600	187100	4˚00’40″	51˚33’50″
11	91	104	37100	Limeslade Bay	262500	187000	4˚00’40″	51˚33’50″
11	91	104	37000	Bracelet Bay	263000	187100	4˚00’40″	51˚33’50″
12	100	109	36900	Swansea Bay	264400	192100	3˚57’20″	51˚36’10″
13	111	101	36800	Aberafan	273900	189600	3˚49’00″	51˚35’20″
14	160	42	36200	Whitmore Bay Barry	311450	166250	3˚16’20″	51˚23’20″
14	160	42	36100	Jacksons Bay Barry	312200	166570	3˚16’20″	51˚23’20″
15	116	80	36700	Rest Bay Porthcawl	280000	177900	3˚43’40″	51˚29’10″
16	121	77	36600	Sandy Bay Porthcawl	282400	176500	3˚41’30″	51˚28’20″
16	121	77	36500	Trecco Bay Porthcawl	283100	176300	3˚41’30″	51˚28’20″
17	126	70	36400	Southerndown	288400	172900	3˚36’30″	51˚26’40″
18	157	44	36300	Cold Knap Barry	309650	166400	3˚18’00″	51˚23’20″
19	79	108	37400	Oxwich bay	250700	186200	4˚08’30"	51˚33'45"
20	70	106	37500	Port Eynon Bay	247200	184800	4˚11'25"	51˚33'00”

Table 3.2 River input locations and associated model grid cell within the 2-D domain

No	Model grid cell		Catchment (see Figure 3.2)		OS grid (metres)		Co-ordinate	
	I	J			Easting	Northing	Longitude	Latitude
Input 1	101	109	1	Tawe	266598	191653	3°55’26″	51°36’20″
Input 1	101	109	2	Nedd	271881	192432	3°55’26″	51°36’20″
Input 2	111	107	3	Afan	274556	188667	3°48’28″	51°35’05″
Input 3	113	94	4	Kenfig	277919	183473	3°45’35″	51°32’12″
Input 4	117	78	5	Ogwr	286123	175787	3°38’50″	51°28’00″
Input 5	170	42	6	Ely	318583	172672	3°09’20″	51°26’40″
Input 5	170	42	5	Taff	318218	172672	3°09’20″	51°26’40″
Input 6	184	52	8	Rhymney	322282	177474	3°07’20″	51°28’30″
Input 7	201	55	9	Ebbw	331480	183805	2°58’30″	51°31’18″
Input 7	201	55	10	Usk	331798	183633	2°58’30″	51°31’18″
Input 8	210	40	15	Avon	350115	178583	2°43’20″	51°30’20″
Input 8	210	40	16	Portbury Ditch	347817	177420	2°43’20″	51°30’20″
Input 9	206	39	17	Land Yeo	338862	170310	2°52’40″	51°26’00″
Input 10	195	36	18	Congresbury Yeo	336494	166748	2°55’30″	51°23’55″
Input 10	195	36	19	Banwell			2°55’30″	51°23’55″
Input 11	184	29	20	Axe	330852	158536	3°01’10″	51°13’20″
Input 12	172	20	21	Brue	329428	147527	3°00’15″	51°13’20″
Input 12	172	20	22	Parrett	329130	146844	3°00’15″	51°13’20″
Input 13	153	11	23	Kilve Stream	314335	144453	3°13’50″	51°11’50″
Input 14	144	18	24	Doniford Stream	309059	143213	3°18’15″	51°11’35″
Input 14	144	18	25	Washford River	306997	143524	3°18’15″	51°11’35″
Input 15	135	17	26	Pill River	302706	143520	3°23’25″	51°11’35″
Input 15	135	17	27	Avill River	300883	144247	3°23’25″	51°11’35″
Input 16	116	32	28	Aller-Horner Water	289210	148512	3°35’15″	51°13’58″
Input 17	91	43	29	East-West Lyn	272291	149678	3°49’45″	51°14’20″

Table 3.3 River input locations and associated model segment within the 1-D domain

No	Model segment	Catchment (see Figure 3.2)		OS grid	
	Node no.	ID	Catchments	Easting	Northing
Input 1	3	11	Wye	354231	190223
Input 2	300	12	Severn	381548	219350
Input 3	206	13	Frome	375173	210497
Input 4	100	14	Little Avon	366257	200314

Table 3.4 Wastewater treatment works effluent outfall locations and associated model segment within the 1-D domain

No.	Name (and reference on Figure 3.3)	Model segment	OS grid		Co-ordinate	
		Node No.	Easting	Northing	Longitude	Latitude
1	Thornbury WwTW (23)	4	359990	193010	2°34′40″	51°38′00″
1	Sedbury WwTW (14)	4	353990	193420	2°40′08″	51°38′10″
2	Blakeney WwTW (16)	150	369110	206040	2°26′50″	51°45′00″
2	Frampton WwTW (21)	150	373570	208530	2°23′00″	51°46′25″
3	Cheltenham WwTW (19)	335	389930	224860	2°09′47″	51°55′10″
3	Gloucester Longford WwTW (18)	335	384730	221180	2°13′20″	51°53′13″
4	Gloucester Netheridge WwTW (20)	295	380900	215900	2°16′40″	51°50′30″
5	Longhope WwTW (17)	120	369060	217880	2°27′02″	51°51′25″
6	Lydney WwTW (15)	95	363760	200550	2°31′40″	51°42′05″
6	Sharpness WwTW (22)	95	367000	201500	2°29′00″	51°42′35″

Table 3.5 Wastewater treatment works effluent outfall locations and associated model grid cell within 2-D domain

No.	Name (and reference on Figure 3.3)	Model grid cell		OS grid		Co-ordinate	
		I	J	Easting	Northing	Longitude	Latitude
1	Afan WWTW (5)	111	97	274055	185075	3° 48.9'	51°33'00"
1	Magor Brewery Effluent (13)	111	97	343765	184585	3°48'30"	51°33'40"
2	Bishopston WwTW (3)	89	104	258605	187305	4°1'07'	51°34'55"
3	Cardiff WWTW (9)	186	44	325085	173955	3°4'40"	51°27'40"
4	Cog Moors WwTW (10)	173	44	319306	167576	3°9'40"	51°24'05"
5	Llantwit Major WWTW (7)	136	53	296355	167145	3°29'25"	51°24'05"
6	Nash WwTW (11)	96	104	333455	184115	3°57'25"	51°33'10"
7	Overton WwTW (1)	68	107	246395	184485	4°12'05"	51°33'20"
8	Pen y Bont WwTW (6)	125	70	287845	176845	3°36'20"	51°29'10"
9	Ponthir WwTW (12)	101	109	334665	190435	3°56'20"	51°36'40"
10	Southgate WwTW (2)	82	108	255385	187005	4°4'20"	51°34'40"
11	Swansea WwTW (4)	103	108	268370	189437	3°53'05"	51°36'05"
12	The Leys outfall, Aberthaw (8)	145	46	302305	165605	3°24'00”	51°23'00"
13	Avonmouth WwTW (24)	204	40	351900	180700	2°41'50"	51°31'20"
13	Portbury Wharf WwTW (25)	204	40	348550	178150	2°44'25"	51°29'50"
14	Bridgewater WwTW (30)	170	20	330340	138810	3°00'05"	51°08'02"
14	West Huntspill WwTW (29)	170	20	329420	146840	3°00'55"	51°12'30"
15	Doniford Outfall (31)	140	18	308740	144010	3°18'30"	51°10'58"
15	Watchet WwTW (32)	140	18	306520	144550	3°20'20"	51°11'20"
16	Kingston Seymour WwTW (26)	195	36	338400	168660	2°53'10"	51°24'40"
16	Wick St Lawrence WwTW (27)	195	36	336510	166600	2°54'45"	51°23'30"
17	Minehead WwTW (33)	129	26	299450	146970	3°26'30"	51°12'30"
18	Porlock WwTW (34)	113	33	288350	148300	3°36'00"	51°13'20"
19	Weston-Super-Mare WwTW (28)	184	29	330580	158690	3°00'00"	51°19'20"

Table 4.1: Details of the sample sites and model grid cell reference in the Porthcawl/Southerndown surveys

Site No.	Site Description	NGR	Model grid cell	
			I	J
1	Offshore, *Water Guardian*, 1m depth sample	SS 8600 7200	124	69
2	Offshore, *Water Guardian*, 60% depth sample	SS 8600 7200	n/a	n/a
3	Offshore, rib, 1m depth sample	SS 8100 7400	120	72
4	Trecco Bay bathing water	SS 8310 7630	121	77
5	Southerndown bathing water	SS 8840 7920	126	70
6	Afon Ogwr at suspension bridge, Merthyr Mawr	SS 8300 7300	n/a	n/a
7	Afon Ewenni, Verville Farm bridge	SS 8940 7720	n/a	n/a
8	Pen-y-Bont WwTW final effluent	SS 8760 6700	n/a	n/a

Table 4.2: Details of the sample sites and model grid cell reference in the Minehead/Blue Anchor Bay surveys

Site No.	Site Description	NGR	Model grid cell	
			I	J
1	Offshore, *Water Guardian*, 1m depth sample	SS 9800 4800	137	20
2	Offshore, *Water Guardian*, 60% depth sample	SS 9800 4800	n/a	n/a
3	Offshore, rib, 1m depth sample	ST 0300 4700	128	25
4	Minehead Terminus bathing water	SS 9730 4650	129	27
5	Dunster North West bathing water	SS 9970 4550	140	19
6	Park/Puritan Streams at outfall	SS 9730 4640	n/a	n/a
7	Butlins Stream at outfall	SS 9830 4650	n/a	n/a
8	Minehead WwTW final effluent	SS 9890 4520	n/a	n/a
9	River Avil at outfall	SS 9970 4550	n/a	n/a

Table 4.3: Summary of water quality results from Porthcawl/Southerndown on 24 July 2001 (survey one)

		Enterococci		Conduct-ivity	Turbidity	Susp'd solids	Total dissolved solids	Practical salinity
		Presum. cfu 100ml	Conf. cfu 100ml	mS cm^{-1}	NTU	mg l^{-1}	mg l^{-1}	
Site 1	Mean[1]	1	1	54.78	10.71	43.04	38345	46.71
Offshore	Min	<1	<1	53.60	5.00	25.75	37520	45.56
(csv) 1m	Max	2	2	55.80	15.00	56.09	39060	47.71
Site 2	Mean[1]	4	3	54.73	11.67	46.71	38313	46.67
Offshore (csv)	Min	4	3	54.00	9.00	35.29	37800	45.95
60% depth	Max	4	3	55.40	15.00	55.11	38780	47.32
Site 3	Mean[1]	1	1	54.98	8.59	39.16	38487	46.91
Offshore	Min	<1	<1	54.00	5.00	25.73	37800	45.95
(rib)	Max	2	2	56.30	13.00	54.53	39410	48.20
Site 4	Mean[1]	15	8	54.53	24.50	115.55	38168	46.47
Trecco Bay BW	Min	5	2	53.50	11.00	42.77	37450	45.47
	Max	39	33	55.20	70.00	250.46	38640	47.12
Site 5	Mean[1]	20	14	54.22	29.77	160.83	37951	46.16
S'down BW	Min	5	4	53.70	15.00	66.13	37590	45.66
	Max	85	57	54.80	69.00	333.19	38360	46.73
Site 6	Mean[1]	242	149	0.24	1.76	7.63	170	0.15
Afon Ogwr	Min	92	53	0.23	1.00	0.67	163	0.14
	Max	600	330	0.25	5.00	47.74	174	0.15
Site 7 Afon	Mean[1]	381	183	0.51	1.00	3.34	355	0.31
Ewenni	Min	119	99	0.48	1.00	1.65	338	0.29
	Max	1600	390	0.52	1.00	6.70	365	0.32
Site 8	Mean[1]	69414	21791	0.83	2.29	5.66	583	0.51
Pen-y-bont FE	Min	12000	5000	0.78	1.00	2.86	547	0.48
	Max	224000	81000	0.92	5.00	11.82	647	0.57

[1] Enterococci concentration expressed as geometric mean

Table 4.4: Summary of water quality results from Porthcawl/Southerndown on 26 July 2001 (survey two)

		Enterococci		Conduct-ivity	Turbidity	Susp'd solids	Total dissolved solids	Practical salinity
		Presum. cfu 100ml	Conf. cfu 100ml	mS cm^{-1}	NTU	mg l^{-1}	mg l^{-1}	
Site 1	Mean[1]	1	1	54.74	7.93	32.46	38320	46.68
Offshore	Min	<1	<1	53.70	4.00	19.78	37590	45.66
(csv)	Max	2	1	55.80	12.00	44.39	39060	47.71
Site 2	Mean[1]	1	<1	54.85	7.75	33.47	38395	46.78
Offshore (csv)	Min	<1	<1	54.20	6.00	29.11	37940	46.15
60% depth	Max	2	<1	56.10	10.00	37.36	39270	48.00
Site 3	Mean[1]	2	2	55.34	7.40	31.89	38741	47.26
Offshore	Min	<1	<1	54.70	3.00	16.99	38290	46.63
(rib)	Max	4	3	56.20	12.00	49.51	39340	48.10
Site 4	Mean[1]	15	10	54.68	28.31	111.08	38279	46.62
Trecco Bay BW	Min	5	4	54.10	10.00	56.94	37870	46.05
	Max	59	22	55.20	65.00	231.56	38640	47.12
Site 5	Mean[1]	6	4	54.64	34.08	128.60	38247	46.57
S'down BW	Min	2	1	54.20	9.00	32.27	37940	46.15
	Max	17	12	55.30	100.00	401.15	38710	47.22
Site 6	Mean[1]	2471	145	0.22	1.65	2.92	151	0.13
Afon Ogwr	Min	140	30	0.21	1.00	1.63	146	0.13
	Max	11464	330	0.23	5.00	8.83	160	0.14
Site 7 Afon	Mean[1]	355	171	0.56	1.00	2.57	390	0.34
Ewenni	Min	100	88	0.52	1.00	1.41	365	0.32
	Max	1255	401	0.58	1.00	4.65	405	0.35
Site 8	Mean[1]	112893	29280	0.82	2.11	6.62	576	0.51
Pen-y-bont FE	Min	33636	10750	0.76	1.00	1.41	531	0.47
	Max	256364	61527	0.86	3.00	8.91	599	0.53

[1] Enterococci concentration expressed as geometric mean

Table 4.5: Summary of particle size results from Porthcawl/Southerndown on 24 July 2001 (survey one) (the values quoted are mean values from all samples analysed from each site)

	Mean (µm)	Median (µm)	Mode (µm)	Standard deviation (µm)	d10 (µm)	d90 (µm)	*n*
Site 1 Offshore (csv) 1m	14.2	10.5	13.8	15.2	3.2	26.3	4
Site 2 Offshore (csv) 60% depth	21.6	12.8	41.2	29.1	3.1	47.6	3
Site 3 Offshore (rib)	21.1	16.0	16.4	21.6	4.5	40.0	1
Site 4 Trecco Bay bathing water	18.5	11.1	13.0	22.7	3.0	39.3	4
Site 5 Southerndown BW	18.6	14.5	16.5	16.1	3.6	39.3	4
Site 6 Afon Ogwr	71.9	45.4	50.2	71.4	13.7	173.1	1
Site 7 Afon Ewenni	47.9	31.3	34.7	45.3	8.9	110.5	2
Site 8 Pen-y-bont WwTW FE	99.1	85.8	106.4	78.9	25.1	174.2	3

Table 4.6: Summary of particle size results from Porthcawl/Southerndown on 26 July 2001 (survey two) (the values quoted are mean values from all samples analysed from each site)

	Mean (µm)	Median (µm)	Mode (µm)	Standard Deviation (µm)	d10 (µm)	d90 (µm)	*n*
Site 1 Offshore (csv) 1m	19.3	10.0	14.3	28.2	2.8	59.1	4
Site 2 Offshore (csv) 60% depth	31.1	10.9	13.6	56.9	2.3	132.0	1
Site 3 Offshore (rib)	24.7	10.1	12.1	35.2	2.6	78.2	3
Site 4 Trecco Bay bathing water	19.3	13.1	15.4	24.7	3.5	36.3	4
Site 5 Southerndown BW	40.8	24.9	15.5	37.6	7.2	96.1	4
Site 6 Afon Ogwr	31.5	28.1	35.0	21.3	8.8	56.6	3
Site 7 Afon Ewenni	24.4	22.2	28.7	13.6	9.4	46.0	2
Site 8 Pen-y-bont WwTW FE	30.1	17.4	14.9	32.9	5.0	77.6	2

Table 4.7a: Particle size distributions of suspended sediments sampled during Porthcawl/Southerndown survey one (24 July 2001)

Particle diameter (µm)	Percentage (%) less than particle diameter														
	Site 1 9:05	Site 1 12:00	Site 1 16:00	Site 1 18:30	Site 2 7:13	Site 2 17:00	Site 2 18:15	Site 3 18:30	Site 4 9:30	Site 4 12:30	Site 4 15:30	Site 4 18:30	Site 5 9:30	Site 5 12:30	Site 5 15:30
0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	6.9	1.9	6.3	5.4	7.6	4.7	6.8	4.1	5.4	5.3	5.8	5.0	3.4	5.1	5.1
3.9	15.1	16.8	14.7	9.1	17.9	9.1	15.5	8.5	23.9	11.9	14.6	13.8	8.2	13.7	8.5
7.8	38.6	49.0	41.2	22.2	32.0	26.0	38.5	20.7	51.4	28.5	34.3	29.9	15.2	30.0	19.5
15.6	72.7	87.6	76.7	51.6	49.5	63.3	71.4	48.5	78.9	57.1	68.5	56.6	36.1	61.0	44.8
53.0	99.9	100.0	100.0	92.5	79.6	95.9	97.4	95.2	98.0	97.8	99.3	87.0	91.4	95.7	93.4
105.0	100.0	100.0	100.0	96.3	96.8	96.6	99.4	98.7	100.0	100.0	100.0	91.8	100.0	100.0	98.7
210.0	100.0	100.0	100.0	98.7	100.0	98.3	100.0	100.0	100.0	100.0	100.0	92.3	100.0	100.0	99.7
420.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
840.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1680.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Particle diameter (µm)	Percentage (%) less than particle diameter						
	Site 5 18:30	Site 6 9:50	Site 7 9:33	Site 7 14:55	Site 8 6:43	Site 8 11:30	Site 8 17:58
0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	6.8	1.6	2.9	1.7	0.6	0.5	0.7
3.9	15.6	2.9	5.9	3.2	1.4	1.1	1.4
7.8	37.5	5.1	13.4	6.5	2.7	2.4	3.2
15.6	69.8	12.5	26.3	15.2	6.1	5.0	7.0
53.0	96.3	56.3	76.4	64.0	28.0	25.4	29.9
105.0	100.0	78.1	92.4	82.8	61.9	63.5	69.0
210.0	100.0	92.5	100.0	95.9	96.0	93.7	99.1
420.0	100.0	100.0	100.0	100.0	100.0	98.0	100.0
840.0	100.0	100.0	100.0	100.0	100.0	99.8	100.0
1680.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.7b: Particle size distributions of suspended sediments sampled during Porthcawl/Southerndown survey two (26 July 2001)

Particle diameter (µm)	Percentage (%) less than particle diameter Site 1 8:00	Site 1 8:30	Site 1 11:30	Site 1 14:30	Site 2 11:30	Site 3 11:30	Site 3 14:30	Site 3 17:30	Site 4 8:30	Site 4 11:30	Site 4 17:30	Site 5 8:30	Site 5 11:30	Site 5 14:30	Site 5 17:30
0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	2.7	4.4	6.0	4.4	7.3	6.3	5.3	6.1	6.0	5.5	6.2	6.8	0.0	4.5	6.7
3.9	17.3	16.3	25.4	15.3	18.2	20.9	14.5	20.6	13.3	11.0	11.7	14.0	0.0	11.2	15.2
7.8	38.3	41.6	46.6	37.2	46.9	49.7	31.3	41.8	33.1	27.0	28.7	33.6	0.0	24.7	36.7
15.6	72.5	74.2	76.5	65.8	69.7	74.0	56.7	71.6	65.1	56.8	60.9	65.2	0.6	52.5	69.8
53.0	100.0	98.7	97.0	86.4	88.0	94.8	79.5	100.0	99.0	93.6	96.2	96.4	46.7	99.6	98.7
105.0	100.0	99.3	97.4	86.8	89.0	95.9	82.2	100.0	100.0	97.2	99.2	98.4	56.4	100.0	99.9
210.0	100.0	100.0	100.0	94.4	97.6	100.0	95.7	100.0	100.0	99.6	100.0	99.8	78.6	100.0	100.0
420.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
840.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1680.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Particle diameter (µm)	Percentage (%) less than particle diameter Site 6 8:31	Site 6 14:26	Site 6 17:26	Site 7 8:54	Site 7 14:39	Site 8 9:05	Site 8 14:49
0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	2.3	2.4	1.3	2.5	5.9	0.5	0.5
3.9	3.9	4.7	3.1	5.7	6.2	1.0	0.9
7.8	8.2	10.0	6.3	17.8	6.7	3.2	2.2
15.6	22.0	22.9	20.0	39.5	16.7	6.7	5.0
53.0	86.0	88.4	89.1	99.7	93.7	33.8	29.0
105.0	96.1	100.0	100.0	100.0	100.0	79.2	74.9
210.0	99.8	100.0	100.0	100.0	100.0	100.0	100.0
420.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
840.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1680.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.8: Summary of water quality results from Minehead/Blue Anchor Bay on 30 July 2001 (survey three)

		Enterococci Presum. cfu 100ml	 Conf. cfu 100ml	Conduct -ivity mS cm^{-1}	Turbidity NTU	Susp'd solids mg l^{-1}	Total dissolved solids mg l^{-1}	Practical salinity
Site 1	Mean[1]	2	2	50.94	11.92	37.30	35656	43.00
Offshore	Min	<1	<1	48.30	5.00	8.21	33810	40.47
(CSV)	Max	3	2	53.90	25.00	57.22	37730	45.86
Site 2	Mean[1]	3	1	49.60	25.00	71.40	34720	41.71
Offshore(csv)	Min	3	1	49.60	25.00	71.40	34720	41.71
60% depth	Max	3	1	49.60	25.00	71.40	34720	41.71
Site 3	Mean[1]	3	2	52.03	5.87	28.27	36421	44.05
Offshore	Min	<1	<1	50.50	2.00	19.22	35350	42.57
(rib)	Max	9	7	54.20	12.00	51.30	37940	46.15
Site 4	Mean[1]	32	19	51.51	32.15	107.61	36055	43.54
Mineh'd Ter.	Min	7	3	50.60	11.00	38.29	35420	42.67
BW	Max	600	230	52.20	55.00	180.00	36540	44.21
Site 5	Mean[1]	15	12	50.55	25.31	94.57	35382	42.62
Dunster NW	Min	3	3	49.90	10.00	36.33	34930	42.00
BW	Max	128	116	51.80	39.00	168.78	36260	43.82
Site 6	Mean[1]	3779	3287	0.44	1.50	6.95	311	0.27
Park Str.	Min	2400	2000	0.43	1.00	5.03	304	0.26
	Max	6400	5700	0.47	2.00	10.22	326	0.28
Site 7	Mean[1]	76	63	12.62	1.60	14.98	8834	9.19
Butlins Str.	Min	49	46	12.20	1.00	8.10	8540	8.87
	Max	112	103	13.40	2.00	20.00	9380	9.82
Site 8	Mean[1]	152	55	0.94	3.43	16.07	660	0.50
Mineh'd FE	Min	64	11	0.90	2.00	10.88	627	0.06
	Max	291	224	1.01	5.00	22.80	704	0.61
Site 9	Mean[1]	454	380	0.32	1.82	45.45	224	0.19
R. Avil	Min	310	220	0.31	1.00	10.23	220	0.19
	Max	730	730	0.33	4.00	157.50	230	0.20

[1] Enterococci concentration expressed as geometric mean

Table 4.9: Summary of water quality results from Minehead/Blue Anchor Bay on 1 August 2001 (survey four)

		Enterococci		Conduct-ivity	Turbidity	Susp'd solids	Total dissolved solids	Practical salinity
		Presum. cfu 100ml	Conf. cfu 100ml	mS cm^{-1}	NTU	mg l^{-1}	mg l^{-1}	
Site 1	Mean[1]	3	3	50.30	13.69	44.40	35210	42.39
Offshore	Min	<1	<1	47.90	4.00	20.88	33530	40.09
(CSV)	Max	15	8	53.40	30.00	78.10	37380	45.37
Site 2	Mean[1]	6	6	51.87	26.00	75.03	36307	43.89
Offshore(csv)	Min	6	6	49.80	5.00	26.40	34860	41.90
60% depth	Max	6	6	52.90	66.00	168.20	37030	44.89
Site 3	Mean[1]	3	2	52.22	7.26	32.73	36555	44.23
Offshore	Min	<1	<1	50.50	1.00	16.56	35350	42.57
(rib)	Max	8	5	54.10	16.00	58.37	37870	46.05
Site 4	Mean[1]	27	23	50.85	31.08	99.76	35592	42.91
Mineh'd Ter.	Min	10	9	47.30	14.00	48.57	33110	39.52
BW	Max	230	200	52.20	55.00	165.96	36540	44.21
Site 5	Mean[1]	62	52	49.06	42.08	127.81	34343	41.20
Dunster NW	Min	7	6	47.10	18.00	55.71	32970	39.34
BW	Max	400	281	50.40	80.00	274.62	35280	42.48
Site 6	Mean[1]	1762	996	0.44	1.11	6.46	308	0.27
Park Str.	Min	1255	589	0.43	1.00	4.29	298	0.26
	Max	2718	1763	0.48	2.00	14.59	334	0.29
Site 7	Mean[1]	587	367	8.73	1.67	6.96	6110	6.18
Butlins Str.	Min	320	230	7.98	1.00	6.14	5586	5.61
	Max	1170	530	9.98	2.00	9.65	6986	7.14
Site 8	Mean[1]	771	259	1.00	4.75	17.72	700	0.62
Mineh'd FE	Min	26	23	0.96	2.00	7.16	669	0.59
	Max	32000	1080	1.07	19.00	58.20	749	0.67
Site 9	Mean[1]	369	211	0.32	1.54	20.99	226	0.19
R. Avil	Min	25	19	0.32	1.00	3.30	221	0.19
	Max	2400	780	0.35	2.00	45.75	242	0.21

[1] Enterococci concentration expressed as geometric mean

Table 4.10: Summary of particle size results from Minehead/Blue Anchor Bay on 30 July 2001 (survey three) (the values quoted are mean values from all samples analysed from each site)

	Mean (µm)	Median (µm)	Mode (µm)	Standard deviation (µm)	d10 (µm)	d90 (µm)	*n*
Site 1 Offshore (CSV)	15.5	8.3	13.1	19.0	2.6	48.6	4
Site 2 Offshore (csv) 60% depth							
Site 3 Offshore (rib)	29.6	9.6	11.1	41.2	2.6	102.7	5
Site 4 Minehead Terminus BW	12.8	10.2	12.7	11.0	2.8	25.4	4
Site 5 Dunster North West BW	15.3	11.0	13.6	19.5	3.1	27.9	4
Site 6 Park/Puritan Stream	88.1	74.9	73.0	56.3	27.3	171.4	1
Site 7 Butlins Stream	35.9	32.7	34.6	21.9	8.1	67.0	1
Site 8 Minehead WwTW FE	50.9	35.9	38.0	47.8	10.8	121.6	2
Site 9 R. Avil	38.2	27.8	28.7	33.0	8.1	83.3	1

Table 4.11: Summary of particle size results from Porthcawl/Southerndown on 1 August 2001 (survey four) (the values quoted are mean values from all samples analysed from each site)

	Mean (µm)	Median (µm)	Mode (µm)	Standard deviation (µm)	d10 (µm)	d90 (µm)	*n*
Site 1 Offshore (CSV)	28.1	10.6	11.3	43.9	2.8	89.8	4
Site 2 Offshore (csv) 60% depth	21.6	11.6	14.5	28.9	3.4	68.9	4
Site 3 Offshore (rib)	13.8	10.0	13.8	16.7	2.9	24.5	6
Site 4 Minehead Terminus BW	19.7	11.2	12.9	27.7	3.0	38.4	4
Site 5 Dunster North West BW	17.6	12.2	14.0	21.2	3.3	33.6	4
Site 6 Park/Puritan Stream	65.4	57.6	62.9	39.7	20.5	121.8	2
Site 7 Butlins Stream	23.7	22.0	21.8	14.4	5.3	44.3	2
Site 8 Minehead WwTW FE	38.4	33.0	36.3	26.3	12.7	70.4	2
Site 9 R. Avil	88.8	66.7	104.9	67.2	26.0	207.0	4

Table 4.12a: Particle size distributions of suspended sediments sampled during Minehead/Blue Anchor Bay survey three (30 July 2001)

Particle diameter (μm)	Percentage (%) less than particle diameter														
	Site 1 11:30	Site 1 14:30	Site 1 15:30	Site 1 17:30	Site 3 15:00	Site 3 15:30	Site 3 16:30	Site 3 17:00	Site 3 17:30	Site 4 8:30	Site 4 12:30	Site 4 14:30	Site 4 18:30	Site 5 8:30	Site 5 11:30
0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	7.7	3.6	5.6	4.4	3.5	7.5	8.8	4.4	4.6	6.6	6.3	6.2	5.9	6.7	6.9
3.9	25.0	15.6	23.4	20.9	15.5	24.2	26.9	16.7	17.2	13.7	12.8	12.5	12.6	13.8	15.9
7.8	59.6	36.8	47.4	48.6	32.2	47.4	59.7	34.4	38.3	34.2	31.1	30.3	32.8	34.3	39.5
15.6	96.1	64.9	80.0	83.9	57.8	77.3	91.7	59.3	66.4	69.7	63.6	61.8	66.8	68.6	73.1
53.0	100.0	83.1	100.0	100.0	81.3	99.9	100.0	72.4	79.1	99.5	98.3	95.6	99.6	97.2	96.9
105.0	100.0	85.2	100.0	100.0	84.4	100.0	100.0	74.9	80.5	100.0	100.0	98.7	100.0	97.9	97.9
210.0	100.0	98.4	100.0	100.0	99.6	100.0	100.0	97.1	95.0	100.0	100.0	100.0	100.0	99.7	100.0
420.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
840.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1680.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Particle diameter (μm)	Percentage (%) less than particle diameter						
	Site 5 14:30	Site 5 18:30	Site 6 17:31	Site 7 11:52	Site 8 16:05	Site 8 17:03	Site 9 16:30
0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	5.9	6.2	0.8	1.8	0.8	0.8	5.3
3.9	12.6	12.6	1.0	5.0	2.0	2.2	7.2
7.8	32.6	31.1	1.5	9.7	6.6	6.1	9.8
15.6	67.5	63.8	3.4	18.0	18.2	15.2	24.9
53.0	100.0	97.0	31.9	78.2	75.1	65.7	75.9
105.0	100.0	98.9	68.2	99.7	93.8	83.9	94.7
210.0	100.0	99.6	95.8	100.0	99.3	96.1	100.0
420.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
840.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1680.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.12b: Particle size distributions of suspended sediments sampled during Minehead/Blue Anchor Bay survey four (1 August 2001)

Particle diameter (µm)	Percentage (%) less than particle diameter Site 1 7:30	Site 1 10:30	Site 1 14:30	Site 1 17:30	Site 2 13:30	Site 2 17:30	Site 2 18:30	Site 3 9:30	Site 3 10:30	Site 3 13:30	Site 3 15:00	Site 3 16:30	Site 4 7:30	Site 4 10:29	Site 4 13:30
0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	6.9	6.7	6.7	4.1	5.2	1.7	1.2	6.3	4.6	5.1	4.9	7.2	5.0	6.1	6.9
3.9	18.3	14.3	15.1	15.5	8.9	14.3	13.2	14.3	9.4	13.4	22.0	21.1	11.1	14.5	15.2
7.8	43.4	36.1	39.0	32.1	22.2	32.9	33.2	36.4	23.9	31.5	50.2	46.1	27.7	34.2	38.4
15.6	74.7	70.2	75.7	57.6	52.5	63.1	64.5	70.9	54.8	66.6	85.4	79.7	56.4	68.4	69.8
53.0	88.0	92.5	99.5	74.9	97.2	86.4	84.8	95.6	94.7	100.0	100.0	99.9	88.0	99.8	94.2
105.0	89.1	94.8	100.0	77.2	99.8	87.8	86.8	96.9	96.6	100.0	100.0	100.0	91.3	100.0	95.9
210.0	98.0	99.6	100.0	93.1	99.9	97.9	98.6	99.5	98.5	100.0	100.0	100.0	95.0	100.0	99.9
420.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
840.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1680.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Particle diameter (µm)	Percentage (%) less than particle diameter Site 4 16:30	Site 5 7:30	Site 5 10:30	Site 5 13:30	Site 5 16:30	Site 6 8:00	Site 6 15:30	Site 7 13:40	Site 7 15:10	Site 8 16:10	Site 8 18:40	Site 9 7:30	Site 9 10:30	Site 9 13:30	Site 9 16:30
0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	6.2	5.1	6.3	6.7	4.8	0.0	1.2	2.7	2.0	1.0	0.5	1.7	0.0	1.6	1.0
3.9	17.0	10.6	13.7	13.7	11.3	0.0	1.8	6.6	3.9	2.1	1.5	3.6	0.0	2.7	2.2
7.8	37.7	26.9	34.8	33.8	26.4	0.0	3.2	15.3	14.8	6.4	3.7	6.2	0.0	5.5	4.1
15.6	72.6	57.1	70.4	68.0	58.4	4.8	6.8	27.9	28.9	19.7	10.4	12.4	0.0	11.5	6.6
53.0	99.5	91.4	97.9	99.3	97.5	65.6	33.7	92.8	100.0	81.8	75.4	70.5	4.3	53.7	40.3
105.0	100.0	95.4	99.2	100.0	100.0	98.9	70.3	100.0	100.0	99.4	96.2	100.0	46.3	71.0	63.6
210.0	100.0	98.3	100.0	100.0	100.0	100.0	95.6	100.0	100.0	100.0	99.6	100.0	80.8	87.8	86.3
420.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
840.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1680.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 6.1 Predicted mean sediment concentrations (mg l^{-1}) at bathing water compliance monitoring locations

ID	Beach location (site no.)	Non-cohesive sediment mg l^{-1}	Cohesive sediment mg l^{-1}	Suspended solids mg l^{-1}
36000	Clevedon Beach, 4	286.2	2523.9	2810.1
35000	Minehead Terminus, 10	112.7	4711.3	4824.0
35200	Blue Anchor West, 7	90.9	4988.5	5079.4
35100	Dunster North West, 7	90.9	4988.5	5079.4
35900	Weston-s-mare Sand Bay, 1	223.2	2526.8	2750.0
35800	Weston Main, 2	173.4	2271.7	2445.1
35700	Weston-s-Mare Uphill Slipway, 2	173.4	2271.7	2445.1
35500	Berrow north of Unity Farm, 3	95.8	1360.0	1455.8
35600	Brean, 3	95.8	1360.0	1455.8
36300	Cold Knap Barry, 18	181.4	1426.5	1607.9
36200	Whitmore Bay Barry, 14	213.9	1564.5	1778.4
36100	Jacson Bay Barry, 14	213.9	1564.5	1778.4
36400	Southerndown, 17	32.3	424.7	457.0
34900	Porlock Weir, 9	25.3	508.0	533.3
34800	Lynmouth 8	17.4	315.0	332.4
36700	Rest Bay Porthcawl 15	52.0	274.4	326.4
36600	Sandy Bay Porthcawl, 16	37.4	194.3	231.7
36500	Trecco Bay Porthcawl 16	37.4	194.3	231.7
34600	Ilfracome Hele, 6	35.6	168.2	203.8
34700	Combe Martin 6	35.6	168.2	203.8
34450	Ilfracombe Tunnels Beach, 5	23.7	329.7	353.4
34500	Ilfracombe Capstone 5	23.7	329.7	353.4
36900	Swansea Bay 12	1.2	2.5	3.8
37200	Langland Bay, 11	15.5	57.0	72.5
37100	Limeslade Bay, 11	15.5	57.0	72.5
37000	Bracelet Bay, 11	15.5	57.0	72.5
37500	Port Eynon Bay, 20	19.8	117.7	137.5
37400	Oxwich Bay, 19	21.5	70.6	92.1
36800	Abrafan, 13	0.3	0.6	0.9

Table 7.1 Enterococci concentration (cfu $100ml^{-1}$) and water quality type at bathing water compliance monitoring locations

ID	Beach location (site no.)	Enterococci[1] cfu $100ml^{-1}$		Water quality[3]	Reference[2]
		Mean	Max		
36000	Clevedon Beach, 4	115.0	697	Type I	44.50
35000	Minehead Terminus, 10	93.8	448	Type I	0.99
35200	Blue Anchor West, 7	88.2	630	Type I	3.38
35100	Dunster North West, 7	88.2	630	Type I	3.38
35900	Weston-s-mare Sand Bay, 1	84.4	375	Type I	7.47
35800	Weston Main, 2	83.4	400	Type I	4.52
35700	Weston-s-Mare Uphill Slipway, 2	83.4	400	Type I	4.52
35500	Berrow north of Unity Farm, 3	57.1	380	Type II	2.00
35600	Brean, 3	57.1	380	Type II	2.00
36300	Cold Knap Barry, 18	50.3	297	Type II	2.33
36200	Whitmore Bay Barry, 14	46.8	265	Type II	2.26
36100	Jacson Bay Barry, 14	46.8	265	Type II	2.26
36400	Southerndown, 17	32.7	210	Type II	5.92
34900	Porlock Weir, 9	34.6	253	Type II	0.09
34800	Lynmouth 8	18.5	121	Type II	0.69
36700	Rest Bay Porthcawl 15	15.4	171	Type II	1.66
36600	Sandy Bay Porthcawl, 16	13.3	141	Type II	1.03
36500	Trecco Bay Porthcawl 16	13.3	141	Type II	1.03
34600	Ilfracome Hele 6	10.4	66	Type III	0.00
34700	Combe Martin 6	10.4	66	Type III	0.00
34450	Ilfracombe Tunnels Beach, 5	10.3	55	Type III	0.00
34500	Ilfracombe Capstone 5	10.3	55	Type III	0.00
36900	Swansea Bay 12	8.5	85	Type III	17.60
37200	Langland Bay, 12	5.5	56	Type III	2.21
37100	Limeslade Bay, 12	5.5	56	Type III	2.21
37000	Bracelet Bay, 11	5.5	56	Type III	2.21
37500	Port Eynon Bay, 20	3.3	38	Type III	0.09
37400	Oxwich Bay, 19	3.3	32	Type III	0.51
36800	Abrafan, 13	0.4	7	Type III	0.19

[1] Predicted results (mean values) associated with suspended solids concentrations

[2] Predicted results associated with no suspended solids concentrations

[3] Type I: those affected by both outfalls <u>and</u> entrainment
Type II: those affected by either outfalls <u>or</u> entrainment
Type III: those <u>not</u> affected by outfalls or entrainment

Table 8.1 Dilution modelling results – predicted mean enterococci concentrations (cfu $100ml^{-1}$) at the bathing water compliance monitoring sites

Location	Mean[1] (cfu $100ml^{-1}$)	Mean[2] (cfu $100ml^{-1}$)	Location	Mean[1] (cfu $100ml^{-1}$)	Mean[2] (cfu $100ml^{-1}$)
Site 1	93	300.4	Site 11	38	11.5
Site 2	76	292.2	Site 12	98	12.6
Site 3	58	198.6	Site 13	26	0.7
Site 4	168	327.8	Site 14	86	176.0
Site 5	0	38.6	Site 15	92	44.2
Site 6	0.02	30.2	Site 16	95	41.3
Site 7	18	580.6	Site 17	191	91.1
Site 8	1	61.2	Site 18	91	171.8
Site 9	4	113.6	Site 19	16	8.5
Site10	11	602.3	Site 20	7	11.9

[1] Predicted from dilution model
[2] Predicted from dilution model with sediment transport

Table 8.2 Modelled enterococci concentrations (cfu $100ml^{-1}$) for the 'decay' and 'decay with SS' approaches

Location	Mean[1] (cfu $100ml^{-1}$) decay with SS	Mean[2] (cfu $100ml^{-1}$) decay	Maximum (cfu $100ml^{-1}$) decay with SS	Minimum (cfu $100ml^{-1}$) decay
Site 1	84.4	7.47	375	0
Site 2	83.4	4.52	400	0
Site 3	57.1	2	380	0
Site 4	115.0	44.5	697	0
Site 5	10.3	0	55	0
Site 6	10.4	0	66	0
Site 7	88.2	3.38	630	0
Site 8	18.5	0.69	121	0
Site 9	34.6	0.086	253	0
Site 10	93.8	0.99	448	0
Site 11	5.5	2.21	56	0
Site 12	8.5	17.6	85	0
Site 13	0.36	0.19	7	0
Site 14	46.6	2.26	265	0
Site 15	15.4	1.66	171	0
Site 16	13.3	1.03	141	0
Site 17	32.7	5.92	210	0
Site 18	50.3	2.33	297	0
Site 19	3.27	0.51	32	0
Site 20	3.33	0.087	38	0

[1] Predictions for first order decay model with SS (decay with SS)
[2] Predictions for first order decay model without SS (decay)

Figures

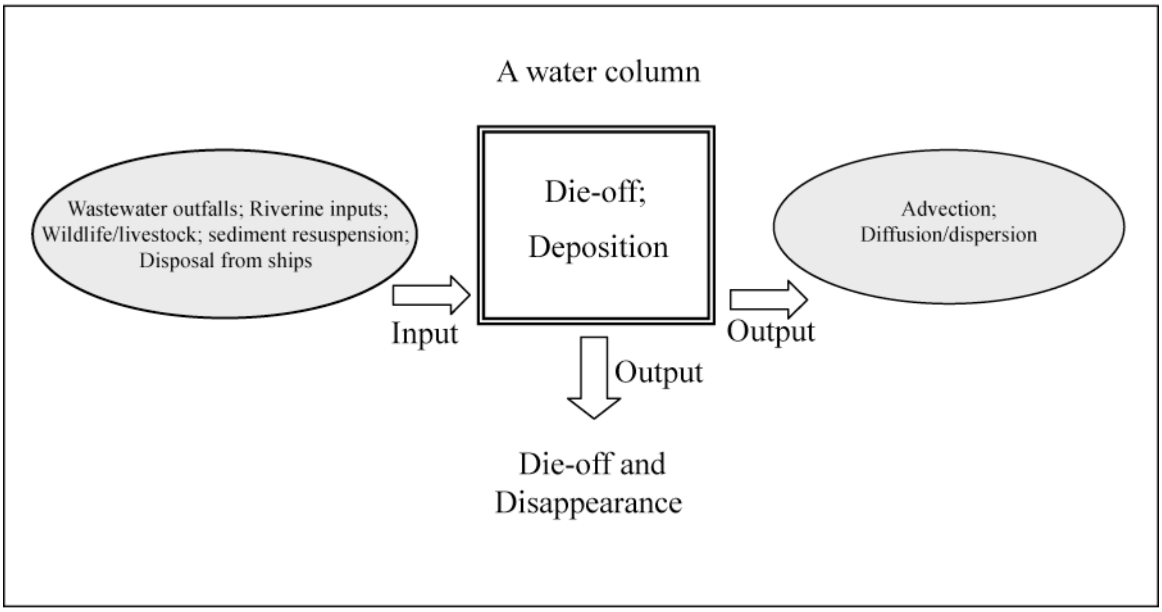


Figure 2.1: **Conceptual model of faecal indicator organism transport in natural waters**

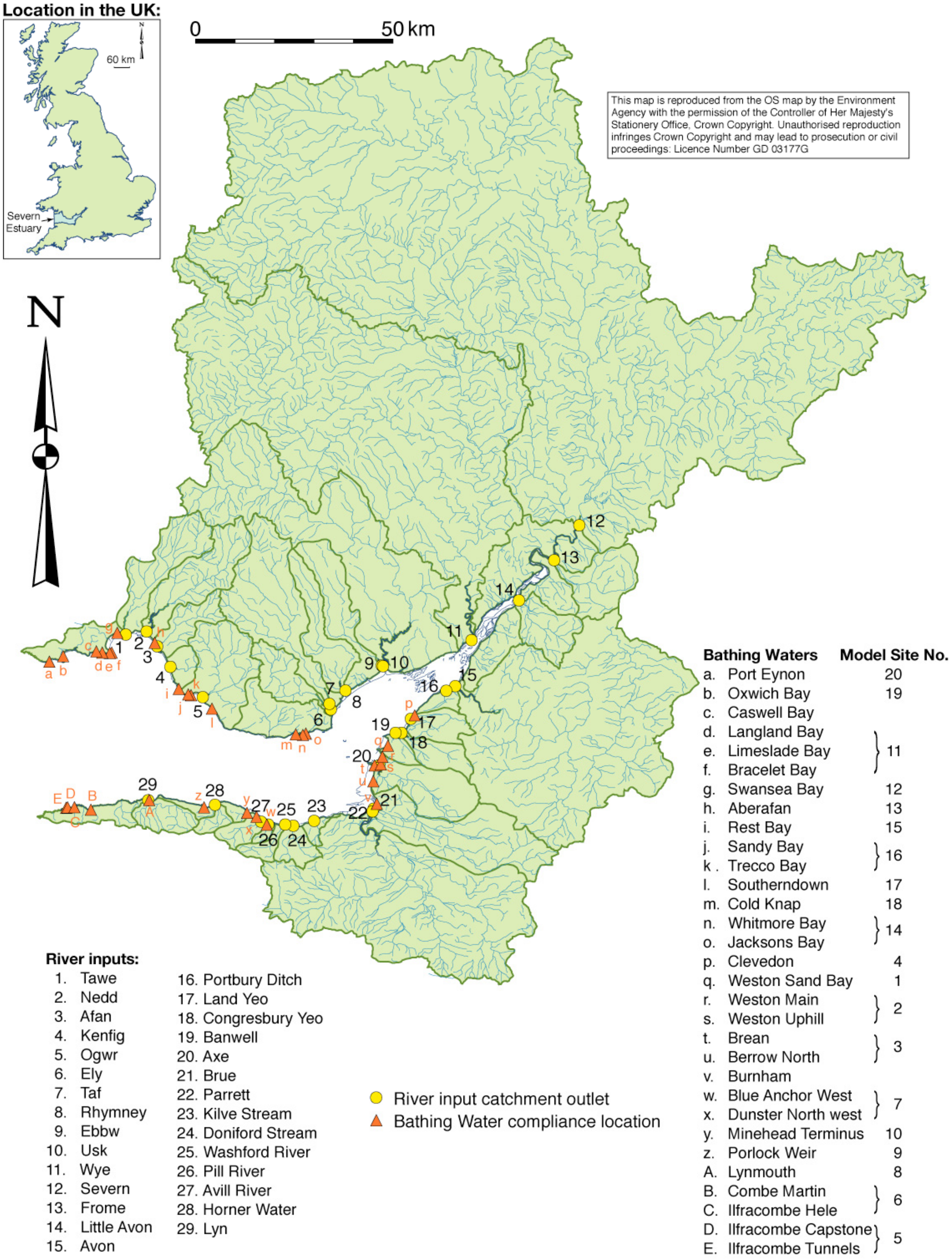


Figure 3.1: Bathing water compliance monitoring sites, main river catchments and locations of outlets to the Severn estuary

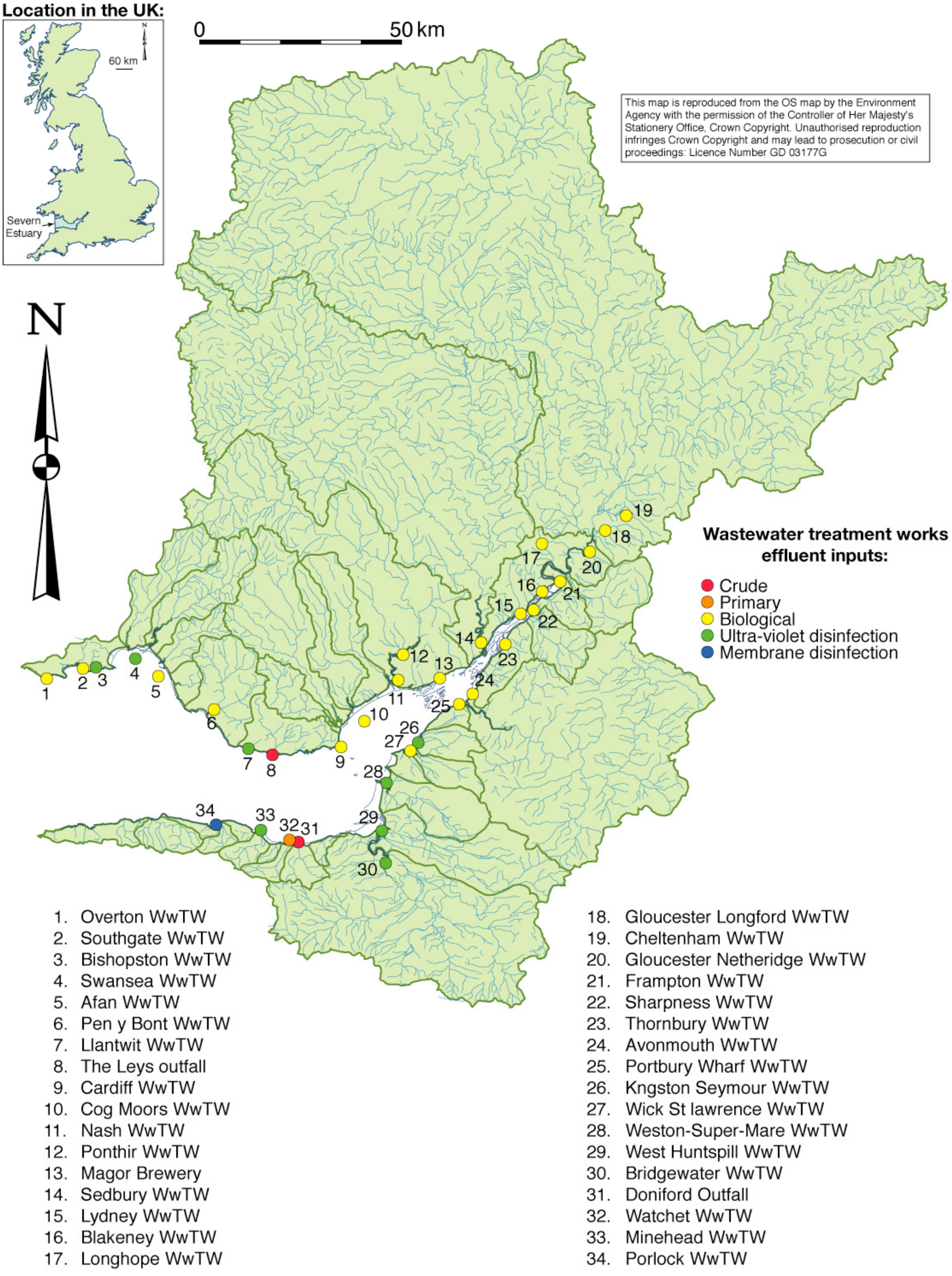


Figure 3.2: Location and treatment type of wastewater treatment works effluent inputs with population equivalents greater than 2000 to the Severn estuary

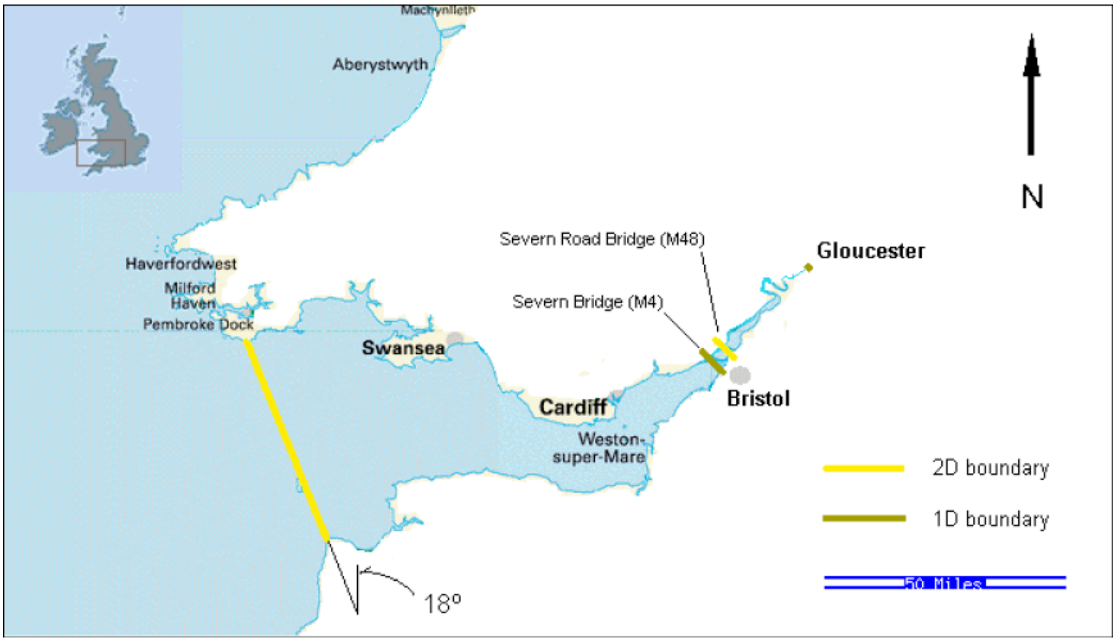


Figure 4.1: Boundaries of the 1-D and 2-D modelling domains

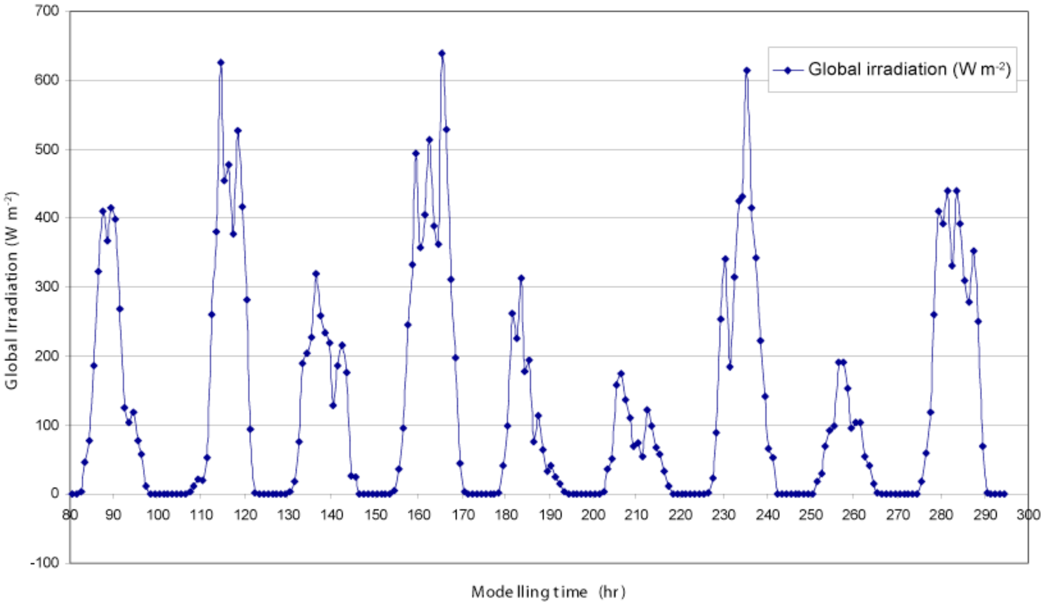


Figure 4.2: Global irradiation (W m^{-2}) for the Guildhall, Swansea, for the period 24 July to 1 August 2001 (source: City and County of Swansea Council)

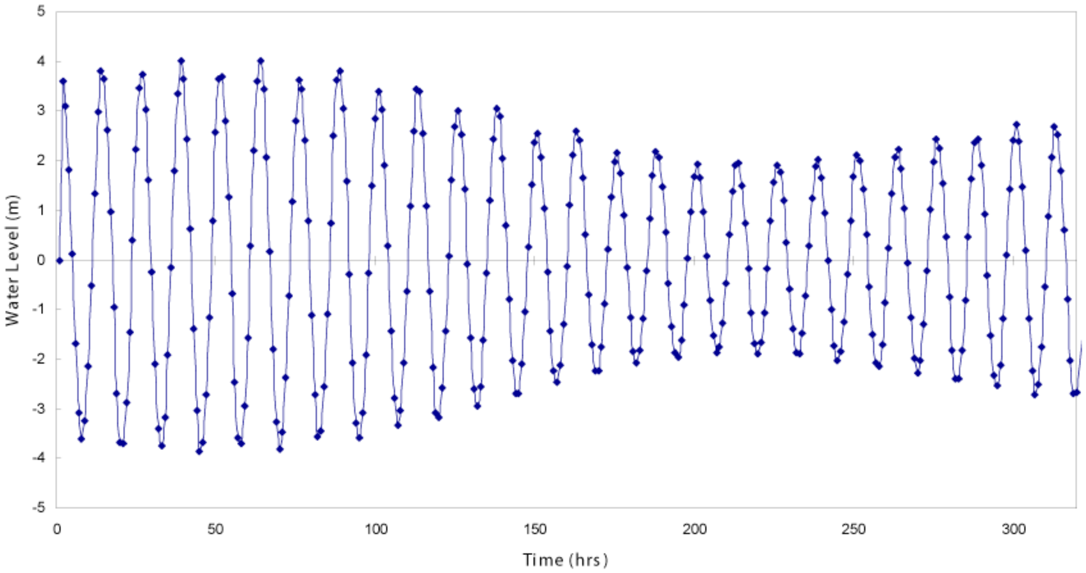
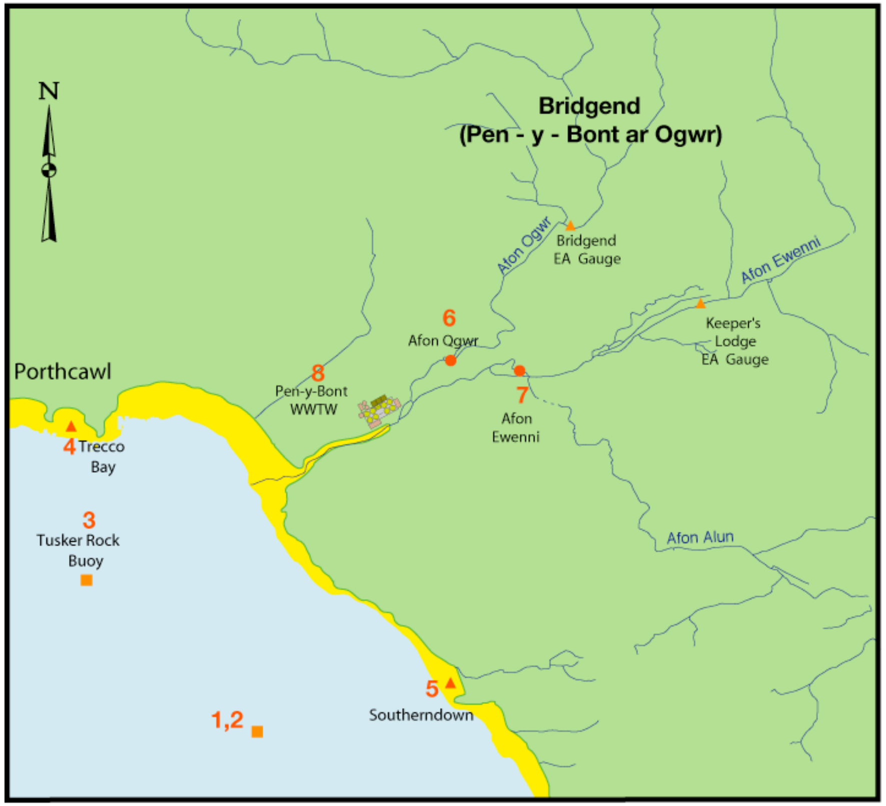


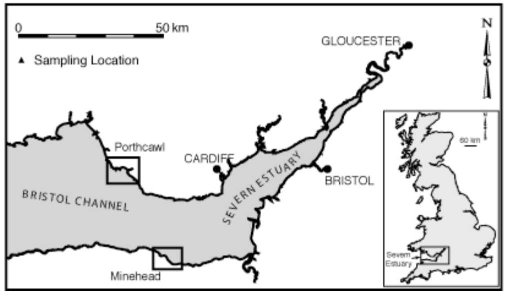
Figure 4.3: Water levels at the outer (western) boundary of the 2-D model domain used as input data

(a) Porthcawl/Southerndown

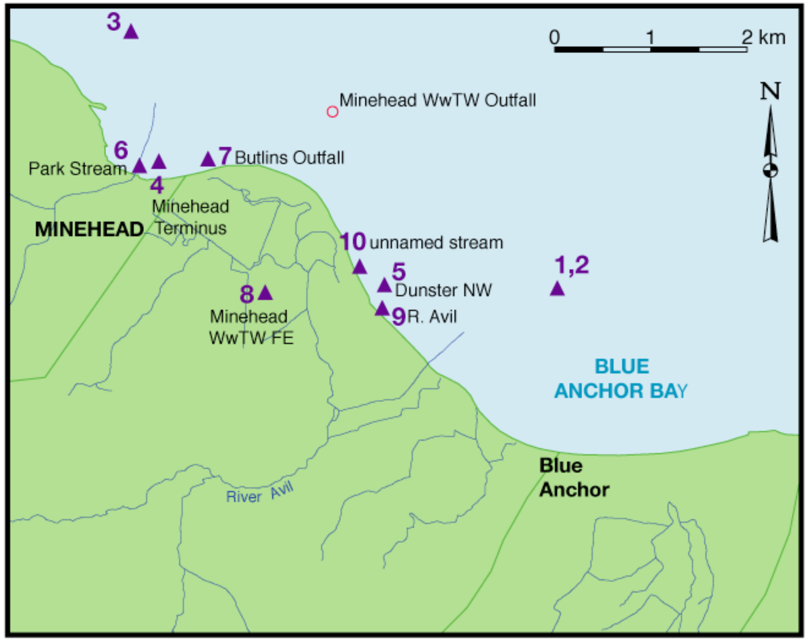


■ **Porthcawl/Southerndown sample sites**

1 Offshore (csv Water Guardian), 1 m depth
2 Offshore (csv Water Guardian), 60% depth
3 Offshore (rib), 1m depth
4 Trecco Bay bathing water
5 Southerndown bathing water
6 Afon Ogwr
7 Afon Ewenni
8 Pen-y-Bont WwTW FE



(b) Minehead/Blue Anchor Bay

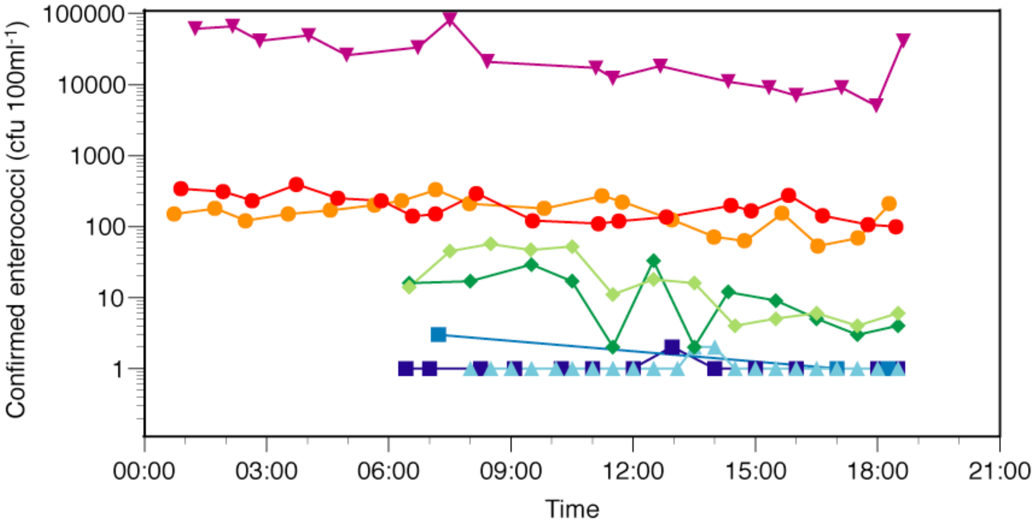


▲ **Minehead/Blue Anchor Bay sample sites**

1 Offshore (csv Water Guardian), 1 m depth
2 Offshore (csv Water Guardian), 60% depth
3 Offshore (rib), 1m depth
4 Minehead Terminus bathing water
5 Dunster North West bathing water
6 Park/Puritan streams outfall
7 Butlins Stream outfall
8 Minehead WwTW FE
9 River Avil

Figure 4.4: Location of the field survey sites: (a) Porthcawl/Southerndown; (b) Minehead/Blue Anchor Bay

(a) Survey 1: 24/7/01



(b) Survey 1: 26/7/01

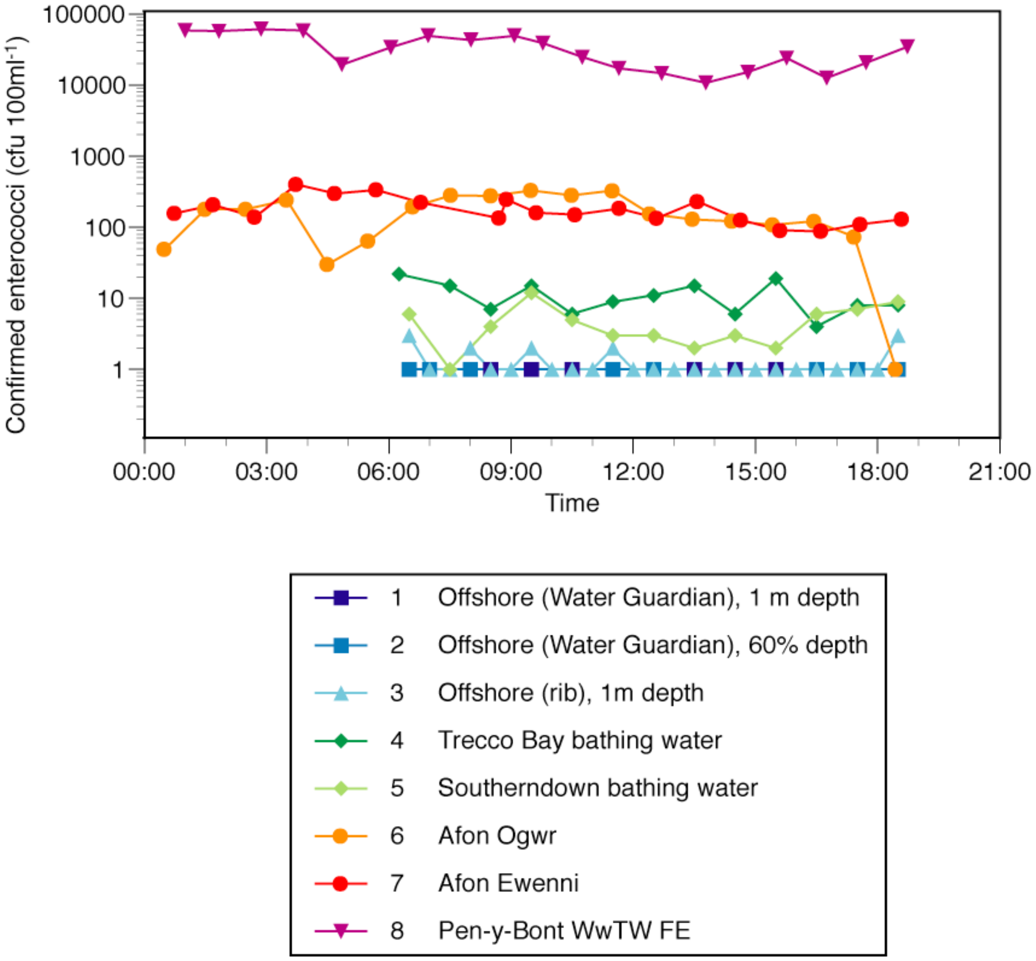


Figure 4.5: Confirmed enterococci concentrations (cfu 100ml^{-1}) within the Portcawl/Southerndown study area: (a) survey one (24 July 2001); (b) survey two (26 July 2001)

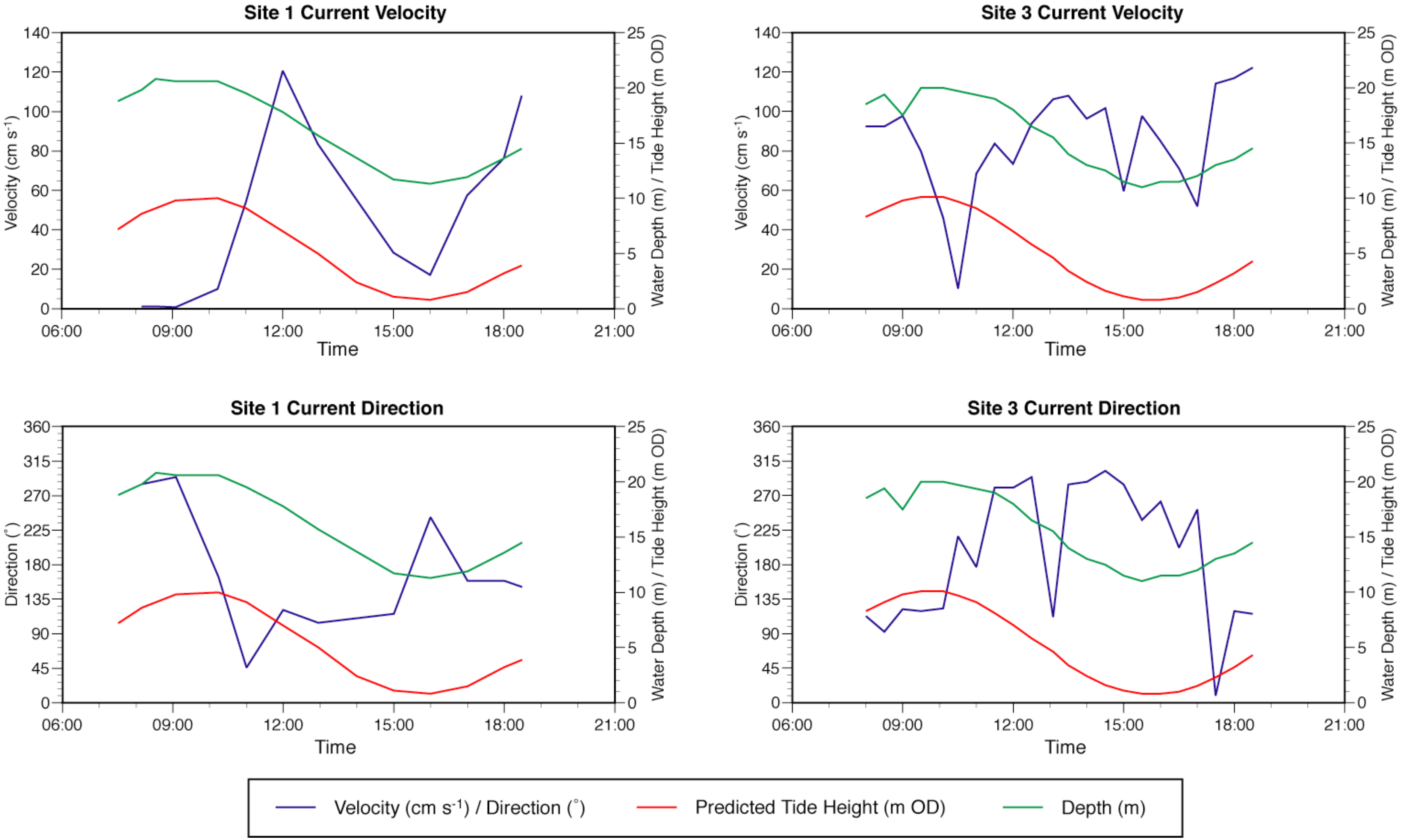


Figure 4.6a: Current velocity (cm s^{-1}) and direction (˚), water depth (m) and predicted tide height (m OD) at sites 1 and 3 in the Porthcawl/Southerndown study area during survey one (24 July 2001)

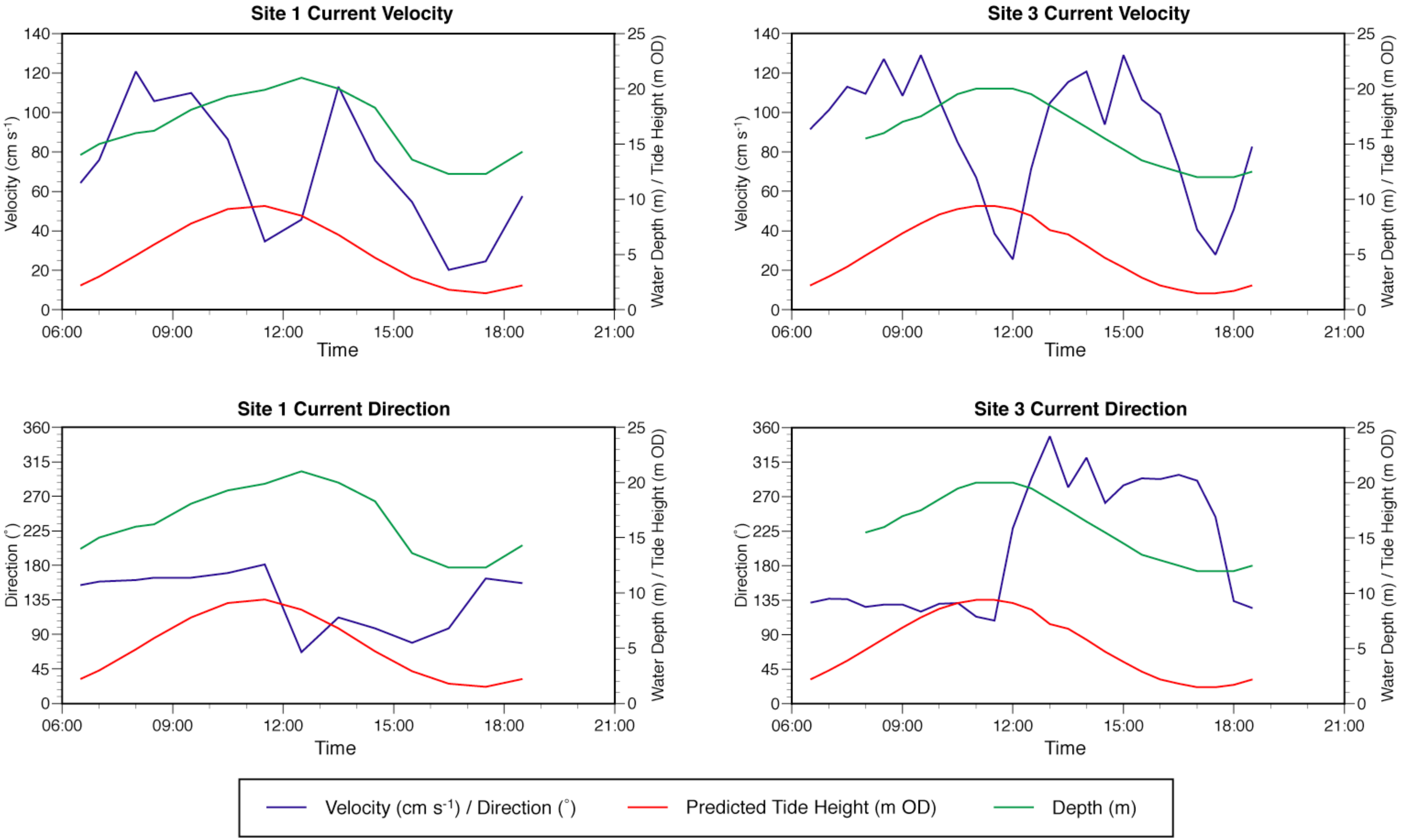


Figure 4.6b: Current velocity (cm s^{-1}) and direction (˚), water depth (m) and predicted tide height (m OD) at sites 1 and 3 in the Porthcawl/Southerndown study area during survey two (26 July 2001)

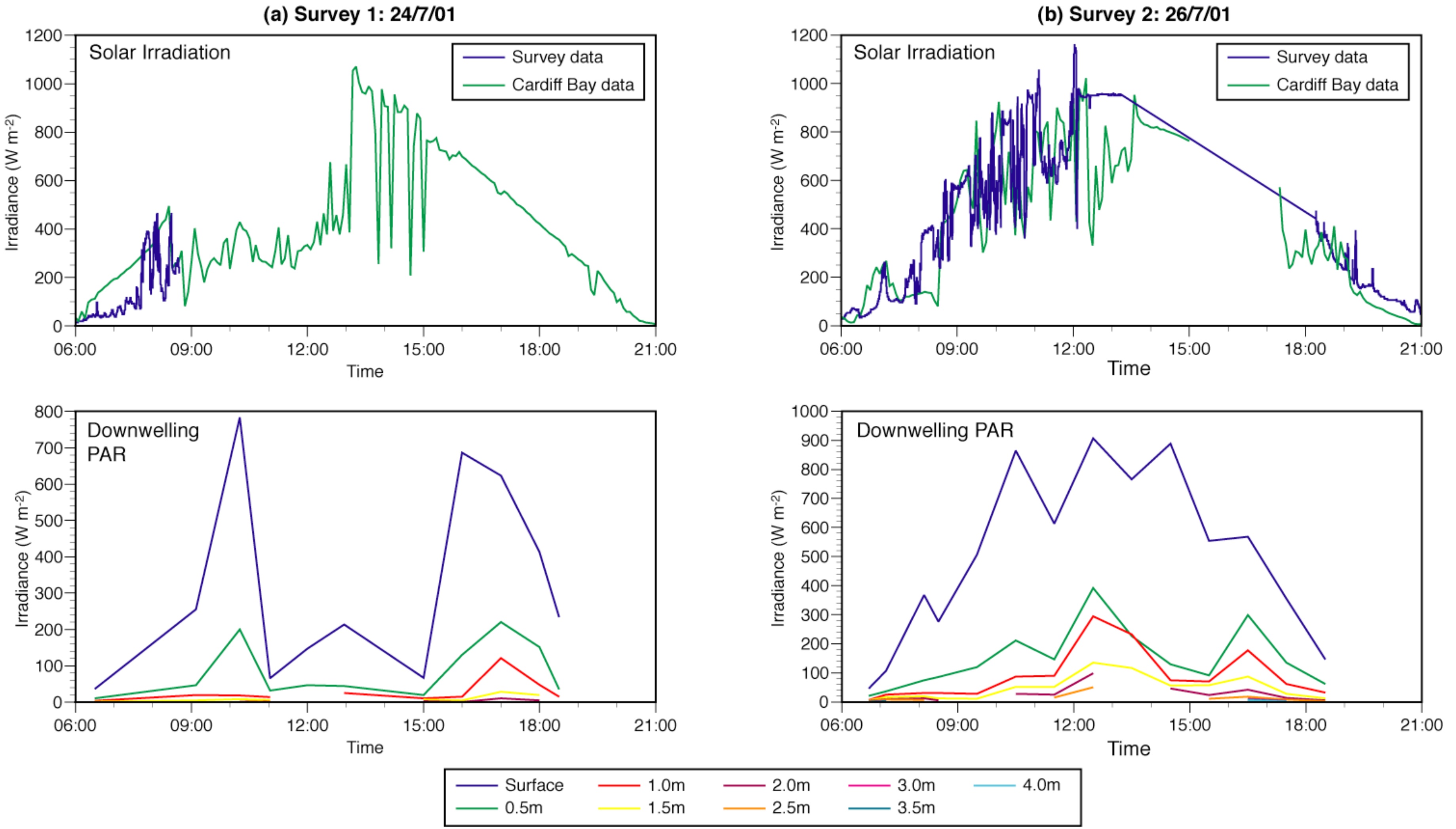
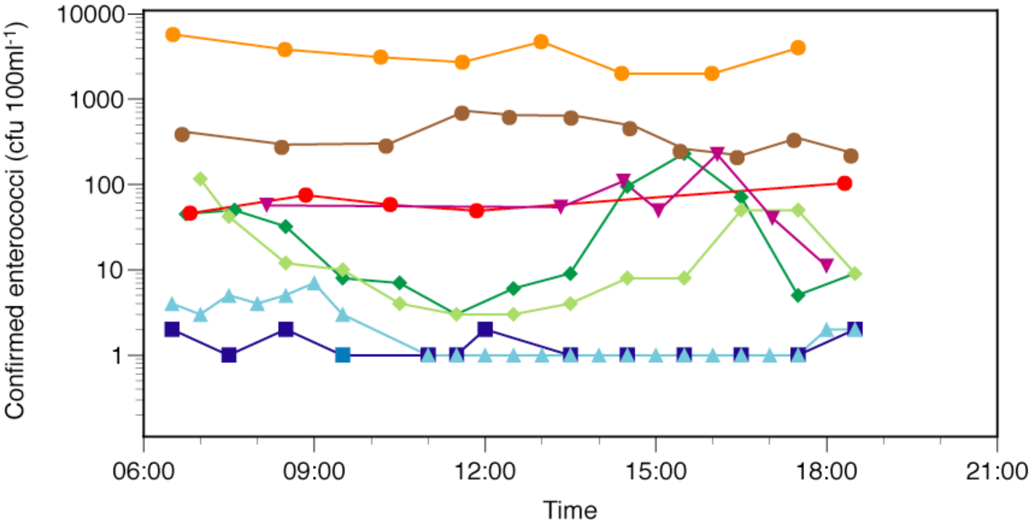


Figure 4.7: Irradiance data (W m^{-2}) measured at the coastal survey vessel *Water Guardian* (site 1) during the Porthcawl/Southerndown surveys (upper graphs show solar irradiance measured at Cardiff Bay using an Aanderra 2770 solar radiation sensor; lower graphs show downwelling photosynthetically-available radiation (PAR) at 0.5m depth intervals measured using a Skye Instruments quantum sensor: (a) survey one (24 July 2001); (b) survey two (26 July 2001)

(a) Survey 3: 30/7/01



(b) Survey 4: 1/8/01

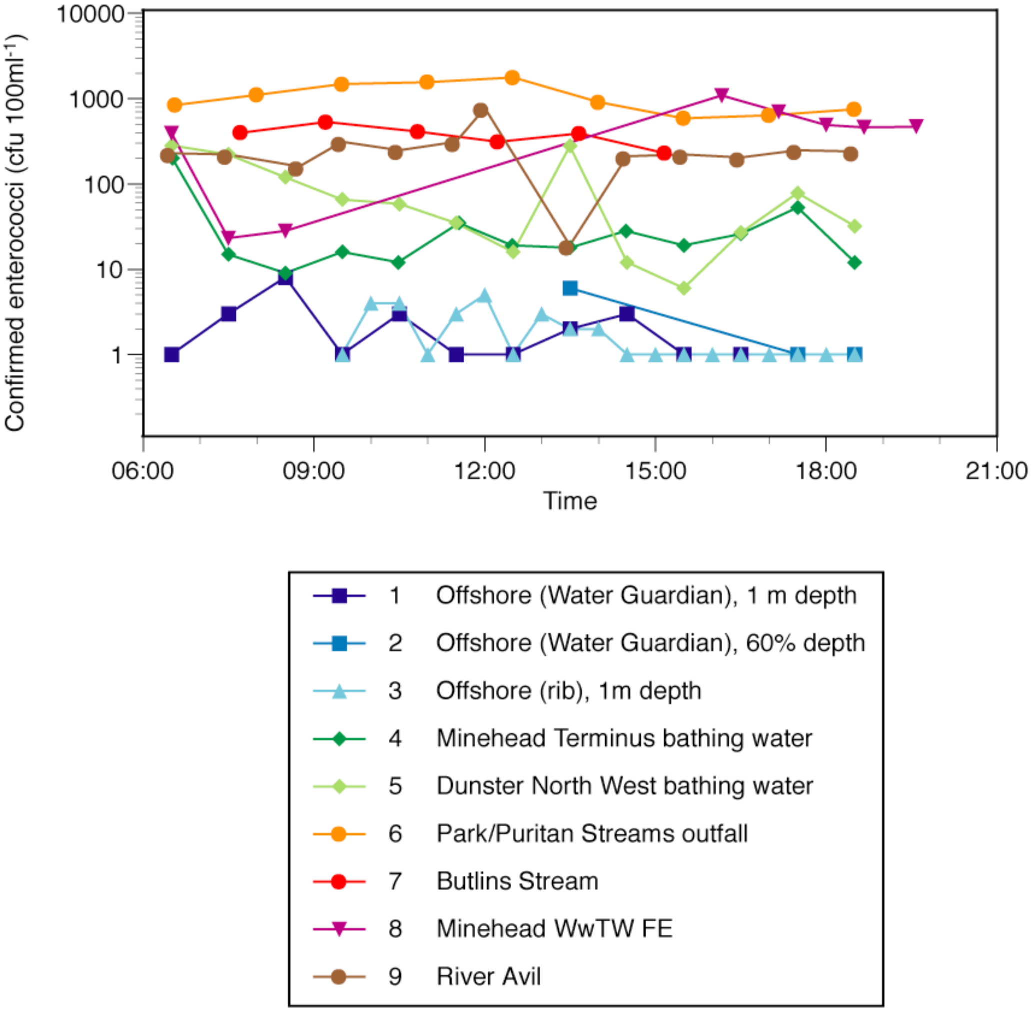


Figure 4.8: **Confirmed enterococci concentrations (cfu 100ml^{-1}) within the Minehead/Blue Anchor Bay study area: (a) survey three (30 July 2001); (b) survey four (1 August 2001)**

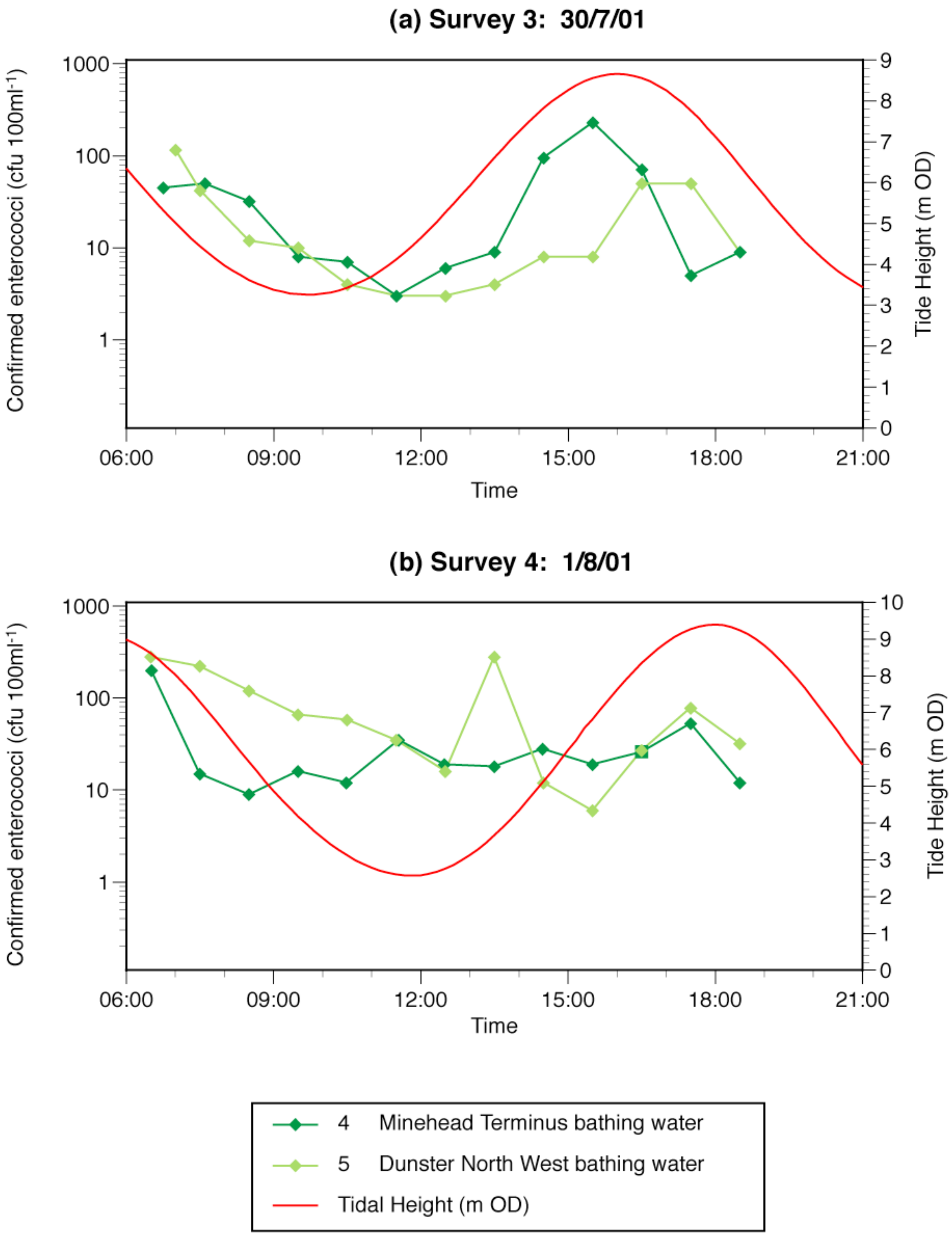


Figure 4.9: Relationship between confirmed enterococci concentration (cfu 100ml^{-1}) and tide height (m OD) at Minehead Terminus and Dunster North West bathing water compliance points: (a) survey three (30 July 2001); (b) survey four (1 August 2001)

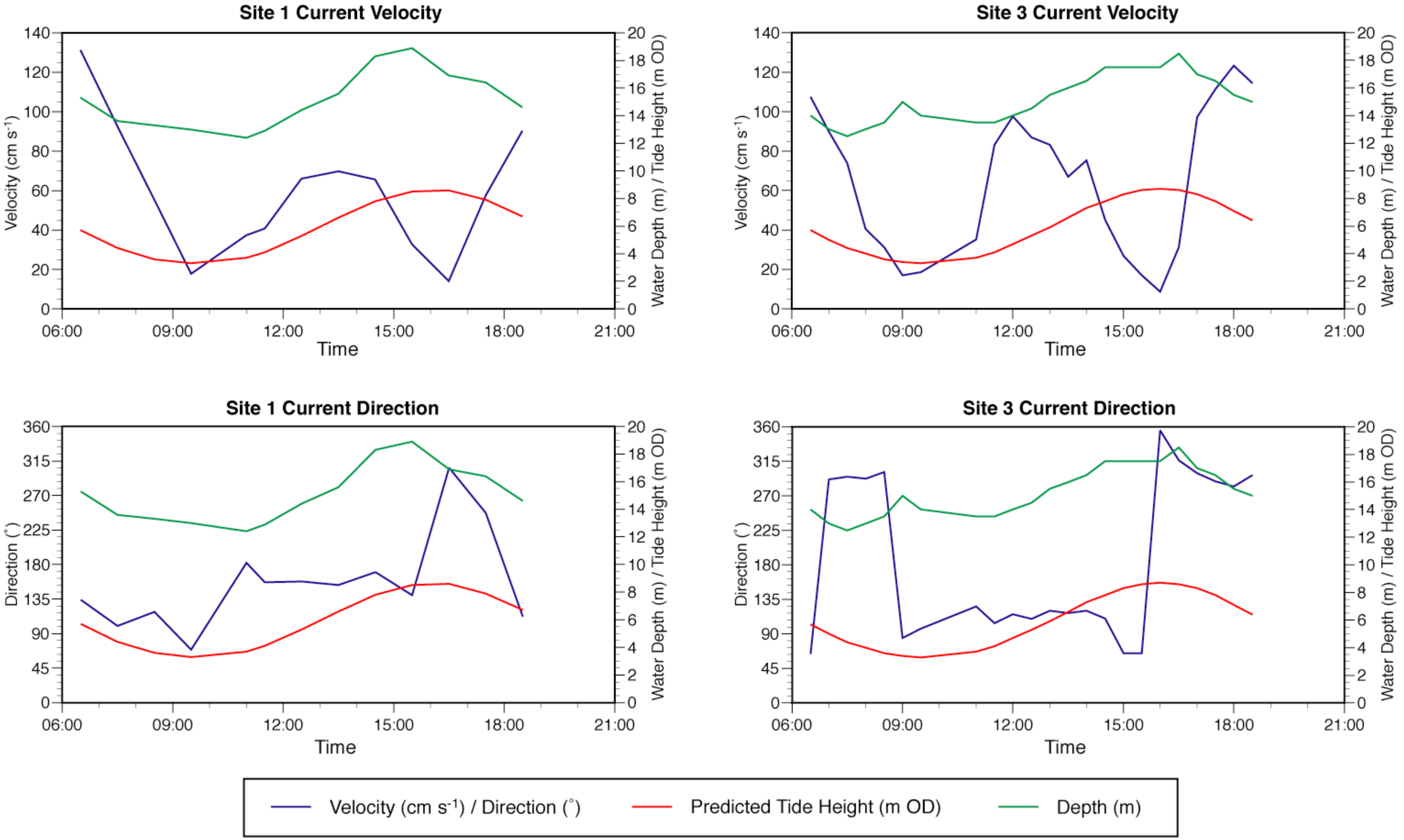


Figure 4.10a: **Current velocity (cm s^{-1}) and direction (˚), water depth (m) and predicted tide height (m OD) at sites 1 and 3 in the Minehead/Blue Anchor Bay study area during survey three (30 July 2001)**

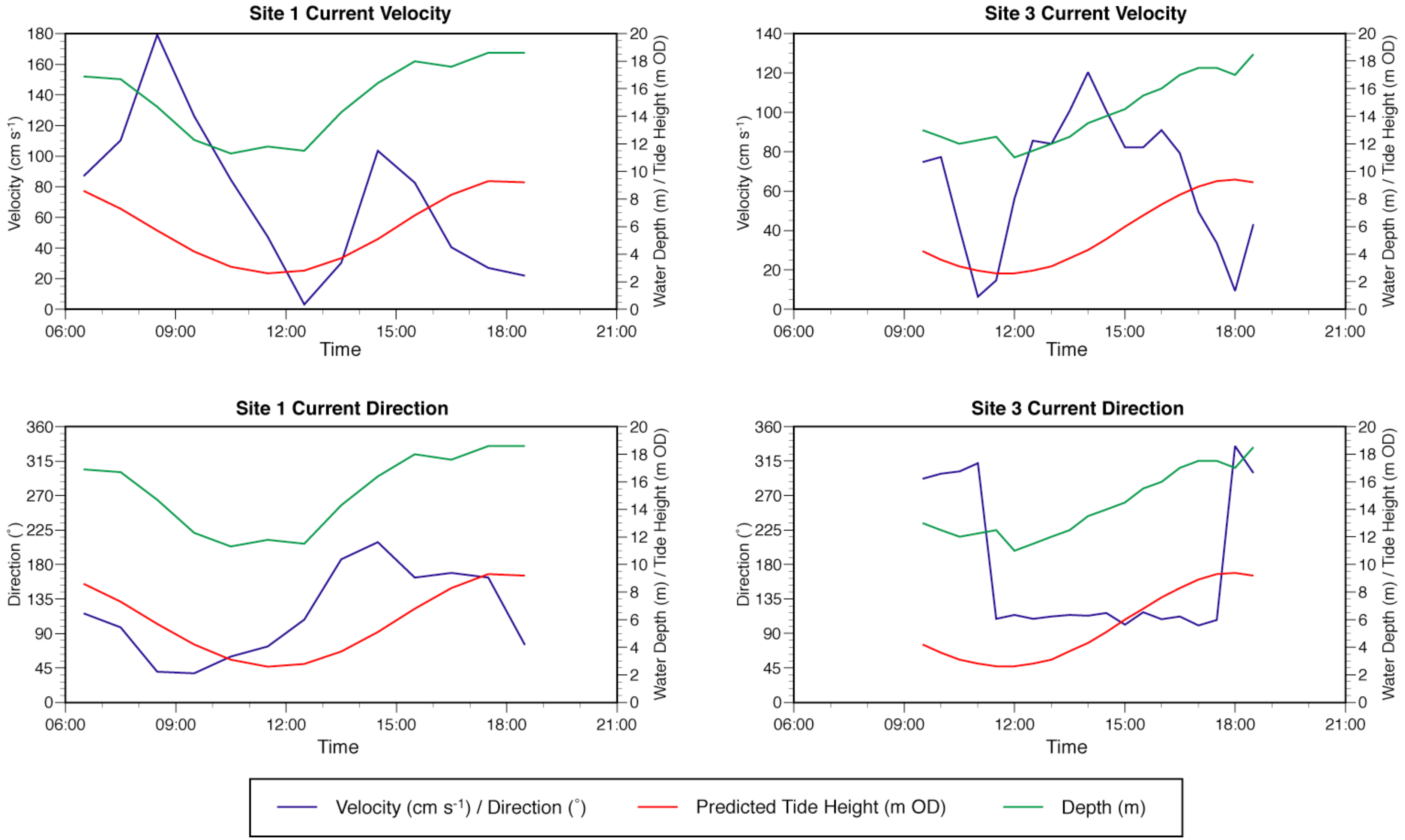


Figure 4.10b: Current velocity (cm s^{-1}) and direction (˚), water depth (m) and predicted tide height (m OD) at sites 1 and 3 in the Minehead/Blue Anchor Bay study area during survey four (1 August 2001)

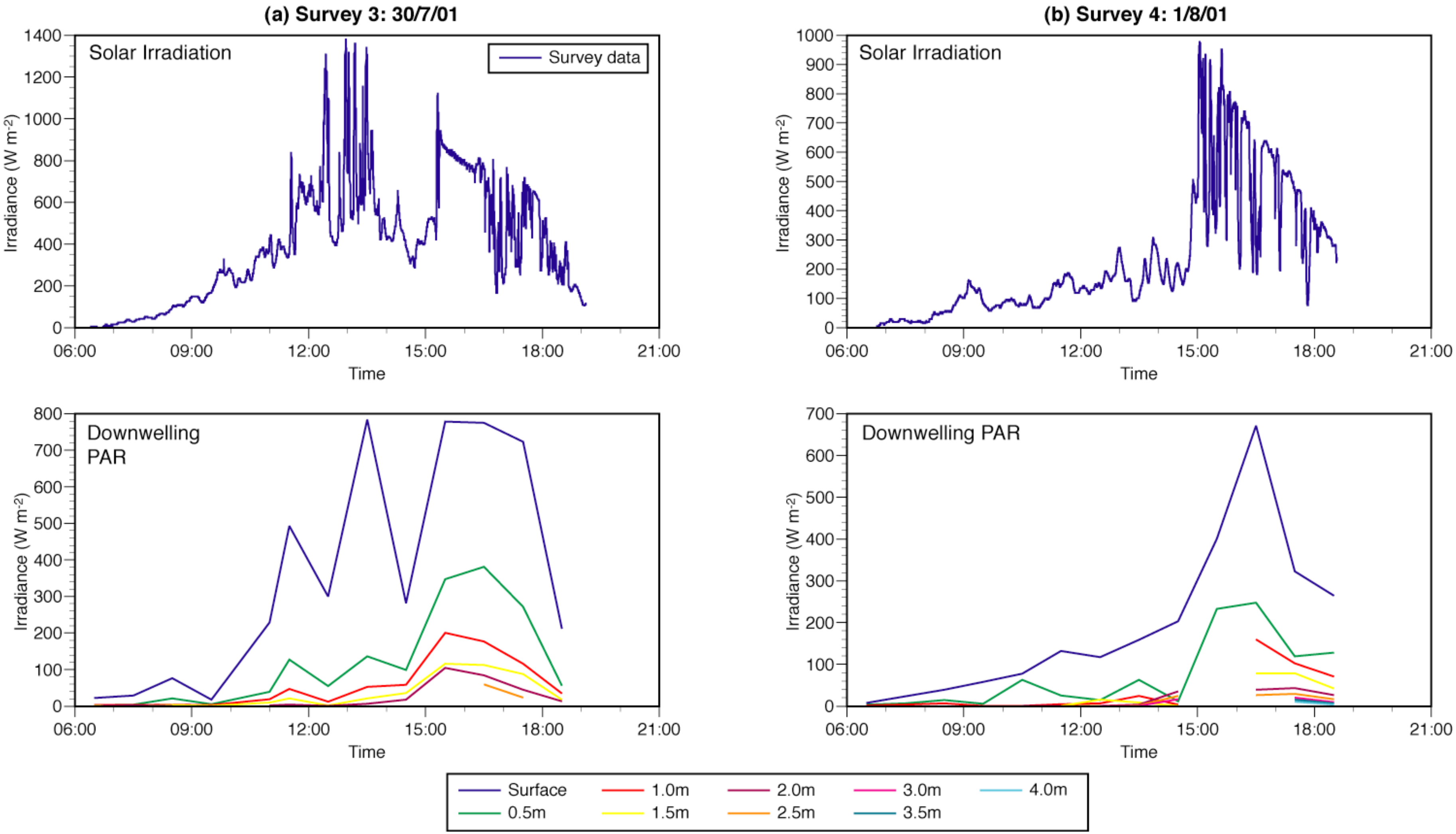


Figure 1.8: **Irradiance data (W m^{-2}) measured at the coastal survey vessel *Water Guardian* (site 1) during the Minehead/Blue Anchor Bay surveys (upper graphs show solar irradiance measured at Cardiff Bay using an Aanderra 2770 solar radiation sensor; lower graphs show downwelling photosynthetically-available radiation (PAR) at 0.5m depth intervals measured using a Skye Instruments quantum sensor: (a) survey three (30 July 2001); (b) survey four (1 August 2001)**

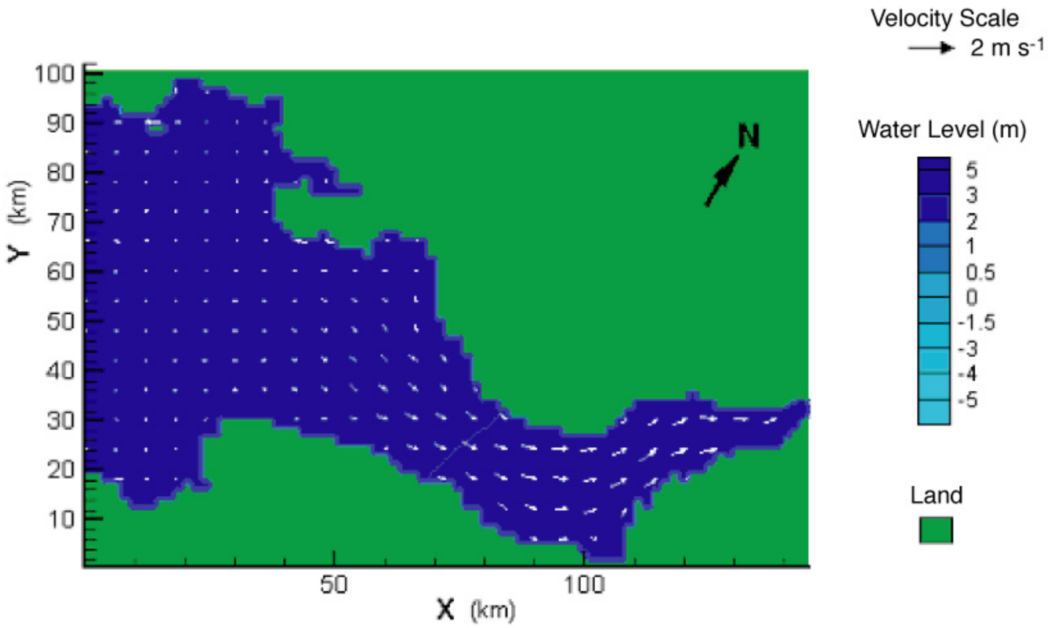


Figure 5.1: Predicted water level and velocity distributions for spring tide high water at the seaward boundary

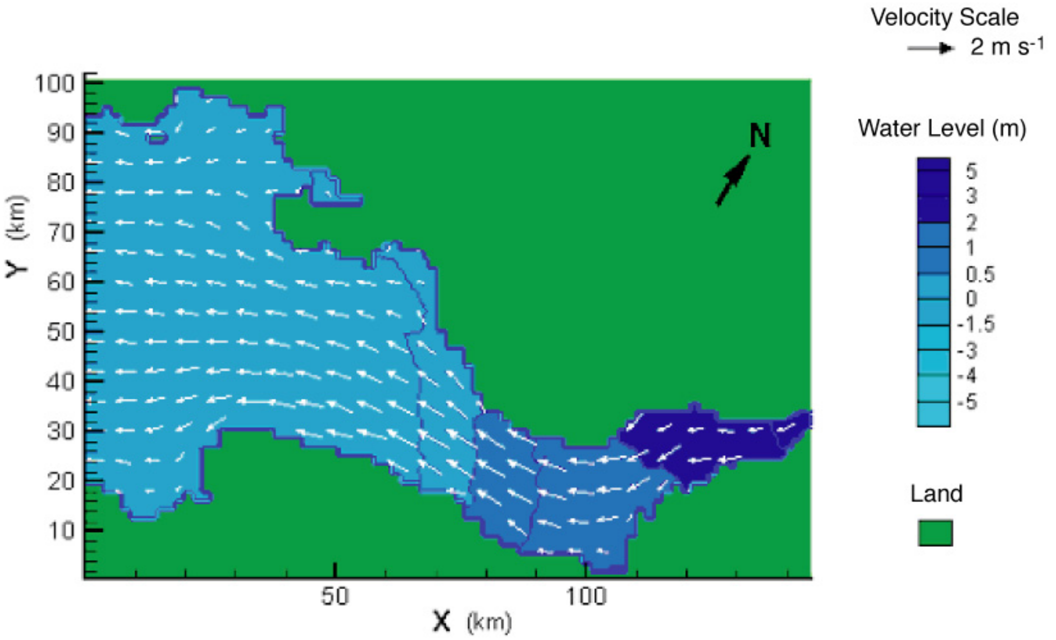


Figure 5.2: Predicted water level and velocity distributions for spring tide mid-ebb at the seaward boundary

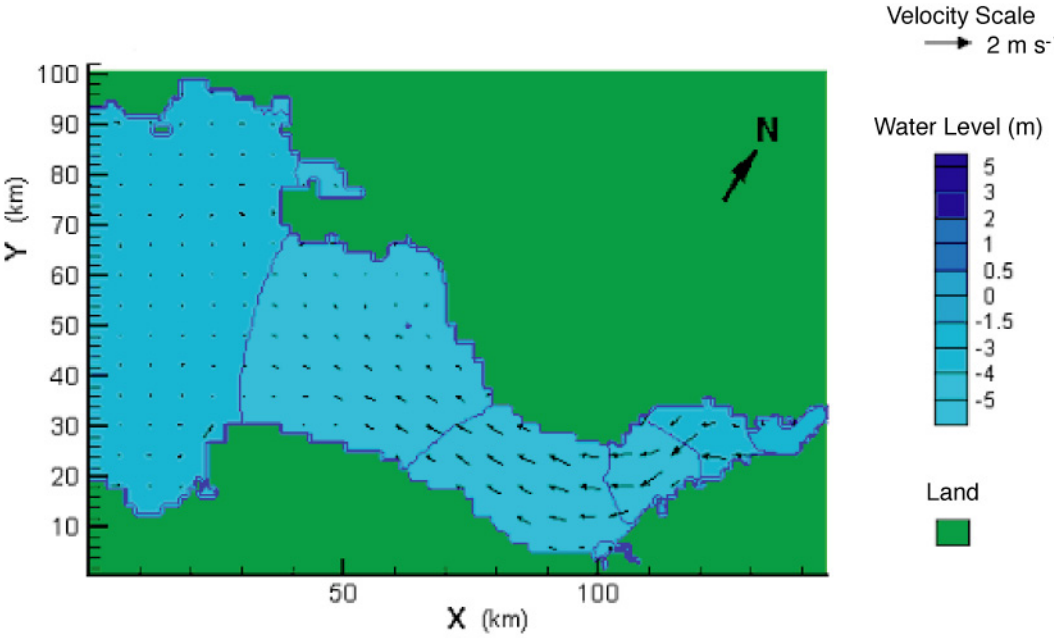


Figure 5.3: **Predicted water level and velocity distributions for spring tide low water at the seaward boundary**

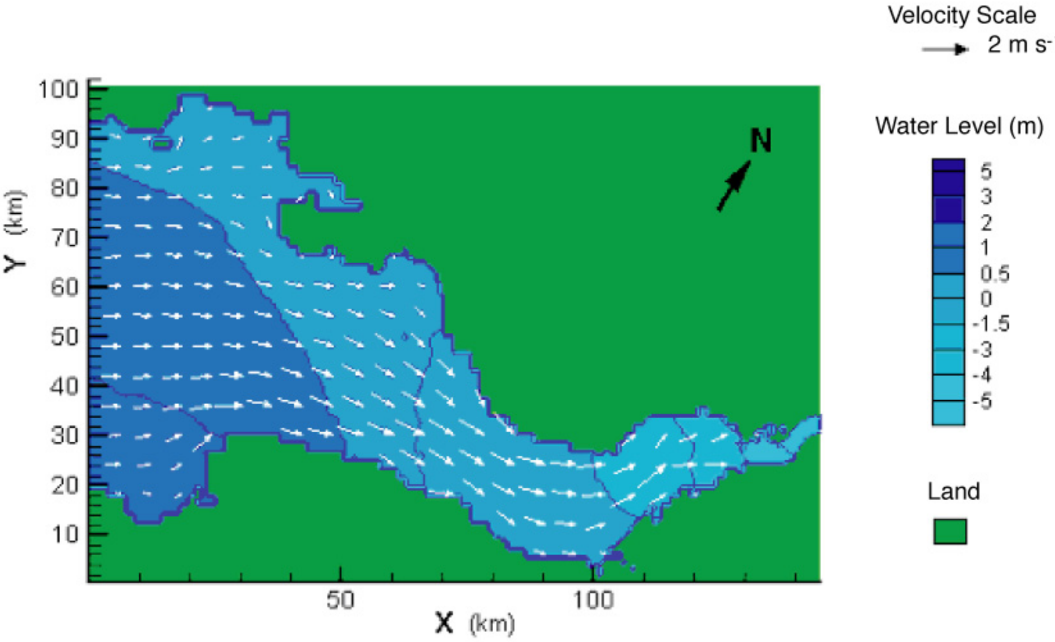


Figure 5.4: **Predicted water level and velocity distributions for spring tide mid-flood at the seaward boundary**

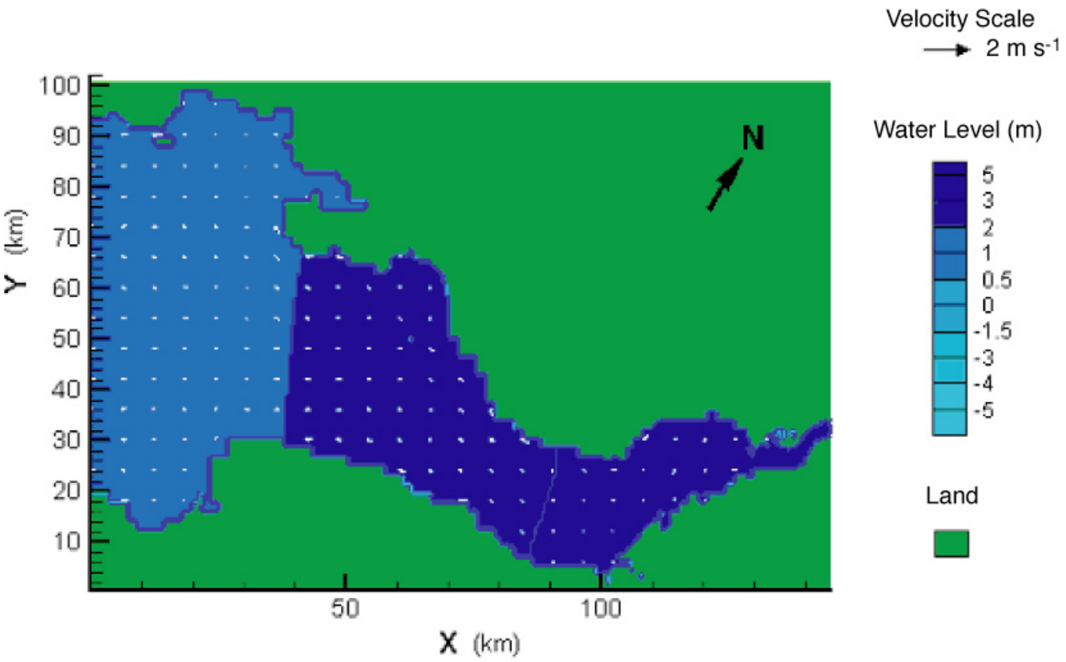


Figure 5.5: Predicted water level and velocity distributions for neap tide high water at the seaward boundary

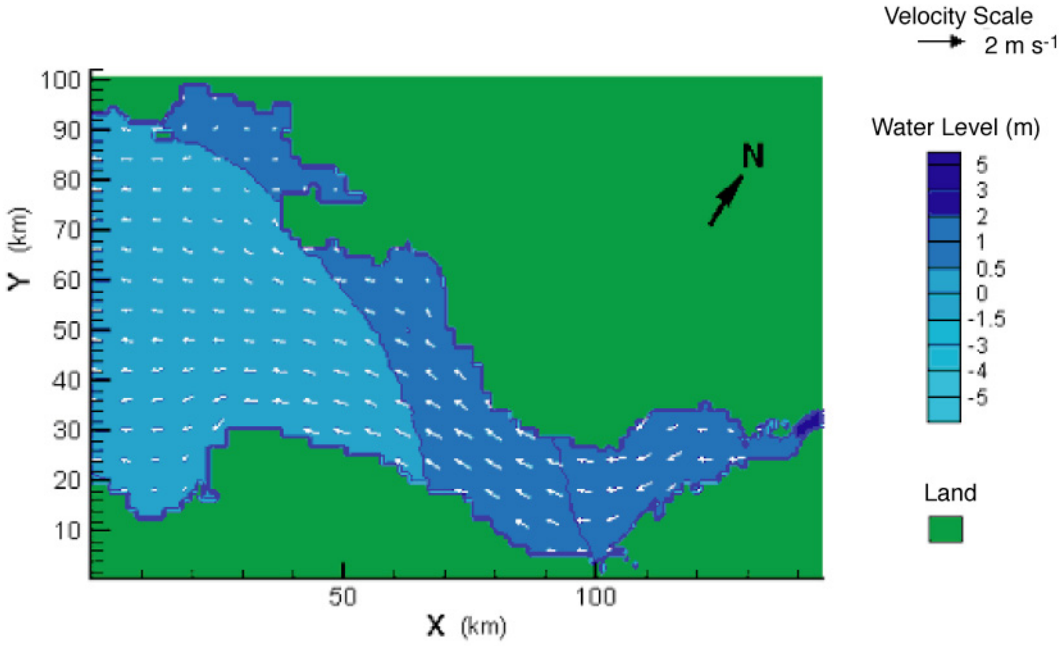


Figure 5.6: Predicted water level and velocity distributions for neap tide mid-ebb at the seaward boundary

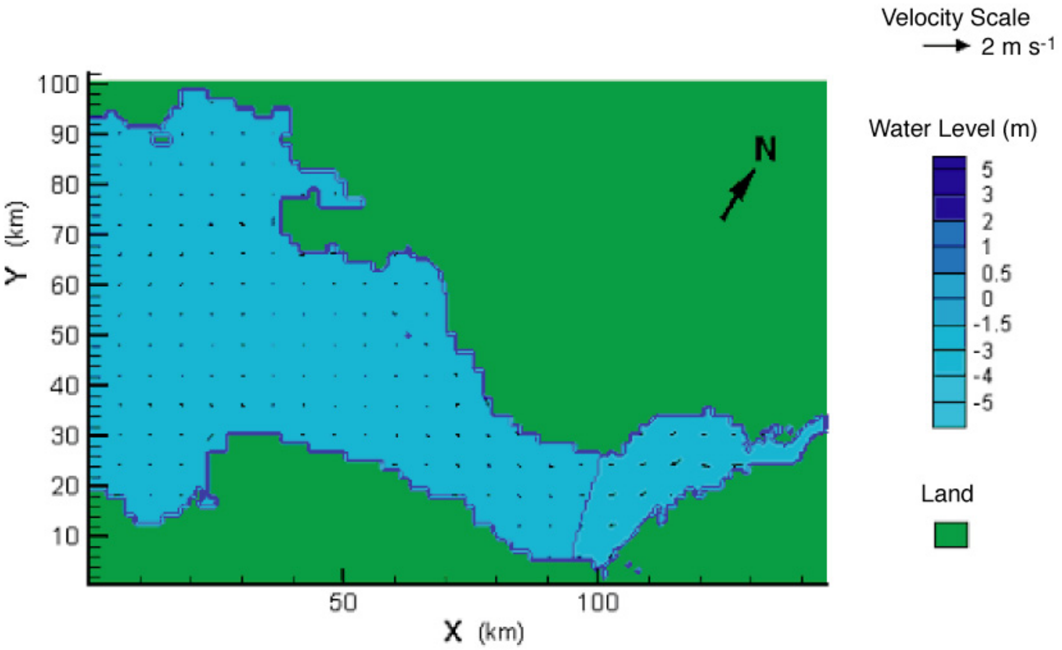


Figure 5.6: Predicted water level and velocity distributions for neap tide mid-ebb at the seaward boundary

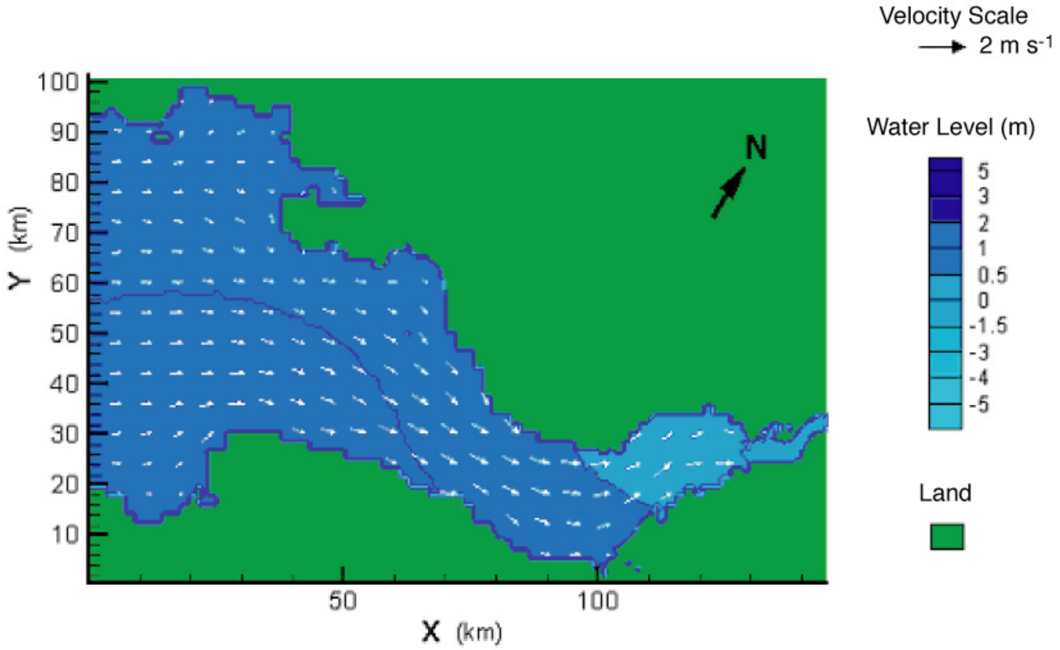


Figure 5.8: Predicted water level and velocity distributions for neap tide mid-flood at the seaward boundary

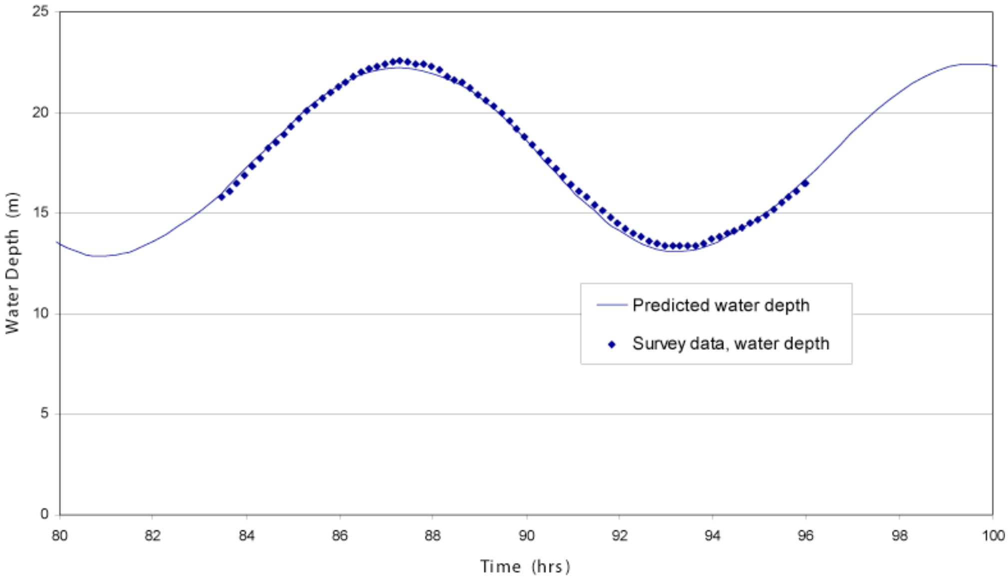


Figure 5.9: Comparison between predicted and measured water depth (m) at South Wales site 1 (csv Water Guardian) on 24 July 2001 (survey one)

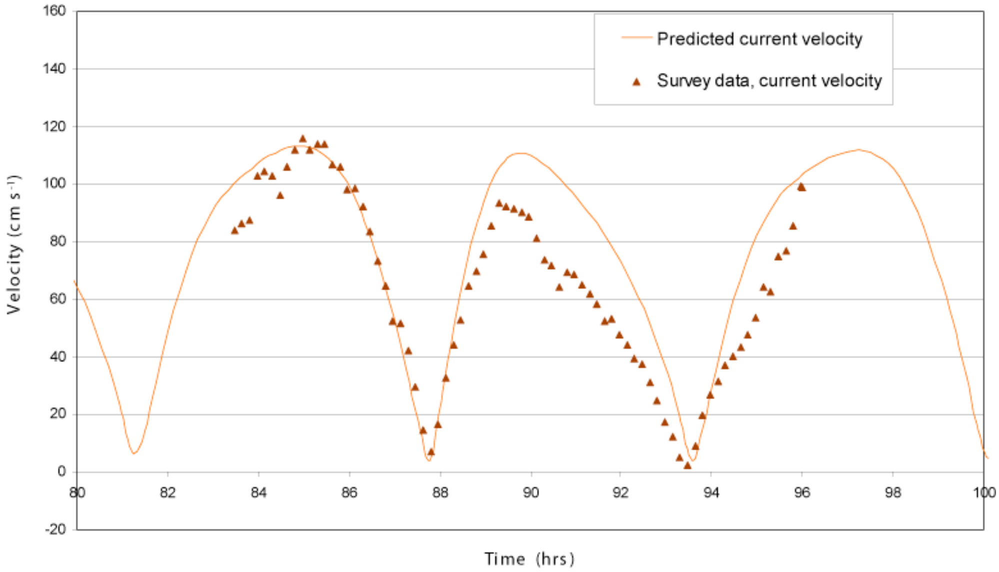


Figure 5.10: Comparison between predicted and measured current velocity (cm s^{-1}) at South Wales site 1 (csv Water Guardian) on 24 July 2001 (survey one)

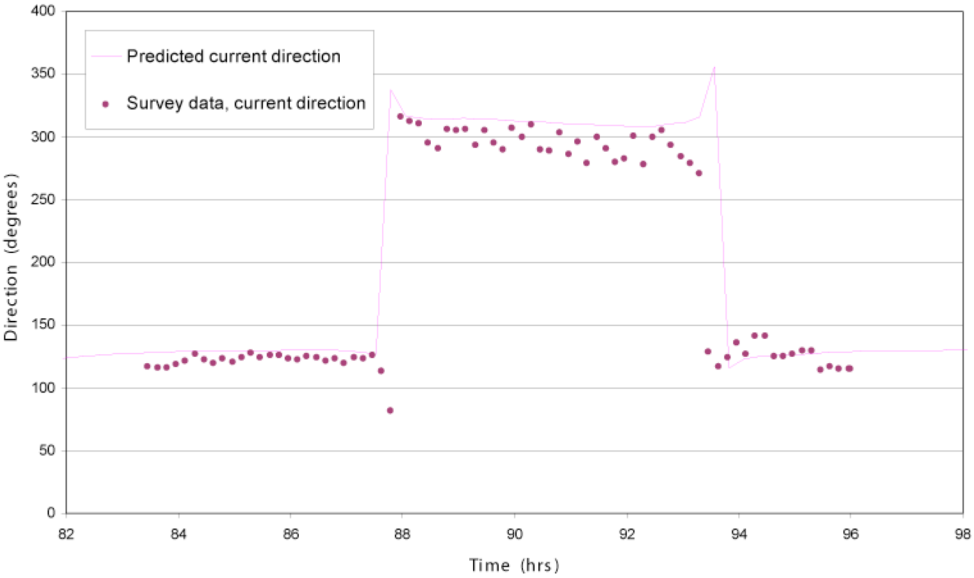


Figure 5.11: Comparison between predicted and measured current direction (degrees) at South Wales site 1 (csv Water Guardian) on 24 July 2001 (survey one)

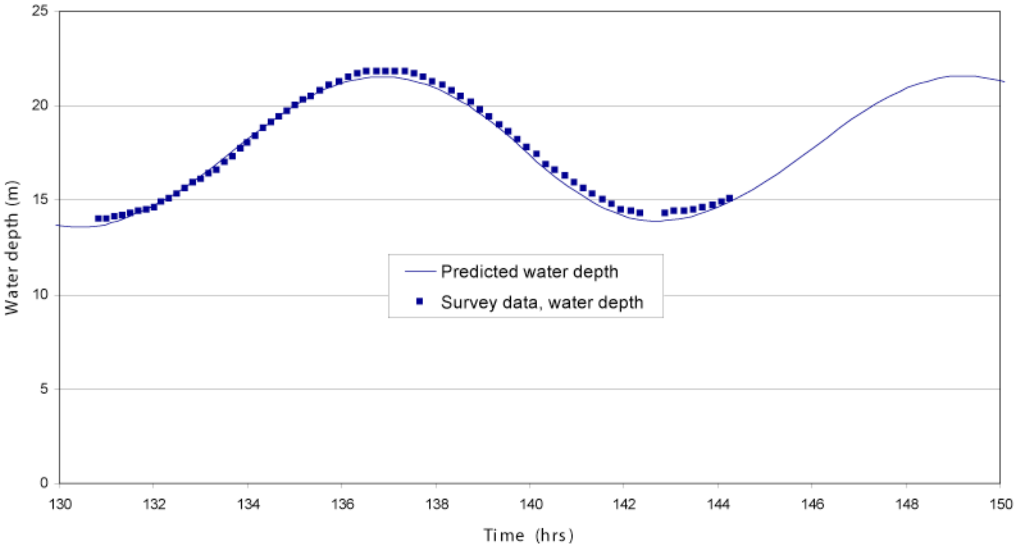


Figure 5.12: Comparison between predicted and measured water depth (m) at South Wales site 1 (csv Water Guardian) on 26 July 2001 (survey two)

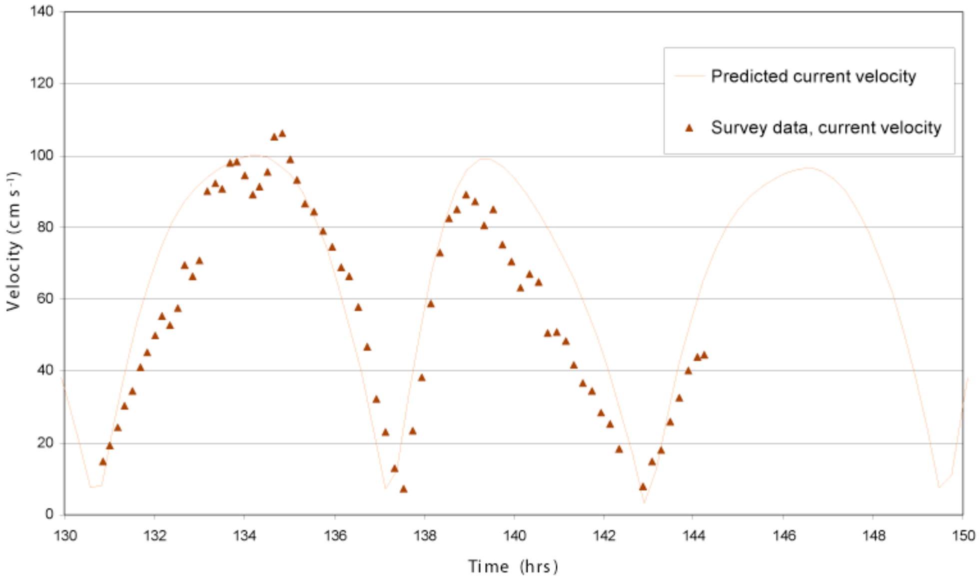


Figure 5.13: Comparison between predicted and measured current velocity (cm s^{-1}) at South Wales site 1 (csv Water Guardian) on 26 July 2001 (survey two)

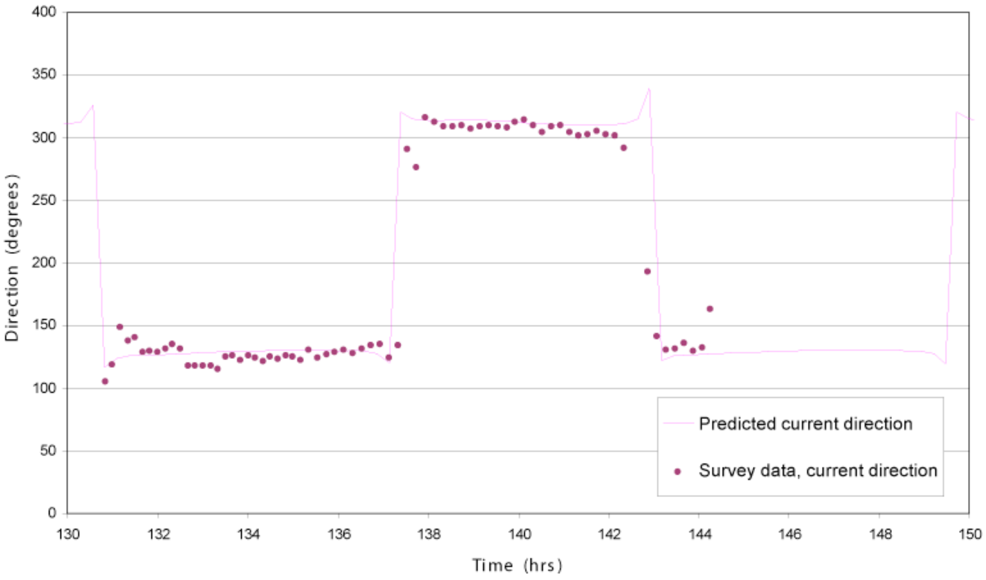


Figure 5.14: Comparison between predicted and measured current direction (degrees) at South Wales site 1 (csv Water Guardian) on 26 July 2001 (survey two)

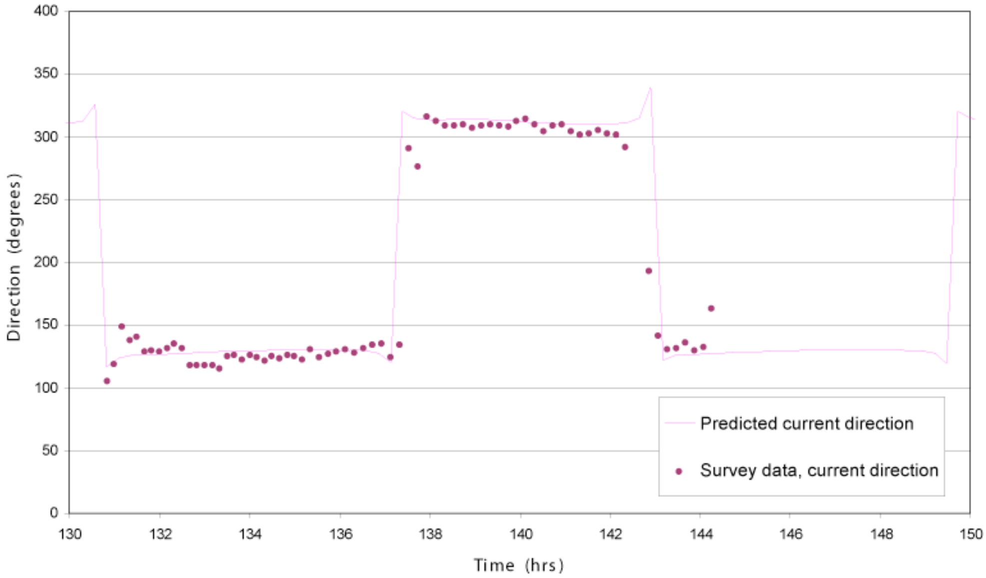


Figure 5.15: Comparison between predicted and measured water depths (m) at Somerset site 1 (csv Water Guardian) on 30 July 2001 (survey three)

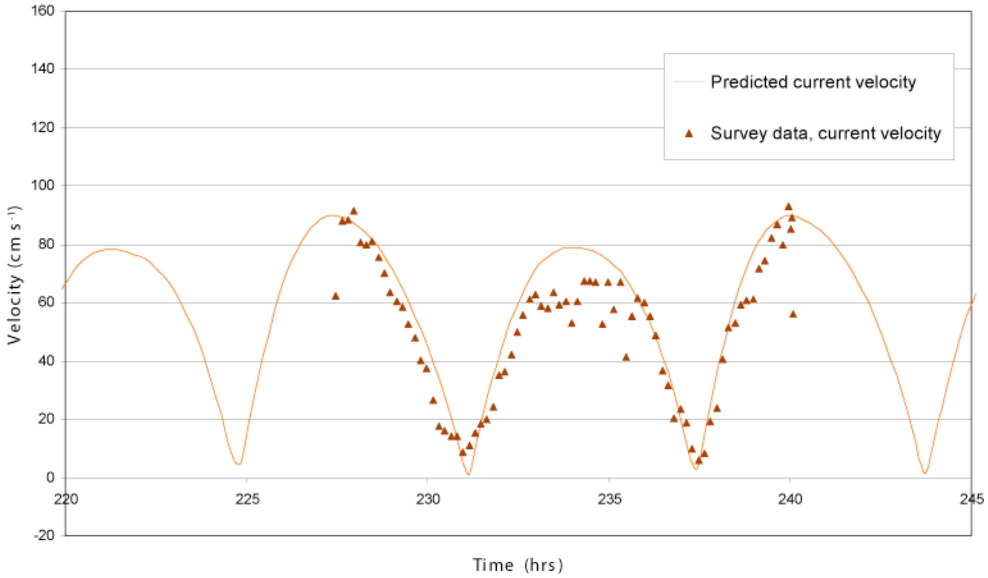


Figure 5.16: Comparison between predicted and measured current velocity (cm s^{-1}) at Somerset site 1 (csv Water Guardian) on 30 July 2001 (survey three)

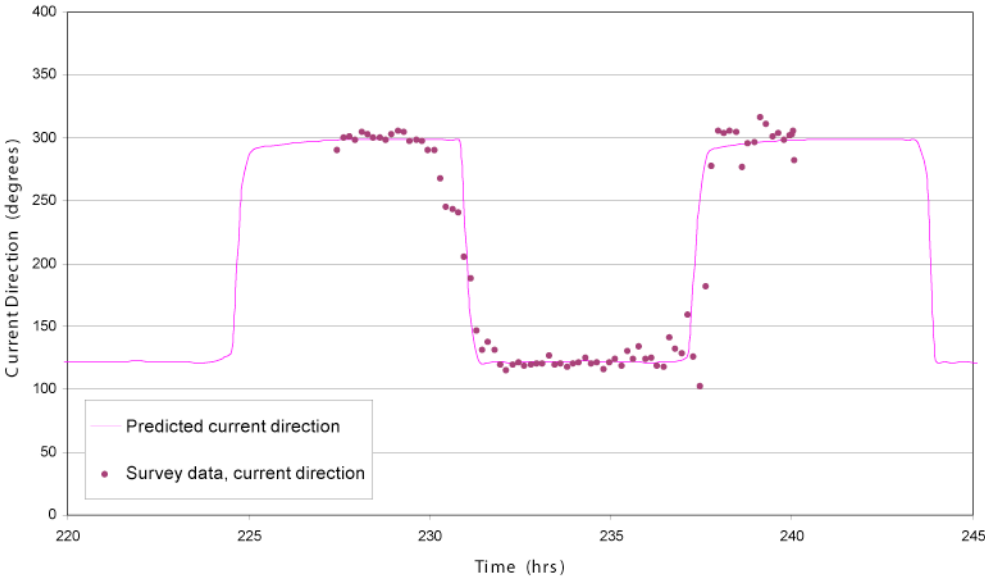


Figure 5.17: Comparison between predicted and measured current direction (degrees) at Somerset site 1 (csv Water Guardian) on 30 July 2001 (survey three)

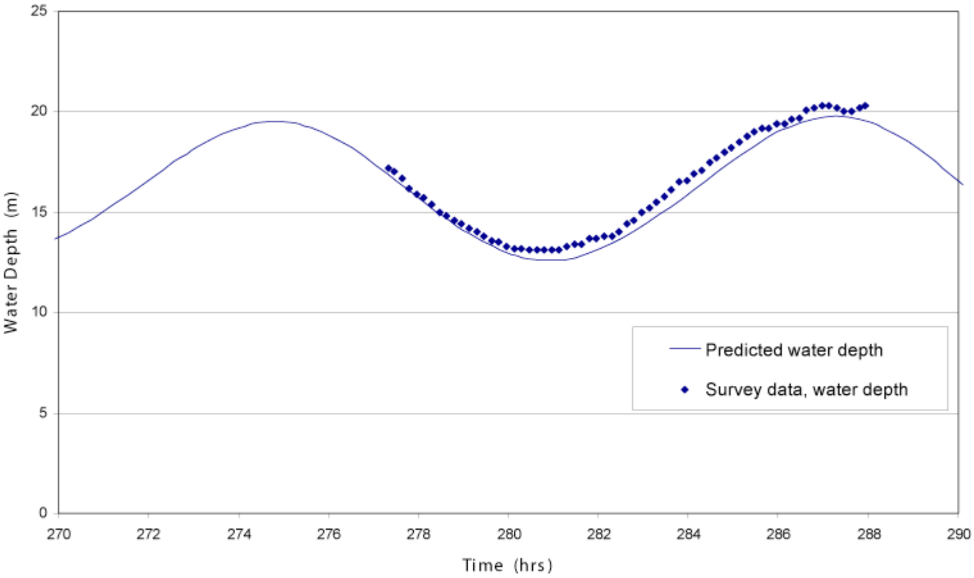


Figure 5.18: Comparison between predicted and measured water depth (m) at Somerset site 1 (csv Water Guardian) on 1 August 2001 (survey four)

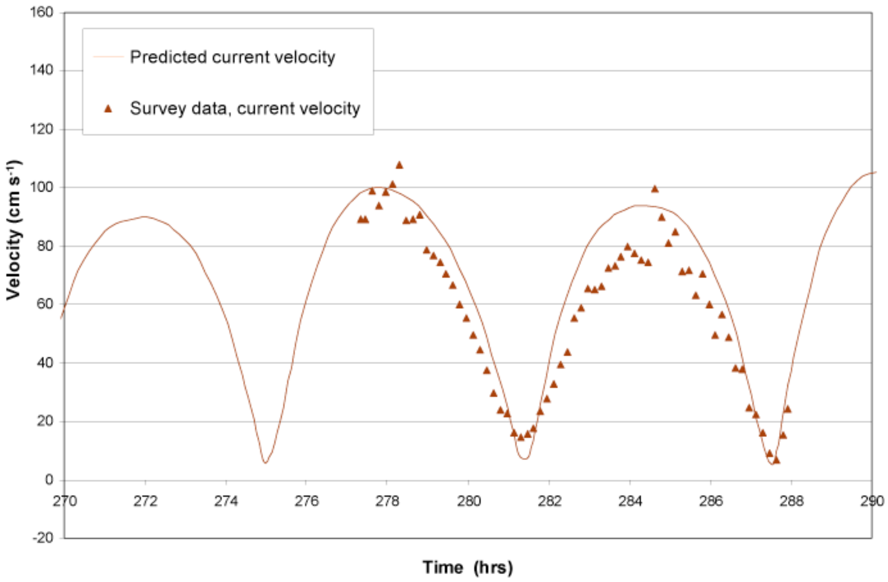


Figure 5.19: Comparison between predicted and measured current velocity (cm s^{-1}) at North Devon site 1 (csv Water Guardian) on 1 August 2001 (survey four)

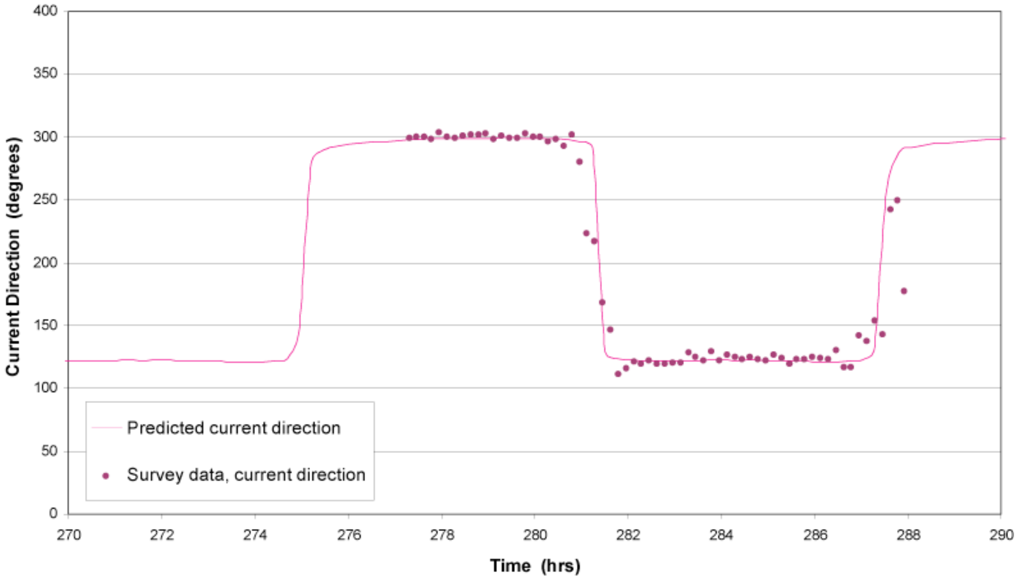


Figure 5.20: Comparison between predicted and measured current direction (degrees) at North Devon site 1 (csv Water Guardian) on 1 August 2001 (survey four)

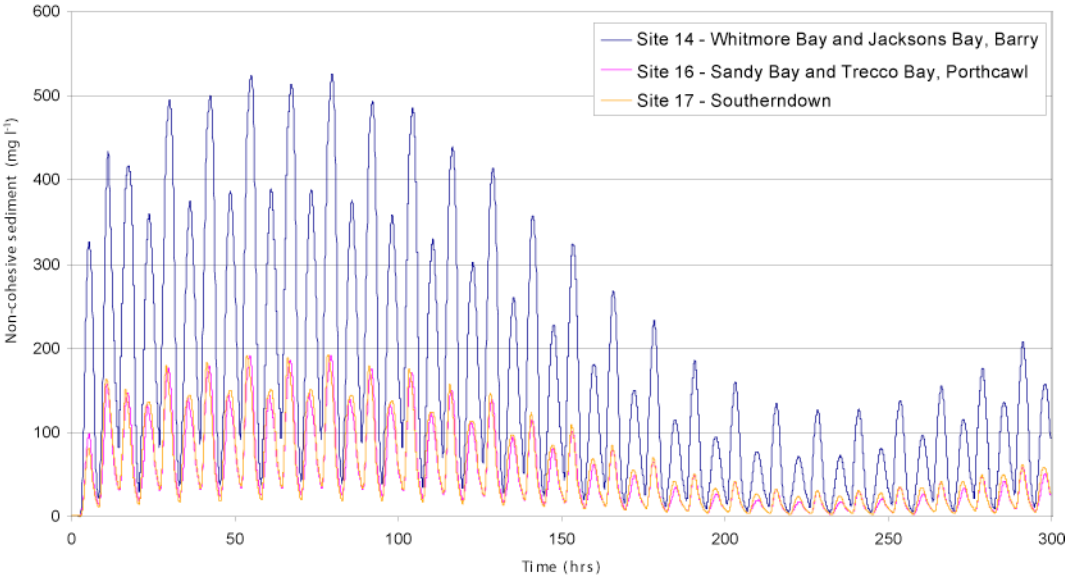


Figure 6.1 Predicted non-cohesive sediment concentrations (mg l^{-1}) at Whitmore Bay and Jacksons Bay, Barry (model site 14), Sandy Bay and Trecco Bay, Porthcawl (model site 16), and Southerndown (model site 17) bathing water compliance monitoring points

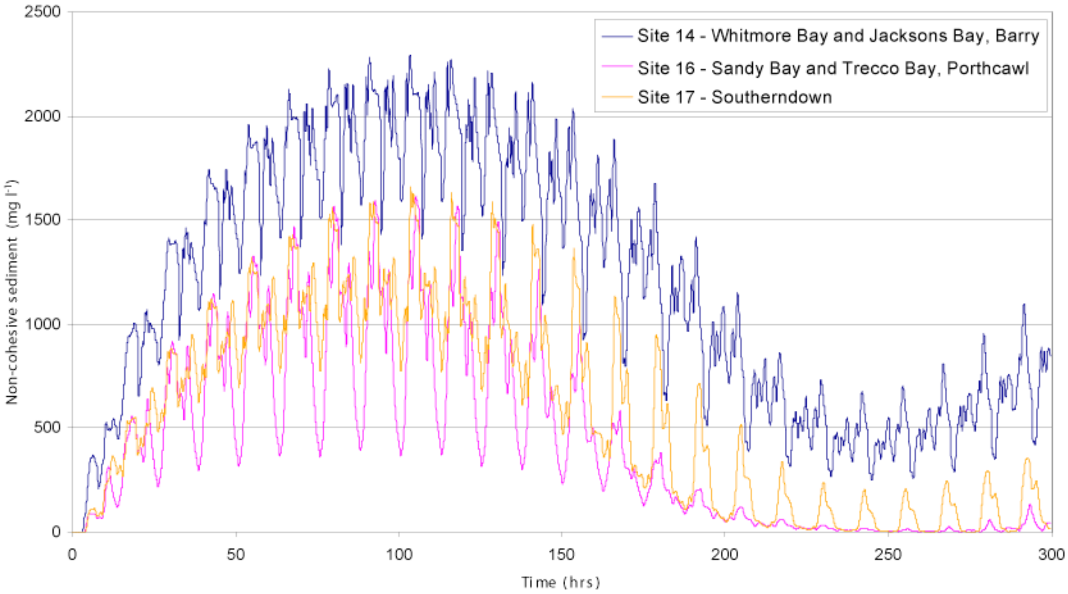


Figure 6.2 Predicted cohesive sediment concentrations (mg l^{-1}) at Whitmore Bay and Jacksons Bay, Barry (model site 14), Sandy Bay and Trecco Bay, Porthcawl (model site 16), and Southerndown (model site 17) bathing water compliance monitoring points

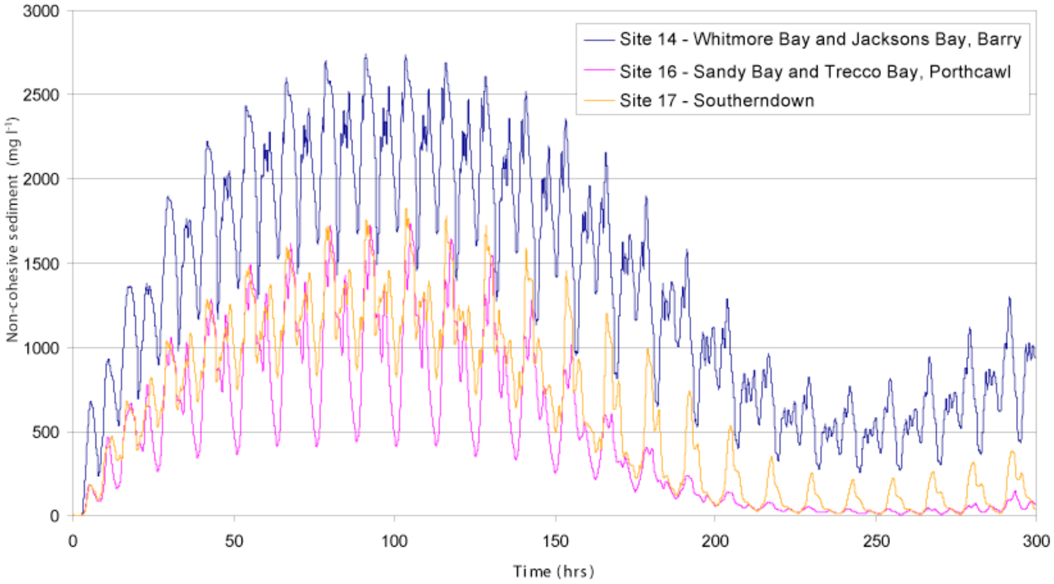


Figure 6.3 Predicted cohesive sediment concentrations (mg l^{-1}) at Whitmore Bay and Jacksons Bay, Barry (model site 14), Sandy Bay and Trecco Bay, Porthcawl (model site 16), and Southerndown (model site 17) bathing water compliance monitoring points

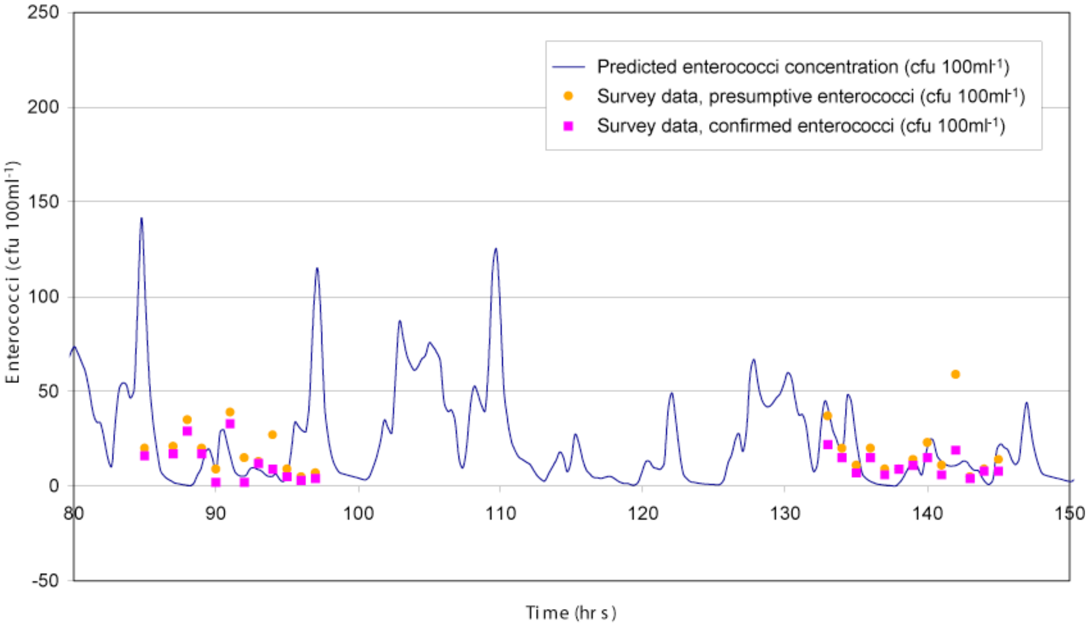


Figure 7.1 Comparison between predicted and observed enterococci concentrations (cfu 100ml^{-1}) at Trecco Bay, Porthcawl, bathing water compliance monitoring point (observed data from survey one (24 July 2001) and survey two (26 July 2001))

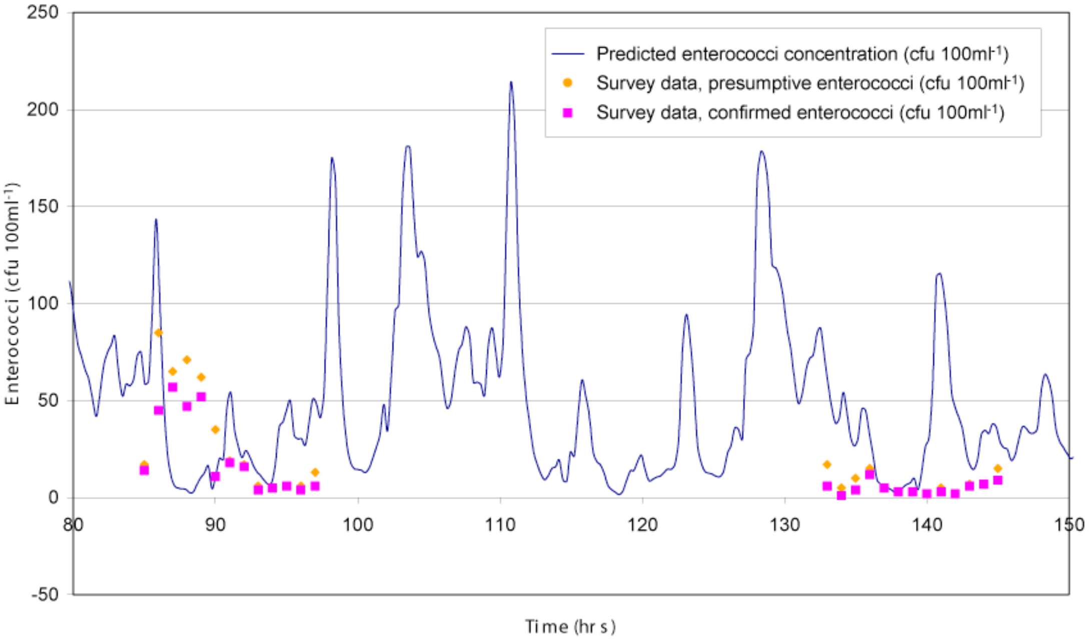


Figure 7.2 Comparison between predicted and observed enterococci concentrations (cfu 100ml^{-1}) at Southerndown bathing water compliance monitoring point (observed data from survey one (24 July 2001) and survey two (26 July 2001))

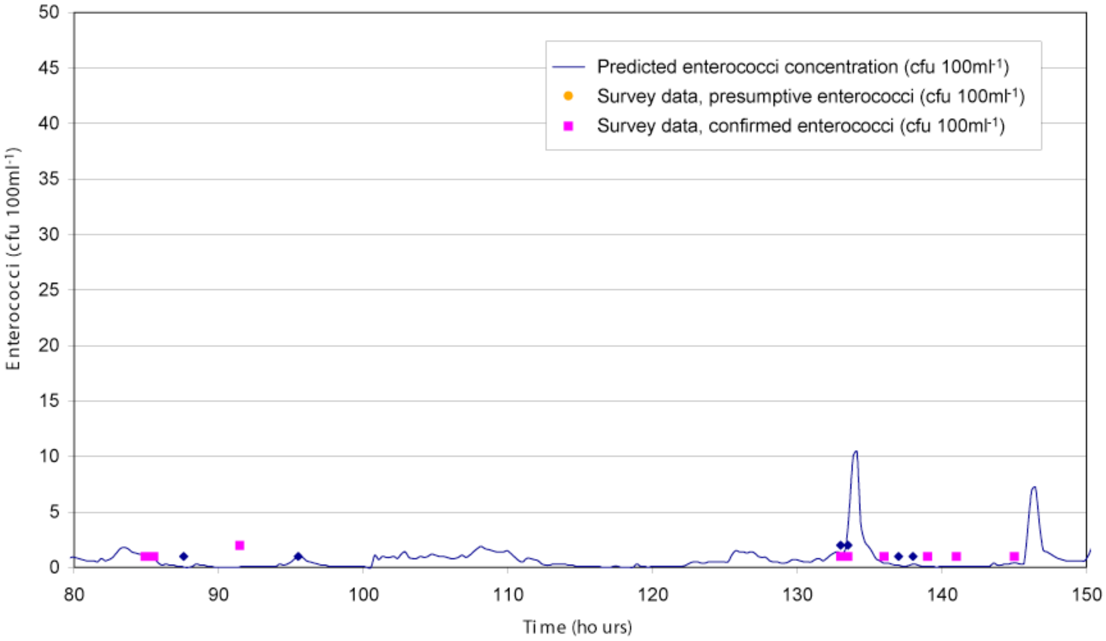


Figure 7.3 Comparison between predicted and observed enterococci concentrations (cfu 100ml^{-1}) at Porthcawl/Southerndown site 1 (offshore, csv *Water Guardian*) (observed data from survey one (24 July 2001) and survey two (26 July 2001))

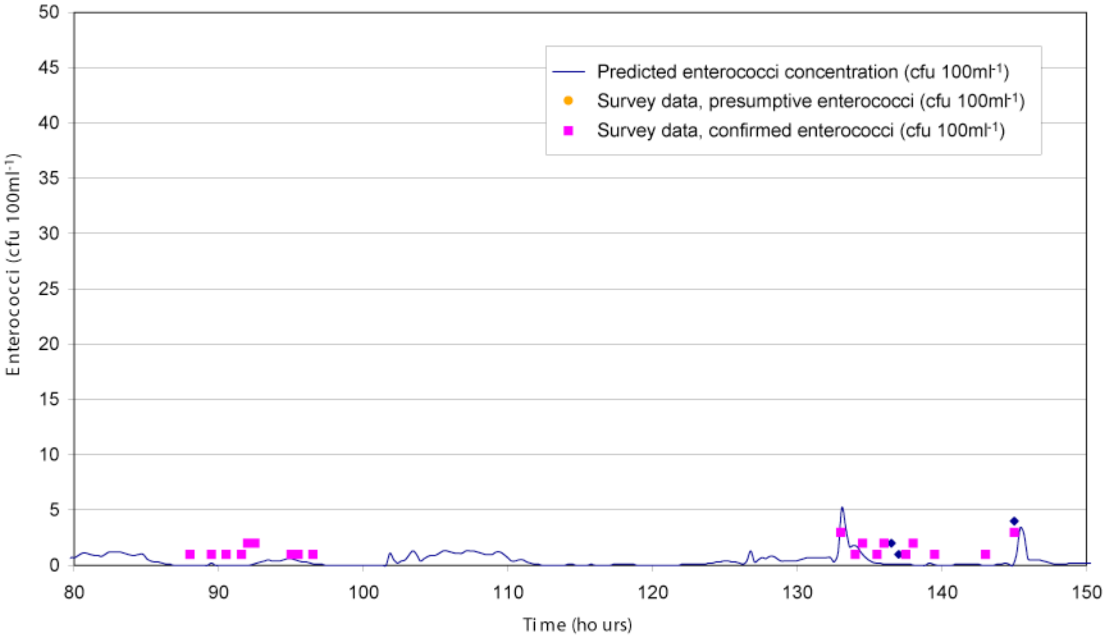


Figure 7.4 Comparison between predicted and observed enterococci concentrations (cfu 100ml^{-1}) at Porthcawl/Southerndown site 3 (offshore, rib) (observed data from survey one (24 July 2001) and survey two (26 July 2001))

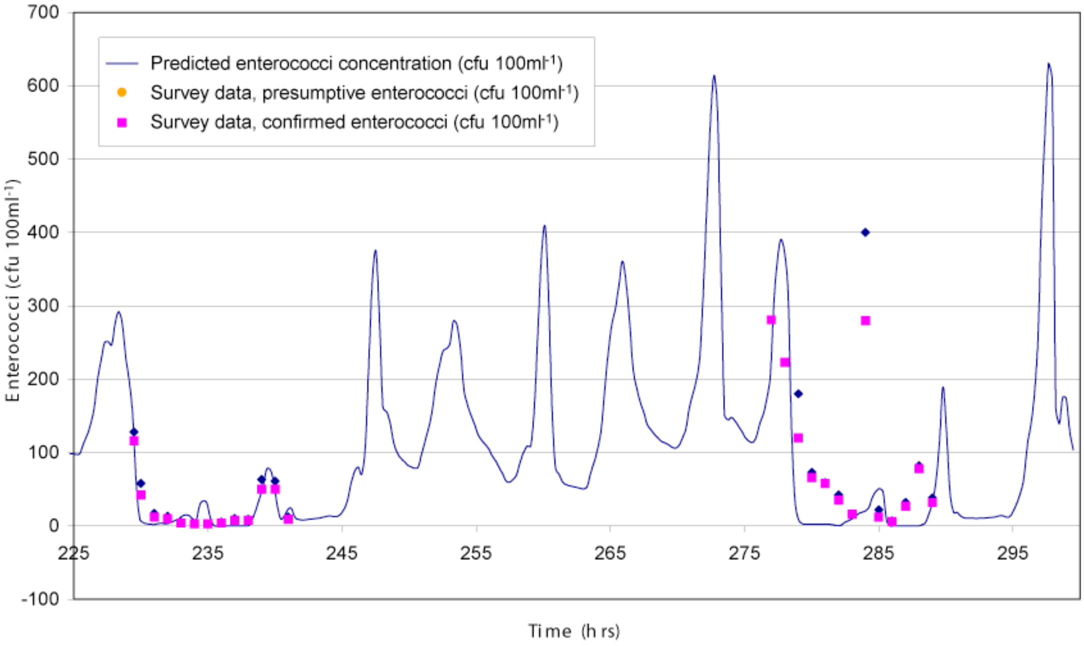


Figure 7.5 Comparison between predicted and observed enterococci concentrations (cfu 100ml^{-1}) at Dunster North West bathing water compliance monitoring point (observed data from survey three (30 July 2001) and survey four (1 August 2001))

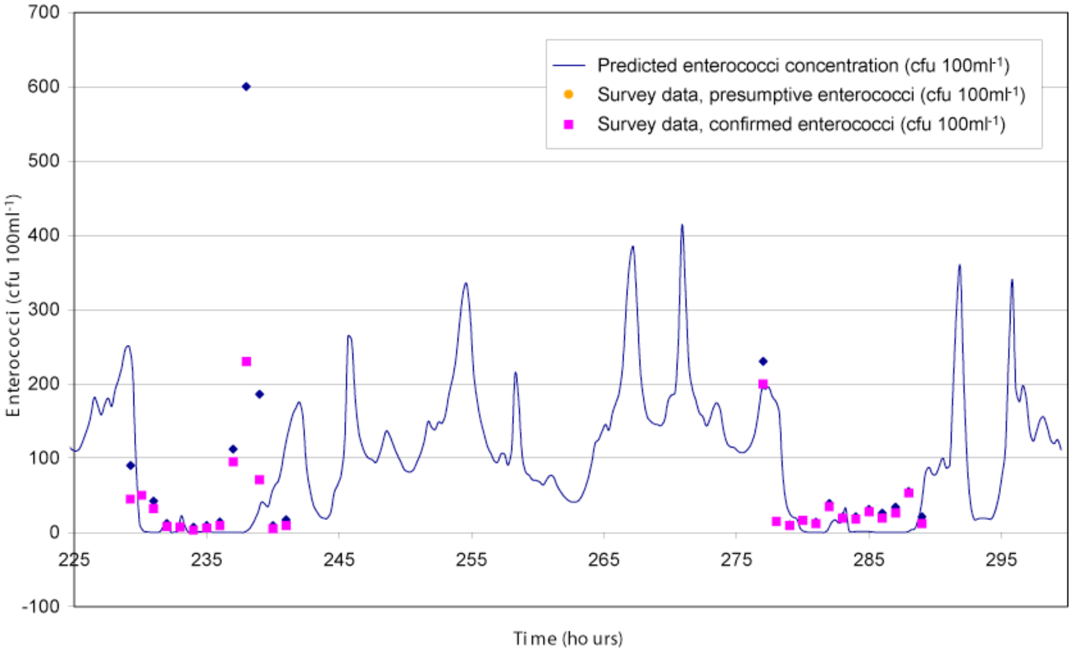


Figure 7.6 Comparison between predicted and observed enterococci concentrations (cfu 100ml^{-1}) at Minehead Terminus bathing water compliance monitoring point (observed data from survey three (30 July 2001) and survey four (1 August 2001))

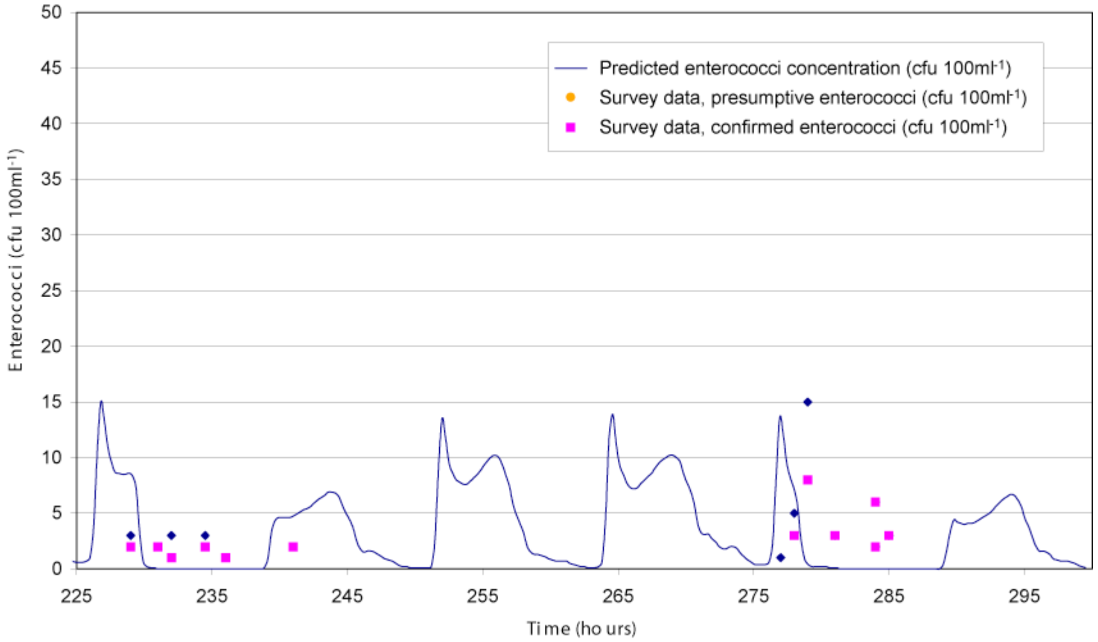


Figure 7.7 Comparison between predicted and observed enterococci concentrations (cfu 100ml^{-1}) at Minehead/Blue Anchor Bay site 1 (offshore, csv *Water Guardian*) (observed data from survey three (30 July 2001) and survey four (1 August 2001))

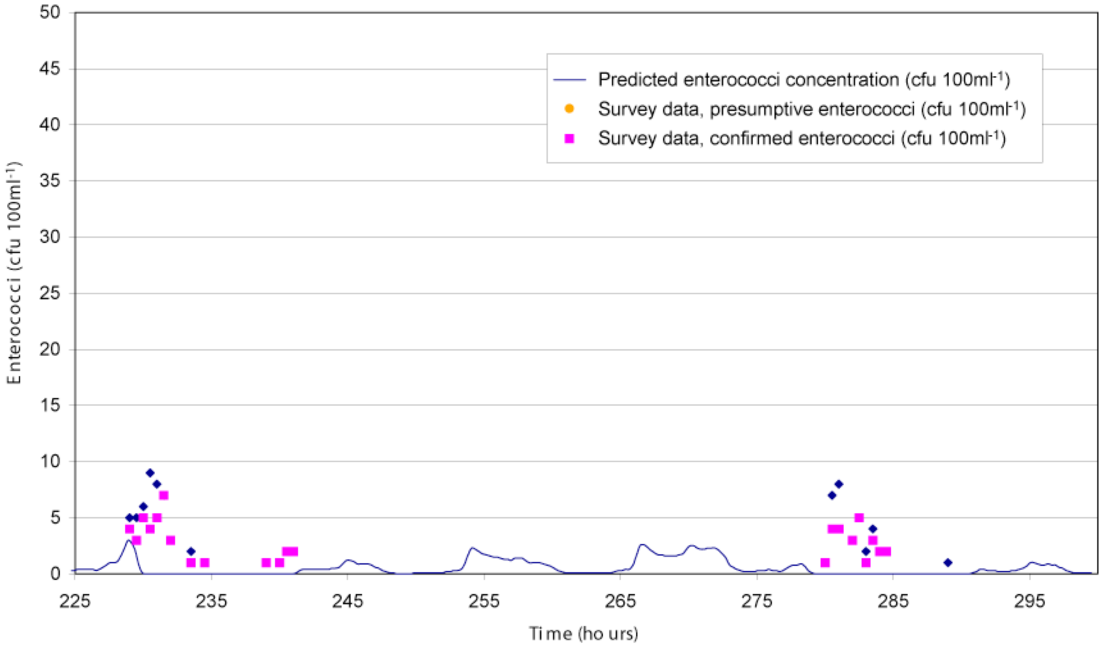


Figure 7.8 Comparison between predicted and observed enterococci concentrations (cfu 100ml^{-1}) at Minehead/Blue Anchor Bay site 3 (offshore, rib) (observed data from survey three (30 July 2001) and survey four (1 August 2001))

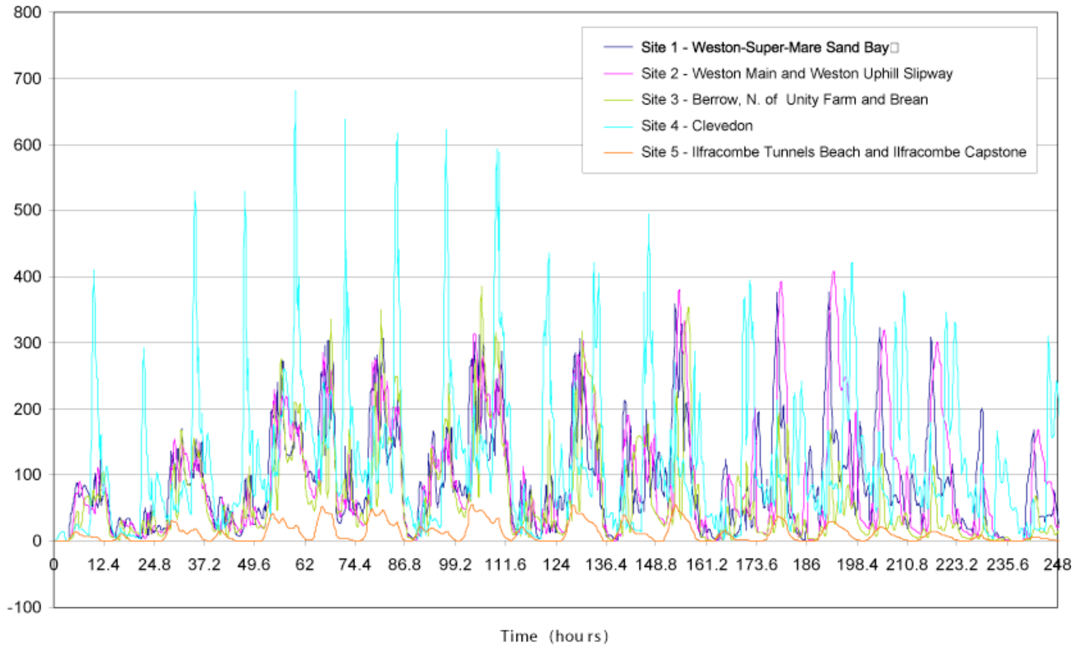


Figure 7.9 Predicted enterococci concentration (cfu 100ml^{-1}) at bathing water compliance monitoring points furthest into the Severn estuary (model sites 1–4) compared with points at the seaward limit of the Bristol Channel (model site 5)

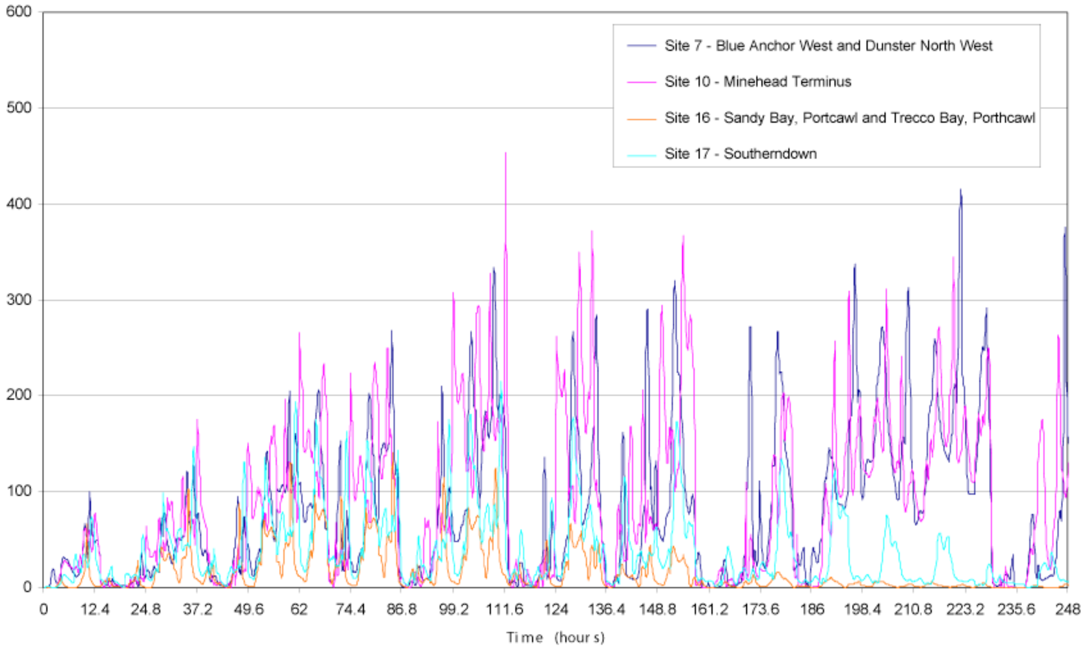


Figure 7.10 Predicted enterococci concentration (cfu 100ml^{-1}) at bathing water compliance monitoring points sampled during the calibration field surveys (model sites 7, 10, 16 and 17)

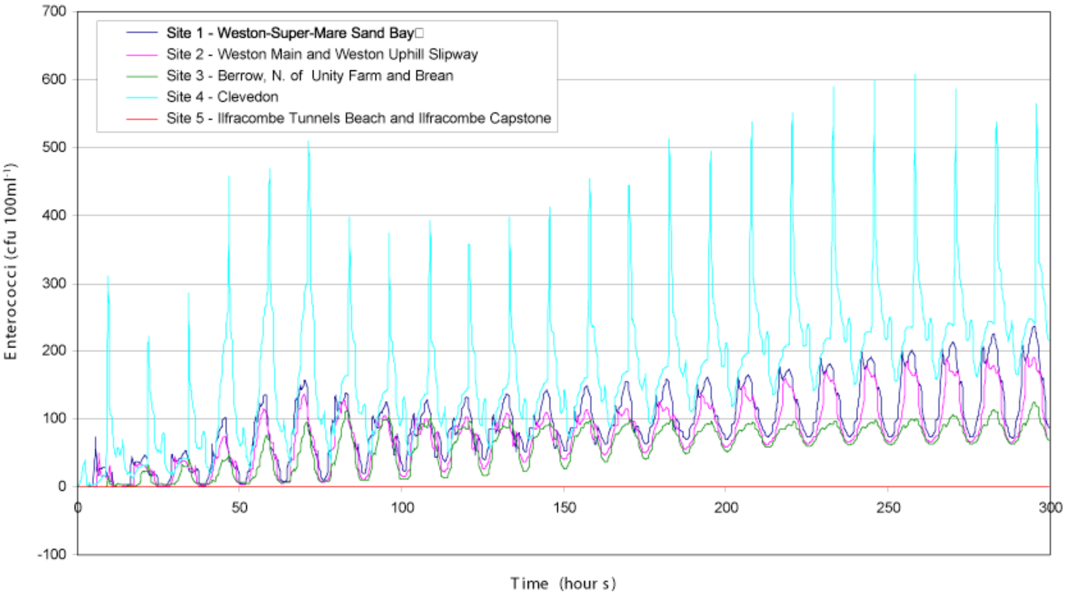


Figure 8.1 Enterococci concentrations (cfu 100ml^{-1}) at bathing water compliance monitoring points furthest into the Severn estuary (model sites 1–4) compared with points at the seaward limit of the Bristol Channel (model site 5), predicted using the dilution only model

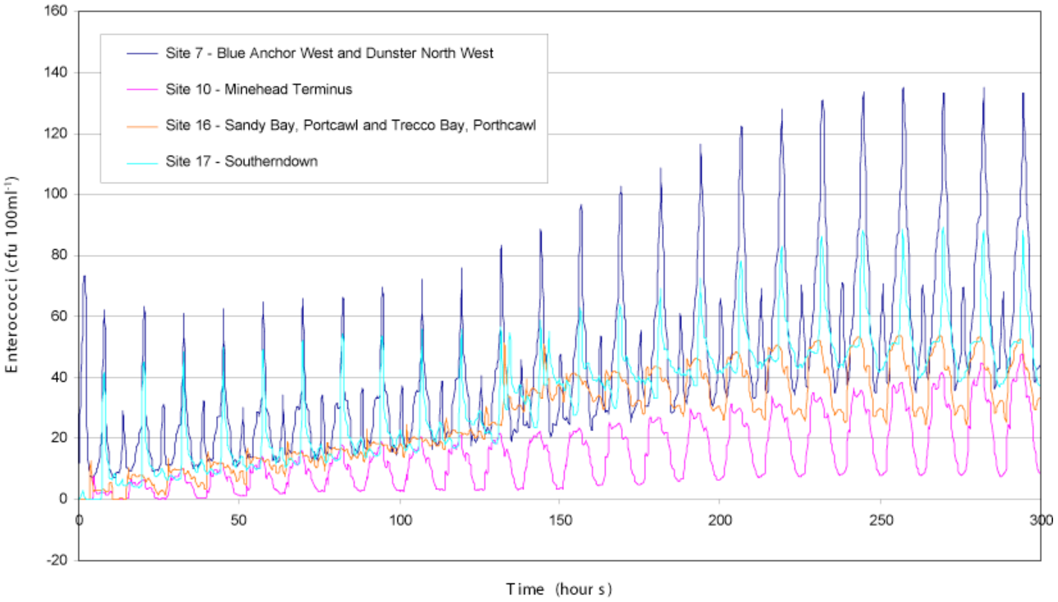


Figure 8.2 Enterococci concentrations (cfu 100ml^{-1}) at bathing water compliance monitoring points sampled during the calibration field surveys (model sites 7, 10, 16 and 17), predicted using the dilution only model

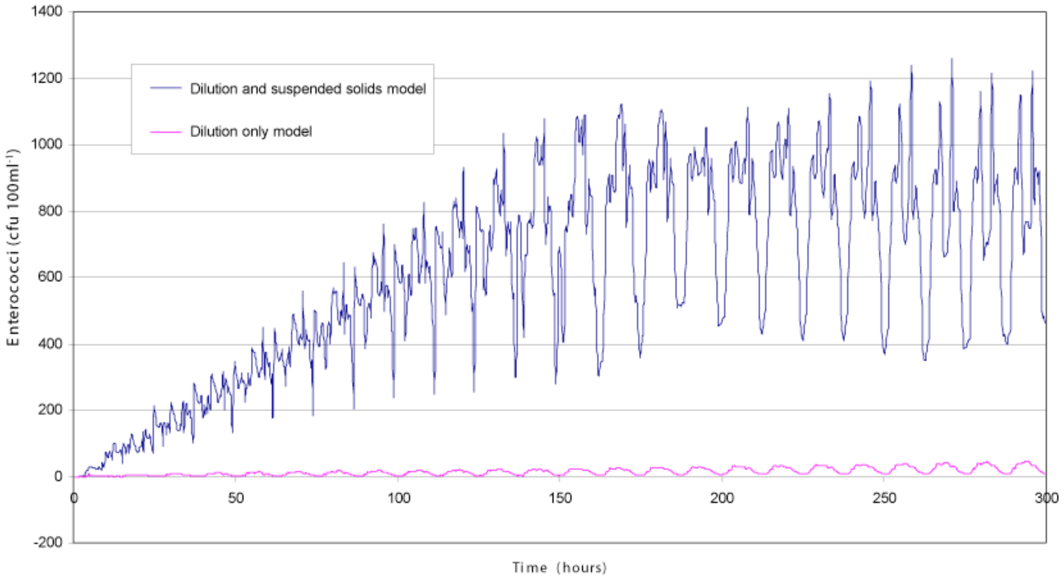


Figure 8.3 Comparison of enterococci concentrations at Minehead Terminus bathing water compliance monitoring point (model site 10) predicted using the 'dilution only' and 'dilution and suspended solids' models

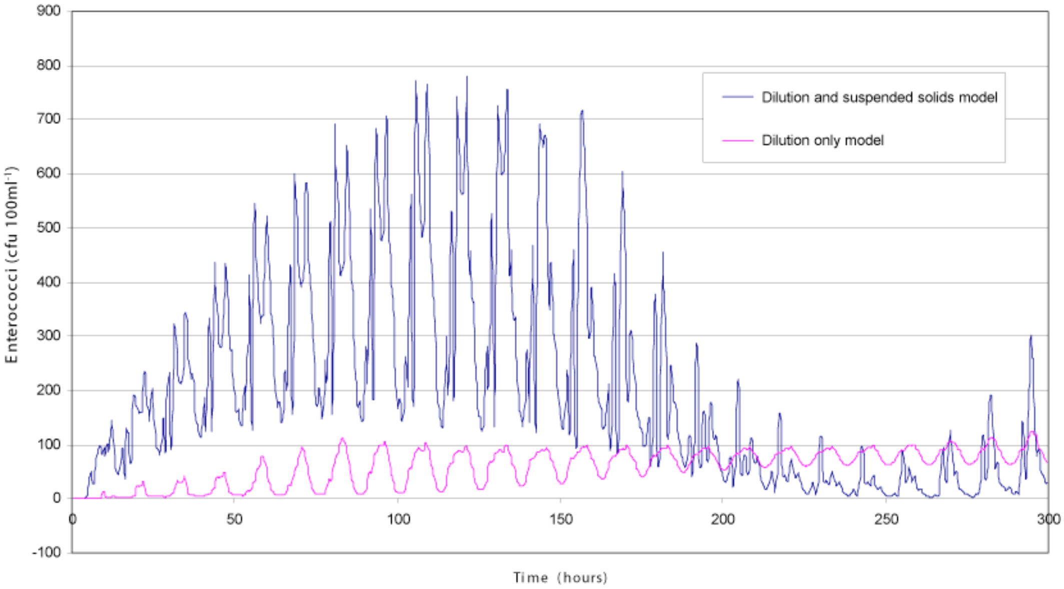
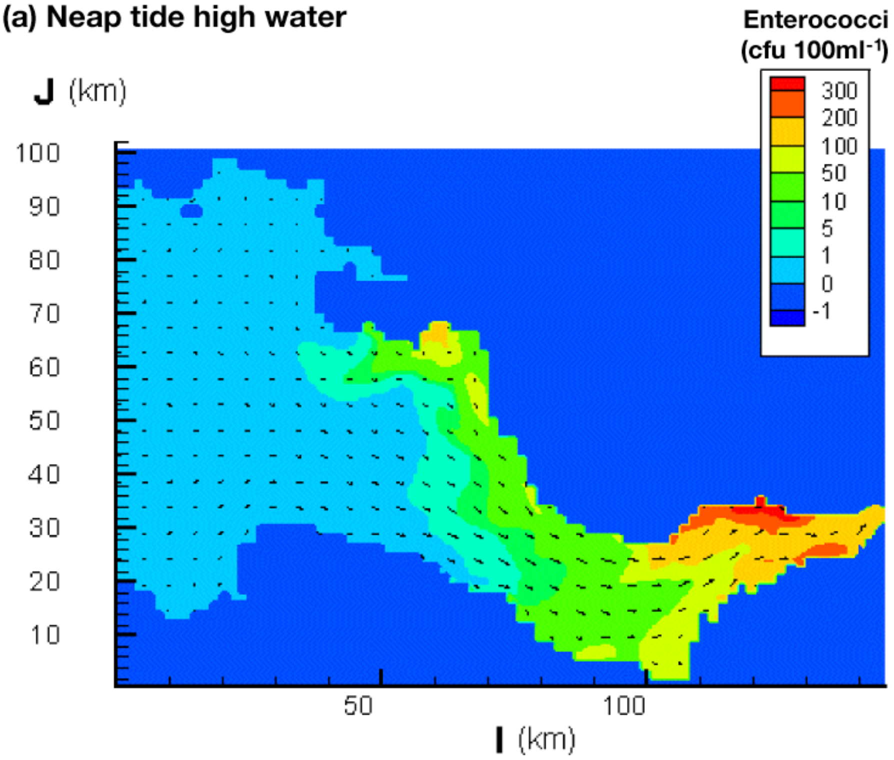


Figure 8.4 Comparison of enterococci concentrations at Berrow North of unity Farm and Brean bathing water compliance monitoring point (model site 3) predicted using the 'dilution only' and 'dilution and suspended solids' models

(a) Neap tide high water



(b) Neap tide mid-ebb

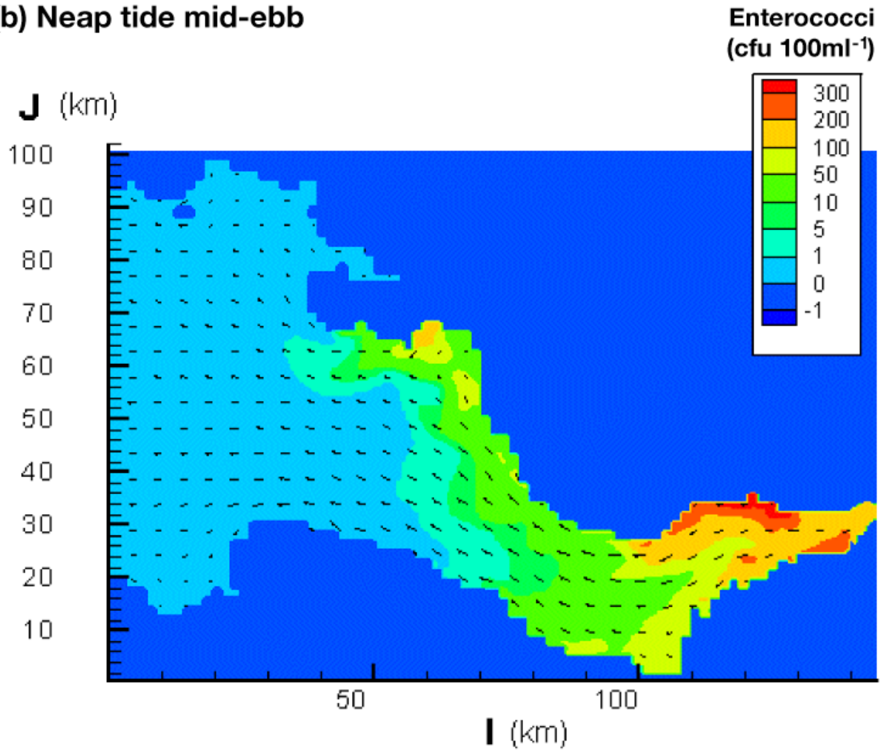
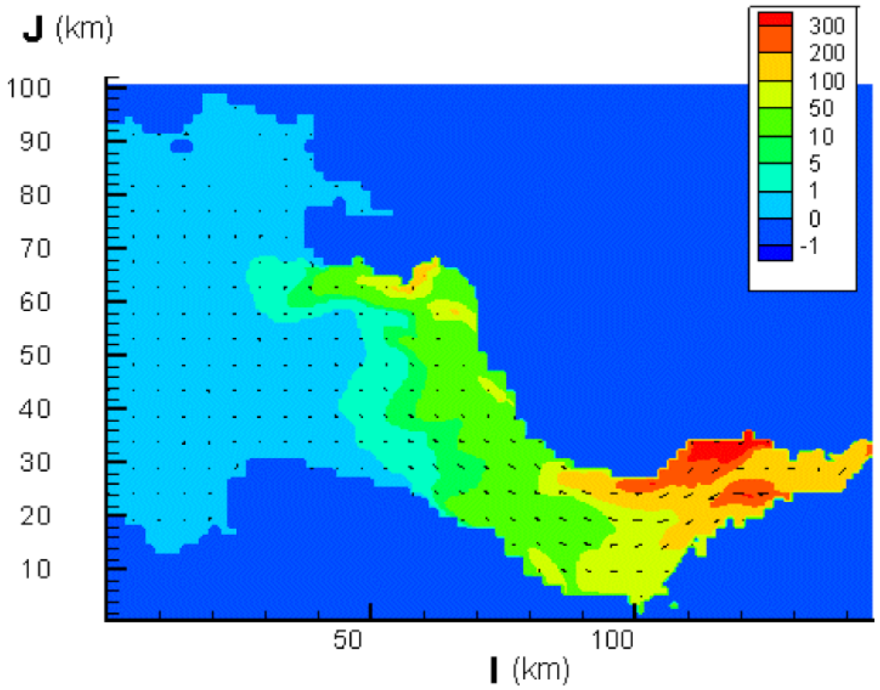


Figure 8.5 Neap tide enterococci concentrations (cfu $100ml^{-1}$) within the 2-D model domain predicted using the 'dilution only' model: (a) high water; (b) mid-ebb

(c) Neap tide low water



(d) Neap tide mid-flood

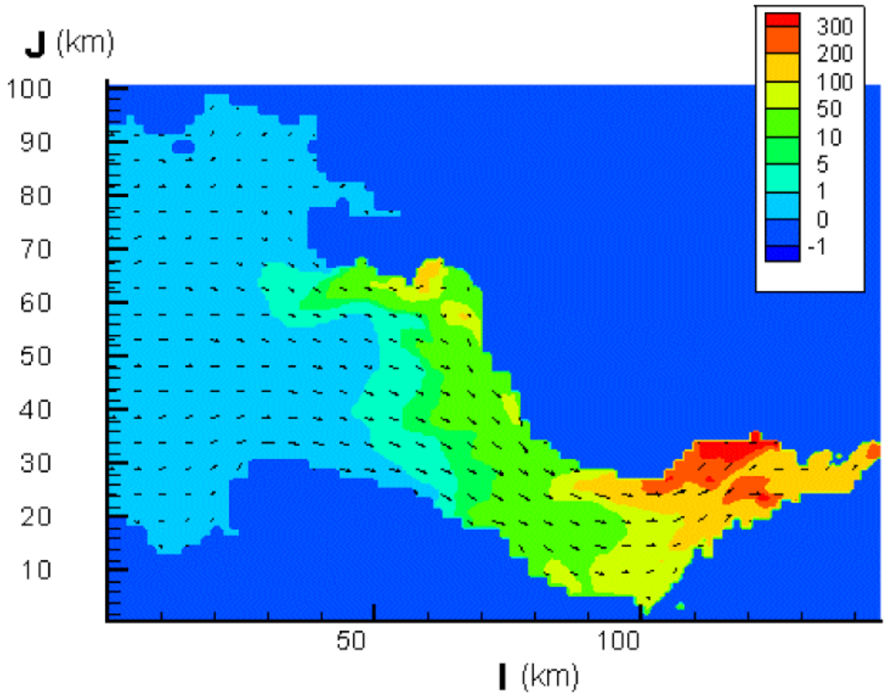


Figure 8.5 Neap tide enterococci concentrations (cfu 100ml^{-1}) within the 2-D model domain predicted using the ‘dilution only’ model: (c) low water; and (d) mid-flood

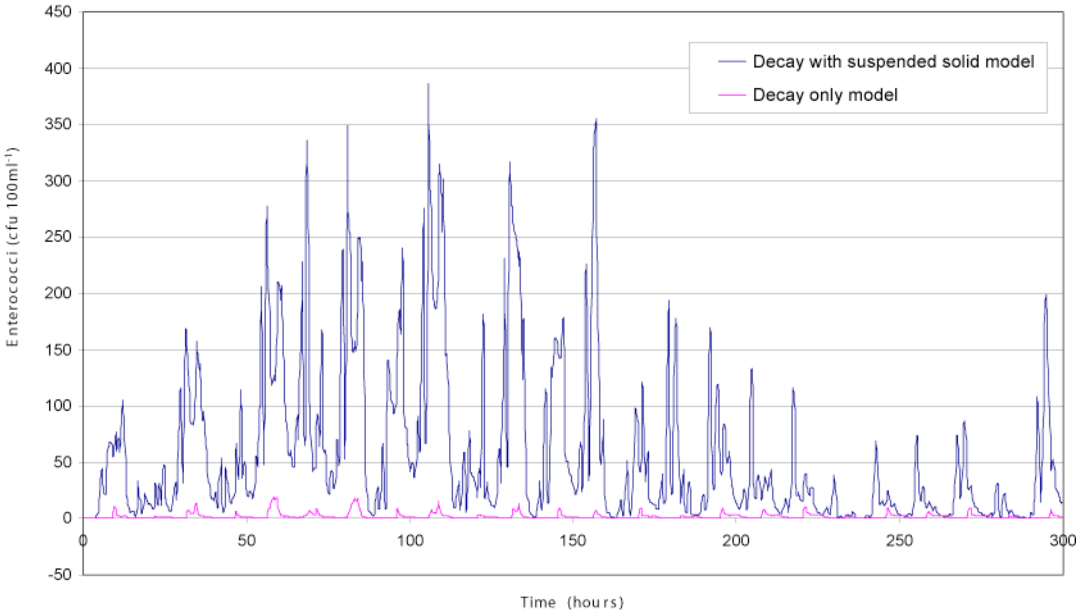


Figure 8.6 **Comparison of enterococci concentrations at Berrow North of Unity Farm and Brean bathing water compliance monitoring points (model site 3) predicted using the 'decay only' and the 'decay with suspended solids' models**

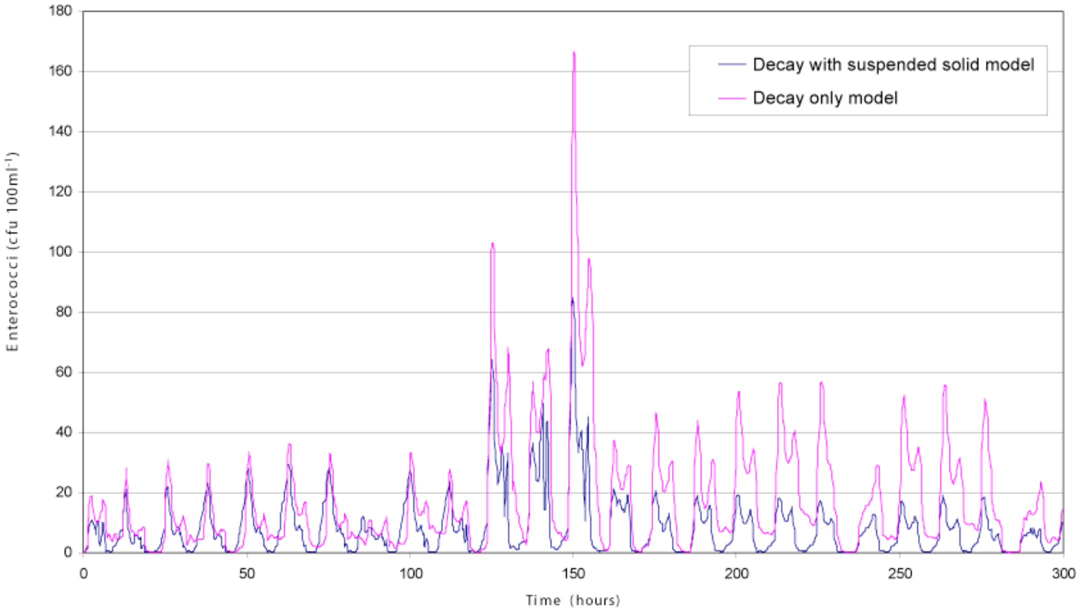


Figure 8.7 **Comparison of enterococci concentrations at Swansea Bay bathing water compliance monitoring points (model site 12) predicted using the 'decay only' and the 'decay with suspended solids' models**

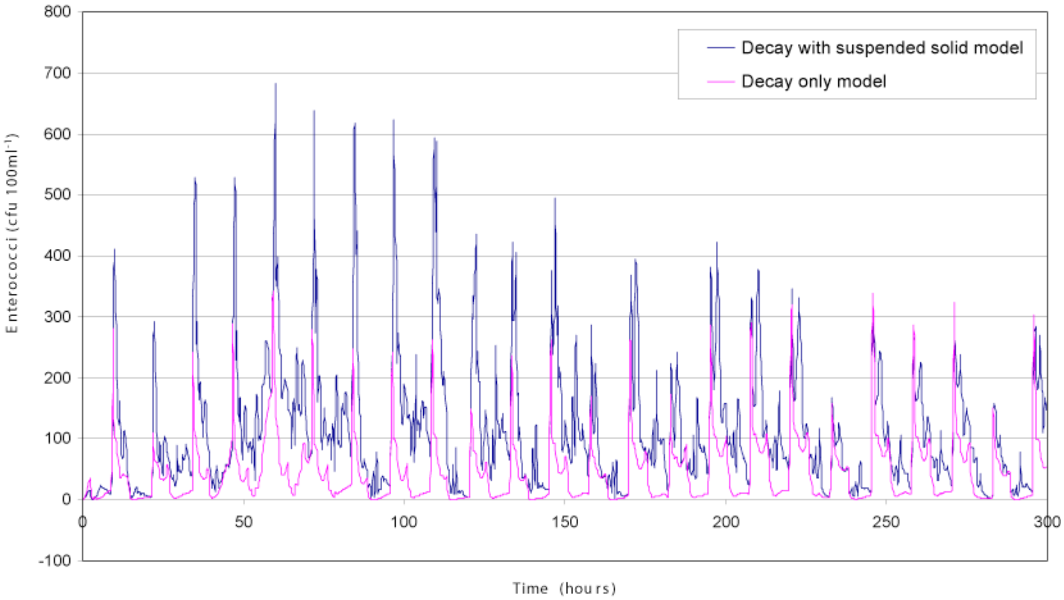


Figure 8.8 Comparison of enterococci concentrations at Clevedon Beach bathing water compliance monitoring points (model site 4) predicted using the ‘decay only’ and the ‘decay with suspended solids’ models

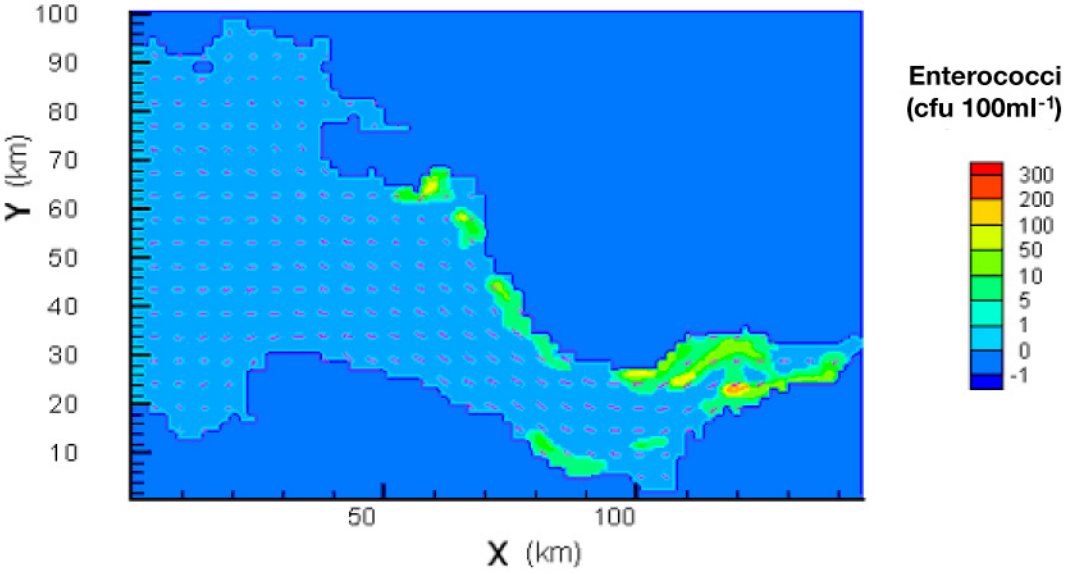


Figure 8.9 Spring tide mid-ebb enterococci concentrations (cfu 100ml^{-1}) within the 2-D model domain predicted using the 'decay only' model

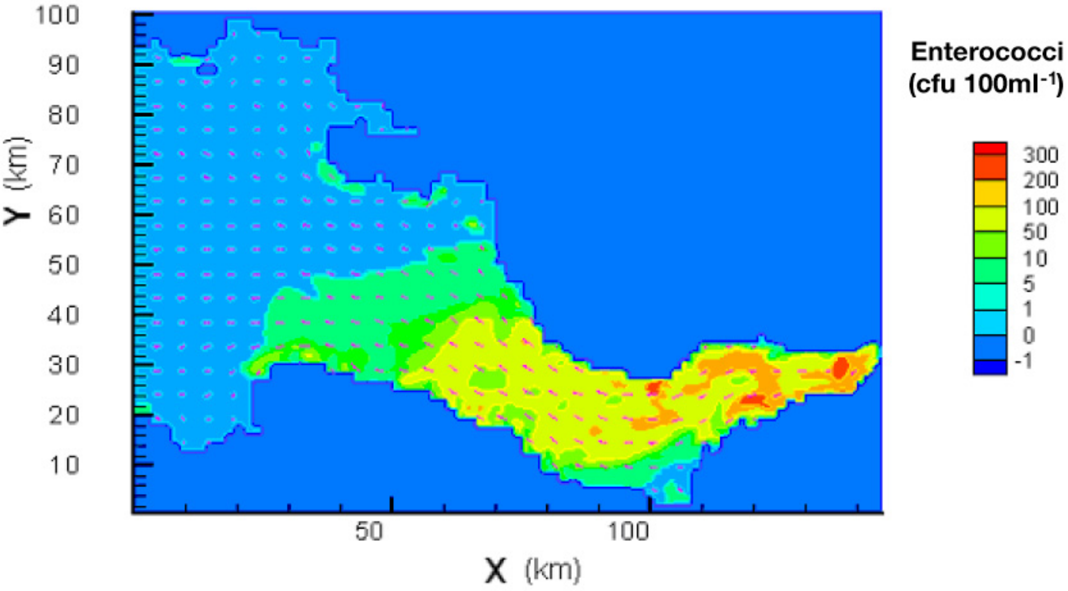


Figure 8.10 Spring tide mid-ebb enterococci concentrations (cfu 100ml^{-1}) within the 2-D model domain predicted using the 'decay with suspended solids' model

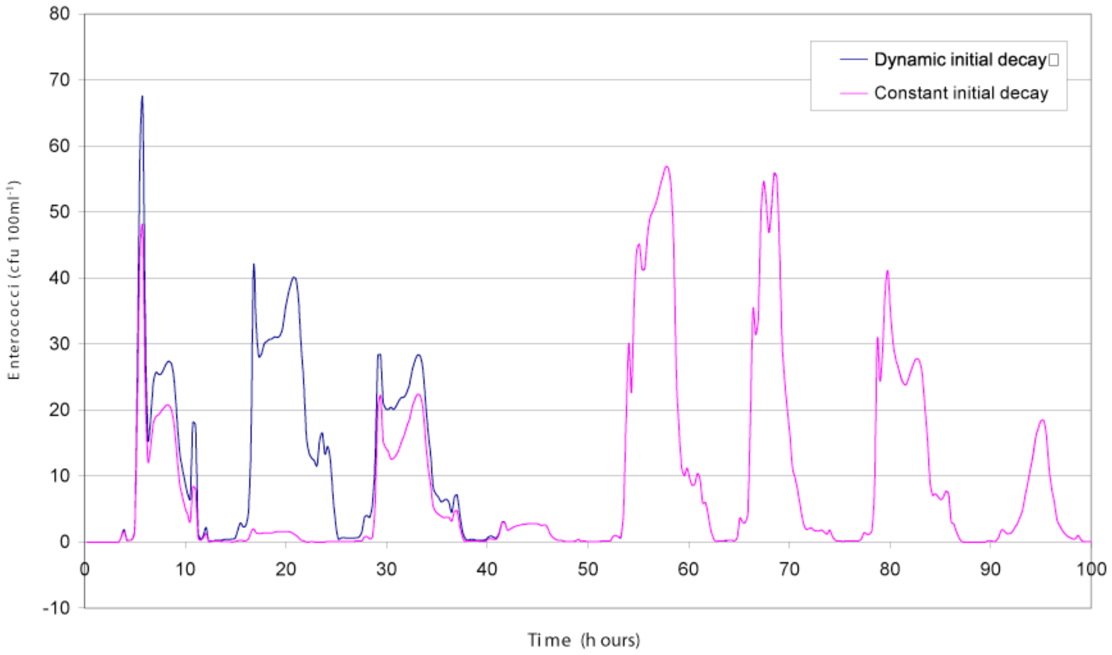


Figure 8.11 Comparison of predicted enterococci concentrations (cfu 100ml^{-1}) at Weston-Super-Mare Sand Bay bathing water compliance monitoring point (model site 1) using a dynamic initial decay rate and a constant initial decay rate

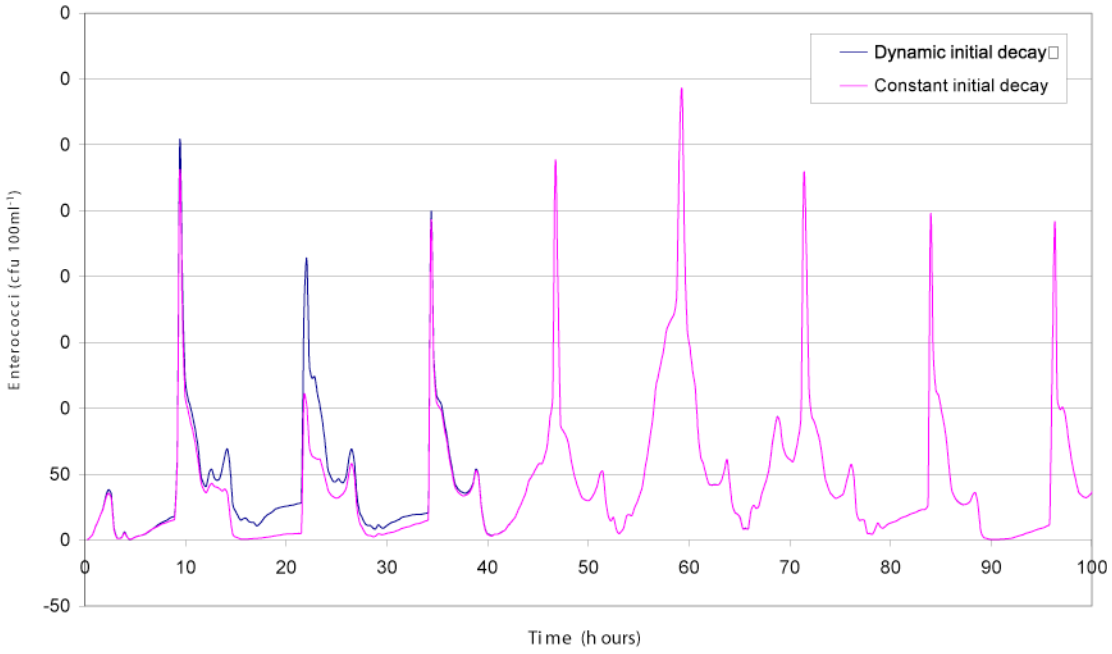


Figure 8.12 Comparison of predicted enterococci concentrations (cfu 100ml^{-1}) at Clevedon Beach bathing water compliance monitoring point (model site 4) using a dynamic initial decay rate and a constant initial decay rate

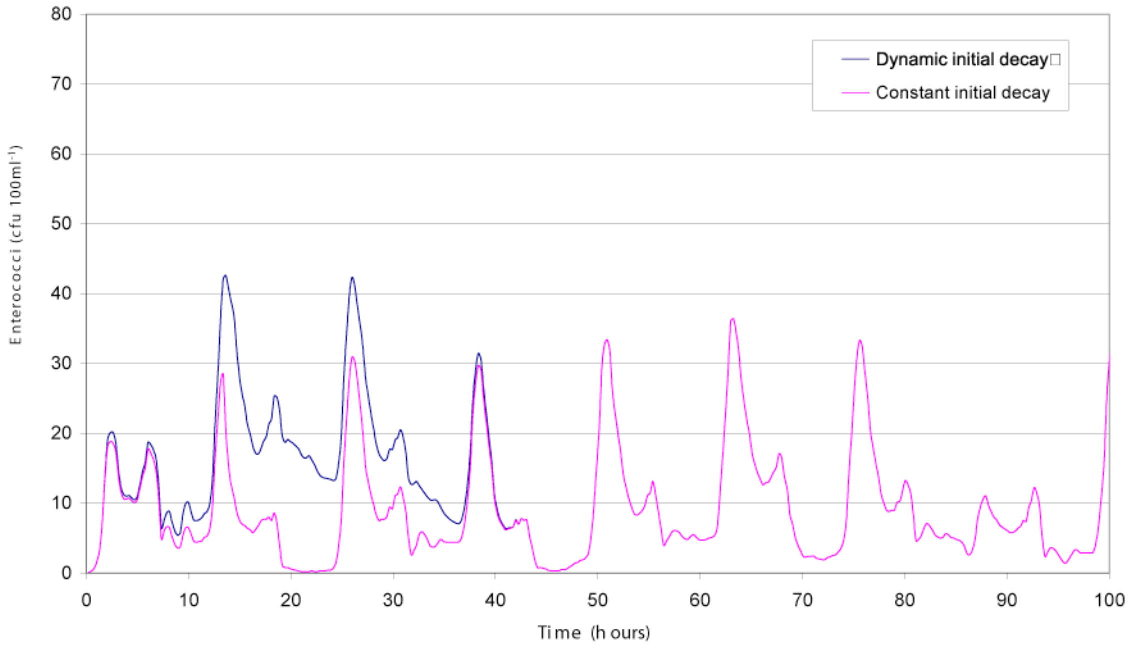


Figure 8.13 Comparison of predicted enterococci concentrations (cfu 100ml^{-1}) at Swansea Bay bathing water compliance monitoring point (model site 12) using a dynamic initial decay rate and a constant initial decay rate

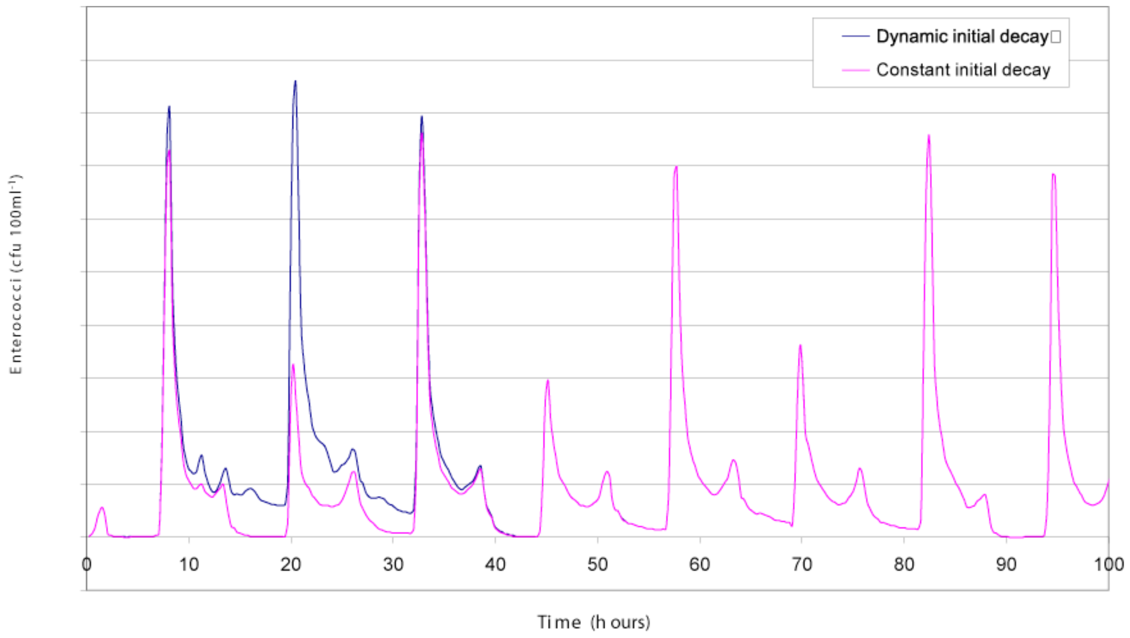


Figure 8.14 Comparison of predicted enterococci concentrations (cfu 100ml^{-1}) at Southerndown bathing water compliance monitoring point (model site 17) using a dynamic initial decay rate and a constant initial decay rate

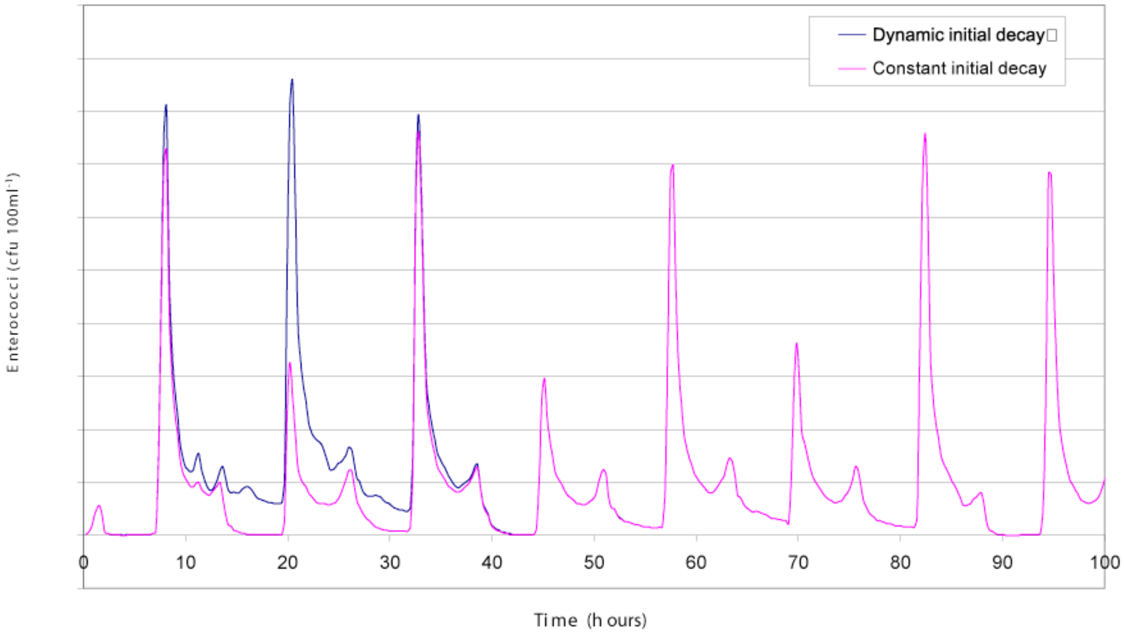


Figure 8.15 Comparison of predicted enterococci concentrations (cfu 100ml^{-1}) at Weston-Super-Mare Sand Bay bathing water compliance monitoring point (model site 1) using different bed sediment enterococci concentrations

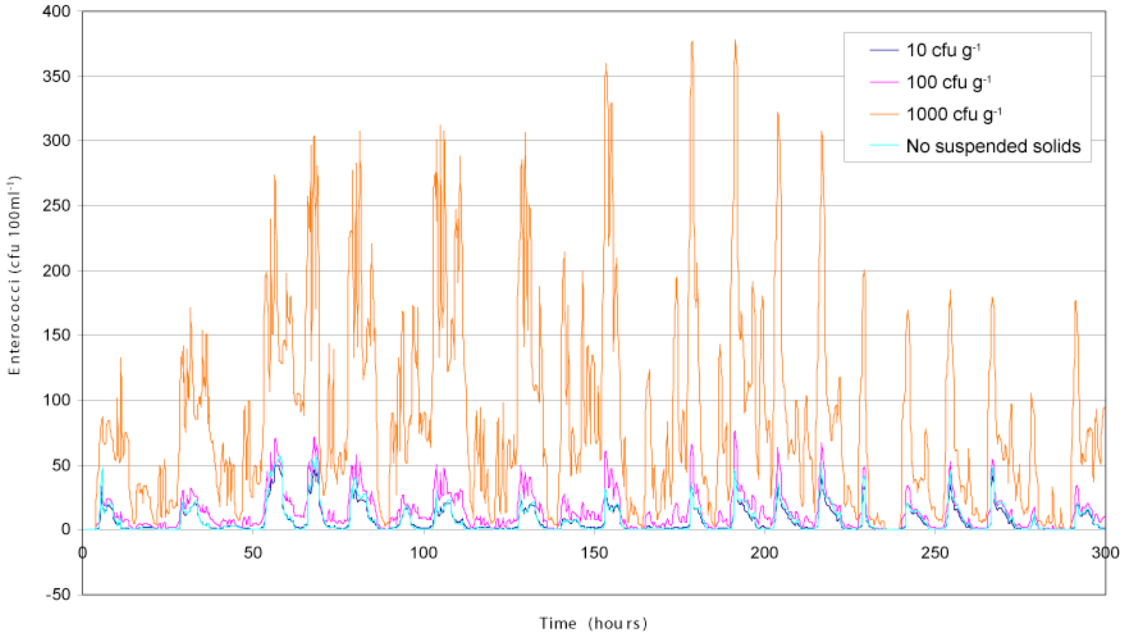


Figure 8.16 Comparison of predicted enterococci concentrations (cfu 100ml^{-1}) at Swansea Bay bathing water compliance monitoring point (model site 12) using different bed sediment enterococci concentrations

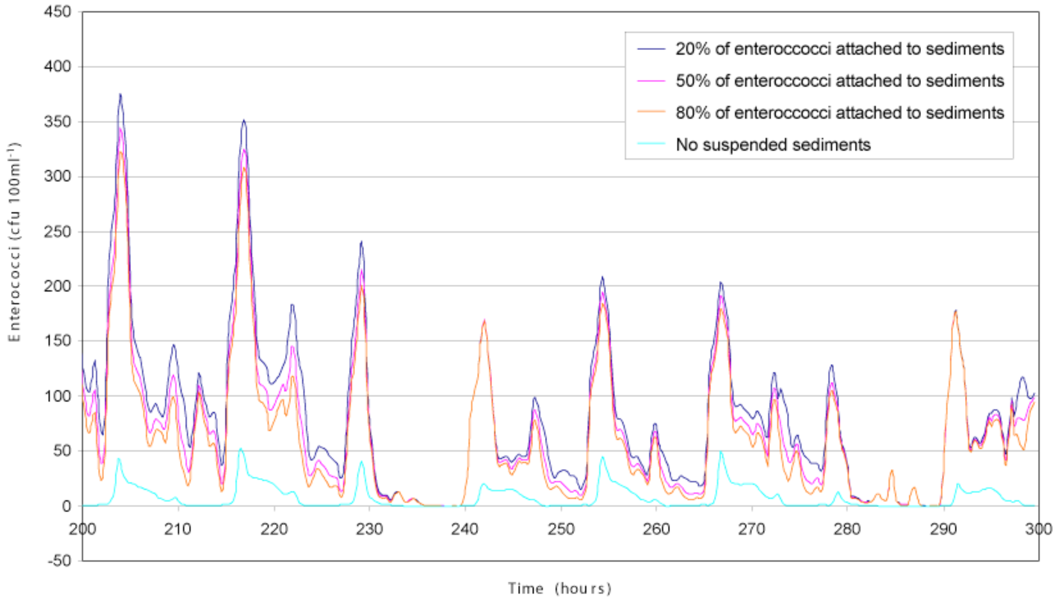


Figure 8.17 Comparison of predicted enterococci concentrations (cfu 100ml^{-1}) at Weston-Super-Mare Sand Bay bathing water compliance monitoring point (model site 1) using different proportions of enterococci attached to sediments

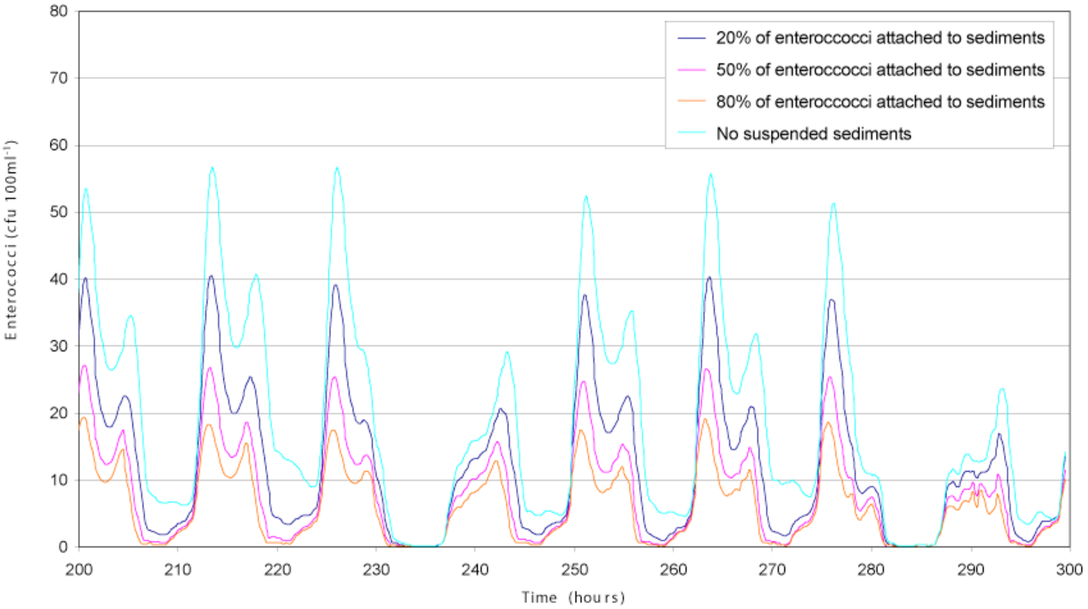


Figure 8.18 Comparison of predicted enterococci concentrations (cfu 100ml^{-1}) at Swansea Bay bathing water compliance monitoring point (model site 1) using different proportions of enterococci attached to sediments

Appendix I:
Calibration field survey data.

Water Quality Results **Survey 1 - Porthcawl** **24/7/01**

Site	Grid Reference	Lat. Long.	Description
Site 1: Offshore CSV	SS 8600 7200	51° 26.102 N 3° 38.414 W	Surface Samples (1m depth)
Site 2: Offshore CSV	SS 8604 7200	51° 26.102 N 3° 38.414 W	Sub-surface Samples taken at depth indicated
Site 3: Offshore Rib		51° 26.796 N 3° 40.617 W	Surface Samples (1m depth)
Site 4: Trecco Bay BW	SS 8310 7630		Bathing Water Samples
Site 5: Southerndown	SS 8840 7290		Bathing Water Samples
Site 6: Afon Ogwr	SS 8830 7730		River Water Samples
Site 7: Afon Ewenni	SS 8940 7720		River Water Samples
Site 8: Pen-y-Bont WwTW	SS 8760 7670		Secondary treated sewage final effluent

Sample No.	Sample Time	pH	Temp °C	Presumptive Enterococci cfu 100ml	Confirmed Enterococci cfu 100ml	Conductivity mS cm^{-1}	Turbidity NTU	Suspended solids mg L^{-1}	Total dis. Solids mg L^{-1}	Practical salinity	Cloud Cover oktas	Tide m ACD	Water Depth m	Depth of Sample m
Site 1 A	24/7/01 6:25	7.8		1	1	54.400	10	42.37	38080.0	46.34	3	4.45	18.8	1.0
Site 1 B	24/7/01 7:00	7.86		1	1	54.400	15	52.89	38080.0	46.34	3	5.63	19.8	1.0
Site 1 C	24/7/01 8:15	7.84		<1	<1	55.800	10	46.41	39060.0	47.71	3	8.57	20.8	1.0
Site 1 D	24/7/01 9:05	7.83		1	<1	55.100	12	45.66	38570.0	47.03	3	9.75	20.6	1.0
Site 1 E	24/7/01 10:14	7.78		<1	<1	55.300	13	48.87	38710.0	47.22	3	9.98	20.6	1.0
Site 1 F	24/7/01 11:00	7.79		<1	<1	55.700	11	42.97	38990.0	47.61	2	9.30	19.5	1.0
Site 1 G	24/7/01 12:00	7.79		<1	<1	55.600	5	25.75	38920.0	47.51	4	7.40	17.8	1.0
Site 1 H	24/7/01 12:57	7.82		2	2	54.900	14	56.09	38430.0	46.83	4	4.97	15.7	1.0
Site 1 I	24/7/01 14:00	7.75		<1	<1	54.900	9	40.87	38430.0	46.83		2.72		1.0
Site 1 J	24/7/01 15:00	7.67		<1	<1	54.300	11	44.89	38010.0	46.24	1	1.21	11.7	1.0
Site 1 K	24/7/01 16:00	7.73		<1	<1	53.800	8	32.54	37660.0	45.76	0	0.74	11.3	1.0
Site 1 L	24/7/01 17:00	7.74		1	<1	53.600	8	36.44	37520.0	45.56	0	1.34	11.9	1.0
Site 1 M	24/7/01 18:00	7.75		<1	<1	54.500	10	40.98	38150.0	46.44	3	2.87	13.6	1.0
Site 1 O	24/7/01 18:29	7.74		<1	<1	54.600	14	45.83	38220.0	46.54	1	3.90	14.5	1.0
Site 2 B	24/7/01 7:13	7.84		4	3	55.400	15	55.11	38780.0	47.32	3	6.42	18.8	10.0
Site 2 L	24/7/01 17:00	7.81		<1	<1	54.000	9	35.29	37800.0	45.95	0	1.34	11.7	7.2
Site 2 M	24/7/01 18:15	7.78		<1	<1	54.800	11	49.74	38360.0	46.73	2	3.54	13.6	8.1
Site 3 C	24/7/01 8:00	7.85	16.64	<1	<1	54.700	10	42.49	38290.0	46.63	8	7.91	18.5	1.0
Site 3 D	24/7/01 8:30	7.82	16.89	<1	<1	56.300	10	42.89	39410.0	48.2	8	8.88	19.4	1.0
Site 3 E	24/7/01 9:00	7.67	16.89	<1	<1	55.000	9	37.67	38500.0	46.93	8	9.58	17.5	1.0
Site 3 F	24/7/01 9:30	7.76	17.23	1	1	55.600	10	35.89	38920.0	47.51	3	10.00	20.0	1.0
Site 3 G	24/7/01 10:06	7.78	17.18	<1	<1	55.500	10	36.94	38850.0	47.42	3	10.06	20.0	1.0
Site 3 H	24/7/01 10:30	7.56	17.27	<1	<1	55.700	8	36.56	38990.0	47.61	3	9.87		1.0
Site 3 I	24/7/01 11:00	7.7	17.00	1	1	55.400	9	35.00	38780.0	47.32	2	9.30		1.0
Site 3 J	24/7/01 11:30	7.58	18.10	<1	<1	55.300	5	32.15	38710.0	47.22		8.46	19.0	1.0
Site 3 A	24/7/01 12:00	7.63	18.06	1	1	55.400	8	37.53	38780.0	47.32		7.40	18.0	1.0
Site 3 B	24/7/01 12:30	7.83	18.84	<1	<1	55.100	11	45.16	38570.0	47.03		6.21	16.5	1.0
Site 3 K	24/7/01 13:05	7.58	18.10	1	1	54.800	12	54.53	38360.0	46.73	3	4.57	15.5	1.0
Site 3 L	24/7/01 13:30	7.8	17.76	2	2	54.900	13	51.24	38430.0	46.83	3	3.78	14.0	1.0
Site 3 M	24/7/01 14:00	7.76	17.71	2	2	54.900	11	48.85	38430.0	46.83	3	2.72	13.0	1.0
Site 3 N	24/7/01 14:30	7.7	18.15	<1	<1	54.000	10	40.87	37800.0	45.95	1	1.85	12.5	1.0
Site 3 O	24/7/01 15:00	7.66	17.76	<1	<1	54.400	7	37.61	38080.0	46.34	1	1.21	11.5	1.0
Site 3 P	24/7/01 15:30	7.79	17.76	<1	<1	54.400	6	38.88	38080.0	46.34	1	0.84	11.0	1.0
Site 3 Q	24/7/01 16:00	7.82	17.96	<1	<1	54.800	6	31.65	38360.0	46.73	1	0.74	11.5	1.0
Site 3 R	24/7/01 16:30	7.72	18.25	1	1	54.600	5	34.16	38220.0	46.54	1	0.91	11.5	1.0
Site 3 S	24/7/01 17:00	7.71	17.86	1	1	54.400	8	35.83	38080.0	46.34	1	1.34	12.0	1.0
Site 3 T	24/7/01 17:30	7.74	17.71	<1	<1	54.900	5	25.73	38430.0	46.83	1	2.01	13.0	1.0
Site 3 U	24/7/01 18:00	7.77	17.66	1	1	54.900	6	32.09	38430.0	46.83	1	2.87	13.5	1.0
Site 3 V	24/7/01 18:30	7.75	17.37	<1	<1	54.600	10	47.84	38220.0	46.54	1	3.90	14.5	1.0
Site 4 A	24/7/01 6:30	7.87	17.00	20	16	54.800	20	114.25	38360.0	46.73	4	4.45		1.0
Site 4 C	24/7/01 8:00	7.81	17.50	21	17	54.600	11	88.47	38220.0	46.54	5	7.91		1.0
Site 4 D	24/7/01 9:30	7.69	17.00	35	29	53.600	12	66.93	37520.0	45.56	5	10.00		1.0
Site 4 E	24/7/01 10:30	7.68	17.50	20	17	55.000	11	73.14	38500.0	46.93	4	9.87		1.0
Site 4 F	24/7/01 11:30	7.87	17.00	9	2	54.500	11	42.77	38150.0	46.44	4	8.46		1.0
Site 4 G	24/7/01 12:30	7.84	17.80	39	33	55.100	18	85.85	38570.0	47.03	4	6.21		1.0
Site 4 H	24/7/01 13:30	7.67	18.50	15	2	54.800	40	250.46	38360.0	46.73	4	3.78		1.0
Site 4 I	24/7/01 14:20	7.75	18.50	13	12	54.500	28	125.63	38150.0	46.44	1	2.11		1.0
Site 4 J	24/7/01 15:30	7.77	18.00	27	9	55.200	27	78.50	38640.0	47.12	1	0.84		1.0
Site 4 K	24/7/01 16:30	7.82	19.00	9	5	53.900	70	238.46	37730.0	45.86	1	0.91		1.0
Site 4 L	24/7/01 17:30	7.83	19.00	5	3	53.500	25	104.05	37450.0	45.47	1	2.01		1.0
Site 4 M	24/7/01 18:30	7.87	19.00	7	4	54.800	21	118.08	38360.0	46.73	1	3.90		1.0
Site 5 A	24/7/01 6:30	7.76	17.00	17	14	54.700	26	230.00	38290.0	46.63	4	4.45		1.0
Site 5 B	24/7/01 7:30	7.64	17.50	85	45	54.200	18	82.16	37940.0	46.15	6	6.81		1.0
Site 5 C	24/7/01 8:30	7.9	17.00	65	57	54.200	16	192.21	37940.0	46.15	6	8.88		1.0
Site 5 D	24/7/01 9:29	7.88	17.50	71	47	54.400	17	95.13	38080.0	46.34	5	10.00		1.0
Site 5 E	24/7/01 10:30	7.85	17.50	62	52	53.900	15	66.82	37730.0	45.86	4	9.87		1.0
Site 5 F	24/7/01 11:30	7.76	18.00	35	11	53.700	17	66.13	37590.0	45.66	5	8.46		1.0
Site 5 G	24/7/01 12:30	7.77	18.00	19	18	53.900	16	81.52	37730.0	45.86	4	6.21		1.0
Site 5 H	24/7/01 13:30	7.84	19.00	17	16	54.800	24	93.41	38360.0	46.73	4	3.78		1.0
Site 5 I	24/7/01 14:30	7.78	19.00	6	4	54.300	69	321.86	38010.0	46.24	1	1.85		1.0
Site 5 J	24/7/01 15:30	7.84	19.00	5	5	54.100	65	252.18	37870.0	46.05	0	0.84		1.0
Site 5 K	24/7/01 16:30	7.74	19.50	6	6	53.900	58	333.19	37730.0	45.86	0	0.91		1.0
Site 5 L	24/7/01 17:30	7.75	18.50	6	4	54.000	29	135.03	37800.0	45.95	0	2.01		1.0
Site 5 M	24/7/01 18:30	7.77	19.00	13	6	54.700	17	141.12	38290.0	46.63	1	3.90		1.0
Site 6 1	24/7/01 0:45	7.99	16.00	210	150	0.244	3	0.94	170.8	0.15	0	4.58		Surface
Site 6 2	24/7/01 1:45	7.83	16.00	540	180	0.240	<1	0.67	168.0	0.14	0	2.34		Surface
Site 6 3	24/7/01 2:30	7.68	15.00	200	120	0.242	<1	1.57	169.4	0.15	0	1.28		Surface
Site 6 4	24/7/01 3:33	7.75	15.00	410	150	0.233	1	0.69	163.1	0.14	0	0.57		Surface
Site 6 5	24/7/01 4:35	7.65	15.00	290	170	0.248	1	1.82	173.6	0.15	5	1.14		Surface
Site 6 6	24/7/01 5:40	7.66	15.00	500	200	0.248	1	2.13	173.6	0.15	3	2.67		Surface
Site 6 A	24/7/01 6:20	7.6		600	230	0.245	1	3.54	171.5	0.15	4	4.07		Surface
Site 6 B	24/7/01 7:10	7.76		400	330	0.244	1	1.49	170.8	0.15	6	6.03		Surface
Site 6 C	24/7/01 8:00	7.82	18.80	250	210	0.249	1	6.00	174.3	0.15	7	7.91		Surface
Site 6 D	24/7/01 9:50	7.8	17.40	220	180	0.241	2	18.43	168.7	0.15	6	10.11		Surface
Site 6 E	24/7/01 11:15	8.07	16.00	300	270	0.245	3	19.88	171.5	0.15	4	8.77		Surface
Site 6 F	24/7/01 11:45	8.08	17.00	270	220	0.243	2	4.61	170.1	0.15	5	7.70		Surface
Site 6 G	24/7/01 12:58	8.3	17.00	124	124	0.243	1	4.21	170.1	0.15	3	4.97		Surface
Site 6 H	24/7/01 14:00	8.57	16.00	118	71	0.241	1	2.80	168.7	0.15	2	2.72		Surface
Site 6 I	24/7/01 14:45	8.4	17.80	94	63	0.239	1	4.44	167.3	0.14	2	1.39		Surface
Site 6 K	24/7/01 15:40	8.74	17.00	299	154	0.243	3	9.34	170.1	0.15	1	0.77		Surface
Site 6 L	24/7/01 16:33	8.81	18.00	117	53	0.241	2	9.88	168.7	0.15	1	1.02		Surface
Site 6 M	24/7/01 17:32	8.52	17.40	92	69	0.241	1	4.83	168.7	0.15	1	2.27		Surface
Site 6 N	24/7/01 18:18	8.19	21.90	300	210	0.242	5	47.74	169.4	0.15	1	3.54		Surface
Site 7 1	24/7/01 0:55	7.76	14.00	1600	340	0.483	1	4.11	338.1	0.29	0	4.17		Surface
Site 7 2	24/7/01 1:57	7.64	13.00	1500	310	0.500	1	6.70	350.0	0.3	0	2.04		Surface
Site 7 3	24/7/01 2:40	7.6	13.00	1470	230	0.510	1	2.99	357.0	0.31	0	1.09		Surface
Site 7 4	24/7/01 3:45	7.6	13.00	1600	390	0.499	<1	2.39	349.3	0.3	0	0.59		Surface

Sample No.	Sample Time	pH	Temp °C	Presumptive Enterococci cfu 100ml	Confirmed Enterococci cfu 100ml	Conductivity mS cm^{-1}	Turbidity NTU	Suspended solids mg L^{-1}	Total dis. Solids mg L^{-1}	Practical salinity	Cloud Cover oktas	Tide m ACD	Water Depth m	Depth of Sample m
Site 7 5	24/7/01 4:46	7.55	12.00	1030	250	0.510	<1	2.57	357.0	0.31	5	1.33		Surface
Site 7 6	24/7/01 5:50	7.65	12.00	1080	230	0.500	<1	3.05	350.0	0.3	3	2.99		Surface
Site 7 A	24/7/01 6:36	7.64		790	140	0.506	<1	3.03	354.2	0.31	6	4.84		Surface
Site 7 B	24/7/01 7:10	7.73	14.80	530	150	0.517	<1	2.71	361.9	0.31	6	6.03		Surface
Site 7 C	24/7/01 8:10	7.61	13.00	400	290	0.511	<1	3.33	357.7	0.31	7	8.25		Surface
Site 7 D	24/7/01 9:33	7.61	14.00	230	120	0.521	<1	4.84	364.7	0.32	7	10.08		Surface
Site 7 F	24/7/01 11:10	7.66	14.60	125	109	0.506	<1	3.19	354.2	0.31	4	9.05		Surface
Site 7 G	24/7/01 11:40	7.62	20.90	119	119	0.522	<1	1.65	365.4	0.32	5	8.12		Surface
Site 7 H	24/7/01 12:50	7.8	15.00	136	136	0.515	<1	2.39	360.5	0.31	4	5.38		Surface
Site 7 I	24/7/01 14:25	8.02	17.10	208	198	0.514	1	3.50	359.8	0.31	2	1.85		Surface
Site 7 J	24/7/01 14:55	8	17.60	183	166	0.507	1	3.89	354.9	0.31	1	1.21		Surface
Site 7 L	24/7/01 15:50	7.95	17.40	281	274	0.490	1	4.53	343.0	0.3	1	0.74		Surface
Site 7 K	24/7/01 16:40	8.07	18.10	142	142	0.499	1	2.91	349.3	0.3	1	1.02		Surface
Site 7 M	24/7/01 17:47	7.95	18.80	122	106	0.506	<1	2.73	354.2	0.31	1	2.56		Surface
Site 7 N	24/7/01 18:28	7.86	18.40	119	99	0.510	1	2.92	357.0	0.31	1	3.90		Surface
Site 8 1	24/7/01 1:15	7.4		162000	61000	0.788	5	11.82	551.6	0.49	0	3.39		Surface
Site 8 2	24/7/01 2:10	7.4		224000	66000	0.850	3	6.36	595.0	0.53	0	1.76		Surface
Site 8 3	24/7/01 2:50	7.36		169000	41000	0.839	3	4.94	587.3	0.52	0	0.93		Surface
Site 8 4	24/7/01 4:02	7.41		214000	49000	0.815	3	6.30	570.5	0.5	0	0.72		Surface
Site 8 5	24/7/01 4:58	7.44		80000	26000	0.856	2	6.55	599.2	0.53	5	1.56		Surface
Site 8 6	24/7/01 6:43	7.33		123000	33000	0.877	3	4.35	613.9	0.54	6	5.23		Surface
Site 8 A	24/7/01 7:30	7.44		140000	81000	0.869	3	4.72	608.3	0.54	6	6.81		Surface
Site 8 B	24/7/01 8:25	7.5		68000	21000	0.924	3	2.86	646.8	0.57	7	8.88		Surface
Site 8 C	24/7/01 11:05	7.39		50000	17000	0.862	1	7.03	603.4	0.53	5	9.05		Surface
Site 8 D	24/7/01 11:30	7.36		24000	12200	0.854	1	5.81	597.8	0.53	4	8.46		Surface
Site 8 E	24/7/01 12:40	7.34		43000	18000	0.836	2	3.40	585.2	0.52	4	5.79		Surface
Site 8 F	24/7/01 14:20	7.48		51000	11000	0.796	1	4.95	557.2	0.49	2	2.11		Surface
Site 8 G	24/7/01 15:20	7.54		61000	9000	0.782	2	6.46	547.4	0.48	1	0.93		Surface
Site 8 H	24/7/01 16:00	7.5		57000	7000	0.786	1	4.77	550.2	0.48	1	0.74		Surface
Site 8 I	24/7/01 17:07	7.48		12000	9000	0.793	2	5.00	555.1	0.49	1	1.54		Surface
Site 8 J	24/7/01 17:58	7.31		18000	5000	0.813	2	4.71	569.1	0.5	1	2.87		Surface
Site 8 K	24/7/01 18:38	7.33		83000	41000	0.824	2	6.16	576.8	0.51	1	4.27		Surface

Sediment Particle Size Results **Survey 1 - Porthcawl** **24/7/01**

Site	Grid Reference	Lat. Long.	Description
Site 1: Offshore CSV	SS 8600 7200	51° 26.102 N 3° 38.414 W	Surface Samples (1m depth)
Site 2: Offshore CSV	SS 8604 7200	51° 26.102 N 3° 38.414 W	Sub-surface Samples taken at depth indicated
Site 3: Offshore Rib		51° 26.796 N 3° 40.617 W	Surface Samples (1m depth)
Site 4: Trecco Bay BW	SS 8310 7630		Bathing Water Samples
Site 5: Southerndown	SS 8840 7290		Bathing Water Samples
Site 6: Afon Ogwr	SS 8830 7730		River Water Samples
Site 7: Afon Ewenni	SS 8940 7720		River Water Samples
Site 8: Pen-y-Bont WwTW	SS 8760 7670		Secondary treated sewage final effluent

	Site 1 D	Site 1 G	Site 1 K	Site 1 O	Site 2 L	Site 2 M	Site 3 V	Site 4 Da	Site 4 Db	Site 4 G	Site 4 J	Site 4 M	Site 5 D	Site 5 G	Site 5 J	Site 5 A	Site 5 B	Site 5 M	Site 6 D	Site 7 D
Mean:	12.28	8.93	10.64	24.82	21.08	14.25	21.11	12.39	13.62	16.85	13.40	36.21	24.87	16.88	22.94	18.21	14.22	14.48	71.90	37.64
Median:	9.90	7.91	9.25	15.13	12.53	9.97	16.03	7.52	10.78	13.24	10.79	13.15	21.09	12.36	17.34	14.34	11.43	10.21	45.41	27.73
D(3,4):	12.28	8.93	10.64	24.82	21.08	14.25	21.11	12.39	13.62	16.85	13.40	36.21	24.87	16.88	22.94	18.21	14.22	14.48	71.90	37.64
Mean/Median Ratio:	1.24	1.13	1.15	1.64	1.68	1.43	1.32	1.65	1.26	1.27	1.24	2.75	1.18	1.37	1.32	1.27	1.24	1.42	1.58	1.36
Mode:	13.61	14.94	8.54	18.00	13.61	13.61	16.40	13.61	6.45	18.00	10.29	16.40	23.81	14.94	19.76	16.40	13.61	10.29	50.23	37.96
S.D.:	9.37	4.81	6.62	40.18	39.27	16.46	21.61	12.77	10.70	13.29	10.49	66.45	17.59	14.87	24.44	14.73	10.88	13.97	71.44	33.06
Variance:	87.76	23.16	43.83	1615.00	1542.00	270.90	467.10	163.10	114.50	176.60	110.10	4416.00	309.30	221.20	597.30	217.00	118.50	195.30	5103.00	1093.00
C.V.:	76.31	53.92	62.21	161.90	186.30	115.50	102.40	103.00	78.60	78.89	78.26	183.50	70.71	88.11	106.50	80.87	76.57	96.49	99.36	87.81
Skewness:	1.39	0.47	0.60	5.20	5.26	4.29	3.81	1.89	1.27	1.21	1.59	2.84	0.91	1.57	5.02	1.36	1.24	2.08	1.66	1.46
Kurtosis:	2.09	-0.81	-0.50	33.01	29.53	26.50	20.92	3.10	1.06	1.00	3.32	6.78	0.32	2.18	44.95	1.82	1.32	4.71	2.09	1.62
d10:	2.79	3.00	2.94	4.23	4.18	2.76	4.49	2.56	2.89	3.35	2.96	3.10	4.76	3.11	4.52	3.54	3.14	2.78	13.74	6.21
d50:	9.90	7.91	9.25	15.13	12.53	9.97	16.03	7.52	10.78	13.24	10.79	13.15	21.09	12.36	17.34	14.34	11.43	10.21	45.41	27.73
d90:	25.18	16.12	20.96	42.85	30.10	28.29	40.03	31.14	28.56	36.51	27.08	73.19	50.84	39.36	44.94	39.24	30.29	31.30	173.10	78.86
Specific Surf. Area:	11954.00	10014.00	11777.00	15358.00	8858.00	12266.00	8380.00	13716.00	9824.00	10092.00	11553.00	10280.00	7157.00	10563.00	13335.00	15945.00	12738.00	12199.00	3370.00	7372.00
% <	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size
5	1.48	2.44	1.65	1.69	2.13	1.45	2.41	1.87	2.21	1.90	1.72	2.00	2.71	1.96	1.96	1.52	1.61	1.44	7.56	3.25
16	4.07	3.78	4.14	6.12	5.72	3.99	6.43	3.08	4.51	4.99	4.20	4.43	8.19	4.44	6.67	5.26	4.48	3.97	17.77	9.61
25	5.61	5.17	5.51	8.53	7.60	5.57	9.03	4.04	5.83	7.04	6.06	6.73	11.74	6.69	9.50	7.57	6.25	5.60	23.24	15.11
84	20.46	14.94	18.36	31.85	23.95	22.18	32.36	23.16	22.78	29.37	22.32	43.88	43.47	29.11	36.33	31.54	24.37	24.04	132.90	68.88
95	32.00	17.31	23.37	77.43	45.03	38.86	52.16	46.39	38.69	46.84	33.56	242.30	61.26	51.33	59.04	49.81	37.62	46.73	258.90	118.40
Size	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <
1	3.39	0.45	2.83	4.04	2.13	3.79	2.37	4.69	1.76	3.11	3.68	3.57	2.56	3.45	3.53	4.03	3.45	3.72	0.95	1.68
10	50.50	64.60	54.00	30.70	37.40	50.10	28.30	59.20	48.00	38.20	46.10	39.90	20.40	40.30	26.60	34.50	43.60	49.00	6.58	16.40
100	100.00	100.00	100.00	96.10	96.50	99.30	98.60	100.00	100.00	100.00	100.00	91.80	100.00	100.00	98.60	100.00	100.00	100.00	76.80	91.90
1000	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Particle Diameter (μm)	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <
0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	6.85	1.90	6.29	5.40	4.74	6.79	4.05	5.41	3.56	5.31	5.81	5.01	3.41	5.11	5.06	5.94	6.06	6.78	1.62	2.86
3.9	15.10	16.80	14.70	9.12	9.13	15.50	8.50	23.90	13.90	11.90	14.60	13.80	8.21	13.70	8.54	11.20	13.30	15.60	2.85	5.94
7.8	38.60	49.00	41.20	22.20	26.00	38.50	20.70	51.40	40.40	28.50	34.30	29.90	15.20	30.00	19.50	25.90	32.90	37.50	5.14	13.40
15.6	72.70	87.60	76.70	51.60	63.30	71.40	48.50	78.90	67.80	57.10	68.50	56.60	36.10	61.00	44.80	54.00	65.50	69.80	12.50	26.30
53	99.90	100.00	100.00	92.50	95.90	97.40	95.20	98.00	99.99	97.80	99.30	87.00	91.40	95.70	93.40	96.10	99.70	96.30	56.30	76.40
105	100.00	100.00	100.00	96.30	96.60	99.40	98.70	100.00	100.00	100.00	100.00	91.80	100.00	100.00	98.70	100.00	100.00	100.00	78.10	92.40
210	100.00	100.00	100.00	98.70	98.30	100.00	99.99	100.00	100.00	100.00	100.00	92.30	100.00	100.00	99.70	100.00	100.00	100.00	92.50	100.00
420	100.00	100.00	100.00	99.98	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
840	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1680	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Sediment Particle Size Results **Survey 1 - Porthcawl** **24/7/01**

Site	Grid Reference	Lat. Long.	Description
Site 1: Offshore CSV	**SS 8600 7200**	**51° 26.102 N 3° 38.414 W**	**Surface Samples (1m depth)**
Site 2: Offshore CSV	**SS 8604 7200**	**51° 26.102 N 3° 38.414 W**	**Sub-surface Samples taken at depth indicated**
Site 3: Offshore Rib		**51° 26.796 N 3° 40.617 W**	**Surface Samples (1m depth)**
Site 4: Trecco Bay BW	**SS 8310 7630**		**Bathing Water Samples**
Site 5: Southerndown	**SS 8840 7290**		**Bathing Water Samples**
Site 6: Afon Ogwr	**SS 8830 7730**		**River Water Samples**
Site 7: Afon Ewenni	**SS 8940 7720**		**River Water Samples**
Site 8: Pen-y-Bont WwTW	**SS 8760 7670**		**Secondary treated sewage final effluent**

	Site 7 J	**Site 8 4**	**Site 8 D**	**Site 8 J**
Mean:	58.25	93.61	104.50	83.10
Median:	34.89	86.35	85.17	78.70
D(3,4):	58.25	93.61	104.50	83.10
Mean/Median Ratio:	1.67	1.08	1.23	1.06
Mode:	31.50	116.30	96.49	96.49
S.D.:	57.47	59.55	98.32	48.35
Variance:	3303.00	3546.00	9666.00	2338.00
C.V.:	98.68	63.61	94.09	58.19
Skewness:	1.73	0.90	3.91	0.48
Kurtosis:	2.65	1.12	21.50	-0.23
d10:	11.60	22.87	27.42	21.36
d50:	34.89	86.35	85.17	78.70
d90:	142.20	170.70	177.70	150.20
Specific Surf. Area:	3645.00	1963.00	1656.00	2924.00
% <	Size	Size	Size	Size
5	5.98	13.35	15.56	11.52
16	15.99	33.19	38.80	32.05
25	20.05	48.29	52.50	46.14
84	110.40	150.30	151.40	133.30
95	184.80	199.90	231.50	171.10
Size	% <	% <	% <	% <
1	0.69	0.43	0.24	0.52
10	8.57	3.58	3.16	4.26
100	81.70	58.90	60.40	65.70
1000	100.00	100.00	99.99	100.00
Particle Diameter (μm)	Volume % <	Volume % <	Volume % <	Volume % <
0.04	0.00	0.00	0.00	0.00
2	1.70	0.61	0.52	0.74
3.9	3.20	1.37	1.11	1.39
7.8	6.53	2.74	2.43	3.19
15.6	15.20	6.06	5.01	7.01
53	64.00	28.00	25.40	29.90
105	82.80	61.90	63.50	69.00
210	95.90	96.00	93.70	99.10
420	100.00	100.00	98.00	100.00
840	100.00	100.00	99.80	100.00
1680	100.00	100.00	100.00	100.00

Water Quality Results **Survey 2 - Porthcawl** **26/7/01**

Site	Grid Reference	Lat. Long.	Description
Site 1: Offshore CSV	SS 8604 7200	51˚ 26.103 N 3˚ 38.375 W	Surface Samples (1m depth)
Site 2: Offshore CSV	SS 8604 7200	51˚ 26.103 N 3˚ 38.375 W	Sub-surface Samples taken at depth indicated
Site 3: Offshore Rib		51˚ 26.797 N 3˚ 40.659 W	Surface Samples (1m depth)
Site 4: Trecco Bay BW	SS 8310 7630		Bathing Water Samples
Site 5: Southerndown BW	SS 8840 7290		Bathing Water Samples
Site 6: Afon Ogwr	SS 8830 7730		River Water Samples
Site 7: Afon Ewenni	SS 8940 7720		River Water Samples
Site 8: Pen-y-Bont WwTW	SS 8760 7670		Secondary treated sewage final effluent

Sample No.	Sample Time	pH	Temp ˚C	Presumptive Enterococci cfu 100ml	Confirmed Enterococci cfu 100ml	Conductivity mS cm^{-1}	Turbidity NTU	Suspended solids mg L^{-1}	Total dis. Solids mg L^{-1}	Practical salinity	Cloud Cover oktas	Tide m ACD	Water Depth m	Depth of Sample m
Site 1 A	26/7/01 6:30	7.9		2	1	54.400	5	30.00	38080.0	46.34	6	2.02	14.0	1.0
Site 1 B	26/7/01 7:00	7.92		<1	<1	54.600	5	21.98	38220.0	46.54	6	2.73	15.0	1.0
Site 1 C	26/7/01 8:00	7.8		<1	<1	55.800	10	42.55	39060.0	47.71	5	4.56	16.0	1.0
Site 1 D	26/7/01 8:30	7.75		<1	<1	55.000	11	42.70	38500.0	46.93	5	5.58	16.2	1.0
Site 1 E	26/7/01 9:30	7.89		1	1	55.000	12	44.39	38500.0	46.93	2	7.54	18.1	1.0
Site 1 F	26/7/01 10:30	7.87		1	<1	55.100	10	40.23	38570.0	47.03	2	8.97	19.3	1.0
Site 1 G	26/7/01 11:30	7.85		<1	<1	55.000	7	30.00	38500.0	46.93	3	9.42	19.9	1.0
Site 1 H	26/7/01 12:30	7.87		1	1	55.100	5	19.78	38570.0	47.03	2	8.74	21.0	1.0
Site 1 I	26/7/01 13:30	7.82		<1	<1	54.800	4	23.15	38360.0	46.73	2	7.13	20.0	1.0
Site 1 J	26/7/01 14:30	7.82		1	1	54.400	10	40.00	38080.0	46.34	4	5.07	18.3	1.0
Site 1 K	26/7/01 15:30	7.78		<1	<1	55.000	10	34.76	38500.0	46.93	6	3.17	13.6	1.0
Site 1 L	26/7/01 16:30	7.61		<1	<1	54.600	8	30.22	38220.0	46.54	5	1.90	12.3	1.0
Site 1 M	26/7/01 17:30	7.81		<1	<1	53.700	8	33.52	37590.0	45.66	7	1.50	12.3	1.0
Site 1 N	26/7/01 18:30	7.83		1	1	53.900	6	21.20	37730.0	45.86	7	2.00	14.3	1.0
Site 2 A	26/7/01 6:30	7.79		<1	<1	54.200	7	29.11	37940.0	46.15	6	2.02	30.0	8.0
Site 2 B	26/7/01 7:00	7.91		2	1	54.200	8	35.23	37940.0	46.15	6	2.73	22.0	5.0
Site 2 C	26/7/01 8:00	7.88		<1	<1	55.100	9	35.68	38570.0	47.03	5	4.56	42.6	5.0
Site 2 G	26/7/01 11:30	7.88		1	<1	56.100	7	29.70	39270.0	48.00	3	9.42	30.0	
Site 2 H	26/7/01 12:30	7.84		<1	<1	55.600	7	34.89	38920.0	47.51	2	8.74	19.8	12.0
Site 2 L	26/7/01 16:30	7.81		<1	<1	54.700	10	37.36	38290.0	46.63	5	1.90	30.2	7.4
Site 2 M	26/7/01 17:30	7.22		<1	<1	54.500	8	32.93	38150.0	46.44	7	1.50	33.5	7.4
Site 2 N	26/7/01 18:30	7.84		<1	<1	54.400	6	32.86	38080.0	46.34	7	2.00	21.2	8.0
Site 3 A	26/7/01 6:30	7.88	17.42	3	3	55.000	6	28.60	38500.0	46.93	6	2.02		1.0
Site 3 B	26/7/01 7:00	7.85	17.37	<1	<1	55.100	6	28.91	38570.0	47.03	6	2.73		1.0
Site 3 C	26/7/01 7:30	7.83	17.32	1	1	55.700	10	38.91	38990.0	47.61	7	3.59		1.0
Site 3 D	26/7/01 8:00	7.86	17.47	2	2	55.200	10	49.51	38640.0	47.12	2	4.56	15.5	1.0
Site 3 E	26/7/01 8:30	7.9	17.47	<1	<1	55.000	11	47.30	38500.0	46.93	6	5.58	16.0	1.0
Site 3 F	26/7/01 9:00	7.83	17.18	1	1	55.400	11	44.64	38780.0	47.32	3	6.60	17.0	1.0
Site 3 G	26/7/01 9:30	7.87	17.34	2	2	55.400	11	47.28	38780.0	47.32	3	7.54	17.5	1.0
Site 3 H	26/7/01 10:00	7.87	18.69	2	<1	55.500	8	38.54	38850.0	47.42	3	8.35	18.5	1.0
Site 3 I	26/7/01 10:30	7.84	18.79	1	<1	56.200	9	26.35	39340.0	48.10	3	8.97	19.5	1.0
Site 3 J	26/7/01 11:00	7.88	19.67	1	1	55.800	7	25.15	39060.0	47.71	4	9.33	20.0	1.0
Site 3 K	26/7/01 11:30	7.85	20.16	2	2	55.600	5	23.33	38920.0	47.51	5	9.42	20.0	1.0
Site 3 L	26/7/01 12:00	7.85	19.23	<1	<1	55.600	3	16.99	38920.0	47.51	6	9.22	20.0	1.0
Site 3 M	26/7/01 12:30	7.81	19.48	<1	<1	55.900	4	21.43	39130.0	47.81	2	8.74	19.5	1.0
Site 3 N	26/7/01 13:00	7.81	20.85	1	1	55.600	4	27.39	38920.0	47.51	3	8.03	18.5	1.0
Site 3 O	26/7/01 13:30	7.82	21.15	<1	<1	55.600	6	25.30	38920.0	47.51	2	7.13	17.5	1.0
Site 3 P	26/7/01 14:00	7.81	20.46	<1	<1	55.000	6	27.43	38500.0	46.93	3	6.12	16.5	1.0
Site 3 Q	26/7/01 14:30	7.76	21.65	<1	<1	55.600	9	37.72	38920.0	47.51	4	5.07	15.5	1.0
Site 3 R	26/7/01 15:00	7.84	19.87	<1	<1	54.900	10	38.03	38430.0	46.83	4	4.07	14.5	1.0
Site 3 S	26/7/01 15:30	7.85	18.64	<1	<1	55.000	12	48.16	38500.0	46.93	6	3.17	13.5	1.0
Site 3 T	26/7/01 16:00	7.84	18.74	<1	<1	54.700	9	23.08	38290.0	46.63	6	2.43	13	1.0
Site 3 U	26/7/01 16:30	7.85	18.35	1	1	55.100	8	35.38	38570.0	47.03	5	1.90	12.5	1.0
Site 3 V	26/7/01 17:00	7.85	18.49	<1	<1	55.200	5	25.14	38640.0	47.12		1.58	12	1.0
Site 3 W	26/7/01 17:30	7.85	18.54	<1	<1	55.400	5	25.62	38780.0	47.32	7	1.50	12	1.0
Site 3 X	26/7/01 18:00	7.79	18.35	<1	<1	55.200	5	22.99	38640.0	47.12	7	1.65	12	1.0
Site 3 Y	26/7/01 18:30	7.85	18.25	4	3	54.900	5	24.09	38430.0	46.83	7	2.00	12.5	1.0
Site 4 A	26/7/01 6:15	7.81	18.00	37	22	54.900	65	201.15	38430.0	46.83	5	1.82		1.0
Site 4 B	26/7/01 7:30	7.92	18.00	20	15	55.100	32	104.39	38570.0	47.03	6	3.59		1.0
Site 4 C	26/7/01 8:30	7.88	18.20	11	7	55.200	16	93.33	38640.0	47.12	5	5.58		1.0
Site 4 D	26/7/01 9:30	7.91	19.00	20	15	54.200	16	93.83	37940.0	46.15	3	7.54		1.0
Site 4 E	26/7/01 10:30	7.9	19.00	9	6	55.100	15	60.44	38570.0	47.03	3	8.97		1.0
Site 4 F	26/7/01 11:30	7.98	21.00	9	9	54.400	13	60.67	38080.0	46.34	4	9.42		1.0
Site 4 G	26/7/01 12:30	7.91	20.50	14	11	54.100	11	80.33	37870.0	46.05	2	8.74		1.0
Site 4 H	26/7/01 13:30	7.94	21.50	23	15	54.700	12	56.94	38290.0	46.63	1	7.13		1.0
Site 4 I	26/7/01 14:30	7.96	20.00	11	6	54.500	42	142.84	38150.0	46.44	1	5.07		1.0
Site 4 J	26/7/01 15:30	7.82	20.00	59	19	54.600	10	60.33	38220.0	46.54	3	3.17		1.0
Site 4 K	26/7/01 16:30	7.88	20.00	5	4	54.700	16	62.91	38290.0	46.63	4	1.90		1.0
Site 4 L	26/7/01 17:30	7.88	20.50	9	8	55.000	55	231.56	38500.0	46.93	7	1.50		1.0
Site 4 M	26/7/01 18:30	7.89	20.50	14	8	54.400	65	195.27	38080.0	46.34	7	2.00		1.0
Site 5 A	26/7/01 6:30	7.87	18.00	17	6	54.300	55	147.69	38010.0	46.24	6	2.02		1.0
Site 5 B	26/7/01 7:30	7.89	18.00	5	1	54.700	27	90.78	38290.0	46.63	7	3.59		1.0
Site 5 C	26/7/01 8:30	7.82	18.00	10	4	54.700	32	105.03	38290.0	46.63	6	5.58		1.0
Site 5 D	26/7/01 9:30	7.87	18.50	15	12	55.300	34	156.51	38710.0	47.22	3	7.54		1.0
Site 5 E	26/7/01 10:30	7.87	19.00	5	5	54.600	28	121.00	38220.0	46.54	3	8.97		1.0
Site 5 F	26/7/01 11:30	7.85	19.50	3	3	54.700	16	55.56	38290.0	46.63	5	9.42		1.0
Site 5 G	26/7/01 12:30	7.83	19.50	3	3	54.700	16	67.00	38290.0	46.63	2	8.74		1.0
Site 5 H	26/7/01 13:30	7.86	19.50	2	2	54.500	15	53.03	38150.0	46.44	0	7.13		1.0
Site 5 I	26/7/01 14:30	7.96	20.00	5	3	54.300	15	73.11	38010.0	46.24	1	5.07		1.0
Site 5 J	26/7/01 15:30	7.82	20.00	2	2	54.200	9	32.27	37940.0	46.15	6	3.17		1.0
Site 5 K	26/7/01 16:30	7.87	20.50	7	6	55.100	100	401.15	38570.0	47.03	6	1.90		1.0
Site 5 L	26/7/01 17:30	7.68	20.00	7	7	54.600	26	87.62	38220.0	46.54	7	1.50		1.0
Site 5 M	26/7/01 18:30	7.82	20.00	15	9	54.600	70	281.03	38220.0	46.54	7	2.00		1.0
Site 6 1	26/7/01 0:30	8.21	17.00	1100	49	0.211	1	2.32	147.7	0.13	1	8.23		Surface
Site 6 2	26/7/01 1:30	8.1	17.00	5082	179	0.215	1	2.18	150.5	0.13	1	6.50		Surface
Site 6 3	26/7/01 2:30	7.87	17.00	6955	179	0.213	1	1.72	149.1	0.13	1	4.24		Surface
Site 6 4	26/7/01 3:30	7.7	17.00	4645	242	0.214	<1	2.53	149.8	0.13	1	2.36		Surface
Site 6 5	26/7/01 4:30	7.4	16.00	10855	30	0.212	<1	2.76	148.4	0.13	4	1.29		Surface
Site 6 6	26/7/01 5:30	7.7	16.00	10009	64	0.216	1	2.26	151.2	0.13	1	1.19		Surface
Site 6 A	26/7/01 6:36	7.94	16.00	6136	194	0.208	5	5.24	145.6	0.13	1	2.24		Surface
Site 6 B	26/7/01 7:32	7.7	16.00	11091	282	0.229	2	2.74	160.3	0.14	6	3.90		Surface
Site 6 C	26/7/01 8:31	7.74	16.00	11464	277	0.220	2	3.00	154.0	0.13	4	5.92		Surface
Site 6 D	26/7/01 9:30	8.29	17.80	10000	330	0.208	2	1.76	145.6	0.13	4	7.54		Surface
Site 6 E	26/7/01 10:30	7.66	17.90	4727	282	0.213	2	1.76	149.1	0.13	2	8.97		Surface
Site 6 F	26/7/01 11:30	8.52	17.50	2100	326	0.216	1	2.59	151.2	0.13	4	9.42		Surface
Site 6 G	26/7/01 12:25	7.55	19.10	2509	154	0.219	1	3.52	153.3	0.13	4	8.74		Surface
Site 6 H	26/7/01 13:28	8.61	19.70	140	130	0.220	2	2.42	154.0	0.13	1	7.13		Surface

Sample No.	Sample Time	pH	Temp ˚C	Presumptive Enterococci cfu 100ml	Confirmed Enterococci cfu 100ml	Conductivity mS cm^{-1}	Turbidity NTU	Suspended solids mg L^{-1}	Total dis. Solids mg L^{-1}	Practical salinity	Cloud Cover oktas	Tide m ACD	Water Depth m	Depth of Sample m
Site 6 I	26/7/01 14:26	8.82	18.00	300	122	0.223	2	8.83	156.1	0.13	2	5.07		Surface
Site 6 J	26/7/01 15:26	7.88	19.20	236	108	0.218	2	3.65	152.6	0.13	5	3.17		Surface
Site 6 K	26/7/01 16:27	8.74	20.00	400	121	0.221	1	2.24	154.7	0.13	5	1.90		Surface
Site 6 L	26/7/01 17:26	9.01	19.00	782	73	0.218	1	1.63	152.6	0.13	6	1.50		Surface
Site 6 M	26/7/01 18:27	9.14	19.60			0.215	1	2.40	150.5	0.13	7	2.00		Surface
Site 7 1	26/7/01 0:45	7.68	14.00	500	157	0.574	1	1.92	401.8	0.35	1	7.92		Surface
Site 7 2	26/7/01 1:42	7.65	14.00	664	208	0.567	1	3.67	396.9	0.35	1	5.74		Surface
Site 7 3	26/7/01 2:43	7.63	14.00	873	139	0.577	1	2.15	403.9	0.35	1	3.54		Surface
Site 7 4	26/7/01 3:44	7.55	13.00	782	401	0.579	1	2.03	405.3	0.35	1	1.90		Surface
Site 7 5	26/7/01 4:41	7.59	13.00	1118	299	0.573	1	2.76	401.1	0.35	5	1.14		Surface
Site 7 6	26/7/01 5:42	7.6	13.00	882	337	0.571	1	2.35	399.7	0.35	1	1.37		Surface
Site 7 A	26/7/01 6:48	7.75	13.00	836	224	0.552	1	2.54	386.4	0.34	1	2.47		Surface
Site 7 B	26/7/01 8:43	7.75	13.00	1255	135	0.556	1	2.27	389.2	0.34	4	6.26		Surface
Site 7 C	26/7/01 8:54	7.79	13.00	773	247	0.547	1	2.70	382.9	0.33	3	6.60		Surface
Site 7 D	26/7/01 9:38	7.94	14.70	309	160	0.548	1	2.00	383.6	0.33	4	7.83		Surface
Site 7 E	26/7/01 10:35	7.96	14.90	230	150	0.531	1	1.81	371.7	0.32	3	9.12		Surface
Site 7 F	26/7/01 11:40	7.93	15.10	218	185	0.550	1	1.41	385.0	0.33	6	9.39		Surface
Site 7 G	26/7/01 12:35	8.01	16.00	145	134	0.522	1	1.90	365.4	0.32	2	8.53		Surface
Site 7 H	26/7/01 13:35	8	15.30	282	230	0.545	1	4.65	381.5	0.33	1	6.80		Surface
Site 7 I	26/7/01 14:39	8.12	16.90	136	126	0.569	1	3.04	398.3	0.35	2	4.73		Surface
Site 7 J	26/7/01 15:37	8.15	18.20	100	90	0.565	1	2.53	395.5	0.34	6	2.90		Surface
Site 7 K	26/7/01 16:37	8.13	18.50	100	88	0.559	1	2.64	391.3	0.34	6	1.77		Surface
Site 7 L	26/7/01 17:35	8.23	18.70	140	110	0.557	1	3.62	389.9	0.34	6	1.52		Surface
Site 7 M	26/7/01 18:36	8.16	18.50	130	130	0.546	1	2.87	382.2	0.33	7	2.17		Surface
Site 8 1	26/7/01 1:00	7.34		176364	58788	0.823	2	8.91	576.1	0.51	1	7.58		Effluent
Site 8 2	26/7/01 1:50	7.38		190909	57273	0.830	3	8.51	581.0	0.51	1	5.74		Effluent
Site 8 3	26/7/01 2:52	7.36		256364	61527	0.812	2	6.97	568.4	0.50	1	3.22		Effluent
Site 8 4	26/7/01 3:54	7.46		131818	58245	0.813	3	7.74	569.1	0.50	1	1.71		Effluent
Site 8 5	26/7/01 4:51	7.44		123636	19521	0.825	2	5.60	577.5	0.51	4	1.11		Effluent
Site 8 6	26/7/01 6:03	7.41		186364	33884	0.852	2	6.94	596.4	0.53	3	1.65		Effluent
Site 8 A	26/7/01 6:58	7.44		145455	49787	0.847	2	5.96	592.9	0.52	1	2.73		Effluent
Site 8 B	26/7/01 8:01	7.65		147273	43200	0.852	2	6.46	596.4	0.53	1	4.89		Effluent
Site 8 C	26/7/01 9:05	7.53		159091	49716	0.847	2	5.94	592.9	0.52	1	6.92		Effluent
Site 8 D	26/7/01 9:47	7.64		151818	38980	0.856	2	6.77	599.2	0.53	1	8.1		Effluent
Site 8 E	26/7/01 10:45	7.56		122727	24743	0.841	2	5.20	588.7	0.52	1	9.24		Effluent
Site 8 F	26/7/01 11:39	7.51		53636	17204	0.806	2	6.10	564.2	0.50	6	9.39		Effluent
Site 8 G	26/7/01 12:42	7.58		40909	14610	0.818	2	6.50	572.6	0.50	2	8.29		Effluent
Site 8 H	26/7/01 13:47	7.47		39091	10750	0.826	2	6.13	578.2	0.51	1	6.46		Effluent
Site 8 I	26/7/01 14:49	7.42		33636	15190	0.758	1	7.91	530.6	0.47	2	4.39		Effluent
Site 8 J	26/7/01 15:46	7.41		79091	24028	0.779	2	6.50	545.3	0.48	6	2.66		Effluent
Site 8 K	26/7/01 16:45	7.38		134545	12583	0.804	3	7.30	562.8	0.50	6	1.66		Effluent
Site 8 L	26/7/01 17:43	7.56		119091	20669	0.816	2	1.41	571.2	0.50	6	1.57		Effluent
Site 8 M	26/7/01 18:44	7.45		164545	34693	0.838	2	8.89	586.6	0.52	7	2.35		Effluent

Sediment Particle Size Results Survey 2 - Porthcawl 26/7/01

Site	Grid Reference	Lat. Long.	Description
Site 1: Offshore CSV	SS 8604 7200	51° 26.103 N 3° 38.375 W	Surface Samples (1m depth)
Site 2: Offshore CSV	SS 8604 7200	51° 26.103 N 3° 38.375 W	Sub-surface Samples taken at depth indicated
Site 3: Offshore Rib		51° 26.797 N 3° 40.659 W	Surface Samples (1m depth)
Site 4: Trecco Bay BW	SS 8310 7630		Bathing Water Samples
Site 5: Southerndown	SS 8840 7290		Bathing Water Samples
Site 6: Afon Ogwr	SS 8830 7730		River Water Samples
Site 7: Afon Ewenni	SS 8940 7720		River Water Samples
Site 8: Pen-y-Bont WwTW	SS 8760 7670		Secondary treated sewage final effluent

	Site 1 C	Site 1 D	Site 1 G	Site 1 J	Site 2 G	Site 3 K	Site 3 Q	Site 3 W	Site 4 C	Site 4 Fa	Site 4 Fb	Site 4 Fc	Site 4 La	Site 4 Lb	Site 4 Lc	Site 5 C	Site 5 F	Site 5 I	Site 5 L	Site 6 C
Mean:	12.17	13.60	14.54	36.79	31.14	17.52	44.45	12.15	14.38	21.20	24.22	23.34	16.91	18.55	16.29	17.04	114.40	18.24	13.68	34.00
Median:	9.86	9.96	8.30	11.95	10.94	7.93	12.96	9.52	11.51	13.57	14.76	13.78	12.67	12.71	12.54	11.36	62.94	14.87	10.36	26.87
D(3,4):	12.17	13.60	14.54	36.79	31.14	17.52	44.45	12.15	14.38	21.20	24.22	23.34	16.91	18.55	16.29	17.04	114.40	18.24	13.68	34.00
Mean/Median Ratio:	1.23	1.37	1.75	3.08	2.85	2.21	3.43	1.28	1.25	1.56	1.64	1.69	1.33	1.46	1.30	1.50	1.82	1.23	1.32	1.27
Mode:	14.94	13.61	14.94	13.61	13.61	13.61	11.29	11.29	14.94	14.94	16.40	16.40	14.94	14.94	14.94	13.61	21.69	16.40	10.29	28.69
S.D.:	8.79	15.93	23.01	65.25	56.88	28.23	67.67	9.62	11.42	29.40	35.49	35.67	17.40	25.57	17.69	23.33	100.90	13.39	12.64	30.38
Variance:	77.33	253.90	529.40	4257.00	3235.00	797.00	4579.00	92.55	130.40	864.20	1259.00	1272.00	302.70	654.00	312.90	544.10	10176.00	179.40	159.90	923.00
C.V.:	72.28	117.20	158.20	177.30	182.60	161.10	152.20	79.20	79.44	138.60	146.50	152.80	102.90	137.80	108.60	136.90	88.19	73.44	92.39	89.35
Skewness:	1.13	5.49	4.43	2.34	2.47	3.71	1.80	1.18	1.54	4.70	4.25	4.20	3.36	5.15	5.79	5.31	0.71	0.86	2.83	2.87
Kurtosis:	1.00	44.79	21.55	4.10	4.56	14.10	1.84	0.96	2.79	30.47	21.53	20.40	16.16	34.08	58.21	37.60	-0.94	-0.15	13.30	10.91
d10:	3.00	2.84	2.53	2.90	2.34	2.39	2.99	2.52	3.08	3.61	3.87	3.61	3.41	3.49	3.37	2.97	19.65	3.54	2.80	9.08
d50:	9.86	9.96	8.30	11.95	10.94	7.93	12.96	9.52	11.51	13.57	14.76	13.78	12.67	12.71	12.54	11.36	62.94	14.87	10.36	26.87
d90:	25.63	25.87	28.56	156.30	132.00	34.69	173.20	26.69	29.17	40.49	45.09	42.87	32.42	32.87	30.99	33.31	281.50	41.31	28.09	61.07
Specific Surf. Area:	9931.00	11051.00	13753.00	10625.00	13891.00	14423.00	10679.00	12967.00	10749.00	13606.00	14060.00	15125.00	16607.00	15262.00	16868.00	17655.00	1347.00	9396.00	12043.00	4816.00
% <	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size
5	2.40	2.10	0.92	2.13	0.75	0.71	1.93	1.84	1.73	1.74	1.79	1.65	1.38	1.53	1.34	1.23	18.01	2.16	1.48	5.03
16	3.72	3.84	3.05	4.06	3.19	2.87	4.23	3.27	4.50	5.21	5.62	5.24	4.98	5.04	4.93	4.33	21.38	5.48	4.06	12.65
25	5.25	5.29	3.85	5.76	5.13	5.11	6.29	4.58	6.28	7.33	7.95	7.40	7.01	7.05	6.94	6.11	24.32	7.88	5.75	16.90
84	21.37	22.11	22.87	40.42	35.41	22.91	131.30	21.71	23.96	30.53	33.65	31.54	25.87	26.03	25.14	25.60	254.10	32.15	22.41	50.16
95	30.02	37.95	44.21	215.70	196.80	55.64	205.20	32.47	39.17	62.24	74.59	72.93	46.25	48.69	41.87	46.54	301.80	46.17	37.40	86.10
Size	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <
1	1.84	2.88	5.25	3.48	5.72	5.72	2.33	2.32	2.84	3.56	3.65	3.86	4.28	3.98	4.34	4.50	0.00	3.17	3.71	1.12
10	50.60	50.20	60.70	43.70	48.80	50.60	40.10	52.20	43.60	36.30	33.00	35.80	38.60	38.50	39.10	44.10	0.00	33.60	48.30	11.40
100	100.00	99.30	97.40	86.80	89.00	95.80	82.00	100.00	100.00	97.10	96.10	95.90	99.00	97.80	99.40	98.40	55.90	100.00	99.80	95.90
1000	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Particle Diameter (μm)	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <
0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	2.73	4.43	5.97	4.35	7.28	6.33	5.27	6.07	5.96	5.54	5.38	5.67	6.18	5.91	6.26	6.81	0.00	4.53	6.66	2.26
3.9	17.30	16.30	25.40	15.30	18.20	20.90	14.50	20.60	13.30	11.00	10.10	11.00	11.70	11.50	11.90	14.00	0.00	11.20	15.20	3.94
7.8	38.30	41.60	46.60	37.20	46.90	49.70	31.30	41.80	33.10	27.00	24.40	26.70	28.70	28.40	29.00	33.60	0.00	24.70	36.70	8.22
15.6	72.50	74.20	76.50	65.80	69.70	74.00	56.70	71.60	65.10	56.80	52.70	56.00	60.90	60.80	61.60	65.20	0.56	52.50	69.80	22.00
53	100.00	98.70	97.00	86.40	88.00	94.80	79.50	99.99	99.00	93.60	92.30	92.70	96.20	95.70	97.30	96.40	46.70	99.60	98.70	86.00
105	100.00	99.30	97.40	86.80	89.00	95.90	82.20	100.00	100.00	97.20	96.20	96.10	99.20	98.00	99.40	98.40	56.40	100.00	99.90	96.10
210	100.00	100.00	100.00	94.40	97.60	100.00	95.70	100.00	100.00	99.60	99.00	99.00	100.00	99.70	99.90	99.80	78.60	100.00	100.00	99.80
420	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
840	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1680	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Sediment Particle Size Results **Survey 2 - Porthcawl** **26/7/01**

Site	Grid Reference	Lat. Long.	Description
Site 1: Offshore CSV	SS 8604 7200	51° 26.103 N 3° 38.375 W	Surface Samples (1m depth)
Site 2: Offshore CSV	SS 8604 7200	51° 26.103 N 3° 38.375 W	Sub-surface Samples taken at depth indicated
Site 3: Offshore Rib		51° 26.797 N 3° 40.659 W	Surface Samples (1m depth)
Site 4: Trecco Bay BW	SS 8310 7630		Bathing Water Samples
Site 5: Southerndown	SS 8840 7290		Bathing Water Samples
Site 6: Afon Ogwr	SS 8830 7730		River Water Samples
Site 7: Afon Ewenni	SS 8940 7720		River Water Samples
Site 8: Pen-y-Bont WwTW	SS 8760 7670		Secondary treated sewage final effluent

	Site 6 I	Site 6 L	Site 7 C	Site 7 I	Site 8 C	Site 8 I
Mean:	29.59	30.82	20.90	27.88	71.10	76.71
Median:	27.22	30.32	18.71	25.77	70.44	75.49
D(3,4):	29.59	30.82	20.90	27.88	71.10	76.71
Mean/Median Ratio:	1.09	1.02	1.12	1.08	1.01	1.02
Mode:	34.58	41.67	28.69	28.69	96.49	87.90
S.D.:	17.30	16.15	12.88	14.39	36.24	37.73
Variance:	299.30	260.80	166.00	207.00	1314.00	1424.00
C.V.:	58.46	52.40	61.64	51.60	50.98	49.19
Skewness:	0.47	0.17	0.62	0.32	0.05	0.10
Kurtosis:	-0.45	-0.84	-0.39	-0.28	-0.92	-0.76
d10:	7.81	9.44	5.95	12.88	21.79	25.89
d50:	27.22	30.32	18.71	25.77	70.44	75.49
d90:	54.82	53.78	42.41	49.50	122.00	129.20
Specific Surf. Area:	4915.00	3622.00	5547.00	21139.00	1834.00	1641.00
% <	Size	Size	Size	Size	Size	Size
5	4.40	5.48	3.22	0.59	12.81	15.65
16	11.95	12.97	7.33	15.37	30.74	36.05
25	16.54	17.94	10.60	18.08	42.90	48.27
84	48.61	48.82	33.04	44.04	112.00	118.60
95	61.48	58.43	46.61	54.49	131.20	140.40
Size	% <	% <	% <	% <	% <	% <
1	1.15	0.14	0.26	5.59	0.31	0.24
10	13.20	11.60	23.80	7.01	3.95	2.91
100	100.00	100.00	100.00	100.00	75.60	71.30
1000	100.00	100.00	100.00	100.00	100.00	100.00
Particle Diameter (μm)	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <
0.04	0.00	0.00	0.00	0.00	0.00	0.00
2	2.41	1.34	2.45	5.85	0.52	0.47
3.9	4.66	3.08	5.69	6.24	1.04	0.92
7.8	9.98	6.27	17.80	6.66	3.18	2.17
15.6	22.90	20.00	39.50	16.70	6.71	4.98
53	88.40	89.10	99.70	93.70	33.80	29.00
105	100.00	100.00	100.00	100.00	79.20	74.90
210	100.00	100.00	100.00	100.00	100.00	100.00
420	100.00	100.00	100.00	100.00	100.00	100.00
840	100.00	100.00	100.00	100.00	100.00	100.00
1680	100.00	100.00	100.00	100.00	100.00	100.00

Water Quality Results Survey 3 - Minehead/Blue Anchor Bay 30/7/01

Site	Grid Reference	Lat. Long.	Description
Site 1: Offshore CSV		51° 12.820 N 3° 23.300 W	Surface Samples (1m depth)
Site 2: Offshore CSV		51° 12.820 N 3° 23.300 W	Sub-surface Samples taken at depth indicated
Site 3: Offshore Rib		51° 13.534 N 3° 28.303 W	Surface Samples (1m depth)
Site 4: Minehead Terminus BW	SS 9730 4650		Bathing Water Samples
Site 5: Dunster NW BW	SS 9970 4550		Bathing Water Samples
Site 6: Park/Puritan Stream	SS 9730 4640		River Water Samples
Site 7: Butlins Outfall	SS 9380 4650		River Water Samples
Site 8: Minehead WwTW	SS 9890 4520		UV disinfected sewage effluent (discharges at SS 9945 4697)
Site 9: River Avil	SS 9970 4550		River Water Samples
Site 10: Stream NW of R. Avil	SS 9965 4570		River Water Samples

Sample No.	Sample Time	pH	Temp °C	Presumptive Enterococci cfu 100ml	Confirmed Enterococci cfu 100ml	Conductivity mS cm^{-1}	Turbidity NTU	Suspended solids mg L^{-1}	Total dis. Solids mg L^{-1}	Practical salinity	Cloud Cover oktas	Tide m ACD	Water Depth m	Depth of Sample m
Site 1 A	30/7/01 6:30	7.94		3	2	49.100	10	30.11	34370.0	41.23	8	5.88	15.3	1.0
Site 1 B	30/7/01 7:30	7.96		<1	<1	49.000	20	49.46	34300.0	41.14	8	4.62	13.6	1.0
Site 1 C	30/7/01 8:30	7.98		2	2	49.000	25	55.93	34300.0	41.14	8	3.73	13.3	1.0
Site 1 D	30/7/01 9:30	7.96		1	1	48.900	17	47.36	34230.0	41.04	8	3.29	13.0	1.0
Site 2 E	30/7/01 11:00	7.98		<1	<1	48.300	10	46.18	33810.0	40.47	7	3.60	12.4	1.0
Site 1 F	30/7/01 11:30	7.94		<1	<1	48.800	10	35.38	34160.0	40.95	6	3.97	12.9	1.0
Site 1 G	30/7/01 12:00	7.92		3	2	51.600	20	57.22	36120.0	43.63	7	4.46	14.4	1.0
Site 1 H	30/7/01 13:30	7.96		1	1	52.600	16	55.72	36820.0	44.60	5	6.38	15.6	1.0
Site 1 I	30/7/01 14:30	7.95		<1	<1	53.500	5	8.21	37450.0	45.47	6	7.64	18.3	1.0
Site 1 J	30/7/01 15:30	7.94		<1	<1	53.900	5	24.08	37730.0	45.86	6	8.48	18.9	1.0
Site 1 K	30/7/01 16:30	8.03		<1	<1	53.800	5	24.33	37660.0	45.76	3	8.61	16.9	1.0
Site 1 L	30/7/01 17:30	8.02		<1	<1	53.000	5	23.19	37100.0	44.98	4	7.94	16.4	1.0
Site 1 M	30/7/01 18:30	8		2	2	50.700	7	27.74	35490.0	42.76	5	6.65	14.6	1.0
Site 2 D	30/7/01 9:30	7.95		3	1	49.600	25	71.40	34720.0	41.71	8	3.29	13.0	7.8
Site 3 A	30/7/01 6:30	7.99	18.05	5	4	51.100	10	43.39	35770.0	43.15	8	5.88	14.0	1.0
Site 3 B	30/7/01 7:00	7.95	17.36	5	3	51.100	11	37.67	35770.0	43.15	8	5.22	13.0	1.0
Site 3 C	30/7/01 7:30	7.98	18.05	6	5	51.000	12	51.30	35700.0	43.05	8	4.62	12.5	1.0
Site 3 D	30/7/01 8:00	7.98	18.01	9	4	51.000	11	40.22	35700.0	43.05	8	4.12	13.0	1.0
Site 3 E	30/7/01 8:30	7.95	17.96	8	5	51.200	10	34.84	35840.0	43.24	8	3.73	13.5	1.0
Site 3 F	30/7/01 9:00	7.98	18.01	7	7	50.500	8	34.78	35350.0	42.57	8	3.45	15.0	1.0
Site 3 G	30/7/01 9:30	7.94	18.05	3	3	50.500	8	27.96	35350.0	42.57	8	3.29	14.0	1.0
Site 3 J	30/7/01 11:00	7.96	18.25	2	1	50.600	6	26.85	35420.0	42.67	7	3.60	13.5	1.0
Site 3 K	30/7/01 11:30	7.98	18.50	<1	<1	51.700	4	22.89	36190.0	43.73	7	3.97	13.5	1.0
Site 3 L	30/7/01 12:00	7.92	18.15	1	1	51.800	5	23.07	36260.0	43.82	6	4.46	14.0	1.0
Site 3 M	30/7/01 12:30	7.95	18.40	<1	<1	52.200	4	21.80	36540.0	44.21	7	5.05	14.5	1.0
Site 3 N	30/7/01 13:00	7.98	19.33	<1	<1	52.900	3	24.58	37030.0	44.89	7	5.71	15.5	1.0
Site 3 O	30/7/01 13:30	7.93	18.74	<1	<1	54.100	3	20.00	37870.0	46.05	7	6.38	16.0	1.0
Site 3 P	30/7/01 14:00	7.99	18.25	<1	<1	53.500	4	21.04	37450.0	45.47	8	7.04	16.5	1.0
Site 3 Q	30/7/01 14:30	8.01	18.01	<1	<1	54.200	4	22.37	37940.0	46.15	7	7.64	17.5	1.0
Site 3 R	30/7/01 15:00	7.99	17.62	<1	<1	52.700	3	19.90	36890.0	44.69	4	8.13	17.5	1.0
Site 3 S	30/7/01 15:30	7.98	17.86	<1	<1	53.600	2	19.90	37520.0	45.56	2	8.48	17.5	1.0
Site 3 T	30/7/01 16:00	8.01	17.96	<1	<1	52.300	4	24.94	36610.0	44.31	3	8.65	17.5	1.0
Site 3 U	30/7/01 16:30	7.99	18.01	1	1	51.500	5	26.35	36050.0	43.53	3	8.61	18.5	1.0
Site 3 V	30/7/01 17:00	8	18.45	<1	<1	50.800	6	37.08	35560.0	42.86	3	8.37	17.0	1.0
Site 3 W	30/7/01 17:30	8.01	18.35	1	1	51.400	7	29.90	35980.0	43.44	3	7.94	16.5	1.0
Site 3 X	30/7/01 18:00	8.01	18.49	2	2	53.600	3	20.11	37520.0	45.56	3	7.34	15.5	1.0
Site 3 Y	30/7/01 18:30	8.01	18.20	2	2	53.400	2	19.22	37380.0	45.37	3	6.65	15.0	1.0
Site 4 A	30/7/01 6:45	7.98	18.50	90	45	51.500	20	69.33	36050.0	43.53	8	5.43		1.0
Site 4 B	30/7/01 7:36	7.94	18.50	50	50	51.900	28	91.71	36330.0	43.92	8	4.44		1.0
Site 4 C	30/7/01 8:30	7.97	18.50	42	32	52.000	55	139.67	36400.0	44.02	8	3.73		1.0
Site 4 D	30/7/01 9:30	7.97	19.00	12	8	50.600	11	38.29	35420.0	42.67	8	3.29		1.0
Site 4 E	30/7/01 10:30	7.88	19.00	8	7	50.900	26	73.11	35630.0	42.96	8	3.36		1.0
Site 4 F	30/7/01 11:30	7.96	19.50	7	3	51.400	34	123.91	35980.0	43.44	7	3.97		1.0
Site 4 G	30/7/01 12:30	7.89	20.00	9	6	51.400	55	180.00	35980.0	43.44	7	5.05		1.0
Site 4 H	30/7/01 13:30	7.96	20.00	14	9	51.900	35	120.61	36330.0	43.92	7	6.38		1.0
Site 4 I	30/7/01 14:30	8.02	21.00	112	95	51.500	46	159.81	36050.0	43.53	7	7.64		1.0
Site 4 J	30/7/01 15:30	8.04	21.50	600	230	51.500	40	153.47	36050.0	43.53	1	8.48		1.0
Site 4 K	30/7/01 16:30	8.12	21.50	186	71	50.900	36	146.30	35630.0	42.96	2	8.61		1.0
Site 4 L	30/7/01 17:30	8.01	22.00	9	5	52.200	12	40.89	36540.0	44.21	3	7.94		1.0
Site 4 M	30/7/01 18:30	8.08		17	9	51.900	20	61.86	36330.0	43.92		6.65		1.0
Site 5 A	30/7/01 7:00	8.01		128	116	50.100	17	69.00	35070.0	42.19	8	5.22		1.0
Site 5 B	30/7/01 7:30	7.96		58	42	50.300	20	72.71	35210.0	42.38	8	4.62		1.0
Site 5 C	30/7/01 8:30	7.98	19.00	17	12	49.900	38	126.04	34930.0	42.00	8	3.73		1.0
Site 5 D	30/7/01 9:30	7.94	19.00	13	10	50.100	39	123.48	35070.0	42.19	8	3.29		1.0
Site 5 E	30/7/01 10:30	7.99	19.00	5	4	50.700	32	106.04	35490.0	42.76	8	3.36		1.0
Site 5 F	30/7/01 11:30	7.91	20.00	3	3	50.200	20	59.66	35140.0	42.29	7	3.97		1.0
Site 5 G	30/7/01 12:30	7.94	21.00	3	3	50.500	10	36.33	35350.0	42.57	7	5.05		1.0
Site 5 H	30/7/01 13:30	7.95	21.00	5	4	50.700	14	46.82	35490.0	42.76	8	6.38		1.0
Site 5 I	30/7/01 14:30	7.9	21.00	10	8	50.800	30	168.78	35560.0	42.86	8	7.64		1.0
Site 5 J	30/7/01 15:30	7.99	22.00	9	8	51.300	24	112.04	35910.0	43.34	2	8.48		1.0
Site 5 K	30/7/01 16:30	7.98	23.00	63	50	50.100	18	61.81	35070.0	42.19	1	8.61		1.0
Site 5 L	30/7/01 17:30	8.03	21.00	61	50	50.600	39	137.14	35420.0	42.67	2	7.94		1.0
Site 5 M	30/7/01 18:30	8.01	21.00	12	9	51.800	28	109.58	36260.0	43.82	3	6.65		1.0
Site 6 A	30/7/01 6:32	8.43	16.00	6400	5700	0.463	2	7.54	324.1	0.28	8	5.66		Surface
Site 6 B	30/7/01 8:30	8.43	16.00	4400	3800	0.434	1	5.03	303.8	0.26	8	3.73		Surface
Site 6 C	30/7/01 10:11	8.46	16.00	4000	3100	0.439	1	10.22	307.3	0.27	8	3.31		Surface
Site 6 D	30/7/01 11:37	8.36	16.00	3000	2700	0.466	2	9.28	326.2	0.28	7	4.12		Surface
Site 6 E	30/7/01 13:00	8.35	16.50	5000	4700	0.443	2	6.00	310.1	0.27	7	5.71		Surface
Site 6 F	30/7/01 14:25	8.52	16.50	2500	2000	0.434	1	5.30	303.8	0.26	7	7.64		Surface
Site 6 G	30/7/01 16:00	8.42	17.00	2400	2000	0.436	1	5.68	305.2	0.26	1	8.65		Surface
Site 6 H	30/7/01 17:31	7.55	17.00	4100	4000	0.434	2	6.52	303.8	0.26	3	7.75		Surface
Site 7 A	30/7/01 6:50	8.14	19.00	84	46	12.200	2	14.02	8540.0	8.87	8	5.43		Surface
Site 7 B	30/7/01 8:52	8.09	19.00	92	75	12.400	1	17.16	8680.0	9.03	8	3.45		Surface
Site 7 C	30/7/01 10:21	7.88	19.00	58	58	13.400	2	15.63	9380.0	9.82	8	3.36		Surface
Site 7 D	30/7/01 11:52	7.74	19.00	49	49	12.600	2	8.10	8820.0	9.11	6	4.46		Surface
Site 7 E	30/7/01 18:20	8.1	19.00	112	103	12.500	1	20.00	8750.0	9.11	2	6.89		Surface
Site 8 A	30/7/01 8:10	7.43		91	57	1.005	4	18.50	703.5	0.06	8	3.97		Effluent
Site 8 B	30/7/01 13:20	7.42		261	54	0.920	5	22.80	644.0	0.57	8	6.16		Effluent
Site 8 C	30/7/01 14:26	7.36		218	109	0.920	3	16.16	644.0	0.57	8	7.64		Effluent
Site 8 D	30/7/01 15:03	7.45		291	49	0.915	3	18.44	640.5	0.57		8.26		Effluent
Site 8 E	30/7/01 16:05	7.47		273	224	0.896	3	11.20	627.2	0.55	3	8.66		Effluent
Site 8 F	30/7/01 17:03	7.53		70	40	0.950	2	10.88	665.0	0.59	1	8.25		Effluent
Site 8 G	30/7/01 18:00	7.51		64	11	0.989	4	14.52	692.3	0.61	1	7.34		Effluent
Site 9 A	30/7/01 6:45	8.18		510	410	0.320	4	157.50	224.0	0.19	8	5.43		Surface
Site 9 B	30/7/01 8:30	8.02	18.40	390	290	0.323	1	19.64	226.1	0.19	8	3.73		Surface
Site 9 C	30/7/01 10:20	8.41	19.00	370	300	0.322	2	47.74	225.4	0.19	8	3.31		Surface
Site 9 D	30/7/01 11:40	8.64	19.00	730	730	0.315	1	12.07	220.5	0.19	7	4.12		Surface
Site 9 E	30/7/01 12:30	8.72	19.00	720	650	0.314	2	14.32	219.8	0.19	7	5.05		Surface
Site 9 F	30/7/01 13:35	8.87	19.00	650	640	0.316	2	10.23	221.2	0.19	8	6.61		Surface

Sample No.	Sample Time	pH	Temp ˚C	Presumptive Enterococci cfu 100ml	Confirmed Enterococci cfu 100ml	Conductivity mS cm^{-1}	Turbidity NTU	Suspended solids mg L^{-1}	Total dis. Solids mg L^{-1}	Practical salinity	Cloud Cover oktas	Tide m ACD	Water Depth m	Depth of Sample m
Site 9 G	30/7/01 14:37	8.84	19.00	520	480	0.326	2	71.95	228.2	0.20	6	7.82		Surface
Site 9 H	30/7/01 15:30	8.79	19.00	310	260	0.323	2	30.89	226.1	0.19	2	8.48		Surface
Site 9 I	30/7/01 16:30	8.81	23.00	330	220	0.329	2	88.75	230.3	0.20	1	8.61		Surface
Site 9 J	30/7/01 17:30	8.86		410	350	0.318	1	29.16	222.6	0.19	1	7.94		Surface
Site 9 K	30/7/01 18:30	8.71	19.00	310	230	0.314	1	17.69	219.8	0.19	3	6.65		Surface
Site 10 A	30/7/01 6:50	7.93		218	190	2.050	5	41.82	1435.0	1.32	8	5.43		Surface
Site 10 B	30/7/01 8:45	7.94	19.00	155	136	2.470	4	15.31	1729.0	1.61	8	3.53		Surface
Site 10 C	30/7/01 10:47	8.19	19.00	132	113	2.910	4	10.75	2037.0	1.91	8	3.51		Surface
Site 10 D	30/7/01 12:20	8.06	20.00	300	210	2.910	4	13.57	2037.0	1.91	7	4.85		Surface
Site 10 E	30/7/01 17:30	8.83	24.00	59	50	2.550	3	11.12	1785.0	1.66	2	7.94		Surface
Site 10 F	30/7/01 18:30	8.89	24.00	77	57	2.540	3	9.89	1778.0	1.65	3	6.65		Surface

Sediment Particle Size Results **Survey 3 - Minehead/Blue Anchor Bay** **30/7/01**

Site	Grid Reference	Lat. Long.	Description
Site 1: Offshore CSV		51˚ 12.820 N 3˚ 23.300 W	Surface Samples (1m depth)
Site 2: Offshore CSV		51˚ 12.820 N 3˚ 23.300 W	Sub-surface Samples taken at depth indicated
Site 3: Offshore Rib		51˚ 13.534 N 3˚ 28.303 W	Surface Samples (1m depth)
Site 4: Minehead Terminus BW	SS 9730 4650		Bathing Water Samples
Site 5: Dunster NW BW	SS 9970 4550		Bathing Water Samples
Site 6: Park/Puritan Stream	SS 9730 4640		River Water Samples
Site 7: Butlins Outfall	SS 9380 4650		River Water Samples
Site 8: Minehead WwTW	SS 9890 4520		UV disinfected sewage effluent (discharges at SS 9945 4697)
Site 9: River Avil	SS 9970 4550		River Water Samples
Site 10: Stream NW of R. Avil	SS 9965 4570		River Water Samples

	Site 1 F	Site 1 I	Site 1 J	Site 1 L	Site 3 R	Site 3 S	Site 3 U	Site 3 V	Site 3 W	Site 4 Ca	Site 4 Cb	Site 4 Cc	Site 4 Ga	Site 4 Gb	Site 4 Gc	Site 4 I	Site 4 M	Site 5 C	Site 5 F	Site 5 I
Mean:	7.25	35.21	10.11	9.51	36.16	10.79	7.58	50.32	43.28	12.90	13.15	13.64	14.85	14.02	15.31	17.51	13.84	16.17	14.66	13.56
Median:	6.85	10.20	8.07	7.94	12.80	8.28	6.58	10.62	9.60	10.87	10.85	10.88	11.95	11.67	12.03	12.30	11.30	10.93	9.70	11.26
D(3,4):	7.25	35.21	10.11	9.51	36.16	10.79	7.58	50.32	43.28	12.90	13.15	13.64	14.85	14.02	15.31	17.51	13.84	16.17	14.66	13.56
Mean/Median Ratio:	1.06	3.45	1.25	1.20	2.83	1.30	1.15	4.74	4.51	1.19	1.21	1.25	1.24	1.20	1.27	1.42	1.23	1.48	1.51	1.20
Mode:	7.78	14.94	14.94	14.94	14.94	8.54	8.54	14.94	8.54	13.61	13.61	13.61	14.94	14.94	14.94	14.94	13.61	13.61	13.61	13.61
S.D.:	4.16	57.76	7.61	6.64	52.69	9.00	5.08	69.85	69.58	9.62	10.69	12.87	12.00	10.38	13.34	19.86	10.43	24.73	20.19	9.99
Variance:	17.28	3336.00	57.85	44.10	2776.00	80.90	25.78	4879.00	4842.00	92.58	114.30	165.80	144.10	107.70	177.90	394.30	108.70	611.60	407.80	99.76
C.V.:	57.31	164.00	75.27	69.80	145.70	83.39	67.01	138.80	160.80	74.59	81.28	94.36	80.81	74.04	87.12	113.40	75.32	152.90	137.70	73.65
Skewness:	0.51	2.13	1.22	1.27	1.83	1.49	1.12	1.36	1.76	1.53	2.44	3.91	1.71	1.17	2.32	3.70	1.36	5.62	4.46	1.31
Kurtosis:	-0.41	3.44	1.07	1.51	1.93	2.33	1.32	0.51	1.66	3.48	12.06	26.59	4.00	1.33	8.82	18.95	1.96	37.45	22.72	1.77
d10:	2.28	2.95	2.59	2.70	2.98	2.29	2.13	2.93	2.87	3.04	2.99	2.96	3.20	3.07	3.17	3.25	3.25	3.01	2.71	3.24
d50:	6.85	10.20	8.07	7.94	12.80	8.28	6.58	10.62	9.60	10.87	10.85	10.88	11.95	11.67	12.03	12.30	11.30	10.93	9.70	11.26
d90:	13.71	143.10	20.59	16.97	139.20	23.14	14.74	167.90	168.70	24.90	25.30	25.81	29.94	28.68	30.90	35.12	27.99	27.21	26.19	26.83
Specific Surf. Area:	15285.00	9844.00	13271.00	12157.00	8799.00	14867.00	15700.00	10217.00	10607.00	16489.00	16911.00	16884.00	16757.00	16941.00	16629.00	16217.00	10731.00	16782.00	12115.00	10695.00
% <	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size
5	1.01	2.28	1.74	2.11	2.24	1.65	1.49	2.16	2.09	1.34	1.29	1.26	1.41	1.31	1.36	1.44	1.71	1.31	1.50	1.69
16	2.87	4.02	3.12	3.29	4.01	2.92	2.75	3.78	3.71	4.39	4.34	4.33	4.65	4.50	4.63	4.73	4.66	4.35	3.92	4.65
25	3.90	6.19	4.15	4.62	6.09	4.01	3.69	6.12	5.56	6.11	6.06	6.06	6.54	6.37	6.54	6.68	6.38	6.07	5.48	6.39
84	11.72	84.00	16.43	15.62	99.11	18.58	12.39	142.20	134.10	21.00	21.19	21.45	24.49	23.72	24.92	26.88	23.04	22.11	20.53	22.32
95	15.27	176.60	27.77	25.72	162.40	30.19	17.79	194.70	209.70	31.41	32.43	33.63	39.20	35.51	40.96	50.33	36.13	37.75	36.22	34.78
Size	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <	% <
1	4.97	2.73	4.67	3.24	0.84	3.22	2.90	3.76	3.47	4.23	4.32	4.37	4.18	4.31	4.23	4.11	2.98	4.29	3.47	2.89
10	76.80	49.40	65.20	66.10	40.90	58.60	74.10	48.00	52.00	45.70	45.80	45.70	41.50	42.60	41.30	40.40	44.00	45.60	51.50	44.00
100	100.00	84.90	100.00	100.00	84.00	100.00	100.00	74.50	80.20	100.00	99.90	99.50	100.00	100.00	99.80	98.60	100.00	97.80	97.80	100.00
1000	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Particle Diameter (µm)	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <
0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	7.67	3.57	5.55	4.38	3.54	7.45	8.83	4.43	4.59	6.60	6.72	6.83	6.32	6.63	6.43	6.22	5.86	6.66	6.85	5.92
3.9	25.00	15.60	23.40	20.90	15.50	24.20	26.90	16.70	17.20	13.70	13.90	14.00	12.80	13.30	12.90	12.50	12.60	13.80	15.90	12.60
7.8	59.60	36.80	47.40	48.60	32.20	47.40	59.70	34.40	38.30	34.20	34.40	34.40	31.10	32.10	31.00	30.30	32.80	34.30	39.50	32.60
15.6	96.10	64.90	80.00	83.90	57.80	77.30	91.70	59.30	66.40	69.70	69.50	69.20	63.60	64.90	63.20	61.80	66.80	68.60	73.10	67.50
53	100.00	83.10	100.00	100.00	81.30	99.90	100.00	72.40	79.10	99.50	99.10	98.60	98.30	99.80	97.80	95.60	99.60	97.20	96.90	99.96
105	100.00	85.20	100.00	100.00	84.40	100.00	100.00	74.90	80.50	100.00	99.90	99.60	100.00	100.00	99.90	98.70	100.00	97.90	97.90	100.00
210	100.00	98.40	100.00	100.00	99.60	100.00	100.00	97.10	95.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.70	100.00	100.00
420	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
840	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1680	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Sediment Particle Size Results **Survey 3 - Minehead/Blue Anchor Bay** **30/7/01**

Site	Grid Reference	Lat. Long.	Description
Site 1: Offshore CSV		**51° 12.820 N 3° 23.300 W**	**Surface Samples (1m depth)**
Site 2: Offshore CSV		**51° 12.820 N 3° 23.300 W**	**Sub-surface Samples taken at depth indicated**
Site 3: Offshore Rib		**51° 13.534 N 3° 28.303 W**	**Surface Samples (1m depth)**
Site 4: Minehead Terminus BW	**SS 9730 4650**		**Bathing Water Samples**
Site 5: Dunster NW BW	**SS 9970 4550**		**Bathing Water Samples**
Site 6: Park/Puritan Stream	**SS 9730 4640**		**River Water Samples**
Site 7: Butlins Outfall	**SS 9380 4650**		**River Water Samples**
Site 8: Minehead WwTW	**SS 9890 4520**		**UV disinfected sewage effluent (discharges at SS 9945 4697)**
Site 9: River Avil	**SS 9970 4550**		**River Water Samples**
Site 10: Stream NW of R. Avil	**SS 9965 4570**		**River Water Samples**

	Site 5 M	Site 6 H	Site 7 D	Site 8 E	Site 8 F	Site 9 I	Site 10 E
Mean:	16.73	88.10	35.94	42.62	59.27	38.16	46.61
Median:	11.91	74.86	32.70	33.34	38.51	27.81	33.26
D(3,4):	16.73	88.10	35.94	42.62	59.27	38.16	46.61
Mean/Median Ratio:	1.40	1.18	1.10	1.28	1.54	1.37	1.40
Mode:	13.61	72.95	34.58	37.96	37.96	28.69	34.58
S.D.:	23.11	56.25	21.88	36.99	58.57	32.98	45.02
Variance:	534.00	3164.00	478.60	1368.00	3431.00	1087.00	2027.00
C.V.:	138.10	63.85	60.87	86.79	98.83	86.42	96.60
Skewness:	7.34	0.92	0.59	2.57	1.76	1.59	2.42
Kurtosis:	76.48	0.33	-0.06	10.22	2.43	2.74	7.24
d10:	3.25	27.29	8.06	10.21	11.35	8.07	10.13
d50:	11.91	74.86	32.70	33.34	38.51	27.81	33.26
d90:	31.33	171.40	66.96	83.41	159.80	83.32	97.64
Specific Surf. Area:	15292.00	1803.00	4436.00	4180.00	3487.00	18481.00	4324.00
% <	Size	Size	Size	Size	Size	Size	Size
5	1.50	19.26	3.88	6.59	6.71	1.71	6.03
16	4.69	34.97	13.91	14.21	16.16	12.04	14.18
25	6.56	45.43	20.09	19.59	22.16	15.62	19.32
84	24.82	146.20	59.08	66.48	106.10	67.81	73.99
95	43.22	203.60	76.27	114.90	200.00	107.20	142.20
Size	% <	% <	% <	% <	% <	% <	% <
1	3.93	0.45	0.40	0.57	0.47	4.57	0.87
10	41.60	1.77	12.00	9.69	8.50	12.20	9.82
100	98.90	65.70	99.50	93.20	83.20	93.90	90.40
1000	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Particle Diameter (µm)	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <	Volume % <
0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	6.15	0.75	1.81	0.77	0.79	5.25	1.57
3.9	12.60	1.01	5.03	1.96	2.19	7.19	2.95
7.8	31.10	1.46	9.73	6.61	6.14	9.79	7.02
15.6	63.80	3.42	18.00	18.20	15.20	24.90	18.40
53	97.00	31.90	78.20	75.10	65.70	75.90	72.60
105	98.90	68.20	99.70	93.80	83.90	94.70	91.20
210	99.60	95.80	100.00	99.30	96.10	100.00	98.30
420	100.00	100.00	100.00	100.00	100.00	100.00	100.00
840	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1680	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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