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Fate and transport of particles in estuaries

Volume II: Estimation of enterococci inputs to the Severn estuary from point and diffuse sources

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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 enterococcal 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 Environment 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 Environment 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 done 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 aquired in the summer of 2001.

Overall, the study presents the first attempt to estimate 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 for enterococci mortality rates.

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

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

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1. Introduction

This volume describes the methods used to determine the level of enterococci organisms being discharged into the Severn estuary. An evaluation of such loads was required to characterise boundary condition inputs for the hydrodynamic model developed as part of this project (see Volume IV). The Project Management Group agreed that the project should focus on enterococci because of (i) its increasing importance as a regulatory indicator (CEC, 2002; WHO, 2003; Kay *et al*., 2004) and (ii) the relatively small amount of data on this indicator in the literature.

Faecal indicator organisms can be deposited into the estuarine environment from human or animal sources (Booth *et al.,* 2003). The former would include effluents discharged to rivers, estuaries or the sea and spills from combined sewage overflows (CSOs) and/or storm tanks. The latter would include various agricultural activities. Previous CREH work for the Environment Agency, SEPA, the Scottish Executive and water companies, suggests a highly episodic and complex input pattern dominated by periods of high bacterial contamination following rainfall (Fewtrell *et al*., 1998; Stapleton *et al*., 1999; 2000a; 2000b; 2002; Wyer *et al.*, 1998a; 1998b; 1998c; 1999a; 1999b; 2001; 2003).

It was never the intention in this project to characterize these inputs by collecting empirical field data, given the spatial scale of the Severn estuary and the resources that would be required to underpin such a field sampling programme. Rather, the approach has been to apply models developed by the CREH, which describe water quality by using land cover data to predict enterococci concentrations at the outlets of the river catchments that discharge to the Severn estuary. These predictions of high and low flow microbiological concentrations have been combined with hydrological data, collected by the Environment Agency at their network of river gauging stations, to derive estimates of bacterial fluxes from riverine diffuse sources (a combination of catchment diffuse sources and upstream inputs to rivers from human sources). Discharges of faecal indicator organisms from point sources, such as final effluents from wastewater treatment works (WwTWs), were calculated from effluent bacterial concentrations acquired through past empirical studies combined with flow estimates from Environment Agency and water company data sources. It was not possible to characterize intermittent discharges from CSOs and storm tank overflows due to the lack of flow data for these spill events. This represents a significant gap in the knowledge base and highlights a limitation of this type of modelling study in estimating absolute bacterial flux. However, it was not considered to be a fatal flaw to the aims of this project, which sought to assess the impact of far-field inputs to the estuary on bathing beach compliance.

2. Development of land cover-water quality models to predict enterococci concentrations in rivers

2.1 Introduction to the modelling approach

The regression models developed in the present study to predict enterococci concentrations in rivers draining into the Severn estuary are based on the results of previous CREH empirical investigations. These generated data on land use and faecal indicator concentrations during the May–September bathing season in six UK watercourses (Figure 2.1):

- Staithes Beck, Yorkshire (Wyer *et al.*, 1996, 1998; Crowther *et al.*, 2001);
- Afon ('River') Nyfer, south-west Wales (Wyer *et al.*, 1997, 1998; Crowther *et al.*, 2001);
- Afon Ogwr, south Wales (Wyer *et al.*, 1998);
- River Irvine, west Scotland (Wyer *et al.*, 1999);
- Holland Brook, Essex (Wyer *et al.*, 1999); and
- Afon Rheidol/Afon Ystwyth, west Wales (Wyer *et al.*, 2000; Crowther *et al.*, 2003).

As part of these investigations, faecal indicator concentrations (including enterococci) were monitored over a period of 7–10 weeks at 15–31 sampling points on streams and rivers covering a total of 131 subcatchments within the study areas. Details of the sampling periods and number of stream/river sampling points are presented in Table 2.1. Detailed field mapping of land use was undertaken within the catchments using the classification scheme shown in Table 2.2. The percentage area covered by each principal land use type within the six study areas, together with data on catchment area and maximum altitude, are presented in Table 2.3. Whilst there are differences in land use between all six study areas, the Holland Brook study area clearly stands out as being very different from the others, in that it is predominantly arable (67.1 per cent) and has only very small areas of improved pasture (5.0 per cent) and rough grazing (1.6 per cent). It is also has low relief: the maximum altitude within the 93.8 km^2 catchment being 39 m ordnance datum (O.D). The remaining five study areas, which are more representative of the Severn Estuary subcatchments (see below), have larger areas of improved pasture and rough grazing, and also extend to higher altitudes.

For each of these study areas, regression models have been developed that predict geometric mean (GM) enterococci concentrations at individual sampling points during periods of both base flow (dry weather flow) and high flow (maximum flow caused by rainfall)[1] from the percentage of different land use types within their subcatchments. Preliminary work has shown that it is possible to develop generic models by combining the results from all six study areas. During the generic modelling, it became apparent that faecal indicator concentrations were generally lower in those studies conducted under wetter conditions, when the amounts of runoff were greater. This is presumed to be attributable to a dilution effect and the depletion of ‘ground surface’ and ‘stream bed’ stores of faecal indicators during periods of prolonged wet weather. In the present investigation, the effects of variation in the volume of runoff in the six studies have been quantified in order to: (i) increase the accuracy of the generic models; and (ii) allow the predicted concentrations to be adjusted for different volumes of runoff.

Because of the large size of the catchment draining to the Severn Estuary (24,156 km^2) as defined in the present study (Figure 2.2), it was impractical to conduct field mapping of land use. Rather, the Landsat-derived Centre for Ecology and Hydrology (CEH) Land Cover Map of Great Britain for 1990, which provides data at a 25m cell resolution, was utilised. Parallel CEH land cover data were acquired for five of the previous CREH study areas (Figure 2.1): Staithes Beck, Holland Brook and the three Welsh study areas (100 sub catchments or data points). CEH land cover data were not available for the Irvine study area (31 subcatchments).

Where the CEH land cover proved inaccurate, digital OS 1:50,000 map data were used to ensure, for example, that areas of built-up land and woodland were properly categorised and delimited. This was undertaken for the 100 subcatchments in the five ‘ground truth’ study areas and the 29 main river inputs to the Severn estuary (Figure 2.2). The catchment boundaries for these 29 rivers were supplied by the Environment Agency. Details of the approach adopted are presented in Section 2.4.1 below.

2.2 Statistical methods

Multiple regression, incorporating the forward selection stepwise selection procedure (SPSS, 1999), was used to model the relationships between GM enterococci concentrations (dependent variables, *y*) and percentage land use within subcatchments (independent variables, *x*). Independent variables with ≥25 per cent zero values were excluded and $\log_{10}$ transformations applied where skewness exceeded 1.00. In the regression analysis, relationships of the following form were generated:

$$y = a + b_1x_1 + b_2x_2 + ... + b_ix_i \pm u$$

where a is the intercept (y at x = 0), b is the slope (change in y per unit change in x) and u is the stochastic disturbance or random error term. Independent variables with a variance inflation factor >5 (tolerance, 0.200) were excluded to minimise multicollinearity (Rogerson, 2001); the probability of F-to-enter was set at 0.05; the strength of relationships was assessed using the coefficient of determination (r^2),

[1] See Section 3.1.1 for details of how total flow is separated into base flow and high flow

adjusted for degrees of freedom (MINITAB, 1995) and expressed as a percentage; and the normal probability plot of standardised residuals was examined to confirm the normality of the residuals for each model. Pearson correlation (*r*) was also used to investigate simple bivariate relationships. All statistical tests were assessed at the 95 per cent confidence level (α=0.05), where the significance value for a statistical test, *p*, must be $<\alpha$.

2.3 Effects of runoff volumes on enterococci concentrations in the previous study areas

The volume of runoff (total, base flow and high flow – expressed in terms of rainfall equivalent, mm day^{-1}) recorded at the lowest sampling point in each of the six study areas are presented in Table 2.1. These figures reveal very marked variations between the six studies. Total volumes of runoff, for example, range from 0.110 mm day^{-1} (Holland Brook) to 3.660 mm day^{-1} (River Irvine).

The effects of runoff volume cannot be assessed purely on the basis of the GM enterococci concentrations at the catchment outlet (the lowest downstream sampling point) because of the different proportions of individual land use types within the six study areas. The regression models developed for high flow and base flow GM enterococci concentrations in each of the study areas (Figure 2.3a) were therefore used to establish directly comparable indicator concentrations.

During periods of high flow, when discharges of faecal indicator organisms to coastal waters are at their highest (Wyer *et al.*, 1998), the percentage area of improved pasture was entered as the primary variable in the stepwise multiple regression models for the five study areas with relatively high proportions of improved pasture. Given the importance of improved pasture as a source of indicator organisms in these study areas, and its likely importance in the Severn Estuary subcatchments, the Holland Brook study was excluded in this part of the analysis. For the five remaining study areas, a figure of 50 per cent improved pasture was chosen as the basis for deriving comparable high flow GM enterococci concentrations for each study area, using the bivariate relationships between improved pasture and high flow mean $\log_{10}$ enterococci concentrations (Figure 2.3b). This proportion was broadly characteristic of the Severn input subcatchments (see Table 2.7), which had a mean improved pasture cover of 41 per cent. For each study area, the regression equations for the relationship between the percentage area of improved pasture and the mean $\log_{10}$ enterococci concentrations were used to calculate the concentrations for a hypothetical subcatchment with 50 per cent improved pasture (Figure 2.3b). The relationship between high flow runoff (mm per day) in each of the five study areas and predicted mean $\log_{10}$ concentration showed a negative correlation (r = -0.860, p = 0.061, n = 5). The inverse trend demonstrates that high flow microbial concentrations are reduced during wetter 'studies' with higher runoff, producing a dilution effect. The best fit bivariate regression equation for the relationship was used as the basis for standardising the enterococci concentrations in all five study areas for a total volume of runoff of 1.0 mm day^{-1} (Figure 2.3b). These regression equations were subsequently used as a basis for adjusting the predicted GM enterococci concentrations for the Severn Estuary input catchments to allow for the specific volumes of flow recorded during the time period for which the predictions are made (May to September 2001 (see Section 3.1.1)).

The same approach was applied to base flow conditions where the dominant predictor variable selected was the percentage of built-up land (Figure 2.3a). A figure of 5 per cent built-up land was selected as the basis for deriving comparable base flow GM concentrations in the five study areas. Based on the figures in Table 2.7, the mean built-up land cover in the Severn Estuary inputs catchments was 7.2 per cent. Again, an inverse correlation (r = -0.843, p = 0.073, n = 5) was found between the base-flow mean $\log_{10}$ enterococci concentrations and the total volume of base-flow runoff ($\log_{10}$-transformed to increase normality). As with high flow analysis, the relationship was, marginally, not statistically significant (p = 0.073) due to the low number of observations available. The best fit bivariate regression equation (Figure 2.3b) was used as described for high-flow conditions above.

2.4 Derivation of land use maps from CEH 1990 land cover and OS digital map data

2.4.1 Characteristics and limitations of the CEH land cover data

A list of the 25 land use classes identified in the CEH 1990 land cover data is presented in Table 2.4, together with the CREH land use types that correspond most closely with these (based on detailed notes that accompany the CEH 1990 Land Cover Map). Whilst the CEH 1990 data set has the advantage of providing cover for the whole of Great Britain, it is inevitable that quite high proportions of land are misclassified, particularly at local levels in smaller catchment areas. Previous work undertaken in the Ribble catchment, Lancashire, for example, revealed serious inaccuracies in the classification of built-up land (Wyer *et al*., 2003), because extensive limestone quarrying in remote rural areas was classified as land cover type 20 or 21 (built-up land). Similarly, in the Rheidol/Ystwyth and Staithes catchments, bare land on the banks of reservoirs and even water surfaces in the centre of reservoirs are classified as built-up. Similar misclassification of woodland and improved pasture has been observed. In one lowland subcatchment within the Rheidol/Ystwyth catchment, the CEH 1990 land cover suggests woodland cover of 13.09 per cent but a field survey identified only 2.39 per cent woodland cover. In another subcatchment, CEH 1990 data suggest 48.86 per cent woodland whereas a field survey identified 87.50 per cent conifer plantations. The extent of improved pasture (CEH classes 6 and 7) is also underestimated, with 92.38 per cent improved pasture identified by 100 per cent ground truth survey and only 55.82 per cent suggested by CEH. It should be noted, however, that CEH classes 6 and 7 will inevitably include areas of parkland, sports grounds and golf courses. This shows that the CEH 1990 data have substantial limitations and need to be used with circumspection and appropriate corrections.

2.4.2 Addressing some of the limitations of the CEH 1990 data

Given the magnitude of the potential errors observed in the CEH 1990 data, they do not on their own provide a sound basis for developing generic land use-water quality models. The present study has sought to minimise these errors by combining the CEH 1990 data with information extracted from Ordnance Survey (OS) 1:50,000 Scale Colour Raster image data (a digital map based on the OS Landranger series) at an output cell resolution of 25m. This was accomplished using Environmental Systems Research Institute (ESRI) ARC/INFO geographical information system (GIS) software, which required that the image data be converted into a 25m cell resolution grid (a cell-based geographic dataset of attribute values for use with ARC/INFO's GRID software). It was then possible to extract an accurate distribution of built-up land and woodland from the resultant digital map based on the unique colours (attribute values). Further detail on the procedure employed is described below. CEH 1990 data were, however, used for improved pasture (the other key land use variable). An evaluation of this land use type is also presented below.

2.4.2.1 Built-up land

All land classified as 'built-up' in the CEH 1990 land cover (CEH classes 20 and 21) was re-classified as 'unclassified' (CEH class 0). Buildings depicted on the 1:50,000 OS digital map were then extracted on the basis of their unique colour depiction and combined with the CEH 1990 data. Three minor problems arise in extracting the built-up land in this way: (i) only buildings are identified, and not the roads and gardens, which would conventionally be regarded as part of the built up area of settlements; (ii) certain public buildings are excluded because they are depicted in a different colour, which, unfortunately, is not used uniquely for public buildings; (iii) lettering is often superimposed on top of built-up land, thereby further reducing the amount of built-up land extracted. In order to quantify the extent to which the area of built-up land is under-estimated in this procedure, a total of twenty five 500 x 500m squares were selected in the Severn estuary subcatchments, comprising land that would be conventionally classified as 100 per cent built-up. For each of these, the area of built-up land from the OS map was used to calculate the extent to which built-up land is under-estimated. On average, built-up land is under-represented by a factor of 3.11 using the OS 1:50,000 digital map. This factor is used in determining the overall area of built-up land within catchments (see below).

2.4.2.2 Woodland

All land classified as woodland in the CEH 1990 land cover was re-classified as 'unclassified'. Woodland depicted on the 1:50,000 OS digital map was then extracted on the basis of its unique colour depiction and combined with the CEH 1990 data. The woodland extracted in this way corresponds very closely with that identified by field mapping in the 100 subcatchments that make up the five CREH 'ground truth' study areas for which CEH 1990 data were available (excluding the River Irvine catchment).

2.4.2.3 Improved pasture

The CEH 1990 land cover data were used to define improved pasture, despite the inherent limitations noted above. An analysis comparing the results of field mapping with the CEH 1990 data for the 100 CREH ‘ground truth’ subcatchments revealed a strong linear relationship between the two. It should be noted, however, that the CEH 1990 data over-estimate the area of improved pasture in subcatchments where very little is actually present, but under-estimate where a high proportion is present. For example, in a subcatchment with around 80 per cent improved pasture, the corresponding CEH 1990 land cover figure would be around 60 per cent. In addition, it should be noted that five of the 100 subcatchments stood out as clear anomalies. In two of these, which are very small subcatchments in the Staithes Beck catchment, the area of improved pasture is much smaller in the CEH 1990 land cover map than has been mapped in the field. This may reflect actual changes in land use within these subcatchments between 1990 and 1995 as a result of the rotation of fields between grassland and arable production. The same may also apply to a small subcatchment in the Holland Brook study, where the CEH 1990 figure is much higher than that revealed by field mapping in 1997. (Such changes are much more likely to be manifested in small catchments than larger ones.) The final two anomalies are attributable to the presence of an extensive area of recently reclaimed coal mine spoil in the uplands of the Ogwr catchment, which is largely used as rough grazing but was classified as improved pasture in the CEH land cover map. These five anomalous subcatchments have been excluded from the land use-water quality modelling, which was undertaken using the remaining 95 subcatchments.

2.4.2.4 Re-allocation of unclassified land/correction for under-estimation of built-up land

The CEH land cover map includes small areas of unclassified (class '0') land. In addition, the procedures outlined above for dealing with the built-up land and woodland generated additional unclassified land. To determine the area of different land use types within the various subcatchments, the following procedure was adopted. First, unclassified land within each subcatchment was re-allocated as improved pasture, rough grazing, arable and 'other' in proportion to the area of these land use types already identified within the subcatchment (assuming that the data for built-up land and woodland are correct and making no adjustments to them). Second, the area of built-up land was increased to allow for the fact that, in extracting ‘built-up’ data from the OS 1:50,000 map, the built-up area had been underestimated by a factor of 3.11. The area of land required to make this adjustment was subtracted proportionately from improved pasture, rough grazing, arable and 'other'.

2.5 Development of generic models

Stepwise multiple regression analysis was used to model relationships between enterococci concentrations and the percentage area of different land use types within subcatchments. Details and acronyms used to describe the dependent (mean $\log_{10}$ enterococci) and independent (land use) variables used in the analysis are presented in Table 2.5. The results of this analysis are shown in Table 2.6.

During base flow conditions, the enterococci model is statistically significant (*p*<0.0001). Built-up land (LGBLT) is entered at step one and improved pasture (IMPP) at step two. For both variables the regression coefficient is positive and accounts for an explained variance of 38.6 per cent. In previous modelling work (Crowther *et al.,* 2003), built-up land has almost invariably been the dominant predictor variable under base-flow conditions.

At high flow, the explained variance is higher (55.4 per cent). Improved pasture is entered at step one, followed at steps two and three by built-up land and rough grazing (ROUGH). For all three variables, the *b* value is positive. Improved pasture was the dominant predictor of high flow faecal indicator concentrations in the individual studies undertaken in the five study areas with significant proportions of improved pasture (see Figure 2.3a).

2.6 Land use data for the Severn Estuary subcatchments

The land use (derived from the CEH 1990 land cover/OS 1:50,000 digital data) and catchment area of the 29 main input catchments discharging into the Severn estuary are presented in Table 2.7. Over 15 per cent of the catchment areas are made up of improved pasture, which is the key predictor of faecal indicator concentrations at high flow. Indeed, improved pasture accounts for over 40 per cent of the area in two-thirds of the subcatchments (maximum – 74.35 per cent in River Brue subcatchment). The percentage area of built-up land is mostly less than 10 per cent. For example, the Severn subcatchment, which is by far the largest (1,042,264 ha), includes 6.28 per cent built-up land. Only the River Banwell subcatchment, which is one of the smallest (4,591 ha), stands out as having a particularly high proportion of built-up land (25.88 per cent). The majority of the subcatchments include reservoirs, which will tend to reduce the downstream concentrations of faecal indicators. The Frome subcatchment has the highest proportion of land upstream of reservoirs (24.18 per cent).

2.7 Predicted base flow and high flow GM enterococci concentrations for the Severn estuary input catchments

The results of applying the regression models to the land use data are presented in Table 2.8. It should be noted that these figures for base flow and high flow are standardised for 1.00 mm day^{-1} total runoff and 1.00 mm day^{-1} high-flow runoff, respectively. The high flow concentrations are generally an order of magnitude higher than those at low flow, which is consistent with the findings of the previous CREH catchment investigations. The highest predicted high flow GM concentration is for the River Brue (3.0×10^4 cfu 100 ml^{-1}).

3. Enterococci budgets for riverine sources to the Severn Estuary

This section presents the results of calculations to estimate enterococci loads from the 29 main river inputs that discharge to the Severn estuary (Figure 2.2, Table 3.1). Where possible, the calculations were based on time series of discharge ($m^3 s^{-1}$) recorded at Environment Agency discharge gauging stations. In the absence of gauging station data, the time series was estimated using catchment area and discharge time series from an adjacent catchment. Corresponding enterococci concentrations were based on geometric mean concentrations estimated using the land-use water quality models described in Section 2 (Table 2.8). The values were adjusted to reflect the discharge volumes, expressed as mm rainfall equivalent and estimated for each catchment.

3.1 Estimate of river discharge

Discharge time series data, based on 15 minute intervals, were collected for a total of 46 Environment Agency discharge gauging stations within the catchment areas draining to the Severn estuary. The data covered the months from May to September 2001. Data from those stations closest to the catchment outlets (n = 36) were used to estimate discharge rates to the Severn estuary (Figure 3.1, Table 3.1). Each station's time series data was checked for missing values and, where short sequences were missing (<10 hours), linear interpolation was used to fill in the record. For longer sequences of missing data, linear regression was used to model discharge at the station of interest based on discharge at neighbouring station(s), as detailed in the remaining discharge record. This applied to four sites and the models are summarised in Table 3.2. In each case, a variety of lag times in the predictor sequence(s) were studied and the best model was selected based on explained variance (r^2) and the fit of predicted values to empirical data. For those catchments with more than one gauging station, the total discharge measured at each time interval was calculated as the sum discharges from all stations (Table 3.1). The sum of areas to each station (Table 3.1) was also used to calculate the area of catchment contributing to this total (the gauged catchment area). The discharge was then scaled using the ratio of the gauged area to the total catchment area and the sequences of mean hourly discharge were calculated for each catchment. For the eight inputs with no gauging stations, a discharge sequence was calculated from the time series for an adjacent catchment, scaled according to the catchment area (Table 3.1).

3.1.1 Flow separation, runoff and adjusted faecal indicator concentrations

The hourly discharge records from Environment Agency discharge monitoring stations were used to split total flow (Q_t) into two components: (i) base flow (Q_b) and

(ii) high flow (Q_h). This was achieved using a combination of computer programs (Pascal) and visual inspection of individual events. The computer programs apply smoothing to the time series and then examine the change in the smoothed values at each time step to define the start and peak of events above a defined threshold. The event end, or cut off, was set at a decay of 56 per cent of the event peak. This value was derived from an analysis of over 100 events separated manually in previous CREH catchment investigations (Figure 2.1). Whilst this process worked well for larger events, a greater degree of manual intervention was required for smaller events and some event sequences. The final separation was then applied to the unsmoothed hourly time series covering 150 days between 9.00am GMT on 2 May 2001 and 8.00am GMT on 29 September 2001.

The base flow, high flow and total discharge values (m^3) for each input are summarised in Table 3.3. These discharge values were used along with the catchment area (A) (Table 3.1), both suitably scaled (discharge in mm^3 and area in mm^2), to express the runoff as mm of rainfall equivalent (RE (mm day^{-1})) during the study period:

$$RE = (Q/A)/150 \tag{3.1}$$

Two RE parameters were calculated for use in the adjustment calculations: (i) RE_t, which is based on Q_t and (ii) RE_h, which is based on Q_h. In both cases, the calculation was based on the full 150-day period.

The predicted GM base flow enterococci concentrations (C_{pb}) in Table 2.8 were adjusted (C_{ab}) for rainfall equivalent using the following equation:

$$\log_{10}C_{ab} = \log_{10}C_{pb} – (0.670291 \times \log_{10} RE_t) \tag{3.2}$$

The predicted GM high flow enterococci concentrations (C_{ph}) in Table 2.8 were adjusted (C_{ah}) for rainfall equivalent using the following equation:

$$\log_{10}C_{ah} = \log_{10}C_{ph} – (0.850585 \times \log_{10} RE_h) \tag{3.3}$$

The coefficients for each flow condition were derived from the regression modelling described in Section 2.3. Where $RE > 1$: $C_a < C_p$, representing dilution under wetter conditions. Conversely, where $RE < 1$: $C_a > C_p$. The adjusted GM concentrations are listed in Table 3.4.

3.2 Enterococci organism load estimates

Enterococci load estimates were made using the base flow and high flow GM concentrations in Table 3.4 (predicted values in Table 2.8 adjusted for runoff equivalent (RE) in Table 3.3). For each hour the load (L (organisms $second^{-1}$)) was calculated for each source depending on the categorisation of the hour into base (b) and high flow (h) components:

$$L_{ib} = Q_{ib} \times C_{ib} \tag{3.4}$$
$$L_{ih} = Q_{ih} \times C_{ih} \tag{3.5}$$

where:

Q_{ib} = discharge (m^3 s^{-1}), base-flow category
Q_{ih} = discharge (m^3 s^{-1}), high-flow category
C_{ib} = geometric mean (GM) concentration (m^{-3}), base flow category
C_{ih} = geometric mean (GM) concentration (m^{-3}), high flow category

This produced hourly time series of estimated enterococci organism load ($second^{-1}$) for each of the 29 river and stream inputs for the 150-day period. These sequences were used as inputs to the hydrodynamic model of the Severn estuary. A summary of overall load estimates is provided in Table 3.5.

The proportion (per cent) of the total discharge to the Severn estuary from the 29 catchment inputs for the 150-day study period is summarised in Table 3.6. This table also summarises the proportional contribution of the base flow and high flow discharge components to the total discharge from each site. Overall figures show just under 40 per cent of the total discharge (m^3) to be associated with high flow conditions. The largest contributions are associated with the largest catchments, such as the Severn, Wye and Usk. Individual inputs show variation in the proportion of discharge associated with high flow conditions: mean 28 per cent, range 12 per cent to 49 per cent. The highest proportions (> 44 per cent) are associated with the larger input catchments. The duration of high flow periods also varied between inputs, ranging from 6.7 per cent to 40.1 per cent of the study period (mean 16.3 per cent). The longest durations (> 30 per cent) were again associated with the largest inputs.

Table 3.7 summarises the proportion (per cent) of the predicted enterococci load to the Severn estuary supplied by the 29 catchment inputs for the 150-day study period. Overall, this suggests that over 90 per cent of the enterococci load to the estuary is associated with high flow conditions. As would be expected, the largest proportional contribution is from the largest catchment inputs, with the River Severn, during high flow, contributing over a quarter of the total estimated enterococci loads. A summary of the proportional (per cent) base and high flow contribution for each input is provided in Table 3.8. This shows that high flow conditions dominate the modelled enterococci flux for every site (mean 92.4 per cent, range 83.6 per cent–97.3 per cent)).

4. Enterococci budgets for consented discharges to the Severn Estuary

This section presents the results of calculations to estimate enterococci inputs from discharges of sewage effluent to the Severn estuary (point sources of sewage effluent). This analysis was restricted to the main discharges with population equivalents (PE) greater than 2,000. Where possible, the calculations were based on details of measured dry weather flow (DWF) values from 2001. Where such data were unavailable, consented flow values (DWF and maximum flow) from the Environment Agency consents database were used, with the most recent consent values used where available. In the absence of defined discharge values, flow rates were estimated using PE assuming 180 litres of effluent per PE day^{-1} (taken from Water Quality Consents Manual EAS/2301 - Standard Flows to Full Treatment V2), with an added 50 per cent infiltration (from discussions with water company officials). Where maximum flow data were not available this value was assumed to be 3 x DWF.

Corresponding values for enterococci concentrations were based on microbial levels in effluent samples taken during previous CREH investigations and categorised by the level of treatment (untreated, primary settled, biologically treated, disinfected and storm overflow). The appropriate concentration was then assigned to each source based on the discharge type (final effluent or storm overflow) and treatment level specified in the consent details.

4.1 Waste water treatment works

A total of 34 discharges with PE >2000 were identified, made up of 33 wastewater treatment works (WwTW) final effluents and one brewery effluent treatment plant (Figure 4.1, Table 4.1). Table 4.1 also summarises available discharge data ($m^3 s^{-1}$).

4.2 Enterococci concentrations in sewage effluent

Calculating enterococci fluxes from WwTW effluents requires information on faecal indicator concentrations in effluent. Bacterial concentrations are, generally, not monitored for individual works, as final effluent discharge consents are normally based on other parameters such as suspended solids concentration, biological oxygen demand (BOD) and ammoniacal nitrogen concentration.

CREH have undertaken budget studies at a range of locations across the UK (Fewtrell *et al*., 1998; Stapleton *et al*., 1999, 2000a, 2000b, 2002 Wyer *et al*., 1995, 1996, 1997, 1998b, 1998c, 1999a, 1999b, 2000a, 2000b, 2001, 2003) (Figure 2.1).

These have invariably involved sampling sewage and associated overflow effluents. Stapleton *et al*. (2002) compiled, analysed and presented a database of faecal indicator organism concentrations (including enterococci) in effluent samples containing data from all these studies. Their analysis found little evidence of statistically significant differences in mean $\log_{10}$ faecal indicator organism concentrations between various primary treated effluents. Likewise, there was little difference in mean $\log_{10}$ faecal indicator organism concentrations in effluent from various biological treatment types (such as activated sludge, percolating filter, oxidation ditch) and the data were therefore grouped into six broad categories. The results are summarised in Table 4.2 and Figure 4.2.

Each of the effluents was assigned GM enterococci concentrations according to the treatment type in Table 4.1. In one case (input 34, Porlock WwTW), the treatment type – defined as biological plus disinfection by membrane filtration – was not covered in the previous effluent quality studies. Enterococci concentrations were assumed to be negligible in this effluent (following consultation with water company personnel) and it has been effectively discounted as a significant source of enterococci. The estimated enterococci loads (organisms second^{-1}) for dry weather and maximum effluent flows were calculated as the product of discharge ($m^3\ s^{-1}$) and concentration (cfu m^{-3}) for each input and are summarised in Table 4.3. Unlike the river inputs, no time series of effluent discharge was available for the sewage effluent inputs. The results were therefore used to provide general background loading data from major sewage effluent sources to the Severn estuary hydrodynamic model. Due to lack of reliable data, estimates of inputs from storm overflows such as storm tanks and combined sewer overflows were not included.

Table 4.4. summarises the proportional contribution (per cent) of each source to both the total dry weather and total maximum flow load to the Severn estuary. This shows that the two main WwTW sources of enterococci organisms to the Severn estuary were Cardiff and Avonmouth. These two sources provide over 46 per cent of the effluent discharge and at least half of the estimated loads from all the inputs that were analysed.

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Tables

Table 2.1: The six study areas used in developing the generic models: study period, total number of stream/river sampling points and volumes of runoff (total, base flow and high flow: expressed in terms of rainfall equivalent, mm day^{-1}) recorded at the outlet of the catchment

Study Area	Study period	Sample points	Volume of runoff (rainfall equivalent, mm day^{-1})		
		(*n*)	Total	Base flow	High flow
Staithes Beck	July–September 1995	15	0.215	0.124	0.091
Afon Nyfer	June–August 1996	28	0.472	0.329	0.143
Afon Ogwr	July–September 1997	18	2.602	1.475	1.127
River Irvine[1]	August–September 1998	31	3.660	1.250	2.410
Holland Brook[2]	June–July 1998	15	0.110	0.049	0.061
Afon Rheidol/Ystwyth	August–September 1999	24	1.373	0.493	0.880

[1] Used in investigating relationships between geometric mean indicator concentrations and volume of runoff, but not in developing models using Centre for Ecology and Hydrology 1990 land cover (data not available for project)

[2] Used in developing models using Centre for Ecology and Hydrology 1990 land cover, but not in investigating relationships between geometric mean indicator concentrations and volume of runoff (see text)

Table 2.2: Land use types in the classification scheme used by CREH in land use-water quality modelling projects

Land use type[1]	Description/comments/subtypes
Improved pasture	Improved permanent or ley grassland on dairy/livestock farms that is intensively used for grazing and/or silage production + moderately to slightly improved permanent grassland, which is generally less intensively used, mostly for grazing, and often shows localised signs of reversion (with *Juncus* spp.)
Rough grazing	Moorland + poor quality grassland, enclosed and improved in the past, but showing no sign of recent improvement – now used as rough pasture, mostly for sheep and beef cattle, with lower stocking levels than the improved pasture
Arable	Individual crop types are identified as subtypes
Woodland	Deciduous woodland, mixed woodland and conifer plantations are identified as subtypes
Built up	Residential/commercial, light industry, heavy industry, caravan parks and farmyards are identified as subtypes
Other	Includes the following subtypes: parkland, waste ground, recently felled forest and waterbodies

[1] In the modelling work undertaken, reservoirs/other water bodies on the river network and the land within their catchments have been re-classified as 'reservoir catchment' (see text)

Table 2.3: Total area, maximum altitude and percentage area of principal land use types within the six CREH study areas

Study Area	Total area (km^2)	Max altitude (m)	Area (% of land area within catchment)						
			Improved pasture	Rough grazing	Arable	Woodland	Built-up	Other	Reservoir catchment
Staithes Beck	42.8	299	36.6	15.3	19.8	10.2	1.8	3.1	13.1
Afon Nyfer	118.9	537	63.9	19.2	6.4	6.8	2.6	1.1	-
Afon Ogwr	272.3	568	45.7	20.0	5.6	12.0	10.8	5.9	-
River Irvine	726.9	350	59.7	12.9	2.4	9.2	5.2	2.5	8.2
Holland Brook	93.8	39	5.0	1.6	67.7	3.1	14.6	8.0	-
Afon Rheidol/ Ystwyth	379.3	752	30.7	14.1	0.3	12.0	1.7	1.3	39.9

Table 2.4: Details of the Centre for Ecology and Hydrology (CEH) 1990 land cover classification and the corresponding CREH land use type to which they have been attributed

CEH class	Description	CREH land use type to which the CEH class has been attributed[1]
0	Unclassified	Unclassified
1	Sea, coastal waters and estuaries, inland to first bridging point or barrier	Other
2	Inland fresh waters and estuarine waters above the first bridging point or barrier	Other
3	Bare coastal mud, silt, sand shingle and rock, including coastal accretion and erosion features above high water	Other
4	Intertidal seaweed beds and salt marshes up to normal levels of high water spring tides	Other
5	Semi-natural, mostly acid, grasslands of dunes, heaths and lowland-upland margins	Rough grazing
6	Pastures and amenity swards, mown or grazed, to form a turf throughout the growing season	Improved pasture
7	Meadows, verges, low intensity amenity grasslands and semi-natural cropped swards, not maintained as short turf	Improved pasture
8	Lowland marsh/rough grasslands, mostly uncropped and unmanaged, forming grass and herbaceous communities, of mostly perennial species, with high winter litter content	Rough grazing
9	Montane/hill grasslands, mostly unenclosed *nardus/molinia* moorland	Rough grazing
10	Upland, dwarf shrub/grass moorland	Rough grazing
11	Upland evergreen dwarf shrub-dominated moorland	Rough grazing
12	Bracken-dominated herbaceous communities	Rough grazing
13	Lowland evergreen shrub-dominated heathland	Rough grazing
14	Deciduous scrub and orchards	Other
15	Deciduous broadleaved woodland and mixed woodlands	Woodland
16	Conifer and broadleaved evergreen trees	Woodland
17	Lowland herbaceous wetlands with permanent or temporary standing water	Rough grazing
18	Arable and other seasonally or temporarily bare ground	Arable
19	Ruderal weeds colonising natural and man-made bare ground	Other
20	Suburban and rural developed land comprising buildings and/or roads but with some cover of permanent vegetation	Built-up
21	Industrial, urban and any other developments lacking permanent vegetation	Built-up
22	Ground bare of vegetation, surfaced with 'natural' materials	Other
23	Felled forest, with ruderal weeds and rough grass	Other
24	Lowland herbaceous wetlands with permanent or temporary standing water	Rough grazing
25	Lowland dwarf shrub/grass heathland	Rough grazing

[1] Based on detailed notes that accompany the classification scheme.

Table 2.5: Details of the variables used in the stepwise multiple regression analysis for modelling relationships between subcatchment land use and microbial water quality in 95 subcatchments in the Staithes Beck, Afon Nyfer, Afon Ogwr, Holland Brook and Afon Rheidol/ Ystwyth study areas

Variable code	Details
DEPENDENT VARIABLES[1]	
	BASE FLOW:
AMLENTB	Adjusted (for total flow volume) mean $\log_{10}$ enterococci concentration
	HIGH FLOW:
AMLENTH	Adjusted (for high flow volume) mean $\log_{10}$ enterococci concentration
INDEPENDENT (LAND USE) VARIABLES[2] (% area of subcatchment)	
IMPP	Improved pasture
ROUGH	Rough grazing
LGWOOD	Woodland
LGBLT	Built-up land
LGVLRSK	Combination of land uses (reservoir catchment + arable + woodland) which pose a very low risk of high enterococci concentrations in watercourses

[1] The GM enterococci concentrations, both base flow and high flow, have been adjusted to a standard runoff volume (rainfall equivalent) of 1.00 mm/day – details of the regression analysis used as the basis for these adjustments are described in the text

[2] The land use is based on a combination of CEH 1990 land cover and OS 1:50,000 digital map data (see text). Variables were excluded from the regression analyses when ≥ 25% of the data values were 0.0, which accounts for the exclusion of other potential land use variables (such as arable, reservoir catchment). The skewness of all the independent variables was checked and $\log_{10}$ transformations applied where values exceed 1.0 (as indicated by the prefix LG to the variable code)

Table 2.6: Results of regression analysis for relationships between land use and microbial water quality in 95 subcatchments in the Staithes Beck, Afon Nyfer, Afon Ogwr, Holland Brook and Afon Rheidol/ Ystwyth study areas[1]

Dependent variable[2]	Variables entered in regression equation	Sign of *b* value[3]	Adjusted r^2 (%)	Fit of normal probability plot of standardised residuals[4]	Significance *p*
BASE FLOW:					
AMLENTB	LGBLT	+	31.7		
	IMPP	+	38.6	*	<0.0001
HIGH FLOW[5]:					
AMLENTH	IMPP	+	43.0		
	LGBLT	+	50.4		
	ROUGH	+	55.4	*	<0.0001

1 The models shown have been used to predict enterococci concentrations in the Severn estuary subcatchments
2 Details of the variables are given in Table 2.5
3 This indicates whether the relationship is positive or negative
4 ** = good fit; * = acceptable fit; ? = poor fit
5 In the high flow model LGWOOD or LGVLRSK was entered as a further predictor variable, but with +ve *b* values rather than the expected -ve values. These have not therefore been included in the model used to predict high flow enterococci concentrations in the Severn Estuary subcatchments

Table 2.7: Catchment area and percentage of different land use types (derived from the CEH 1990 land cover/OS 1:50,000 digital data) of the 29 subcatchments that discharge into the Severn estuary

Input no. and Catchment		Area (ha)	Improved pasture (%)	Rough grazing (%)	Arable (%)	Woodland (%)	Built-up land (%)	Other (%)	Resr catch (%)
01	Tawe	27830.00	20.82	52.94	2.35	8.61	6.73	3.36	5.20
02	Nedd	31784.38	18.36	38.78	2.32	29.10	4.86	3.78	2.80
03	Afan	12751.25	17.71	24.08	1.59	46.39	6.60	3.63	0.00
04	Kenfig	5832.69	43.80	13.85	9.58	8.74	8.11	5.82	10.11
05	Ogwr	32821.31	48.18	21.51	10.60	9.84	7.77	2.10	0.00
06	Ely	16059.50	45.35	18.21	7.69	8.98	12.26	2.10	5.41
07	Taf	53570.94	24.94	26.99	3.12	15.73	9.16	2.57	17.48
08	Rhymney	22646.87	36.58	22.69	7.10	6.81	12.50	1.90	12.41
09	Ebbw	26256.94	35.38	25.31	6.88	7.33	9.79	1.87	13.43
10	Usk	148140.62	46.96	28.11	6.82	8.26	4.15	1.47	4.23
11	Wye	417765.12	45.57	17.22	17.09	9.53	2.40	1.30	6.89
12	Severn	1042263.94	40.63	7.61	29.69	6.07	6.28	1.69	8.04
13	Frome	22834.81	32.02	10.49	14.71	8.14	8.72	1.74	24.18
14	Little Avon	17356.88	49.46	7.85	18.49	8.59	4.27	1.99	9.34
15	Avon	221451.31	41.78	5.44	23.44	4.20	10.98	2.28	11.87
16	Portbury Ditch	4042.94	48.72	7.86	13.35	10.24	14.47	5.36	0.00
17	Land Yeo	10782.00	56.44	6.27	14.13	9.66	11.33	2.18	0.00
18	Congresbury Yeo	10505.50	53.77	7.72	7.91	5.30	5.33	1.26	18.71
19	Banwell	4590.50	53.72	2.74	11.46	3.96	25.88	2.25	0.00
20	Axe	26379.12	71.44	6.62	10.93	3.18	6.22	1.62	0.00
21	Brue	52430.31	74.35	3.99	11.09	2.28	6.05	1.09	1.15
22	Parrett	169919.63	50.03	3.83	28.64	4.27	5.63	1.84	5.76
23	Kilve Stream	2689.94	15.89	30.19	35.79	10.83	2.05	5.25	0.00
24	Doniford Stream	7998.44	40.54	10.93	27.57	7.29	3.69	2.16	7.83
25	Washford River	4813.50	45.59	9.42	25.14	14.69	2.69	2.49	0.00
26	Pill River	1632.94	31.39	9.33	44.28	8.31	3.60	3.10	0.00
27	Avill River	6089.38	42.59	20.51	10.92	19.78	4.24	1.96	0.00
28	Horner Water	3835.63	30.34	25.41	12.24	15.31	1.21	0.86	14.63
29	Lyn	10467.94	40.72	53.32	1.15	3.58	0.83	0.40	0.00

Table 2.8: Predicted base- and high-flow geometric mean (GM) enterococci concentrations (cfu 100 ml^{-1}) for the 29 Severn estuary input catchments, based on 1.00 mm day^{-1} total runoff and 1.00 mm day^{-1} high-flow runoff, respectively

Input no. and Catchment		Base flow GM Enterococci (cfu 100ml^{-1})	High flow GM Enterococci (cfu 100ml^{-1})
01	Tawe	3.2×10^2	3.0×10^3
02	Nedd	2.3×10^2	1.6×10^3
03	Afan	3.0×10^2	1.5×10^3
04	Kenfig	6.2×10^2	6.8×10^3
05	Ogwr	6.5×10^2	9.9×10^3
06	Ely	9.3×10^2	1.1×10^4
07	Taf	4.6×10^2	3.0×10^3
08	Rhymney	7.8×10^2	6.9×10^3
09	Ebbw	6.1×10^2	5.7×10^3
10	Usk	3.8×10^2	6.9×10^3
11	Wye	2.4×10^2	3.8×10^3
12	Severn	4.6×10^2	4.2×10^3
13	Frome	5.2×10^2	3.3×10^3
14	Little Avon	4.1×10^2	5.7×10^3
15	Avon	7.8×10^2	6.3×10^3
16	Portbury Ditch	1.2×10^3	1.2×10^4
17	Land Yeo	1.1×10^3	1.6×10^4
18	Congresbury Yeo	5.3×10^2	8.5×10^3
19	Banwell	2.2×10^3	2.3×10^4
20	Axe	8.8×10^2	2.7×10^4
21	Brue	9.2×10^2	3.0×10^4
22	Parrett	5.2×10^2	6.5×10^3
23	Kilve Stream	1.2×10^2	7.4×10^2
24	Doniford Stream	3.0×10^2	3.2×10^3
25	Washford River	2.6×10^2	3.6×10^3
26	Pill River	2.4×10^2	1.8×10^3
27	Avill River	3.5×10^2	4.7×10^3
28	Horner Water	1.1×10^2	1.3×10^3
29	Lyn	1.2×10^2	3.4×10^3

Table 3.1: Details of Environment Agency gauging stations, catchment area gauged (km^2) and total catchment area (km^2) used to estimate discharge from the 29 Severn Estuary input catchments

Input no. and Catchment		Gauging station(s) used to define discharge	Area Gauged (km^2)	Catchment Area (km^2)
01	Tawe	Ynystanglws	227.7	278.301
02	Nedd	Resolven (Nedd) + Cilfrew (Dulais)	233.9	317.830
03	Afan	Marcroft Weir	87.8	127.505
04	Kenfig	None – discharge scaled from input 03 – Afan	—	58.334
05	Ogwr	Bridgend (Ogwr) + Keeper's Lodge (Ewenni)	220.5	328.226
06	Ely	St Fagans	145.0	160.594
07	Taf	Pontypridd	454.8	535.710
08	Rhymney	Llanyderyn	178.7	226.484
09	Ebbw	Rhiwderyn	216.5	262.545
10	Usk	Trostrey (Usk) + Olway Inn (Olway Brook)	1032.3	1481.369
11	Wye	Redbrook	4010.0	4177.735
12	Severn	Saxons Lode (Severn) + Bredon (Avon) + Wedderburn Bridge (Leadon)	9817.0	10423.000
13	Frome	Ebley Mill	198.0	228.000
14	Little Avon	Berkeley Kennels	134.0	173.595
15	Avon	Bathford (Avon) + Frenchay (Frome) + Bitton (Boyd) + Compton Dando (Chew)	1878.9	2214.522
16	Portbury Ditch	None – discharge scaled from input 17 – Land Yeo	—	40.432
17	Land Yeo	Wraxhall Bridge	23.3	107.824
18	Congresbury Yeo	Iwood	66.6	105.051
19	Banwell	None – discharge scaled from input 18 – Congresbury Yeo	—	45.926
20	Axe	None – discharge scaled from input 21 – Brue	—	263.771
21	Brue	Lovington (Brue) + Fenney Castle (Sheppey)	194.8	524.304
22	Parrett	Halsewater (Halsewater) + Ashford (Isle) + Bishops Hull (Tone) + Pen Mill (Yeo) + Chiselborough (Parrett) + Somerton (Cary) + Curry Pool Farm (Currypool Stream)	765.9	1699.186
23	Kilve Stream	None – discharge scaled from input 24 – Doniford Stream	—	26.898
24	Doniford Stream	Swill Bridge	75.8	79.971
25	Washford River	Beggearn Huish	36.3	48.154
26	Pill River	None – discharge scaled from input 26 – Washford River	—	16.331
27	Avill River	None – discharge scaled from input 26 – Washford River	—	60.895
28	Horner Water	West Luccombe	20.8	38.357
29	Lyn	None – discharge scaled from input 28 – Horner Water	—	104.674

Table 3.2: Linear regression models[1] used to predict discharge (Q) at gauging stations with long sequences of missing data

Catchment	Variables	Slope (a)	Intercept (b)	Random Error Term (u)	Lag in x (hours)	r^2 (%)[2]	p[3]
Nedd	Dependent (y): Q@Cilfrew (Dulais)	+ 0.180	+ 0.0102	±0.7027	None	90.1	0.000
	Predictor (x): Q@Resolven (Nedd)						
Usk	Dependent (y): Trostrey (Usk)	+0.949	+3.060	±1.5030	None	95.2	0.000
	Predictor (x): Q@Chain Bridge (Usk)						
Severn	Dependent (y): $\log_{10}$Q@Wedderburn Bridge (Leadon)	+0.903	-0.936	±0.1055	-3.5	81.1	0.000
	Predictor (x): $\log_{10}$Q@Bredon (Avon)						
Washford	Dependent (y): Q@Beggearn Huish (Washford River)	0.606	-0.060	±0.0525	+3.75	91.5	0.000
	Predictor (x): Q@Swill Bridge (Doniford Stream)						

[1] Model form: $y = ax + b \pm u$
[2] r^2 = % variance in Y explained by X
[3] p = significance – the model is significant at the 95 per cent confidence level when $p < 0.05$

Table 3.3: Summary of discharge estimates (m^3), high flow duration (hours) and runoff rainfall equivalent (*RE*) values (mm day^{-1}) for the 29 Severn Estuary input catchments for a 150-day period between 2 May 2001 and 29 September 2001

Input no. and Catchment		Total flow Q_t (m^3)	Base flow Q_b (m^3)	High flow Q_h (m^3)	High flow (hours)	RE_t[1] (mm day^{-1})	RE_h[2] (mm day^{-1})
01	Tawe	$8.29x10^7$	$4.69x10^7$	$3.60x10^7$	503	1.9857	0.8614
02	Nedd	$8.86x10^7$	$5.04x10^7$	$3.83x10^7$	551	1.8592	0.8026
03	Afan	$4.83x10^7$	$3.31x10^7$	$1.52x10^7$	385	2.5272	0.7966
04	Kenfig	$2.21x10^7$	$1.51x10^7$	$6.97x10^6$	385	2.5272	0.7966
05	Ogwr	$9.15x10^7$	$6.21x10^7$	$2.94x10^7$	451	1.8592	0.5977
06	Ely	$3.38x10^7$	$2.04x10^7$	$1.34x10^7$	498	1.4035	0.5550
07	Taf	$1.35x10^8$	$9.31x10^7$	$4.16x10^7$	499	1.6758	0.5175
08	Rhymney	$4.54x10^7$	$3.01x10^7$	$1.53x10^7$	502	1.3365	0.4491
09	Ebbw	$5.51x10^7$	$3.75x10^7$	$1.76x10^7$	633	1.3992	0.4470
10	Usk	$2.20x10^8$	$1.11x10^8$	$1.09x10^8$	1445	0.9902	0.4903
11	Wye	$4.07x10^8$	$2.27x10^8$	$1.80x10^8$	1246	0.6492	0.2865
12	Severn	$7.39x10^8$	$3.99x10^8$	$3.41x10^8$	1099	0.4728	0.2179
13	Frome	$3.05x10^7$	$2.47x10^7$	$5.80x10^6$	674	0.8915	0.1697
14	Little Avon	$1.05x10^7$	$8.03x10^6$	$2.50x10^6$	362	0.4044	0.0960
15	Avon	$1.39x10^8$	$8.92x10^7$	$4.99x10^7$	805	0.4187	0.1502
16	Portbury Ditch	$3.20x10^6$	$2.03x10^6$	$1.17x10^6$	902	0.5276	0.1934
17	Land Yeo	$8.53x10^6$	$5.40x10^6$	$3.13x10^6$	902	0.5275	0.1934
18	Congres. Yeo	$8.09x10^6$	$6.72x10^6$	$1.37x10^6$	241	0.5136	0.0871
19	Banwell	$3.54x10^6$	$2.94x10^6$	$6.00x10^5$	241	0.5136	0.0871
20	Axe	$2.14x10^7$	$1.72x10^7$	$4.15x10^6$	455	0.5400	0.1049
21	Brue	$4.25x10^7$	$3.42x10^7$	$8.25x10^6$	455	0.5400	0.1049
22	Parrett	$1.15x10^8$	$9.06x10^7$	$2.45x10^7$	610	0.4514	0.0960
23	Kilve Stream	$2.56x10^6$	$2.21x10^6$	$3.55x10^5$	420	0.6348	0.0879
24	Doniford Str.	$7.61x10^6$	$6.56x10^6$	$1.05x10^6$	420	0.6348	0.0879
25	Washford R.	$4.76x10^6$	$4.18x10^6$	$5.80x10^5$	360	0.6589	0.0803
26	Pill River	$1.61x10^6$	$1.42x10^6$	$1.97x10^5$	360	0.6589	0.0803
27	Avill River	$6.02x10^6$	$5.28x10^6$	$7.34x10^5$	360	0.6589	0.0803
28	Horner Water	$3.81x10^6$	$2.94x10^6$	$8.70x10^5$	642	0.6623	0.1511
29	Lyn	$1.04x10^7$	$8.03x10^6$	$2.37x10^6$	642	0.6624	0.1511
	Total	$2.39x10^9$	$1.44x10^9$	$9.5x10^8$			

[1] RE_t = Total discharge expressed as rainfall equivalent per day based on a 150-day period (3600 hours)

[2] RE_h = High flow discharge expressed as rainfall equivalent per day based on a 150-day period (3600 hours)

Table 3.4: Rainfall equivalent runoff adjusted base and high flow geometric mean (GM) enterococci concentrations (cfu 100 ml^{-1}) for the 29 Severn estuary input catchments

Input no. and Catchment		Base flow GM enterococci (cfu 100 ml^{-1})	High flow GM enterococci (cfu 100 ml^{-1})
01	Tawe	$2.04 x 10^2$	$3.39 x 10^3$
02	Nedd	$1.54 x 10^2$	$1.96 x 10^3$
03	Afan	$1.60 x 10^2$	$1.77 x 10^3$
04	Kenfig	$3.33 x 10^2$	$8.23 x 10^3$
05	Ogwr	$4.32 x 10^2$	$1.53 x 10^4$
06	Ely	$7.39 x 10^2$	$1.76 x 10^4$
07	Taf	$3.28 x 10^2$	$5.19 x 10^3$
08	Rhymney	$6.46 x 10^2$	$1.36 x 10^4$
09	Ebbw	$4.89 x 10^2$	$1.12 x 10^4$
10	Usk	$3.80 x 10^2$	$1.27 x 10^4$
11	Wye	$3.25 x 10^2$	$1.11 x 10^4$
12	Severn	$7.67 x 10^2$	$1.55 x 10^4$
13	Frome	$5.56 x 10^2$	$1.48 x 10^4$
14	Little Avon	$7.47 x 10^2$	$4.19 x 10^4$
15	Avon	$1.40 x 10^3$	$3.18 x 10^4$
16	Portbury Ditch	$1.78 x 10^3$	$4.93 x 10^4$
17	Land Yeo	$1.68 x 10^3$	$6.46 x 10^4$
18	Congresbury Yeo	$8.35 x 10^2$	$6.76 x 10^4$
19	Banwell	$3.48 x 10^3$	$1.82 x 10^5$
20	Axe	$1.34 x 10^3$	$1.82 x 10^5$
21	Brue	$1.39 x 10^3$	$2.04 x 10^5$
22	Parrett	$8.80 x 10^2$	$4.79 x 10^4$
23	Kilve Stream	$1.58 x 10^2$	$5.82 x 10^3$
24	Doniford Stream	$4.07 x 10^2$	$2.54 x 10^4$
25	Washford River	$3.48 x 10^2$	$3.03 x 10^4$
26	Pill River	$3.21 x 10^2$	$1.51 x 10^4$
27	Avill River	$4.63 x 10^2$	$4.01 x 10^4$
28	Horner Water	$1.52 x 10^2$	$6.37 x 10^3$
29	Lyn	$1.57 x 10^2$	$1.71 x 10^4$

Table 3.5: Summary of total enterococci loads (organisms) for the 29 Severn Estuary input catchments during the 150-day period between 2 May 2001 and 29 September 2001

Input no. and Catchment		Base flow enterococci (organisms)	High flow enterococci (organisms)
01	Tawe	9.60×10^{13}	1.22×10^{15}
02	Nedd	7.78×10^{13}	7.50×10^{14}
03	Afan	5.30×10^{13}	2.70×10^{14}
04	Kenfig	5.04×10^{13}	5.73×10^{14}
05	Ogwr	2.68×10^{14}	4.49×10^{15}
06	Ely	1.51×10^{14}	2.35×10^{15}
07	Taf	3.05×10^{14}	2.16×10^{15}
08	Rhymney	1.95×10^{14}	2.07×10^{15}
09	Ebbw	1.83×10^{14}	1.98×10^{15}
10	Usk	4.22×10^{14}	1.38×10^{16}
11	Wye	7.38×10^{14}	2.00×10^{16}
12	Severn	3.06×10^{15}	5.27×10^{16}
13	Frome	1.37×10^{14}	8.60×10^{14}
14	Little Avon	6.00×10^{13}	1.05×10^{15}
15	Avon	1.24×10^{15}	1.58×10^{16}
16	Portbury Ditch	3.61×10^{13}	5.78×10^{14}
17	Land Yeo	9.06×10^{13}	2.02×10^{15}
18	Congresbury Yeo	5.61×10^{13}	9.28×10^{14}
19	Banwell	1.02×10^{14}	1.09×10^{15}
20	Axe	2.30×10^{14}	7.57×10^{15}
21	Brue	4.75×10^{14}	1.68×10^{16}
22	Parrett	7.98×10^{14}	1.17×10^{16}
23	Kilve Stream	3.48×10^{12}	2.07×10^{13}
24	Doniford Stream	2.67×10^{13}	2.68×10^{14}
25	Washford River	1.46×10^{13}	1.76×10^{14}
26	Pill River	4.55×10^{12}	2.97×10^{13}
27	Avill River	2.45×10^{13}	2.94×10^{14}
28	Horner Water	4.46×10^{12}	5.54×10^{13}
29	Lyn	1.26×10^{13}	4.06×10^{14}
	Total	8.92×10^{15}	1.62×10^{17}

Table 3.6: Summary of proportional (%) contributions of discharge for the 29 Severn estuary input catchments during the 150-day period between 2 May 2001 and 29 September 2001

		Proportion (%) of total discharge – 2.39×10^9 m^3:			Proportion (%) by catchment		
Input no. and Catchment		Base flow Discharge	High flow Discharge	Total Discharge	Base flow Discharge	High flow Discharge	High flow Duration
01	Tawe	1.9657	1.5060	3.4717	56.6212	43.3788	13.9722
02	Nedd	2.1097	1.6026	3.7123	56.8299	43.1701	15.3056
03	Afan	1.3863	0.6381	2.0244	68.4803	31.5197	10.6944
04	Kenfig	0.6342	0.2919	0.9262	68.4803	31.5197	10.6944
05	Ogwr	2.6013	1.2324	3.8337	67.8535	32.1465	12.5278
06	Ely	0.8560	0.5599	1.4160	60.4564	39.5436	13.8333
07	Taf	3.8984	1.7417	5.6401	69.1198	30.8802	13.8611
08	Rhymney	1.2626	0.6389	1.9016	66.3996	33.6004	13.9444
09	Ebbw	1.5705	0.7373	2.3078	68.0514	31.9486	17.5833
10	Usk	4.6524	4.5632	9.2155	50.4839	49.5161	40.1389
11	Wye	9.5192	7.5185	17.0377	55.8714	44.1286	34.6111
12	Severn	16.6914	14.2670	30.9583	53.9156	46.0844	30.5278
13	Frome	1.0338	0.2431	1.2769	80.9653	19.0347	18.7222
14	Little Avon	0.3364	0.1047	0.4410	76.2668	23.7332	10.0556
15	Avon	3.7365	2.0892	5.8256	64.1386	35.8614	22.3611
16	Portbury Ditch	0.0849	0.0491	0.1340	63.3456	36.6544	25.0556
17	Land Yeo	0.2264	0.1310	0.3573	63.3438	36.6562	25.0556
18	Congresbury Yeo	0.2815	0.0575	0.3389	83.0497	16.9503	6.6944
19	Banwell	0.1231	0.0251	0.1482	83.0497	16.9503	6.6944
20	Axe	0.7210	0.1738	0.8948	80.5792	19.4208	12.6389
21	Brue	1.4332	0.3454	1.7787	80.5792	19.4208	12.6389
22	Parrett	3.7940	1.0250	4.8190	78.7304	21.2696	16.9444
23	Kilve Stream	0.0924	0.0149	0.1073	86.1518	13.8482	11.6667
24	Doniford Stream	0.2748	0.0442	0.3189	86.1515	13.8485	11.6667
25	Washford River	0.1750	0.0243	0.1993	87.8066	12.1934	10.0000
26	Pill River	0.0594	0.0082	0.0676	87.8066	12.1934	10.0000
27	Avill River	0.2213	0.0307	0.2521	87.8069	12.1931	10.0000
28	Horner Water	0.1232	0.0364	0.1596	77.1803	22.8197	17.8333
29	Lyn	0.3362	0.0994	0.4356	77.1806	22.8194	17.8333
	Total	60.2007	39.7993	100.0000			

Table 3.7: Summary of proportional (%) contributions of enterococci loads for the 29 Severn estuary input catchments during the 150-day period between 2 May 2001 and 29 September 2001

		Total enterococci load (organisms) from which proportions are calculated: 1.71×10^{17}	
Input no. and Catchment		Base flow enterococci (%)	High flow enterococci (%)
01	Tawe	0.0561	0.7130
02	Nedd	0.0455	0.4386
03	Afan	0.0310	0.1578
04	Kenfig	0.0295	0.3354
05	Ogwr	0.1570	2.6273
06	Ely	0.0884	1.3749
07	Taf	0.1784	1.2616
08	Rhymney	0.1139	1.2118
09	Ebbw	0.1073	1.1564
10	Usk	0.2467	8.0827
11	Wye	0.4317	11.6751
12	Severn	1.7881	30.8073
13	Frome	0.0803	0.5034
14	Little Avon	0.0351	0.6126
15	Avon	0.7281	9.2702
16	Portbury Ditch	0.0211	0.3384
17	Land Yeo	0.0530	1.1823
18	Congresbury Yeo	0.0328	0.5427
19	Banwell	0.0598	0.6369
20	Axe	0.1347	4.4283
21	Brue	0.2780	9.8423
22	Parrett	0.4666	6.8538
23	Kilve Stream	0.0020	0.0121
24	Doniford Stream	0.0156	0.1569
25	Washford River	0.0085	0.1030
26	Pill River	0.0027	0.0174
27	Avill River	0.0143	0.1720
28	Horner Water	0.0026	0.0324
29	Lyn	0.0074	0.2373
	Total	5.2164	94.7836

Table 3.8: Summary of proportional (%) contributions of enterococci loads under base and high flow conditions for each of the 29 Severn estuary input catchments during the 150-day period between 2 May 2001 and 29 September 2001

Input no. and Catchment		Base flow enterococci (%)	High flow enterococci (%)
01	Tawe	7.2991	92.7009
02	Nedd	9.4028	90.5972
03	Afan	16.4266	83.5734
04	Kenfig	8.0847	91.9153
05	Ogwr	5.6398	94.3602
06	Ely	6.0412	93.9588
07	Taf	12.3891	87.6109
08	Rhymney	8.5927	91.4073
09	Ebbw	8.4943	91.5057
10	Usk	2.9623	97.0377
11	Wye	3.5659	96.4341
12	Severn	5.4856	94.5144
13	Frome	13.7638	86.2362
14	Little Avon	5.4197	94.5803
15	Avon	7.2823	92.7177
16	Portbury Ditch	5.8721	94.1279
17	Land Yeo	4.2895	95.7105
18	Congresbury Yeo	5.7046	94.2954
19	Banwell	8.5798	91.4202
20	Axe	2.9519	97.0481
21	Brue	2.7468	97.2532
22	Parrett	6.3739	93.6261
23	Kilve Stream	14.4278	85.5722
24	Doniford Stream	9.0580	90.9420
25	Washford River	7.6400	92.3600
26	Pill River	13.2755	86.7245
27	Avill River	7.6775	92.3225
28	Horner Water	7.4444	92.5556
29	Lyn	3.0086	96.9914

Table 4.1: Treatment and flow details for the 34 main sewage effluent inputs to the Severn estuary

ID	Final effluent	Treatment	UV[6]	Population Equivalent *	Dry Weather Flow ($m^3 s^{-1}$)†	Maximum Flow ($m^3 s^{-1}$)¶
1	Overton STW	Biological	No	3185[1]	0.00810[7]	0.02315[4]
2	Southgate STW	Biological	No	2950[1]	0.00789[7]	0.02060[4]
3	Bishopston STW	Biological	Yes	3800[1]	0.01627[7]	0.03256[4]
4	Swansea STW	Biological	Yes	155000[1]	0.65500[7]	1.30000[4]
5	Afan STW	Biological	No	138000[1]	0.58699[7]	1.20500[4]
6	Penybont STW	Biological	No	122239[1]	0.26620[7]	1.90972[4]
7	Llantwit Major STW	Biological	Yes	14000[1]	0.04502[7]	0.10500[4]
8	The Leys outfall, Aberthaw	Crude	No	6092[1]	0.00954[7]	0.05722[4]
9	Cardiff STW	Biological	No	880000[1]	3.58750[7]	6.06000[4]
10	Cog Moors STW	Biological	No	245000[1]	1.00301[7]	2.14500[4]
11	Nash STW	Biological	No	152000[1]	0.67014[7]	1.41500[4]
12	Ponthir STW	Biological	No	110053[2]	0.38132[7]	0.88600[4]
13	Magor Brewery Effluent	Biological	No	Industrial	0.03858[8]	0.11574[4]
14	Sedbury STW	Biological	No	4500[2]	0.00718[7]	0.02153[5]
15	Lydney STW	Biological	No	17994[3]	0.06661[7]	0.13900[5]
16	Blakeney	Biological	No	13047[3]	0.04344[7]	0.08700[5]
17	Longhope STW	Biological	No	3165[3]	0.01134[7]	0.04200[5]
18	Gloucester Longford STW	Biological	No	32037[3]	0.07546[7]	0.20600[5]
19	Cheltenham STW	Biological	No	104015[3]	0.40509[7]	0.86800[5]
20	Gloucester Netheridge STW	Biological	No	178205[3]	0.49537[7]	1.21500[5]
21	Frampton	Biological	No	2362[3]	0.00828[7]	0.01900[5]
22	Sharpness	Biological	No	4273[2]	0.02344[7]	0.07031[5]
23	Thornbury STW	Biological	No	16630[1]	0.05105[9]	0.15316[5]
24	Avonmouth STW	Biological	No	935190[1]	2.45924[9]	7.37771[5]
25	Portbury Wharf STW	Biological	No	22258[1]	0.07181[9]	0.21542[5]
26	Kingston Seymour STW	Biological	Yes	66772[1]	0.32909[9]	0.98726[5]
27	Wick St Lawrence STW	Biological	No	8947[1]	0.02796[10]	0.05592[5]
28	Weston-Super-Mare STW	Biological	Yes	105967[1]	0.30424[9]	0.91271[5]
29	West Huntspill STW	Biological	Yes	45924[1]	0.12911[9]	0.38733[5]
30	Bridgewater STW	Biological	Yes	96112[1]	0.19084[9]	0.57253[5]
31	Doniford Outfall	Crude	No	4849[1]	0.01566[7]	0.04698[5]
32	Watchet STW	Primary	No	7197[1]	0.02233[7]	0.04700[4]
33	Minehead STW	Biological	Yes	31237[1]	0.11473[9]	0.34420[5]
34	Porlock STW	Membrane	No	3451[1]	0.01227[9]	0.03681[5]

[1] = recent water company data.
[2] = Environment Agency consent data base.
[3] = recent Environment Agency consent data.
[4] = Environment Agency consent data.
[5] = 3 x Dry Weather Flow.
[6] UV = Ultra-violet disinfection.
[7] = Environment Agency consent data.
[8] = 0.33 x Maximum Flow.
[9] = water company flow data for 2001.
[10] = based on population equivalent.

Table 4.2: Summary of geometric mean enterococci concentrations (cfu 100ml^{-1}) and 95% confidence intervals (CI) in broad effluent categories examined during CREH catchment studies

Effluent type	Flow	Geometric Mean	Lower 95 per cent CI	Upper 95 per cent CI	*N*[1]
Crude	Base	$1.3x10^6$	$9.8x10^5$	$1.7x10^6$	265
Crude	High	$8.9x10^5$	$6.7x10^5$	$1.2x10^6$	79
Primary treated	Base	$9.9x10^5$	$7.2x10^5$	$1.4x10^6$	113
Primary treated	High	$9.8x10^5$	$4.4x10^5$	$2.2x10^6$	14
Overflows	High	$3.8x10^5$	$3.2x10^5$	$4.6x10^5$	124
Biological filtration	Base	$3.0x10^4$	$2.6x10^4$	$3.5x10^4$	444
Biological filtration	High	$5.8x10^4$	$3.9x10^4$	$8.6x10^4$	83
Reedbed/grass plot	Base	$4.4x10^2$	$1.8x10^2$	$1.0x10^3$	39
UV Disinfection	Base	$1.0x10^2$	$6.2x10^1$	$1.8x10^2$	62
UV Disinfection	High	$1.2x10^3$	$8.4x10^1$	$1.6x10^4$	9

[1] *n* = number of observations

Table 4.3: Enterococci load estimates (organisms second^{-1}) for the 34 main sewage effluent inputs to the Severn estuary

ID	Final effluent	Dry weather flow enterococci load (organisms second^{-1})	Maximum flow enterococci load (organisms second^{-1})
1	Overton STW	$2.43x10^6$	$1.34x10^7$
2	Southgate STW	$2.37x10^6$	$1.19x10^7$
3	Bishopston STW	$1.79x10^4$	$3.91x10^5$
4	Swansea STW	$7.21x10^5$	$1.56x10^7$
5	Afan STW	$1.76x10^8$	$6.99x10^8$
6	Penybont STW	$7.99x10^7$	$1.11x10^9$
7	Llantwit Major STW	$4.95x10^4$	$1.26x10^6$
8	The Leys outfall, Aberthaw	$1.24x10^8$	$5.09x10^8$
9	Cardiff STW	$1.08x10^9$	$3.51x10^9$
10	Cog Moors STW	$3.01x10^8$	$1.24x10^9$
11	Nash STW	$2.01x10^8$	$8.21x10^8$
12	Ponthir STW	$1.14x10^8$	$5.14x10^8$
13	Magor Brewery Effluent	$1.16x10^7$	$6.71x10^7$
14	Sedbury STW	$2.15x10^6$	$1.25x10^7$
15	Lydney STW	$2.00x10^7$	$8.06x10^7$
16	Blakeney	$1.30x10^7$	$5.05x10^7$
17	Longhope STW	$3.40x10^6$	$2.44x10^7$
18	Gloucester Longford STW	$2.26x10^7$	$1.19x10^8$
19	Cheltenham STW	$1.22x10^8$	$5.03x10^8$
20	Gloucester Netheridge STW	$1.49x10^8$	$7.05x10^8$
21	Frampton	$2.48x10^6$	$1.10x10^7$
22	Sharpness	$7.03x10^6$	$4.08x10^7$
23	Thornbury STW	$1.53x10^7$	$8.88x10^7$
24	Avonmouth STW	$7.38x10^8$	$4.28x10^9$
25	Portbury Wharf STW	$2.15x10^7$	$1.25x10^8$
26	Kingston Seymour STW	$3.62x10^5$	$1.18x10^7$
27	Wick St Lawrence STW	$8.39x10^6$	$3.24x10^7$
28	Weston-Super-Mare STW	$3.35x10^5$	$1.10x10^7$
29	West Huntspill STW	$1.42x10^5$	$4.65x10^6$
30	Bridgewater STW	$2.10x10^5$	$6.87x10^6$
31	Doniford Outfall	$2.04x10^8$	$4.18x10^8$
32	Watchet STW	$2.21x10^8$	$4.61x10^8$
33	Minehead STW	$1.26x10^5$	$4.13x10^6$
34	Porlock STW	0	0
	Total	$3.64x10^9$	$1.55x10^{10}$

Table 4.4: Proportional contribution (%) from each of the 34 main sewage effluent inputs to total enterococci loads to the Severn estuary

ID	Final effluent	Dry weather flow enterococci load (% of total - Table 4.3)	Maximum flow enterococci load (% of total – Table 4.3)
1	Overton STW	0.0668	0.0866
2	Southgate STW	0.0651	0.0770
3	Bishopston STW	0.0005	0.0025
4	Swansea STW	0.0198	0.1006
5	Afan STW	4.8387	4.5065
6	Penybont STW	2.1944	7.1420
7	Llantwit Major STW	0.0014	0.0081
8	The Leys outfall, Aberthaw	3.4067	3.2838
9	Cardiff STW	29.5726	22.6632
10	Cog Moors STW	8.2680	8.0219
11	Nash STW	5.5241	5.2918
12	Ponthir STW	3.1433	3.3134
13	Magor Brewery Effluent	0.3180	0.4328
14	Sedbury STW	0.0592	0.0805
15	Lydney STW	0.5491	0.5198
16	Blakeney	0.3581	0.3254
17	Longhope STW	0.0935	0.1571
18	Gloucester Longford STW	0.6221	0.7704
19	Cheltenham STW	3.3393	3.2461
20	Gloucester Netheridge STW	4.0835	4.5439
21	Frampton	0.0682	0.0711
22	Sharpness	0.1932	0.2630
23	Thornbury STW	0.4208	0.5728
24	Avonmouth STW	20.2720	27.5911
25	Portbury Wharf STW	0.5919	0.8056
26	Kingston Seymour STW	0.0099	0.0764
27	Wick St Lawrence STW	0.2305	0.2091
28	Weston-Super-Mare STW	0.0092	0.0706
29	West Huntspill STW	0.0039	0.0300
30	Bridgewater STW	0.0058	0.0443
31	Doniford Outfall	5.5938	2.6960
32	Watchet STW	6.0734	2.9701
33	Minehead STW	0.0035	0.0266
34	Porlock STW	0.0000	0.0000

Figures

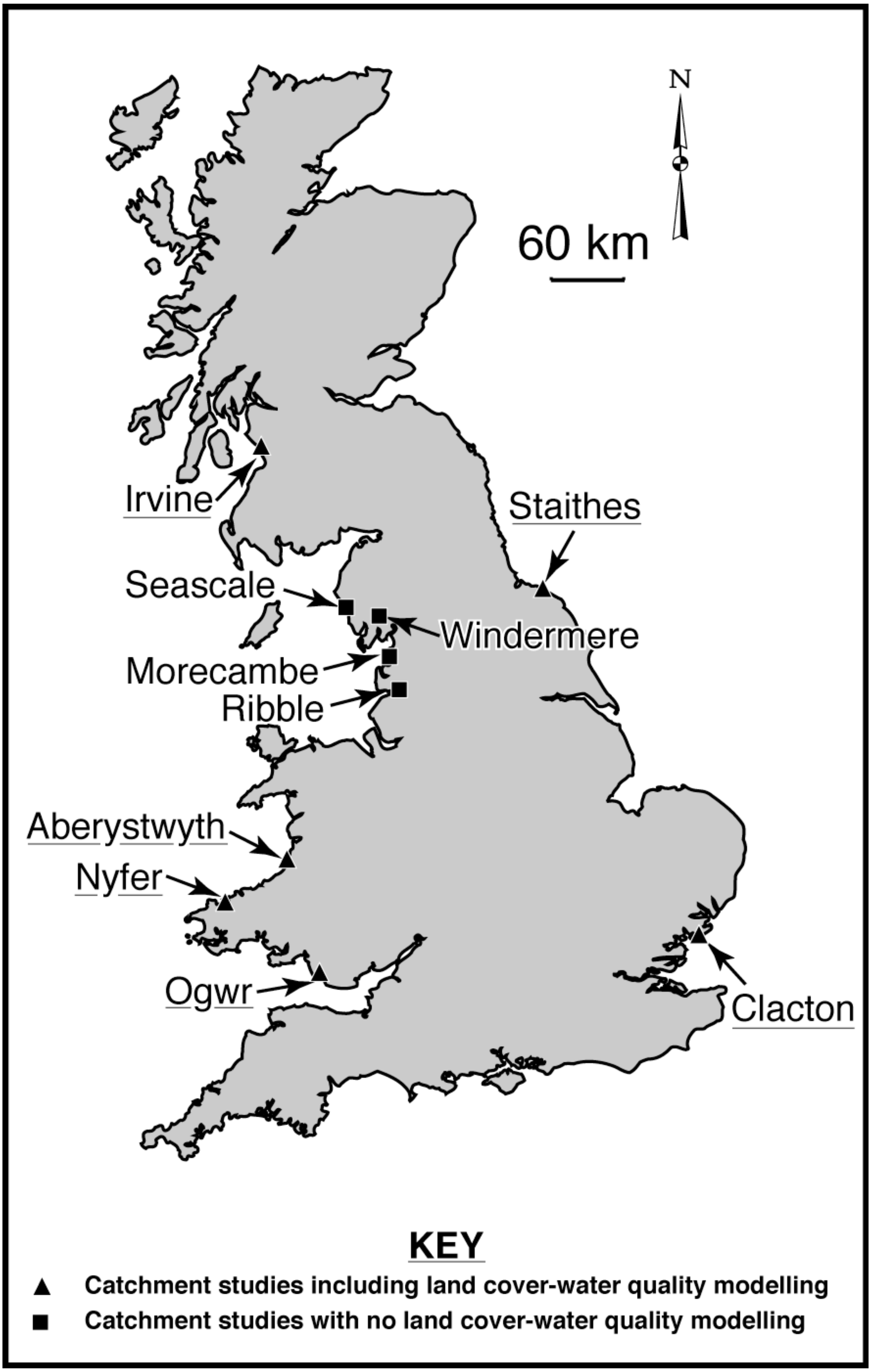


Figure 2.1: Location of CREH catchment studies

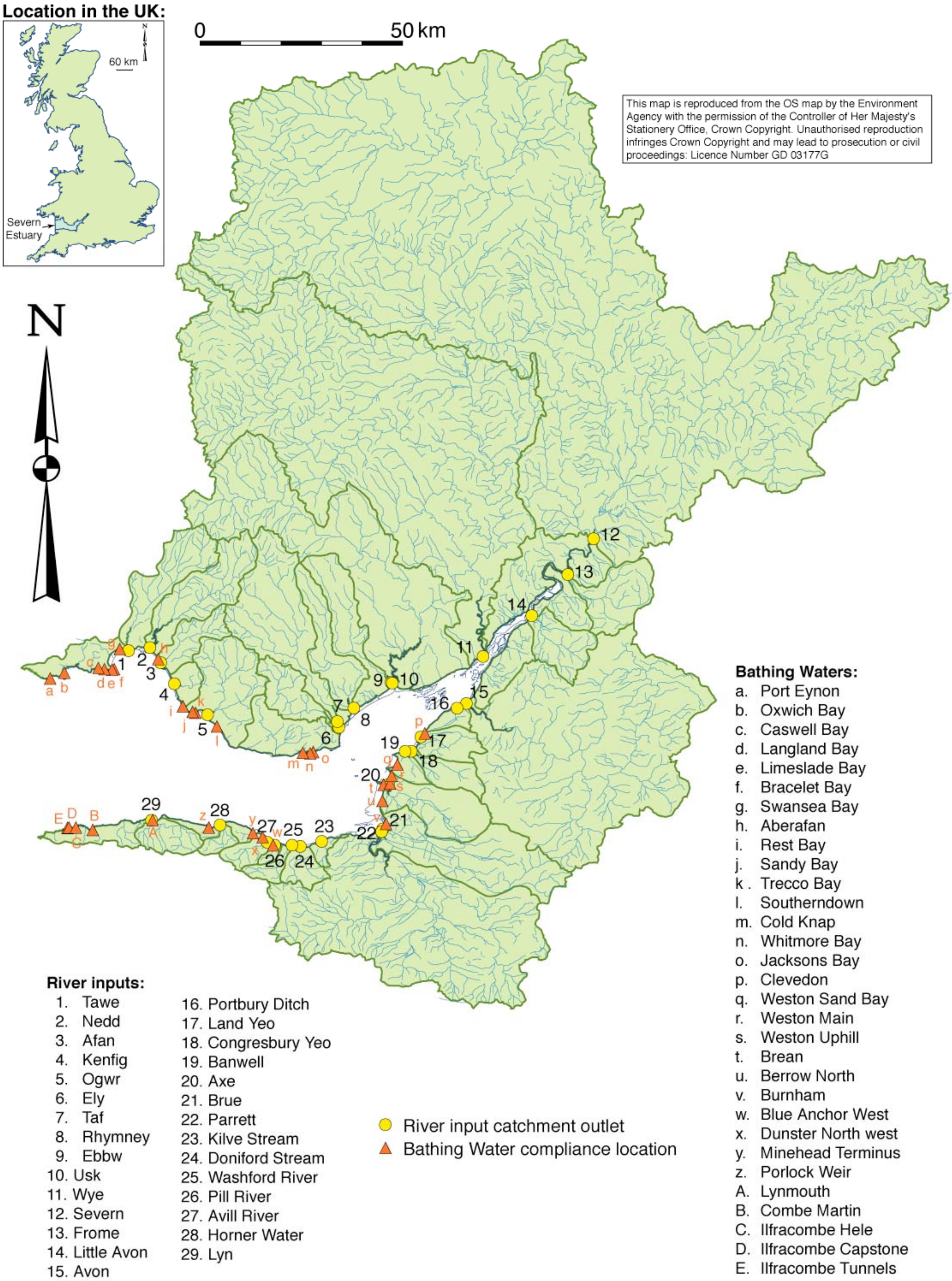
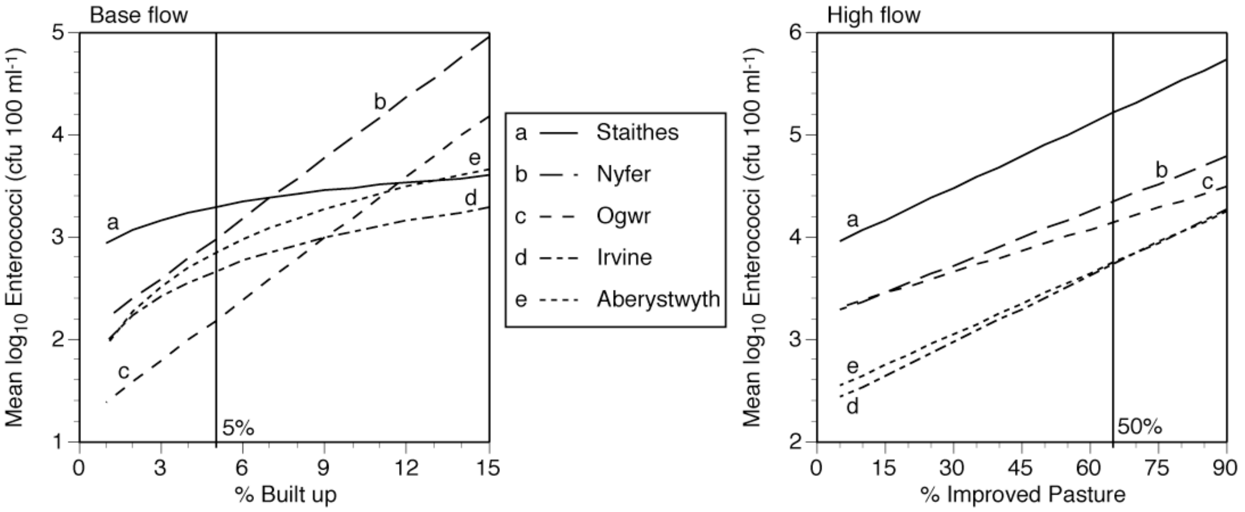


Figure 2.2: Bathing water compliance monitoring sites, main river catchments and locations of outlets to the Severn estuary

(a) Bivariate regression curves describing relationships between the major land cover predictor variables (% cover) and mean $\log_{10}$ Enterococci concentration (cfu 100 ml^{-1}) in five study areas



(b) Bivariate regression curves describing relationships between runoff equivalent (mm day^{-1}) and predicted mean $\log_{10}$ Enterococci concentrations at specified land cover values (Base flow - 5% Built up, High flow 50% Improved Pasture - based on (a) above)

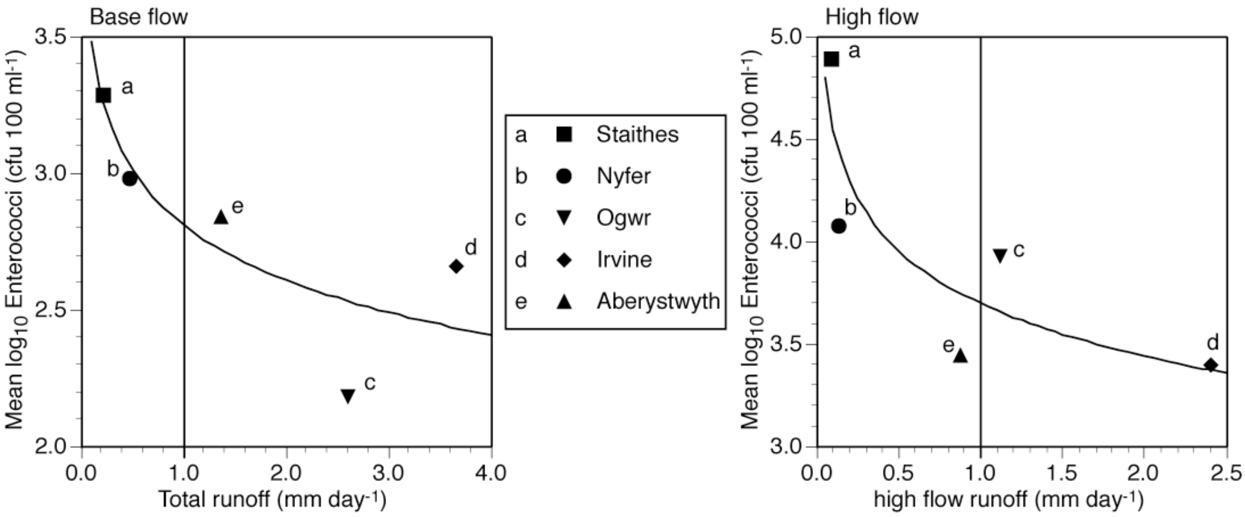


Figure 2.3: Bivariate regression curves used to standardise mean $\log_{10}$ enterococci concentrations (cfu 100 ml^{-1}), based on: (a) observed land cover; (b) runoff conditions in five study areas, for use in multivariate regression modelling of water quality using modified Centre for Ecology and Hydrology land cover data

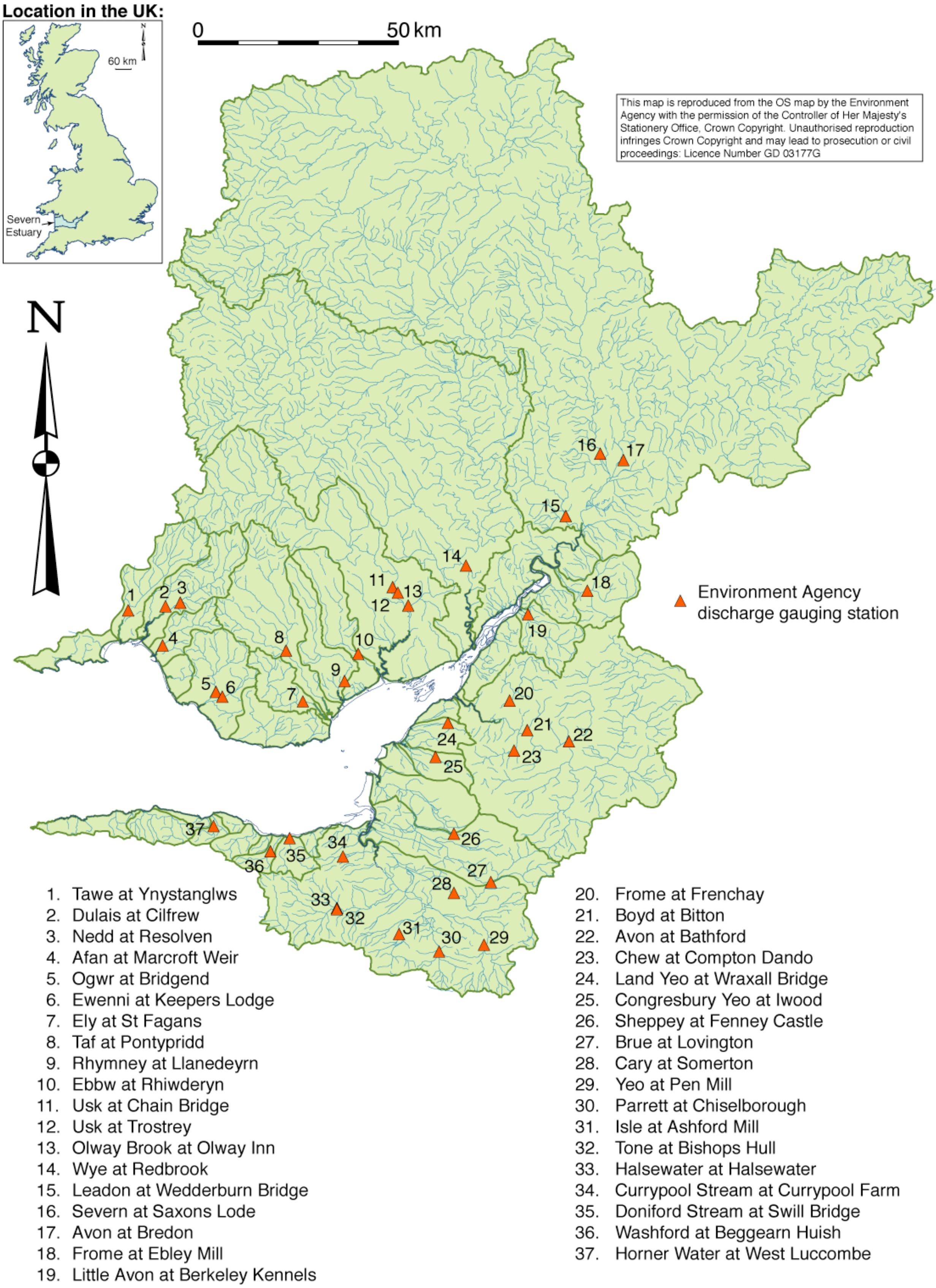


Figure 3.1: Location of Environment Agency discharge gauging stations used to estimate river discharge inputs to the Severn estuary

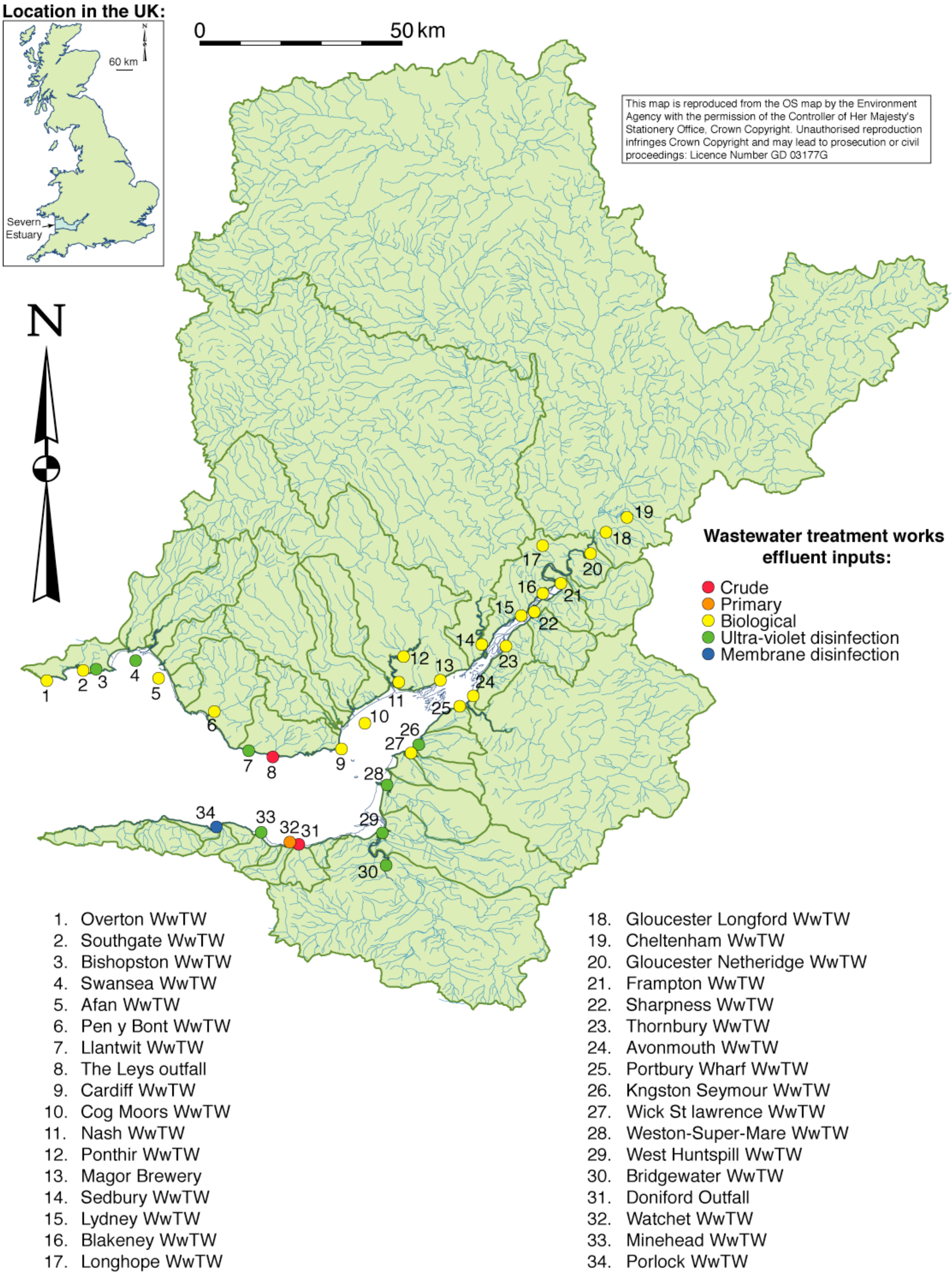


Figure 4.1: Location and treatment type of wastewater treatment works effluent inputs with population equivalents greater than 2000 to the Severn estuary

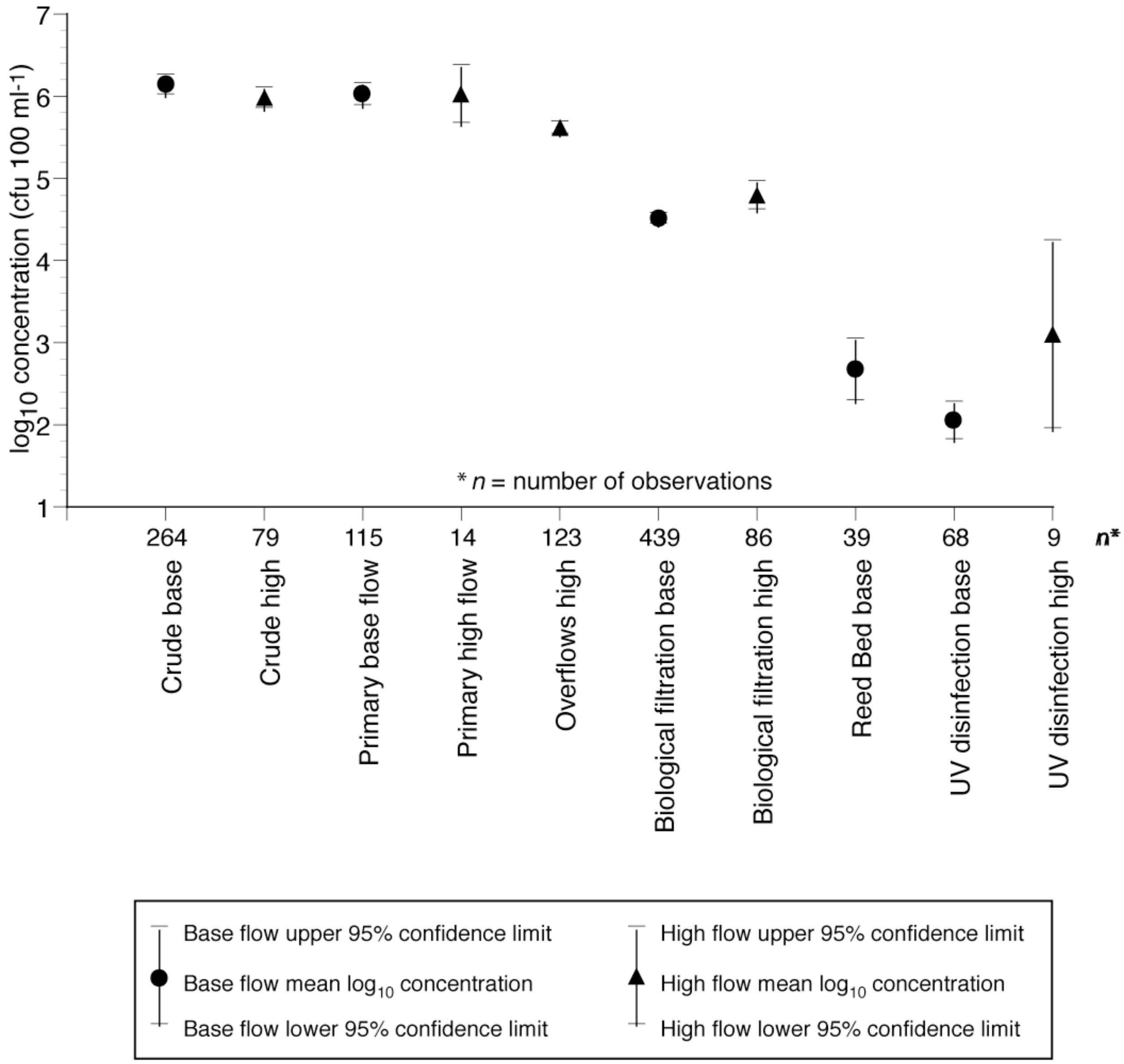


Figure 4.2: Comparison of mean (±95% confidence interval) $\log_{10}$ transformed enterococci concentrations (cfu 100 ml^{-1}) in samples taken during CREH catchment investigations grouped into broad treatment categories

We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

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