ESTIMATION OF DIFFUSE AND POINT SOURCE MICROBIAL POLLUTION IN THE RIBBLE CATCHMENT DISCHARGING TO BATHING WATERS IN THE NORTH WEST OF ENGLAND

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ABSTRACT

Achieving compliance with the mandatory standards of the 1976 Bathing Water Directive (76/160/EEC) is required at all UK identified bathing waters. The Fylde coast has been an area of significant infra-structure investments in recent years. However, these investments in 'point source' control have not proven, in isolation, sufficient consistently to achieve compliance with the mandatory *Imperative*, let alone the recommended *Guide*, levels of water quality specified in the Directive. The potential impact of riverine sources of pollution was first confirmed after a study in 1997 prior to infrastructure commissioning (Fewtrell *et al*., 1998). The completion of sewerage system enhancements therefore offered the potential for the study of faecal indicator delivery from upstream sources comprising both point sources discharged to rivers and diffuse agricultural sources. A research project to define these elements commenced in 2001. Initially, a desk study reported here, estimated the principal infrastructure contributions within the Ribble catchment. A second phase of this investigation has involved acquisition of empirical water quality and hydrological data from the catchment during the 2002 bathing season. These data have been used further to calibrate the 'budgets' and 'delivery' modelling and these data are still being analysed. This paper reports the initial desk study approach to faecal indicator budget estimation using available data from the sewerage infrastructure and catchment sources of faecal indicators.

Key Words: bathing water, diffuse pollution, sewage, faecal indicators.

INTRODUCTION

The Fylde coast of the United Kingdom has some of the UK's most popular holiday resorts. Here, sea bathing has been part of the holiday experience since Victorian times. Notwithstanding the importance of these beaches to the local economy, water quality at many of the Fylde beaches has, until recently, failed consistently to achieve the mandatory standards defined in Directive 76/160/EEC (CEC, 1976, Crowther *et al*., 2001). Indeed, the United Kingdom has been subject to infraction proceedings by the Commission of the European Communities for its failure to meet the mandatory coliform standards in Directive 76/160/EEC. Thus, achieving compliance with microbiological standards at the Fylde beaches has local, national and international political, legal and economic significance.

To rectify this position, the sewerage undertaker, United Utilities, has undertaken a series of point source remediation measures involving sewerage infrastructure improvements, new secondary sewerage treatment plants, the addition of terminal disinfection and sewage storage to reduce the spill frequency of untreated sewage effluent. These measures have resulted in a slow but discernable improvement in the compliance of the eight Fylde beaches (Figure 1)

Coastal point source remedial measures have now largely been completed. However, further improvement in bathing water quality is desirable at this site in order to move towards the *Guideline* standards of Directive 76/160/EEC and to ready the bathing waters for the tighter microbiological standards proposed in CEC (2002). These standards are broadly based on new WHO 'health based' standards (WHO, 2003 *in press*). In the preamble to the proposed new Directive concerning bathing waters (CEC, 2002) it is stated that:

> *this Directive needs to be closely co-ordinated with other Community legislation concerning water such as Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action the field of water policy.*
>
> (CEC, 2002 preamble point (8))

This statement is important because Directive 2000/60/EC has set out a new management paradigm in which lawful uses of the water environment are first identified and then water quality objectives are defined to facilitate these. The objectives are achieved through the integrated management of point and diffuse pollution sources in upstream river basin districts. This is of particular relevance to the Ribble catchment and the Fylde beaches because the Ribble and adjacent catchments form the relevant river basin districts which should be managed to facilitate the lawful use of sea bathing and thus requires appropriate water quality objectives defined by Directive compliance levels. This regulatory paradigm was first espoused in NRA (1991). In addition, the Ribble catchment has been selected as a test area for the acquisition of environmental information needed to underpin UK implementation of Directive 2000/60/EC. Thus, the present study has immediate relevance for compliance with Directive 76/160/EEC and presents an opportunity to assess a number of methods for the acquisition of data needed to underpin implementation of 2000/60/EC and, in due course, CEC (2002).

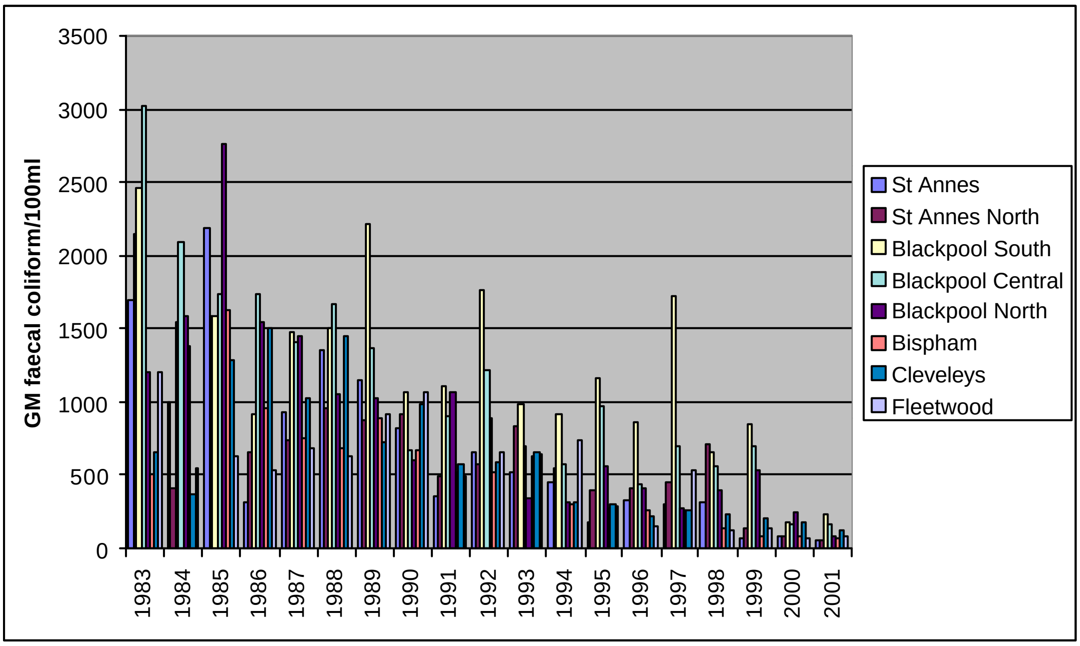

Figure 1 Geometric mean faecal coliform concentration since 1983 for the eight Fylde beaches (Source Environment Agency, 2002)

METHODS AND RESULTS

The study had four detailed and logically sequential objectives. First to undertake a review of the Agency's existing daily river bacterial quality and flow data for the Rivers Darwen, Douglas, Yarrow and Ribble. This would focus subsequent investigations of the spatial location of, and temporal conditions under which, microbial load was delivered in the sub-catchments. Second, use these data, combined, where appropriate, with data in Fewtrell *et al*., (1998), to improve the estimates of faecal indicator loadings derived from the inland catchments and compare with those from sources around the estuary. This can be used to prioritise future research investment. Third, it was next necessary to identify the information available locating, describing and quantifying faecal indicator inputs from point sources within the catchments including inputs from sewage treatment works, private sewage inputs, trade effluents, overflows from sewerage networks and any other significant point sources to estimate the faecal indicator loads from those sources. Finally it was hoped to identify gaps in information availability which will need to be addressed in a subsequent empirical data acquisition exercise.

Riverine faecal indicator fluxes

The Ribble catchment and the main monitoring points are shown in Figure 2. Figure 3 presents a schematic diagram of the principal estuarine inputs. These locations were sampled approximately daily by the Environment Agency during the 1999 bathing season and during the late summer of 1997 (Fewtrell *et al*., 1998). The data for the four principal riverine inputs are summarised in Table 1.

Faecal indicator organism budgets to the tidal limits of the Ribble estuary were calculated for the 1999 bathing season (9am GMT 1/5/99 - 9am GMT 1/10/99; 183 days = 4392 hours). The load (L (organisms)) of each indicator organism was calculated under low and high flow conditions by multiplying the geometric mean faecal indicator concentration for each source (i) by the appropriate base flow (b) and high flow (h) discharge volume components during the study period (Wyer *et al*., 1998a):

$$L_{bi} = Q_{bi} \text{ x } C_{bi} \quad (1)$$

$$L_{hi} = Q_{hi} \text{ x } C_{hi} \quad (2)$$

where: Q = flow (m^3) during the study period
C = geometric mean concentration (per m^3)

Total load (L_{ti} (organisms)) from each source was calculated as:

$$L_{ti} = L_{bi} + L_{hi} \quad (3)$$

The total load for each budget (L_t) is given by:

$$L_t = \quad L_{ti} \quad (4)$$

The rainfall at Moor Park Preston and the high and low flow discharge periods of the river Ribble at Salmesbury is shown for illustrative purposes in Figure 4. Comparable data for all sites is reported in Stapleton *et al*. (2002).

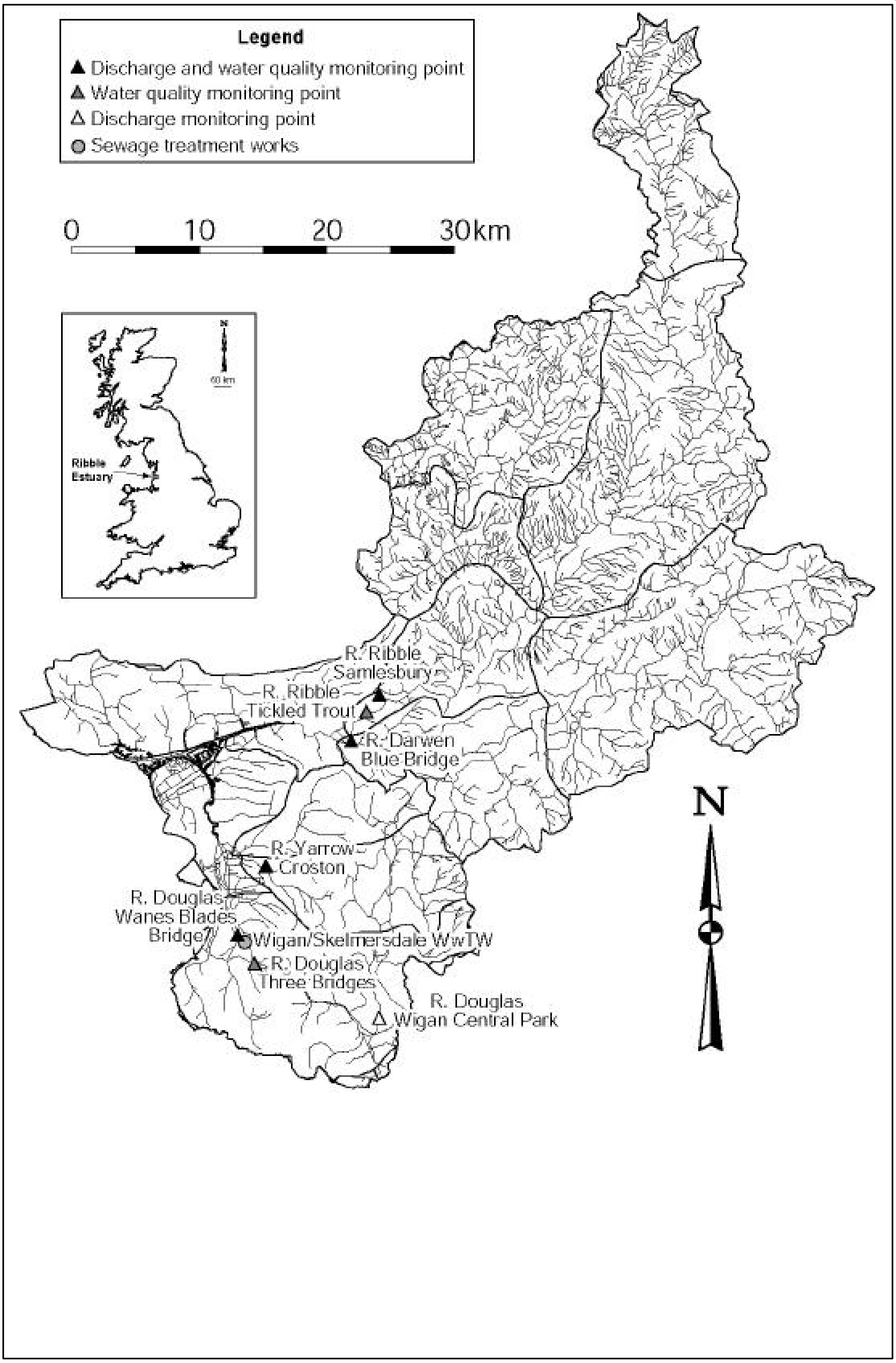

Figure 2 Environment Agency discharge and water quality monitoring sites used in the budget calculations

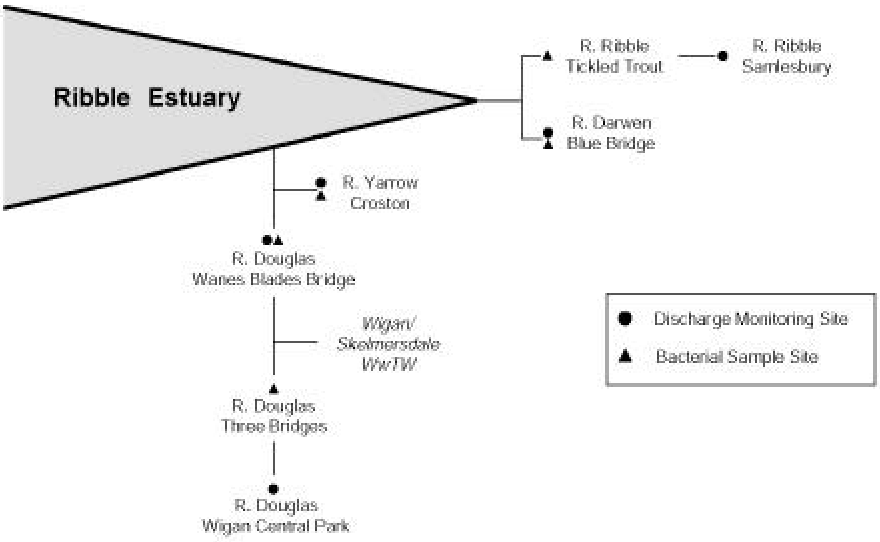

Figure 3 Schematic diagram showing the relationship between bacterial sampling sites and discharge monitoring stations used in the budget estimates.

Table 1: Summary of base flow and high flow faecal indicator organism concentrations for the Rivers Ribble at Samlesbury, Darwen at Blue Bridge, Douglas at Wanes Blades Bridge and Yarrow at Croston.

	Base Flow			High Flow		
	Total coliforms (cfu $100ml^{-1}$)	Faecal coliforms (cfu $100ml^{-1}$)	Faecal streptococci (cfu $100ml^{-1}$)	Total coliforms (cfu $100ml^{-1}$)	Faecal coliforms (cfu $100ml^{-1}$)	Faecal streptococci (cfu $100ml^{-1}$)
River Ribble, Samlesbury						
Geometric Mean	4,169	644	132	46,147	10,452	2,013
Log_{10} Standard Dev.	0.55	0.56	0.33	0.51	0.63	0.67
River Darwen, Blue Bridge						
Geometric Mean	49,198	5,321	407	166,889	50,565	8,710
Log_{10} Standard Dev.	0.518	0.605	0.648	0.470	0.497	0.581
River Douglas, Wanes Blades Bridge						
Geometric Mean	480,526	56,389	4,289	632,020	125,222	32,259
Log_{10} Standard Dev.	0.60	0.78	0.84	0.33	0.51	0.41
River Yarrow, Croston (includes data from Fewtrell *et al*., 1998)						
Geometric Mean	49,484	11,279	795	531,283	76,036	12,775
Log_{10} Standard Dev.	0.52	0.50	0.46	0.61	0.46	0.72

Figure 5 shows the faecal indicator budget for the 1999 bathing season for each of these inputs to the estuary. It is clear from these plots that the River Ribble at Salmesbury dominates the discharge budget but that the River Douglas, sampled at Wanes Blades, dominates the faecal indicator organism budget. This is particularly true at low flow when the River Douglas contributes 76.8% of the faecal coliform loading which reduces to 44.9% of the high flow loading when the catchment derived diffuse sources of faecal indicators gain in importance. Indeed, the Ribble catchment contributes only 5.1% of the low flow faecal coliform budget but this increases to 27% of the high flow budget. Figure 6 shows the hourly rainfall and faecal coliform delivery from the four riverine sources discharging to the estuary from 1st May to 30th September 1999. The percentage contribution, i.e. the lower plot in Figure 6, clearly shows the major contribution of the River Douglas during dry periods with the other sources, especially the River Ribble, gaining in prominence following rainfall events. It was thought that this pattern may have been simply a reflection of the fact that a major effluent input to the River Douglas was discharged immediately upstream of Wanes Blades (see Figure 3). Disinfection of the Wigan and Skelmersdale effluents was planned at the time of the investigation. To simulate the effect of this investment, a further budget was constructed using the quality of the River Douglas at Three Bridges (Figure 3) which is situated upstream of the Wigan and Skelmersdale effluent inputs. Figure 7 shows this plot and the drastically reduced faecal indicator organism contribution of the River Douglas which might be expected assuming successful disinfection of the treated sewage effluent from Wigan and Skelmersdale works.

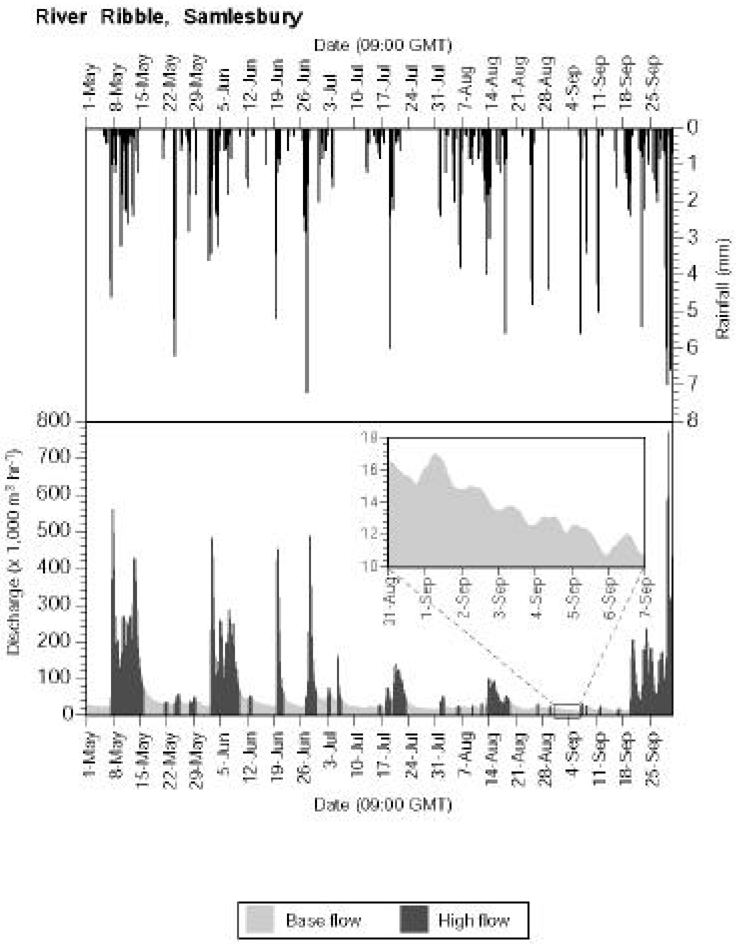

Figure 4: Hourly rainfall (mm) at Moor Park, Preston and discharge (m^3 hr^{-1}) for the River Ribble at Samlesbury.

Sewage effluent inputs

Some 53 significant sewage treatment works were discharging to the four rivers noted above. These are located, together with their dry weather flow on Figure 8. To characterise the quality of these effluents, a new data set was constructed using effluent quality data for the three faecal indicators collected during a series of previous CREH investigations (Fewtrell *et al*., 1998; Stapleton *et al*., 1999, 2000a,b; Wyer *et al*., 1995,1996, 1997, 1998a,b; 1999a,b; 2000a,b; 2001). Faecal indicator geometric means and ranges were summarised for: crude discharges, primary settled effluents, primary stored effluent, septic tank effluent, sewage overflows, activated sludge works, tricking filter plants, oxidation ditch works, biodisc plants, reed beds and UV disinfected effluent. Figure 9 shows the geometric mean low and high flow faecal coliform concentrations from each treatment type and the numbers of samples used to underpin this assessment.

For each sewage treatment works, appropriate concentration values were combined with the consented dry weather flow (base flow) and flow to full treatment (high flow) values (m^3 day^{-1}), Q_{bi} and Q_{hi}, to calculate base and high flow faecal indicator organism fluxes (organisms s^{-1}), L_{bi} and L_{hi}:

$$L_{bi} = C_{bi} \times Q_{bi} \quad (5)$$

and

$$L_{hi} = C_{hi} \times Q_{hi} \quad (6)$$

The total base flow flux, L_b, was than calculated as:

$$L_b = \Sigma L_{bi} \quad (7)$$

and the corresponding total high flow flux, L_h, as:

$$L_h = \Sigma L_{hi} \quad (8)$$

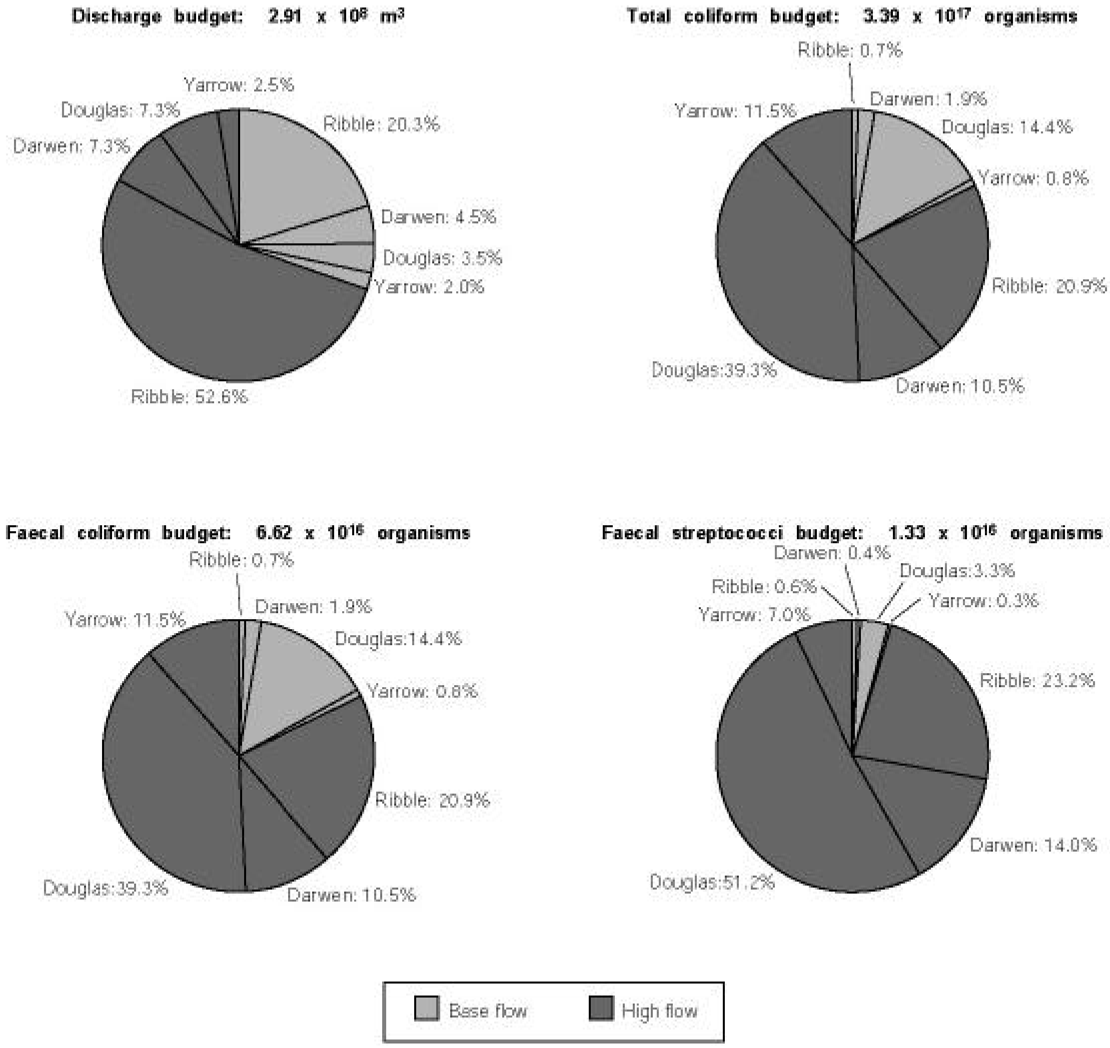

Figure 5 Estimated total discharge and indicator organism budgets for the tidal limits of the Rivers Ribble. Darwen. Douglas and Yarrow (Budget 1).

Figure 10 shows the dry weather flow of the 53 sewage treatment works and the cumulative percentage of the dry weather flow for these plants. This analysis demonstrates that >99% of the dry weather bacterial load to these four river catchments is contributed by the 18 largest plants shown in Figure 11.

The catchments also contain 574 consented discharges for intermittent sewage overflows which are recorded on the Environment Agency data base. These comprise overflows at waste water treatment works, pumping station overflows, network overflows (principally CSOs) and emergency overflows which should only discharge in exceptional circumstances. Only four of these sites had a recorded consent for flow volume and estimating the likely contribution of faecal indicator loadings from overflows is a perennially difficult problem. For 97 of the overflows urban pollution modelling (UPM) studies had been completed under asset management plan 3 (AMP3).

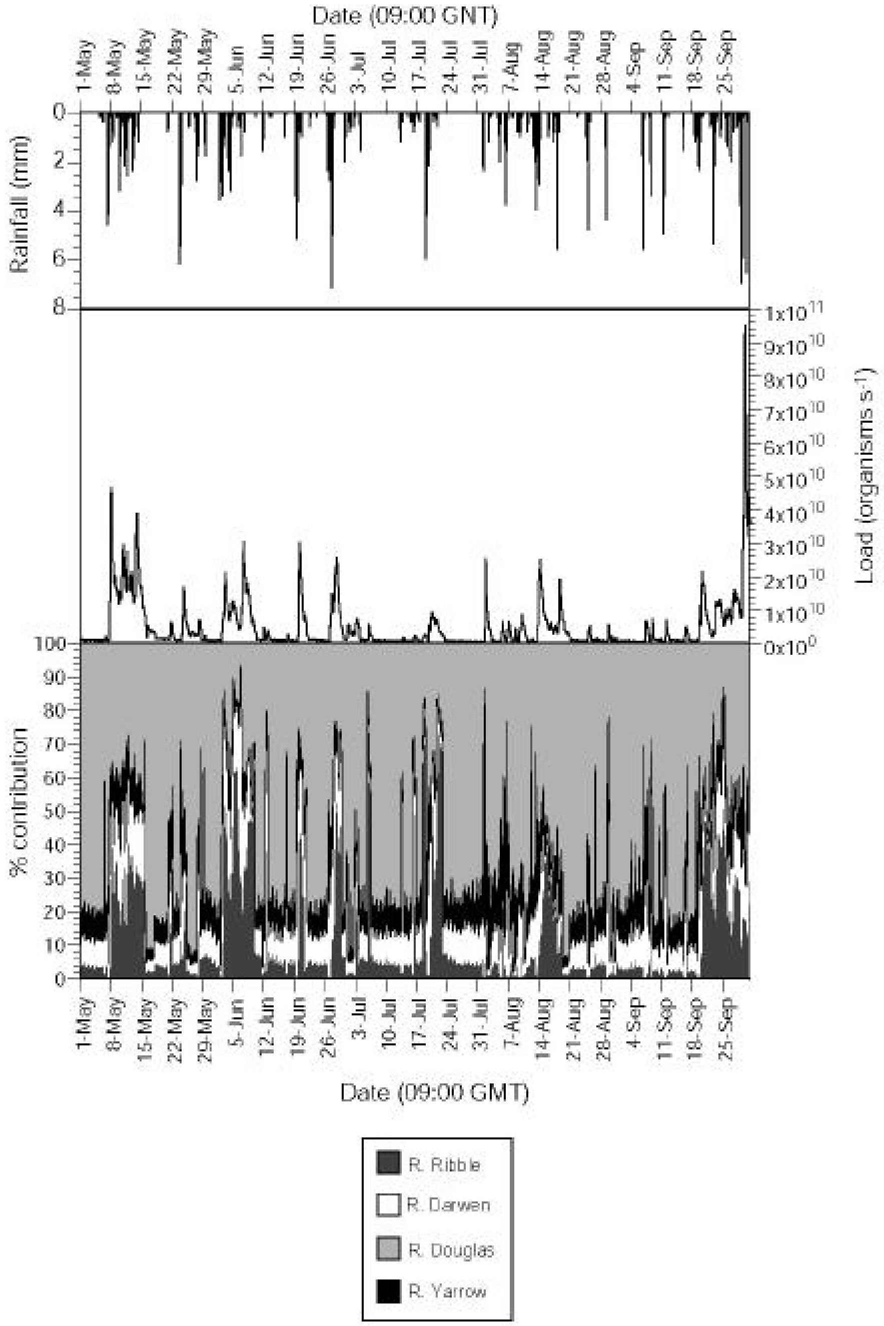

Figure 6 **Hourly rainfall (mm) at Moor Park, Preston, instantaneous faecal coliform load (organisms s^{-1}) and hourly proportional contributions (%) of riverine sources to the hourly load input to the Ribble Estuary tidal limits (Budget 1).**

Clearly, any estimate of the overflow volume in a complex catchment such as this will be contentious. The method employed here was to utilise data acquired in an earlier study (Wyer *et al*., 1998a,b). Flow records for the Pen-y-Bont treatment works in South Wales, UK were used. Examination of these data suggest that overflows ranged from a tiny fraction of the total flow to the works (0.001%) to just over of two thirds of the total flow (66.7%, i.e. 200% of the corresponding flow to full treatment).

The frequency distribution of the 288 hourly overflow values observed at the Pen-y-Bont plant, expressed as the proportion (%) of total flow, are presented in Figure 12. This pattern suggests that large overflow proportions (e.g. in the range 45%-66% of total flow or 80% to 200% of the corresponding flow to full treatment) occur infrequently, making up a relatively small proportion of the observations. The proportions in Figure 12 were applied to a hypothetical flow to full treatment of 100 m^3 day^{-1} and yield an overall overflow value of 26% of the total flow to the WwTW. Using this figure as a basis, and for illustrative purposes only, an overflow value of 25% was applied to the Ribble catchment works and the organism fluxes calculated, using the concentration values for overflow effluent derived from the investigations noted above (Figure 9). Further calculations were made assuming a range of overflow proportions based on the class mid-points in Figure 12 (Table 5). It is important to note that these, illustrative, estimates assume all works behave similarly and do not account for variations between individual works. For example, some works have a relatively high flow to full treatment compared to dry weather flow (e. g. Ribchester and Brindle works) and overflow would be less likely.

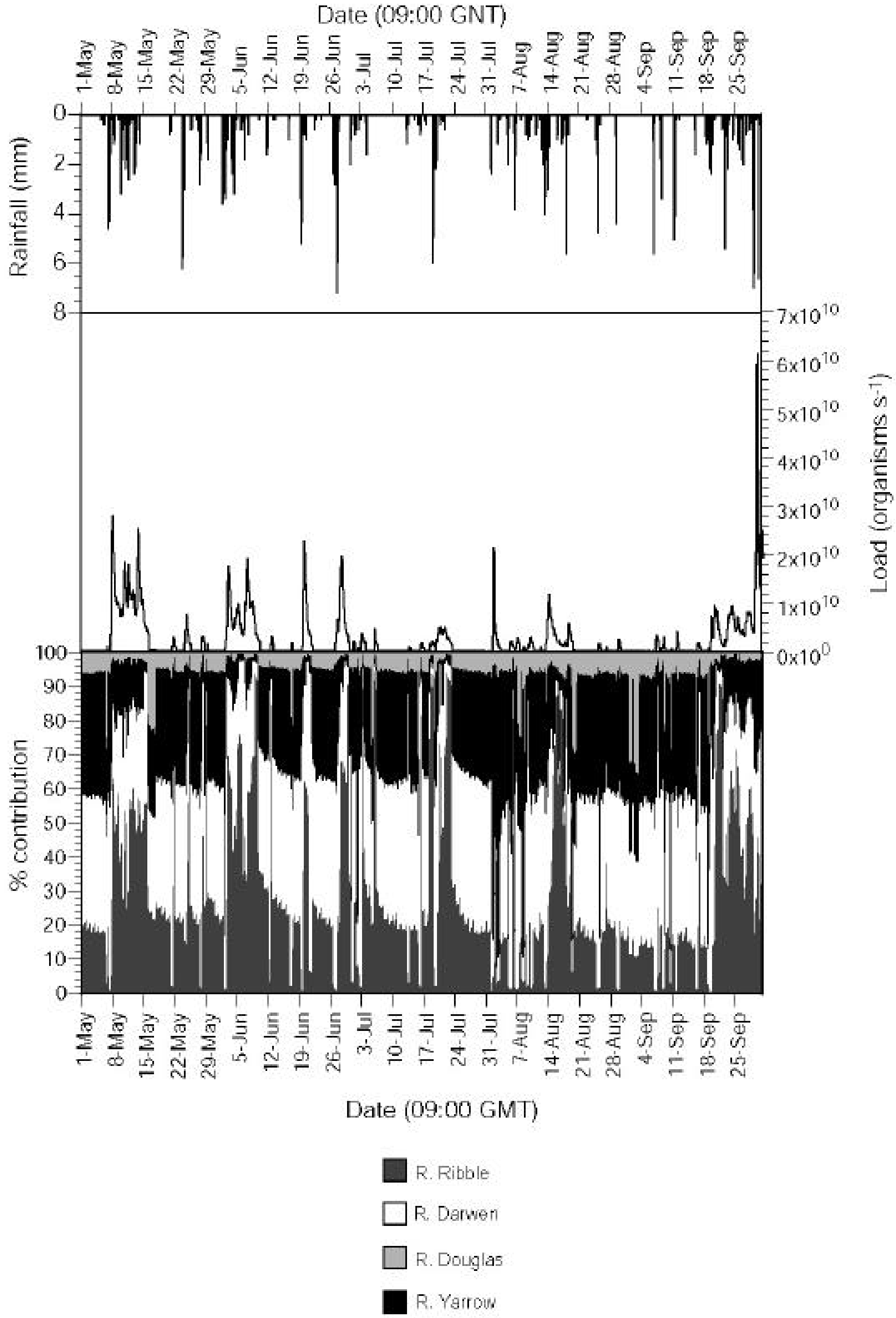

Figure 7 **Hourly rainfall (mm) at Moor Park, Preston, instantaneous faecal coliform load (organisms s^{-1}) and hourly proportional contributions (%) of riverine sources to the hourly load input to the Ribble Estuary tidal limits discounting Wigan/Skelmersdale WwTW**

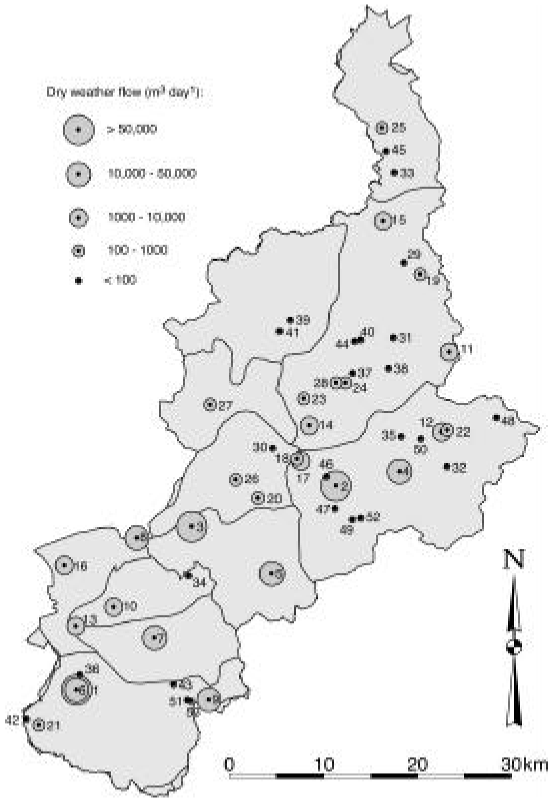

Figure 8 Location of major sewage works in the Ribble study catchments

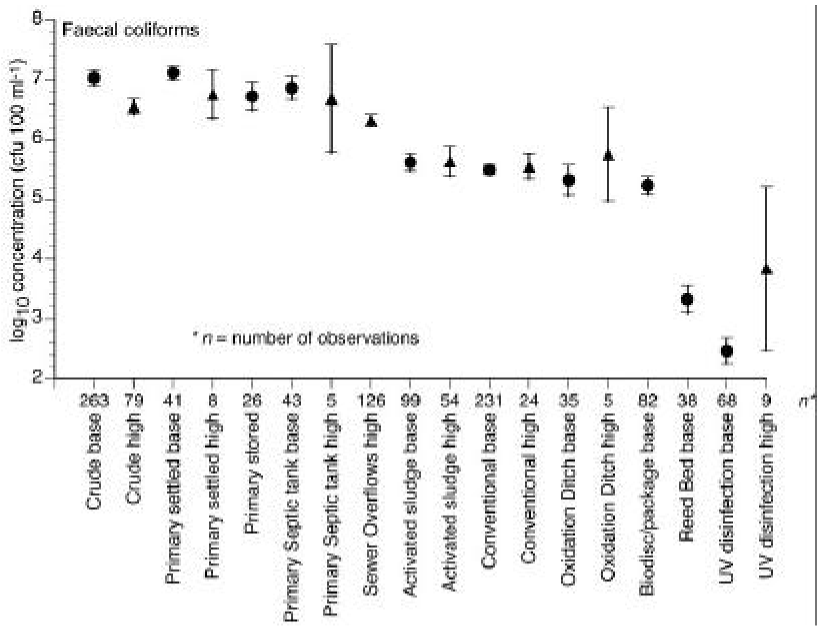

Figure 9 Effluent microbiological concentrations used in the study

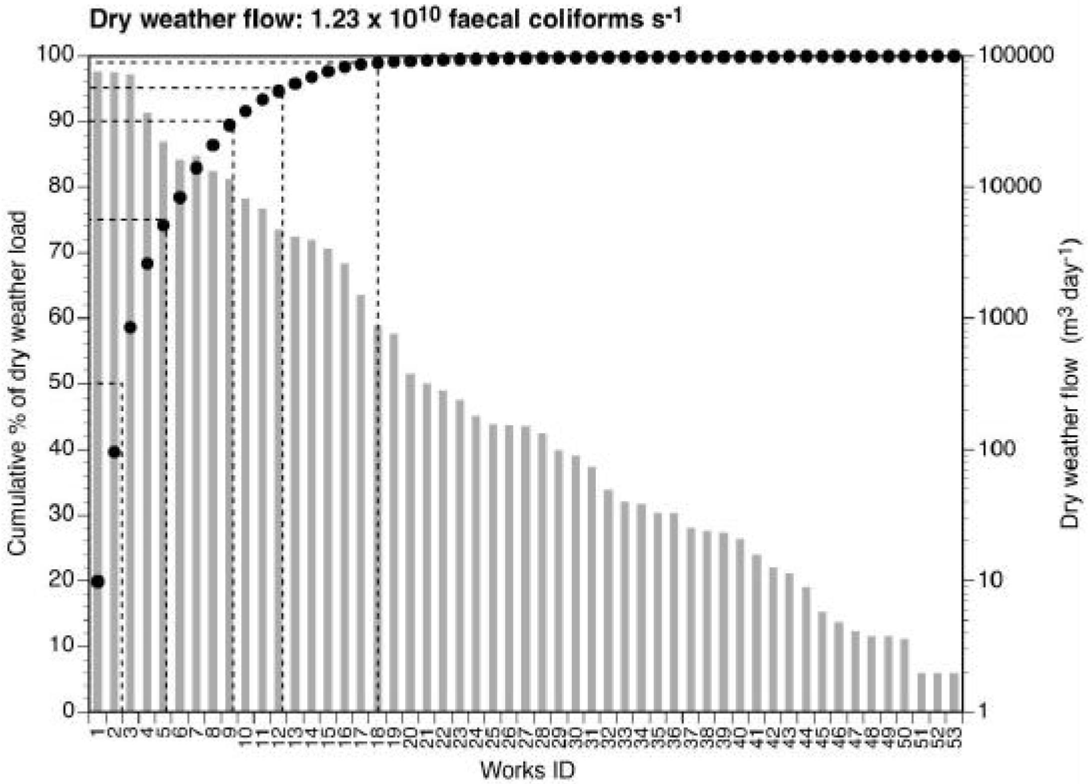

Figure 10 Dry weather flow for the 53 sewage treatment plants (grey bars) and cumulative faecal coliform load from all plants (circles).

CONCLUSIONS

The faecal indicator organism budgets constructed from the Agency data indicate the River Douglas to be the primary contributor of organisms to the Ribble estuary during both base flow and high flow conditions. This is due to the effluent discharged from Wigan/Skelmersdale works. Budgets using data from upstream of the effluent discharge point suggest that the River Douglas catchment is a relatively small contributor of organisms. Discounting the effects of Wigan/Skelmersdale works, shows that the Rivers Ribble, Darwen and Yarrow all contribute considerable proportions to the faecal indicator organism budgets of the Ribble Estuary.

Faecal indicator flux estimates from consented sewage related discharges in the Ribble catchment show that, under dry weather flow conditions, 18 out of the 53 WwTWs account for 99% of the input from this source type.

The flux estimates, based on an assumed flow to full treatment and 25% overflow, show increases in load of between 8 fold (total coliforms) and 15 (faecal streptococci) compared to dry weather flow estimates. This reflects the high proportion of faecal indicator organisms delivered during hydrograph event conditions identified in the river budget estimates. The largest single component derives from the 'estimated' overflow from the United Utilities plants (>58% of total flux).

Sewage related points source inputs are concentrated in the urbanised southern area comprising the following subcatchments: Calder, Lower Ribble, Darwen, and the catchments draining to the Douglas estuary (i.e. Douglas, Lostock and Yarrow). The Hodder, Loud and Upper Ribble subcatchments have a relatively low density of sewage related point sources.

This desk study was made possible by a bathing season sampling effort during 1999 of significantly greater intensity (approximately daily) than normally available with any routine monitoring data. In addition these data could be supplemented with a previous empirical study (Fewtrell *et al*., 1998). The work was completed prior to a field data acquisition campaign in the summer of 2002 better to refine the data available on diffuse source pollution discharging to the Fylde coast. The desk study is reported here to illustrate the types of analysis that can be undertaken to inform both remediation decisions and research protocols needed to fill the clear gaps in information generated from data of the type reported above. The most significant gap in current data is clearly the discharges from sewage overflows. The sensitivity analysis reported in Table 5 suggests very wide variation is possible and careful quantification of this element, involving as much actual discharge measurement and sample analysis as possible, is clearly prudent in any field programme designed to quantify the contribution of this element of total bacterial loading.

The desk study approach is relatively inexpensive and can yield useful data on, for example, the potential of UV disinfection at the Wigan and Skelmersdale plants (see for example Figures 6 and 7). The results of the subsequent field data acquisition programme conducted in the summer of 2002 which filled many of the data gaps identified will further provide the opportunity to assess the accuracy of the desk study conclusions when the newly acquired data become available.

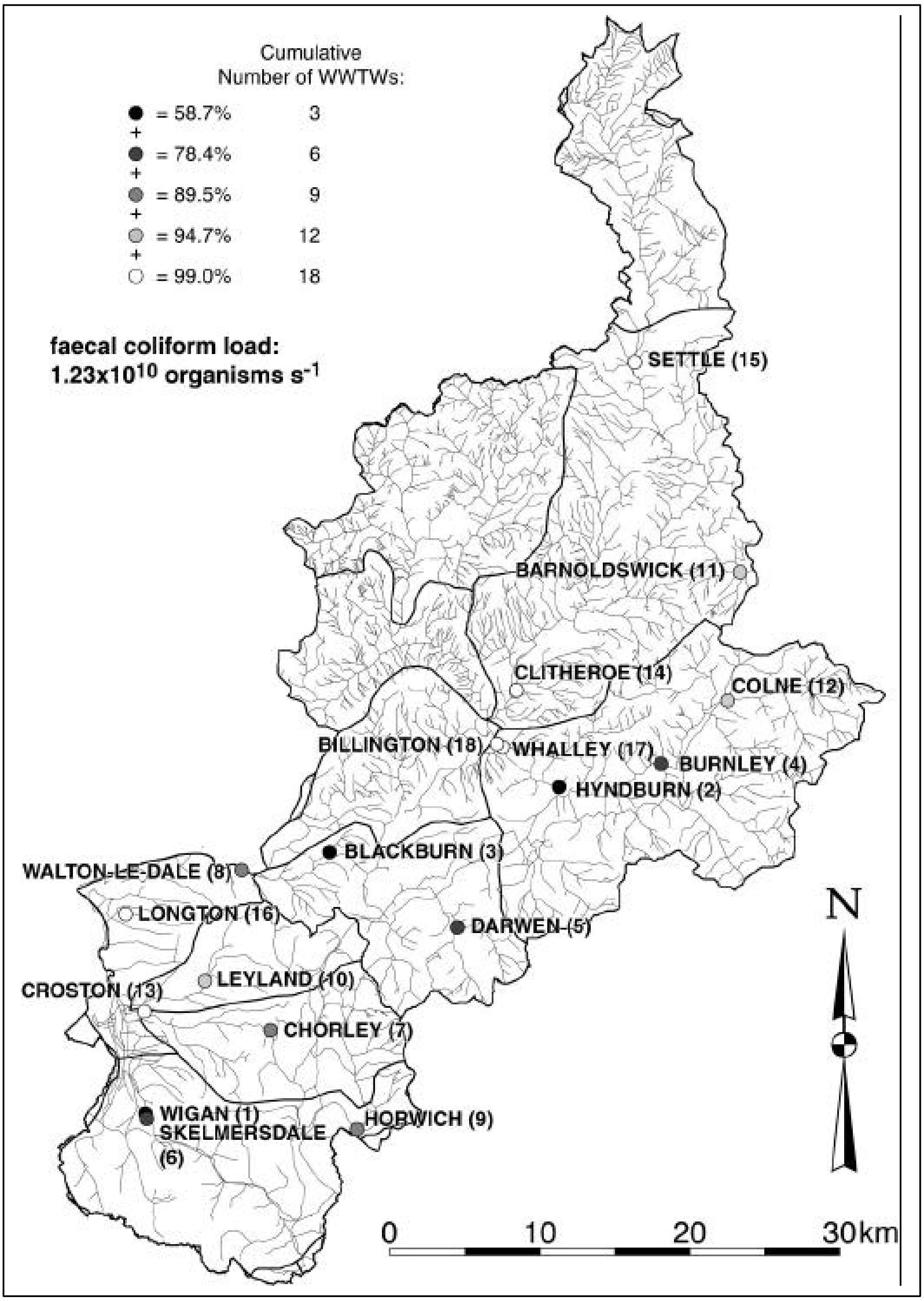

Figure 11 The 18 largest plants contributing 99% of the estimated dry weather faecal coliform loading.

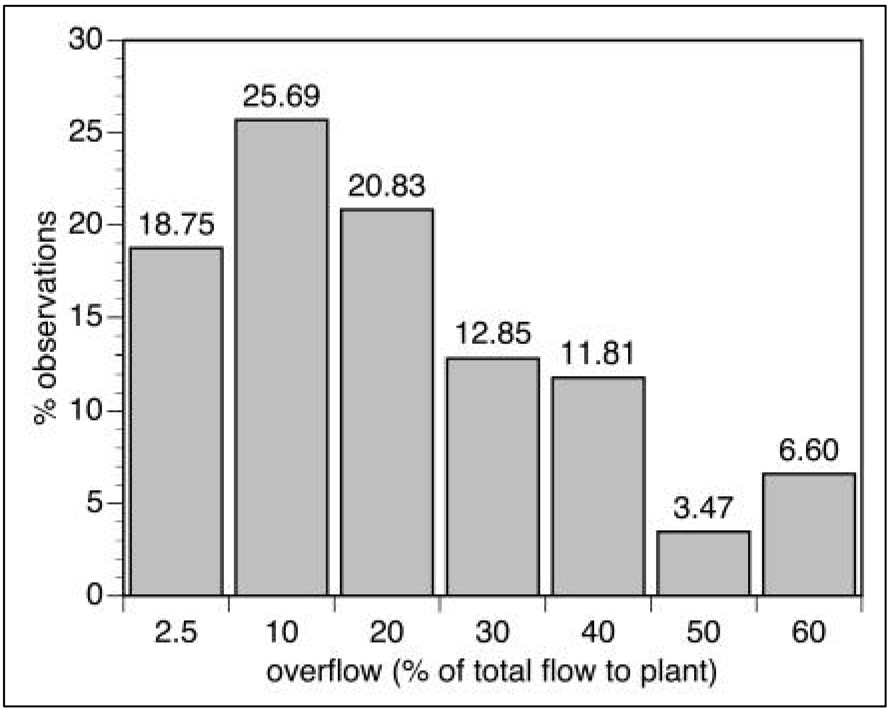

Figure 12 Frequency distribution of hourly overflow values as % of total flow to the plant for the Pen-y-Bont treatment works, South Wales for an eight week summer period in 1997.

Table 5 Faecal indicator flux estimates for storm overflow (L_o, orgs. s^{-1}) and flow to full treatment (L_h, orgs. s^{-1}) from United Utilities wastewater treatment plants in the catchment draining to the Ribble estuary for a range of over flow conditions (overflow as % of total flow to works).

Organism/overflow proportion (%)	L_o	L_h	% overflow
Total coliforms			
2.5	$1.91x10^{10}$	$1.79x10^{11}$	9.67
10.0	$8.29x10^{10}$	$1.79x10^{11}$	31.69
20.0	$1.86x10^{11}$	$1.79x10^{11}$	51.07
30.0	$3.20x10^{11}$	$1.79x10^{11}$	64.15
40.0	$4.97x10^{11}$	$1.79x10^{11}$	73.57
50.0	$7.46x10^{11}$	$1.79x10^{11}$	80.67
60.0	$7.31x10^{12}$	$1.79x10^{11}$	86.23
Faecal coliforms			
2.5	$5.62x10^{9}$	$4.58x10^{10}$	10.94
10.0	$2.44x10^{10}$	$4.58x10^{10}$	34.74
20.0	$5.48x10^{10}$	$4.58x10^{10}$	54.50
30.0	$9.40x10^{10}$	$4.58x10^{10}$	67.25
40.0	$1.46x10^{11}$	$4.58x10^{10}$	76.16
50.0	$2.19x10^{11}$	$4.58x10^{10}$	82.73
60.0	$3.29x10^{11}$	$4.58x10^{10}$	87.78
Faecal streptococci			
2.5	$1.07x10^{9}$	$6.48x10^{9}$	14.16
10.0	$4.63x10^{9}$	$6.48x10^{9}$	41.68
20.0	$1.04x10^{10}$	$6.48x10^{9}$	61.66
30.0	$1.79x10^{10}$	$6.48x10^{9}$	73.38
40.0	$2.78x10^{10}$	$6.48x10^{9}$	81.09
50.0	$4.17x10^{10}$	$6.48x10^{9}$	86.55
60.0	$6.25x10^{10}$	$6.48x10^{9}$	90.61

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