MICROBIAL POLLUTION: RIVER CATCHMENT STUDIES IN IRELAND AND BATHING WATER COMPLIANCE.

Allen, J.[1], Bruen, M.P.[2], Chawla, R.[3], Clarke, J.[4], Masterson, B.F.[3], O'Connor, P.E.[2], Parmentier, B.[2], Real, K.[3], Stokes, J-A.[2] and Thorp, M.B.[1]

[1]Department of Geography, [2]Department of Civil Engineering, [3]Department of Biochemistry, University College Dublin, Belfield, Dublin 4, Ireland. [4]M.C.O'Sullivan & Co. Ltd., Blackrock, Co. Dublin, Ireland. Email: b.masterson@ucd.ie

ABSTRACT

Results of a recent study of the Dargle catchment in Ireland and of the prospective compliance of Irish coastal bathing areas under a proposed new Bathing Water Directive are discussed with reference to the EU Water Framework Directive. The catchment study showed that human activities, even within small settlements, contributed a significant microbial load to the Dargle river and its tributaries. In general, faecal indicator organism concentrations greatly increased as a result of rainfall events with coincident deterioration in the microbial water quality of an adjacent bathing area. The process of classification of the bathing area under the proposed new Bathing Water Directive and under World Health Organisation criteria is demonstrated. The bathing area—Bray South Beach—would be classified as "Poor" quality under both procedures. This case is used to examine the 'discounting' proposition that rainfall-related high microbial concentrations might be waived or disregarded without compromising the effectiveness of the proposed Bathing Water Directive. It is concluded that discounting processes that might lead to waiver of high microbial concentrations would require an understanding of the stochastic nature of near-shore dispersal and land-use imp acts to attain the predictability required.

Keywords: water quality, bathing, discounting, catchment, Directive, coastal, microbial, indicator organism, compliance

INTRODUCTION

The EU Water Framework Directive (WFD; 2000/60/EC) takes a holistic "joined up" approach to pollution regulation on a river catchment basis. The catchments, referred to as "river basins" in the Directive, are grouped as Districts; cross-border catchments are assigned by agreement to "International" River Basin Districts. At a first reading the Directive may seem to cater for just the ecological and the physicochemical aspects of water quality, and studies completed in Ireland to date relevant to the Directive, namely the Lough Ree/Derg catchment, the Lough Leane catchment study, and the "Three Rivers Project" covering the Boyne, the Liffey and the Suir catchments accord with this. Yet the Directive entertains microbial water quality implicitly; all the Community water legislation is ensconced within. Indeed, designated bathing waters are scheduled as Protected Areas in the WFD, as are areas designated for the extraction of water for human consumption and for aquaculture. A Commission communication (COM 2000 860: "Developing a New Bathing Water Directive", 21/12/00, p. 4) expresses the link with the Bathing Water Directive (BWD) in very direct terms, stating that "the Bathing Water Directive should be the driver for a focussed implementation of the Water Framework Directive, the Nitrates Directive and the Urban Waste Water Directive"; currently the EU Member States are negotiating a revised BWD (Commission of the European Communities 2002). In Ireland the BWD is scheduled in the "Guidelines for the Establishment of River Basin Management Systems" published by the Department of the Environment and Local Government (2000); so it would seem that those endeavouring to deliver the improvements required by the Water Framework Directive (WFD), the Urban Wastewater Directive and the Nitrates Directive will bear in mind the requirements of the BWD too.

There is no certainty that improvements obtained under the WFD will deliver the improvements in microbial water quality required by the revised Bathing Water Directive. Additional specialised studies that focus on diffuse microbial pollution and other microbial pollution sources and establish their impact on bathing areas are likely to be required. This paper draws on the results of a recent study of the Dargle catchment in Ireland and of the prospective compliance of Irish coastal bathing areas under the proposed BWD to exemplify the need for specialised studies and to identify some of the issues involved.

The Dargle catchment drains to the Irish sea at Bray Harbour, Co. Wicklow, and a bathing area (Bray South Beach) is close by. A study of the catchment (Bruen et al., 2001) showed that the microbial bathing water quality of Bray South Beach was vulnerable to rainfall-related combined sewage overflow (CSO) discharges, and runoff from the catchment in a manner that related to the CSO discharges and to the pattern of catchment land use. Bray South Beach has been subject to frequent episodic failures to comply with the standards of the existing BWD, and there is concern about the impact of the standards of the proposed BWD on future compliance; the proposed standards are more stringent than those of the present Directive (EEC 1976). The high costs of substantial improvements to sewerage infrastructure and changes in agricultural practices that might be required to obtain compliance is of particular concern. How Bray South Beach might be classified under the proposed BWD and under World Health Organisation proposals (WHO 1999) is examined here. Also consideration is given to the proposition that rainfall-related high microbial concentrations might be 'discounted' (i.e. waived or disregarded) without compromising the effectiveness of the proposed BWD.

METHODS

The proposed Bathing Water Directive provides for the "classification" of designated bathing areas based upon 95 percentile evaluation of the $\log_{10}$ normal probability density function of all the microbiological data acquired from the particular bathing area during the preceding three consecutive years (Table 1). 'Excellent' classification would be attained where the upper 95 percentile (95%ile) concentrations of intestinal enterococci (IE) and Escherichia coli (EC) did not exceed 100 and 250 colony-forming units per 100 millilitres (cfu/(100 ml)) respectively; 'Good" classification would require non-exceedance of 200 IE and 500 EC cfu/(100 ml) 95%ile values; where the 'Good' classification thresholds were exceeded a bathing area would be classified as 'Poor'. The 95 percentile concentration is to be derived as follows:

(i) take the $\log_{10}$ value of the microbial data,
(ii) calculate the arithmetic mean (μ) and standard deviation (σ) of the $\log_{10}$ values,
(iii) calculate the upper 95 percentile point of the data probability density function from the following equation:

$$\text{Upper 95\%ile} = \text{antilog}\,(\mu + 1.65\,\sigma) \quad (1)$$

Table 1. Upper 95%ile values pertaining to Excellent and Good Quality classification specified in the proposed EU Bathing Water Directive 2002/0254 (COD). Values have the unit cfu/(100 ml).

Microbial Parameters	Excellent Quality *(guide)*	Good Quality *(obligatory)*
Intestinal Enterococci	100	200
Escherischia coli	250	500

As a means of estimating the impact of the proposed Bathing Water Directive on the Irish coastal bathing areas, Masterson and Chawla (2003) applied the E. coliform (EC) and intestinal enterococci (IE) water-quality standards of the proposed Directive retrospectively to the monitoring data for 1999-2001 (faecal coliform and faecal streptococci data were transformed to EC and IE data on a one to one basis). The results obtained in the study for Bray South Beach are considered below.

To obtain classification of Bray South Beach under the WHO proposals (WHO 1999), the Sanitary Inspection Category was derived using Tables 2 and 3, and the Microbial Assessment Category was derived from the estimates of Masterson and Chawla (2003). Then the two Categories were used in the Classification Matrix shown in Table 4 to derive the resulting bathing area classification. Explanations accompany Tables 2-4 which are given for convenience in the results section below.

Finally, results of the studies of the Dargle catchment and Bray South Beach (Bruen et al., 2001; Masterson and Chawla 2003) were used to illustrate some of the practical implications of the 'discounting' of high microbial concentrations associated with high rainfall events.

RESULTS AND DISCUSSION

The analysis of Masterson and Chawla (2003) classified Bray South Beach as "Poor" quality under the standards of the proposed BWD using data for the three-year period 1999-2001; the 95%ile values for EC and IE were 260 and 257 cfu/(100 ml) respectively.

The risk components required for entry in the WHO classification matrix are derived in Tables 2 and 3. The relative risk potential to human health is "High" (Table 2) because of the presence of the Bray CSO that has a short outfall close to Bray South Beach. The relative risk potential to human health through exposure to sewage through riverine flow and discharge is also "High" (Table 3) because of an upstream CSO at Enniskerry; the population (about 50000) is taken as medium size and the Dargle river as medium flow. The overall Sanitary Inspection Category is taken as "High" for Table 4. Finally, while the WHO procedure uses microbial data for a five-year period, for consistency the data for the three-year period 1999-2001 is used here to obtain the Microbiological Assessment Category; Bray South Beach falls into category C. Hence, the WHO classification procedure classifies Bray South Beach as "Poor" quality.

So, under both the proposed BWD and the WHO classification procedures Bray South Beach would be classified as "Poor" quality. A contingent question is whether 'discounting' might operate for Bray South Beach to obtain relief of its 'Poor' classification; essentially the proposition is that high microbial concentrations associated with high-rainfall events might be discounted—the United States draft Implementation Guidance for Ambient Water Quality Criteria for Bacteria (USEPA 2002) makes similar allowance and the WHO classification procedure permits 'reclassification' under certain conditions (WHO 1999; Bartram and Rees 2000).

At the outset, the relative contributions of the CSO and diffuse pollution components of microbial pollution of Bray South Beach during a 10-day period of wet weather in the Dargle catchment can be judged by comparing the measured amounts of faecal indicator organisms delivered (Table 5). The accumulated delivery rate of the Bray CSO was surprisingly similar to that of the Dargle river plus the small Enniskerry CSO upstream of Bray (the Enniskerry CSO accounted for about one-third of the upstream rate).

Table 2. Relative risk potential to human health through exposure to sewage through outfalls (after WHO 1999).

Treatment	Discharge Type		
	Directly on beach	Short outfall [a]	Effective outfall [b]
None [c]	Very high	High	NA
Preliminary	Very high	High	Low
Primary (including septic tanks)	Very high	High	Low
Secondary	High	High	Low
Secondary plus disinfection	Moderate	Moderate	Very low
Tertiary	Moderate	Moderate	Very low
Tertiary plus disinfection	Very low	Very low	Very low
Lagoons	High	High	Low

a. The relative risk is modified by population size. Relative risk is increased for discharges from large populations and decreased for discharges from small populations.
b. This assumes that the design capacity has not been exceeded and that climatic and oceanic extreme conditions are considered in the design objective (i.e. no sewage on the bathing area).
c. Includes combined sewer overflows.

Table 3. Relative risk potential to human health through exposure to sewage through riverine flow and discharge (from Bartram and Rees 2000, p.193).

Dilution effect [a,b]	Treatment level				
	None	**Primary**	**Secondary**	**Secondary plus disinfection**	**Lagoon**
High population with low river flow	Very high	Very high	High	Low	Medium
Low population with low river flow	Very high	High	Medium	Very low	Medium
Medium population with medium river flow	High	Medium	Low	Very low	Low
High population with high river flow	High	Medium	Low	Very low	Low
Low population with high river flow	High	Medium	Very low	Very low	Very low

a. The population factor includes all the population upstream from the recreational-water environment to be classified and assumes no in-stream reduction in hazard factor used to classify the recreational-water environment.
b. Stream flow is the 10% flow during the period of active beach use. Stream flow assumes no dispersion plug flow conditions to the beach.

Also, comparison of the high-flow and low-flow potential delivery rates is made in Table 6; the potential rates are obtained by averaging amount discharged over the period of discharge, and they estimate the average "intensity" challenge of the microbial pollution to the affected bathing area. The rates for the Bray CSO are one to two orders of magnitude greater than the upstream rates during high-flow, and two to three orders greater than during low flow. The comparatively high CSO rates arise because pumping during high-flow conditions occurs for short periods of time delivering high microorganism concentrations.

Given that the Bray CSO is beside the south beach bathing area, a strong correspondence between the CSO discharges and the bathing area water quality would be expected *a priori*. The temporal correspondence of faecal indicator organism concentrations found at Bray South Beach and for Bray CSO discharges during September 2000 is examined in Table 7 from which the following observations emerge.

1. The Bray CSO discharge on 9th September of short duration was followed on 10th September by high FC (17667 cfu/(100 ml)) and FS concentrations (917 cfu/(100 ml)) at Bray South Beach with potential to classify it as "Poor" under the proposed Bathing Water Directive.

2. There was substantial CSO discharge on 21st September, and a high FS concentration (3600 cfu/(100 ml)) found late on the same day at Bray South Beach with potential to classify it as "Poor" (the FS concentrations was unusually high relative to the FC concentration).
3. There was substantial CSO discharge on 24th September, and a FC concentration (280 cfu/(100 ml)) found early on the same day at Bray South Beach had potential to classify it as "Good" under the proposed Bathing Water Directive.
4. There were high CSO discharges on 25-27th September, and a FS concentration (180 cfu/(100 ml)) found early on the 27th September at Bray South Beach had potential to classify it as "Good" under the proposed Bathing Water Directive.

Table 4. Classification matrix for recreational-water environments (after WHO 1999).

		Microbiological Assessment Category (95 percentile value as cfu/(100 ml))			
		A <40	**B** 40–200	**C** 201–500	**D** >500
Sanitary Inspection Category (susceptibility to faecal influence)	**Very low**	Very good	Very good	Follow up	Follow up
	Low	Very good	Good	Fair	Follow up
	Moderate	Follow up	Good	Fair	Poor
	High	Follow up	Follow up	Poor	Very poor
	Very high	Follow up	Follow up	Poor	Very poor

Note: An "exceptional circumstances" category is omitted for brevity; this relates to known periods of higher risk, such as during an outbreak in the local community with a pathogen that may be waterborne, trunk sewer/combined sewer rupture in the beach catchment, etc. Under such circumstances, the classification matrix would be superseded.

Table 5. Amounts of faecal indicator organisms as colony-forming units (cfu) delivered in high-flow conditions during 21st to 30th September 2000 (from Bruen et al., 2001).

Indicator bacteria	**Delivery rate (21st - 30th September 2000) (10^{12} x cfu)**	
	From upstream of Bray*	**From Bray CSO**
Total coliforms	2497	3463
Faecal coliforms	837	845
Faecal streptococci	162	168

* Including the delivery rate from the upstream Enniskerry CSO.

Table 6. Potential bacterial delivery rates as colony-forming units (cfu) per second in low river flow and high river flow (high rainfall) conditions (after Bruen et al., 2001).

Indicator bacteria	**Delivery rate (10^6 x cfu per second)**		
	From upstream of Bray		**From Bray CSO**
	Low flow	***High flow***	
Total coliforms	322	2706	134850
Faecal coliforms	39	708	36574
Faecal streptococci	8	190	13252

So the correspondence between the CSO discharges and the bathing area water quality, as seen in the available data (Table 7), was variable both temporally and in degree, and of poor predictive quality (e.g. the smallest discharge on 9th September was associated with the greatest bathing-area impact). In view of the likelihood that any such new Directive will require a discounting "stratagem" to be predictive, clearly full near-shore dispersal modelling of the CSO discharge involving the many hydrological and other relevant environmental factors will most likely be required to attain sufficient statistical credibility.

The diffuse sources of microbial pollution in the Dargle catchment were clearly of much less significance (Table 6) than the Bray CSO source considered above and are not discussed further here, save to point out that discounting processes required to counter the influence of episodic diffuse microbial pollution would have not alone to take account of near-shore dispersal, but would require reliable estimates of land-use impacts as well.

Turning to the data for the three-year period 1999-2001, the Bray CSO records showed that for two separate days when high IE values had been measured at Bray South Beach, pumping had taken place within the two previous days. When the two high EI results were discounted, the bathing area quality classification improved from 'Poor' to "Good". So at first glance, the stratagem of discounting high 95%ile values to improve classification when CSO discharge had occurred within a short time previously would seem workable. But as above, predictability remains an issue; sometimes when there is a CSO discharge of certain magnitude the bathing area may be badly affected and sometimes not (Table 7). Furthermore a discounting procedure would require a management response such as restricting use of the bathing area or advising users of a risk to health. Such responses on occasions whenever the CSO discharged would be probably be excessive in number (for example, the CSO at Bray discharged eight times during the 2000 bathing season).

Table 7. Temporal correspondence of faecal indicator organism concentrations found at Bray South Beach and for Bray CSO discharges during September 2000.

Date	Bray South Beach			Bray CSO discharge			
	Time	cfu/(100 ml)		Duration	Volume	10^{10} x cfu	
		FC	FS	(hr)	(m^3)	FC	FS
9-Sep-00				0.1334	432	1821*	709*
10-Sep-00	10:11	17667	917				
21-Sep-00	15:20	90	40	1.1667	3780	14427	4977
	17:20	220	3600				
24-Sep-00	11:25	280	80	0.8000	2592	10920*	4254*
	15:30	137	27				
	16:00	90	37				
25-Sep-00				0.7667	2484	10465*	4077*
26-Sep-00				0.1333	432	1819*	709*
27-Sep-00	18:09	133	180	0.2833	918	3396	1010

* Estimated from average discharge concentration.

CONCLUSIONS

Under both the proposed Bathing Water Directive and the WHO classification procedures Bray South Beach would be classified as “Poor” quality.

Discounting processes that might lead to waiver of high microbial concentrations would require an understanding of the stochastic nature of near-shore dispersal and land-use impacts to attain the predictability required. Studies in the Liffey catchment and Dublin Bay are in progress with this in mind.

ACKNOWLEDGEMENTS:

This work was supported under measure 1.3 of the Maritime Ireland/Wales INTERREG programme (1994-1999), and by a grant from the Environmental Protection Agency (Ireland).

REFERENCES

Bartram, J. and Rees, G. (eds.) (2000) Monitoring bathing waters: a practical guide to the design and implementation of assessments and monitoring programmes. E & F N Spons, London.

Bruen, M.P., Chawla, R., Crowther, J., Francis, C.A., Kay, D, Masterson, B.F., O’Connor, P.E., Parmentier, B., Stokes, J-A., Thorp, M.B., Watkins, J. and Wyer, M.D. (2001) Achieving EU Standards in Recreational Waters. (Maritime Ireland/Wales INTERREG Report No. 6) The Marine Institute, Dublin.

Commission of the European Communities (2000) COM 2000 860: Developing a new bathing water directive. p.4. CEC, Brussels.

Commission of the European Communities (2002) Proposal for a directive of the European Parliament and of the Council concerning the quality of bathing water. 2002/0254 (COD).

Department of the Environment and Local Government (2000) Guidelines for the Establishment of River Basin Management Systems. DOELG, Dublin.

EEC (European Economic Community) (1976). Council of 8 December 1975 concerning the quality of bathing water (76/160/EEC). Official Journal of the European Communities L31: 1-7.

European Union (2000) Directive of the European Parliament and of the Council (2000/60/EC) Establishing a Framework for Community Action in the Field of Water Policy.

Masterson, B. and Chawla, C. (2003) Retrospective compliance of Irish coastal bathing areas with the proposed EU Bathing Water Directive. Desk study report to the Environmental Protection Agency (Ireland).

USEPA (2002) Implementation guidance for ambient water quality criteria for bacteria (May 2002 Draft). EPA-823-B-02-003.

WHO (1999) Health-based monitoring of recreational waters: the feasibility of a new approach (the “Annapolis Protocol”). World Health Organization, Geneva.