THE EC WATER FRAMEWORK DIRECTIVE AND MONITORING LAKES IN THE REPUBLIC OF IRELAND

KENNETH IRVINE, GARY FREE, ELVIRA DE EYTO,
JONATHAN WHITE, NORMAN ALLOTT AND PAUL MILLS

*(Drs K. Irvine, G. Free, E. de Eyto, J. White, N. Allott,
Department of Zoology, University of Dublin, Trinity College, Dublin 2,*
and *P. Mills, Compass Informatics, 19 Nassau Street, Dublin 2, Ireland.)
[Email: Kirvine@tcd. ie]*

Introduction

In this contribution we explore and discuss the effects of implementing the EC Water Framework Directive (WFD) in the Republic of Ireland, and we summarise some of the findings from a survey of 31 lakes sampled regularly between March 1996 and December 1997 (Irvine et al. 2001).

Background to monitoring Irish lakes and implementation of the WFD

There is without doubt a continuing deterioration of the quality of surface waters in Ireland. Although many lakes and rivers retain high quality water and habitats, the need to address a worsening situation overall has been highlighted in the recent report: *Ireland's Environment - A Millennium Report* by the (Irish) Environmental Protection Agency (EPA 2000). This focus on declining water quality coincides, perhaps fortuitously, with the development of the EC WFD, establishing a framework for Community action in the field of water policy. The EC's pursuance of legal action over phosphorus emissions and failure to implement EC Directive 76/4645/EEC focuses further attention on the issues, and particularly the causes, of eutrophication. In the Republic of Ireland, these are generally attributed to intensification of agriculture. This has involved the increasing application of inorganic nutrients (Tunney et al. 1997) and large-scale disposal of animals wastes, usually achieved through spreading on land.

The WFD places water and its associated ecological quality within the context of the catchment through the implementation of River Basin Management Plans. It will supersede and amalgamate a number of existing Directives that have arisen somewhat piecemeal in response to environmental pressures on aquatic environments, and will be the effective document under which national legislation will address quality issues within rivers, lakes, transitional waters (mainly estuaries), coastal waters and groundwaters. It will, however, also address those pressures within the catchment that lead to deterioration or provide risk to water and its ecology. As such, the WFD is extensive in its coverage and has major implications for the sustainable management of both terrestrial and water habitats.

The WFD departs from traditional thinking in one other and significant way. It requires quality status to be defined relative to reference conditions, with a key defining issue that quality will be based largely around the concept of "ecological quality". This is of fundamental importance to both surface and groundwater assessment protocols. It necessitates the identification of baseline or reference conditions for rivers, lakes, transitional waters and coastal waters in terms of hydromorphology, chemistry and biology. For heavily modified or artificial waters the WFD refers to an "ecological potential". The approach to definition of "good status" for groundwaters is broadly similar, dependent on a number of chemical parameters but also on the diminution of chemical or ecological quality of associated terrestrial systems. The requirements of the proposed WFD include the setting of quality standards, supported with ecotoxicological testing, for listed priority substances for both ground and surface waters.

The response of Member States to the demands of the WFD is in its infancy and the next few years will require the development of the methodological and political instruments necessary for effective implementation. The WFD provides the paradox of a set of seemingly stringent policies, written in fairly general terms. Despite an extensive list of definitions, the WFD does not provide real guidance on the workable meaning of many of its aspirational policies. This has led to considerable debate over a whole range of meanings contained within the Directive and the mechanisms required for its implementation. This debate relates to all types of waters and will probably go to the heart of questions about catchment use and its consequence on aquatic environments. There will be a need to establish criteria for environmental risk for each category of aquatic habitat and identify the causative pressures on them.

Recent monitoring of lakes in the Republic of Ireland

Risk assessment and monitoring will form an iterative process, with the extent of risk determining the intensity of monitoring. This poses numerous problems, not least with regard to determining the scale and intensity of monitoring programmes. In the Republic of Ireland there already exists an extensive network for monitoring rivers (e.g. Lucey et al. 1999), based mainly on macroinvertebrate surveys but also including measurement of chemical variables for many sites. In comparison, lake monitoring has been much less extensive and has not developed as an integrated strategy.

Although there was a national survey covering 53 lakes in the 1970s (Flanagan & Toner 1975), sampling of lakes has occurred generally as a response to perceived problems of water quality and has focussed on the larger, often "higher profile" waters. In the most recent national *Water Quality in Ireland* report covering the period 1995-1997 (Lucey et al. 1999), quality assessment was based on 120 lakes, of which 39 were sampled in only one of the three sampling years and 43 lakes were sampled only once. Assessment of 51 lakes was based on six or more samples taken within a one-year period, with 30 of those lakes sampled at least six times annually in more than one year. The assessment included the majority of the 24 larger (>750 ha area) lakes, with information given for 23 of them. In the previous reporting period, covering 1991-1994, Bowman et al. (1996) provided information on 135 lakes, including 17 of the larger lakes.

While it can be argued that, in terms of water volume, monitoring the majority of the larger lakes provides an adequate coverage overall, it is also clear that the number of lakes that were monitored regularly represents a very small proportion of the estimated 4000 to 5000 lakes present in the Republic. It is also true that the intra-annual frequency of sampling for water chemistry has been generally lower than the recommended periodicity given in the WFD. With the exception of phytoplankton chlorophyll-α, biotic variables generally have not been included in the evaluation of lake quality. Over the last twenty years, some detailed but short-term studies of lakes have included plankton counts (e.g. Horkan & Toner 1984; Bowman 1985; Bowman 1991), and macrophytes have been intensively surveyed in some lakes (King & Caffrey 1998). Monitoring of fish stocks is well established through the work of the Central and Regional Fisheries Boards, but is traditionally related to a "beneficial use" of angling (Central Fisheries Board 1986), although this has been increasingly accompanied by monitoring for other fauna in lakes such as Loughs Derg, Sheelin, Ennell, Corrib and Conn. With one notable exception (monitoring profundal animals in Lough Leane, Killarney (Twomey 1995; Irvine et al. 2001)), macroinvertebrates have not been included routinely in lake assessment protocols. This contrasts markedly with the ongoing programme of river quality assessment by the Irish EPA that is dependent on sampling macroinvertebrates. However, the contrast between assessment of rivers and *ad hoc* monitoring of lakes is not a uniquely Irish phenomenon. Monitoring of lakes across Europe is generally less comprehensive than that of rivers (Kristensen & Bogestrand 1996).

Recent strategies for monitoring the lakes in the Republic of Ireland are insufficient to meet the demands of the WFD. In addition to the limited spatial and temporal coverage, current practice evaluates trophic status of lakes by estimating the maximum annual concentration of chlorophyll-α (e.g. DELG 1997). In some cases this has been done with only a single annual sample. Recent introduction of nutrient management regulations (DELG 1998), the provision of nutrient management by-laws as recently passed in County Cavan, and the restriction of spreading wastes on land under Section 12 of the Water Pollution Act (1977), will assist with addressing nutrient pollution of waters. Nevertheless these measures provide a much more limited vision of pollution control than that contained in the WFD. A national monitoring programme for lake water quality currently under development by the EPA will considerably extend coverage of assessment (J. Bowman, EPA, personal communication), but has been designed to fulfill a requirement under Section 65 of the Environmental Protection Agency Act (1992). It is, therefore, not as encompassing in its assessment philosophy as the WFD.

In recognition of the limitations of previous sampling in the Republic's lakes and realisation of the need to extend the rationale of lake assessment away from water quality *per se* and into wider concepts of "ecological quality", in 1995 the Irish EPA instigated a number of projects that would start the process of preparing for what has evolved into the WFD from its 1994 precursor, the draft *Ecological Quality of Water* Directive. Results of this programme 'either have been published recently (O'Mongain et al. 1999; Patersen et al. 1999; Tunney et al. 2000) or are in final stages of preparation (Irvine et al. 2001; McCarthy et al. 2001). In addition to the extensive amount of information collected, the projects have progressed the implementation of the WFD in two general ways. First, they have extended the coverage of lakes sampled in the Republic. Second, they have included biotic sampling and information on catchment use concurrent with physico-chemical sampling of lakes. A number of the projects have also contributed to the development of a national lake database and the application of Geographical Information Systems to information storage and dissemination.

Seasonality - a basic problem for effectively monitoring lakes

The WFD provides guidelines for the frequency of monitoring biotic and physico-chemical variables in lakes (Table 1). These guidelines are designed to address seasonal variation and to ensure that sampling frequencies effectively monitor inter-annual changes.

Table 1. Frequencies for monitoring biotic and physico-chemical elements for assessing lakes, recommended by the EC Water Framework Directive.

Quality element	Monitoring frequency
Biological:	
Phytoplankton	6 months
Other aquatic flora	3 years
Macroinvertebrates	3 years
Fish	3 years
Physico-chemical:	
Thermal conditions	3 months
Oxygenation	3 months
Salinity	3 months
Nutrient status	3 months
Acidification status	3 months
Other pollutants	3 months
Priority substances	1 month

Any monitoring programme of temperate lakes (and, incidentally, many tropical lakes) attests to the fact that seasonal variation of physico-chemical and biotic variables tends to be the norm rather than the exception. This is central to the philosophy of limnology and any serious programme designed to monitor a lake involves a trade-off between ideal sampling frequencies and logistical constraints. For studies of single lakes, this often means accepting a frequency of monthly or fortnightly sampling. In some well funded catchment studies, automatic samples and analyses enable more frequent sampling. Such intensive work is usually done to establish important principles such as the relationship between land-use or climate with nutrient loading. The dilemma for a national monitoring programme of lakes is obvious. What is the minimum number of intra-annual samples that are needed to evaluate a lake's quality status?

Use of biotic quality elements for assessing lakes

The WFD places emphasis on monitoring biotic as well as physico-chemical variables. Biotic elements required for lakes are phytoplankton, macrophytes and phytobenthos, benthic invertebrates and fish. Whether all of these elements are required for all lakes that are monitored remains uncertain, but it is unlikely that elements could be discounted without good scientific argument. It is also necessary that baseline reference conditions for the biotic elements (as well as for the physico-chemical and hydromorphological elements) are established. Reference states will be used as benchmarks to classify elements as having "high, good, moderate, poor or bad status". Currently, there is no established methodology for determining the quality status of any biotic element in Irish lakes. Expert judgement is of course useful but, almost inevitably, will be influenced by experience of only a limited number of lakes.

The way forward for incorporation of biotic variables into lake assessment is not straightforward. Reference conditions are likely to vary among lakes with apparently similar hydromorphology and water chemistry, and collection of historic data from sediment cores can be expensive and technically difficult. A first step for use of biotic variables in the assessment of lakes is to establish relationships between biotic and physico-chemical variables within a range of lakes with varying morphological and catchment characteristics. This, at least, provides an understanding of biotic community structure in varying ecological conditions and can identify taxa that are useful as bioindicators. At the same time it is important to acknowledge that sampling a biotic variable that has clear associations with water chemistry may not be any more informative than simply obtaining chemical measurements. However, without the first stage of identifying these relationships, it is difficult to envisage the development of a more sophisticated methodology. The largely successful use of macroinvertebrates in river monitoring is based on a century of investigations of such associations (Washington 1984) culminating in sophisticated monitoring methodologies (Wright et al. 1998, 2000).

A recent study of 31 lakes in the Republic of Ireland

Between March 1996 and December 1997, 31 lakes (Table 2) in the Republic of Ireland were sampled regularly for a range of physico-chemical and biotic variables that probably would be important for monitoring programmes implemented under the WFD. The lakes represented a range of hydromorphological and physico-chemical conditions throughout the Republic. It included lakes with severe anthropogenic disturbance and those that were thought to be in fairly pristine condition. In addition to limnological sampling, catchment and land-use data were also collected. Each lake was assigned a unique national identification code and all data

Table 2. Locations of 31 Irish lakes sampled in 1996 and 1997. Depth is maximum depth (m).

Lake	Depth	Catchment	County	Easting	Northing
Ballycullinan		Fergus	Clare	129000	185800
Ballyquirke		Corrib	Galway	123200	231700
Bray Lower		Dargle	Wicklow	313704	216253
Bunny		Fergus	Clare	137500	196600
Caragh		Caragh	Kerry	72797	91291
Cullaun		Fergus	Clare	131500	190600
Dan		Ovoca	Wicklow	315384	203652
Doolough		Annageeragh	Clare	112200	172000
Dromore		Fergus	Clare	134400	185800
Easky		Easky	Sligo	144600	323000
Egish		Erne	Monaghan	279400	313400
Feeagh		Srahmore	Mayo	96709	300241
Gara Lower (S)		Shannon Upper	Sligo	169500	296500
Gowna		Erne	Cavan	228800	292200
Graney		Shannon Lower	Clare	155700	192800
Inchiquin		Fergus	Clare	127000	189600
Leane		Laune	Kerry	93700	88100
Lene		Boyne	Westmeath	251500	268300
Lettercraffroe		Corrib	Galway	105800	237600
Lickeen		Inagh	Clare	117600	191000
Maumwee		Corrib	Galway	97700	248400
Moher		Owenwee	Mayo	97700	276600
Muckno		Fane	Monaghan	285100	319100
Muckross		Laune	Kerry	95300	85200
Mullagh		Boyne	Cavan	267700	285400
Oughter		Erne	Cavan	234935	305143
Owel		Inny	Westmeath	240000	258100
Pollaphuca		Liffey	Wicklow	2999875	210115
Ramor		Boyne	Cavan	260300	286800
Rea		Kilcolgan	Galway	161500	215700
Talt		Moy	Sligo	139800	315000

that had been collected was stored within a Geographical Information System (GIS), designed to be compatible with national requirements. A full methodology and the results of this project are provided by Irvine et al. (2001). For the purposes of this account, we highlight two main points.

(1) The inherent seasonal variability of the common descriptors of lake trophic status, i.e. Total phosphorus (TP) and chlorophyll-α.

(2) Aspects of the data collected for littoral invertebrates that will assist towards meaningful incorporation into monitoring programmes designed to meet the requirements of the WFD.

We have chosen to focus on trophic status, as nutrient enrichment is the greatest environmental pressure on Irish lakes.

Total phosphorus and chlorophyll-α

Eleven lakes were sampled approximately monthly and the other 20 in April, June, July and September of each year. Sampling stations were located using a SCUBAPRO PDS-2 hand-held echo sounder and were generally at lake maximum depth. Vertically integrated samples for chemical and physical analysis were taken using a tube of 2.5 cm internal diameter and 6 metres in length. Two 6-m vertically integrated samples provided 5 litres of water. Where the depth was insufficient or the hypolimnion extended above 6 m, a dip sample was taken at c.0.5 m depth.

Total phosphorus (TP) was determined in duplicate according to Eisenreich et al. (1975) and measured spectrophotometrically at 882 nm. All determinations of TP followed calibration with five standards in duplicate. Chlorophyll-α was determined using methanol extraction according to the Standing Committee of Analysts (1980). Depending on sample turbidity, 0.1 to 2.5 litres of sample was filtered through GF/C filter paper using a field hand-operated filter pump. The filter paper was placed into a centrifuge tube containing 10 ml of methanol, placed in darkness and stored at 4°C upon return to the laboratory. Samples were brought to boiling point (c.75°C) for 60 seconds. After cooling, the filter papers were removed and samples were centrifuged at 3500 rpm for 9 minutes. Absorbance was measured with a spectrophotometer at 665 and 750 nm.

Seasonality of total phosphorus and chlorophyll-a

Of the eleven lakes sampled at the higher frequency (c. monthly, Table 3), maximum concentrations of TP occurred between October and March in six lakes, and between April and October in the other five (Ballyquirke, Gowna, Lene, Owel, Ramor). Minimum concentrations were found in June-July for four lakes in both years (Feeagh, Inchiquin, Lickeen, Moher), and in another four lakes in one of the years sampled (Dan, Doolagh, Gowna, Ramor). In the other lakes, or years, minimum concentrations were found in autumn (September-October) or early spring (January-April).

Table 3. Mean concentrations (|ig per litre) ± 95% confidence limits for Total phosphorus and chlorophyll-α in eleven Irish lakes sampled approximately monthly between March 1996 and December 1997; n is the number of samples each year.

Lake	n	Total phosphorus	Chlorophyll-*a*
Ballyquirke 1996	7	19.4 ± 2.4	15.1 ± 6.0
Ballyquirke 1997	10	20.2 ± 2.5	7.2 ± 2.8
Dan 1996	8	9.6 ± 2.7	1.1 ± 0.4
Dan 1997	10	13.6 ± 3.0	1.2 ± 0.7
Doolough 1996	8	13.8 ± 1.9	5.4 ± 1.5
Doolough 1997	10	17.5 ± 2.8	7.7 ± 2.4
Feeagh 1996	8	11.8 ±1.9	1.5 ± 1.0
Feeagh 1997	10	10.4 ± 1.6	1.6 ± 0.9
Gowna 1996	8	37.5 ± 9.1	22.8 ± 6.8
Gowna 1997	10	47.2 ± 10.3	18.2 ± 6.3
Inchiquin 1996	7	16.0 ± 8.8	6.2 ± 3.5
Inchiquin 1997	10	26.2 ± 8.9	3.2 ± 1.5
Lene 1996	8	10.8 ± 3.2	5.9 ± 3.2
Lene 1997	10	12.5 ± 3.4	4.5 ± 1.2
Lickeen 1996	8	15.1 ± 3.7	11.1 ± 3.3
Lickeen 1997	10	17.3 ± 3.6	14.7 ± 9.1
Moher 1996	8	9.8 ± 2.9	3.8 ± 1.5
Moher 1997	10	12.8 ± 2.4	4.4 ± 1.9
Owel 1996	8	8.9 ± 2.5	5.9 ± 2.1
Owel 1997	10	10.8 ± 2.3	6.6 ± 1.4
Ramor 1996	8	84.1 ± 18.4	60.2 ± 31.9
Ramor 1997	10	91.0 ± 31.7	56.5 ± 36.7

Seasonal pattern of TP was variable among lakes and more pronounced in some, as exemplified by four lakes located within 50 km of each other in the west of the Republic (Fig. 1).

Lough Lickeen and Inchiquin showed clear patterns of TP winter maxima and summer minima, while in Doolough this pattern was much less clear and in Ballyquirke it was not evident at all (Fig. 1).

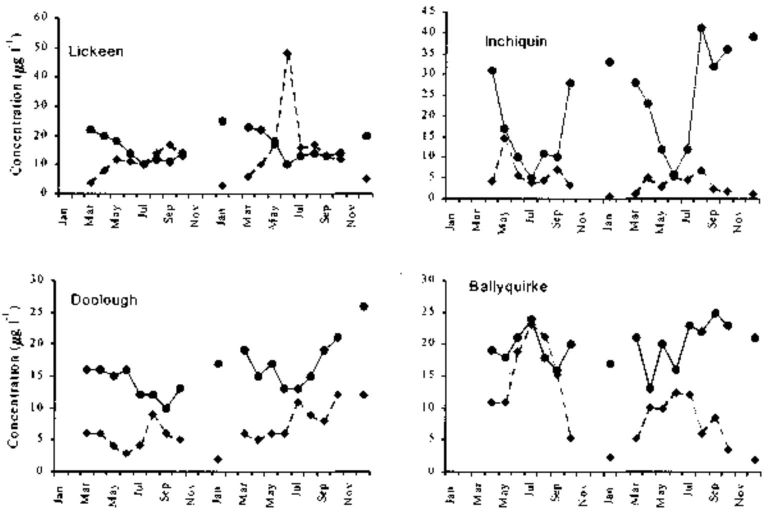

FIG. 1. Concentrations (µg per litre) of Total phosphorus (solid lines) and chlorophyll-α (dashed lines) in four Irish lakes during 1996 and 1997.

No single annual measurement was a reliable estimate of either annual maxima or mean TP among the eleven lakes for which monthly data was collected. The 95% confidence limits indicated that for many of the lakes the spread of seasonal samples provided a reliable estimate of the mean. For some lakes, however, such as Inchiquin, Gowna and Ramor, there was high variance around the mean. Nevertheless, a spread of four samples across the annual cycle provided a mean value within 10% of the mean calculated from the original sampling effort for 18 out of the 22 lake-years sampled; the maximum deviation from the original mean was 19% (Lickeen 1996). The combination of four samples providing the best fit to the annual mean TP estimated from the original samples was, for 1996, March (excepting Ballyquirke and Inchiquin, for which n = 3), June, September and the following January. For 1997, the 4-month combination was January, March, June, and September. When the sample for December (1996) was used instead of the January (1997) sample to represent the winter variable for TP in 1997, 16 of the estimates were within 10% of means based on a larger sample size (Table 3) and the maximum deviation was also 19%.

Concentrations of phytoplankton chlorophyll-α also displayed marked seasonal variation (Table 3 and Fig. 1) but the seasonal pattern was quite different from that of TP. Maximum chlorophyll-α in nine of the 22 lake-years occurred in August, and another eight occurred between June and October. In three lakes (Inchiquin, Lene and Moher) maxima occurred in spring (March-May). Seasonal patterns of maximum chlorophyll-α were normally consistent between years for the lakes. Notable exceptions were Lough Inchiquin (maximum concentrations in May 1996 and August 1997) and Lickeen (maximum concentrations in September 1996 and June 1997). Annual variation among chlorophyll-α concentrations was generally more pronounced than for TP. With the same four seasonally spread samples that were used for TP estimates, mean values for chlorophyll-α were within 10% of the original means for 11 lake-years, with a maximum deviation of 37% (Lough Lene 1996). The spread of four samples that provided the closest fit to the overall seasonal means (Table 3) was for samples collected in March, May, July and September. This provided estimates of mean chlorophyll-α within 10% of the original means for 12 lake-years, with a maximum deviation of 37% (Lough Inchiquin 1996).

Littoral macrinvertebrates

Macroinvertebrates were sampled from the littoral of 29 lakes between April 1996 and June 1997. Sampling for benthic macro-invertebrates was done using a 0.25 x 0.25 m sweep-net with a mesh size of 1 mm. The net was trawled behind feet kicking the substrata for 12 seconds, covering a distance of 1 metre and in water no deeper than 0.5 m. Samples were taken from mineral substrata of predominantly pebbles (16 to 64 mm diameter) and cobbles (64 to 256 mm diameter) from all lakes with the exception of Lough Dromore, where this habitat type was not within easy access. Samples were preserved in the field in 70% industrial methylated spirits (IMS) and sorted and identified later using stereo and compound microscopy. Additional samples were collected for chydorids (Cladocera). These were sampled by kick-sampling using a net with 240 μm mesh, which was swept over *c.*\ m of the lake bed for 12 seconds. The sample was washed from the net and preserved in 70% alcohol. The samples were taken from the littoral zone of each lake in a depth of c.30 cm. As chydorid species have quite specific habitat preferences, sampling was standardised by collecting from a stony/gravely substratum and, where possible, a bed of aquatic plants was included at each site. The samples were taken from the same locations on each visit. Eighteen taxa were significantly related to major physico-chemical variables of the lakes (Table 4). Some of these taxa were only found in a minority of the lakes studied but others, such as the gastropod mollusc *Valvata,* the isopod cructacean *Asellus,* and the

Table 4. Spearman rank correlation coefficients for relationships between the mean abundances of littoral macroinvertebrate taxa identified as potentially useful indicators for lake assessment and three major physico-chemical variables indicative of geological, acidity and trophic status of Irish lakes; n is the number of lakes where taxa were recorded. Significance levels *p<0.05, **p<0.01.

Taxa	n	Mean conductivity	Median pH	Mean Total P
Tricladida				
Polycelis	22	0.54*	0.54*	0.45*
Mollusca				
Valvata	29	0.36	0.20	0.49**
Bithynia/Potamopyrgus	12	0.83**	0.28	0.10
Physa fontinalis	7	0.18	−0.78*	0.47
Ancylidae	9	−0.77*	−0.79*	−0.54
Ephemeroptera				
Leptophlebia	13	−0.65*	−0.79**	−0.53
Plecoptera	9	−0.90**	−0.81*	−0.30
Leuctra	6	−0.99*	−0.79	−0.53
Hemiptera	24	−0.51*	−0.35	0.13
Crustacea Isopoda				
Asellus	2	0.61**	0.51*	0.57**
Crustacea Chydoridae				
Alona guttata	7	0.42*	0.36	0.08
Alona rustica	11	−0.36	−0.37*	−0.11
Alonella excisa	11	−0.19	−0.01	−0.57*
Alonopsis elongata	15	−0.43*	−0.26	−0.79*
Chydorus piger	9	−0.39*	−0.40*	−0.18
Chydorus sphaericus	28	0.45*	0.23	0.58*
Pleuroxus truncatus	11	0.57*	0.32	0.03
Pleuroxus uncinatus	11	0.06	−0.01	0.57*

chydorid cladocerans *Chydorus sphaericus* and *Alonopsis elongata,* were widespread. Analysis of community structure through multivariate techniques suggested that community structure could assist with lake classification (Irvine et al. 2001). However, further analysis using a dataset from a larger number of lakes is required to develop methodology that would be useful for a meaningful assessment of lakes. Assessments of the potential of profundal invertebrates and open-water zooplankton for monitoring programmes are presented by Irvine et al. (2001).

Problems of monitoring lake types with varying seasonal patterns

The requirements of the WFD imply a radical departure from the accepted view that successful management of lakes requires detailed assessment and that lake ecology can only be evaluated on a case by case basis. Logistical and financial limits inevitably put the onus on European Member States to provide cost-effective assessment techniques. The WFD is, however, clear in its dictates that inherent temporal and spatial variability must be taken into account when devising monitoring programmes. Therein lies the challenge to provide an effective monitoring protocol. The work summarised here demonstrates the difficulty of monitoring different lake types with varying patterns of seasonality. The common indicators of trophic status - Total phosphorus and chlorophyll-α - showed different degrees and patterns of variance. Sampling of biotic elements illustrated other problems. Lakes often have varying types of substrata and the distribution of invertebrate taxa amongst a series of lakes can be quite variable. Multivariate techniques offer a powerful tool for quantifying biotic communities indicative of lake types and quality status, but they require a large sample of lakes before they can be used with confidence in lake assessment. However, many of the questions that we need to answer are now well formulated and should form the next stage of research. They include finding solutions to difficulties relating to seasonal and spatial variation of physico-chemical and biotic elements, the choice of those elements in routine monitoring, and the establishment of baseline status for lakes. It would be important to resist a headlong charge into routine monitoring without further elucidation of the underlying distribution patterns of those elements that the WFD requires to be monitored.

Classification of lakes and the meaning of terms

The meaning of many terms defined in the WFD require clarification, not least the working definition of "high", "good", "moderate", "poor" and "bad" status. Selection of a system of classification for Irish lakes is also currently uncertain. If one of the suggested classification schemes (System A) of the WFD is employed then the majority of lakes in the Republic will fall below the minimum surface area of 50 hectares. If this occurs it will not be in keeping with the spirit of the WFD. The use of fixed-boundary assessment schemes such as the OECD (1982) trophic classification should be re-evaluated, even though this has been enshrined recently in Local Government Regulations in the Irish Republic (DELG 1998). The fixed-boundary scheme, while useful for general categorisation of lakes, can place too much emphasis on small differences that straddle boundaries and do not assess the trophic status of lakes relative to reference conditions. The DELG (1998) regulations permit assessment of trophic status based on a single seasonal measurement of chlorophyll-a, and allow baseline target conditions to be established through monitoring done after 1995. This permits, respectively, a "hit or miss" approach to monitoring, and enables management to discount recent degradation of lakes, in cases where the first sampling after 1995 classifies a lake as mesotrophic or oligotrophic. For many Irish lakes, a mesotrophic rating may already indicate significant departure from high quality within the meaning of the WFD.

Assessing risk from activities on the catchment

In addition to the development of assessment protocols within each lake, the WFD also requires the assessment of risk from activities on the catchment. Over the last few years there has been a considerable amount of work in the development of mathematical models that describe and predict the relationship between catchment activities and nutrient runoff (e.g. Beaulac & Reckhow 1982; Clesceri et al. 1986; Johnes et al. 1996; Muller et al. 1998; Kronvang et al. 1999; Arheimer & Brandt 2000). Much of this work has occurred in relative isolation as different workers favour their own version of the art. The time probably has come to collate and evaluate the effectiveness of catchment and nutrient transport models to provide a realistic assessment of risk to lakes from differing catchment use.

In the Irish Republic, recent large-scale catchment management programmes such as those for the catchments of the Shannon and the Killarney lakes, bear testament to a shift in political acceptance of the need to understand and implement catchment management for the protection of surface and groundwaters. The recently announced *National Development Plan 2000-2006* indicates an allocation of nearly Ir£3 billion pounds for investment in water and wastewater services. New research programmes funded by the Irish EPA will be in nutrient losses from agricultural catchments, a study of the state of preparation for WFD implementation, and a pilot field programme of lake monitoring with regard to the requirements of the WFD. Therefore the Republic of Ireland appears to be taking its responsibilities under the WFD quite seriously. For many years, ecologists may have been critical of a *laissez faire* attitude by Government and the public to the rich water resources of the country, and it remains to be seen if recent encouraging rhetoric on policies and funding translate into protection and restoration of surface waters. If so, it may soon be the case that it is ecologists who will be criticised for failing to provide the effective techniques for lake and catchment management.

Acknowledgements

Data presented in this contribution was collected under a project part-financed by the European Regional Development Fund through the Operational Programme for Environmental Services 1994-1999. The authors thank the Irish Environmental Protection Agency and its staff for support. The opinions expressed above are, however, not necessarily those of the Agency or its staff. KI would like to thank Peter Hale and the Environment and Heritage Service of Northern Ireland for providing the opportunity to attend the meeting on Lake Assessment and the EC Water Framework Directive, in Enniskillen, NI, at which this contribution, in part, was presented.

References

Arheimer, B. & Brandt, B. (2000). Watershed modelling of nonpoint nitrogen losses from arable land to the Swedish coast in 1985 and 1994. *Ecological Engineering* 14, 389-404.

Bowman, J. J. (1985). *The trophic status of Irish Lakes. Lough Derg.* An Foras Fortartha, Dublin.

Bowman, J. J. (1991). *Acid sensitive surface waters in Ireland.* Environmental Research Unit, Dublin.

Bowman, J. J., Clabby, K. J., Lucey, J. McGarrigle, M. L. & Toner. P. E. (1996). *Water quality in Ireland 1991-1994.* Environmental Protection Agency, Ireland.

Central Fisheries Board (1986). *Inland fisheries. Strategies for management and development.* Central Fisheries Board, Dublin.

Beaulac, M. N. & Reckhow, K. M. (1996). An examination of land use-nutrient export relationships. *Water Resources Bulletin* 18, 1013-1024.

Clescerin, L., Curren, S. J & Sedlak, R. I. (1986). Nutrient loads to Wisconsin lakes: Part I. Nitrogen and phosphorus export coefficients. *Water Resources Bulletin* 22, 983-990.

Department of the Environment and Local Government (DELG), Ireland (1977). *Local government (Water Pollution Act).* Government Supplies Agency, Dublin.

Department of the Environment and Local Government (DELG), Ireland (1992). *The Environmental Protection Agency Act.* Government Supplies Agency, Dublin.

Department of the Environment and Local Government (DELG), Ireland (1997). *Managing Ireland's rivers and lakes. A catchment based strategy against eutrophication.* Government Supplies Agency, Dublin.

Department of the Environment and Local Government (DELG), Ireland (1998). *Local government (Water Pollution) (Nutrient Management Planning Consultation) regulations.* Statutory Instruments No 257 of 1998. Government Supplies Agency, Dublin.

Eisenreich, S. J., Bannerman, R. T. & Armstrong, D. E. (1975). A simplified phosphorus analysis technique. *Environmental Letters* 9, 43-53.

EPA (2000). *Ireland's environment - a millennium report.* Environmental Protection Agency, Wexford.

Flanagan, P. J. & Toner, P. F. (1975). *A preliminary survey of Irish lakes.* An Foras Forbartha, Dublin.

Horkan, J. P. K. & Toner, P. F. (1984). *The trophic status of Irish lakes: Lough Muckno.* An Foras Forbartha, Dublin.

Irvine, K., Allott, N., De Eyto, E., Free, G., White, J., Caroni, R., Kennelly, C, Keaney, J., Lennon, C, Kemp, A., Barry, E., Day, S., Mills, P., O' Riain, G., Quirke, B., Twomey, H. & Sweeney, P. (2001). *Ecological assessment of Irish lakes: the development of a new methodology suited to the needs of the EU Directive for surface waters.* Environmental Protection Agency, Wexford.

lohnes, P., Moss, B. & Phillips, G. (1996). The determination of total nitrogen and total phosphorus concentrations in freshwaters from land use, stock headage and population data: testing of a model for use in conservation and water quality management. *Freshwater Biology*36,451-473.

King, J. J. & Caffrey, J. M. (1998). Macrophytes in Irish lakes and rivers: an overview of investigations and current knowledge. In *Studies in Irish limnology* (ed. P. S. Giller), 101-124. Marine Institute, Dublin.

Kristensen, P. & Bogestrand, I. (1996). *Surface water quality monitoring.* Topic report 2/96. European Topic Centre on Inland Waters.

Kronvang, B, Svendsen, L. M., Jensen, J. P. & Dorge, J. (1999). Scenario analysis of nutrient management at the river basin scale. *Hydrobiologia* 410,207-212.

Lucey, J., Bowman, J. J., Claby, K. J., Cunningham, P., Lehane, M., MacCarthaigh, M. L. & Toner, P. F. (1999). *Water quality in Ireland 1995-1997.* Environmental Protection Agency, Wexford.

McCarthy, T. K. and others (2001). *Investigation of eutrophication processes in the littoral zones of western lakes.* Environmental Protection Agency, Wexford.

Muller B, Lotter, A. F., Sturm, M. & Ammann, A. (1998). Influence of catchment quality and altitude on the water and sediment composition of 68 small lakes in Central Europe. *Aquatic Sciences* 60, 316-337.

OECD (1982). *Eutrophication of waters. Monitoring assessment and control.* Organisation for Economic Cooperation and Development, Paris.

O'Mongain, E., Collons, A., Green, S., O'Riain, G. & Caffrey, J. (1999). *Remote sensing of lakes - improved chlorophyll calibration and data processing.* Environmental Protection Agency, Wexford.

Petersen, A., Keevil, C. W., Hunter, P. R., Merrett, H. & Reynolds, C. S. (1999). *Investigation of toxins produced by Cyanobacteria.* Environmental Protection Agency, Wexford.

Standing Committee of Analysts (1980). *The determination of chlorophyll-a in aquatic environments.* Her Majesty's Stationary Office, London.

Tunney, H, Breeuwsma, A., Withers, P. J. A. & Ehlert, P. A. I. (1997). Phosphorus fertilizer strategies: present and future. In *Phosphorus loss from soil to waters* (eds H. Tunney, O. T. Carton, P. C. Brookes & A. E. Johnston), pp. 177-203. CAB International.

Tunney, H., Coulter, B., Daly, K., Kurz, I., Coxon, C, Jeffrey, D., Mills, P., Kiely, G. & Morgan, G. (2000). *Quantification of phosphorus (P) losses to water due to soil P desorption.* Environmental Protection Agency, Wexford.

Twomey, H. (1995). *Biological investigations of Lough Leane, Killarney National Park.* Unpublished Report to National Parks and Wildlife Service.

Washington, H. G. (1984). Diversity, biotic and similarity indices. A review with special reference to aquatic ecosystems. *Water Research* 18, 653-694.

Wright, J. F., Furse, M. T. & Moss, D. (1998). River classification using invertebrates: RIVPACS applications. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8,617-631.

Wright, J. F., Sutcliffe, D. W. & Furse, M. T. (2000). *Assessing the biological quality of fresh waters: RIVPACS and other techniques.* Freshwater Biological Association, Ambleside, xxiv + 373 pp.