Irish estuaries: Water quality status and monitoring implicationsunder the water framework directive

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Abstract

The status of water quality of Irish estuaries is reviewed; this sheds light on the rationale behind the design of the national monitoring programme. Relative to other EU Member States, Ireland's coastal monitoring programme is relatively young and not as advanced. The monitoring programmes in Ireland pre Water Framework Directive (WFD) were structured on a salinity-based typology, with an emphasis on quantifying the variability of the component elements. Although monitoring is a significant obligation under the WFD, there is little guidance on developing monitoring protocols; Member States are developing ad hoc monitoring programme. The Irish Environmental Protection Agency (EPA), responsible authority, undertook research programmes to assist design and implementation of the WFD. A substantial new national monitoring programme was developed. However, the Irish programme is not optimised; the programme is being refined to include elements not yet covered, notably the biota. New research, by the authors, aims to develop a robust approach towards monitoring integrating data and model results. This paper presents changes in Irish marine water quality monitoring policy and some of the associated research necessary to change policy. Monitoring water quality status throughout EU Member States has developed in an individualistic and piecemeal fashion. Relative to other EU Member States, Ireland's coastal monitoring programme is relatively young and not as advanced . The monitoring programmes in Ireland pre Water Framework Directive (WFD) was structured on a salinity-based typology, with monitoring of 56 transitional waters and an emphasis on quantifying the variability of the component elements.

Keywords: WFD, Irish estuaries, water quality, monitoring, Bayesian maximum entropy

1.1 Introduction

Estuaries in Ireland, as elsewhere, have long been associated with human settlements, and have long been subject to the consequences of the full range of human activities. These include reclamation of saltmarsh and mudflat, modifications (e.g. canalisation, dredging) for shipping and transport along with the discharges and dumping from such, extraction of renewable natural resources such as fisheries, and of course the discharge of domestic and industrial wastes. All of these changes have impacted on the functioning of the system. McLusky and Elliott [1] have summarised and codified the consequences of major changes under the DPSIR (Driver, Pressure, State, Impact, Response) framework, and in particular have emphasised the inter-relatedness of many of the features. Of particular importance in the drive toward sustainable management of estuarine systems has been Costanza et al.'s seminal paper [2] of the economic value of such ecosystems, highlighting not just the obvious economic activities, but also the value of what are termed the 'natural goods and services' of the system and which are crucially dependent on its proper functioning.

Historically, a number of Irish legal instruments were adopted to address monitoring in estuaries and other surface waters; the most significant are considered here. The Local Government (Water Pollution) Act, 1977 placed the onus for monitoring of industrial and domestic discharges and monitoring of receiving waters on local authorities. The Act lays down requirements for the drafting of water quality management plans (WQMP). An integral component of WQMP's is that monitoring aspects of a plan becomes a legal obligation on the relevant local authority. Details of monitoring, however, were non-specific. The Quality of Bathing Water Regulations 1988 prescribes responsibilities for bathing waters monitoring programmes on local authorities and, subsequently, on the EPA. The Environmental Protection Agency Act, 1992 sets out requirements for local authorities to report to the EPA monitoring results of, inter alia, (i) discharges from urban waste water plants and, in prescribed circumstances, (ii) receiving waters. The EPA publishes reports on discharges biannually. The second requirement is met by joint EPA-local authority monitoring programmes for general water quality in estuaries. The Fisheries (Amendment) Act, 1997 governs licensing and control of the aquaculture industry. The Act contains powers to enforce licensees to monitor water quality and biological activity.

Ireland is a Contracting Party to the OSPAR Convention, 1992. The Joint Assessment and Monitoring Programme (JAMP), was established under OSPAR in 1995 to provide an evolving framework for obtaining relevant and reliable information for marine water quality assessment based on routine monitoring. With the adaption of the WFD into Irish law, monitoring obligations have increased further and monitoring objectives have changed significantly; consequently, new monitoring programmes have been devised to ensure compliance with the WFD and other legal obligations.

This paper considers monitoring requirements for Irish transitional waters in relation to WFD and discusses implications for Ireland relative to other EU Member States. The sea change in moving from pre-WFD monitoring to the monitoring devised to fulfil WFD requirements are discussed. The policy adopted by the Irish EPA is presented and

discussed. Research undertaken by the Authors and others relating to WFD and monitoring of water quality is presented. The current status of Irish transitional waters, based on the reporting of recent monitoring, is also presented. This is informative with respect to understanding the context of the design of the national monitoring programme. The paper attempts to provide a balance for the reader between some of the technical aspects behind designing monitoring programmes and policy issues.

1.2 Background

The estuaries along the east coast of Ireland show the greatest morphological modification, most notably in the form of polderisation and loss of marshland and mudflat. The inner part of Dublin Bay has been greatly altered by human activity, with the northern half of the Bay now dominated by the evolution at the end of the 18th century of Bull Island following the construction of sea wall north and south to keep the channel clear for shipping. Further reclamation has continued – and is still being sought – to the present day. Likewise the estuary of the Boyne has been both canalised and reclaimed, and significant dredging works are regularly undertaken to maintain and even deepen the channel for shipping. The Slaney estuary at Wexford is less impacted, although again here there has been substantial reclamation of the north and south sloblands. The major port, established on the open coast at Rosslare just to the south of the Slaney estuary entrance has nonetheless been implicated in the increasing erosion problems of the shoreland and cliffs to the north.

Estuaries are also the prime interface between land and sea and the river input brings with it the accumulated inputs, both natural and anthropogenic, from the whole of the catchment area. These influences are recognised by the Water Framework Directive (WFD, 2000/60/EC) most notably in its emphasis that River Basin Districts are the basic unit of management. The 18th century also saw the issue in Dublin Bay of the first documented lease of oyster beds, granting permission for the extraction of tens of thousands of oysters per year, and shellfish (of all species) continued to be taken from Dublin Bay until the beginning of the 20th century saw the practice banned on health grounds. Public health was also the driver of the construction, in the second half of the 18th century, of centralised urban sewage collection and disposal, if not always treatment.

Typically, the collected wastes were discharged at, or near, the mouth of the estuary, causing not only the public health problems with the shellfish, but also siltation, de-oxygenation and algal blooms. The Report of the Royal Commission on Sewage Disposal [3] drew heavily on the scientific investigations in the Liffey estuary. This report was well ahead of its time, in that it not only noted the above consequences of waste disposal practice, but also pointed to the abundance of small worms as an indicator of sewage pollution and suggested that the nuisance blooms of green macro-algae were a consequence of an excess of Nitrogen (N) in the system.

While domestic wastes were a problem, only in Belfast was there sufficient heavy industry to generate significant amounts of industrial wastes and persistent contaminants like heavy metals. One exception to this was the legacy of old mining activities on the

banks of the Avoca River, which still brings down a substantial load of metals into the estuary[4]. Other instances of persistent metal contamination were very localised and comparatively short-lived, for example Hg in the Liffey, Cr in Dungarvan [5] and Cu in the Lee [4]. Other anthropogenic inputs through the rivers remained small until Ireland's accession to the European Community (EC) in 1973. This resulted in, among other impacts, a great increase in the application of fertilisers to farmland and also a shift to a much more intensive agriculture, both of which contributed to a greatly-increased nutrient input to estuarine systems from their rivers.

Accession to the EC also brought Ireland under the many environmental Directives, some of which, like the Urban Wastewater Treatment Directive (91/271/EC) have fundamentally changed the existing situation. The WFD not only brings these under a common framework, but also lays down for the first time quality goals and a timetable for their implementation. The purpose of the WFD is to establish a framework for the preservation and, where necessary, the improvement of water quality of inland surface waters, transitional and coastal waters and groundwater. The prime and overriding objective of the WFD is for all surface waters, artificial and heavily modified waters and groundwaters to achieve at least good water status by 2015. Article 4 of the Directive requires that Environmental Objectives must be defined for each waterbody on an individual basis. Article 8 requires that Member States shall ensure the establishment of programmes for the monitoring of water status in order to establish "a coherent and comprehensive overview" of water status in each waterbody. Monitoring is required to establish the status of waterbodies identified as being at risk of failing to achieve their environmental objectives. Monitoring programmes are designed in accordance the general requirements of Guidance on Monitoring for the WFD (WFD Common Implementation Strategy Working Group 2.7: Monitoring).

The WFD has brought about a significant shift in the entire approach to the management of water quality. Previously, management emphasis was on ensuring that the various individual uses to which water and the aquatic environment were put were protected, so different aspects of the impacts and pressures on the environment were assessed under individual and self-contained programmes. As a consequence, there was a generally low level of co-ordination of the monitoring activities undertaken by the various agencies, and the accessibility of results between agencies and to the wider public was often poor. The WFD is designed towards the protection of the aquatic environment as a common heritage. The WFD provides a comprehensive framework for the protection of all aspects of the aquatic environment, introducing a catchment-centred approach based on specific issues and needs of each catchment (river basin district). The Directive also proceeds further than previous 'first generation' Directives towards the full and transparent communication of information, including the results of monitoring.

The following two sections discusses water quality monitoring programmes prior to the WFD and the major sea change in Ireland developing new the policies necessary to implement marine monitoring programmes to ensure compliance with WFD. The paper considers the research required to design the new monitoring programmes and the national bodies mobilised in order to deliver the programme. Section 4 considers the

current water quality status in Irish estuaries with respect to trophic status, harmful algal blooms, biological quality elements and other contaminants. This snapshot in time provides understanding for the design of the national monitoring programmes.

2 Policy changes in monitoring water quality in Ireland

In general, in order to ensure compliance with national and international regulations monitoring is mandatory; however, the development of acceptable monitoring systems is often neither well-defined nor trivial. Monitoring in EU coastal waters was initiated at different times in order to meet either national or EU requirements and obligations. The Dutch water monitoring programme began in 1901; monitoring was used in coastal engineering projects such as the Deltaplan. Coastal water quality (BOD, oxygen and faecal coliforms) monitoring began in the early 1960s and in 1964, a total of 87 stations were being monitored. In the UK prior to the implementation in 1985 of the Control of Pollution Act 1974 few estuaries and no coastlines were monitored. Irish coastal water monitoring dates back to the early 1980s, similar to the UK. Throughout Europe some existing monitoring networks are more easily adaptable to meet the requirements of the WFD than others, [6]; regions such as the UK network, the French network [7], the Italian network [8] and the Basque network [9] are relatively easily adapted to meet requirements of the WFD.

Prior to WFD adaption, Ireland had a relatively well-developed marine environmental monitoring programme that primarily addresses Ireland's responsibilities with respect to national legislation, EU Directives and the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic (1992). The substantive Irish primary legislation relating to water quality is presented in Table 1.

Table 1 – Substantive Irish primary legislation on water quality

Irish Legalisation
European Communities Act 1972
Local Government (Water Pollution) Act 1977
The Quality of Bathing Water Regulations 1988
Local Government (Water Pollution) Act 1990
EPA Act (1992)
Local Government Act 1994
Waste Management Act 1996
The Fisheries (Amendment) Act 1997

The main Irish agencies involved in marine monitoring were the EPA, Marine Institute and the Radiological Protection Institute of Ireland. Each agency focuses on its own environmental sectors, impacts and measurements; monitoring pre-2005 was not highly integrated and was quite selective with respect to the elements monitored.

The EPA [10] undertook a review of water quality management planning in Ireland. Up to that time the primary legal instrument driving policy in this area was the 1977 Local Government Water Pollution Act. Under this Act it was a requirement to develop WQMP for all major river and estuary catchments of Ireland (over 100 in total). However, just prior to the adaption of the WFD into Irish law there were only 20 plans developed. During the implementation of WFD the country has been divided into 8 river basin districts, and plans had to be developed for each river basin district. This change alone has a major significance for the management and monitoring of transitional waters. Water bodies are no longer considered as separate catchments but as components of larger interacting systems. As part of the review, inter alia, the following particular conclusions were drawn:

- Implementation of the plans was not consistent.
- There had been no systematic review of the plans
- Given the continuing deterioration of water quality up to that point in time water quality management planning was not adequately protecting the quality of the waters being protected by the plans.
- National catchment management and monitoring systems did not have any statutory status and were not incorporated into WQMP.

Among the recommendations made were:

- Water quality management planning should be carried out in such a war that common issues are dealt with in an integrated way
- Monitoring systems should be developed and used as a basis for updating statutory WQMP's.

The above situation reveals a disparate approach to water quality management planning in Ireland prior to the implementation of WFD. With the legal enforcement of WFD into Irish law policy relating to water quality management and planning changed significantly and quickly. Annex VIII of the WFD lists the main pollutants to be considered as supporting water quality elements in river basin management plans; these pollutants are divided into groups 1-9 'specific relevant pollutants' and groups 10-12 as 'general components'. Both groups were addressed separately under two EPA initiatives.

The EPA [11] developed environmental quality standards (EQS) for general compliance in surface waters in Ireland. As part of this exercise it was determining pre-existing water quality standards were inadequate to address the full suite of quality elements considered by the WFD, and did not take the typology systems introduced by WFD into account. Therefore, the implementation of WFD in Ireland necessitated a comprehensive review of existing standards to provide a WFD compliant system. Annex V of WFD define thermal conditions, oxygenation conditions, salinity, acidification status, nutrient conditions and transparency as the general components supporting water quality elements. The EPA [11] then focused on formulating Irish standards for general components in all Irish waters, including transitional waters. Datasets were collated and analysed, the resulting proposed standards were subjected to peer review and a preliminary implementation analysis was undertaken to identify scientific constraints in the application of the standards. As part of this process ten national water quality

datasets (provided by different national agencies) were analysed to aid the formulation of appropriate Irish national standards. Where new standards were developed these have been implemented, however, where existing standards relating to other legislation, for example Bathing waters designated areas, were more stringent these standards were retained. It is acknowledged that, due to a lack of data, some of the standards developed may need to be revised.

Regarding specific relevant pollutants, the WFD stipulates that the Member States must identify and prioritise pollutants that are discharged into waters in 'significant quantities'. In Ireland [12] the significance of a substance was determined by the following factors: presence in water in high concentrations; know levels of use, and risk posed by the substance. The methodology for developing standards for priority substances developed by Lepper [13, 14] was adopted in Ireland.

The specific relevant pollutants were selected as follows:

- Eight substances that had previously been prioritised by Irish EPA
- Twelve substances considered by Irish eco-region neighbour via the UK Technical Advisory Group (UKTAG).
- Ten additional substances selected on the basis of routine detection by the ongoing National Dangerous Substances Screening Programme.

In general with respect to both general components and specific relevant components, it is planned that the Irish standards will be reviewed over future planning cycles based on:

- Availability of more WFD monitoring data
- The sensitivity of particular catchments may require more stringent standards
- A better understanding of the role of certain pollutants as a result of new research
- Availability of information from the monitoring programmes of other EU states
- Harmonisation of data across international borders

The above paragraphs clearly illustrate that it was necessary in Ireland to design and implement a more comprehensive monitoring programme to satisfy WFD requirements; this lead to the development of a National Environmental Monitoring Programme for Transitional, Coastal and Marine Waters, [15]. A policy decision was taken so that this programme was developed to fulfil monitoring requirements under all national and European legislation and international conventions that have been transposed into Irish law. In total the programme addresses 20 different regulations; the responsibility for delivering the national monitoring programme resides with 12 different Irish agencies based on their historical monitoring activities [15]. The overall programme, which is very ambitious relative to historical Irish marine monitoring, consists of 36 sub-programmes grouped under the following six subject areas:

- Physical aspects
- Ecological integrity and biodiversity
- Water quality and trophic status
- Hazardous substances
- Food safety and human health
- Radioactive substances

The sub-programmes contain both pre-existing monitoring programmes and several new programmes specifically designed to fulfil WFD requirements; many pre-existing programmes were extended to fully cover WFD requirements. For example, existing programmes did not measure changes in benthic invertebrate communities. Some of the sub-programmes were amended due to differences in approach between WFD requirements and other requirements. Consider that the ultimate objectives of OSPAR and WFD are similar insofar as protection of marine ecosystems, their approaches differ. The priority for OSPAR is contaminant reduction without a requirement to demonstrate biological effects, a broad interpretation of the precautionary principle. Whereas the WFD focuses on maintaining ecological quality and compliance with environmental quality standards; hence, within a WFD context contaminant reduction may assume a lower priority. OSPAR concentrates on chemical monitoring; it also contains a biological monitoring programme that is optional to member states. Prior to WFD implementation Ireland had not implemented the biological monitoring component of OSPAR. Thus, for Ireland, implementing the WFD the design and implementation of a biological monitoring programme constituted a major expansion of the national monitoring programme and associated policy issues. The national programme has been developed so that assessment of the monitoring data, and the human pressures to which they are subjected, is based on the significance of the impact to the whole water body.

Much of the planning activities associated with designing the national monitoring programmes were carried out through research projects funded by the Irish EPA [16]. Most research was carried out in the areas of monitoring biological elements and hydromorphological quality elements in transitional and coastal waters. Table 2 details research carried out associated with biological monitoring and Table 3 details research associated with hydromorphological element elements.

3 Implementation of WFD water quality monitoring in Ireland

The WFD stipulates that three different monitoring programmes must be deployed: surveillance monitoring, operational monitoring and investigative monitoring. Each type of programme has specific, multiple objectives. For example, an objective of surveillance monitoring is to assess long-term changes resulting from widespread anthropogenic activity and an objective of investigative monitoring is to ascertain magnitude and impacts of accidental pollution. The operational modelling programme supports the measures aimed at achieving the WFD main objective and is thus designed to provide highly targeted information on the success or otherwise of particular measures within river basin catchments. The design requirements of each programme type are quite different and vary with respect to temporal and spatial granularity. Given that pre-WFD in Ireland only a small percentage of quality elements were being monitored, the implementation and ongoing maintenance of these monitoring programmes will lead to a much larger marine monitoring programme in Ireland and will have substantial financial implications.

Table 2 - Monitoring biological elements in transitional and coastal waters.

Element Monitored	Pre WFD activities	Research undertaken
Phytoplankton	Phytoplankton measured at 50 sites during summer. Chlorophyll regularly monitored in major bays/estuaries	Reference basis established for surveillance monitoring. Research carried out into natural variability.
Macroalgae/ Angiosperms	No routine monitoring Good baseline exists	Development of type-specific reference conditions for macroalgae and angiosperms. Development of standard method for monitoring composition and density of seaweed beds.
Benthic invertebrate fauna	Routine monitoring at aquaculture sites	Identification of reference sites for long-term monitoring
Fish fauna	No monitoring	Complete monitoring programme developed

Table 3 - Monitoring hydromorphological quality elements in transitional and coastal waters.

Element Monitored	Pre WFD activities	Research undertaken
Tidal regime:		
Transitional waters	Tidal limit of major rivers monitored	Establishment of inter-annual variability
Coastal waters	No routine monitoring	Developed monitoring programme
Morphological:		
Transitional waters	No routine monitoring	Development of morphological condition indices
Coastal waters	No routine monitoring	Development of morphological condition indices

For Irish coastal and transitional waters two primary monitoring programmes have been established – the surveillance monitoring (SM) and operational monitoring (OM) programmes. In accordance with the WFD, a number of representative water bodies were

selected to provide an assessment of the overall status of Ireland's transitional and coastal waters. The monitoring programme deployed was designed around previous and existing programmes in place in Irish tidal waters since the early 1970s. Although both programmes are essential to WFD implementation, the focus here is on the operational monitoring programme whose main objectives are to:

- establish the status of those bodies identified as being at risk of failing to meet their environmental objectives
- assess any changes in status of such bodies resulting from the programme of measures

A major aspect of monitoring programmes in general is the choice of sampling locations. The selection of sampling points and the design of the Irish OM Programme network is based on key sub-networks ('subnets') each designed to fulfill one or more of the main objectives of the monitoring programme. Table 4 summarises the 6 subnets developed by the Irish EPA for OM.

In total, 309 water bodies were considered for inclusion in the Irish National Coastal and Transitional Waters monitoring programme. These water bodies were identified as a consequence of a typology project that was concluded in 2003. A subset of these water bodies was selected on the basis of the risk assessment procedure whereby significant pressures were identified in tandem with a series of subnets describing specific conditions warranting monitoring. The subnets presented in Table 4 consist of 79 water bodies of which 56 are transitional waters and 23 coastal water bodies.

Table 4 - Summary of Operational Monitoring subnets common to all surface water categories.

Subnet	Title	Coastal Waters	Transitional Waters
OM1	Establish status of at risk water bodies	13	48
OM2	Effectiveness of diffuse and point source pollution measures	5	39
OM3	Effectiveness of measures to reduce hydromorphological pressures	5	32
OM4	Effectiveness of measures aimed at retaining high and good status	10	8
OM5	Electronic alert and remote sensing	N/A	N/A
OM6	Species and habitat protected areas	10	47

The choice of quality elements to include in the monitoring programme was made with assistance from the joint United Kingdom - Ireland Marine Task Team. As part of this programme component an analysis was completed to identify the quality elements most sensitive to relevant pressures. Table 5 presents the quality elements monitored and also the monitoring frequency with respect to coastal and transitional waters. Table 5 also shows that not all quality elements are necessarily monitored at all sites.

Analysis of data collected through monitoring systems deployed in the natural environment can be very difficult. The inherent natural variability together with the frequency of monitoring determines confidence in the data collected for physico-chemical parameters. In order to provide confidence in monitoring data the Irish EPA uses the coefficient of variation (CV) which is a statistical measure of the scatter in datasets. CVs have been developed for different types of water bodies for selected physico-chemical determinants. In this instance, CVs have been computed for whole-river datasets and also averaged across a number of rivers based on 28,000 individual measurements. The precise CV for an individual water body may vary greatly even for the same parameter. When publishing results the EPA provides estimates of the confidence and precision attached to individual sets of results for particular water bodies.

Table 5 (a) - Summary of Transitional Waters Monitoring Programme

Quality Element*	**P**	**M**	**A**	**BI**	**H**	**P-C**	**RP**	**PS**
Total no. operational sites	53	42	30	74	38	191	13	13
No. of sites required on:								
Annual basis	53(4)	-	-	-	-	191(4)	13(4)	13(12)
3-year cycle	-	14(1)	10(1)	25(1)	-	-	4(4)	4(4)
6-year cycle	-	-	-	-	6	-	-	-

Table 5 (b) - Summary of Coastal Waters Monitoring Programme

Quality Element*	**P**	**M**	**A**	**BI**	**H**	**P-C**	**RP**	**PS**
Total no. operational sites	16	41	26	96	10	92	1	0
No. of sites required on:								
Annual basis		-	-	-	-	92(4)	1(4)	-
3-year cycle	16(12)	14(1)	9(1)	25(1)	-	-	-	-
6-year cycle	-	-	-	-	2	-	-	-
	-							

* P – phytoplankton; M – macroalgae; A – angiosperms; BI – benthic invertebrates; H – hydromorphology; PC – physico-chemical; RP – related pollutants; PS – priority substances

De Jonge et al [17] discuss inherent spatial and temporal complexities associated with variability of coastal systems and the associated problems for meaningful monitoring. In order to develop a more systematic approach to monitoring Kabuta and Laane [18] also highlight the need and difficulties associated with increased spatial and temporal monitoring. The Irish EPA is also funding the Authors to carry out research into improving the design of efficient and accurate monitoring programmes [19]. Currently there is no coherent methodology for designing water quality monitoring programmes for water bodies in which water quality parameters vary widely on both spatial and temporal scales. Generally speaking, the WFD is quite vague with respect to monitoring locations and monitoring frequency; the guidance on sample site selection given in Annex V of the WFD is not prescriptive about the appropriate distribution or density of sites to be sampled. Guidance on monitoring frequency is also limited and vague. Maximum intervals between collecting samples is specified, however, it up to each Member State to determine specific intervals for individual programmes.

Estuarine waters often exhibit complex pollutant transport patterns. Boundaries between transitional and coastal waters are almost never distinct and vary with tide, season and weather conditions. Interactions between coastal and offshore waters significantly affect contaminant distributions and their effects on marine ecosystems. This poses many difficult questions for monitoring, such as: where is an appropriate location to deploy samplers to obtain data representative of the wider water body? A research project being undertaken by the Authors has been funded by EPA in which spatio-temporal random field theory (STRF) will bring together results from monitoring datasets and outputs from numerical models to develop an approach for: (a) assessing the effectiveness of monitoring programmes, and (b) for devising optimized programmes. In particular, this novel research will incorporate both hard (monitored) and soft (modelled) data to deliver a structured approach for developing monitoring systems for compliance assessment. Bayesian maximum entropy provides a formal framework to combine information (hard and soft) and to provide estimates, along with uncertainty information, at any point throughout an estuary. Information on how a parameter then varies over time and space is determined using STRF theory which in turn is then used to determine defined ranges of plausible estimates for the parameters of interest. This EPA funded research will augment the current approach using CVs for assessing physico-chemical water quality parameters. Through the integration of data and numerical model output, using STRF theory, more efficient, accurate and cost effective monitoring programmes will be put in place throughout the river basin districts in Ireland.

4 Water quality status of Irish Estuaries

This section considers results from recent monitoring programmes and some of the water quality issues affecting Irish estuaries. The latest report on water quality monitoring published by the EPA [6] concluded that eutrophication was the still the main threat to Irish estuarine quality status, with little overall change over the past decade, see Table 6.

Table 6 - Trophic status (% length) of Irish estuaries 2004-6 compared with 1995-9 and number (N) surveyed [20]

Trophic status	**1995-9 %**	**2004-6%**
Eutrophic	25	19
Potentially eutrophic	5	3
Intermediate	30	39
Unpolluted	40	39
N	60	69

Because of the variable characteristics of tidal water in respect of salinity, the EPA [20] developed a methodology for trophic assessment of estuaries and bays in terms of three types of waters:

1. tidal fresh waters (TFW)
2. intermediate salinity waters -17 psu median (ISW)
3. full salinity waters - 35 psu median (FSW)

The trophic status is dependent on four water quality parameters: dissolved inorganic nitrogen (DIN), orthophosphate (MRP), chlorophyll a and dissolved oxygen (DO). The methodology also differentiates between summer (S) and winter (W) trophic status. The criteria determined for use in trophic assessment are presented in Table 7. Values in Table 7 relate to median values of samples unless otherwise stated.

Table 7 - Criteria for eutrophication in Irish estuaries and coastal waters by salinity division and season(see also text for explanation)

Salinity type	TFW		ISW		FSW	
Season	S	W	S	W	S	W
Quality Element						
DIN ($mg.l^{-1}$ N)	>2.6	>2.6	>1.4	>1.4	>0.25	>0.25
MRP ($\mu g.l^{-1}$ P)	>60	>60	>60	>60	>40	>40
Chlorophyll_a ($mg.m^{-3}$)	>15	-	>15	-	>10	-
	or		**or**		**or**	
	>30[1]	-	>30[1]	-	>20[1]	-
DO (% saturation)	<70[2]	-	<70[2]	-	<80[2]	-
	or		**or**		**or**	
	>130[3]	-	>130[3]	-	>120[3]	-

[1] 90 percentile; [2] 5 percentile; [3] 95 percentile.

To establish trophic status for waters whose median salinity lies between these salinity levels, linear interpolation is used. The application of the EPA approach requires '...a number of years' data' [21]. Also, direct application of the criteria specified in Table 7 alone is not meant to provide a fully self-contained means of trophic status classification. For example, information on excessive macroalgal growth and distribution patterns is also relevant.

The focus on nutrients and eutrophication is backed up by [4] findings based on estuarine sediment contaminant loads. This study identified nutrients (both N and P) as the principal contaminant, and noted that in those estuaries for which prior data were available, the situation if anything seemed to have worsened [4]. Those estuaries for which P was the lowest-scoring contaminant included most of the major estuaries on the east coast (Boyne, Rogerstown, Tolka, Slaney), with the highest P concentration recorded in Rogerstown at 6669 ugP g^{-1} dry weight sediment [4].

Although nutrients and eutrophication are considered suitable assessment variables, the EPA methodology is not very clear regarding implementation of the approach. The assessment is based on the above four quality elements, however, no guidance is provided regarding the monitoring programme to collect data. No guidance is presented regarding spatial or temporal sampling. As estuaries are generally highly dynamic environments concentrations of the quality elements may change rapidly with time and location. Research carried out for EPA [22] used a numerical model along with monitoring data to undertake a trophic assessment of Lough Mahon in Cork Harbour. Through integrating data and model outputs, several regions of isoconcentrations were defined within Lough Mahon; the above methodology was then applied to the value of the quality element within each separate region. This approach proved highly successful and was used by the Irish Department of Environment and Local Government in the planning of an outfall from a major sewage treatment plant for Cork City, population equivalent of 300,000. In the Author's view when applied in this manner the EPA trophic assessment methodology is highly appropriate and illustrates how it may be utilised to consider interventions or proposed developments.

Eutrophication is linked into oxygen depletion, and the EPA [20] noted significantly lowered dissolved oxygen (DO) levels and/or elevated BOD in a number of estuaries, notably those at Avoca, Upper Lee (Tralee), Upper Bandon, Erne, Cashen Feale, Liffey, Lee and Upper Swilly, along with South Wexford Harbour, Youghal Harbour and coastal waters of McSwyne's Bay. The other side of the coin (oxygen supersaturation) was noted in Rogerstown (Inner), Lower Slaney, Colligan, Upper Blackwater, Upper and Lower Bandon estuaries and in Dungarvan Harbour.

The EPA [20] covers a range of other contaminants as well, although these are not covered by the systematic estuarine sampling programme, but by other programmes in coastal waters rather than estuaries *per se.* Metals and synthetic organics in commercial fish and shellfish are sampled in the Marine Institute as part of Ireland's contribution to the Joint Assessment and Monitoring Programme (JAMP) of the OSPAR Convention. Their data ([23] and [24]) suggest few problems, as apart from isolated high values, the

levels are well below those likely to be of concern. However, samples from estuaries, and in particular from inner zones not covered by the JAMP sampling suggest there are localized areas of concern. The Avoca estuary has high metal levels and the lowest biological quality possible [4]; inner Dublin Bay (Tolka and Liffey estuaries) are also affected, although not completely abiotic [4]. In addition to the above, Cork Harbour has areas with elevated levels of metals [25], PAHs and synthetic organics [26], and organotins [27] with significant deleterious effects on the fauna. Organotins remain a concern around many parts of the Irish coast, albeit a decreasing concern since the ban in 1987, but the Quality Status Report [28] noted that residues persist in the sediments of many Irish harbours, and that comparatively high concentrations have been found in inner Bantry Harbour, Casteltownbere, inner Cork Harbour and Killybegs.

Harmful algal blooms (HABs) can be taken as a symptom of system dysfunction, although there is also clear evidence that their occurrence can be a natural phenomenon and blooms can be initiated offshore [29]. HABs have been reported from all round the Irish coast, with *Dinophysis* spp. the commonest cause [20], but the problem has been particularly acute in some years on west and south-west coasts. Other HAB species have been detected and Table 8 lists the species and the type of poisoning, although it should be noted that toxic effects have only been reported in respect of the first two species (*Dinophysis acuminata* and *Alexandrium tamarense*).

Table 8 - HAB species noted from Irish waters and their effects [28]

Species	Effects
Dinophysis acuminata	Diarrhetic Shellfish Poisoning (DSP)
Alexandrium tamarense	Paralytic Shellfish Poisoning (PSP)
Pseudo-nitzschia australis	Amnesiac Shellfish Poisoning (ASP)
Gambierdiscus toxicus	Ciguatera Shellfish Poisoning (CSP)
Trichodesmuim sp.	Cyanobacteria Toxin Poisoning (CTP)
Gyrodinium aureolum	Cytotoxic effects (selective)
*Pfiesteria*sp.	Toxic/allergic inflammatory reaction, ulcers
Phaeocystis pouchetti	Foams, minor allergy
Noctiluca sp	'Red' tides

The assessment of biological or ecological status in estuaries is problematic [30], in that natural stressors, notably salinity, can evoke a similar response to pollution stress, and the suggestion has been made (e.g. [4]) that many estuarine species themselves display opportunistic or r-strategist traits. Wilson [4] summarised the biological status of a range of estuaries around Ireland, and found only the Liffey, the Dodder and the Avoca estuaries had Biological Quality Index ((BQI) scores of <1.0, that is where the majority of the system was dominated by opportunistic species or completely abiotic. However, no estuary scored a perfect 10.0, and the conclusion must be that there are some portions of estuarine systems which will always show some deleterious effects, however produced. More focused toxicity tests have shown a range of impacts on fauna in Dublin bay ([31] and [32]), Cork harbour ([33] and [25]), Dunmore east [34] and Youghal [32], although there is in general a dearth of information in this area.

In terms of human health, the levels of contaminants, including radioactivity, across the board are considered well within EU limits for human consumption [21], and the major concerns are those of shellfish quality and bathing water quality. Shellfish quality encompasses two aspects, of which the first, shellfish poisoning is covered above with the HABs which have closed some areas of production. The second, concerned with microbial and pathogen contamination, is covered by the designation of selected areas under the various Shellfish Waters Directives (79/923/EC, 91/942/EC and 2006/113/EC). A total of 49 waters have been so designated around the Irish coast, and these are sampled regularly along with a number of other areas. The results [20] suggest that around a quarter meet the highest standards (direct human consumption) and all bar one of the remainder into Category B sites (that is they have a 90% compliance with the standards and a 48 hours depuration is sufficient). The situation for noting water quality is more complicated. The Bathing Waters Directive (76/160/EC) is still the foundation, although its replacement, Directive 2006/7/EC, came into force on 24 March 2006 but will not supersede the existing 1976 Directive until 31 December 2014. In the interim, 'good' classification indicates compliance with guide and mandatory values, 'sufficient' with the mandatory values only, whereas the 'poor' indicates non-compliance with mandatory values. Of the 122 designated marine bathing waters around the Irish coast, some 95% (116) met the minimum standards ('sufficient') [21], with the great majority (98 areas) achieving 'good' classification. It is worth noting that over the years, compliance of bathing waters with Directive 76/160/EC has always been high [21], but that the numbers of waters under consideration, including some with urban discharges, has more than doubled over the past 20 years, suggesting that the situation overall is improving.

A final factor to be considered is the presence of invasive species, which are increasingly being noted in Irish waters and especially estuaries [35]. While the presence alone of alien species does not affect the quality classification, any impact on the biological elements lowers condition status and of course excludes that location from any consideration of reference status. These impacts include HABs, for which there is some suggestion at least that the causative organisms in some cases may be introduced aliens (see e.g. *Pseudo-nitzschia australis*, Table 8).

5 Discussion and Conclusions

The major problem in Irish estuaries is that of eutrophication; problems of persistent contaminants are few, and those that have been reported have either greatly lessened since first recorded or are of a local and confined nature. Coastal management and monitoring has long suffered from a piecemeal approach in Ireland, with a plethora of national, regional and local authorities along with NGOs having a statutory right of consultation, and as many more voluntary organisations and trade agencies willing and anxious to make representations. O'Boyle and Silke [36] review phytoplankton in coastal, shelf and estuarine waters around Ireland. O'Boyle and Silke suggest that monitoring of phytoplankton as part of WFD compliance should be carried out in a pragmatic manner. Monitoring should not be overly prescriptive, rather monitoring should be based on assessing generic features such as phytoplankton biomass, intensity of blooms and species diversity. This review highlights the significant role that interactions

between open Atlantic waters and coastal waters leading to high levels of natural variability; this provides Ireland with a different situation to many other EU Member States.

The WFD implementation programme for estuaries in Ireland has lagged behind those of other components, most notably because of the lack of data especially on the biological side. The current programme is structured on a salinity-based typology, with monitoring of 56 transitional waters and an emphasis on quantifying the variability of the component elements. The programme is being further developed to include the elements not yet covered in Ireland, notably the biota.

The lack of conclusive evidence of anthropogenic impacts on the ecology of Irish estuaries is due to a number of factors. The first is a general lack of background data, with relatively few locations for which there are systematic biological data, and even the best-studied have considerable temporal gaps. Thus reference data for the WFD have to be deduced from existing situations or in comparison to standards (or locations) elsewhere. Physico-chemical data are more plentiful, but there is still considerable debate as to whether meaningful limit values can be established. As the monitoring data for the WFD are assembled these limits will be continually refined and updated. Finally, and this is not just a problem in the Irish context, there are suggestions that each individual estuary may respond in an idiosyncratic fashion, such that the drivers and limits that apply in one situation may combine differently in another (example, see Yarrow and Marin [37] for discussion). If this does pertain, then any establishment or attempt to manage through widely-based "reference conditions" will either be so vague as to be no real advance on the current practice or unworkable and possibly even damaging. This last poses a major challenge to the WFD itself.

The pre-existing Irish water quality monitoring network for transitional waters was not as easily adaptable to meet the WFD obligations as the networks of other EU Member States and incurred there significant financial implications. A large number of research projects were commissioned to assist in planning and designing the national monitoring programmes. A budget of €50M was allocated to support local authority expenditure on River Basin Management Projects. Relevant local authorities appointed GIS data managers to assist with informatics aspects of WFD implementation. Implementation of the WFD has placed significant demands on technical and personnel resources within the responsible organisations. Although exact details are not available on the additional resources, the main factors contributing to the additional burden are the number of sites needed for operational monitoring and the increased frequency of monitoring in Ireland over pre_WFD commitments. Some countries, such as UK, are implementing a cost-neutral network, with costs being borne by polluters. This approach is not yet being considered by Irish authorities.

Some of the main policy changes in Irish water quality management associated with WFD implementation are:

- Pre-WFD Irish monitoring programmes and plans were static, now monitoring is reviewed routinely and revised where necessary.

- Monitoring is now planned and implemented in a more systematic manner and integrated sets of EQS's have been developed that are now internationally recognised
- Reporting is regular and structured.
- A major policy decision was to develop one national monitoring programme to meet the requirements of various national and international pieces of legislation. It remains to be seen if this is the most appropriate approach.
- Over time, the results from monitoring programmes will be analysed to develop more optimised sets of parameters, EQS's and monitoring programmes.
- EU-wide experiences of WFD monitoring are shared and now inform national programmes.
- Probably a weakness with current policy is that the Irish national monitoring programme is not centralised; monitoring functions are spread among many independent agencies.

There is still much research to be carried out to incorporate likely impacts of climate change on WFD monitoring. In an Irish context, there has been little research carried out into downscaling global climate models to assess local impacts around the Irish coast. Research is also necessary to develop incorporate quality elements into the monitoring programme, in particular, the biota. Also, current research being funded by Irish EPA is investigating the use of Bayesian Maximum Entropy for optimising both spatial and temporal water quality monitoring programmes. This approach facilitates the systematic integration of data and model results to optimise programmes. The WFD clearly indentifies a role for modelling in implementing the WFD programmes; however, in Ireland to date models have not being widely used. BME provides a systematic and structured use of models in this context and it is likely that modelling will contribute more to the WFD implementation in Ireland when monitoring data becomes available.

The WFD not only has imposed a structure and methodology to confront problems of water quality in Irish estuaries, it has also provided the opportunity to develop our understanding of these systems necessary for sustainable management. Despite the wealth of data in some areas, it is evident that in the Irish situation there are substantial information deficits in other areas and even if the UK example can largely be used as a guide, there is no substitute for specific and local data. Although the first report on water quality status from the new national monitoring plan has yet to be published, it is obvious that significantly more data has been collect during the last monitoring period than had previously been collected – a positive and welcome step for protecting our marine environment.

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