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Review

Monitoring of Surface Waters in Germany under the Water Framework Directive—A Review of Approaches, Methods and Results

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Abstract: The European Commission Water Framework Directive (WFD) was established 16 years ago and forms the current basis for monitoring surface waters and groundwater in Europe. This legislation resulted in a necessary adaptation of the monitoring networks and programs for rivers, lakes, and transitional and coastal waters to the requirements of the WFD at German and European levels. The present study reviews the most important objectives of both the monitoring of surface waters and the principles of the WFD monitoring plan. Furthermore, we look at the changes water monitoring in Germany has undergone over the past sixteen years and we summarize monitoring results from German surfaces waters under the WFD. Comparisons of European approaches for biological assessments, of standards set for physical and chemical factors and of environmental quality standards for pollutants reveal the necessity for further European-wide harmonization. The objective of this harmonization is to improve comparability of the assessment of the ecological status of waters in Europe, and thus also to more coherently activate action programs of measures.

Keywords: Water Framework Directive; monitoring network; freshwater monitoring; monitoring types; ecological status; river basin specific pollutants; adaptive freshwater management

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1. Introduction

Water management poses a major challenge in many densely populated countries throughout the world. In Europe, and due to the WFD [1], stewardship of water resources is of paramount importance now and in the future. The major aim of the WFD is to reach good water quality in all European waters by managing water bodies, *i.e.*, lakes, rivers, groundwater bodies, transitional waters and coastal waters by 2027 at the latest. Official implementation of the WFD started on 22 December 2000 and marked the beginning of a new era in European water management. The WFD declares a unified and harmonized water protection framework for all European countries. Unified in this context means that European waters have been consolidated into large river basin districts managed collaboratively by the Member States (MS) concerned. The successful management of such river basin districts across national boundaries necessitates efficient collaboration in a spirit of partnership between all MS concerned. Hence the WFD aims at harmonized water protection regulations within the European Union (EU). The monitoring and management unit of the WFD is the "water body". It is defined as a discrete and significant element of surface water, which is uniform in type and status.

2. The Monitoring Program and Its Objectives under the WFD

The WFD monitoring program aims at collecting data for a status assessment and at controlling the efficiency of water protection measures applied. This is the reason why monitoring results have to facilitate resilient and reproducible statements. Annexes II and V of the WFD specify a comprehensive assessment and monitoring plan for waters. Annex V of the WFD specifies in depth the minimum requirements of the monitoring itself. Key aspects here include the monitoring types and objectives, the choice of monitoring sites, the quality elements (QEs) to be monitored, and the required monitoring frequencies ([1] compare Annex V 1.3). Pursuant to Article 7 WFD, the MS have to ensure that monitoring programs are set up to allow for a continuous and comprehensive view of the status of waters. By 22 December 2006, applicable monitoring programs had to be produced. The results of the pollution inventory of 2004 were the basis for drafting the first monitoring programs. For the purpose of ensuring consistent monitoring programs all over Germany, the German Working Group on Water Issues of the Federal States and the Federal Government (called Bund/Länder Arbeitsgemeinschaft Wasser, LAWA) compiled a conceptual framework for drafting monitoring programs and assessing the status of surface waters (called "Rahmenkonzeption Monitoring", RAKON). The essentials of this assessment and monitoring approach were implemented through the Ordinance for the Protection of Surface Waters ([2] Oberflächengewässerverordnung, OGewV) as of 20 July 2011 (Federal Gazette I, page 1429). This ordinance, which will be updated in 2016, sets up, among others, environmental quality standards (EQSs) for certain substances and outlines monitoring programs. It furthermore specifies sampling sites across the different water categories, determines how and how often samples have to be taken and sets the assessment rules for water status on the basis of the monitoring results. The monitoring results are presented in a management plan that is submitted to the EU-Commission. If the aims of the WFD, *i.e.*, the "good ecological status" or "good ecological potential" and the "good chemical status" are not reached, measures have to be planned and subsequently implemented (*cf.* [3,4]). German status assessments for surface water bodies are based on data from the monitoring programs. For surface water bodies, ecological status or ecological potential is to be assessed using different assessment methods in accordance with the biological quality elements (BQEs): Fish fauna, benthic invertebrates, macroalgae, phytobenthos and phytoplankton. Finally, the worst assessment result for the BQEs is used as the overall assessment result (the "one-out-all-out" principle, meaning that the worst assessment result for a BQE determines the overall assessment result). The classification scheme for the ecological status of water bodies includes five status classes: 1: very good, 2: good; 3: moderate; 4: poor and 5: bad. For Classes 3 to 5, measures need to be implemented to reach the WFD objectives. Heavily modified and artificial waters are distinguished from natural waterbodies by the WFD. These were either created artificially (e.g., a canal), or their structure has been modified so extensively that a "good ecological status" can no longer be achieved without significantly impairing an existing, economically significant water use that cannot be achieved by other means. For such waters, the environmental objective of a "good ecological potential" has been defined, which requires improvements to be made to the hydromorphological pressures without impairing non-substitutable water uses. In Germany, 50% of all surface water bodies were classified as heavily modified (35%) or artificial water bodies (15%). The WFD objective "good chemical status" applies to natural, artificial and heavily modified water bodies and the chemical status is determined by compliance with Environmental Quality Standards (EQSs) for several pollutants with European-wide significance Moreover, together with the BQEs so called supporting QEs are assessed: River basin-specific pollutants (RBSPs), physico-chemical QEs (e.g., temperature, oxygen, pH, nutrient conditions) and hydromorphological QEs. These supporting QEs are classified as "good" or as "less than good", according to good-moderate boundaries, which were defined for most of these QEs for different water body types in each water category. The requirements for achieving the overall "good ecological status" are (1) that all BQEs must reach the "good status" (Class 2 or better); (2) all EQSs (with defined threshold concentrations) of RBSPs should not be exceeded ("good") and (3) values for other physico-chemical supporting QEs and hydromorphology must fall within a range that allows for good ecosystem functionality ("good ecological status").

Chemical status of water bodies is classified as "good" or "not good". The chemical status is determined from the defined EU-wide EQSs for the 33 priority substances listed in the WFD and

8 other substances regulated on a European-wide basis under the older Directive on pollution caused by certain dangerous substances discharged into the aquatic environment (Directive 2006/11/EC, formerly: 76/464. The provisions of the Environmental Quality Standard Directive 2008/105/EC and the Nitrates Directive were adopted into Annex 7 of the Surface Waters Ordinance in 2011. The environmental quality standards Directive 2008/105/EG was updated in 2013 (2013/39/EU), and now regulates a total of 45 priority substances, which shall be included into the German Surface Waters Ordinance by 2016. The standards for the new priority substances will come into force in 2018. Additional standards for eleven "old" substances have been amended. Currently a prioritization process under the WFD is going on to select 12 to 15 new substances for the priority substance list. The selection criteria for substances are:

- an EU-wide relevance, this means an EQS exceedance in more than three MS in surface waters and
- a detailed substance dossier take into account state of science and the criteria for EQS derivation from the CIS Technical Guidance Document No. 27 for deriving EQSs [5].

The prioritization process based on three aspects:

- the monitoring based exercise [6],
- modeling based exercise [7] and
- substances which are high ranked in the last prioritization but not finial prioritized because of a lack of evidence or monitoring data.

One of the major challenges in the prioritization was the quality of monitoring data from the different sources (MS, scientific research and online databases). The minimum data requirements were substance name, CAS-No., unit, date, limit of quantification (LoQ), limit of detection (LoD), water category (river, lake, coastal), matrix of measurement (biota, sediment or surface water) and the identity of monitoring station. Furthermore, additional criteria like "LOQ is lower than EQS" which was only fulfilled by less than 20% of the monitoring data, were used. The main problem were missing LoQ and LoD values in the monitoring data set. The reasons for missing data in the data set was not evaluated until now.

With this framework the monitoring programs of the WFD essentially aim at:

- controlling the water status and level, up to which environmental objectives are being complied with;
- observing long-term natural and anthropogenic developments and identifying trends;
- ascertaining extent and effects of pollution and changes;
- creating the basis for planning measures, reporting and the efficiency review of measures implemented;
- gauging the effectiveness of water protection measures on the basis of quality data;
- preventing potential dangers to human health.

The above aims require different monitoring methods, which are uniformly regulated throughout the Federal Republic of Germany by the Surface Waters Ordinance [2]. According to their purpose, these methods imply differences in monitoring density, in the number of parameters to be investigated, in the spatial area and in the measurement frequency. Article 7 of the WFD differentiates between the following monitoring methods: **Surveillance monitoring, operational monitoring, and investigative monitoring.**

Surveillance monitoring predominantly ensures the assessment of the overall surface water status within a river basin or sub-basin of a river basin district. Thus, it is especially suited for identifying large-scale and long-term trends in the development of water quality. The German Federal States specified more than 500 monitoring stations for surveillance monitoring of surface waters (Table 1). The surveillance monitoring network is wide-meshed (with a catchment area of up to 2500 km^2 per monitoring site), but must be representative of the assigned hydrological unit and must be permanent in time. The selected monitoring sites are designed to provide an integrative view of the overall status of the assigned hydrological unit and enable researchers to gauge target achievement in the region. Mostly, they are located in the main flows of the major rivers and at the inflow of major tributaries. In case they represent a pressure to the relevant water body, biological, hydromorphological and physico-chemical QEs, RBSPs and substances relevant for the classification of the chemical status of waters have to principally be measured at the monitoring sites for surveillance monitoring [8]. Surveillance monitoring sites usually measure all the QEs of ecological status, *i.e.*, biological, hydromorphological, chemical and physico-chemical QEs. BQEs are investigated at least twice during each six yearly river basin management plan period. RBSPs must be monitored if discharged in significant quantities. Furthermore, priority substances that are relevant for the classification of chemical waterbody status must also be measured if discharged into the respective waterbody.

Table 1. Number of monitoring stations for different monitoring types and categories of surface waters in Germany. Data source: Federal Environment Agency (Umweltbundesamt) data from the Working Group on Water Issues of the Federal States and the Federal Government (LAWA). Data origin: Reporting portal WasserBLIcK/BfG as of 22 March 2010 after Mohaupt *et al.*, 2012 [9] and reporting portal WasserBLIcK/BfG as of November 2015.

Type of Monitoring and Year		Streams & Rivers	Lakes	Transitional Waters	Coastal Waters
Surveillance monitoring	2010	290	67	5	32
	2014	318	127	42	76
Operational monitoring	2010	7252	449	20	100
	2014	12,342	711	13	76
Investigative monitoring	2010	375	0	0	0
	2014	1074	25	0	0

Operational monitoring is the tool for assessing the status of those water bodies that probably may not meet the environmental objectives. It is also used to control whether measures have been successfully implemented. Germany has delineated nearly 10,000 water bodies out of its rivers, lakes, transitional and coastal waters and more than 13,000 monitoring stations for the operational monitoring of surface waters have been specified (Table 1).

Hence, operational monitoring is the main focus of surface water monitoring. Along rivers and streams, an average of one monitoring site is to be found every 10–15 kilometers and the average size of the delineated stream and river water bodies is 15.2 km (median = 8.7 km; min < 1 km; max = 242 km). This means that there may be several monitoring sites along one water body. The operational monitoring generally deals with those biological, chemical and physico-chemical QEs that indicate the presence of pressures significant to the status of the water bodies being assessed [9] and that are indicative of the cause of pollution. In Germany, the operational monitoring sites are analyzed as set out in Table 2.

Investigative monitoring is necessary if the reasons as to why the water quality of a particular water body could not be assessed as "very good" or "good", or in order to ascertain the magnitude and spatial scale of impacts of accidental pollution. It applies, e.g., to unforeseen accidental discharges of pollutants or to sudden fish mortality in the water body. This is the reason why there are currently only 1074 sites of this kind installed in German surface waters.

Table 2. Minimum requirements for monitoring frequencies and intervals for the quality elements under the ecological status and the chemical status as defined by the EC Water Framework Directive. OM = operational monitoring; SM = surveillance monitoring; p.a. = per annum, p.m. = per month.

Status—Component	Quality Element	Water Category			
		Streams & Rivers	Lakes	Transitional Waters	Coastal Waters
Ecological status	**Biological quality elements (BQE)**				
	Phytoplankton	6× p.a. (relevant vegetation period); every 1 to 3 years per site (SM) and every 3 years per site (OM), monitored in large rivers only	6× p.a. (relevant vegetation period); every 1 to 3 years per site (SM) and every 3 years (OM)	6× p.a. (relevant vegetation period); every 1 to 3 years per site (SM) and every 3 years (OM)	6× p.a. (relevant vegetation period); every 1 to 3 years per site (SM) and every 3 years (OM)
	Large algae/angiosperms	-	-	1 to 2 times p.a., every 1 to 3 years per site (SM) and every 3 years (OM)	1 to 2 times p.a., every 1 to 3 years per site (SM) and every 3 years (OM)
	Macrophytes/phytobenthos	1 to 2 times p.a., every 1 to 3 years per site (SM) and every 3 years (OM)	1 to 2 times p.a., every 1 to 3 years per site (SM) and every 3 years (OM)	-	-
	Macroinvertebrates	1 to 2 times p.a.; every 1 to 3 years per site (SM) and every 3 years (OM)	1× p.a., every 1 to 3'years per site (SM) and every 3 years (OM)	1× p.a., every 1 to 3 years per site (SM) and every 3 years (OM)	1× p.a., every 1 to 3 years per site (SM) and every 3 years (OM)
	Fish	1 to 2 times p.a.; every 1 to 3 years per site (SM) and every 3 years (OM)	1 to 2 times p.a.; every 1 to 3 years per site (SM) and every 3 years (OM)	1 to 2 times p.a.; every 1 to 3 years per site (SM) and every 3 years (OM)	BQE not used under the WFD
	Hydromorphological quality elements				
	Continuity	1 time, needs-based monitoring, updated every 6 years	-	-	-
	Hydrology	continuously	1 time per month	-	-
	Hydromorphology	1 time, needs-based monitoring, updated every 6 years	1 time needs-based monitoring, updated every 6 years	1 time, needs-based monitoring, updated every 6 years	1 time, needs-based monitoring, updated every 6 years

Table 2. *Cont.*

Status—Component	Quality Element	Water Category			
		Streams & Rivers	**Lakes**	**Transitional Waters**	**Coastal Waters**
	Physical and chemical quality elements				
	General physical and chemical elements	Depending on the parameters; for most parameters 4 to 13 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM)	Depending on the parameters; for most parameters 4 to 13 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM)	Depending on the parameters; for most parameters 4 to 13 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM)	Depending on the parameters; for most parameters 4 to 13 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM)
	River basin-specific pollutants	4 to 13 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM)	4 to 13 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM)	4 to 13 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM)	4 to 13 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM)
Chemical Status	Chemical quality elements (45 priority pollutants with European-wide consistent ecological quality standards)	For priority pollutants in the water phase: 12 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM); For priority pollutants in biota: 1–2 times p.a.; at least 1× in 6 years (SM), at least 1× in 3 years (OM). A reduced level of monitoring is required for the so-called ubiquitous, widespread substances and substances on a mandatory watch list of the EU Commission.			

3. Selection of Monitoring Sites

In general, the monitoring sites are selected by regional water managers. The selection of the monitoring sites is based on estimates with respect to the representativeness of a monitoring site for the specific water body. The term "representativeness" is not quantitatively defined. With respect to selecting monitoring sites, the following questions had and still have to be answered or continuously checked:

- How many monitoring sites are necessary to obtain reliable assessment results for each water body?
- Where to place monitoring sites to be sure that they really are representative of an entire water body?
- What assessment uncertainties can be expected and to what extent will they appear?
- In how far does the natural variability of biocenoses influence the assessment results?
- Going beyond the minimum requirements of the WFD, should the number of monitoring sites and the frequency of measurement be adjusted to the predominant pressures on a water body?

Many of these questions persist to date. The challenge now is to answer these questions as to the basis of experiences gained from monitoring and on the basis of additional analyses of monitoring data, both being part of an adaptive management process.

4. Monitoring Frequencies

Minimum requirements for monitoring frequencies and intervals for the quality elements of the ecological status and the chemical status as defined by the WFD are listed in Table 2. BQEs relevant for the assessment of the ecological status are generally reviewed at least every three years per monitoring site during operational monitoring. Hydromorphological and physico-chemical QEs are only used as supporting elements in the assessment of the ecological status and to provide supporting indications of major pressures in a specific water body (*i.e.*, hydromorphological degradation, organic pollution or eutrophication), which is important for the subsequent determination of measures. The basic idea of this assessment philosophy is that the "biological community", as represented by the BQE´s, is seen as the all-integrating element that reflects abiotic conditions and their interplay (natural factors and anthropogenic pressures). RBSPs are assessed within the context of a classification of ecological status. They are defined as pollutants that are discharged in significant quantities. The MS must derive EQSs to protect the aquatic community on the basis of longer-term ecotoxicological effect data ([1] compare Annex V, 1.2.6). In Germany, substances discharged into freshwaters leading to concentrations of more than half the EQS at representative monitoring sites were defined as "significant" and legally binding EQSs have been specified for a total of 162 RBSPs. Up to now, compliance with EQSs is verified using annual averages. EQSs for the ecological status of surface waters are defined on the basis of an EU chemical assessment as prescribed in Annex V, 1.2.6 of the WFD [1]. Valid long-term tests regarding the substance's effects on organisms at different levels of the aquatic food chain, *i.e.*, algae, invertebrates and fish, are compiled, and the most sensitive of these values is selected. However, as organisms in nature may be even more sensitive than those used to perform the laboratory tests, this value is divided by a safety factor in order to calculate the EQS. If valid long-term toxicity tests are available for all levels of the aquatic food chain, this factor is generally 10. If data are missing, it will be 100 or greater. The quality element RBSPs can lead, in contrast to hydromorphological and physico-chemical QEs, to a downgrading of the ecological status. Exceedance of even just one EQS for RBSPs in a specific water body means that the ecological status (or ecological potential) can only be "moderate" (Class 3), even if the biological quality elements are all "good" or above. Monitoring frequencies are increased if considered necessary for a reliable and accurate statement on status. A QE can be exempt from assessment if it proves impossible to define reliable reference conditions due to the high degree of natural variability in a specific water body type. For RBSPs that are emitted in significant quantities, sampling should be carried out at least once every three months, and for pollutants relevant to chemical status at least once a month, unless higher frequencies are required for a reliable and precise assessment of status. If the EQS of a RBSP is exceeded, the substance will remain in the monitoring program until the monitoring results show that this substance is no more relevant in the water body concerned.

5. Modifications in Water Monitoring due to the WFD

Due to the specifications of the WFD, water monitoring has strongly changed over the past 15 years. In particular, this has affected

- the change monitoring focus (more biology and fewer individual substances);
- the temporal rate and areal scope of biological water monitoring;
- the range of BQEs monitored;
- the development, improvement and addition of biological assessment methods;
- and the level of standardization and harmonization of biological assessment methods.

Due to the WFD specifications, European water monitoring no longer focuses on the primary monitoring of saprobity, nutrients and pollutants, but concentrates on a comprehensive, integrative assessment concept which gives priority to biological QEs being indicators for the overall assessment of influences on the aquatic environment. Furthermore, the assessment includes both physical and chemical factors serving as supporting QEs and RBSPs as well as the hydrology and hydromorphology. Thus, monitoring and assessment of the water status under the WFD pursue a noticeably more holistic approach than in the past [10].

6. Changes in the Temporal Rate and Areal Scope of Biological Water Monitoring

Analyses by Beck *et al.* [11], which are based on data by the European Environment Agency (EEA) between 1965 and 2005, strongly indicated that water monitoring intensity, scope and extent in Europe distinctly increased over the past 40 years. In the course of the implementation of the WFD, the temporal rate and areal scope of German biological water monitoring continued to noticeably rise in the past 13 years. However, individual MS often feature considerable differences regarding monitoring density and sampling frequency [12]. Nevertheless, it is difficult to exactly quantify the degree to which European water monitoring has intensified. This is because the monitoring and assessment of the environmental state of European waters are performed by regional and national authorities, and the results are summarized for the state of the environment (SOE) assessments by the EEA at river basin district scale. SOE reporting covers many but not all monitoring sites of the MS resulting in an underestimation of monitoring activities. However, to our knowledge the EEA database forms the most comprehensive overview of freshwater monitoring activities in Europe. As of May 2012, the EEA database [13] included information on the water quality from

- more than 10,000 monitoring sites along running waters in 37 European countries,
- 3500 monitoring sites in lakes in 35 European countries, and
- 5000 monitoring sites in coastal waters in 28 European countries.

In the context of implementing the WFD, MS designated more than 127,000 surface water bodies. Eighty-two percent of these surface water bodies are running waters, 15% are lakes and 3% are coastal and transitional waters. Thus, the EEA database includes information on the 2009 water status of each of these water bodies, representing 1.1 million kilometers of running waters, about 19,000 lakes, approximately 370,000 km^2 of coastal and transitional waters and 3.8 million km^2 of groundwater bodies (*cf.* [13]).

7. Changes in the Range of Monitored Biological Quality Elements

Traditional monitoring of inland waters in Europe focused on the investigation of physical and chemical parameters. Prior to the entry into force of the WFD, water management applied just a few differing biological methods to assess the pressures on the water bodies (e.g., saprobic index). In the early 1990s, only half of the European MS used biological assessment methods to complement the monitoring of physical and chemical elements [14]. Today, monitoring under the WFD comprises many more biological quality elements (aquatic flora, invertebrate fauna and fish fauna) than formerly. Moreover, the monitoring frequency of biological quality elements noticeably increased due to the strict specifications of the WFD. Meanwhile, the volume of collected data available for the assessment of the water status in Europe is nowhere near as comprehensive as that available hitherto. Such a comprehensive picture of the flora and fauna of European waters had never been gained before. At the same time, biological data collected under the WFD monitoring may considerably support the implementation of other EU Directives (e.g., Habitats Directive [15], Marine Strategy Framework Directive [16]). In this context, the parallel and increasing collection of biological, physical and chemical data is extremely important since it facilitates the further statistical analysis of these data. In future, such data and analyses will increasingly be used to allow the assessment of the relative importance of different pressures on water systems for reaching good ecological status, which is an essential step towards prioritizing management measures in multiple pressure situations and also contributes to a better justification of their necessity.

8. Data Availability and Participation of Applied Sciences

Nowadays, many more German and European monitoring data are publicly available than was the case in the past. This is due to strikingly increased transparency regarding the publication of water monitoring results and to the reporting obligations to the European Commission. Such increased transparency might be considered a success of the WFD. The data collected within the framework of the WFD are of great interest for applied water ecology as well. This interest finds expression in an enormous number of scientific publications over the past years (*cf.* Figure 1).

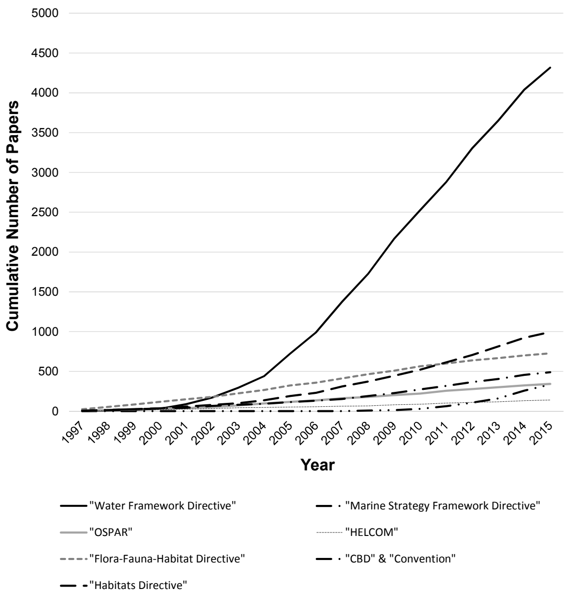

Figure 1. Comparison of the cumulative number of scientific publications referring to the Water Framework Directive (title, keywords, abstract) and other EU Directives, International Conventions on the Protection of the Marine Environment for the North Sea (OSPAR) and the Baltic Sea (HELCOM), the Habitats Directive, and the Convention on Biological Diversity (CBD) (Source: www.scopus.com, queried in December 2015).

9. Development, Improvement and Addition of Biological Assessment Methods

Numerous new biological assessment methods had to be developed to ensure that the biological assessment is compliant with the WFD specifications (*cf.* [1] Annex V, 1.2 *Normative definitions of ecological status classifications*). Hundreds of scientists were involved and helped to develop, at European and national levels, complex new sampling and assessment methods. In many MS, the development of national assessment methods was delayed. Although the attributes and properties of the "good ecological status" and the "very good ecological status" were precisely defined as standards in the WFD annexes, the scientific community had to specify these definitions, translating them into applicable methods in terms of indices and metrics [12]. Many of the newly developed assessment methods have a modular and multimetric design in common. It is intended to guarantee a pressure-specific assessment and analysis by using trait-based metrics of different BQEs as indicators of different pressures. The MS methods often differ with respect to the taxonomic resolution of the assessment methods, the way reference conditions are defined, interpreted or specified, and the indices and metrics applied with the method. In all German assessment systems, the organisms are identified to the lowest taxonomic level possible. Analyses of gathered WFD monitoring data sets have shown that the resolution of indication of trait-based metrics for lakes often work well, probably because "eutrophication" is the most dominant pressure in these systems. In river systems, with often multiple overlapping pressures acting, the resolution of pressure indication on the basis of trait-based approaches in many cases showed rather mixed results, making pressure prioritization much more difficult. One very important requirement for the development of the biological assessment systems was the differentiation of water categories into different types based on their natural biocenosis. In addition to these biological characteristics, geological, geographical, morphological and hydrological characteristics of the water categories were also used in Germany to distinguish twenty-five stream and river types, fourteen lake types, nine coastal water types and two types of transitional waters. As a result of the WFD, water type-specific and pressure-specific biological assessment systems are now the standard in Europe.

10. Level of Standardization and Harmonization of Biological Assessment Methods

Whereas many sampling and analysis methods for physical and chemical QEs were standardized long before the entry into force of the WFD and others became standard all over Europe in the course of the implementation of the WFD (e.g., CEN), formerly none or only national standards (e.g., DIN, Deutsches Institut für Normung/German Institute for Standardization) existed for biological assessment methods in the EU. The WFD addressed requirements of the MS to develop national assessment methods. By 2012, almost 300 assessment methods for biological quality elements had been developed in Europe to implement the WFD [17]. This is the reason why the WFD with its Annex V, 1.4.1 introduced a comprehensive harmonization process called "intercalibration". Its purpose is the establishment of consistent ecological status thresholds for the good-moderate and very good-good boundaries of the biological assessment systems by harmonizing the strengths of the different national approaches to biological assessment, rendering the assessment results comparable [18]. The biological assessment methods within the framework of the WFD have been intercalibrated by means of comprehensive statistical and numerical approaches. Class boundaries of the "very good" ecological status class and the "good" ecological status class are compared and harmonized through the intercalibration exercise. The three principal intercalibration methods developed are described by Birk *et al.* [17]. Although leading not to complete comparability of assessment systems in a mathematical-quantitative sense, allowing still considerable variability, the whole intercalibration process highly encouraged, at the international level, the exchange between experts on biological assessment methods, and thus brought about increased levels of harmonization of ecological standards (but for the good-moderate and very good-good boundaries only) relevant for water management at the European level. Major doubts on the level of comparability attained by the biological intercalibration approach are for instance:

- The three different methods (direct comparison, indirect comparison, common boundary setting with subsequent comparison; see Poikane *et al.* [19]) on which intercalibration was carried out were never compared as to whether they produce similar results.
- The so-called "intercalibration harmonization band", which marks the upper and lower limits of variability accepted by the intercalibration approach between good-moderate boundaries of MS's assessment methods, allows differences of up to 0.5 classes, which is considerable when only five status classes are being used.
- The "boundary bias", which was used as the major criterion for the evaluation of comparability, is defined as the deviation of a class boundary relative to the common view of the MS *(cf.* Poikane *et al.* [19]). Because the MS "common view" is defined via common metrics and by the global mean of all national assessment methods, the results of the intercalibration completely depend on the common or pseudo-common metrics selected, meaning that different metrics can lead to completely different overall results.
- In many instances, intercalibration was carried out by using so-called "common intercalibration metrics" as yardsticks for the comparison of different assessment methods. This leads to an intercalibration of different methods along only one dimension. This approach takes no account of the multidimensionality of the (multimetric) assessment methods. As a result, the decision as to which of the MS need to adjust their good-moderate boundary completely depends on the "common intercalibration metric" used. Changing this "metric" can completely change the result of the analysis.
- The intercalibration was carried out based on EQR values, which are defined as a ratio between observed assessment results and the expected value under reference conditions. An EQR = 1 marks the references status and EQR = 0 the most degraded one. Within the intercalibration approach, no method is integrated to compare whether the MS have a truly similar or comparable understanding of this "reference" and "most degraded" status. Without a common and quantitatively comparable understanding of this reference status no real comparability could be expected and the EQR scale used will mask differences of this issue rather than allowing for transparency.
- In many cases, only one metric or module of the multimetric assessment systems was harmonized instead of the whole system.
- Intercalibration was performed only at the BQE-level, but no comparison was made between the good-moderate boundaries among different BQEs.
- Intercalibration was carried out within so called geographic intercalibration groups (GIGs) and specific national typologies were forced into these much coarser groups (intercalibration types), which increased the variability within these groups and decreased the possibility of harmonization. In many cases, only the assessment methods of a few national types were officially intercalibrated. The grouping of specific national types, each with different reference communities, into broader types inevitable led to variability which is not controlled by the intercalibration methodology. The effects of this variability on the intercalibration results have not yet been quantified. Intercalibration of the same BQEs across geographic intercalibration groups (GIGs) and intercalibration across different BQEs was not performed.
- Regression and correlation analyses used to describe the relationships between "common or pseudocommon intercalibration metrics" and the national methods take only the variation explained by the models (R^2) into account and $R^2 \geqslant 0.5$ are deemed acceptable for the comparison of different assessment methods via intercalibration, but variation around the mean trend (uncertainty level of national methods) was not taken into account.
- Checks for feasibility of intercalibration included tests of comparability of water body types applied within each of the geographic group (GIG). In a considerable number of cases, the comparability tests lead to different assumptions as to what constitutes comparable national types within different GIGs.

However, the assessment strength of almost all German assessment methods was comparable to those of our neighbor states (*cf.* Commission Decision of 20 September 2013 [20]). A third period until the end of 2016 will complete the intercalibration of biological assessment methods of natural waters. To date, the harmonization of the assessment of the ecological potential of heavily modified water bodies at the European level remains to be completed. Within this activity, comparisons are being made on the basis of measures implemented by the MS for defined pressure categories (land drainage, water storage and others). Consequently, future scientific improvements of biological assessment methods must to be adjusted to the fixed and legally valid Commission Decision results. This may result in a never-ending intercalibration process. On the other hand, continuous improvements of biological assessment methods conflict with their role as decision-making tools for status and therefore for measures as part of the management process. In extreme cases, changes in the original assessment results could lead to results in the light of which measures taken and investments made might appear unnecessary. This would substantially lower their public acceptance. It is, therefore, important to balance improvements of the assessment systems with the needs of administration and management. Our opinion is that administration and management need reliable assessment results, and repeated changes of assessment systems within short time-frames will decrease the chances of successful WFD implementation and have large potential to lower public acceptance of the overall process. Consequently, an important issue within an adaptive management strategy is to explore timescales that are optimal for revisions and adjustments of the assessments systems.

11. Comparison of Supporting Physical and Chemical Quality Elements' Monitoring at European Level

Good-moderate boundaries for physical and chemical quality elements were set by the MS in order to reach a good ecological status of the biological communities. Analyses based on data from 20 MS (*cf.* [21]) of the first reporting to the European Commission on the river basin management plans in 2010 revealed that these MS monitor many different physical and chemical QEs potentially as a result of different national monitoring traditions. For rivers, 20 MS reported to monitor 32 different variables; for lakes, 16 MS reported to monitor 28 different variables; for coastal waters, 12 MS monitored 24 different variables, and for transitional waters 11 MS monitored 22 different variables (*cf.* Table 3 & Claussen *et al.* [21]). Within one water category, MS monitored a differing number of supporting physical and chemical variables (e.g., rivers: Slovakia and Poland monitored 16 variables, Finland monitored just three variables, and Germany was in the mid-range with nine variables). Total phosphorus, dissolved oxygen and total nitrogen were the three physical and chemical QEs that were monitored most in Europe. Only very few MS monitored hydromorphological variables. Good-moderate boundaries specified by the MS often showed significant differences for many supporting physical and chemical QEs. Figure 2 shows exemplary the high variability of the good-moderate boundaries specified by the MS for total phosphorous and orthophosphate in streams and rivers. In Figure 2, the order of MS from left to right on the x-axis is based on maximum values observed and shall not be interpreted as a ranking, because the differences among the MS may either be attributed to different river typologies due to river sizes, climate, geology and geographical position or to a different statistical information content or to different assumptions on reference conditions (e.g., background concentrations) but also on different assumptions on good-moderate boundaries which might reflect different ambitions of the MS on the "good status". Alternatively, the observed differences might also reflect different interpretations by the MS on the levels of nutrients that are acceptable in order to reach good ecological status or potential. To differentiate between reasons of variation was not part of the analysis, but is part of the ongoing work at European level within the CIS Working Group A on Ecological Status ("Ecostat"). Harmonization of rules to set good-moderate boundaries for supporting physical and chemical QEs is still necessary.

Table 3. Overview of supporting physical and chemical quality elements used by the EU Member States (MS). Source: modified after Claussen *et al.* 2011 [21]. Numbers indicate the total number of MS (a total of 20 MS were included in the analysis) that reported good-moderate boundary values for variables for different surface water categories. Missing numbers imply that good-moderate boundary values were not defined (the variable was not used in monitoring) or not reported for this variable.

Supporting Physical and Chemical Variables	**Rivers & Streams (20 MS)**	**Lakes (17 MS)**	**Transitional Waters (11 MS)**	**Coastal Waters (12 MS)**	***Totals***
Total phosphorus or total dissolved phosphorus or soluble reactive phosphorus or orthophosphate (mg· L^{-1})	19	17	7	7	50
Dissolved oxygen concentration (mg· L^{-1})	13	7	7	6	33
Total nitrogen (mg· L^{-1})	9	9	5	7	30
Total ammonium (mg· L^{-1})	16	5	3	2	26
pH or delta pH	14	7	3	2	26
Secchi depth (m) & transparency (m)	2	9	6	9	26
Nitrate (mg· L^{-1})	13	3	4	4	24
Oxygen saturation (%)	7	5	4	5	21
BOD5 (mg· L^{-1})	12	2	3	2	19
Water temperature (°C) or delta temperature	9	3	1	2	15
Nitrite (mg· L^{-1})	7	2	2	2	13
Chloride (mg· L^{-1})	8	4			12
Total inorganic nitrogen or dissolved inorganic nitrogen (mg· L^{-1})		1	5	6	12
Sulfate (mg· L^{-1})	5	2			7
Conductivity (μS· cm^{-1})	3	4			7
Morphological and/or hydromorphological conditions	2	2	1	1	6
CODCr (mg· L^{-1})	4	1			5
Total organic carbon (mg· L^{-1})	2	1		2	5
River continuity	4				4
Non ionized ammonia, NH4-N (mg· L^{-1})	1	1	1	1	4
Structure of riparian zone	3				3
Hydrological regime	2	1			3

Table 3. *Cont.*

Supporting Physical and Chemical Variables	Rivers & Streams (20 MS)	Lakes (17 MS)	Transitional Waters (11 MS)	Coastal Waters (12 MS)	*Totals*
COD (mg·L^{-1})	1	2			3
Salinity (‰)			1	2	3
Organic nitrogen (mg·L^{-1})			2	1	3
Kjeldahl nitrogen (mg N·L^{-1})	2				2
Structure and substrate of river bed	2				2
River depth and width variation	2				2
Alkalinity (mmol·L^{-1})	1	1			2
Hypolimnion oxygen (%)		2			2
Lake depth variation		2			2
Silicate (mg·L^{-1})			1	1	2
N total soluble (mg/kg settled sediment)			1	1	2
P total (mg/kg settled sediment)			1	1	2
DIN, winter, November–February, 0–10 m (EQR)			1	1	2
Turbidity (NTU)			1	1	2
Dissolved organic carbon (DOC) (mg·L^{-1})	1				1
BOD7 (mg·L^{-1})	1				1
CODMn (mg·L^{-1})	1				1
Connection to groundwater	1				1
Water flow	1				1
Acid neutralizing capacity (μ equivalents L^{-1})		1			1
Hardness (dH)		1			1
Nitrate/orthophosphate ratio		1			1
Wave exposure (after CIS Guidance 2.4)				1	1

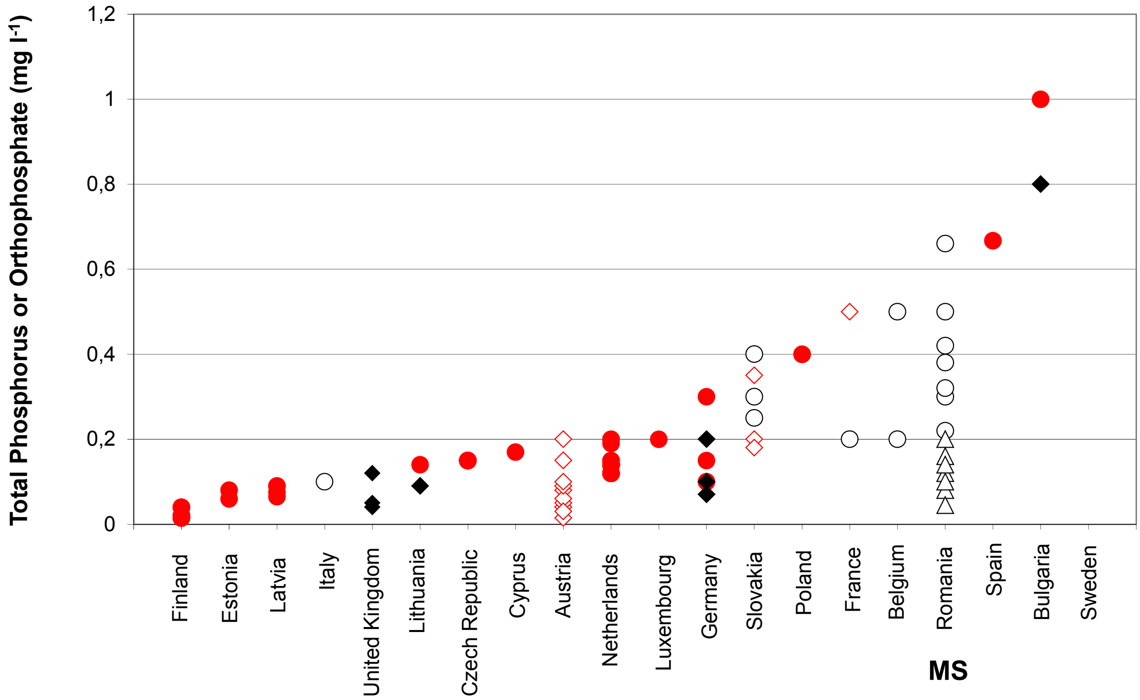

Figure 2. Total phosphorus or orthophosphate values for good-moderate boundaries of ecological status in European streams and rivers. Filled circles = Total phosphorus as annual mean values or mean values for defined seasons or no entry. Open circles = Total phosphorus as 90 percentile values of annual measurements. Triangles = Total phosphorus median values. Filled diamonds = Orthophosphate/soluble reactive phosphorus as annual mean values. Open diamonds = Orthophosphate as 90 percentile values of annual measurements. Values provided by CZ, FR, BG, PL, LT, LU, CYP and IT are good-moderate boundaries set for "All rivers" (without typological differences). Multiple points for other MS denote good/-moderate boundaries set for different river and stream types. Sweden reported good-moderate boundaries as EQR (not shown). Spain reported a value with unknown unit of measurement (mg/L^{-1} or EQR). UK values refer to soluble reactive phosphorus.

12. Comparison of RBSP Monitoring at the European Level

At present, EU MS classify the ecological status under the WFD on the basis of a highly varying number of RBSPs ([22,23], Figure 3). Within the first management plan period, the Czech Republic and the Netherlands reported the highest number of RBSPs, *i.e.*, 169 and 162 respectively. Germany came in third place, reporting 152 pollutants. Cyprus (three pollutants) implemented the lowest number of RBSPs (*cf.* Arle *et al.* [22]). At the European level, the mean of RBSPs amounted to 47 RBSPs. The EQSs were comparable between the MS in part, but there were also significant differences for the same pollutants. Irmer *et al.* 2014 [23] extended the comparisons made by Arle *et al.* [22] and found a total number of 452 substances regulated as RBSPs in the European Union. The average number of RBSPs per MS increased to 55 substances. Seven MS regulated more than the mean number of 55 substances (Figure 3). One hundred and eighty nine substances were regulated by only one MS each. EQSs for 263 substances were regulated by at least two MS and thus enabled a comparison of EQSs. Copper and zinc were both regulated by 22 MS and thus were the most often monitored RBSPs in the EU and should be the first candidates for EU-wide regulation as priority substances within chemical status.

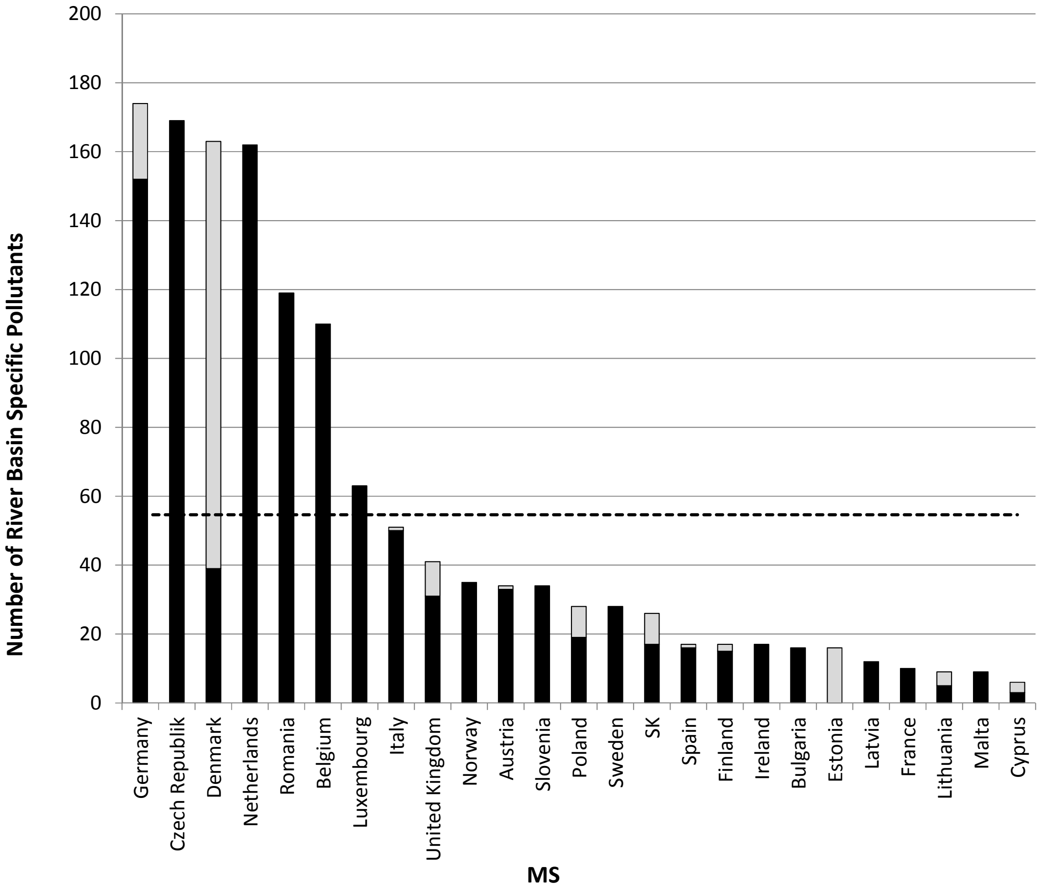

Figure 3. Number of river basin specific pollutants of the Member States as reported to the EU Commission within the first management plan period (black bars after Arle *et al.*, 2012 [22]) and updated numbers based on MS requests (grey bars after Irmer *et al.*, 2014 [23]). Dotted line = mean number of substances used by the MS as RBSPs, after Irmer *et al.*, 2014 [23].

The divergence between highest and lowest EQS for the same substance is exemplary for some substances visualized in Figure 4. All MS in question indicated identical EQSs for 40 substances (about 15%). Minimum and maximum EQS values for one third of the listed substances differ up to tenfold from each other. The values of a little more than half (53%) of all substances differ from more than tenfold to 10^5-fold from each other. Most of the differences observed seemed to not be caused by differences in the safety factors used by the MS. Rather the differences are indicative of differing approaches used by the MS to derive the EQSs. Under the WFD, EQSs for RBSPs are derived according to rules set out in Annex V, 1.2.6 which should eliminate flexibility of standard values in future. In many cases, the results for other water categories (lakes, transitional waters and coastal waters) also showed similar discrepancies between the highest and lowest EQSs for the same substance. The number of RBSPs regulated by the MS in lakes, transitional waters and coastal waters was considerably lower than those regulated in rivers. Comparisons of the MS EQSs for different pollutants with $PNEC_{freshwater}$—values available at the official webpage of the European Chemicals Agency (ECHA) (*cf.* [24]) and the National Recommended Water Quality Criteria—Aquatic Life Criteria Table of the United States Environmental Protection Agency (*cf.* [25]) indicate a generally high international variability in the threshold levels for different pollutants that are assumed to be protective of aquatic life. To ensure that the assessments of the ecological status in the EU may be comparable and that programs of measures aiming at reducing pollutant inputs into surface waters may coherently be initiated under the WFD, harmonization, at the European level, of EQSs for RBSPs is needed.

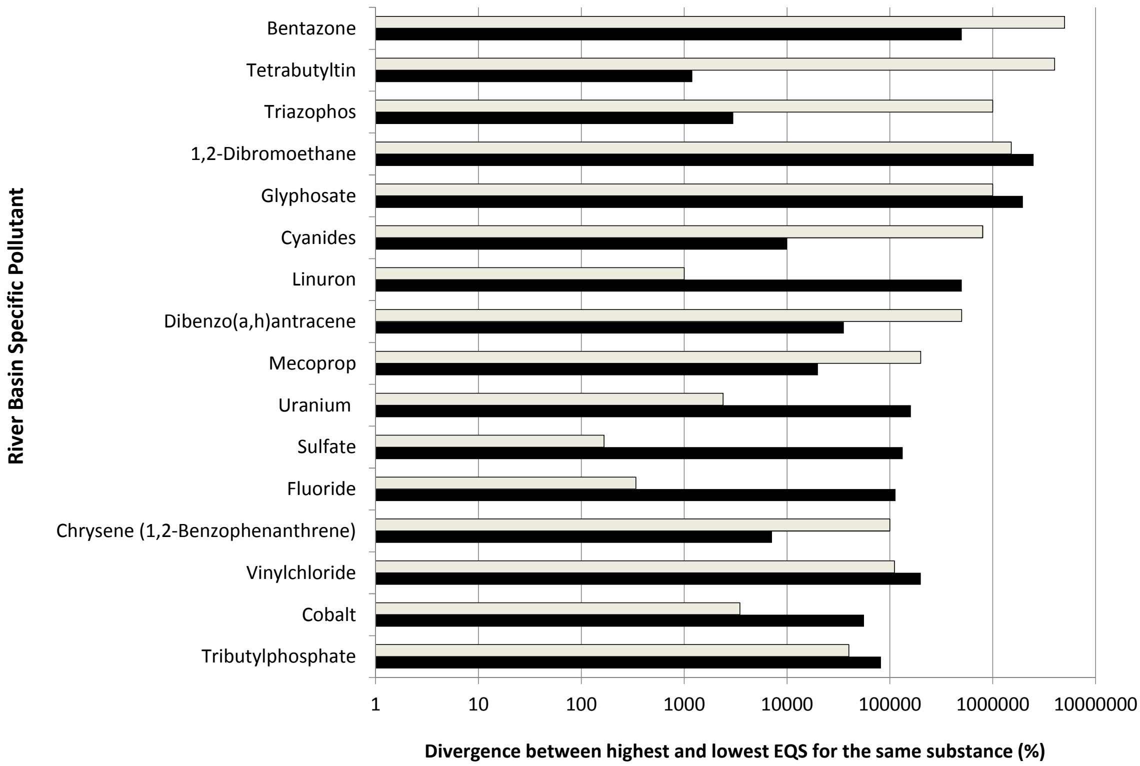

Figure 4. Divergence (in %) between minimum values and maximum values of EQSs for RBSPs reported by different MS. 16 substances are shown exemplary. Medium of measurement for the substances = water. Grey bars = values reported by Arle *et al.*, 2012 [22], Black bars = values reported by Irmer *et al.*, 2014 [23]. Under the WFD, EQSs for RBSPs are derived according to fixed rules which should eliminate flexibility in the determination of standard values. Similar to the quality standards for substances under the chemical status classification, the EQSs for RBSPs should show identical values.

13. Results of WFD Monitoring in Germany and the EU

Figure 5 shows the assessment results of ecological status/ecological potential of surface water bodies in Germany based on the preliminary drafts of the second river basin management plan. The results are within the range observed during the first management cycle. Of more than 9900 surface water bodies (including rivers, lakes, transitional and coastal waters) only 8.2% actually reach good or very good ecological status or potential, whereas >90% of all water bodies are classified to be at a moderate, poor or bad status. Slight improvements of the ecological status or potential in comparison to the assessment results of the first river basin management cycle (2010, as reported to the Commission) occurred in the lower classes. The number of water bodies at moderate status or potential increased, whereas the number of water bodies at poor or bad status slightly decreased. The final assessment results of the second river basin management cycle were submitted to the Commission in 2016. The most common reasons for failing to achieve a "good ecological status" are changes in hydromorphology of streams and rivers and high levels of nutrient loads originating from agricultural land use. In 2014, of the about 9000 streams and river water bodies, only 6.7% were in "very good" or "good" ecological status or potential. For the individual river biological quality elements higher percentages were at "very good" or "good" ecological status or potential: 20.2% of monitoring sites for fish (n = 5918), 27.5% of monitoring sites for macroinvertebrates (n = 8105), 21.3% of monitoring sites for macrophytes and phytobenthos (n = 5647) and 58% of monitoring sites for phytoplankton (n = 241, monitored in very large rivers only). These results show that the application of the "one-out-all-out" principle has major effects on the overall assessment result. The chemical status of all German water bodies is currently "not good".

This is because of the ubiquitous distributed substance Mercury. It was found in all water bodies. In addition the priority substances Cadmium, Nickel, Polycyclic Aromatic Hydrocarbons (PAH), Tributyltin, Fluoranthene, Diruron, Isoproturon measured in concentrations higher than the EQS in more than the half of the ten river basin districts in Germany. Lead, Brominated Diphenylether, 1.2 Dichloorethane, Anthracene, Bis(2-ethylhexyl)phthalate, Hexachlorobenzene, Hexachlorobutadiene, Naphthalene, Nonylphenol, Octylphenol, Pentachlorobenzene, Tetrachloroethylene, Trichlorobenzene, Trichloroethene, Trichloromethane, Hexachlorocyclohexane, DDT and Chlorpyrifos exceeded the EQS in five or less river basin districts.

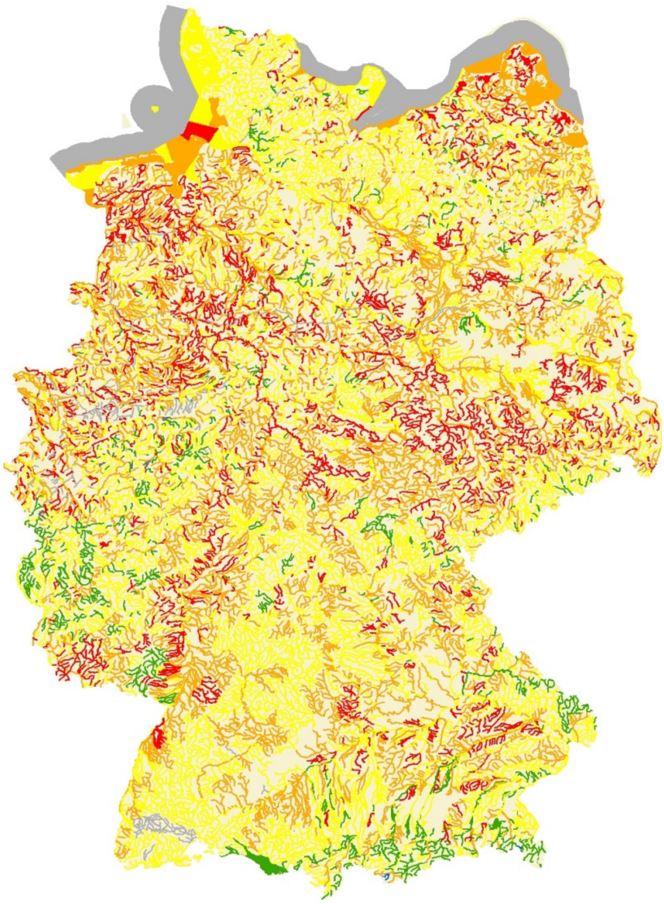

Figure 5. Ecological status/ecological potential of surface water bodies in Germany. Blue color = very good status; Green color = good status/potential; Yellow color = moderate status/potential; Orange color = poor status/potential; Red color = bad status/potential; Grey color = status/potential unknown. Source: Federal Environment Agency after data from the German reporting portal WasserBLIcK/BfG 2015.

In 2012, the European Environment Agency (EEA) presented several comprehensive reports on the European monitoring results according to the WFD *(cf.* [13]). These reports are based on assessments of both data that the MS had conveyed to the EU Commission as part of official WFD reporting (WISE-WFD database) and data the MS make available to the EEA on a one-year-cycle. According to the evaluation of the first river management plans by the EEA, more than half of the European surface waters are not at a "good ecological status" or do not reach a "good ecological potential" at present. On average, European rivers and transitional waters show a considerably worse ecological status and are subject to noticeably higher pressures than lakes and coastal waters [13]. As in Germany, many MS of the EU identified diffuse nutrient inputs and hydromorphological changes as the main pressures on European rivers. For the first river basin management cycle the EEA has criticized the insufficient knowledge of the status of waters in Europe [13]. The chemical status, for example, of 51% of rivers and of 54% of the lakes was not known in the EU due to the lack of data and assessments by some MS during the first river basin management plan cycle. In sum, about 90% of the surface waters assessed in Europe were at a good chemical status. Polycyclic aromatic hydrocarbons as well as mercury, for example, are considered to be the main reason why rivers in the EU fail to reach a good chemical status.

14. Using Biological Monitoring and Assessment Results to Determine Most Important Pressures

According to the WFD, the BQEs (fish, macroinvertebrates, phytobenthos, phytoplankton, macrophytes) and their assessment results are used in Germany as indicators for a "coarse" identification of the potentially most important pressures in a specific water body. For instance, fish is used as an indicator for hydromorphological degradation and disruptions of the longitudinal continuity in rivers, macroinvertebrates are used as indicators for organic pollution, whereas phytoplankton and phytobenthos are used as the primary indicators for eutrophication in lakes and rivers. The way to identify the relevant pressures in a specific water body does not follow a legally binding approach and so each stream manager can use his/her own knowledge. The identification of the most important pressures via the BQEs can be validated by the assessment of physical and chemical QEs (for instance pH, chloride, sulfate, phosphorous, nitrogen, oxygen, TOC, variables for hydromorphological degradation, variables for the extent of longitudinal discontinuity, and others). This often provides more detailed information for the identification of potential measures for a specific water body, which then should be subjected to economic analysis in order to check for feasibility and proportionality (cost-benefit ratio). The experiences gained from WFD implementation show that although the method described above is very useful to determine "major pressures" at larger scales and key measures, at the local level of the "water body" it sometimes is much more difficult to determine the most important pressures. This is especially the case in river systems where multiple natural factors and anthropogenic pressures act and interact. The resulting complexity does in many cases strongly limit our ability to draw explicit conclusions on the "relative importance of different pressures and natural factors" in a water body. Because of this, a prioritization of measures to be taken against different pressures is also difficult, though required due to financial constraints for measures. Many problems also arise from the questions of "how much of a measure is necessary?", "to what extent must a measure be taken in order to achieve good ecological status?", the effectiveness of a specific measure, and the selection of the measures with the best cost-benefit ratios. This is especially the case for pressures resulting from hydromorphological degradation, often because of uncertain correlative relationships with the ecological status. For many large-scale pressures, which cannot be tested in the laboratory for their effect on the biological community, pressure-response relationships are used to determine "management thresholds" for the WFD based on correlation analysis. However, because correlation does not necessarily imply causality, the derivation of measures can be difficult. For most of the chemical pollutants the derivation of EQSs is seen as much more reliable, because they are derived by extrapolating results to the real world from laboratory toxicity tests on common standard organisms for single pollutants. Although this is an international accepted strategy, some new results based on data analyses of WFD monitoring data have partly called this strategy into question [26]. The variability of EQSs for RBSPs presented in this review should not be seen as a contradiction to this ecotoxicological approach. Rather, it appears to be a result of inaccurate usage of the approach. A fundamental review of the way of deriving EQSs for RBSPs listed by at least three MS could noticeably reduce the divergence between the values, which in many cases differ by several degrees of magnitude. An EQS database by the European CIS Working Group on Chemicals (WG CHEM) could also contribute to reducing divergences, as could actions such as the harmonization of EQSs of particular substances or groups of substances such as herbicides, if effect values exist that are based on European-level certification. Since only three MS reported to have used the CIS Guidance

No. 27 of 2011 [5] to select and derive EQSs for RBSPs, it will hopefully be harmonized in the course of its further application. For this purpose, the developments should continuously be monitored and recorded because a harmonized list of EQSs for RBSPs is important to achieving the same "good ecological status" for all European surface waters and to the coherent implementation of the WFD.

15. Summary and Conclusions

Biological water monitoring in Europe has noticeably intensified due to the specifications of the WFD. Never before has a comparably comprehensive view of the flora and fauna of European waters existed. The data collected under WFD monitoring are a solid basis for future water management due to their large quantity and high quality. The harmonization of assessment methods and management approaches has notably progressed within the European Union, but it needs further attention. German water quality has improved over the past 50 years. However, further efforts and measures are necessary to reach the ambitious aims of the WFD by e.g., reducing nutrient losses from agriculture and by supporting natural hydromorphology, but also by addressing other anthropogenic pressures.

To further improve freshwater management practice under the WFD, the following topics need to be addressed by basic and applied research:

- The international harmonization of EQSs for pollutants,
- the interactions of multiple factors (natural factors and anthropogenic pressures) and their effects on freshwater communities,
- effects of "land use" as a large-scale pressure and attempts to disentangle the "land use—pressure bundle",
- the estimation of the relative importance of different pressures in their effect on the biological communities, in order to prioritize specific measures against different pressures,
- the role of biological interactions on the ecological status (e.g., non-native species),
- the determination of the efficiency of measures against different pressures, and
- the question as to whether biological systems of freshwaters "can be managed" or "can be restored" to a defined "ecological state", which is determined by the WFD as "slight deviation" from past reference conditions.

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