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Risk and monitoring based indicators of receiving water status: alternative or complementary elements in IWRM?

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ABSTRACT

The European Water Framework Directive (WFD) was enacted in the year 2000 with a stepwise approach. After legal implementation in the various member states large efforts were undertaken for the initial characterization of water bodies, risk assessment, to implement extensive monitoring schemes and to develop management plans at different aggregation levels by the year 2010. The initial characterization process and risk assessment had to be finalized by 2004 and delineated water bodies including a typological classification and identified the significant pressures and impacts in a screening procedure. In parallel, monitoring programmes and new biological indicator systems were developed in order to proof and refine the results of the risk assessment with an ecological indicator based assessment in a subsequent step which was finalized in 2009. Although the risk assessment for Germany was based on existing data that were originally collected for other purposes and came from a large variety of environmental or economical sectors, the results differ only slightly from the monitoring and indicator based information with respect to classifications of the 'ecological status' and 'chemical status'. From this result we conclude that a risk assessment based on a careful application and intelligent combination of existing data sources with proven quality allows the recognition of trends and the identification of priorities for action of measures already at an early stage of a management process. However, monitoring schemes and advanced sets of ecological indicators are essential in later management steps both for narrowing uncertainties remaining from the risk assessment and to allow for effect controls of implemented measures. Moreover, these monitoring indicators should differentiate the effects of multiple stressors more factor specific and with respect to ecosystem states and functions. In conclusion, we see risk and indicator based assessments as complementary elements in Integrated Water Resources Management (IWRM), which have to be linked in systematic and phased procedures.

Key words | ecological status of water bodies in Germany, indicators, river basin management strategies, Water Framework Directive

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THE WATER FRAMEWORK DIRECTIVE

The purpose of the European Water Framework Directive (WFD) (European Parliament and Council 2000) is to attain and protect an almost natural status for water bodies both for human usage and ecological functions. The main objective of the WFD is to achieve a 'good status' for all surface water bodies by 2015. This encompasses a 'good ecological status' and a 'good chemical status'. The achievement of these objectives is dependent on a shift in strategy from traditional water quality focused approaches towards ecologically orientated management. In many cases the existing ecological deficits in running waters are determined by point sources, but in addition to this a range of complex anthropogenic pressures exist, including diffuse pollution and morphological alterations.

The WFD lays down a clearly defined timeline (Figure 1). The first part of this included the characterization process, which was completed in 2004 and consisted of the first assessment of water bodies based on WFD requirements that had ever been carried out. Monitoring programmes were then established and implemented on the basis of the results obtained. Monitoring results and programmes of measures were documented in the first river basin

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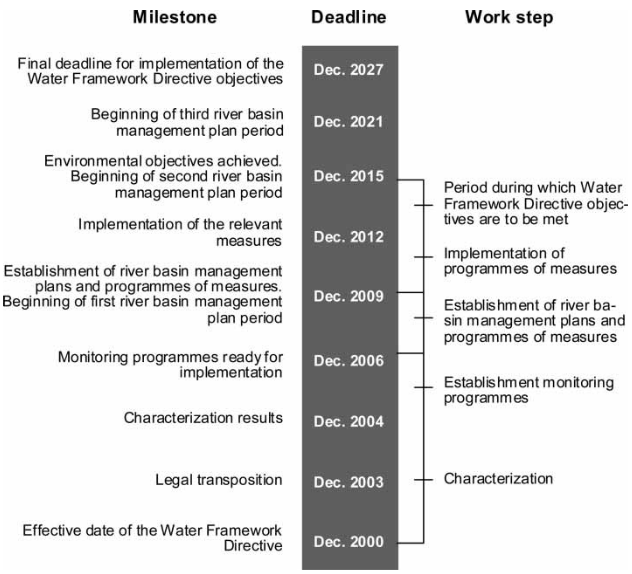

Figure 1 | Implementation timeline for the Water Framework Directive (Richter & Völker 2010, modified).

management plans presented in late 2009. The first management period will be completed by 2015. Two more 6-year periods will follow. A status check is to be carried out at least once within these 6 years, so that comprehensive information about the status of water bodies will be available Europe-wide every 6 years.

Whereas existing data and methods were used to assess water body status during the risk assessment phase, several new assessment methods for biological quality elements and supporting elements have been developed to assess the status of surface water bodies for the monitoring programmes and the first river basin management plans. These methods have been designed to permit conclusions to be drawn regarding the importance of a multitude of different stressors, mainly loss of hydromorphology, the absence of river continuity and the issue of nutrient input from diffuse and point sources. These indicators will also be used to evaluate improvements by comparing the status of waters now and following the implementation of measures in the first, second and third management plan periods.

CHARACTERIZATION PROCESS AND RISK ASSESSMENT

Procedure and methods

The characterization of water bodies and the anthropogenic pressures to which water bodies are subjected represented one of the most important steps toward implementation of the WFD in the Member States. The Directive required that the effects of anthropogenic activity on the statuses of surface and ground water bodies have to be assessed. Once all testing has been completed and the relevant data have been processed, a decision is then made as to whether the environmental objectives of the WFD can be met without further measures.

The risk assessment revolves around the following three questions:

- Which water bodies have failed to satisfy the environmental WFD objectives?
- Which chemical and non-chemical pressures are responsible for the failure to meet these objectives?
- Which mechanisms and effects should be placed at the focus of operative monitoring?

The initial characterization process for surface waters consisted of three phases. In the characterization and typology definition phase, each water body was identified as belonging to a given water body category, and a decision was then made as to which organisms and substances would occur in each of these habitats in a state largely uninfluenced by anthropogenic activity. In the second phase, an assessment was made of the anthropogenic pressures to which the water body in question is currently being subjected and the impact of these pressures on the status of the water body (risk assessment). To this end, Annex II(1)(4) of the WFD requires that pressures from substances, water abstraction, water flow regulation and morphological alterations are to be identified and that their impact on water bodies is to be assessed. This process has been described in various Guidance Documents and the LAWA guidelines (CIS 2002a, b: LAWA 2003). The assessment of pressures and impacts was based on existing data as well as assessment methods and indicators that have been used in Germany for decades. Threshold criteria for several indicators were recommended by LAWA (2003) (Table 1). The results were used as a basis for determining whether a water body meets its objectives as defined by the WFD or whether additional measures are required. For the assessment, the worst-case scenario was applied, i.e. a water body was considered to be at risk or possibly at risk of failing the WFD objectives if it was not compliant with even one assessment criterion.

In the third step of the characterization process, economic issues were addressed such as cost and the efficiency of measures.

Table 1 | Assessment indicators and criteria recommended by LAWA (2003) to assess the impact of water body status within the characterization process of the WFD (Source: Borchardt *et al*. 2005).

Indicator	Criteria resulting in failure to meet the WFD objectives
Pressures on oxygen balance (saprobia)	Ecomorphological status lower than class II (LAWA 2000) for more than 70% of watercourse length. If more than 30% of the water body is affected, it is identified as being possibly at risk of failing to meet the objectives.
Nutrient pressures (trophic status)	Eutrophication worse than class II (LAWA 2000) or annual mean concentration of orthophosphate-P >= 0.2 mg/l and nitrate-N > =6.0 mg/l.
Specific pollutant levels	Exceed environmental quality standards.
Warming	Exceeds upper limit for temperatures or temperature increases as required under the Freshwater Fish Directive.
Salinization	Mean annual chloride concentration exceeds 200 mg/l.
Acidification	Acid status classification not compliant with LAWA (2003).
Abstractions	Abstractions exceed one-third of mean low-water flow, 50 l/s, or 10% of mean flow.
Flow regulation	Structures with the following properties: • High vertical barriers exceeding 30 cm in height that are characterized by smooth surfaces are devoid of structures that promote river continuity and aquatic wildlife movement. • Backwater scenario in which at least 20% of the water body is almost stationary at the mean water level.
Morphological alterations	Water body morphology, transverse structures, backwater or other key structural parameters have been designated as class 6 or 7 along more than 70% of the length of the water body (LAWA 2000). If more than 30% of the length of the water body falls into this category, it is classified as possibly at risk of failing to meet the objectives.

Results

In the interests of obtaining a clear picture of the extent to which a given water body is at risk of failing to fulfil 'good status' requirements, Germany's surface water bodies were assigned to the following categories:

- Water bodies that are likely to achieve good status (not at risk of failing to meet the WFD objectives).
- Water bodies that may fail to achieve good status (possibly at risk of failing to meet the WFD objectives). This assessment is often attributable to a lack of sufficient data.
- Water bodies that are unlikely to achieve good status (at risk of failing to meet the WFD objectives).

According to the initial characterization undertaken in Germany in 2004, approximately 14% of the water bodies assessed are likely to meet the WFD objectives. 26% of the water bodies assessed are possibly at risk and approximately 60% of the water bodies assessed are at risk of failing to meet the WFD objectives.

Failure to meet the Directive objectives was generally attributable to physical alterations affecting the hydrology and/or geomorphology of a water body, as well as transverse structures such as weirs and sills that impede the upstream migration of fish and smaller aquatic organisms. Other significant causal factors were found to be nutrient input from diffuse sources, mainly agricultural activities, as well as other chemical pressures such as those resulting from wastewater treatment plants and precipitation drainage. The results of the characterization also showed that in most cases the (potential) failure of a water body to achieve good status is attributable to several factors acting simultaneously. Thus, for example, dam-regulated watercourses that are also subject to nutrient pressures regularly develop algal growth.

MONITORING BASED ASSESSMENT OF WATER BODY STATUS

Ecological status

Procedure and methods

Status assessments for water bodies in Germany are based on monitoring programmes. They have been designed and are being carried out on the basis of the results of the risk assessment in 2004. The monitoring programmes were elaborated for surface waters, groundwater and water-dependent protected areas. In Germany more than 8,500 surface monitoring sites were established (90% of which

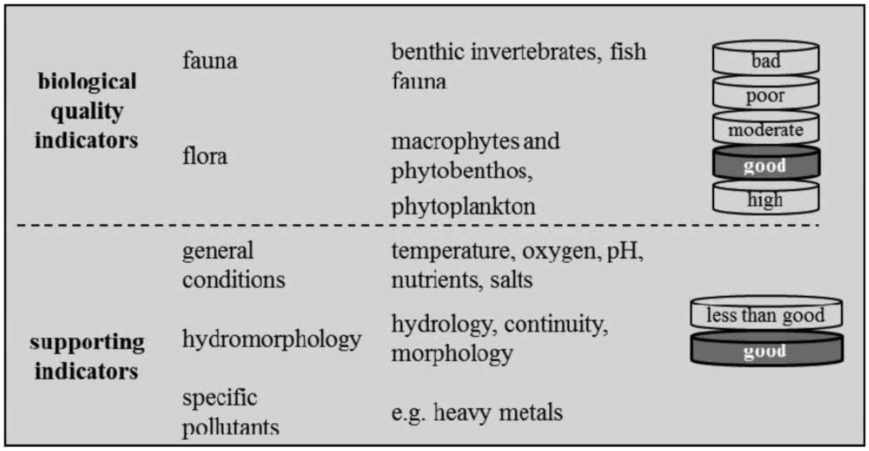

Figure 2 | Indicators and classification for assessment of the ecological status of water bodies according to the Water Framework Directive.

are located in rivers). Nine thousand sites were chosen to monitor groundwater bodies.

For surface water bodies, the ecological status is to be assessed in accordance with the biological elements fish fauna, benthic invertebrates and aquatic flora. Different assessment methods are used for each biological group (see e.g. Hering *et al.* 2003; AQEM Consortium 2004; Rolauffs *et al.* 2004; Meilinger *et al.* 2005). The assessment methods for the biological quality elements are based mainly on species taxonomic composition, and are adapted to reference conditions. Species composition and abundance under reference conditions are defined in accordance with the typology of rivers and lakes. For the typology of surface waters within Germany, this involved the definition and identification of reference conditions for a total of 24 different river types and 14 types of lakes.

The ecological status of water bodies in respect of biological quality elements is classified using five classes: 1: high; 2: good; 3: moderate; 4: poor; and 5: bad. From class 3 up to class 5 measures need to be taken to reach the objectives according to the WFD. The following aspects need to be assessed in conjunction with the biological elements: river basin specific pollutants, physico-chemical quality elements (e.g. temperature, oxygen, pH value and nutrient concentrations as descriptors of the general conditions) as well as hydromorphological features. These supporting elements are classified into 'good' and 'less than good' (Figure 2). The determining factor for the overall assessment is the worst assessment within a given group ('worst-case' or 'one out, all out' approach). The requirements for achieving 'good ecological status' are: (i) all biological elements must be rated 'good'; (ii) environmental quality standards (defined concentrations) of river basin specific pollutants must not be exceeded ('good'); and (iii) the results for the general conditions as well as the hydromorphology must fall within a range that allows for good ecosystematical functionality ('good').

Results

Of all the surface water bodies, 10% are classified as having a 'high' or 'good' ecological status at present. 90% of surface water bodies fall within the classes 'moderate' (30%), 'poor' (34%) and 'bad' (23%). A small percentage of surface water bodies (3%) has not yet been assessed and is thus classified as 'uncertain' (Figure 3).

In Germany, the main reasons for failure to achieve the WFD objectives in respect of ecological status are changes in hydromorphology including disrupted river continuity and high nutrient input introduced from wastewater treatment plants and agriculture.

Chemical status

For the assessment of the chemical status of surface water bodies, EU-quality standards for 33 priority substances in

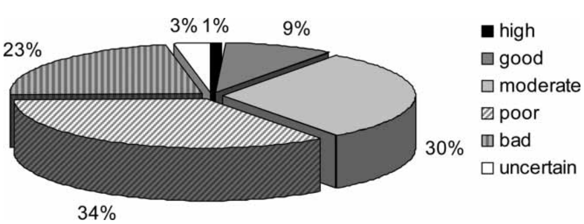

Figure 3 | Ecological status of surface water bodies in Germany. Data source: Portal WasserBLIcK (2010).

accordance with Annex X of WFD have to be taken into account. The list of priority substances includes pollutants that fall within the scope of Directive 2006/11/EC (European Parliament and Council 2006) as well as nitrates in accordance with Directive 91/676/EEC.

Of the 33 priority substances listed in Annex X of the WFD, 13 are classified as priority hazardous substances. They are subdivided into the groups heavy metals, pesticides, industrial pollutants and other pollutants. Ensuring that water bodies remain free of hazardous substances is one of the key goals of the European water protection effort.

The chemical status requirements were modified in the new subsidiary Directive 2008/105/EC that came into force in July 2010. Some states have already implemented the Directive. A comparison of the requirements of the new and old Directives shows that implementation of the former translates into significantly fewer water bodies with a 'good chemical status'. For example, under the old Directive 9% of all assessed water bodies in the Elbe river basin fail to achieve 'good chemical status', whereas under the new Directive the failure rate is 17%.

The chemical status of surface water bodies is classified into 'good status' and 'failing to achieve good status'. In sum, 88% of all surface water bodies exhibit 'good chemical status' according to present estimates (Figure 4). This figure will be less favourable following implementation of the new subsidiary directive on environmental quality standards (2008/105/EC) with its extended requirements for assessing chemical status.

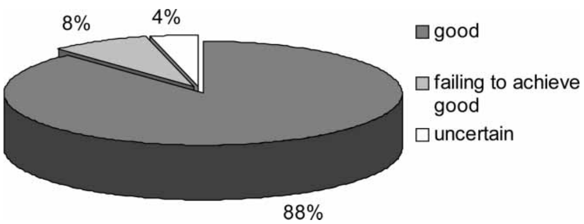

Figure 4 | Chemical status of surface water bodies in Germany. Data source: Portal WasserBLIcK (2010).

A COMPARISON OF WATER BODY STATUS ASSESSMENT METHODS

The results obtained through monitoring based assessment for surface water bodies are, in the main, reasonably consistent with the risk assessment classification of German rivers on account of the large number of river water bodies involved (9,070 of the total of 9,900 surface water bodies in Germany). Comparison of the two sets of results yields useful insights.

Figure 5 shows the ecological and chemical status of the rivers as returned through risk assessment and monitoring based assessment respectively. For better clarity, the ecological and chemical statuses arrived at through monitoring based assessment are collated into the categories 'WFD objectives achieved' (classifications 'very good' and 'good'),

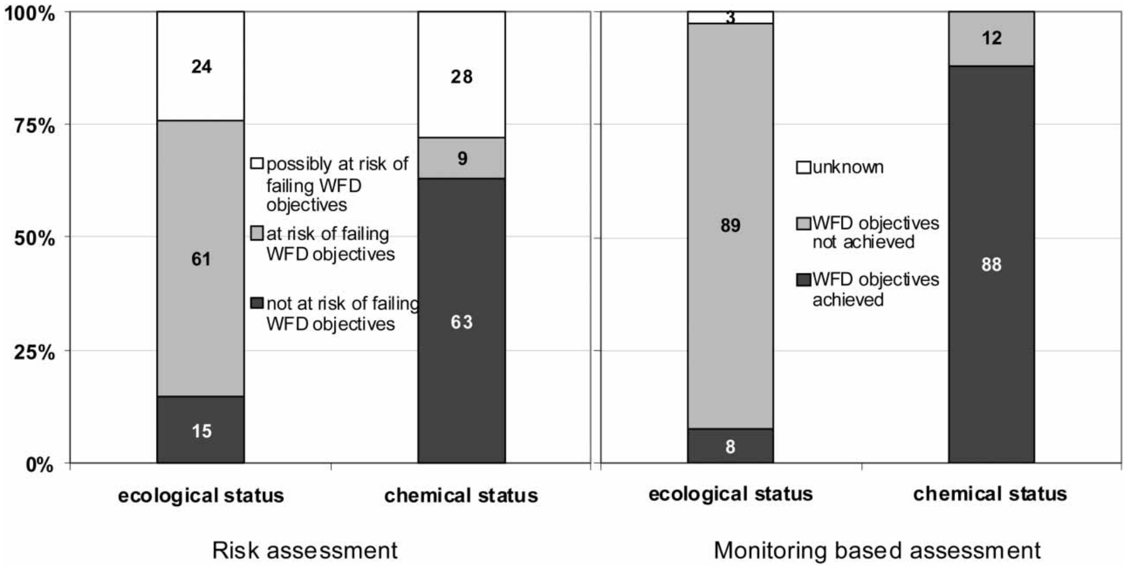

Figure 5 | Ecological and chemical river water body status based on risk assessment in 2004 (left) and the monitoring process in 2009 (right). Data source: Borchardt et al. (2005); Portal WasserBLIcK (2010).

'WFD objectives not achieved' (classifications 'moderate', 'poor' and 'bad'; i.e. failure to achieve 'good' status) and 'unknown'.

The results of the ecological water body status in the risk assessment show a relatively high number of water bodies being possibly at risk of failing to meet the WFD objectives. The main reasons for this were insufficient data and a lack of knowledge about pressures and impacts on the aquatic community (biological quality elements).

In order to obtain the missing information, operative monitoring was carried out for water bodies that are 'possibly at risk' or 'at risk' of failing to meet the WFD objectives. In addition, new assessment methods were developed with a focus on biological quality elements. In the comparison between the two assessments, water bodies 'possibly at risk' according to their ecological status were generally included in the 'WFD objectives not achieved' classification in the monitoring based assessment.

In contrast to the ecological status, a higher percentage is classified as being 'not at risk', i.e. 'WFD objectives are achieved' in respect of the chemical water body status. Water bodies that were originally considered to be 'possibly at risk of failing chemical WFD objectives' were generally moved to the 'WFD objectives achieved' category following monitoring based assessment.

The comparison of the two different assessment approaches reveals a generally good degree of consistency for a large proportion of the water bodies.

SUMMARY AND CONCLUSIONS

The assessment of the European water bodies has been carried out within the framework of the EU-WFD. The identification of pressures and impacts as part of the characterization process according to Art.5, WFD formed a useful basis for an initial estimation of water body status. The comparison of risk assessment and monitoring based results shows that risk assessment is a suitable tool for the initial evaluation of water bodies which also allows for the recognition of trends at an early stage. Methods that focus directly on existing pressures can be used to identify basic problems and provide explanations for failure to achieve the environmental objectives. Therefore, it is not necessary to wait for large-scale monitoring results before trends can be identified and effective action can be taken. However, it must be borne in mind that a risk assessment is no substitute for a comprehensive status assessment on account of several inherent uncertainties, in particular those involving status assessment on a water body scale. However, there are also many uncertainties in respect of water body assessment as well: the number of biological results realized for a water body may not be representative; the water body may not be amenable to assessment due to the absence of a reference water body or due to methodological uncertainties; the impact of management measures cannot be forecasted, and the prognostication of long-term changes in climatic patterns or the impact of natural disasters such as flooding or drought present significant difficulties. The use of biological indicators is common, but the varying resistance of indicators to the pollutants must be borne in mind. The exposure of biological indicators to contamination over a long period of time will render the indicators more resistant. However, the use of existing pressure and impact data indicators provides a helpful starting point for the identification of problems and development of effective management strategies. Subsequently, monitoring results can be used for backing up, confirming and as necessary modifying initial programmes of measures. In conclusion, we see risk and indicator based assessments as complementary elements in Integrated Water Resources Management which have to be linked in systematic and phased procedures.

Beyond the development of indicators to assess the status of water bodies and the efficiency of environmental improvement there is a need to develop indicators for water management purposes further. In Germany (as well as in the other European member states) different approaches have been adopted with respect to the status of the water bodies, the pressures and programmes of measures, the data and data quality, the management structures and prevailing socioeconomic conditions.

Current activities are being devoted to establish wider sets of indicators, e.g. to evaluate the improvements reached in a given river basin on the basis of highly aggregated data, to identify synergistic effects of multiple stressors and to assess the performance or effects of measures and of water management.

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