Water **2012**, *4*, 887-904; doi:10.3390/w4040887

OPEN ACCESS

water

ISSN 2073-4441

www.mdpi.com/journal/water

Article

Ecological Status of Rivers and Streams in Saxony (Germany) According to the Water Framework Directive and Prospects of Improvement

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Received: 28 August 2012; in revised form: 23 September 2012 / Accepted: 1 November 2012 / Published: 9 November 2012

Abstract: The Federal State of Saxony (Germany) transposed the EU Water Framework Directive into state law, identifying 617 surface water bodies (rivers and streams) for implementation of the water framework directive (WFD). Their ecological status was classified by biological quality elements (macrophytes and phytobenthos, benthic invertebrates and fish, and in large rivers, phytoplankton) and specific synthetic and non-synthetic pollutants. Hydromorphological and physico-chemical quality elements were used to identify significant anthropogenic pressures, which surface water bodies are susceptible to, and to assess the effect of these pressures on the status of surface water bodies. In 2009, the data for classification of the ecological status and the main pressures and impacts on water bodies were published in the river basin management plans (RBMP) of the Elbe and Oder rivers. To that date, only 23 (4%) streams achieved an ecological status of "good", while the rest failed to achieve the environmental objective. The two main reasons for the failure were significant alterations to the stream morphology (81% of all streams) and nutrient enrichment (62%) caused by point (industrial and municipal waste water treatment plants) and non-point (surface run-off from arable fields, discharges from urban drainages and decentralized waste water treatment plants) sources. It was anticipated that a further 55 streams would achieve the environmental objective by 2015, but the remaining 539 need extended deadlines.

Keywords: ecological status; impact assessment; anthropogenic pressures; streams; environmental objectives; specific synthetic pollutants; non-specific pollutants

1. Introduction

Biodiversity and ecosystem integrity of rivers and streams in Central Europe has been impacted on by human activities for centuries [1]. Waste water effluents [2], arable land use [3,4] and mining activities [5] have caused water pollution through the introduction of nutrients, pesticides, heavy metals and other pollutants. Urbanization in watersheds altered natural water balances and flow regimes [6]. Stream morphology has degraded due to channel straightening and deepening, natural riparian vegetation removal and discharge regulated by weirs and dams. Furthermore, water intake, for various purposes, particularly for the use of hydropower, increased the negative influence of the aforementioned pressures.

The classification of the ecological status of rivers and streams is the basis for the future sustainable management of natural water resources. Consequently, the Water Framework Directive (WFD) requires the protection of the ecological status of water bodies and the improvement of deteriorated water ecosystems [7]. The WFD addresses the ecological problems associated with multipurpose water usage, which caused widespread deterioration of river and stream ecosystems within all European countries. For the first time, a standardized classification of the ecological status of freshwater ecosystems based on biological key components is required. Indicator organisms have often been used to evaluate the intactness of biological systems or to detect anthropogenic pressures impairing the ecosystems. By using plant components (macrophytes and phytobenthos including diatoms, additionally including phytoplankton for large rivers) as well as different animal components (benthic invertebrates and fish) for the classification of the ecological status, it is now possible to assess different stressors of stream ecosystems [8]. While this methodical approach set out by the WFD might not fully correspond with recent scientific research [9], it allows a transparent classification of the ecological status of rivers and streams which is easy to understand even for non-scientists. Furthermore results of the monitoring program, including biological, hydromorphologial and physico-chemical quality elements provide some detailed indications of anthropogenic stressors impairing ecosystem integrity of rivers and streams.

These indications could be used to plan mitigation measures to reduce the effects of anthropogenic pressures. The analysis of bioassessment data, together with supporting data on hydromorphology, especially habitat diversity and physico-chemical components often reveal the main stressors of stream ecosystems. Physico-chemical parameters used to detect stressors were concentrations of total phosphorus, soluble reactive phosphorus, ammonium, dissolved organic carbon, oxygen, as well as specific conductivity, pH, biological oxygen demand.. Analyzing complementary data on human land use (urbanization, agriculture, mining, *etc.*) in a particular stream catchment, presence of waste water treatments plants (WWTP), water abstractions, dams and weirs and other human activities will finally lead to necessary measures addressing specific polluters. Consequently the WFD demands a program of measures to reduce the human impacts on the ecological status of water bodies for each river basin, but also to list the environmental objective according to Article No. 4 of the WFD [7] for each water body that must be achieved until the end of the six-year duration of the RBMPs. Every member state of the European Union must report the RBMPs to the European Commission (EU-COM), which will examine the quality of each single step of the implementation to fulfill the preset requirements of the WFD. However, the ambitious reporting requirements [10] are sometimes very complex and difficult to present to anyone who is not involved in the implementation process of the WFD.

This paper focuses solely on the classification of the ecological status of the identified water bodies, as well as the predicted improvement of the ecological status that might be achieved by implementing the program of measures. With this, the obligation to report the implementation of the WFD to the EU-COM was partly complied by Saxony according to annex VII. All data were used to produce the demanded river basin management plans according to Article No. 13 of the WFD [7]. However, the WFD also demands the classification of the ecological status of water bodies that represent lakes and the classification of the chemical status of all water bodies (surface and groundwater) as well as the quantitative status of groundwater bodies. In Saxony, the ecological potential of 34 lake water bodies, mainly representing reservoirs and mining lakes with a surface area >0.5 km² were classified, as all of these were designated as heavily modified or being artificial water bodies. Additionally, 70 groundwater bodies were monitored and the chemical and quantitative status was classified. This data has not been considered in this paper.

2. Study Area

Saxony is a federal state of Germany with an area of approximately 18,500 km² and a total population of 4.3 million, with a decreasing tendency. It shares the two large river basin districts of the Elbe and Odra with the neighboring countries Poland and the Czech Republic (Figure 1). The Saxon part of the Odra catchment is rather small (840 km²) and confined to the Neiße catchment, while 95% of the area of Saxony belongs to the Elbe catchment.

Land use in Saxony is dominated by arable fields covering *ca.* 39% of the area, while forests cover *ca*. 27%. Settlements of the three main cities of Dresden, Leipzig and Chemnitz account for *ca*. 12%. Grassland; other agricultural land (e.g., vineyards and fruit farms) represent *ca*. 13% and 3% of land use respectively. Lakes and other land use categories (e.g., open vegetation, lignite mining or military areas) were less important with *ca*. 2% and 4% respectively (Figure 2).

In 2008 waste water of approximately 5.7 million population equivalents was treated in 730 municipal waste water treatment plants (WWTP with a treatment capacity of >50 population equivalents), which additionally receive and treat commercial and industrial waste water. Thus *ca*. 85% of Saxons were connected to municipal WWTPs, 4% were connected to sewer systems but not to a municipal WWTP and 11% were not connected to sewer systems using private small scale WWTPs or septic tanks. Furthermore, urban drainage water from separated sewer systems, and during storm events from mixed sewer systems, as well as waste water from 154 industrial WWTPs entered the stream system in

Saxony. The total nitrogen load entering the stream system in Saxony in 2008 was estimated to be 3,440 tons per year (t/a) from municipal WWTPs, 279 t/a from industrial WWTPs and 1,631 t/a from urban drainage via separated and mixed sewer systems. Total phosphorus loads were estimated to be 382 t/a from municipal WWTPs, 12 t/a from industrial WWTPS and 302 t/a for urban drainage systems. Loads of heavy metals and arsenic from urban point sources in 2008 were slightly reduced compared to 2001, but no significant trend could be detected [11].

Figure 1. Map of Germany, Czech Republic and part of Poland with the location of Saxony in the tri-border region and the German parts of the rivers Elbe and Odra catchments.

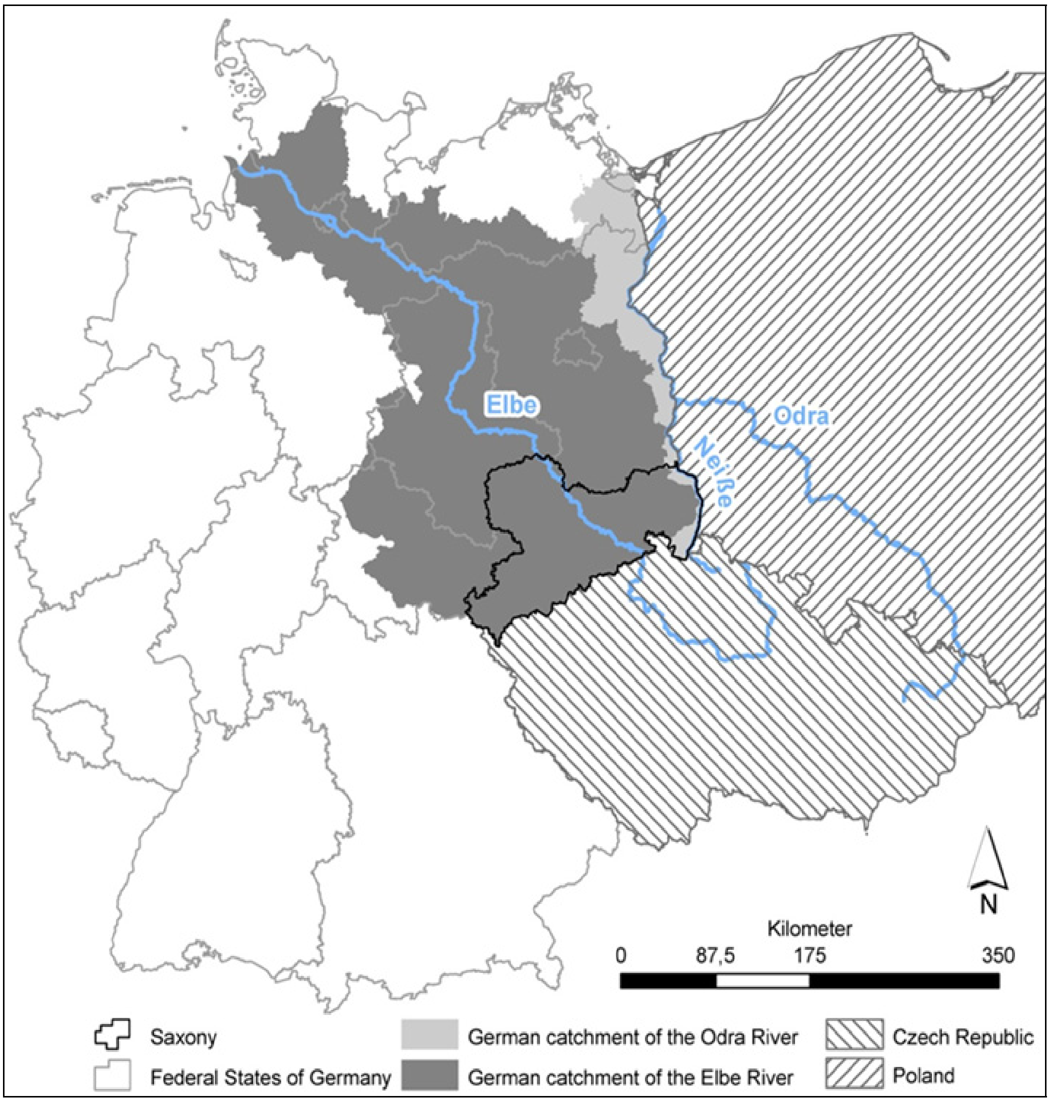
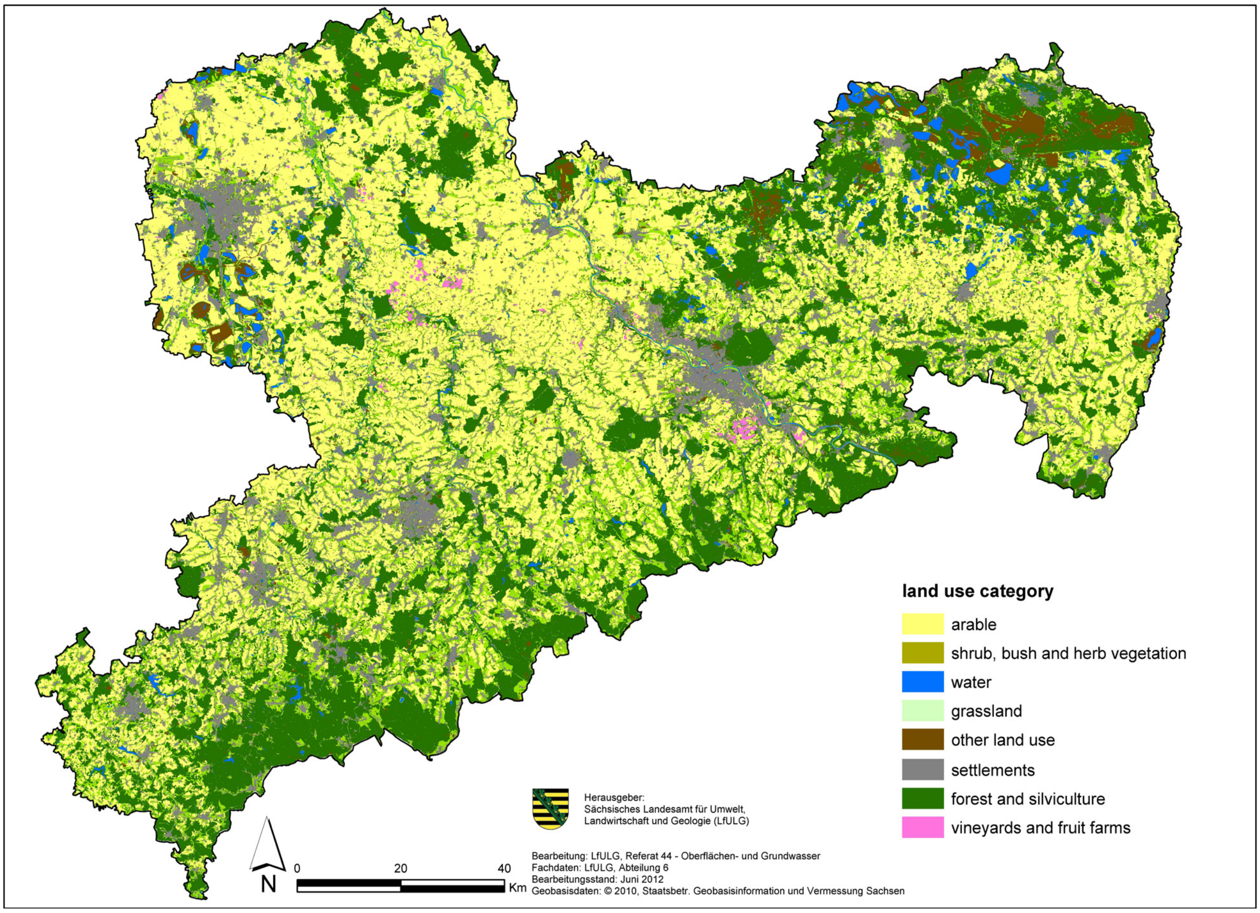


Figure 2. Land use in Saxony (based on aerial photographs from 2005/2006).



Typology and Delineating of Water Bodies from Rivers and Streams According to Annex II of the WFD

The typology of streams was defined by an ecoregion (lowland and upland region) and river landscape types depending on geological and geochemical characteristics (carbonate and siliceous geology), catchment size (rivers, mid-sized and small streams) and size of streambed substrate (sand, lose-loam, gravel). In Saxony streams were classified into 14 types, dominated by small siliceous gravel bottom streams (Table 1).

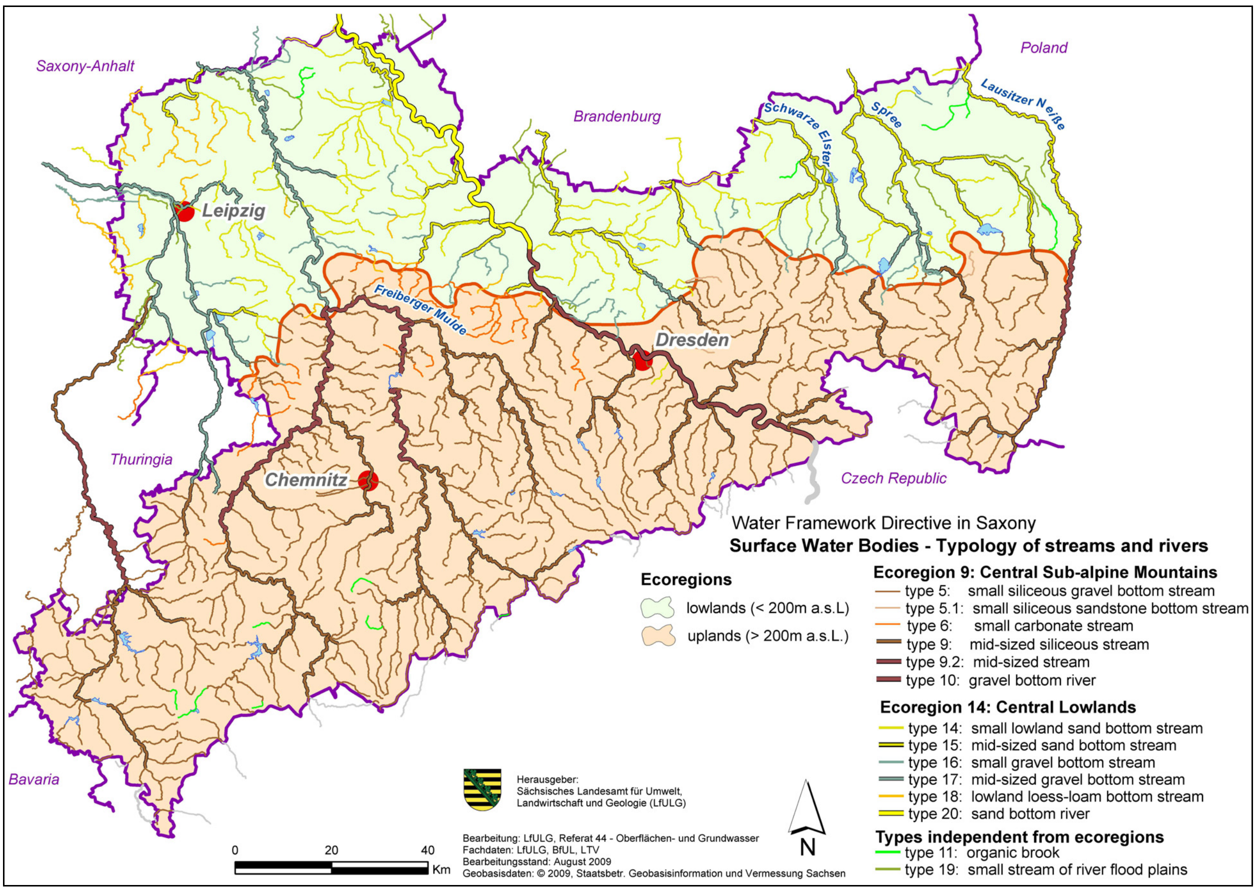
Delineating of water bodies was undertaken according to the criteria set out in the guidance document No. 2 of the common implementation strategy [12] for the identification of water bodies. According to the guidance document on page 2 "the main purpose of identifying "water bodies" is to enable the status to be accurately described and compared to environmental objectives". Criteria for identification of stream water bodies were (a) size of the catchment that must be >10 km²; and (b) the length that must be >5 km. Applying these criteria to the stream system in Saxony (*ca.* 22,000 km), reduced the stream system used for reporting to the EU-COM to approximately 7,000 km.

Criteria for delineating water bodies from rivers and streams were (i) the change between water body categories (e.g., change from river to lake caused by large impoundments); (ii) the change of stream typology (e.g., a river that changes its characteristic from an upland stream to an upland river); (iii) changes of physical characteristics (e.g., caused by a river confluence); and (iv) significant changes in hydromorphology (e.g., designation of a heavily modified water bodies due to channelization of the natural stream course). Finally, 505 river and streams were delineated to 617 water bodies with a catchment size >10 km² and a length >5 km (Figure 3).

Table 1. Stream types in Saxony (ecoregions according to [13]).

Stream types	Total length of streams (km)	No. of water bodies
ecoregion 9: central sub-alpine mountains	-	-
type 5: small siliceous gravel bottom stream	3,207	308
type 5.1: small siliceous sandstone bottom stream	25	3
type 6: small carbonate stream	223	26
type 9: mid-sized siliceous stream	826	47
type 9.2: mid-sized stream	180	6
type 10: gravel bottom river	108	2
eco region 14: central lowlands	-	-
type 14: small lowland sand bottom stream	814	96
type 15: mid-sized sand bottom stream	480	24
type 16: small gravel bottom stream	273	31
type 17: mid-sized gravel bottom stream	322	15
type 18: lowland loess-loam bottom stream	175	20
type 20: sand bottom river	75	1
types independent from ecoregions	-	-
type 11: organic brook	93	12
type 19: small stream of river flood plains	266	26

Figure 3. Stream types in Saxony.



3. Methodological Approach

3.1. Designation of Heavily Modified and Artificial Water Bodies According to Article 4 (3) of the WFD

The WFD allows the designation of surface water bodies, which have been physically altered by human activity, as "heavily modified", if the specified uses of such water bodies (e.g., flood protection or urban settlement) would be significantly affected by the restoration measures required to achieve an ecological status of "good". These water bodies may then be designated as "heavily modified" and a "good ecological potential" would then be the environmental objective [14]. Heavily modified water bodies (HMWB) and artificial water bodies (AWB) in Saxony were designated according to the presetting of the common implementation strategy groups [14].

Firstly, the extent of hydromorphological alteration of the streams and rivers was assessed by river habitat surveys (RHS). The results showed the deviation of stream morphology from natural reference conditions rated from 1 (no deviation from reference conditions) to 7 (completely modified). It was assumed that morphology of more than 50% of the stream length must not be rated as 5 (strongly modified) or worse by the RHS to achieve an ecological status of "good". All streams that do not fulfill this requirement of morphological potential for natural development were identified as HMWB.

Secondly, the specific use of the streams was identified by analyses of land use adjacent directly to the stream. Results of the RHS illustrated that most streams were straightened, streams beds and banks were reinforced and channels were incised, thus natural habitat diversity for aquatic organisms was low or worse.

In general, it was assumed that the most effective restoration measure to enhance habitat diversity could be the initialization of a controlled inherently dynamic stream development, by introducing natural flow deflectors such as larger stones in upland streams or snags in lowland streams to increase flow diversity. Additionally, the development of natural riparian vegetation, especially alder and willow trees, in appropriate stream sections were believed to be most effective for an enhancement of stream habitat diversity, positively influencing the ecological status of the stream water bodies. However, rehabilitation of flow diversity and the desired effect of an inherently dynamic stream development (erosion of stream banks, development of near-to-natural stream course, formation of pool and riffle structures *etc.*) will affect riparian sites that were often used for urban settlement, streets, agriculture or other purposes. Thus, stream sections rated with 5 or worse by RHS and directly influenced by urban settlements and/or streets in a distance of up to 30m from the stream banks were supposed to be irreversibly modified. Irreversibility means that bank reinforcement could be not removed without putting adjacent streets or houses at risk.

Additionally, stream sections that had been relocated from its natural stream bed due to exploitation of lignite coal deposits were also designated as irreversibly modified, as these sections were technically constructed without natural rehabilitation potential and without connection to the natural floodplains. Other land use categories such as agriculture were not defined to be irreversible, especially due to the statutory regulations of riparian buffer strips in German and Saxon water laws.

Finally, 125 of 617 stream water bodies were designated as HMWB and 5 were designated as AWB, as these streams were completely man-made (e.g., canals). For these water bodies the environmental objective of "good ecological potential" has to be achieved, whereas the ecological status "good" was the environmental objective for the remaining 487 natural stream water bodies.

3.2. Ecological Status of Stream Water Bodies

Ecological status of stream water bodies was classified by biological quality elements and the presence of specific synthetic and non-synthetic pollutants according to Annex V of the WFD. Biological quality elements were collected for each water body, with uniform nationwide methods at one sampling site that was stipulated to be almost representative for most of the stream sections in terms of water quality and stream morphology. Representative sampling sites were chosen by analyzing available data on stream morphology and pressure and impacts. Physicochemical quality elements (e.g., concentrations of total phosphorus, soluble reactive phosphorus, ammonia, nitrite, oxygen) were surveyed near the mouth of the stream water bodies to capture the influence of all point and non-point sources affecting the water quality in the particular catchment.

Assessment systems used for the classification of the ecological status of water bodies by macrophytes and phytobenthos, benthic invertebrates and fish preset the sampling procedure. The seasonal time frame for sampling depends on stream type and the methods for data analysis (Table 2).

Table 2. Assessment methods for classification of the ecological status of streams by biological quality elements (BQE).

BQE	**Phyto-plankton**	**Macrophytes and Phytobenthos**	**Benthic invertebrates**	**Fish**
parameters	species, abundances, biomass, chl-*a*	species, abundances	species, abundances	species, abundances, age structure
sampling time and frequency	sampling of phytoplankton by water scooper during April to October monthly and sampling of chl-*a* two-weekly both for at least 3 subsequent years	stream section (100 m) representative for most of the stream in terms of water quality and morphology 1 sampling per year during the main vegetative period (June–September), in acidified streams additional sampling after snow melt	stream section (20–100 m, depending on stream width) representative for most of the stream in terms of water quality and morphology sampling at the river Elbe were exceptionally performed at 8 sites due to the size of the river 1 sampling per year	electro-fishing in stream sections depending on fish zonation, (mainly 2 sampling stretches per water body) 1 sampling per year
method by	[16]	[17]	[8]	[18]
analysis software	PhytoFluss	PHYLIB DV-Tool	ASTERICS	FIBS

The assessment methods were multi-metric approaches, developed to indicate specific stressors affecting the ecological status of streams [8]. Results of the biological quality elements were summarized to a final classification of the ecological status of each water body by the "one-out, all-out rule" [15]. Thus, the worst classified status by one of the biological quality elements determines the overall ecological status of the water body (e.g., macrophytes and phytobenthos were classified as "moderate status", benthic invertebrate as "good status" and fish as "bad status", thus the overall ecological status of the water body was classified as "bad status"). HMWB were also classified by the described assessment system for natural water bodies, because no specific method to assess the ecological potential was available.

According to the WFD consideration needs to also be given to the presence of specific synthetic and non-synthetic pollutants which should not exceed threshold values preset by environmental quality standards (EQS). In total, 149 stream water bodies displayed annual mean concentrations of non-synthetic pollutants mainly arsenic, copper and zinc originating from abandoned ore mines or in the case of copper and zinc probably also to some extent from urban sewer systems exceeding the particular EQS. Some streams were also affected by elevated concentrations of synthetic pollutants such as polychlorinated biphenyls (PCB), pesticides or dibutyltin (DBT).

3.3. Impacts and Pressures According to Article 5 of the WFD

Impacts were categorized according to the reporting requirements of the EU-COM regarding following categories (i) "nutrient enrichment" identified by concentrations of total phosphorus (TP) and/or soluble reactive phosphorus (SRP) exceeding the orientation values of the Federal State Working Group Water (LAWA) (Table 3); (ii) "organic enrichment", identified by concentrations of ammonia exceeding the orientation values of the LAWA; (iii) "contaminated sediments", identified by concentrations of specific synthetic and non-synthetic pollutants exceeding the EQS in stream sediments; (iv) "acidification", identified by pH-values below the minimum values of the LAWA; and (v) "altered habitats", identified by RHS and assessment of mean habitat diversity that indicated distinct modifications of natural stream morphology as well as, the occurrence of dams and weirs that blocks the migration of fish and/or cause significant stream tailback. These categories were attributed to each stream water body not achieving the ecological status "good", depending on the data of the monitoring programs.

Significant pressures causing the identified impacts were also categorized by the reporting requirements of the EU-COM into "point sources", "non-point sources", "water abstractions" and "water flow regulations and morphological alterations". While the first two pressure types were attributed to pollution impacts on water quality (nutrient and organic enrichment, contaminated sediments and acidification), the latter two were attributed to impacts on stream flow and habitats. Pressure categories of nutrient enrichment were identified by using the model STOFFBILANZ, which quantifies nitrogen, phosphorus and sediment inputs from catchment areas to surface water bodies [19]. Loads of phosphorus and nitrogen inputs were compared between non-point sources (agriculture and urban drainages) and point sources (WWTPs) for each stream water body. A "significant pressure" category was attributed to a stream when orientation values of TP and/or SRP were exceeded and the sum of either non-point or point sources accounted for more than 70% of the total phosphorus load. Both categories were attributed to be "significant pressures", when neither category accounted for ≥70% of the total P-load from the stream catchment. Non-point sources were assigned to streams in certain regions of Saxony which were subjected to acidification due to the long term influence of acid rain caused by dust emission from lignite coal-burning power plants. Water abstractions were assigned as "significant pressure" when water abstractions exceeded 50 L/s in smaller streams or total volume of abstraction was >1/3 of the mean discharge of the stream. It was expected that no water body failed to achieve the ecological status "good" solely due to water abstractions, but it was assumed that water abstractions increased the effects of other significant pressures due to the reduced discharge. Finally, "water flow regulations and morphological alterations" were assigned as "significant pressure" to water bodies that displayed low habitat heterogeneity indicated by the results of the RHS (>50% of the stream length was rated as strongly modified or worse). Furthermore, the sum of weirs and dams in the water bodies, as well as, the presence of diversion dams were used to estimate the effects of tailbacks and water diversions on the natural discharge regime and flow diversity, depending on the stream size.

Table 3. Orientation values of physicochemical quality elements according to the LAWA. Exceedance or shortfall of these threshold concentrations (annual mean concentrations, minimum and maximum values for pH) at which a significant impairment of BQE was expected.

Stream types	O_2 (mg/L)	TOC (mg/L)	BOD_5 (mg/L)	TP (mg/L)	SRP (mg/L)	NH_4-N (mg/L)	pH
Ecoregion 9: Central sub-alpine mountains							
type 5	>7	7	4	0.1	0.07	0.3	6.5–8.5
type 5.1	>7	7	4	0.1	0.07	0.3	6.5–8.5
type 6	>7	7	4	0.1	0.07	0.3	6.5–8.5
type 9	>7	7	4	0.1	0.07	0.3	6.5–8.5
type 9.2	>6	7	6	0.1	0.07	0.3	6.5–8.5
type 10	>6	7	6	0.15	0.07	0.3	6.5–8.5
Ecoregion 14: Central lowlands							
type 14	>7	7	4	0.1	0.07	0.3	6.5–8.5
type 15	>6	7	6	0.1–0.15*	0.07	0.3	6.5–8.5
type 16	>7	7	4	0.1	0.07	0.3	6.5–8.5
type 17	>6	7	6	0.1–0.15*	0.07	0.3	6.5–8.5
type 18	>7	7	4	0.1	0.07	0.3	6.5–8.5
type 20	>6	7	6	0.15	0.07	0.3	6.5–8.5
Types independent from ecoregions							
type 11	>6	10	6	0.15	0.1	0.3	5–8
type 19	>6	10	6	0.15	0.1	0.3	5–8

O_2 = Oxygen; TOC = total organic carbon; BOD = biological oxygen demand; TP = total phosphorus; SRP = soluble reactive phosphorus; NH_4-N = ammonium nitrogen; * = value 0.15 mg/L for streams with small and 0.1 mg/L for stream with large catchment; explanation of stream types see Table 1

The final allocation of "significant pressure" categories (more than one category per water body were allowed), was a by the consideration of experts, including the criteria listed before and by putting them in context with the results of the biological monitoring program. Thus, a direct causal relationship was used for the direct pressure allocation, such as linking elevated phosphorus concentrations to high P-loads from non-point sources and classification of macrophytes/phytobenthos worse than a "good status". Other more indirect effect, such as the influence of elevated P-concentrations on benthic invertebrates and fish were considered in the process of deciding which pressures are most likely to cause the failure to achieve the environmental objectives. A number of stream water bodies did not achieved the ecological status "good" classified by the BQEs, but no significant pressure could be identified through water quality monitoring data, RHS or other data. For these streams no "significant pressure" type was assigned.

3.4. Program of Measures (POM) According to Article 11 of the WFD

First of all, the POM consists of basic measures that were derived directly from water laws or statutory regulations. These comprised for example, the postulation of "good agricultural practices" or governmental ordinance for minimum flows at hydropower plants with diversion channels. The WFD demands the planning of supplementary measures, if basic measures alone will not be sufficient to achieve the environmental objectives. Generally, mitigation measures were planned on the level of water bodies without concrete localization of specific measures. Thus, the POM represents mainly the financial aid program for sustainable agriculture (e.g., non-plough tillage, intermediate crop or grassed waterways), statutory legislation to reach the widely accepted rules of technology for waste water treatment in municipal and industrial WWTPs, as well as, biological treatment of waste water in decentralized WWTP (small scale WWTPs) or connection to a municipal WWTP until 2015. These measures were incorporated into the POM for all water bodies with arable fields and central or de-centralized WWTPs that did not fulfill the demands of the acknowledged rules of technology for waste water treatment.

Other supplementary measures were also planned for certain water bodies. Removal of small dams and weirs, or the construction of fish ladders was adopted from the status of planning within the Saxon Fish Migration Program. In this program, financial support is granted by the Federal State of Saxony to the owner of particular dams or weirs for measures to re-establish migration alleyways for fish or the complete removal of the weir. However, it is also statutory legislation of German and Saxon water laws that up- and downstream migration of fish must be possible at all dams and weirs if this is necessary to achieve the environmental objectives. Exemptions were very large dams or fish ponds directly within the stream, as such a measure would affect the use of the impoundment significantly or cause inappropriate costs and might not be necessary when stable and stream type specific fish populations are developed up- and downstream of these migration barriers.

Restoration measures were planned for most of the streams and rivers, as stream morphology is often strongly modified or worse. Unfortunately, despite the need to implement such measures it is very difficult to put them into practice [20]. Some water bodies were also subjected to anthropogenic pressures with unknown origin, or pressures were caused by past activities such as contaminated stream sediments from ore mining. Often natural rehabilitation from former pollution takes place [21] but actually the good ecological status of the particular water body could not be achieved due to the aftermaths of these past pressures. For these streams with unknown origin of pollution the search for possible sources and entry routes are the key activities prior to the survey for appropriate mitigation measures.

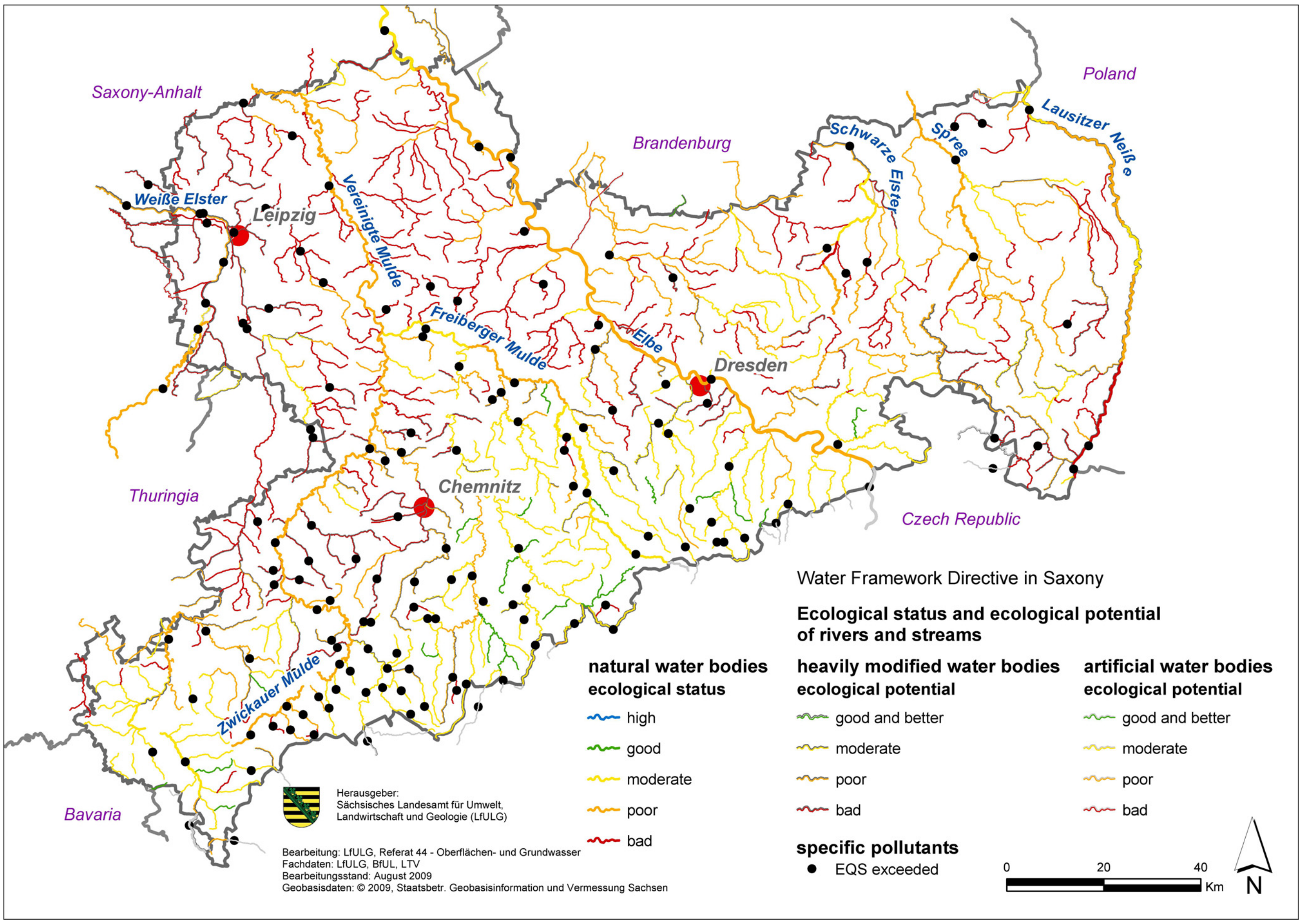
This framework planning of measures will be successively transferred into concrete localized mitigation measure and more detailed plans for each particular water body. Therefore regional working groups including all water agencies were built on the level of river sub-basins.

4. Results

4.1. Classification of Ecological Status According to Annex V of the WFD

In total, only 23 stream water bodies achieved the ecological status "good" according to the WFD, while the rest failed to achieve this environmental objective. These streams are mainly located in the southern upland region of Saxony and characterized by catchments with high amounts of native forests and low intensity of land use and low numbers of urban settlements. Further 16 stream water bodies achieved the ecological status "good" for all relevant BQE, but were downgraded to a 'moderate' ecological status due to exceedance of the EQS of specific synthetic or non-synthetic pollutants. In total, the EQS of specific synthetic or non-synthetic pollutants was exceeded by 149 stream water bodies (Figure 4).

Figure 4. Ecological status and potential of stream and river water bodies in Saxony.



EQS = Environmental Quality Standards.

Most of the streams were classified into a bad ecological status due to the one-out, all-out principle. Classification of the BQE fish was mostly responsible for the bad classification of stream water bodies (Table 4), especially for small lowland streams.

Generally, the ecological status "good" of more than one BQE was not achieved for stream water bodies. Six larger river water bodies failed to achieve the ecological status "good" for all four BQE and additionally exceeded the EQS of at least one specific synthetic or non-synthetic pollutant. Mostly three of the BQE failed to achieve the ecological status "good" for the particular stream (386 water bodies), while the failure of two BQEs (130 water bodies) or only one BQE (56 water bodies) were less numerous.

Table 4. Results of the classification of the ecological status of stream water bodies by biological quality elements (BQE) and final classification results (according to the "one-out, all-out rule").

Ecological status	Phytoplankton*	Macrophytes and Phytobenthos	Benthic invertebrates	Fish	Final classification
Very good	0	9	1	26	0
Good	3	103	132	92	23
Moderate	11	332	185	146	159**
Poor	4	158	163	107	146
Bad	0	15	136	246	289

* Phytoplankton is only relevant for 18 river water bodies in Saxony with a catchment size >10,000 km²;
** 16 streams achieved a good ecological status for all relevant BQE but were downgraded to moderate ecological status due to exceedance of the EQS of specific synthetic or non-synthetic pollutants.

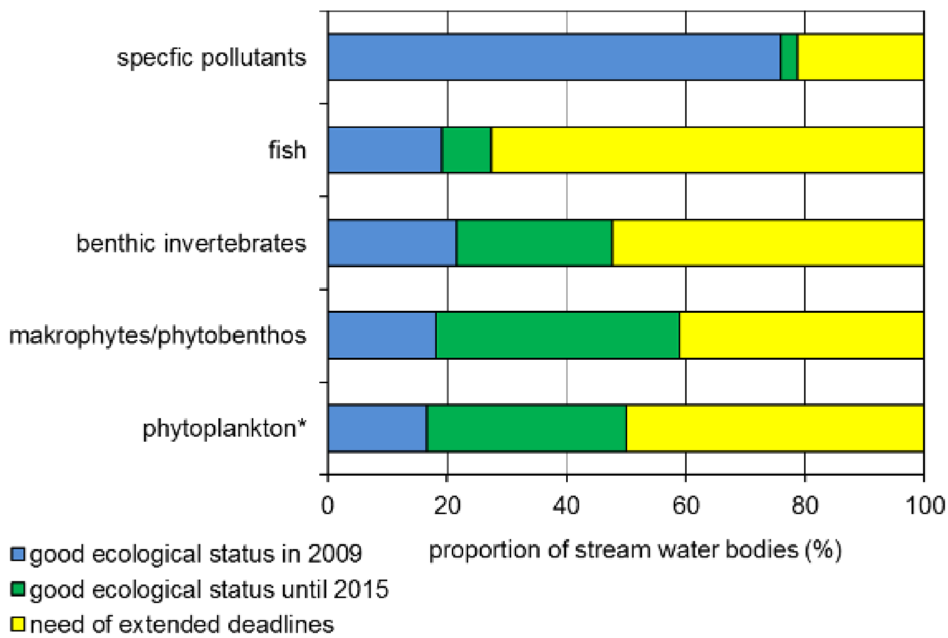
4.2. Significant Pressures and Impacts

Most of the stream water bodies were subjected to more than one impact and also to more than one significant pressure category. Main impacts affecting the ecological status of stream water bodies were morphological alterations of habitat diversity and flow regulations caused by water abstractions as well as construction measures to reduce increased flow velocities caused by stream straightening and deepening (86% of all stream water bodies). Eutrophication impairing the ecological status was allocated to 62% of all stream water bodies, while other impacts were less relevant (organic pollution allocated to 25% of stream water bodies, contamination by specific synthetic and non-synthetic pollutant to 24% and acidification to 2%). Corresponding to the allocation of impact categories, the significant pressures category "water flow regulations and morphological alterations" was also allocated to the above mentioned 86% of stream water bodies, while diffuse pollution from non-point sources was assumed to be at least jointly responsible for the failure of achieving the ecological status "good" in 77% and point sources in 20% of the stream water bodies. Finally, water abstractions were identified as significant pressure for 7% of stream water bodies. For 12 streams that did not achieve the ecological status "good" no significant pressure and impact could be identified.

4.3. Prospects of Improvement, Environmental Objectives and Exemptions

According to the WFD and the reporting requirements of the EU-COM, each biological BQE and each category of synthetic and non-synthetic pollutants (heavy metals, industrial pollutants, pesticides and other pollutants) must be assessed as to whether the ecological status "good" will be achieved by 2015, will require extended deadlines or other exemptions according to Article No. 4 WFD [7]. The probability of improvement for each BQE in every stream water body was assessed for Saxon stream water bodies by expert consideration. For synthetic and non-synthetic pollutants, it was generally expected that concentrations of pesticides, which are actually exceeding the EQS in stream water bodies in agricultural application, will be significantly reduced by 2015. For all other pollutants it was assumed that no significant reduction of concentrations will be possible, due to the mainly unknown sources and entry routes or the temporarily release of contaminated stream sediments that could not be reduced by appropriate mitigation measures (Figure 4). The improvement of BQE that failed to achieve the status "good" by 2015 was assessed by the magnitude of the identified impacts (e.g., mean annual concentration of nutrients) and significant pressures in relation to the possible effectiveness of measures that have been realized in the past (natural rehabilitation) or with respect to the effectiveness of measure that will be implemented between 2010 and 2012 (according to the requirements of the WFD to report the progress of implementation of POMs). For instance, where concentrations of nutrients (total phosphorus or SRP) significantly decreased over the last few years, it was assessed that a "moderate" status of the BQE macrophytes/phytobenthos will be improved to a "good" status by 2015 by natural recovery. Furthermore, it was expected that both the financial aid program for sustainable agriculture as well as the improvement of waste water treatment, especially in rural areas will cause a significant decrease in nutrient input into streams. Therefore, the main improvements to the ecological status "good" were expected for the BQE macrophytes/phytobenthos, which were in fact classified as a "moderate" ecological status. Benthic invertebrates and fish were rated for the probability of improvement to a "good" ecological status for every stream by putting the recent data of the RHS into relation to the classification of the ecological status of the two BQE's. Stream water bodies without significant impairment of water quality (e.g., elevated nutrient concentrations) and only moderate modification of stream morphology indicated by the data of the RHS were expected to have a high probability of improvement for the BQE's benthic invertebrates to achieve the good ecological status by 2015 (Figure 5).

Figure 5. Prospects of improvement for all biological quality elements (BQE) and specific synthetic and non-synthetic pollutants.



N = 617 stream water bodies; * classification of phytoplankton was only relevant for 18 stream water bodies in Saxony.

Effects of potential mitigation measures reported within the POM that might improve the ecological status of stream water bodies classified as "moderate" or worse ecological status, were cautiously rated as the POM represents only a planning framework without detailed and localized restoration plans. Additionally, the effect of other human activities that might impair the ecological status of one or more BQE, such as essential flood protection measures or other water construction projects could not be taken into account considering the potential negative effect on the prospects of improvement. However, it was assumed, improvements were achieved in many streams, mainly for the BQE macrophytes/phytobenthos, as significant reductions of nutrient inputs from arable fields and small waste water treatments plants were not expected by 2015. Generally, stream water bodies with deficits in only one BQE were expected to have the highest probability to achieve the ecological status "good" in total by 2015. The achievement of a "good" ecological status or at least a "good ecological potential" (heavily modified water bodies) was prospected for a further 55 stream water bodies by 2015. Assuming that no deterioration of the "good" ecological status for those stream water bodies achieving this objective already in 2009 takes place, the number of stream water bodies that achieve the environmental objective demanded by the WFD will increase to 78 (12.6% of all stream water bodies).

5. Conclusions

Freshwater ecosystem function and biodiversity are still threatened by a variety of human impacts [22] Worldwide. Thus, the WFD tries to provide a clear political direction towards a more sustainable management of water resources and to establish a higher level of protection for water ecosystems for the first time. However, exemptions from achieving the required ecological status "good" have to be considered. Usage of freshwater ecosystems has taken place for centuries in Central Europe and to some extent, it has been intensified to an overuse of water resources and severe modification of natural ecosystems. These threats to freshwater ecosystems have to be addressed by programs of measures and significant pressures, and impacts must ultimately be reduced.

Unfortunately, it is almost impossible to classify freshwater ecosystems such as streams and rivers with feasible effort into states of naturalness, taking into account that for Saxony alone the ecological (and chemical) status of 617 water bodies comprising approximately 7,000 km of streams and rivers have to be classified. New assessment methods derived from the recent state of scientific knowledge, considering the demands of the WFD and the limited financial budget available for monitoring programs have been developed for each biological quality element (BQE), but the data could not easily be analyzed to identify significant pressures and impact sources and automatically provide appropriate measures that will guarantee the achievement of the environmental objectives. A lack of sufficient data made it harder to exactly identify significant pressures, particularly as most streams were affected by (interacting) multiple stressors (e.g., strong modification of stream morphology or significant alteration of flow regime) and additionally by temporarily occurring disturbances (e.g., inflow of waste water from mixed sewer systems or surface runoff from arable field during storm events). Furthermore, it seems also nearly impossible to predict changes in the taxonomic composition of benthic invertebrates or fish by small scale restoration measures on the level of water bodies with lengths up to 90 km [23]. Thus, the "one-out, all-out rule" for the final classification of the ecological status of water bodies is currently under critical appraisal [24] and the presented prospects of improvements were at best estimates with a high degree of uncertainty.

Nevertheless, the classification of the ecological status of streams and rivers revealed to some extent that past human activities, as well as recent water usage still impair stream ecosystem functions and biodiversity indicated by the relevant BQEs. This data will now be used to lower the impacts and effects of significant pressures on stream ecosystems by appropriate measures. But the level of uncertainty to identify appropriate measures is still very high, as monitoring data and known pressures and impacts did not fit very well in some cases and additional analyses (e.g., the pollution "history" of the stream) and detailed plans (e.g., for a near-to-natural stream habitat development) are necessary for the improvement of the ecological status. Generally, river management plans will be needed even for smaller streams, due to the variety of interacting factors influencing the ecological status of the particular stream. To date no competent authority can compile such detailed plans for every water body due to limited personal capacities and budgets. Additionally, the distribution of responsibilities (e.g., stream maintenance for which either the Federal State of Saxony (streams of the first order according to Saxon water law) or the municipalities (streams of the second order according to Saxon water law) are responsible) complicates integrative planning. Besides this problem, the main obstacles to the implementation of river rehabilitation projects are currently the lack of areas adjacent to the streams that are available for a near-to-natural stream habitat restoration, and not in use (e.g., agriculture), limited financial means of the responsible actor (especially municipalities) and contradicting individual and community goals [20]. In summary, the improvement of stream water bodies that shall achieve the environmental objective according to the WFD were predicted very cautiously with respect to many uncertainties in the assessment of the ecological status, identification of significant pressures and impacts and the feasibility of mitigation measures.

Acknowledgments

Many thanks to all colleagues from the Betriebsgesellschaft für Umwelt und Landwirtschaft (BfUL) for the provision of data on physicochemical quality elements, phytoplankton, macrophytes/phytobenthos and benthic invertebrates. Furthermore, we thank the colleagues from the Saxon State Office for Environment, Agriculture and Geology, Division of Fisheries for data on fish. Finally we thank Andrea Bell-Booth for correcting and improving the English text.

References

1. Meybeck, M. Global analysis of river systems: From earth system controls to anthropocene syndromes. *Phil. Trans. R. Soc. Lond. B* **2003**, *358*, 1935–1955.
2. Canobbio, S.; Mezzanotte, V.; Sanfilippo, U.; Benvenuto, F. Effect of multiple stressors on water quality and macroinvertebrate assemblages in an effluent-dominated stream. *Water Air Soil Pollut.* **2009**, *198*, 359–371.
3. Kronvang, B.; Bechmann, M.; Lundekvam, H.; Behrendt, H.; Rubæk, G.H.; Schoumans, O.F.; Syversen, N.; Andersen, H.E.; Hoffmann, C.C. Phosphorus losses from agricultural areas in river basins: Effects and uncertainties of targeted mitigation measures. *J. Environ. Qual.* **2005**, *34*, 2129–2144.

4. Schulz, R. Field studies on exposure, effects, and risk mitigation of aquatic nonpoint-source insecticide pollution: A review. *J. Environ. Qual.* **2004**, *33*, 419–448.
5. Mestre, M.A. Environmental Impact of Mine Drainage and Its Treatment on Aquatic Communities. Ph.D. Dissertation, University of Birmingham, Birmingham, UK, 2009.
6. O'Driscoll, M.; Clinton, S.; Jefferson, A.; Manda, A.; McMillan, S. Urbanization effects on watershed hydrology and in-stream processes in the Southern United States. *Water* **2010**, *2*, 605–648.
7. European Commission. *Directive 2000/60/EC of the European Parliament and of the Council: Establishing a Framework for Community Action in the Field of Water Policy*; European Commission: Kirchberg, Luxembourg, 2000.
8. Hering, D.; Johnson, R.K.; Kramm, S.; Schmutz, S.; Szoszkiewicz, K.; Verdonschot, P.F.M. Assessment of European streams with diatoms, macrophytes, macroinvertebrates and fish: A comparative metric-based analysis of organism response to stress. *Freshwat. Biol.* **2010**, *51*, 1757–1785.
9. Moss, B. The water framework directive: Total environment or political compromise? *Sci. Total Environ.* **2008**, *400*, 32–41.
10. European Commission. *Common Implementation Strategy for the Water Framework Directive*; Guidance for Reporting under the Water Framework Directive, Guidance Document No. 21; Office for Official Publications of the European Communities: Kirchberg, Luxembourg, 2009.
11. Saxon State Agency for Environment, Agriculture and Geology. *Emissionsbericht Abwasser 2010* (in German); Saxon State Agency for Environment, Agriculture and Geology: Dresden, Germany. Available online: http://www.umwelt.sachsen.de/umwelt/wasser/download/EBAbw2010_gesamt5_karten.pdf (accessed on 1 November 2012).
12. European Commission. *Common Implementation Strategy for the Water Framework Directive*: *Identification of Water Bodies*; Guidance Document No. 2; Office for Official Publications of the European Communities: Kirchberg, Luxembourg, 2003.
13. Illies, J. *Limnofauna Europeae* (in German), 2nd ed.; Gustav Fischer Verlag: Stuttgart, Germany, 1978; p. 552.
14. European Commission. *Common Implementation Strategy for the Water Framework Directive: Identification and Designation of Heavily Modified and Artificial Water Bodies*; Guidance Document No. 4; Office for Official Publications of the European Communities: Kirchberg, Luxembourg, 2003.
15. European Commission. *Common Implementation Strategy for the Water Framework Directive: Overall Approach to the Classification of Ecological Status and Ecological Potential*; Guidance Document No. 13; Office for Official Publications of the European Communities: Kirchberg, Luxembourg, 2005.
16. Mischke, U.; Behrendt, H. *Handbuch zum Bewertungsverfahren von Fließgewässern Mittels Phytoplankton zur Umsetzung der EU-WRRL in Deutschland* (in German); Weißensee Verlag: Berlin, Germany, 2007.

17. Schaumburg, J.; Schranz, C.; Stelzer, D.; Hofmann, G.; Gutowski, A.; Förster, J. *Verfahrensanleitung für die ökologische Bewertung von Fließgewässern zur Umsetzung der EU-Wasserrahmenrichtlinie: Makrophyten und Phytobenthos* (in German); Bayerisches Landesamt für Umwelt: Augsburg, Germany, 2006. Available online: http://www.lfu.bayern.de/wasser/gewaesserqualitaet_seen/phylib_deutsch/verfahrensanleitung/doc/verfahrensanleitung_fg.pdf (accessed on 21 May 2012).
18. Diekmann, M.; Dußling, U.; Berg, R. *Handbuch zum fischbasierten Bewertungssystem für Fließgewässer (FIBS)* (in German); Fischereiforschungsstelle Baden-Württemberg: Langenargen, Germany, 2005. Available online: http://www.flussgebiete.nrw.de/Unterlagen/FIBS_Handreichungstext_2005.pdf (accessed on 21 May 2012).
19. Gebel, M.; Halbfaß, S.; Bürger, S.; Friese, H.; Naumann, S. Modelling of nitrogen turnover and leaching in Saxony. *Adv. Geosci.* **2010**, *27*, 139–144.
20. McDonald, A.; Lane, S.N.; Haycock, N.E.; Chalk, E.A. Rivers of dreams: On the gulf between theoretical and practical aspects of an upland river restoration. *Trans. Inst. Brit. Geogr.* **2004**, *29*, 257–281.
21. Adams, M.S.; Ballin, U.; Gaumert, T.; Hale, B.W.; Kausch, H.; Kruse, R. Monitoring selected indicators of ecological change in the Elbe River since the fall of the Iron Curtain. *Environ. Conserv.* **2001**, *28*, 333–344.
22. Vörösmarty, C.J.; McIntyre, P.B.; Gessner, M.O.; Dudgeon, D.; Prusevich, A.; Green, P.; Glidden, S.; Bunn, S.E.; Sullivan, C.A.; Liermann, R.C.; Davies, P.M. Global threats to human water security and river biodiversity. *Nature* **2010**, *467*, 555–561.
23. Hering, D.; Borja, A.; Carstensen, J.; Carvalho, L.; Elliott, M.; Feld, C.K.; Heiskanen, A.-S.; Johnson, R.K.; Moe, J.; Pont, D.; Solheim, A.L.; van de Bund, W. The European Water Framework Directive at the age of 10: A critical review of the achievements with recommendations for the future. *Sci. Total Environ.* **2010**, *408*, 4007–4019.
24. Caroni, R.; van de Bund, W. *Review of Approaches for Combining BQEs in WFD Assessment*; Wiser Deliverable D6.2-1; WISER (Water bodies in Europe: Integrative Systems to assess Ecological status and Recovery): Essen, Germany, 2012. Available online: http://www.wiser.eu/download/D6.2-1.pdf (accessed on 21 May 2012).