BALTIC FLOWS

New knowledge on Diffuse Load Monitoring – State of art review

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Executive summary

The present document is part of a series of reports that document the results and implications of the FP7 project "Baltic Flows". Baltic Flows addressed the challenges resulting from rainwater run-off in the Baltic Sea catchment area and how these are monitored and managed. Much of the rain-water in urban and rural areas drain through drainage and surface water systems and eventually discharges to the Baltic Sea. This surface runoff may result in stormwater and flood events, cause significant damage on infrastructure, cause erosion, and transport nutrients and hazardous sub-stances. The latter accumulate in the Baltic Sea and may cause severe environmental problems. Therefore it is crucial to assess and control the amount of rainwater runoff and the potentially harmful loads it carries. The key objectives of the Baltic Flows project was to assess the current status of and methods and technologies used in storm water management and diffuse load moni-toring and citizen involvement water quality monitoring (WQM) activities. This document does not only provide a summary of the current practices, it identifies the expertise and innovation potential in the project region that may be utilized to grow a region of excellence for WQM and management.

This report focuses on diffuse load monitoring, that is uptake and transport of nutrients, hazardous substances and particles. It addresses the existing legal frameworks for diffuse load monitoring, the available technologies, and the existing educational, professional and scientific competences in the project region. The report highlights the common achievements but also identifies the develop-ment potential for more effective diffuse load monitoring in the project region and European Union (EU). Through comparison with global monitoring practices and competences, the report empha-sizes the excellence that exists in all diffuse load monitoring related fields in the project region. The project results indicate that the region has the potential to develop into a global "Region of Excel-lence" in diffuse load and water quality monitoring.

Project approach

Surface runoff and diffuse loading are global phenomena. Stormwaters and floods are generated locally but the loads they carry may affect large and distant areas. Therefore diffuse loads should be treated as regional rather than local problem. Therefore national and international monitoring

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and management regulations and networks are needed to mitigate negative impacts of diffuse loads.

The Baltic Flows project assessed the existing national and EU frameworks that regulate diffuse load and water quality monitoring, their regional implementation and used methods and technologies. To provide a representative overview on the current practices, technologies and needs in the project region and EU, extensive literature reviews and interviews with experts and policy makers were conducted. Additionally, information on current practices from all participating countries were obtained through the distribution of questionnaires among national experts and authorities. The survey results identify the achievements and development potential in diffuse load monitoring practices in all related disciplines: policy making, environmental administration, monitoring, and technology. The regional situation is put in a global context through case studies on diffuse load monitoring in the USA, South America and Asia. The global perspective indicates a significant potential for technological, educational, and legislative knowhow export from the project region.

Current best practices

Diffuse load monitoring is coordinated and conducted by environmental authorities or ministries in the project countries. The responsible authorities develop a monitoring scheme, including number of stations, sampling intervals and measured parameters and ensure the implementation of the scheme. The sampling is in most cases based on manual grab sampling; only few automated stations exist. The generated data is often compiled in local databases from where it is fed to a national data repository. The national data is reported to HELCOM and the EU. The latter in accordance with the Water Framework Directive (WFD) which regulates WQM on EU level.

Though 1000s of monitoring stations exist in the project region, monitoring efforts are not carried out uniformly and regional to national heterogeneities exist. This heterogeneities are largely due to the limited financial resources for monitoring and the great differences in the number of surface waters between the project countries.

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Policies and regulations concerning diffuse load monitoring

Water quality and diffuse load monitoring in the Baltic Flows countries is regulated through the EU WFD and additionally through HELCOM. The WFD (adopted in 2008) aimed to establish a good environmental status (GES) of the EU surface waters by 2015. To achieve this goal the EU countries are obliged to, e.g. assess the status of their water bodies, set baselines for the GES, estimate pollutant loads, monitor status changes, identify causes that prevent a GES, and eliminate these causes, and to produce risk assessments for accidental spills. The WFD is complemented by the Nitrate Directive (from 1991), that aims to reduce nitrate leaching from agriculture into groundwater.

Though the WFD helped to improve the surface water quality in the EU countries, induced the establishment of more comprehensive monitoring networks, and improved the data exchange on EU level, it failed to achieve the set goals by 2015.

More specific to the project region are the diffuse load monitoring requirements set by HELCOM that aim to reduce the terrestrial pollution input into the Baltic Sea. In contrast to the WFD, HELCOM does not require a uniform monitoring scheme for all countries but rather monitoring that matches established practices and existing long-term data sets. Yet, the data collection practices should aim for a high degree of comparability across the Baltic Sea region. The major objectives include the identification of sources and monitoring of water-borne pollutants to the sea, the assessment of long-term changes and the improvements of pollution input from individual countries.

The regulations and policies existing in the EU provide a base for comprehensive diffuse load monitoring programs which are needed to improve and maintain a GES of the water resources and allow for their sustainable use. However, improvements of the current policies are needed to make diffuse load and WQM more efficient. It appears desirable that the legal framework would enable the use of innovative technologies, especially for automated online monitoring. This is needed to reduce monitoring costs, expand networks, foster RDI activities and enable companies to market new solutions. A crucial prerequisite for this might be the liberalization of technology certification standards. An EU-wide uniform data management policy would ease the exchange of information and integrated water quality management effort across the EU in the long term.

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Diffuse load monitoring on global scale

The diffuse load monitoring and management practices that are applied in the project region have been compared with example form across the globe. The comparison indicates the expertise that exists in the project region. While the USA, as a globally leading country, have a very comprehensive WQM program, in many other countries WQM is in its infancy. The density of diffuse load monitoring stations and applied quality standards in the project region and the USA are on the same level. However, the legislation in the USA actively encourages the application of automated, smart technologies which helps to reduce costs and has positive effects on the commercial development of new technologies. The EU and Baltic Flows region could benefit from such practices in future.

The examples from developing countries illustrate the importance of the interplay of legal frameworks, environmental awareness and sufficient financial resources for diffuse load monitoring. Many of the developing counties suffer from insufficient sanitation and drinking water treatment and cannot prioritize monitoring of diffuse loads and actions to improve the quality of surface waters. Yet, the examples from Brazil and India show that the establishment of monitoring networks and incremental improvement of the environmental status are possible using targeted actions and applicable policies and regulations. The development of low-cost monitoring solutions in combination with education in WQM and policy making are the most important factors improve the water quality across the developing world.

Current and future monitoring technologies

The report presents an overview of state-of-the-art technologies available for water quality and diffuse load monitoring; evolving technologies that have the potential to change monitoring practices and the scale of deployed networks in future are presented. The current bottlenecks in technologies and limitations of monitoring are identified.

Generally, the most relevant parameters can be measured in-situ using current technologies. Exceptions include the sensing of certain hazardous substances as pesticides. Shortcomings of available technologies relate to their costs, energy consumption, and reliability and robustness for long-term deployments. Further, development potential exists in data storage, transmission and processing. In order to build truly autonomous, real-time monitoring and early warning systems a uniform data format and processing scheme is needed. To establish an integrated monitoring scheme

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in the project region and EU, or in any other part of the world, data should be collected in similar intervals and processed using similar routines and eventually stored in one data base. The recent advancements in cloud computing and data storage might accelerate the development of "smart monitoring networks" in future.

Towards a region of excellence

In the Baltic Flows region significant expertise and experience exists in all WQM and management related fields. Authorities and research organizations benefit from well-established monitoring programs and often work hand-in-hand. Driven by legal requirements and research and economic interests, RDI activities constantly strive to develop new methods and technologies for WQM. Official monitoring programs are complemented by involving the public through citizen science campaigns. The current need to reduce monitoring costs is a challenge for labor and cost-intensive long-term monitoring. However, the project region has the potential to turn this into an opportunity to foster the development of low-cost solutions for which a global demand exists.

The official monitoring programs in the project region are regulated through the EU Water Framework Directive (WFD) and HELCOM but the implementation of these regulations remains heterogeneous. This is an obstacle for authorities to exchange data and to establish integrated monitoring campaigns. For companies it hinders the marketing of WQM services and products. Therefore the harmonization of data collection and data bases should be of highest priority. Yet, through the interaction between authorities, research and education, and companies (the *triple-helix*) innovative WQM concepts and technologies are developed at a high rate. The triple-helix approach is supported by tailored education programs that provide young professional with excellent technological, problem-solving and innovation skills in international environments. From the region's expertise in policy making, RDI and education stems a large mentoring potential for other regions which are in need to build WQM frameworks and networks.

A demand for innovative, low-cost WQM solutions exists virtually globally and the region fulfils all prerequisites to serve this market. In the Baltic Flows countries, existing excellence in other technology fields such as ICT, smart cities, alternative energy harvesting or arctic technologies are utilized to drive innovations in WQM. Experts in the Baltic Flows countries are able to design monitoring programs and the required technologies for different challenging environmental conditions. This knowhow could serve markets in both, the developing world and industrialized countries.

Conclusion

Water quality and diffuse load monitoring in the Baltic Flows countries is on a globally competitive level. Existing regulations and policies provide a good base for comprehensive monitoring though there is potential for improvements concerning the implementation of these regulations. A global demand exists for low-cost, automated monitoring technologies. From a technological point of view it would therefore be desirable that the regional and EU regulations would liberate the use of innovative, automated monitoring techniques. This could improve the existing EU WQM monitoring infrastructure on the one hand, and foster commercial developments in the project region on the other.

To make better use of the generated data and to foster international collaboration, common data collection, processing and storage standards should be developed. Ultimately, WQM data should be available to at least authorities and environmental and research organizations through one data base. Despite existing bottlenecks in current WQM regulations, practices and technologies, the Baltic Flows project clearly showed that its participating countries have an outstanding experience and expertise in WQM related research, education, technology development and policy making. One of the regional strength is the active collaboration between these different stakeholders that creates an enabling and creative environment for innovation. The Baltic Flows project helped to strengthen these collaborations and to harmonize WQM activities among the project countries. The project demonstrated that the creation of local clusters may provide support for SMEs to capitalize their expertise by building international networks with other companies and customers. Further, the project showed that pooling of expertise in WQM and close technologies as ICT, medical diagnostics or energy harvesting technologies, have the potential to boost globally desired low-cost, online WQM technologies.

Given that sufficient funding for projects like Baltic Flows is available, the region may develop to a global leader in developing low-cost in-situ monitoring solutions and programs that build upon

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these technologies. Through the integration of proven citizen science activities and smart integration of other environmental data WQM could be taken to a new level.

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1. Introduction to diffuse load monitoring practices in Baltic Sea countries

In the Baltic Sea countries where most of the point sources of pollution have been taken into control, the significance of controlling diffuse loading is growing. However, while the need for accurate and timely data is growing, the resources available for monitoring are decreasing to the point where the sampling schemes and analyses are so reduced that they fail to produce representative data.

This chapter presents the practices Baltic Sea countries currently use to get data on sources and amounts of diffuse loading. It discusses the strengths and weaknesses of both traditional sampling schemes and novel automated monitoring stations. What is the best way of producing meaningful knowledge on sources and amounts of diffuse loading?

The concept of diffuse loading, as opposed to point source loading, is used to describe loading from agricultural activities, managed forest areas, scattered settlements and stormwater flows. The significance of diffuse loading in the protection of the Baltic Sea has increased since the loading from point sources was gradually reduced. According to HELCOM (2015b), the direct point source inputs of nitrogen and phosphorus have decreased by 43% and 63%, respectively, from 1994 to 2010, whereas e.g. the share of agricultural phosphorus loading is almost half of the total waterborne inputs to the sea. Still the diffuse pollution has a significant affect to 90% of river basin districts and 50% of surface water bodies. The European directorate of Environment named diffuse loading and hydromorphological alterations as the most important reasons for the non-accomplishment of Water Framework Directive (WFD) 2015 goals. (European Commission 9.3.2015) Detailed information on the sources and magnitude of diffuse loading as well as the impacts of different control measures is needed in order to target and design the most efficient water protection measures.

> *"The significance of diffuse loading in the protection of the Baltic Sea has increased since the loading from point sources has gradually reduced."*

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Diffuse loading is by definition something, which cannot be measured directly from the end of a discharge pipe. Most of the diffuse loading is generated during high runoff events that leach and carry nutrients and solids into the waterbodies. The quantity and quality of diffuse loading varies from site to site and is strongly dependent on weather conditions. In addition, the complex interrelations between various factors affecting the loading cannot always be established with certainty. Thus, in order to produce realistic monitoring data, the temporal and spatial coverage of observations should be extensive.

The water quality monitoring authorities, programs and methods

Water quality monitoring surface waters is most commonly based on manual grab sampling and laboratory analyses which are carried out according to a previously agreed monitoring program. An example of the structure of the water district based monitoring programs is presented in Figure 1. The responsible actors in different implementation and planning levels of the monitoring programs in participating countries are presented in Table 1. However, national legislation and EU directives set out the obligations and framework for the design and implementation of water quality monitoring (WQM) and assessment in practice.

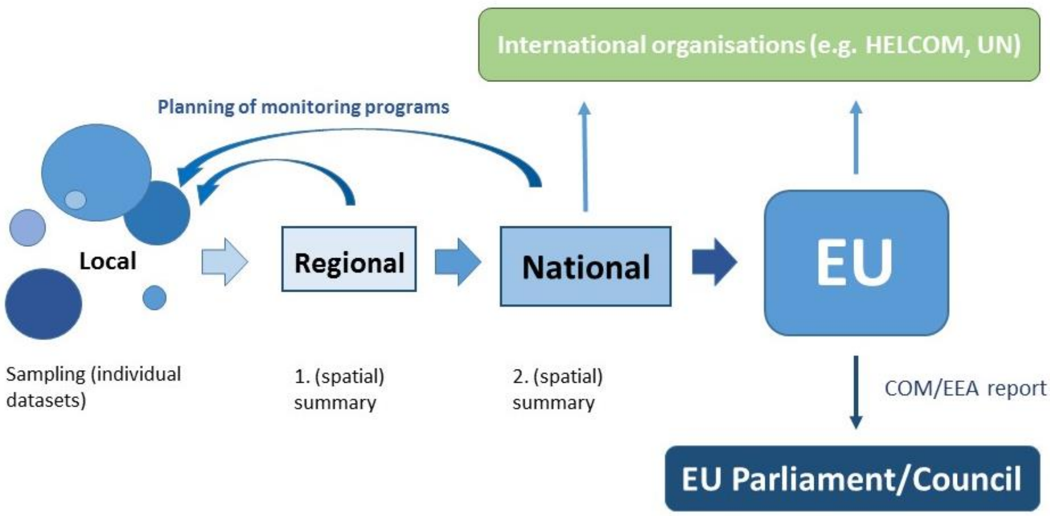

***Figure 1**. The General process of monitoring and reporting in EU. (European Commission 2016e)*

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Table 1. The organizations responsible for water quality monitoring in the Baltic Flows project countries.

Country	Reporting to EU	National level monitoring	Regional monitoring (based on river basin management plans)	Planning of monitoring programs
Finland	Finnish Environmental Institute (SYKE)	Finnish Environmental Institute (SYKE)	ELY- Centres (regional authority)	ELY- Centres (regional authority)
Estonia	the Ministry of Environment & the Estonian Environment Agency	the Estonian Environment Agency	the Environmental Board (6 regions) & Estonian Environment Agency	Estonian Environment Agency
Germany (state of Hamburg)	Freie und Hansestadt Hamburg , Behörde für Umwelt und Energie, NeueNfelder Strasse 19. 21109 Hamburg	Bundesmimisterium für Umwelt, Naturschutz, Reaktorsicherheit und Bauwesen	Member States of the Flussgebietsgemeinschaft Elbe	Member States of the Flussgebietsgemeinschaft Elbe
Latvia	Latvian Environment, Geology and Meteorology Centre (state Ltd.)	Latvian Environment, Geology and Meteorology Centre (state Ltd.)	Latvian Environment, Geology and Meteorology Centre (state Ltd.) & Latvian Institute of Aquatic Ecology and the Latvian University of Agriculture	Latvian Environment, Geology and Meteorology Centre (state Ltd.)
Sweden	the Swedish Agency for Marine and Water Management	the Swedish Agency for Marine and Water Management & Swedish University of Agricultural Sciences	County Administrative Boards of respective county & Swedish University of Agricultural Sciences	Regional water authority

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The analyzed parameters taken from water samples vary between monitoring stations, but typically include nitrogen, phosphorus and suspended solids and/or total organic carbon. In addition, metals are analyzed in numerous stations. The sampling frequency varies from 1 to 24 samples per year. Samples are generally taken at predetermined times during the year, although some additional samplings may be taken at certain flow conditions.

When planning a monitoring program, following aspects should be taken into consideration:

- the selection of appropriate parameters and their monitoring accuracy
- the selection of a representative location
- data reliability
- requirements set by legislation and reporting > selection of methods

While water quality is monitored through grab samples, the flow quantity is commonly monitored with an automated device that measures the flow quantity usually on a daily basis, or even more frequently. The data from grab samples are combined with flow data in order to create an estimation of annual loads. The information provided by continuous hydrological monitoring is ideally used in combination with (flow-proportional) sampling to make assessments of total diffuse loading. A rating curve can be determined when average water velocities and the cross-sectional area of the stream are measured in several discharge conditions. The total discharge may be determined when this data is combined together with the data from the continuous level recording device located at the rated cross-section. More precise assessments of total loading are feasible together with water samples taken in different flow conditions. Use of event-driven (e.g. time, water level, concentration threshold) sampling has increased in recent years. Together with water quality and/or quantity sensors it is possible to take samples automatically by using automated water samplers, triggered by specified thresholds. These samples can be taken as individual samples or as one collective sample, for example for a certain period of time.

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It should be noted that monitoring stations cover only a part of the rivers and load estimations for unmonitored areas are usually done by using modelled data. This applies especially to Finland and Sweden which have large numbers of lakes and rivers. In Finland, for example, 172 stations are operated in the official diffuse loading monitoring program that will be reported for WFD in 2016. 77 of these stations are located in rivers and streams. The total number of all reported surface water monitoring stations is around 3600. Though the number of monitoring stations is large, only a fraction of all water bodies is covered. Additionally, variations in sampling intervals exist. The current situation and future monitoring plans in the Baltic Flows participating countries are discussed below.

Successful WQM by traditional grab sampling consists of many stages starting from the planning phase and ending with the implementation of measures. Figure 2 presents the different stages of the research activities related to traditional monitoring (blue) and continuous monitoring activities (green) and how they differ from traditional sampling. The successful implementation of monitoring programs starts from planning and definition of used methods, monitoring location, and parameters of interest. These considerations are essential regarding the later implementation and costs and to be assessed for traditional sampling and continuous monitoring (step 1). The determination of appropriate sampling procedures and training of field personnel are essential for the data collection and in the representativeness of samples. An unsuccessful, contaminated or unrepresentative sample invalidates all other efforts and costs allotted to the monitoring activities (steps 1 to 3). The responsibility regarding the execution of steps 2 to 7 (Figure 2) has been divided between different organizations in the Baltic Sea countries. For example, in Finland the activities are carried out by an independent laboratory, chosen by the regional environmental center through competitive bidding, whereas in Sweden, the Swedish University of Agricultural Sciences (SLU) has been commissioned by the government to carry out the monitoring and assessment of waterbodies. Despite this national variation, all responsible laboratories share the requirement for quality assurance systems and must, in addition, use validated methods and preferably measure only officially accredited parameters.

Both quality control and data processing are essential and this work is usually done manually (step 5). In addition, the collected information needs to be entered into a database prior to utilization

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(manually or automatically), which demands data transfer and extra data processing. Moreover, the collected information should be reviewed and reported to use it effectively for planning, policy making and implementation of water protection measures (steps 6 to 8).

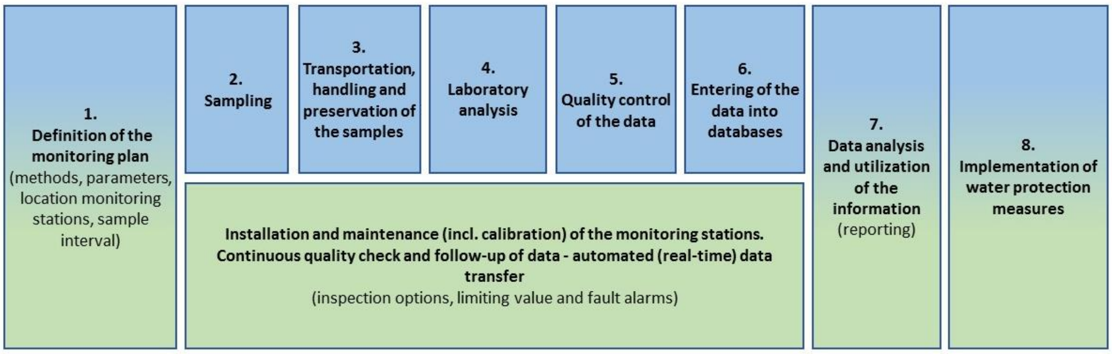

***Figure 2**. Stages of traditional monitoring (blue) and activities related to continuous monitoring (green).*

A reliable data collection, handling, and reporting system that is organised into an information system on the national level, is an important tool. It should reflect the priorities and societal demands of public and environmental authorities, as well as public interest. It gives up-to-date information to water specialists and authorities, enabling a better understanding and more consistent decisions in water management. Further, it should provide water quality information to the public.

Each Baltic Flows country (Finland, Sweden Germany, Estonia and Latvia) has several databases for authorities and research and the public. Access to these databases varies, but in future more and more data will follow an open data policy. Currently some databases are open to public, but require registration. Some databases are restricted to scientific or official use.

Grab sampling vs. continuous monitoring stations

Traditional sampling is labor-intensive and therefore time-consuming and expensive. Consequently, sampling may not be implemented comprehensively enough to obtain sufficient information of the spatial and temporal changes in water quality (Figure 3). Therefore, special attention needs to be given to the selection of sampling sites and timing of the sampling to improve the

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reliability and to account for natural variability. Sampling stations are typically chosen to represent the observed water body and regional and temporal variations. Nevertheless it is challenging to get representative data on the total loading if rapid changes in run-off occur, which might comprise a significant share of the total annual loading. Rapid changes in run-off typically occurs in smaller catchment areas during heavy rain events and snowmelt. In agricultural areas these events can cause heavy erosion that inflicts run-off of solids and nutrients to the water bodies. Some of the challenges, strengths, possibilities and weaknesses in the use of continuous monitoring are presented in Figure 4. Currently available and emerging water quality sensors and solutions are presented in detail in Chapter 4. There, also the potential and shortcomings of state-of-the-art solutions are discussed.

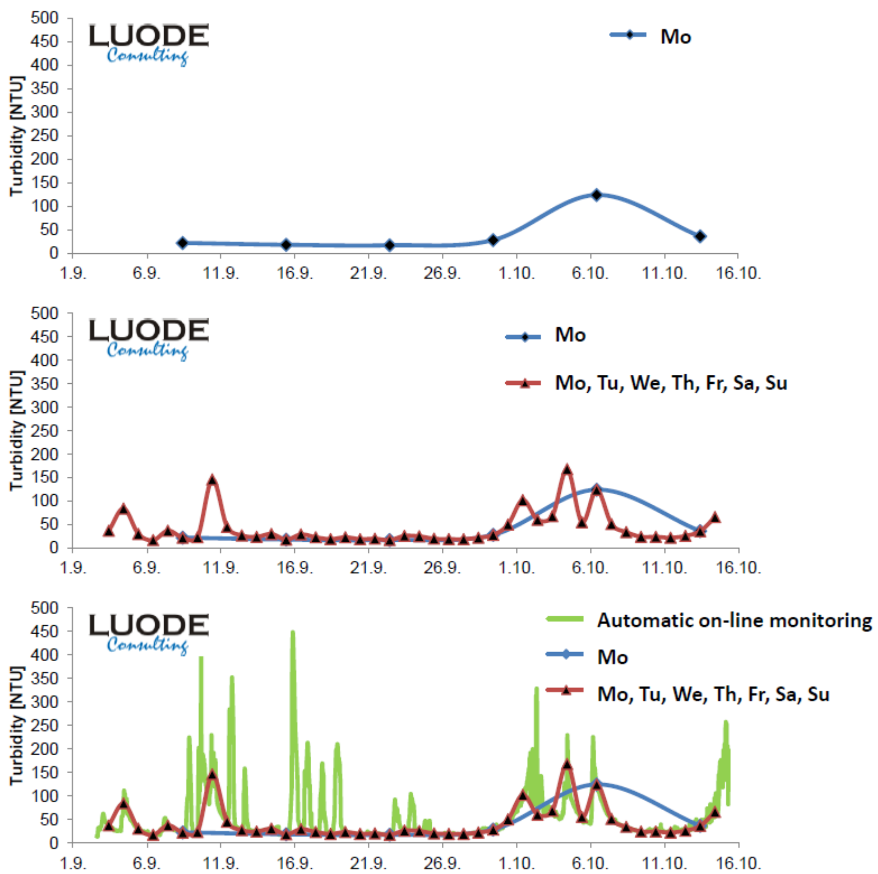

***Figure 3**. Comparison between river turbidity results of grab samples taken once a week (blue), once a day (red) and continuous monitoring (green). Figure illustrates the importance of sample interval in order to detect rapid changes in water quality. (Figure: Luode Consulting Ltd.*

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Despite their various drawbacks, traditional sampling methods have their advantages. In Finland, for example, diffuse loading has been monitored following the environmental authorities' uniform instructions since the 1960s'. This has produced long, consistent data series, which can be used to assess long-term trends in water quality and causes and consequences changes. Long-term data series are also needed for developing and validating water quality models.

Another advantage of sampling-based methods is that the exact concentration of virtually any parameter or compound of interest can be analyzed and a variety of well-proven, certified analysis methods are available for different parameters.

Basic methods used in water quality monitoring

- Grab sampling & laboratory analyses
- Continuous/online monitoring by using modern sensors/probes
- In-situ/discrete sampling by using modern sensors/probes
- Event driven sampling (flow or time proportional) – automated or manual
- Remote-sensing

Long-term grab sampling based data series could be complemented in future by state-of-the-art automatic continuous water monitoring technologies. Such technologies allow to monitor diffuse loads in high-resolution and minimize the risk to miss singular discharge events. These technologies may, e.g., be used to detect water discharges and accidents, or to differentiate between abnormal changes and natural variations; they may provide information on the complex relationship between hydrologic systems and water quality (Wang 1999).

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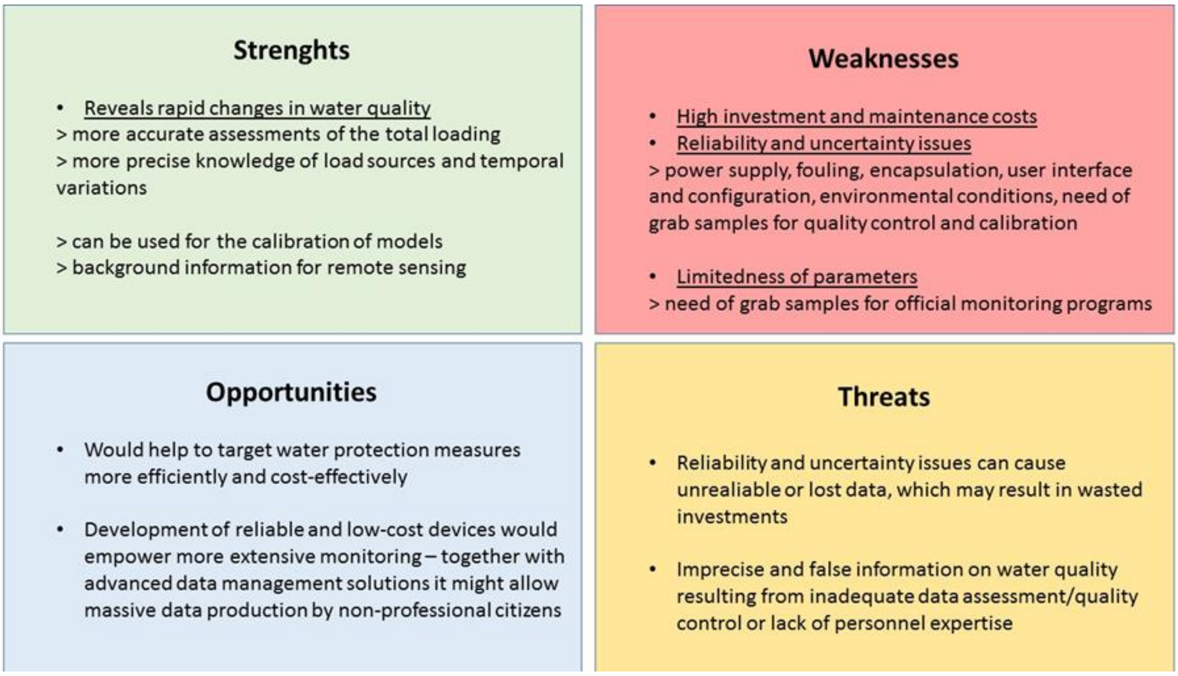

Figure 4. *SWOT analysis of continuous monitoring*

Current situation and future plans of monitoring programmes in the Baltic Flows project area

In Baltic Flows project area the WQ and diffuse load monitoring programs are part of the Water Framework Directive's (WFD) implementation and complies with the reporting requirements by the Nitrates Directive. The WFD and Nitrate Directive requirements are discussed in detail in chapter 3 and the monitoring methods above. Following chapter describes the situation and future plans of national monitoring programs in Baltic Flows project area (Finland, Sweden, Latvia, Estonia and Germany). It also presents the situation of River Basin Management Plans (RBMP) that have just been under revision.

Finland

In Finland, the environmental authorities’ launched the current diffuse load monitoring program in 2007. Presently, the monitoring is largely based on grab sampling. The sample interval and analysed parameters vary depending on location and the type of the waterbody. Typically, samples are taken

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1-12 times/year, depending on weather and flow conditions. In addition to grab sample-monitoring stations, few continuous WQM stations exist in agricultural catchment areas. In total there are over 3600 monitoring stations that are reported for the WFD. 172 of these stations belong to the official diffuse load monitoring program (77 stations located in rivers and streams). In Southwest Finland there are 11 diffuse load monitoring stations operated by environmental authorities. (SYKE/Vesikeskus 2016)

The Finnish government endorsed the river basin management plans for 2016-2021 in December 2015. Finland has 8 river basin districts, two of which are shared with Sweden and Norway. The Åland Islands district has its own legislation and implementation due to its self-governing position. (European Commission 2016b) According to the Southwest Finland Centre for Economic Development, Transport and the Environment (ELY Centre) and The Finnish Environment Institute (SYKE), Finland will have to cut 20 % of the WQM-related costs (sampling and laboratory analyses) in 2016 (Suomela 11.12.2015, Tattari 9.2.2016) In the European Commission's (EC) communication report (9.3.2015) Finland's situation was considered good in terms of development of methods and monitoring networks and the assessment of the ecological status (European Commission 2015a).

In order to reach the cost reductions, the sampling and laboratory analysis were outsourced. A competitive tendering for laboratories was organised in 2015. In addition, it is planned to reduce the number of monitoring stations and frequency of sampling. However, river monitoring, e.g. required in the HELCOM framework, will not be affected by the reductions. Also monitoring that is obligated by the European Environmental Agency (EEA) is not effected. (Tattari 9.2.2016).

Even though there is pressure for cost reduction, the long-term aim is to increase the number of continuous monitoring stations. Automated water quality sensors have been used in Finland since early 2000s mostly in research projects by universities and research institutes, but in recent years their use for supporting traditional sampling in authoritative monitoring has increased. Currently, the Finnish environmental authorities have 50-70 continuous water quality monitoring sensors or probes in use. (Linjama 17.4.2014) Further, the environmental authorities have produced reports and brochures which present instructions and cost factors that need to be taken into account when implementing continuous monitoring and acquiring devices (Tattari, Koskiaho & Tarvainen 2015,

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Tarvainen, Kotilainen & Suomela 2015). The role of the continuous monitoring will increase especially in the monitoring of mining industries and diffuse load in order to assess discharges and total loading more accurately. At present, especially the costs and lack of parameters limit the wider use of continuous measurement devices. In Finland the total cost for one continuous monitoring station is around 10 000-20 000 euros (including sensors, data logging and other appurtenances needed) Approximate annual cost for maintenance and data surveillance is 5000€. (Tattari, Koskiaho & Tarvainen 2015, Lindfors 17.3.2016)

Sweden

In Sweden the diffuse load monitoring program of the environmental authorities began in the mid-1970´s. Currently, 21 catchments are used for assessment of impacts of agriculture on surface and drainage water quality:

- 8 national catchments with flow-proportional composite water sampling and annual field management inventory, etc.
- 13 regional catchments with water discharge measurements and bi-weekly grab sampling

Also in Sweden the number of monitoring stations that is reported to the EU is large due to the number of waterbodies. Currently, there are around 12 000 monitoring stations with about 6000 being located in rivers and streams. In Sweden the annual cost per monitoring station is approx. 3500-4500€ including personnel, travel and laboratory costs. The total costs largely depend on the number of monitored parameters and the sample interval. (Fölster, personal communication 2016, Denward, Måns personal communication 13.4.2016 2016) Monitoring of inland water is predominantly done by taking monthly grab samples or by biweekly flow-proportional sampling especially in small agricultural streams. The typically sampling interval is 1-12 samples/year. The Swedish University of Agriculture is responsible of data processing and analyses of the water quality data. Presently continuous monitoring devices are mainly used for water level and flow measurements. In addition, there are a few continuous water quality monitoring stations equipped with turbidity sensors or multiparameter probes, but they are not yet used in larger scale. According to Fölster (2014) the price and need for maintenance and data surveillance are the biggest bottlenecks for the utilization of continuous water quality monitoring devices in Sweden. As in Finland, in Sweden water

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quality has been monitored with similar methods for many years resulting in long time series of water quality data. Transition to new methods, e.g. automated sampling, would complicate the comparison of the data.

The Environmental Protection Agency, the Swedish Agency for Marine and Water Management and the Geological Survey of Sweden have the overall responsibility for coordinating national and regional monitoring of waters in Sweden. The Swedish Agency for Marine and Water Management is responsible for the reporting to the EU. However, it is the five water authorities, who are responsible for developing monitoring programs that follow the WFD and the Water Regulation. These five water authorities also monitor the implementation. The national freshwater programme was heavily audited in 2007, in order to better fulfil the demands set by the EU WFD. Presently, the water authorities are in the process of revising the environmental monitoring programs to address the criticism voiced by the EU Commission regarding the present environmental monitoring programs. Yet, the second river basin management plan for Sweden's 5 river basin districts have not been adopted. Online monitoring may be part of the revision. (European Commission 2016d)

The EU commission's main criticism and comments concerned risk assessment, which is not implemented in the monitoring plans. Further the EC criticized that the monitoring is not sufficient regarding biological quality elements. In future, the monitoring will be more focused on risk assessment. As in Finland, the water bodies are also going to be grouped. (European Commission 2015a)

Estonia

In Estonia the investigative monitoring of surface waters started in early 1970s. The first national routine monitoring programme for agricultural rivers was initiated in the mid-1990s. This monitoring network consisted of continuous flow rate measurements and flow-proportional sampling in two catchment areas. Additionally, three more watercourses were included to the monitoring program in 2002. The Department of Environmental Engineering of the Technical University of Tallinn (TUT) was responsible for the monitoring of these agricultural stations until 2015. Currently there are 63 monitoring stations that belong to the national environmental monitoring program, yet just 6 of them represent areas with agricultural land use. The monitoring is mostly based on grab samples taken on monthly basis. In addition flow-proportional sampling was used especially in 2 small

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agricultural catchments. Continuous monitoring devices are used just for the hydrological measurements (58 stations). Water quality monitoring sensors have been used mostly in research projects by universities and research institutes.

In Estonia, an update of the river basing management plans for the 3 river basin districts (2 international) has been drawn up in January 2016 for the period 2016-2021. One of priorities is stormwater pollution load investigation as well specification of required measures to minimise stormwater impact. There are also plans to increase the role of public involvement. Further, an automatic online stormwater monitoring program for the Tallinn Bay is currently under preparation. Development of water quality sensors, with regard to continuous water monitoring in addition to grab sampling is planned. The EC has stated that Estonia needs to improve the consistency of impact and pressure analyses, as well as the assessment of methods and monitoring for rivers and lakes. (European Commission 2015a, European Commission 2016a)

Latvia

In Latvia diffuse load monitoring in rivers started in 1970s' and has been reported to HELCOM (PLC) since late 1980'. Currently, Latvia has 35 monitoring stations that belong to the national diffuse loading monitoring programme. Intensive monitoring (12 samples/year) is carried out at 13 stations. In other cases samples are taken at least once a year. Also one continuous water quality monitoring station is included in the network. Additionally there are 76 continuous discharge monitoring stations that enable to register high flow conditions and run-off peaks. Grab samples are usually taken more often during run-off peaks. Continuous automated water quality monitoring stations are operational since 1996 in the Daugava river. In 2014, the station was equipped with a modern multiparameter probe that provides more detailed information on changes in water quality. Additionally, few continuous water quality monitoring devices have been used by universities in research projects.

At the end of 2015 River basin management plans (2016-2021) for four river basin districts (Daugava, Lielupe, Gauja, Venta) were adopted. The authorities plan to carry out monitoring in accordance with the approved network of monitoring stations. The planning also includes development of national legislation and awareness raising campaigns for different target groups, including in the agriculture sector, the local municipal sector and different educational activities for the public in

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general. European Commission has stated that Latvia should improve the assessment methods for surface water during next reporting period of the WFD. Especially the analyses of pressures and impacts was considered insufficient in the first river basin management plans. (European Commission. 2016, European Commission 2015a)

While the monitoring plans do not include specific targets for creating a separate online monitoring system, there are efforts to involve different groups of society to get feedback on different issues related to the implementation of the plans. The monitoring plans are focused on the main activities that need to be implemented by 2021, and the engagement of stakeholders is described in general. (European Commission 2016a)

Many of the activities related to online monitoring depend on the availability of financial resources for the implementation of the respective task. Since the financial resources for the described tasks are limited, the plan outlines the overall objective of involving different target groups in the online monitoring activities, and defines the minimum required outcome of the online monitoring. At the same time, the plans includes the opportunity for NGOs and other stakeholders to contribute with additional resources to the implementation of the plan.

Germany

The second River Basin Management plans for Germany were adopted in December 2015 for the 10 river basin districts (6 international). The process was carried out mainly on the Federal State level, because the state level authorities are responsible to carry out monitoring in their region. (European Commission 2016c) Nowadays the implementation of the monitoring is strongly guided by WFD, but still some regional differences exist in practice which has caused difficulties order to fulfill the WFD objectives. This paragraph mainly introduces the current situation and practices in the state of Hamburg. In Germany monitoring is divided to three forms: surveillance, operational, and investigative monitoring. Surveillance monitoring is intended to estimate the status of the catchments based on the river basin management plans. In total there are around 400 monitoring stations that belong to the surveillance monitoring network. In surveillance monitoring stations all quality elements required for WFD are monitored. Additionally, there are about 7800 operational and 400 investigative monitoring stations. Depending on the location, samples are taken 1-12 times /year and at least once in every three years. Also continuous monitoring is being used.

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The amount of nutrient inputs were reduced significantly in Germany during the past decades. Currently, loads sourcing from agriculture and municipal wastewater treatment plants are the major cause of nutrient loading. Nutrients are monitored in about 250 monitoring stations that are used for the ecological classification of water bodies. (Arle 2013, Bartel 2010)

The region of Hamburg maintains a large monitoring program, which is largely based on network of automated (continuous) monitoring stations that provide real time data concerning water quality. There are long expertise and experience of development and use of automated continuous monitoring devices in the region. Automated stations are used for the monitoring of parameters such as oxygen, pH, conductivity, turbidity, chlorophyll and algae pigments. The Institut für Hygiene und Umwelt (IHU) maintains nine monitoring station installed along the rivers of Hamburg. In total there are 26 monitoring stations in the region that are reported to the EU.

The European commission has stated that the harmonization of monitoring methods should be improved in Germany at national level. Further, Germany should enhance the monitoring of nutrients - currently the assessment of agriculture (diffuse loading) is insufficient. With to respect to assessment improvements also the standards for nutrient levels should be revised to be consisted with the biological requirements (European Commission 2015a).

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2. Diffuse load monitoring on global scale

In the EU water quality monitoring is largely regulated by the WFD and still differences in applied practices exist among the member countries. On global scale, water quality monitoring is even more diverse, ranging from development and application of cutting edge technologies and methods to virtually being non-existent. This chapter provides examples from different parts of the world to rank the Baltic Flows countries' effort and competences in water quality monitoring on a global scale. It shall also provide an overview on which expertise the Baltic Flows countries can provide to the rest of the world.

Diffuse load monitoring in the European Union

The methodology and legislation behind the implementation of surface water quality monitoring in the EU is presented in Chapters 1 and 3. Within EU diffuse loading is an important issue. According to a recent report 90 % of the river basin districts are significantly affected by diffuse loading and agriculture has been identified as main source of diffuse pollution. (European Commission 2015a)

In 2009, around 57 00 stations for the WFD monitoring of surface waters existed in EU member states. The highest numbers of monitoring stations are counted in the United Kingdom (12 807 stations), Italy (8311 stations) and Germany (6688 stations). Calculating the ratio between the number of stations and the land area reveals a large variation between the member states. In the UK there are around 52 stations/1000km^2, while in the Nordic countries the number is 5 or less stations/1000km^2. This variation is largely explained by the differences in population densities, water use and natural characteristics. There are also different concepts in the design of monitoring programs between member states and even regions, which influence the number of monitoring stations. Based on the EC report to the European Parliament and Council (2009) the monitoring is generally implemented well across the EU. For the last reporting over 107 000 stations were reported (75% in rivers). Though the Commission wishes some of the member states to improve their monitoring concepts for the WFD. (European Commission 2009)

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United States – pioneer in the use of modern water quality monitoring devices and data management

> *"USGS has over 7000 continuous monitoring stations nationwide for surface and groundwater level and quality monitoring of which 1300 provide real-time water quality data."*

Water quality monitoring frameworks and technologies are among the most advanced in the world. The WQM in the USA is largely regulated, organized, and maintained by the Environmental Protection Agency (EPA), the United States Geological Survey (USGS), and regional authorities. The ESA monitors industrial and waste water, the USGS, among others, the diffuse loads in rivers. The national diffuse load monitoring is further managed through 10 regional coordinators and complemented by state-specific programs. Diffuse loads from agriculture have been identified as single most important causes of surface water contamination and wetland impairments. In order to combat the negative impacts of agriculture, the National Water Quality Initiative (NWQI) was established in 2012.(EPA 2016b, EPA 2015)

> **USGS databases provide water quality data**
>
> - grab sample results and time series from 1,5 million sites across the country – 5 million samples
> - diffuse load results and estimates from 102 rivers and streams
> - Real-time data every 5 to 60 minutes
>
> (United States Geological Service 2015)

Diffuse load monitoring is performed through a dense network of traditional and real-time monitoring stations. Online real-time data on diffuse loads in rivers is available through 1300 USGS stations and complemented by more than 5500 offline continuous monitoring stations across the country. Additionally, time-series based on grab samples are available for 1.5 million sites (United States Geological Service 2015). The standard parameters recorded at monitoring sites include pH, conductivity, DO, temperature, turbidity, DOM, chlorophyll, blue-green algae and nitrate.

The EPA, in collaboration with local authorities and associations, does not only provide the legal framework and guideline for WQM but also has a dedicated "Advanced Monitoring Systems Center and Test and Evaluation Center" which tests and verifies WQ technologies. The EPA had and has

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projects that foster the development of innovative WQ monitoring solutions, e.g. through development of low-cost or higher accuracy sensors (EPA 2016a, EPA 2013). In the wakes of the governmental efforts in WQM, many of the leading WQM technology companies developed in the USA.

Diffuse load monitoring in the developing world

Thanks to water quality monitoring, waste water treatment and water purification technologies, provision of drinking water is ensured in the developed countries. Still actions are required to establish a good environmental status of surface and groundwaters in these countries. In contrast, quality of natural water bodies and drinking water, and availability of appropriate sanitation technologies remains poor in many developing counties countries (UNICEF, WHO 2016), a group to which most of the countries belong (UN 2015). Inadequate sanitation and polluted surface waters cause severe health problems and amplify problems in wellbeing as hunger and poverty that stem from climate-driven water scarcity in many countries. Due to the increasing water demand due to growing populations and need for irrigation in food production, water quality has become one of the major economic factors in developing countries.

> *"When planning the water use and management, water protection activities and the reduction of water pollution, functional and reliable water quality monitoring has a key role."*

Especially in the African countries the limited financial resources are invested in the control of point pollution sources and improved sanitation. The improvement of diffuse load and general water quality monitoring is also impeded by the lack of legal frameworks, technical expertise and education. The development of low-cost monitoring technologies for comprehensive WQM may be considered as a prerequisite for the establishment of WQM programs and large scale improvement of water quality and availability. Creation of technical infrastructure should be supported through import of knowhow and education in WQM. This need exists also in the developing countries of South and Latin America and Asia.

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Brazil – a driver for sustainable water and water quality management in South and Latin America?

Sanitation, water scarcity, diffuse pollution from agriculture and poor quality of available drinking water is also the major challenge in the South and Latin American countries (National Water Agency 2012, Clevelario, Junior. J. et al. 2005). These problems are amplified by uneven distribution of resources and population across the continent. Among the countries south of the USA, Brazil takes a leading role in the establishment of water quality monitoring frameworks, networks and education programs (National Water Agency 2012, UNEP 2014, Ortiz 2014). WQM activities in Brazil date back to the 1970s and comprise more than 3500 monitoring stations today which are operated by federal and state institutions and the National Water Agency (ANA). Due to problems in sanitation and sewage systems, the monitoring is still mostly focused on waste water treatment and drinking water production. However, also some diffuse load monitoring programs are being established. To overcome problems related to inconsistent datasets and uneven spatial and temporal resolution of monitoring networks, the National Water Quality Evaluation Program was established in 2010 (National Water Agency 2012).

> *"However due to problems in sanitation and sewage systems, monitoring is focused in urban areas and in addition the implementation and coverage is highly depending on social, economic and political conditions."*

The role of Brazil in fostering WQM in Latin America was boosted through the establishment of an interregional center for water quality monitoring by agreement between the ANA and The United Nations Environment Programme (UNEP) in 2014. The center's objective is to engage in capacity building, establishment of national water centers and in the dissemination of monitoring techniques and programs (Ortiz 2014, National Water Agency 2012, UNEP 2014). The biggest challenge for establishing a good WQM infrastructure and achieving a good environmental status of water bodies might originate from the very heterogeneous social, economic, and political conditions on the continent

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China – increasing environmental awareness boosts demand and progress of sensor development and monitoring practices

Though China has large water resources, it suffers from water scarcity due to its large population. Problems in water supply are affected by heterogeneity in climate and water availability, population and economic activities and severe pollution of all major river basins (UN WATER 2014, FAO 2014).

In response to the severe contamination of water resources, the Water Pollution Prevention and Control Law (WPPCL), covering groundwater and all surface waters including canals and reservoirs was enacted in 1984 and revisited in 2008. The law contains regulates pollution prevention and standards on water quality and discharges, including monitoring of point and diffuse sources and the establishment of WWT. The WPPCL induced the establishment of more sustainable management practises (China.org.cn 2014a, China.org.cn 2014b). Since 2008 monitoring of discharges in obligatory and companies might be charged a penalty of illegal discharges. The water management and monitoring is carried out by the Ministry of Water Resources and the Ministry of Environmental Protection and seven river basin agencies and Regional Supervision Centres.

Like in most developing and newly industrialized countries water quality monitoring in China is limited to point and drinking water sources. Water quality in rivers is usually monitored only in urban areas, lake estuaries and river mouths. In addition to traditional sampling, online continuous monitoring devices and portable or automatic early-warning systems are used for monitoring of point sources. The major point sources (quantity of waste water greater than 5,000 tons/day) are monitored with continuous automatic water quality and discharge monitoring and by traditional sampling and laboratory analysis. In addition to obligatory monitoring, supervisory monitoring is implemented 2-4 times per year.

> *"There is still a large demand for continuous water quality monitoring solutions"*

D Due to technological and economic development China has been adopting continuous monitoring technologies in recent years. The first continuous automatic WQM was setup in Tianjin 1988; today

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145 continuous WQM stations cover seven river basins and important lakes. The stations are networked and managed by the National Environment Monitoring Center (EMC) and its local EMC offices.

China is developing fast, but is still lacking expertise

- Large number of monitoring stations, rapid growth in recent years (14 000 new stations during 2012-2014) - need for expertise and new technologies
- Demand for security of drinking water resources → increased demand for continuous water monitoring solutions
- Disperse and poorly organized monitoring and data handling – methodological differences and problems caused by inadequate planning of monitoring programs

Though monitoring networks in China have with a reasonable coverage, a large demand for continuous WQM solutions exist. New water policies and environmental objectives set by the government, boost the Chinese environmental monitoring technology industry. However, China still lacks local research and development in WQM and has to import much of the key technologies.

WQM in India – a developing country benefiting from its global IT expertise

Water quality problems in India arise from its large, fast growing population, insufficient sanitation and uncontrolled discharges of industrial and agricultural waste waters. However, the WQ problem is recognized by the authorities and efforts are made to build comprehensive WQM networks and to improve the water quality. Since the first national water monitoring program (Global Environmental Monitoring System GEMS, Water Programme) was established in 1978, the number of WQM stations rose from 24 surface- and 11 groundwater stations to 870 in 2005. In 2012 already 2500 station were operational (Bhardwaj

"In 2014 the Central Pollution Control Board of India (CPCB) mandated in 17 most significant industries across river Ganga basin to install continuous online monitoring systems for monitoring pollution discharges of their effluents."

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2005, CPCB 2013). Surface water monitoring is based on the monthly assessment of approx. 28 different parameters (Centre for Science and Environment 2015, CPCB 2013). Yet, monitoring of diffuse loads from agriculture remains underrepresented in the monitoring scheme. However, since 2015 the Central Pollution Control Board of India requires that industrial discharges (including pH, turbidity, TSS, COD, BOD, ammonia and industry specific parameters) from the 17 most significant industries across the Ganga river basin are continuously monitored (CPCB 2014, Centre for Science and Environment 2015).

The development of WQM technologies and their implementation benefits from India's global strength in information and sensor technology and associated RDI activities.

Conclusion – diversity in diffuse load monitoring

On a global scale, diffuse load monitoring is available and implemented very heterogeneously. In most parts of the developed world WQM technologies and legal frameworks exists and the largest challenges are the integrated implementation and extension of measurement systems and the establishment or maintenance of a good environmental status of water bodies based on the monitoring efforts. In contrast, in the developing countries only sparse diffuse load monitoring networks exist, if at all.

The major global challenges in WQM and water management are very complex. In many countries fundamental WWT and sanitation infrastructure needs to established, followed by legal frameworks that regulate the sustainable use of water and minimize negative impacts from industries and agriculture. However, the later may only be successfully implemented if the living standards of developing countries allows for it. In order to monitor and improve water quality, new cost-efficient, easy-deployable technologies are required. Further, a high demand for knowhow and education export form the developed countries exist. Low-cost WQM technologies are also required in the developed world to establish comprehensive, smart WQM and early warning networks to improve the sustainable use of water resources.

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3. Policies and regulation

Regulation drives the monitoring programs by determining the aims, parameters and methods for monitoring. Even if the ideology behind the monitoring programs is to produce information for the purpose of water protection and act as a baseline for actions towards improved water quality, in practice, the national monitoring programs are rather planned so that they serve to accomplish the minimum reporting requirements of the directives. Thus, the regulation can either prevent or promote the smart development of monitoring programs. This chapter presents the current regulative framework and discusses how it could be developed to encourage countries to establish more innovative, representative and cost efficient monitoring programs which would eventually result in practical and sufficient water protection actions.

The chapter starts by presenting and discussing the current regulatory framework for water quality monitoring. It presents the monitoring requirements of those EU policies that are relevant concerning diffuse loading monitoring, namely The EU Water Framework Directive and the Nitrates Directive, as well as HELCOM requirements for diffuse load monitoring in the Baltic Sea catchment.

EU level regulation – Monitoring requirements of EUs Water Framework Directive and Nitrates Directive

The EU's Water Framework Directive (WFD) was adopted in 2000 to make European water policies and legislation more coherent and harmonized (European Commission (DG Environment) 2008). The WFDs article 8 sets aims for monitoring (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. 2000): "Member States shall ensure the establishment of programs for the monitoring of water status in order to establish a coherent and comprehensive overview of water status within each river basin district". The objective of the monitoring is to help to assess the status of the EU's water bodies within river basin districts.

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According to the European Environment Agency (EEA), monitoring information requirements should include (requirements for ground water has been omitted) (European Environment Agency 2008):

- Classification of the status of surface waters.
- Estimates of pollutant loads transferred across international boundaries or discharged into seas.
- Assessments of changes in the status of water bodies.
- Causes of water bodies failing to achieve environmental objectives.
- The magnitude and impacts of accidental pollution.
- The inter-calibration exercise.
- Compliance assessments with the standards and objectives of protected areas.
- A quantification of reference conditions (where they exist) for surface water bodies.

The Nitrates Directives purpose is to protect ground and surface waters from nitrates from agricultural sources (European Environment Agency 2008). The Article 5 (Council of the European Union 1991), states: "Member States shall draw up and implement suitable monitoring programmes to assess the effectiveness of action […]." Member States are required to monitor the nitrate content of both surface waters and ground waters.

The EU Member States have integrated EU water policies in their national legislation. Table 2 presents which national laws implement the WFD in participating countries.

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Table 2. National legislation implementing the EU Water Framework Directive.

Country	Laws that implement the Water Framework Directive
Latvia	Water Management Law (adopted 2002, last amendments 2015). In accordance with Cabinet of Ministers' Regulation No. 92 (adopted 2004) and Cabinet of Ministers Regulation No.174 - *Regulations on public water services and use* (adopted 22.03.2016). Requirements for the Monitoring of Surface Water, Groundwater and Protected Areas and the Development of Monitoring Programmes (amendments with Cabinet of Ministers' Regulation No.65 (2015))
Sweden	Act on Water Resources Management (2004:660)
Estonia	Water Act. Environmental Monitoring Act provides for the organisation of environmental monitoring.
Finland	Act on Water Resources Management (1299/2004), the Decree on River Basin Districts (1303/2004), the Decree on Water Resources Management (1040/2006) and the Decree on Hazardous and Harmful Substance on Aquatic Environment (1022/2006). The Environmental Protection Act and the Water Act have both been amended as necessary.
Germany	Water Resources Act (WHG) (31.7.2009) The Hamburg water act (HwaG) in the state of Hamburg

The need to decrease the costs of monitoring creates challenges concerning environmental information. The EC pointed out that already the currently available resources leave gaps in surface water monitoring performed by the Member States. According to the Communication from the Commission to the European Parliament and the Council (2015b), there are significant gaps in monitoring of the chemical status of surface waters. Due to these gaps, in 2012, the status of over 40 % of water bodies was unknown which impedes a baseline establishment. According to the Communication, the Commission states that the monitoring should be maintained and/or improved.

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The Commission's recommendation:

"Recommendation to Member States: Improve and expand monitoring and assessment tools to ensure a statistically robust and comprehensive picture of the status of the aquatic environment for the purpose of further planning."

Data gaps have also been recognised by the report on the implementation of the Nitrates Directive which states that some Member States have provided no or incomplete data on eutrophication of rivers and lakes. In addition, the report points out that the assessment of the trophic status of fresh surface waters varied widely. This concerned both the used parameters and methodologies used for the definition of trophic status classes. The data gaps where noticed also concerning the saline waters. However, the report concludes that regardless of the gaps, monitoring of water quality has improved due to increase of the total number of monitoring stations. (European Commission 4.10.2013)

Based on the evaluations of the WFD and Nitrates Directive implementation there seems to be a need to firstly harmonize methodology, measurements methods and parameters and secondly to produce more data.

According to the DG Environment Water Unit there are several reasons for gaps in information on water bodies. One of the reasons is that there have been problems with the methodology and implementation of water body classification. For example, water bodies may have been classified as insignificant (e.g. small size) or the monitoring has been insufficient. Additionally, the Member States lack resources for monitoring activities. Various different elements need to be monitored in numerous locations and this creates challenges. (Capitão Personal Communication 23.2.2016)

Errors in the classification methodology of water bodies could lead to an incorrect assessment of the water bodies' state. An incorrectly stated base line can result in the situations in which activities to improve the status of water bodies are insufficient or they are oriented towards wrong sectors of society. For instance, a wrong classification can prevent water bodies from achieving the "good ecological status" if the baseline has been set too low. Alternatively, the ecological status of the

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water body might be evaluated to good. An incorrect interpretation of the base line might also effect the selection of elements and parameters that are considered as important to be included into the monitoring programmes.

The DG Environment Water Unit expects that more information about water bodies will be available in near future. The situation and status of the EU's waters will be assessed during 2016 and 2017. The assessment and overview covering the whole EU is based on river management plans that are currently prepared by the Member States. The deadline for the Member States to submit the information is in March 2016. However, it is already foreseen that some states cannot keep the deadline. However, improvements of established monitoring networks have been made since the last WFD evaluation on 2012. Additionally, there are positive developments in the Member States to use electronic reporting systems. Increased use of electronic system allows the production of comprehensive information including maps and graphical presentations. (Capitão Personal Communication 23.2.2016). This will support information dissemination both for the authorities and the public.

The 3rd conference of the European Innovation Partnership on Water (EIP Water) (Leeuwarden, the Netherlands, February 2016), attended by more than 500 water experts, resulted in a declaration, that includes the following statement: "*We recommend insisting on joint approaches and harmonisation to enable a more rapid and widespread uptake of innovation, smart business models and integrated IT-based water solutions in rural and urban areas, aiming for a single European Union market that supports the uptake of water innovations*". The need for harmonisation of databases and data collection methods has also been expressed both by the EC and HELCOM monitoring programmes. The INSPIRE directive is an Europe-wide effort towards harmonisation and shared efficient use of environmental monitoring data.

The EU's WFD will be revised during the following years. 2015 was the end of the first management cycle (European Commission 2015b). The development and revision process of the WFD is starting with the assessment of river management plans. A first communication concerning the EU's waters status shall be published in the end of 2017. Then the need for the revision of the WFD is assessed and an economic analysis of EU water policies is prepared. The EC is currently in a process to open call for tenders for contracting a study on the economic benefits of the EU water policy and the

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costs of non-implementation. According to the European Commission (European Commission 2016e) the study "*aims at generating new and solid economic arguments to promote effective protection and efficient use of water resources for the well-being of European nature and citizens.*" However, it seems that online monitoring will not be included in the study (Capitão Personal Communication 23.2.2016).

The regulation concerning diffuse load monitoring methods

Concerning the monitoring methodology of chemical and physico-chemical elements, the WFD refers to laboratory analyses using applicable CEN/ISO standards. The Nitrates Directive refers to sampling methodology presented in COUNCIL DECISION of 12 December 1977 establishing a common procedure for the exchange of information on the quality of surface fresh water in the Community (77/795/EEC), as amended by Decision 86/574/EEC. For example, according to the COUNCIL DECISION's Annex III (1986), the reference method for nitrate measurements is molecular absorption spectrophotometry. Tables 3 and 4 present monitoring parameters required by the EU WFD and Nitrates Directive.

The real-time field measurements are not approved by the directives and member states using them in monitoring additionally have to perform all analyses using the grab sampling approach. However, technically it would be possible to use real-time automated equipment to monitor many of the chemical, physico-chemical and hydromorphological elements, such as oxygen, temperature, pH and nitrate. On the other hand, biological information for the classification of the ecological status of surface waters can only be obtained using traditional methods. (Tarvainen, Kotilainen & Suomela 2015)

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***Table 3**. Requirements set for monitoring of chemical and physico-chemical elements in Water Framework Directive.*

Chemical and physico-chemical elements for monitoring	**Monitoring frequencies**
Transparency (lakes, Transitional waters, coastal waters)	_
Thermal conditions	3 months
Oxygenation conditions	3 months
Salinity	3 months (2.)
Acidification status (rivers, lakes)	3 months (3.)
Nutrient conditions	3 months
Specific pollutants (1.)	1 – 3 months (4.)

1. Pollution by all priority substances identified as being discharged into the body of water
Pollution by other substances identified as being discharged in significant quantities into the body of water
2. in Rivers, lakes and transitional waters
3. in Rivers and lakes
4. Other pollutants 3 months and priority substances 1 month

***Table 4**. Requirements set for monitoring in the Nitrates Directive.*

Parameters	**Monitoring frequencies**
Nitrate concentration (surface waters)	At least monthly and more frequently during flood periods over a period of one year. To be repeated at least every four years (5.).
Review the eutrophic state of their fresh surface waters, estuarial and coastal waters	Every four years

5. except for those sampling stations where the nitrate concentration in all previous samples has been below 25 mg/1 and no new factor likely to increase the nitrate content has appeared, in which case the monitoring programme need be repeated only every eight years
6. Stipulated in COUNCIL DECISION of 12 December 1977 establishing a common procedure for the exchange of information on the quality of surface fresh water in the Community (77/795/EEC) (OJ L 334, 24.12.1977, p. 29) Annex III

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HELCOM recommendations for monitoring

HELCOM Monitoring and assessment strategy

HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, known as the Helsinki Convention. The contracting parties are Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. To reach the goal of protecting the marine environment of the Baltic Sea and to evaluate effects of protection actions, HELCOM collects a multitude of monitoring data. HELCOM has its own strategy for monitoring. According to HELCOM: "The Monitoring and Assessment Strategy sets out the basis for how the HELCOM Contracting Parties commit themselves to design and carry out their national monitoring programmes and work together to produce and update joint assessments." (HELCOM 2013)

From financial perspective, it is important that the monitoring and reporting practices are harmonized so that the monitoring activities and collected data support national needs and fulfil the EU's monitoring requirements. Harmonisation would also save currently scarce resources. This has been taken into account and according to the monitoring and assessment strategy (2013): *"It is designed to also enable production of data and information that can be used to fulfil other international requirements, in particular by those Contracting Parties that are also EU Member States in relation to:*

- *Marine Strategy Framework Directive (MSFD),*
- *Water Framework Directive (WFD),*
- *Habitats and Birds Directives,*
- *The EU Strategy for the Baltic Sea Region (EUSBSR), and*
- *EU Integrated Maritime Pol."*

The coverage of monitoring stations included in HELCOM monitoring programs is presented in Table 5 and the parameters and sampling frequencies are presented in Table 6.

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***Table 5**. Number of monitored rivers and percentage of their total coverage of the Baltic Sea catchment by country in 2006. Stations are sampled approx. 1-2 times/month. (HELCOM 2011)*

Country	Number of monitoring stations	% monitored of total catchment
Finland	30	89
Estonia	15	70
Germany	26	56
Latvia	8	78
Sweden	38	88
Russia	3	90
Denmark	38	35
Lithuania	3	73
Poland	12	92

***Table 6**. Parameters reported for HELCOM (Pollution Load Compilation) from diffuse sources and monitored rivers (table 2). (HELCOM 2006)*

	Parameter	Diffuse sources (discharging into inland surface water or directly to Baltic Sea)	Monitored rivers (see table above)	Note
Nutrients	total P	X	X	X =obligatory, V = voluntary
	PO_4		X	
	total N	X	X	
	NH_4		X	
	NO_2		X	can be monitored and reported as $NO_{2,3}$-N
	NO_3		X	can be monitored and reported as $NO_{2,3}$-N
Heavy metals	Hg		X	except for rivers where concentration are below detection limit
	Cd		X	except for rivers where concentration are below detection limit
	Zn		X	except for rivers where concentration are below detection limit
	Cu		X	except for rivers where concentration are below detection limit
	Pb		X	except for rivers where concentration are below detection limit
	Ni		V	except for rivers where concentration are below detection limit
	Cr		V	except for rivers where concentration are below detection limit
Other	Oil	X	X[1]	[1] Reported for the major assessments for the following rivers: Neva, Vistula, Nemunas, Daugava, Oder, Narva, Göta Älv, and at the largest oil refi nery in each Contracting Party using the analytical method EN-ISO 9377-2
	BOD_5[4]	X[2]	X[3]	[2]only in rivers discharging directly into the BS, [3]except for rivers where concentration are below detection limit
	TOC		V	
	Flow		X	

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The HELCOM monitoring and assessment strategy (2013) includes common principles and two of them takes stand on how monitoring should be performed:

- *collection* of data is based on agreed standards, guidelines and procedures to ensure comparability across the Baltic Sea Region
- it is recommended that sampling should be carried out using certified methods […].

In HELCOM's monitoring strategy it is recognized that, in relation to marine research, the need exists to: "encourage scientific co-operation for development and testing of new monitoring techniques, methods, sensors and devices and their integration with traditional ship-based data." In general, the strategy encourages countries to co-operate in monitoring. The strategy states that, for example, equipment used in online monitoring is expensive and suggests to share investments for equipment, maintenance and data. This could increase the cost-efficiency of monitoring. Sharing of responsibilities is seen also a way to improve reliability of the measurements. HELCOM suggests to use cross sectoral platforms to share data which would also improve data availability. For example institutes responsible for meteorological, oceanographic and environmental monitoring could share data platforms. A concrete example to increase monitoring efficiency is to use systems such as the Alg@line ferry-box network (HELCOM 2013). Alg@line is a part of the FerryBox Task Team, which is a community aiming for improved and shared data. The community's objective is to share information on fluctuating pelagic ecosystems that is generated by "ship-of-opportunity platforms" (SOOP). SOOP facilitates extensive automated sampling done on board on merchant ships and fer-ries. (Suomen ympäristökeskus 2015)

There are several monitoring guidelines that instruct Contracting Parties in monitoring activities: COMBINE Manual, Guidelines for Monitoring of Radioactive Substances, PLC Guidelines, Guidelines for Coastal Fish Monitoring and Guidelines for Seal Abundance Monitoring. Here we discuss briefly the one that concerns load monitoring in rivers: Pollution Load Compilation (PLC) guidelines.

According to the PLC guidelines the Waterborne Pollution Load Compilation is dealing with point and non-point pollution sources located within the catchment area of the Baltic Sea. Waterborne pollution compilations are conducted in two phases. Total waterborne loads of nutrients and haz-

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ardous substances are reported by the Contracting Parties to HELCOM annually. The gathered information is assessed and annual indicator reports are prepared. Additionally, every sixth year, *Comprehensive Waterborne Pollution Load Compilations* are prepared. These quantify waterborne discharges from point sources and losses from non-point sources. In addition, background losses into inland surface waters are quantified.

According to the PLC 6 guidelines, the objective of PLC-Water concerning the land based pollution to the Baltic Sea are (HELCOM 2016)

- to compile information on the waterborne inputs via rivers and direct discharges of important pollutants entering the Baltic Sea from different sources in the Baltic Sea catchment area on the basis of harmonized monitoring and modelling methods;
- to follow up the long-term changes in the pollution load from various sources through data normalization and trend analyses using standardized methodologies;
- to identify the main sources of pollution to the Baltic Sea in order to support prioritization of measures;
- to assess the overall effectiveness of measures taken to reduce the pollution inputs into the Baltic Sea catchment area;
- to assess the development of waterborne and airborne nutrient inputs from different countries to the different Baltic Sea sub-basins in order to evaluate the progress in fulfilling nutrient reduction targets of the Baltic Sea Action Plan and
- to provide pollution input information for the assessment of long-term changes and the state of the marine environment in the open sea and the coastal zones.

Monitoring methods in HELCOM PLC guidelines

The aim of HELCOM's PLC guidelines is to provide a framework for Contracting Parties for harmonized monitoring, quantification and reporting of waterborne inputs of nitrogen, phosphorous and specific heavy metals.

The flow measurements should be done according to the World Meteorological Organisation (WMO) *Guide to Hydrological Practices* (WMO 2008). In rivers without permanent hydrological monitoring stations, flow measurements should be done at least 12 times per year.

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Concerning the sampling strategy for water quality monitoring, the following instructions are given: "*The sampling strategy should be designed on the basis of historical records and cover the whole flow cycle (low, mean and high river flow). It is important to cover periods of expected high river flow, if continuous monitoring is not performed. It is known that a positive (but not necessarily linear) correlation between high flow and load input exists. This applies especially for substances transported with suspended solids, e.g. some nutrient species and heavy metals. Sampling should therefore be done at different high flow conditions. For all monitored rivers a minimum of 12 sample sets should be collected over a year in order to estimate the annual input load. The samples must not be collected at regular monthly intervals but at a frequency that appropriately reflects the expected river flow pattern"* (HELCOM 2015a). Further, pooled sampling strategies are recommended where it is expected that the water quality varies strongly over short periods of time.

Concerning estimations of diffuse nutrient loads the PLC guidelines recognize that there exists currently no generally agreed method and that "*in the absence of harmonized quantification procedures, the Contracting Parties should apply the most appropriate method/model to quantify losses from diffuse sources taking into account the relevant geological, topographical, soil type, climatological, land use and agricultural practices condition in their region*" (HELCOM 2015a).

Initiative for establishing the role and position of water quality monitoring innovations within EU water legislation – Proposal by EIP Water Action Group (AG100)

There is an apparent need to re-assess the role of latest monitoring technologies in producing water quality data required by the EU water directives. A group of experts have formed an initiative called EIP Water – Action Group (AG100) "RTWQM - Real Time Water Quality Monitoring" Action Group, which strives for the removal of regulatory and technological barriers that currently limit the use of innovative real-time monitoring technologies in official WQM programmes. According to a paper by the RTWQM-group, the challenge is that due to time consuming processes, legislation, i.e. water directives, always lag behind the latest technical developments. This might lead to a situation where legal frameworks can inhibit the use of new and cost-efficient technologies (Carpentier et al. 2015).

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The RTWQM-group conducted an online survey map among othe things the needs of water sector. According to the survey: "*70% of the answers point out that the current water sampling strategies stipulated in the water directives are not properly representing the real status of the water bodies and treatment processes. And this pattern is common for the 3 water sectors under analysis: water bodies protection, drinking water supply and wastewater treatment*." (RTWQM Action Group)

The group states that often compliance monitoring (for example for the EU Drinking Water Directive) requires specific parameters that need to be analysed in laboratories since no appropriate online monitoring technologies are currently available. However, supporting parameters (e.g. pH, conductivity, dissolved oxygen) which can indicate changes in water quality can be monitored online. While it is evident that all monitoring technologies should meet certain standards of reliability, precision and repeatability, the exact requirements may differ according to the purpose of monitoring. Examples include nitrate monitoring: "nitrate monitoring in the catchment is important in order to determine the required treatment capabilities, but the precision of these measurements does not have to be as high as for nitrate monitoring at the tap, nor does the detection limit have to be as low." The RTWQM -group suggests that requirements for monitoring technologies should be set according to their location and purpose (catchment – tap, early warning – compliance monitoring). This would allow for the application of new monitoring technologies where they are appropriate. (Carpentier et al. 2015)

The white paper further discusses how to determine the validity of novel monitoring technologies. The group suggests that this could be done via the EU Environmental Technology Verification Programme (ETV). This is a DG Environment's pilot program which offers an independent procedure for performance assessment of new technologies. Companies, such as sensor manufacturers, can join this program and showcase their technology which is then independently assessed. One of the advantages would be that ETV programme verification is valid in all Member States so manufactures do not have to prove their technology separately in each State. The group suggests that the requirements for monitoring methods in the EU water policies and directives should be expressed without endorsing precise methods, but rather by requiring the use of ETV certified technologies. Concept note concludes that the major barrier to online monitoring is the specification of compulsory laboratory analysis methods. (Carpentier et al. 2015).

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Conclusion – Towards enabling, enhancing and inspiring legislation in water quality monitoring

Europe needs regulations and policies that would drive the member countries towards monitoring program that would:

- provide a more realistic picture of diffuse loading considering large spatial and temporal variations
- produce data fit for use in planning of water protection measures, not only to serve the regulation and obligatory reporting
- be as cost efficient as possible
- make the full use of existing expertise in the region
- accelerate the development, uptake and marketing of new monitoring solutions and products

The current regulation relies on the assumption that the monitoring data is reliable, if the sampling and analysis of the sample have been performed using certified and standardized methods. However, a sample may be taken using certified methods, analysed in a certified laboratory using ISO standard methods and yet, it may give a false picture of the diffuse loading, if the temporal concentration variations are not considered. Actually, in order to get a realistic estimate of diffuse loading in a river, it is more important to get data on the magnitude of loading during different seasons and weather conditions than getting an exact and reliable analysis result of pollutant concentrations in monthly samples. Thus, rather than stating requirements for laboratory analysis methods, the regulation should be purpose-driven and require that the monitoring programme is designed so that it can provide a realistic picture of the diffuse loading in different conditions. Such a programme could include, for example, the continuous real-time monitoring of basic physical and/or chemical parameters, combined with laboratory analyses of samples taken during different seasons and weather conditions. One promising method would be event-driven sampling where automated water sampler is connected with the continuous monitoring devices and the water sampler will take samples “on event” activated by the values or thresholds of the continuous parameters.

The cost efficiency of monitoring could be increased by establishing relations between concentrations chemical pollutants and physical parameters that can be measured by using simple automated sensors. The number of laboratory analyses could be reduced for those parameters whose concentration relates directly to certain flow conditions. Further, the cost efficiency of monitoring could be improved by making full use of monitoring data produced by different research organisations. This could be achieved by requiring all EU funded research projects to enter their water monitoring data in a national open database in a predetermined format. This would also increase the dialogue between the universities and environmental authorities.

The shift of the regulation requirements from determination of methods and devices to smart design of monitoring programmes could enhance the development of new products and consulting services linked with customized design of monitoring strategy for different rivers, deployment, maintenance and data handling services of automated online monitoring stations and extraction and analysis of water quality data. Further, approving of real-time field sensors as alternative data collection method would speed-up the development of new, low-cost and robust measurement technologies that would allow the real-time in-situ monitoring of a variety of parameters.

The future of the EU's WFD is formed during the following years. It seems that the method-centred approach of the current Directive has allowed the member states to fulfil the minimum reporting requirements by analysing too few samples that fail to reveal the real water quality and loading in different situations. It would be important to change the parts concerning water quality monitoring so that they would drive the member states to produce more realistic water quality and loading knowledge that will enable realization of well targeted and cost efficient water protection measures.

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4. Monitoring technologies

The following chapter provides a brief overview of state-of-the-art monitoring technologies currently used for diffuse load monitoring. They cover sensor types, data recording, transmission and management solutions. The chapter concludes with the identification of the most relevant development needs and –potentials that emerge from the mismatch between established technologies and required or desired monitoring needs in the Baltic Sea region.

As illustrated in the previous chapter, there is a need for spatially comprehensive monitoring of diffuse loads in EU inland waters. Ideally such monitoring would comprise of a dense network of corresponding sensors, real-time data transmission and open access data. However, currently available sensors for diffuse load monitoring usually cost several 1000 Euros which is the most important factor precluding the establishment of dense sensor networks. This may be due to the fact that most sensors have been initially developed for, and are traditionally used for, sporadic in-situ field or oceanographic measurements. They usually fulfil high standards of precision and accuracy, often combined with deep water deployment capabilities. Though later developments added some long-term deployment and remote data access capabilities, available monitoring technologies still require regular on-site maintenance and the requirement for large investments remain. These limitations may be, besides the legislative framework, the most important reason for the practise to monitor diffuse loads in the Baltic Sea region by sporadic, discontinuous field measurements and laboratory analyses.

Sensor technology review

A variety of measurement technologies and devices exist for WQM. As WQM may refer to drinking water monitoring, point source or diffuse load monitoring a broad range of physical, chemical, and biological parameters are considered in WQM. Here, we focus on technologies for WQM parameters that have relevance in diffuse load monitoring in the EU (see Table 6, Chapter 3).

Traditional WQM devices have been designed for discontinuous point measurement and often suffer from high energy consumption and maintenance need when being deployed for longer periods of time. Yet, most devices today allow for both, in-situ and online measurements in combination

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with data logging and transmission systems. The latter is especially practical for monitoring rivers and streams where changes in water quality can be rapid and short-term. However, long-term continuous monitoring is characterized by particular requirements regarding the technical properties of the devices (e.g. power consumption and anti-fouling systems).These challenges are discussed below. Despite existing technical limitations as durability and accuracy of devises or lack of reliable methods for the in-situ measurement of important parameters as phosphorus and other nutrients, the future of WQM is in online monitoring using sensor networks (Dong et al. 2016, Mason, Korostynska & Al-Shamma'a 2013). Based on recent developments, often driven by requirements from drinking WQM, industrial or pharmaceutical applications or food production, new technologies and devices become available that enable more sustained online diffuse load monitoring. These developments are presented further in this chapter.

Used measurement devices or *probes* are commonly referred to as *sensors* but strictly speaking sensors are just a component of the actual probe. The sensor measures the quantity and quality of a specific analyte. The actual probe, contains beside the sensor all ancillary components as energy supply, data processing, storage and/ or transmission unit etc.

> *"Modern continuous online or in-situ water quality sensors can detect various water quality elements, such as physical characteristics (e.g. temperature, pH, turbidity, conductivity), presence and concentration of chemical parameters (e.g. oxygen, nutrient compounds) and biological factors (e.g. algae, fish, bacteria)."*

WQ parameters considered in diffuse load monitoring affect the physical (e.g. turbidity, temperature), chemical (e.g. DO, nutrient concentration) and biological (e.g. algae) properties of the water body. These parameters can be qualitatively and quantitatively measured using different optical, electrochemical or biological techniques or a combination of these. Measurement techniques and commercially available devices covering a broader range of WQM applications are covered in recent reviews e.g. (Banna et al. 2014a, Storey, van der Gaag & Burns 2011, Raich 2013).

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Optical sensors

Optical measurements are based on the interaction between light emitted by the sensor and the particulate or dissolved compounds in water. Either the sensor measures how the emitted light is altered in the water, e.g. through absorption, reflection or scattering or it measures the response of a compound that is induced by the emitted light, e.g. fluorescence. Based on the difference between emitted and received light, the sensor assesses parameters as particle size or concentration of a certain substance. All optical sensor types comprise a light source and a detector (Figure 5.) and usually further components like optical filters, gratings or analytes which vary depending on the parameter-specific measurement technique (Bhardwaj, Gupta 2015, Pellerin, Bergamaschi 2014) The most common optical sensing methods applicable in diffuse load monitoring are described in the following paragraphs in order to illustrate the potential but also the limitations these sensors provide for the establishment of an integrated, large area diffuse load online monitoring network

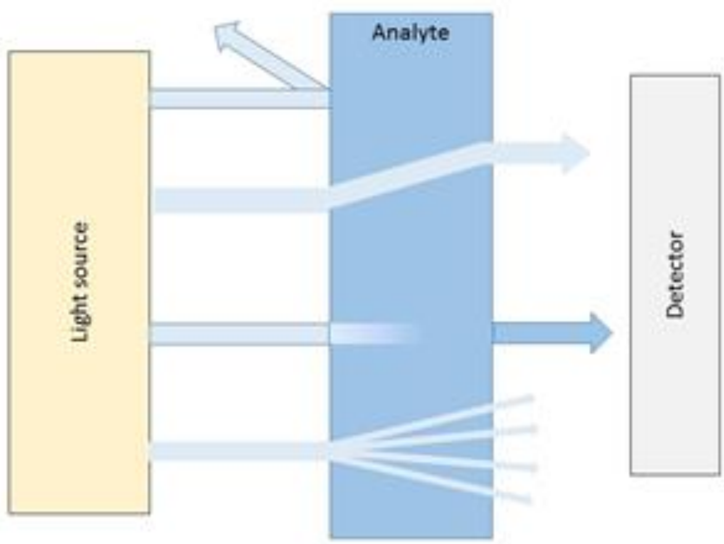

__Figure 5__. The four basic principles of light and analyte interaction in optical sensors. Four basic intercations are: reflection, deflection, absorption and scattering.

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Spectrometers and spectrophotometers

Spectro- and spectrophotometers allow to measure a variety of parameters relevant for diffuse load monitoring (e.g. Turbidity, TSS, DO, BOD, TOC, DOC, NO_2) with a single device (Storey et al. 2011). Both, spectrometers and spectrophotometers often use a light source with a broad bandwidth. In WQM usually the ultraviolet (~100-400 nm) to visible (~400-700 nm) (UV-Vis) light spectrum is used. In some case the spectrum is limited to the UV spectrum.

While spectrometers measure the wavelengths a compound reflects and the ones it absorbs, a spectrophotometer measures the amount of light of a specific wave length that is reflected or absorbed. (Carpentier et al. 2015) Therefore, a spectrophotometer may provide more specific information on compounds in the water. Presence or concentration of a specific compound can be determined based on the measured absorption spectrum.

Fluorescence based sensors

In diffuse load and WQM fluorometric sensors are used to measure e. g. dissolved organic matter, chlorophyll, phycocyanin or PAH traces in surface waters. Fluorescence sensors are based on molecular absorption of light at a certain wavelength and its imminent re-emission in another wavelength. Most molecules fluorescent naturally and each molecule has unique absorption and emission characteristics. For instance, to measure phycocyanin (a proxy for blue-green algae concentrations in fresh water), light with a wave length of 620 nm (*excitation* wave length) is emitted by the sensor to stimulate fluorescence, that is re-mission of longer wave length (*emission wavelength*). In the case of phycocyanin this wavelength corresponds to 655 nm.

Fluorescence measurements have certain advantages compared to spectrometric measurements. Fluorometers are more sensitive to distinct compounds, less susceptible to interference, and have lower calibration costs. However, due to the distinct excitation and emission wave length utilized by fluorometers, they are usually limited to measure a single to very few compounds within one probe. Fluorescence sensors or fluorometers are either used independently or as part of multiparameter probes. Though fluorometers for the detection of various parameters exist, their application in nutrient monitoring remains limited. (Ahmad, Reynolds 1999, Pellerin, Bergamaschi 2014).

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Luminescence based sensors

In the field of WQM, luminescence based sensors are predominantly used for measurements of dissolved oxygen (DO) concentrations, biological oxygen demand (BOD), and carbonaceous oxygen demand (CBOD).

Luminescence sensors exploit the effect that a certain parameter, e.g. DO concentrations, has on the fluorescence lifetime of a material. The sensing element is coated with a specific luminescent material which is excited by an internal light source with a specific wavelength (e.g. blue light in case of a DO sensor). The excitation causes fluorescence of the coating, i.e. the emission of light with a longer wavelength (e.g. red light in case of a DO sensor). A photodetector in the probe measures the fluorescence duration. As the strength (intensity and duration) of the induced fluorescence is proportional to the concentration of the measured parameter (e.g. DO), the concentration of the measured parameter can be determined (Trettnak et al. 1996, DeGraff, Demas 2005)

The major difference between fluorometers and luminescence based sensors is, that a fluorometer induces and measures the fluorescence of the parameter to be measured directly, while a luminescence based sensor measures the concentration of a parameter based on the effect it has on the fluorescence of a material. Luminescence based sensors are usually less susceptible to interferences than fluorometers.

Electrochemical sensors

Electrochemical sensors are among the most commonly used for environmental monitoring. Typical applications in WQM include measurements of pH, conductivity, or dissolved oxygen.

Electrochemical measurements are based on the relationship between electrical signals (e.g. current, voltage, conductance, capacitance) between two electrodes, and specific chemical parameters. The most commonly used electrochemical sensor types for in-situ field monitoring can be divided into to three categories: potentiometric (e.g. ph, sulphide, pCO_2, chloride, ammonium/ammonia, nitrate and nitrite), amperometric/voltammetric (e.g. DO, N_2O, Cl) and conductimetric (e.g. salinity) sensors. (Brett 2001) Their working principles are shortly described below and in Figure 6.

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Benefits of modern electrochemical sensors are their sensitivity, selectivity and stability. They provide a wide linear measurement range and can be produced at relatively low cost and with a small form factor (Hanrahan, Patil & Wang 2004, Banna et al. 2014a). Except for classic glass electrode based electrochemical sensors, they have a low need for maintenance, calibration and power which predestines them for in-situ monitoring in harsh field conditions.

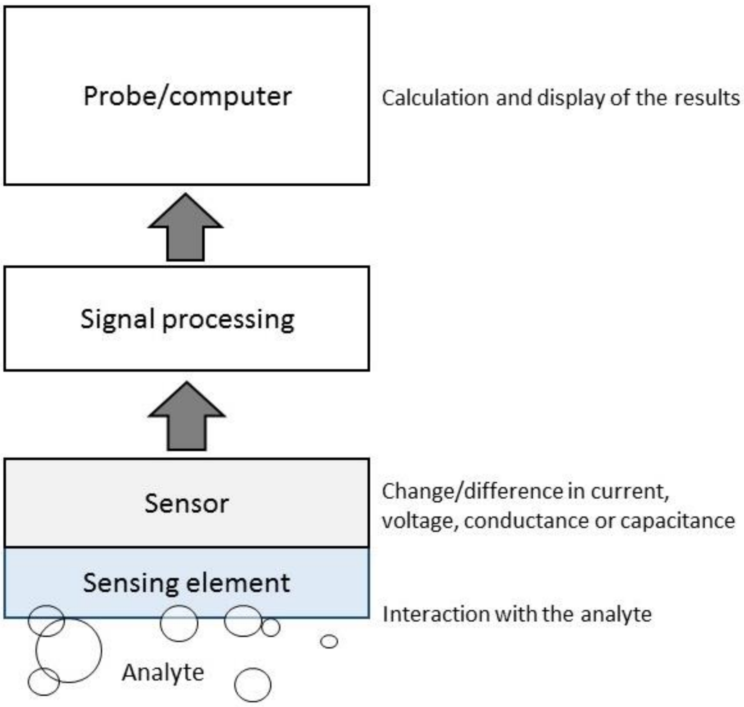

Figure 6. *Basic composition and working principles of electrochemical sensor system.*

Potentiometric sensors

Potentiometry is based on the measurement of potential differences between a reference and a working electrode. While the potential at the reference electrode is kept constant, the potential of the other electrode changes in dependency of the ion concentration of the target parameter in the water. The working electrode is usually separated from the water through an ion-selective membrane through which only specific ions can diffuse. Therefore, it is called ion-selective electrode

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(ISE). The measured potential difference is directly proportional to the analyte concentration. (Quevauviller, Roose & Verreet 2011)

Ion sensitive field-effect transistors (ISFETs)

Ion sensitive field-effect transistors (ISFETs) were introduced in the 1970s and since then received tremendous attention in the research field and are nowadays commercially available as pH meters. The structure of the original ISFET is based on metal oxide semiconductor field-effect transistors (MOSFETS) (Banna et al. 2014a). The gate of the MOSFET is removed and the underlying oxide is used for detection of hydrogen ions in the solution. The detection is based on the change of the surface charge, which creates a potential change across the solution, which is then referred against the reference electrode immersed in the solution. This modulates the transistor channel conductance and subsequently the drain current. (Cané, Gràcia & Merlos 1997, Yuqing, Jianrong & Keming 2005)

Conductimetric sensors

"Conductimetric sensors are conceptually the simplest of the electroanalytical techniques, but they are inherently non-specific. The concentration of the charge is obtained through the measurement of solution resistance" (Hanrahan, Patil & Wang 2004). Measurements of electrical conductivity are commonly used as proxy for the salinity of the monitored water body. As the electrical conductivity of water depends on the ion-concentration, a conductivity-probe can be utilised to measure the concentration of salt ions in the water by inducing a current between to electrodes (e.g. Acevedo, 2015). The conductivity is further influenced by the ambient temperature and therefore usually a thermistor is incorporated into the conductivity sensor (Acevedo 2015).

Amperometric and voltammetric sensors

Amperometric sensors measure the current between two electrodes with a fixed potential. The measured electrical current is directly proportional to the concentration of the target analyte. (Quevauviller, Roose & Verreet 2011).

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Voltammetric sensors measure electrical currents between electrodes with changing potential difference. The current at a certain potential difference is a proxy for a specific analyte concentration (Quevauviller, Roose & Verreet 2011).

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Challenges and bottlenecks related to diffuse load monitoring probes

How to plan and implement a continuous diffuse load monitoring station

Figure 7 presents factors that need to be taken into account when choosing the monitoring site and used sensor(s) with respect to costs, data certainty and reliability.

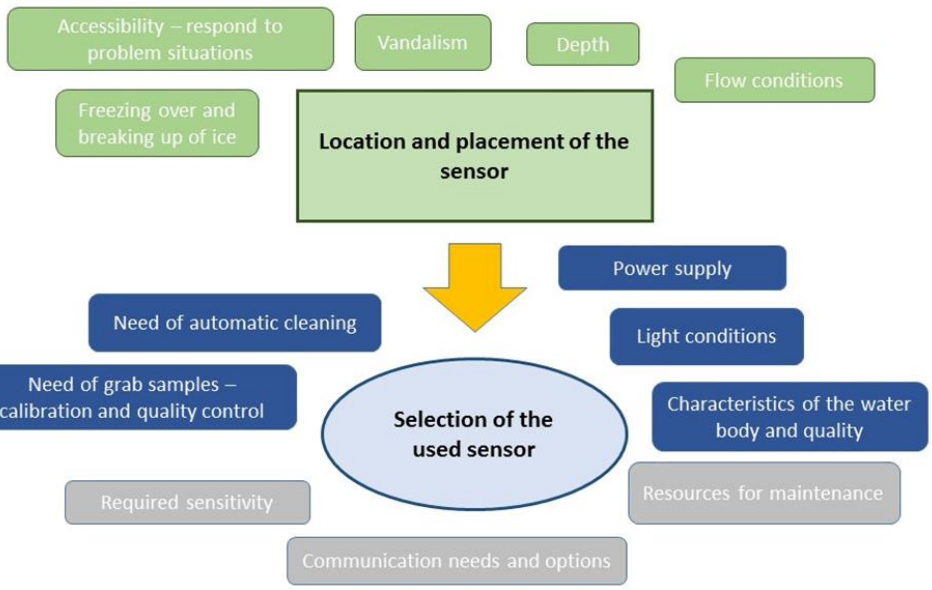

__Figure 7__. Factors that should be taken in account in the selection of monitoring site and used monitoring devices

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While most of the parameters relevant to diffuse load monitoring in the EU can be reliably measured, not only via grab sampling and laboratory analyses but also in-situ, a number of challenges and bottlenecks need to be overcome before automated monitoring solutions may be established on large scale. Technical problems include sensors' robustness towards biofouling and measurement drift, energy supply, sensing of certain parameters, and, most significantly, costs. The most crucial shortcomings of current state-of-the art in-situ WQM devices are discussed in the following paragraphs. The technical and legislative development potential for long-term in-situ monitoring solutions that originate from these shortcomings are discussed below.

Parameters that cannot be measured sufficiently

Many parameters that are relevant to diffuse load monitoring (see Table 6, Chapter 3) can be measured in-situ with sufficient accuracy and precision. However, some parameters cannot be measured in-situ or available sensor probes do not fulfill the resolution, precision and accuracy required by public authorities. Examples of such parameters relevant to diffuse load monitoring in the project region and EU are nutrients such as phosphate. Further, many sensors need to be frequently calibrated against laboratory standards due to sensor drift. For instance, a state-of-the-art pH sensor might have to be calibrated as frequently as every second week (YSI/ Fondriest Environmental). Such calibration requires field visits; grab samples and subsequent laboratory analyses might be required for calibration and data quality control in order to meet the demands of authorities and environmental regulations. This creates significant costs that may be eliminated by reducing sensor calibration needs and establishing internationally accepted measurement standards to which sensors are certified.

Challenges caused by corrosion and biofouling

Sensors and especially the housing of probes used in online WQM are usually permanently immersed in water for extended periods of time (weeks to years). In both, fresh- end saltwater environments, the surfaces of sensors and their encapsulation are prone to chemical physical and biological corrosion. Figure 8. illustrates a) rusting and wear of a long-term deployment and b) and beginning biofouling of a probe. While chemical corrosion may be avoided in most cases by the

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choice of materials such as Titanium or Polyoxymethylene (POM), biocorrosion or *biofouling* remains a significant problem in long-term WQM. Biofouling refers to the process of accumulation of mostly biogenic material on sensor and encapsulation surfaces (Flemming 2009). The process of biofouling is usually a succession that starts with the attachment of small organic and non-organic particles to surfaces, which provide a base for microorganisms as algae, and finally macroorganisms as mussels (L. Delauney, C. Compère,and M.Lehaitre 2010, Lawlor et al. 2012). This process is dependent on the deployment location, its chemical and hydrological characteristics, sensor type and the time of the year. Biofouling can impair the performance of a sensor by isolating the sensor from the environment (Figure 8.) and by creating microenvironments that change the chemical concentration of the parameters of interest. Biofouling is the main limiting factor in long-term in-situ monitoring as it affects the maintenance interval, data quality and reliability. It should be noted that certain sensor types are more affected by biofouling than others. The performance of electrochemical sensors, pH and conductivity, is more robust towards biofouling than the performance of optical sensors (e.g DO, turbidity). The accumulation of surfactants and organisms on the surface of optical sensors, severely alters the measurement performance and reliability.

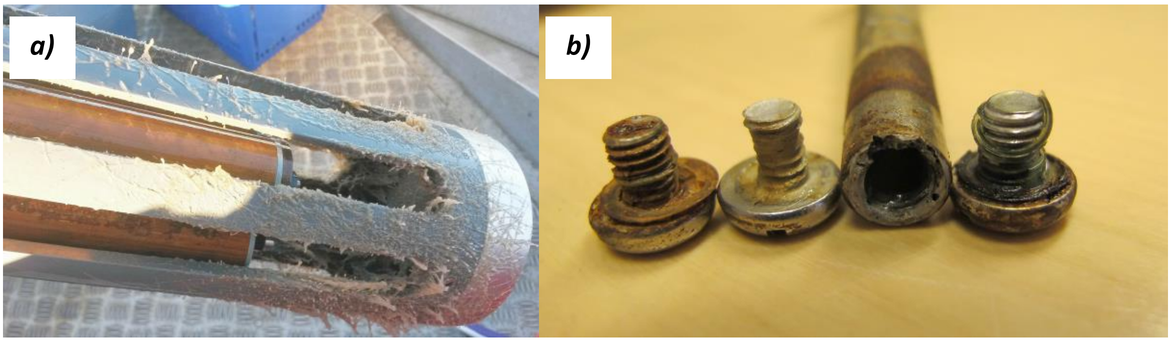

Figure 8. *Examples for results of bi-chemical stress on sensors and parts during long-term deployment. a) Beginning biofouling of a probe. b) rusting and wear of screws.*

Several methods exits to minimize negative effects of biofouling on housings and sensors (see Delauney et al., 2010 for a comprehensive review). Commercially available and test methods can be divided into active and passive techniques, volumetric and surface methods (Manov, Chang &

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Dickey 2004). Active surface biofouling prevention methods include e.g. mechanical wipers for optics, whereas an example for passive, volumetric methods is biocide leaching around the sensor (L. Delauney, C. Compère,and M.Lehaitre 2010, see Table 7).

Table 7. *Overview of biofouling mitigation methods/technologies (modified from Delauney et al. 2009)*

Method	Active	Passive
Volumetric	Copper shutter to enclose the sensing element during inactivity periods	Protective ring
	Chlorine production	Biocide substance leaching
Surface	Wiper, water jet, ultrasonic sounds for surface cleaning, Chlorine production, UV radiation, bleach injection to prevent accumulation of organisms	Material nature (e.g. copper) Biocide coating Nano coating

Active mechanical solutions such as a wiper for optics or a shutter made of copper (which acts as biocide) are proven field technologies to enable long-term maintenance free deployments. Yet, they require a motor and controller and therewith increase the energy demand of the probe. In case of autonomous, non-cabled WQM stations this may be a problem as energy supply is a limiting factor for long-term deployments. Passive solutions that utilize, e.g., leaching of biocide substances around the sensor do not require energy, but might alter the measurements by changing the chemical and biological properties of the water around the sensor (Marcel Babin, Collin S. Roesler & John J. Cullen 2008, Lawlor et al. 2012).

Challenges caused by encapsulation and material properties

Aquatic environments pose many challenges for the encapsulation of WQM devices (sensors, data loggers and transmission units), such as large temperature ranges, mechanical stress from wind and

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wave action or chemical corrosion by saltwater. The design of the housings, connectors, and mountings significantly affects the reliability, cost and life-time of the sensors and auxiliary equipment. Any encapsulation should protect the sensors from mechanical stress and other parts, as electronics and data loggers, from humidity without disturbing the measurements.

State-of-the-art WQM technologies used for diffuse load monitoring overcome most of these challenges by using corrosion resistant housing materials as POM or Titanium, roughed wet-mateable brass or titanium connectors, Kevlar-reinforced cables and cable clamps. However, these components and materials are costly and significantly contribute to the high price levels of WQM devices. In many cases, the probes and data loggers used for diffuse monitoring are similar to those used in oceanography and therefore are made to be used in deep waters. Costs for diffuse load monitoring equipment might be reduced by using materials which withstand environmental stresses in surface but not in deeper waters.

Challenges related to power supply and endurance

Power supply is one of the biggest challenges concerning the use of in-situ WQM devices. The probe, data loggers and data transfer all require electricity. The actual power consumption is influenced by the probe (both, measurement technique and number of measured parameters), measurement interval, the data transfer method and interval. As diffuse load monitoring stations are usually located in rural areas, power supply is largely based on batteries. For a diffuse load monitoring station usually at least one (multi-parameter) probe is required. Possibly an external data logger and, for online monitoring, a data transmission unit need to be integrated. In case, these devices do not have sufficient internal power supply, an external battery unit is required. This increases the costs for the station as additional housings and connectors are required to integrate all components. In addition, energy might be harvested from solar panels, small wind- or even hydro-electric turbines, in remote areas. Yet, currently these alternative energy sources still require batteries with sufficient capacity to provide a stable power supply and as backup in case the energy harvesting units fail or are not able to produce energy (e.g. due to insufficient sun light or wind). Besides the power requirements of the monitoring station, large temperature fluctuations might limit the endurance of batteries.

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In order to realize dense networks of long-term, online diffuse load monitoring stations, further developments in reliable energy generation and supply are needed. This is especially relevant in remote areas where GSM coverage is insufficient and data transmission should be realized through wireless sensor networks, which require a great number of nodes or repeaters.

High costs hamper the establishment of diffuse load monitoring networks

As mentioned above WQM requires a set of expensive sensors and ancillary devices, which generate significant costs for a single monitoring station. Cost for regular maintenance add to these investments. Concrete cost for sensors used in WQM depend much on the measured parameter, measurement technique and required precision. While, for instance, basic optical turbidity sensors for integration in a multi-parameter probe cost a few hundred Euros, optical fluorometers may cost well above 15,000 Euro (Raich 2013, Pires 2010). The need for external data loggers and transmission, energy supply and wiring results in additional investments of several hundreds of Euro. These significant costs related to WQM impede the establishment of dense monitoring networks in the EU and globally. As discussed in Chapter 3, the available resources for diffuse load WQM in the EU will be reduced. This emphasizes the need for field-proven low-cost solutions further. Recent R&D has shown that the design of cost-efficient (10s of € rather than 1000s) devices is achievable, especially for measurement of basic parameters as pH (Yang et al. 2014) or turbidity (Murphy et al. 2015). Promising emerging low-cost technologies are discussed below.

Overview of data recording and management technologies

The above discussed technologies for WQ/ diffuse load monitoring are the prerequisites to measure relevant environmental parameters. However, the data which is produced by these devices needs to be stored for later analyses. In the special case that diffuse load monitoring should be "online", the data needs to be stored locally and transmitted in near-real time to a server or online data base. This section provides a general overview of established and commercially available data logging and transmission solutions. A separate paragraph is dedicated to the challenges related to data logging, transmission and management in the field or WQM.

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Data loggers and data platforms

The development of sensor technologies, small robust computers, and mobile communication enable online, continuous WQM networks though still at a high cost.

Automated, in-situ diffuse load monitoring reduces the overall costs of data collection (compared to grab-sampling), significantly increases the quantity and quality of collected data on spatial and temporal scales and minimizes time delays and possible errors originating from manual sampling. Modern WQM stations usually consist of at least a sensor or probe and data logger, and possibly a wireless communication interface for data transmission. Usually data logging, management, and possible processing, are managed by a single unit. Recent advances in mobile communication and web-based data storage allow to transfer data continuously or sequentially to web-servers. Yet, in-situ data loggers remain important for intermediate storage and backup.

Data loggers suitable for WQM are provided by various manufacturers and are often compatible with probes and sensors of different makes. Recent developments in low-cost, high capacity solid state/ flash memory data storage solutions allow the integration of data loggers directly in the WQM probes. The most common data logger types used in WQM can be divided in the following categories:

Stand-alone loggers are usually compact, reusable and portable, and offer easy setup and deployment. Stand-alone loggers are often used with external sensors (flexible inputs channels for a range of external sensors).

Web-based data logging systems are used for online in-situ monitoring, and can be usually connect with several sensor options/channels. They enable remote data access, sensor performance control, and setup changes. Communication between the monitoring station and the web-server is realized through GSM communication in most cases, but also the potential of alternative short range wireless communication as WIFI, WiMax or ZigBee has been successfully tested (Regan et al. 2009, Xu, Shen & Wang 2014).

Wireless independent data loggers transmit data in (near) real-time to a central computer. Wireless logging systems eliminate the need for manual data download from individual logger units.

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Despite the availability of wireless data transmission and online data logging options, the majority of WQM stations still record data offline. The data is then read out during maintenance visits to the station and post-processed in the lab.

Data transmission and communication solutions

Wireless communication has many advantages in continuous online monitoring applications. It, for example, enables remote data collection and inspection, which improves the reliability of the data and reduces the need for field visits and manual data handling. This decreases costs significantly. The used communication technology is usually chosen based on the location of the monitoring station and environmental conditions. Also, the costs for a specific communication solution is taken into consideration when determining the most feasible and practical solution.

Communication options:

- Ethernet
- Cellular connections (GSM/GPRS(SMS)
- Satellite
- Wi Fi
- VHF and UHF
- Spread spectrum radio
- Bluetooth
- ZigBee (local networks)
- WiMax

At present, data transmission and communication with remote WQM stations is dominated by GSM/GPRS though significant efforts are being made to advance technical solutions for wireless sensor networks based on short range communication (Regan et al. 2009, O'Flynn et al. 2007, M. T. Lazarescu 2013).

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The advantage of GPRS/GSM based data transmission is its relatively low-cost, high speed, and wide service area (areal coverage). GPRS/GSM enables remote system and data control (data schedule, data surveillance, data acquisition). Data loggers can be equipped with a built-in GSM-modem or with a GSM-gateway for external GSM-modems.

In areas where GSM/GPRS network coverage is insufficient and the setup of RF systems is impractical, satellite telemetry (e.g. IRIDIUM) can be used for communication with the monitoring station and data transfer. However, satellite telemetry can be used only for data transmission in specified intervals and the size of transmitted data packets is small. Also the hardware and data plans for satellite communications are significantly higher than for mobile communication.

The use of afore mentioned wireless networks based on standards like ZigBee, WiMax or WIFI/WLAN are still in its infancy in WQM. Their major limitation is the distance over which data can be transmitted, usually only a few 10 to max 100s of meters. In order to transmit data over longer distances in remote areas, for instance to the closest location from where GSM/GPRS communication with a web-server is feasible, a great number of network nodes or repeaters are required (Regan et al. 2009, Yue, Ying 2012, Xu, Shen & Wang 2014). These in turn require power supply and need to be weather proof which increases costs and maintenance needs. Currently, these solutions seem to be applicable mostly in urban areas where wireless communication is already available (e.g. Gubbi et al., 2013).

Challenges related to data recording, transfer and management

Incomplete data sets originating from malfunctioning devices or interrupted communication connections cause uncertainty in data interpretation. This may induce public authorities' doubt in the reliability of automated WQM technology and impede the acceptance of large-scale online monitoring networks. Redundancy in data logging, e.g. with a local data logger and on a web-server, options for remote control of sensor performance and data quality, and automated data quality control routines are approaches to overcome these uncertainties.

Technical challenges in data recording, transmission and management might also originate from the use of different sensors (different manufacturers, generations, etc.). To-date there is no uniform standard for data and metadata formats, possible encryption, and communication protocol.

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Rather exist serval standards and protocols, which might require on-the-fly data transformation when sending data from different sensors in near real time to a web-server. Even the set-up of a single offline WQM station using sensors that employ different communication protocols and interfaces might be problematic when using a single external data logger. However, recent developments in WQM equipment provide a higher degree of modularity, customizability and flexibility. For instance, many devices are capable of measuring multiple parameters and can be interfaced with loggers and networks using different protocols.

Challenges in data transmission using mobile networks originate mainly from insufficient network coverage or communication disturbances. Problems in network stability might be partly compensated through an automated data management and control system through the incremental comparison of data stored on a local logger and web-server.

Where data transmission cannot be realized via GSM/GPRS satellite communication is currently the only solution. However, the abilities of, e.g. IRIDIUM services to transmit data remain limited and are connected to high costs. Wireless networks are promising technologies but in order to be applicable in remote areas, the range of these networks needs to be extended significantly in future.

Need and potential for innovations in diffuse load monitoring and emerging technologies

Deriving from the challenges sketched in the previous paragraphs there remains a need for innovations and developments in several fields related to diffuse load monitoring. To establish automated online monitoring networks with a sufficient number of monitoring stations and good spatial coverage also in remote areas, the development of cost efficient, low-energy sensors needs to advance significantly. Cost efficiency may include inexpensive sensors and probes (2 orders of magnitude below current price levels), but also advanced robustness against biofouling and sensor drift, and reliable automatic data quality control and processing. Also, the overall reduction in energy demand of autonomous monitoring stations as well as systems for in-situ energy harvesting should be developed further. To connect areas with insufficient communication infrastructure to automated monitoring networks, both, the advancement of network expansion and of wireless network technology is required.

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From a legislative perspective standards for WQM technology and measured parameters are required within the project area and the EU. These should include standards for data formats, sampling intervals and data base structures. It appears desirable, to collect all diffuse load and other WQ monitoring data in a single EU data base which is open for at least all authorities and research.

The following paragraphs provide a brief overview of emerging technologies relevant to diffuse load monitoring and an outlook on the innovation potential in the project region with respect to technological innovations. Comprehensive reviews of emerging technologies covering all fields of WQM can be found in literature. (Storey, van der Gaag & Burns 2011, Graveline et al. 2010, Kokkali, van Delft 2014, Bharhwaj, J., Gupta, K.,Gupta, R. 2015, Banna et al. 2014a)

Emerging monitoring technologies

Many recent developments in sensor technology have reached the proof-of-concept phase and been successfully tested under laboratory conditions (Banna et al. 2014b, Banna et al. 2014a). Yet, most of these developments have not been adapted for field deployments and testing and certification is still missing. Among others, current developments in LED technology (Li et al. 2016, Murphy et al. 2015), solid state sensors (Zhuiykov 2012), lab-on-the-chip (Wade et al. 2012) technologies, or screen printed electrochemical sensors (Hayat, Marty 2014) allowed for major advancements in the development of low-cost sensors. Below, some of the most promising emerging technologies, which might improve diffuse load monitoring in future, are discussed briefly. Many of the presented technologies represent a new opportunity to detect certain diffuse load related parameters using low-cost and/ or low-power sensors or sensor elements. However, many of these work in conjunction with established methods (e.g. fluorescence sensing) or require significant auxiliary equipment (e.g. pumps or flow cells), which might impede their development towards field-deployable WQM devices.

Microelectronic Mechanical Systems (MEMS)

Microelectromechanical systems (MEMS) are combined electrical components such as processors and mechanical components such as valves and pumps. One of the great advantages of MEMS is that they may be manufactured at low costs and require a minimum of energy. The technology allows for fabrication of large systems of MEMS devices, which individually perform simple tasks, but can also jointly perform complicated functions. MEMS allow sensing, controlling, and activating

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physical and chemical processes on a miniature scale. MEMS array sensors provide a possibility for multi-analyte detection and are also robust option for in-situ monitoring. (Mukhopadhyay, Mason 2013, Meyer, Bischoff & Feltrin 2009)

Fibre optic sensors

Fiber optic sensors cover a broad spectrum of principles and applications (Otto S. Wolfbeis 2008, Utzinger, Richards-Kortum 2003). In fibre optic sensors, an optical fibre might be either used to simply guide light of a certain wavelength from the source to the sensor and medium and the measured response back to a detector, or the fibre might be the sensor itself. In the latter case the fibre is, e.g doped/ coated to produce luminescence of a certain compound in the water or it is coated with a dye that changes its light absorption spectrum depending on the pH value of the water (e.g. Banna et al. 2014).

In diffuse load and WQM, fiber optic sensors are most often used for water contaminant detection in combination with ultraviolet- visible (UV-VIS) spectroscopy. For such applications, an optic fiber is either doped with rare earth elements (e.g. Nd, Eu, Dy) or activated with transition metal ions (e.g. Mn, Co, Cu). Polymeric fibers are doped with a dye. Fibre optic sensors have fast response and decay times and can achieve high efficiency through the design of appropriate delivery optics. They are particularly suitable for harsh climates and remote places. The design and selection of the fiber determines the peak wavelength of the output illumination; options exist to cover the ultraviolet, visible light and near infrared (UV–VIS–NIR) spectrum. Though fiber optic sensors are developed and used in many fields since decades, they remain an emerging technology in WQM (Banna et al. 2014).

Electronic Tongues based sensors

Electric tongues are devices that usually employ and array of different sensors which are not specific to certain compounds and which usually do not provide a quantitative but only qualitative measurement (e.g. (Krantz-Rülcker et al. 2001). The electric tongue approach combines signals from different sensors and uses signal processing methods to identify a certain response pattern of the sensor array to a specific, e.g., water quality property or parameter (Krantz-Rülcker et al. 2001, Mason, Korostynska & Al-Shamma'a 2013, Vlasov Yu. et al. 2009, Mukhopadhyay, Mason 2013)

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Mukhopahyah & Mason, 2013). The used sensing techniques might be electrochemical, as potentiometry (Mimendia et al. 2010) and voltammetry (Toko 1998) optical-chemical (John J. Lavigne et al. 1998) or based on surface acoustic waves (Groves, Grey & O'Shaughnessy 2006). However, for WQM and diffuse load monitoring voltammetric electronic tongues and electronic tongues combining different sensing technologies appear to have the largest potential for the development of field-deployable probes (Krantz-Rülcker et al. 2001, Campos et al. 2012). The greatest advantage of electronic tongue sensor arrays is their relative low-cost, simplicity and the broad applicability. WQ parameters that may be monitored using electronic tongues include COD, BOD, orthophosphate and sulphate (Campos et al. 2012).

Lab-on-a-chip technologies

Lab-on-a-chip (LOC) technologies are an emerging field of analytics covering various disciplines from medical applications to food production, with WQM related RDI activities being only a minor branch (Jang et al. 2011). The LOC technology derives from attempts to integrate a specific laboratory analytical process (sampling, preparation, analysis) onto a thumbnail-sized chip. As LOC analyses techniques operate with minute volumes of fluids and miniaturized electronics and mechanical components, LOC technology is closely related to microfluidics (Whitesides 2006) and MEMS (Jang et al. 2011). LOC might utilize the electrochemical (Jang et al. 2011), biochemical (Lakard et al. 2004), or optic properties of the analyte (Psaltis, Quake & Yang 2006). In WQM, LOC technologies are a promising development towards cost-efficient, low-energy consuming sensing devices for, e.g. pH, ORP, nitrate, and phosphate (Jang et al. 2011). However, most developments for WQM applications are in an initial stage and technical limitations as, encapsulation and long-term resistivity to field conditions need to be overcome.

Surface acoustic wave sensors

Surface acoustic wave sensors (SAW) have been identified as promising low-cost, highly specific sensing technique for WQM applications (Storey, van der Gaag & Burns 2011). Possible application in WQM include the detection of volatile organic chemicals (Groves, Grey & O'Shaughnessy 2006). SAW sensors measure the alteration of an acoustic surface wave through a certain compound. The surfaces of SAW sensors are coated with certain substances, e.g. polymers that absorb the target analyte (Groves, Grey & O'Shaughnessy 2006). A transduces creates a surface wave with a distinct

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frequency on the sensor surface. This frequency is altered depending on the amount of analyte that is absorbed by the sensor surface (Storey, van der Gaag & Burns 2011). The frequency change might be calibrated to concentrations of the analyte. The advantage of SAW based sensors is their small form factor (chip size; (Ho et al. 2003) and the potential for low-cost production (Storey, van der Gaag & Burns 2011). Among their disadvantages are sensor drift and low sensitivity (Storey, van der Gaag & Burns 2011). Also, SAW based sensors require significant auxiliary components as pumps and signal processing units as well as adaptation to field conditions.

Microwave based sensors

Microwave based in-situ sensors have been successfully used for various industrial applications, including water level and quality measurements. Microwave based analyses utilize the interaction between the measured compound and electromagnetic waves which changes the permittivity of the compound. Therefore, the composition of a sample may be linked to the variation of the frequency and transmittance of the microwaves. Microwave sensors have the potential to detect several compounds in the water (Mukhopadhyay, Mason 2013). Among the most promising applications in WQM is monitoring of nutrients, such as phosphate and nitrate (Al-Dasoqi et al. 2011; Mason, Korostynska & Al-Shamma'a 2013). Microwave based sensors permit direct, continuous and instantaneous measurements thus reducing the need for sample preparation and pre-processing. Therefore, microwave based sensors may be a cost-efficient technology for future WQM applications.

Self powered-power nano sensors

The emergence of nano materials and sensors appears to have a great potential for the development of low-cost and low-energy WQM applications. Examples of novel materials and sensors based on them are graphene (Chang et al. 2014) or fibre optics (Lin 2000). Common to nano technologies is the small form factor of sensors or sensor arrays and the very low power consumption. The low energy demand of nano sensors that can measure, for instance heavy metals (Chang et al. 2014, Wang 2012) or pH (Lin 2000), make it feasibly the develop sensor systems that are completely self-sustained. The advancement of nanogenerators that harvest energy from physical strain, vibration, or flow of air or water, allow to supply not only the sensor but also additional components as data transmission units with sufficient energy for discontinuous measurements (Wang 2012, Wang,

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Wu 2012). Further developments of these technologies might enable the establishment of dense, autonomous, online WQM systems in future. Yet, sensitivity of relevant sensor need to be improved along with their robustness for deployments in non-laboratory environments.

Biosensors

While biosensors are well established for biomedical applications (Nayak et al. 2009, Chiappini et al. 2010), their use in WQM is still in its infancy (Quevauviller, Roose & Verreet 2011). A biosensor consists of two main components: a bioreceptor or biorecognition element and a transducer. The bioreceptor, which may be e.g. an enzyme, entire cell or bacteria, responds to the presence and concentration of a specific analyte which is detected by and electrochemical or optical transducer (Quevauviller, Roose & Verreet 2011, Su et al. 2011). Despite the development of many promising proof-of-concepts for WQM applications only a very limited number of biosensors suitable for WQM has been commercialized (Quevauviller, Roose & Verreet 2011, Su et al. 2011). Examples include probes for detection of NOx (e.g. Unisense A/S) or BOD (e.g Biosensores SL).

Microbial fuel cells (MFC)

Microbial fuel cells (MFC) link electrochemical measurement techniques with biological indicators (Su et al. 2011). In MFCs a chemical compound or analyte is metabolized by microbes which alters the electricity production in the cell. Alternatively, the presence of a certain toxin might negatively alter the microbial metabolic pathway, which also generates a measurable change in electricity production (Su et al., 2011). MFC applications in WQ and diffuse load monitoring may include the assessment of BOD, COD (Di Lorenzo et al. 2009), or levels various toxicants (Di Lorenzo et al. 2014). The benefits of MFC based WQM include the relative drift stability of MFC, extreme low-cost, and compactness (Chouler, Di Lorenzo 2015). Future development needs for long-term, online field usability of MFCs are the increase of specificity, resistivity to environmental impacts and integration with data logging and transmission systems (Chouler, Di Lorenzo 2015)

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Bio- and immunoassay application potential in WQM

Bio- and immunoassays usually work in conjunction with other physical transducers or sensors and might therefore be considered as integral part of biosensors (Chouler, Di Lorenzo 2015). Bioassays utilize various levels of biological indicators for (changing) water quality, especially toxicity levels (Allan et al. 2006). These indicators include cells, microorganisms, and higher level species such as fish (Kokkali, van Delft 2014). The fundamental principle of bioassays is that changes in water quality, e.g. increase in toxicity, affect the state or vitality of an organism. For instances, the natural luminescence of the bacterium Vibrio fischeri decreases as toxin levels in the water increase (Storey, van der Gaag & Burns 2011). Other bioassays, or biomonitors, utilize the activity changes of, e.g. fish, in response to changing water quality (Brack et al. 2016). While specific bioassays have been developed to measure and monitor different chemical parameters relevant to WQM, most application are designed for laboratory-based analyses and their applicability to in-situ, online monitoring remains limited (Kokkali, van Delft 2014). The major disadvantage or bioassay applications in field measurements is that the biologic response to a chemical parameter has to be assessed with auxiliary devices such as cameras or fluorometers. This increases the costs, maintenance, and energy demands. However, for instance the integration of cell-based bioassays and lab-on-a-chip technologies could further advance the online monitoring potential for bioassay-based sensors.

Immunoassays are based on the interaction of antibodies and antigens and may be used as a proxy for certain toxins, e.g pesticides, in water (Allan et al. 2006). Immunoassays do not provide a direct measure of analyte concentrations as they only allow to measure the number of free binding sites on an antibody after it has been in contact with the antigen (here: the analyte, e.g. toxin). The number or free binding sites is assessed using additional tracers based on, e.g. fluorescence or radioisotopes. The advantage of immunoassays in water quality analyses is their low-cost, rapid response, and low sample preparation need. (Allan et al. 2006) Yet, their integration into in-situ, online monitoring devices needs further developments and testing.

Citizen science based monitoring

Citizen science refers to the involvement of non-expert groups into research and environmental monitoring by recording and analyzing observations made by the interested public. Citizen science is mentioned here, as it greatly benefits from recent developments in easy-to-use, low-cost sensors

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and especially smart phone applications that allow an untrained person to collect and share quality controlled data (Newman et al. 2012). Examples for WQM based on citizen science are the algae bloom monitoring in Finland (2011-2013) or the CyanoTracker project by the University of Georgia, USA. For the earlier project, public could either report observations on algae occurrence to a web-portal or use a smart phone application to submit a photo showing possible algae blooms to an online data base (Kotovirta et al. 2014). Examples, for citizen science that use low-cost devices that allow non-experts to collect calibrated data are the Secchi3000 project for the assessment of water turbidity (RW.ERROR - Unable to find reference:515, Toivanen et al. 2013) or the development of inexpensive paper based test kits to measure concentrations of organophosphate pesticides in water (Sicard et al. 2015). For the turbidity assessment a water container and phone application were developed to measure calibrated water turbidity using the phone's camera (RW.ERROR - Unable to find reference:515). For the latter example a phone application was developed that is able to derive the organophosphate concentration from a paper test stripe using the phone's camera as well. The use of smart phones allows not only to add some degree of quality control to the collected data but also, add geographic information to the collected sample and to transmit the data to an online data base (Newman et al. 2012).

Further developments of low-cost sensors for the most important WQ parameters and corresponding software could attract a large number of citizens to contribute to monitoring campaigns and lead to a major improvement of monitoring networks. The possibilities of citizen activity in WQM are more closely discussed in another Baltic Flows project report "Citizen Activity in Water Monitoring – How to Boost It?" (Final report D4.2, April 2016)

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Innovations in data recording and management

Wireless Sensor Networks

Due to developments in wireless network technology, new opportunities for online WQM in rural areas emerge. In recent years numerous studies demonstrated the potential of Wireless Sensor Networks (WSN) to interconnect distributed monitoring stations and eventually link them to a web-server (Regan et al. 2009, O'Flyrm et al. 2007, Xu, Shen & Wang 2014). WSN are usually based on RF wireless communication standards as ZigBee or WiMax, which have a limited range of operation (Baronti et al. 2007, M. T. Lazarescu 2013). The limitations related to the short range communication distances between different sensor nodes or local gateways or repeaters may be overcome by careful planning of the sensor distribution and a sufficient integration of gateways and repeaters (M. T. Lazarescu 2013, Xu, Shen & Wang 2014).

During the design phase of a WSN it should be considered that each repeater/ gateway is autonomous and usually has no redundancy. It is therefore beneficial if the network structure is reconfigurable (Xu, Shen & Wang 2014) and each sensor node can communicate with at least two repeaters/ gateways (M. T. Lazarescu 2013).

The available technology for WSNs is advanced and reliable for most indoor or limited outdoor operations. Yet, significant challenges remain for large area outdoor operations in remote areas and therewith WQM applications. As each sensor node, repeater or gateway is an autonomous system, they require an own power supply. To enable long-term deployments additional infrastructure for energy harvesting, e.g. solar panels, is needed. Further, all data collected by a sensor needs to be transmitted, possible via several repeaters, to a gateway node from where the data from the entire network is send to a web-server. This architecture may accumulate large data volumes and may require some pre-processing and quality control already in the sensor node to minimize data streams (M. T. Lazarescu 2013).

While WSN are a good option to realize online WQM networks or individual stations in areas with insufficient GSM coverage, they remain costly solutions due to the required number of nodes, power supply, local processing and backup resources and required weather-proof encapsulation.

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Internet of Things (IoT) in WQM applications

The concept of the Internet of Things (IoT) integrates physical objects (e.g. machines, buildings, living environment) with the internet. The objective of this combination of real and virtual environments may be to just record where a certain object (e.g. car) is, to get detailed information of its physical status (e.g. speed of a car) or to control the object remotely (e.g. trigger the collection of a water sample) (Perera et al. 2014).

With respect to WQM the IoT offers the opportunity to network and control a virtually infinite number of sensors and WQM station and collect data in a centralized data base. Currently, such scenario is most realistic in urban or densely populated areas where network infrastructure is well developed (Perera et al. 2014, Gubbi et al. 2013). However, also rural areas with insufficient network infrastructure might be connected to the IoT via the establishment of a wireless sensor network (WSN) (M. T. Lazarescu 2013, Regan et al. 2009). The IoT's full potential in WQM might only be exploited once inexpensive, maintenance, and calibration free sensors are available and/ or new technologies enable citizen scientist to access all essential WQM parameters using smart phones and multi-sensor devices.

To date the IoT provides the opportunity to fuse data from various monitoring stations and local data bases and relevant complementary data as satellite remote sensing or meteorological data, to provide more global information on environmental and anthropogenic processes that influence WQ. Yet, there exists a large potential for improved data mining and online processing routines.

Web-based data management and processing

The majority of diffuse loading and other WQ data collected continuously in-situ is recorded to an on-site data logger and sporadically downloaded, e.g. during maintenance visits. This data, along with sporadic in-situ measurements and data from laboratory analyses, are often manually post-processed and quality controlled, and subsequently uploaded to a local database or stored at the data-collection institution. Online measurements of WQ are in most cases send to a local web-server in intervals (hourly, daily, weekly) but not in near-real time. The sharing and distribution of such data is often hampered by different data formats, processing routines, and data base structures in use at different institutes and authorities (Sun 2013).

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With the advancement of more sophisticated in-situ, online monitoring technologies and envisaged deployment of spatially comprehensive WQM networks, the need for a centralized data management and evaluation systems increases. Though data sets generated at single WQM station are rather small, a, e.g. national, WQM network will generate a significant amount of data assuming continuous measurements. Such data volumes might be considered as spatial big data (Shekhar et al. 2012) and require large storage and processing capacities. This data load would potentiate if WQM data from several countries was streamed to one, e.g. European data base. To handle such constantly growing data volumes, the potential of cloud computing services might be more exploited in future (A. Eldawy, M. F. Mokbel 2015).

Cloud computing services can provide flexible on-demand assess to a virtually infinite pool of configurable computing and data storage resources (Sun 2013, Shekhar et al. 2012). Cloud service provide the opportunity to join data from a large number of actors that acquire WQM data on different scales. The development of open standards and software infrastructure for handling and visualizing spatial big data in cloud computing environments with web-GIS frontends also provides the opportunity to process, quality control, and analyze large data sets (Yu, Sen & Jeong 2013, Sun 2013). This allows to establish WQM systems that continuously measure, analyze, model and visualize diffuse loading for an entire region in near-real time (Sun 2013).

However, to utilize the capabilities of already existing cloud computing services for spatial data, a legislative framework has to be empowered which defines data and metadata formats and regulates data sharing conditions across national and international research institutes and authorities that are involved in WQM activities. The establishment of such framework within the project region would be a major step towards an integrated European smart WQM network and would boost the collaboration between the national WQM authorities.

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Open monitoring data and smart solutions

"Smart water" is a key term in the development of WQM and many real-time monitoring stations are labelled as "smart". However, just measuring something real-time does not make the system smart – a really smart system integrates also all available external data in order to build a high-resolution picture of the diffuse loading, for the basis of better informed decisions.

> "SMART" is the efficient use of all available real-time information to make better informed decisions to enable a more optimized set of outcomes.

As discussed earlier in this report, large efforts are made by authorities to manage the collected data and make it available to authorities, research organisations, and public. In the future, in order to develop smart solutions for diffuse load control, it will be essential to automatize as much as possible the collection of data and its integration to other available monitoring data, such as weather data. Benefiting from the long experience in WQM, public authorities, for instance in Finland, are able to streamline the national data management, by combining different databases previously used by different monitoring instances. An example of an open access WQ database is the Finnish OIVA-database that hosts data from different environmental authorities. The extension and improvement of WQ data coverage through the involvement of the public is continuously developed. This includes the design of mobile phone applications that allow citizens to share quality controlled data on, e.g. algae blooms (Kotovirta et al. 2014) and the Finnish public access webpage "Lakewiki" which integrates observations of citizens and authorities. It provides people with valuable information about the status of near-by waters, raises awareness and interest for WQ issues and at the same time provide valuable information for authorities and research organizations which would not have the capacities to collect these data. Another example is the Uppsala smart city project, where IoT solutions are used to connect all types of sensors to the cloud services to integrate data and allow performance of applied actions. Expertise gained from the integration of citizen observations into these databases and the establishment of corresponding data quality management parameters may help other project countries to establish similar systems in near future.

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Development potential in the project area

A large WQM innovation potential for technologies, education and legislation exists in the project region. Driven by EU and national legislation, great efforts are being made to constantly expand and improve diffuse load and other WQM efforts. Not only national environmental authorities but especially public R&D institutes as universities and public research institutes conduct WQM related research and maintain local monitoring stations and networks. The importance to foster (international) collaboration in environmental monitoring technology development, data management via integration of different data bases and existing monitoring networks into more uniform and accessible systems, is also reflected in recent regional and EU wide funding programs. Examples may be the BONUS BlueBaltic call with theme 5.2 “Developing and testing innovative in situ, remote sensing and laboratory techniques”, Horizon 2020 funded projects like PROTEUS (“AdaPtive micROfluidic- and nano-enabled smart systems for waTEr qUality Sensing”; project reference 644852), or FP7 project COMMON SENSE (commonsenseproject.eu).

The project area benefits from established international collaborations in WQM and advanced infrastructure. The project countries have experience in online data management and data base fusion; for example in Finland currently a national environmental data base (Envibase) is developed to facilitate the use of environmental data. The major aim is to improve the availability and use of environmental data across environmental authorities and research institutes and foster environmental monitoring and research through integration of citizen observations and improved geoformation technologies (Finnish Environment Insitute 2016). This knowhow could be used to either develop commercial services, e.g. WQM program planning and implementation aid, or to support other counties in building up WQM infrastructure through mentoring programs.

Due to its northerly position and seasonal variations with large annual temperature ranges and variable precipitation, the region has built up expertise in WQM solutions for cold climates. Winter conditions, especially in the Nordic Countries, may be harsh and require tailored technical solutions. Currently, many ongoing R&D activities focus on robust, arctic technologies. The project region has the potential to bundle this knowhow into technologies and service products that can be exported into other regions situated in colder climates, including, Russia, China or mountainous

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regions in the European Union. Closer cooperation with RDI institutes and industries in in the northern parts of United States and Canada, where similar expertise exists, could foster the regional development in future.

Beyond academic R&D and IT knowhow, there is also significant industrial knowhow accumulated in the project region in terms of companies that are based in the Baltic Sea countries or have their origin there. Examples of global leaders in development and sales of WQM devices include the Germany-based company Trios GmbH or OTT Hydromet. These industries are supported by a multitude of research groups at universities that continuously advance the sensor technologies. The academic RDI activities lead in many cases to new commercial products or even the spin-off of new companies (e.g. Trios GmbH).

As discussed below there is a large global market potential for low-cost, reliable, online WQM devices and initiatives should be taken to exploit the existing knowhow of the project- and neighboring regions to enter this emerging market with innovative developments in sensor and data infrastructure technology.

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Conclusion – contemporary and future WQM technologies

An overview of existing WQM technologies has been given, including sensor, data, and communication technologies as well as participatory methods as citizen science. Further the most promising emerging technologies have been introduced.

Currently, two major limitations exist that hamper the installation of comprehensive, automated online diffuse load monitoring networks: the cost of measurement hardware and the legislative framework. In addition, some important parameters, such as phosphorus or hazardous substances, cannot yet be measured directly with on-line in-situ equipment. In order to increase the number of online WQM stations significantly, the cost for sensors and ancillary devices would have to be reduced by two orders of magnitude and the R&D efforts should be increased for making the use of latest innovations in measurement technologies for developing methods for measuring the lacking parameters. On the legislative side, e.g. with the EU WFD, automated measurement techniques need to be approved.

To reduce the costs for WQM sensors, new measurement techniques and novel low-energy sensor technology needs to be developed which can autonomously operate in demanding field conditions. Though many promising approaches and proves-of-concept exists, significant efforts are required to bring these developments to the field. The development of automated online diffuse load monitoring may greatly benefit from current advancements in communication and cloud computing technology. Synergies with technology fields as IoT or smart city application could further boost the advancement of real-time WQM.

The Baltic Flows project countries have a strong position in WQM RDI in the EU and the potential to drive future developments, not only on an academic and public level but also in the related business sector. The regions expertise is reflected in the number of authorities, research institutes and companies being active in WQM and related technological developments.

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5. Make use of each other's expertise and experience – building a region of excellence

THE VISION:

The Baltic Flows project area becomes a fostering region of excellence in diffuse load monitoring; a region

- ***where the use of innovative water monitoring solutions in official monitoring programs is taken for granted,***
- ***the authorities use their creativity to establish an enabling and encouraging regulative framework that, in turn creates a predictable and encouraging environment for the companies to develop new products and services for diffuse load monitoring***
- ***where new professionals are educated to meet the level of latest developments in the field and to take them forward***
- ***where innovative monitoring solutions are developed and marketed around the world***

Is this a realistic vision? - How many of the boxes can we check now or in the near future? The earlier chapters of this report have presented the current state of water quality monitoring in the project area (Chapter 1), the regulative framework for water quality monitoring (Chapter 3) and the technology development potential (Chapter 4). This Chapter summarizes the findings, analyses the current potential and next steps for the Baltic Flows project area to develop into a region of excellence in diffuse load monitoring.

Use of innovative monitoring solutions in official monitoring programs

The research organizations and authorities located in the project region have well established programs for WQM and water management. Consequently, the region has accumulated a lot of experience in R&D linked to WQM methods and technologies including continuous water monitoring. The applied methods and practices are precise and well tested and data gathering is comprehensive. The water management and WQM practices have resulted in long data series, which are

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needed to understand the complex links between human activities, environmental factors and water quality. For example, Sweden, Finland and Germany have long term monitoring experience in both diffuse loading and monitoring of point sources. Based on the long experience and strong national legislative requirements for WQM and the EU WFD, these countries do not only utilize state-of-the-art monitoring technologies but actively strive to improve the existing networks, methods, and technologies. In most of the countries in the region the constant dialogue between the researchers and the authorities is integrated in the working culture. The WQ data collected by the authorities are complemented through citizens' observations, especially in Sweden and Finland. This increases the amount of data and raises the public awareness of WQ issues.

The project countries with a long history of water quality monitoring and management may support those partner regions which are still in the process of building up diffuse pollution management systems and monitoring networks by providing information on technologies and practices that have been proven to be suitable for regional conditions. Projects like Baltic Flows are especially suited to exchange competences and to develop regional competences further.

Recently the pressure for cutting down the costs of monitoring has increased in all countries of the project region. This can be both a threat and an opportunity. The threat is that the cuttings will make the regional demand for monitoring solutions plunge, which in turn can result in monitoring companies going out of business. However, the need for cost savings can also have positive results; provided that the R&D funding for developing low cost monitoring solutions is increased, the region may become a forerunner in the development of novel monitoring programs based on integration of low cost in-situ sensor networks, citizen participation and smart integration of data from multiple sources.

An enabling and encouraging regulative framework

The EU WFD and the HELCOM monitoring programs form the common backbone of the regulative framework in water quality monitoring in the Baltic Sea countries and any national regulations and policies must comply with these. However, there are still quite large differences in the way international regulations have been taken into practice in different countries. This makes it more difficult for companies to develop WQM services that could exported to neighbouring countries. On

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the other hand, there is a high pressure to reduce monitoring costs in all Baltic Sea countries. Harmonized data collection methods and databases would not only facilitate the work of authorities, but also encourage companies to develop new, cost-efficient services for WQM.

In the Baltic Flows project region, functional and open co-operation between regional research organizations, private companies and authorities is a common way of working. The small size of communities and organisations in countries with a small population size, such as Latvia, Estonia and Finland, facilitates the interaction between different actors. This so-called triple helix co-operation has been supported by the European Union through projects, such as Baltic Flows, and has thus become a well-established working model in most of Europe. However, direct every-day co-operation at the triple helix –level is not that common globally.

In the Baltic Flows project region there are many examples of combined business and research networks, which collaborate closely with water management authorities and assist in implementing WQ directives, strategies and policies. The triple helix –model can be an excellent platform for developing regulations and new innovations because it allows direct communication of authorities' needs and realities to experts in public and private R&D organizations.

Globally, the region could offer mentoring in building up networks involving authorities, private companies and research organizations. In addition, providing good examples on the benefits of the culture of open exchange and citizen involvement might encourage many developing countries in Asia and Africa to build co-operation and open communication between water monitoring authorities, businesses, research organizations and citizens.

Education of future professionals

There are numerous universities and research organizations in the project region, which offer high-level degree programs in water quality monitoring, water protection strategies, IT-solutions and sensor technologies. Many degree programs offer courses also in English. The degree programs are often linked to various research activities. Especially in Universities of Applied Sciences the collaboration and interaction with local companies is encouraged, which provides students with good practical know-how in field work, problem-solving skills and ability for applied R&D. The education is characterized by flexible curricula, internationalisation and entrepreneurship that allow students to study in a cross-disciplinary, social learning environment with involvement in academic and industrial RDI activities. The education methods and knowhow in competence building, also related to WQ relevant subjects, are already actively exported through existing academic collaborations within the project region and EU. These initiatives do not only help the partner regions to improve the technical expertise of future professionals, but it is also beneficial by improving language skills as well as cultural and social competences of students, teachers and professionals. In addition to educating students, the region has good potential to become a globally significant provider of training for teachers in water quality monitoring and management.

Potential for developing innovative monitoring solutions and serving global WQM markets

There is a growing demand for online monitoring solutions by public and private/ commercial actors. This includes solutions for the design and implementation of monitoring programs, development of measurement technologies, data handling and distribution.

The EU is already the global leader in waste water treatment and monitoring technologies (EPEC analyses for EU ETV scheme) and utilizing the synergies between WWT and WQM technology RDI and related services may be considered as natural industrial evolution. Advancing commercial development of WQM technologies and services in the project area bears a large economic potential. For instance, it has been assessed previously, that globally up to 570 M $ annually may be saved through development and implementation of sufficient automated, online water sampling and monitoring (Sensus 2012). Thus, there is a large industrial market for advances in WQM technologies and services, in addition to the needs of public WQM authorities. The EPEC market analysis for EU ETV scheme states the economic feasibility of developing and certifying new WQM related technologies (DG Environment 2011). The analysis included, among others, case studies in Finland.

In the Baltic Flows project area, the knowledge base on monitoring technologies and IT solutions is at a globally competitive level. There are also closely related areas of expertise, such as the IoT technologies used in air quality measurements in the Uppsala smart city projects, the medical diagnostics and chemistry expertise in the Turku region. Latvia has expertise in hydropower technologies, including energy-efficient solutions for small-size stand-alone electrical devices using flowing

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water, which could have potential to feed in new innovations in water quality monitoring technologies.

The development of new innovative monitoring devices will not alone offer a solution to the diffuse load monitoring needs. The technological solutions will always need to be fitted to local environmental, social and economical realities and conditions. The experts from the Baltic Flows project countries stand out from the crowd of technology developers by their ability to tailor the monitoring programs to challenging hydrological and meteorological conditions and to make full use of the monitoring data in planning of environmentally, socially and economically sustainable water protection measures.

The most easily exploitable potential for knowhow export from the Baltic Flows project area is in the neighbouring Eastern European countries, due to existing market relations, cultural and historical connections and similarity of geo-hydrological environment. Here, the project countries could significantly support the establishment of monitoring programmes, infrastructure and education. Knowhow export might not only include technology and IT-expertise, such as tailored WQ data solutions including data viewing, remote maintenance and continuous WQM but also the establishment of citizen science projects. In many countries access to WQ data is restricted and the great potential of civic activities related to WQ issues is not, yet, recognized. In such countries, positive examples of citizen involvement may result in new opportunities, improved water quality, reduced costs in WQM, and increased credibility of environmental authorities.

On global scale, the region's export potential of WQM expertise is good, but it is still not fully capitalized. According to the study carried out within the Baltic Flows project it has been challenging, especially for SME companies, to market expertise and services outside of the Baltic Sea region, for example to large developing economies. The SMEs would need support for developing business models for capitalizing their expertise, for establishing relations and contacts to their target countries and to build larger clusters of companies to be able to scale up from small local solutions. The active regional clusters, formed within the Baltic Flows project have the potential to offer the needed support and thus, it would be important to secure their continuation in the long term.

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Conclusion - Towards the Region of Excellence of Diffuse Load Monitoring

- ✓ ***the use of innovative water monitoring solutions in official monitoring programs is taken for granted,***
- ✓ ***the authorities use their creativity to establish an enabling and encouraging regulative framework that, in turn creates a predictable and encouraging environment for the companies to develop new products and services for diffuse load monitoring***
- ✓ ***new professionals are educated to meet the level of latest developments in the field and to take them forward***
- ✓ ***innovative monitoring solutions are developed and marketed around the world,***

A large demand for novel online WQM solutions exists globally. The project region bears great potentials to develop these technologies and serve regional to global markets. Through combining the regional strength in WQM technology, education and research with other fields of expertise as smart cities and medical diagnostics applications new products and services might be developed.

Regional environmental authorities use state-of-the-art technology, increasingly involve citizen science projects and constantly aim for advancements in WQM. Diffuse load monitoring in the project countries is supraregionally regulated by the EU WFD and HELCOM, still differences exist in the national implementations of these regulations. The lack of harmonized data collection and management in the EU is an obstacle for companies to develop and market WQM related services. The Baltic Flows countries could export their expertise and experience that stems from long tradition in WQM and close cooperation between education, research, authorities and companies, to other parts of the EU and globally. Within the EU this expertise could help to implement comprehensive monitoring networks, generate long-term data sets which would allow to better understand the environmental changes and the human role in these. Provided that the R&D funding for developing low cost monitoring solutions is increased, the region may become a forerunner in the development of novel monitoring programs based on integration of low cost in-situ sensor networks, citizen participation and smart integration of data from multiple sources. Globally, especially developing countries could benefit from and export of expertise in education, legislation and technology. Here, the knowhow from the project region could help to initiate the fundamental monitoring networks

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that are needed to improve the environmental situation and human wellbeing through provision of sustainable water use and improvement of water quality.

Projects as Baltic Flows help to improve the regional networking and exchange of experiences and knowhow and support the harmonization of WQM activities. The project has been an important step towards the development of a region of excellence in water quality and diffuse load monitoring. The active regional clusters, formed within the Baltic Flows project, have the potential to offer SMEs support for developing business models for capitalizing their expertise, for establishing relations and contacts to their target countries and to build larger clusters of companies to be able to scale up from small local solutions.

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BALTIC FLOWS

Baltic Flows is a European Commission 7th Framework Programme research project which aims at creating a framework for future research cooperation in the management and monitoring of rain-water flow into Baltic Sea catchment areas by establishing common methods of managing and monitoring water quality and quantity and to have a common goal in protecting the Baltic Sea from further environmental degradation.

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