D3.4

Demands and challenges for miniaturised water monitoring technology in urban catchments

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Contents

1. Introduction

Contamination of water resources has become a global issue of concern as a threat to human health and has considered as one of the key environmental problems facing humanity. According to the World Health Organization, water borne illnesses cause about 1.8 million deaths annually (WHO, 2014). Water is the universal solvent, therefore natural water generally contains a variety of contaminants such as heavy metals, salts, minerals, organic compounds, radioactive residues microbiological materials e.g. parasites, fungi, and bacteria. However, during the last decades, as a result of anthropogenic activities, the concentration of these compounds is drastically increasing.

Land use modifications associated with urbanization e.g. removal of vegetation, replacement of pervious areas with impervious surface (e.g. roads) increase stormwater runoff volumes and peak flows (Barbosa et al., 2012; Sänkiaho et al., 2014). During storms and/or rainfalls wastes and a vast range of different pollutants generated on the catchment surfaces are washed out to water bodies (Barbosa et al., 2012; Ledin et al., 2007; U.S. EPA, 2014). An exceeded level of contaminants in the surface water poses a health risk to humans and to the environment, and reduces an amount of available drinking-water.

Apart from the practices, methods described in D3.2 Interim report on new knowledge on urban stormwater management and D3.3 Analysis of potential regions in urban stormwater management, one important component in the context of urban stormwater management (USWM) is the water monitoring (WM). WM is considered as an essential tool and basis foundation for water management in general (He et al., 2011). This report focuses one major aspect of WM, which is water quality monitoring (WQM, chapter 1.1). A successful realisation of such water quality measures directly depends on the effective development of water resource management programs (He et al., 2011). Therefore a water quality analysis that is a base for decision making process regarding water resource management requires a constant monitoring of the different water quality parameters (Zhuiykov, 2012).

This report undertakes an analysis of global needs (Chapter 2) and demands (Chapter 4.1) for miniaturised water quality monitoring. Chapter 3 outlines market opportunities in Europe. The report also describes challenges for miniaturised water quality monitoring (Chapter 4.2) and presents technologies in place and under development (Chapter 5). An extensive but surely uncompleted list of instruments and technologies is in Annex I. The document concludes with an outlook for the water quality monitoring in urban catchments (Chapter 6).

This document highly related to work package 5 (Diffuse load monitoring). Specific aspects for urban catchments is the occurrence of industrial and urban pollutants and the need for a rapid assessment and response in case of stormwater events. Some terms are defines in the following:

Water monitoring

Is defined as "the programmed process of sampling, measurement and subsequent recording or signaling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives" (RS Hydro, 2014). Water monitoring (WM) includes quantitative and qualitative methods. Quantitative methods, like the estimation of water discharge rate or rain gauge are focused on the water amount, while water quality monitoring (WQM) deals with the assessment of the quality of water regarding water use and its function as a natural habitat. Regarding the monitoring approach in can be distinguished between point measurements (point sources for pollution) and diffuse load monitoring (see D5.2 and D5.3). The discharge of pollutants by urban surface runoff is defined as a non-point pollution (Gnecco et al., 2005).

Water quality monitoring

Water quality monitoring provides qualitative and quantitative information on the physical, chemical, and biological characteristics of a water body over time and space (Sanders et al., 1983 in Strobl & Robillard, 2008). These characteristics are compared with water quality guidelines or standards (United Nations, 2014), which define the water quality status of a water body (chapter 2). The process requires customized apparatus, comparable data and trained staff (Korostynska et al., 2013). Water characteristics, such as dissolved oxygen (DO), pH, nutrients, and temperature, are known as parameters. Parameters can be physical, chemical or biological in nature. Table 1 gives an overview of parameters of each category. This table does not provide the finite list of water components that can be measured due to the vast number of chemical and biological components. Additional parameters may be listed in D5.2. This variety already points out the challenge of (miniaturised) water quality monitoring.

Table 1: List of water quality parameters.

Category	Parameter
Physical	Temperature, conductivity/salinity, pH, transparency/turbidity, suspended/dissolved solids, DO, acidity and alkalinity, water colour
Chemical	Nutrients (e.g. ammonia, nitrogen, phosphorus), (heavy) metals such as cadmium, mercury, copper and zinc, major ions such as (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), sulphur (S), organic matter, total organic carbon (TOC), biochemical oxygen demand (BOD), organic micro-pollutants, such as fertilisers, pesticides and numerous chemical substances
Biological	Algae species, chlorophyll, phytoplankton, bacteria, flourescence

Characteristic pollutants in urban catchments are chemicals like mineral oil products (e.g. motor fuel) and combustion products (e.g. polycyclic aromatic hydrocarbons (PAHs), heavy metals, industrial chemicals, but also fertilisers and pesticides.

Miniaturised

This monitoring approach means to reduce the effort for data measurement, collection and analysis. At the same time the outcome of the monitoring should be maximised with regard to data amount in time (continuous measurements) and space (coverage of a water body) as well as the speed-up of data collection, processing and dissemination. The aim of the development of miniaturised water monitoring is to move away from offsite laboratory testing to low cost and compact test kits that provide real time data analysis on site and which can be used by staff with minimal training. Portability and miniaturisation of devices makes it possible to move the lab to the sample using user-friendly analytical instruments. Such devices indicate a high degree of compactness, are light and small enough to be easily carried or moved (Capitán-Vallvey & Palma, 2011).

2. The needs for miniaturised water monitoring in urban catchments

During the last decades climate change e.g. droughts in Australia, Africa, Middle East and southern parts of Europe and USA as well a growing urbanisation level have resulted in general decline in the level of water in rivers, water catchments and surface collection dumps, with increasing concern over deteriorating water quality in these water bodies (Zhuiykov, 2012). On the other hand, due to climate change, stormwater events with increasing precipitation occur more often.

The urbanisation process has led to increase in impervious surfaces (roads, parking lots and sidewalks), which increase the effect of stormwater events by increasing the surface runoff. These surfaces (mostly built from materials such as asphalt and concrete) carry polluted stormwater to storm drains during precipitation events. Stormwater contains pollutants and nutrients, which can endanger soils, groundwater and slowly flowing receiving waters when it is discharged. Rain contains sulphate, chloride, ammonia and phosphate in remarkably high concentrations. In addition to atmospheric contaminants, pollutants can also be emitted by roof material (Dierkes et al., 2013). Water running off these impervious surfaces also picks up a variety of pollutants, such as gasoline, motor oil, heavy metals, trash and other pollutants from roadways and parking lots. Moreover, the water tends to pick up fertilizers and pesticides from lawns. Urban runoff is considered to be a leading source of water quality problems related to pollutants increase in rivers, streams, fish and even groundwater aquifers. Furthermore, urban flooding is also related to stormwater management issues and extra financial costs.

Nowadays, the problem with existing urban drainage systems in Europe, which are commonly built as combined sewers, is that they are now endangering receiving waters. Most municipal storm sewer systems discharge untreated stormwater to streams, rivers and bays. The results of a study conducted in the municipality of Albertslund (Denmark) have shown that, the quantity of heavy metals transported with stormwater to water bodies is higher compared to treated municipal wastewater on an annual basis (Rasmussen et al., 2006 in Ledin et al., 2007).

Today, very complex water pollution problems require complicated multi-staged treatment processes (Zhuiykov, 2009). At the beginning of the process chain, water monitoring identifies problems and is used to measure the effectiveness of efforts to minimize a level of contamination. It also provides reliable data required for effective management of water resources (Johnson, 2014), and early warning systems, to signal when critical pollution levels are exceeded or toxic effects occurred (World Meteorological Organization, 2013) and remedial action are needed to be taken (Flynn et al., 2010). In addition, knowledge of the characteristics of stormwater quality e.g. pollutant types, sediment particle size distributions, and how soluble pollutants and heavy metals attach themselves to sediment particles enables urban planners to incorporate the most appropriate stormwater management strategies to mitigate the effects of stormwater pollution (Boogaard et al., 2014). Furthermore, water quality monitoring and control provide scientific and reasonable technical support for water resources integrated planning, water environment assessment, water treatment and conservation technology (He et al., 2011). The ability to take tailored measures could also reduce cost in USWM.

The traditional, sophisticated WQ measurement methods via laboratories, performed with sufficient quality-assurance procedures provides accurate results. However there is a number of disadvantages to be named. The monitoring campaigns are very expensive, less flexible (e.g., meters generally have to be read in the field) and require periodic calibration (U.S. EPA, 2012), trained staff, fresh supply of chemicals (Korostynska et al., 2012). The instruments have a poor portability (Deng et al., 2013) and the transportation of samples may disturb their chemical properties, thus leading to unreliable water quality testing results. Overall the process of WQM is time-consuming (World Meteorological Organization, 2013), give limited point measurements and furthermore, become an expensive method for remote sites. For instance, traditional measurements of nutrients, such as phosphorous, ammonia and volatile fatty acids in water are mostly based on off-line monitoring and imply low frequency data sampling and delay between sampling and availability of the results (Korostynska et al., 2012).

It can be concluded, that according to these disadvantages, the traditional monitoring programmes do not meet the needs of WQM in general and USWM in particular. Daily monitoring of the water quality and track of the pollution emergency require a low-cost and mobile online monitoring devices (Deng et al., 2013). The state-of-the-art WQM needs a regular monitoring with frequent measurements with sufficient spatial coverage to provide a timely warning of potential contamination incidents (U.S. EPA, 2010). It also needs a quick data transmission, integration and analysis in order to take appropriate measures in time.

The requirements and needs of WQM monitoring defined in policies and legislative regulations (Chapter 2.2). Fortunately improvements and technology solutions are today in place (Chapter 5, Annex I). For instance, information on water quality obtained by means of innovative biosensor technologies can assist monitoring programs to verify compliance with legislation (Rodriguez-Mozaz et al., 2004, Rickerby, 2009) and contribute to the development of improved water management strategies (Rickerby, 2009). Also, the rapid development of wireless sensor technologies indicates the possibility to change radically the existing methods of data collection and monitoring that are used by sewer network operators. This can be achieved via the deployment of massive, self-organised sensor networks that able to convey real or near real-time data to managers who can then respond appropriately (See et al., 2012).

2.1 Policy driving needs

The toughening of international ecological standards require also more sensitive instruments with faster response time and better antifouling resistance (Zhuiykov, 2012). One of the most important roles in maturing water monitoring industry plays the Water Framework Directive (WFD, 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). The WFD is a European Union directive which commits European Union member states to achieve good qualitative and quantitative status of all water bodies by 2015. The directive aims for 'good status' for all ground and surface waters (rivers, lakes, transitional waters, and coastal waters) in the EU. The WFD committed to achieve the ecological and chemical status of surface waters is assessed according to the following criteria:

- Biological quality (fish, benthic invertebrates, aquatic flora);
- Hydromorphological quality such as river bank structure, river continuity or substrate of the river bed;
- Physical-chemical quality such as temperature, oxygenation and nutrient conditions;
- Chemical quality that refers to environmental quality standards for river basin specific pollutants.

To fulfil the WFD requirements water monitoring reliability and quality need to be improved. For this, a continuous on-line monitoring with automatic instrumentation is required.

Furthermore, the implementation of the WFD has triggered the need for new methods and systems, which enable the monitoring of chemical and biological pollutants in real time (Korostynska et al., 2013). In addition, the EU stresses on the strengthening of water monitoring and information management in order to assess current progress in sustainable water resources management (Freshwater Society, 2014).

In recent addition to the WFD, the Directive 2008/105/EC of the European Parliament and of the Council on environmental quality standards in the field of water policy analyses monitoring needs and sets detailed requirements on 33 prioritized substances that are important to consider how to be measured and reported – to develop national programs and laws how to reduce and limit in natural water.

A policy framework for water monitoring in the context of USWM is not yet in place, but urgendly needed to foster accordant actions. Such policies are for instance already in place in the U.S. and Australia (Urban Stormwater Initiative Executive Group, 2005). Further legislative regulations on regional and national level are describes in D5.2. However, the implementation of miniaturised water quality monitoring is already taking place because of the need of maintaining drinking water quality and cost reduction (Chapter 4.1).

One special monitoring issue in urban catchments is sewer flooding and pollution incidents, which are the most problematic issues encountered by water companies. In UK, their performance is regulated by the Office of Water Regulation (OFWAT) via a number of performance indicators. Failure to meet these indicators can result in severe financial penalties. The government places a legal responsibility on the water companies not only to maintain the structural and operational reliability of the sewer system, but also to reduce progressively its risk of failure. In order to become more operationally efficient, the UK's water industry is currently investing in excess of £200 million per annum (Hayward, 2002).

3. Market opportunities

Emerging markets for water monitoring and testing technologies are located in Europe due to compliance with EU directives. Industrial, agricultural and water supply industries invest a great deal of time and effort in collecting precise water quality data in order to be able efficiently handle polluting effluents before they enter the environment and lead to irreversible consequences (European Commission, 2005). State regulators, local governments, industries, consultants, catchments groups, community groups, land holders, research and education organisations need quality monitoring devices in order to reach water quality targets required by regulations, as well to avoid the consequence of inadequate monitoring that can result in substantial health risks, and economic (recovery costs) and reputational damages and liabilities (de Graaf et al., 2012). The opportunities have been elaborated by the European Policy Evaluation Consortium (EPEC, Lonsdale et al., 2011). The global turnover for environmental sensing and monitoring technologies was estimated at €6.5 billion in 2008 and €7.4 billion in 2009 - a compound annual growth rate (CAGR) of 5.2% (Lonsdale et al., 2011).

One component of the environmental monitoring sector is water quality monitoring and testing. The global water testing market is estimated to be worth €2.6 billion in 2009, approximately 35% of the total environmental monitoring sector. The total value of extra EU exports of water monitoring technologies in 2009 was €447 million. Germany was the leading exporter (38% share) with around €170 million of equipment exports (see Figure 1). France and the UK exported similar levels at around €60 million. A third cluster of exports included Sweden, the Netherlands, Italy, Austria and Ireland at around the €10m to €30m level (Lonsdale et al., 2011).

Cost reduction is also a leading driver since developments can reduce costs associated with the collection, analysis and interpretation of environmental data while providing a more comprehensive dataset. There is also an identified need for cost reduction in environmental measurements which is driving the demand for measurement technologies without the need for laboratory testing (Lonsdale et al., 2011).

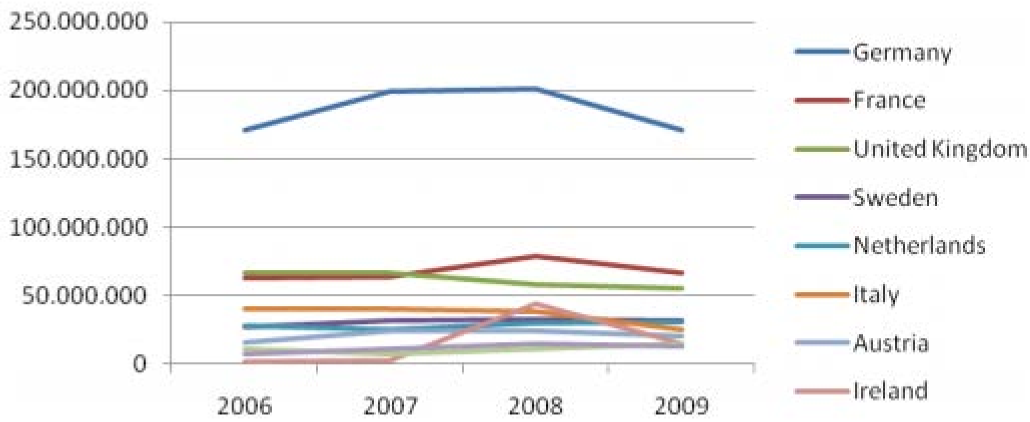

Figure 1: The extra-EU export value of top 10 EU member states for water monitoring2006-2009 (Euros). Source: GHK analysis of Eurostat data (Lonsdale et al., 2011)

Innovation Type The UK's Environmental Knowledge Transfer Network, recognizing the importance of the sector to the UK, produced two reports addressing water monitoring in the UK and Europe: Rapid Measurement Tools (2007) and Environmental Monitoring and Forensics (2008). The reports conclude that key driver of innovation is changing industry perceptions of gathering data simply for compliance to one that generates commercial benefits. The UK has a good reputation in early stage company development in this space (see Table 2).

Table 2: Source: GHK analysis of Eurostat data (Lonsdale et al., 2011).

Company	Country	Technology
Salamander Group (licensed to Siemens)	UK	Water quality monitoring via hydrants
Modern Water	UK	Bioluminescence process for real time detection of toxins
i20 Water	UK	Smart water/monitoring and control
Shaw Technologies	UK	Physical water quality monitoring
Sens-Innov	France	Smart water/sensors
Sorbisense	Denmark	Smart water/sensors

Source: GHK market analysis, Cleantech Group LLC, 2010. Note: companies not ranked

In general, the market for water monitoring and testing technologies is maturing, although there is scope for new innovations around instant detection of contaminants. The ability to coordinate data sets from numerous sites, for example to build up a picture of water quality across a river basin catchment is also driving innovation in sensors, software and telemetry as well as analytical and decision support tools. Innovation in the water monitoring sector is incremental, largely due to the resistance of users to adopt new technologies and the overall maturing of the market (Table 3).

Scope for innovation exists in the need for the miniaturisation of equipment that is able to analyse data onsite and produce real time results. These types of technology have the potential to generate huge cost savings by eliminating the amount of testing required in laboratories (Lonsdale et al., 2011).

Table 3: Leading EU technology producers (Detailed…, 2011).

Company name	Country	Sector
Suez	France	Water treatment & monitoring
Veolia	France	Water treatment & monitoring
SAUR	France	Water treatment & monitoring
RWE	Germany	Water treatment & monitoring
Siemens	Germany	Water filtration
Norit X-Flow	Netherlands	Membrane filtration
Agbar	Spain	Water treatment & monitoring

GHK analysis, adapted from Cleantech Group LLC (2010) and Pinsent Masons (2010)

The water monitoring and testing industry covers a large range of end uses. Water must be tested and monitored for chlorine levels, biochemical oxygen demand (BOD) and the presence of micro-organisms. Utility and industrial water must be tested for volatile organic compounds (VOCs), polychlorinated biphenyls, herbicides and pesticides as well as nitrogen, phosphorus, and magnesium nutrients. This has resulted in the development of numerous technologies for the testing of different contaminants across diverse applications, since testing requirements differ according to the water source (i.e. groundwater, wastewater, surface water etc.) (Lonsdale et al., 2011). The largest scope for innovation is seen as the growth of xenobiotics issues in the EU. Xenobiotics include substances such as common pain relievers, human and veterinary antibiotics, birth control medications and personal grooming products. Advanced testing technologies have allowed the detection of xenobiotics at parts per trillion levels, their impact is unknown and the water monitoring industry must anticipate whether or not they will become controlled and regulated substances that must be tested and monitored (Lonsdale et al., 2011).

4. Demands and challenges on miniaturised water quality monitoring

4.1 Demands for miniaturised water quality monitoring

The demand for miniaturised water monitoring technologies and devices is shaped by demand for reliable, high quality and high resolution information about water quality that is essential for water management and for improving the environmental quality of water resources (Cleary et al., 2013). The currently applied monitoring practices are unsatisfactory due to very high per sample costs because of the manpower requirement for sample collection and the cost of analysis. In the case of drinking water, consumers expect water supply companies to deliver safe drinking water that meets both health quality standards and aesthetic requirements such as colour, turbidity, taste and odour (Korostynska et al., 2013). It requires intensive, precise and reliable water quality analysis. Today citizens as well as companies are using small devices to monitor water quality and make readings of various pollutants. Cell phone technology enables the devices to send out the readings immediately, and they can be reported in intervals of 15 minutes or less (Thomason, 2013).

Legislation has become another major driver for a growing need for increasing the frequency of monitoring of water quality across a broad range of applications (Chapter 2), including municipal and industrial wastewaters, and drinking water (Cleary et al., 2013).

Contamination of water resources may take place at different locations. Therefore it is necessary to detect a wide range of chemical and bacterial contaminants as quickly and reliably as possible (Rickerby, 2009). The demand for chemical monitoring is expected to intensify because of the requirements of WFD, according to which, a list of 33 priority chemicals (inorganic and organic pollutants and substances) will be reviewed every 4 years (Allan et al., 2006). Already in 90s, remarkable advances in the sensor design, miniaturised electronics and computing dramatically have reduced costs, size and increased lifetime of water quality monitoring devices, e.g. chemical, gas and biosensors (Alexander et al., 1996).

Moreover, modern devices typically require a small amount of the sample without any reagents or with the reagents immobilized on a disposable element or included as a solution in a small reservoir included in the instrument, producing less or no waste (Capitán-Vallvey & Palma, 2011).

Deployment characteristics of instruments, costs, robustness, sensitivity and the type of measures and information required have a direct impact on the choice of monitoring type (Allan et al., 2006), therefore, for example, demand for optical sensors is increasing due to such characteristics as sensitivity, versatility possibility of on-line detection and miniaturization (Ibañez & Escandar, 2013). Photometric sensors (e.g. Colorimetric; UV Absorption; and UV-Visible Absorption sensors) are among the most commonly used. They are employed because of their simplicity and rapid response. UV-Vis absorption sensors are used, mainly, because samples can be analysed with very little sample preparation, no chemicals, and they have low operational costs (Halloran et al., 2009).

The use of innovative biomolecular-based monitoring methods allows the assessment of the ecotoxicological status of water bodies, identification of specific biomarkers and the development and implementation of more sensitive techniques for assessing water quality based on DNA arrays and proteomics (Rickerby, 2009).

An additional factor that has an impact on a choice of end-users is more useful, continuous monitoring capabilities provided by wireless sensing systems that give accurate information on the changing environmental and water quality in real time. It is particularly important for measurements of the true maximum and/or mean concentration for a particular physicochemical variable in a water body with marked temporal variability. Thus, in-situ sensors used for continuous sampling of parameters required under the WFD cut monitoring costs provide more up-to-date information and better coverage representing long-term trends in fluctuations of pollutant concentrations. (Flynn et al., 2010).

The demand for miniaturised water quality devices is also influenced by such advantages as:

- Immediate sending of rapid results;
- Continuous monitoring;
- Automatic monitoring;
- Short-term management;
- Monitoring of decontamination processes;
- Early warning systems and applications;
- Reduction in error associated with sample preparation, transport and storage

(World Meteorological Organization, 2013).

An increasing demand for microfluidic sensing systems is explained by the following benefits:

- The small sample sizes used, minimise reagent consumption and waste generation;
- The small size of the microfluidic manifold facilitates the development of compact and portable analytical systems;
- Fast analysis times result from performing chemical analysis on the micro scale, where diffusion based mixing can be an efficient process, allowing high sample throughput and/or frequent measurements;
- Low-cost sensing devices can be developed by combining microfluidic systems with simple, low cost detectors

(Cleary et al., 2013).

4.2 Challenges for miniaturised water quality monitoring

A number of challenges regarding designing, developing and using of miniaturised WQM technologies and devices includes such aspects as performance and power consumption optimisation, robustness, reliability of obtained data, and simultaneous measurement of several water quality parameters. In the design and development of devices, which are going to be used in situ, environmental conditions such as temperature, pressure, humidity and moisture, corrosive fumes, aerosols, organic vapours, and electromagnetic interference need to be considered carefully (Capitán-Vallvey & Palma, 2011).

There is no a unique method or equipment that might be the most appropriate for all monitoring studies of urban stormwater. The optimal approach for each case should take into account, specific conditions, e.g. the intensity and the amount of precipitation or the pollutants (Hvitved-Jacobsen et al., 2010 in Barbosa et al., 2012), and stormwater quantity and quality characteristics related to seasonal variability. Sampling of stormwater is considerably more difficult because of the lack of control over sampling times and conditions, since rainfall events do not follow a predetermined schedule (Department of Irrigation and Drainage Penang, 2012). Placement of a sensor at a particular location requires consideration of such factors as accessibility, electricity, physical security, data transmission capability, sewage drains, and temperatures within the manufacturer specified range for the instrumentation (ASCE, 2004 in Zhuiykov, 2012). In addition, temperature controls is needed to avoid freezing or heat damage (Zhuiykov, 2012).

Although researchers are developing optimization strategies, a sensor measuring data with 100% reliability is clearly unrealistic (U.S. EPA, 2010). Selection of a monitoring tool require consideration of the level of uncertainty of the procedure and of the fact, whether a collected sample is truly representative (over time, space and bioavailability) of the chemical conditions prevailing in the water body (Allan et al., 2006). There are also drawbacks associated with micro-scale sample sizes, in terms of adequately representing the complete body of water which is to be measured. Due to the small dimensions of the microfluidic channels, they are susceptible to blockage or interference by fine particulate matter (Cleary et al., 2013).

One of the problems that attributable to almost all water monitoring systems is biofouling. Biofouling is the undesirable accumulation of microorganisms, plants, algae, and/or animals on water-exposed surfaces. The system suffered from biofouling within days of deployment requires regular maintenance. It decreases the operating lifetime of sensors in the field and introduce a degree of error into the collected data (Korostynska et al., 2012). In addition, periodically, sensors require re-calibration and devices are vulnerable to damage (Department of Irrigation and Drainage Penang, 2012).

Optical absorption and reflectivity spectrometers, available for a number of substances, limited in their concentration range with only medium sensitivity compared with standard laboratory analysis (World Meteorological Organization, 2013). The methods and algorithms employed in single probes or combinations of sensors are commercially sensitive, that makes independent validation of these systems difficult (Korostynska et al., 2012).

Among the disadvantages of the process of miniaturization of devices, experts name trade-offs, usually made in order to optimise weight, power, and performance. Devices should be self-consistent, which means that the final result (reading) displayed on a screen, must be internally stored in the memory, or sent elsewhere wirelessly. Therefore, a device should contain the hardware and software for the minimum control of the measurement configuration and for signal processing (Capitán-Vallvey & Palma, 2011). One of the main goals of developers is to reduce power consumption of devices. Today, most instruments can work off of batteries and/or autonomous power (mainly through photovoltaic energy from miniaturized solar cell panels). Both primary and re-chargeable batteries are used. Although voltage levels can be raised or lowered, energy-saving and low noise constraints mean that voltage use should be limited to the levels of the supply batteries, keeping the stages of voltage level conversions to a minimum (Capitán-Vallvey & Palma, 2011).

5. Miniaturised water monitoring technologies

An extensive table of miniaturised WAQM instruments is listed in Annex I. However it does not contain all instruments that are on the market or under development. The situation and used systems of continuous monitoring systems in the Baltic regions and the differences between the partner countries was elaborated in work package 5 (Diffuse load monitoring).

Among currently available technologies for the water quality monitoring are field-measured devices such as thermometers or thermistors, portable pH and conductivity meters, DO meters or optodes, optical turbidity meters, fluorometers, UV-absorption devices etc. (World Meteorological Organization, 2013). Measurement technologies can the grouped in biological, chemical and physical methods.

5.1 Biological monitoring techniques

Biosensors are analytical devices, which convert a biological response into an electrical signal (Korostynska et al., 2012). These include biomarkers, biosensors, biological early warning systems and whole-organism bioassays. Biosensors are able to detect and measure concentrations of pollutants and to perform toxicity analysis of water samples as well are also available for monitoring PAHs, pesticides and heavy metals, while enzyme assays are being tested to detect phenols (Allan et al., 2006; Rickerby, 2009).

5.2 Chemical monitoring techniques

The concept of chemical sensors involves a change of paradigm in analytical chemistry from general analytical systems to dedicated systems. The chemical information sought about matter is obtained in real time, possibly on site, as a result of the interaction between sensor and chemical/s in a two-step process: recognition and signal treatment (Capitán-Vallvey & Palma, 2011). According to the Cambrigde definition, a chemical sensor is a miniaturized device that can deliver real-time and on-line information on the presence of specific compounds or ions even in complex samples (Ibañez & Escandar, 2013).

The method of passive sampling, is based on a reference (or receiving) phase that is exposed to the water phase, without aiming to quantitatively extract the dissolved contaminants. All passive sampling devices absorb/adsorb pollutants from water (Allan et al., 2006). Currently available passive sampling devices are applicable to monitoring chemicals with a broad range of physicochemical properties and the detection limits obtained or the lowest measured concentrations. Passive sampling devices can be used to monitor more than 75% of the organic micropollutants listed in water-quality criteria of the EU and US, the EU Water Framework Directive and the recommendations of The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) (Vrana et al., 2005).

Deployment of passive samplers based on the uptake of truly dissolved contaminants or the establishment of continuous monitoring stations with both biological and chemical testing capabilities may be implemented at lower cost and provides more useful data on the variability of contaminant concentrations or temporal changes in toxicity (Allan et al., 2006).

5.3 Physical monitoring techniques

Electrochemical sensors offer a suitable platform for the development of microsystems for the remote detection and monitoring of pollution in waters (Korostynska et al., 2013). The major advantages of the microelectrode array sensors include the ability to penetrate samples to perform measurements, small tip size for in situ measurements, array structure for higher robustness, and possibility of multi-analytical detection (Korostynska et al., 2013).

Among the variety of sensors are E-tongues, which are analytical measuring devices comprising an array of potentiometric chemical solid-sate sensors with relatively low selectivity albeit, high sensitivity to several components of a solution (cress-sensitivity) and an advanced data processing engine such as pattern recognition or multivariate calibration (Zhuiykov, 2012). Experts consider the development of miniature, reliable, inexpensive water quality solid-state sensors using metal oxide sensing electrodes (SEs) as a promising alternative to the contemporary time consuming analytical methods of water quality monitoring (Zhuiykov 2012).

UV-absorption devices and fluorometers are simple, sensitive and rapid, and do not use chemicals (World Meteorological Organization, 2013), whereas, laboratory-based analytical methods require frequent calibration and maintenance and often consume large quantities of chemical reagents and buffers, which produce secondary forms of pollution that require safe disposal (Halloran et al., 2009).

Moreover, remote sensing using optical, thermal sensors on aircrafts and satellites may be used to monitor water quality parameters like nutrients, temperature, turbidity, chlorophyll and chemicals. High resolution remotely sensed data is then correlated by empirical or/and analytical models to a water quality. Since, this is an expensive solution which application is limited for regions covered by the satellites. Furthermore, data may not be available in real time and data sampling frequency may be insufficient. Advancements in micro-electro-mechanical systems (MEMSs), low-power and low-cost microcontrollers and radio modules enabled Water System Networks (WSNs) for environmental monitoring, which overcame the limitations of previous expensive, and bulky monitoring equipment with low spatio-temporal resolution to a certain extent. WSNs are networks of small embedded computers referred to as sensor nodes or 'motes', spatially distributed to cooperatively monitor environment and transmit data wirelessly. The relatively low cost of a WSN allows in principle, the deployment of a dense population of nodes that can adequately represent the variability present in the environment. Water quality parameters such as pH, dissolved oxygen (DO), turbidity, salinity and nitrates have been measured in the reviewed applications using WSNs.

Another techniques have emerged in recent years is a number of commercial 'Zigbee' compliant wireless sensor platforms (Johnson et al., 2009). Not all of them are suited to this work due to the inclusion of proprietary communication protocol and the lack of Ethernet IP connection from the gateway node in some of these sensor platforms. The advantages associated with employing such a commercial wireless sensor system include immediate "out-of-the-box" operation, availability of technical support from the platform manufacturer, and low unit costs. Nevertheless, constructing and distributing a wireless sensor networks over a large scale monitoring application has only become possible with some fundamental advances in the enabling technologies. The most important advance has been the miniaturization of hardware. Smaller feature size in chips has driven down the power consumption of the basic components of a sensor node to a level that means that the construction of battery powered WSNs can be contemplated. By comparing the existing Zigbee-compliant wireless communication system manufactures (Johnson et al., 2009) it was found that Crossbow (MEMSIC, 2011) is the only supplier which is capable of furnishing the most complete wireless communication system for this monitoring application. At present, the virtual sensor technology is still under development. But already, and despite the expected difficulties associated with this strongly transdisciplinary approach, some promising results have been obtained. Microfluidic technology provides a route to the development of miniaturised analytical instruments that could be deployed remotely, and operate autonomously over relatively long periods of time (months–

years). These instruments are: optical detection based on UV-LED light source and photodiode detector – Wireless communications (GSM modem, Zigbee radio, Bluetooth), autonomous phosphate sensor, microfluidic chip for performing mixing and reaction on micro-scale (22µL per analysis).

Limitations of remote monitoring:

• Data available for limited range of parameters

• Availability can be limited by natural factors, like cloud cover

• Resolution

5.4 Technologies specific to USWM

While the number of on-line measurable water quality variables remained limited for a long time, miniaturisation of wet-chemistry methods and spectroscopic methods with dedicated data analysis algorithms now allow for measurement of many important quality parameters, even in the difficult conditions encountered in sewer systems (Gruning and Orth, 2002; Vanrolleghem and Lee, 2003). During wet weather flow, two phenomena typically occur in combined sewer systems. A first flush event resulting in a peak load of total suspended solids (TSS) (measured through turbidity analysis) to the plant (Figure 2, right) is observed when the storm event occurs after a long period of dry weather flow, which allowed sedimentation of TSS in the sewer system. The figure shows the same period as the latter half of the flow data (Figure 2, left). The peak brings about ten times the normal TSS load to the plant. This number is, however, dependent on the sewer system and the dry weather period preceding the event. Figure 2 also illustrates this dependence on the antecedent period as during the second storm (on 19/4) no TSS peak is observed. A few important variables remain unaccounted for in the on-line measurement portfolio, e.g. pathogens and micro-pollutants such as pharmaceutical and personal care products, heavy metals, pesticides, etc. Laser diode thermal desorption – atmospheric pressure chemical ionization tandem mass spectrometry analysis of selected steroid hormones in wastewater (Miles et al., 2011) the availability of such data still seems far away. For now the practical use of water quality sensors in automatic control remains limited to WWTPs (Olsson et al., 2005), where they are not only applied for effluent quality control but also for reduction in resource use such as energy and chemicals. Very recently sewer systems have been equipped with UV/VIS spectroscopic sensors to control sulphide-induced corrosion problems by chemical addition (Oriol et al., 2010). Trial runs are also starting up regarding the use of on-line TSS measurements to control sewer systems (Hoppe et al., 2011).

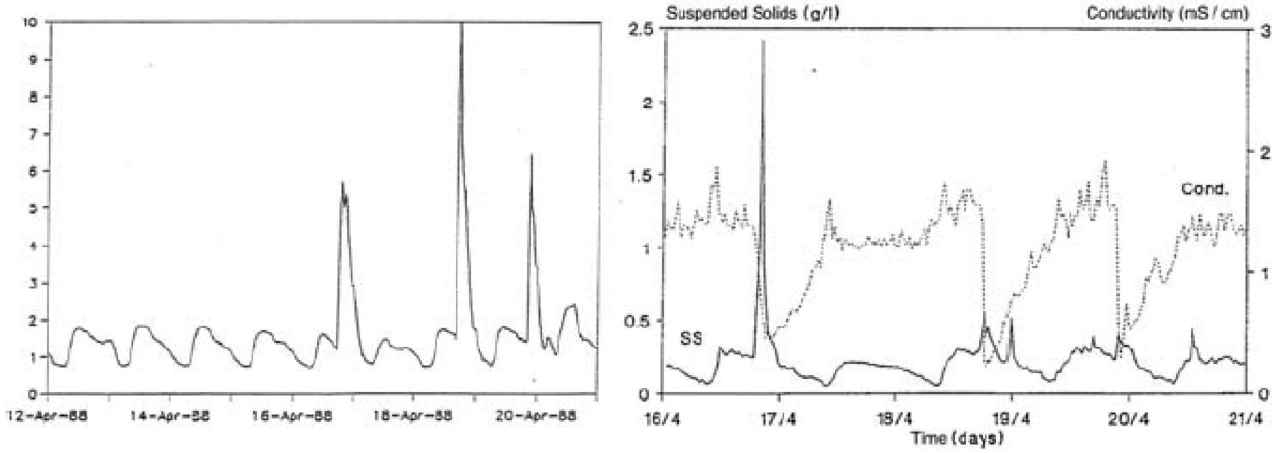

Figure 2: Illustration of the effect of rain events on flow (left) and water quality (right): conductivity (dilution) and suspended solids (first flush effect) measured in the catchment of Brussels (Belgium). Note that the right figure's time axis is the latter half of the left figure.(Campisano et al., 2013).

In terms of telecommunication, many technologies including fibre optic and dedicated phone lines permit a fast data transmission rate with very few communication failures. However, other equipment such as water quality sensors still have to be improved or embedded in fault detection systems, which explains why most of the (RTC) Real Time Control systems developed for (UDSs) Urban Drainage Systems are currently operated to achieve environmental objectives that are only based on quantity parameters (e.g., flood protection, minimisation of CSO Combined Sewer Overflows frequency and volume) and not on quality parameters (Campisano et al., 2013).

A number of comprehensive mechanistic models are also available for estimating sediment concentrations and loadings discharged from urban drainage systems. All however, require substantial local data to set variable parameters in the calibration step and to verify them for the intended application. In the UK, the National Rivers Authority has identified a strategic modelling framework for implementing the intermittent discharge requirements of the EU Urban Wastewater Treatment Directive. The framework advocates the use of a suite of deterministic sewer quality models (MOSQITO, QM) which can model various SS fractions as well as BOD/COD and total ammonia. An alternative stochastic modelling approach (MOUSETRAP) based on EMC lognormal assumptions is also widely used throughout Europe whilst the US-based models ILLUDAS, STORM and SWMM have been in wide global use over the last decade. These models structure the water quality components on a mass balance framework with sediment additions (deposition) computed as a linear function of time and with losses represented by a first-order wash off function (Ellis, 1996).

Screening Methods and Emerging Tools (SMETs) for water quality monitoring may be quantitative, semi-quantitative and qualitative methods. SMETs main characteristics are, that they:

- Offer field measurements, which are on-site, in-situ, or continuous;
- Provide fast measurement response;
- E easy to use
- Improve knowledge of water quality (composition variation);
- Capture low concentrations of certain pollutants;
- May provide time average measures;
- Have fast response times for result assessment;
- Provide supplementary information and they may be used as a complement of classical methods;
- May be cost-effective in certain situations than classical chemical methods.

Their main disadvantages are that they:

- In general not validated as classical screening methods;
- Lacking adaptation on large scale operations;
- Not widely accepted by monitoring experts;
- May not always be cost-effective depending on the monitoring situation.

The current water quality monitoring practice is primarily based on laboratory analysis of spot samples collected at prescribed periods of time. But water quality monitoring faces temporal and spatial variability. SMETs are in general easy to use and they allow field measurements at the source, they assess spatial and time water quality evolution and they provide additional information about the biological and chemical quality of the water.

There are three major categories of SMETs, all categories are listed in Table 4:
1. In situ: where the measurement is made directly in the water body (e.g. dipping a sensor), sampling therefore is not necessary.

2. On-site: the measurement is made in the field close to where a sample was taken (e.g. using a test kit or sensor to analyse a bottle sample on the river bank).

3. Laboratory: for some methods field sampling is followed by transport to a laboratory for analysis (the laboratory can be any distance from the sampling site).

On-site and Laboratory SMETs require a sampling protocol. The different types of sampling protocols include:

- No sampling: a technique which does not require any sampling.
- Spot sampling: the sample is taken in a very short time.
- Passive sampling: a technique where the sampling device (e.g. passive sampler) is deployed for an extended period of time to obtain time-weighted average pollutant concentrations.
- Continuous sampling: sampling is made, without interruptions (or with very high frequency), throughout an operation or for a predetermined time. For example, water can be pumped from the river to a laboratory close to the intake site where it can be monitored in a flow-through system (e.g.
- SAMOS).

Table 4: SMETs Categories and their use as to sampling mode, type of analysis and parameter groups ((SWIFT-WFD, 2003).

	Sampling				Analysis/ Mesaurement			Parameters		
Emerging Tool/ Method	Spot Sampling	Contin uous	Passive Sampling	No Sampling	On Site	Lab	In Situ	Physico/ Chemical	Specific Pollutants	Toxicity
Laboratory based methods (on-line or portable)	✓				✓	✓		✓	✓	✓
		✓			✓	✓		✓	✓	✓
Chemical Test Kits	✓				✓			✓	✓	
		✓			✓			✓	✓	
Elisa/ Immunoassays	✓				✓				✓	
		✓			✓				✓	
Sensors (Probes)	✓				✓			✓	✓	
		✓			✓			✓	✓	
			✓			✓		✓	✓	
				✓			✓	✓	✓	
Biosensors	✓				✓			✓	✓	✓
		✓			✓			✓	✓	✓
			✓			✓		✓	✓	✓
				✓			✓	✓	✓	✓
Bioassays	✓				✓	✓			✓	✓
			✓			✓			✓	✓
Biological Early Warning Systems		✓		✓	✓				✓	.
				✓			✓		✓	✓
Biomarkers	✓					✓			✓	✓
Passive Samplers			✓			✓			✓	✓

6. Conclusions and outlook

A review and analysis of demands and challenges of miniaturised water monitoring technologies and devices indicate on rapid development and expansion of the field. Among the main drivers are water related legislation, climate change, availability of drinking water and prevention of health risks, high costs of currently used equipment, extensive water quality data processing, as well technological advances in materials, electronics, computing and telecommunications systems. Experts point out advantages of miniaturisation of water quality monitoring devices such as reduction of production, maintenance and calibration costs, a possibility to merge various technologies for monitoring of different water parameters into a single system, reduction of time required to obtain, transfer and process measurement results. There is already a significant response to the needs for monitoring improvements and market opportunities are on the table.

However, there are also a number of challenges associated with development and usage of such devices. For example, currently, there are no broadly agreed international standards or developed methods that allow for large-scale, online, reliable and cost-effective data to be acquired, integrated and applied (Halloran et al., 2009). Further technological development and improvement in the area of increasing of the level of performance, reliability and robustness of monitoring devices is needed.

The challenge in supervision and monitoring unwanted pollution substances in stormwater is growing in the same pace as cities expands. Not only Mega Cities affect and changes the natural paths of rainwater or waste water, but also small cities with large hard covered ground areas for buildings or parking areas forces all precipitations into stormwater systems. Stormwater is normally separated from wastewater in developed countries, where wastewater cleaning is managed by sewage treatment plants. Stormwater was expected to contain less waste and is forwarded with less treatment into lakes or streams. However it is no proven that urban stormwater is a great risk for contamination of drinking water sources and to the ecological status of water bodies. Therefore, national and EU regulations are focusing on monitoring and early warning systems in this area. Since stormwater events can lead to a rapid pollution by numerous contaminants, there is a need for a fine grain warning system with realtime monitoring.

The cost of a high density monitoring system using today's expensive sensors and analytic methods is extremely high. Most of experts agree that a possible solution must rely on miniaturized and low cost sensors that are communicating in real time with a central supervision and warning instance. Preferably these low cost sensors shall also use wireless communication to reduce installation costs.

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Annex I

Table 1- Some examples of miniaturised WQM instruments

Name of a device	**Description**	**Link**
Single parameter water quality sensor instruments		
WaterBot	Real-time conductivity sensor and data logger. Enables inexpensive and convenient monitoring of well and watershed systems with high temporal frequency and high spatial density. **Developer:** CREATE Lab at Carnegie Mellon University	http://waterbot.org/
Orion AQ4500 Turbidimeter	Operates on the nephelometric and ratiometric principles. Dual source to comply with EPA 180.1 and ISO 7027. Readings in the range of 0 to 1000 NTU. **Manufacturer**: Thermo Scientific	http://www.rshydro.co.uk/AQUAfast-AQ4500-Turbidity-Meter-pr-16489.html
NEP9000/9500 Turbidity Probe	Non wiping turbidity probes, specific to fast and cold running water or in short monitoring deployment applications where bio-fouling will not build up and obscure the optics. Available standard ranges are 100NTU, 400NTU and 1000NTU plus custom range up to 3000NTU. Probes use 90 optics and employ infrared light in accordance with ISO7027. Factory calibrated using non-toxic AEPA polymer solutions. **Manufacturer**: McVan	http://www.rshydro.co.uk/NEP9000-9500-Turbidity-Probe-pr-16589.html
DTS-12 Turbidity Water Quality Sensor	Measures turbidity, size - cm (L x D): 30.48 x 5.08; inches (L x D): 12.0 x 2.0 Price: $3,005.00	http://www.stevenswater.com/water_quality_sensors/single-parameter.aspx

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	on	Link
Greenspan TS3000	Measures turbidity, size - cm (L x D): 41.80 x 4.7; inches (L x D): 16.46 x 1.85	http://www.stevenswater.com/water_quality_sensors/single-parameter.aspx
Single parameter water quality sensor instruments		
Greenspan EC3000	Measures Electrical Conductivity, size - cm (L x D): 49.07 x 4.69; inches (L x D): 19.32 x 1.85	http://www.stevenswater.com/water_quality_sensors/single-parameter.aspx
Greenspan pH 3000	Measures pH, size - cm (L x D): 38.43 x 4.69; inches (L x D): 15.13 x 1.85	http://www.stevenswater.com/water_quality_sensors/single-parameter.aspx
Multi parameter water quality sensor instruments		
Orion Star A329 Multi-Parameter Portable Meter	Water quality meter. Advanced features: a non-volatile memory, a multi-language interface, stability, averaging options and AUTO-READ with ready indicator to lock in the stable reading. Battery Life: 800 hrs. **Manufacturer**: Thermo Scientific	http://www.rshydro.co.uk/Portable-pH-ISE-Conductivity-Dissolved-Oxygen-Meter-pr-16602.html
Orion Star A326 pH / Dissolved Oxygen Portable Meter	Measures pH and dissolved oxygen. Non-volatile memory; memory capacity to store up 5000 time and date stamped data points. PH measurement range from -2.000 to 20.000. DO measurement range from 0 to 90 mg/L. **Manufacturer:** Thermo Scientific	http://www.rshydro.co.uk/Portable-pH-and-Dissolved-Oxygen-Meter-High-Range-pr-16601.html

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Project no. 319923 BalticFlows
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	on	Link
Orion Star A324 pH / ISE Portable Meter	Features: timed end point, linear point to point, nonlinear selectable auto-blank and low concentration range stability. PH measurement range from -2.000 to 20.000, Ion Selective Eletrodes (ISE) measurement range from 0 to 19999. A memory capable of storing up to 5000 data points with time and date stamps plus stability and averaging options providing additional options allowing for es-sential accuracy to laboratory standard. **Manufacturer**: Thermo Scientific	http://www.rshydro.co.uk/Portable-pH-and-ISE-Meter-High-Range-pr-16599.html
Multi parameter water quality sensor instruments		
PCSTestr 35	Measures pH, conductivity and temperature, low, medium and high conductiv-ity/TDS ranges. Adjustable TDS factor (0.40 to 1.00) and temperature coefficient feature (0.0 to 10.0%). The instrument has a multi-range salinity measurement of up to 10.00 pt or 1.00% and up to 5 point pH calibration and 3 point conductiv-ity/TDS/salinity calibration with the option of ATC or MTC for convenience. **Manufacturer**: Eutech Instruments	http://www.rshydro.co.uk/PCSTestr-35-pr-411.html
CyberScan CD 650	Measures conductivity, dissolved oxygen, salinity, temperature and pressure compensation. Offers the widest dissolved oxygen measurement ranges offered on the market today. **Manufacturer** Eutech Instruments	http://www.rshydro.co.uk/CyberScan-CD-650--pr-403.html

	on	Link
Orion AQ3700 Portable Colorimeter	Used for Total Phosphate and Total Nitrogen measurements. Waterproof casing with IP67 rating. **Manufacturer**: Thermo Scientific	http://www.rshydro.co.uk/AQ3700-Portable-Colorimeter-pr-320.html
Manta 2 Water Quality Sonde	Sizes range: from 1.95 inch to 4 inch. Suitable for use in any natural water up to 50°C. Used as an unattended logger and for spot testing and profiling. Measures temperature, polargraphic (Clark) DO, optical DO, conductivity (SC), salinity, TDS, turbidity, ORP, pH, ammonium, nitrate, chloride, TDG, chlorophyll a. **Manufacturer:** Eureka	http://www.rshydro.co.uk/Manta-2-Multi-Parameter-Water-Quality-Sonde-pr-16499.html
Rental - Manta 2 Water Quality Sonde	Sizes range from 2 to 4.5 inch. Suitable for use in any natural water up to 50°C. Capable to record and measure multiple readings at the same time. **Parameters**: temperature, pH, ORP, conductivity, turbidity, DO **Manufacturer**: Eureka	http://www.rshydro.co.uk/Rental---Manta-2-Water-Quality-Sonde-pr-467.html
Orion Star A321 pH Portable Meter	Used for pH and ORP monitoring. PH measurement range from -2.000 to 20.000. Up to 5 point pH calibration which automatically recognizes USA/NIST and DIN buffers. Relative Accuracy pH: ±0.002 mV/RmV range: ±2000.0 mV. Relative Accuracy mV/RmV: ±0.2 mV or ±0.05 % of reading whichever is greater. **Manufacturer**: Thermo Scientific	http://www.rshydro.co.uk/Portable-pH-Meter-High-Range-pr-16596.html

	on	Link
smarTROLL™ Multiparameter Handheld	Used to measure dissolved oxygen, pH, ORP (**O**xidation –**R**eduction **P**otential), conductivity (actual or specific), salinity, total dissolved solids, resistivity, density, water temperature, water level, and water pressure. **Conductivity**: ±0.5% + 1 µS/cm typical; ±1% max. range **Dissolved Oxygen**: ±0.1 mg/L from 0 to 8 mg/L; ±0.2 mg/L from 8 to 20 mg/L; ±10% of reading from 20 to 50 mg/L **Level/Depth/Pressure:** Typical ±0.1% full scale (FS) @ 15° C; ±0.3% FS max. from 0 to 50° C. **ORP**: ±5.0 mV **pH**: ±0.1 pH unit from 0 to 12 pH units **Manfacturer**: In-Situ Inc.	http://www.in-situ.com/rentals/water-quality/handheld-systems/smartroll-multiparameter-handheld
Chloroclam® Water Quality Monitor	A purpose-built system for online monitoring of water quality in the distribution system. It measures free or total chlorine residual and pressure. Size of 150mm x 164mm (6” x 6.5”). Accuracy Chlorine: ± 5% of full scale or ± **Manufacturer**: Evoqua Water Technologies Ltd.	http://www.evoqua.com/en/products/chemical_feed_disinfection/analyzers_process_controllers/Pages/chloroclam-water-quality-monitor.aspx
600XL Water quality analysers	Analysis of pH, conductivity, dissolved oxygen, salinity, TDS, specific conductance, resistivity, depth, ORP, and temperature. Dimensions 1.65 dia.x16 inch (4.9 dia.x40.6 cm). Weight: 1.3 lbs (0.59 kg). Price: $3,580 - $4,500 **Manufacturer:** Global Water	http://www.globalw.com/products/600xl.html

	on	Link
WQMS Water quality monitoring systems	Monitor temperature, dissolved oxygen (DO), pH, conductivity, and 5 additional parameters simultaniously. The standard unit includes a datalogger, temperature sensor, pH sensor, conductivity probe (WQ-Cond-3 Conductivity Sensor, 2-20mS), and DO sensor. Price: $3,286 **Temperature Sensor:** Range from -58 to +122°F (-50 to +50°C), accuracy from ±0.2°F or ±0.1°C, size of: 4-1/2 inch L x 3/4 inch Diameter (11.4 cm x 1.9 cm Dia.), weight: 8 oz (227 g). **PH Sensor:** Range: 0-14 pH, accuracy: 2% of full scale, operating temperature: 23 to 131°F (-5 to +55°C), size of probe: 10 inch L x 1-1/4 inch Diameter (25.4 cm L x 3.2 cm Dia.), weight: 1 lb. (454 g). **Conductivity Sensor:** Range: 0-5,000, 0-10,000, 0-20,000 Micro Siemens (micro mhos) per cm, accuracy: 1% of full scale, operating temperature: -40 to +131°F (-40 to +55°C), size of: 12 inch L x 1 inch Diameter (30.5 cm L x 2.54 cm Dia.), weight: 8 oz (227 g). **DO Sensor:** Range: 0-100% Saturation, 0-8 ppm, temperature compensated to 25°C, accuracy: ±0.5% of full scale, operating temperature: -40 to +131°F (-40 to +55°C), combined error: 2% FS, size of probe: 11 inch L x 1-1/4 inch Diameter (28 cm L x 3.2 cm Dia.), weight: 1 lb. (454 g) **Manufacturer**: Global Water	http://www.globalw.com/products/wqms.html
Multi-Parameter Water Quality Sensors, Producer Stevens Water Monitoring Systems, Inc.		

	on	Link
Hydrolab DataSonde 5	Measures: Hach LDO (luminescent dissolved oxygen), temperature, dissolved oxygen, conductivity, pH, turbidity: self-cleaning, turbidity: 4-beam, ORP, Chlorophyll a, total dissolved gas, size: cm (L x D): 58.4 x 8.9, inches (L x D): 23 x 3.5	http://www.stevenswater.com/water_quality_sensors/multi-parameter.aspx
Hydrolab MiniSonde 5	Measures: Hach LDO (luminescent dissolved oxygen), temperature, dissolved oxygen, conductivity, pH, turbidity: self-cleaning, ORP, Chlorophyll a, Total Dissolved Gas, size - cm (L x D): 74.9 x 4.4; inches (L x D): 29.5 x 1.75	http://www.stevenswater.com/water_quality_sensors/multi-parameter.aspx
Hydrolab Quanta G	Measures: temperature, dissolved oxygen, conductivity, pH, ORP, size - cm (L x D): 38.1 x 4.4; inches (L x D): 15 x 1.75	http://www.stevenswater.com/water_quality_sensors/multi-parameter.aspx
Greenspan CTDP 300	Measures: EC, D, T, pH, size: cm (L x D): 50 x 6; inches (L x D): 19.7 x 2.4	http://www.stevenswater.com/water_quality_sensors/multi-parameter.aspx