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Review of sensors to monitor water quality

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Deliverable D1 - Task 1

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1. Executive summary

Surface water in European countries is monitored by permanent monitoring stations from public agencies in accordance with the water framework directive (2000/60/EC) and national water legislation. In addition, water companies also monitor surface or ground water near the intake of the drinking water treatment plant, but also drinking and waste water. Part of the monitoring is performed by sensors; however, these are for basic physico-chemical parameters only, such as flow rate, turbidity, pH, temperature, conductivity and pressure. Apart from these parameters and as a function of specific requirements of each site, other parameters such as chlorine, fluoride, nitrate, particle count or total organic carbon can also be monitored online.

In recent years the increase in concerns that possible deliberate or accidental contamination will reach the final consumer, has contributed to early warning systems being a good alternative for water managers. An early warning system is an integrated system for online monitoring, collecting data, analysing, interpreting, and communicating monitored data, which can then be used to make decisions early enough to protect public health and the environment, and to minimise unnecessary concern and inconvenience to the public. To these ends, new sensors are being placed into the market by small to medium-sized enterprises especially. Their main objective is the detection of chemical and microbiological compounds, measuring single or a combination of parameters at same time. In addition, due to the large amount of data collected, easy-to-use and robust software is necessary to treat all data generated and provide clear information to the end-user.

The main drawbacks at the moment to effectively implement sensors are that, on one hand, there is a lack of standards for contamination testing in drinking water both in the EU and in USA and, on the other hand, poor links between available sensor technologies and water quality regulations exist.

2. Introduction

In the different countries of the European Union, surface water is monitored by permanent monitoring stations of public agencies which monitor such parameters in accordance with the water framework directive (2000/60/EC) and national water legislation from each country. In addition, in many cases, water companies also monitor surface or ground water near the intake of the drinking water treatment plant, but also treated water (drinking water and waste water) also in accordance with European directives/national legislation. Part of the monitoring is performed by sensors; however this method is used only for basic physico-chemical parameters such as flow rate, turbidity, pH, temperature, conductivity and pressure. Apart from these parameters and as a function of specific requirements of each site, other parameters such as chlorine, fluoride, nitrate, particle count or total organic carbon (TOC) as an example, can be also monitored online. Table 1 shows the top 10 parameters monitored online from raw to distributed water, based on the percentage of monitoring for each parameter, by different water companies from different countries around the world.

Table 1. Top 10 parameters monitored online by drinking water companies in the USA, Belgium and the Netherlands, the United Kingdom and Australia [1].

Rate	Parameter	USA (%) n=52	Parameter	BandN (%) n=10	Parameter	UK (%) n=7	Parameter	Australia (%) n=6
1	Flow rate	100	Flow rate	100	Flow rate	100	Flow rate	100
2	Turbidity	89	Turbidity	100	Turbidity	100	Turbidity	100
3	pH	79	pH	90	pH	100	pH	100
4	Water temperature	77	Oxygen	90	Chlorine	100	Water temperature	100
5	Conductivity	39	Water temperature	80	Water temperature	86	Free chlorine	100
6	Particle count	37	Conductivity	60	Conductivity	72	Pressure	83
7	Fluoride	21	Ca/Mg/Hardness	50	Pressure	72	Conductivity	83
8	Oxygen	17	Biomonitors	50	Iron	72	Fluoride	83
9	Chlorine	14	Particle count	30	Oil in water	57	Particle count	83
10	TOC	14	Spectral absorption	30	Nitrate	57	Total chlorine	50

n: number of water utilities interviewed

However, various cases of intentional and also accidental water contamination that have occurred historically remind us of the necessity to improve water monitoring. In 1972, a right-wing neo-Nazi group acquired 30–40 kg of typhoid bacteria cultures with the intention to use this against water supplies in Chicago [2]. More recently, in 2000, workers at the Cellatex chemical plant in northern France dumped 5 000 litres of sulphuric acid into a tributary of the Meuse River, when they were denied workers' benefits [3]. In other episodes, the contamination was accidental, like the incidence of *Aeromonas* in drinking water that happened in Scotland in 1996 [4], or in Finland where large areas of the water supply were contaminated when sewage water became mixed with drinking water in 2007 [5]. In addition, during recent years, concerns regarding the possibility that deliberate attacks on water take place, and contaminant agents reach the final consumer, leading to a crisis situation, have increased. Therefore, early-warning systems (EWS) have become a good alternative for water managers. Moreover, to address this issue, the International Organisation for Standardisation (ISO) is preparing globally applicable guidelines to ensure water utilities respond successfully to any crisis situation — the future ISO 11830 on the crisis management of water utilities. This ISO 11830 will aim to meet water utilities' needs for guidance on preparing and coping with possible crises. It will make it easier for national regulators to adopt a national policy for reducing risk and increasing resilience in the water industry, and prioritising these matters in policy implementation. ISO 11830 will therefore contribute to the effective implementation of emergency management tools.

Water utilities management will be in charge of implementing the future ISO 11830 standard. Regulators, local authorities or water utilities directorates will be responsible to follow up. Currently, more than 35 countries are participants in the working group Crisis management of water utilities, and many others are registered as observers. Formal publication of the ISO guidelines is expected by the end of 2013.

2.1 Early-warning system

Early-warning systems are generally integrated systems consisting of monitoring instrument technology, with an ability to analyse and interpret results in real time [6]. An ideal EWS should:

- provide a rapid response;
- include a sufficiently wide range of potential contaminants that can be detected;

- exhibit a significant degree of automation, including automatic sampling;
- allow acquisition, maintenance and upgrades at an affordable cost;
- require low skill and training;
- identify the source of the contaminant and allow an accurate prediction of the location and concentration downstream of the detection point;
- demonstrate sufficient sensitivity to detect contaminants;
- permit minimal false-positives/false-negatives;
- exhibit robustness and ruggedness to continually operate in a water environment;
- allow remote operation and adjustment;
- function continuously.

Nevertheless it is not feasible at the moment to deploy an EWS that will accomplish all the requirements mentioned above. To attempt to rectify this situation, quite a lot of public funding is being invested in many countries such as USA, Singapore, Australia, Israel and European countries, to develop an EWS which could be useful for water companies and public agencies. In this context, the European Union under the seventh framework programme (FP7) of the security research programme has funded EUR 1 400 million (EC funding) from 2007 to 2013 in the different security and research areas. Within this amount, around EUR 160 to 180 million has been set aside for chemical, biological, radiological and nuclear (CBRN) contamination in the area of drinking water security, resulting in around 45 CBRN projects [7] in which crisis situations and EWS, among other concepts, have been assessed.

As an example, SecurEau was an FP7 European project with EU funding of EUR 5 269 168 led by Université de Lorraine for restoring distribution systems after deliberate CBRN attacks. It involved 12 partners from 6 countries and lasted for 4 years (2009–12) [8]. As can be seen in Figure 1, where a diagram of work of the project is shown, WP2 and WP3 dealt specifically with the detection of contaminants and early-warning systems.

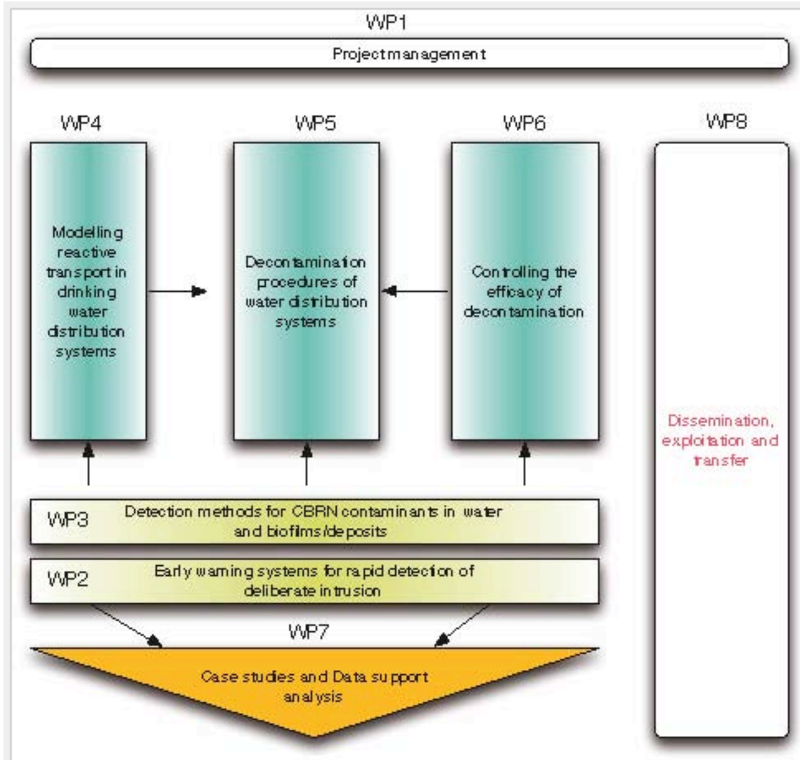

Figure 1. Diagram of work of SecurEau Project

Some of the results obtained during this project in the area of sensors will be mentioned in Chapter 3 of this **deliverable which will be focused on the monitoring of chemical and biological contaminants** as part of an EWS, according to contaminants of main interest within the 'Chemical and Biological Risks to Water Sector Group'.

3. Technology

Although many commercially available technologies used for the detection of routine water quality parameters, like measures of free chlorine and TOC [9], continue to provide a very reliable means of detecting anomalies within water systems, there exists a need for further online monitoring of water systems given that existing laboratory-based methods are too time-consuming to develop operational responses and so, they do not provide a level of public health protection in real time.

Different sensors, both at prototype scale on one hand, and already in the market on the other hand, which have been developed during recent years to monitor water quality, will be presented in Chapter 2. The **information given** on each of them will be that **provided by the manufacturer**. It should be stressed that some of these sensors may be more useful than others to particular water quality managers depending on location and/or the different and changing guidelines present in a given country. Indeed in some instances a combination may be most beneficial.

3.1. Prototype and pre-industrial scale

At the forefront of emerging water quality sensor technologies are fluorescence-based optical sensors. As an example, the United States Geological Survey (USGS) has already been researching for a decade the measuring of dissolved organic matter by fluorescence detection. In situ fluorescence-dissolved organic matter (FDOM) sensors have been used in many different environments to provide a relatively inexpensive high resolution proxy for dissolved organic carbon (DOC) concentration and in some cases, other related biogeochemical variables such as trihalomethane (THM) precursors and methyl mercury (MeHg) concentrations [10].

Recently, the SecurEau project developed a sensor to monitor water quality which is now at pre-industrial scale. The **Kapta^{TM} 3000 OT3** sensor measures transmission at two wavelengths (254 nm for organic matter and 625 nm for turbidity measurements) thanks to two light emitting diodes (LEDs). Two optic paths are used for each wavelength in order to compensate for fouling. Currently, two European drinking water systems are equipped with 40 sensors measuring water quality online and sending results to operational centres every 2 hours. Although up to date, the Kapta™ 3000 OT3 probe is still under development; some of its specifications are summarised in Table 2.

Table 2. Kapta™ 3000 OT3 specifications (pre-industrialisation) [8]

Parameter	Range	Resolution	Fidelity	Maintenance	Precision	Response time
Organic matter TOC equivalent	0.1–10 mgC/L	0.1 mgC/L	±5 %	The multi-parameter probe should be replaced every year	±5 %	<6s
UV absorbance (254 nm)	0.01–0.3 AU/cm	0.01 UA/cm	±5 %		±5 %	<6s
Turbidity equivalent	2–50 NTU	1 NTU	Not evaluated yet		Not evaluated yet	<6s

3.2. Commercial

3.2.1. The Kapta™ 3000 AC4

The **Kapta™ 3000 AC4** sensor was also developed under the SecurEau project. It measures free chlorine, pressure, temperature and conductivity. Within the frame of the project, two European drinking water systems were equipped with 80 of these sensors to measure water quality online and results were sent to operational control centres every 2 hours. Table 2 shows its specifications. **The cost of the sensor is ~ EUR 3 600** including installation, communication, maintenance, supply, back-up data, web data access and visualisation service. It is commercialised by **ENDETEC (Veolia Water).**

Table 3. Kapta™ 3000 AC4 specifications [8]

Parameter	Range	Resolution	Fidelity	Maintenance	Precision	Response time
Active chlorine	0–2.5 mg/L	0.01	±5 %	The multi-parameter probe should be replaced every year	±10 %	<30s
Conductivity	100–1000 µS/cm	1	±5 %		±5 %	Not reported
Pressure	1–10 bars	1 mbar	±2 %		±10 %	Not reported
Temperature	0–40 ºC	0.1 ºC	±5 %		±5 %	<15s/ºC

Figure 2. Kapta™ 3000 AC4 sensor installed in a distribution network [11]

3.2.2. The Spectro::lyser™

The **Spectro::lyser™** probe was developed by **S::CAN**. S::CAN is a family-owned SME from Vienna (Austria) since 1999. It established online spectrometry as an accepted method for many parameters in many countries. Nowadays it is by far the world leader in online UV spectrometry with more than 4 000 systems sold, and it provides a full range of plug-and-measure water quality sensors for different water types.

The Spectro::lyser™ UV-Vis probe online-monitors an individual selection of TSS, turbidity, NO_3-N, COD, BOD, TOC, DOC, UV254, colour, BTX, O_3, H_2S, AOC, fingerprints and spectral-alarms, temperature and pressure, depending on the application it is installed for.

The characteristics of the probe are:

• s::can plug and measure;

• measuring principle: UV-Vis spectrometry over the total range (220–720 nm or 220–390 nm);

• multi-parametric probe;

• applicable for surface water, ground water, drinking water and waste water;

• long-term stable and maintenance free in operation;

• factory pre-calibrated;

• automatic cleaning with compressed air;

• mounting and measurement directly in the media (in situ) or in flow cell (monitoring station);

• operation via s::can terminals and s::can software.

Figure 3. Spectro::lyser™ UV-Vis probe [12]

Technical specifications of Spectro::lyser™ are summarised in Table 4

Table 3. Spectro::lyser™ specifications [12]

Measuring principle	UV-Vis spectrometry 220–720 nm UV spectrometry 220–390 nm Xenon flash lamp, 256 photo diodes
Automatic compensation instrument	Two beam measurement, complete spectrum
Automatic compensation cross sensitivities	Turbidity/solids/organic substances
Pre-calibration	All parameters
Accuracy standard solution (>1 mg/L)	NO_3-N : ± 2 % +1/OPL (mg/L)* COD-KHP: ± 2 % +10/OPL (mg/L)* OPL: optical path length in mm
Access to raw signals	Access to spectral information
Reference standard	Distilled water
Integrated temperature	-10 to 50 ºC
Resolution temperature	0.1 ºC

The cost of the probe is around ~ EUR 12 000

3.2.3. The i::scan

Another sensor developed in S::CAN is the **i::scan** (see Figure 4). I::scan is a new in-pipe LED-based spectrometer probe measuring colour (div. standards), UV254, organics (TOC, DOC, COD, BOD), turbidity and UV-Vis spectral-alarm, as well as combinations of them all.

The characteristics of the sensor are:

• turbidity measurement according to EPA 180.1 and ISO 7027, combined 180° and 90° scattering;

• s::can plug and measure;

• new light emitting technology;

• no consumables;

• no moving parts;

• low power consumption (less than 1 W typical);

• dual-beam compensated optics;

• optional automatic cleaning (compressed air in situ or auto brush in flow cell);

• multiple versions for multiple applications;

• long-term stable, 100 % corrosion free;

• plug connection or fixed cable;

• 5 000 hours maintenance-free operation;

• mounting and measurement directly in the media (in situ) or in a flow cell (monitoring station);

• can be mounted directly in a mains pipe/pressure pipe;

• operation via s::can terminals and s::can software.

Figure 4. i::SCAN probe [12]

Technical specifications of i::SCAN are summarised in Table 5

Table 5. i::SCAN specifications [12]

Measuring principle	Combined 180º absorption and 90º scattering Turbidity according to EPA 180.1 and ISO 7027
Resolution	Turbidity : 0.001 NTU/FTU Colour: 0.01 Hazen UV254: 0.015 Abs/m TOC: 0.01 mg/L
Accuracy	Turbidity submersed: 0.1 NTU/FTU or ±5 % In flow cell: 0.02 NTU/FTU or ±5 % Colour: 1 Hazen or ±2.5 % TOC: 0.1 mg/L or ±2.5 %

	UV254: 0.1 Abs/m or ±2.5 %
Automatic compensation instrument	Dual-beam and 180º path
Pre-calibration	All parameters
Reference standard	Distilled water
Integrated temperature	-20 to 70 ºC
Resolution temperature	0.06 ºC

The cost of the sensor is ~ EUR 4 000.

3.2.4. The EventLab

EventLab is a probe developed by **Optiqua Technologies** which is an SME that provides the water industry with innovative tools for both online and sample-based water quality monitoring. All Optiqua products leverage their award-winning and patented lab-on-chip sensor technology. Based in Singapore and the Netherlands, they serve international drinking water companies to safeguard the distribution of safe drinking water.

EventLab offers a real-time water quality monitoring solution or EWS for water distribution networks with no consumables and low maintenance. The integrated system is based around Optiqua's patented optical Mach-Zehnder Interferometer (MZI) technology (see Figure 5), with dedicated electronics, data communication, event-detection algorithms and control software. Deployed as a sensor network throughout the water distribution grid, it provides water companies with an economically viable EWS that monitors the entire network online in real time. Target-specific testing of water samples remains an important component in an integrated approach towards water quality monitoring.

(a) (b)

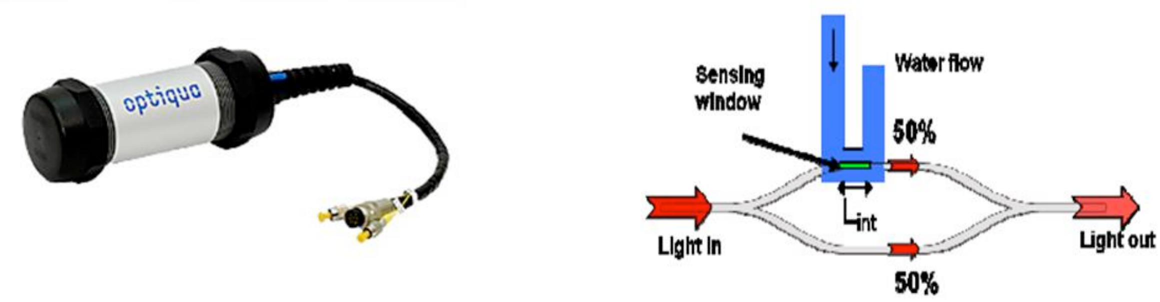

Figure 5. (a) Optiqua EventLab probe (b) MZI detection principle [13]

Optiqua's patented MZI optical chip is a highly sensitive sensor for refractive index (RI) changes. RI is a useful generic indicator of water quality as any substance, when dissolved in water, will change the refractive index of the water matrix in proportion to its own RI as well as its concentration. The generic Optiqua sensor chip operates at a sensitivity level equivalent to parts per million (ppm) levels for any chemical contaminant.

Technical specifications of EventLab are summarised in Table 6.

Table 6. EventLab specifications [13]

Refractive Index	
Method	Mach Zender Interferometer
Range	-10 000 to +10 000 Rad
Accuracy	NA
Precision	±3.2 mrad
Temperature	
Method	Resistance Temperature Detector (RTD)
Range	Default Settings: 5 to 35 ºC
Accuracy	±0.26 ºC
Precision	±0.002 ºC

The cost of EventLab is around ~ EUR 14 000

3.2.5. The Lab-on-Chip

Optisense is a Dutch-based SME that develops innovative sensor technologies for sensitive, real-time and on-site detection of contamination in water. Optisense was founded in 2005 to commercialise an optical lab-on-a-chip sensor for refractive index measurements. A key element in the Optisense technology is its generic optical sensor concept based on the MZI which was explained above. However, as can be seen in Figure 6 it also allows selective binding of target molecules.

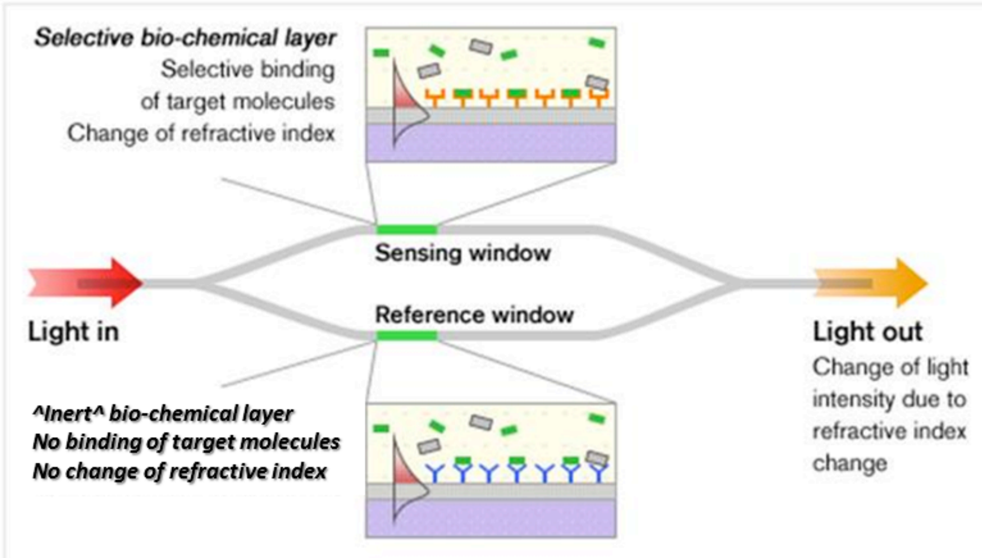

Figure 6. Detection scheme of Lab-on-Chip sensor [14]

By applying selective bio-chemical layers to the generic platform, and according to the manufacturer, the Lab-on-Chip sensor can be tailored for the detection of any specific (bio) chemical substance.

No information about the **cost and technical specifications** were given by the manufacturer.

3.2.6. The TOX control

The **TOX control** is a toxicity monitor (see Figure 7) developed by **MicroLAN** which is a Dutch company specialising in bioassays.

Figure 7. TOX control equipment [15]

The TOX control is a completely automated system that uses freshly cultivated light-emitting bacteria (*Vibrio fischeri*) as a biological sensor. The luminescence is measured before and after exposition to calculate the inhibition in percentage.

Technology: the use of living organisms is the only reliable way to measure the potential biological impact (toxicity) of a water sample. The TOX control combines the advantages of whole-organism toxicity testing and instrumental precision. This completely automated system uses freshly cultivated light-emitting bacteria (*Vibrio fischeri*) as a biological sensor. The luminescence is measured before and after exposition to calculate the inhibition in percentage. The more toxic the sample, the greater the percentage light loss from the test suspension of luminescent bacteria. For low concentration of contaminants a pre-concentration step is required which may facilitate detection when the water matrix is a complicated one.

Standards: the luminescent bacteria test has an achieved official standards status in several countries including an ASTM Standard (D-5660) in the US, AFNOR T90-320 in France and NVN 6516 in the Netherlands. The final ISO Draft (DIN EN ISO 11348) entitled Water Quality-Determination of the Inhibitory Effect of Water Samples on the Light Emission of *Vibrio fischeri* (Luminescent Bacteria) Test was approved.

The cost of it is ~ EUR 40 000.

3.2.7. The Algae Toximeter

The **Algae Toximeter** presented in Figure 8, from **BBE Moldaenke** a leading German company in environmental technology products, continuously monitors water for the presence of toxic substances. Standardised algae are mixed with the sample water and the instrument detects the photosynthetic activity of the algae. Damage to the algae, caused by herbicides for instance, causes a reduction in algae activity and activates an alarm above a predefined threshold.

Figure 8. The Algae Toximeter equipment [16]

Measurements: direct chlorophyll fluorescence corresponds to wet-chemical chlorophyll analysis and active chlorophyll fluorescence in the sample (Genty method). It determines the percentage of active chlorophyll under illumination and serves as a toxicity measurement. There is a differentiation of fluorometric algae classes: to simultaneously determine the content of chlorophyll according to green algae, blue-green algae, brown algae (diatoms and dinoflagellates) and cryptophytes. Finally, transmission takes place automatically during each analysis and, if necessary, can be used to compensate the influence of substances which cause turbidity.

Advantages

- Highly sensitive with regard to the detection of herbicides and their by-products
- Sensitive to a wide range of toxic substances
- Controlled independent cultivation of algae

- Cultivation control due to active chlorophyll measurement
- No exclusion period after alarm
- Anti-fouling system due to automatic cleaning of the measuring unit
- Auto start function after power failure

The specifications are summarised in Table 7 below.

Table 7. Algae toximeter specifications [16]

Inhibition	0–100 %
Measurement procedure	Comparison of photosynthesis activity between sample and control
Chlorophyll	0–200 µg Chl/L
Measurement procedure	Spectral fluorimetry
Resolution	0.05 µg Chl/L
Transmission	0–100 %
Sample temperature	0–30 ºC
Sample volume	30 mL
Maintenance interval	7 days

The cost of it is ~ EUR 30 000.

Finally, an example of commercial equipment named **COLIGUARD®** which is a microbial detection technology is shown below.

3.2.8. The COLIGUARD®

Mb Online GmbH is a start-up company situated in St. Pölten (Austria). The company was founded in 2007 by two companies and two private individuals for the purpose of developing, producing, marketing and selling novel devices for microbial online-monitoring. COLIGUARD® (see Figure 9), in 2009, was the first product on the market to detect *Escherichia coli*. The company targets mainly drinking water and drinking water treatment and nowadays has customers in Austria, Switzerland, Germany, Slovakia, the Netherlands and Denmark.

Figure 9. COLIGUARD® equipment [17]

COLIGUARD® specifications can be seen in Table 8.

Table 8. COLIGUARD specifications

Technology used	Fluorescent optical analysis of biochemical activity without breeding of bacteria (activity of ß-Glucuronidase)
Measurement volume	Variable: 20–3 000 ml, manual or automatically variable, typically 1 000 ml
Analysis time	2h–4h
Specificity	*Escherichia coli*
Limit of detection	1 cel/300 ml
Characteristics	Online. Fully automatic
Maintenance	Every 3 months (to change reagent and filter) Full service every 1–3 years
Sample volume	Variable: 20–3 000 ml, manual or automatically variable, typically 1 000 ml

The cost of it is ~ EUR 50 000.

Two other pieces of equipment to detect coliforms and a combination of *E. coli* and coliform were also developed under the same basis:
COLIGUARD®CF: **Coliforms:** activity of ß-Galactosidase
COLIGUARD®ECC: **Combi-Instrument** for *E. coli* and coliforms

In general, big water utilities throughout Europe and the United States are deploying some of the technologies described in this section. The focus in Europe has been for the most part on the protection of source waters and largely river intake monitoring, whilst in the United States a greater emphasis has been placed on distribution system protection with regard to homeland security in recent years.

4. Software and validation

The disposal of proper **software** to collect and get information from all data collected by sensors is of prime importance. Too much data which is not properly treated and presented is not useful for the operator of a water company, neither for an employer from the public administration in charge of control of surface water quality. Thus, the use of advanced and user-friendly event-detection software is critical. In addition, adding event-detection-system (EDS) software allows the integration of existing and new installed sensors to be used for event detection and water protection, resulting in the most economical solution. While in Europe sensor manufacturers develop their software (e.g. ana::tool software from S::CAN), in the USA Sandia National Laboratories have developed the 'CANARY' software, financed by substantial funding from the United States Environmental Protection Agency (US-EPA). The CANARY software uses a range of detection algorithms to evaluate standard water quality parameters such as free chlorine, pH and total organic carbon, and uses mathematical and statistical techniques to identify the onset of anomalous water quality incidents [18].

The most difficult part in EWS is to distinguish contamination from naturally fluctuating matrix. The detection of events by simply using upper and lower thresholds of parameter concentration is not possible. This has been proven in each single case by the US Water Security Initiative (WSI). The WSI is a programme of the National Homeland Security Research Centre (NHSRC) from the US-EPA. Following the attacks on 11 September 2001 and the *Amerithrax* incidents, EPA was asked to help in addressing many challenging questions about national security. In 2002, the agency created the NHSRC to address homeland security issues. The WSI aimed at addressing the risk of intentional contamination of drinking water distribution systems. The WSI target is to 'develop robust, comprehensive, and fully coordinated surveillance and monitoring systems, including international information for water quality, that provides early detection and awareness of disease, pest, or poisonous agents' [19]. US-EPA is implementing the WSI in three phases:

Phase I: develop the conceptual design of a system for timely detection and appropriate response to drinking water contamination incidents to mitigate public health and economic impacts;
Phase II: test and demonstrate contamination warning systems through pilots at drinking water utilities and municipalities and make refinements to the design as needed based upon pilot results;
Phase III: develop practical guidance and outreach to promote voluntary national adoption of effective and sustainable drinking water contamination warning systems.

Five major water utilities (in Cincinnati, San Francisco, New York, Philadelphia, and Dallas) were recruited for the WSI, which involves the deployment of real-time monitors and early warning systems to detect possible contamination in drinking water distribution systems. Water quality monitoring stations and analytes (pH, turbidity, temperature, conductivity, TOC and chlorine) were chosen on the basis of their sustainability for long-term operation [20].

A **validation** programme to test both sensors and software was also implemented within the WSI at NHSRC. It manages research and technical assistance efforts to provide appropriate, affordable, effective, and validated technologies and methods for addressing risks posed by chemical, biological, and radiological terrorist attacks. Research focuses on enhancing the ability to detect, contain, and decontaminate in the event of such attacks. On the other hand, the NHSRC has created the Technology Testing and Evaluation Programme (TTEP) in an effort to provide reliable information regarding the performance of homeland security-related technologies. TTEP provides independent, quality assured performance information that is useful to decision-makers in purchasing or applying the tested technologies. In this context, Battelle University did a lot of the testing, and developed testing standards and procedures. However, the procedures are rather simple ‘spike-into-closed-loop’ procedures, and quite far from real-life situations [21].

In Europe, different countries have also allocated public funding for research projects under the frame of water security, where new sensors and their software are being validated. Some examples of national security funding programmes are:

- France: Research Programme CSOSG — Concepts, Systèmes et Outils pour la Sécurité Globale (French National Research Agency (ANR)).
- Netherlands: R & D Programme on Security, Safety and Technology.
- Sweden: National Security Technology Research and Innovation Programme.
- Finland: Technology Programme on Safety and Security
- United Kingdom: CBRN Resilience Programme.
- Austria: KIRAS the Austrian Security Research Programme.
- Germany: Research for Civil Security Programme

In addition, important European water companies such as Vittens from the Netherlands, Veolia and Suez Environnement from France or Agbar from Spain, also set aside private funding research programmes to develop and validate sensors of interest together with public national research and technology institutes. Although some of them dispose of platforms to test and validate new sensors, the output of the validation will be treated confidentially. Therefore, sensor manufacturers do not currently find public, available platforms to test their products in Europe.

5. Regulation and future perspectives

Although sensors are increasingly appearing on the market, effective implementation in water utilities has not been realised for several reasons.

- Sensors do not meet practical utility needs (Most sensors and EWS components have not been tested/verified by a third party — utilities will require verification and demonstration studies to sort through manufacturer's claims).
- Verification schemes do not sufficiently match utility practices.
- Poor links between available sensor technologies and water quality regulations.
- Types of contaminants and levels of exposure are not yet well defined to support selection of sensor technologies.
- Challenge of managing large data quantities and translating them into meaningful information for operational processes. Standardised methods/guidance for data analysis and interpretation are needed.

Recently, the joint position paper presented in May 2013 in Brussels regarding Water in Horizon 2020, with a focus on priority 5 'Climate action, environment, resource efficiency and sustainable use of raw materials' referred to this topic in Chapter 2.1. Prevent and monitor water pollution, by stating:

'… Many SMEs are active in designing new water quality sensors, though they lack a test market with several real end-users to enable them to demonstrate benefits and then gain production efficiency through scale-up'.

Joint Position Paper of AquaEuropa, EurAqua, EWA, EWP, Eureau and WssTP

Brussels, 6 May 2013

This statement shows the necessity to increase more the collaboration between SMEs and end-users in the future.

6. List of acronyms

AFNOR: French national organisation for standardisation

ANR: French National Research Agency

AOC: Assimilate Organic Carbon

ASTM: American Society for Testing and Materials

BOD: Biological Oxygen Demand

BTX: Benzene, toluene and xylenes

CBRN: Chemical, Biological, Radiological and Nuclear

CFU: Colony Forming Unit

COD: Carbon Oxygen Demand

CSOSG: Concepts, Systèmes et Outils pour la Sécurité Globale

DOC: Dissolved Organic Carbon

DOM: Dissolved Organic Matter

EDS: Event Detection System

EWS: Early Warning System

FDOM: Fluorescence Dissolved Organic Matter

FP7: Framework Programme 7

ISO: International Organisation for Standardisation

LED: Light emitting diode

MZI: Mach Zender Interferometer

NHSRC: National Homeland Security Research Centre

NVN: Dutch National Standards

ppm: Parts per million (mg/L)

RI: Refractive Index

SME: Small and medium-sized enterprise

USGS: United States Geological Survey

UV: UltraViolet

UV254: UltraViolet at λ:254 nm

WP: Work Package

WSI: Water Security Initiative

THM: Trihalomethanes

TOC: Total Organic Carbon

TSS: Total Suspended Solids

TTEP: Technology Testing and Evaluation Programme

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Abstract

Surface water in European countries is monitored by permanent monitoring stations by public agencies in accordance with the Water Framework Directive (2000/60/EC) and national water legislation. In addition, water companies also monitor surface or ground water near the intake of the drinking water treatment plant, but also drinking and waste water. Part of the monitoring is performed by sensors; however, these are for basic physico-chemical parameters only, such as flow rate, turbidity, pH, temperature, conductivity and pressure. Apart from these parameters and as a function of specific requirements of each site, other parameters such as chlorine, fluoride, nitrate, particle count or total organic carbon can be also monitored online.

During recent years, the increase in concerns that possible deliberate or accidental contaminations might reach the final consumer, has contributed to early warning systems becoming a good alternative for water managers. An early warning system is an integrated system for online monitoring, collecting data, analysing, interpreting, and communicating monitored data, which can then be used to make decisions early enough to protect public health and the environment, and to minimise unnecessary concern and inconvenience to the public. To this end, new sensors are being placed into the market by small to medium-sized enterprises especially. Their main target is the detection of chemical and microbiological compounds, measuring single or a combination of parameters at the same time. In addition, due to the large amount of data collected, an easy to use and robust software is necessary to treat all data generated and provide clear information to the end-user.

The main drawbacks at the moment to effectively implement sensors are that, on one hand, there is a lack of standards for contamination testing in drinking water both in the EU and in USA and, on the other hand, there are poor links between available sensor technologies and water quality regulations.

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