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► **To cite this version:**

Benoit Roig, Estelle Baurès, Olivier Thomas. Perspectives on Drinking-Water Monitoring for small scale water systems. *Water Science and Technology*, 2013, 14 (1), pp.1-12. 10.2166/ws.2013.211 . hal-00877973

HAL Id: hal-00877973

<https://hal.science/hal-00877973>

Submitted on 22 May 2024

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Perspectives on Drinking-Water Monitoring for small scale water systems

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Abstract:

Drinking water (DW) is increasingly subject to environmental and human threats that alter the quality of the resource and potentially of the distributed water. These threats can be both biological and chemical in nature, and are often cumulated. The increase of technical frame of water quality monitoring following the evolution of water quality standards guarantee the regulation compliance in general but is not sufficient for the survey of small scale water system (SSWS) efficiency. The existing monitoring is not well suited to insure a good quality of distributed water, especially in the event of a sudden modification of quality. This article aims to propose alternative solutions, from the examination of monitoring practices, in a bid to limit the risk of deterioration of DW quality.

Key words

Drinking water quality, monitoring, threat, management

Context

A relevant regulatory frame

Water supply is becoming a matter of concern with regard to a growing population and concomitant usages for industries or agriculture. Even where water quantity does match water demand, the quality of resources may be degraded by natural (climate) or anthropogenic (discharges, runoff, etc.) pressures. The provision of improved-quality water for the entire, worldwide population is now an objective mentioned on the agendas of major international organizations and national governments (Unicef and WHO, 2012).

The United Nations General Assembly has recently recognized that “safe and clean drinking-water and sanitation is a human right essential to the full enjoyment of life and all other human rights” (United Nation, 2010). This recognition of this right implies the protection of water resources used for drinking-water supply. Water producers are required to comply with increasingly exacting legislation on water quality. They also need to face emerging issues related to the constant appearance of new chemicals in water (pharmaceutical, endocrine disruptors, etc.) whose effects on the environment and health are still not very well known.

Even if earlier laws did exist (USA Clean water act in 1972, French first water law in 1964), water quality regulations have been strengthened since the end of the 1990s. For example,

under the amendment of the Safe Drinking Water Act (SDWA) in 1996, the American Environmental Protection Agency (USEPA) sets health based quality standards of several contaminants in drinking water. The European Commission approved the Drinking-water Directive (DWD) in 1998 and the Water Framework Directive (WFD) in 2000. This last one establishes an objective of good status for all waters by 2015, a framework to ensure public health security for water intended for human consumption and an obligation to promote a policy for the management and protection of water resources. In 2011, the EU concluded that no legislative revision of the DWD under the ordinary procedure was required and challenged for a coordinated implementation of both (Falkenberg and Bloech, 2011). However, even if knowledge of the status of water has considerably improved (three implementation reports were published), according to the commission, more efforts are needed to ensure the achievement of the directive objectives in the 2015, 2021 and 2027 planning cycles (Falkenberg and Bloech, 2011)

Australian Drinking Water Guidelines (ADWG) was published also in 2004 providing a comprehensive list of potential hazardous agents in drinking water. These guidelines consider continuous, intermittent or seasonal pollutions patterns, as well as extreme and infrequent events such as droughts and floods. In the same time, the World Health Organization (WHO) proposed in the revised Water Quality Guidelines the development and implementation of water safety plans (WSP) by water suppliers for a new preventive risk management approach (Bartram, Corrales, et al., 2009). This approach, aims to ensure the safety of a drinking-water supply through the use of a comprehensive risk assessment and risk management approach (Hulsmann, 2005). These plans should address all aspects of the drinking-water supply, focusing on control of abstraction, treatment and delivery of drinking-water. They consist in particular of the identification of control measures in the drinking-water system that will collectively control identified risks and ensure that health-based targets are met. For each control measure identified, an appropriate means of operational monitoring should be defined so as to ensure that any deviation from required performance is detected both rapidly, and in good time.

Some efforts to be pursue

Despite this regulatory framework, water quality compliance is not fulfilled in small scale water systems (SSWS) in particular for microbiological quality (Pitkänen, Karinen, et al., 2010; Risebro, Breton, et al., 2012). It is stated that in Europe, 30 to 50% of water distributed by SSWS would be often of impaired quality (Richardson, Nichols, et al., 2009; Falkenberg and Bloech, 2011).

More generally, water resource quality is influenced by both 'natural' and anthropogenic driving forces. The former include spatial and temporal variation in water availability (Richardson, Nichols, et al., 2009), wildlife, topography, geology, vegetation and the impact of climate change, particularly with respect to the frequency and severity of droughts or rainfalls. Anthropogenic driving forces come from each of the key sectors that use water (industry, energy production, public water supply and agriculture) and include point sources (e.g. wastewater discharges) and non-point sources (e.g. surface runoff). For example, municipal wastewater discharge can be a major source of pathogens; urban runoff and livestock can contribute substantial microbial load; body contact recreation can be a source of faecal contamination; and agricultural runoff, including agrochemicals and manure (the main sources of nitrate and pesticides) can lead to increased treatment challenges. Water contamination by pathogens is of particular interest both because of its consequences (waterborne infectious disease) and because of the difficulty of predicting it (due to failure of the use of indicator organisms (Harwood, Levine, et al., 2005). Emerging pollutants are also

increasingly under consideration (Deblonde, Cossu-Leguille, et al., 2011; Tiehm, Schmidt, et al., 2012; Boxall, 2012), due to poor knowledge of their impact on the population at ultratrace concentrations (Touraud et al., 2011; Stuart et al., 2012). For the first time, three substances (diclofenac, 17 β -estradiol, 17 α -ethynylestradiol), was just included in the priority list of the WFD. Even though there are no environmental quality standards (EQS) decided at the moment, such molecules are monitored in a number of installations as well as in many resources since several years (Deblonde, Cossu-Leguille, et al., 2011; Rodil, Quintana, et al., 2012).

Climate change issues

Climate changes act as an indirect aggravating factor for the anthropogenic pressures on the environment (Cromwell, J. . Smith, et al., 2007; Delpla, A.-V. Jung, et al., 2009; Roig, B. Baures, et al., 2012). In particular, the main determinants of climate change having a direct or indirect impact on water quality are air temperature and extreme water events (flood, drought) (Van Vliet and Zwolsman, 2008; Brodie and Egodawatta, 2011; Hrdinka, Novický, et al., 2012). Resource availability is linked to these periods (Ranjan, Kazama, et al., 2006; Nan, Bao-hui, et al., 2011; García-ruiz, López-moreno, et al., 2011), and it becomes important to consider these extreme events in assessing both evolution of water stress and efficiency of the treatment processes (Wilby et al., 2006; Johnson et al., 2009; Emelko et al., 2011).

Changes in water temperature may modify the ecology of freshwater ecosystems and degrade water quality (Delpla, A.-V. Jung, et al., 2009). Most physico-chemical (solubilisation, complexation, degradation, evaporation, photolysis, etc.) and biological (microorganisms catabolism, etc.) reactions are promoted by an increase in temperature and/or in solar irradiation (Malmaeus, Blenckner, et al., 2006; Monteith, Stoddard, et al., 2007; Soh, Roddick, et al., 2008). Droughts, for example, increase the concentration of dissolved substances in water while at the same time decreasing the concentration of dissolved oxygen (Prathumratana, Sthiannopkao, et al., 2008; van Vliet and Zwolsman, 2008). But droughts can also promote the assimilation of nutrients by plants or the adsorption/complexation of heavy metals on Total Suspended Solids or sediment.

Phototransformation processes occurring in the environment should also be considered because of they generate transformation products (Buerge, Poiger, et al., 2006; Petrovic and Barceló, 2007; Canonica, Meunier, et al., 2008), the toxicity of which remains questionable in some cases.

Heavy rainfall events produce an increase in river flow rates, the higher risk of which is an increased transport of pollutants by runoff. In temperate countries, predictions forecast an increase in mean volume of each rainfall event (Brunetti, Maugeri, et al., 2001; Bates, Kundzewicz, et al., 2008). In addition, rainfall is admitted to be one of the more climatic factor affecting the microbial quality of very small (private) water supplies (Richardson, Nichols, et al., 2009).

Climate change is not the sole factor responsible for alteration of water quality. Global changes, including soil use, urbanization and its consequences on moisture, etc. also contribute to water quality degradation (DiDonato, Stewart, et al., 2009; Carlson, Lohse, et al., 2011; Astaraie-Imani, Kapelan, et al., 2012).

Specificity of SSWS

In addition to natural and anthropogenic pressure, drinking water quality degradation can be affected by treatment plant inefficiency through the process itself and the water supply size. Concerning treatment processes, some outbreaks in a recent past (Curriero, Patz, et al., 2001;

Tickner and Gouveia-Vigeant, 2005; Schuster, Ellis, et al., 2005; Aryal, Joshi, et al., 2012), showed a need for regular reevaluation of techniques to ensure effective drinking-water disinfection. This is particularly important to protect small (vulnerable) water supplies (Pitkänen et al., 2011). Indeed, such processes, in addition to effectively eliminating harmful microorganisms, are strong oxidants (chlorine, ozone, chlorine dioxide, chloramines) that oxidize the organic matter and bromide naturally present in most source waters, forming so called disinfection by-products (DBP), the trihalomethane (THM) of which such as haloacetic acids, oxyhalides, haloacetonitriles, halonitromethanes, haloamines, iodo-acids, haloamines, nitrosamines, iodo-THM (Mouly, Joulin, et al., 2008), have been more investigated due to their potential cancerigen suspected effect (Singer, 1993). In addition, many factors significantly influence the formation of DBP: temperature, pH and dissolved organic carbon (DOC), ammonia and ions bromides concentrations, as well as the types of treatment applied, the doses of chlorine and time of contact (Nikolaou, Golfinopoulos, et al., 2004; Teksoy, Alkan, et al., 2008).

Water supply size can also be involved in water quality degradation. Small Scale Water Supply is of particular interest, and remains a significant challenge for many countries - partly because human, technical and financial resources are limited (Hulsmann, 2005; United Nation and WHO, 2011). Sadiq et al., (2010) have shown, with the small utility performance indicators, that a link could be established between the various technical (source and treated water quality, infrastructure) and non-technical (human and operational factors) characteristics of water supply system and the distributed water quality of small utilities. WHO estimates that 10% of European citizens receive drinking-water from these small or very small systems, including private wells. But only 60% of the small water supply zones deliver water which is fully compliant with the requirements of the Drinking Water Directive 98/83/EC.

Lastly, socio-economic factors like demographic developments, urbanization, economic progress, and social changes, as well as lack of investment in rural and municipal water supplies, can also influence water quality.

1. Monitoring Systems

Parameters and proxies

With the implementation of Water Safety Plans, water quality control is a key point both in ensuring the safety of a drinking-water supply and in assessing hazards linked to the deterioration of water body quality, for example surface and karstic resources (Bates, Kundzewicz, et al., 2008; Bartram, Corrales, et al., 2009). Drinking water guidelines are proposed from country to another country based on the WHO Guidelines for Drinking Water Quality (WHO, 2011). They may be different among countries. For example, the management framework of drinking water quality in Australia (with ADWG), UK (with BS6700) and US are considered stronger compared than the Canadian one, while as developing countries, India needs to improve its BIS 10500-1991 and China is still working on its premature water standards (Kusumawardaningsih, 2010).

In Europe, the regulations organize water quality control from catchment to treatment plant, using a number of parameters (Table 1). In regular situations, characterized by a limited seasonal variation and a homogeneous composition in time and space, water quality monitoring based on these parameters is, on the whole, satisfactory. Quality limits have been established to allow quantified quality control.

Conventional parameters are generally recognised as relevant for health risk assessment for drinking water and easy to measure in a qualified laboratory (accredited and agreed).

However, the list of parameters even completed by specific hazardous substances is actually not complete as some emerging substances showing toxic or ecotoxic effects, will likely be soon considered (e.g. estrogens). Another limitation of such parameters becomes clear when water is subjected to unexpected quality variations, in particular in case of global changes (namely climatic events with change in heavy rain pattern) or accidental or intentional contamination. These parameters can also fail to provide the right answer with regard to public health concern. For example, the use of indicator organisms (total and faecal coliforms, enterococci, *Clostridium perfringens*) has often proved to be powerless to predict the presence or absence of pathogens (Harwood, Levine, et al., 2005; Field and Samadpour, 2007). Simple monitoring schemes based on detection of a single indicator are not adequate for public health protection.

In this context some proxies giving a global assessment of one or several parameters may be used (as for example: turbidity for bacterial contamination, UV spectrometry for organic contamination). Generally more rapid and simple to measure than conventional parameters (proxies can be implemented on line), they are meanwhile less specific. But they can be used after comparative validation with the related parameter(s), including all analytical criteria in particular reproducibility and repeatability in order to estimate the measurement error. This is of high importance especially when decision making is based on these proxies.

Table 1: Parameters and proxies used for quality control of surface (SW), ground (GW) and treated waters (adapted from Mons, 2008)

Parameter	Resource		Treated Water	Proxy	
	SW	GW			
<i>Microbiological parameters</i>					
E. coli				Turbidity, NH ₄ ⁺ , UV	
Enterococci, <i>Clostridium perfringens</i>					
Total coliforms					
Colony count, Total cell counts, Cultivation-free viability analysis					
Giardia/Cryptosporidium, Enteric viruses, <i>Campylobacter</i>					
<i>Chemical parameters</i>					
Arsenic, fluoride, selenium, Nitrate				Organoleptic, UV absorption, global toxicity, genotoxicity, endocrine disruption	
Benzene, Benzo(a)pyrene, Boron, Bromate, 1,2-dichloroethane, Nitrite, Antimony, cadmium, copper, chromium, lead, mercury, nickel, PAHs, Organic micropollutants*, Tetra- & trichloroethene, Disinfection by-products, Sodium, calcium, magnesium, sulphate					
Cyanides					
Pesticides					
Ammonium					
Iron, manganese					
<i>Physico-chemical parameters</i>					
DOC/TOC, Turbidity					UV visible absorption
Taste, odour, colour, pH, chloride,					

alkalinity, conductivity, T°, O ₂				
Other parameters				
Genotoxicity, acute toxicity, Algae toxins, AOC/BDOC				
Radioactivity				

PAHs: Polycyclic aromatic hydrocarbon, DOC: Dissolved Organic Carbon, TOC: Total Organic Carbon, UV: Ultraviolet, T°: temperature, O₂: dissolved Oxygen, AOC: Assimilable Organic Carbon, BDOC: Biodegradable Dissolved Organic Carbon

* general group, consisting of e.g. pharmaceuticals, industrial pollutants, EDCs etc.

About sampling programs relevance

Because monitoring is carried out under a discontinuous way (based on sampling and laboratory analysis) the choice of sampling frequency may be not adapted to transient water degradation. For example, in sanitary control, the frequency of monitoring a SSWS, serving less than 5,000 people is performed between once a year and once every five years (depending on the flow rate) for the resource and between once a month and once every 5 years for the corresponding treated water (distribution and consumption points) (Table 2).

Table 2: Example of sampling schedule and water sanitary control analysis programme for small and medium water supplies (adapted from the French Decree of 11th January 2007 (Journal Officiel, 2007; Bessonneau, Chaumet, et al., 2011))

Water resource		Annual frequency			
Flow (m ³ /day)	<10	GR*	SR*		
	10 to 99	0.2**	0.5		
	100 to 1 999	0.2	1		
	2 000 to 5 999	0.5	2		
Distribution and consumption points		Annual frequency			
Population supplied (inhabitant)	Flow (m ³ /day)	P1***	P2	D1	D2
0 to 49	0 to 9	1	0.1/0.2	2/4	0.1/0.2
50 to 499	10 to 99	2	0.2/0.5	3/4	0.2/0.5
500 to 1 999	100 to 399	2	1	6	1
2 000 to 4 999	400 to 999	3	1	9	1
5 000 to 14 999	1 000 to 2 999	5	2	12	2

* Source of raw water: groundwater resource (GR) and surface resource (SR)

** 0.1, 0.2 and 0.5: analysis frequency every 10 years, 5 years and 2 years respectively

*** The P (production) and D (distribution) analyses provide information about the parameters specified in the regulations and are carried out (P2 and D2 are complementary to P1 and D1 respectively, giving only microbiological and organoleptic quality data treatment effectiveness).

Water sampling frequencies vary from a country to another sometimes depending on the type of quality parameters. For example the sampling frequency varies from once a month (< 100 inhab.) to once a day (> 100 000 inhab.) for microbiological monitoring in Australia. For chemical monitoring the frequency varies from 2 per year (< 5000 inhab.) to once a month (> 5000 inhab.).

Appropriate techniques for water quality monitoring imply consideration of the entire analytical chain, from sampling strategy to transmission of results. Numerous analytical

techniques are available, as reported in the WHO Guidelines for drinking-water quality (WHO, 2011). However, it is not unusual to find different results for an identical sample because of variability in one, or several, steps of the analytical procedure (including sampling, transport, storage, and sample preparation and analysis).

Commonly-used methods are based on spot sampling. But this approach is not always representative of the overall quality of the water body. In particular it is limited where it consists of producing data that is both geographically and temporally representative of the chemical and biological quality of a water body.

Monitoring evolution

The cost of monitoring is also an influencing criterion for the implementation of water control, due to the demand that more and more substances/parameters be examined in order to ensure water quality. Alternatives to standardized methods are now on offer, such as onsite measurement (in situ, on line) and sampling (passive samplers). The methods are complementary to laboratory analysis, and can be used to track the dynamic of the contaminant, map the distribution of pollutants in time and space, measure evolution rather than concentration, and for water quality screening.

These methods started to be developed 20 years ago, out of the miniaturization, automation and adaptation of laboratory techniques to make direct use in the field a possibility. There is a set of current methods (on site, in situ, on line) (Greenwood et al., 2007; Roig et al., 2009) which are able to provide quantitative, semi-quantitative and qualitative information by expressing conventional parameters and/or proxies in a faster way. New on line and/or in situ monitoring tools, based on integrated sensor technology (measurement + results interpretation) (Hassan, 2005) have emerged in recent years. These consist more of evaluation of quality difference between a normal situation and a contamination event due to biochemical and physical interaction (Kroll, 2009; Storey, Gaag, et al., 2010) than a quantitative assessment of a contaminant. They are mainly used to detect intentional as well as accidental contamination events in a more reliable and less expensive way (Skadsen, Janke, et al., 2008).

Initially based on physico-chemical principle, other monitoring tools have emerged by exploiting the sensitivity of biological systems. Bioindicators, bio or immunoassay and biomarkers, based on living organism or part of them respectively, were proposed as on-line or field methods. Their sensitivity is not only used for the detection of ultra-trace level of contaminant but to detect more early any perturbation of the water body considered. These early warning system, able to analyze and interpret results in real time (Storey, Gaag, et al., 2010) are in general, not specific (some are like immunoassays), but inform of the overall water quality (presence/absence or toxic/not toxic, ...) as for example daphnia and algal toximeter that detect the whole toxicity in environmental samples (Jeon, J. H. Kim, et al., 2008; Mons, 2008). These methods permit frequent and rapid analysis and are adapted to manage sensitive locations such as SSWS However, one of the main drawbacks of these biological based methods for drinking water monitoring could be in some cases their cross-reactivity with chlorine.

Performance assessment is a requirement for a large use of these techniques. Currently, it is based on linearity domain, repeatability, limit of detection, limit of quantification, specificity, robustness and includes (i) validation of the performances in the lab using reference material and calibrated solutions followed by (ii) a verification of the analytical characteristic directly on the field by insisting on the robustness (Gonzalez et al., 2007; Roig et al., 2007). However, this methodology, well adapted for laboratory transposed chemical methods becomes limited when qualitative, semi quantitative as well as biological methods are considered.

The next evolution in such techniques is currently underway, with the association of telecommunication and/or data transfer procedures (Figure 1). Such progress favours transport of the signal (obtained by onsite devices) instead of transport of the sample itself.

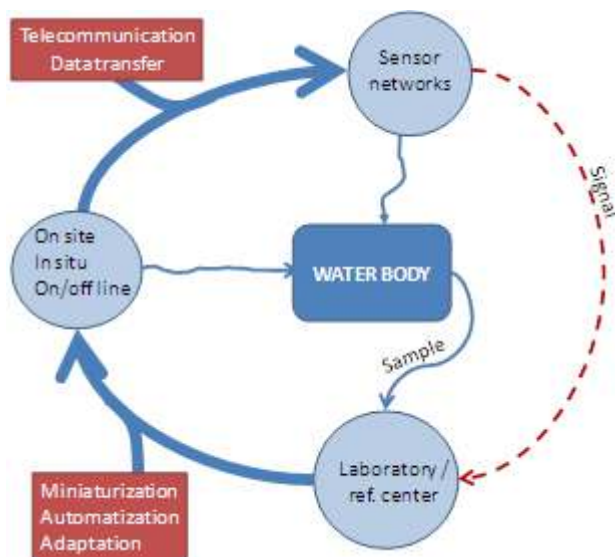


Figure 1: Evolution of monitoring techniques

However the ability to collect, store and use large amounts of data from in situ sensors networks require new techniques and approaches for quality assurance/quality control (QAQC). Indeed, sensors can occasionally malfunction in particular in extreme environment, or are prone to fouling and drift, and communication systems can corrupt data (Wagner, Boulger, et al., 2006). QAQC need to include sensor calibration methods, and data-correction approaches, in particular correction of out of range/anomalous values, correction for instrument fouling and drift, correction of values, and correction of any, known bias in the sensor data (Pellerin, Bergamaschi, et al., 2012). In practice, quality assurance algorithms can be employed for each measured quantity within a subset of neighboring sensors, or for averages of multiple sensors (Collins, Bettencourt, et al., 2006).

Finally, modeling can also be envisaged

2. How can these new threats be managed?

It is possible to propose different mitigation options for ensuring the quality of distributed water. The first approach could be to consider the use of long and short term health effect monitoring. Several information systems (compulsory or voluntary reporting, syndromic or toxic surveillance) are available to alert the general public to health-related issues, but specific field investigation are however to be carried out to establish a link with water whatever the system (Beaudeau, Mathilde Pascal, et al., 2011). New data sources can be also used. For example, data relating to the reimbursement of medication collected by the Health Service (in France) may facilitate the daily monitoring of health-related events at local level (Tuppin, De Roquefeuil, et al., 2010); or multi-source system which will join together various databases of medical and medical-administrative activity (hospital admissions, medical insurance and anatomical pathology) (Beaudeau, Mathilde Pascal, et al., 2011; Tuppin, de Roquefeuil, et al., 2010). However, this approach remains limited for a study of the dynamic of the water quality evolution.

Effective catchment management has many benefits. Decreasing water source contamination means that less treatment is required. This may in turn reduce production of treatment by-products and minimize operational costs. Understanding the reasons for variations in raw water quality is important, because this will influence treatment requirements, efficiency and the resulting health risk associated with the finished drinking-water.

The end-of-pipe approach can also be of benefit, particularly in adapting the treatment process to the water quality and the dynamic of its evolution. This is of particular interest when rapid environmental modifications occur.

In practice, remediation actions of stakeholders (people, organisms water authorities...) implemented with respect to regulation compliance or local initiatives must be considered for the reduction of point source discharge and non-point source (diffuse) pollution. As an example, the impact of intensive agriculture on surface water quality coupled to climate change effects with modification of rain patterns can be limited both by animal farming and fertilization control and redesign of protection area of catchment including wetlands and long residence time reservoirs acting as passive pretreatment steps. In this context, remediation actions must be coherently implemented at local or regional scale depending on the size of the catchment

Regardless of whether the approach is from the source or end-of-pipe, flexible monitoring tools (devices, practices, and methodologies) are assets in orientating adaptation toward new threats, particularly in the event of sudden disruption to normal functioning. In such situations, reactivity and decision-making in management of local and global changes need to be improved in order to anticipate the impact downstream of the source of contamination. This is even more challenging for shared water bodies at national or international level. It is estimated that two out of three of the great rivers and aquifers in the world are shared between several countries, and that two out of five people depend on these shared waters. Although this partition is often the source of significant regional tensions, few international agreements on water management exist.

Environmental Sensor Networks (ESN) is a trend which is currently developing as a result of technological advances in the miniaturization of electronics and wireless communication technology. Several systems have been already developed, but they include only specific generic environmental parameters such as meteorological, Global Positioning System (GPS), water, air and soil temperature, conductivity, pressure, humidity, and soil moisture, pH, dissolved oxygen and chlorophyll, and are dedicated to monitoring ocean conditions, volcanic processes, and so on (Hart and Martinez, 2006). They are well suited to large-scale environmental processes, but need to be adapted to suit specific actions such as water production, and the protection of water bodies and sensitive areas. ESN Perspectives need to include sensor modules producing data on chemical and biological parameters. The possibility of being constantly connected to the data source allows water managers to be in close contact with the environment they depend upon (in terms of water resource, natural and anthropogenic pressure).

Until we have an intelligent system capable of autonomous decision-making, Environmental Sensor Networks, combined with a network of laboratory-based experts, offer the possibility of collection and analysis of data at all levels (as appropriate), from local to global.

In addition occurrence data is not enough to assess the population's exposure and make links between water quality failure and environmental or public health outcomes. Water quality management can therefore be improved through consideration of issues such as:

- Structural changes in water systems, annual flows transferred between interconnected water systems, and hydraulic residence time distribution parameters (e.g. percentiles 50, 90, 100 and corresponding areas. In France, the SISE-eaux database (Health and Environment information system – water supply) introduces these new items and functionalities to improve knowledge of exposure throughout the country.
- Water operators' safety rules: anti-intrusion alarms, pump break-downs, excess turbidity, lack of chlorine, and frequency of follow-up visits. The reporting and recording of such signals would also help identify adverse acute water contamination factors and spot any water systems subject to a sudden threat.
- Worldwide consequences of water contamination, in particular for transboundary water bodies or catchment. International and regional exchanges about both risk and mitigation measures are crucial in anticipating, and efficiently allocating, national resources (Pascal, 2010). For example, concerns about climate change consequences spread worldwide. Southern France shares the threat of drought with Mediterranean countries, whereas Northern France could experience wetter winters like North European countries.
- Risk surveillance, based on the collection of both environmental and health data (medical treatment, drug prescription, epidemiological studies, etc.) and the development of tools for modelling the link function between water factors and health outcomes (Quenel, 1995).

From the above considerations, an enlargement of the DW quality monitoring purpose could be proposed with the integration of water system breakdowns and accidental or intentional contamination, leading both to water of impaired quality with likely health consequences. In this frame, Figure 2 displays the necessary adaptation of monitoring schemes between classical monitoring for the survey of water quality and the operational monitoring for a rapid diagnosis in case of accidental or intentional contamination of water. On one hand the implementation of classical monitoring based on sampling and laboratory analysis is well fitted for long term survey and regulation compliance. On the other hand the use of rapid measurement devices giving suited information (on time, easily understandable, and available) constitutes an adapted monitoring for early warning. In between, the monitoring must be designed if needed for measuring transient water quality variations following hydroclimatic conditions (heavy rain for example) or more simply to detect water treatment breakdowns.

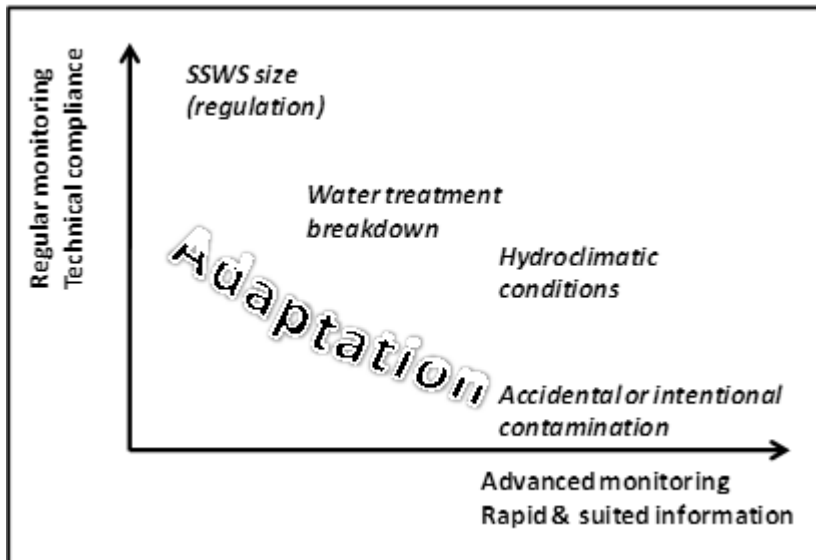


Figure 2: Evolution of water quality monitoring from

Finally, Table 3 summarizes the main information used, and required, for a better water quality management.

Table 3: Data for water quality management and prediction

Type of information		Relevance	Availability
Water quality	Lab measurement	Linked to monitoring design Regulation	Sampling delay Analysis delay
	On line/ on site measurement	Transient variations Remote assistance	Parameters limitation EWS*
	Sensors network	Process control Decision making	Very partial EWS
Complementary	Treatment plant and networks supervision	Material breakdown	EWS
	Public health data	Waterborne Epidemics Selectivity	Delay in data collection Authorization needed
	Hydro meteorological data	Climate Event Anticipation	External data validation and storage
	Historical quality data	Characterization of normal conditions	Data collection

* early warning systems

Conclusion

Drinking water quality (from resource to tap) must be monitored thoroughly in order to preserve the population from the consequences of contamination (natural, anthropogenic, accidental or intentional). Face to increased threats due to environmental or human pressure, monitoring should be flexible and able to be adapted to any variation, in order to drive water managers in their decision-making. In particular, during exceptional events leading to a high variation in water quality (raw or treated water), they should be very responsive and able to

1 adapt the general procedure to comply with quality standards and ensure the safety of the
2 population.

3 In recent years, many emerging technologies have been developed to complement the existing
4 laboratory-based methods (based on the expression of a parameter or proxy) which are too
5 slow to develop operational response and do not provide an adequate level of public health
6 protection in real-time. While these techniques are promising, particularly in terms of
7 reactivity and response time, they remain insufficient when prediction or anticipation are
8 required - in the event, for example, of global-scale water management.

9 With a view to further improvement in operational drinking water monitoring, a network of
10 sensors with remote piloting will allow a sample signal (rather than an actual sample) to be
11 sent to the laboratory (expert network). Yet this evolution still needs years of development
12 before it will, on the one hand, be available for numerous pollutants, and on the other, be
13 accepted by the authorities and operators.

14 The integration of secondary data in addition to real-time interpretation and analysis of quality
15 data now seems essential to ensuring reliable drinking water management. This type of data
16 should be considered as a preliminary alert to potential causes of water quality failure (which
17 may be more or less long-term), and consequently, could be useful in mitigating the effect of
18 such crises.

19 Such evolutions in drinking-water monitoring are required in particular for small water
20 supplies, serving 50 to 5,000 citizens, which appear to be the most vulnerable drinking water
21 systems regarding sanitary outbreaks.

22 **Acknowledgements**

23 The authors would like to acknowledge the invaluable help of Fleur Chaumet, Hardiesse
24 Bessonneau and Ianis Delpla.

25 **References**

- 26 Aryal, K., Joshi, H., Dhimal, M., Singh, S., Dhakal, P., Dhimal, B., and CL, B. (2012)
27 Environmental burden of diarrhoeal diseases due to unsafe water supply and poor
28 sanitation coverage in Nepal. *J Nepal Health Res Council.*, **10**(21), 125–129.
- 29 Astarai-Imani, M., Kapelan, Z., Fu, G., and Butler, D. (2012) Assessing the combined effects
30 of urbanisation and climate change on the river water quality in an integrated urban
31 wastewater system in the UK. *Journal of environmental management*, **112**, 1–9.
- 32 Bartram, J., Corrales, L., Davison, A., Deere, D., Drury, D., Gordon, B., Howard, G.,
33 Rinehold, A., and Stevens, M. (2009) *Water Safety Plan Manual: Step-By-Step Risk
34 Management for Drinking-Water Suppliers*,
- 35 Bates, B., Kundzewicz, Z., Wu, S., and Palutikof, J. (2008) *Climate Change and Water.
36 Technical Paper of the Intergovernmental Panel on Climate Change*,
- 37 Beaudeau, P., Pascal, Mathilde, Mouly, D., Galey, C., and Thomas, Olivier (2011) Health
38 risks associated with drinking water in a context of climate change in France : a review
39 of surveillance requirements. *Journal of Water and Climate Change*, **02**(4), 230–246.
- 40 Bessonneau, H., Chaumet, F., Roig, B., Thomas, O, and Baures, E. (2011) Evolution issues of
41 water quality monitoring for small and medium water supply systems. *European journal
42 of water quality- cahier de l'ASEES*, **16**(1), 7–15.
- 43 Boxall, A. (2012) New and Emerging Water Pollutants arising from agriculture. *OECD
44 Report*, 1–48.
- 45 Brodie, I. M. and Egodawatta, P. (2011) Relationships between rainfall intensity, duration and
46 suspended particle washoff from an urban road surface. *Hydrology Research*, **42**(4),
47 239–249.

- Brunetti, M., Maugeri, M., and Nanni, T. (2001) Changes in total precipitation, rainy days and extreme events in northeastern Italy. *International Journal of Climatology*, **21**(7), 861–871.
- Buerge, I. J., Poiger, T., Müller, M. D., and Buser, H.-R. (2006) Combined sewer overflows to surface waters detected by the anthropogenic marker caffeine. *Environmental science & technology*, **40**(13), 4096–102.
- Canonica, S., Meunier, L., and Von Gunten, U. (2008) Phototransformation of selected pharmaceuticals during UV treatment of drinking water. *Water research*, **42**(1-2), 121–8.
- Carlson, M. a., Lohse, K. a., McIntosh, J. C., and McLain, J. E. T. (2011) Impacts of urbanization on groundwater quality and recharge in a semi-arid alluvial basin. *Journal of Hydrology*, **409**(1-2), 196–211.
- Collins, S. L., Bettencourt, L. M., Hagberg, A., Brown, R. F., Moore, D. I., Bonito, G., Delin, K. a., Jackson, S. P., Johnson, D. W., Burleigh, S. C., Woodrow, R. R., and McAuley, J. M. (2006) New opportunities in ecological sensing using wireless sensor networks. *Frontiers in Ecology and the Environment*, **4**(8), 402–407.
- Cromwell, J. ., Smith, J. ., and Raucher, R. S. (2007) Implications of Climate Change for Urban Water Utilities. Association of Metropolitan water agencies Report, 1–20.
- Curriero, F. C., Patz, J. a, Rose, J B, and Lele, S. (2001) The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994. *American journal of public health*, **91**(8), 1194–9.
- Deblonde, T., Cossu-Leguille, C., and Hartemann, P. (2011) Emerging pollutants in wastewater: a review of the literature. *International journal of hygiene and environmental health*, **214**(6), 442–8.
- Delpa, I., Jung, A.-V., Baures, E., Clement, M., and Thomas, O (2009) Impacts of climate change on surface water quality in relation to drinking water production. *Environment international*, **35**(8), 1225–33.
- DiDonato, G. T., Stewart, J. R., Sanger, D. M., Robinson, B. J., Thompson, B. C., Holland, a F., and Van Dolah, R. F. (2009) Effects of changing land use on the microbial water quality of tidal creeks. *Marine pollution bulletin*, **58**(1), 97–106.
- Emelko, M. B., Silins, U., Bladon, K. D., and Stone, M. (2011) Implications of land disturbance on drinking water treatability in a changing climate: demonstrating the need for “source water supply and protection” strategies. *Water research*, **45**(2), 461–72.
- Falkenberg, K. and Bloech, H. (2011) *Drinking Water Directive, future implementation efforts. Summary record or the meeting of the Committee under article 12 of Directive 98/83/EC*,
- Field, K. G. and Samadpour, M. (2007) Fecal source tracking, the indicator paradigm, and managing water quality. *Water research*, **41**(16), 3517–38.
- García-ruiz, J. M., López-moreno, J. I., Vicente-serrano, S. M., Lasanta, T., and Beguería, S. (2011) Mediterranean water resources in a global change scenario. *Earth Science Reviews*, **105**(3-4), 121–139.
- Gonzalez, C., Spinelli, S., Gille, J., Touraud, E., and Prichard, E. (2007) Validation procedure for existing and emerging screening methods. *TrAC Trends in Analytical Chemistry*, **26**(4), 315–322.
- Greenwood, R., Mills, G A, and Roig, B. (2007) Introduction to emerging tools and their use in water monitoring. *Trends in Analytical Chemistry*, **26**(4), 263–267.
- Hart, J. K. and Martinez, K. (2006) Environmental Sensor Networks: A revolution in the earth system science? *Earth-Science Reviews*, **78**(3-4), 177–191.
- Harwood, V. J., Levine, A. D., Scott, T. M., Chivukula, V., Lukasik, J., Farrah, S. R., and Rose, Joan B (2005) Validity of the Indicator Organism Paradigm for Pathogen

- Reduction in Reclaimed Water and Public Health Protection. *Appl. Environ. Microbiol.*, **71**(5), 3163–3170.
- Hassan, J. (2005) *Technologies and Techniques for Early Warning Systems to Monitor and Evaluate Drinking Water Quality: State-of-the-Art review*,
- Hrdinka, T., Novický, O., Hanslík, E., and Rieder, M. (2012) Possible impacts of floods and droughts on water quality. *Journal of Hydro-environment Research*, **6**(2), 145–150.
- Hulsmann, A. (2005) Small systems large problems. A European inventory of small water system and associated problems. Web based European Knowledge Network on Water, (June).
- Jeon, J., Kim, J. H., Lee, B. C., and Kim, S. D. (2008) Development of a new biomonitoring method to detect the abnormal activity of *Daphnia magna* using automated Grid Counter device. *The Science of the total environment*, **389**(2-3), 545–56.
- Johnson, A. C., Acreman, M. C., Dunbar, M. J., Feist, S. W., Giacomello, A. M., Gozlan, R. E., Hinsley, S. A., Ibbotson, A. T., Jarvie, H. P., Jones, J. I., Longshaw, M., Maberly, S. C., Marsh, T. J., Neal, C., Newman, J. R., Nunn, M. A., Pickup, R. W., Reynard, N. S., Sullivan, C. A., Sumpter, J. P., and Williams, R. J. (2009) The British river of the future: how climate change and human activity might affect two contrasting river ecosystems in England. *The Science of the total environment*, **407**(17), 4787–98.
- Journal Officiel (2007) “French Decree of 11 janvier 2007 relative to « limites et références de qualité des eaux brutes et des eaux destinées à la consommation humaine » mentionned in articles R. 1321-2, R. 1321-3, R. 1321-7 et R. 1321-38 of the French public health code. Journa” in French public health code., R. 1321–2, R. 1321–3, R. 1321–7 et R. 1321–38 of t.
- Kroll, D. (2009) “Monitoring for Terrorist-Related Contamination” in S. Ahuja (ed.), *Handbook of Water Purity and Quality*. Amsterdam, Elsevier Inc., 343–377. [online] <http://dx.doi.org/10.1016/B978-0-12-374192-9.00015-7>.
- Kusumawardaningsih, Y. (2010) A Preliminary Review of Some Drinking Water Quality ’ s Guidelines and Standards in the World. *Jurnal Kompetensi Teknik V*, **1**(2), 75–82.
- Malmaeus, J. M., Blenckner, T., Markensten, H., and Persson, I. (2006) Lake phosphorus dynamics and climate warming: A mechanistic model approach. *Ecological Modelling*, **190**(1-2), 1–14.
- Mons, M. (2008) Monitoring and control of drinking water quality Inventory and evaluation of monitoring technologies for key-parameters. *Techneau*, (October), 306.
- Monteith, D., Stoddard, J., Evans, C., De Wit, H., Forsius, M., Høgåsen, T., Wilander, A., Skjelkvåle, B., Jeffries, D., Vuorenmaa, J., Keller, B., Kopáček, J., and Vesely, J. (2007) Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature*, **450**(7169), 537–540.
- Mouly, D., Joulin, E., Rosin, C., Beaudeau, P., and Zeghnoun, A. (2008) *Les sous-produits de chloration dans l ’ eau destinée à la consommation humaine en France Campagnes d ’ analyses dans quatre systèmes de distribution d ’ eau et modélisation*,
- Nan, Y., Bao-hui, M., and Chun-kun, L. (2011) Impact Analysis of Climate Change on Water Resources. *Procedia Engineering*, **24**, 643–648.
- Nikolaou, A. D., Golfopoulos, S. K., Arhonditsis, G. B., Kolovoyiannis, V., and Lekkas, T. D. (2004) Modeling the formation of chlorination by-products in river waters with different quality. *Chemosphere*, **55**(3), 409–20.
- Pascal, M (2010) *Health impact of climate change in France What are the challenges for the French Institute for Public Health Surveillance (InVS)?*,
- Pellerin, B. A., Bergamaschi, B. A., and Horsburgh, J. . (2012) *In Situ Optical Water-Quality Sensor Networks — Workshop Summary Report: U.S. Geological Survey Open-File Report 2012–1044*,

- Petrovic, M. and Barceló, D. (2007) LC-MS for identifying photodegradation products of pharmaceuticals in the environment. *TrAC Trends in Analytical Chemistry*, **26**(6), 486–493.
- Pitkänen, T., Karinen, P., Miettinen, I. T., Lettojärvi, H., Heikkilä, A., Maunula, R., Aula, V., Kuronen, H., Vepsäläinen, A., Nousiainen, L.-L., Pelkonen, S., and Heinonen-Tanski, H. (2010) Microbial Contamination of Groundwater at Small Community Water Supplies in Finland. *Ambio*, **40**(4), 377–390.
- Prathumratana, L., Sthiannopkao, S., and Kim, K. W. (2008) The relationship of climatic and hydrological parameters to surface water quality in the lower Mekong River. *Environment international*, **34**(6), 860–6.
- Quenel, P. (1995) Public health surveillance and the environment. *Rev Epidemiol Sante Publique*, **43**(5), 412–422.
- Ranjan, P., Kazama, S., and Sawamoto, M. (2006) Effects of climate change on coastal fresh groundwater resources. *Global Environmental Change*, **16**(4), 388–399.
- Richardson, H. Y., Nichols, G., Lane, C., Lake, I. R., and Hunter, P. R. (2009) Microbiological surveillance of private water supplies in England: the impact of environmental and climate factors on water quality. *Water research*, **43**(8), 2159–68.
- Risebro, H. L., Breton, L., Aird, H., Hooper, A., and Hunter, P. R. (2012) Contaminated small drinking water supplies and risk of infectious intestinal disease: a prospective cohort study. *PloS one*, **7**(8), e42762.
- Rodil, R., Quintana, J. B., Concha-Graña, E., López-Mahía, P., Muniategui-Lorenzo, S., and Prada-Rodríguez, D. (2012) Emerging pollutants in sewage, surface and drinking water in Galicia (NW Spain). *Chemosphere*, **86**(10), 1040–9.
- Roig, B., Allan, I., Mills, Graham A, Guigues, Nathalie, Greenwood, R., and Gonzalez, C. (2009) “Existing and new methods for chemical and ecological status monitoring under the WFD” in C. Gonzalez, R. Greenwood, and P. Quevauviller (eds.), *Rapid Chemical and Biological Techniques for Water Monitoring*. Chichester, John Wiley & son, 39–50.
- Roig, B., Baures, B., Jung, A., Delpla, I., and Thomas, O (2012) “Rainfall and Water Quality” in O. E. Martín and T. M. Roberts (eds.), *Rainfall: Behavior, Forecasting and Distribution*. Nova Publisher, 91–104.
- Roig, B., Valat, C., Berho, C., Allan, I. J., Guigues, N, Mills, G A, Ulitzur, N., and Greenwood, R. (2007) The use of field studies to establish the performance of a range of tools for monitoring water quality. *Trends in Analytical Chemistry*, **26**(4), 274–282.
- Sadiq, R., Rodríguez, M. J., and Tesfamariam, S. (2010) Integrating indicators for performance assessment of small water utilities using ordered weighted averaging (OWA) operators. *Expert Systems with Applications*, **37**(7), 4881–4891.
- Schuster, C., Ellis, A., Robertson, W., Charron, D., Aramini, J., Marshall, B., and Medeiros, D. (2005) Infectious disease outbreaks related to drinking water in Canada, 1974-2001. *Can J Public Health.*, **96**(4), 254–258.
- Singer, J. (1993) “Formation and characterization of disinfection by-products.” in Craun. GF (ed.), *Safety of Water Disinfection: Balancing Chemical and Microbial Risks*. Washington, ILSI Press, 201–221.
- Skadsen, J., Janke, R., Grayman, W., Samuels, W., Tenbroek, M., Steglitz, B., and Bahl, S. (2008) Distribution system on-line monitoring for detecting contamination and water quality changes. *Journal of American water works association*, **100**(7), 81–94.
- Soh, Y. C., Roddick, F., and Van Leeuwen, J. (2008) The future of water in Australia: The potential effects of climate change and ozone depletion on Australian water quality, quantity and treatability. *The Environmentalist*, **28**(2), 1586165.
- Storey, M. V, Gaag, B. Van Der, and Burns, B. P. (2010) Advances in on-line drinking water quality monitoring and early warning systems. *Water Research*, **45**(2), 741–747.

- Stuart, M., Lapworth, D., Crane, E., and Hart, A. (2012) Review of risk from potential emerging contaminants in UK groundwater. *The Science of the total environment*, **416**, 1–21.
- Teksoy, A., Alkan, U., and Başkaya, H. S. (2008) Influence of the treatment process combinations on the formation of THM species in water. *Separation and Purification Technology*, **61**(3), 447–454.
- Tickner, J. and Gouveia-Vigeant, T. (2005) The 1991 cholera epidemic in Peru: not a case of precaution gone awry. *Risk analysis : an official publication of the Society for Risk Analysis*, **25**(3), 495–502.
- Tiehm, A., Schmidt, N., Lipp, P., Zawadsky, C., Marei, A., Seder, N., Ghanem, M., Paris, S., Zemann, M., and Wolf, L. (2012) Consideration of emerging pollutants in groundwater-based reuse concepts. *Water Science and Technology*, **66**(6), 1270–1276.
- Touraud, E., Roig, B., Sumpter, J. P., and Coetsier, C. (2011) Drug residues and endocrine disruptors in drinking water: risk for humans? *International journal of hygiene and environmental health*, **214**(6), 437–41.
- Tuppin, P., De Roquefeuil, L., Weill, A., Ricordeau, P., and Merlière, Y. (2010) French national health insurance information system and the permanent beneficiaries sample. *Rev Epidemiol Sante Publique*, **58**(4), 286–290.
- Unicef and WHO (2012) Progress on Drinking Water and Sanitation. 2012 update. Report, 1–61. [online] www.unicef.org/media/files/JMPPreport2012.pdf.
- United Nation (2010) *Resolution 64/292. The Human right to water and sanitation*,
- United Nation and WHO (2011) Small-scale water supplies in the pan-European region. WHO report, 1–54.
- Van Vliet, M. T. H. and Zwolsman, J. J. G. (2008) Impact of summer droughts on the water quality of the Meuse river. *Journal of Hydrology*, **353**(1-2), 1–17.
- Wagner, R. J., Boulger, R. W., Oblinger, C. J., and Smith, B. A. (2006) *Guidelines and Standard Procedures for Continuous Water-Quality Monitors : Station Operation , Record Computation , and Data Reporting. U.S. Geological Survey Techniques and Methods 1–D3*,
- WHO (2011) *WHO guidelines for drinking-water quality.*, [online] <http://www.ncbi.nlm.nih.gov/pubmed/15806952>.
- Wilby, R. L., Orr, H. G., Hedger, M., Forrow, D., and Blackmore, M. (2006) Risks posed by climate change to the delivery of Water Framework Directive objectives in the UK. *Environment international*, **32**(8), 1043–55.