Water Safety Plan Enhancements with Improved Drinking Water Quality Detection Techniques

Maria J. Gunnarsdottir[1], Sigurdur M. Gardarsson[1], Maria J. Figueras[2], Clàudia Puigdomènech[3], Rubén Juárez [3], Gemma Saucedo[4], Ricardo Santos[5], Silvia Patricia Nunes Monteiro[5], Lisa Avery[6], Euelyn Pagaling[6], Richard Allen[6], Claire Abel[6], Janis Eglitis[7], Beate Hambsch[8], Micheal [8], Andreja Rajkovic[9], Nada Smigic[9], Boja [9], Hans-Jörgen Albrechtsen[10], Alma Lopez-Aviles[11], Paul Hunter[12]

1) University of Iceland, 2) Universitat Rovira i Virgili, 3) Cetaqua, 4) Aigües de Barcelona, 5) Instituto Superior Technico, 6) The James Hutton Institute, 7) Water Resource Centre, 8) Water Technology Centre, 9) University of Belgrade, 10) DTU Environment, 11) University of Surrey, 12) University of East Anglia

Abstract

Drinking water quality has been regulated in most European countries for nearly two decades by the drinking water directive 98/83/EC. The directive is now under revision with the goal of meeting stricter demands for safe water for all citizens, as safe water has been recognized as a human right by the United Nations. An important improvement to the directive is the implementation of a risk-based approach in all regulated water supplies. The European Union Framework Seventh Programme Aquavalens (EU FP7 AQV) project has developed severalnew detection technologies for pathogens and indicators and tested in water supplies in seven European countries. One of the tasks of the project was to evaluate the impact of these new techniques on water safety and on water safety plan management. Data was collected on risk factors to water safety with a questionnaire. Samples were collected from the water supplies from all stages of water production and delivery from raw water to network. Pathogens were detected in around 23% of the nearly 500 samples tested, where some were site specific and others country specific. Fecal contamination was high, even in treated water at the small supplies. Old infrastructure was considered a challenge at all the water supplies. The results showed that the AQV platforms, if implemented as part of the water safety plan, can detect rapidly the most common waterborne pathogens and fecal pollution indicators and therefore has a great early warning potential, can improve water safety for the consumer, validate whether mitigation methods are working as intended, and confirm the quality of the water at source and at the tap, including detection of possible contamination events.

Introduction

Drinking water quality in the member states of the European Union and European Economic Area has been regulated by the Council Directive 98/83/EC (DWD) on the quality of water intended for human consumption since 1998. There is a consensus that compliance rates have improved and that it has had a positive effect on public health in Europe (Klaassens et al., 2016). As an example, there has been a significant reduction in the presence of the fecal indicator *E. coli* in drinking water (EC, 2014 & 2016). However, many studies have shown that the water quality and information of small water supplies is poorer than in large water supplies (EC, 2014; Beaudeau et al., 2010; Hulsmann, 2005; Pitkänen et al., 2011; Hendry & Akoumianaki, 2016; Gunnarsdottir et al., 2017a; Gunnarsdottir et al., 2016; Gunnarsdottir et al., 2015). Sixty-five million European citizens, or around 8%, are estimated to be served by small water supplies and two million are without water service (Klaassens et al., 2016; Hulsmann, 2011).

The human right to water and sanitation was recognized by the United Nations General Assembly on July 28, 2010 and is reflected in the new UN Sustainable Development Goals (UN-SDGs) of September 2015. Goal 6 ensures universal access to safe and affordable drinking water for all by 2030 (Resolution 64/292; UN-SDGs, 2015). If the UN-SDGs goals with the human right to safe water are to be met in Europe, the water safety of the small supplies, that have limited surveillance and poor water quality, needs to be addressed. The first European Citizens Initiative (ECI) Right2Water was conducted in 2013-14, in accordance with the Lisbon Treaty, to encourage greater democratic involvement of citizens in European affairs, and to urge the European Commission to implement the human right to water into DWD legislation. The ECI was signed by over 1.8 million citizens of Europe in 13-member states[1].

The European Commission started in 2003 to discuss the key elements that should be modified in the DWD considering current knowledge and advances in technology (Figueras and Borrego, 2010) and has recently published an evaluation report on the performance of the EU-DWD (Klaassens et al., 2016). It was emphasized in the EC evaluation report that in the twenty years that have passed since the EU-DWD was written there have been various developments, including technology and identification of new contaminants, that together require updating of the DWD. For example, the implementation of a risk-based approach, such as the Water Safety Plan (WSP) can lead to a faster decision-making process in the case of incidents, which will increase water safety (Bartram et al., 2009; Figueras and Borrego, 2010; Gunnarsdottir et al., 2012a). The report also points out that the use of new methods, such as molecular methods in testing water quality, give results faster, are more sensitive and more specific than the current methods based on culturing. Furthermore, it is emphasized in the report that the implementation of the newly developed information and communication technologies (ICT) with various tools could enhance water quality and performance of services.

A systematic preventive approach for managing risk to water safety, the WSP, is now internationally recognized as an important and modern method for reducing health risk from drinking water. This approach has been advocated by the World Health Organization (WHO) since 2004 and is now used in at least 93 countries around the world and as policy or regulatory requirement or under development in 69 countries (WHO/IWA, 2017). This approach aims at shifting surveillance from control at the tap to preventive management for the whole supply chain. The WSP implementation has been shown to improve drinking water quality and public health as well as being beneficial in management (Gunnarsdottir et al., 2012a; 2012b; Summerill et al., 2010a & 2010b; Setty et al., 2017). The approach used in some

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[1] ECI Right2Water: http://www.right2water.eu/.

European countries (e.g. Switzerland, Iceland, France, Slovenia, Norway and Sweden) is to classify drinking water as food that needs to be protected in a systematic way has been shown to positively change the mindset of people working in the water sector (Baum & Bartram, 2017; Gunnarsdottir et al., 2012b).

The microorganisms which can cause waterborne outbreaks are not directly included in the EU-DWD, rather only indicator parameters, whereas pathogens are only investigated when an outbreak is suspected or occurs. The main regulatory indicators for pathogens are now the bacteria *E. coli* and Enterococci, both indicating presence of fecal contamination but may not necessarily reflect whether there is a threat to human health. However, other microbes may be present, in the absence of the indicator bacteria, that can pose a risk to human health, such as viruses and parasites. Survival of pathogens in the environment depends on many factors, such as temperature, acidity and composition of the strata, and it is not the same for all kingdoms of pathogens. For example, parasites live much longer than bacteria in water and viruses travel longer in the strata, being much smaller in size (Yates et al., 1985; Figueras and Borrego, 2010). For example, in a norovirus outbreak infecting 100 people at a hotel in northern Iceland in 2004, there were no indicator bacteria found, whereas water samples were registered as very strongly positive for Norovirus (NoV) GII. The cause of the outbreaks was a septic tank situated near to a water well and in a groundwater stream to the well (Gunnarsdottir et al., 2013). Therefore, it is important to develop techniques to measure pathogens and suitable indicators instead of relying mostly on indicators of only one kingdom (i.e. bacteria).

Since the EC evaluation report a paragraph was added in a new amendment to the DWD that allows reduction of sampling if a risk-based approach is used (EC, 2015). This acknowledged the merit of preventive management, such as WSP, to be included in formal legislation (Baum & Bartram, 2017). New proposal for revision of the DWD has been published (Feb. 2018; Oct 2018)[2]. This is a follow-up on the ECI Right2Water initiative. The main change in the proposal that affects the objective of this research is that all water supplies that provide more than 10 m^3 a day (or 50 people) are to carry out a risk-based approach to water safety, new parameters are added (e.g. Clostridium perfringens spores, Somatic coliphages, Legionella, Per-fluorinated and Endocrine compounds) and information on drinking water to consumers is to be increased considerably, using information technology. In addition, the competent authorities should regularly audit the WSP and, when implemented, the supplies can either decrease monitoring of parameters or drop them. However, this does not apply to core parameters such as *E. coli* and Coliform. The new proposal also assists in fulfilling the objective of the Water Framework Directive and applying the Polluters Pay Principle.

[2]http://ec.europa.eu/environment/water/water-drink/;
http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P8-TA-2018-0397+0+DOC+XML+V0//EN&language=EN https://ec.europa.eu/info/law/better-regulation/initiatives/com-2017-753_en#initiative-givefeedback

The objective of this research was evaluation of the impact of the implementation of improved modern detection techniques for pathogens and indicators on water safety plan management.

Methods

The methods employed to reach the objectives of this study used results from work done in the FP7 Aquavalens (AQV) project (www.aquavalens.org), mainly in work packets 13, 10 and 11 (Gunnarsdottir et al., 2018, 2017b, 2017c; Eglitis et al., 2017; Puigdoménech et al., 2017; Monteiro & Santos, 2017; López-Avilés & Pedley, 2017a & 2017b). Data were gathered from the test sites with questionnaires, results from monitoring with the new AQV techniques, verification control, surveillance monitoring, and sanitary inspection performed for the small water supplies as shown in Table 1. Twenty water supplies participated in the project and answered questionnaires whereas nineteen of them tested the AQV technique.

Table 1. Information on questionnaires, sanitary inspection and samples

	Large water supplies	Small water supplies	Sum
No of water supplies participating in AQV project	5	15	20
People served by the 20 water supplies	12.200.000	1.045	12.201.045
WP13 Questionnaire 1: Information about the water supplies and risk to water quality	5	15	20
WP13 Questionnaire 2: Performance of AQV technique	5	3	8
WP11: Sanitary Inspection	0	15	15
WP10 and WP11 testing AQV technique: No of water supplies	4	15	19
Surveillance monitoring 2013-2014	4	10	14
No of samples tested with AQV technique	215	263	478
No of samples tested in verification control	177	153	330
No of samples gathered for two year of regular surveillance (2013 and 2014)	2 906	134	3 040

The data were used to analyse the possible impact on water safety and preventive management tools such as WSP. Analyses of the impact from the improved techniques developed in the AQV project on WSP was done by using the WHO's WSP manual for large supplies (Bartram et al., 2009). The details on the WSP framework and modules are given in the Appendix.

The AQV platforms tested included one concentration procedure based on the use of the commercially available filter Rexeed™. The concentration of the water samples was performed either at the laboratory or on site at the sampling point using a protocol developed in the AQV project. The recovery protocol developed in AQV was used to eluate the filter, to do a secondary concentration and to perform the acid nucleic extraction. Using the Rexeed filter within the AQV protocol allows simultaneously concentrating and recovering pathogens of the three kingdoms (bacteria, viruses and parasites), which is more economical than conventional methods that require different specific filters and concentration procedures for each kingdom. With the conventional cultural method, the detection process takes 18-48 hours, whereas with the AQV techniques it takes 4 to 7 hours.

The techniques that were developed in the project were tested for one year (2016-2017) at nineteen water supplies in seven countries of Europe (Denmark, Germany, Portugal, Serbia, Scotland, Spain and England & Wales), at four large supplies and fifteen small supplies. The tested methods included three off-line detection techniques; two molecular techniques produced by the two industrial partners Ceeram and GPS; one fluorescent in-situ hybridization (FISH) technique from Vermicon AG testing total cells (DAPI staining) and viable cells (EUB probe) as well as *E. coli* and thermophilic *Campylobacter* cells (these include *C. jejuni, C .coli* and *C. lari*); and one online system BACTcontrol, from the partner MicroLAN, measuring enzymatic activity with fluorescence that tested total activity and the indicator bacteria, total coliform and *E. coli*.

The molecular techniques from Ceeram and GPS were tested on samples from the nineteen sites, large and small alike, whereas FISH and BACTcontrol were only tested at the four large supplies. In all, testing was carried out for nineteen pathogens and indicators, as shown in Table 2.

Table 2. Pathogens and indicators tested with the AQV detection technique

SME's	Type of technique	Pathogens and indicators tested	
		4 large water supplies (number of supplies tested)	15 small water supplies (number of supplies tested)
Ceeram	Molecular qPCR	NoV GI and GII (All) HAV (1) *Giardia* spp (3) *Cryptosporidium* spp (3)	NoV GI and GII (All) HAV (All) and HEV (9) Enterovirus (6) *Giardia* spp (All) *Cryptosporidium* spp (All)
GPS	Molecular qPCR	*E. coli* (All), *C. jejuni* (All) *Salmonella* spp (1) *L. pneumophila* (1) *Campylobacter* spp (3) *Cryptosporidium* spp (2) *Toxoplasma gondii* (1) *Giardia intestinalis* (1)	*E. coli* (All) *E. coli* 0157 (All) *Campylobacter coli* (All) *C. jejuni* (All)
Vermicon	FISH (Fluorescent in-situ hybridization)	Total cell counts (All), Total viable cells (All), *E. coli* cells (All) Thermophilic *Campylobacter* cells (All)	None
MicroLAN	Online BACTcontrol system measuring enzymatic activity with fluorescence of specific enzymes	Total activity (2) *E. coli* (1) Total coliform (1)	None

Verification control was performed with conventional methods (such as culture and/or immunomagnetic separation methods) using improved conventional methods at the large supplies and conventional at the small supplies, except in one country with six small sites where 20-50 L were concentrated instead of the usual 100 ml.

The results from regular surveillance monitoring were gathered for the water supplies participating in the testing from the local surveillance authorities, and for two years 2013 and 2014. The surveillance monitoring was performed with the conventional culturing methods (100 mL).

Results and discussions

This section is divided into five parts: 1) results from survey of WSP performance at the large supplies, 2) general risk factors and challenges in the water supplies surveyed; 3) results from the tests performed at the large supplies; 4) results from the tests performed at the small supplies; and 5) the impact the AQV platforms could have in improving WSP, if implemented.

WSP Performance and benefits

Five large water supplies in four countries (Denmark, Germany, Spain, England & Wales) that participated in AQV answered WP13 Questionnaire 1. All had a WSP in place. It is mandatory to have a WSP in two of the countries, Denmark and England & Wales. Two sites had WSP certified as ISO 22000 and three had WSP developed by WHO. All scored high in performance in all five components of WSP as can be seen in Figure 1. Internal auditing was lacking at two supplies, and WSP team was not active and periodic reviewing was lacking at one supply. The two that used ISO 22000 scored highest in the WSP process; the reason could be that ISO 22000 includes regular external audit which, if violated, will produce the loss of the ISO certificate. Two of the small sites had WSP and six had recently done a risk assessment when surveyed in the AQV project. However, none of the small supplies answered on WSP performance with the small supplies.

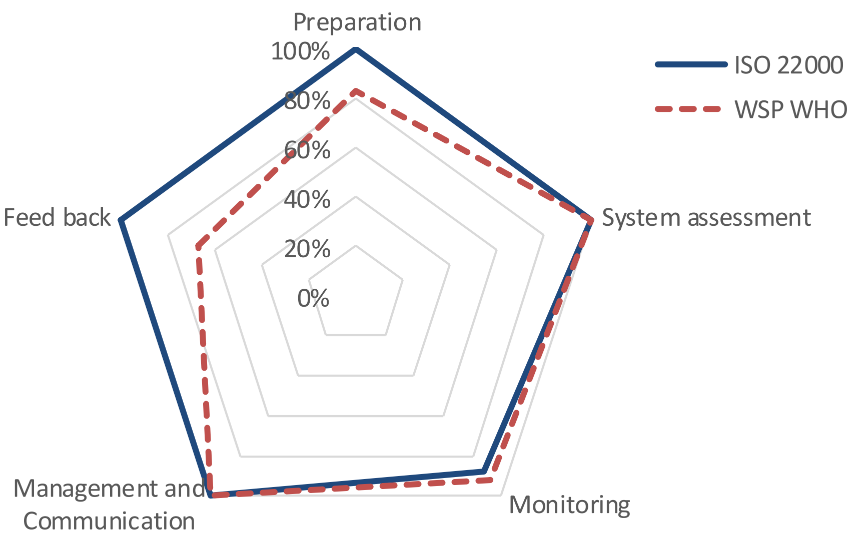

Figure 1 Performance of WSP in five large European water supplies as percentage of 11 modules in the 5 components of WHOs WSP (Fig. 9)

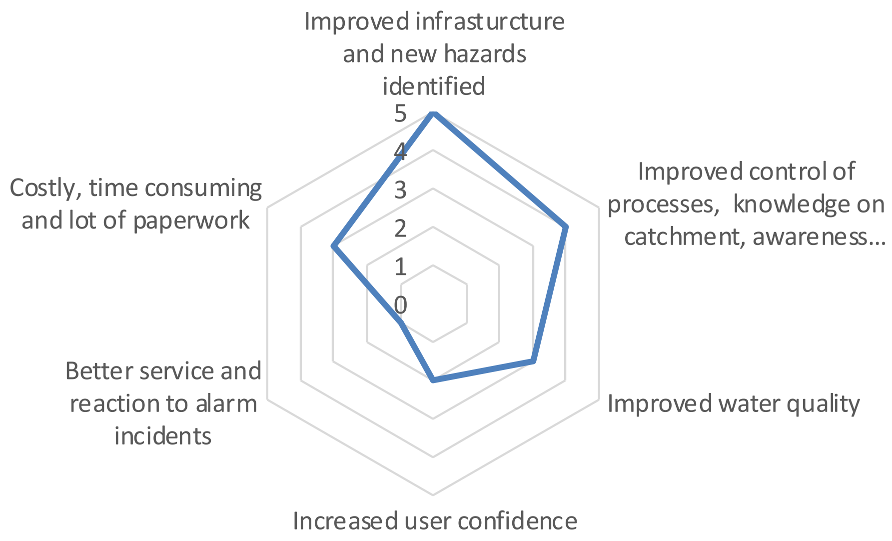

Figure 2 Main benefits and drawback reported for WSP from five European large water supplies

The main benefits with WSP were considered that infrastructure was improved, and new hazards were identified (Figure 2). Improved control processes, water quality and knowledge on the status of the catchment was also considered beneficial. As to management the main benefits experienced were that professionalism improved, and user confidence increased were experienced at two. Improved internal communication was also mentioned as a benefit by one respondent. The drawbacks cited by three supplies were that WSP is costly and time consuming as well as involving a lot of paper work. Two supplies considered WSP to have no drawbacks. The conclusion is that all five large water suppliers considered WSP as beneficial in many aspects that should result in safer water.

Risk factors and challenges in the twenty European water supplies

All twenty water supplies answered questions on risk to water safety. There were substantial activities on the catchment of many of them as shown in Figure 3. Many had some fecal contamination source in the catchment area (85%), i.e. sewage work, septic tanks or presence of animal fecal matter. Many supplies (70%) had agriculture, either cultivation or livestock or both, practiced in the catchment area. Farm waste in the catchment was common for the small supplies, and two large supplies had oil tanks in their catchment. All the large supplies had residential areas in the catchment and three of the small supplies also had some residential areas.

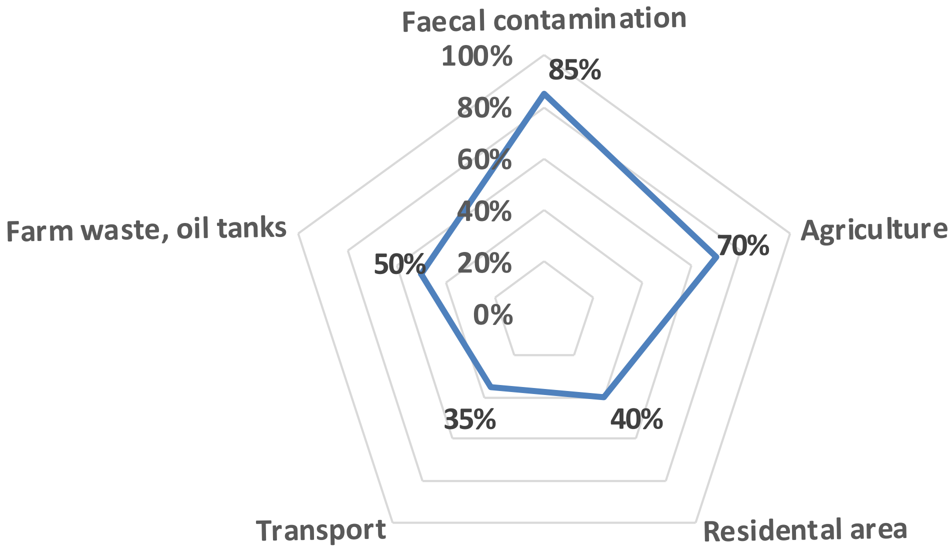

Figure 3. Activity in the catchment for the twenty European water supplies

The pipes were old, especially at the large supplies, and more so in the transport pipelines from the water source to the urban areas compared to the distribution network, and pipe breaks were frequent in the large supplies (information was not available for the small supplies). Pipe breaks per year were on average 0.68 per km (Table 3). However, pipe breaks were much more frequent in the network than in the transport pipelines (0.82 versus 0.07 pipe break per km). The explanation was most likely due to a higher stress on the infrastructure from traffic and other activity in the urban areas. The median pipe age in the large supplies was 51 years and 10 years for the small supplies. The oldest pipes in the large systems were reported as 99 years old, and one site in the small supplies reported that the pipes were 140 years old. Sewage was reported in the same ditch as drinking water pipes in two of the large supplies increasing risk of faecal contamination. Two large water supplies reported leakage, 8% and 17%. The average leakage from the supply network in the EU is 23% (EU, 2015). Leaking pipes increases also risk of contamination. In the new EU DWD proposal there is requirement of reporting and reducing leakage.

The source of fecal contamination of the drinking water can either be fecal matter in the catchment or entering into the network via cracks in the aging infrastructure where sewage pipes are too close to drinking water pipes or due to some cross-connection to the sewage system. This situation with aging infrastructure and fecal contamination at the catchment or in the system could, to some extent, be representative of the situation in the water sector in Europe. Summarizing causes of the twenty-nine examples of waterborne outbreaks in the developed part of the world in Hrudey & Hrudeys (2014) reveals that pathogenic outbreaks were divided equally into source contamination and contamination happening in the network, the latter often caused by accidental cross-contamination.

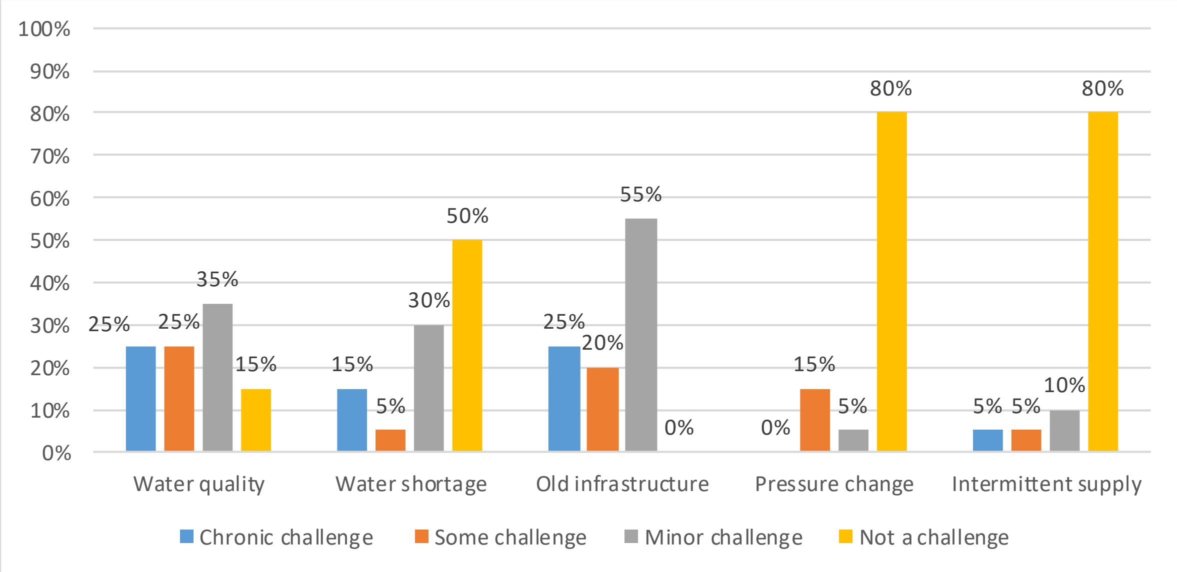

Figure 4. Main challenges in twenty European water supplies

Figure 4 shows the main challenges regarding water quality reported from at the twenty water supplies. They were old infrastructure at all water supplies (100%), water quality (85%) and water shortage (50%). To a lesser extent there were challenges with pressure changes and intermittent supply (20%) that occurred almost only in the small supplies. Five of the nineteen water supplies have had to cope with old infrastructure as a chronic challenge (25%), and pipe breaks and the resulting leaks were likely to have posed a risk to water safety. Challenges with pressure changes and intermittent supply pose an increased risk to water quality, especially in old pipes system and if in the same ditch as sewage pipes. This reveals that there is a need to improve resource efficiency in Europe with improved leakage control and renewing the infrastructure, preferably done through requirement in the drinking water directive.

Table 3. Infrastructure data at the twenty European water supplies as indicator of water quality risk

	Units	Large water supplies	Small water supplies
Source of water[1]	%	G = 42% S = 58%	G = 87% S = 13%
Sites with treatment	No	4	10
Length of pipelines	km	6 860	40
Length of pipelines per person	km per person	0.76	38
Main pipe types	%	Ductile (33%), Cast iron (20%), PEH (16%), Asbestos (14%), Steel (6%), Concrete (5%), PVC (2%), Other (4%)	PVC, PEH and Cast iron[2]
Median pipe age	Years	51	10
Average pipe age	Years	54	28
Pipe breaks	No. per year	4 633	n.a.[3]
Pipe breaks	Per km/year	0.68	n.a.

1) G= groundwater, S= surface water from river and/or lake; 2) Information on length of each type of pipe type not available 3) n.a. information not available.

Test results for the large supplies

In the large supplies there were 104 incidents of pathogens found in samples with the AQV techniques. The ones most frequently detected were norovirus (52) and *Campylobacter* (39). All kingdoms of pathogens were detected in raw and processed water, though mainly viruses and bacteria, as can be seen in Table 4. There were also sporadic incidents in treated water leaving the treatment station and in the distribution network. In all, 24% of the samples were detected with pathogens though mostly in raw and processed water, 40% and 31% respectively (Table 4).

Table 4. Pathogens tested at the 4 large water supplies

	No. of samples tested for pathogens	No. of samples with pathogens	% of sample with pathogens	No. of pathogen incidents	Kingdom of pathogens		
					Bacteria	Virus	Parasites
Raw water	57	23	40%	47	20	25	2
Processed water*	67	21	31%	48	23	24	1
Treated water	39	4	10%	5	3	2	0
Network	54	4	6%	4	1	2	1
SUM	217	52	24%	104	47	53	4

*Processed water includes treatments such as flocculation/sedimentation, sand filtration, dissolved air flotation, and GAC filtration with a prior ozonation at the different demonstration sites.

Results from monitoring pathogens with the AQV techniques: qPCR Ceeram, qPCR GPS and FISH in the large supplies in each member state, are shown in Figure 5. NoV GI and GII were detected in 12 to 24% of the samples in raw and processed water, and some few in treated water and in the network in a very low concentration (<1 GU/L). Most pathogens were found in untreated surface water and less often in groundwater. *Cryptosporidium* were found sporadically in raw and processed water, and in the network. *Giardia* was never found with the AQV molecular techniques in the large supplies but several times with the AQV improved conventional verification method (IMS, Immunomagnetic separation) in raw and processed water (not shown in Fig. 5).

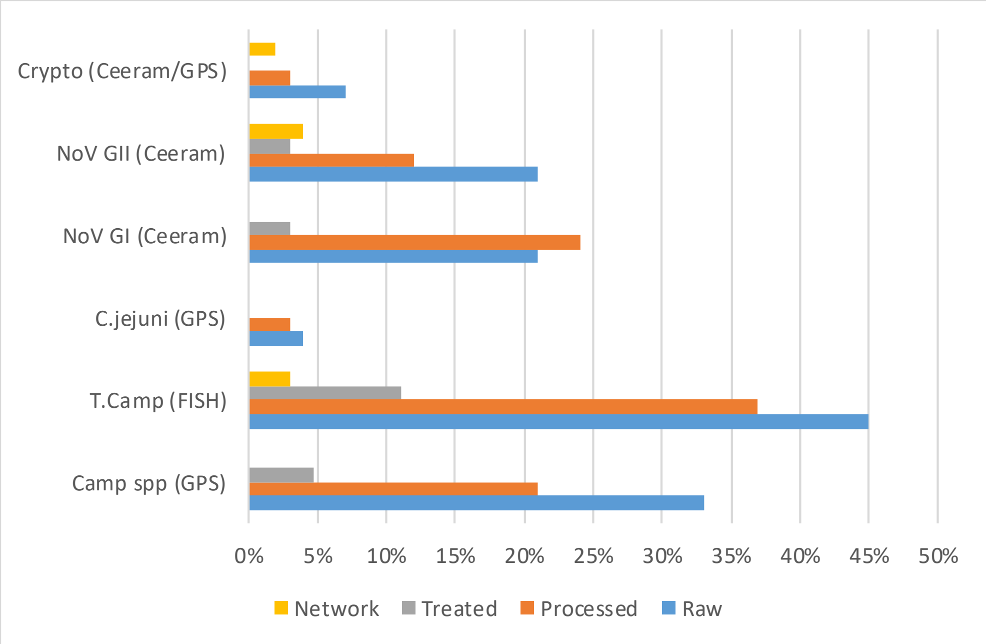

Figure 5. Pathogens tested and detected with the AQV platform in the 4 large European water supplies as a percentage of sample tested

Detection of pathogens was to some extent site-specific. For instance, norovirus was only found at two of the four supplies tested, both using surface water source and mostly in raw water and processed water, whereas *Campylobacter* spp, *C. jejuni* or thermophilic *Campylobacter* were found at three sites. *Cryptosporidium* was only found at one site (four incidents), and at all stages. It has also to be noted that the amount of testing for pathogens was not the same at all sites as at one site there was much more testing, especially in the network. There were tests for other pathogens at that one site such as Hepatitis A (HAV), *Salmonella* and *Legionella* (*L. pneumohila*) and these results are not included in Figure 5. HAV was only detected in one sample in raw water, *Salmonella* was found in one processed water sample and *Legionella* in seven samples, one in raw water and six in processed water. The same large water supply was also tested for *Toxoplasma gondii,* but it was not detected in any sample.

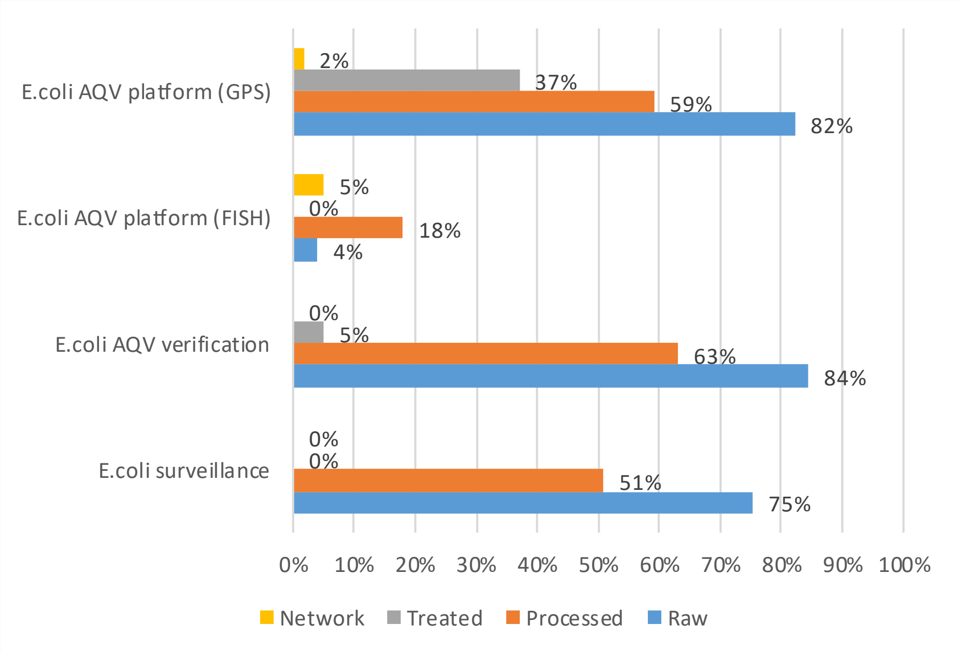

Figure 6. Detection of *E. coli* with AQV techniques, AQV verification and in regular surveillance monitoring in 4 large European water supplies as a precentage of sample tested

The results from monitoring *E. coli,* as an indicator of fecal contamination, with the AQV techniques (qPCR kits of GPS) in the large supplies showed a high percentage of positive samples in both raw and processed water (82% and 59%), and even in treated water (37%), and on one occasion in the network at a very low level (< 50 GU/L), as shown in Figure 6. Similar results for *E. coli* were measured with AQV verification control in raw and processed water but were lower in treated water. This could indicate that the AQV platform is more sensitive when PCR inhibitors are not influential, as they are in raw surface water. However, an important challenge associated with the molecular qPCR detection is that there is no distinction between live and dead cells. This possibly explains the difference between the *E. coli* detected with AQV techniques and with the AQV conventional verification method, 32% (37% minus 5%) when water has been treated with disinfection that inactivated/killed pathogens and is therefore not detected with the cultural method. Much lower detection of *E. coli* was found with the FISH method and mixed results, as can be seen in Figure 6.

Figure 6 also shows that somewhat lower detection was found with regular surveillance than with the GPS and AQV verification methods, and none in treated water. The regular surveillance monitoring was done with a conventional culturing method.

Test results for the small supplies

Table 5 shows that in the small supplies there were 61 incidents of pathogens found with the two AQV detection techniques used, qPCR Ceeram and qPCR GPS. The most frequently found were *Cryptosporidium* (28) and *Campylobacter coli* (11). All kingdoms were detected in both raw and treated water, though most were parasites. There were fewer incidents in raw water of the pathogens in the small supplies than in the large supplies. The reason could be that the raw water was mostly groundwater in the small supplies, 87% as against 42% in the large supplies (see Table 3). Another explanation for the higher incident rate of pathogens in raw water at the large supplies could be the denser population in the catchment of the urban areas. However, pathogens were more frequent in treated water in the small supplies than in the large ones, 23% and 10%, respectively. This reflects on the water quality issues at the small supplies discussed in the introduction. The length of the pipeline infrastructure is also much longer per user in the small supplies than in the large ones (Table 3). This reveals the relatively higher investment cost and operational cost needed for the small supplies as well as higher risk at contamination and shows part of the problems that small water suppliers must deal with.

As in the large supplies, pathogens were site-specific and country-specific in the small supplies. *Cryptosporidium* was the dominant pathogen in one country and *Campylobacter* in another. No pathogens were detected in one of the three countries (with 3 test sites) though *E. coli* was detected in all samples from the three test sites with AQV GPS and with verification testing.

Enterovirus was only tested for in one country, at six test sites, and for HEV in two countries at nine sites. There was no verification testing of pathogens in the small supplies, whereas verification testing was performed for *E. coli* with traditional culturing except in one country (6 sites) using a higher volume than in the traditional one used in surveillance monitoring, concentrating 20-50 L instead of 100 ml.

Table 5. Pathogens tested at the 15 small water supplies

	No. of samples tested for pathogens	No. of samples with pathogens	% of samples with pathogens	No. of pathogen incidents	Kingdom of pathogens		
					Bacteria	Virus	Parasites
Raw water	159	35	22%	37	10	9	18
Treated water	92	21	23%	24	8	3	13
SUM	251	56	22%	61	18	12	31

Pathogens were found in samples from the small water supplies, equally in raw and treated water, as shown in Figure 7. The detection of *E. coli* was very high, around 80%, in both raw and treated water at all fifteen small supplies combined, as can be seen in Figure 8. It was much higher than with the verification method done in connection with the AQV testing with traditional culturing methods and even more so when done in regular surveillance monitoring. This could question the quality of the routine analytical methods in surveillance. Ten of the fifteen small supplies participating in the testing had disinfection treatment, either UV or chlorination. However, at all there was a high detection of *E. coli*, in 50% to 100% of samples, revealing insufficient treatment.

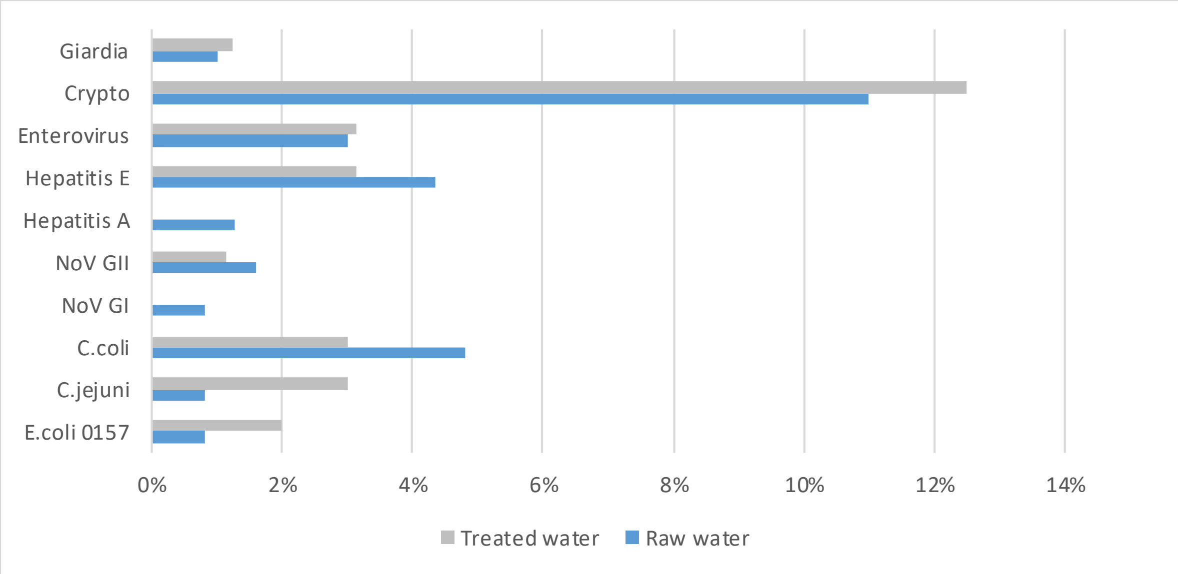

Figure 7. Pathogens detected with the AQV platform in 12 small European water supplies as percentage of samples tested. No pathogens were detected in one of the three countries participating in the AQV trial

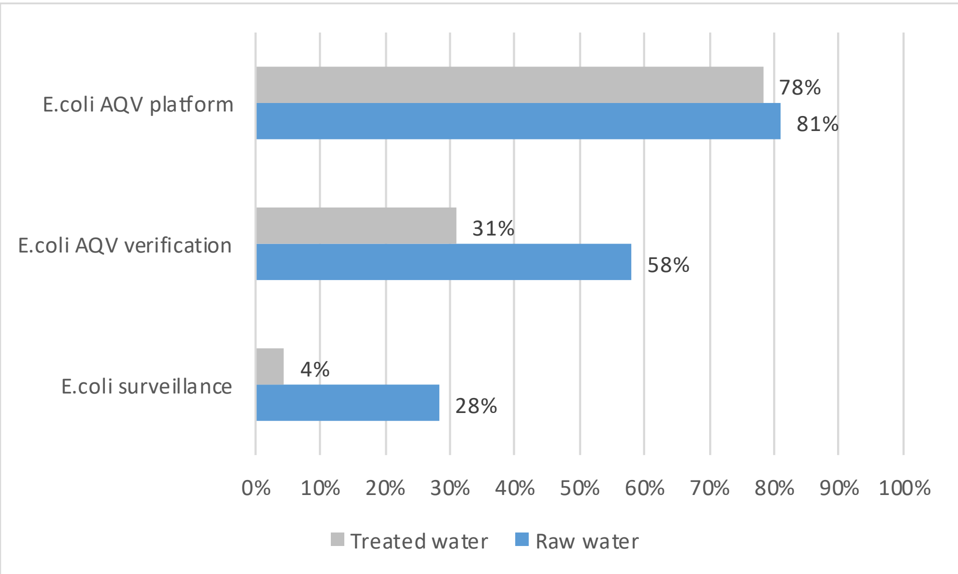

Figure 8. Detection of *E. coli* with AQV techniques, AQV verification in 15 European small water supplies and regular surveillance monitoring in 10 small water supplies as percentage of samples tested

Impact of new monitoring techniques on Water Safety Plans

The WSP presented in the WHO WSP manuals consists of five main components: 1) the preparation stage; 2) system assessment; 3) monitoring performance; 4) management and communication; and 5) feedback and improvement. For the large supplies these components are divided into eleven modules, as shown in Figure 9 (Bartram et al., 2009). The WHO's WSP components and the eleven modules with key actions are shown in the Appendix.

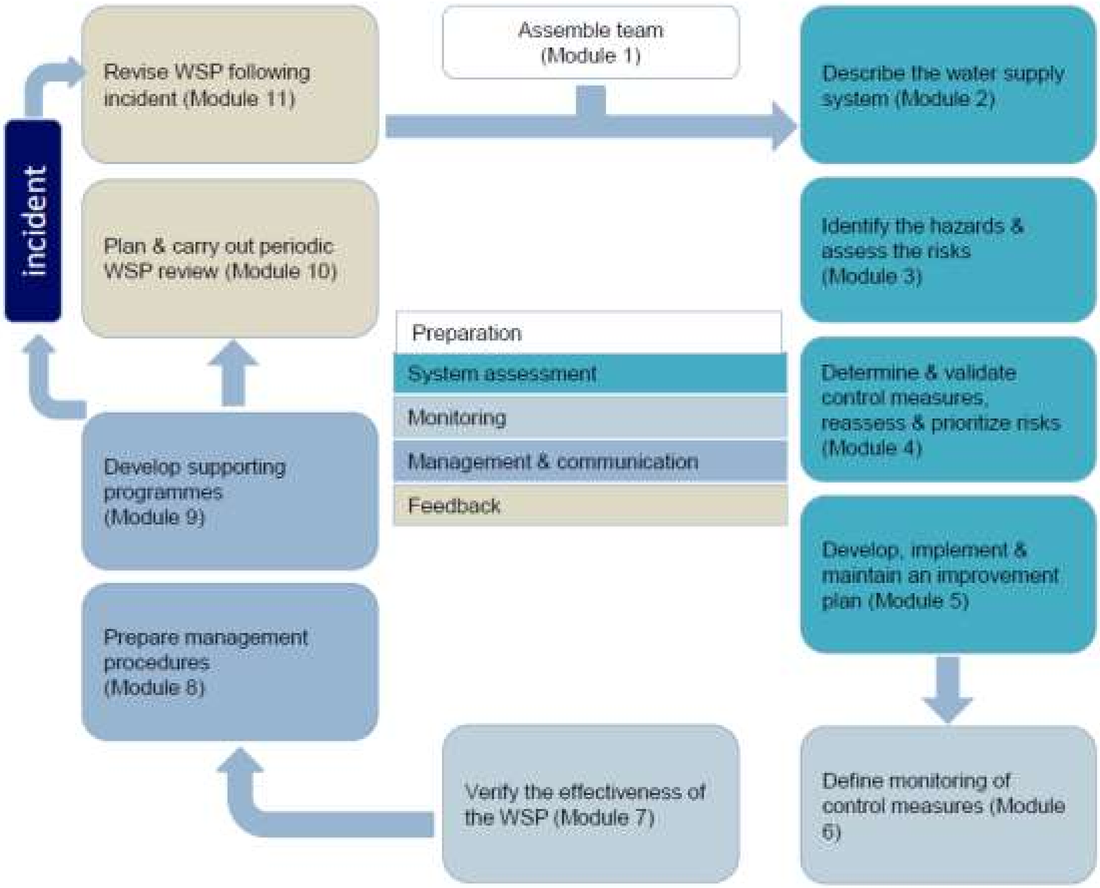

Figure 9. Overview of the 11 modules described in the WHO-WSPs manual (Bartram et al., 2009)

Improved knowledge on water quality and on the presence of pathogens in water will have an impact on water safety management, such as WSP, in many ways. The AQV testing showed that fecal contamination and pathogens are frequent in raw water. This calls for improved control and preventive measures at the water source as a part of WSP and supports the objective of the Water Framework Directive to gain former water quality status of aquifers. Pathogens and fecal contamination were also high in treated water at the small supplies, emphasizing the need to improve treatment with training and guidelines.

The results from employing the AQV platforms revealed that the pathogens were both site- and country-specific. This local or countrywide knowledge should be included in the risk assessment for individual water supplies. The possible impact from improved monitoring with the AQV platform is summarized in Table 6, along with the impact on each of the five components and discussed in following sub-sections.

Table 6. Summary of impact from faster and improved monitoring on each module in WSP

Phase	Module	Impact on WSP
Preparation	**Module 1** Assemble a WSP team	Knowledge of presence and impact of pathogens will have to be added to the WSP team skills, as well as basic knowledge of the new detection technique and of ICT to inform consumers.
System assessment	**Module 2** Describe the water supply system	Knowledge of the presence of microbes will assist in identifying water quality status and status of infrastructure.
	Module 3 Risk assessment	Knowledge of pathogenic status will assist in risk assessment and give more accurate risk scoring.
	Module 4 Determine control measures	Identification of source of pollution will support necessary control measures, e.g. agreement with stakeholders on catchment.
	Module 5 Improvement plan	Identification of source of pollution will support and prioritize improvement plan as renewal of infrastructure
Monitoring	**Module 6** Monitoring effectiveness of control measures	Operational monitoring of common waterborne pathogens validates control measures. Fast off-line molecular monitoring and online monitoring of microbes will increase water safety. It will also assist in treatment processes.
	Module 7 Verification external	Validation of regular external surveillance monitoring
Management and communication	**Module 8** Management procedure	Revised SOPs for treatment process are needed with improved management with online telematics monitoring. With the new possibility in ICT consumers can be informed more promptly of water quality status and boil advisory if needed.
	Module 9 Supporting program	Improved training of staff is needed to adapt to this new technique and guidelines for running treatment station as UV.
Feedback	**Module 10** Periodic review	New information on pathogenic status will be included in periodic review and confirm performance.
	Module 11 Revise following incident/ near misses	Improved and faster simultaneous monitoring of many pathogens will assist in case of incidents, emergencies or near misses.

Preparation

The preparation phase includes assembling a team responsible for the WSP and setting the agenda for the team. The implementation of the AQV platform would require increased knowledge of the WSP team skills. Knowledge of the presence and impact of pathogens, as well as performance of treatment to reduce them, should be added to the WSP team skills, As well as knowledge of the advantages and limitation of the monitoring techniques. The possibilities of the information and communication techniques to increase information to the consumers should also be a part of the team knowledge.

System assessment

The second phase assesses the system, describing it from catchment to consumers' tap and identifying places where water quality problems could arise (defined as critical control points, CCP), and performs the risk assessment, deciding on actions needed to prevent pollution, and carrying them out. The implementation of the AQV platform would increase knowledge of relevant pathogens and improve detection of indicators and hence assist in identifying water quality problems in the system and verifying current risk assessment. The platform should assist in finding the source of pollution, will support necessary control measures and will improve plans to mitigate risk. Furthermore, as previously discussed, the results from the small supplies show high fecal contamination in the water provided, even in treated water, so risk assessment and preventive management should be applied in all supplies or improved if they are already in place. The AQV platform also has the potential to help in microbiological management of treatment processes and to prioritize any necessary improvement plans. New knowledge on total cell count and viable cells with FISH, or the measure of the total activity by the online BACTcontrol, will add understanding of the bacterial dynamics and possible associated risks and may help to verify whether the CCP had been well defined.

Monitoring

The third phase is monitors performance of control measures, both with operational monitoring and external regulatory surveillance. The implementation of the AQV platform with molecular methods, which can detect many pathogens quickly, has an important early warning potential in preventive management. The AQV platform monitoring pathogens and indicators may also be used to validate if WSP, with its control measures, is working as it should in all stages of the water delivery, from catchment to users' taps. The AQV platform will also validate external regular surveillance testing. The online AQV platform has the potential to give early warning (in a few hours) of total activity, coliform or *E. coli,* and thus prevent any large spread of contamination, either by closing wells or boreholes or improving treatment.

Management and communication

The fourth phase addresses management, including support programs with training and communication to users and stakeholders. The implementation of the AQV platform is expected to improve treatment management and procedures in the treatment process. Procedures in managing water resources will also change with improved knowledge of pathogens and early warning of any change in water quality. As treatment at the small supplies is inadequate, as shown in this project, guidelines and training of staff for running of treatment instruments is an essential part of WSP. Considering the great progress in ICT, there are now great possibilities to provide consumers with more timely information about their drinking water. This will enhance water quality and performance of services. Improved communication to the public and other stakeholders is high on the agenda of the European Commission and therefore the availability of more rigorous results possible with the AQV platform that could be transmitted to the EU citizens is very relevant.

Feedback

The fifth phase addresses feedback, both regular and in the case of incidents or near misses/close calls. The implementation of the AQV platform will lead to better knowledge of sporadic incidents of pathogens that will assist in feedback and support revision of risk assessment. Knowledge of the status of pathogens will also support external auditing of WSP.

Conclusion

Improved knowledge of water quality and of the presence of pathogens in water will have an impact on water plan safety management in many ways. The results from employing the AQV technique showed presence of pathogens in water. Pathogens were detected in 24% of samples from the large supplies, mostly in raw water (40%) and less in treated water (10%). In samples from the small supplies 22% had pathogens, equally in raw and treated water. Testing also indicated that pathogens, to some extent, are site- and country-specific. The current practice of measuring an indicator of one kingdom, bacteria, is not enough to secure safe water as 50% of the pathogens detected in the large supplies were viruses and 50% of the pathogens detected in the small supplies were parasites. The current revision of the EU Drinking Water Directive (EU DWD) adds indicators for the kingdoms of viruses and parasite, with indicators for somatic coliphages and *Clostridium perfringens* spores. The AQV platform has developed improved methods in detecting contamination by using a modern and advantageous technology to detect directly the pathogens, instead of relying on indicators. These techniques can be used, together with up-to-date information technology, for the consumer that will lead to increased confidence and trust in the safety of the water.

The results showed high fecal contamination in water, even in treated water, at the small supplies. This emphasizes the need for risk-based management at the small supplies, as is applied in the current EU DWD revision proposal. The AQV project has also revealed the need to include good guidelines and training in treatment e.g. UV treatment in the small supplies. Old infrastructure and fecal contamination on catchments are a challenge. This was demonstrated in the frequent fecal contamination in raw water and frequent pipe breaks which emphasize the need for leak control and systematic risk-based renewal of infrastructure as also is added to the new proposal of the EU DWD.

The results of testing show that monitoring with molecular methods allows fast detection of the most common waterborne pathogens, and that fecal pollution has a great early warning potential in preventive management. The new methods allow for obtaining results from monitoring in about half a day instead of nearly two days, and that counts in safety. The AQV platforms can also validate whether the control measures that have been implemented as a part of WSP are working as they are intended and confirm high quality source water. The online monitoring AQV platform has the potential to give early warning (1-2 hours) of total activity, total coliform or *E. coli* and therefore allows immediate closing down of sources where needed and thus preventing contaminating drinking water. The AQV platforms can also be important in detecting early and timely impact from natural hazards to water quality, as from extreme weather events and assist in reacting to climate change.

The current EU DWD has now been in use for nearly twenty years and has improved water quality for most citizens of Europe. However, many still live with unregulated or poorly regulated water in the case of the small supplies, or even complete lack of access to safe drinking water. Now the human right to water and sanitation has been recognized by the UN and the goal is that before 2030 everyone should have access to safe and affordable drinking water. EU has also recognized the human right to water in the new proposal for DWD inspired by the Right2Water initiative. The AQV project, with its emphasis on water safety plan management and tracing pollution with advanced and fast technology, can assist in achieving the goals of EU DWD and national regulations on safe water for all.

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Appendix: WSP framework and modules as described in the WHO's WSP manual

Phase	Module	Key actions of WSP
Preparation	**Module 1**	**Assemble the WSP team** Set up a small inclusive team with a clear mandate that works with everyone within the supply and outside when needed, depending on catchment and system complexity (e.g. hydrologist, health workers, locals, and microbiologist). Decide on the methodology to be used in WSP, particularly in risk assessing.
System assessment	**Module 2**	**Describe the water supply system** Describe and assess the status of the water supply system from catchment to consumers, using e.g. maps, flow diagram and on-site visits. Identify water quality problems by assessing e.g. monitoring results, pipe break history, leakage, age of infrastructure, dead ends, proximity to sewage and customer complaints.
	Module 3	**Identify hazards and hazardous events and evaluate the risks** Identify the potential hazards following possible hazardous event in each stage of the supply chain and the level of risk it presents. Assess the risk by weighting likelihood with consequences giving risk scores for each hazard.
	Module 4	**Determine control measures, reassess and prioritise the risks** Document existing and decide on potential control measures and consider whether the controls are effective to mitigate risk. Reassess risk.
	Module 5	**Develop, implement and maintain an improvement/upgrade plan** The risk assessment can reveal that infrastructure change is needed. The improvement plan can be short-, medium- or long-term according to risk scores.
Monitoring	**Module 6**	**Monitoring of control measures** Monitoring of the effectiveness of control measures is needed. This can include direct measurement of parameters and inspection of integrity of control measures, e.g. well cover, fence and vermin control.
	Module 7	**Verification** This includes compliance (surveillance) and operational monitoring, monitoring consumer satisfaction and auditing of WSP both internal and external.
Management and communication	**Module 8**	**Prepare management procedures** Document and develop existing and new standard operating procedure (SOPs) for example with reservoir cleaning, pipe repair, chlorination, and emergency response plans e.g. boil advisory.
	Module 9	**Develop supporting programs** Supporting program should include training of staff, communication with customer and stakeholder's, customer's complaint protocol.
Feedback	**Module 10**	**Plan periodic review of WSP** Regularly review WSP through analyzing of data and other performance indicators.
	Module 11	**Revise WSP following incident** Reassess risk and control measures following any incident, emergency or near-miss event and included into improvement plan if needed.