DEVELOPMENT AND IMPLEMENTATION OF A WATER SAFETY PLAN FOR THE DRINKING WATER SUPPLY SYSTEM OF FLORENCE, ITALY

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Abstract

The adoption of the Water Safety Plan (WSP) approach, as recommended by the World Health Organization, represents the most effective means to guarantee public health protection and improve drinking water safety. WSP is a risk assessment and management approach applied to all phases of the water supply chain. This study presents the development and implementation of the WSP for the municipality of Florence. The Florence drinking water supply system (DWSS) has two drinking water treatment plants and supplies a population of about 380,000 inhabitants. The main water resource is the River Arno, characterised by high seasonal and daily variations of water quality and quantity and by extensive anthropogenic contamination. The results of our case-study allowed the identification of more than 70 hazardous events including source water contamination, treatment failures, sedimentation in storage tanks, biofilm erosion in the network. The phases with the highest percentage of hazardous events are the catchment and the treatment steps. According to the risk analysis results, the main corrective actions identified are the installation of an early warning station in order to forecast the changes in the source water quality, the analysis of the main contaminants of emerging concern in the source and treated water, the installation of turbidity probes in the pipes with the lowest flow velocity. The implemented WSP enabled an assessment of the DWSS performance. Moreover, it represents a useful tool for the water manager to improve system management and control, to increase consumer confidence and to reduce the risk of water contamination.

Key words: drinking water, risk assessment, risk management, water safety plan, water treatment plant

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1. Introduction

The provision of safe drinking water represents a significant target in order to ensure public health protection in high-income as well as developing countries. The traditional approach of end-product testing alone, which consists of monitoring the drinking water quality at the delivery point, is not sufficient to constantly ensure the safety of water. Waterborne diseases and outbreaks still occur, even in developed countries (Cann et al., 2013; Hrudey and Hrudey, 2007; Laine et al., 2010; Moreira and Bondelind, 2016). The adoption of risk assessment and management approaches, such as a Water Safety Plan (WSP), has become necessary to reduce the incidence of waterborne diseases. A WSP is a systematic, preventive risk management approach that includes all the phases of the water supply chain, from catchment to consumer (WHO, 2009). WSPs, introduced in 2004 by the World Health Organization (WHO), represent “the most effective means of constantly ensuring the safety of a drinking-water supply” (WHO, 2017a). The principles of a WSP are based on different

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systematic management approaches such as the multi-barrier principle and the hazard analysis and critical control points principle (HACCP) (WHO, 2017a). Since their introduction in 2004, WSPs have been implemented at least in 93 countries, covering each region of the world, both in pilot form and on a large scale (WHO and IWA, 2017). Countries and regions for which WSP experiences are reported in literature include: Uganda (Howard et al., 2005); Australia (Jayaratne, 2008); Germany (Mälzer et al., 2010); South Africa (Viljoen, 2010); the Pacific Islands (Hasan et al., 2011); Jamaica, Brazil, Peru, and Costa Rica (Hubbard et al., 2013; Rinehold et al., 2011); Iceland (Gunnarsdottir et al., 2015); France and Spain (Setty et al., 2017); Italy (Sorlini et al., 2017); Portugal (Roeger and Tavares, 2018; Vieira, 2011); Bangladesh (Shamsuzzoha et al., 2018); Ethiopia (Rickert et al., 2019); Colombia (Pérez-Vidal et al., 2020). WSP are included in the Directive (EU) 1787/2015 (EC Directive, 2015) and in the upcoming Drinking Water Directive (EC Directive, 2018).

Implementation of a WSP can provide improvements in hazard control and water quality, and benefits in asset management and public health outcomes (Baum et al., 2015; Gunnarsdottir et al., 2012; Mahmud et al., 2007; Setty et al., 2018; Tsitsifli and Tsoukalas, 2019). The main phases of a WSP can be summarized as follows (Lucentini et al., 2014): 1) drinking water supply system (DWSS) description and analysis; 2) identification of all possible hazards and hazardous events; 3) risk evaluation and definition of an upgrade plan; 4) revision of the WSP on a regular basis.

This paper presents the case-study analysis of the WSP implementation for the municipality of Florence (Italy). The WSP has been implemented following the national and international guidelines (Lucentini et al., 2014; WHO, 2009a). It is the first Italian WSP applied to a large-scale DWSS supplied by a surface water body (River Arno).

2. Material and methods

2.1. The Florence drinking water supply system

The DWSS of Florence treats surface water coming from the River Arno by means of two drinking water treatment plants (DWTPs), Plants A and B, and supplies 380 000 inhabitants. The catchment area upstream from the treatment plants (4 200 km² and about 500 000 inhabitants) is characterised by a high density of industrial and agricultural activities, wastewater treatment plant discharges and human activities.

This causes significant and heterogeneous anthropogenic pressure on the system. During the summer period, because of the low river water levels, the flow rate is integrated with water from the Bilancino basin: an artificial lake, located about 10 km north of the city of Florence. For this reason, in summer, about half of the flow rate treated by the two plants comes from Lake Bilancino.

The total production of the DWTPs (85 Mm³/year) is supplied to the municipality of Florence (55 Mm³/year) as well as to other surrounding areas (30 Mm³/year). Plant A is the main DWTP in the system, with an average treated flow rate of 2 200 L/s and a nominal flow rate of 3 100 L/s. The treatment train is reported in Fig. 1. The water entering the plant is pre-oxidized with ClO₂ after being screened. Then, a clari-flocculation process takes place, followed by rapid sand filtration (two lines) for the removal of turbidity. Clari-flocculation is crucial for the removal of turbidity, sedimentable and colloidal solids. The coagulant (Polyaluminium chloride) dosage ranges on average between 60-70 ppm depending on the source water characteristics (suspended solids, temperature, etc.). Before the sand filtration, intermediate disinfection is carried out with ClO₂ (less frequently with NaClO). Subsequently, the water is treated with Granular Activated Carbon (GAC) for the adsorption of a wide range of organic molecules (natural organic matter, pesticides etc.) and for the reduction of taste and odour.

A final disinfection is carried out with ClO₂ in order to ensure a free chlorine residual concentration of 0.3 mg/L. Plant A treats about 70 Mm³ each year. Plant B has an average treated flow rate of 350 L/s and a nominal flow rate of 750 L/s. The treatment train is almost equal to that of Plant A (Fig. 1): clari-flocculation, rapid sand filtration, GAC adsorption, and three disinfection steps (initial, intermediate and final disinfection). Moreover, in addition to the surface water resource, Plant B also treats groundwater (20% of the overall treated volume). The groundwater is only oxidized with ClO₂, together with the surface water, before being distributed.

Plant B treats about 15 Mm³ each year. The two plants are monitored through different probes (UV₂₅₄, turbidity, Redox, pH, temperature, ammonia, residual chlorine) located at each treatment steps which allow the real-time control and supervision of all the treatment processes. Laboratory analysis are carried out in order to check and record the quality of the treated and distributed water according to the National regulation limits (Italy Decree, 2001).

The treated water leaving the DWTPs is pumped directly into the distribution network which is about 900 km long. The main pipe materials are cast iron (50%) and spheroidal cast iron (42%). Within the distribution system there are also 20 storage tanks supplying the hilly areas around the city of Florence.

2.2. Water safety plan implementation
The implemented WSP includes the following steps (Lucentini et al., 2014):
1) Formation of a multidisciplinary team (more than 40 experts), in March 2018, supervised by the National Institute of Health (ISS).

Fig. 1. Plant A - 1: Raw surface water; 2: Screen; 3: Pre-disinfection; 4a: Clari-flocculation line 1; 4b: Clari-flocculation line 2; 5a: Intermediate disinfection line 1; 5b: Intermediate disinfection line 2; 6a: Rapid sand filtration line 1; 6b: Rapid sand filtration line 2; 7: GAC adsorption; 8: Final disinfection; 9: Pumping and distribution. Plant B - 1: Raw surface water; 2: Screen; 3: Pre-disinfection; 4: Clari-flocculation; 5: Intermediate disinfection; 6: Rapid sand filtration; 7: GAC Adsorption; 8: Final disinfection; 9: Pumping and distribution

Each member was chosen in order to cover all the necessary expertise: 1) the DWSS water company (responsible for the WSP implementation); 2) regional environmental and health protection agencies (because of their role in monitoring and controlling the status of the environment and the quality of the drinking water distributed); 3) University of Florence (for the scientific supervision of the study); 4) Tuscany Region and Northern Apennines River Basin District Authority (because of their focusing on water resources conservation, assessment and mapping of flood and geological risks); 5) Tuscany Water Authority (responsible for the planning, organization and control over the management of the integrated water service). The team leader which coordinated the WSP was a DWSS manager, chosen for his extensive experience and knowledge of the system. The team actively participated in all of the project phases bringing expertise, know-how and data and approving the WSP output. This was crucial for the definition of the risk matrix and the subsequent corrective action assessment;

2) Description of the DWSS which includes on-site inspections, historical data analysis, examination of the DWSS management data and characteristics (water treatment processes, storage tank volumes, pipe materials and diameters etc.);
3) Identification of hazardous events, definition of the subsequent hazards, and evaluation of the risks using a semi-quantitative risk matrix approach;
4) Identification of the existing control measures, validation of their effectiveness and second risk evaluation;
5) Development, implementation and maintenance of an improvement/upgrade plan;
6) Verification of the effectiveness of the WSP and periodical revision of the plan.

Since the main purpose of the WSPs is to ensure public health and safety, the consumers play an important role and were therefore involved in and informed of the process steps. For each element of the DWSS, on-site inspections were made and checklists were completed in order to highlight any possible hazardous event or system deficiency. Laboratory data from three years (2015-2017) were analysed for each system infrastructure (catchments, WTPs outlet, storage tanks) and the distribution network (about 70 monitoring points covering the full service area). The sampling frequency varied according to the type of the monitoring point: a weekly sample for the catchments; a daily sample for the WTPs outlet and about 40 samples per month for the network. Approximately 250 parameters were considered (i.e., IPA, VOC, pesticides, microbiological parameters, disinfection by-products, metals, etc.), and more than 150 000 pieces of data were analysed.

The treatment plants efficiency was defined by evaluating the degree of removal of the chemical and microbiological contaminants. Moreover, for the same time period (years 2016-2017), consumer complaints were considered in order to evaluate the population’s degree of satisfaction and to highlight the DWSS areas characterised by a higher concentration of complaints. The complaints were analysed per class: odour (which is predominantly related to the chlorine residual concentration in the water), taste (which is mainly related to turbidity and chlorine residual), and
aesthetic impact (which is generally linked to the colour of the water). A hydraulic model of the distribution network was activated in order to assess the water age, that is, the time spent by a parcel of water in the network, along the aqueduct. This is a non-specific measure of the overall water quality within the distribution pipes. Since the distribution network is supplied by two different DWTPs, the hydraulic model was also used to assess the area of influence of each plant and, consequently, the extension of possible water contamination.

Subsequently, typical hazards were identified for each hazardous event, such as chemical, microbiological and physical contamination, failures and water scarcity. According to the WHO guidelines, the semi-quantitative risk matrix approach was used to estimate the risk as the product of the likelihood (P) and the severity of the consequences (G) (WHO, 2009). The two factors, P and G, were classified as reported in Table 1 and the risk was evaluated as in

Table 2. Semi-quantitative matrix approach
(adapted from WHO, 2009)

<table>
<thead>
<tr>
<th>Likelihood frequency</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severity</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>20</td>
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<tr>
<td></td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>12</td>
<td>15</td>
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<td></td>
<td>2</td>
<td>4</td>
<td>6</td>
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<td>10</td>
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<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Risk score</td>
<td>&lt; 6</td>
<td>6 – 9</td>
<td>10 – 15</td>
<td>&gt; 15</td>
<td></td>
</tr>
<tr>
<td>Risk rating</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Very High</td>
<td></td>
</tr>
</tbody>
</table>

Then, the multidisciplinary team was involved in order to share and validate the matrix results. A two-stage risk assessment was carried out in order to determine the effectiveness of the existing risk reduction control measures. Corrective actions to be implemented were proposed by the DWSS manager when the residual risk was more than six, and the most suitable solutions were identified within the team.

3. Results and discussion

3.1. Data analysis results

The three-year data analysis highlighted the high treatment efficiency of the two DWTPs. Table 3 shows the average values of the main monitored data from the Florence DWSS. The raw water is characterised by a large degree of seasonal and daily variability. One of the most important parameters for the DWTP management is inflow turbidity. High turbidity levels can reduce the efficiency of the disinfection by generating a chlorine demand whose removal is a well-known indicator of the effectiveness of clari-flocculation and filtration processes (AWWA, 1999; 2006, WHO, 2017b). The average turbidity value in the raw water is 21 NTU (standard deviation 46 NTU) while in the treated water it is 0.12 NTU for Plant A and 0.24 for Plant B. The high turbidity removal efficiency and the effectiveness of the multiple-step disinfection system ensure adequate microbiological safety of the treated water. A recent study revealed that a complete treatment train with multiple disinfection steps can reduce the microbiological risk associated with the River Arno water turbidity by more than 600 times (Muoio et al., 2020).

The risk levels were divided into very high (> 15), high (10 - 15), medium (6 - 9) and low (< 6). Each hazardous event was analysed for all the different phases (catchment, treatment, storage and distribution), where it could be present. The P and G scores are case specific. For example, the presence of pesticides in the source water was classified with P = 5 (almost certain) and G = 5 (catastrophic public health impact), while the same hazardous event in the treated water was classified with P = 1 (rare) and G = 5 (catastrophic public health impact). Moreover, the presence of turbidity in the treated water was classified with P = 1 (rare) and G = 3 (moderate aesthetic impact), while the same hazardous event in the storage tanks was classified with P = 2 (unlikely) and G = 3 (moderate aesthetic impact). The DWSS managers, under the supervision of the ISS and the University of Florence, implemented a first semi-quantitative risk matrix draft with the identification of the hazardous events, the assignment of the P and G scores and the identification of the existing control measures.

Table 1. Identification of the likelihood (P) and severity (G) factors

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rare: once every 5 years</td>
<td>1. Insignificant or no impact</td>
</tr>
<tr>
<td>2. Unlikely: once a year</td>
<td>2. Minor compliance impact</td>
</tr>
<tr>
<td>4. Likely: once a week</td>
<td>4. Major regulatory impact</td>
</tr>
<tr>
<td>5. Almost certain: once a day</td>
<td>5. Catastrophic public health impact</td>
</tr>
</tbody>
</table>

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<tbody>
<tr>
<td>Severity</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td></td>
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<td>8</td>
<td>12</td>
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The main anthropogenic chemical contaminants in the River Arno are pesticides (especially glyphosate and AMPA). AMPA concentrations exceeded the 0.5 µg/L national regulatory limit for human consumption (Italy Decree, 2001) in the 100% of the raw water samples, while glyphosate resulted always below the limit. However, this does not represent a risk for the consumers since both Plants A and B led to almost complete removal efficiency and hence a concentration in the treated water of less than 0.03 µg/L in 100% of the samples for both plants. In the distribution network, the most concerning parameters are the disinfection by-products (trihalomethanes, chlorite and chlorate) which form during disinfection and propagate in the distribution system in the presence of naturally occurring organic compounds (AWWA, 1999). The Italian legislation suggests a 0.2 mg/L concentration of the free chlorine residual in the distribution network, making it necessary to use chlorine disinfectants, and sets the limit values for disinfection by-products (see Table 3). In order to comply with both these obligations, in Plants A and B the disinfection is provided in multiple steps using both ClO₂ and NaClO, with the disinfectant dosage automatically calculated considering the current chlorine demand. Thanks to this process, the 2015-2017 data showed low concentrations of disinfection by-products in Plants A and B as well as in the distribution network. An appropriate water filtration and disinfection is crucial to ensure the microbiological safety of the water distributed, particularly for WTPs which treat water coming from surface waterbodies in urban areas, as the River Arno. The main indicator organisms in the raw water vary over a wide range (see Table 3), while in the plants outlet and within the distribution network they are almost absent, thus revealing the effectiveness of filtration and disinfection processes and the integrity of the distribution system against possible regrowth and biofilm formation.

Two-years of water quality specific customer complaints were analysed in the full-service area dividing them into classes (odour, taste, aesthetic impact) totalling for about 400 complaints. The main complaints were related to the aesthetic impact (154, 38%), odour (100, 24%) and a combination of the two (aesthetic impact and odour, 133, 33%), while the remaining are related to taste problems (20, 5%). The number of complaints per 1000 consumers resulted equal to 0.7.

We observed a moderate positive correlation (r = 0.44) between the number of complaints and the number of maintenance and/or replacement of water mains, thus highlighting the importance of correct valve operations in order to contain consumer complaints. The water quality complaints will continue to be recorded and analysed after the WSP implementation since they represent a useful evaluation criteria of the WSP effectiveness (Lockhart et al., 2014).

3.2. Risk assessment and proposed control measures

For the risk assessment, more than 70 hazardous events and 110 subsequent hazards were identified (24% during catchment, 43% during treatment, 12% during storage and 20% during distribution). Considering the number of DWSS infrastructures (three abstraction points, two DWTPs, 20 storage tanks, 15 water districts), this led to a risk matrix of about 450 rows.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>U.M.</th>
<th>Raw surface water</th>
<th>Treated water (Plant A outlet)</th>
<th>Treated water (Plant B outlet)</th>
<th>Distributed water (distribution network)*</th>
<th>Italian Regulation Limit (Italy Decree, 2001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>21 (46)</td>
<td>0.12 (0.09)</td>
<td>0.24 (0.11)</td>
<td>0.30 (0.23)</td>
<td>1b</td>
</tr>
</tbody>
</table>
The multidisciplinary team met 12 times in two years (2018-2019) and the risk matrix was revised twice before all the experts approved it. Since the WSP is an iterative approach, the team will revise the matrix each time a significant modification of the system or a treatment failure will occur, or a new contaminant will be detected etc. The main hazardous events assessed were contamination events, treatment failures, disinfectant overdosing, insufficient disinfectant dosage, insufficient flocculant dosage, vandalism, sedimentation in storage tanks, biofilm erosion in the distribution network and microbial contamination during pipe maintenance.

The water data analysis together with the on-site inspections highlighted that approximately 90% of the risks are mitigated thanks to the existing control measures. These include water treatment processes (chemical and physical barriers), alarms and remote controls, routine inspections, maintenance programmes, management procedures etc. In order to reduce the remaining 10% of the risks, appropriate control measures were assessed and have already been or will be implemented according to a timeline set by the WSP team (short, medium- and long-term actions). The upgrade plan with the identification of responsibilities and deadlines for the control measures is one of the main pieces of output of the WSP.

Some of these measures have been already implemented, such as the renovation and cleaning of the main storage tanks of the city (total volume 33000 m³), the installation of an early warning station at the catchment of Plant A, the integration and the revision of all the procedures about operational monitoring and management of the treatment plants, the analysis of specific chemical and microbiological contaminants in the source and treated water. Others, such as the turbidity probes installation in the network and the implementation of video surveillance systems in storage tanks when necessary, will be soon implemented. The most relevant risks and the suitable control measures identified during the implementation of the plan are described below.

### Water contamination due to industrial and agriculture activities

Given the great exposure of the system to pollution and contamination events, even though the DWTP treatment is already efficient (Table 3), a preventive approach was implemented against water contamination events using early-warning systems in the DWTP inlet and outlet. The newly installed UV and NPOC (not purgeable organic carbon) probes together with the turbidity, Redox and pH probes already in place, allow changes in water quality to be forecast and perform proactive actions to avoid the consequences of such variations. As far as the probes are concerned, calibration guidelines, frequency of data collection, alarm threshold definition have been assessed.
Chemical water contamination due to emerging contaminants

The occurrence of contaminants of emerging concern (CECs) in water resources, even at trace level, has been detected in different parts of the world, increasing public concern over their presence (López-Pacheco et al., 2019; Pal et al., 2010). CECs originate from various anthropogenic activities and include personal care products (PCPs), pharmaceuticals, pesticides, drugs, per- and polyfluoroalkyl substances (PFASs) etc. The conventional water treatment processes (clari-flocculation, filtration and chlorination) do not seem to provide for sufficient CEC removal, while GAC adsorption and advanced oxidation processes are more suitable for this end (Rossner et al., 2009; Snyder et al., 2007; Yang et al., 2017).

In this study, in order to evaluate the presence of CECs and their removal during the treatment steps, 35 CECs (i.e., pharmaceuticals, drugs, PFASs and endocrine disruptors (EDs)) were analysed in both the raw and treated water. The concentrations were below the quantification limit (LOQ) in all of the samples. A sporadic occurrence of PFASs was detected in the raw water samples, while no PFASs were found in the treated water, thus confirming that GAC adsorption represents an effective barrier for the levels currently found in the source water at the time of study. A CEC monitoring plan was defined and will be applied on a regular basis. Since only PFASs were detected, Table 4 refers to these and not to all of the CECs that were monitored.

Microbial contamination by waterborne pathogens

Several waterborne pathogens (bacteria, virus and protozoa) were analysed, in the raw and in the treated water, in order to evaluate the DWTPs’ removal efficiency. The detection of traditional indicator organisms alone, such as Total Coliforms and E.Coli, provides an insufficient safeguard to public health because their absence in treated water does not indicate freedom from all viruses and protozoa. As a matter of fact, viruses and protozoa are more resistant to conventional treatment technologies, including filtration and disinfection by chlorine (WHO, 2017a).

For this reason, in this case-study, the detection of more resistant indicators, such as somatic coliphages, was considered. Error! Reference source not found. and Table 4 refer to these and not to all of the CECs that were monitored.

Sedimentation in storage tanks, microbial growth and accumulation of biofilm in pipes

The main hazardous events in the distribution network include biofilm growth and erosion because of the high-water age and loss of residual chlorine. The current maintenance and cleaning programmes, together with the free chlorine residual concentration measures along the aqueduct, led to adequate protection against bacterial growth. In addition, the planned installation of turbidity probes in pipes with a low flow velocity will be a useful tool to determine when the flushing of dead-end zones is necessary.

Error! Reference source not found.-8 shows the risk matrix of selected hazardous events for the Florence DWSS.
### Table 5. Virological analysis results

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Filtered volume (L)</th>
<th>Enterovirus</th>
<th>Norovirus GI (n°)</th>
<th>Norovirus GII (n°)</th>
<th>Adenovirus (n°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw surface water</td>
<td>08/04/2019</td>
<td>5500</td>
<td>0</td>
<td>344</td>
<td>344</td>
</tr>
<tr>
<td>Groundwater (Plant B)</td>
<td>09/04/2019</td>
<td>10220</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Treated water (Plant A)</td>
<td>05/06/2019</td>
<td>7150</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Treated water (Plant B)</td>
<td>09/04/2019</td>
<td>5980.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 6. Microbiological analysis results

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Campylobacter spp</th>
<th>Campylobacter jejuni</th>
<th>Free-living amoebae</th>
<th>Somatic coliphages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw surface water (Plant A)</td>
<td>05/06/2019</td>
<td>Absent/2L</td>
<td>Absent/2L</td>
<td>Present/100 mL</td>
</tr>
<tr>
<td>Raw surface water (Plant B)</td>
<td>08/04/2019</td>
<td>Absent/1L</td>
<td>Absent/1L</td>
<td>Present/100 mL</td>
</tr>
<tr>
<td>Groundwater (Plant B)</td>
<td>08/04/2019</td>
<td>Absent/1L</td>
<td>Absent/1L</td>
<td>-</td>
</tr>
<tr>
<td>Treated water (Plant A)</td>
<td>05/06/2019</td>
<td>Absent/1L</td>
<td>Absent/1L</td>
<td>Present/10L</td>
</tr>
<tr>
<td>Treated water (Plant B)</td>
<td>08/04/2019</td>
<td>Absent/1L</td>
<td>Absent/1L</td>
<td>0 UFP/5980.5L</td>
</tr>
</tbody>
</table>

### Table 7. Example of risk assessment and definition of corrective actions (continue…)

<table>
<thead>
<tr>
<th>Process step</th>
<th>Hazardous event</th>
<th>Current control measures</th>
<th>V</th>
<th>P</th>
<th>G</th>
<th>R2 score</th>
<th>R2 class</th>
<th>Proposed corrective actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment</td>
<td>Water contamination due to industrial and agriculture activities, urban runoff etc.</td>
<td>Treatment with clari-flocculation, sand and GAC filtration, multiple disinfection steps</td>
<td>E</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>Low</td>
<td>Early warning system</td>
</tr>
<tr>
<td>Treatment plant outlet</td>
<td>Presence of contaminants of emerging concern (CECs) and/or waterborne pathogens (viruses, protozoa etc.)</td>
<td>Treatment with GAC adsorption and multiple oxidation steps</td>
<td>PE</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>High</td>
<td>Definition of the CEC monitoring plan</td>
</tr>
<tr>
<td>Storage tanks</td>
<td>Sedimentation and microbial growth</td>
<td>1. Tank cleaning programme 2. Routine inspections 3. Laboratory analysis</td>
<td>E</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>Low</td>
<td>Documentation and constant review</td>
</tr>
<tr>
<td>Distribution network</td>
<td>Microbial growth and accumulation of biofilm</td>
<td>1. Water main cleaning programme 2. Residual disinfectant 3. Laboratory analysis</td>
<td>E</td>
<td>1</td>
<td>5</td>
<td>10</td>
<td>Low</td>
<td>Installation of turbidity probes in pipes with low flow velocities where sedimentation can occur</td>
</tr>
</tbody>
</table>

Note: P = likelihood; G = severity; R1 = risk before considering the current control measures; V = validation; R2 = risk after considering the current control measures; PE = partially effective; E = effective.
4. Conclusions

This paper presents the results of a WSP case-study successfully implemented in a large-scale DWSS supplied by a surface water body. The plan, applied in the municipality of Florence, was carried out, since March 2018, by the water utility manager with a multidisciplinary team of more than 40 experts, which promoted coordinated work between the stakeholders.

The approach was strictly team-based: all data, expertise and decisions were shared among the experts; the risk matrix and the subsequent corrective measures were discussed and proposed within the team. The implemented WSP allowed the utility manager to assess the current DWSS performance, to define all the possible risks associated with drinking water consumption and to outline new control measures in order to improve the water safety while reducing public health risks and increasing consumer confidence.

The major difficulties faced during the WSP implementation were the assessment of the correct P and G values for the risk evaluation and the identification of the cost-effective solutions among the measures proposed by the team. The DWSS steps characterised by the highest percentage of hazardous events were the catchment and the treatment. Most of the identified risks (90%) are already sufficiently reduced by the current control measures; appropriate control measures were identified in order to reduce the remaining 10%. An upgrade plan was assessed, which established responsibilities and deadlines.

The main actions identified are: the installation of an early warning station at the catchment in order to forecast the changes in the source water quality and to perform proactive actions; the definition of a monitoring plan for the analysis of the CECs which represent a worldwide concern and which are commonly present in the surface waters; the installation of turbidity probes in the pipes with low flow velocity where biofilm growth may occur.

Most of the corrective actions have already been implemented, while others will be applied according to the upgrade plan schedule. All the measures will be applied by 2022. The WSP will be revised by the team on a regular basis and the effectiveness of the implemented measures will be assessed over time. Since the correct implementation of a WSP is time-consuming and cost-intensive, it is important to create a detailed procedure in order to extend more easily the already implemented plan to other supplied water systems.

References


Anthropogenic contaminants of high concern: Existence in water resources and their adverse effects, Science of the Total Environment, 690, 1068-1088.


