Water quality, compliance, and health outcomes among utilities implementing Water Safety Plans in France and Spain

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Abstract: Water Safety Plans (WSPs), recommended by the World Health Organization since 2004, seek to proactively identify potential risks to drinking water supplies and implement preventive barriers that improve safety. To evaluate the outcomes of WSP application in large drinking water systems in France and Spain, we undertook analysis of water quality and compliance indicators between 2003 and 2015, in conjunction with an observational retrospective cohort study of acute gastroenteritis incidence, before and after WSPs were implemented at five locations. Measured water quality indicators included bacteria (*E. coli*, fecal streptococci, total coliform, heterotrophic plate count), disinfectants (residual free and total chlorine), disinfection by-products (trihalomethanes, bromate), aluminum, pH, turbidity, and total organic carbon, comprising about 240K manual samples and 1.2M automated sensor readings. We used multiple, Poisson, or Tobit regression models to evaluate water quality before and after the WSP intervention. The compliance assessment analyzed exceedances of regulated, recommended, or operational water quality thresholds using chi-squared or Fisher's exact tests. Poisson regression was used to examine acute gastroenteritis incidence rates in WSP-affected drinking water service areas relative to a comparison area. Implementation of a WSP generally resulted in unchanged or improved water quality, while compliance improved at most locations. Evidence for reduced acute gastroenteritis incidence following WSP implementation was found at only one of the three locations examined. Outcomes of WSPs should be expected to vary across large water utilities in developed nations, as the intervention itself is adapted to the needs of each location. The approach may translate to diverse water quality, compliance, and health outcomes.

Keywords: Water Safety Plan, HACCP, drinking water quality, gastrointestinal illness, water treatment, regulatory compliance

Chemical compounds: Aluminum (PubChem CID: 5359268); Bromate (PubChem CID: 84979); Chlorine (PubChem CID: 24526)

Highlights

- WSP implementation typically resulted in unchanged or improved water quality.
- WSPs generally improved compliance with water treatment performance thresholds.
- A reduction in acute gastroenteritis incidence was observed at only one location.

Introduction

In 2004, the World Health Organization Guidelines for Drinking Water Quality recommended that water suppliers develop and implement Water Safety Plans (WSPs) to help proactively maintain safe public drinking water supplies and reduce health impacts from water contamination events (Bartram et al., 2009). WSPs are now used in many world regions and required by national legislation in some countries. They were introduced into the European Union Drinking Water Directive in 2015 (Commission Directive (EU) 2015/1787) and may be required as early as 2018. In contrast to reactive approaches to water quality surveillance and management, water purveyors who use WSPs seek to comprehensively prevent problems from occurring. This management ("software") intervention involves a continuous feedback loop of risk identification, implementation of controls, and evaluation of whether risks are under control, stemming from the hazard analysis and critical control point (HACCP) approach used widely to ensure food safety. WSPs may or may not involve concurrent infrastructure ("hardware") upgrades or changes, depending on which risks are identified and prioritized for each system. The WSP team, once formed, conducts a thorough analysis of all potential risks to the drinking water supply from source to tap, prioritizes these risks, and establishes critical control points where ongoing monitoring should take place (Bartram et al., 2009).

More recently, evaluation frameworks and indicators have been proposed to measure progress toward WSP goals and evaluate gains. Numerous indicators can relay the effectiveness of WSPs, broadly spanning inputs (e.g., funding and time commitment), activities/outputs (e.g., number of team meetings), outcomes (e.g., operational efficiency or cost savings), and impacts (e.g., water quality or health improvements) (Gelting et al., 2012). Changes related to the WSP process can take place across all categories, although the former categories may show earlier and more measurable change when compared to more distal outcomes and impacts. Lockhart et al. (2014) recommends evaluating specific indicators within four categories: institutional, operational, financial, and policy outcomes. A review of WSP evaluations to date (Kot et al., 2015) found primary reported benefits of the WSP approach to include improvements in organizational structure or daily procedures, better risk awareness among water operators, more efficient water management practices, improved compliance with water regulations, and a reduction in customer complaints. Another systematic review suggested financial outcomes of WSPs have the clearest evidence base, even though operational outcomes are more frequently documented (String and Lantagne, 2016). The review concludes that outcome and impact evaluation data demonstrating WSP value remain weak.

Although a central goal of WSPs is to reduce the risk of water contamination events, limited evaluation data is available to demonstrate WSP effectiveness at decreasing drinking water pathogen or chemical exposures, as well as corresponding health improvements. The impact of WSPs on human health has been investigated in Iceland, one of the first countries to legislate their use in 1995. Data collected before and after WSPs were introduced showed measurably less contaminated water, significantly fewer cases of diarrhea, and improved compliance with drinking water standards (Gunnarsdóttir et al. 2012a). Iceland is a unique developed country with a high quality groundwater supply, where chlorination is not used to disinfect drinking water supplies. We sought to repeat this type of investigation at five locations in France and Spain, with a focus on generalizing outcomes across large population centers in developed nations served by chlorinated surface water and surface-influenced groundwater supplies. These regions have relatively low burdens of diarrheal disease compared to developing nations (WHO, 2004); still, the population experiences a costly annual health burden from viral gastroenteritis (especially norovirus) transmission, some of which stems from water-related outbreaks (Kowalzik et al., 2015; Flahault and Hanslik, 2010; Beaudeau et al., 2008; Lopman et al., 2003). Surface drinking water sources in France and Spain are affected by diverse human and animal fecal influences, such as overland runoff and cross-contamination from wastewater pipes (Therre et al., 2008). Cryptosporidiosis and giardiasis remain a concern for drinking water managers, especially in spring and autumn periods of heavy rainfall.

The primary goals of this study were to characterize changes in water quality, compliance, and gastrointestinal disease incidence following WSP implementation. We aimed to demonstrate the impacts of WSPs, as well as to note the presence of factors that might be used to improve WSP implementation and performance in the future. A secondary goal was to evaluate the outcomes of full versus partial WSPs, where the scope is limited to only the production or distribution system. This project followed an earlier phase of research into WSP inputs and outcomes within the Suez network of utilities. Suez is a large multinational company based in France, named for their involvement in building the Suez Canal. A 2014 study, which quantified costs and ranked perceived benefits of WSPs by surveying utility managers, helped to narrow the goals and possible study locations for this project (Loret et al., 2016). It led to a ranking of reported WSP benefit categories among 21 drinking water utility managers as well as an average WSP labor investment estimate of 10.5 person-months (full-time equivalent) for implementation and 4 person-months/year for ongoing WSP maintenance.

Methods

Site Selection

To evaluate water quality, compliance, and health outcomes of WSP implementation, we undertook an observational retrospective cohort study at five locations (locations 1-4 in France and location 5 in Spain) where WSPs were implemented between 2006 and 2013. Three (locations 1, 3, and 5) included a paired nearby comparison area with no WSP implementation. Data availability was a strongly limiting factor, so intervention and comparison areas were not randomly selected (comparison area selection criteria are listed in table A.1). The five locations included in the study correspond to a total of 15 drinking water treatment plants and groundwater treatment facilities (table 1). Inclusion criteria specified either surface water or influenced groundwater sources, WSP implementation in the production and/or distribution system, and water quality data available for at least two years before and after WSP implementation. Each system had obtained ISO 22000 food safety management certification at the end of the WSP implementation period, one of several existing WSP models (ISO, 2005). At locations 1, 2, and 4, only the production system was certified (the drinking water treatment plants and/or groundwater treatment facilities). Location 5 included two intervention areas: a “full WSP” where the production and distribution systems were certified and a “partial WSP” certifying only the distribution system. In the partial WSP area, water from another purveyor’s drinking water treatment plant is delivered to the local service area via a main pipe. Most locations provided both production and distribution network water quality monitoring data; location 2 was limited to production samples only and the partial WSP area of location 5 was limited to distribution samples only.

Table 1. Characteristics of each study location, including the nature of the WSP intervention, comparison area characteristics (if available), population served (rounded to nearest thousand), the number of matched municipalities included in health effects analysis for locations 1, 3, and 5, and the source water and treatment scheme of drinking water treatment plants (DWTPs) or groundwater treatment facilities (GTFs).

Location (and nature of WSP intervention)	**Pop Served**	**Municipalities Served** (and percent exposure to water supply)	**DWTP or GTF Water Source**	**DWTP or GTF Treatment Scheme**[1]
1	**645,000**			
Intervention (production only)	43,000	1 (100%)	Surface water	Coagulation/sedimentation, rapid sand filtration, ozonation, GAC filtration, ultrafiltration, pH stabilization, chlorination
Comparison	602,000	10 (60%)	Surface water	Coagulation/sedimentation, rapid sand filtration, ozonation, GAC filtration, chlorination
2	**1,000,000**			
Intervention (production only)			Surface water	Coagulation/sedimentation, GAC filtration, ozonation, GAC filtration, UV, chlorination
			Surface water	Coagulation/sedimentation, GAC filtration, ozonation, ultrafiltration and chlorination
			Surface water	Coagulation/sedimentation, GAC filtration, ozonation, GAC filtration, UV, chlorination
			Groundwater	GAC filtration, chlorination
			Groundwater	GAC filtration, chlorination
			Groundwater	GAC filtration, chlorination
3	**77,000**			
Intervention (production/ distribution)	43,000	4 (2 at 60%, 2 at 20-30%)	Influenced groundwater	Direct GAC filtration, UV, chlorination
Comparison	24,000	1 (100%)	Protected groundwater	Iron removal, chlorination
4	**73,000**			
Intervention (production only)			Surface water	Coagulation/sedimentation, rapid sand filtration, ozonation, chlorination
			Groundwater (summer only)	Iron removal, filtration, and chlorination
			Groundwater (summer only)	Chlorination
5	**325,000**			

Intervention (production/ distribution)	148,000	2 (100%)	Surface and groundwater	Pre-oxidation (ClO_2), coagulation/sedimentation, rapid sand filtration, (50% to line 1) ozonation/GAC filtration, (50% to line 2) ultrafiltration/reverse osmosis, chlorination
Intervention (distribution only)	117,000	4 (100%)	Surface water	Pre-oxidation (Cl_2 + ClO_2), coagulation/sedimentation, GAC filtration, chlorination
Comparison	60,000	1 (100%)		

[1]GAC=granular activated carbon

In some cases, the municipal boundaries where health data was reported did not fully coincide with the water service areas. The location 1 intervention area, location 3 comparison area, and all areas for location 5 were considered to have virtually 100% correspondence between the population served by health care providers and water service providers. In contrast, the comparison area for location 1 was being supplemented at a rate of about 40% by drinking water from another source, although it was groundwater expected to be of higher quality than the 60% water supplied by the surface water treatment plant included in the study. At location 3, water supply coverage ranged from 21.5% to 60% within the four "intervention" municipalities where health data was collected. The two municipalities with 60% coverage were again receiving mixed water supplemented by another higher quality groundwater source. In the two municipalities with lower coverage rates, 20-30% of inhabitants were receiving all of their water from the WSP-affected source, while others were receiving only water from another source. 60% was considered the minimum coverage percentage, so the main health results (tables 5 and 6) exclude the two municipalities with less than 30% exposure to the drinking water intervention, although they were considered for sensitivity analysis.

Because this was a retrospective, observational study and gathering additional data was not possible, power calculations were not performed to designate minimum sample sizes. A minimum of two years of water quality data and one year of health data was required in the before and after periods, and all possible data was requested. Specific pre- and post-WSP implementation time periods for each study location were then trimmed to sets of 12-month intervals preceding the initiation of WSP team meetings ("before") and following ISO 22000 certification ("after") (table 2). Differences in climate exist among locations 1 and 2 (in northern France where rainfall peaks in May), locations 3 and 4 (southwestern France where rainfall peaks November to January), and location 5 (northeastern Spain where rainfall peaks September to November). Because heavy seasonal rainfall could affect source water quality parameters such as turbidity and might influence the utilities' performance, this approach served to maximize the period of observation and sample size while controlling for seasonal influences on health and water quality data. Data from "during" WSP implementation (periods of 10-24 months from the initiation of team meetings to certification) was excluded.

Table 2. Time periods of water quality and health/population data availability at each location, trimmed to 12-month intervals before and after WSP implementation.

Location	Water Quality Data Availability	Health/Population Data Availability
1	Before: 1 Jan 2008 – 31 Dec 2010 (3 years)	Before: 1 Jan 2010 – 31 Dec 2010 (1 year)
	WSP Implementation: 1 Jan 2011 – 31 Oct 2011 (10 months)	
	After: 1 Nov 2011 – 31 Oct 2015 (4 years)	After: 1 Nov 2011 – 31 Oct 2015 (4 years)[2]

2	Before: 1 Jan 2003 – 31 Dec 2005 (3 years)	(data not available)
	WSP Implementation: 1 Jan 2006 – 31 Mar 2007 (15 months)	
	After: 1 Apr 2007 – 31 Mar 2015 (8 years)	
3	Before: 13 Nov 2010 – 12 Nov 2012 (2 years)	Before: 13 Nov 2010 – 12 Nov 2012 (2 years)
	WSP Implementation: 13 Nov 2012 – 20 Dec 2013 (13 months)	
	After: 21 Dec 2013 – 20 Dec 2015 (2 years)	After: 21 Dec 2013 – 20 Dec 2015 (2 years)[2]
4	Before: 1 Jan 2003 – 31 Dec 2006 (4 years)	(data not available)
	WSP Implementation: 1 Jan 2007 – 31 Mar 2008 (15 months)	
	After: 1 Apr 2008 – 31 Mar 2015 (7 years)	
5	Before: 1 Jan 2005[1] – 31 Dec 2007 (3 years)	Before: 1 Jan 2005 – 31 Dec 2007 (3 years)
	WSP Implementation: 1 Jan 2008 – 31 Dec 2009 (24 months)	
	After: 1 Jan 2010 – 31 Dec 2015 (6 years)	After: 1 Jan 2010 – 31 Dec 2015 (6 years)

[1]Some datasets (online sensors datasets for turbidity, total organic carbon, and free chlorine; and critical control parameters used for compliance analysis including trichloroethylene/tetrachloroethylene, nickel, chromium VI, and iodine absorption) begin 1 Jan 2006 for a total of two years in the before period.
[2]For locations 1 and 3, extrapolated population data was used during the after period to enable comparison with case numbers for 2014 and 2015.

Water Quality Analysis

Water quality data were provided by employees of the Suez-affiliated drinking water supplier at each study location, including the parameter, unit, date, time (if applicable), and monitoring station. Data sets were produced via either routine internal water quality monitoring or external quality control involving independent sampling and analysis by health authorities. Data from manual sampling records were pooled while data sets from online sensors were considered separately where available (locations 3 and 5). We selected twelve water quality parameters to evaluate water quality, treatment process effectiveness, and possible human health risk, including *E. coli*, fecal streptococci, total coliform, heterotrophic plate count, trihalomethanes (THMs), bromate, free residual chlorine, total residual chlorine, aluminum, total organic carbon, turbidity, and pH. Data cleaning involved attribution of the study location, time period (before, during, or after the intervention), and presence or absence of a WSP intervention, comprising about 240,500 manual samples and more than 1.24 million online sensor readings for a total of nearly 1.5 million water quality data points.

Detection limits for the equipment and/or test method used in water quality data collection are listed in table A.2. Left-censored data with detection limits of one or lower were set to zero (to match pre-processing of the French data), while left-censored data with detection limits above one were set to half the detection limit. Right-censored data were set to the detection limit. For microbial water quality parameters, absence was set to zero and presence was set to one. Data points that were blank or otherwise could not be resolved were left as missing data. In some cases, water quality data represented water that did not reach the consumer, (e.g., an alarm or scheduled maintenance event might trigger containment and disposal of a water batch and/or emergency cross-connection with alternate water supplies), but it was nevertheless included as an event relevant to the WSP and performance history. Precise historical records of maintenance, flushing, spiking, equipment failure and other events/activities that potentially affected individual samples were not available; therefore, suspected outliers remained in the dataset.

All statistical analyses were performed using SAS 9.4 software. For chemical parameters, multiple regression was applied to detect significant differences between the pre-intervention ("before") and post-intervention ("after") time periods. The model controlled for a clustered sampling design (samples clustered by monitoring station), proximity to the treatment facility (production versus distribution samples), and, if available, non-WSP comparison site conditions over the same time period (at locations 1, 3, and 5). Chemical parameters censored by a high detection limit, especially bromate, occasionally achieved better fit with a Tobit regression model of the same form. Microbial parameter data sets were fit with a corresponding Poisson regression model (based on the natural log of the dependent variable, value), owing to the non-continuous count nature of the data.

For the locations with comparison areas, beta coefficients are reported for the interaction term consisting of time period (before/after) and WSP presence (no/yes) (equation 1). For locations 2 and 4, the beta value represents the effect of time period alone (equation 2). For location 5, two sets of dummy and interaction variables were used to represent the full (production and distribution) WSP versus the partial (distribution only) WSP intervention (equation 3). To determine significance, a p-value correction was applied within each location's family of water quality statistical tests using the adaptive Holm procedure. Sensitivity testing examined the effect of suspicious extreme values in the data set that may have been affected by maintenance or other events, even though imperfect historical records were available to justify data removal. Finally, variance ratios were computed between the pre- and post-intervention period as another indicator of water quality control.

$$\text{Value or } \ln(\text{Value}) = \beta_0 + \beta_1{*}\text{Time} + \beta_2{*}\text{Proximity} + \beta_3{*}\text{Site} + \beta_4{*}\text{Time}{*}\text{Site} \qquad \text{(eq. 1)}$$

$$\text{Value or } \ln(\text{Value}) = \beta_0 + \beta_1{*}\text{Time} + \beta_2{*}\text{Proximity} \qquad \text{(eq. 2)}$$

$$\text{Value or } \ln(\text{Value}) = \beta_0 + \beta_1{*}\text{Time} + \beta_2{*}\text{Proximity} + \beta_3{*}\text{Full Site} + \beta_4{*}\text{Partial Site} + \beta_5{*}\text{Time}{*}\text{Full Site} + \beta_6{*}\text{Time}{*}\text{Partial Site} \qquad \text{(eq. 3)}$$

Compliance Analysis

The compliance analysis compared water quality data before and after WSP implementation to relevant thresholds, including: European Union (EU) Drinking Water Directive quality limits and quality references, national quality limits and quality references, Suez internal recommended practices (for France), location-specific WSP critical limits, and location-specific WSP operational limits. National quality limits and references for France and Spain often closely matched the EU Drinking Water Directive (98/83/CE) (Ministère de La Santé et des Solidarités, 2007; Ministerio de la Presidencia, 2003; EU, 1998; EU, 2015). Some regional legislation was applied to location 5 only (Generalitat de Catalunya, 2005). Within French and Spanish national regulations, "quality limits" are intended as upper limits while "quality references" are intended as indicators of good practice. Internally defined thresholds were generally the most stringent, since compliance had operational but not regulatory implications.

We evaluated compliance for the same set of 12 parameters used for water quality modeling, as well as any additional parameters relevant to critical control points (at location 5 only). Between 9 and 22 relevant thresholds existed and were investigated at each location. A 2x2 table was constructed using the number of passes and fails in each time period. Significant differences in cell sizes were then evaluated using either a chi-squared or Fisher's exact test for unequal proportions (Fisher's exact test was used when any cell size was five or less). A p-value correction was again applied within each location's family of compliance statistical tests using the adaptive Holm procedure. Data analysis definitions of "compliance" were matched as closely as possible to the utility managers actual use of the data (e.g., reporting of manual monitoring data to regulatory bodies and use of real-time online sensor data for internally maintained critical control points), but needed to be simplified in some cases to permit analysis of incomplete historical data records. These analyses are denoted as "simplified" in tables 4 and B.9. For example, if the time resolution of historic sampling was twice daily, the data could not be analyzed for hourly changes. Therefore, analysis results may differ from the utilities' self-reported compliance records, since more complex verifications involving time persistence, equipment substitution, and repeat sampling apply to some thresholds in practice.

Health Analysis

To evaluate health before and after WSP intervention, acute gastroenteritis incidence data was provided by the national or regional public health authorities: Santé Publique France (formerly Institut de Veille Sanitaire) at locations 1 and 3 and Servei Català de la Salut (CatSalut) at location 5. The data collection mechanism in Spain relies on the Spanish Minimum Basic Data Set (MBDS) hospital registry, whereas the French data collection method was revised in 2010 to capture a greater percentage of acute gastroenteritis cases (estimated at around 32% of all cases) by relying on state-provided prescription drug reimbursements (Bounoure et al., 2010). Case numbers reported by municipality of residence were pooled for locations 1, 3, and 5 by matching the geographical boundaries of intervention (WSP) and comparison (non-WSP) water service areas with between one and ten corresponding municipalities ("municipalities served" in table 1). Population data at the level of municipality was provided by the National Institute of Statistics and Economic Studies (INSEE) in France and the Statistical Institute of Catalonia (IDESCAT) in Spain. Because the French population data is released after a two-and-a-half-year time lag, population estimates needed to be extrapolated for the years 2014-2015 to enhance or enable comparison with cases reported at locations 1 and 3, respectively. Extrapolations were based on linear estimates of growth for each municipality using 2010-2013 data.

Because the number of years in each time period varied, acute gastroenteritis was characterized as a rate: the incidence (number of new cases) per 1,000 person-years. Population data could further be matched to existing age divisions in the health data to stratify the analysis by ages under 5, 5-14, 15-64, and over 65 years at locations 1 and 3, and by ages 0-14 and over 15 at location 5. To statistically compare acute gastroenteritis incidence before and after WSP implementation, a Poisson regression model was applied with population as the offset (person-years) and controlling for the comparison area conditions (the base level of the site variable; equation 4). Comparison area values were included to isolate the effect of the drinking water intervention, as opposed to data reporting, overall health, or other changes that may have affected the whole region. The location 5 model separated the full WSP (production and distribution) and partial WSP (distribution only) intervention areas (equation 5). Cases reported by municipality were pooled within each area and clustering was not considered in the model. Finally, sensitivity of the model was tested relative to assumptions of population extrapolation and service area coverage.

$$\ln(\text{Cases/Person-Year}) = \beta_0 + \beta_1 * \text{Time} + \beta_2 * \text{Site} + \beta_3 * \text{Time} * \text{Site} \qquad \text{(eq. 4)}$$

$$\ln(\text{Cases/Person-Year}) = \beta_0 + \beta_1\text{*Time} + \beta_2\text{*Full Site} + \beta_3\text{*Partial Site} + \beta_4\text{*Time*Full Site} + \beta_5\text{*Time*Partial Site} \quad \text{(eq. 5)}$$

Informal Audits

Lastly, qualitative questionnaires were developed to better understand the nature of the data and the WSP intervention at each site, as well as to gather information about perceptions and expectations of undertaking the WSP. Informal WSP audits were carried out in June/July 2016 at locations 1, 3, and 5, incorporating a semi-structured group discussion and a guided tour of a drinking water treatment plant. Questions were developed using the World Health Organization and International Water Association's Practical Guide to Auditing Water Safety Plans (WHO and IWA, 2015) as well as an interview guide used in Iceland by Gunnarsdóttir (2012; Appendix 1). Because the questionnaires were intended as a starting point for discussion, sessions were structured loosely and answers were not forced on all questions; however, information was specifically requested on significant events that took place during the study period, and expectations of change in water quality or health data as a result of the WSP (reported in tables B.2 and B.3, respectively). Shorter questionnaires adapted for electronic rather than in-person delivery were then developed and completed by a member of the Suez research team for locations 2 and 4 in August 2016.

Results

Water Quality

Several significant water quality differences were observed between the pre-implementation and post-implementation periods at the intervention area. Mean values and model results by location, parameter, and time period are detailed in tables B.4 through B.8, and summarized as improvements, degradation, and neutral outcomes in table 3. Changes listed in the "improvements" column are considered desirable, since drinking water quality managers seek to reduce the concentration of these constituents for operational or health reasons. In contrast, "degradation" refers to an increase in a parameter that managers seek to minimize. Changes in "neutral" parameters, while statistically significant, might or might not be considered desirable (and therefore relevant to operational or health outcomes) depending on the goals of the particular drinking water utility at any given time.

Table 3. Summary of statistically significant water quality outcomes reported in tables B.4 through B.8, grouped by improvement, degradation, and neutral changes. "Neutral" changes may or may not be considered desirable depending on the individual needs of the drinking water utility.

Location	Improvements in water quality post-intervention	Degradation in water quality post-intervention	Neutral changes in water quality post-intervention
1	Aluminum[2]	Bromate	pH
2	Trihalomethanes	--	--
3	--	Total coliform, heterotrophic plate count, turbidity (sensors)	Free chlorine (sensors)
4	Heterotrophic plate count, aluminum, turbidity	--	Free chlorine, total chlorine, pH

5 (full WSP[1])	Trihalomethanes, total organic carbon, turbidity (manual and sensors)	Bromate	Free chlorine (sensors), pH
5 (partial WSP[1])	Turbidity	--	Free chlorine, pH

[1]The full WSP applied to both the production and distribution system; the partial WSP applied to the distribution system only.
[2]Remained constant relative to comparison area.

The water quality parameters that changed significantly varied from one location to the next, and few patterns were observed (table 3). Several microbial water quality parameters demonstrated little variation from zero and models could not be fit (tables B.4 through B.8). Heterotrophic plate count and total coliform worsened at location 3, while heterotrophic plate count improved at location 4. Likewise, turbidity increased at location 3, but decreased at locations 4 and 5 (full and partial WSPs). Bromate (a byproduct of using ozonation to treat water) increased at locations 1 and 5 while trihalomethanes (a byproduct of chlorination) decreased at locations 2 and 5 (full WSP). In the neutral category, free residual chlorine increased at locations 3 and 4 while it decreased at location 5 (full and partial WSPs), although free chlorine levels at location 5 were intentionally kept higher than locations 3 and 4 due to a difference in local regulatory standards (see typical median values in table B.1).

Increased numbers of samples, especially with regards to online sensor data, increased statistical power to detect small differences. Of potential relevance to water utility managers, some changes in sample means were observed with descriptive statistics but not found to be statistically significant, possibly due to relatively low power or low numbers of non-zero data points. Examples included a decrease in heterotrophic plate counts, turbidity, and trihalomethanes at location 1 and a decrease in heterotrophic plate count and aluminum at location 5 (full WSP) (detailed in tables B.4 and B.8). As another indicator of water quality control, the WSP intervention sometimes resulted in changes in the distribution of data around the mean, reported as the variance and variance ratio (F-value) in tables B.4 through B.8. Both increases and reductions in variance were observed; variance declined notably (with a variance ratio equal to or exceeding 4:1) for turbidity at location 1, heterotrophic plate count at locations 4 and 5 (full WSP), and trihalomethanes at location 5 (full WSP).

With regards to sensitivity testing, exclusion of extreme values did not alter significance of the statistical test for free chlorine or turbidity at location 2, free chlorine and free chlorine sensors at location 3, total chlorine at location 4, or free chlorine and turbidity sensors at location 5. Testing did indicate a potential reduction in free and total chlorine levels (neutral management outcomes) at location 1. Exclusion of four extreme values for total chlorine at the location 1 intervention area showed a statistically significant reduction where it was not found to change originally ($\beta=-0.044$, raw p-value<0.001). Likewise, dropping two extreme values for free chlorine at the location 1 comparison area improved the model fit and made the reduction statistically significant ($\beta=-0.047$, raw p-value<0.001). Additional sensitivity testing at locations 2 and 4 examined the effects of seasonality, since several months of additional partial-year data was available in the after period. It showed no changes in the significance of test results when this data was included.

Compliance

Like water quality, changes in compliance following WSP implementation also varied, as measured by rates of noncompliance with between nine and twenty-two relevant internal or external water quality benchmarks per location. Significant outcomes ranged from zero to ten per location (summarized in table 4). Nearly all represented improvements in water quality, with a couple of exceptions. While turbidity compliance increased at locations 1 and 5 (full WSP, outlet), it decreased at location 5 (full WSP, operational and critical limits after sand filters). Aluminum compliance increased at both locations 4 and 5 (full WSP). Location 2 and the location 5 partial WSP area showed no changes in compliance. Some parameters displayed movement around a relevant threshold in this component of the study, even though the change in the values themselves from before to after WSP implementation was not statistically significant as reported in table 3 (e.g., turbidity at location 1; bromate at location 4). The opposite also held true, in that some statistically significant changes in water quality levels as reported in table 3 did not correspond to increased or decreased compliance with applicable thresholds. Full results of the compliance analysis can be found in the appendix (table B.9).

Table 4. Summary of statistically significant changes in compliance after WSP implementation at each intervention location. Detailed noncompliance rates and other test results can be found in table B.9.

Location	Parameter	Change post-intervention	Threshold definition[2]	Source
1	Total coliform	Increase in compliance	>0 MPN/100ml	EU and French quality limit
	Turbidity	Increase in compliance	>2 NTU	French quality reference for tap
2	None			
3	Free chlorine (sensors)	Increase in compliance	<0.05 mg/l	WSP critical limit for chlorination
4	Bromate	Increase in compliance	>10 µg/l	EU and French quality limit
	Free chlorine (surface water plant only)	Increase in compliance	<0.2 mg/l *simplified	WSP operational limit (surface water plant)
	Aluminum	Increase in compliance	>100 µg/l	Suez internal recommended practice
5 (full WSP[1])	Total coliform	Increase in compliance	>0 MPN/ 100ml	EU and Spanish quality limit
	THMs	Increase in compliance	≥50 µg/L	Suez recommendation for plant outlet (in France)
		Increase in compliance	>100 µg/l	EU and Spanish quality limit for network
	Free chlorine (sensors)	Increase in compliance	<0.2 mg/l *simplified	Catalunya/WSP critical limit for chlorination
	Aluminum	Increase in compliance	>200 µg/L	EU and Spanish and regional quality limit
		Decrease in compliance	≥0.75 NTU	WSP operational limit

	Turbidity (sensors after sand filters)	Decrease in compliance	≥1 NTU *simplified	WSP critical limit
	Turbidity (sensors)	Increase in compliance	>0.5 NTU	Spanish quality reference for plant outlet
	Nickel	Increase in compliance	>20 µg/L	EU and Spanish quality limit (for tap)
5 (partial WSP[1])	None			

[1]The full WSP applied to both the production and distribution system; the partial WSP applied to the distribution system only.
[2]Direction indicates when a sample does not attain the recommended range of values. Some thresholds were simplified to enable comparison with historical data. Self-reported records might differ based on the application of time duration, repeat sampling, or equipment validation procedures.

Health

Health outcomes for the overall population also varied across locations (table 5). Location 1, where total coliform and turbidity compliance improved, showed a statistically significant decrease in the incidence of acute gastroenteritis relative to a comparison area, following the implementation of a WSP ($p=0.043$, $\alpha=0.05$). This corresponds to about a 4% reduction in acute gastroenteritis incidence, when comparing the incidence rate ratios between the intervention and comparison areas. At location 3, where total coliform and turbidity levels increased, the WSP intervention area did not experience a significant change in acute gastroenteritis relative to the comparison area ($p=0.640$). Looking at the overall population for location 5, where water quality and compliance generally improved, initially showed no significant change in acute gastroenteritis for the full or partial WSP intervention areas ($p=0.091$ and 0.056, respectively). The larger case numbers at locations 1 and 3 enhanced the statistical power of the overall population test to detect smaller differences in incidence rates. Location 1 had the largest sample size on the order of 278,000 total cases and 3.2 million person-years, while location 3 (excluding two municipalities with low water service coverage) included roughly 20,000 total cases and 189,000 person-years. Both case numbers and incidence rates for location 5 (which had a total of about 1,300 cases and 2.9 million person-years) were much lower than those for locations 1 and 3 due to differences in public health surveillance methods between Spain and France.

Table 5. Incidence of acute gastroenteritis before and after WSP implementation at both intervention and comparison ("comp") areas and model interaction term between time and site. Negative beta values correspond to a reduction in acute gastroenteritis in the intervention area.

Location	**Incidence rate** (cases per 1,000 person-years) (before)	**Incidence rate** (cases per 1,000 person-years) (after)	**Incidence rate ratio and 95% confidence interval** (after: before)	**Ratio of incidence rate ratios and 95% confidence interval** (interv: comp)	**Model beta and 95% confidence interval** (time* site)	**Wald Chi-Square**	**Model p-value** *significant
1	93.6	100.2	1.07 (1.03, 1.11)	0.96 (0.93, 1.00)	-0.037 (-0.072, -0.001)	4.11	0.043*
(comp)	78.0	86.5	1.11				

			(1.10, 1.12)				
3	126.5	111.8	0.88 (0.85, 0.92)	1.01 (0.96, 1.07)	0.013 (-0.042, 0.069)	0.22	0.640
(comp)	102.6	89.5	0.87 (0.84, 0.91)				
5 (full WSP[1])	0.304	0.418	1.37 (1.13, 1.68)	1.32 (0.96, 1.82)	0.276 (-0.044, 0.597)	2.86	0.091
5 (partial WSP[1])	0.397	0.564	1.42 (1.17, 1.73)	1.37 (0.99, 1.87)	0.310 (-0.008, 0.628)	3.66	0.056
(comp[1])	0.513	0.534	1.04 (0.81, 1.34)				

[1]The full WSP applied to both the production and distribution system, the partial WSP applied to the distribution system only, and the comparison area had no WSP. All areas of location 5 have much lower case numbers due to the differences in public health surveillance methods between France and Spain.

Stratification of health data by age group offered additional information (table 6). The pooled results appeared to be driven by the adult population (ages 15+), which contributed about four to five times the number of person-years to the analysis. When data were stratified by the four possible age groups (under 5, 5-14, 15-64, and 65+) at location 1, only the 15-64 age group demonstrated a statistically significant reduction in acute gastroenteritis incidence (p=0.016). Likewise, stratification by children (ages 0-14) and adults (ages 15+) at location 5 showed a statistically significant increase in acute gastroenteritis incidence for adults only at both the full WSP and partial WSP intervention areas (p=0.026 and 0.009, respectively). At all three locations, incidence rates for children were higher than those reported among adults. Normally populations with poorer immunity (young children and the elderly) might be expected to exhibit greater changes in health outcomes, but this held true only for the 65+ age group. It should be noted that for French data (locations 1 and 3), the reported case numbers of acute gastroenteritis (numerators of the rates) in the under 5 age group exclude infants (under age 1), because they are not expected to consume tap water. The population data (denominators of the rates) does include infants, serving to artificially reduce incidence rates for this age group at locations 1 and 3 across both intervention and comparison areas.

Table 6. Incidence of acute gastroenteritis by age group at location 1, 3, and 5 intervention and comparison ("comp") areas. Negative beta values correspond to a reduction in acute gastroenteritis in the intervention area.

Location	**Age group**	**Incidence rate** (cases per 1,000 person-years) (before)	**Incidence rate** (cases per 1,000 person-years) (after)	**Incidence rate ratio and 95% confidence interval** (after: before)	**Ratio of incidence rate ratios and 95% confidence interval** (interv: comp)	**Model beta and 95% confidence interval** (time* site)	**Wald Chi-Square**	**Model p-value** *signif.
1	1-4/ 0-4[2]	236.9	301.2	1.27 (1.18, 1.37)	1.02 (0.94, 1.10)	0.017 (-0.057, 0.091)	0.21	0.644
(comp)		235.5	294.3	1.25 (1.22, 1.28)				

1	5-14	168.5	174.9	1.04 (0.97, 1.11)	0.95 (0.88, 1.02)	-0.051 (-0.123, 0.020)	1.97	0.160
(comp)		141.1	154.2	1.09 (1.07, 1.12)				
1	15-64	70.8	70.8	1.00 (0.95, 1.05)	0.94 (0.89, 0.99)	-0.062 (-0.112, -0.011)	5.78	0.016*
(comp)		57.1	60.7	1.06 (1.05, 1.08)				
1	65+	24.9	26.4	1.06 (0.87, 1.29)	0.90 (0.73, 1.10)	-0.109 (-0.313, 0.095)	1.09	0.296
(comp)		21.5	25.4	1.18 (1.12, 1.25)				
3	1-4/ 0-4[2]	398.4	353.7	0.89 (0.81, 0.97)	0.96 (0.84, 1.09)	-0.043 (-0.169, 0.083)	0.45	0.505
(comp)		388.2	359.7	0.93 (0.85, 1.01)				
3	5-14	238.8	198.1	0.90 (0.83, 0.97)	1.03 (0.92, 1.16)	0.032 (-0.083, 0.148)	0.30	0.583
(comp)		198.1	172.6	0.87 (0.80, 0.95)				
3	15-64	97.3	84.7	0.87 (0.83, 0.92)	1.03 (0.95, 1.12)	0.032 (-0.047, 0.110)	0.63	0.429
(comp)		79.7	67.2	0.84 (0.79, 0.89)				
3	65+	55.4	55.0	0.99 (0.86, 1.15)	1.12 (0.91, 1.37)	0.109 (-0.094, 0.313)	1.11	0.293
(comp)		43.8	39.1	0.89 (0.78, 1.02)				
5 (full WSP[1])	0-14	1.025	1.128	1.10 (0.83, 1.46)	0.96 (0.55, 1.69)	-0.039 (-0.602, 0.523)	0.02	0.891
5 (partial WSP[1])		1.535	1.734	1.13 (0.87, 1.47)	0.99 (0.57, 1.71)	-0.014 (-0.565, 0.537)	0.00	0.961
(comp[1])		0.871	0.997	1.14 (0.70, 1.86)				
5 (full WSP[1])	15+	0.174	0.276	1.58 (1.19, 2.10)	1.59 (1.06, 2.38)	0.462 (0.055, 0.869)	4.95	0.026*
5 (partial WSP[1])		0.192	0.335	1.74 (1.29, 2.35)	1.74 (1.15, 2.65)	0.557 (0.138, 0.975)	6.80	0.009*
(comp[1])		0.449	0.448	1.00 (0.75, 1.34)				

[1] The full WSP applied to both the production and distribution system, the partial WSP applied to the distribution system only, and the comparison area had no WSP. All areas of location 5 have much lower case numbers due to the differences in public health surveillance methods between France and Spain.

[2] For French data (locations 1 and 3), the number of acute gastroenteritis cases exclude infants under age 1, because they are not expected to be exposed to tap water consumption. The population data includes infants.

Regarding sensitivity analyses, exclusion of extrapolated 2014-2015 population data from the location 1 analysis did not substantially affect the outcome. Assessing only data reported through 2013 resulted in a similar approximately 5% reduction in acute gastroenteritis incidence at the intervention area relative to the comparison area (β=-0.055, p=0.005). Further, where health data and water supply coverage did not completely coincide, the effects of WSP implementation on acute gastroenteritis incidence may have been diluted (in the case of no change in the additional water source over time) or confounded (in the case of beneficial or detrimental changes in the additional water source over time) by exposure to other drinking water sources. At location 3, addition of the two municipalities with less than 30% water supply coverage did not alter significance of results, which showed no effect of the WSP implementation on acute gastroenteritis (table 7).

Table 7. Sensitivity test of acute gastroenteritis outcomes in the overall population and by age group at location 3 intervention and comparison ("comp") areas, adding health data from two municipalities with less than 30% water coverage to the intervention area. Values from the comparison area remain unchanged.

Location	**Age group**	**Incidence rate** (cases per 1,000 person-years) (before)	**Incidence rate** (cases per 1,000 person-years) (after)	**Incidence rate ratio and 95% confidence interval** (after: before)	**Ratio of incidence rate ratios and 95% confidence interval** (interv: comp)	**Model beta and 95% confidence interval** (time* site)	**Wald Chi-Square**	**Model p-value** *signif.
3	All	127.0	115.4	0.91 (0.88, 0.93)	1.04 (0.99, 1.10)	0.041 (-0.008, 0.091)	2.71	0.100
(comp)		102.6	89.5	0.87 (0.84, 0.91)				
3	0-4/ 1-4[1]	389.1	373.1	0.96 (0.90, 1.02)	1.03 (0.93, 1.16)	0.034 (-0.076, 0.145)	0.37	0.542
(comp)		388.2	359.7	0.93 (0.85, 1.01)				
3	5-14	237.5	211.4	0.89 (0.84, 0.94)	1.02 (0.92, 1.13)	0.022 (-0.081, 0.125)	0.17	0.678
(comp)		198.1	172.6	0.87 (0.80, 0.95)				
3	15-64	98.8	89.2	0.90 (0.87, 0.94)	1.07 (1.00, 1.15)	0.068 (-0.002, 0.139)	3.61	0.058
(comp)		79.7	67.2	0.84 (0.79, 0.89)				
3	65+	54.9	52.4	0.96 (0.86, 1.07)	1.07 (0.90, 1.28)	0.070 (-0.106, 0.246)	0.60	0.438
(comp)		43.8	39.1	0.89 (0.78, 1.02)				

[1]For French data (locations 1 and 3), the number of acute gastroenteritis cases exclude infants under age 1, because they are not expected to be exposed to tap water consumption. The population data includes infants.

Discussion

Water Quality and Compliance Outcomes

Many beneficial water quality and compliance changes, corresponding to an expectation of reduced risk to consumers, were identified in this study. Changes in specific water quality parameters between the pre- and post-implementation periods varied from one location to the next. This finding is compatible with the nature of the intervention, since the general WSP approach should be adapted to each location based on the specific prioritized risks. Owing to the observational nature of the study, sample sizes were not assigned and were not always consistent across parameters and locations; therefore, statistical power to detect changes varied among data sets. Individual parameter models at each site had a sample size ranging from 12 (for bromate at location 3, where a model could not be fit) to 16,203, with an average of about 4,296 samples (tables B.4 through B.8). Significant changes were more easily detected in online sensor datasets with sample numbers up to 531,603. Some undesirable changes were observed at some locations (tables 3 and 4), but a widespread harmful effect was not indicated over the period of the intervention.

In particular, microbial indicator levels at location 3 appeared to worsen following the WSP intervention. This might be explained by the utility managers' desire to keep chlorine levels as low as possible in response to concerns about disinfection by-products and their potential adverse health effects. Due to local socio-political pressure to eliminate chlorine usage, this location is looking to pilot an unchlorinated water supply in the near future. The WSP at this location did not emphasize control of microbial contamination due to the perceived high quality of the groundwater source. Interim turbidity compliance (after the sand filters) at location 5 also worsened, although the finished water saw the opposite effect, with an improvement (decrease) in turbidity levels and improved compliance based on manually sampled and sensor water quality data. Finally, bromate formation increased at locations 1 and 5, potentially due to changes in ozonation practices.

The microbial water quality data, especially for *E. coli* and fecal streptococci, overwhelmingly consisted of values below the detection limit (i.e., absence or less than one colony-forming unit per 100 ml). This scenario is common across developed nations with chlorinated drinking water supplies. Although a sign of low health risk, such a data distribution hinders the ability to characterize changes in baseline water quality. By reducing both pathogen and indicator bacteria levels, the practice of chlorine disinfection may even preclude detection of potential health risks if the signal from the indicator organism is eliminated but the pathogen remains viable. A quantifiable value might be elicited by (a) sampling water just prior to disinfection, (b) using larger sample volumes, or (c) detecting the presence of pathogens themselves rather than indicator organisms. Under current regulatory scenarios, these measures would add to (not replace) ongoing compliance monitoring efforts. Owing to the potential advantages, molecular methods for direct pathogen detection were being developed and validated during the study's site visits. Drinking water utilities may adopt rapid testing methods in the future as the technology becomes more refined and widely available.

Among the four measured microbial water quality indicators, total coliform and heterotrophic plate counts showed greater variability than *E. coli* and fecal streptococci, demonstrating significant changes in some cases. Total coliform compliance improved significantly at locations 1 and 5 (full WSP), while levels worsened at location 3. Heterotrophic plate counts decreased significantly at only one of the five locations, and were not examined in the compliance portion of our study (owing to the lack of applicable compliance thresholds for piped water supplies in France and Spain). This finding corresponds somewhat with results from Iceland, where two out of the five locations examined individually showed significant drops in mean heterotrophic plate counts (Gunnarsdóttir et al., 2012a). When pooled across locations included in the Iceland study, heterotrophic plate counts exceeding 10 colony-forming units were significantly less likely following the WSP intervention (Gunnarsdóttir et al., 2012a). The Iceland study examined unchlorinated drinking water suppliers and also included smaller water suppliers (<5,000 inhabitants) that typically have higher initial non-compliance rates.

Health Outcomes

Changes in the incidence of acute gastroenteritis are generally difficult to discern due to public health surveillance data limitations and the existence of multiple exposure routes (CDC, 2011). Bottled water consumption and self-treatment of gastrointestinal disease apply to large swaths of the population in France and Spain, inhibiting the ability to associate WSPs and health outcomes. Only about two-thirds of the population is expected to consume tap water (Therre et al., 2008), and the majority of acute gastroenteritis cases are self-treated or resolve without treatment (Lopman et al., 2003). Large background fluctuations in acute gastroenteritis stem from the dominance of other pathogen transmission routes, especially the annual winter peak in person-to-person norovirus transmission (Chikhi-Brachet et al., 2002; Arena et al., 2014), making drinking water exposure a relatively minor contributor to the burden of disease (Lopman et al., 2003).

Further, the acute hospital records used in Spain are expected to capture only a small percentage (perhaps 1-2%) of actual cases, making trend extrapolation fairly difficult. Representatives of Santé Publique France indicated the prescription-based reporting used since 2010 in France may have strengthened the location 1 and 3 analyses by capturing about 32-33% of total cases (Bounoure et al., 2011). Our estimates of acute gastroenteritis incidence were generally on the same order of magnitude as others in the literature (Van Cauteren et al., 2012, Kowalzik et al., 2015; Chikhi-Brachet et al., 2002). The overall incidence rates found in France were somewhat higher than other sources, while the incidence rates found in Spain were somewhat lower, illustrating differences in surveillance methods. Performing pooled analysis across locations (e.g., via a multi-level model) would be useful, but is precluded by the small number of case studies and differences in data collection methods. A prospective, randomized controlled study design might be recommended as the gold standard for overcoming confounding and data consistency constraints.

One of the three case studies did demonstrate a reduction in acute gastroenteritis incidence following WSP implementation, corresponding to about a 4% decrease in acute gastroenteritis incidence in the overall population, or 6% in the 15-64 age group (tables 5 and 6). This occurred at location 1, which had the largest health dataset. Location 5 full (production and distribution) and partial (distribution only) WSPs showed the opposite of the expected effect, with significantly higher post-implementation rates of acute gastroenteritis among adults in both intervention areas, relative to the comparison area. Of the three locations examined, location 5 had the lowest reported case numbers, leading to low statistical power and wide confidence intervals. Unfortunately, the low number of cases per municipality could have been driven by outbreak events, whether stemming from drinking water, foodborne, or other exposures. CatSalut was unable to share any additional information about possible outbreaks during the after-WSP study period.

The health outcome at location 1 (an overall 4% reduction in acute gastroenteritis) corresponds fairly well with the magnitude of the 14% reduction in diarrhea found by pooling results across locations studied in Iceland (Gunnarsdóttir et al., 2012a). At an individual level, diarrheal incidence declined significantly at five of seven observed locations in Iceland. Observation periods were longer, averaging nearly 12 years (compared to an average of six years for the locations in France and Spain), which may have enabled enhanced observation of health impacts. The Iceland study was also an observational retrospective cohort study and, like our study, was limited by data nonconformity and lack of control for confounding factors. Differences in our findings could also stem from the practice of chlorination in France and Spain, which may provide a residual protective effect against some waterborne pathogens, in contrast to the unchlorinated treatment schemes in Iceland.

Relationship between Water Quality and Health Outcomes

Stability or decreases in bacteria levels might be expected as a precursor to declining acute gastroenteritis incidence, demonstrative of the mode of disease transmission. Fecal indicator bacteria, including *E. coli* and fecal streptococci are interpreted as signs of fecal contamination, whereas total coliform and heterotrophic plate count are more indicative of general sanitary conditions and potential pathogen presence. Higher turbidity may also be correlated with poor pathogen removal and increased rates of acute gastroenteritis (Beaudeau et al., 2012). At location 1, where a significant health effect was found, turbidity and total coliform compliance correspondingly improved and turbidity variance decreased significantly post-intervention ($F=12.85$, $p<0.0001$; table B.4). Location 3, in contrast, where no health effect was found, exhibited a worsening of total coliform, heterotrophic plate count, and turbidity levels (table B.6).

At location 5 for the full WSP intervention only, the variance of heterotrophic plate count decreased significantly ($F=153.8$, $p<0.0001$), and total coliform compliance improved (tables 3 and 4). Further, turbidity levels in the treated water improved, although turbidity compliance after the sand filters (an interim measurement within the treatment plant) was noted to worsen after the intervention (table 4). Finally, compliance with free chlorine standards improved at the full intervention area, while free chlorine levels dropped slightly at both the full WSP and partial WSP intervention areas. Thus, the overall water quality evidence does not necessarily support increase pathogen exposure as a causal precursor for increased acute gastroenteritis incidence. Possible hypotheses to explain the outcome might be: (1) other exposures related to acute gastroenteritis, such as foodborne pathogen outbreaks (as mentioned above), or (2) presence of pathogenic organisms that are not well-correlated with fecal indicator bacteria and/or resistant to current treatment schemes.

Comparison among Locations

Although the five case studies were not directly compared, the full WSP at location 5 resulted in the most dramatic water quality improvements, probably because (a) some baseline values (e.g., trihalomethanes, total organic carbon) were initially higher (table B.1) due to the nature of the primary water source (a small, seasonally dry river with several upstream influences) and (b) the WSP implementation and post-implementation periods involved several major upgrades to drinking water treatment processes (table B.2). This suggests that ongoing, iterative improvement (a core characteristic of the WSP approach) may help produce lasting effects on water quality. Location 4 also reported several "hardware" upgrades and showed a number of significant improvements in water quality and compliance, although no comparison area was available to confirm these stemmed from the WSP.

The study design did evaluate differences among WSPs applied to (a) the production system (drinking water treatment plants or groundwater treatment facilities) only, (b) the distribution system only, or (c) both the production and distribution systems. The partial WSP at location 5 did not seem to have as strong an effect on water quality, compliance, and health outcomes as the full WSP covering both the drinking water treatment plant(s) and the distribution system. This indicates that most WSP outcomes found in our study stemmed from changes related to the drinking water treatment plants. Locations where only the treatment plant was certified (locations 1, 2, and 4) did not show a discernable trend when compared to the locations with a WSP covering both production and distribution (location 3 and the location 5 full WSP area). This is understandable because each location had its own distinctive attributes.

Based on these case studies, a piecemeal approach to WSP implementation would not be recommended. Locations that purchase water from or sell water to other suppliers might be constrained to managing and improving only partial components of the drinking water supply system. Further, household-level piping and delivery systems, where some distribution monitoring samples are taken, can only be partially manipulated by a water utility-focused intervention (e.g., via residual chlorine dosing), and this lack of control over privately owned delivery systems could reduce WSP effectiveness. Where possible, the World Health Organization's WSP guidance recommends considering all risks from the source to the tap (Bartram et al., 2009). If prioritizing limited resources is necessary, and in the absence of other indications, the evidence from this study suggests concentrating on the water treatment facilities.

Limitations and Future Recommendations

Further study would help to elicit which particular attributes of the locations and/or WSPs most strongly enable beneficial outcomes. In this study, changes in water quality, compliance, and health were tied to the time period of the WSP intervention (from the initiation of WSP team meetings to the ISO 22000 certification date). Specific causal investigations of identified changes were not undertaken. Reported significant events that coincided with the study period can be found in table B.2. Measures taken during the WSP implementation process typically included team formation and meetings, documentation and posting of operating and emergency procedures, initiation of special staff training sessions on risk management, designation of critical control points, installation of online sensors, and occasionally equipment or treatment technology upgrades.

Utility managers' expectations of the degree of change matched fairly well with actual outcomes (table B.2), suggesting that awareness and deliberate intent or action to address specific water quality issues may have played a key role in creating that change. Expectations were gathered before data analysis results were shared, although managers were likely able to make qualitative judgments based on pre-existing familiarity and knowledge of the drinking water treatment system. For example, managers at location 5 added a reverse osmosis step to the drinking water treatment plant about the same time the ISO 22000 was certified, fully intending to reduce levels of trihalomethanes to meet new European Union regulatory requirements.

Some prominent transformations attributed to the WSP mechanism, as cited by utility managers during site visits, included formalization/documentation of risk management procedures and the recognition of water as a food product among all levels of staff, including those with primarily construction-oriented tasks, which resulted in greater awareness of potential health risks during daily operations. Additional mechanisms suspected of affecting change come from 2014 cost/benefit questionnaires administered among WSP-adopting Suez utilities, which cite both changes in human behavior and improved reaction time to alarms for critical control points, especially chlorination (Loret et al., 2016).

In addition to those already mentioned, factors of interest for future study might include sensitivity of outcomes to time since certification, age/condition of the water treatment and distribution system, and diversity/cohesiveness of the WSP team. The political economy, including local community and organizational readiness is expected to influence WSP outcomes (Kot et al., 2015). One study observing cultural influences on WSP implementation in India, Uganda, and Jamaica identified twelve themes that enable, limit, or are neutral to WSP implementation, including the perception of aesthetics as a surrogate for water safety (enabling) and belief that water should be free (limiting) (Omar et al., 2016). Factors found to correlate with higher performing WSPs in Iceland included: frequent internal and external audits; a working WSP steering group; good understanding of the WSP among staff; cooperation among senior management, health authorities, and the local government; and a training plan, especially for field workers (Gunnarsdóttir et al., 2012b). Factors inherent to WSP effectiveness across twelve Asian Pacific countries included external financial support, formal policies/regulations, and WSP-related record keeping, especially for often-overlooked qualitative measures (Kumpel, In prep).

Conclusions

We selected five case studies of WSP implementation outcomes that were likely to be generalizable to other chlorinated drinking water treatment systems in developed nations. WSP implementation improved water quality and compliance with relevant water quality thresholds at a majority of locations (tables 3 and 4). Identified adverse effects were fewer, adding to the weight of evidence that WSPs offer operational performance benefits (String and Lantagne, 2016; Kot et al. 2015). Epidemiological analysis at one of three locations suggested that WSPs among large chlorinated drinking water treatment systems in developed nations may reduce acute gastroenteritis incidence (table 5), although validity of this finding is limited by differences among the three observed case studies and potential sources of confounding. In particular, location 5 showed an anomalous increase in acute gastroenteritis that was not clearly explained by water quality trends. Outcomes of WSPs should be expected to vary across locations, since the intervention itself is adapted to the needs of each site. As such, the WSP approach may translate to diverse water quality, compliance, and health outcomes. Scenarios of stability or beneficial change identified in this study might be considered desirable among drinking water utility managers. Future research should focus on eliciting the causal factors that enhance successful application of the WSP approach, and on identifying best practices. Such information can be used to improve individual utilities' WSP implementation practices and refine global WSP guidance.

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References

Arena, C., Amoros, J.P., Vaillant, V., Ambert-Balay, K., Chikhi-Brachet, R., Jourdan-Da Silva, N., Varesi, L., Arrighi, J., Souty, C., Blanchon, T., Falchi, A., Hanslik, T. (2014). Acute diarrhea in adults consulting a general practitioner in France during winter: incidence, clinical characteristics, management and risk factors. *BMC Infectious Diseases* 14: 574. doi: 10.1186/s12879-014-0574-4.

Bartram, J., Corrales, L., Davidson, A., Deere, D., Drury, D., Gordon, B., Howard, G., Rinehold, A., Stevens, M. (2009). Water safety plan manual: step-by-step risk management for drinking-water suppliers. World Health Organization. Geneva, Switzerland.

Beaudeau, P., de Valk, H., Vaillant, V., Mannschott, C., Tillier, C., Mouly, D., Ledrans, M. (2008). Lessons learned from ten investigations of waterborne gastroenteritis outbreaks, France, 1998-2006. *Journal of Water and Health* 6(4): 491–503. doi: 10.2166/wh.2008.051.

Beaudeau, P., Le Tertre, A., Zeghnoun, A., Zanobetti, A., Schwartz, J. (2012). A time series study of drug sales and turbidity of tap water in Le Havre, France. *Journal of Water and Health* 10(2):221-35. doi: 10.2166/wh.2012.157.

Bounoure, F., Beaudeau, P., Mouly, D., Skiba, M., Lahiani-Skiba, M. (2011). Syndromic surveillance of acute gastroenteritis based on drug consumption. *Epidemiology and Infection* 139: 1388–1395. doi: 10.1017/S095026881000261X.

Centers for Disease Control and Prevention (CDC). (2011). A Conceptual Framework to Evaluate the Impacts of Water Safety Plans. Atlanta. Retrieved from http://www.cdc.gov/nceh/ehs/gwash/publications.htm.

Chikhi-Brachet, R., Bon, F., Toubiana, L., Pothier, P., Nicolas, J.C., Flahault, A., Kohli, E. (2002). Virus diversity in a winter epidemic of acute diarrhea in France. *Journal of Clinical Microbiology* 40(11):4266–72.

European Union (EU). (1998). Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. *Official Journal of the European Communities* L 330/32.

European Union (EU). (2015). Commission Directive (EU) 2015/1787 of 6 October 2015 amending Annexes II and III to Council Directive 98/83/EC on the quality of water intended for human consumption. *Official Journal of the European Union* L 260/6.

Flahault, A., Hanslik, T. (2010). Epidemiology of viral gastroenteritis in France and Europe. *Bulletin De l'Academie Nationale De Medecine* 194(8): 1415–25, discussion 1424–1425.

Gelting, R.J., Delea, K., Medlin, E. (2012). A conceptual framework to evaluate the outcomes and impacts of water safety plans. *Journal of Water, Sanitation and Hygiene for Development* 2(2): 103-111.

Generalitat de Catalunya, Departament de Salut, Direcció General de Salut Pública. (2005). Vigilància i Control Sanitaris de les Aigües de Consum Humà de Catalunya.

Gunnarsdóttir, M.J. (2012). Safe drinking water: Experience with Water Safety Plans and assessment of risk factors in water supply (Doctoral dissertation). Faculty of Civil and Environmental Engineering, University of Iceland. Reykjavik. ISBN 978-9935-9069-4-6.

Gunnarsdóttir, M.J., Gardarsson, S.M., Elliott, M., Sigmundsdottir, G., Bartram, J. (2012a). Benefits of Water Safety Plans: Microbiology, compliance, and public health. *Environmental Science & Technology 46* (14): 7782–7789. doi: 10.1021/es300372h.

Gunnarsdóttir, M.J., Gardarsson, S.M., Bartram, J. (2012b). Icelandic Experience with Water Safety Plans. *Water Science & Technology* 65(2): 277–288.

International Organization for Standardization (ISO). (2005). Food safety management systems -- Requirements for any organization in the food chain. Retrieved from http://www.iso.org/iso/home/standards/management-standards/iso22000.htm.

Kumpel, E., Delaire, C., Peletz, R., Kisiangani, J., Rinehold, A., DeFrance, J., Sutherland, D., Khush, R. (In prep). Evaluating Water Safety Plans: Lessons Learned from Assessments in the Asia-Pacific Region.

Kot, M., Castleden, H., Gagnon, G.A. (2015). The human dimension of water safety plans: a critical review of literature and information gaps. *Environmental Reviews* 23: 24–29. dx.doi.org/10.1139/er-2014-0030.

Kowalzik, F., Riera-Montes, M., Verstraeten, T., Zepp, F. (2015). The burden of norovirus disease in children in the European Union. *The Pediatric Infectious Disease Journal* 34(3): 229–34. doi: 10.1097/INF.0000000000000546.

Lockhart, G., Oswald, W.E., Hubbard, B., Medlin, E., Gelting, R.J. (2014). Development of indicators for measuring outcomes of water safety plans. *Journal of Water, Sanitation and Hygiene for Development* 4(1): 171-181.

Lopman, B, Reacher, M., van Duijnhoven, Y., Hanon, F.X., Brown, D., Koopmans, M. (2003). Viral Gastroenteritis Outbreaks in Europe, 1995–2000. *Emerging Infectious Diseases* 9(1): 90–96. doi: 10.3201/eid0901.020184.

Loret, J.F., Blaudin de Thé, C., Martin Alonso, J., Puigdomenech Serra, C., Kayser, G., Bartram, J. (2016). Assessing the costs and benefits of water safety plans. Paper presented at the IWA World Water Congress, Brisbane, Australia.

Ministère de La Santé et des Solidarités. (2007). Arrêté du 11 janvier 2007 relatif aux limites et références de qualité des eaux brutes et des eaux destinées à la consommation humaine mentionnées aux articles R. 1321-2, R. 1321-3, R. 1321-7 et R. 1321-38 du code de la santé publique. *Journal Officiel De La République Française* NOR: SANP0720201A.

Ministerio de la Presidencia. (2003). Real decreto 140/2003, de 7 de febrero, por el que se establecen los criterios sanitarios de la calidad del agua de consumo humano. BOE núm. 45.

Omar, Y.Y., Parker, A., Smith, J.A., Pollard, S.J.T. (2017). Risk management for drinking water safety in low and middle income countries - cultural influences on water safety plan (WSP) implementation in urban water utilities. *Science of the Total Environment* 576: 895–906.

String, G., Lantagne, D. (2016). A systematic review of outcomes and lessons learned from general, rural, and country-specific Water Safety Plan implementations. Water Science and Technology: Water Supply 16(6): 1580–1594. doi: 10.2166/ws.2016.073.

Therre, H., de Valk, H., Vaillant, V., Beaudeau, P., Mouly, D. (2008). Assessment of waterborne outbreaks investigated in France since 1998 and key recommendations. Saint-Maurice, France: French Institute for Public Health Surveillance (InVS). Retrieved from: http://opac.invs.sante.fr/doc_num.php?explnum_id=8081.

Van Cauteren, D., De Valk, H., Vaux, S., Le Strat, Y., Vaillant, V. (2012). Burden of acute gastroenteritis and healthcare-seeking behaviour in France: a population-based study. *Epidemiology and Infection* 140(4):697-705. doi: 10.1017/S0950268811000999.

World Health Organization (WHO). (2010). Burden of disease (in DALYs) attributable to water, sanitation and hygiene ('000), by disease and WHO Member State, 2004. Global Health Observatory (GHO) Data. Retrieved from: http://www.who.int/gho/phe/water_sanitation/burden/en/index2.html.

World Health Organization (WHO) and International Water Association (IWA). (2015). A practical guide to auditing water safety plans. Geneva, Switzerland.

Appendices

Appendix A: Methodological Detail

Table A.1. Criteria for selection of paired comparison areas at locations 1, 3, and 5.

Study location	Comparison area selection criteria
Locations 1 and 3	• Geographical proximity (same metropolitan area) • Accessibility of water quality and health data over the study period • Sufficient population (minimum of the same order of magnitude as the intervention area) • Status of WSP implementation (municipality not served by an ISO22000-certified drinking water treatment facility or distribution network) • Same (preferred) or similar water source • Similar water treatment scheme
Location 5	• Geographical proximity (same metropolitan area) • Accessibility of water quality and health data over the study period (required consent of one non-Suez utility to participate) • Sufficient population (minimum of 60,000 inhabitants) • Status of WSP implementation (municipality not served by an ISO22000-certified drinking water treatment facility or distribution network)

Table A.2. Detection limits for left- and right-censored data applicable to monitoring equipment/test procedures used during the study period and data cleaning procedures.

Parameter	Locations 1-4 (manual monitoring)	Location 1 (automated sensors)	Location 5 (manual monitoring)	Location 5 (automated sensors)
E. coli	<1/100 ml set to 0	--	Pres/100ml set to 1; Abs/100ml set to 0; Blanks set to missing (2 values)	--
Fecal Streptococci	<1/100 ml set to 0	--	--	--
Total coliform	<1/100 ml set to 0	--	Pres/100ml set to 1; Abs/100ml set to 0; >2400 set to 2400; blanks set to missing (2 values); 4 values with decimal places rounded to nearest whole colony	--
Heterotrophic plate count (22°C)	<1/ml set to 0	--	<1/ml set to 0; >300/ml set to 300 (one value)	--
Trihalomethanes	<1 µg/l set to 0	--	<2, <3.5, <4 µg/L set to 1, 1.75, 2	--

Bromate	<1 µg/l set to 0	--	<0.5, <1.5, <2, <7.5, <10 µg/l set to 0, 0.75, 1, 3.75, 5	--
Free chlorine	<0.01 mg/l set to 0	<0.01 mg/l set to 0	<0.1, <0.15, <0.2 mg/l set to 0	<0.10 mg/l set to 0
Total chlorine	<0.01 mg/l set to 0	--	<0.05, <0.10, <0.2 mg/l set to 0	--
Aluminum	<0.005 mg/l set to 0	--	<20, <25 µg/l set to 10, 12.5	--
Total organic carbon	<0.2 mg/L set to 0	--	<1 mg/l set to 0	<0.2 mg/l set to 0
Turbidity	<0.1 NTU set to 0	<0.02 NTU set to 0	<0.10, <0.20 NTU set to 0	<0.015, <0.10, <0.20 NTU set to 0
pH	All values within range	--	All values within range	--
Trichloroethylene + tetracholorethylene	--	--	<0.5, <0.6, <1 µg/l set to 0	--
Nickel	--	--	<1,<4,<5,<8 µg/l set to 0, 2, 2.5, 4	--
Chromium VI	--	--	--	<10 µg/l set to 5
Iodine Index	--	--	Blanks set to missing (176 values)	--

Appendix B. Results detail

Table B.1. A comparison of median water quality values (based on manually collected treated water samples) for each parameter across intervention locations prior to WSP implementation shows differing baseline water quality, attributable to variation in source water and treatment schema.

		Median water quality value prior to WSP implementation					
Parameter	**Unit**	**Location 1**	**Location 2**	**Location 3**	**Location 4**	**Location 5 (full)**	**Location 5 (partial)**
E. coli	MPN/100ml	0	0	0	0	0	0
Fecal Streptococci	MPN/100ml	0	0	0	0	--	--
Total coliform	MPN/100ml	0	0	0	0	0	0
Heterotrophic plate count (22°C)	MPN/ml	0	0	1	1	1	0
Trihalomethanes	µg/l	12.70	11.25	3.25	--	106.30	50.55
Bromate	µg/l	0	0	0	0	2.40	--
Free chlorine	mg/l	0.17	0.34	0.07	0.05	0.63	0.53
Total chlorine	mg/l	0.23	0.40	0.11	0.05	0.71	0.80
Aluminum	mg/l	0.011	0.026	0.007	0.069	0.045	0.070
Total organic carbon	mg/l	1.103	1.10	0.58	0.80	1.80	2.10
Turbidity	NTU	0	0.06	0.10	0.10	0.31	0.21
pH	pH units	7.36	7.58	7.40	8.185	7.445	7.69

Table B.2. All reported significant events occurring during the study period (prior to, during, and after WSP implementation) at each intervention location.

Location	Date	Event
1	2010	Merger with company on opposite side of river
	July 2010	Ultrafiltration installed
	1 Jan 2011	WSP implementation begins
	31 Oct 2011	WSP implementation ends
	2011-13	Interim plant manager
	Dec 2015 - Jan 2016	Replaced ultrafiltration membranes to reduce breakage/cut down on bench testing
2	1 Jan 2006	WSP implementation begins
	31 Mar 2007	WSP implementation ends
	2007	Replacement of sand filtration with GAC filtration at one surface water plant
	2010	UV treatment installed at one of three surface water plants
	2011	UV treatment installed at another of the three surface water plants
3	2008	Renovation of distribution system (including replacement of main pipe)
	2007-09	HACCP planning on production sites
	2009	Gasoline spill at supermarket resulted in legal suits
	2010	HACCP planning on the distribution network

	2011	Perchlorate contamination event (one water source discontinued)
	2011	Several upgrades implemented, including: • Chlorine dioxide and chlorine and UV disinfection added before chlorine and GAC filtration to reinforce disinfection capacity); previously discarded water when turbidity was high • Online sensors added to network • Water batch isolation
	13 Nov 2012	WSP implementation begins
	20 Dec 2013	WSP implementation ends
	2014	Flood event spikes total organic carbon (treatment stopped; water did not reach consumers)
4	01 Jan 2007	WSP implementation begins
	2007-08	Several upgrades implemented, including: • Adaptation of ozonation to limit bromate formation • Monitoring station installation upstream of the water intake and batch reservoir • Emergency interconnection with other treatment plants
	31 Mar 2008	WSP implementation ends
5	1 Jan 2008	WSP implementation begins
	2008	Severe drought
	Sept-Oct 2009	Gradual commissioning of reverse osmosis membranes
	31 Dec 2009	WSP implementation ends
	2010-2011	Improvements in sand filtration (post coagulation with ferric chloride) to address aluminum
	Early 2013	Low water availability
	May 2013	Replacement of all the sand filter beds
	2013	Replacement of ultrafiltration membranes
	Oct 2013 - Feb 2014	Switch to groundwater sources only due to dioxin contamination of surface water by wastewater treatment plant
	2013-14	Raw water pH adjustment to optimize coagulation with aluminum sulfate
	2014	Replacement of reverse osmosis membranes began
	2014	Improvements to water mixing step before division into two treatment lines (increased amount treated by ultrafiltration/reverse osmosis)
	2013-2015	Adjustment of the ozone treatment to minimize formation of bromides
	2015	Decrease use of chlorine dioxide in the pretreatment step
	Oct-Dec 2015	Switch to groundwater sources only due to dioxin contamination of surface water by wastewater treatment plant

Table B.3. Utility managers' expectations of change at each location ("Should the water quality parameter increase, decrease, or stay the same following WSP implementation?").

Parameter	**Location 1**	**Location 2**	**Location 3**	**Location 4**	**Location 5 (full/partial)**
E. coli	same	same	same	same	same
Fecal Streptococci	same	same	same	same	--
Total coliform	same	same	same	same	same

Heterotrophic plate count (22°C)	same	same	same	same	same
Trihalomethanes	decrease	same	same	--	decrease
Bromate	same	same	same	decrease	increase
Free chlorine	same	same	same	same	same
Total chlorine	decrease	same	same	same	same
Aluminum	same	same	same	same	decrease
Total organic carbon	decrease	same	same	same	decrease
Turbidity	decrease	same	same	same	decrease
pH	same	same	same	same	same

Table B.4. Minimum, maximum, and mean water quality values before and after WSP implementation, along with the number of samples, direction/magnitude of change, variance ratio, and raw and adjusted p-value for regression model interaction term at location 1 intervention and comparison ("comp") sites.

Parameter (units)	**N**	**% non-zero**	**Mean/ variance (before)**	**Mean/ variance (after)**	**Change in mean**	**Variance ratio (F)** *reduced by ≥4:1	**Model beta (time*site)**	**Model p-value (raw)**	**Model p-value (adjusted)** *significant
E. coli (MPN/100ml)	1390	0%	0 (0)	0 (0)	0	--	--	--	--
(comp)	5744	0.03%	0 (0)	0.002 (0.005)	0.002	--			
Fecal streptococci (MPN/100ml)	1018	0%	0 (0)	0 (0)	0	--	-1.40	1.000	1.000
(comp)	5493	0.05%	0 (0)	0.002 (0.006)	0.002	--			
Total coliform (MPN/100ml)	1390	0.65%	0.019 (0.039)	0.001 (0.001)	-0.018	39.00*	-2.30	0.094	0.658
(comp)	5737	0.64%	0.044 (1.157)	0.033 (0.342)	-0.011	3.38			
Heterotrophic plate count (MPN/ml)	1122	35.7%	10.032 (1434)	2.949 (405)	-7.083	3.54	-1.01	0.085	0.595
(comp)	5517	29.1%	7.716 (2277)	6.745 (1094)	-0.971	2.08			
THMs (µg/l)	78	98.7%	12.298 (32.7)	11.153 (23.3)	-1.145	1.40	-4.81	0.100	0.658
(comp)	96	72.9%	7.939 (103.2)	10.850 (110.4)	2.911	1.07			
Bromate (µg/l)	101	42.6%	0 (0)	1.244 (2.62)	1.244	--	14.81[1]	<0.001	<0.001*
(comp)	210	40%	0.684 (3.67)	1.331 (2.38)	0.647	1.54			

Free chlorine (mg/l)	1393	96.7%	0.190 (0.016)	0.190 (0.012)	0	1.33	-0.047	0.810	1.000
(comp)	5818	96.4%	0.377 (44.99)	0.423 (67.70)	0.046	1.50			
Total chlorine (mg/l)	1392	97.9%	0.243 (0.019)	0.275 (0.438)	0.032	23.05	-0.218	0.259	1.000
(comp)	5181	98.2%	0.315 (0.280)	0.560 (111.6)	0.245	398.57			
Aluminum (mg/l)	909	68.0%	0.013 (0)	0.014 (0)	0.001	--	-0.016	<0.001	<0.001*
(comp)	3928	72.9%	0.010 (0)	0.026 (0)	0.016	--			
Total organic carbon (mg/l)	407	100%	1.181 (0.076)	0.966 (0.032)	-0.215	2.38	-0.014	0.893	1.000
(comp)	205	100%	1.280 (0.172)	1.053 (0.072)	-0.227	2.40			
Turbidity (NTU)	1003	31.3%	0.243 (1.684)	0.148 (0.131)	-0.095	12.85*	-0.106	0.280	1.000
(comp)	4910	92.6%	0.220 (0.046)	0.225 (0.078)	0.005	1.70			
pH (pH units)	936	100%	7.371 (0.020)	7.582 (0.010)	0.211	2.00	0.222	<0.001	<0.001*
(comp)	5753	100%	7.568 (0.020)	7.565 (0.024)	-0.003	1.20			

[1]Tobit regression was used with highly censored data sets.

Table B.5. Minimum, maximum, and mean water quality values before and after WSP implementation, along with the number of samples, direction/magnitude of change, variance ratio, and raw and adjusted p-value for regression model time parameter among location 2 intervention site production samples.

Parameter (units)	**N**	**% non-zero**	**Mean/ variance (before)**	**Mean/ variance (after)**	**Change in mean**	**Variance ratio (F)** *reduced by ≥4:1	**Model beta (time)**	**Model p-value (raw)**	**Model p-value (adjusted)** *signif.
E. coli (MPN/100ml)	9069	0%	0 (0)	0 (0)	0	--	--	--	--
Fecal streptococci (MPN/100ml)	11183	0.02%	0 (0)	0 (0)	0	--	--	--	--
Total coliform (MPN/100ml)	11170	0.06%	0 (0)	0.001 (0.001)	0.001	--	--	--	--
Heterotrophic plate count (MPN/ml)	4610	22.5%	1.151 (110.6)	1.545 (146.2)	0.004	1.32	0.294	0.082	0.328
THMs (µg/l)	535	94.8%	10.956 (44.91)	7.492 (42.435)	-3.464	1.06	-3.464	0.006	0.024*

Bromate (µg/l)	843	15.3%	0.975 (7.014)	0.467 (2.063)	-0.508	3.40	-0.739[1]	0.307	1.000
Free chlorine (mg/l)	11713	100%	0.344 (0.003)	0.390 (16.076)	0.046	5358.67	0.046	0.311	1.000
Total chlorine (mg/l)	10008	100%	0.410 (0.003)	0.415 (0.003)	0.005	1.00	0.005	0.429	1.000
Aluminum (mg/l)	3615	87.6%	0.028 (0.001)	0.029 (0)	0.001	--	0.000	0.965	1.000
Total organic carbon (mg/l)	4134	99.5%	1.124 (0.068)	1.066 (0.076)	-0.058	1.12	-0.057	0.257	1.000
Turbidity (NTU)	10846	78.9%	0.064 (0.004)	0.061 (0.032)	-0.003	8.00	-0.003	0.065	0.260
pH (pH units)	8126	100%	7.538 (0.035)	7.624 (0.012)	0.086	2.92	0.086	0.126	0.504

[1]Tobit regression was used with highly censored data sets.

Table B.6. Minimum, maximum, and mean water quality values before and after WSP implementation, along with the number of samples, direction/magnitude of change, and raw and adjusted p-value for model interaction term at location 3 intervention and comparison ("comp") sites. Data sets are from manual water samples unless otherwise noted as coming from online sensors.

Parameter (units)	**N**	**% non-zero**	**Mean/ variance (before)**	**Mean/ variance (after)**	**Change in mean**	**Variance ratio (F)** *reduced by ≥4:1	**Model beta (time* site)**	**Model p-value (raw)**	**Model p-value (adjusted)** *significant
E. coli (MPN/100ml)	499	0.40%	0 (0)	0.793 (146.5)	0.793	--	--	--	--
(comp)	301	0%	0 (0)	0 (0)	0	--			
Fecal streptococci (MPN/100ml)	500	0.20%	0 (0)	0.182 (9.09)	0.182	--	--	--	--
(comp)	303	0%	0 (0)	0 (0)	0	--			
Total coliform (MPN/100ml)	499	1.40%	0.004 (0.004)	1.128 (170.2)	1.124	42550	7.07	<0.001	<0.001*
(comp)	302	1.66%	0.062 (0.334)	0.014 (0.014)	-0.048	23.86*			
Heterotrophic plate count (MPN/ml)	523	56.4%	14.689 (3302)	60.456 (109796)	45.767	33.25	2.09	0.019	0.019*
(comp)	303	38.0%	11.230 (2368)	5.366 (873.1)	-5.864	2.71			
THMs (µg/l)	41	82.9%	4.620 (23.32)	6.245 (14.10)	1.625	1.65	1.39[1]	0.275	0.275
Bromate (µg/l)	12	0%	0 (0)	0 (0)	0	--	--	--	--

Free chlorine (mg/l)	361	80.6%	0.091 (0.011)	0.193 (3.312)	0.102	301.1	0.109	0.422	0.422
(comp)	158	84.8%	0.088 (0.006)	0.073 (0.004)	-0.015	1.50			
Free chlorine (sensors)	419982	97.6%	0.125 (0.018)	0.140 (0.006)	0.015	3.00	0.015[1]	<0.001	<0.001*
Total chlorine (mg/l)	189	86.2%	0.114 (0.010)	0.115 (0.014)	0.001	1.40	0.029	0.289	0.289
(comp)	14	57.1%	0.027 (0.003)	0.020 (0.001)	-0.007	3.00			
Aluminum (mg/l)	92	93.5%	0.008 (0)	0.006 (0)	-0.002	--	-0.002	0.305	0.305
(comp)	17	47.1%	0.001 (0)	0.002 (0)	0.001	--			
Total organic carbon (mg/l)	130	100%	0.734 (0.194)	0.986 (0.228)	0.243	1.18	0.199	0.069	0.069
(comp)	51	100%	0.222 (0.004)	0.343 (0.022)	0.121	5.5			
Turbidity (NTU)	411	65.2%	0.169 (0.142)	0.266 (1.419)	0.097	9.99	0.185	0.058	0.058
(comp)	224	45.5%	0.182 (0.208)	0.094 (0.032)	-0.088	6.50*			
Turbidity (sensors)	436293	99.4%	0.282 (0.361)	0.336 (0.341)	0.054	1.06	0.055[1]	<0.001	<0.001*
pH (pH units)	83	100%	7.419 (0.017)	7.406 (0.014)	-0.013	1.21	0.031	0.256	0.256
(comp)	246	100%	7.889 (0.009)	7.853 (0.007)	-0.036	1.29			

[1]Where comparison data sets were not available, the beta reported is for time only.

Table B.7. Minimum, maximum, and mean water quality values before and after WSP implementation, along with the number of samples, direction/magnitude of change, and raw and adjusted p-value for model time parameter at the location 4 intervention site.

Parameter (units)	**N**	**% non-zero**	**Mean/ variance (before)**	**Mean/ variance (after)**	**Change in mean**	**Variance ratio (F)** *reduced by ≥4:1	**Model beta (time)**	**Model p-value (raw)**	**Model p-value (adjusted)** *significant
E. coli (MPN/100ml)	3165	0.19%	0.001 (0.001)	0.005 (0.036)	0.004	36.00	--	--	--
Fecal streptococci (MPN/100ml)	3529	0.11%	0.003 (0.003)	0 (0)	-0.003	--	--	--	--
Total coliform (MPN/100ml)	3515	0.94%	0.010 (0.017)	0.030 (0.304)	0.020	17.88	1.059	0.086	0.258
Heterotrophic plate count (MPN/ml)	3307	39.13%	10.375 (9170.4)	3.367 (327.3)	-7.008	28.02*	-1.120	<0.001	<0.001*

Bromate (µg/l)	742	19.27%	2.446 (30.44)	1.643 (22.27)	-0.803	1.37	-0.257	0.619	1.000
Free chlorine (mg/l)	3440	75.15%	0.134 (0.023)	0.147 (0.020)	0.013	1.15	0.022	0.002	0.006*
Total chlorine (mg/l)	3476	73.16%	0.130 (0.027)	0.166 (0.409)	0.036	15.15	0.042	0.013	0.039*
Aluminum (mg/l)	2589	91.35%	0.069 (0.002)	0.041 (0.000)	0.028	--	-0.030	<0.001	<0.001*
Total organic carbon (mg/l)	562	99.11%	0.828 (0.070)	0.812 (0.185)	-0.016	2.64	-0.017	0.808	1.000
Turbidity (NTU)	3401	82.95%	0.167 (0.063)	0.130 (0.072)	-0.037	1.14	-0.036	0.003	0.009*
pH (pH units)	893	100%	8.133 (0.086)	8.103 (0.105)	-0.030	1.22	-0.118	<0.001	<0.001*

Table B.8. Minimum, maximum, and mean water quality values before and after WSP implementation, along with the number of samples, direction/magnitude of change, and raw and adjusted p-value for model interaction term at location 5 intervention and comparison ("comp") sites. Data sets are from manual water samples unless otherwise noted as coming from online sensors.

Parameter (units)	**N**	**% non-zero**	**Mean/ variance (before)**	**Mean/ variance (after)**	**Change in mean**	**Variance ratio (F)** *reduced by ≥4:1	**Model beta (time*site)**	**Model p-value (raw)**	**Model p-value (adjusted)** *signif.
E. coli (MPN/100ml)	1641	0.1%	0.002 (0.002)	0 (0)	-0.002	--	--	--	--
(partial)[1]	1992	0.05%	0 (0)	0.001 (0.001)	0.001	--	--	--	--
(comp)	360	0%	0 (0)	0 (0)	0	--			
Total coliform (MPN/100ml)	1641	2.6%	0.181 (4.69)	2.942 (7050)	2.761	1502.9	--	--	--
(partial)	1992	0.8%	0.006 (0.008)	0.157 (22.08)	0.151	2760.4	--	--	--
(comp)	329	1.2%	0 (0)	0.208 (5.56)	0.208	--			
Heterotrophic plate count (MPN/ml)	64	45.3%	18.545 (3121)	1.619 (20.29)	-16.926	153.8*	-3.083	0.031	0.062
(partial)	144	38.2%	3.708 (350.1)	3.896 (937.8)	0.188	2.68	-0.596	0.707	1.000
(comp)	156	40.4%	620.2 (7.42M)	1335.9 (237M)	715.6	32.00			
THMs (µg/l)	4683	100%	112.508 (2421.5)	11.817 (51.84)	-100.691	46.71*	-96.168	<0.001	<0.001*

(partial)	138	100%	51.177 (157.8)	52.095 (275.1)	0.918	1.74	5.124	0.253	0.759
(comp)	35	100%	57.133 (313.6)	48.012 (219.3)	-9.121	1.43			
Bromate (µg/l)	2150	99.5%	3.127 (7.76)	5.384 (26.60)	2.257	3.43	2.263	<0.001	<0.001*
(partial)	71	100%	--	4.940 (0.254)	--	--	--	--	--
(comp)	6	100%	5 (0)	5 (0)	0	--			
Free chlorine (mg/l)	5034	98.1%	0.529 (0.002)	0.520 (0)	-0.009	--	-0.072	0.079	0.158
(partial)	11354	99.7%	0.620 (0.030)	0.588 (0.037)	-0.032	1.23	-0.096	0.004	0.012*
(comp)	325	97.9%	0.462 (0.042)	0.545 (0.038)	0.083	1.11			
Free chlorine (sensors)	283678	100%	1.068 (0.036)	0.893 (0.025)	-0.175	1.44	-0.175[2]	<0.001	<0.001*
Total chlorine (mg/l)	4970	99.6%	0.722 (0.062)	0.643 (0.047)	-0.079	1.32	-0.022	0.681	1.000
(partial)	11220	100%	0.799 (0.032)	0.771 (0.043)	-0.028	1.34	0.028	0.552	1.000
(comp)	13	92.3%	0.214 (0.001)	0.157 (0.011)	-0.057	11.00			
Aluminum (µg/l)	6699	100%	54.010 (1638)	36.317 (950)	-17.693	1.72	-21.070	0.121	0.242
(partial)	141	100%	72.011 (1355)	60.609 (706)	-11.402	1.92	-14.863	0.319	0.957
(comp)	79	100%	47.650 (1658)	50.169 (714.8)	2.519	2.32			
Total organic carbon (mg/l)	67	76.1%	1.924 (0.585)	0.945 (0.623)	-0.979	1.06	-1.067	<0.001	<0.001*
(partial)	143	99.3%	2.085 (0.220)	2.330 (0.383)	0.245	1.74	0.157	0.428	1.000
(comp)	35	100%	2.467 (0.200)	2.492 (0.588)	0.025	2.94			
Total organic carbon (sensors)	18925	93.1%	2.760 (0.588)	0.918 (0.187)	-1.842	3.14	-1.842[2]	<0.001	<0.001*
Turbidity (NTU)	1592	65.1%	0.369 (0.201)	0.162 (0.092)	-0.207	2.18	-0.234	<0.001	<0.001*
(partial)	1990	64.6%	0.208 (0.165)	0.093 (0.140)	-0.115	1.18	-0.143	0.011	0.033*
(comp)	327	93%	0.312 (0.053)	0.344 (0.573)	0.032	10.81			
Turbidity (sensors)	87054	77.5%	0.257 (0.008)	0.120 (6.510)	-0.137	813.75	-0.138[2]	<0.001	<0.001*

pH (pH units)	503	100%	7.475 (0.044)	7.440 (0.056)	-0.035	1.27	-0.219	<0.001	<0.001*
(partial)	797	100%	7.683 (0.031)	7.577 (0.056)	-0.106	1.81	-0.289	<0.001	<0.001*
(comp)	325	100%	7.639 (0.019)	7.820 (0.035)	0.181	1.84			

[1]The full WSP applied to both the production and distribution system; the partial WSP applied to the distribution system only.

[2]Where comparison data sets were not available, the beta reported is for time only.

Table B.9. Detailed results of compliance analysis involving relevant internal and external thresholds. Both raw and adjusted p-values are shown.

Location	**Parameter**	**Data Source**	**Threshold[2]** (Definition of exceedance)	**Threshold Source**	**% Non-compliance** (before)	**% Non-compliance** (after)	**Chi-Square[C] or Fisher's Exact Test[F]**	**P-value (adjusted)** *signif.
1	*E. coli*	Prod/Dist	>0 MPN/ 100ml	EU and French quality limit	0%	0%	--	--
	Total coliform	Prod/Dist	>0 MPN/ 100ml	EU and French quality limit	1.17%	0.14%	673[F]	0.019 (0.038)*
	THMs	Production	>30 µg/l more than 10% of the time	WSP operational limit	0%	0%	--	--
		Production	≥50 µg/l	Suez internal recommended practice for plant outlet	0%	0%	--	--
		Distribution	>100 µg/l	EU and French quality limit for network	0%	0%	--	--
	Bromate	Prod/Dist	>10 µg/l	EU and French quality limit	0%	0%	--	--
	Aluminum	Prod/Dist	>200 µg/l	EU and French quality reference	0%	0%	--	--
		Production	>100 µg/l	Suez internal recommended	0%	0%	--	--

				practice and WSP operational limit				
	Turbidity	Production	>0.5 NTU	French quality reference for plant outlet	1.03%	0.55%	192[F]	1.000 (1.000)
		Production	>1 NTU	French quality limit for plant outlet	0%	0%	--	--
		Distribution	>2 NTU	French quality reference for tap	4.04%	0.98%	309[F]	0.020 (0.040)*
	pH	Prod/Dist	<6.5 or >9 pH units	EU and French quality limit	0%	0%	--	--
2	*E. coli*	Production	>0 MPN/ 100ml	EU and French quality limit	0%	0%	--	--
	Total coliform	Production	>0 MPN/ 100ml	EU and French quality limit	0%	0.09%	3188[F]	0.203 (1.000)
	THMs	Production	≥50 µg/l	Suez internal recommended practice for plant outlet	0%	0.21%	56[F]	1.000 (1.000)
	Bromate	Production	>10 µg/l	EU and French quality limit	0.68%	0.29%	145[F]	0.435 (1.000)
	Free chlorine	Production	≤0.05 or ≥0.7	WSP critical limit	0.03%	0.02%	3202[F]	1.000 (1.000)
	Aluminum	Production	>200 µg/l	EU and French quality reference	0%	0.03%	674[F]	1.000 (1.000)
		Production	>100 µg/l	Suez internal recommended practice	0.45%	0.37%	671[F]	0.734 (1.000)
	Total organic carbon	Production	>2 mg/l	French quality reference	0.08%	0.03%	1224[F]	0.505 (1.000)
	Turbidity	Production	>0.5 NTU	French quality reference for plant outlet	0.04%	0.26%	2776[F]	0.025 (0.225)
		Production	>1 NTU	French quality limit for plant outlet	0%	0.07%	2777[F]	0.349 (1.000)

	pH	Production	<6.5 or >9 pH units	EU and French quality limit	0%	0%	--	--
3	*E. coli*	Prod/Dist	>0 MPN/ 100ml	EU and French quality limit	0%	0.73%	224[F]	0.504 (1.000)
	Total coliform	Prod/Dist	>0 MPN/ 100ml	EU and French quality limit	0.44%	2.19%	224[F]	0.135 (0.810)
	THMs	Production	≥50 µg/l	Suez internal recommended practice for plant outlet	0%	0%	--	--
		Distribution	>100 µg/l	EU and French quality limit for network	0%	0%	--	--
	Free chlorine	Production (sensors)	<0.05 mg/l	WSP critical limit for chlorination	7.53%	2.81%	4783[C]	<0.001 (<0.001)*
	Aluminum	Prod/Dist	>200 µg/L	EU and French quality reference	0%	0%	--	--
		Prod/Dist	>100 µg/L	Suez internal recommended practice	0%	0%	--	--
	Total organic carbon	Prod/Dist	>2 mg/l	French quality reference	2.08%	1.41%	47[F]	1.000 (1.000)
	Turbidity	Production (sensors)	>0.5 NTU *simplified	Suez internal recommended practice	4.72%	4.73%	0.0004[C]	0.983 (1.000)
		Production	>0.5 NTU	French quality reference for plant outlet	2.38%	0%	41[F]	0.452 (1.000)
		Production	>1 NTU	French quality limit for plant outlet	0%	0%	--	--
		Distribution	>2 NTU	French quality reference for tap	0.65%	1.23%	154[F]	1.000 (1.000)
	pH	Prod/Dist	<6.5 or >9 pH units	EU and French quality limit	0%	0%	--	--
4	*E. coli*	Prod/Dist	>0 MPN/100ml	EU and French quality limit	0.13%	0.21%	797[F]	1.000 (1.000)
	Total coliform	Prod/Dist	>0 MPN/100ml	EU and French quality limit	0.78%	1.02%	0.47[C]	0.495 (1.000)

	Bromate	Prod/Dist	>10 µg/l	EU and French quality limit	13.11%	4.55%	8.24[C]	0.004 (0.040)*
	Free chlorine	Production	<0.2 mg/l *simplified	WSP operational limit (surface water)	14.79%	7.65%	11[C]	0.001 (0.010)*
		Production	<0.15 mg/l	WSP operational limit (groundwater)	44.83%	55.70%	1.01[C]	0.316 (1.000)
		Production	<0.1 mg/l	WSP critical limit (surface water)	2.57%	2.19%	0.13[C]	0.718 (1.000)
		Production	<0.05 mg/l *simplified	WSP critical limit (groundwater)	6.90%	18.99%	27[F]	0.149 (1.000)
	Aluminum	Prod/Dist	>200 µg/l	EU and French quality reference	0.28%	0%	721[F]	0.078 (0.780)
		Prod/Dist	>100 µg/l	Suez internal recommended practice	23.79%	1.18%	384[C]	<0.001 (0.001)*
	Total organic carbon	Production	>2 mg/l	French quality reference	0%	1.79%	172[F]	0.107 (1.000)
	Turbidity	Production	>0.5 NTU	French quality reference for plant outlet	2.84%	4.12%	1.03[C]	0.309 (1.000)
		Production	>1 NTU	French quality limit for plant outlet	0.28%	1.15%	351[F]	0.270 (1.000)
		Distribution	>2 NTU	French quality reference for tap	0.12%	0.12%	814[F]	1.000 (1.000)
	pH	Prod/Dist	<6.5 or >9 pH units	EU and French quality limit	0%	0.13%	110[F]	1.000 (1.000)
5 (full WSP[1])	*E. coli*	Prod/Dist	>0 MPN/ 100ml	EU and Spanish quality limit	0.24%	0%	822[F]	0.500 (1.000)
	Total coliform	Prod/Dist	>0 MPN/ 100ml	EU and Spanish quality limit	4.49%	0.61%	787[F]	<0.001 (<0.001)*
	THMs	Production	≥50 µg/L	Suez recommendation for plant outlet (in France)	94.92%	0.32%	4217[C]	<0.001 (<0.001)*

		Distribution	>100 µg/l	EU and Spanish quality limit for network	84.21%	0%	6[F]	<0.001 (<0.001)*
	Bromate	Prod/Dist	>10 µg/l	EU and Spanish quality limit	2.82%	4.14%	69[F]	1.000 (1.000)
		Production	≥7.5 µg/l *simplified	Regional internal recommended practice/WSP critical limit	7.04%	6.59%	66[F]	0.808 (1.000)
	Free chlorine	Distribution	>1 mg/l	Spanish quality limit in network	1.50%	0.85%	3.63[C]	0.057 (0.399)
		Production (sensors)	<0.5 mg/l	Catalunya/WSP operational limit	0.50%	0.45%	3.85[C]	0.050 (0.398)
		Production (sensors)	<0.2 mg/l *simplified	Catalunya/WSP critical limit for chlorination	0.13%	0.06%	35.9[C]	<0.001 (<0.001)*
	Total chlorine	Distribution	>2 mg/l	Spanish quality limit in network	0.06%	0%	3372[F]	1.000 (1.000)
	Aluminum	Prod/Dist	>200 µg/L	EU and Spanish and regional quality limit	0.55%	0.06%	1450[F]	<0.001 (0.003)*
	Turbidity (after sand filters)	Production (sensors)	≥0.75 NTU	WSP operational limit	0.12%	1.27%	3473[F]	<0.001 (<0.001)*
		Production (sensors)	≥1 NTU *simplified	WSP critical limit	0.03%	0.38%	3476[F]	<0.001 (<0.001)*
	Turbidity (at outlet)	Production (sensors)	>0.5 NTU	Spanish quality reference	1.44%	0.24%	402[C]	<0.001 (<0.001)*
		Production (sensors)	>1 NTU	EU and Spanish quality limit for plant outlet	0.01%	0.04%	15071[F]	0.156 (0.936)
	Turbidity (in network)	Distribution	>5 NTU	Spanish quality limit	0.13%	0%	771[F]	0.485 (1.000)
	pH	Prod/Dist	<6.5 or >9.5 pH units	EU and Spanish quality limit	0%	0%	--	--
	Iodine adsorption	Production	<550 mg I2/g	WSP operational level for granular activated carbon	--	20.56%	--	--

		Production	<400 mg I2/g	WSP critical level for granular activated carbon	--	9.25%	--	--
	Nickel	Production	>20 µg/L	EU and Spanish quality limit (for tap)	0.43%	0%	1400[F]	<0.001 (0.002)*
	Chromium VI	Production	>50 µg/L	EU and Spanish quality limit	0%	0%	--	--
	Trichloro-ethylene + tetrachloro-ethylene	Production	>10 µg/L	EU and Spanish quality limit	0%	0%	--	--
5 (partial WSP[1])	*E. coli*	Distribution	>0 MPN/ 100ml	EU and Spanish quality limit	0%	0.09%	826[F]	1.000 (1.000)
	Total coliform	Distribution	>0 MPN/ 100ml	EU and Spanish quality limit	0.48%	1.11%	822[F]	0.147 (0.882)
	THMs	Distribution	>100 µg/l	EU and Spanish quality limit for network	0%	1.02%	40[F]	1.000 (1.000)
	Bromate	Distribution	>10 µg/l	EU and Spanish quality limit	0%	0%	--	--
	Free chlorine	Distribution	>1 mg/l	Spanish quality limit in network	0.35%	0.33%	0.05[C]	0.827 (1.000)
	Total chlorine	Distribution	>2 mg/l	Spanish quality limit in network	0%	0%	--	--
	Aluminum	Distribution	>200 µg/L	EU and Spanish and regional quality limit	0%	1.04%	45[F]	1.000 (1.000)
	Turbidity	Distribution	>5 NTU	Spanish quality limit	0.12%	0.09%	825[F]	1.000 (1.000)
	pH	Distribution	<6.5 or >9.5 pH units	EU and Spanish quality limit	0%	0%	--	--

[1]The full WSP applied to both the production and distribution system; the partial WSP applied to the distribution system only.

[2]Some thresholds were simplified to enable comparison with historical data. Self-reported records might differ based on the application of time duration, repeat sampling, or equipment validation procedures.