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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 240 K manual samples and 1.2 M 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.

1. 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) 2015/1787EU, 2015) 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,

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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, 2010); 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.

2. Methods

2.1. 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 A1). 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.

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