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Article

The Toledo Drinking Water Advisory: Suggested Application of the Water Safety Planning Approach

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Abstract: On 2 August 2014 the city of Toledo, in Ohio USA issued a "do not drink" water advisory and declared a state of emergency. This was as a result of elevated levels of the toxin microcystin in the final treated water, a dangerous toxin produced by the algae cyanobacteria. The Toledo water crisis is a key focusing event that can advance dialogue on eutrophication governance in the context of public health. This paper examines the Toledo water ban with the aim of determining whether this crisis could have been averted. Further, we explore how this event can be used to stimulate action on eutrophication governance, to motivate action to protect water at its source. We use the World Health Organization's Water Safety Planning Methodology to show that the crisis could have been averted with some simple risk management actions. We also show that a water safety planning approach could lead to well developed operational and maintenance planning resulting in a higher probability of safe drinking water.

Keywords: drinking water advisory; Toledo water; water safety planning; Great Lakes; eutrophication; cyanobacteria

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1. Introduction

On 2 August 2014, the city of Toledo, Ohio, in the United States of America issued a "do not drink" water advisory. This put the city in the local, regional and international media spotlight, with headlines reading "Water crisis grips hundreds of thousands in Toledo area, state of emergency declared" [1], and "400,000 in Toledo, Ohio, water scare await test results" (CNN) [2]. A state of emergency was declared by Ohio Governor John Kasich in Toledo amidst national and local efforts to test the water. Efforts were also made to secure potable water for residents, with the governor calling on the National Guard to aid in the delivery of safe water to residents [3]. While the water ban in Ohio's fourth largest city did not result in any fatalities and was lifted after three days, could this crisis have been avoided entirely? This paper aims to show how the World Health Organization's (WHO) water safety planning approach could lead to a well-developed operational and maintenance planning system resulting in a highly reliable safe drinking water system with a greater probability of safe drinking water more of the time. This paper describes the Toledo water crisis as an opportunity to frame the conversation on eutrophication governance in the context of the protection of public health to spur immediate action. Historically, extreme events have resulted in the development of new policy. For example, the Cuyahoga River catching fire, organic contaminants in the Love Canal and Hurricane Sandy all have shifted the way Americans view environmental issues and have shaped their responses. Perhaps the Toledo case is an example of an event that could be a catalyst in progress toward a better water management strategy, linking the health of the lakes with land-based activities and human health. In the end it is the re-framing of the problem and evidence based research that can lead to development of policy, as in the case of policy and law on pesticide use on lawns in Canada [4].

Further, urban water management issues are best described as wicked problems, with high levels of complexity, uncertainty and multi-actor involvement. The governance literature [5,6] advances a new approach to public problem solving that places emphasis on the centrality of collaborative approaches that allow for multi-actor involvement, where government is one actor among many. An important consideration is the means by which regulatory authorities fulfill their mandates in such structures. Vabo and Røiseland [7] address the challenges faced by public leaders arising from new governance arrangements (networks) where government is just one of many stakeholders, thus rendering hierarchical approaches problematic. Engle *et al.* [8] also point towards fundamental water governance issues associated with networked forms of governance, that is, the limitations of hierarchical institutional arrangements and decision-making in an environment of uncertainty. This paper describes a governance regime that could contribute to the prevention of such incidents in the future.

2. Background

The city of Toledo was founded in 1833 and has a history of innovation in the glass industry, leading to its nickname as "The Glass Capital of the World" [9]. The city is located at the western end of Lake Erie and on the northern border of Ohio, as shown in Figure 1.

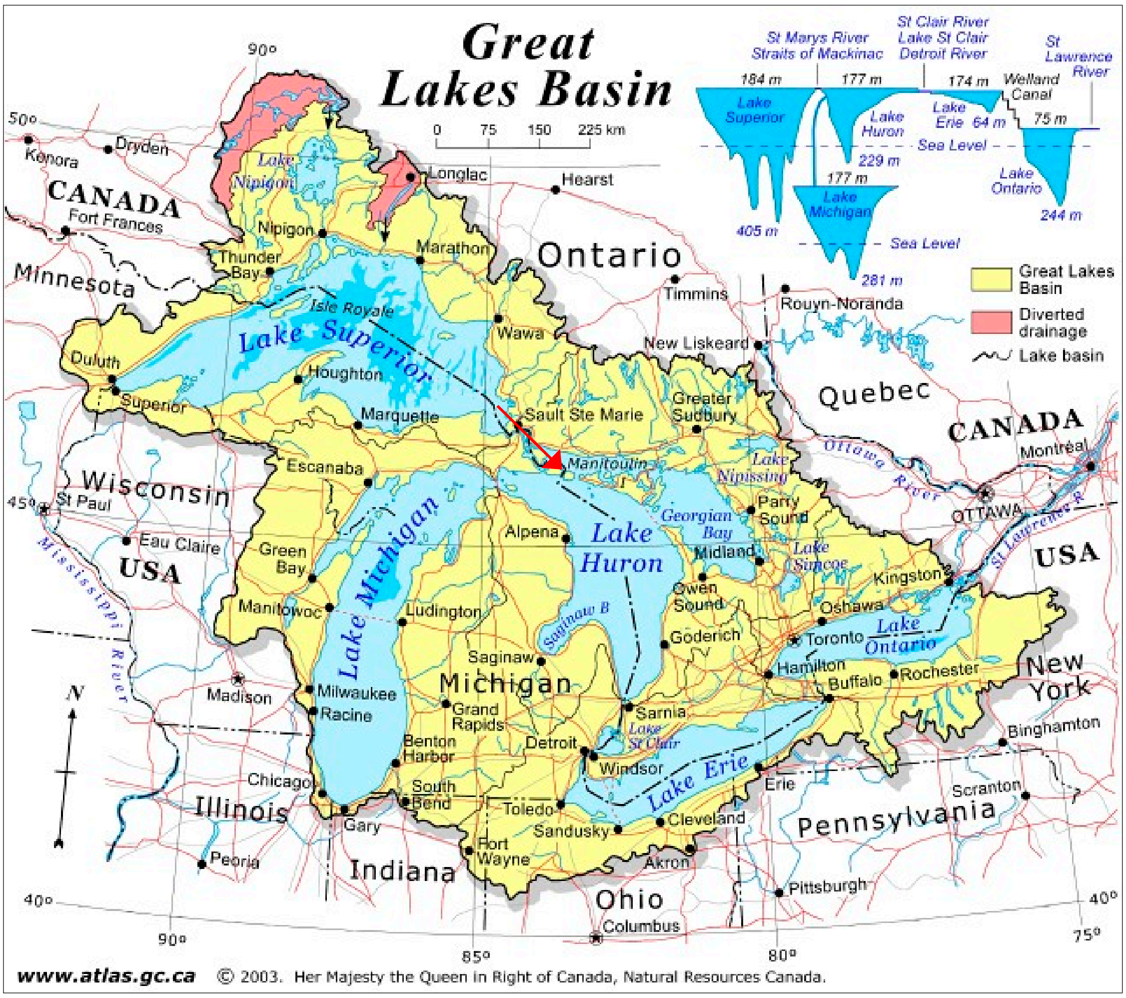

Figure 1. Map showing the city of Toledo, Ohio, USA [10].

The city lies along the banks of the Maumee River, which was the first source of water for the city's 30,000 residents in 1870. In the first year of operation, water was pumped (pump capacity was 30,000 gallons) untreated to the first customers (twelve) through 85 miles of pipeline [11]. As the population of the city grew, water quality in the Maumee deteriorated. Initially, pollution was the result of untreated residential sewage discharges to the river, leading to epidemics of diseases such as typhoid. While the initial water system was driven by the goal for residents to have a convenient source of water supply and to have water more readily available for fire safety, the increase in pollution and associated epidemics led to an increasing call by residents for treated water. According to the City of Toledo [11], this resulted in the commissioning of Brookford Filtration Plant (with a capacity of 20 million gallons per day) on 2 February 1910. From that time forward, Maumee River water has been filtered and treated before being pumped to residents.

In 1941, the growing population and increasing pollution of the Maumee River led to relocation of the city's drinking water source to Lake Erie when the Collins Water Treatment plant began operation with a capacity of 80 million gallons per day. During the 1950s and 1980s changes were made to the water treatment plant to increase the volumetric capacity, with 146.8 million gallons pumped in 1988. The first processing change was made in 1997, with a sludge dewatering facility being brought online [11]. This allowed the lime sludge to be recycled into other products. The treatment plant has made other changes such as the installation of a backup power facility that began construction in 2004 and the installation of a potassium permanganate feed system facility in 2009 to control the zebra mussels that were obstructing the water intake and damaging the water treatment lines. According to the City of Toledo [11], some of the improvements made at the plant between 2011 and 2013 included updating pumps to variable speed drive, installation of a solar panel field to provide one million kilowatt hours of energy per year (2011), replacement of the flocculator drive systems (2012), roof and impeller replacements, rebuilding of the motor, drive and pump for the Heatherdowns Pump Station pump and the installation of a gas chromatograph/mass spectrometer for detection of compounds that cause taste and odor problems (2013).

2.1. The Toledo "Do Not Drink" Water Advisory

On 1 August 2014 at 6:30 p.m., the city of Toledo notified the Ohio EPA that the testing results for microcystin were above the drinking water advisory threshold (1 ppb), a finding that was later confirmed with a second set of samples [12]. Additional samples at 11:00 p.m. again confirmed this result in the final treated water. According to the Ohio EPA [12], a sudden spike in algal blooms in Lake Erie, combined with an unusual amount of extracellular toxin in Lake Erie, overwhelmed the treatment plant and the operators were unable to adjust their treatment regime proactively. Ohio EPA [12] advised the City at 12:00 a.m. to issue a "Do not drink" advisory, and such an advisory was issued to half a million water customers at 2:00 a.m. on 2 August 2014. On the same day, the Ohio Emergency Operations Center was activated at 5:00 a.m. and at 10:00 a.m. Governor Kasich declared a state of emergency for Wood and Lucas Counties and then extended the announcement to Fulton County.

During this time, sample protocols were being examined by the US EPA and partners to determine whether they were resulting in representative results. There was collaboration amongst agencies on sample collection, testing and interpretation of results. On 3 August, at 4:00 p.m., federal, state and City of Toledo water quality experts arrived at consensus on protocols for sample collection, and handling and testing, and additional samples were analyzed. On 4 August 2014 at 9:35 a.m., after water analysis showed that the water was safe to drink, the Mayor announced the lifting of the "do not drink" water advisory. During this time, there was extensive coverage of the event in local, regional and international media including the Toledo Blade, Bedford Now, Great Lakes Echo, CNN, BBC News, USA today and the New York Times. This interest was captured in a Google trends report, which recorded 100 searches for "Toledo Water Crisis" in August 2014. Interest waned over time, with Google searches dropping to 5 in September 2014.

2.2. Current US Water Legislation

The US Safe Drinking Water Act (SDWA) requires periodic testing of drinking water for contamination, and response to detected risks [13]. Still, an estimated 25% of the US water treatment systems violated the SDWA in 2011 [14]. Of these total violations, about 25% were of health-based standards [14], including violations related to microbial waterborne illnesses, which are estimated to affect 19.5 million Americans annually [15]. These waterborne illnesses can be the result of both regulated and non-regulated contaminants. For example, cyanotoxins from algal blooms in the Great Lakes recently caused the shutdown of a local drinking water treatment plant. However, cyanotoxins, an unregulated contaminant group harmful to human health, are currently on the Contaminant Candidate List to be considered for regulation in the next five years. Testing for this group in Toledo and elsewhere is therefore voluntary at present, but has nevertheless led to boil water advisories [16]. This means that until cyanotoxin testing becomes a regulatory requirement, some drinking water systems may not test for these compounds and therefore not take precautions against them [13].

3. Water Safety Planning: Literature Review

3.1. Background

The Water Safety Plan (WSP) approach has been developed and recommended by the World Health Organization (WHO) to ensure the safety of drinking water supplies. WSP is a methodology to assess, prioritize and manage risks to the water supply from catchment to consumer [17]. It is a combination of more traditional multiple-barrier risk management approach and the hazard analysis critical control point (HACCP) approach [18]. The main focus of WSP is on safe drinking water supply but it also has health-based targets to evaluate the quality of the water supplied and the condition of the water supply system. WSP includes a system assessment approach that determines if the water supply system, from source to tap, delivers a water quality to the consumer that also meets health-based targets ([19] p. 127). System assessment evaluates whether the suite of control measures in a given location are sufficient for this purpose, based on an analysis of local hazards, hazardous events and the efficacy of local control measures [19].

WSP has been a successful approach to maintain drinking water safety and is now used in many countries; it is also a regulatory requirement in several countries [17]. Some countries that have implemented WSP include: Iceland (legislated in 1995: [17]); Bangladesh, Belgium [20], Switzerland [21], the Netherlands [22], Argentina, Bolivia, Brazil, Guyana, Honduras, Jamaica, St. Lucia, Uruguay, Ecuador, Peru, Portugal [23] and Nigeria [24]. Implementation of WSP in the European Union was promoted by the International Water Association and supported by the WHO [25–27].

The motivation behind introduction of WSP and the methodology of implementation differs from country to country. For example, in Iceland, Slovenia and Switzerland, drinking water comes under food legislation and risk assessment is mandatory. In Flanders (Belgium), a few incidents highlighted the need for a framework that would address emerging issues (such as emerging pollutants) and this need became a key driver for implementation of WSP [28]. In some countries, WSP has been implemented as recommended by the WHO, while in other places there have been linkages to risk assessment and management [28]. A similar concept is sanitation safety planning (covering wastewater and sanitation), which is based on WSP and was also developed by the WHO [29].

3.2. Case Studies Where WSP Has Been Implemented

The following case studies show that implementing WSPs improves water quality and reduces the incidence of microbiological contamination.

3.2.1. Germany

In Germany, the WSP [30] concept was adopted in a modified version termed "Technical Risk Management" (TRM), where in addition to health-based targets additional targets such as quality, quantity, pressure and continuity are also identified (mainly to satisfy German drinking water standards and the expectations of consumers) [31]. This is an interesting case because unlike other countries, which depend only on one source of water supply, Germany has applied the TRM concept at water treatment plants that draw water from both surface and groundwater sources. Periodic evaluation of the existing raw water data has been helpful in understanding the variability and impacts of various land-use activities in the catchment areas. GIS-based hazard source maps are used to monitor hazardous sites with the potential to affect drinking water sources. While, it would be helpful if certain agricultural practices (especially use of fertilizers, pesticides, *etc.*) could be modified within a given catchment, such changes have proved to be more difficult in practice because such measures involve policy and are often beyond the control of water suppliers [31].

A study from a German hospital has shown a clear linkage between WSP implementation and positive health outcomes, specifically a reduction in hospital-acquired infections and neonatal sepsis ([32,33]). In 2004, very high concentrations of microorganisms occurred in a newly opened part of the hospital, resulting in the Department of Health (DHC) declaring unacceptable water testing results three months before the opening. A taskforce on water safety was formed and initiated a program to implement WSP in the hospital. To evaluate the efficacy of the WSP the microbiological results were recorded from May 2004 to April 2006. Results revealed a decrease in the density of microorganisms following implementation of the program.

3.2.2. Iceland

In Iceland most of the drinking water supply is from groundwater and is not generally disinfected. However, it is the responsibility of Local Competent Authority (LCA) to protect drinking water. The Icelandic Drinking Water Regulation (IDWR) legally requires protection of sources of drinking water, which makes it obligatory for the LCA to define protection around drinking water intakes ([17] p. 7783). Implementing WSP has resulted in increased compliance with the IDWR and improved water quality, and has also resulted in a culture which regards drinking water as a public health issue [17]. The results from Iceland show an overall significant reduction in diarrheal incidences after the implementation of WSP.

3.3. Systems Assessment

Assessment of surface water drinking water systems in industrialized countries tends to involve site-specific monitoring of pathogens in source water. For example, the US drinking water regulation LT2 ESWTR under the Safe Drinking Water Act [34] requires pathogen monitoring in source water as the basis for system assessment. In this case, the health-based targets are taken as treatment performance objectives. A system assessment under this regulation looks at the pathogens present in the water source and evaluates treatment processes to see if they can remove the pathogens at source. The regulation specifies some important considerations for evaluation of both factors. For example, sample size, frequency, location, method, processing method and data analysis are important for monitoring pathogens in source water, while turbidity monitoring, measurement location, measurement frequency, accuracy at low turbidity levels, calibration and maintenance of the monitors and data analysis are important for monitoring the treatment process [19] (p. 130). It is also important to take into account rainfall events or snowmelt events when pathogens or turbidity in water might peak [19] (p. 131).

In the case of surface water drinking supply systems, data on pathogen occurrence in source waters and efficacy of water treatment processes is sometimes not available. In response, some water utilities have developed predefined health targets to set water quality targets and have used published data on pathogen occurrences to identified preferred treatment methods. Results of this type of system assessment have also been used to prioritize investment in specific treatment optimization or upgrades to meet the health-based treatment performance targets [19] (p. 128).

Decisions about the level of investment in treatment systems or drinking water supply systems should be based on local conditions. For example, in Kampala (Uganda), 72% of people use piped water supply from Lake Victoria (treated via coagulated, rapid sand filtration and chlorination) and of this only about 20% of people have household connections. The remaining population gets water from protected springs. Data has shown a large number of incidences of pathogens and associated diseases in Kampala, with treatment failure the main cause of the disease burden. In this case, studies have suggested that the most cost effective investment would be in improving access to piped water supply at homes. Similarly, a study in Bangladesh found that risks of microbial contamination and incidence of diarrheal disease were reduced when water supply infrastructure was improved and safer water sources were chosen [33,35].

WSP has been modified and implemented for small systems as well. For example, New Zealand has a public health risk management plan and Australia has an electronic tool to support development and implementation of WSP for small systems. Small-scale community-based WSP pilot projects were also tested in Bangladesh, with positive results. Newer versions of WSP have emerged since these pilot studies to reflect lessons learnt during the pilot stage. However, it has been observed in Bangladesh and other places that while there is an improvement in water quality and overall reduction in microbial contamination following implementation of WSP, it is difficult to achieve complete removal of indicator bacteria such as Thermo Tolerant Coliform Bacteria [35–37]. Robust monitoring tools and sustained surveillance are important to the success of these kinds of initiatives to remove Thermo Tolerant Bacteria [35].

3.4. Challenges/Issues with Implementation of WSP

Although WSP is widely regarded as one of the most effective frameworks to ensure safe drinking water delivery, there are some problems with the way WSPs are developed, implemented and evaluated. The first problem is in the way WSP is written. At times (for example in the case of Pacific Island countries), the focus is on writing the document with no emphasis on monitoring and evaluation. In some cases, the plan is also weak in terms of the effectiveness of control measures [33]. It would therefore be desirable to establish standard procedures to ensure consistency in development of WSPs, especially with respect to detailed system description, risk assessment and prioritization, improved schedule, monitoring plans and evaluation. Another problem is the lack of benchmarks, indicators or performance measurements against which the effectiveness of a WSP can be evaluated. As discussed by Davison and Deere [38], key public health and operational targets should be used to measure the effectiveness of WSPs; however, most jurisdictions lack measurable performance indicators associated with WSP. To rectify this, it would be important to identify the Key Performance Indicators (KPIs) to track WSP progress. The next challenge is then to evaluate these KPIs, which should include systematic verification and validation measures. It is essential to recognize that the evaluation of water supply and the evaluation of WSP are two different things, and a different set of performance indicators is needed for each. WSP targets thus need to be set at two levels: macro-targets (measuring health outcomes and overall performance improvement because of WSP implementation) and micro-targets (measuring improvements in the performance of individual systems and processes from implementing WSP) [33]. Other challenges include: limited staff to develop and implement WSPs; lack of financial aid; lack of supporting policy and regulatory environment; and lack of training and guidance materials (especially in local languages) [28].

3.5. Conclusion of Literature Review

Most of the conventional methods for testing drinking water quality focus on end-point testing to make sure that the drinking water meets the required biological and chemical standards. WSP, however, is more comprehensive and addresses the whole water system from source to the consumer to ensure prevention of contamination at each stage [17,30]. The WSP methodology has built-in structures for improved maintenance policies and procedures, systematic repairs of pipes, a cleaning plan (e.g., regular flushing of fire hydrants and cleaning of reservoir tanks), and regular improvements in the systems (e.g., backflow prevention) [17] (p. 7782).

Implementation of WSPs in Portugal has also shown that independent auditing is valuable for successful operation of WSPs at a national level. All the major stakeholders, such as drinking water suppliers, environmental protection authorities, authorities responsible for maintaining water quality, research and educational institutions, *etc.*, should be engaged in the process from the very beginning. Furthermore, as one author has noted, “A strategic approach for WSP implementation at a national scale will enable legislators and policy makers to better apply a step-by-step phased process for effective risk assessment and risk management in water supply systems, and what this implies for the achievement of sound mechanisms in protecting public health” [39] (p. 115).

Experiences of pathogen related illnesses via drinking water in Australia also led to implementation of WSP approach in that country. It was concluded that the communities cannot just rely on monitoring of end of the pipe water quality, because by then it is usually too late—by the time results come out of the tests consumers have already consumed this water. Implementation of preventive risk-management approach such as WSP is more reliable from the perspective of public health [40]. We recommend this approach for our case study, Toledo.

4. Applying the Water Safety Plan to the Toledo Case to Avoid Future Water Crisis

Based on the discussion in Section 3 on the success of WSP in reducing the incidence of microbiological contamination, the authors recommend that WSP should be applied to Toledo to avoid future crises. The WHO guidelines for drinking water quality [41] list three main sections of the WSP as follows:

(1) System assessment: This involves documenting the components of the entire water system from source to the consumer. This will aid in the determination of the ability of the system to meet set health based standards and the identification of points that are vulnerable to potential contamination. This leads to identification of corrective actions to mitigate these risks.
(2) Operational Control Measures: This section enhances risk management through developing of operational control measures and concomitant monitoring procedures to assess effectiveness.
(3) Management and Communication Plans: This is the documentation of all sections of the water safety plan, including system assessment, operational monitoring and verification procedures. This would also include actions to be taken to optimize routine operations and also emergency procedures.

These three parts are elaborated in 11 modules, each of which will be applied to the case study of the Toledo "do not drink" water advisory in the manner of a gap analysis.

4.1. Assembling the Team

The first step in the water safety planning process is the establishment of an expert team to develop the water safety plan, implement it and assess and make changes in an adaptive manner. Due to the nature of these roles, it is imperative that these persons have combined expertise in the water system from catchment to consumer, and would include expertise such as environmental protectors, regulatory agencies, health specialists, utility managers, process treatment specialists, laboratory personnel, financing agents, administrative personnel, private sector representatives and non-governmental organizations. In the case of the Toledo water crisis, there is already an established working relationship between the Ohio Environmental Protection Agency, the Ohio Department of Natural Resources and the Ohio Department of Health formed during the development of the State of Ohio Harmful Algal Bloom Response Strategy [42]. However, this team does not have the expertise in drinking water abstraction, treatment and distribution. As such, it could be expanded to include professionals from the Collins Water Treatment Plant, from the City of Toledo, from private sector organizations (possible polluters and innovators) and from local non-governmental organizations with expertise in pollution mitigation and with close contact with stakeholders.

This group should also have the political authority to facilitate implementation of the recommendations emanating from the water safety planning process. To this end, it is recommended that senior officials from the relevant agencies be a part of the Water Safety Plan steering committee. In an event such as the Toledo "do not drink" water crisis, there would have been an established communication structure in place and trust amongst these individuals, leading to a more rapid action. However, with the implementation of the WSP approach, microcystin levels would not have been elevated to the extent that they were, as the contamination would have been mitigated through risk management. The engagement of senior officials in the process would facilitate tasks that require senior decision making, such as the development and implementation of standards for cyanotoxins in drinking water, developing regulatory measures and providing necessary resources for these actions. Key actions that this team would take include the appointment of a team leader, identifying the skills and personnel needed to be on the team, deciding on the scope of the water safety plan and the time frame for development, developing terms of reference for the team (norms, *etc.*), developing stakeholder engagement strategies and finally, the development and implementation of the water safety plan. For the Toledo water safety planning team, one key challenge would include organizing the workload of the team to fit in with the existing organizational structures and roles. This challenge can be mitigated by recognizing the importance of the process and incorporating the roles into daily workloads.

4.2. Describe the Water Supply System

This step involves a thorough mapping of the water supply system from source to the consumer. It usually consists of a detailed flow diagram that is validated through on-site checking and should be an almost exact representation of the system to allow the identification of vulnerable points in the system. It should provide information on where the system is vulnerable to hazardous events, types of hazardous events and control measures. For the Toledo case, the water supply system description would describe the water quality standard (or lack of it), the source water of Lake Erie and an alternative source in case of the pollution incident (or point out that there is no viable alternative source for the treatment plant), potential changes in water quality due to algal blooms in Lake Erie, details of land use in the catchment area such as farming practices, details of weather conditions and their impact on land use activities, the point in Lake Erie from which water is abstracted, details on the storage of water, details on the treatment plant processes including the chemicals that are used and the capability/limitation of the treatment system and the vulnerability of the system, the details of the distribution system, including storage in the network and tankers, identification of the end users of the Collins Water Treatment plant, availability of trained staff and how well existing procedures are documented. During the Toledo water crisis, there was a lack of agreed upon standards for testing of the water for cyanotoxins, there was no back-up plan for alternative water sources for the treatment plant and treatment plant vulnerability and control measures were not thoroughly thought through and documented. It should be relatively easy to document the treatment process of the Collins water treatment plant as the plant is fully automated and has an existing flow diagram. Documenting the distribution system, however, might prove a challenge due to the age and extent of the system.

4.3. Identify Hazards and Hazardous Events and Assess the Risks

This process involves the identification of the potential biological, physical and chemical hazards in each step of the flow diagram that can impact the safety of the drinking water supply; it identifies all hazards or events that can result in the water supply being or becoming contaminated, compromised or interrupted. For the Toledo case study, this can take the form of a quantitative or semi-quantitative approach. A quantitative approach could involve investigation of the likelihood/frequency and the severity/consequence of contaminated, compromised, or interrupted supplies. A qualitative approach might be based on the expert judgment of the water safety plan steering committee. For Toledo, this step would identify hazardous events such as agricultural contaminant loads, heavy precipitation leading to hazards such as microbial contamination, phosphorus enrichment of the water, and algal blooms. The most important consideration is the impact on public health, but other factors such as continuity, aesthetics, adequacy of supplies and utility reputation should be considered. Another hazardous event would be the capacity of the treatment plant (lack of capacity due to age) leading to inadequate treatment for toxins such as microcystin. One of the most critical threats to the Toledo system is institutional, including lack of operator training (as a trained operator would know that source water quality needs to be monitored to optimize the treatment process), a lack of system accountability to ensure routine monitoring of the source water quality, and a lack of standard operating procedures for source water monitoring.

4.4. Determine and Validate Control Measures, Reassess and Prioritize the Risks

This step occurs concurrently with the previous step of identifying hazardous events, hazards and identifies risks. The Water Safety Plan team would document existing and potential control measures aimed at reducing or mitigating the identified risks. The validation steps should also be documented. Validation of control measures is the process of obtaining evidence on their performance. Operational monitoring would show that a validated control continues to function. For the Toledo Case study, this step would involve the prioritization of risks in terms of their impact on the likelihood of the system to supply safe water. In the case of Toledo, the hazardous event could be the presence of the cyanotoxin hazard from contaminated source water. One control measure could be protection of the catchment through implementation of agricultural best management practices. The critical limit to trigger action would be any non-permitted development or activity in catchment.

One of the challenges to the Toledo case study would be uncertainty in estimating the effectiveness and value of some catchment and treatment controls. For example, there would be difficulty with measuring and enforcing the permitted land use in the Lake Erie watershed due to the vastness of the watershed and the large number of farmers in the watershed. There would also be difficulty in having confidence in the effectiveness of the control measures. For example, there is still a great deal of uncertainty as to the operational effectiveness of best management practices, even if they were used as a control measure for agriculture. One of the likely findings of the WSP team in the Toledo case would be that standards and protocols are not always carried out as indicated or might be inadequate. The State of Ohio Harmful Algal bloom response strategy for freshwater [42] had a documented sampling strategy, yet during the Toledo water crisis there was disagreement amongst the agencies on the sampling protocol [12]. The review of current systems operations that are incorporated in the WSP process would be useful in understanding the effectiveness of practices and control measures.

4.5. Develop, Implement and Maintain an Improvement/Upgrade Plan

The Toledo water crisis demonstrates that control measures are not working to assure water safety. This step calls for an improvement plan, with the aim of reducing risks and improving control measures. Since the Collins water treatment plant is dated to 1940, the plant may be in need of an upgrade to deal with surprises such as spikes in microcystin in the source water. There is a time lag between the action to treat a contaminant at the plant and the impacts of that action in finished water. This plant is also sole-source dependent, so an upgrade plan for this might include investigation of alternative sources of water or backup storage. An improvement plan would also include standards for cyanotoxins in water and a standard testing protocol with all the key partners. This plan would also indicate who is accountable for what action and set out expectations about timelines and cost sharing.

4.6. Define Monitoring of the Control Measures

This step calls for the multidisciplinary WSP team to define and validate the monitoring of control measures, including the corrective actions to be taken when targets are not met. A corrective action in response to the lack of monitoring of source water quality would have been introduction of a monitoring program in the Collins water treatment plant. This would have allowed proactive treatment through the plant and would have significantly reduced the likelihood of microcystin contaminated finished water. This step allows for a corrective action for each control if monitoring shows that the critical limit is being exceeded and thus could compromise final water safety. This step would also reiterate the need for standards for cyanotoxins in drinking water.

4.7. Verify the Effectiveness of the WSP

This step involves auditing the WSP to ensure that it is working effectively. For the Toledo case study, a third party auditor such as a representative from the Ministry of Health or the Environmental Protection Agency would have been able to easily check the plan against the actual operations. An audit can also verify that customers are satisfied with the water supplied to them.

4.8. Prepare Management Procedures

This step requires documentation of management procedures under normal operating conditions and under incident conditions. This would ensure that practices are based on best available knowledge and that there is consistency in operation regardless of the person attending to the plant. Standard operating procedures (SOPs) can be documented for the monitoring of treatment plant operations, for the operator hand-over of shift protocol, for dealing with an incident, for equipment operation, for dealing with heavy pollution in raw water and for reporting and recording of information. Since the EPA found the testing protocol "questionable" [12], it can be inferred that there was also no robust management procedure for monitoring source water quality to optimize the treatment process.

4.9. Develop Supporting Programs

Supporting programs ensure that there is commitment to the water safety plan and build capacity to execute the water safety plan. Supporting programs for the Toledo case study that would have mitigated the risk of contaminated finished water would include the required training of plant operators, research on treatment plant optimization and processes to remove microcystin. Training could also have resulted in a standardized protocol sample collection and analysis of water samples. There could also be awareness training so that all personnel understand the impacts of their actions on drinking water safety. Supporting programs for Toledo could include stakeholder workshops to educate farmers on the impact of their practices and discussions on how best management practices can improve water quality while ensuring farmers' productivity.

4.10. Plan and Carry Out Periodic Review of the Water Safety Plan

This stage of the WSP process ensures the team keeps in regular contact and regular communication to review the progress of the WSP and discusses new hazardous events and risks. It also facilitates capacity building initiatives, secures funding and facilitates smooth transitions through staff changes for continuity of the WSP. Having this step in the Toledo case would have facilitated smoother communication and more rapid and coordinated responses during the Toledo "do not drink" water advisory.

4.11. Revise the Water Safety Plan Following an Incident

This step is designed to invoke changes following the "do not drink" water advisory in Toledo. It would have led to revision of the WSP once standards were developed and agreed upon for cyanotoxins in water and would have also led to the development of SOPs for the monitoring of source water and for response to elevated levels of contaminants in source water.

5. Discussion

Drinking water can be contaminated by both microbial and chemical pollutants and thus impact human health [40]. Public health authorities generally require testing and monitoring of drinking water quality at the point of distribution, but this rarely prevents outbreaks [38]. This can be attributed to the fact that by the time something is detected at the source, customers have already consumed contaminated water. Water monitoring programs also lack predictive values to real world situations thus the results need to be interpreted with caution [43]. Most traditional water surveillance systems are retrospective and reactive. A robust and proactive water quality monitoring system is needed to provide early warning of contamination outbreaks, including a preventive risk-management approach [40]. WSP responds to this need. As shown in the examples above in the German hospital case study and in Australia, implementation of WSP has reduced the risk of contamination incidences. We recommend such an approach for Toledo as well. The 11 elements or modules recommended above mirror the approach recommended in Australia, triggered by microbiological contamination in Sydney in 1998 [40]. It moves away from reliance on point-of-distribution testing of water quality and instead emphasizes early identification and correction of issues, reducing the likelihood of contamination and water consumption advisories. The framework also requires an incident and emergency response protocol and a communication plan for consumers. WSP emphasizes the protection of source water, implying the need for government to take proactive steps to link land-use (especially non-point sources of pollution) to water quality impairment.

In the Toledo case, state, provincial and federal governments in the Great Lakes should develop and implement policies and plans to prevent the pollution Great Lakes waters as a drinking water source. This would include nutrient pollution leading to eutrophication. Although it is admittedly more difficult to manage non-point source pollution than point sources, risk management approaches adopted under WSP could help governments become more proactive in their response to drinking water impairment.

The discussion now follows two strands: how does WSP compare with federal drinking water legislation? And how would reframing the issue of eutrophication and adoption of WSP help reduce waterborne outbreaks?

5.1. Comparison of WSP with Federal Drinking Water Legislation

As shown by Baum *et al.* [13], WSP will add value to federal drinking water legislation, such as the US Safe Drinking Water Act (SDWA). The comparison done by Baum *et al.* [13] clearly shows that the focus of the U.S. regulations is on setting national standards for maximum contaminant levels, best treatment processes, and best available technologies for contaminant reduction, by which each utility determines the safety of their water through the detection of pathogens and toxins in treated water. The problem with this process is that by the time these contaminant levels have been detected, contaminated water may have already been distributed and customers exposed to risks caused by the contaminant, as has been seen in the case of Toledo. However, implementation of WSPs provides an additional focus on prevention of contamination, so that water is not supplied before it is tested. The difference in focus between US drinking water regulations and WSPs can be seen in three main steps or areas: internal risk assessment and prioritization; management procedures and plans; and team procedures and training. Based on 28 drinking water related outbreaks between 2009–2010, five factors have been identified as leading contributors to outbreaks: back flow from cross-connection, corrosion and aging of pipes or storage tanks, distribution monitoring and maintenance failures, lack of treatment and disinfection, and source water contamination [13]. All of these factors would have been eliminated by the adoption of a WSP approach. As recommended by Baum *et al.* [13], one of the changes that the US SDWA needs is a more tailor-made, local approach such as is provided through WSP. This means that instead of attempting to control the risks (and regulating them) at the national level (regardless of their differences in size, location or water source), specific issues and risks should be regulated locally. Just as in the case of WSP, local identification and regulation of risks and issues gives a sense of ownership. It also improves understanding of local risks and aid prioritization of risks for each water system. Issues such as backflow and contamination from cross-connections are preventable using the WSP approach. For example, step 3 of the WSP includes the identification of hazards such as cross-connection. In this step, control measures would be identified, developed and monitored. Although the SDWA requires operators to know the system risks, it does not require specific systems risk analysis or prioritization of risks. Similarly, infrastructure updates (aging and corrosion of pipes), distribution maintenance (low pressure or failure to flush the system) and monitoring are not fully regulated under current US legislation but will require better procedures and monitoring under WSPs. WSPs would also require SOPs to cover "response actions, operational monitoring, responsibilities of the water system, communication protocols and strategies, emergency situation responsibilities, and review and revision of plans" [13] (p. 7). While SDWA requires certified water operators it does not require such detailed SOPs, the review or update of the system, or revision of existing practices [13].

WSP requires staff to have a thorough understanding of the entire water supply system, from the source to the point water reaches the consumers. This increases the responsibility of individual employees to understand the treatment and distribution system and associated procedures. WSP also adds training, research, development, and preventive maintenance in addition to daily operations for individuals. This stands in contrast to the SDWA, which requires recertification but do not require the other supporting programs [13].

It must be recognized that the regulatory-based, reactive approach to water quality risk management has substantially reduced waterborne disease risk over the last several decades. On the other hand, management of system-specific risks via a preventive approach (WSP) could reduce the risk of waterborne diseases even further. An incentive-based system that encourages specific water systems to identify and control their specific risks could promote a preventive approach to reduce waterborne outbreaks and related diseases. Implementation and adoption of WSPs could be an important mechanism to reduce future water-borne diseases. However, given the current focus on regulatory controls in the US, and the time and resources needed for WSP, it may be more realistic to expect adoption of WSPs if they are required under the law [13].

5.2. Reframing Eutrophication Governance through the Lens of Public Health Using WSP

Many North American cities along the Great Lakes shoreline depend on water from the lakes, and eutrophication of the water leads to contamination of drinking water and a potential health crisis, as demonstrated in the Toledo case study. Reconsidering governance through the lens of a WSP approach would reframe the eutrophication issue by showing it is not just an environmental issue, but one that also affects our health and as such, needs focused attention and priority. It also places more responsibility on agencies like the US Environment Protection Agency and Environment Canada/Health Canada to develop better standards for toxins in the Great Lakes. Further, proactive source water protection will require government to work more with land-based activities, especially urban and agricultural systems.

One of the sources of eutrophication in the Great Lakes is manure from farmlands. Agricultural operations have intensified across the region over the past several decades, with concomitant increases in fertilizer and manure input. However, there are few regulatory controls to deal with this issue, unlike the point source controls on nutrients (such as the phosphorus ban in detergents) in the 1960s and 1970s. The US federal Clean Water Act regulates large Confined Animal Feeding Operations, but not drainage from the vast area of cropland across the Great Lakes basin that is believed to be a major source of current nutrient loadings into the Great Lakes [44]. As discussed by Pralle [4], issue redefinition and venue shopping are key strategies for enacting agenda and policy change. Issue redefinition not only involves change in the image of an issue but also the bases for considering these issues. For the purposes of this paper and case study, it would mean that the problem of eutrophication needs to be reframed with a lens of human health (and risks defined under a WSP framework) by showing that the health of source water (in this case, from Lake Erie) directly impacts human health. It can be argued that farming is linked to the breadbasket and food security of the region, which is as difficult to regulate as the non-point source pollution. Some steps have nevertheless been taken in partnership with farmers to resolve this issue. This includes simple steps such as engaging farmers on the linkages between source water and human health, but also the development of innovative methods to use in agriculture. For example, Fox P Trade, a Great Lakes Commission (GLC)-led project with funding from the US Department of Agriculture's Natural Resources Conservation Service (NRCS), is adopting and applying water quality trading principles to help alleviate high nutrient levels in the lower Fox River

(Wisconsin) watershed. Another NRCS-funded partnership with the GLC is creating demonstration farms in the Fox River watershed, places where innovative agriculture practices can be tested, monitored and showcased [44].

In addition to developing and implementing innovative agricultural practices to deal with eutrophication, some proactive policy initiatives are also needed. As recommended by the International Joint Commission (IJC)'s Lake Erie Ecosystem Priority (LEEP) [45] report, the policies can be grouped under four main categories:

(1) Setting phosphorus reduction targets for Lake Erie;
(2) Reducing phosphorus loading into Lake Erie from agricultural sources and septic systems;
(3) Reducing phosphorus loading into Lake Erie from urban sources; and
(4) Strengthening monitoring and research in the Lake Erie basin.

As pointed out by the IJC report [45] (p. 9):

…the IJC recommends that governments throughout the watershed refocus agri-environmental management programs to explicitly address DRP [dissolved reactive phosphorus]. This includes an emphasis on best management practices (BMPs) most likely to reduce DRP, such as improving the rate, timing, location and form of phosphorus applied to fields, and reducing *runoff* from those fields. Such nutrient management initiatives should focus on reducing the load delivered during the spring period and on priority sub-watersheds that are delivering the most phosphorus to the lake. The IJC also recommends that governments increase the scale and intensity of BMP programs that have been shown to reduce nutrient runoff, while strengthening and increasing the use of regulatory mechanisms including linking crop insurance with conservation performance. And to address a concern raised repeatedly by the public regarding the health of Lake Erie, the Commission recommends that Ontario, Michigan, New York, Ohio, Pennsylvania and Indiana ban the application of manure, biosolids and commercial fertilizer containing phosphorus on frozen ground or ground covered by snow.

5.3. Using the WSP Approach to Achieve Water Governance Goals

The Water Safety Planning process is designed to be a multi-stakeholder collaborative process to effectively identify risks and management plans to mitigate those risks from catchment to consumer. The expert team required for this process includes a diversity of stakeholders such as experts in environmental protection, from regulatory agencies, health specialists, utility mangers, laboratory personnel, private sector representatives and non-governmental organizations. This multi-stakeholder collaboration characteristic of the Water safety planning process makes it compatible with other water governance models. For example, Integrated Water Resources Management (IWRM) provides a governance platform that allows for multiple-actor decision-making processes at watershed scales. Adaptive management (AM) paradigms enable decision-making in the face of uncertainty where policy is shaped through continuous feedback loops that create "systemic experimentation and learning". AM thus has an inherently self-organizing ability [8]. Schoeman *et al.* [46] adds a third governance arrangement, Ecosystem-based Approach (EBA), which provides adaptation to climate change while attempting to minimize the risk. To realize the outcomes of IWRM, a WSP framework is important as it facilitates multi-stakeholder collaboration to protect the water from source to consumer. To help attain proposed phosphorus targets, a governance model as proposed by the IJC [45] envisions the USEPA working with the governments of Michigan, Ohio and Indiana to develop a tri-state phosphorus total maximum daily load (TMDL) targets for the western Lake Erie Basin. Since Ontario does not have this mechanism, collaborative decision making under the Great Lakes Water Quality Agreement urges their involvement in target setting. The measures would take into account all significant sources of phosphorus loadings and allocate specific reductions of phosphorus according to relative contributions from point and non-point sources. Clearly, an issue of this magnitude goes beyond the responsibility of one jurisdiction for response. All of this can be linked to WSP framework in identifying risks and hazards to the water system and how to improve and monitor it.

We conclude that by utilizing the water safety planning approach, the city of Toledo could have significantly reduced the risks to the provision of safe water to residents and could have averted the crisis on 2 August 2014. The Waters Safety plan (WSP) approach would have resulted in the monitoring of the source water, which would have identified the elevated levels of microcystin in the source water and lead to operational adjustments to assure the final drinking water quality. These steps would have been detailed as part of the standard operating procedures (SOP) included in the "Management and Communication" step of the WSP (Figure 2). The systematic application of the WSP process to the city of Toledo reveals significant gaps, including the lack of a multi-stakeholder team representing key personnel along the entire process from source water to consumer. Other findings of this assessment are shown in Figure 2. The WSP approach is relevant to municipalities throughout the Great Lakes and beyond. This approach can also inform other areas with similar water quality impairment problems, such as Pelee Island [47] and the Carroll water treatment system in Ohio, US [16] and Pelee Island in Windsor-Essex County, Canada [47]. In September 2013 the Carroll water treatment plant was shut down due to elevated levels of microcystin in the treated water (3.8 ppb) resulting from elevated levels of microcystin in the Lake Erie source water (50 ppb) [16]; a year later in September 2014 the Windsor-Essex County Medical Health Officer issued a water ban to residents of Pelee Island for one week due to elevated levels of microcystin in the water [47].

6. Conclusions

The water safety planning (WSP) process can be a useful tool to assure the safety of drinking water supplies. This paper has shown that if this process had been used for the Collins Water Treatment system in Toledo, Ohio, it would have averted a water crisis situation by mitigating risks associated with hazardous events such as unmonitored source water, increased algal blooms, increased microcystin concentrations in source water, and lack of treatment capacity to remove contaminants. It would also have resulted in operator training that in turn would have encouraged independent thinking and improved the ability of the operator to suggest process and operational improvements, Identifying and evaluating risk at the local level (as compared to national standards) encourages local operational staff to take responsibility for prevention of waterborne disease outbreaks.

In addition, re-framing the problem of eutrophication in a new way to tell a new story with linkages to health might lead to more effective governance. If we shift the focus of the problem from solely protecting the environment to protecting our own health, and regulate from a public health standpoint (through WSP), we broaden and strengthen the framework for eutrophication governance.

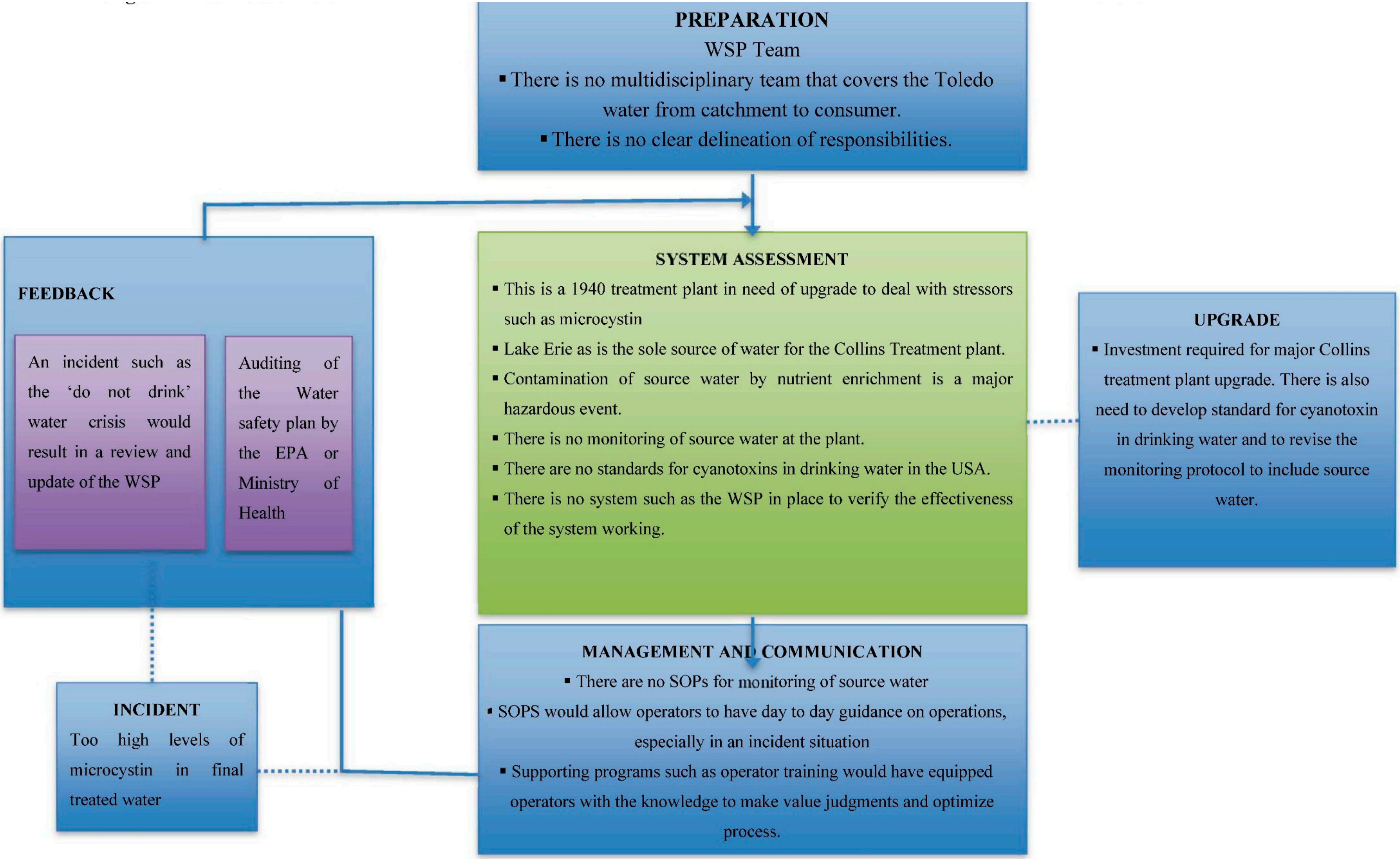

Figure 2. WSP assessment of Toledo water crisis.

The adaptive (co-) management literature contains four institutional prescriptions: collaboration in a polycentric governance system, public participation, an experimental approach to resource management, and management at the bioregional scale. These prescriptions largely resonate with the theoretical and empirical insights embedded in the (water) governance literature [48]. However, this literature also predicts various problems. In particular, this case study demonstrates the need to overcome complexities associated with participation and collaboration, and de-politicizing discussion on governance at the regional scale. The Systematic application of the steps of the water safety planning process requires a multi-stakeholder team representing key personnel along the entire process from source water to consumer. This methodological approach is relevant to the Great Lakes bioregion, and has implications for municipalities and other stakeholders and orders of government.

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Author Contributions

Savitri Jetoo conceptualized this research and is the main author of this paper. She assessed the Toledo water crisis from a WSP perspective and made all changes to reviewers' comments. Velma Grover contributed to the paper through the literature review and initial editing while Gail Krantzberg provided oversight of the research and edited the paper and made additions on Great Lakes governance. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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