

Demonstration of the Health Canada Quantitative Microbial Risk Assessment Tool for Two Drinking Water Plants in the United Kingdom

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Key Findings

- The Health Canada tool is well-suited for use in risk assessment and water safety planning for the studied WTWs.
- Routine pathogen monitoring would not improve risk estimation significantly at either plant, though monitoring for other purposes could provide benefits.
- Monthly average process data predicted risks similar to those predicted with daily process data, indicating that the tool framework produces reliable risk estimates.
- The tool allowed for relatively easy assessment of failure scenarios and produced outputs describing important risk features such as the risk-driving pathogen and the relative contributions of physical removal and chemical disinfection for *Giardia* control.

OVERVIEW

The drinking water laws for water suppliers in England, Wales, and Scotland require risk assessments of treatment works and connected supply (distribution) systems, as well as continuous review and upkeep of the risk assessment. Risk analysis, as required for water suppliers, is a significant undertaking involving data collection, quantitative analysis, and risk characterization. This study demonstrates use of the spreadsheet-based Health Canada quantitative microbial risk assessment (QMRA, Health Canada 2014) tool for analysis of two water treatment works (WTWs) in the UK. The tool was designed for users with and without specialized training in risk analysis and for overcoming the significant challenges associated with risk analysis of complex WTWs. Application of the tool to the WTWs required analysis of processes not currently part of the tool and resulted in recommendations for future tool development.

Objectives

The objectives of this study were to:

- Demonstrate application of the Health Canada tool for analysis of two drinking water treatment plants
- Research treatment processes not currently part of the tool (but in use at the WTWs), and make recommendations for including them in the tool

Background

In the UK, risk assessments are conducted using a water safety plan (WSP) approach and contain the following elements:

- Documentation of potential hazards or hazardous events in the catchment area, during treatment, within the distribution system, and within building plumbing systems
- Characterization of risk for each hazard and hazardous event using a scoring system based on likelihood and consequence criteria both before and after taking account of existing permanent control measures

The benefits of the water safety planning and risk assessment approach are multifold and include identifying and mitigating risks and, prior to events, the opportunity to assess the adequacy of barriers in place in the overall treatment works context, an opportunity to weigh competing risks against each other, and a framework for prioritizing risk management activities.

The Health Canada tool produces site-specific risk estimates through use of site-specific raw water pathogen concentration data (when available), process water quality and operations data (contact time, disinfectant type and dose, temperature, pH) for estimation of inactivation by disinfection, and characterization of physical removal for estimation of pathogen removal. As a spreadsheet tool, the Health Canada tool can be used by most water treatment professionals. The tool facilitates analysis by providing data that are difficult for many practitioners to obtain, such as microbial dose-response parameters and default estimates for unit process operation log removals. The tool's accessibility promotes meaningful risk assessment and reduces dependence on external experts and expert judgment when developing and refining WSPs.

Approach

Effective use of the Health Canada tool is a multi-step process. Those steps are:

- Conducting an engineering assessment to identify specific microbial hazards for a source water, to collect process data, and to develop an understanding of the way microbial risks are managed at a given plant
- Characterization of source water pathogen concentrations, either based on pathogen monitoring or use of default pathogen concentration estimates

- QMRA analyses and risk characterization

These steps were undertaken and documented for the WTWs assessed in this study. Engineering assessment reports generated QMRA model inputs and allowed project staff to develop a comprehensive view of microbial risk management at the WTWs. In our experience, a systematic engineering assessment frequently is as valuable as, if not more valuable than, risk calculations. Data collected in the engineering assessments, along with historic source water monitoring data, were used as inputs to the Health Canada tool. QMRA analyses conducted for the WTWs explored the adequacy of treatment barriers under normal operating conditions and under failure conditions such as reduced disinfectant dosing or failure of individual unit operations. Simulations were conducted at daily and monthly timescales to determine the temporal variability in risk (consistency in performance) of the WTWs and to determine whether monthly average process data allowed sufficiently accurate characterization of risk for the WTWs.

Results/Conclusions

Engineering analyses of the WTWs identified livestock operations as important potential pathogen sources for both WTWs, and treated wastewater effluent as a potential source for one WTW. The WTWs employ multiple processes for reduction of bacteria, viruses, and *Giardia*, and rely on coagulation, dissolved air flotation (DAF), and filtration for *Cryptosporidium* control. The WTWs employ several processes not specifically addressed in the Health Canada tool – DAF, filter backwash recycle (FBR), and secondary filtration in manganese contactors.

Three sets of QMRA analyses were done for the WTWs. First, reverse QMRAs (determination of source water pathogen concentration for a given level of finished water risk) were used to determine the source water concentrations that would pose a risk above a benchmark health level and to assess the value of routine pathogen monitoring for refining risk estimates. For both WTWs, the level of treatment is high enough that even high concentrations of pathogens (relative to historic concentrations) in the source water do not pose a significant risk. Limited additional (beyond ongoing routine monitoring) source water pathogen monitoring would be unlikely to yield significant benefits in improved risk analysis. This finding does not imply that pathogen monitoring would yield no benefit for purposes other than developing input to, and refinement of, the Health Canada tool. For example, genotyping *Cryptosporidium* and *Giardia*, microbial source tracking, capturing event concentrations of pathogens, or ongoing surveillance for changes in pathogen occurrence at the WTWs would all be beneficial for purposes such as improved source water characterization and hazard identification.

The second set of QMRA analyses was the assessment of risk under normal plant operating conditions. Risks were estimated using both monthly-averaged and daily-averaged process data. Outcomes of monthly and daily analyses were similar, indicating that monthly-averaged process data are adequate as model inputs for these WTWs. Analyses for routine plant operation indicate that *Cryptosporidium* risk predominates for both WTWs, followed by *Giardia*. Bacteria and virus removals are so high (and risks so low) under normal operations at the WTWs that they exceed the maximum that can be reliably estimated by the Health Canada tool.

The third set of analyses involved assessment of the impact of failure of different processes on overall risk. Physical treatment failures (coagulation or clarification failures) would have lower short-term impacts on risk than chemical disinfection failures. However, physical treatment failures have the potential to become progressively worse given the practice of FBR. Failure of coagulation would have a much higher short-term impact on protozoa risks than failure of clarification. Complete failure of primary chlorination would have a profound impact on risk for one of the WTWs and a significant impact at the other. Given the importance of chlorine for control of bacteria and viruses, QMRA indicates that focusing on disinfection process control and reliability is a better route to risk management than maintaining high disinfectant concentration relative to that required for maintaining risks below a 10^{-6} DALY (disability adjusted life year)/year benchmark.

A literature review on performance of DAF indicates that removal via well-designed and well-operated DAF processes is higher than that from equivalent sedimentation processes. This finding is tempered by the small number of studies available for comparing the two processes and by the high variability in removal reported within and between studies. FBR has a net effect of reducing overall removal for coagulation-clarification-filtration. However, FBR also has the potential to cause a build-up of pathogens in the process water, particularly if clarification processes underperform. The literature generally supports assigning a log removal of 0.5 for secondary filtration processes such as manganese contactors. Because no studies have been done on removal in manganese contactors, it cannot be predicted whether manganese contactor removal would differ significantly from that of other secondary granular filtration processes. A general finding of the literature review on DAF, FBR, granular activated carbon (GAC), and manganese contactors is that estimates of their performance are based on few studies, many of which were conducted prior to widespread adoption of practices like enhanced coagulation.

Applications/Recommendations

WTWs Recommendations

Both WTWs manage microbial risks consistently and with a high margin for error. That high margin for error provides an opportunity to explore strategies for managing competing risks, such as disinfection byproduct (DBP) risks. Analyses with the Health Canada tool and a similar tool for predicting DBP formation could be done in parallel in an attempt to balance the risks and reduce health risks from all hazards (microbiological and chemical). Such analyses are complex, since chemical disinfection and other processes are in place for multiple purposes and because of the need to maintain multiple barriers to microbial breakthrough. Routine pathogen monitoring would not improve risk estimation significantly at either plant, though monitoring for other purposes could provide benefits.

Health Canada Tool Recommendations

The research team found that the Health Canada tool is well suited for use in risk assessment and water safety planning for the studied WTWs. Monthly average process data predicted risks similar to those predicted with daily process data, indicating that the tool framework (developed for accessibility to practitioners without specific risk analysis and computer programming training) produces reliable risk estimates. The tool allowed for relatively easy assessment of failure scenarios and produced outputs describing important risk features, such as the risk-driving pathogen and the relative contributions of physical removal and chemical disinfection for *Giardia* control. While the Health Canada tool can accommodate DAF, FBR, and second-stage filtration through user input selected process values, the research team recommends explicit addition of those processes to the tool for use by engineers at other WTWs.

Research and Modeling Recommendations

Given the importance of unit process removal estimates on plant designs and water regulation, the research team advocates renewed research on process performance to update and supplement available data. Studies on DAF indicate better performance than equivalent sedimentation processes, though removal estimates differ widely among studies, and the difference in performance between the processes is likely to depend on specific process designs and operation. FBR has a net effect of reducing the log reduction from a coagulation-clarification-filtration process, since pathogens retained on filters are returned to process water and given additional chances to break through treatment. Maintaining sufficient clarification is key to avoiding build-up of pathogens in the process water for plants practicing FBR. In the absence of additional process performance data, QMRA analyses can include point estimates for risk over a range of unit operation removals or a more complete sensitivity analysis that quantifies the impact of assumptions of unit operation performance on risk estimates.

Research Partners

Research partners in this study included UK DEFRA and an anonymous UK water supplier. Their contributions to the research and commitment to producing high-quality drinking water are greatly appreciated.

Related WRF Research

- Canadian QMRA Case Studies to Estimate Health Risks of Pathogens in Drinking Water, project #4597
- Using QMRA to Estimate Health Risks of Pathogens in Drinking Water, project #4598