ASSESSING WATERBORNE HEALTH RISKS
THROUGH QUANTITATIVE RISK ASSESSMENT MODELS

PIERRE PAYMENT, CENTRE INRS-INSTITUT ARMAND-FRAPPIER

CANADIAN WATER NETWORK
RÉSEAU CANADIEN DE L'EAU

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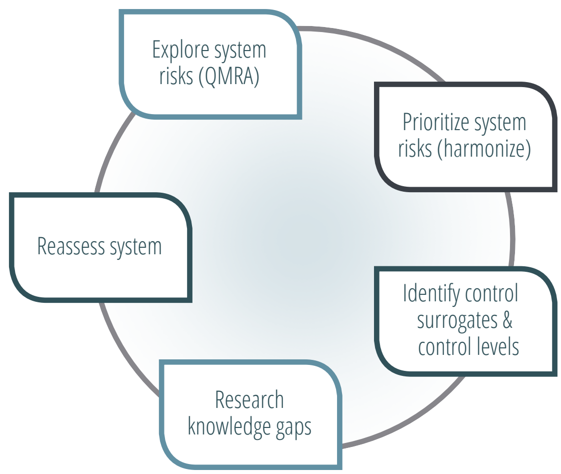
WHY DID WE DO THIS RESEARCH?

In drinking water treatment, a balance must be maintained between the highest microbial safety, while limiting the long term chemical risk from disinfection by-products. To achieve this, Quantitative Microbial Risk Assessment (QMRA) models are used to attain a level of acceptability in engineering and public health. Models for QMRA are being increasingly used internationally by regulatory agencies. The objective of applying these models is to help define when safe is 'safe enough.' It is a systematic and science-based approach to warrant that systems will deliver safe water and efficient safety management. QMRA models are often perceived as a superior approach as they provide a numerical output with, depending on the model used, confidence intervals. However, unfamiliar users may under-appreciate the uncertainty in these risk estimates due to variations in model assumptions or data analysis. There is a need for a better understanding by the intended users (government, managers, decision-makers) of when and how the models can and should be used. In Canada, Health Canada is promoting the use of a QMRA model by water utilities to assess their systems. Risk models have been used mostly in two contexts: to define environmental regulations on water or to assist water utilities in discriminating between various scenarios of improved water treatment investments. Two main issues were addressed by the project: how can QMRA risk estimates be improved or validated and how can user-friendly QMRA models be deployed in Canada. The goals of this project were to gain a better understanding of: 1) the limitations of QMRA models in terms of microbiology, process engineering, statistical analysis and epidemiology, and 2) interpretation and use of QMRA models. To that end; this project was aimed at: 1) Linking Canadian researchers and utilities with international experts on QMRA; 2) Providing stakeholders a better understanding of the process; 3) Improving the conceptual model for decision-making; 4) Establishing appropriate goals to drive management or technology solutions/decisions.

QMRA WITHIN RISK MANAGEMENT



QMRA FOR MUNICIPALITIES

If models are too conservative, additional treatment will be prescribed resulting in capital overspending and unnecessary long-term operation costs in the order of millions of dollars for large drinking water treatment plants. If models are not conservative enough, public health may not be adequately protected with potentially serious consequences such as waterborne outbreaks. In addition, QMRA models may differ greatly depending on key decisions such as the target organisms or dose-response parameters. A consensus approach is needed for expanding the use of QMRA in Canada. All stakeholders (water suppliers, regulators, health authorities, risk assessment scientists) must be involved in reviewing the applicability of QMRA models to support risk management.

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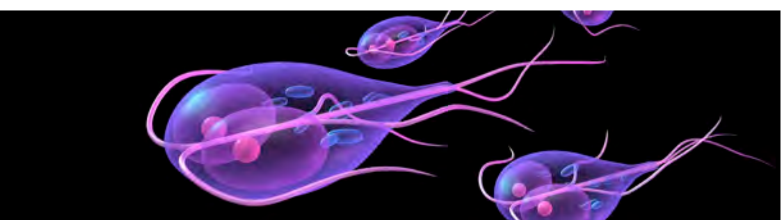
WHAT DID WE DO?

Several research groups were involved in this project to address key issues. A first group at INRS, acting as leader, provided microbiological expertise and support to collect data from selected water utilities with microbiologically challenged raw water. Sampling involved concentrating human enteric viruses and protozoan parasites (Giardia cysts and Cryptosporidium oocysts) from volumes of water ranging from 100 to over 1000 liters. Virus analysis was performed at Institut national de la recherche scientifique (INRS) while parasites were processed at the British Columbia Centre for Disease Control (BCCDC) in Vancouver. The objective was to validate the key treatment modules of QMRA models by pilot and full-scale plant investigations of pathogen and indicator removals. QMRA was also used to assess recreational risks associated with the Montreal wastewater plant and to select an appropriate disinfection method that satisfies both environmental and health criteria.

A group of epidemiologists at Laval University (Québec City), studied the relationship between the presence of Giardia in untreated drinking water and the prevalence of gastroenteritis in Québec. The objective was to evaluate the relationship between the incidence of giardiasis and the predicted probability of illness generated by QMRA models. Could a QMRA model predict the occurrence of giardiasis in drinking water consumers, and if so, does the model have a detection limit? Preliminary results from the QMRA model do not appear to correlate with disease outcomes. This was expected because the models do not accurately predict disease and because reported cases are only a small proportion of infected individuals.

At the University of Waterloo, researchers developed statistical frameworks for describing the methodological uncertainty associated with quantifying pathogen concentrations and removals and the risk of pathogen passage through drinking water treatment processes and plants. This research will help improve the QMRA models and refine the calculated risk estimate.

At the School of Public Health of the University of Alberta in Edmonton, researchers studied affinity methods for capture, detection and identification of viable pathogens by molecular and electronic microarray techniques. Pathogens non-detectable by current methods present a special challenge as they are still disease-causing but unaccounted for in risk models. The results can help improve detection methods and have a better estimate of the concentration of viable pathogens to account for in the QMRA models. Another group from this university assessed whether additional disinfection barriers or upgrades were required at Calgary's water treatment plants to address current and future operational and regulatory risks with respect to pathogenic parasites. This will help the regulators in planning their infrastructure management.



INTERPRETATION AND USE OF QMRA MODELS

Collaborations with the National Water Research Institute (NWRI) (Burlington) and the Region of Peel (Ontario) enabled researchers to apply QMRA to source water protection in the Lake Ontario region to assess how actions taken upstream of water treatment plants could reduce risk levels. Results obtained from local samples provided data to establish level of risk at the water treatment plants.

In Montréal, researchers at École Polytechnique de Montréal worked on improving the Health Canada model (source water characterization, CT calculations) and were involved with local water utilities. Using QMRA models, they provided risk estimations for management decisions on upgrading treatment plants. QMRA was also applied to estimate risks of pathogen intrusion in the water distribution system.

CONSIDERING MUNICIPAL APPLICATIONS OF QMRA MODELS

1. QMRA models provide risk estimations, which can inform management decisions for water treatment plants.
2. Actual measurements of indicators and pathogens can be used to resolve model discrepancies and confirm the efficacy of current water treatment processes.

CONSIDERING OPPORTUNITIES TO IMPROVE IMPLEMENTATION OF QMRA

1. Education, training and certification programs for operators are crucial to the effective implementation of QMRA models.
2. Necessity to develop a common language around QMRA and to explore methods for effective communication of information to the public.

CONSIDERING THE LIMITATIONS OF QMRA MODELS

1. QMRA is an ineffective tool for day-to-day operational control/adjustments and performance monitoring.
2. Comparing outputs from different models is difficult due to differing assumptions and limited use of QMRA in Canada;
3. Accurate comparisons between models are currently constrained and further refinement of inactivation models is needed to improve model accuracy.

WHAT DID WE FIND?

QMRA models provide risk estimations. These estimates can be used by water utilities in management decisions on upgrading water and wastewater treatment plants to protect public health from drinking water risks and recreational risks.

LIMITATIONS OF QMRA MODELS

Comparison of inactivation levels predicted by current models has shown large discrepancies between advanced inactivation models (+/- 2 to 4 log). Inactivation models also need to be refined to better predict correct levels of inactivation of pathogens.

Actual measurements of indicators and pathogens can resolve model discrepancies and decrease the uncertainty in the risk predictions from the model.

QMRA is not used widely so it is difficult to compare anything in Canada. In addition, outputs from different models are not comparable due to the various assumptions and the building of the models themselves. The acceptance of the Health Canada model as a tool for Canadian stakeholders will minimize differences in the data generated and will provide more accurate comparisons.

INTERPRETATION AND USE OF QMRA MODELS

The concept of QMRA requires knowledge and understanding of several fields: epidemiology, microbiology, engineering, management and so on. In order to be able to discuss this concept, it is necessary to customize our vocabulary for our audience to make this concept more understandable to various end-users. Users of these models should remain aware that they do not predict actual disease outcomes. They are a tool for management of risks. Conveying the results of these models to the general public remains a communication challenge.

This project provided a number of decision-makers with a better understanding of the concepts driving this model. The Health Canada QMRA model was improved through collaborations with researchers and international experts. Learning how to handle the data for the various parameters of the model benefited all participants.

QMRA is a tool for regulating agencies that have to set levels of action. The impact of QMRA in making decisions on acceptable levels of risk has become extremely important and this project has been clearly endorsed by Federal and Provincial agencies that see in it a source of expertise that they can tap.

Current QMRA models are worthy, but improvements can be made to improve their accuracy. This will be an important step to resolve the dilemma of over or underestimating the risk level in a cost-benefit analysis.

Actual measurements of indicators and pathogens at selected treatment plants can be used to confirm that current water treatment processes can attain the proposed Health Canada objectives.

QMRA models provide risk estimations. These estimates can be used by water utilities in management decisions on upgrading water and wastewater treatment plants to protect public health from drinking water risks and recreational risks.

WHAT DO THESE FINDINGS MEAN FOR MUNICIPALITIES?

LIMITATIONS OF QMRA MODELS

QMRA is currently used as a drinking water management tool in three major areas of application: regulatory constraints development, treatment system design/evaluation and establishment of operational control criteria such as used in the Hazard analysis and critical control points (HACCP) approach. QMRA's roles and capabilities in each of these areas draw upon different aspects and premises of the science and therefore must be clearly established and effectively communicated to end-users.

Most operators have not received adequate technical training and guidance for using QMRA, nor have they been informed about the limitations and uncertainty associated with the model outputs.

Education concerning the appropriate use and assumptions of QMRA models varies substantially – this is highlighted by the appreciable differences in outcomes of the same QMRA model by different users. Most operators have not received adequate technical training and guidance for using QMRA, nor have they been informed about the limitations and uncertainty associated with the model outputs. A training and/or certification framework (similar to the Leadership in Energy and Environmental Design (LEED) program), standardization of data set requirements and/or models were suggested as effective means to administer widespread, coordinated QMRA implementation. Upon successful application of the QMRA model, the output must be effectively communicated to all users and stakeholders.

UNDERSTANDING AND APPLYING QMRA

A workshop was organized to discuss the application of QMRA and some of the gaps for its use. The participants were from various areas, including the municipal sector, provincial and federal regulatory agencies, researchers, engineers and many others. The outcome of that workshop provided the different levels of end-users with a better understanding of QMRA and its applications. The following are some of the key messages that were identified during this workshop.

In the regulatory context, QMRA has been used to determine the potential health risk of consumers to waterborne pathogens based on source water concentrations after barrier/reduction/treatment estimates have been applied according to its end use. QMRA provides a framework for translating risk outcomes from water treatment processes to legislative health-based targets. Whereas public health authorities are responsible for establishing such health targets (i.e. What are the consequences should an unwanted event occur?), QMRA is used to explore and inform, on a case-by-case basis, potential treatment designs and operational controls to achieve these targets (i.e. What can go wrong? How likely is it to happen?).

Most QMRA models are originally designed for application to mid- to large- scale treatment systems and subsequently retrofitted for application to smaller systems. Resource availability for adequate data collection and model user training/education were identified as constraints for the effective use and implementation of this tool for smaller systems. While a tiered approach may be deemed appropriate for some resource-limited utilities (through a preliminary vulnerability assessment), pathogen risk cannot be adequately portrayed or estimated without sufficient quantitative data (which may take upwards of three years to complete).

While QMRA may be used to better inform treatment design and operational controls, it is ineffective as a tool for day-to-day operational control/adjustments and performance monitoring and accordingly, a poor object for regulatory compliance. QMRA's effectiveness for understanding and "knowing-your-system" is often under-emphasized: Its use as a sensitivity analysis tool can be used to focus efforts and resources through predicting susceptible/vulnerable areas and processes. Given the appreciable uncertainty associated with pathogen fate and transport (and the data for assessing these processes), QMRA should not be the only tool relied upon to assess the robustness and resiliency of a drinking water treatment system. QMRA's effective use as a comparative tool between systems is further convoluted by jurisdictional and governance contexts (e.g. diverse North American context vs. relatively homogeneous Dutch context).

EDUCATION, EDUCATION, EDUCATION

As mentioned previously, education concerning the appropriate use and assumptions of QMRA models varies substantially – this is highlighted by the appreciable differences in outcomes of the same QMRA model by different users. As such, the need for training programs was identified.

THE "KNOW-YOUR-SYSTEM" APPROACH

If well implemented, QMRA can serve as a useful tool for risk managers of drinking water systems to better understand their systems. To ensure the best application of QMRA to practice:

- A common language for communicating risk to the public and other stakeholders must be developed;
- An education tool and guidance can be developed to better facilitate widespread, coordinated implementation of QMRA models;
- Focused, "smart" sampling programs should be improve quality of data acquired by targeting times of treatment challenges to better characterize threats to water quality (this should not be prescriptive [i.e. take n samples], but adaptive to prioritizing source water and treatment process assessments).

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