TURBIDITY AND MICROBIAL RISK IN DRINKING WATER

Prepared by: Martin J. Allen, Ronald W. Brecher,
Ray Copes, Steve E. Hrudey (Chair), and Pierre Payment
Ministerial Technical Advisory Committee

February 28, 2008

Prepared for
The Minister of Health
Province of British Columbia
pursuant to Section 5 of the
Drinking Water Act (S.B.C. 2001)

The B.C. Ministerial Technical Advisory Committee

Further to consultation with the B.C. Provincial Health Officer on the issue of drinking water risk assessment and risk communication, the B.C. Minister of Health, pursuant to Section 5 of the Drinking Water Protection Act (S.B.C. 2001) exercised his authority to establish an advisory committee to provide advice and recommendations with respect to drinking water matters, including advice and recommendations respecting standards and requirements to be established under the Act. Committee Members selected for this task were:

Martin J. Allen, Ph.D.
Awwa Research Foundation (retired)
Denver, Colorado
Email: mallen@awwarf.org

Ronald W. Brecher, Ph.D., D.A.B.T., C. Chem.
GlobalTox International Consultants Inc.
Guelph, Ontario
Email: rbrecher@globaltox.ca

Ray Copes, M.D., M.Sc.
Director
Environmental Health Services Division
BC Centre for Disease Control
Scientific Director
National Collaborating Centre for Environmental Health
Vancouver, British Columbia
Email: ray.copes@bccdc.ca

Chair:
Steve E. Hrudey, F.R.S.C., F.S.R.A., Ph.D., D.Sc.(Eng.), P. Eng.
Professor Emeritus
University of Alberta
Edmonton, Alberta
Email: steve.hrudey@ualberta.ca

Pierre Payment, Ph.D.,
Professeur
INRS-Institut Armand-Frappier (INRS-IAF)
Laval, Quebec
Email: pierre.payment@iaf.inrs.ca

Technical Writer:
P. Dale Waldorf, B.A., B.Ed.
Waldorf on Water Design
Vancouver, British Columbia
Email: pdwaldorf@mac.com

Table of Contents

EXECUTIVE SUMMARY

"Turbidity and Microbial Risk in Drinking Water" is written in response to the B.C. Minister of Health's request "*to provide advice and recommendations with respect to drinking water matters"* including, "*advice and recommendations respecting standards and requirements to be established"* under the B.C. Drinking Water Protection Act. A Ministerial Technical Advisory Committee (TAC) was established with five experts in this field whose purpose was to:

- o Review the risk assessment and risk communication issues concerning public notification of drinking water risks in B.C.,
- o Examine the scientific relationships between turbidity in raw water supplies and microbial human health risk in finished drinking water; and,
- o Provide advice and recommendations to the Minister on scientifically-based approaches to protect public health through advisory mechanisms, to help guide future policy development.

The TAC's mandate was to respond in the form of a report based on seven questions that provided the Terms of Reference.

1. *"What factors of a watershed/drinking water system (e.g., climate, temporal patterns and site-specific information – geography/geology, land use, infrastructure–chlorine residual concentrations, UV transmissivity, turbidity relative to CT) may be used to predict the risk of acquiring a waterborne gastro-intestinal (GI) illness?*

2. *What is the relationship (quantitative and/or qualitative) between each factor determined in response to Question #1 and the risk of GI microbial illness?*

3. *Is source water or turbidity (or turbidity at a certain NTU level in an unfiltered surface water source) a valid decision criteria for issuing boil water notices and/or water quality advisories to protect consumers against pathogen risk, and are there other water quality indicators that could be similarly used?*

4. *Can the various factors identified in response to question #1 be effectively combined to provide consistent decision criteria to assist Health Officials in determining whether boil water notices/water quality advisories are necessary?*

5. *Would it be scientifically feasible and practical to develop and use a "water quality index" or an algorithm based on numerous parameters as a means to accurately portray the level of public health risk in a water supply?*

6. *If a "water quality index" might be a feasible approach to pursue, please provide a scientific assessment on the necessary components and relationships of such a "water quality index"?*

7. *What kind of guidance exists in the literature on how to most effectively communicate and sustain attention to drinking water advisories?"*

A comprehensive *Introduction* provides the basis for the TAC's report, followed by the TAC's answers to the seven questions posed in the Terms of Reference. These ultimately lead to conclusions and closing remarks for the planning of future policy regarding risk management as it relates to public health and drinking water. The focus of the overall report ultimately relates to the "safety" of drinking water and what is meant by "safe drinking water".

A thorough examination of *"turbidity"* as a measure of the relative clarity of water, indicators of turbidity, how turbidity is monitored and how the watershed influences drinking water quality, leads to the relationship between drinking water regulations and the ultimate human health risk in finished drinking water. The sources of infection for gastrointestinal (GI) illnesses in developed countries are multiple and numerous studies concerning the association between GI illness and drinking water turbidity have concluded that turbidity by itself is not a causal explanation for infectious illnesses.

A number of factors can be related to the risk posed to drinking water safety both by the watershed and the drinking water system, but a main problem arises: *How good is the risk prediction for guiding any specific actions?* The proportion of risk that can be explained by one or many factors is variable with place and time. Overall, reducing the risk factors will make water safer; however, risk reduction has a cost, regardless of the risk reduction activity. The final choice in balancing the level of risk reduction against cost is a choice that scientific inquiry cannot answer.

Drinking water regulations have been established nationally and internationally to provide filtration specifications in response to water quality concerns and the need for future public health protection. TAC members have had direct involvement with many of these national and international situations and their experiences provide a comprehensive review of microbial human health risks when filtered and/or unfiltered water systems are employed.

Risk communication (proactive or reactive) plays an essential role with the goal of safe drinking water and is an essential element of risk management. A relevant example of risk communication, which may occur between purveyors of drinking water and their customers, is a water quality advisory. However, there are factors that may limit the effectiveness of water quality advisories for reducing risk to public health. Some water quality advisories in B.C. have been in place for many years and recent interviews conducted by the TAC suggest that some people may no longer pay much attention to these advisories. There is very little specific research available on the effectiveness of communication through water quality advisories. There is also limited information available on communicating and sustaining attention to drinking water advisories. The TAC found that, in general, drinking water advisories are only effective as a measure of last resort and they do not provide an effective alternative to securing the safety of a drinking water system, with appropriate multiple barriers.

There is no simple, invariant quantitative relationship between factors of a watershed/drinking water system and the risk of disease among drinking water consumers, but there is no doubt that contaminated drinking water can harm people. Appropriate treatment must be geared towards source water characteristics, both current and anticipated. Other than direct knowledge of an event known to have compromised treatment or integrity of distribution in a drinking water

system, no single source indicator, for source water or unfiltered treated water, is by itself a reliable criterion for issuing a water quality notice, unless there is an empirically demonstrated relationship between turbidity or microbial load for the specific system in question, a challenging demand. In addition, development of a water quality index will not accurately portray the level of public health risk in a water supply; judgment will always be necessary.

Evidence and feed back, based on consultation with personnel from a number of health regions and water purveyors within B.C., accompanied by relevant national and international documentation, leads the TAC to consider a broader drinking water issue - *whether filtration of surface water supplies should be mandatory*. All parties involved agree that protecting public health is essential, consequently disinfection is essential. The majority of parties agree that a multiple barrier approach, to assure drinking water safety, is sound. Therefore, the way forward, to resolve the debate about mandatory filtration for surface waters, is to explore how the commitments to protect public health and implement an effective multiple barrier approach can be adapted to the specific circumstances which exist in British Columbia. Fortunately, recent advances in water treatment technologies, particularly the demonstrated capabilities of UV disinfection, offer the potential to develop equally effective alternative means to conventional filtration for achieving the agreed upon public health protection goals.

INTRODUCTION

> *Science is not an encyclopedic body of knowledge about the universe. Instead it represents a* process *for proposing and refining theoretical explanations about the world that are subject to further testing and refinement* (AAAS & NAS 1992).

Science can tell us the way things are, but science cannot tell us the way things should be (Marchant & Coglianese 2000). To the extent possible, the Technical Advisory Committee (TAC) seeks to advise what we know about the way things are so that the B.C. Ministry of Health can apply these insights towards policies that affect the way things should be.

The TAC's Terms of Reference include a statement of purpose which refers to *risk assessment* and *risk communication*. The overall task relates to measures aimed at protecting public health from drinking water risk, which amounts to *risk management*. While there is an enormous body of scientific literature addressing these terms, the Technical Advisory Committee views these terms, in a pragmatic manner, to mean:

Risk assessment is an organized, rational process used to evaluate available evidence to understand a problem and try to predict danger,

Risk management is a practical response to the identified problem that seeks to manage risks to tolerable levels, and

Risk communication is a process that seeks to inform affected parties about the meaning of risk assessment predictions and the capabilities of risk management actions. This process is most effective when the communication involves listening as well as informing. Risk communication is often an essential aspect of overall risk management.

To the extent possible, these risk-based processes should be informed by a preponderance of evidence. But, inevitably when available evidence must be applied to make practical decisions about real problems, there is usually a mismatch between the amount and quality of available evidence and the complexity of the factors underlying the decision needed. This mismatch makes it necessary for decisions to be based on judgments that often cannot be fully grounded in as much evidence as would be desired. This situation of decision-making becomes particularly challenging with regard to who bears the burden of proving whether something poses an unacceptable risk. Whoever bears the burden of proof will encounter the disadvantage: the inevitable uncertainty arising from incomplete evidence will usually weigh heavily against the limited evidence that may be available to support a position. Such circumstances are often encountered in applying risk management to best assure the safety of drinking water and the issue of who must bear the burden of proof, for any risk management decision, is a critical question in very practical terms.

Although not directly stated in our Terms of Reference, the purpose outlined for the TAC and the questions that are posed all relate to the "safety" of drinking water. However, the notion of what is "safe" drinking water is not as clear as might be commonly imagined. A recent review

concerning safe drinking water for First Nations in Canada (Swain et al. 2006) revealed that no legislation or regulations in Canada, or the Safe Drinking Water Act in the U.S., actually define what is meant by safe drinking water.

The latest edition of the Guidelines for Canadian Drinking Water Quality (GCDWQ) also does not define *safe drinking water*. Presumably the intention of these guidelines is that water meeting the specified quality criteria is deemed to be *safe*, but that is not explicitly stated. The World Health Organization (WHO) Guidelines for Drinking-water Quality, 3rd edition (WHO 2004a, 2006) more explicitly states: *"Safe drinking-water, as defined by the Guidelines, does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. Safe drinking water is suitable for all usual domestic purposes, including personal hygiene."*[1]

A Strategy for Safe Drinking Water (O'Connor 2002a), the second report of the Walkerton Inquiry called to address a disaster in which drinking water that was clearly *unsafe* killed seven people and made thousands of others ill, explains the goal of recommendations to achieve safe drinking water as: *"While it is not possible to utterly remove all risk from a water system, the recommendations' overall goal is to ensure that Ontario's drinking water systems deliver water with a level of risk so negligible that a reasonable and informed person would feel safe drinking the water."* This goal for safe drinking water posing negligible risk recognizes individual perspectives on safety and implies an obligation to provide consumers with information about drinking water risks in addition to assuring that risks are negligible. Risk communication, in this case, is an essential element of overall risk management.

Individual perspectives on safety often involve a misconception that safety can be judged as a strict *yes* or *no* decision, i.e. something is either *safe* or *unsafe*. This situation may be considered through an analogy with an all too common risk of injury or death, traveling our streets and highways. Most would agree that driving through a red light is *unsafe*. Yet, doing so does not guarantee a crash. However, we expect that if done often enough, a crash is inevitable. We generally regard driving through a green light as being *safe*, but we also know that it is not entirely free of risk. None of the conditions for *safe* or *unsafe* traffic risks are absolute despite knowing and understanding, based on a tragically compelling amount of evidence, the source of the risks.

The multiple barrier approach (Table 1) to assure safe drinking water, was espoused by the Walkerton Inquiry (O'Connor 2002a), in the GCDWQ, in the Source to Tap Guidance from the Canadian Council for Ministers of Environment (CCME 2004) and numerous other international documents, e.g. WHO (2004a, 2007), NHMRC (2004), IWA (2004), US EPA (2006). An analogous approach is used to prevent deaths and injuries from motor vehicle accidents. Road design, driver licensing, regulations on "rules of the road", motor vehicle safety standards, ambulance and emergency services, and finally analysis of accidents and accident statistics are all part of a "multi-barrier" system to prevent deaths and injuries from motor vehicles.

---

[1] With respect to turbidity, the WHO Guidelines for Drinking Water Quality state: "No health-based guideline for turbidity has been proposed; ideally, however, median turbidity should be below 0.1 NTU for effective disinfection, and changes in turbidity are an important process control parameter."

Table 1   Multiple Barrier Approach Explanations

Reference	Elements	Elaboration of Elements
A Strategy for Safe Drinking Water. Part 2 Report of the Walkerton Inquiry (O'Connor 2002a) (Hrudey & Hrudey 2004)	Source protection	Keeps the raw water as clean as possible to reduce the risk that contamination breaches the drinking water system
	Treatment	Often involving more than one process to remove or inactivate contaminants, must be effectively designed, operated and maintained
	Distribution	System security to protect against intrusion of contaminants and disinfectant residual to assure delivery of safe water to consumers
	Monitoring	To control treatment processes and detect contamination in a timely manner to inform risk management processes
	Response	Capabilities that are well-conceived thorough and effective to respond to adverse conditions
From Source to Tap: the Multibarrier Approach to Safe Drinking Water (CCME 2004)	Source water protection	An integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking water from source to tap in order to reduce risks to public health
	Treatment	
	Distribution	
	Monitoring	
	Management	
The Multiple Barrier Approach to Public Health Protection (US EPA 2006)	Risk Prevention	Selecting or protecting the best source of water
	Risk Management	Using effective treatment technologies, properly designed and constructed facilities and employing trained and certified operators to properly run system components
	Monitoring Compliance	Detecting and fixing problems in the source and / or distribution system
	Individual Action	Providing consumers with information on water quality and health effects so they are better informed about their water system
Australian Drinking Water Guidelines (NHMRC 2004)	Catchment management and source water protection	Developing and implementing a catchment management plan which includes preventive measures to protect surface and groundwaters Ensuring that planning regulations include protection of water resources from potentially polluting activities and are enforced Promoting awareness in the community of the impact of human activity on water quality
	Detention in reservoirs or storages	Reduce faecal microorganisms through settling and solar inactivation Settle suspended material Reservoir mixing and destratification Exclusion or restriction of human, pet & livestock access Diversion of local storm flows
	Extraction management	Use flexibility in raw water source drawn. Use multiple extraction points to avoid horizontal or vertically distributed contamination
	Treatment	Coagulation, flocculation, sedimentation (or flotation) and filtration to remove particles
	Disinfection	Chlorination, chloramination, ozone, UV and chlorine dioxide, plus storage to assure adequate contact times
	Protection and maintenance of the distribution system	Fully enclosed storages Backflow prevention policies applied and monitored Repair and maintenance protocols Security to prevent unauthorized access Corrosion control Biofilm growth control Training of all maintenance personnel

Not all barriers in a drinking water system need to be physical elements. For example, to require well-trained operators who are knowledgeable in the public health risks which may be posed by their drinking water system is a vital component of delivering an effective multiple barrier approach.

The concept of having more than a single barrier to prevent contaminants posing a human health risk from reaching consumers involves intentional redundancy to assure that the failure of one or more barriers will not allow failure of the whole system in a manner that will allow consumers to be exposed to preventable health risk. The outbreak case studies reviewed (Appendix A), including at least 5 from B.C., provide numerous examples of how one or more barriers have failed, ultimately resulting in drinking water disease outbreaks. Achieving negligible risk to consumers, as espoused in the O'Connor report from the Walkerton Inquiry, requires effective implementation of a multiple barrier approach and assurance that these barriers (treatment) are functioning as designed. This is an inherently precautionary approach that is in direct contrast to one that is optimized on economic grounds to minimize cost and provide the minimal level of protection estimated to be just adequate to avoid disaster.

RISK ASSESSMENT

Turbidity in Relation to Other Indicators of Pathogen Risk

History of Turbidity

Introduced in 1804 in Scotland, water filtration was essentially aimed at producing high quality water for a clothes-washing industry. Water from the River Cart was passed through trenches filled with stones before being passed through a ring-shaped settling chamber. The water was clear, contained less suspended solids, did not soil the clothes and the surplus water produced was sold to the town inhabitants. Sand filters were developed in England in the 1820s and by the end of the century it was common to have filtered water. By the end of the 19th century and early 20th century, filtration of water supplies took an important place to provide water supplies that were both practical and esthetically pleasing. Practical because engineers rapidly realized the need to keep the distributed water clean: suspended matter from the source water sedimented in the pipes and would rapidly block them, reducing the available amount of water especially for firefighting. As access to distributed water came to more and more dwellings, people became more aware of its general appearance and required the clearest water.

Until 1984 most regulations recommended that the turbidity of water be kept lower than 25 NTU as it could interfere with the potability of drinking water (WHO 1963, 1971). In its 1984 guidelines, WHO recommended turbidity should be maintained at less than 5 NTU, but if water was disinfected, it would be better to aim for values of less than 1 NTU. At this time, drinking water at less than 1 NTU was considered safe if it was disinfected by chlorine with a free residual of 0.5 mg/l maintained for 30 minutes at less than pH 8. The basis for this recommendation was essentially that this dose was considered to be sufficient to obtain safe drinking water free of bacterial and viral pathogens. Maintaining a low turbidity was also required as there had been reports of interference with the detection of indicator bacteria by membrane filtration methods. This can now be overcome by the use of new liquid-based media developed to more selectively detect coliforms and *Escherichia coli* (*E. coli*).(Edberg 2000)

In the 1980s and 1990s, viruses were found in water that had been treated as required and researchers started to question these recommendations. One of the proposed hypotheses was that aggregates and particulates could afford protection to microorganisms. While numerous papers have described the effects of aggregation, this still remains a question to be answered and remains an unproven hypothesis in terms of public health risk. There is however, no doubt that turbidity and disinfectant demand, will affect the treatment to inactivate microbial contaminants, especially viruses and parasites. Furthermore, a wide range of susceptibility of the various enteric viruses to disinfection has been reported. While some viruses are inactivated by more than 99.9% in a few minutes, some strains require much longer periods to be inactivated to the same level (Table 2).

Table 2: Typical Disinfection Efficiency (Ct$_{99}$) for Microbial Pathogens (adapted from WHO 2004a, 2007)

Chlorine	Bacteria	0.08 mg·min/L at 1-2°C, pH 7; 3.3 mg·min/L at 1-2°C, pH 8.5
	Viruses	12 mg·min/L at 0-5°C; 8 mg·min/L at 10 ^{o}C; both at pH 7-7.5
	Protozoa *(Giardia)*	230 mg·min/L at 0.5 ^{o}C; 100 mg·min/L at 10 ^{o}C; 41 mg·min/L at 25 ^{o}C; all at pH 7-7.5
Monochloramine	Bacteria	94 mg·min/L at 1-2 ^{o}C, pH 7; 278 mg·min/L at 1-2 ^{o}C, pH 8.5
	Viruses	1240 mg·min/L at 1 ^{o}C; 430 mg·min/L at 15 ^{o}C; both at pH 6-9
	Protozoa *(Giardia)*	2550 mg·min/L at 1 ^{o}C; 1000 mg·min/L at 15 ^{o}C; both at pH 6-9 *Cryptosporidium* not inactivated

Ct$_{99}$ refers to the product of disinfectant concentration (C) times contact time (t) with the microorganism required to achieve 99% inactivation of the population.

In the 1980s and 1990s, there was a recognition that several outbreaks were caused by *Giardia* whose cysts were found to be much more resistant to disinfection than bacteria and viruses. This was particularly true in the US where the recording of these outbreaks was more intensive and thereby the attribution of risk was more evident. Because it was readily possible to remove a large proportion of the cysts by filtration, the U.S. Environmental Protection Agency (USEPA) decided to require all surface water sources to be filtered and set a 1 NTU level as the achievable objective that led it to issue its Surface Water Treatment Rule in 1989, and subsequently the National Primary Drinking Water Regulations.[2]

In the 1990s, the Milwaukee outbreak (case study, Appendix A), and several others due to *Cryptosporidium,* occurred and the focus changed from *Giardia* cysts to *Cryptosporidium* oocysts. Since the oocysts were still even more resistant to chemical disinfection and more difficult to remove by filtration, being still smaller (2 to 5 micron) than *Giardia* cysts, enhanced filtration became the only logical choice at that time. Slowly the requirements to achieve the best possible filtration decreased the 1 NTU value to 0.5 NTU, then to 0.3 NTU, considered achievable by most conventional treatment plants at minimal costs, and finally to 0.1 NTU, achievable at some costs but attainable. During the same period, an international consensus (WHO 2004) (NHMRC 2004) (IWA 2004) (CCME 2004) was reached on the necessity to protect source water from fecal pollution in order to minimize the risks and the concept of multiple barriers changed from its engineering perspective, i.e., multiple treatments, to a more philosophical approach (Table 1), for example, protection from source to tap, including source water protection, quality

---

[2] Title 40, Volume 19 - Protection of Environment, Chapter I - Environmental Protection Agency, Part 141 - National Primary Drinking Water Regulations. The entire volume can be accessed and downloaded at http://www.acess.gpo.gov/nara/cfr/waisidx_02/40cfr141_02.html

of treatment, competence of water suppliers, and integrity of the water storage distribution system, monitoring of treatment process and finished water and emergency response plan.

In the early 2000s, ultra violet (UV) treatment was demonstrated to be an efficient and cost effective method of inactivating waterborne pathogens, including the protozoan parasites such as *Giardia* and *Cryptosporidium* (oo)cysts. This opened a new avenue for the treatment of water, an avenue quite welcomed as researchers had reported still finding (oo)cysts in water meeting the stringent USEPA turbidity standards. Membrane filtration had also been developing in the same period and was becoming another cost effective method to remove pathogens and chemical contaminants from water.

Both conventional sand filtration and membrane filtration have a drawback: pathogens are essentially concentrated on/in the filters and the backwash/reject water needs to be further treated at a second stage to inactivate the concentrated pathogens. It is now recommended practice to return the wastewaters from filtration to wastewater treatments plants or treat backwash waters prior to discharge or reuse. Direct discharge of untreated filter backwash waters back to source waters will increase their level of contamination.

Worldwide, a large number of water supplies are still unfiltered and are considered a public health risk when their source water is fecally (human or animal) polluted and not well controlled. On the other side, some large cities continue to use unfiltered supplies with no apparent health effect in cases where the source water supply is highly protected from contamination. These circumstances are not universal and will be discussed later in relation to the need for filtration.

Extensive reviews on the characteristics and significance of turbidity in drinking water have been prepared by various international and regulatory agencies. The intent of this short review is simply to summarize what is reported to enable the reader to understand the various factors that should be taken into account before making decisions about turbidity and public health.

Meaning of Turbidity

Turbidity is a measure of the relative clarity of water.

Turbidity values above 5 NTU become perceptible to the eye, especially in large volumes such as a white sink or bath. This effect might be increased if the water also contains coloured materials such as humic acid or inorganic colored products such as iron compounds.

> *Turbidity in water is caused by suspended and colloidal matter, such as clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms. Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample. Correlation of turbidity with the weight or particle number concentration of suspended matter is difficult because the size, shape and refractive index of particles affect the light-scattering properties of the suspension (APHA, WERF, AWWA 2005).*

Each of the constituents of turbidity in any given sample of water can affect differently the disinfection processes and the level of inactivation of pathogens in that water.

Strengths of Turbidity

Turbidity values and characterization can provide data to determine what type and level of treatment are needed when designing or upgrading drinking water treatment processes.

In water sources subjected to significant levels of fecal pollution, some correlation can be expected between turbidity and fecal indicators or pathogens. The strength of this correlation is variable and while some approximations can be made, its value in decision making will be site-specific.

Turbidity levels are a simple but efficient parameter to assess source water variations as well as filtration efficiency during conventional treatment of drinking water. In-line continuous turbidity monitoring is a simple cost effective method to monitor turbidity.

Turbidity, monitored from remote locations within the watershed, can provide advance notice of incoming water quality changes so that appropriate actions can be taken, e.g., treatment modifications, temporary shut-down of pumping if storage reserves are sufficient, public advisories.

Turbidity is also a useful indicator of groundwater quality changes. Groundwater, especially if under a more or less direct influence of surface water, will experience rapid movements during recharge periods or after rain events. This will displace sediment and turbidity can be an indicator of such changes. Turbidity in groundwater does not indicate pathogen presence but provides information on general water quality and is an indicator of surface influence on groundwater quality.

Limitations of Turbidity

Turbidity over 5 NTU can affect water appearance, even if higher values are still acceptable to consumers.

Sporadic high turbidity in source water can overwhelm treatment processes.

As a filtration efficiency parameter, turbidity has poor predictive value for the presence of pathogens whose occurrence is usually a rare event and will not always reflect significant changes in turbidity. This limitation of turbidity is distinct from its excellent performance as an easily measured parameter of filtration performance for the removal of fine particulate matter overall, of which pathogens will form an unpredictable and generally insignificant subset.

Turbidity can be a significant source of chemical disinfectant demand when the particles causing turbidity are composed of organic constituents. The type of turbidity is more important than the

amount and similar disinfection efficiency curves are usually observed at turbidities of less than 5 NTU. Parameters that should possibly be considered, in addition to turbidity, include total organic carbon or nitrogenous compounds in the suspended solids.

In relatively unpolluted source waters, turbidity is not an indicator of the presence of pathogens. In these sources a simple mathematical correlation between turbidity and pathogens cannot be expected and if a correlation is found to be statistically significant in a particular situation, the predictive value of turbidity for pathogens is still likely to be poor.[3] The occurrence of the pathogens becomes a probability event that is not always linked to turbidity levels and reflects watershed specific characteristics. Cyst contamination has been modeled in terms of watershed characteristics: water reuse and sewage contamination are the important factors in predicting cyst concentrations.

Turbidity can interfere with filtration-based enumeration methods for bacteriological indicators. Recent microbiological methods can circumvent this problem (Edberg 2000) (Allen 2004) (Rice 1990).

When chemical disinfection is used, turbidity containing a significant organic content can result in increased production of disinfection by-products that may have long-term health effects, especially when elevated disinfectant dosages are required to better ensure microbially safe water.

Turbidity can limit the efficacy of UV disinfection by blocking or absorbing UV light, i.e., color, humic acid, coagulants. However, UV dose-response of microorganisms is not affected (Clancy Environmental Consultants, Inc. 2007). However, the presence of humic materials and coagulants has been shown to significantly impact UV disinfection efficacy with lower inactivation levels being achieved. This interference can be compensated by increasing the UV dose to achieve a similar level of disinfection.

Turbidity has been linked epidemiologically to various health outcomes, as will be elaborated in the later section on endemic disease and turbidity. For unfiltered water supplies, there is ample evidence that chlorine-disinfected only drinking water, prepared from a fecally polluted source, allows gastrointestinal (GI) illnesses and outbreaks. In both filtered and unfiltered drinking water, increases in turbidity have been observed to coincide with patient visits at hospitals.

---

[3] The correlation coefficient (r) is a quantitative measure (ranging between -1 for perfect negative correlation, 0 for no correlation, and 1 for perfect positive correlation) of the degree of linear association between two normally distributed parameters, in this case, turbidity and fecal indicators (or pathogens).
The statistical significance of the correlation coefficient (r) between two parameters can be tested to determine if it is significantly different from zero, and if so, it is judged to be statistically significant. The more important aspect is the degree to which variation in one parameter is found to be associated with variation in the other. This aspect is expressed as the coefficient of determination (r^2) between two normally distributed parameters. There may be cases where the correlation coefficient between two parameters is statistically significant, but this correlation may be of no practical utility for predictive purposes, e.g. like lack of clinical significance in medical practice, because the proportion of variation in the parameter to be predicted by the indicator parameter is irrelevantly small for the parameter to be predicted. This situation of inadequate ability to predict a useful proportion of variation is likely to be the best case for the use of turbidity as an indicator of pathogens but for the general case, the predictive value of variation in turbidity for variation in pathogens is likely be negligible.

Whether there is a causal link or whether the epidemiological observation is an ecological fallacy, i.e. non-causal, remains to be determined.

Turbidity and Other Indicators

Apart from turbidity that has been discussed previously, numerous indicators, i.e., microbial and physico-chemical, have been proposed for various purposes: water treatment evaluation, fecal source-tracking and potential health risk. In the present context of unfiltered water supplies, some indicators could be used to evaluate source water quality, disinfection efficiency and potential health risks (Dufour et al. 2003) (Payment et al. 2003).

Escherichia coli

> *E. coli* is now internationally acknowledged as the most appropriate indicator of fecal pollution. In source water, *E. coli* level of occurrence is correlated with the inputs of fecal pollution (human or animal) (Edberg 2000). The survival time of *E. coli* is shorter than it is for enterococci or clostridial spores that survive longer but are present in lower numbers in feces. *E. coli* comprise more than 90 percent of the microbial population in human and animal fecal material.

> *E. coli* should never be present in treated drinking water: its presence is an indicator that the minimal disinfection requirements for bacterial pathogens have failed.

> *E. coli* is very sensitive to disinfection by chlorine and it is not a suitable indicator for more resistant viruses and protozoan parasites.

Enterococci

> *Enterococci* are fecal streptococci that can be used as indicators of fecal pollution. They are however less frequent in surface water than *E. coli,* thereby limiting their value as sensitive indicators of fecal pollution. Their presence generally reflects fecal sources so they exhibit limited false positive behaviour.

Clostridium perfringens

> *Clostridium perfringens* bacteria are present in human and several animal feces. The vegetative cells do not survive well in the environment, but the sporulated form is extremely resistant. The presence of this bacterium has been used as an indicator of less recent fecal pollution as well as an indicator of treatment efficiency when present in sufficient numbers in the source water.

Aerobic sporeformers

> The spores of aerobic sporeformers (mainly *Bacillus* spp) are generally present in water and their level increases with pollution. They are not an indicator of fecal pollution but their spores are quite resistant to disinfection processes and, if present in sufficient number in source water, they can be used to assess the level of disinfection of the treated water.

Treatment Monitoring

Chlorine residual levels can be used to determine whether sufficient disinfection has taken place. In-line continuous monitoring is widely available and cost-effective in providing real-time measurement of chlorine concentrations. Continuous monitoring of chlorine residual should be used whenever possible. The Walkerton Inquiry concluded that adoption of continuous chlorine residual monitoring, as had been the Ontario Ministry of Environment policy since 1994 for vulnerable water supplies like Walkerton, would likely have prevented the disastrous outbreak in May 2000 (O'Connor 2002b).

In chlorine-disinfected distribution systems, chlorine residual can serve as an indicator warning of intrusion in the distribution system or inadequate dosages to ensure there is chlorine residual throughout the distribution system; chlorine level will decrease with ingress of water and contaminants that create disinfectant demand.

Particle Counting Measurements

Particle counting does not provide any indication of the presence or absence of pathogens.

Particle counting can provide a general index of removal effectiveness of treatment processes; as such, is a good quality control parameter for filtration. However, factors other than size; such as, electric charge on the particles, may affect removal processes. Particle size monitors are available as in-line instruments; however, the equipment is expensive and requires a greater level of skill than turbidity analysis.

When source water is contaminated, the surveillance during filtration of the removal of particles in the 2 - 5 micrometer size-range, for example, the size of oocysts of *Cryptosporidium*, could be a surrogate for the removal of (oo)cysts.

Monitoring Turbidity

The needs and rationale for monitoring drinking water quality strategically has been recently considered in an Australian research study (Rizak and Hrudey 2007) which observed:

A water supplier wishing to maximise its ability to detect contaminated drinking water and provide greater public health protection must ensure that monitoring programs are effectively designed to support collecting data that increase understanding of an individual water supply system and the risks that are present, both in normal operation and during events. Risk is not managed merely by apparent achievement of water quality guideline or standard numbers. In general, monitoring programs which emphasise only treated drinking water quality monitoring will not effectively guarantee the safety of drinking water. Not only does end-point monitoring rationale make missing the opportunity to be preventive and identify contamination episodes as they are occurring more likely, it also frequently misses the opportunity to collect data that would provide improved insights on hazards and treatment performance, and the overall vulnerability of the system. Intermittent, event-driven contamination or system failure is not likely to be

recognised nor adequately characterised by random and infrequent sampling programs that are commonly used for assessing treated drinking water quality. . .

The design of more directed, strategic drinking water quality monitoring systems is also important for enhancing interpretation and understanding the significance of monitoring results. Interpretation of monitoring data particularly for the purpose of making decisions to safeguard public health is a challenging task. Interpreting monitoring data and deciding on actions appropriate to a monitoring result requires effective judgement and a defensible strategy. Designing more strategic water quality monitoring systems can provide the understanding and supportive evidence to judge more effectively the meaning of any given adverse result. Clearly the greater the understanding and knowledge there is of the water system, its catchment and source water, and barrier performance and capabilities, the better interpretation of monitoring data and decision-making can be. Recognising the limitations in monitoring and effectively designing monitoring programs to support risk management should enhance the interpretation of monitoring data, ultimately resulting in improved public health decision-making.

Implementation of such changes in our approach to monitoring strategies for greater public health protection requires appropriate recognition and support through revisions to national guidelines and regulatory practices. Discussion should take place within the water industry on current regulatory focus and how evidence-based monitoring may be effectively incorporated within compliance requirements to enable a closer linkage between monitoring and applied risk management. Many of the elements of evidence-based monitoring systems are already being implemented in drinking water systems but this information may not be utilised effectively. As long as the primary emphasis on compliance monitoring of treated drinking water quality is perpetuated through regulation, many of these necessary additional aspects will not get the focus and attention they deserve, nor adequate resources devoted towards them.

Source Water and Treatment Factors

There is ample evidence that the nature of the watershed influences drinking water quality. Pathogens in fecal contamination from human, domestic animals and wildlife sources have been identified as variables that affect the risks posed to drinking water sources and water used for irrigation purposes. There is also evidence that it is not possible to generalize conclusions obtained at a specific site. Pathogen occurrence is linked to the dynamics of infectious diseases in a population and can vary significantly in time; municipal or individual sewage inputs and livestock wastes are the major source of pathogens in a watershed and constitute the largest risk factor. For example, the shallow groundwater source that led to the Walkerton outbreak had been recognized as being subject to livestock fecal contamination from nearby farms from the time of the well's installation in 1978, yet the disastrous outbreak did not occur until May 2000. Agriculture and animal raising practices also affect pathogen occurrence and must be controlled, by using best management practices, to protect a watershed used as a drinking water source. Wildlife can contribute to the occurrence of pathogens but this source is difficult to control. While human infectivity with some of these pathogens is low, i.e., the probability of ingesting

sufficient numbers of infectious microorganisms from treated drinking water to cause the onset of disease, some segments of the population may be at greater risk of infection because of being immunocompromised or because of other individual-specific risk factors, e.g., greater water consumption, greater vulnerability to serious consequences of infection (see Young, Old, Immunocompromised).

Parasites have been identified as the major threat in B.C. for areas that have no significant human sewage impacts. However, UV disinfection has been shown to provide sufficient protection even in the presence of turbidities as high as 50 NTU (Clancy Environmental Consultants, Inc. 2007). Bacterial pathogens are easily inactivated at the UV doses used in most drinking water treatment plants. Viruses are more resistant to UV, but the addition of a final chlorine-based disinfection at adequate doses provides sufficient kill to reach the 4-log (Table 3) disinfection goal.

Table 3: Log_{10} Microbial Reductions Starting With 1,000,000 Microbes*

Log Removal	Percent Reduction	Surviving Microbes
1	90.0	100,000
2	99.0	10,000
3	99.9	1,000
4	99.99	100
5	99.999	10

*The concentration of human pathogens in surface waters is very low in comparison to naturally occurring non-pathogenic microorganisms and the desired log_{10} reduction to protect public health is achieved by multiple water treatment processes.

Canadian Guidance Regarding Turbidity

There is no federally mandated drinking water legislation in Canada. The Guidelines for Canadian Drinking Water Quality are produced by the Federal / Provincial / Territorial Committee on Drinking Water and a summary table of numerical guideline values for specified drinking water parameters is updated annually (F-P-T CDW 2007).

The guideline for turbidity was updated in 2004, to replace a previous guideline of 1 NTU. The new guideline provides different values for different treatment scenarios and was explained in a background technical document (F-P-T CDW 2003) as:

Waterworks systems that use a surface water source or a groundwater source under the direct influence of surface water should filter the source water to meet the following health-based turbidity limits, as defined for specific treatment technologies. Where possible, filtration systems should be designed and operated to reduce turbidity levels as low as possible, with a treated water turbidity target of less than 0.1 NTU at all times. Where this is not achievable, the treated water turbidity levels from individual filters:

1. *For chemically assisted filtration, shall be less than or equal to 0.3 NTU in at least 95% of the measurements made, or at least 95% of the time each calendar month, and shall not exceed 1.0 NTU at any time.*
2. *For slow sand or diatomaceous earth filtration, shall be less than or equal to 1.0 NTU in at least 95% of the measurements made, or at least 95% of the time each calendar month, and shall not exceed 3.0 NTU at any time.*
3. *For membrane filtration, shall be less than or equal to 0.1 NTU in at least 99% of the measurements made, or at least 99% of the time each calendar month, and shall not exceed 0.3 NTU at any time. If membrane filtration is the sole treatment technology employed, some form of virus inactivation[4] should follow the filtration process.*

The new turbidity guidance was designed for drinking water systems drawing from either a surface water source or a groundwater source that is deemed to be under the direct influence of surface water. The expectation is that such systems would normally use some form of filtration technology. Criteria were proposed for exemption from this filtration requirement if the source water could be shown to be reliably pristine, i.e., demonstrably free from substantial fecal contamination, and these were articulated as (F-P-T CDW 2003):

*Filtration of a surface water source or a groundwater source under the direct influence of surface water may not be necessary if **all of the following conditions are met**:*

1. *Overall inactivation is met using a minimum of two disinfectants:*
   - *ultraviolet irradiation or ozone to inactivate cysts/oocysts;*
   - *chlorine (free chlorine) to inactivate viruses; and*
   - *chlorine or chloramines to maintain a residual in the distribution system.*

   Disinfection should reliably achieve at least a 99% (2-log) reduction of Cryptosporidium *oocysts,* a 99.9% (3-log) reduction of* Giardia lamblia *cysts and a 99.99% (4-log) reduction of viruses. If mean source water cyst/oocyst levels are greater than 10/1000 L, more than 99% (2-log) reduction of* Cryptosporidium *oocysts and 99.9% (3-log) reduction of* Giardia lamblia *cysts should be achieved. Background levels for* Giardia lamblia *cysts and* Cryptosporidium *oocysts in the source water should be established by monitoring as described in the most recent "Protozoa" guideline document, or more frequently during periods of expected highest levels (e.g., during spring runoff or after heavy rainfall).*

2. *Prior to the point where the disinfectant is applied, the number of Escherichia coli bacteria in the source water does not exceed 20/100 mL (or, if E. coli data are not available, the number of total coliform bacteria does not exceed 100/100 mL) in at least 90% of the weekly samples from the previous 6 months.*

3. *Average daily source water turbidity levels measured at equal intervals (at least every 4 hours), immediately prior to where the disinfectant is applied, are around 1.0 NTU but do*

---

[4] Some form of virus inactivation is required for all technologies. The difference is that chemically assisted, slow sand and diatomaceous earth filters are credited with log virus reductions and membrane filters receive no credit.

not exceed 5.0 NTU for more than 2 days in a 12-month period. Source water turbidity also does not show evidence of protecting microbiological contaminants.

4. *A watershed control program (e.g., protected watershed, controlled discharges, etc.) is maintained that minimizes the potential for faecal contamination in the source water.*

While this Canadian guideline is not binding in B.C., it does provide a frame of reference for expectations regarding the treatment of surface water or groundwater sources under the influence of surface waters in many parts of Canada. Some provinces, such as Alberta, have adopted the health-based guideline values by reference in their provincial regulatory regime thereby making them legally binding on regulated drinking water purveyors.

Status of U.S. Drinking Water Regulations

In 2006, the U.S. EPA issued final drinking water regulations that require public water systems that use surface water or ground waters, under the influence of ground water, to install appropriate treatment technologies to protect public health. These regulations impacted several large water systems, e.g., Seattle, Portland, New York City, Tacoma, Boston, and numerous smaller unfiltered but disinfected public water systems that use high quality surface waters with low turbidity and protected or somewhat protected watersheds. The above large water systems are now investigating which treatment processes are the most cost effective, e.g., conventional filtration, ozonation, UV treatment, membranes, or a combination of these processes, to protect public health. Boston is permitted to use ozone in lieu of filtration and will add UV by 2013. With no recent water-borne outbreaks attributed to lack of treatment at these water utilities and the large size of these utilities, EPA is allowing for a reasonable timetable for the selection and installation of adequate water treatment processes. Public water purveyors are working with their respective state agencies, responsible for enforcing EPA regulations, to determine what is required, i.e., additional treatment, modifications to existing treatment, e.g., changing to chloramines , possible waivers, timetables for compliance (for pathogens, chemicals, DBPs, etc).

The EPA regulations provide "Criteria for Avoiding Filtration" (40CFR 141.171). The EPA criteria can be compared with those recommended by Health Canada to ensure consistency for granting waivers from filtration. Public water systems using surface water or ground water under the influence of surface water may determine the appropriate treatment technologies that may or may not include filtration, but need to provide a prescribed level, e.g., documented $\log_{10}$ reduction of pathogens, of public health protection. States may grant or deny a request to avoid filtration. Many Canadian water utilities, that have added or are planning to add additional treatment processes, are basing designs on EPA's regulations for microbial $\log_{10}$ reductions.

In the U.S., water utilities that need to add additional treatment processes or will request a waiver from filtration would need to have extensive and historical water quality data from their watershed so that a determination can be made as to the level of treatment that satisfies EPA's regulations on log reduction of pathogens; principally, although not exclusively, determined by *Cryptosporidium* data.

Water utilities will continue to monitor watershed water quality to ensure their current treatment processes are providing the desirable level of public health protection since increased human activities on or adjacent to the watershed can adversely alter surface water quality and compromise the existing treatment technology. Thus, watershed monitoring will be practiced by drinking water purveyors using surface waters.

The comprehensiveness of an acceptable watershed monitoring program includes factors such as:
- o extent of water utility ownership and security of the watershed;
- o type and extent of human and agricultural activities allowed on the watershed;
- o presence and extent of domestic livestock on the watershed;
- o changes in logging, residential/commercial development and management of sanitary waste; and
- o more frequent or abnormal precipitation events.

The responsible state drinking water agency will approve watershed monitoring programs based on EPA requirements and states may also impose more stringent requirements.

The annual costs of a watershed monitoring program differs widely and cannot be determined on a utility size basis, i.e., more extensive monitoring is required for water systems that request a filtration waiver and systems that are in the process of selecting appropriate treatment that is necessary to provide the prescribed level of public health protection.

Turbidity and Health Risk

Endemic Disease

A Review of Turbidity - Endemic Disease Studies

The sources of infection for GI illnesses in developed countries are multiple: personal contacts with infected individuals, contaminated foods, contaminated water, environmental exposure (e.g., soil, surfaces, aerosol), animals (e.g., contact with livestock or livestock waste, petting zoos, household pets) (Payment and Riley 2002).

The current level of endemic GI illnesses in the US and Canada average about 1 episode/person/year and varies by season between 0.2 and 4 episodes/per person/per year when assessed through prospective studies; lowest during summer months and highest during winter and spring. Children younger than 5 years experience a higher level of GI since they are acquiring these infections through contacts with other infected children and environmental sources (Payment et al. 1997) (Payment and Hunter 2003).

The association between GI illness and drinking water turbidity has been evaluated in several studies. These studies, including the Greater Vancouver Regional District studies (Aramini et al. 2000), have been recently reviewed (Mann et al. 2007) to assess the evidence for an association between drinking water turbidity and endemic GI illness in settings with public water supplies; a focus being on the United Kingdom. The authors concluded that:

> *Associations between drinking water turbidity and GI illness have been found in two settings, in people of various ages, but not in other settings. It is likely that studies observed different results because of differences in the mean turbidity level between settings. Important methodological differences, such as in the level of adjustment for seasonal confounders, might also help to explain conflicting results.* (Mann et al. 2007)

Biological plausibility remains the primary basis for explaining associations; turbidity by itself is not a plausible explanation for infectious illnesses. It is more plausible that pathogens associated with turbidity can be the source of disease at specific sites. However, one of the factors that none of the studies evaluated, was the relationship between turbidity level and pathogen occurrence at the studied sites. Sites with low level occurrence of pathogens, but significant turbidity events, cannot be compared to those with high levels of pathogens.

Turbidity levels at sites with minimal pathogen occurrence will not be correlated with levels of pathogens in a consistent manner. While some association might be identified, the probability of false positive association is high.

At sites with higher pathogen occurrence, treatment facilities will rely on conventional filtration-disinfection processes and the turbidity levels of drinking water will reflect failures in the treatment barriers; such failures, even small excursions from normal values, are bound to let pathogens through the system if they are challenging the treatment at the time of process failure.

"It should be noted, however, that these studies of turbidity and adverse health outcome are 'ecological', in that they measure exposure of populations rather than of individuals and, as

such, potentially suffer from bias due to the so called 'ecological fallacy' (Walter 1991)."

"While this does not mean that these studies are invalid, they cannot be taken as proof of an association in their own right (Hunter et al. 2003)."

In a population, the proportion of waterborne disease attributable to drinking water is a factor that will drive regulations:

> *. . . Studies of drinking water are important because exposure is nearly universal, such that even small effects on GI illness could have considerable public health impact . . . However, any changes to drinking water regulations must be based not only on the demonstration of an association with GI illness, but also on the realistic impact that any regulatory changes would have on public health – in terms of the number of cases and societal costs averted – and the level of risk that is considered acceptable from drinking water.* (Mann et al. 2007*)*

An eloquent paper on the risk of minimal drinking water treatment of fecally contaminated raw water is the one by Beaudeau et al. (1999). The researchers studied the population of the city of Le Havre, France that uses karstic and surface water resources that are subject to episodic microbiological quality degradation. During the study period, chlorine residual was not always maintained and there were significant variations in turbidity. An ecological time series study was carried out on records of sales of gastroenteritis medication. Interruption of chlorination of the unfiltered water, often due to power failures, resulted in a significant increase of medication sales three to eight days later, suggesting bacterial or viral infections. Even if chlorine disinfection was maintained, raw water turbidity increases resulted in increases of medication sales during the following three weeks, suggesting the presence of pathogens with increased resistance to chlorine such as protozoan cysts. Such failures have the potential of causing major outbreaks if raw water microbiological quality degrades significantly after rainfall events.

A time series analysis by Lim et al. (2002) found no significant relationship between turbidity in raw or finished water and gastroenteritis among residents served by Edmonton's Rossdale water treatment plant. This suggests that effective water treatment provided a high quality, low risk treated water supply, despite some raw water quality challenges for this system.

Aramini et al. (2000) estimated that less than 2% of the GI disease in the Vancouver area is attributable to drinking water. Given that the average rate is about 1 episode/per person/per year implies that each year in the Greater Vancouver Regional District about 2,000,000 episodes occur annually from all causes. If less than 2% of these illnesses are water-related, the societal impact is low compared to the impact of food-borne and person-to-person transmission of these infectious illnesses. The results of this study showed numerous statistically significant associations between turbidity and measures of enteric illness. However, lag periods were variable and many of the associations were not consistent in the data. While identifying many associations worthy of further investigation, it is difficult to attribute causality to the reported associations. However, the societal consequences may be substantial and these cases of illness, if truly attributable to waterborne pathogens, may be more amenable to control than other means of disease transmission which are dependent upon individual behaviour.

The City of Kamloops, B.C. draws its drinking water from the South Thompson River. The watershed for this river encompasses a large portion of interior B.C. with multiple land uses, including raising cattle, logging and manufacturing. Spring runoff results in increases in turbidity. During the early 1990s, Kamloops' drinking water was treated by simple chlorination. Sampling for protozoa had shown low levels of *Cryptosporidium* and *Giardia* present during most of the year. To determine whether there was a relationship between turbidity and enteric illness a time series analysis of weekly turbidity and physician office visits for enteric illnesses and laboratory services was performed for the period from January 1, 1994 to June 15, 1996. A statistically significant relationship was seen between turbidity and physician/lab services at 3 week lags. A weaker association was seen at 2 weeks lag. The relationship was driven primarily by physician laboratory billings for stool culture and ova/parasite exams. The relationship explained approximately 10% of the weekly variation in service billings.

The results of this analysis were taken to city council and a citizen's advisory council was formed to make recommendations on what to do. The advisory council recognized the need for an upgrade to water treatment. A turbidity-based daily public water quality advisory was put in place March 1998. Turbidity levels of <1 NTU were considered 'Good', 1-5 NTU 'Fair', and >5 NTU 'Poor'. Turbidity of 1-5 NTU was considered normal or background for this system; at this level no advice was given apart from the province-wide advice for immunocompromised people not to drink the water without additional treatment. At levels >5, the public was advised that risk of enteric illness increased and that people could reduce this risk by boiling their water or seeking other sources. A 25% reduction in physician services for enteric illnesses was noted in the 2 year period after the turbidity based daily water quality advisory. Kamloops now has implemented membrane filtration.

Epidemic Disease
Role of Turbidity Among Other Risk Factors in Drinking Water Outbreaks

Drinking water disease outbreaks are now relatively rare in the developed world, particularly in contrast to experience a century ago, which unfortunately continues today in the developing world. The WHO (2004b) estimates that over 600,000 deaths a year from diarrheal diseases could be prevented by household chlorination of drinking water. The pervasive risk of human disease from waterborne pathogens is an irrefutable certainty that must be managed to be avoided. Despite that knowledge, drinking water disease outbreaks continue to occur in the developed world with surprising frequency (Hrudey & Hrudey 2004). When they are analyzed for cause, they usually prove to be eminently preventable.

The evidence available from investigations of drinking water disease outbreaks in developed countries bears directly on the questions asked of the Technical Advisory Committee. Accordingly, the available evidence over the past 30 years has been reviewed in some detail (Appendix A) and is summarized below regarding the empirical insights which can be gained concerning any relationship that may exist between turbidity or other measurable factors and epidemic waterborne disease. These outbreak case studies were organized under five headings:

1. Unfiltered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of the disease outbreak

Five outbreaks are considered in this category: the toxoplasmosis outbreak in Victoria, B.C. (1994-95), the cryptosporidiosis outbreak in Cranbrook, B.C. (1996), the campylobacteriosis outbreak in Bennington, Vermont (1978), the giardiasis outbreak in Bradford, Pennsylvania (1979) and the giardiasis outbreak in Red Lodge, Montana (1980). All of these communities employed unfiltered, but chlorinated or chloraminated, surface water sources with varying degrees of source water protection. While there is some evidence of the value of raw water turbidity as a signal warning of contamination in advance of disease occurrence in these outbreaks, the clarity of that signal ranged from somewhat distinct to marginal at best. In no case, is there sufficient evidence reported to conclude that raw water turbidity provided a unique or particularly reliable warning sufficient to anticipate accurately an impending outbreak of waterborne disease.

2. Filtered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of a disease outbreak

Three outbreaks are considered in this category: the cryptosporidiosis outbreak in Milwaukee, Wisconsin (1993), the cryptosporidiosis outbreak in Ogose, Saitama, Japan (1996) and the viral gastroenteritis outbreak in Eagle-Vail, Colorado (1981). The first of these two water systems employed conventional coagulation, filtration and chlorination, or chloramination, while the latter provided pressure filtration without chemical coagulation prior to chlorination. Milwaukee demonstrated two distinct turbidity spikes; ~1.5 NTU in the treated water that coincided with the likely passage of oocysts through the filtration process in sufficient numbers to cause a massive epidemic. Noteworthy however, is the observation that at least five other water filtration plants on Lake Michigan experienced treated water turbidity spikes above 1 NTU; the highest was 5.2 NTU, and none of these other plants experienced an outbreak of cryptosporidiosis. The treated water turbidity at Eagle Vail was elevated to a level 2.5 to 3.5 NTU, indicative of poor filtration performance which may have signalled the outbreak, but there was insufficient data reported to indicate whether this turbidity signal was unique to the outbreak. The Ogose outbreak demonstrated potentially predictive raw water turbidity spikes, ~160 and ~25 NTU, in advance of the outbreak curve, but their utility as predictors was undermined by the occurrence of major turbidity spikes of ~30 and ~50 NTU more than 3 weeks before the 160 NTU spike that preceded the outbreak. Taken together, these data do not provide a compelling case for turbidity, particularly raw water turbidity, as a reliable signal of an impending outbreak.

3. Filtered or unfiltered surface water systems having a waterborne epidemic where turbidity unambiguously failed to provide any warning of the disease outbreak

Three outbreaks are considered in this category: the Camas, Washington (1976) giardiasis outbreak, the North Battleford, Saskatchewan (2001) cryptosporidiosis outbreak and the Aspen, Colorado region (1981) outbreak. In all three cases, neither raw nor treated water turbidity provided any reliable basis to predict the occurrence of an outbreak.

4. Unfiltered groundwater systems having a waterborne epidemic where turbidity failed to provide an effective warning of the disease outbreak

One outbreak is considered in this category: the Walkerton, Ontario (2000) enterohemorrhagic *E. coli* and *Campylobacter* spp. outbreak. In this case, no consistent warning of the outbreak could be attributed to the raw water turbidity.

5. Filtered or unfiltered, surface or ground water systems having a waterborne epidemic where the efficacy of a turbidity warning of the disease outbreak cannot be determined with any confidence.

There are countless outbreaks which could be listed under this heading, but only a few selected cases of high relevance were reviewed, either because they occurred in B.C. or in geographic locations similar to B.C. The six outbreaks considered in this category are: the Kelowna, B.C. (1996) cryptosporidiosis outbreak, the Creston / Erickson, B.C. (1985, 1990) giardiasis outbreaks, the Penticton, B.C. (1986) giardiasis outbreak, the 100 Mile House, B.C. (1981) giardiasis outbreak, the Alpine, Wyoming (1998) enterohemorrhagic *E. coli* outbreak and the South Bass Island, Ohio (2004) mixed gastroenteritis; including *Campylobacter* spp., Norovirus, *Giardia* spp. and *Salmonella typhimurium*. As the heading suggests, none of these outbreaks have sufficient clear evidence on turbidity to judge the potential efficacy of turbidity as a reliable warning for avoiding an outbreak, but each elaborates features which further illustrate the challenges of predicting waterborne outbreaks on the basis of feasible predictive factors other than the identifiable vulnerability of the inadequate treatment barriers that were in place at the time of the outbreak.

Other relevant insights provided by the collection of outbreak case studies

Collectively, the 18 outbreak case studies summarized in Appendix A demonstrate some other relevant points. Each of the case studies, even with the widely variable degrees of effort devoted to outbreak investigation and depth of reporting available, illustrate that the details of causation are normally difficult to elaborate, even when massive illness has been caused. For example, the largest of the outbreak case studies, Milwaukee, was subjected to substantial misunderstanding in its earliest published investigative reports which speculated about contamination arising from sources associated with cattle fecal waste (manure). Because this outbreak was so massive as to demand clearer answers and because molecular biology advances allowed for strain typing of archived samples of the pathogen from infected patients more than 5 years later, it was determined that the contamination must have arisen from human sewage sources. To this date, the exact means by which this massive contamination occurred at an intake location 12.8 m below the surface and 2.3 km offshore in Lake Michigan remain unknown. For most outbreaks which receive much less intensive investigation, many details of exactly how the contamination occurred remain uncertain. Some uncertainty is true to a degree even for the Walkerton disaster. The relevant message to the task of this Technical Advisory Committee is that **if uncovering the details of what happened to cause an authentic outbreak proves so difficult, even with the benefit of hindsight:** ***How likely is it that routine monitoring of any one or any combination of parameters or factors in some sort of water quality index will accurately predict, in a functional preventive way, a disease outbreak or endemic disease threat?***

The information from these outbreak case studies is also informative regarding the issue of communicating about health risk in the form of boil water advisories. In most of the case studies, a boil water advisory notice or order of some type was issued. Where evidence is available about the timing of that risk management communication relative to the progress of the outbreak curve, invariably the risk management advice has been issued in the latter stages of the outbreak or even after the outbreak is over. There are few, if any, cases (perhaps Milwaukee which had massive disease occurrence) that point to where the evidence during an outbreak was timely, clear and compelling enough to issue, with confidence, an advisory which substantially reduced the impact of the outbreak on the community. **If it is that difficult to be confident in issuing a timely warning when an outbreak is unfolding and disease is evident:** *How realistic is it to expect that there can be valid, evidentiary criteria for confidently issuing precautionary water quality advisories before an outbreak is allowed to happen?*

Young, Old, Immunocompromised

Risk Involved in Drinking Water Outbreaks

The objective of water treatment is to reduce the probability of acquiring an infection, with or without disease. However, the severity of an outcome resulting from an infection will depend on a variety of factors related to the microorganism and the infected individual. Some of the factors include: virulence of the microorganism, number of organisms ingested, previously acquired immunity (i.e. previous infection), poor immunity (i.e. immunosuppressed or immunocompromised), or a general fragility (i.e. infants or older individuals suffering from other diseases). While exposure to pathogens in contaminated water will result in a given probability of infection, the objective is to reduce, as much as possible, the risk of life-threatening situations.

Immunosuppressed, immunocompromised and older individuals having an increased risk due to other underlying diseases are typically under medical supervision and are aware of the need to minimize a risk of infection and the precautions to take. Drinking water is usually a minor factor because pathogens in water are the same as those transmitted regularly through personal contact, food and animals. These people are usually given advice on how to manage such risks.

For infants, most pediatricians already recommend the use of boiled water for food preparation. The one difficulty that 6 month to 2 year olds have is that they can become rapidly dehydrated: in our part of the world that should not be a problem as an electrolyte solution is routinely given. Older children may already have developed some immunity and therefore tend to be as susceptible to infection as the rest of the population.

RISK COMMUNICATION

As outlined earlier, *risk communication* is a process that seeks to inform affected parties about the meaning of risk assessment predictions and the capabilities of risk management actions. In simpler terms, *risk communication* refers to the process of communicating health risks to affected stakeholders. *Risk communication* should be informed by research aimed at understanding those factors that influence how risk information is perceived, transferred, understood, assimilated, and acted upon. Using this understanding, risk communicators seek to establish meaningful dialogue between risk managers and their stakeholders, founded on effective communication. An early review of the key principles of risk communication that remain applicable was published by Slovic (1986).

Risk communication may encounter one of two extremes, or be located somewhere in between the whole range of possibilities. At one extreme, the stakeholders may not be concerned about a health risk when they should be concerned. In this extreme, the challenge is to motivate them into appropriate action. At the other extreme, stakeholders may be overly concerned about what they believe to be a serious health risk, which according to our best evidence, does not warrant such deep concern. In this extreme, the challenge is to reassure them that the health risk is negligible. In either case, if stakeholders have a low level of trust or confidence in the authorities, who may be perceived by stakeholders to be responsible for the cause and management of the issue, communication is likely to be ineffective.

In the context of this document, a relevant example of risk communication is that which occurs between purveyors of drinking water and their customers, in the form of a *water quality advisory*. This example, according to some of the feedback the TAC has received from health authorities and water purveyors, is seen in some individual situations as being the first case by health authorities and as being the second case by water purveyors, for the same situation. In these situations, the most important communication needs to occur between these two parties to reach a more common understanding, otherwise communication with the public is likely to be futile. While there is clearly evidence that there have been attempts to reach a common understanding, it is equally clear that those attempts have not been successful in all cases.

Risk communication can be undertaken proactively or reactively. An example of proactive risk communication by a water purveyor might include efforts to establish a productive, ongoing dialogue with customers, even in the absence of water quality issues. An example of reactive communication might be issuing a water quality advisory in response to adverse testing results. An effective risk communication process often involves both proactive (strategic) and reactive (contingent) communication efforts.

Proactive communication with stakeholders has proven effective in other settings for establishing trust and credibility of the water purveyor, raising awareness of emergency communication protocols, educating stakeholders about the ongoing processes and results of the purveyor's efforts to maintain high water quality, and establishing a basis for consulting customers about possible process improvements, e.g., adding or modifying treatment regimes.

The TAC has found from prior experience that when more than one authority is involved in a community-based risk issue, e.g., a drinking water purveyor and a local health department, public disagreement or lack of consensus between these authorities is likely to undermine public confidence in both organizations and the decision process. This, in turn, has the potential to negatively affect proactive efforts to engage and inform stakeholders. Conversely, effective communications and relationships between partners responsible for risk management can bolster the belief that everyone is on the "same page", and is likely to improve the potential for effective risk communication.

In B.C., both proactive and reactive risk communication tools have been used. For example, the use of a turbidity index has been preceded by a community education program seeking to inform the public about its purpose. In cases where the turbidity level triggers have been exceeded, a variety of *water quality notices* have been used in the province. The latter communication is largely reactive, since the condition prompting the advisory must arise before the notice is issued. In other jurisdictions, such notices are generally issued only as a last option, i.e., when the supplied water cannot be made safe by immediate improvements in the system.

Research on drinking water advisories suggests that, for many people, these notices alone are unlikely to be effective at preventing risk of waterborne illness for the entire or even a majority of the population. (LaCroix 2006) (O'Donnell et al. 2000) (Willocks et al. 2000). These researchers found that many people, more than 80% in one of these studies, continued to engage in risk-increasing behaviours, e.g., using non-boiled water for brushing teeth or washing raw foods. In the case of boil water advisories, it has also been suggested that the elderly may be at increased risk of scalds or burns.

The following factors may limit the effectiveness of water quality advisories in B.C. for reducing risk to public health:

o   Some information reviewed by the TAC contained terms that are either subjective or open to interpretation, e.g., Interior Health pamphlets 823511 and 823512 (April 2007) "the very young and the very old", and may not provide clear guidance to readers.

o   Some information reviewed by the TAC contained terms that are inaccurate, e.g., Interior Health pamphlet 823521 (April 2007) refers to "Canadian Drinking Water Standards" and "Canadian Standards." Canada sets guidelines, not standards, for drinking water, which may make it difficult for interested readers to locate additional information so they can better evaluate their own risks. The term *standard* may also be perceived to have more regulatory force than the term *guideline*.

o   As noted above, the appearance of poor relations between health authorities and water purveyors, with respect to drinking water issues, is likely to undermine the public's confidence in both of these organizations, including the credibility of communications from them. A preferable situation would be to have these two agencies collaborate on an on-going basis and in a positive way, to the benefit of the water consumer. Such a proactive and positive collaboration should be communicated to the public, elected officials, and the media.

o Some water quality advisories in B.C. have been in place for many years. Recent media reports, supported by interviews conducted by the TAC, suggest that some people may no longer pay much attention to water quality advisories. Research suggests that communities with long-term water quality advisories are less likely to boil their water and more likely to use bottled water (Harding and Anadu 2000). The same study found that most respondents are willing to pay for drinking water improvements.

o Several documents examined by the TAC point out that boil water advisories should contain information about the criteria for lifting the advisory and when the advisory may be lifted (O'Donnell et al 2000). For long-term boil water notices that are issued as a precautionary measure, in lieu of improved treatment, it is not clear when, if ever, the advisory will be lifted.

o Several documents reviewed by the TAC identify the need for multiple approaches and vehicles to communicate with people about health advisories (Burger et al 2003) (Connelly and Knuth 1998). While these research studies focus on fish consumption advisories, vs. water quality, both concluded that multiple communication vehicles are required because people have different learning capacities and styles. The risk communication literature generally supports the position that people have different preferred learning styles, access different sources of information, find different sources more or less credible, and have different literacy and numeracy skills which can affect the accessibility and comprehension of information in various formats. In the Harding and Anadu (2000) study, residents in four communities: one under a short-term boil water advisory, one under a long-term boil water advisory, and two control communities, considered newspapers their *primary* source of information about drinking water; however, mail from the water utility and county health department were named as the most *reliable* sources of information.

ANALYSIS, ADVICE AND RECOMMENDATIONS

The Terms of Reference for the Technical Advisory Committee posed a series of seven questions to be answered. For completeness, we have reproduced those questions followed by our analysis and answers.

1.   What factors of a watershed/drinking water system (e.g., climate, temporal patterns and site-specific information - geography/geology, land use, infrastructure-chlorine residual concentrations, UV transmissivity, turbidity relative to CT) may be used to predict the risk of acquiring a waterborne gastro-intestinal (GI) illness?

There are a number of factors that are related to the risk posed to drinking water safety both by the watershed and the drinking water system.

Factors of a watershed system related to risk include:

- o Sources of fecal material, such as the presence of wild or domestic animals, e.g., cows, horses.
- o Changes in hydrological characteristics, e.g., human development.
- o Turbidity characteristics (inorganic vs. organic) and the source, particularly in unfiltered systems.
- o Precipitation intensity and anomalies, e.g., the amount and timing of rain, snow or snowmelt.

Factors of a drinking water system related to risk are:

- o Loss of chlorine residual, if chemically disinfected.
- o A decrease in UV dose, if there is a lamp failure when disinfected by UV.
- o Absence of practices that can deal with potentially increased risk, e.g., cross-connection control program, assurance of sufficient pressure at all times, secure storage reservoirs, rapid/effective response to water main ruptures.
- o Inadequate qualifications of the operators.

Monitoring indicators of water quality include:

- o Any substantial, unexpected and unexplained change in any water quality parameter.
- o Consumer complaints of water quality problems.
- o Significant turbidity increase in finished water, but this by itself is not always a good predictor.
- o Evidence of a reliable indicator of fecal contamination, such as *E. coli*.

A change in a microbial indicator in source water does not have the same meaning as a change in the indicator in distributed water. The former is a signal of the need to provide adequate treatment to that source water while the latter is a signal that the treatment which has been

provided has failed to perform as intended. Resulting actions are likely to be very different depending on whether the indicator change is in the source water, the distributed water, or both.

The foregoing lists present some major factors that can be used to predict risk, but the main problem arises with: *How good is the risk prediction for guiding any specific actions?* The proportion of risk that can be explained by one or many factors is variable with place and time. Therefore, findings in one study cannot be quantitatively transferred to other locations or events. Currently risk factors can be identified, but not completely enough to develop a quantitative model that can predict risk with adequate confidence for general application. Changes in risk factors can be used to broadly predict the expected changes in risk direction and magnitude, but again not with a high degree of confidence about the specific situation. This limitation can be characterized as presenting problems both with the accuracy[5] and precision[6] of risk predictions.

Overall, reducing the risk factors can make water safer. However, risk reduction always has a cost, regardless of the risk reduction activity. The final choice in balancing the level of risk reduction against the cost is a choice that scientific inquiry cannot answer. However, it is accurate to note that the multiple barrier approach (Table 1), that is widely advocated for public drinking water supplies (O'Connor 2002a), requires such balancing decisions be made to assure that the risk of drinking water contamination is negligible and that the balance of caution in the face of uncertainty is taken towards protecting consumers.

2.   *What is the relationship (quantitative and/or qualitative) between each factor determined in response to Question 1 and the risk of GI microbial illness?*

There is no simple, invariant quantitative relationship between factors of a watershed/drinking water system and the risk of disease among drinking water consumers, but there is no doubt that contaminated drinking water can harm people. Because current information is inadequate and future evidence is not likely to substantially improve, it is futile to try to produce a quantitative relationship, given the inevitable inadequacy of predictive value that any such relationship will experience. To deal with this reality, many jurisdictions use a multi-barrier approach to reduce risks to a negligible level. With such an approach, it is essential to manage all the barriers so they can operate as intended. Upgrades in treatment technology are an important element of a multiple barrier approach, along with a renewed awareness of the importance of source water protection. Appropriate treatment must be geared towards source water characteristics, both current and anticipated.

3.   *Is source water or turbidity (or turbidity at a certain NTU level in an unfiltered surface water source) a valid decision criteria for issuing boil water notices and/or water quality advisories to protect consumers against pathogen risk, and are there other water quality indicators that could be similarly used?*

---

[5] Is the expected value of the prediction correct?
[6] Is the confidence range around the predicted expected value narrow enough to guide meaningful action?

Other than direct knowledge of an event[7] known to have compromised treatment or integrity of distribution in a drinking water system, no single source indicator, for source water or unfiltered treated water, is by itself a reliable criterion for issuing a water quality notice, unless there is an empirically demonstrated relationship between turbidity and/or microbial load for the specific system in question. That relationship could only be developed with a large data base collected with sufficient frequency of measurement for both turbidity and microbial indicators to cover the full range of extreme events which may occur within the system. Current, routine levels of microbial indicator monitoring are unlikely to be of sufficient frequency to provide the necessary range of data values required to develop a robust predictive relationship for a specific system. The ability to establish a meaningful relationship between turbidity and enteric disease in a community is an even more daunting challenge and this is not a direction that the TAC sees as a valuable investment of professional resources compared with improving the effectiveness of barriers in a multiple barrier approach.

Where disinfection is the only treatment, significant failure to disinfect at the level required is a valid decision criterion to issue a water quality notice. Public health officials should be informed immediately so they can determine whether to issue a water quality notice. A decision regarding the issue of a notice should consider whether residents can be informed before the problem is rectified. The TAC noted that there is ample scientific evidence to indicate that failure to disinfect increases the likelihood of viable pathogens being present in the treated water; therefore, a greater risk of enteric infection. The significance of a failure to disinfect should be assessed in the context of relevant information, such as the source and the history of the system. In order to maximize effectiveness in an emergency situation, a notice must be issued very quickly, i.e., within hours of a problem discovery.

The foregoing advice does not mean that the TAC endorses long term use of boil water advisories in lieu of fixing the problem that triggers the advisory. The TAC does not endorse the use of long term advisories in this manner. A chronic advisory does not make water safe, it merely warns consumers that individually they need to deal with unsafe drinking water. The matters related to ineffective communication are discussed in the answer to *Question 7*.

4. ***Can the various factors identified in response to question #1 be effectively combined to provide consistent decision criteria to assist Health Officials in determining whether boil water notices/water quality advisories are necessary?***

As explained in the answer to *Question 1*, the proportion of risk that can be explained by one or many factors is variable with place and time. Therefore, findings in one study cannot be quantitatively transferred to other locations or events. Currently, risk factors can be identified, but not enough to develop a quantitative model that can predict risk with confidence. Changes in the factors can be used to predict changes in risk direction and magnitude, but not with a high degree of confidence about the specifics.

Considering a number of the risk factors of a watershed/drinking water system together can help make better informed decisions, but this can only be done on a case-by-case basis, not as a universal generic index.

---

[7] For example: chlorination failure, power failure, a contaminant spill, flooding, pressure loss.

5.   ***Would it be scientifically feasible and practical to develop and use a "water quality index" or an algorithm based on numerous parameters as a means to accurately portray the level of public health risk in a water supply?***

Development of a water quality index will not accurately portray the level of public health risk in a water supply; judgment will always be necessary. Consideration of existing knowledge about the source, the treatment system and experience with the source/treatment system is likely to lead to better decisions than considering only a triggering event, such as a change in turbidity or even a broader water quality index. The TAC is of the opinion that regular sharing of information between purveyors and decision authorities, even in the absence of a water quality issue, will lead to better decision-making concerning the need for water quality notices.

6.   ***If a "water quality index" might be a feasible approach to pursue, please provide a scientific assessment on the necessary components and relationships of such a "water quality index".***

Given our answer to *Question 5* above that a "water quality index" is not a feasible approach to pursue, no further answer to *Question 6* is required.

7.   ***What kind of guidance exists in the literature on how to most effectively communicate and sustain attention to drinking water advisories?***

There is very little specific research available on the effectiveness of communication through drinking water advisories. Some information is identified on factors influencing the understanding of fish consumption advisories, but this is also limited.

There is also limited information available on communicating and sustaining attention to drinking water advisories; but much is opinion evidence rather than rigorous research-based information.

There is nothing that would provide an expectation of being able to sustain a high level of compliance with a long term advisory.

Regarding proactive communication, the Awwa Research Foundation has developed guidance on how water utilities can communicate more effectively with stakeholders. *Appendix B* includes AwwaRF reports relevant to communication strategies with purveyors and stakeholders. Limited guidance regarding form and content of boil water advisories is available from Canada's Federal-Provincial-Territorial Committee on Drinking Water (2001). Also, in response to Recommendation 7 of Part 1 of the Walkerton Inquiry, the Ontario Ministry of Health and Long-Term Care developed a guidance document for responding to adverse water quality incidents, which addresses communications between stakeholders (OMHLTC 2007). The City of Guelph (undated-a) discusses the form and content of, and procedures for, issuing and rescinding water

quality advisories related to microbial contamination. A related document provides guidance on communicating with the public and the media about risk related to adverse drinking water quality events (City of Guelph undated-b). EPCOR et al. (2007) has worked with Edmonton's Capital Health Authority and Alberta Environment over more than a decade to develop their protocols for calling and removing water quality advisories. Additional related information is available from a variety of Canadian and US water purveyors and associations concerning themselves with drinking water safety, for example, the Ontario Water Works Association. The Ontario Clean Water Agency provides a template that small and medium-sized water treatment plants can use for developing emergency response plans.

After a thorough review of risk assessment and risk communication issues concerning public notification of drinking water, in general and B.C. in particular, along with the examination of scientific relationships between turbidity in raw water supplies and microbial human health risk in finished drinking water, the Technical Advisory Committee found:

- o In general, drinking water advisories do not provide an effective alternative to securing the safety of a drinking water system with appropriate multiple barriers. Advisories can be issued, and rescinded, in the context of an emergency response plan.

- o Setting criteria for lifting the advisory at the time it is issued will help clarify the reason it has been put in place. This may reduce confusion.

- o For clarity, the advisory can also contain the reason for the advisory, actions members of the community should take and where they can get further information.

- o Limited research and anecdotal information suggests that the longer the advisory remains in place, the less impact it will have on behaviour.

- o Many people do not fully understand advisories, i.e., they may not drink unboiled water but may brush their teeth with it or use it for uncooked food preparation.

- o Different people have different learning styles, e.g. visual, auditory, tactile, etc., and different levels of literacy and numeracy. Furthermore, advisories may not physically reach the entire intended audience. Therefore, advisories work better when combined with other forms of information delivery, e.g., face-to-face meetings (in-home or public), information in news media, internet-based information.

- o If information about drinking water quality is provided to consumers regularly, such as a regular newspaper feature, it is critical to provide not only data but information about the *meaning* of the data, particularly with respect to actions consumers can/should take to protect themselves and so avoid confusion.

- o Use of precise language will help communicate who needs to do what, e.g., avoid imprecise terms such as *"the very young and the very old"*. Accurate references to other information will allow interested readers to successfully search for the additional

information, such as correctly referencing Canadian Drinking Water Guidelines rather than referring to Canadian drinking water standards.

o Provision of consistent information by local health authorities and local water purveyors will help avoid undermining confidence in the advice and in the organizations communicating it.

o Advisories are currently issued by regional health authorities. While this has the advantage of incorporating local site-specific factors, it may create the impression that different processes and criteria are used when issuing advisories. A consistent province-wide process to be used by all regional health authorities will help minimize this.

o Anecdotal information suggests that repeated or continuous advisories undermine confidence in the water supply, the regulator, or both.

o Additional risks can come from boiling water, such as an increase in burn frequencies.

CLOSING REMARKS

Overall, there is not an adequate evidentiary basis to develop a water quality index that will predict risk of waterborne illness with sufficient confidence that it can be used to drive the issuance of meaningful water quality advisories. In reviewing the evidence provided and the feedback received from consultations with stakeholders in the province, it is evident that the search for such an index, including the request for the TAC to evaluate evidence for linkages between turbidity and health effects, is really a surrogate for a broader drinking water issue – *whether filtration of surface water supplies should be mandatory*.

Addressing that broader issue is clearly beyond the Terms of Reference for this TAC, but the evidence and feedback considered by us reveals some important insights in relation to that broader issue. All parties agree that protecting public health is essential, consequently disinfection is essential. Furthermore, the clear majority of parties express agreement that a multiple barrier approach for assuring drinking water safety is sound, despite an apparent absence of a commonly agreed-upon description of what a multiple barrier approach (Table 1) means for specific circumstances. Given the foregoing common ground, it is evident that the way forward on resolving the debate about mandating filtration for surface waters is to explore how the commitments to protecting public health and implementing an effective multiple barrier approach can be adapted to the specific circumstances which exist in B.C. Fortunately, recent advances in water treatment technologies, particularly the demonstrated capabilities of UV disinfection, offer the potential to develop equally effective alternative means to conventional filtration for achieving the agreed upon public health protection goals.

Finally, there was substantial feedback about the cost-effectiveness of requiring additional water treatment in relation to the assured reduction of disease that will be achieved. With respect, this expectation inaccurately characterizes the public policy decisions which must be made. Arguably, Walkerton's water system based on a shallow, vulnerable well with minimal treatment was cost-effective for 22 years, from the time it was installed until disaster struck in May 2000, but we doubt anyone would argue it was cost effective with the benefit of hindsight. During those 22 years, it would have been an exceedingly expensive undertaking, if possible at all, to prove conclusively that there would be a public health benefit from upgrading Walkerton's water system. An interim approach of tolerating vulnerable systems, relying on some form of water quality advisory system based on a water quality, or turbidity, index may have become a pragmatic reality in some cases. However, an assessment of the comparative cost of long term reliance on a water quality advisory approach needs to consider not only the public health costs, which are difficult to document and unlikely to be distributed uniformly over time, but also the additional private expenditures of individuals purchasing bottled water or home water treatment devices, the risk posed to visitors and tourists along with a wide variety of other quality of life considerations.

REFERENCES CITED

AAAS & NAS. 1992. Brief for the American Association for the Advancement of Science and the National Academy of Science. *Amici Curiae* to the U.S. Supreme Court No. 92-102 in *Daubert v. Merrell Dow Pharmaceuticals, Inc*. 509 U.S. 570, 590.

Aboytes, A., G. D. Di Giovanni, F. A. Abrams, C. Rheinecker, W. McElroy, N. Shaw and M. W. LeChevallier. 2004. Detection of infectious Cryptosporidium in filtered drinking water. *Journal of the American Water Works Association* 96:88-98.

Akin, E. W. and W. Jakubowski.1986. Drinking water transmission of giardiasis in the United States. *Water Science and Technology*(GB) 18: 219-226.

Alberi, M. R., S. J. Quail and R. A. Kruse. 1987. Solving a Giardia problem in a small treatment system. *Water Engineering Management 134: 23-25.*

Allen, M.J., Edberg, S.C., Reasoner, D.J. 2004. Heterotrophic plate count bacteria-what is their significance in drinking water. *International Journal of Food Microbiology*: 92: 265-274.

APHA, WERF, AWWA. 2005. *Standard Methods for the Examination of Water and Wastewater*, 21st Edition. Washington, D.C.

Aramini, J., C. Stephen and J. P. Dubey. 1998. *Toxoplasma gondii in Vancouver Island cougars (Felis concolor vancouverensis*): serology and oocyst shedding. J. Parasitol. 84(2): 438-440.

Aramini, J., C. Stephen, J. P. Dubey, C. Engelstoft, H. Schwantje and C. S. Ribble. 1999. Potential contamination of drinking water with *Toxoplasma gondii oocysts. Epidemiol. Infect*. 122: 305-315.

Aramini J., J. Wilson, B. Allen, J. Holt, W. Sears., M. McLean, R Copes. 2000. *Drinking water quality and health care utilization for gastrointestinal illness in Greater Vancouver*. Health Canada, Ottawa.

Badenoch, J., C. L. R. Bartlett, C. Benton, D. P. Casemore, R. Cawthorne, F. Earnshaw, K. J. Ives, J. Jeffrey, H.V. Smith, M. S. B. Vaile, D. A. Warrell and A. E. Wright. 1990. *Cryptosporidium in Water Supplies*. London, HMSO, Department of the Environment, Department of Health: 230 pp.

Bahia-Oliveira, L. M. G., J. L. Jones, J. Azevedo-Silva, C. C. F. Alves, F. Orefice and D. G. Addiss . 2003. Highly endemic, waterborne toxoplasmosis in north Rio de Janeiro State, Brazil. *Emergency Infect. Dis*. 9: 55-62.

BCCDC.1996. *Outbreak of cryptosporidiosis associated with municipal drinking water: Cranbrook, British Columbia, June 1996*. B.C. Health and Disease Surveillance; B.C. Centre for Disease Control 5(10): 93-103.

Beaudeau P., P. Payment, D. Bourderont, F. Mansotte, O. Boudhabay, B. Laubies, J. Verdiere. 1999. A time series study of anti-diarrheal drug sales and tap-water quality. *International Journal of Environmental Health Research* 9(4): 293-312.

Bell, A., R. Gill, J. L. Isaac-Renton, A. King, L. Martinez, D. Roscoe, D. Werker, S. Eng, T. Johnstone, R. Stanwick, W. R. Bowie, S. A. Marion, C. Stephen, A. Burnett, J. Cadham, F. Jagdis, P. Macleod, K. Barnard, J. Millar, S. Peck, J. Hull, S. Irwin, J. Hockin, K. Kain, J. Remington and J. P. Dubey. 1995. Outbreak of toxoplasmosis associated with municipal drinking water — British Columbia. *Canadian Commun. Dis. Rep*. 21(18): 161-164.

BGOSHU. 2000. *The Investigative Report of the Walkerton Outbreak of Waterborne Gastroenteritis May-June 2000*. Owen Sound, Ontario, Bruce-Grey-Owen Sound Health Unit: 58 pp. plus appendices.

Boardman G.D., Sproul O.J. 1977. Protection of viruses during disinfection by adsorption to particulate matter. *Journal-Water Pollution Control Fed*. 49(8):1857-61.

Bowie, W. R., A. S. King, D. H. Werker, J. L. Isaac-Renton, A. Bell, S. B. Eng and S. A. Marion. 1997. Outbreak of toxoplasmosis associated with municipal drinking water. *Lancet* 350: 173-177.

Braidech, T.E. and R.J. Karlin. 1985. Causes of a waterborne giardiasis outbreak. *Journal of American Water Works Assoc*. 77(2): 48-51

Burger et al. 2003. Evaluating risk communication about fish consumption advisories: Efficacy of a brochure versus a classroom lesson in Spanish and English. *Risk Analysis* 24(4):791-803

Burkhardt, T. J., J. Jenkins, E. J. Witte, M. McCarthy, T. de Melfi, J. Erb and E. C. Lippy. 1980. Epidemiologic notes and reports: waterborne giardiasis — California, Colorado, Oregon and Pennsylvania. *Morb. Mortal. Weekly. Rep.* 29: 121-123.

CCME. 2004. From Source to Tap: Guidance on the Multi-Barrier Approach to Safe Drinking Water. Federal-Provincial-Territorial Committee on Drinking Water and the CCME Water Quality Task Group. PN1334. www.ccme.ca/assets/pdf/mba_guidance_doc_e.pdf

Chauret et al. 1995. Correlating Cryptosporidium and Giardia with Microbial Indicators. *Journal American Water Works Assoc.* 87(11): 76-84

City of Guelph (undated-a). Waterworks Emergency Plan. Section H1 – Microbial Contamination H5 – *Risk Communications with the Public and the Media*. P. Busatto, Water Works Manager. City of Guelph. February (2008)

City of Guelph (undated-b). Example Waterworks Emergency Plan. Section H5 – *Risk Communications with the Public and the Media*. February (2008)
http://www.owwa.com/hm/inside.php?id=80

Clancy Environmental Consultants Inc. 2007. *An Evaluation of the Effects of Coquitlam Source Water Turbidity on Ozone and UV Disinfection or Greater Vancouver Regional District*. Final Report April 7, 2007.

Connelly, N.A. and B.A. Knuth. 1998. Evaluating risk communication: Examining target audience perceptions about four presentation formats for fish consumption advisory health information. *Risk Analysis* 18(5):649-659

Corso, P. S., M. H. Kramer, K. A. Blair, D. G. Addiss, J. P. Davis and A. C. Haddix. 2003. Cost of illness in the 1993 waterborne Cryptosporidium outbreak, Milwaukee, Wisconsin. *Emergency Infect. Dis*. 9: 426-431.

Craun GF. 1979. Waterborne giardiasis in the United States: a review. *American Journal of Public Health*. 69(8):817-9.

Dufour A., M. Snozzi, W. Koster, J. Bartram, E. Ronchi and L. Fewtrell (Eds). 2003. *Assessing microbial safety of drinking water: Improving approaches and methods*. Edited by A. WHO Drinking Water Quality Series, OECD – WHO, Paris, France [IWA Publishing, London]

Edberg, S.C., Rice, E.W., Karlin, R.J., Allen, M.J. 2000. *Escherichia coli*: the best biological drinking water indicator for public health protection. *Journal of Applied Microbiology* 88: 106S-116S.

Eng, S. B., D. H. Werker, A. S. King, S. A. Marion, A. Bell, J. L. Isaac-Renton, G. S. Irwin and W. R. Bowie. 1999. Computer-generated dot maps as an epidemiologic tool: Investigating an outbreak of toxoplasmosis. *Emergency Infect. Dis*. 5: 815-819.

EPCOR , Capital Health and Alberta Environment. 2007. *Water Emergency Guidelines – Technical and Communications Procedures*: Boil Water Advisory; Chemical Contamination Advisory. Prepared by EPCOR. Revised (October 2007)

F-P-T CDW. 2001. Guidance for Issuing and Rescinding Drinking Water Advisories, *Guidelines for Canadian Drinking Water Quality Supporting Documentation*. Federal-Provincial-Territorial Committee on Drinking Water (revised 2001).

F-P-T CDW, 2003. Turbidity, *Guidelines for Canadian Drinking Water Quality* Supporting Documentation. Federal-Provincial-Territorial Committee on Drinking Water, Health Canada, October 2003.
www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/turbidity/index_e.html

F-P-T CDW. 2007. Guidelines for Canadian Drinking Water Quality - Summary Table. Federal-Provincial-Territorial Committee on Drinking Water, Health Canada, March 2007.
www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sum_guide-res_recom/index_e.html

Fox, K. R. and D. A. Lytle. 1996. Milwaukee's crypto outbreak: investigation and recommendations. *Journal of American Water Works Assoc*. 88(9): 87-94.

Fyfe, M. and A. King. 1997. *Cryptosporidiosis Outbreak in Kelowna: A Report to the Medical Health Officer*. B.C. Centres for Disease Control and Laboratory Centre for Disease Control, Health Canada.

Gammie, L., L. Goatcher and N. Fok. 1998. *A Giardia / Cryptosporidium near miss?* Proc. 8th National Conference on Drinking Water. Quebec City, Quebec. Ed. W. Robertson. Health Canada.

Harding, A.K. and E.C. Anadu. 2000. Consumer response to public notification. *Journal-American Water Works Assoc.* 92(8):32-41

Hoff, JC. 1978. *The Relationship of Turbidity to Disinfection of Potable Water*. Evaluation of the Microbiology Standards for Drinking Water Report EPA-570/9-78-00C, p 103-117, 1978.

Hopkins, R. S., G. B. Gaspard, F. P. Williams, R. J. Karlin, G. Cukor and N. R. Blacklow. 1984. A community waterborne gastroenteritis outbreak: evidence for rotavirus as the agent. *American Journal of Public Health* 74(3): 263-265.

Hopkins, R. S., R. J. Karlin, G. B. Gaspard and R. Smades. 1986. Gastroenteritis: case study of a Colorado outbreak. *Journal-American Water Works Assoc.* 78(1): 40-44.

Hoxie, N. J., J. P. Davis, J. M. Vergeront, R. D. Nashold and K. A. Blair. 1997. Cryptosporidiosis-associated mortality following a massive waterborne outbreak in Milwaukee, Wisconsin. *American Journal of Public Health* 87: 2032-2035.

Hrudey, S. E. and E. J. Hrudey. 2004. *Safe Drinking Water - Lessons from Recent Outbreaks in Affluent Nations*. London, IWA Publishing.

Hrudey, S. E. and R. Walker. 2005. Walkerton - 5 years later. Tragedy could have been prevented. *Opflow* 31(6): 1, 4-7.

Hunter PR, P. Payment, N. Ashbolt and J. Bartram. 2003. Assessment of risk, pp. 79-110, *In Assessing microbial safety of drinking water: Improving approaches and methods*. Edited by A. Dufour et al. WHO Drinking Water Quality Series. OECD – WHO. Paris, France [IWA (International Water Association) Publishing, London]

Irwin, G. S., A. S. King, D. H. Werker, A. A. Bell, R. Gill, J. Issac-Renton, S. B. Eng, T. Johnstone, W. R. Bowie, S. A. Marion, D. Roscoe, A. Burnett, F. Jagdis, P. Macleod, S. Peck and J. Hull. 1996. An outbreak of toxoplasmosis associated with municipal drinking water — water quality and water supply aspects. Seventh National Conference on Drinking Water. Charlottetown, Prince Edward Island. *Canadian Water and Wastewater Association*. Ottawa.

Isaac-Renton, J. L., C. Cordeiro, K. Sarafis and H. Shahriari. 1993. Characterization of *Giardia duodenalis* isolates from a waterborne outbreak. *J. Infect. Dis*. 167: 431-440.

Isaac-Renton, J. L., L. F. Lewis, C. S. L. Ong and M. F. Nulsen. 1994. A second community outbreak of waterborne giardiasis in Canada and serological investigation of patients. *Trans. R. Soc. Trop. Med. Hyg*. 88: 395-399.

Isaac-Renton, J. L., W. R. Bowie, A. King, G. S. Irwin, C. S. Ong, C. P. Fung, M. O. Shokeir and J. P. Dubey. 1998. Detection of Toxoplasma gondii oocysts in drinking water. *Appl. Environ. Microbiol.* 64: 2278-2280.

IWA. 2004. The Bonn Charter for Safe Drinking Water. London: International Water Association. www.iwahq.org/templates/ld_templates/layout_633184.aspx?ObjectId=640178

Jensen H, K. Thomas, DG. Sharp. 1980. Inactivation of coxsackieviruses B3 and B5 in water by chlorine. *Appl Environ Microbiol*. 40(3):633-40

Karlin, R.J. and R.S. Hopkins. 1983. Engineering defects associated with Colorado Giardiasis outbreaks, June 1980 - June 1982. In: Giardia lamblia in water supplies. Technical Research Series. *American Water Works Association*. Denver, CO. pp. 93-96

Kirner, J. C., J. D. Littler and L. A. Anglelo. 1978. A waterborne outbreak of giardiasis in Camas, Washington. *Journal-American Water Works Assoc*. 70(1): 35-40.

LaCroix, B.J. 2006. *Impact of a Boil Water Advisory on In-Home Water and Food Handling Practices*: A Qualitative Study. PhD Thesis, University of Guelph

Laing, R. D. 2002. *Report of the Commission of Inquiry into Matters Relating to the Safety of* the *Public Drinking Water in the City of North Battleford Saskatchewan*, Department of Justice, Government of Saskatchewan: 372 pp. http://www.northbattlefordwaterinquiry.ca

LeChevallier M.W., W.D. Norton, R. G. Lee. 1991. Giardia and Cryptosporidium spp. in filtered drinking water supplies. *Appl. Environ. Microbiol*. 57(9):2617-21.

LeChevallier, M.W., W.D. Norton and R.G. Lee. 1991a. Occurrence of Giardia and Cryptosporidium spp. in surface water supplies. *Appl. Environ. Microbiol*. 57: 2610-2616.

LeChevallier, M.W. and W.D. Norton. 1992. Examining relationships between particle counts and Giardia, Cryptosporidium, and turbidity. *Journal of American Water Works Assoc*., 84: 54-60.

Lim, G. Aramini J,, Fleury, M., Ibarra, R. and R. Meyers (2002) *Investigating the relationship between drinking water and gastroenteritis in Edmonton: 1993-1998*. Health Canada, Ottawa.

Lippy, E. C. 1981. Waterborne disease: occurrence is on the upswing. *Journal American Water Works Assoc*. 73: 57-62.

MacKenzie, W. R., N. J. Hoxie, M. E. Proctor, M. S. Gradus, K. A. Blair, D. E. Peterson, J. J. Kazmierczak, D. G. Addiss, K. R. Fox, J. B. Rose and J. P. Davis. 1994. A massive outbreak in Milwaukee of cryptosporidium infection transmitted through the public water supply. *N. Eng. J. Medicine*. 331: 161-167.

Mann, A.G., C.C. Tam, C.D. Higgins, L.C. Rodrigues. 2007. The association between drinking water turbidity and gastrointestinal illness: a systematic review. *BMC Public Health*. 7: 256 [7 pages].

Marchant, G.E. and C. Coglianese. 2000. Brief for Marchant et al. *Amici Curiae* to the U.S. Supreme Court No. 99-1257 in Browner, U.S. EPA v. American Trucking Association, Inc.

Moorehead, W. P., R. Guasparini, C. A. Donovan, R. G. Mathias, R. Cottle and G. Baytalan. 1990. Giadiasis outbreak from a chlorinated community water supply. *Can. Journal Public Health* 81: 358-362.

NHMRC. 2004. Australian *Drinking Water Guidelines*.Canberra, ACT: National Health and Medical Research Council. http://www.nhmrc.gov.au/publications/synopses/eh19syn.htm

Nilsson, K.A. 2004. Personal communication with S.E. Hrudey.

O'Connor, D. R. 2002a. Report of the Walkerton Inquiry. Part 2. *A Strategy for Safe Water.* Toronto. The Walkerton Inquiry: 582 pp.
http://www.attorneygeneral.jus.gov.on.ca/english/about/pubs/walkerton

O'Connor D. R. 2002b. Report of the Walkerton Inquiry. Part 1. *The Events of May 2000 and Related Issues*. Toronto: The Walkerton Inquiry: 504 pp.
www.attorneygeneral.jus.gov.on.ca/english/about/pubs/walkerton

O'Donnell, M., C. Platt and R. Aston. 2000. Effect of a boil water advisory on behaviour in the management of a water contamination incident. *Comm. Dis. Pub. Health* 3(1):56-59

Olsen, S. J., G. Miller, T. Breuer, M. Kennedy, C. Higgins, J. Walford, G. McKee, K. Fox, W. Bibb and P. Mead. 2002. A waterborne outbreak of *Escherichia coli* O157:H7 infections and hemolytic uremic syndrome: implications for rural water systems. *Emergency Infect. Dis*. 8: 370-375.

Ong, C. S. L., D. L. Eisler, S. H. Goh, J. Tomblin, F. M. Awad-El-Kariem, C. B. Beard, L. Xiao, I. M. Sulaiman, A. A. Lal, M. Fyfe, A. S. King, W. R. Bowie and J. L. Issac-Renton . 1999. Molecular epidemiology of cryptosporidiosis outbreaks and transmission in British Columbia, Canada. *American Journal Trop. Med. Hyg.* 61: 63-69.

Ong, C., M. Pearce, D. Eisler, S. H. Goh, A. S. King, W. R. Bowie, J. L. Issac-Renton and C. B. Beard. 1997. *An outbreak of cryptosporidiosis in southeastern, British Columbia, Canada*. International Symposium on Waterborne Cryptosporidium, 355-365.

Payment, P., J Siemiatycki, L. Richardson, G. Renaud, E. Franco, M. Prévost. 1997) A prospective epidemiological study of gastrointestinal health effects due to the consumption of drinking water. *International Journal of Environmental Health Res*. 7: 5-31

Payment P., and Hunter P.R. 2001. Endemic and epidemic infectious intestinal disease and its relationship to drinking water. Chap 6, pp. 115-134, In Water quality: guidelines, standards & health: risk assessment and management for water related infectious disease. Eds L Fewtrel and J Bartram, World Health Organisation Water Series, [*IWA (International Water Association*) *Publishing*. London].

Payment, P., and M.S. Riley. 2002. Resolving the global burden of gastrointestinal illness: A call to action. *American Academy of Microbiology*, Washington DC, 32 pages.

Payment, P., P. Hunter. 2003. Intervention Studies. Chap. 18 In *Drinking Water and Infectious Disease: Establishing the Links*. Hunter PR, White M and Ronchi E. (Eds), CRC Press Inc, Boca Raton, FL.

Payment P., M. Waite, and A. Dufour. 2003. Introducing parameters for the assessment of drinking water quality. pp. 47-77, In *Assessing microbial safety of drinking water: Improving approaches and methods.* Edited by A. Dufour, M. Snozzi, W. Koster, J. Bartram, E. Ronchi and L. Fewtrell. WHO Drinking Water Quality Series. OECD – WHO. Paris, France [IWA Publishing, London]

Payment, P. 2003. Surveillance of Waterborne Disease. Section 1 In *Drinking Water and Infectious Disease: Establishing the Links.* By Hunter PR, White M and Ronchi E. (Eds), CRC Press Inc, Boca Raton, FL.

Rice, E. W., M. J. Allen, S. C. Edberg. 1990. Efficacy of β-glucuronidase assay for the identification of *Escherichia coli* by the defined substrate technology. *Applied and Environmental Microbiology* 56: 1203-1210.

Rizak S. and S. Hrudey. 2007. *Strategic Water Quality Monitoring For Drinking Water Safety*. Cooperative Research Centre (CRC) for Water Quality and Treatment Research Report 37, Salisbury, Australia,

Shaw P. K., R. E. Brodsky, D. O. Lyman, B. T. Wood, C.P. Hibler, G.R. Healy, K.I. Macleod, W. Stahl, M.G. Schultz.1977. A communitywide outbreak of giardiasis with evidence of transmission by a municipal water supply. *Ann Intern Med*. 87(4):426-32

Slovic., P. 1986. Informing and educating the public about risk. *Risk Analysis* 6(4):403-415

Stirling, R., J. Aramini, A. Ellis, G. Lim, R. Meyers, M. Fleury and D. Werker. 2001a. Waterborne cyptosporidiosis outbreak, North Battleford, Saskatchewan, Spring 2001. *Can. Commun. Dis. Rep*. 27(22).

Stirling, R., J. Aramini, A. Ellis, G. Lim, R. Meyers, M. Fleury and D. Werker. 2001b. North Battleford, Saskatchewan, Spring 2001, Waterborne cyptosporidiosis outbreak. Health Canada, Public Health Branch, September 24, 2001, 67 pp.

Taylor A Jr, Craun GF, Faich GA, McCabe LJ, Gangarosa EJ. 1972. Outbreaks of waterborne diseases in the United States 1961-1970. *J Infect Dis.* 125(3):329-31

US EPA. 2006. The Multiple Barrier Approach to Public Health Protection. Office of Water (4606M) EPA 816-K-06-005. September 2006. www.epa.gov/safewater/smallsys/pdfs/guide_smallsystems_mba_09-06-06.pdf

Vogt, R. L., H. E. Sours, T. Barrett, R. A. Feldman, R. J. Dickinson and L. Witherell. 1982. Campylobacter enteritis associated with contaminated water. *Ann. Intern. Med*. 96: 292-296.

Wallis, P. M., N. Bounsombath and S. Brost. 2002. *Waterborne cryptosporidiosis at North Battleford, SK: the Lab's Perspective*. 10th National Conference on Drinking Water, Halifax, Canadian Water and Wastewater Association, Ottawa.

Walter, S. 1991. The ecological method in the study of environmental health. II. Methodologic issues and feasibility. *Environmental Health Perspectives 94*: 67-73.

Watson, B. 1996. *City of Kelowna – Cryptosporidium Investigation – Updated to August 20, 1996*. Central and East Kootenay Health Units.

Weniger, B.G., M.J. Blaser , J. Gedrose, E.C. Lippy, and D.D. Juranek. 1983. An outbreak of waterborne giardiasis associated with heavy water runoff due to warm weather and volcanic ash fall. *American Journal of Public Health* 73: 868-872.

WHO. 1958. International Standards for Drinking-water, Geneva, *World Health Organization*.

WHO. 1963. International Standards for Drinking-water, 2nd ed., Geneva, *World Health Organization*.

WHO. 1971. International Standards for Drinking-water, 3rd ed., Geneva, *World Health Organization.*

WHO. 1984. Guidelines for drinking-water quality, Volume 1, Recommendations, Geneva, *World Health Organization.*

WHO. 1993. Guidelines for drinking-water quality, 2nd ed., Volume 1, Recommendations. Geneva, *World Health Organization*.

WHO. 1998. Guidelines for drinking-water quality, 2nd ed., Addendum to Volume 1, Recommendations. Geneva, *World Health Organization*.

WHO. 2004a, 2007. Guidelines for Drinking-Water Quality, 3rd (current) edition, including the first addendum. 2007. Geneva, *World Health Organization*.
www.who.int/water_sanitation_health/dwq/gdwq3rev/en/index.html

WHO. 2004b. Water, Sanitation and Hygiene Links to Health, World Health Organization. Facts and Figures. *World Health Organization.*
www.who.int/water_sanitation_health/publications/facts2004/en/

Willocks, L.J., F. Sufi, R. Wall, C. Seng and A.V. Swan. 200). Compliance with advice to boil water during an outbreak of cryptosporidiosis. *Comm. Dis. Pub. Health* 3(2):137-140

Wright RA, Spencer HC, Brodsky RE, Vernon TM. 1997. Giardiasis in Colorado: an epidemiologic study. *American Journal of Epidemiology*. 105(4):330-6.

Yamamoto, N., K. Urabe, M. Takaoka, K. Nakazawa, A. Gotoh, M. Haga, H. Fuchigami, I. Kimata and M. Iseki. 2000a. Outbreak of cryptosporidiosis after contamination of the public water supply in Saitama, Prefecture, Japan in 1996. *Kansenshogaku Zasshi -J. Japanese Assoc. Infect. Dis*. 74(6): 518-526.

APPENDICES

Appendix A**:**

Summary Tables of Selected Relevant Waterborne Epidemics with Turbidity Evidence

Appendix B:

AwwaRF Reports Related to:
Communicating with the Public
Watershed Management and Monitoring Programs

Appendix C:

US EPA Drinking Water Regulations

Appendix A

Summary Tables of Selected Relevant Waterborne Epidemics with Turbidity Evidence

The initial number on each of the following tables corresponds with one of the four categories listed below:

1. Surface water systems without filtration having epidemics involving turbidity as a potential warning.

2. Surface water systems with filtration having epidemics involving turbidity as a potential warning.

3. Surface water systems with or without filtration where turbidity failed to provide any warning.

4. Groundwater systems under the direct influence of surface contamination where turbidity failed to provide an effective warning.

Relevant Waterborne Disease Outbreaks with Some Turbidity Evidence

1.1 Unfiltered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of the disease outbreak

Victoria, B.C.

Date: October 1994 – April 1995

Water Supply System:
Protected catchment with storage reservoirs and chloramination for disinfection.

Health consequences: An estimated 2900 to 7800 possible cases (>100 lab-confirmed) of toxoplasmosis.

References: Bell et al. 1995, Bowie et al. 1997, Eng et al. 1999, Irwin et al. 1996, Isaac-Renton et al. 1998, Aramini et al. 1998, Aramini et al. 1999, Bahia-Oliveira et al. 2003, Hrudey & Hrudey 2004.

Nature of the failures: There was no evidence reported of any problems with the chloramination disinfection process, but this means of disinfection is not effective for protozoan pathogens. The resistance of the specific pathogen, *Toxplasma gondii*, was unreported, but was presumed to be similar to the high chlorine resistance found with *Cryptosporidium* spp. Chloramine is a less effective primary disinfectant than free chlorine. The reservoir implicated in this outbreak had a relatively short residence time (8 to 10 days) and was more accessible to domestic pets than other surface water supplies in the region. The implicated reservoir was taken permanently out of service after the outbreak was identified.

Role of non-turbidity indicators in outbreak: The outbreak curve showed peaks following two heavy rainfall events. Total coliforms were largely unrelated to rainfall peaks, but fecal coliforms were related to the first rainfall peak, data was not collected for the second peak because of sampling site access problems. Intermittent *Giardia* and *Cryptosporidium* monitoring was unrelated to the peaks in cases on the outbreak curve.

Role of turbidity in outbreak: Two obvious turbidity peaks (0.65 NTU and > 1 NTU) above a background average of 0.25 – 0.3 NTU from continuous turbidity monitoring appeared less than 2 weeks before each of the two obvious peaks in cases on the outbreak curve.

Boil Water Advisory: By the time there was an adequate understanding that drinking water was responsible for the outbreak (this was the first reported outbreak of toxoplasmosis in a developed country), the outbreak was over, so no Boil Water Advisory was issued.

Conclusion: *The raw water turbidity spikes which occurred did provide an advance signal for the peaks in toxoplasmosis cases evident in the outbreak curve, but the elevated turbidity levels were modest and similar turbidity spikes had occurred in previous years under similar weather conditions. Interpretation in retrospect is possible only because of the extensive outbreak investigation that was performed, but it is reasonable to conclude that not every turbidity spike experienced in this water system gave rise to a toxoplasmosis outbreak.*

1.2 Unfiltered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of the disease outbreak

Cranbrook, B.C.

Date: May – June 1996

Water Supply System: Two creeks (Joseph and Gold Creeks) provided water to a single fenced, 23 m deep reservoir. Water was withdrawn 7.6 m above the bottom of the reservoir and dosed with 1.5 mg/L chlorine, normally increased to 2.3 mg/L during spring runoff in May and June, to achieve a distribution system residual of 0.5 mg/L

Health consequences: A potential 2000 cases of cryptosporidiosis was estimated (29 cases lab-confirmed).

References: BCCDC 1996, Ong et al. 1997, Ong et al. 1999, Hrudey & Hrudey 2004.

Nature of the failures: The drinking water system relied upon chlorination and *Cryptosporidium* oocysts are resistant to chlorine. Cattle were released to graze on a Crown grazing lease on May 18 and they accessed a portion of Joseph Creek feeding into the reservoir and large quantities of manure were found within 30 m of the banks. *Cryptosporidium* oocysts were isolated from the raw water, from the cattle and in one distribution system sample.

Role of non-turbidity indicators in outbreak: No water quality parameters other than turbidity were discussed in the published outbreak reports. The circumstances of allowing cattle access to the source watershed during spring time for a system that had no effective barrier to *Cryptosporidium* oocysts was the primary warning signal for this outbreak

Role of turbidity in outbreak: The outbreak investigation reported that raw water turbidity during the spring runoff period was typically in the 1.5 to 2 NTU range, but during the period when the contamination is believed to have occurred, turbidity was higher, reaching 2.7 NTU.

Boil Water Advisory: The boil water advisory was issued on June 21 when the outbreak was essentially over (i.e. no new incident cases were reported)

Conclusion: *Although there is a report of an elevated turbidity signal in this case, that turbidity value of 2.7 NTU, when "normal" turbidity might be considered to be as high as 2 NTU, cannot be considered a very effective warning for this contamination episode.*

1.3 Unfiltered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of the disease outbreak

Bennington, VT, USA

Date: June 1978

Water Supply System: Chlorination with no filtration drawing from a local stream.

Health consequences: An estimated 3000 possible cases (15 lab-confirmed) of campylobacteriosis

References: Vogt et al. 1982, Hrudey & Hrudey 2004.

Nature of the failures: The surface water supply was subject to contamination from animal wastes and deficient sewage systems, but treatment was limited to chlorination without filtration.

Role of non-turbidity indicators in outbreak: The water system had experienced bacteriologic contamination the previous year on three occasions when inadequate chlorination was provided. There were no water quality indicators, other than turbidity, reported prior to the outbreak in June 1978. Heavy rainfall occurred on May 31 (3.6 in) and June 1 (1.5 in) following at least 2 weeks with no significant precipitation.

Role of turbidity in outbreak: During the heavy rainfalls, "increased turbidity" was reported, but no measured numbers were reported in the reference documenting this outbreak. The outbreak curve was clearly rising by June 2, implying a short but conceivable incubation time (typical of 2 to 5 days within a range of 1 to 10 days) for campylobacteriosis after the elevated turbidity and heavy rainfall.

Boil Water Advisory: A boil water notice was issued after the investigation of the outbreak began, shortly after the outbreak was over and it remained in effect for 9 months until a new water treatment plant was commissioned. The town had previously been under 3 boil water notices the previous year because of chlorination deficiencies and it was speculated that some residents may have continued to boil their water throughout the outbreak.

Conclusion: *The elevated raw water turbidity (not quantified) which was reported apparently could have provided some advance signal for the rise of cases in the outbreak curve, but the lack of quantification or reported turbidity makes this observation of limited value. Likewise, no history of elevated turbidity in the absence of disease outbreaks is available for this case. At best, this case suggests that turbidity may be observed in advance of an outbreak, but this case study cannot validate a conclusion that a rise in turbidity will signal an outbreak.*

1.4 Unfiltered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of the disease outbreak

Bradford, PA, USA

Date: July - December 1979

Water Supply System: Chlorination with no filtration drawing from three local water reservoirs in what was considered a "protected" water shed.

Health consequences: An estimated 2900 to 3500 possible cases (407 lab-confirmed) of giaridiasis

References: Burkhart et al. 1980, Lippy, 1981, Akin and Jakubowski, 1986, Hrudey & Hrudey 2004.

Nature of the failures: The unfiltered surface water reservoirs experienced heavy rainfall and the only treatment barrier, chlorination, was ineffective as applied, for the disinfection of *Giardia*.

Role of non-turbidity indicators in outbreak: Following heavy rains (not quantified) in July and August, 1979, citizens complained of "discoloured and muddy" water. A number (10 in total) of non-compliant total coliform samples were reported in August, September and October, but some samples experienced 3 to 5 days delays before analysis, so the validity of some bacterial counts was suspect.

Role of turbidity in outbreak: During the heavy rainfall periods, turbidity measures in excess of 10 NTU were reported "on numerous occasions". Ironically, the city had applied for and had been granted an exemption by the Environmental Protection Agency for notifying consumers about exceeding the prevailing maximum contaminant level for turbidity of 5 NTU. No outbreak curve was published to allow an unambiguous determination of whether the turbidity exceedances could have served as effective warning for the outbreak of giardiasis.

Boil Water Advisory: According to one account of this outbreak, advice to boil water was provided by the media after discussions with health officials, but no official boil water advisory was mentioned in any of the published accounts of the outbreak.

Conclusion: *The association of elevated raw water turbidity (> 10 NTU) which was reported to be associated with this outbreak of giardiasis raises the possibility of turbidity having provided some advance signal for the rise of cases in the outbreak curve, but the lack of details on timing of the increased turbidity in relation to the occurrence of disease makes this observation of limited value. This case study provides insufficient evidence to validate a conclusion that a rise in turbidity will signal an outbreak.*

1.5 Unfiltered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of the disease outbreak

Red Lodge, MT, USA

Date: July 1980

Water Supply System: Chlorination with no filtration drawing from a stream collecting runoff from the surrounding Rocky Mountains north of Yellowstone National Park.

Health consequences: An estimated 780 possible cases (24 lab-confirmed) of giardiasis

References: Weniger et al. 1983, Alberi et al. 1987, Hrudey & Hrudey 2004.

Nature of the failures: The unfiltered surface water reservoirs experienced heavy runoff from rapid melting caused by the darkening of the snow cover by ash fallout (on May 19, 1980) from the Mt. St. Helens eruption (May 18, 1980). The only treatment barrier, chlorination, was ineffective as applied, for the disinfection of *Giardia*.

Role of non-turbidity indicators in outbreak: Rapid snow melt leading to heavy runoff caused local flooding occurring from May 20 to 22 and again from June 20 to 22. The first cases were reported at the end of May, with peaks of cases in the outbreak curve observed around mid-June and again in early and mid July. One of two tapwater samples collected in early August was positive for coliforms and no chlorine residual was detectable.

Role of turbidity in outbreak: During the heavy runoff, local flooding periods, raw water turbidity reached over 10 NTU in May and approached 8 NTU in June. Residents reported cloudiness of their tapwater during these heavy runoff events. Outside these two spikes, raw water turbidity was running between 1 and 2 NTU. The turbidity peaks appeared about 3 weeks before the peaks in cases of giardiasis on the outbreak curve, which the investigators interpreted as consistent with reports to that time of a typical incubation period of 15 days for giardiasis. The literature now reports an incubation time of 7 to 10 days within a range from 1 to 75 days for giardiasis. The 3 week incubation suggested in this case, if the turbidity spikes were indicative of exposure to infective *Giardia* cysts, is longer than normally expected.

Boil Water Advisory: The public was advised to boil their water temporarily, but no dates for this warning relative to the outbreak were reported in the published outbreak investigation.

Conclusion: *The association of two raw water turbidity spikes (> 8 - 10 NTU) which appeared (albeit with an unusually long incubation period) to be associated with two peaks of the outbreak curve for giardiasis raises the possibility of turbidity having provided some advance signal for the outbreak . In this case the observed turbidity peaks were considered unusual for this system and, as such, they may have provided a valid warning of contamination.*

2.1 Filtered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of a disease outbreak

Milwaukee, WI, USA

Date: March – April 1993

Water Supply System: Raw water was drawn through a 5.6 km intake pipeline extended 2.3 km into Lake Michigan at 12.8 m depth and treated by pre-chlorination, potassium permanganate (intermittent) coagulation, granular media filtration, and chloramination.

Health consequences: An estimated 400,000 cases of cryptosporidiosis, 4400 hospitalizations and 50 deaths among immun-compromised patients over the subsequent 2 years.

References: Mackenzie et al. 1994, Fox & Lytle 1996, Corso et al. 2003, Hoxie et al. 1997, Badenoch et al. 1990, Hrudey & Hrudey 2004.

Nature of the failures: Sewage contaminated the raw water intake of the Howard Avenue plant in Lake Michigan following severe winter storms. Filtration operation at this plant was sub-standard for fine particle removal and filter backwash water was recycled back into the raw water feed, a practice that had been implicated in the preceding UK cryptosporidium outbreaks and warned against by the UK Badenoch inquiry.

Role of non-turbidity indicators in outbreak: Only total coliform data were reported in the literature for the period surrounding the outbreak. Raw water total coliforms ranged from <1 to ~3200 cfu/100 mL during the period of contamination, but treated water total coliforms were consistently zero. A very distinct peak in complaint calls from a baseline of < 3 per day up to almost 50 on one day occurred about a week before the peak of cases of cryptosporidiosis on the outbreak curve.

Role of turbidity in outbreak: Raw water turbidity showed several peaks (approximately: 20, 14, 17, 12 and 18 NTU) in the 4 weeks before the peak of cases of cryptosporidiosis on the outbreak curve (the last of these raw water peaks of ~18 NTU occurred about a week before the peak in cases), followed by a raw water peak of 44 NTU coinciding with the peak of cases (i.e. too short a time for plausible disease incubation). The treated water turbidity exhibited two peaks above 1.5 NTU about one week before the peak of cases of cryptosporidiosis on the outbreak curve. This period was considered to be a plausible incubation time for cryptosporidiosis.

Boil Water Advisory: After being alerted to a possible outbreak on Monday, April 5, an outbreak investigation team was mobilized on April 7 and a boil water advisory was issued at 8:00 PM that evening. Later data revealed that the outbreak began to be evident on about March 31 and it peaked between April 3 and 6.

Conclusion: *The treated water turbidity spikes which occurred did provide a potentially viable warning for this outbreak (as did the spike in consumer complaints), but the raw water turbidity and total coliforms provided no useful warning for this outbreak because there was intervening and at least partially effective treatment (filtration and disinfection). It is noteworthy that five other water filtration plants on Lake Michigan experienced treated water turbidity spikes exceeding 1 NTU (highest was 5.2 NTU) during the same period, without experiencing outbreaks of cryptosporidiosis*

2.2 Filtered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of a disease outbreak

Eagle-Vail, CO, USA

Date: March 1981

Water Supply System: Direct pressure filtration (no chemical coagulation) and chlorination for raw water drawn from the Eagle River.

Health consequences: Over 80 cases of gastroenteritis were identified among 168 persons interviewed (an attack rate of 48%), but no estimate of total illness among the ~3500 persons potentially at risk of exposure was given. This was likely because the seasonal nature of the resort residences made difficult any accurate estimate of exposed consumers at the time of the outbreak.

References: Hopkins et al. 1984, Hopkins et al. 1986, Hrudey & Hrudey 2004.

Nature of the failures: A combination of factors contributed to this outbreak. The raw water source, the Eagle River, was receiving inadequately treated sewage from the resort community of Vail, the direct filtration plant, operating without chemical coagulation, was ineffective for fine particle removal, the pressure filter bed was poorly maintained and operated and finally, and likely most critical, the chlorinator failed for up to 24 hours between March 4 and 5. The chlorinator was alarmed, but the automatic alarm was apparently shut off with no corrective action being taken.

Role of non-turbidity indicators in outbreak: Numerous flaws were evident in these circumstances sufficient to indicate a high risk scenario, but there was not sufficient water quality monitoring reported to judge whether any non-turbidity measures may have been able to signal trouble.

Role of turbidity in outbreak: Finished water turbidity averaged 2.5 to 3.5 NTU during March when the outbreak occurred, an unacceptably high turbidity value for a filtered water supply. Raw water turbidity was not reported, but it would have almost certainly been higher because no chemical coagulation was practiced to potentially add turbidity to the raw water (only if it performed poorly).

Boil Water Advisory: No information was provided in the published reports about this outbreak concerning whether a boil water advisory was ever issued.

Conclusion: *Turbidity in finished water may have provided a marginal indicator of an outbreak risk, but this risk was likely not made active until the chlorinator failed.*

2.3 Filtered surface water systems having a waterborne epidemic involving turbidity which may have served as a potential warning of a disease outbreak

Ogose, Saitama, Japan

Date: June 1996

Water Supply System: 75% of the water supply was provided by a water treatment plant providing coagulation, granular media filtration, chlorination to raw water drawing from two river sources located downstream from two small sewage treatment plants.

Health consequences: An estimate of more than 9,100 cases of cryptosporidiosis (125 lab-confirmed cases).

References: Yamamoto et al. 2000, Hrudey & Hrudey 2004.

Nature of the failures: The sewage treatment plant discharges (one serving 300 persons, the other serving 185 persons) upstream of the drinking water intake placed a burden to maintain a high efficiency of fine particle removal by the water treatment, processes (coagulation and filtration). There was some mention of discontinuance of the use of the chemical coagulant which may have played a role in the apparently inadequate treatment performance which triggered the outbreak.

Role of non-turbidity indicators in outbreak: No water quality parameters other than turbidity were reported, leaving only the circumstances of the upstream sewage discharges as an indicator of outbreak risk.

Role of turbidity in outbreak: Raw turbidity was monitored continuously and it was shown to spike to an equivalent of 160 NTU. This major spike was a little more than a week before the rise in cases in the outbreak curve. There were two smaller raw water turbidity spikes above an equivalent of 25 NTU which occurred at the beginning of the rise of cases in the outbreak curve. Raw water turbidity spikes of about 50 and 30 NTU also occurred more than 3 weeks before the major 160 NTU spike.

Boil Water Advisory: A boil water advisory was issued on June 19, the day before the second peak on the ~30 day outbreak curve that started with elevated cases about June 1.

Conclusion: *The raw water turbidity spikes preceding the outbreak curve might be interpreted as providing a warning of the outbreak, but long term turbidity data for this source would need to be evaluated to determine that the turbidity spikes preceding the outbreak were truly unusual and therefore reliably indicative of the outbreak risk.*

3.1 Filtered or unfiltered surface water having a waterborne epidemic where turbidity unambiguously failed to provide any warning of the disease outbreak.

Camas, WA, USA

Date: April – May 1976

Water Supply System:
Unfiltered, prechlorinated water drawn from two creeks (Boulder and Jones) draining separate, isolated watersheds was distributed to some residences along raw water pipeline before filtration plant

Health consequences:
Estimated 600 cases of giardiasis (25 lab-confirmed) over more than 6 weeks.

References: Kirner et al. 1978, Hrudey & Hrudey 2004.

Nature of the failures: The Camas water system allowed residential connection to pre-chlorinated, unfiltered water along a pipeline from two surface water sources to the community water filtration plant. The watersheds were regarded as isolated with limited human activity. The pre-chlorination of the piped water before filtration failed on 3 occasions in April because of mechanical problems. There were also numerous problems with the filtration operation and cross connections were located between raw water and the filtered water providing an unreliable filtration barrier.

Role of non-turbidity indicators in outbreak: During the period before and during the outbreak, only one of 8 bacteriological samples (not specified as to whether it was fecal or total coliforms) taken per month was unsatisfactory. The chlorine residual was zero during the three chlorination failures and these periods provided plausible warnings of subsequent cases of illness on the outbreak curve. Retrospective monitoring for *Giardia* cysts found them in sediments in treatment plant reservoirs. Evidence of beaver activity in the watershed was observed, but no beavers could be trapped to confirm that beavers were infected.

Role of turbidity in outbreak: Raw water turbidity was generally low (around 1 NTU), but it spiked to 15 NTU at the end of March (more than 2 weeks before the chlorination failures and even more before the first cases) and spiked on 3 days to 7.0, 5.0 and 10.0 between April 18 and May 4 in the middle and latter part of the outbreak curve. Treated water turbidity was generally < 0.5 NTU. The outbreak investigators concluded: "*Turbidity and coliform count alone are inadequate parameters on which to judge the biological quality of filter effluent*". They also concluded: "*Low turbidity and coliform data in raw and finished waters from a treatment process are inadequate to ensure that all biological contaminants of a filtered water system are subject to disinfection.*"

Boil Water Advisory: A "boil water order" was imposed on all areas that could not be flushed immediately. Although no date was given for the boil water order, the notation that it occurred after determining whether flushing could be performed suggests that the boil water order came late in, if not after the outbreak was evident.

Conclusion: *The raw water turbidity spikes which occurred did not provide a useful warning for this outbreak. The best warning indicator was the chlorinator failure periods.* [i]

3.2 Filtered or unfiltered surface water having a waterborne epidemic where turbidity unambiguously failed to provide any warning of the disease outbreak.

North Battleford, SK

Date: March / April 2001

Water Supply System: The treatment plant provided coagulation, granular media filtration, chlorination to water drawn from a bank intake on the North Saskatchewan River, 3.5 km downstream of the City's chlorine-disinfected sewage effluent outfall on the same bank of the river

Health consequences: An estimated 5,800 to 7,100 cases of diarrheal illness (275 cases of lab-confirmed cryptosporidiosis).

References: Laing et al. 2002, Stirling et al. 2001a,b, Wallis et al. 2002, Hrudey & Hrudey 2004

Nature of the failures: The filtration plant for the City of North Battleford was subjected to routine maintenance on March 20, 2001 after which the plant was not properly brought back online. While chlorination was maintained, fine particle removal performance was impaired with negligible clarification (before filtration) achieved after March 20. The intake location gave rise to limited dilution of the City's sewage effluent. Monitoring of the sewage effluent in May, when the outbreak was already in decline, showed up to 12,000 oocysts per litre.

Role of non-turbidity indicators in outbreak: The in-plant process test for clarification performance showed negligible clarification was being achieved approximately a week before the cases of diarrheal illness began to rise above background at the start of the outbreak curve. Sales of antidiarrheal medications at a local pharmacy began to rise in parallel with the occurrence of cases.

Role of turbidity in outbreak: Average turbidity of the treated water fluctuated from 0.16 to 0.96 NTU during the leadup to and during the outbreak. The 0.96 NTU peak occurred on April 2 (following 2 days at 0.6 NTU) but the outbreak was already well underway by that time. The only other notable treated water turbidity peak before the onset of the outbreak was about 0.5 NTU, but it occurred on February 26, almost a month before the onset of the outbreak. The raw water turbidities during the period of clarifier malfunction ranged from 2.5 to 4 NTU for March 21 to April 7, rising to 7 NTU on April 7, about a week before the highest peak of cases in the outbreak curve. Raw water turbidity ultimately peaked on April 20 at 30 NTU when the outbreak was already about two thirds complete.

Boil Water Advisory: A "precautionary drinking water advisory" was issued on April 25 at the insistence of health officials, over the objections of the Mayor of North Battleford who noted the disruption caused by one called in September 2000 over inadequate chlorine residual. The precautionary advisory was upgraded to a boil water order on April 26 when it was understood by health officials in consultation with the drinking water regulator (Saskatchewan Environment and Resource Management) following revelations from the City that the water treatment plant had been non-functional 20 for fine particle removal since March. These actions came as the outbreak was almost over.

Conclusion: *The raw water turbidity was of essentially no predictive value relative to the outbreak curve. The treated water turbidity showed two distinct peaks (0.5 and 0.96 NTU), neither of which was predictive of the outbreak curve. The most useful indicator prior to the outbreak, was the process performance test that showed negligible clarification performance prior to filtration for a period which coincided with a reasonable incubation period (a week to 10 days) and ongoing non-performance while the outbreak persisted over the following 5 weeks.*

3.3 Filtered or unfiltered surface water systems having a waterborne epidemic where turbidity unambiguously failed to provide any warning of the disease outbreak.

Near Aspen, CO, USA (Highland Water & San. District)

Date: November 1981

Water Supply System: The treatment plant provided prechlorination, sedimentation (with no chemical coagulation) and granular media filtration (with no post chlorination) for water drawn from a snow-fed high mountain stream northwest of the alpine resort of Aspen

Health consequences: Approximately 20 of the 165 persons served suffered giardiasis.

References: Braidech & Karlin 1985, Hrudey & Hrudey 2004.

Nature of the failures: The mountain resort watershed was inhabited by beaver. The water treatment plant was the original unit installed 18 years earlier and investigation after the outbreak revealed that the filters were poorly operated and maintained. A supply outage (treated water storage drawn to zero) occurred and the outbreak happened after the system was restarted.

Role of non-turbidity indicators in outbreak: There were limited water quality parameters measured for this system, but no coliforms were detected in the treated water and a chlorine residual of ~0.4 mg/L was estimated based on dosage, but the actual chlorine residual was not measured and was unknown. The risk of Giardia cysts in the raw water supply was evidently not recognized.

Role of turbidity in outbreak: The treated water daily turbidity ranged from 0.28 to 0.71 NTU during October – November 1981 and the turbidity on October 31, after the supply outage was 0.44 NTU. These values, all <1 NTU were also typical of raw water in this region and there was nothing remarkable about any of the daily values that would have served to warn of the outbreak of giardiasis. The outbreak study authors commented: "*Neither coliform or turbidity tests indicated a potential problem…meeting the MCL for these two parameters is of little or no value in determining whether the finished water of a given system may contain cysts.*"

Boil Water Advisory: The outbreak report makes no mention of a boil water advisory being issued, but the chronology described suggests that the outbreak investigation was launched after the outbreak was finished. The local water system was connected to the larger, nearby Aspen system which provided effective filtration treatment of water from the same creek source and the offending plant was permanently shut down.

Conclusion: *The treated water daily turbidity measure provided no effective warning of the giardiasis outbreak, given knowledge at that time when the allowable filtered water turbidity was 1 NTU. The reported turbidity levels are now recognized as indicative of seriously inadequate filtration performance, but there was no specific turbidity spike to coincide with the breakthrough of the Giardia cysts which caused the outbreak.*

4.1 Unfiltered groundwater systems having a waterborne epidemic where turbidity failed to provide an effective warning of the disease outbreak.

Walkerton, Ontario

Date: May 2000

Water Supply System: Treatment was limited to chlorination only for a shallow well (producing from 5.5 to 7.4 m). This well was located in a low area collecting surface runoff and subject to local fecal contamination (demonstrated on commissioning in 1978) and influenced by nearby cattle manure.

Health consequences: 7 deaths, 65 hospitalizations, 27 cases of haemolytic uremic syndrome and an estimated 2300 cases of gastroenteritis caused by enterohemorrhagic *E. coli* O157:H7 and *Campylobacter* spp.

References: O'Connor 2002, BGOSHU 2000, Hrudey & Hrudey 2004, Hrudey & Walker 2005.

Nature of the failures: Justice O'Connor devoted most of his 500 page Volume 1 Report of the Walkerton Inquiry to describing and commenting on all of the failures which occurred in Walkerton, ranging from a provincial government undermining its provincial regulator, to provincial public health authorities and the drinking water regulator (Ontario Ministry of Environment) failing to properly discharge their responsibilities to the public down to the local authority running a high risk drinking water system with inadequately trained personnel some of whom falsified records and lied to investigators.

Role of non-turbidity indicators in outbreak: A single distribution system sample, which was collected 4 days after the contamination occurred, revealed massive contamination by *E. coli* 6 days after the contamination, but these results were ignored by the system's General Manager (Stan Koebel). The system's foreman (Frank Koebel) failed to measure chlorine residual daily, as required by the regulator, thereby missing an opportunity to reveal the contamination within 24 hours. Because no other water quality indicators signalled a problem, the boil water advisory was not called until 9 days after the contamination. Consumers who were becoming ill within 5 days after the contamination were advised by health officials to drink lots of water until the boil water advisory was issued. Bacterial indicators such as fecal coliforms and later *E. coli* had been shown to be an intermittent problem with raw water from the contaminated Well 5 since the first pump test that was performed at commissioning in 1978, and with regularity thereafter until the fatal outbreak in May 2000.

Role of turbidity in outbreak: The operators in Walkerton were supposed to measure turbidity 4 times per day, but they failed to perform these measurements before and during the outbreak. Some distribution system samples were taken on May 24, 3 days after the boil water advisory and 12 days after the contamination occurred, but the hydrants were not flushed before sampling, so the high turbidity samples (up to 85 NTU in one case) were not representative of water in the distribution system. Water with turbidity above 5 NTU starts to become visibly cloudy, but no reports of water cloudiness were received from any Walkerton residents. Excessive and fluctuating turbidity (greater than 1 NTU) had been an intermittent feature of raw water from Well 5 since it was commissioned in 1978, without being associated with a detectable outbreak before May 2000.

Boil Water Advisory: The Boil Water Advisory was issued on May 21, some 9 days after contamination is believed to have occurred and about half way through the outbreak curve. If the operators had been measuring chlorine residual daily as they were supposed to have done, the inability to establish a chlorine residual in the contaminated water would have provided an immediate signal to shut the system down. The boil water advisory remained in effect for 6 months while the distribution system was flushed and renovated and ultimately a membrane filtration plant was brought online.

Conclusions: *Turbidity might have given some warning of contamination for the Walkerton outbreak. This is difficult to judge accurately because the operators failed to measure it 4 times a day as they were supposed to do. However, it is evident that visible turbidity (>5NTU) was not reported by any Walkerton residents, despite the opportunities to report problems experienced, that was offered by the public inquiry. It is also evident that turbidities greater than 1 NTU had occurred regularly in the 22 years preceding the May 2000 outbreak without signalling a detectable disease outbreak in Walkerton, although endemic disease or smaller scale outbreaks were likely occurring.*

5.1 Filtered or unfiltered surface or ground water systems having a waterborne epidemic where the efficacy of a turbidity warning of the disease outbreak cannot be determined with any confidence. (*There are countless outbreaks which could be listed here, only selected cases of high relevance, i.e. B.C. or related outbreaks, are provided*)

Kelowna, B.C.

Date: July, August 1996

Water Supply System: Chlorination with no filtration drawing from raw water intakes in Okanagan Lake. At the time of the outbreak, 10 different water systems served populations ranging from 32,000 (City of Kelowna) to 1800 (West Kelowna Estates) in the region.

Health consequences: An estimated 14,000 or more possible cases (157 lab-confirmed) of cryptosporidiosis occurred within the region. Furthermore, Kelowna was implicated in 62% of all cryptosporidiosis cases reported from elsewhere in the province (77 of a total of 138 confirmed cases responded to interview) during the outbreak period plus an unknown number of out-of-province visitors. For example, Capital Health in Edmonton investigated a possible cryptosporidium outbreak finding ~30 cases against a background of essentially zero in August through November 1996. These cases turned out to be Edmontonians who returned from the Okanagan.

References: Fyfe and King 1997, Ong et al. 1999, Watson 1996, Gammie et al. 1998.

Nature of the failures: Local creeks feeding Lake Okanagan experienced a 100 year flood level on June 4, 1996. Creek flows remained high until the end of June. One major creek had feedlot and pasture areas that were inundated. The unfiltered surface water system relied upon chlorine disinfection, which is ineffective for Cryptosporidium.

Role of non-turbidity indicators in outbreak: Very little water quality monitoring was being done on these systems, so virtually no water quality data was available to judge whether there were quality warning signals prior to the outbreak. The flood conditions were essentially the only non-turbidity warning.

Role of turbidity in outbreak: Turbidity was only being measured monthly in 1996 and those values were less than 1 NTU in May, June and July 1996. It is certainly possible that spikes in turbidity levels could have occurred during this period and once per month samples provide no basis to determine whether or not turbidity spikes did occur. The outbreak report makes no reference to consumer complaints of cloudy water before or during the outbreak, suggesting that any turbidity spikes that may have occurred would likely be below 5 NTU (approximate level of visibility to consumers).

Boil Water Advisory: The boil water order was issued on August 12 when the outbreak was clearly in decline (onset cases over the following 3 weeks were 3, 1 and 2 out of a total of 157 in the outbreak). Late boil water orders seem to be common in outbreaks of cryptosporiodosis.

Conclusion: *This large outbreak of cryptosporidiosis is essentially neutral on whether turbidity provided or failed to provide any useful warning of the outbreak because of the extremely limited water quality monitoring data, including meagre turbidity data obtained prior to and during the outbreak.*

5.2 Filtered or unfiltered surface or ground water systems having a waterborne epidemic where the efficacy of a turbidity warning of the disease outbreak cannot be determined with any confidence. (*There are countless outbreaks which could be listed here, only selected cases of high relevance, i.e. B.C. or related outbreaks, are provided*)

Creston / Erickson, B.C.

Date: January – April 1990

Water Supply System: The drinking water supply for Creston and the surround Erickson Improvement District was drawn and distributed, completely untreated from Arrow Creek, a mountain stream flowing into the Goat River.

Health consequences: Two outbreaks of giaridiasis were documented in this system, one between January and April 1990 with 124 lab-confirmed cases and one five years earlier in November – December 1985 with 83 lab-confirmed cases. The publications available on these outbreaks did not estimate the plausible total number of cases, but typically, total cases can be 10 or more fold higher than lab-confirmed cases.

References: Isaac-Renton et al. 1993; Isaac-Renton et al. 1994, Nilsson 2004, Hrudey & Hrudey 2004.

Nature of the failures: The use of a completely untreated water source relying upon the water to be "pristine" ignores the pathogen risk from wildlife fecal wastes (in this case *Giardia* carried by beaver). Unlike the multiple barrier approach that is commonly advocated for assuring safe drinking water, this water system had zero barriers. The subsequent outbreaks, five years apart allowed an analysis of cases in the second outbreak to reveal an attack rate of 68% among newcomers to the area compared with only 4% among residents who were present during the previous outbreak.

Role of non-turbidity indicators in outbreak: No water quality data of any sort was reported, other than the positive identification of *Giardia* cysts in all samples taken from the distribution system, so the only indicator for this system was the inherent vulnerability of using a drinking water supply with no treatment whatsoever.

Role of turbidity in outbreak: No mention, was made of any issues with turbidity in this water supply, although concerns were expressed about allowing logging into the watershed, which may have raised some concerns about creating more runoff and possibly higher turbidity in Arrow Creek. Nothing explicit was reported on this, however.

Boil Water Advisory: There is nothing reported in the references on this outbreak concerning a boil water advisory, but other sources are being pursued for information because one was apparently called.

Conclusion: *Because there were no turbidity data reported, turbidity is not even mentioned in the published reports of the giardiasis outbreaks, and the second outbreak lasted over several months, it is likely that turbidity provided no effective warning for this outbreak. However, given the absence of explicit data on turbidity in relation to illness, no confidence can be assigned to this inference.*

5.3 Filtered or unfiltered surface or ground water systems having a waterborne epidemic where the efficacy of a turbidity warning of the disease outbreak cannot be determined with any confidence. (*There are countless outbreaks which could be listed here, only selected cases of high relevance, i.e. B.C. or related outbreaks, are provided*)

Penticton, B.C.

Date: June – August, November 1986

Water Supply System: The water system consisted of upper and lower intake ponds off Penticton Creek, supplemented by a well and an intake on Okanagan Lake. The water was chlorinated only, without filtration.

Health consequences: An estimated 3100 cases of giardiasis (362 laboratory confirmed) in a first outbreak (June to Augsut) and 109 laboratory confirmed cases in a subsequent outbreak (in November).

References: Moorehead et al. 1990, Hrudey & Hrudey 2004.

Nature of the failures: An unfiltered surface water supply subject to *Giardia* contamination from beavers and possibly livestock and domestic pets, relied upon only chlorination during a period of spring runoff.

Role of non-turbidity indicators in outbreak: No water quality data are reported in the publication describing this outbreak, but reference is made to total coliforms having increased 10 fold in the raw creek water during the first half of June, but only a single positive fecal coliform had been reported in treated water, on May 12, well before the population exposure to *Giardia* cysts would have happened.

Role of turbidity in outbreak: The published reference on this outbreak describes the suspected and plausible source for the outbreak as having raw water that was "very turbid" during the spring runoff, but no numbers were reported, nor were any comparisons offered between this spring runoff turbidity and other years.

Boil Water Advisory: Despite the clear and emergent evidence of a waterborne outbreak, no boil water advisory was called. Reference was made to reluctance to make such a call given the reliance of the community on the tourist industry during the summer.

Conclusion: *The data provided in the published reference on this series of two giardiasis outbreaks are insufficient to draw any conclusion about the adequacy of turbidity in the raw water as an effective warning of the outbreak. While elevated turbidity was definitely evident during the spring runoff, no measurements were cited and no comparisons made to allow an assessment of validity of turbidity as a primary indicator.*

5.4 Filtered or unfiltered surface or ground water systems having a waterborne epidemic where the efficacy of a turbidity warning of the disease outbreak cannot be determined with any confidence. (*There are countless outbreaks which could be listed here, only selected cases of high relevance, i.e. B.C. or related outbreaks, are provided*)

100 Mile House, B.C.

Date: Fall 1981

Water Supply System: surface water from Bridge Creek within the uncontrolled Horse Lake watershed was supplied without filtration, with chlorination providing minimal contact time

Health consequences: about 60 laboratory confirmed cases of giardiasis.

References: Bryck et al. 1988.

Nature of the failures:
Beavers and muskrat trapped upstream of the water supply intake were confirmed to be infected with *Giardia* after the outbreak. Reliance on chlorination only, without filtration would have been an inadequate barrier to transmission of *Giardia* through the public water system, but no details of conditions at the time of the outbreak were provided.

Role of non-turbidity indicators in outbreak:
No water quality information was available prior to the outbreak.

Role of turbidity in outbreak:
No turbidity information was available prior to the outbreak, but monitoring during a subsequent *Giardia* treatability study performed on the slow sand filter installed for this community after the outbreak indicated that source water turbidity was generally less than 2 NTU and was typically less than 1 NTU over several months.

Boil Water Advisory:
No information was located about whether a boil water advisory had been called in this outbreak.

Conclusion: *The absence of turbidity or other water quality data before this outbreak occurred preclude drawing substantive conclusions about the role of turbidity in the outbreak, but post-outbreak turbidity monitoring suggested that turbidity levels for this water source were generally low.*

5.5 Filtered or unfiltered surface or ground water systems having a waterborne epidemic where the efficacy of a turbidity warning of the disease outbreak cannot be determined with any confidence. (*There are countless outbreaks which could be listed here, only selected cases of high relevance, i.e. B.C. or related outbreaks, are provided*)

Alpine, WY, USA

Date: mid-June, early-July 1998

Water Supply System: The community water system was fed by an unconfined aquifer through an underground spring supplied through perforated collection pipes into an underground concrete storage tank. No filtration or disinfection was provided.

Health consequences: An estimated 157 people (residents and visitors from 15 states) suffered gastroenteritis, including 71 lab-confirmed cases of enterohemorrhagic *E. coli*.

References: Olsen et al. 1988; Hrudey & Hrudey 2004.

Nature of the failures: The details of water contamination leading to this outbreak were not determined, but the water system was unprotected and untreated. A large pool of water was located over the area where the collection pipes were located and there were elk and deer feces evident. The pathogen responsible for the outbreak was not isolated from any feces samples nor in the water supply in the outbreak investigation that was launched about 2 weeks after the outbreak occurred. A cross-sectional study revealed that among a family reunion group visiting the community, those who drank the community water supply were 9 times more likely to be ill than those who did not and the attack rate among this group of visitors was about 50% compared with an attack rate of 23% among community residents. The latter observation suggests that local residents had acquired some level of immunity. Because this is an alpine resort community, located between Yellowstone and Grand Teton National Parks, the elevated risk to tourist visitors is noteworthy.

Role of non-turbidity indicators in outbreak: The only water quality data reported for this outbreak was total coliform monitoring which showed 1 sample out of 5 positive in April, 4 out of 7 positive in May and 2 out of 10 in June the month of the outbreak.

Role of turbidity in outbreak: No data were reported for turbidity on this vulnerable water supply.

Boil Water Advisory: Although chlorination of the water supply was initiated when it came under suspicion as the vector for this outbreak, no mention was made of a boil water advisory being called.

Conclusion: *The lack of any water quality data for turbidity precludes judging any potential role for turbidity as a warning indicator in this outbreak. The elevated risk for visitors from a vulnerable water supply in this mountain tourist destination was noteworthy.*

5.6 Filtered or unfiltered surface or ground water systems having a waterborne epidemic where the efficacy of a turbidity warning of the disease outbreak cannot be determined with any confidence. (*There are countless outbreaks which could be listed here, only selected cases of high relevance, i.e. B.C. or related outbreaks, are provided*)

South Bass Island, Ohio

Date: mid-July through August 2004

Water Supply System: The village of Put-In-Bay provided chlorinated surface water from Lake Erie, while around the island, private homes and businesses relied on individual groundwater supplies.

Health consequences: An estimated 1450 cases of gastroenteritis (16 cases of campylobacteriosis, 9 cases of norovirus, 3 cases of giardiasis and 1 case of salmonellosis, all lab-confirmed) among 900 residents and thousands of visitors to this resort island.

References: Fong et al. 2007, O'Reilly et al. 2007.

Nature of the failures: The community water treatment plant was functioning properly and was not directly implicated in the outbreak, although cross-connections with private water supplies may have played some role. The outbreak was primarily attributed to pervasive groundwater contamination of the karst aquifer by on-site septic tanks, land application of septage, infiltration of land runoff and a possible direct connection with Lake Erie. An illegal sewage disposal operation using a sink hole was also reported.

Role of non-turbidity indicators in outbreak: A large proportion of individual (30%) and businesses with non-community public (71%) well water supplies tested positive for *E. coli* during the outbreak investigation.

Role of turbidity in outbreak: Although considerable microbiological and pathogen monitoring was done for the outbreak investigation, no data on turbidity was located.

Boil Water Advisory: A total of 21 transient, non-community (public) well water systems were put on "no use" orders between August 26 and September 15, essentially after the outbreak was concluded.

Conclusion: *The absence of any reported turbidity data precludes drawing any conclusions about any possible role of turbidity as a warning indicator. The South Bass Island region is a resort and tourist destination so that many who became ill were visitors.*

Appendix B

AwwaRF Reports related to:
Communicating with the Public
Watershed Management and Monitoring Programs

A complete list of AwwaRF reports including effective approaches to communicating with the public can be found at: www.awwarf.org[8]

The following partial list of AwwaRF reports relates to watershed management and monitoring programs. The practical knowledge in these reports would be useful to water purveyors and the medical health agencies in determining how best to ensure public health protection.

Effective Watershed Management for Surface Water Supplies. 1991. Report # 90587.

Giardia Cysts and Cryptosporidium Oocysts Survival in Watersheds and Factors Affecting Inactivation. 1999. Report # 90761.

Source Water Assessment: Variability of Pathogen Concentrations. 2002. Report # 90906.

Source Water Protection Reference Manual. 2002. CD-ROM. BPM watershed practices in US, Canada, and UK. Report #90907.

Impacts of Major Point and Non-Point Sources on Raw Water Treatability**.** 2003. Report # 90959F.

Fate and Transport of Surface Water Pathogens in Watersheds**.** 2005. Report # 91078F.

Development of Event-based Pathogen Monitoring Strategies for Watersheds**.** 2006. Report # 91114.

---

[8] Permission to copy or distribute sections or pages in AwwaRF reports is required per copyright. Contact the B.C. Ministry of Health and Human Services Library, 1515 Blanshard St., Victoria B.C. V8W 3C8. email: hlth.library@gov.bc.ca

Appendix C

US EPA Drinking Water Regulations

The following section of the Drinking Water Regulation relates specifically to the TAC's report. The entire volume can be accessed and downloaded at http:/www.acess.gpo.gov/nara/cfr/waisidx_02/40cfr141_02.html

Title 40: Protection of Environment

Chapter 1: Environmental Protection Agency
Part 141:   National Primary Drinking Water Regulations

141.73   Filtration.

141.83   Source water treatment requirements.

141.100 Criteria and procedures for public water systems using point-of-entry devices.

141.101 Use of bottled water.

141.171 Criteria for avoiding filtration.

141.173 Filtration.

141.205 Content of the public notice.

141.520 Is my system subject to the updated watershed control requirements?

141.521 What updated watershed control requirements must my unfiltered system implement to continue to avoid filtration?

141.522 How does the State determine whether my system's watershed control requirements are adequate?

141.535 What if my system uses chloramines, ozone, or chlorine dioxide for primary disinfection?

141.552 My system consists of ``alternative filtration'' and is required to conduct a demonstration--what is required of my system and how does the State establish my turbidity limits?