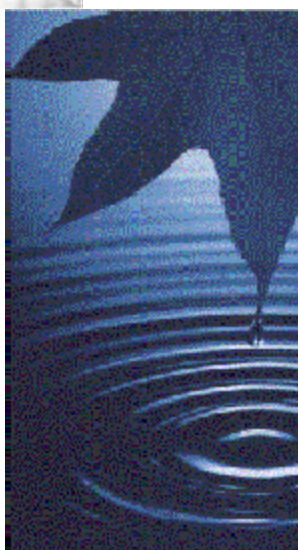




9th NATIONAL CONFERENCE ON DRINKING WATER

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Subcommittee on Drinking
Water



*Maintaining Drinking Water Quality –
Lessons from the Prairies and Beyond*

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Abstracts

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ORAL PRESENTATIONS

CURRENT ACTIVITIES OF HEALTH CANADA'S WATER QUALITY PROGRAM

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The quality of drinking water is of continuing concern to all Canadians. Everyday, each of us comes into contact with this most precious resource and expects our drinking water to be safe, clean and palatable. Health Canada's Drinking Water Program monitors the issues that are of concern to Canadians and provincial and territorial governments and ensures that the necessary guidelines are established.

The *Guidelines for Canadian Drinking Water Quality* are developed in collaboration with all provinces and territories, through the Federal-Provincial Subcommittee on Drinking Water (Subcommittee); Health Canada provides the technical Secretariat to the Subcommittee. The first comprehensive Canadian drinking water quality guidelines were published in 1968; the latest edition (*Guidelines for Canadian Drinking Water Quality- 6th Edition*) includes guidelines for microbiological quality, for more than 80 physical/chemical parameters, and for 78 radiological parameters.

Because drinking water is considered a natural resource, the responsibility to provide safe drinking water to Canadians generally falls under provincial/territorial jurisdiction. The *Guidelines for Canadian Drinking Water Quality* are used by the provinces and territories as a basis for establishing their own enforceable guidelines, objectives or regulations for drinking water quality. As the Secretariat to the Subcommittee, Health Canada's Water Quality Program plays a key leadership role by conducting national drinking water quality surveys and research on health effects and treatment technology, and by evaluating contaminants found in drinking water. The results of these evaluations are published in the *Guidelines for Canadian Drinking Water Quality*. Health Canada is also responsible for the safety of materials that come into contact with drinking water and has introduced legislation into Parliament to that effect.

Most enforceable provincial/territorial drinking water quality requirements are based on the scientific assessments prepared by Health Canada's Drinking Water Program for publication in the *Guidelines for Canadian Drinking Water Quality*. Current issues of concern which will be discussed during this presentation include aluminum, arsenic, chlorinated disinfection by-products (CDBPs) and cyanobacterial toxins (Microcystin-LR).

SESSION 1

GROUND WATER QUALITY IN RURAL SASKATCHEWAN - EMERGING ISSUES FOR DRINKING WATER

By:

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In Saskatchewan, a large portion of rural residents obtain their domestic and drinking water from ground water supplies. In 1997, Sask Water initiated an advisory program for rural residents to address growing public concern about the safety of ground water supplies for domestic and consumption use. Through this program, Sask Water has monitored over 500 wells covering a range of different aquifers, well types, and depths. The analytical results to date have identified a number of parameters that exceed aesthetic objectives, as well as a number of emerging health related issues that need to be addressed if ground water is utilized as a drinking water supply.

Most Saskatchewan ground water supplies experience problems with high total dissolved solids, iron, and manganese. Monitoring results have also shown that many of the source waters tested experience elevated sulphate, sodium, and total hardness levels. In most cases, one or more aesthetic objective set for drinking water was exceeded. A number of health related parameters have also been identified, including: arsenic, selenium, coliform bacteria, and nitrates.

While the presence of dissolved organic carbon has been well documented for surface water supplies, organics are not routinely monitored in ground water supplies. The findings of this monitoring program have found organics to be present at levels above 5 mg/L in a significant number of wells, with concentrations up to 46 mg/L observed for one supply.

The results of this program provide the first comprehensive assessment of ground water quality throughout rural Saskatchewan and form an important component of the Provincial ground water database. This paper presents an overview of the water quality information collected to date, highlighting the health and aesthetic parameters found in Saskatchewan ground water supplies. The results emphasize the importance of regular monitoring, to provide adequate treatment and protection of rural drinking water supplies.

DEVELOPMENT OF A BOIL WATER EMERGENCY RESPONSE PLAN FOR A WATER UTILITY

By:

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With the identification of protozoans such as *Giardia* and *Cryptosporidium* becoming more widespread in surface waters and in treated drinking water, it is advisable for water utilities and health boards to develop plans for dealing with the occurrence of these organisms and to define the guidelines under which "boil water advisories" would be called, and also to confirm conditions whereby the advisories could be rescinded. The calling of boil water advisories is generally the legislated responsibility of the local Medical Officer of Health, but in practice the process will go much more smoothly if all parties involved are aware, in advance, of the conditions for calling such advisories, and of the consequences in terms of dealing with customer concerns, handling the media, and evaluating water treatment plants and water quality data.

AQUALTA, the water utility supplying Edmonton and surrounding areas, undertook an exercise in conjunction with Capital Health, the local health board, to develop such a set of guidelines, following the finding of protozoan cysts in some samples of drinking water in 1997, although no increase in waterborne disease cases was observed in the community.

The process involved the setting up of a Water Quality Advisory Committee in 1998 with representatives from the local Health Boards, from Alberta Environment (the water regulator), from the University of Alberta, and from regional municipalities supplied by the Aqualta drinking water system. Sub-committees of this group looked at Water Quality Issues and at Communications in more detail. These groups met regularly and will continue to meet on ongoing issues.

The Water Quality group reviewed risks, the need for action plans for water utilities and health boards when water quality problems occurred, and developed a set of "Boil Water Guidelines" which all parties could agree upon, and which were accepted for ongoing use in early 1999. The guidelines listed the possible reasons for calling such a notice, the parameters of concern with corresponding intermediate action levels, and emergency boil-water levels, and the rationale for rescinding any advisory notice.

The Communications group looked at ways of improving the exchange of information among all parties involved, developing a rapid response system for alerting responsible agencies of any emergency condition, preparing information materials ready to go out to the public if required. The group also looked at the development of general information pamphlets on waterborne disease, *Giardia/Cryptosporidium* risk scenarios, and the provision of information to high-risk groups (the immune-compromised). A number of tabletop exercises were held to confirm the workability of the boil water advisory plan.

A real benefit of the whole process is that everyone involved met with people in the other areas, and was exposed to a variety of points of view. The communication pathways were greatly improved, and the developed plan was reached by consensus and had appreciable buy-in from all parties. Customers and stakeholders can now rely on prompt coordinated action if there is any risk to public health. The process is strongly recommended for all water utilities.

EXPERIENCE WITH PRODUCT FAILURES TO NSF STANDARDS

By:

Stan Hazan, NSF International, Veronique Morriset, Health Canada

NSF International has worked with Health Canada to develop important statistical information on product testing results for companies seeking certification to ANSI/NSF Standards 60 and 61, for Drinking Water Additives, and to ANSI/NSF Standards 42, 44, 53,58, and 62 for Drinking Water Treatment Units.

These standards address the health effects and toxicology issues of products used to collect, treat, distribute, store, and filter drinking water from municipal source to the tap, and to residential water filters. The standards, and related certification programs have served to protect consumers from potentially harmful levels of contaminants in drinking water.

Legislation in the US. mandates certification to standards 60 and 61 in more than 85% of states. Several provinces in Canada also require certification through policy or legislation. The standards have become widely accepted in plumbing codes in Canada and the US. Additionally, Standard 61 is referenced in ANSI/ASME plumbing products standards and will be referenced in, their counterpart, CSA plumbing standards.

Health Canada commissioned NSF International to review its files and records, and document the types of products failing initial certification caused by leaching of contaminants (not performance of devices), the contaminants causing the failures and the levels at which the contaminants would have occurred in drinking water had the products been allowed to enter the marketplace.

The presentation will provide detailed information on initial product failures due to leachates and will outline how the standards, and accompanying certification programs have protected drinking water quality in the US. and Canada.

THE EUROPEAN DRINKING WATER DIRECTIVE - A SCOTTISH PERSPECTIVE

By:

Colin McLaren
The Scottish Executive
Water Services Unit

The European Union published a new Drinking Water Directive in December 1998. The Member States of the European Union have 2 years to transpose the Directive into national law and 5 years to meet the standards set.

The standards in the new Directive that pose the greatest difficulties for the Scottish water authorities are those for trihalomethanes and lead. At present the national standard for trihalomethanes is 100µg/l based on a rolling 3 month average. In 1998 nearly 50% of supplies in Scotland failed to meet the existing standard. The new Directive sets an interim standard of 150µg/l as a maximum to be achieved by 2003 and a tighter standard of 100µg/l to be met by 2008. It would not be politically acceptable to set a lower standard for THMs than already exists. The new regulations therefore are likely to set a standard of 100 µg/l as a maximum from the outset. As can be seen from the failure rate in 1998, much work remains to be done to achieve the 100 µg/l standard across Scotland. To date, the view has been that in controlling THM formation disinfection should not be compromised. The high failure rate for THMs, while of concern, has not therefore been the primary focus of the Scottish water authorities attention. However, the position is changing and the new regulations reinforce the need to reduce THM formation.

Although 50% of supplies in Scotland failed to meet the THM standard in 1998 it should be noted that the vast majority of the failing supplies were small rural supplies serving just a few hundred people. The large population centres generally have compliant water. The rural supplies often receive very basic water treatment and the highly coloured upland waters from which the supplies are drawn, react with the chlorine to form THMs. One of the favoured solutions for small rural supplies is the use of a membrane treatment plant. A number of these plants have now been installed in Scotland with considerable success. They are however an expensive solution benefiting a relatively small number of people.

The Scottish water authorities must meet the new standards set in the Drinking Water Directive by the specified dates. Failure to do so could result in significant fines being levied on Scotland by the European Court of Justice. To ensure that the water authorities are working towards compliance with the Directive, they are required to provide Scottish Ministers with legally binding undertakings to implement the necessary improvement measures. Failure to meet their undertakings would result in enforcement action being taken against an authority.

The other parameter in the new Directive that is of concern to Scotland is the lead parameter. The current standard for lead in Scotland is 50µg/l in a random daytime sample. The Directive imposes an interim standard of 25µg/l to be met by 2003 and a final standard of 10µg/l to be achieved by 2013. There are no lead water mains in Scotland but a large number of lead communication pipes (the pipe between the main in the street and the property being served) remain in the ownership of the water authorities. In addition, a large number of older properties still have lead internal plumbing. While it should be possible to achieve the interim standard of 25µg/l through the use of pH correction and orthophosphate dosing to reduce the plumbosolvency of the water, it is not considered possible to achieve the 10µg/l standard without replacing the lead pipework. There are substantial costs involved in this exercise and although the Directive allows 15 years to meet the 10µg/l standard, the scale of the problem is so great that the Scottish water authorities are planning their lead replacement programmes now.

Not included in the Drinking water Directive but of concern to Scottish water authorities is cryptosporidium in water supplies. Regulations were adopted in England and Wales in July 1999 that set a standard of 1 oocyst per 10 litres for cryptosporidium. The view was taken in Scotland that while this may be acceptable as a treatment standard it did little to protect public health. A decision was made that in order to protect public health, the most effective measure would be to require the Scottish water authorities to implement the recommendations contained in the third report of the Group of Experts on Cryptosporidium in Water Supplies. The report of the Group chaired by Professor Bouchier was published in November 1998. One of the Groups key recommendations was the carrying out of risk assessments on water supplies.

A common risk assessment methodology was agreed between the three water authorities and the Scottish Executive. A score was assigned to individual water supplies following an assessment of the risk of cryptosporidium being present in a supply. Depending on the score allocated to a supply, the water authorities are required to carry out improvement measures by agreed dates. Where sites are identified as being at highest risk, continuous monitoring of the supply for cryptosporidium has to be carried out until the necessary improvement measures are implemented

These are just some of the challenges that face the water industry in Scotland over the next few years. It is my job as a regulator to ensure that the industry rises to and meets the challenges.

SESSION 2

RISK OF WATERBORNE GIARDIASIS BASED ON MONITORING DATA

By:

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The analysis of water samples for *Giardia* cysts and *Cryptosporidium* oocysts is still an evolving process so public health authorities are reluctant to use the data because its strengths and limitations are not well understood. Protozoan cyst detection relies upon trapping the parasites on filters and direct enumeration by microscopy. The efficiency of cyst recovery depends upon the methodology and the nature of the other particulate matter present in the sample. Concentration estimates therefore tend to be low and variable. Strengths and weakness of the conventional (ICR) methods and the new 1622 and 1623 EPA methods are reviewed. Monitoring data from outbreak and non-outbreak conditions are used to calculate risk using an exponential model and the usefulness of these predictions in the setting and rescinding of Boil Water Advisories is discussed. Viability estimations and human infectivity of waterborne parasites are difficult to evaluate but can be compensated for to some extent in the risk model. Estimates of the effectiveness of water treatment must also be incorporated. Despite these difficulties, risk model predictions tally reasonably well with waterborne disease in the community.

HUMAN EXPOSURE TO HALOGENATED DISINFECTION BY-PRODUCTS

By:

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Epidemiologic studies seeking to establish links between disinfection by-product exposures and adverse health outcomes ranging from bladder cancer to adverse reproductive outcomes rely upon acquiring knowledge of both the disease state of the individual and the exposures of the same individual to hypothesized causative agents. If individual exposures to contaminants are not directly measured, the ability of epidemiology to support causal inference is severely limited. Yet the body of evidence available to date from human studies of disinfection by-products has failed to achieve meaningful assessment of individual exposure to the disinfection by-products.

Recent studies of cancer (King and Marrett 1996) and adverse reproductive outcomes (Waller et al. 1998, Gallagher et al. 1998) have estimated disinfection by-product exposure in terms of estimated exposure to trihalomethanes at the treatment plant or in the distribution system. While these studies deserve to be considered substantial improvements over earlier studies that compared exposures by using individuals served only by chlorinated surface water supplies in contrast to unchlorinated groundwater supplies, they still fall far short of providing individualized exposure assessment. Furthermore, with the possible exception of bromodichloromethane, toxicological evidence on the trihalomethanes does not suggest that this class of compounds are likely to be causal agents for the adverse outcomes which have been studied. Hence, the greatest value of trihalomethanes in epidemiological studies may be as surrogates for other disinfection by-products.

In order for trihalomethanes to serve as viable surrogate measures for other disinfection by-products they must be correlated with those other disinfection by-products after creation and they must follow similar patterns of change in the distribution system. While there is some evidence to support a correlation between trihalomethanes and some other halogenated disinfection by-products, similar behaviour in distribution systems is much less certain (Chen and Weisel 1998)

This research involves analysis of disinfection by-product data from four Canadian municipal distribution systems and from systems serving Adelaide, Australia to determine the correlation of haloacetic acids and other chlorination disinfection by-products with trihalomethanes as a function of travel time, temperature, pH, chlorine residual and dissolved organic carbon. The implications of the relationships determined will be explored in terms of the viability of THMs as a surrogate measure of exposure to other chlorination disinfection by-products. These findings will have application both to future epidemiologic studies and to the reinterpretation of completed studies.

VALIDATION OF SEROLOGY METHODS FOR DETECTION OF *CRYPTOSPORIDIUM* IN HUMAN POPULATIONS

By:

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Background

Cryptosporidiosis is a major concern to water utilities and public health authorities world-wide. Although it may be spread by several routes, *Cryptosporidium* has recently emerged as a major cause of waterborne disease. A number of large waterborne epidemics of cryptosporidiosis have been reported including, Swindon and Oxford, England with an estimated 5000 persons infected and Milwaukee, Wisconsin with over 400,000 persons infected. Some major outbreaks have occurred in communities in which drinking water treatment met current standards. These outbreaks have focused attention on the lack of understanding of the epidemiology of this infection.

It is widely recognized that laboratory tests to identify this parasite in feces are insensitive; many more infections occur than are detected and reported. It appears that an estimate of the prevalence of human *Cryptosporidium* infections is provided by the detection of specific antibody responses in blood samples. This project is intended to validate a test which could be used to determine an individual's prior exposure to *Cryptosporidium* and to estimate the prevalence of infection in the community.

New information from this project will include an estimate of the usefulness of *Cryptosporidium* antigens as markers of recent infection, an estimate of the sensitivity, and if possible specificity, of both the CDC ELISA and the miniblot, and an assessment at a population level, of seroprevalence of antibodies to *Cryptosporidium* in outbreak and nonoutbreak settings.

Objectives

The specific objectives of this project are to:

- 1) Determine the sensitivity of the new CDC ELISA and the immunoblot (miniblot) assay.
- 2) Determine the specificity of the ELISA test and the immunoblot assay.
- 3) Analyze changes in antibody reactivity over time in persons with laboratory-confirmed cryptosporidiosis.
- 4) Evaluate saliva for usefulness in detecting antibodies to *Cryptosporidium*.
- 5) Compare results of the ELISA and immunoblot.
- 6) Assess the ELISA assay at a population level.

Preliminary Results (testing is due to be completed in December 1999 and final analysis will be available after this date): Inter-laboratory comparison of the ELISA IgG assay of *Cryptosporidium* antibody to both 27 kDa and 17 kDa antigens showed excellent correlation. Median values from ELISA IgG testing of cryptosporidiosis cases were calculated for each collection period (time post collection) for the kinetics sera. Peak values were seen at the 1 - 10 weeks interval post-onset. Overall, a fall to what appears to be a "baseline level," was seen by the 51 - 60 week period. *Cryptosporidium* ELISA

IgG testing of toxoplasmosis and giardiasis cases showed poor correlation between tests. Saliva samples tested by ELISA IgG assay for both *Cryptosporidium* antigens showed a low positivity rate. Changes over time during the collection period were seen in the few positive saliva samples. Half-life of serum antibody responses to the *Cryptosporidium* antigens calculated for one case was approximately 52 weeks for the 27 kDa and 22 weeks for the 17 kDa antigens. Further analysis of these data will be carried out.

This project is funded by the American Water Works Association Research Foundation.

TRICHLOROACETIC ACID AS A BIOMARKER OF HUMAN EXPOSURE FOR NON-VOLATILE DISINFECTION BY-PRODUCTS

By:

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Chlorination produces a wide range of disinfection by-products, both volatile and non-volatile. While the trihalomethanes are the dominant volatile disinfection by-products in drinking water, the haloacetic acids are the dominant non-volatile disinfection by-products identified to date. Upon ingestion, disinfection by-products are taken up across the gut and transported directly to the liver. Research has shown that ingested trihalomethanes are rapidly metabolized in the liver and accordingly fail to appear in the bloodstream from this exposure route. Measurement of trihalomethanes in general circulation has been attributed to uptake by inhalation or dermal absorption, exposure routes which avoid the first pass through the liver and the corresponding rapid metabolism.

Haloacetic acids offer negligible uptake from inhalation or dermal exposure routes making ingestion the only significant exposure route for these disinfection by-products in drinking water. Evidence suggests that trichloroacetic acid has a half life in the body of approximately 3 days, on average, making it a potential candidate as a biomarker of human exposure to non-volatile disinfection by-products. Biomarkers of exposure offer the possibility of objective measures to determine individual exposure to disinfection by-products, a deficiency in all currently available epidemiology studies on disinfection by-products.

This study involves a pilot scale evaluation of volunteers among our research collaborators who normally drink tapwater containing readily detectable levels of haloacetic acids. Urinary levels of trichloroacetic acid, along with other detectable haloacetic acids, will be compared with their levels in samples of drinking water consumed according to daily diaries documenting how they have used their drinking water (consumed cold tapwater, heated beverages, etc.). After stable patterns of excretion are established, intervention with bottled water shown to be free of haloacetic acids will be used to validate whether trichloroacetic acid in urine can document exposure levels from drinking water. The results of the pilot trial reported here will be used to design a larger scale intervention trial that will provide important information about the variability of human absorption and excretion of potential biomarkers of human exposure to non-volatile disinfection by-products. These insights will ultimately allow meaningful individual exposure assessment such that future epidemiological studies can begin to test causal hypotheses about disinfection by-products causing adverse reproductive outcomes.

SESSION 3

IDENTIFICATION AND TREATMENT OF OFF-FLAVOURS IN DRINKING WATER

By:

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Drinking water supplies are often impacted by seasonal taste and odour (T/O) episodes caused by volatile organic compounds (VOCs) from algal blooms. Treatment and control of VOCs during these events is important to utility operators, as customer confidence in the safety of drinking water supplies is influenced by aesthetic perceptions, such as taste and odour. In the nutrient poor Glenmore Reservoir (Calgary, Alberta) the chrysophytes *Uroglena americana* and *Dinobryon spp.* are known to produce fishy odour compounds during bloom events. These compounds, specifically unsaturated dienals (2,4-heptadienal 2,4-decadienal and 2,4,7-decatrienal) result from the enzymatic breakdown of intracellular polyunsaturated fatty acids (PUFAs). Where prevention of bloom events is not possible, ameliorative water treatment strategies target physical removal of the algae, or absorption and oxidation of the resultant T/O compounds. Dissolved air floatation (DAF) has been used as an efficient means of removing particulate matter and has the potential to remove intact algae from the treatment process. By the removal of intact cells the production of T/O compounds from cell lysis can be minimized. Preliminary results from this study are presented. DAF was compared to conventional gravity sedimentation (CGS) using bench scale jar-test apparatus with aluminum sulphate coagulation. Chlorination was used as an oxidizing agent in order to observe changes in both the T/O compounds and disinfection by-products (DBPs). Natural and synthetic test waters containing chrysophyte species were used. The treatment efficacy was evaluated in terms of particle removal by measuring turbidity, particle counts and taxonomic enumeration of the algae. Flavour profile analysis (FPA) was used to monitor changes in the magnitude and character of the odour. Changes in soluble constituents were monitored as a composite parameter using total organic carbon (TOC) and as specific organic compounds. T/O compounds were quantified using solid phase microextraction / gas chromatography – mass spectrometry (SPME/GC-MS) while the DBP trihalomethanes (THMs) and haloacetic acids (HAAs) production were measured using gas chromatography.

CYANOBACTERIAL TOXINS: THE DEVELOPMENT AND EVALUATION OF METHODS TO DETERMINE MICROCYSTIN LEVELS IN CANADIAN WATER SUPPLIES.

By:

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Microcystins, potent toxins that affect the liver, are naturally produced by many species of blue-green algae (cyanobacteria). These algae grow in the shallow, warm, slow-moving or still bodies of water common throughout Canada. Many rural farm-type water supplies used for domestic purposes and for livestock watering are subject to repeated blue-green algal blooms, particularly during the hot summer months. While most species of blue-green algae are capable of producing toxins, not all blue-green algal blooms do. When present, the concentration of toxins varies dramatically within the body of water and over time. Microcystins are extremely stable and will persist for long periods once they are released into a water supply.

During the summer of 1993, the cyanobacterial toxin Microcystin-LR was identified in Winnipeg's drinking water distribution system. This discovery prompted the Manitoba Department of Environment to ask Health Canada to establish an 'Emergency Health Advisory' (EHA) for this toxin. Subsequent to the establishment of the EHA, the Federal-Provincial Subcommittee on Drinking Water initiated the development of a drinking water guideline for these toxins. A drinking water guideline of 1.5 µg/L for Microcystin-LR was proposed in 1998. During the guideline development process, however, a number of gaps in the database were identified. The most significant gap was the lack of exposure data for the populations at risk, due to the absence of readily-available, cost-effective analytical and field test methods for toxin identification. Very few laboratories in Canada are capable of quantifying blue-green algae toxins in water and the cost of analysis per sample is expensive.

At the request of Saskatchewan Health, and with the participation of a number of provinces and non-governmental agencies, Health Canada began developing a laboratory method (HPLC-UV) that could be used by the provincial laboratories and agencies for routine monitoring of the toxins in all water supplies. In addition to the lack of a routine laboratory method for quantifying toxin levels, there was a need for a readily available field test for rapidly determining the presence or absence of these toxins within blooms. These methods were developed in collaboration with the University of Alberta protein phosphatase bioassay laboratory, and included surveys of water sources in various provinces during the summers of 1998 and 1999.

The presentation will focus on the survey results, the development, evaluation and testing of both the analytical method and of the prototype field test kit. The applicability of the analytical method and field test kit for routine monitoring will be discussed. The success and implementation of these two methods will provide a more accurate and cost-effective approach to the management of risk associated with blue-green algal toxins to humans and livestock.

RURAL DRINKING WATER ON THE PRAIRIE AND WATERBORNE DISEASES

By:

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Research Institute (Japan)

High levels of dissolved organic material (DOM) and particles in rural prairie water are hampering the production of safe drinking water. A case in point is made by examining two diseases that can be spread by water, giardiasis and Hepatitis A. Saskatchewan will be used as an example and compared with the rest of Canada. These two diseases were two and three times more common per capita in Saskatchewan than the national average (1993-1996 average data for which official information exist). In Saskatchewan the number of reported Hepatitis A cases increased from 64 in 1994 to 450 in 1996. It is a generally accepted practice to multiply the reported cases of waterborne illnesses by 10 or more to reflect actual numbers. The total number of reported Hepatitis A cases in New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland, the Northwest Territories and Yukon was 25 in 1996. Saskatchewan therefore had 18 times more cases of Hepatitis A than all of these provinces combined. On a per capita basis the rate of giardiasis was 4 and 5 times higher in Saskatchewan than in Nova Scotia and New Brunswick; for Hepatitis A the Saskatchewan rate was 14 and 71 times higher, respectively. In addition, water sources in rural Saskatchewan will typically contain high levels of naturally occurring DOM. When this water is chlorinated large quantities of new chemicals are formed; the amount of these chemicals are higher in rural Saskatchewan than in the rest of Canada. The concern is that when chlorinated, the chlorination by-products formed can potentially cause cancer and spontaneous abortions. Detection of microbial illnesses through "indicator" testing is discussed. The health costs of providing unsafe drinking water to rural people has been assessed for the Saskatchewan situation and will be presented using criteria from both Canada and internationally.

SESSION 4

AN EXAMINATION OF NITRIFICATION TRIGGER CONDITIONS WITHIN A BENCH-SCALE, CHLORAMINATED DISTRIBUTION SYSTEM

By:

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With the recent promulgation of the new disinfectant/disinfection byproduct (D/DBP) component of the surface water treatment rule (SWTR) in the United States and lower THM maximum contaminant levels (MCLs) in Canada, some utilities are switching from free chlorine to chloramines to control disinfection byproducts (DBPs). In these chloraminated water treatment systems ammonia has been found to promote the growth of autotrophic nitrifying bacteria, primarily ammonia-oxidizing bacteria in water distribution systems. Nitrification episodes can lead to a decrease in disinfectant residual, an increase in heterotrophic bacteria, and in certain cases, regrowth events of opportunistic pathogens, such as coliforms. Research suggests that nitrification episodes are triggered by certain factors, including water temperature, retention time, and chlorine residual levels.

An examination of trigger conditions responsible for these episodes was initiated in June of 1998, with a study to determine whether nitrification occurs in a non-chloraminated, bench-scale distribution system. Laboratory annular reactors (continuous flow reactor) operated with amended tap water, were used as model distribution systems for these investigations. The tap water was first fed through a granular activated carbon (GAC) column, to remove any chlorine residual, followed by a BAC, or biologically active carbon column, to further remove any easily biodegradable organic matter (BOM) in the tap water. The levels of BOM and chloramine residuals within the reactors were strictly controlled and manipulated according to the pre-selected experimental conditions. As expected, preliminary trials with BOM amended tap water did not provide conclusive evidence of nitrification within the non-chloraminated bench-scale reactors.

Following the preliminary study, an experiment was initiated in January of 1999 to determine whether ammonia oxidizing bacteria (AOB) are indigenous in tap water. A 1 mg/L solution of ammonium sulphate was fed at a rate of 1 mL/min on to the BAC column, to select for ammonia-oxidizing bacteria within the column. It was found that over a three-month period, the level of nitrite increased in the column effluent, and the levels of ammonia-oxidizing bacteria increased. Levels of heterotrophic bacteria dropped as AOB increased, suggesting a competitive interaction within the column environment.

Current experiments are examining the effects of temperature, retention time, and chlorine residual on the incidence of nitrification, following a two-level factorial design, utilizing four annular reactor systems. The study will run for an extended period of time, to allow for colonization of the AOB. The ammonium feed is being maintained on the BAC column, to ensure an adequate inoculum of AOB to the system. Temperature as a trigger condition is being examined in both a high (20-25/C) and low (10-15/C) range. The reactors are being chloraminated, with maintained residuals of 0.05-0.1 mg/L and 0.2-0.3 mg/L. The retention time in all of the reactors is being maintained at 6 hours, and the growth substratum of choice is polyvinyl chloride. These variables were chosen to simulate a portion of a full-scale distribution pipe, in a dead-

end portion of the system.

One of the goals of this research is to better predict the occurrence of nitrification episodes, by understanding the effects that certain trigger conditions have on a nitrifying population within a distribution system environment. This information will be useful in future for predicting, and potentially avoiding, nitrification episodes in full-scale water distribution systems.

**EXAMINING SUSPENDED AND DEPOSITED PARTICULATE MATTER
IN A CANADIAN DRINKING WATER DISTRIBUTION SYSTEM**

By:

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Particulate matter is present under different forms (suspended, deposited) in drinking water distribution systems. As suspended matter, its concentration is usually low under normal flow conditions (Gauthier *et al.*, 1997), but may increase drastically during loose deposits resuspension events. These result from unwanted hydraulic disturbances (pipe breaks, fire flows, consumption peaks). The nature of resuspended deposits may be evaluated by characterizing the water quality during flushing procedures. For most examined cases (de Rosa, 1993; Maier *et al.*, 1997), deposits resuspension was associated to a microbial and/or chemical contamination of water. Moreover, loose deposits accumulate bacteria (LeChevallier *et al.*, 1987) and organic matter inside distribution systems (Schreiber *et al.*, 1994), and may represent a food reservoir and a refuge against disinfectants for micro and macro invertebrates inside drinking water distribution systems (Van Lieverloo *et al.*, 1997; Gauthier *et al.*, 1999).

At this time, increasing efforts are provided to limit the number of particles entering distribution systems through the implementation of particles counters at the outlet of filtration units. However, limited efforts have been allocated to the determination of the concentration (as $\mu\text{g/L}$) and nature (organic/mineral/biological) of particulate matter in distribution systems. This project was designed to consider most aspects of particles in the distribution system of Montreal (Quebec). Suspended particles were characterized in treated and distributed water in normal flow conditions after filtration of 10 to 150 L on fiber-glass or membrane filters. Loose deposits were also collected (a) by pumping them from the bottom of tanks during boat inspection and (b) by resuspending them during pipe flushing procedures.

Results show that in normal flow conditions, suspended particles concentration is less than 100 $\mu\text{g/L}$ both in treated and distributed water, and that organic matter (measured as volatile suspended solids) represents the major fraction (40 to 64%) of these particles. During special turbidity events in raw water, suspended particles concentrations in finished water may increase by a factor 3 to 4 corresponding to the penetration of some mineral particles in the distribution system, mainly silicon/aluminum and iron compounds. In distribution tanks, the quantities of accumulated deposits were small and mainly composed of mineral matter (>80% of dry weight). Microbiological examination only revealed in a few cases the presence of coliform bacteria, and similar results were obtained for pipe deposits. Detailed chemical analysis of the different types of particles indicated differences – mainly in the iron content of particles - between upstream and downstream locations of the distribution systems, and between tank and pipe deposits.

Globally, under normal flow conditions, suspended particles concentrations were found in small quantities compared to organic and total dissolved matter. However, they correspond to several dozen of tons of material per year, a fraction of which is susceptible of accumulating by sedimentation inside the distribution system, thus creating favorable conditions for microbial regrowth, and potentially water quality degradation.

PATHOGEN MONITORING – OLD BAGGAGE FROM THE LAST MILLENNIUM

By:

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At the close of the last millennium, a prevailing concept within the regulatory agencies, public health organizations, and the drinking water community worldwide was that public health could only be ensured by monitoring for pathogens. This concept endures because it is (1) directed by regulations, elected officials, and utility management; (2) expected by consumers and special interest groups; (3) supported by the belief that data from monitoring protects public health; and (4) considered to be a sign of acting responsibly. Experience to date, however, casts doubt on whether pathogen monitoring in the context of protecting public health will become a reality even within the new millennium. During the past decade, millions of dollars have supported the development of a sensitive, specific, and reproducible method for *Cryptosporidium*, and we're still waiting. Should this same scenario continue to be played for other pathogens of concern or is it time to "check the baggage" now?

Given the enormity of the technical and administrative issues associated with protozoan and other pathogen monitoring--and the experience from the ill-fated U.S. EPA Information Collection Rule and the Sydney, Australia situation--the drinking water community and the regulatory-health agencies need to abandon any thought of monitoring as a pretense for protecting public health. Water supply professionals must embrace watershed protection, process optimization, and distribution system integrity as the strategy for public health protection. National regulatory agencies need to accept the fact that pathogen monitoring is not a practical option for ensuring wholesome drinking water.

This presentation describes the overwhelming obstacles inherent in pathogen monitoring and more practical approaches to ensure public health protection.

SESSION 5

INACTIVATION OF ENCYSTED PARASITES USING MEDIUM-PRESSURE ULTRAVIOLET RADIATION IN DRINKING WATER

By:

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The effect of medium pressure ultraviolet radiation on encysted *Giardia* and *Cryptosporidium* was investigated using a bench-scale collimated beam apparatus with infectivity in animal models as the inactivation assay. The data show that *Giardia* and *Cryptosporidium* are readily inactivated by medium-pressure UV with 2.5 log-units of inactivation of both parasites at UV doses of less than 40 mJ/cm². UV also was shown to effectively inactivate the parasites over a wide range of temperatures.

UV dose-parasite response curves were developed over a range of UV doses that can help develop design criteria for application in drinking water.

FULL-SCALE ASSESSMENT OF DISINFECTION FOR *GIARDIA* CYSTS AT THE CITY OF BRANTFORD: BALANCING INACTIVATION AND DISINFECTION BY-PRODUCT FORMATION

By:

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The 1986 amendments to the Safe Drinking Water Act (SDWA) require the United States Environmental Protection Agency (USEPA) to routinely assess the national drinking water regulations for public water systems using surface water or ground water under the direct influence of surface water as its source. As part of this on-going commitment, the Surface Water Treatment Rule (SWTR), a component of the SDWA, was promulgated in 1989 to regulate turbidity, *Giardia lamblia* (*G. lamblia*) cysts, viruses, and *Legionella* and heterotrophic plate count (HPC) bacteria. Most recently in 1998, the Stage 1 B Disinfectants and Disinfection By-products Rule (D/DBPR) was promulgated to regulate the formation of disinfection by-products (DBPs), such as trihalomethanes (THM) and haloacetic acids (HAA), resulting from treatment practices. Although no such regulations currently exist in Canada, some form of more stringent guidelines will likely be adopted in the relatively near future. In the meantime, the US requirements provide a useful benchmark against which Canadian utilities can assess their performance.

Experiments were conducted at the City of Brantford (COB) Water Purification Plant, located in Southern Ontario, to assess the overall treatment capabilities of the process configuration and treatment strategies in adhering to the SWTR guidelines for disinfection and physical removal of *G. lamblia* cysts. Alternate strategies for optimizing the performance of the various treatment processes are being investigated. This investigation includes an assessment of the ability of these strategies to comply with the D/DBPR regulations regarding the formation of DBPs during chemical disinfection.

The SWTR requires that a minimum overall treatment guideline of 3.0 log-inactivation/removal for *G. lamblia* cysts be provided for all communities using a surface water source. The actual requirement, however, is dependent on the concentration of *G. lamblia* cysts in the source water. With five wastewater treatment plants, several industrial discharges, and kilometers of agricultural land upstream of the COB intake, the overall treatment guideline will likely be higher for this plant. In all cases, a minimum of 0.5 log-inactivation of *G. lamblia* cysts should be achieved through disinfection.

Historic data from upstream of the COB intake suggests that a drinking water treatment facility using the Grand River water as its source should provide between 5.0 and 6.0 log-inactivation/removal of *G. lamblia* cysts. A regular sampling program for protozoan cysts and oocysts has been initiated to confirm the overall level of treatment required from disinfection and physical removal strategies at the COB facility.

An examination of historical data was used to provide a theoretical assessment of the level of disinfection achieved by the current treatment configuration. This disinfection assessment was achieved through a sensitivity analysis of the obtainable $C-t$ for log-inactivation of *G. lamblia* cysts, based on the SWTR guidelines, under typical COB operating conditions. More recently, full-scale tracer studies were conducted on the chlorine contact basins to determine the actual t_{10} values and establish the real disinfection level from the process configuration and proposed disinfection strategy. The results from the $C-t$ sensitivity analysis indicate that under the existing process configuration and disinfection strategy, the COB facility may face occasional challenging periods during colder raw water conditions. The assessment also identified several alternative strategies, such as pH adjustment and ultraviolet irradiation, as promising technologies, which could be considered. The COB is currently reviewing these preliminary findings.

This research will assess the overall treatment performance of the COB facility in adhering to the more stringent SDWA guidelines for *G. lamblia* cyst inactivation/removal and DBP formation. In addition, this research will identify alternative conceptual strategies for optimizing the performance of the various treatment processes for this varying raw water source. The comprehensive assessment of the disinfection and physical removal strategies utilized in Brantford may be used by other utilities that wish to be proactive with respect to potential new regulations in Canada.

BROMATE FORMATION AND STRATEGIES FOR CONTROL

By:

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Bromate is formed when drinking water containing bromide is disinfected using ozone. Due to its reported toxicity, the Federal-Provincial Subcommittee on Drinking Water is considering recommending a limit on its allowable concentration in drinking water. Such a limit already exists in the United States (10 µg/L) and in several European countries. In the past, only waters containing elevated bromide concentrations (+ 50+ µg/L) might approach or exceed such a regulatory limit, but as ozone disinfection begins to target *Cryptosporidium*, a very resistant pathogen, ozone doses may increase and bromate formation in waters containing even relatively low concentrations of bromide may begin to form unacceptable levels of bromate. The need to control bromate formation may therefore become much more widespread.

This research addressed the effectiveness of ammonia for controlling bromate under a wide variety of treatment conditions. The ammonia nitrogen-bromine-ozone system was modelled for a pure aqueous system, supplemented by bench-scale experiments to determine the kinetics of the pertinent reactions. Computer simulations were used to predict the effect of ammonia on bromate formation, with the predicted results compared to measured results from bench-scale ozonation tests in a pure aqueous system. The data reflected the importance of the role of pH in bromate formation. Key components in the bromate formation pathway are pH dependent - bromine (OBr⁻ vs. HOBr), ammonia (NH₄⁺ vs. NH₃), and bromamines (NHBr₂ vs. NH₂Br) – and their speciation, influenced by pH, in turn greatly influenced the formation of bromate. The ratio of ammonia to bromide was also a key factor in determining the level of bromate formed. Greater amounts of ammonia could be more effective at inhibiting bromate formation in the short-term, however a high ammonia to bromide ratio would also result in the formation of more unstable intermediates, tending to counteract the long-term bromate inhibition.

Important trends identified in the bench-scale experiments and modelling were then tested at the pilot scale. Together with the bench-scale data, this work provides the water treatment industry with practical guidance to using ammonia for bromate minimisation.

MAINTAINING DRINKING WATER QUALITY – SUMMARY OF RESEARCH PROJECTS ON *CRYPTOSPORIDIUM* AND DISINFECTION BY-PRODUCTS

By:

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American Water Works Association Research Foundation

Providing safe drinking water is becoming an increasingly difficult task as water providers recognize that water supplies are contaminated with difficult-to-detect, and sometimes difficult-to-treat, pathogens. A number of waterborne outbreaks of *Cryptosporidium* have occurred worldwide over the last 15 years where the source was directly linked to drinking water. Consequently, water agencies and public health officials have become increasingly concerned over how to protect source water and optimize treatment processes to prevent such occurrences and to protect public health. On the other hand, pending drinking water reflect the challenges of increasing disinfection levels necessary to reduce the risk of microbial-induced disease, while at the same time imposing stricter standards on the by-products from these disinfection processes. In response to the need, the American Water Works Association Research Foundation (AWWARF) has put forth considerable effort into defining research needs and issues regarding the control of disinfection by products (DBPs) and *Cryptosporidium* s in drinking water.

In fact, *Cryptosporidium* and chlorinated DBPs were identified, by AWWARF subscribers, in a water utility survey as the highest priority issue each year from 1995 through 1999. Through convening issue groups, comprised of researchers and utility managers, specifically focusing on *Cryptosporidium* and DBPs research needs, AWWARF has been able to formulate multi-year research plans addressing current research gaps. The issue groups evaluated past and ongoing research on *Cryptosporidium* and DBPs and defined multi-year research agendas to best address remaining knowledge gaps. In this paper, past and on-going *Cryptosporidium* and DBPs research objectives will be presented along with completed results.

SESSION 6

AN EVALUATION OF FILTER PERFORMANCE IN NOVA SCOTIA WATER TREATMENT PLANTS

By:

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Increased interest in the prevention of waterborne epidemics such as cryptosporidiosis and giardiasis have lead the water industry to examine particle counting as an additional tool to monitor treatment performance. Currently in Atlantic Canada very few water treatment plants employ particle counters. Consequently the amount of data regarding raw and finish water particle size distributions, removal efficiencies and potential lapses in protection from pathogens is very limited.

In response to the need for particle removal information, a survey of particle removal capabilities at various treatment plants in Nova Scotia was undertaken. The survey will evaluate plants that have filtration and will include communities ranging from 5,000 to 250,000 in population. Each facility utilizes one of a number of treatment options, which include direct filtration, flocculation with sedimentation, pressurized filtration and flocculation with dissolved air flotation (DAF). The survey is currently underway and is expected to include at least five utilities.

The equipment used for the water analysis includes a pair of turbidimeters (HACH Company, Model 1720D) and particle counters (HACH Company, Model 1900). The equipment is mounted on a portable skid and is easily transported to different plants. Particle data is collected on-line and in real time for both raw and post-filtered data. The particle counters will also record the particle counts both by number and size that have been discretized into appropriate sizes.

The data analysis will examine the performance of all the treatment facilities. In particular, attention will be given to filter ripening, aging and removal efficiencies over the course of a filter run. The analysis will also focus on the relationship between turbidity and particle counts, specifically the ability of particle counting to act as an appropriate measure of filter performance for timing filter events such as backwashing.

Preliminary results have been collected from a direct filtration plant that adds alum and anionic polymer for coagulation, horizontal flocculation and filtration with anthracite/sand. Typical raw water turbidity at the plant is 0.45 NTU and the plant objective is to produce water that has a turbidity less than 0.1 NTU. A figure will show the total number of particles (>2 μm diameter) per mL for both raw and filter water over the course of one complete filter run (96-hours). Particle counts for the raw water ranged from 1,200 to 1,600 particles/mL and 3 to 200 particles/mL for the filtered water. The first half of the filter run was capable of achieving at least a 2-log removal for particles having a diameter greater than >2 μm . During the last half of the run, the efficiency gradually decreased to 1-log removal.

A second figure will show the turbidity for both raw and filtered water. The average raw water turbidity over the filter run was 0.33 NTU with occasional peaking to 0.45 NTU. The average filtered water turbidity during the first half of the filter run was 0.04 NTU. Over the last 24 hours of the filter run the turbidity increased to 0.09 NTU, still lower than the plant objectives and well within the Canadian Drinking Water Guidelines.

Preliminary results of this research indicate that particle counters are able to detect degradation of filter performance in terms of log-removal for particle sizes greater than 2 μm . From a practical perspective, degradation in filtration performance is significant because design engineers often take a 2-log credit for the removal of *Giardia lamblia* during rapid filtration. These data suggest that long filter runs, that meet low turbidity guidelines, could compromise the ability of a filter to remove potentially harmful pathogens.

REMOVAL OF ARSENIC (III AND V) IN DRINKING WATER BY MANGANESE GREENSAND FILTRATION AND ION EXCHANGE TREATMENT

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Arsenic, a relatively scarce element in the earth's crust, is found in measurable quantities in soils and rocks and generally present in combination with other minerals in rocks. It is the twelfth most abundant element in the human body. Arsenic is a group V metalloid, with atomic number 33 and atomic weight 74.92. It occurs in several different forms depending upon the pH and oxidation potential of the water. Under aerobic conditions arsenic occurs as arsenate (As(V)), while under anaerobic or reducing conditions it occurs as arsenite (As(III)). Arsenic presents serious problems to man and other living organisms because of its toxicity, and is classified as class A carcinogen by USEPA. Various treatment methods such as coagulation-precipitation, adsorption on alumina, adsorption on amorphous ferric hydroxide, and reverse osmosis have been reported in the literature to remove arsenic from drinking water. Chemical precipitation-coagulation is a simple method, in which chemicals are added to water to form precipitates or flocs containing arsenic that are removed by subsequent sedimentation process. The disadvantages of the chemical methods are the production of large amounts of sludge containing arsenic (hazardous in nature) that will pose serious problems for safe disposal. The promulgation of a lower standard for arsenic worldwide necessitated adoption of advance treatment technologies for achieving a low level of arsenic in drinking water. The objective of the present study is to assess the effectiveness of KMnO_4 oxidation followed by manganese greensand filtration, including the influence of Fe (III) addition for the removal of As (both as As(III) and As(V)) below the current maximum contaminant level of 25 $\mu\text{g/L}$. Arsenic removal with ion exchange resins in the cupric form was also studied. Batch isotherm studies were conducted by varying the mass of manganese greensand from 0.25 to 2.3 g for the removal of As(III) spiked in tap water. In case of ion exchange resins the mass was varied from 0.25 to 2 g to remove As(III) spiked in tap water. Column studies were conducted at different filtration rates. Two 4" diameter columns, each 6 feet high were used in this study. The water was pumped from a 55-gallon tank and the flow was adjusted using a flow controller to achieve a filtration rate of 2.75 to 4 gpm/ft^2 for the manganese greensand and 3 to 3.5 gpm/ft^2 for the ion exchange resin. Studies were conducted at intermittent and continuous modes for manganese filtration. In both modes iron was added at a particular ratio (Fe: As ratio of 7:1, 10:1, and 20:1) to study the effect on As removal. The results of the study showed that the presence of iron enhanced arsenic removal. Maximum arsenic (as As(V)) removal of 93.4% was obtained with manganese greensand in continuous mode at Fe: As ratio of 20:1. The capacity of the greensand media to remove arsenic per cubic feet of the media was 3.30 g/ft^3 at Fe: As ratio of 20:1, and highest among all other runs. The removal of As(V) with ion exchange resins was poor resulting in a removal efficiency of 42.53% and a bed capacity for arsenic of 0.54 g/ft^3 . The reason for this poor performance could be attributed to the high filtration rates resulting in a lower contact time to aid As removal. Preliminary cost analysis for small water systems (0.25 MGD) in order to achieve MCL of arsenic using the greensand media showed a cost of \$18370/year to operate and maintain the plant.

The results from the studies indicated that manganese greensand can be effectively used for arsenic removal in small water systems.

REDUCTION OF DISINFECTION BYPRODUCTS, DISSOLVED ORGANIC CARBON AND COLOR USING IMMERSED MICROFILTRATION MEMBRANES

By:

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Natural organic matter (NOM) present in raw water can not only impart color to water but can also cause health risks associated with disinfection by-products (DBP). The most common DBPs found in drinking water are trihalomethanes (THM) and haloacetic acids (HAA) which are formed when NOM reacts with chlorine or chlorine based disinfectants. In order to prevent the formation of DBP's, the US EPA has proposed a two stage Disinfectants-Disinfection Byproduct Rule (D/DBPR). Stage 1 finalized in November of 1998 established the maximum contaminant level (MCL) at 0.080 mg/l for total trihalomethanes (TTHM's) and 0.060 mg/l for haloacetic acids (HAA5). This will be followed by Stage 2 of the D/DBPR which is anticipated to set lower contaminant levels.

Enhanced coagulation has been identified as the best available technology for meeting the requirements of the D/DBP Stage 1 Rule for total organic carbon (TOC) reduction and the removal of disinfection byproduct precursors. With enhanced coagulation, NOM, color and TOC reduction are achieved using a higher coagulant dosage than would be utilized for turbidity removal. The pH of the raw water is also commonly optimized to maximize process efficiency.

The application of immersed microfiltration membranes using enhanced coagulation has recently been developed and applied for disinfection byproduct precursor, color and TOC removal for drinking water applications. With this process coagulation-flocculation-sedimentation-filtration stages of a conventional treatment plant are replaced by a single tank coagulation-microfiltration process. Enhanced coagulation microfiltration has three stages: 1) rapid mix, 2) coagulation/adsorption of NOM, and 3) microfiltration. A high solids concentration is maintained in the membrane tank to promote the adsorption of organics onto the floc. Subsequently, the barrier characteristics of the microfilter is used to separate small non-settling floc, precipitates, and colloidal particles.

Compared to conventional treatment, this novel method of water treatment results in higher color and TOC removal and requires less coagulant. The use of a lower chemical dosage results in significantly less treatment residuals and reduced disposal costs. The system also has a small footprint since it is designed with a lower hydraulic retention time associated with the need to only form floc that exceeds the membrane pore size.

This paper will present the application of immersed microfiltration membranes using the enhanced coagulation process for the reduction of trihalomethanes, haloacetic acids, DOC and color. It will also present pilot and full scale operating data on a number of applications where the process is being effectively used and compare it with performance data reported for conventional treatment facilities using enhanced coagulation.

POSTER PRESENTATIONS P-01 to P-15

P-01 EVALUATION OF TECHNIQUES FOR THE REMOVAL OF CHLORINATED DISINFECTION BY-PRODUCTS FROM DRINKING WATER AT THE POINT OF USE

By:

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A preliminary study of the effectiveness of aeration, boiling, storage and filtration for the removal of chlorinated disinfection by-products (CDBPs) in drinking water at the point of use was completed recently. Each remedial technique was applied at two locations within each of two drinking water distribution systems that used different secondary disinfectants (chlorine or chloramine). The suite of compounds monitored consisted of residual chlorine and 21 commonly occurring CDBPs including, 8 haloacetic acids, 4 trihalomethanes, 4 haloacetonitriles, 2 haloketones, chloral hydrate, chloropicrin and cyanogen chloride.

Filtration was the only technique that was effective for the removal of the full suite of 21 CDBPs. One particular pressure filter achieved > 99 % removal of the total CDBPs but there was considerable variation (48 to >99 % removal rate) between pressure filters (N = 3) from different manufacturers. The only drip filter (N = 1) that was tested achieved a 54 % removal rate. The limited results obtained here represent the effectiveness of new filters (conditioned with 10 L of water) only and cannot be extrapolated throughout the lifetime of the filter.

Water samples were stored in open and closed containers in a refrigerator and at room temperature and sampled periodically over a period of 8 days. In the best case, an open container stored at room temperature showed an average total CDBPs reduction of 68% (day 8); in the worst case, a closed container stored in the refrigerator showed average total CDBPs reduction of 13 % (day 8). The removal rates for individual group of CDBPs varied considerably; only 21 % of the HAAs were removed after 8 days storage at room temperature in an open container compared to 99 and 100 % for the THM and HAN, respectively, and only 8 % of the HAAs were removed after 8 days storage in a closed container in the refrigerator compared to 94 and 60 % for the THM and HAN, respectively. In contrast, chloral hydrate increased by 10 and 21 % during storage in open containers at 4 °C and 21 °C, respectively .

Boiling water for 2 and 5 minutes in a kettle or in a pot reduced the average total CDBP level by 66 % but only 4 % of the HAAs were removed compared to >96% for the remaining CDBPs. There was no evidence of formation of additional CDBP following boiling. Aeration using a faucet aerator or a blender achieved an overall average reduction of 1 to 5 % in the total CDBPs and was the least effective remedial technique.

The effectiveness of the remedial techniques was independent of the sample collection location within a drinking water distribution system and of the secondary disinfectant. The remedial techniques that were effective for the reduction of

CDBP were also effective for the reduction of the residual chlorine.

P-02 CRITICAL PHYSICAL - CHEMICAL CONSTANTS FOR ESTIMATING EXPOSURE TO SELECTED DISINFECTION BY-PRODUCTS

By:

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Key physico-chemical properties of compounds of interest in human health studies can provide essential information for exposure and risk assessment. Two of these properties are the octanol/water partition coefficient (K_{ow}) and the Henry's Law constant, or air/water partition coefficient (K_{aw}). The K_{ow} is a measure of the degree of partitioning of the compound of interest between the water and octanol phases, with the octanol phase being a surrogate for lipid phases found in the human body and the environment. Thus, the K_{ow} is a measure that can aid in estimating likely routes of exposure; for example, whether ingestion or dermal absorption is the more likely route of exposure, and whether a compound is likely to partition into adipose tissue or be excreted in the urine. The K_{aw} is a similar measure involving air and water phases and it indicates the propensity of a compound to volatilize from water.

These measures can be applied to the study of human health effects related to disinfection by-products (DBPs) in drinking water. Many epidemiological studies have investigated possible adverse human health effects related to exposure to products formed during the disinfection of water using chlorine-based disinfectants. While several studies have concluded that there is a link, these same studies have relied on exposure assessment that was inadequate. Without adequate and accurate quantification of contaminant exposure, the power of an epidemiologic study to support a causal link is severely limited. Therefore, a goal for future epidemiologic studies must be improved exposure determination. Biomarkers of exposure present a potential solution to this problem.

There are, however, questions that must be answered before a representative biomarker or biomarkers can be found. Firstly, the question of which chemical or chemicals are the causal agents must be addressed. The trihalomethanes and haloacetic acids have received the most attention, but comprehensive, individual human exposure assessment of these contaminants has been limited. Comprehensive exposure assessment must address how the compounds get into the body, i.e. routes and methods of exposure. Routes of exposure include inhalation, ingestion, and dermal exposure via many different uses of water. In addition, it is important to determine the destination of these compounds in the body for the purpose of sampling for biomarkers. Possible candidate destinations for exposure assessment sampling include breath, blood, and urine, among other body fluids.

The K_{ow} and K_{aw} provide important predictors for addressing these questions. Knowledge of the physical chemical properties of compounds of interest can be a powerful aid in predicting exposure routes and possible partitioning in the body, as well as for designing pharmaco-kinetic studies to address the absorption, distribution, metabolism and excretion of contaminants. A paper exercise can determine the most significant exposure routes, based on likely concentrations of the compounds in various phases and probable partitioning behaviour during various water uses. These physical chemical properties can also be used to predict likely partitioning behaviour in the body.

While the K_{ow} and K_{aw} are known for many DBPs, they are not known for some common DBPs, including several haloacetic acids, halo ketones and haloacetonitriles. Since it is currently unknown which DBPs are potential causal agents of adverse health effects, it is prudent to develop tools to investigate as many DBPs as possible in any epidemiologic study. To this end, the purpose of this study is to fill in gaps in the literature with respect to the K_{ow} and K_{aw} of various DBPs. The values of these physico-chemical properties were experimentally determined using the stir-flask method and are presented in this poster. They are compared to values calculated using estimation software published by the Environmental Sciences Centre at the Syracuse Research Corporation. Examples of some calculated values are provided in the research report. Knowledge of these physico-chemical properties, in addition to those already known, will provide useful insights towards methodically investigating biomarkers of exposure for use in epidemiological studies investigating a link between exposure to DBPs and adverse health effects.

P-03 BIOFILTRATION OF TOXIC AND RADIOACTIVE ELEMENTS BY AZOLLA

By:

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Our research task aims to test and improve the binding and absorption of radioactive trace metals: Sr, Zr, Cs, U, Ru by the Azolla biofilter. It has proven high affinity of the Azolla biofilter to these ions. The research investigates the mechanism of binding to Azolla column by examining the optimal ion concentration, pH dependence, competing ions etc.

We suggest in our research that the carboxylic groups of pectin in Azolla cell wall are mainly responsible for heavy metal binding in the Azolla biofilter. The hypothesis was proven by the following experiments: Treatment of Azolla with pectinase reduced the binding capacity of Azolla to Sr ion. Methylation of Azolla biomass, known to block the carboxyl groups of pectin by esterification, also reduced markedly the Sr binding.

Azolla biomass is a potent and practical tool to decontaminate heavy metals and radioactive elements with high polishing capability. Our research is oriented to develop applicable uses for environmental protection agencies, and to simplify water management control.

P-04 BIOLOGICAL FILTRATION FOR TREATMENT OF PRAIRIE SURFACE AND GROUND WATER SOURCES

By:

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The use of biological filtration to treat surface water supplies in Saskatchewan was pioneered by Saskatchewan Research Council's Water Quality Section in collaboration with Napier University (Scotland) and the Prairie Farm Rehabilitation Administration (PFRA). Through a Napier University research grant the study of the removal of dissolved organic material using Biologically Activated Carbon (BAC) was started. The content of dissolved organic material in surface water reservoirs across Saskatchewan was documented. Consistently high levels of dissolved organic material (>10 mg/L) rapidly exhausted the binding capacity of Granular Activated Carbon (GAC) while biological activity on the GAC showed promising capacities for DOC removals. In 1993 the first full-scale on-farm biological reactor (composed of one sand and one GAC filter) was constructed to treat water from a surface water reservoir. This filter is still in operation with the originally installed filter material. Several more surface water treatment filters have been installed across Saskatchewan. In 1995 the biological filtration work was expanded to treating iron, manganese, arsenic as well as DOC in ground water supplies. Several ground water treatment systems have been installed successfully removing iron, arsenic and DOC, with less success in terms of manganese removal. The long-term treatment performance of both surface and ground water treatment units will be presented. It is believed that biological treatment of both surface and ground water supplies on the Canadian prairies offer solutions for long-term, sustainable treatment of difficult to treat source water supplies. Filter media do not need to be replaced at regular intervals (as with GAC) and chemical use is much reduced making biological treatment a cost-effective treatment as well. Challenges that remain to be resolved include manganese removal and optimum reactor design. It is also recommended that for drinking water purposes the biologically filtered water should be treated with a membrane system, such as a nanofiltration or reverse osmosis membrane. Problems with the proliferation of bacteria in under-the-counter membrane systems do, however, pose some concerns about their suitability for on-farm uses. Biological filtration can also be an effective treatment of surface and ground water for other water-use applications, such as consumptive uses by livestock, industrial and irrigation water uses.

P-05 NITRATE REMOVAL FROM POTABLE WATER

By:

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Many water agencies face problems of increasing concentrations of nitrate in groundwater. The main reason for increasing nitrate concentrations in groundwater is the agricultural practice of extensive application of artificial fertilizers and animal manure on land. The contamination of groundwater by excessive concentrations of nitrate is a significant public health problem. The threat of methemoglobinemia is well documented and reflected in the U.S. drinking water standard of 10 mg/L as nitrate-nitrogen. A wide range of physico-chemical processes such as ion exchange, reverse osmosis, electro dialysis, chemical denitrification and biological denitrification processes are currently being developed for removal of nitrate from drinking water. Although nitrate/nitrogen removal systems are in use in wastewater treatment, no specific nitrate removal system is in operation in Canada as part of drinking water treatment, especially in point-of-use systems in rural regions. Only limited research on nitrate removal from drinking water has been conducted in Canada. Approximately 45% of Saskatchewan's population use groundwater for drinking purposes, out of which, approximately 23% (230,000) are rural residents. The water used is made available from over 48,000 privately owned wells in regions where there is extensive application of agricultural chemicals. Data was obtained from Sask. Environment on nitrate concentrations in different groundwater distribution systems throughout Saskatchewan. Three main distribution systems - Alida, Eyebrow and Ruddell - have mean nitrate levels exceeding the MAC of 45 mg/L. Reverse osmosis, ion-exchange and biological denitrification systems are proposed to be tested for their nitrate removal efficacy. Reverse osmosis (RO) and electro dialysis (ED) can effectively separate nitrate from well water. They are proven and reliable processes for seawater and brackish water desalination and for the production of ultra-pure water from tap water. The commercially available RO membranes are generally highly selective for inorganic salts. RO and ED cannot separate nitrate selectively. The processes will reduce the concentration of all dissolved solids. Biological denitrification (sulfur/limestone process) is based on autotrophic denitrification by *Thiobacillus denitrificans*, where nitrate is converted into nitrogen gas under anoxic conditions. Sulfur is used as electron donor and limestone is used to maintain the pH. Anaerobic fixed-bed reactor can achieve sulfur autotrophic denitrification. The reactor can be seeded using denitrifying cultures that will develop and concentrate in the laboratory. A series of laboratory experiments will be conducted to see the effect of some variables. Some of the variables to be tested include the effect of the sulfur: limestone ratio on reactor performance, the effect of nitrate loading rate on nitrate removal capacity, and the effect of HRT. Data available from Saskatchewan Environment and Resource Management (SERM), Saskatchewan Water Corporation and Prairie Farm Rehabilitation Administration (PFRA) will be examined to identify the extent of the nitrate problem in groundwater. Data from Manitoba and Alberta will also be examined. Laboratory evaluation of RO, Ion exchange and biological systems will be conducted. The final stage of the study would involve field installation of the selected systems and monitoring. Preliminary results of batch studies on the sulfur/limestone process, conducted over a period of 14 days using a sulfur:limestone ratio of 3:1 with an initial sample concentration of 34 mg NO₃⁻/L as nitrogen, showed that nitrate removal efficiency was close to 100%.

P-06 THE USE OF JAR TEST TO SCALE UP AND SCALE DOWN MICROSAND WEIGHTED FLOCCULATION

By:

Christian Desjardins, Boniface Koudjonou, Raymond Desjardins, Jean François Beaudet

Background and Objectives

Since the beginning of the year 90s, the weighted flocculation technology is applied to drinking water production. This innovative technique uses microsand as the core of the flocs formation which results in an increasing the floc density and the settling speed. This allows high hydraulic loading rates (up to 60 m/H) and thus reduces the space requirements. Moreover, this dynamic process produces more stable water quality than the conventional systems. The two objectives of this study are first to develop a Jar-test procedure capable of simulating the full-scale plant and secondly to predict and optimise the full-scale performance through laboratory simulations.

Experimental Setup

The experimental device consists in the Jar-test equipment with six 1-litre beakers. The conventional Jar test procedure was adapted to the parameters of this new concept especially the injection of microsand and polymer. The study was conducted through laboratory experiments followed by validation on three full-scale drinking water treatment plants using the weighted flocculation system called ACTIFLO®.

Findings/Results

To achieve the first objective, various water treatment plants making use of weighted flocculation were simulated in laboratory under their respective treatment conditions. The results on the quality of the settled waters obtained in laboratory were then compared to full-scale data. The comparisons were based on the removal of turbidity, natural organic matter and UV absorbance. The characteristics of the settled waters using the modified Jar-test procedure showed a good laboratory simulation of the actual process applied at the three different drinking water production plants (less than 9 % variation).

In a second step, an experimental design using a statistical approach made it possible to optimise the method by reducing the number of tests and identifying the principal parameters controlling weighted flocculation and to conclude on the importance each parameter on water quality. Other than the quantities of micro-sand and polymer used, the major parameters are the dosage of coagulant and the pH of coagulation, as in conventional coagulation-flocculation-decantation. For waters that do not coagulate easily (low SUVA), it is difficult to find a parameter that has a preponderant effect.

To address the second objective, preliminary lab-simulated conditions were test in an actual plant. Results showed very good simulations near optimal operation conditions but significant discrepancies between simulation and full-scale when non-optimal conditions were applied.

The dynamic aspect of the process ensures the production of decanted water of a relatively stable quality, probably due to the satisfactory elimination of the micro-flocs that are most often responsible for the degradation in the quality of

decanted water. Contact times were not key factors in the process when treating either warm (20°C) or cold water (below 3°C).

Relevance to Industry

The main application of the modified jar test procedure would be to predict performances of any system employing the weighted flocculation concept under any given conditions without the use of a full-scale or pilot-scale unit that are more time and energy consuming. The advantages would not only be economical but also include mobility of the method and prediction of performances before any larger scale testing agenda is considered.

P-07 DETECTION OF TASTE AND ODOUR-PRODUCING ACTINOMYCETES IN DRINKING WATER AND RAW WATER USING A NOVEL POLYCLONAL ANTIBODY AND IMMUNOFLUORESCENCE MICROSCOPY

By:

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Filamentous actinomycetes responsible for causing taste and odour problems in water treatments plants were detected and enumerated using a novel polyclonal antibody coupled with immunofluorescence microscopy. The antibody was generated specifically against taste and odour causing environmental isolates and against ATCC strains (*Streptomyces griseus* and *Streptomyces odorifera*). A rapid 4 hour method was developed to quickly sample and analyse treated and raw water samples in order to determine relative numbers of actinomycetes present in the samples. The polyclonal antibody effectively detected actinomycetes isolated from 4 water distribution systems in Ontario as well as actinomycetes isolated from the Nile river in Egypt. Ontario isolates were all isolated during taste and odour problems occurring in the distribution systems. No cross-reactivity was detected with Gram negative and Gram positive bacteria (*Escherichia coli*, *Pseudomonas aeruginosa*, *Streptococcus faecalis*, *Staphylococcus aureus*, and *Alcaligenes faecalis*), or with *Rhodococcus coprophilus* and *Nocardia amarae*.

**P-08 A NOVEL METHOD FOR RAPID, SPECIFIC AND SENSITIVE ANALYSIS OF
HALOACETIC ACIDS AND OTHER POLAR DISINFECTION BY-PRODUCTS
IN DRINKING WATER**

By:

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Introduction

We have shown that a new analytical technique that combines direct injection electrospray ionization mass spectrometry with ion separation based on gas-phase ion mobility in an electric field (ESI-FAIMS-MS) can provide extremely rapid and sensitive quantitative determination of polar compounds, such as haloacetic acids, chlorate and bromate, in drinking water. Electrospray ionization (ESI) has been shown in recent literature to allow for the direct determination of HAAs in both water and plasma samples (Hashimoto and Otsuki 1998; Brashear et al. 1997), as well as larger polar DBPs (Richardson et al. 1999). While ESI analysis is considered feasible, it is not practical because of the intense background of solvent- and salt-related ions produced by the ionization technique, which interfere with the detection of the compound of interest. Tandem MS has also been used to eliminate the effect of the high background, with Brashear et al. (1997) reporting detection limits at low ppb levels for the chloro-substituted HAAs in plasma.

ESI-FAIMS-MS

High field asymmetric waveform ion mobility spectrometry (FAIMS) is a continuous flow device that separates ions at atmospheric pressure and room temperature (Purves et al. 1998, Guevremont and Purves 1999). FAIMS is based on the change of ion mobility at high electric fields. The change in mobility at high electric field appears to reflect the size of the ion, its interaction with the bath gas, and its structural rigidity. The technique can remove the complex continuum of electrospray background ions, which typically limits the lower levels of detection of small ions (below m/z 200), and the detection limit for these ions can be improved by over a factor of 100.

Methods

A concentrated standard haloacetic acid solution was diluted appropriately in 9:1 methanol:tap water containing 0.2 mM ammonium acetate. In order to evaluate the improvement in the signal to background ion intensity ratio, it is useful to compare mass spectra collected with conventional ESI-MS with those collected using the new tandem ESI-FAIMS-MS system. In Figure 1 are mass spectra of a solution containing the nine chloro- and bromo-acetic acids in 9:1 methanol:tap

water (v/v) containing 0.2 mM ammonium acetate. Monobromoacetic acid (MBAA) and trichloroacetic acid (TCAA)¹ are in the solution at concentrations of 400 ng/mL and 200 ng/mL, respectively. The upper trace, Figure 1 (a), collected using conventional ESI-MS, has been expanded vertically such that the MBAA ion (m/z -137) is full scale. Fragment ions, such as may result from the loss of CO₂ from the bromo-containing acids (e.g., bromo-chloroacetic acid (m/z -171)), will overlap with other acids (e.g. dichloroacetic acid (m/z -127)) making quantitation difficult in the presence of several of the haloacetic acids in solution. The lower trace, Figure 1 (b), was acquired using ESI-FAIMS-MS at DV=-3300 V and CV = 18.0 V. The spectrum is dramatically simplified over that observed from ESI-MS, with only TCAA, MBAA, and Br⁻ (m/z -79 and -81, resulting from fragmentation of MBAA in the mass spectrometer interface), along with some background ions, transmitted at this CV. The TCAA signal in Figure 1 is not seen to be subject to overlap from acetate dimer ions as is the case with ESI-MS as observed in Figure 1 (a), and the expected isotope distribution for the ion is readily apparent. The overall abundance of the ions has increased with ESI-FAIMS-MS due to ion focusing mechanisms. This focusing, along with the decreased background signal, provides improvement in the lower level of detection of these compounds in solution. Using Figure 1 (a), the lower limit of detection of MBAA would arguably be near the 200 ng/mL concentration shown here, whereas the detection limit of MBAA using FAIMS (Figure 1(b)) is reduced to approximately 2 ng/mL.

Using ESI-FAIMS-MS, the detection limits for the regulated HAA's and BCAA tested to date lie between 0.5 and 4 ppb from a 9:1 methanol:tap water solution (v/v) with no preconcentration of the sample required. Preconcentration methods have been described in the literature, and a further concentration of at least 10 to 200 times appears feasible.

There is a very real potential for enhanced sensitivity for many polar contaminants in surface, ground and drinking waters. This has already been demonstrated for chlorate and bromate as well. This technique holds great potential for significantly enhanced sample throughput capability for analysis of polar contaminants in water. We anticipate that the technique will be easily automated and it has the potential for analytical throughput of hundreds of samples per day. Overall, the technique promises to be highly relevant for the drinking water industry.

¹ Note that it is always the corresponding *acetate ion* that is analysed, however, the analytes are referred to as the protonated acids for simplification.

**P-09 CHLOROFORM ASSOCIATED HUMAN HEALTH RISK AND WATER TREATMENT CONTROL TECHNOLOGY: A
CASE STUDY OF NEWFOUNDLAND**

By:

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Chlorine is the most commonly used disinfectant for water treatment and when it contacts with organic precursors, it produces trihalomethanes (THMs). The common forms of trihalomethanes include chloroform (CHCl_3), dichlorobromomethane (CHBrCl_2), dibromochloromethane (CHClBr_2) and tribromomethane (CHBr_3). Chloroform is the most commonly occurring THM and has the highest concentration. The solid phase micro-extraction capillary column gas chromatography and mass spectrometer detector (GC/MS) method was employed for THMs concentration determination in water samples. A study was conducted in Newfoundland for estimating the chloroform content in the drinking water supplies at various locations of the province. Limited number of drinking water samples was collected in Clarenville and St. John's. The sample collection period was divided into two stages. The first stage of samples were collected during July 1998 whereas, the second stage was done during October and November 1998 as the summer and winter sampling, respectively. Due to limited information from collected data, statistical analysis was performed to evaluate the variations and uncertainty in the data. Bootstrap simulations were performed to calculate the possible variation in collected data. The normal distribution was found to be the best distribution among various candidate distributions. For each bootstrapped data set, Monte Carlo Simulations (MCS) were performed. The human health risk associated with chloroform was evaluated using dose-response relationship of chloroform, for both communities. The excess lifetime human cancer risk varied from 0.5×10^{-4} to 1.2×10^{-4} , and zero to 3×10^{-5} for Clarenville and St. John's, respectively. However, the corresponding average risks in Clarenville and St. John's communities were 8.1×10^{-5} and 8.1×10^{-6} . The 0.25 million simulations generated using bootstrap and Monte Carlo simulations, which were then used to calculate the probability of exceedence of 100 ppb drinking water standards proposed by Health Canada (1998). The estimated probability of exceedence for Health Canada Chloroform Standards of 100 ppb, were 100% and 2.45% for Clarenville and St. John's, respectively. The higher violations of the health standards emphasised the need for remedial actions. Granular Activated Carbon (GAC) was reviewed as viable treatment technology to reduce the potential risks. The treatment efficiency of proposed technology of GAC was assumed as the random variable and appropriate distribution was selected for calculating the revised risks after treatment.

P-10 A TRI-COMMUNITY STUDY TO COMPARE WATER TESTING METHODS QUANTITATING THE GIARDIA CYSTS AND CRYPTOSPORIDIUM OOCYSTS IN RAW DRINKING WATER SOURCES

By:

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Background

In a methods evaluation study to quantitate *Cryptosporidium* oocysts and *Giardia* cysts from raw drinking water sources in British Columbia, 156 filters were collected and analyzed from 3 different locations in the province at biweekly intervals over one year. This evaluation compared 2 different types of filters (polypropylene string wound filters with envirochek capsule filters), 2 types of clarification methods (traditional Percoll-Sucrose gradient centrifugation with immunomagnetic separation (IMS), and 2 methods of reading purified pellets (cellulose acetate (CA) membranes with direct slide staining). Viability of recovered organisms was assessed with the nucleic acid vital dyes propidium iodide (on CA membranes), 4',6-diamidino-2-phenylindole (DAPI) and SYTO-59 (on slides). Water collected was split between the 2 filters and run concurrently. An additional 200 ml of bottled water to characterize drinking water samples collected at the time of water filtration was tested for total and fecal coliforms, and indicator organisms *E. coli* (Ec) and *C. perfringens* (Cp). Other water quality data pH, turbidity, and alkalinity was provided by the participating health unit or water utility.

Results

Preliminary data analysis seems to indicate that (predictions based on initial viewing of data):

String wound filters detected cysts and oocysts more frequently and in higher quantities

IMS did not significantly increase recovery compared to PS clarification

Slide staining of purified pellets from one location allowed significantly more numbers of Crypto to be identified, with no differences detected in recovery of Giardia

Percentage viability using PI was significantly different in comparison with DAPI & SYTO-59, higher percentages of oocysts and cysts were viable when stained with PI.

Percentage viability of organisms collected by IMS were significantly lower

Turbidity, pH, Cp, Ec correlated with higher numbers of cysts/oocysts?

This study ends February 2000. Final data analysis will be available after this date.

This project is partially funded by the Greater Vancouver Regional District, Capital Regional District and Health Canada.

P-11 DISSOLVED ORGANIC MATERIAL IN RURAL WATER SUPPLIES

By:

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Dissolved organic material (DOM) in rural water supplies can be several times higher than in city drinking water supplies. Sometimes these differences can be extreme as was the case for the rural community of Weldon which had a dissolved organic carbon (DOC) content exceeding 40 mg/L. In contrast, Calgary's water supply has around 1 mg/L. Rural surface water supplies in Saskatchewan typically exceed 10 mg DOC/L. This is of concern because if this water is properly disinfected using chlorine, the levels of disinfection by-products will by far exceed the Canadian Drinking Water Quality Guidelines. In addition to presenting difficulties in the formation of disinfection by-products, it also becomes more challenging to actually produce a water where the microbes have been inactivated. This is because chlorine reacts with the DOM instead of the microbes. A large amount of the DOM can be used by microbes making the water biologically unstable. This results in bacterial regrowth in distribution systems and potential loss of chlorine residuals. Decreasing these high levels of dissolved organic material is challenging. Conventional chemically assisted filtration removes only a small fraction of the DOC. High coagulation doses (enhanced coagulation) when optimized, can yield relatively high DOC removals (up to 50%), but to reach a target DOC level below 5 mg/L will require further treatment. It has been shown that conventional Granular Activated Carbon (GAC) adsorption is not sustainable for most of these high DOC water supplies with DOC exhaustion occurring within one or two months. The use of Biologically Activated Carbon (BAC) offers a more promising route to dealing with this problem. Membranes also offer promise if the high fouling potential of prairie source waters can be decreased. To find optimum treatment techniques it is necessary to characterize the dissolved organic material in terms of molecular size distribution and chemical properties. The Safe Drinking Water Foundation has made this a priority research area.

P-12 IRON & MANGANESE REMOVAL FROM DRINKING WATER - PRAIRIES STYLE

By:

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For several decades in Western Canada, a single iron and manganese (Fe/Mn) removal process was frequently used. Namely, oxidation of soluble Fe/Mn by dosing potassium permanganate followed by solids/liquids separation by filtration through manganese greensand.

Studies over the last decade identified some of the reasons so many traditional plants experienced difficulty in removing Fe/Mn to less than 0.3 mg/L and 0.05 mg/L respectively. In a preponderance of cases manganese was more difficult to remove to low levels than iron.

Almost every groundwater source in Western Canada contains iron bacteria. In some well waters almost three quarters of the iron was already oxidized biologically or held captive by iron bacteria colonies. In most instances where significant residuals of oxidized iron is found, oxidized manganese is found as well, though more of it than the iron was in a colloidal species. Other bacteria are also abundant, ranging from fluorescing pseudomonads to sulfate reducing species. Some species can be troublesome to water treatment processes.

Where iron bacteria is present it is not unusual to identify eight Fe/Mn species. Methods have been developed to rapidly identify Fe/Mn species in the field. This information can assist in choosing appropriate removal processes for pilot testing. For example, if the species data indicates significant percentages of the Fe/Mn are part of filterable bacteria colonies, use of potassium permanganate or ozone may be deleted as process choices. Strong oxidants stress bacteria, forcing them to release Fe/Mn held captive. In turn, the Fe/Mn so released may be troublesome to remove without adding another treatment step such as particle agglomeration using a polymer filter aide.

Because large areas of the prairies was once the floor of the great inland sea, total organic carbons up to 16 mg/L were found in some ground water. In these waters Fe/Mn frequently behaves as though it is organically complexed. In the presence of organic carbons an oxidation/direct filtration process without additional detention time for oxidation to reach conclusion may not produce low residuals of Fe/Mn, or may result in elevated levels of colloidal Fe/Mn in the treated water. Organic carbons also signal the potential presence of hydrogen sulfide. Its removal may become necessary to prevent reduction of manganese dioxide(s) media.

Removal processes have been developed that may use two or more processes in one treatment train and one filter vessel. For example, controlled oxidation of iron using atmospheric oxygen and calculated contact time followed by adsorption of manganese on site specific volumes of pyrolusite while using precise doses of sodium hypochlorite to restrict development of interfering bacteria colonies, is simple to operate, uses only one chemical and can reduce Fe/Mn to trace amounts. Depending on raw water chemistry, a high rate Fe/Mn adsorption process has been successfully used at rates up to 40 m/hr (17 USgpm/sq.ft.).

Reduction of Fe/Mn to trace amounts frequently results in drinking water with turbidity in the range of 0.1 to 0.5 NTUs, less than 50 total particles per mL >2 mm, extremely low true color, and water free of tastes and odours.

P-13 INFLUENCE OF NOM ON ALUMINUM IN DRINKING WATER

By:

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Natural Organic Matter (NOM) is a term collectively used to define the complex matrix of organic material present in the natural waters. It is a relatively undefined material consisting of numerous organic compounds but is known to contain many functional groups such as carboxyl, phenoxy and hydroxyl radicals that can participate in the formation of metallic complexes during coagulation of natural waters using either Al based or Fe based metal coagulant salts. NOM is approximated by dissolved organic carbon. Fulvic and humic acids represents a major fraction of DOC. Aluminum present in alum as well as naturally occurring aluminum in raw water is transformed into various forms (speciation) during drinking water treatment. The use of a coagulant containing aluminum may either increase or decrease aluminum concentration in the finished water, depending on its speciation in the source water as well as species change during water treatment.

Literature documents that natural organic matter (NOM) or dissolved organic carbon (DOC) at moderate to elevated concentrations strongly interfere with aluminum precipitation and may have a marked effect on the solubility and speciation of Al. Federal - Provincial Subcommittee on Drinking Water recommended for conventional treatment plants using aluminum - based coagulants, that an operational guideline value of 100mg/L as total aluminum is applicable. In the current context of studies on health effects of aluminum, it is prudent to keep the aluminum levels at the lowest possible level and also examine how aluminum content in the finished water at a water treatment plant would be affected by the universally present substances such as NOM in any drinking water source.

Literature suggests that NOM or DOC plays a major role during coagulation at a water treatment plant and for given water quality characteristics, depending upon the quantity of alum added during coagulation, NOM present in the raw water alters aluminum speciation. The exact nature of the Al species change has not been reported at an operating water treatment plant. The authors investigated the influence of NOM on the aluminum content of drinking water at the Buffalo Pound Water Treatment Plant, Saskatchewan.

The objectives of the present study are i) to conduct experiments at the pilot scale treatment plant located within the main plant of BPWTP, only changing alum doses to see how aluminum levels are altered in finished water for a particular (background) organic carbon present in the raw water and ii) to conduct jar tests in order to examine the aluminum species change in the settled water (prior to filtration) by supplementing the total organic carbon present in the raw water by adding fulvic acid obtained from the International Humic Substances Society (IHSS) and at varied alum doses.

Aluminum was fractionated into eight different forms during the present study. They are i) total aluminum; ii) suspended aluminum iii) particulate aluminum iv) soluble + colloidal aluminum v) soluble aluminum vi) organic aluminum vii) inorganic aluminum viii) organic aluminum. The results of the present study showed that depending upon the quantity of alum added during coagulation, dissolved organic carbon, present in the raw water altered Al speciation. Experiments at the pilot scale

water treatment plant, showed that when the Alum/DOC ratio was 5.3, most of the total aluminum in the filtered water was in the form of particulate aluminum. Such an increased particulate aluminum level did not increase the finished water turbidity. Soluble organic aluminum also did increase when the Alum/DOC was 5.3. Al speciation study conducted during jar testing showed that organically bound aluminum increased two times (compared to raw water levels) in the finished water when the Alum/DOC = 1.44. If adequate mixing and settling and optimum pH (pH of near minimum theoretical solubility of Al) are maintained during alum coagulation, jar test results showed that it is possible to avoid both increase in soluble and organically bound aluminum. Jar test results also showed that an Alum/DOC of at least 7.7 should be maintained in the main plant in order to meet the proposed operating guidelines of 100 mg/L of total aluminum suggested by Health Canada.

P-14 CHRYSTOPHYTE TASTE AND ODOUR: UNDER-ICE BLOOMS IN GLENMORE RESERVOIR

By:

S. Watson, T. Satchwill, E. McCauley and E. Hargesheimer

In general, algal taste and odour is associated with open water blooms. However, some taxa show an ability to produce appreciable biomass under the low light and temperature regimes during ice-cover, and may produce sufficient cell numbers to impact water quality. This study presents a synopsis of the odour-causing algal species that have shown outbreaks in winter and early spring in the Glenmore Reservoir, an important oligo-mesotrophic drinking water source for the City of Calgary. During two of these events, we monitored raw water quality with sensory, chemical and microscope analyses. We used bench-scale tests to evaluate the two widely used treatment options (DAF and CGS) for algal biomass and odour removal. In particular, we focus on the most recent event, in December 1999, when the reservoir experienced an under-ice increase in the chrystophyte *Dinobryon*, and an increase in source water odour due to the production of 2,4-decadienal and 2,4,7-decatrienal.

P-15 ULTRAVIOLET (UV) DISINFECTION: A BEST AVAILABLE TECHNOLOGY?

By:

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Ultraviolet (UV) disinfection is emerging as a strong candidate for one of the Best Available Technologies that can be combined with others into multiple barrier processes for production of potable water. This paper reviews the basis for this statement, including integration of new and existing information relevant to development of guidelines and regulations for design and operation of UV systems for water treatment. The issues are addressed within the context of getting UV recognized as an enabling technology that allows cost-effective reduction of risk both to pathogens such as *Giardia* and *Cryptosporidium* and to disinfection byproducts (DBPs) such as chloro-organics or bromate formed by chemical disinfectants. These are the same issues that the U.S. Environmental Protection Agency is currently facing in preparation for the next round of regulation negotiations.

The relative sensitivity of different microbes to UV and the narrow UV dose range needed to cover these sensitivities are key to defining the strategic role of UV when combining it with other unit operations into new and/or retrofitable processes offering effective multiple barrier approaches to pathogen risk reduction. The spectrum of microbe sensitivity to both UV and chlorine are compared and used to define different optional processes that provide cost-effective reduction of microbial risk.

The sensitivity of *Cryptosporidium* oocysts and *Giardia* cysts to UV, but the resistance of these same organisms to chemical disinfectants, points not only to cost-effective strategies for combining chemical and UV disinfection for pathogen control, but also to effective strategies for dramatic reduction in byproduct formation. The balance point between UV dose and chemical disinfectant dose will be determined by how low the chemical disinfectant dose must be reduced to control byproduct formation with the particular water under consideration, and how high the UV dose must be increase to provide the target control of pathogens not addressed by the chemical disinfectant. Examples of byproduct control with effective disinfection are illustrated for combination of UV with ozone and with chlorine-based disinfectants.

The cost-effectiveness of UV is influenced by the choice of the target pathogen for design, the resulting UV doses needed to inactivate these organisms to levels that provide the target risk levels, and the safety factors imposed by regulators upon UV doses to account for uncertainty. The current debate is presented on the choice of target pathogen for design purposes, and data is presented that argues for a far lower safety factor than currently recommended to address uncertainty associated with UV inactivation of microbes. It is additionally argued that the insensitivity of UV disinfection to pH and temperature removes a treatment uncertainty present with chemical disinfectants. Finally, the safety factors inherently present in UV system design are examined.