RURAL DRINKING WATER AND WATERBORNE ILLNESS

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ABSTRACT:

The role of water as a carrier of microbes that are disease-causing in humans is often overlooked with diseases being vastly under-reported. Some waterborne diseases, such as salmonellosis, campylobacteriosis and giardiasis, can exhibit clinically mild symptoms with patients not seeking medical help. The frequency of reporting is also affected by awareness of specific diseases, interest and the availability of resources in different areas. The portion of a specific disease that can be attributed to water is also typically not known. The environmental occurrence of most existing and several emerging waterborne disease agents, such as enteric viruses, has not been established. Waterborne illnesses are not restricted to diarrheal diseases, with several severe diseases being implicated with waterborne transmissions including heart attacks, insulin dependent diabetes (*Coxsackie B* virus), Guillain-Barre syndrome (paralysis, *Campylobacter*) and Hemolytic Uremic Syndrome (HUS, *Escherichia coli* O157:H7). Here we have examined the official health statistics from 1990 to 1998 for five reportable illnesses caused by microorganisms with a potential waterborne transmission path: giardiasis, campylobacteriosis, shigellosis, haemorrhagic colitis or hemolytic uremic syndrome (caused by E. coli O157:H7), and hepatitis A. These diseases were especially prominent in the prairie provinces except for campylobacteriosis. Rural areas in the prairie provinces have especially challenging water quality problems due to high levels of dissolved organic material and predominantly agricultural drainage basins. This makes the water difficult to treat. Waterborne illnesses affect sub-populations differently with the fetus and infants being particularly sensitive. Infants exposed to pathogenic microbes are much more likely to develop disease and the outcome of an infection is much more severe than in the general population. Increased risks of one to two orders of magnitude can be expected. This prompted us to have a look at another health statistic, infant mortality. The three prairie provinces were among the four provinces with highest average infant mortality rates throughout the period. Rural Canada as a whole is not faring well with 40% higher infant mortality rates compared with urban Canada. Can we afford to ignore the possibility of a connection between poor rural water and higher infant mortality? Higher infant mortality in Canada has also been ascribed to First Nations. First Nations, similar to other rural communities, have frequently difficult to treat water with limited expertise on-reserve. While the connections between waterborne microorganisms and a variety of diseases and health indicators (such as infant mortality) remain to be established, it is clear that rural areas cannot take safe drinking water for granted. Mechanisms to produce safe drinking water from poor source waters need to be determined. Simple, yet effective systems need to be designed, which should allow for the lack of highly skilled water treatment plant operators.

***Keywords*:** waterborne illness, disease-causing microbes, human health, infant mortality, Giardia, Campylobacter, Shigella, hepatitis A, Escherichia coli O157:H7, giardiasis, campylobacteriosis, shigellosis, haemorrhagic colitis, hemolytic uremic syndrome.

NTRODUCTION:

Background:

The role of water in transmitting microbial illnesses to humans has frequently been overlooked compared with other transmission paths. An outbreak of cryptosporidosis in Milwaukee in 1993 where 50% of the population were infected has cost $25 billion U.S in 1999 (NRC, 1999) leading regulatory authorities and large water treatment plants around the world to carefully consider waterborne pathogenic organisms. The U.S. Environmental Protection Agency (USEPA) has introduced a series of regulatory standards, including the Surface Water Treatment Rule (SDWA), the Enhanced Surface Water Treatment Rule (ESWTR), The Total Coliform Rule (TCR), Disinfection Byproducts Regulations (DBPR), and in April 2000, comments were requested for the Groundwater Rule (GWR, USEPA, 2000). These rules are designed to primarily deal with microbial concerns although chemicals are also included in both SDWA and GWR. Microbial compliance has been more difficult to achieve than compliance with chemical contaminants with 23.5% of all U.S. community public water systems having violated the microbial standards between 1992 and 1995, while only 1.3% violated the chemical standards (NRC, 1999).

Concerned that even the above rules may not be sufficient to deal with some microorganisms, the USEPA has listed a number of microorganisms requiring further study (Table 1). Several other microbes were considered, but microbes that are adequately controlled by the above rules were excluded from the list. This included rotaviruses and hepatitis A and E viruses, which are expected to be controlled by disinfection. Three protozoan parasites, *Toxoplasma gondii, Cyclospora cayatensis* and *Entamoeba histolytica* were also excluded from the list because they are of similar or larger size than parasites already regulated (*Giardia* and *Cryptosporidium*). Many bacteria were excluded from the list because compliance with existing and proposed rules should control *Salmonella, Shigella, Campylobacter, Yersinia, Vibrio cholerae* and other vibrios. *Legionella* was excluded because it has been extensively dealt with under existing and proposed rules, which are continually being updated.

Several protozoan and bacterial pathogens can infect both humans and animals while human gastrointestinal viruses typically only infect humans. Human and animal waste are therefore both of concern for the transmission of waterborne illnesses. Failures of septic tanks are common with more than 90,000 reported in one year alone in the U.S. (USEPA, 1997a). Fecal contamination can reach surface water supplies and aquifers through a variety of means including direct runoff into surface water, through improperly sealed abandoned wells, along the well casing, and through cracks in the sanitary seal of the well (USEPA, 2000). Sinton et al. (1997) showed that viruses are much more readily transported through subsurface substrata than are bacteria.

Distribution systems can also present problems either through failing cross connections, broken pipes, or growth of microorganisms within the pipes (USEPA, 2000). Some opportunistic bacterial pathogens, such as *Legionella*, *Pseudomonas aeruginosa*, and *Mycobacterium avium* can colonize and grow in distribution system pipes (USEPA, 2000). Although viruses may be protected by the biofilm in distribution systems, they cannot grow (USEPA, 2000). Microbial quality is almost exclusively determined by the presence/absence of total coliforms, fecal coliforms and/or *E. coli* despite the fact that most pathogenic microbes have much greater resistance to disinfectants or can more easily contaminate and survive in groundwater (viruses) resulting in water with no coliforms (especially after disinfection, or in many groundwater sources contaminated by viruses, USEPA, 2000).

Table 1: Drinking water contaminant candidate list (CCL, USEPA 1998, NRC 1999)

Protozoa	*Enterocytozoon*
	Microsporidia
	Septata
Viruses	calciviruses
	adenoviruses
	coxsackieviruses
	echoviruses
Bacteria	*Helicobacter pylori*
	Mycobacterium avium complex
	Aeromonas hydrophila
Algae/Cyanobacteria (blue-green algae)	Cyanobacteria, other freshwater algae, and their toxins

The concept of multiple barriers for microbe removal is the cornerstone of several different water treatment rules in the U.S. including the Surface Water Treatment Rule and the Groundwater Rule. Most Canadian cities are following the different U.S. generated rules to ensure that microbial barriers can achieve high levels of removals through optimization of many different water treatment processes.

In contrast, the multiple barrier approach is seldom used in rural Canada. Rural water is also typically of much poorer chemical quality as it is derived from small surface water reservoirs and aquifers, while cities are mostly located close to large lakes or rivers with much better chemical and biological characteristics. In addition to having better water to treat, cities also have the resources to treat the water well. The City of Calgary, for example, employs 18 people in a research and development laboratory to ensure that one of the best raw water sources in Canada becomes safe for human consumption.

No level of government has invested in research laboratories and scientists to address rural water quality issues and it is against this background the Safe Drinking Water Foundation was formed. Through an international network of scientists we aim to provide drinking water quality solutions for rural people around the world. In this article a background to the issues surrounding microbial quality and rural drinking water is given, and official statistics for diseases that can be caused by waterborne microorganisms are reviewed. Populations at risk for waterborne illnesses are also discussed and trends warranting further scrutiny are identified.

Waterborne bacteria:

Bacteria that cause illness in most individuals are called primary pathogens while those that cause illness mainly in sensitive sub-populations (immuno-compromised, elderly, children) are called opportunistic pathogens. Bacteria can cause illness either through growth within the human body (e.g., *Salmonella*) or by the release of toxins in the human body (e.g., *Campylobacter*, *E. coli* O157:H7). Some bacteria travel freely between humans and animal hosts, such as *Campylobacter*, *E. coli*, and *Salmonella*, while others, such as *Shigella*, are mainly associated with humans (Geldreich, 1996). Comparisons between the environmental occurrence and the disease profile of *Campylobacter* and *Shigella* can potentially be used to determine relative differences in animal vs. human contributions to illness.

Most waterborne pathogenic bacteria can cause gastrointestinal illness, but as shown in Table 2, several can also cause more severe illnesses. For example, *E. coli* O157:H7 can cause bloody diarrhea and hemorrhagic colitis as well as hemolytic uremic syndrome (HUS). *[Editor's note: In mid-May 2000, a waterborne outbreak caused by E. coli O57:H7 was detected in the the rural town of Walkerton Ontario. By the time the outbreak was brought under control in mid-June more than 2300 cases and 7 deaths had been reported.]* Another bacterium, *Legionella,* causes Legionnaires disease, which is a form of pneumonia with a 15% fatality rate; it also causes a less severe illness called Pontiac fever, which most people exposed to *Legionella* will develop (USEPA, 2000).

Table 2: Some illnesses caused by major waterborne bacteria pathogens

Bacterial pathogen	Illnesses
Campylobacter jejuni	Gastroenteritis, meningitis, associated with reactive arthritis and Guillain-Barre paralysis
Escherichia coli (several species)	Gastroenteritis, hemolytic uremic syndrome (kidney failure)
Legionella species	Legionnaires Disease, Pontiac Fever
Salmonella species	Gastroenteritis, septicemia, anorexia, arthritis, cholecystitis, meningitis, pericarditis, pneumonia, typhoid fever
Shigella species	Gastroenteritis, dysentery, hemolytic uremic syndrome, convulsions in young children, associated with Reiters Disease (reactive arthropathy)
Vibrio cholerae	Cholera (dehydration and kidney failure)
Yersinia entercolitica	Gastroenteritis, acute mesenteric lymphadenitis, joint pain

Modified from Encyclopedia of Microbiology (Lederberg, 1999)

Vibrio cholerae non-O1 is increasingly isolated from people that have not traveled outside Canada (Ewan, 1982). In Saskatchewan, *Vibrio cholerae* has been isolated every year for the past ten years with all cases having had exposure to surface water (CCDR, 1998a). Shigellosis causes around 600,000 deaths every year globally with increasing number of *Shigella* strains being resistant to multiple antibiotics (CCDR, 1997a). *Shigella* serves as an example of how antibiotic resistance is developed with resistance acquired to sulfa drugs in the 1940s, to tetracycline and chloramphenicol in the 1950s, to ampicillin in the 1970s, and to trimethoprim/sulfamethoxazole in the 1980s (CCDR, 1997a). Similarly, *Salmonella typhimurium* has emerged as resistant to ampicillin, chloramphenicol, streptomycin, sulfonamides, and tetracycline (CCDR, 1999b).

While drinking water is an important vehicle, contamination of fruits and vegetables by manure or by water containing microorganisms has resulted in a variety of foodstuffs being implicated in various outbreaks. Contamination of unpasteurized apple cider with *E. coli* O157:H7, *Salmonella*, and *Cryptosporidium* have been associated with several outbreaks (CCDR, 1997b). Cattle, deer and sheep can asymptomatically carry *E. coli* and *Cryptosporidium*, and cattle, chickens, and pigs can carry *Salmonella* (CCDR, 1997b). Both *E. coli* and *Cryptosporidium* are acid tolerant and can survive the low pH in apple juice (pH 3-4) for up to four weeks (Millard *et al*., 1994). The addition of a preservative to the apple cider does not consistently kill *E. coli* (Zhao *et al*., 1993). *Cryptosporidium* is even more difficult to kill as it is resistant to bleach, iodine and sodium hydroxide (Campbell *et al*., 1982). Similar outbreaks have occurred with *Salmonella* tainted orange juice and alfalfa sprouts and *Shigella* tainted parsley (Crowe *et al.*, 1998). Such occurrences reflect a need to keep livestock out of orchards and avoid using dropped fruit, and to use potable water for washing of equipment and fruit (CCDR, 1999a). Waterborne microbes can through various routes become food processing problems.

Recreational exposures (water fountains, community and hotel pools etc.) can be particularly problematic for *Cryptosporidium* as this parasite is resistant to disinfection (CCDR, 1999c).

Waterborne viruses:
The USEPA (2000) divides viruses into two separate classes, those that have low-to-moderate infectivity, but relatively severe health effects (Type B viruses, causing for example myocarditis), and those that have high infectivity, but relatively mild health effects (Type A viruses, typically causing gastroenteritis). The illnesses caused by Type B viruses can be extremely costly to treat. Rotaviruses have been used as the model organisms for Type A viruses and echoviruses have been used for Type B. USEPA is trying to estimate the percentage of Type A and Type B viral contamination of different types of wells and suggest that improperly constructed wells have two orders of magnitude greater Type A and Type B viral concentrations than properly constructed wells (USEPA, 2000). Secondary exposures are also a concern. It has been estimated that for every child with a waterborne viral disease, an additional 0.55 people (Type A) and 0.35 people (Type B) will become ill (USEPA, 2000).

The model organism for Type B viruses, echoviruses, was implicated in an outbreak in Southern Saskatchewan in 1998 (CCDR, 1998b). Echovirus 30 meningitis was suspected in 37 cases of viral meningitis and 22 of those cases were later confirmed by viral culture (CCDR, 1998b). The Calgary Health District was also reported to have cases of echoviral meningitis in 1998 (also reported in CCDR, 1998b).

Table 3: Some illnesses caused by fecal viral pathogens

Enteric virus	Illnesses
Astrovirus, Norwalk virus and other calciviruses, rotavirus	Gastroenteritis
Coxsackievirus A	Meningitis, fever, respiratory disease
Coxsackievirus B	Myocarditis, congenital heart disease, rash, fever, meningitis, encephalitis, pleurodynia, diabetes melitis, eye infections
Echovirus	Meningitis, encephalitis, rash fever, gastroenteritis
Enteric adenovirus	Respiratory disease, eye infections, gastroenteritis
Hepatitis A and hepatitis E virus	Hepatitis
Poliovirus	Paralysis

Modified from Encyclopedia of Microbiology (Lederberg, 1999)

Despite the fact that CDC data shows that bacterial pathogens (15% of total) were responsible for more outbreaks than viral pathogens (9% of total), USEPA is re-classifying outbreaks where no agent was identified (63% of total) as virus-caused because it is more difficult to diagnose viral pathogens compared with bacterial pathogens (USEPA, 2000). Correct diagnosis of a viral waterborne outbreak is therefore low while physicians can more readily identify bacteria leading to the above discrepancy. There are several additional reasons why the USEPA decided to classify a majority of waterborne outbreaks as viral. For example, viruses move more readily in the ground than bacteria and they remain viable longer and are more infectious than bacteria (USEPA, 2000). The CDC database shows that for every 20 bacterial illnesses there were 100 viral or unknown etiological agents and USEPA (2000) assumes that viral illnesses are 5 times more common than bacterial illnesses. The data indicate that ground water contamination (51% of total), inadequate treatment or treatment failures (22% of total), and distribution system deficiencies (17% of total) were responsible for most outbreaks, with only 7% being unaccounted for (USEPA, 2000).

Transport of particles in water:
To understand the potential for microorganisms to be transmitted by water it is necessary to consider how their sizes determine settling rates (Table 4). Large particles have small specific areas (surface area of particle/volume of particle), which is a prime determinant of how rapidly particles will move through a column of water. Gravel, sand and clay have specific areas ranging from 600 to 600,000 m^2/m^3 and settle through a one meter column of water from 1 second to 2 hours. Protozoans and some algae are also quite large and can settle through a one meter column of water within a few hours. Bacteria and smaller types of phytoplanktonic algae with diameters around 1 micrometer have specific areas of around 6 million m^2/m^3 and settling rates that are measured in days (Degremont, 1991).

Particles smaller than 0.5 µm are operationally defined as dissolved material, this includes all viruses as well as many dissolved organic substances. Viruses range from 1-100 nm in size with settling rates ranging from 2-200 years (Degremont, 1991). Viruses are also sufficiently small (same size as colloids, such as humic acids etc.) to move with the flow of water without being greatly impeded by structural properties of the soil. The end result of this, is that if water can reach an aquifer so can several viruses. This ease of movement is a major reason that viral contamination of ground water is now featuring prominently as the major cause of waterborne diseases (USEPA, 2000).

Table 4: Settling time of different particles in water.

Particle diameter	Type of particle	Settling time through 1 m of water	Specific area (m^2/m^3)
10 mm	Gravel	1 second	6 x 102
1 mm	Sand	10 seconds	6 x 103
0.1 mm	Fine Sand	2 minutes	6 x 104
10 µm	Protozoa, Algae, Clay	2 hours	6 x 105
1 µm	Bacteria, Algae	8 days	6 x 106
0.1 µm	Viruses, colloids	2 years	6 x 107
10 nm	Viruses, colloids	20 years	6 x 108
1 nm	Viruses, colloids	200 years	6 x 109

Modified from Degremont, 1991

Viruses can therefore travel almost unhindered with their transport medium, water. Viruses can also remain viable for long periods of time resulting in considerable threats to aquifers and other bodies of water (USEPA, 2000). Groundwater velocities are highly variable, but can reach 500 m/h in certain geological formations (USEPA, 1997b) and rapid movement of viruses from permitted waste injection wells to groundwater and surface marine waters has occurred in 10 hours and less (Paul et al. 1997). Even impermeable material, such as bedrock, can transmit water through fractures and equally high ground water velocities can be reached. Gravel aquifers have very little or no removal capabilities, while sand and finer material, provide better removal of microorganisms (Freeze and Cherry, 1979). Confined aquifers (unfractured layers of silt and clay) will, however, provide protection for the aquifer as long as it remains unbreached (Freeze and Cherry, 1979). Breaches can be caused by abandoned wells that have not been plugged, and they can be caused by natural processes, such as fractures, faults, sinkholes and eroded parts (USEPA, 2000). The most sensitive geological settings for contamination include karst, gravel and fractured rock.

The National Research Council (NRC, 1999) reported that PCR determinations of viruses in U.S. groundwater sources showed a presence of enteric viruses in 30% of the wells tested, rotaviruses in 13% and hepatitis A in 7% of the wells. Close proximity of sources of sewage to aquifers used for drinking water purposes can be attributed to some microbial contamination issues as 39% of well sites were within 50 m of a sewage source and another 27% were within 200 m of a sewage source (AWWARF not yet published, reported in USEPA, 2000). Relatively high levels of enteroviruses, rotaviruses and calciviruses were found in surface water (Husman et al. in press). Grabow et al. (in press) reported virus detections in 24% of treated water samples derived from surface water sources. All treated water samples had heterotrophic plate counts <100/mL, and no total or fecal coliforms/100 mL, suggesting good treatment and safe water. However, enteroviruses were detected in 17% of the treated water samples, adenoviruses in 4% and hepatitis A in 3% (Grabow et al. in press). Even sensitive tests, such as the somatic and F-RNA coliphage tests did not detect the presence of viruses in the treated water.

An example to demonstrate the transport of microbes by water is the rapid contamination of a farm well. Several farm water treatment systems were tested for chemical and microbial removal performance during the winter/spring of 1999 (Peterson, 2000). At one of the farm sites where livestock were present in close proximity to the well, there were no signs of coliforms in the raw well water during winter. During snow melt, however, it was observed that while the soil around the large-diameter well casing sloped down, the snow around the well, melted first and literally became the lowest part of the yard with potential for manure-laden water to drain towards the well and possibly into the well. During the snow-melt it was shown that total coliforms went from non-detectable to around 400/100 mL of water. Rapid sand filtration would not have been able to effectively deal with this problem, but this farmer had an experimental system based on a hybrid rapid/slow sand filter/Biologically Active Carbon (BAC) filter (Fig. 1).

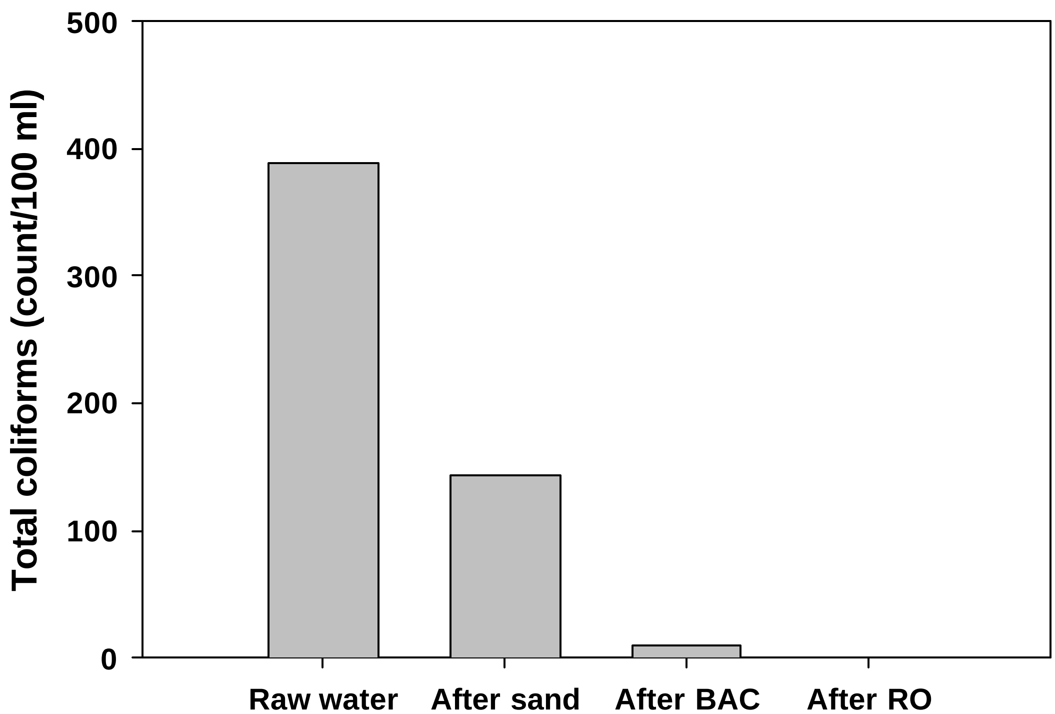

Figure 1: Removal of total coliforms in a ground water treatment system. Data from Peterson, 2000.

The sand filter in this situation removed about a third of the coliforms and the (BAC) filter removed an additional 90%. Even after two large filter units using different support materials there were, however, still coliforms in the processed water. The farmer also has a Reverse Osmosis membrane system (RO) in the kitchen and there was no detection of coliforms after the RO membrane. There are, however, few systems that are employing such extensive treatment on-farm and in small communities. The challenges that rural water users face when trying to produce safe drinking water is explored below.

Rural water treatment:
The quality of the water that rural water treatment plants need to treat is frequently poor, with high levels of dissolved organic carbon (DOC > 10 mg/L) and surface water reservoirs frequently suffer from algal blooms (Sketchell et al. 1993). Chemically assisted filtration is typically a minimum treatment requirement for municipal water treatment plants. To produce water that meets the Canadian Drinking Water Quality Guidelines using chemically assisted filtration is very difficult since DOC removals are low for such treatment systems. Proper chlorination of water with DOC levels above 7 mg/L will frequently result in trihalomethane levels exceeding 100 microgram/L and DOC levels around or below 5 mg/L are much more suitable for drinking water production (Peterson et al. 1993).

In addition to not being able to meet the trihalomethane guidelines many rural water treatment plants and individual users will encounter problems removing particles from the water including microbes. A rural water treatment plant serving 800 people, is used as an example of this. This water treatment plant is pumping water from a small creek into a holding reservoir. The DOC level is around 15 mg/L before treatment with very small reductions after treatment. A standard package treatment plant provides for the chemically assisted filtration (alum and mixed media filter and an upflow clarifier). The quality of the water coming into the treatment plant, after treatment, and in the distribution system is given (Fig. 2). This is compared with the distributed water in Saskatoon.

In both the smallest size fraction, 2-5 µm, and in the 5-10 µm size fraction, the distributed water in the rural community had one thousand times more particles than the City of Saskatoon. These fractions can include pathogenic parasites, such as *Giardia* and *Cryptosporidium*. The quality of the raw water is quite similar to the treated water and for several size fractions the quality of the distributed water is worse than the raw water. Aggressive cleaning of distribution system lines and modifications to the treatment has improved the situation, but to produce high quality, safe drinking water from extremely challenging water sources using simple equipment remains very difficult.

The creek from which this small community is withdrawing water is only flowing for a few weeks during the spring and like many other multipurpose creeks this one is also a recipient of sewage lagoon water from a community upstream. Another disconcerting fact about Yellow Quill First Nations is that this community has had a Boil Water Advisory in effect from 1995 to the present. With dissolved organic carbon levels in excess of 15 mg/L this community cannot meet the trihalomethane guideline either. However, Yellow Quill has frequently not exceeded the trihalomethane guidelines because insufficient levels of chlorine were typically used. It appears that no federal agency has tried to seriously implement safe drinking water for First Nations.

Lack of proper procedures for maintenance, water quality monitoring, and reporting makes it very difficult to assess the extent of problems First Nations across Canada face. Combining this with poor quality source waters, similar to any other rural community, with equipment that is quite limited in the removal of microbes and organic material makes on-reserve drinking water questionable in terms of safety. A program to assess waterborne illness while at the same time implementing proper procedures and a research effort to provide First Nations with solutions to these problems is called for.

When onsite wastewater treatment systems are used, such as septic systems with leach fields, the potential for this material to reach the intake zone of a drinking water well is considerable. In one year in the U.S. there were more than 90,000 reported failures of septic systems (USEPA, 1997a). Fecal contamination can also reach wells or surface water reservoirs through surface water runoff from manure/sewage contaminated sites. Recent testing of 1,000 wells in Manitoba showed that 43% were positive for total coliforms, 3% for *E. coli* and 16% exceeded the Canadian Drinking Water Quality Guidelines for nitrates (L. Frost, Manitoba Conservation, pers. comm). A suspected major cause of unsafe water is on-site contamination and work to determine this is in progress.

In contrast, cities have better source waters and far better treatment facilities. The dissolved organic carbon levels are typically at manageable levels with some having levels as low as 1 mg DOC/L (for example City of Calgary); this is an order of magnitude lower than surface drinking water reservoirs in Saskatchewan (Sketchell et al. 1993). There are several reasons for far better source waters for cities. Cities are typically located close to a large lake or river. Not only is a large, deep lake, suitable for storage of water with minimum deterioration (low biological activity), but the water entering such lakes typically drains catchments with large non-agricultural portions resulting in high quality water entering the lake. In contrast, rural water supplies are small, shallow, and a majority of the watersheds are composed of agricultural land.

Cities also have the financial resources to employ scientists and engineers that can optimize treatment systems through the selection of many different treatment units arranged in series. Treatment systems in cities typically employ processes where it takes one or two hours before the water is treated while rural areas often employ processes that literally will take only a couple of minutes before the water is considered to be treated. The advantage of such rapid treatment is the use of small treatment units and therefore a small foot-print of the treatment plant. Combined with rapid treatment rates are difficult challenges in terms of optimization of the treatment steps. For example, coagulation and the formation of a floc that is suitable to filter out needs to occur within seconds; this is quite a feat especially during winter when the water is cold. This also calls for rather coarse media in the filters also restricting the amount of particle removal that will take place.

A thorough assessment of effectiveness in terms of microbial as well as dissolved organic material removal needs to be made. This cannot be restricted to specifications by the manufacturer, which engineering companies typically rely on when designing water treatment plants, but it also needs to address the performance of these treatment systems in real situations in actual communities. Manufacturers typically test their equipment on water that is of far higher quality than what is available in rural Canada. One such "testing source" is Colorado River water against which all National Sanitation

Foundation products are tested; this is not a challenging water source when compared with water from rural Canada.

Through difficult to treat water sources, poor treatment equipment, and people that have limited training, particles, including microbes, will form a natural part of the “treated” water; not until the distributed water in rural areas is examined for waterborne pathogens will the extent of these problems be known. While drinking water is a provincial mandate, safe drinking water for rural areas in a national requirement and as such will need to be addressed not only by the provinces, but also by others levels of government, academia, and research organizations.

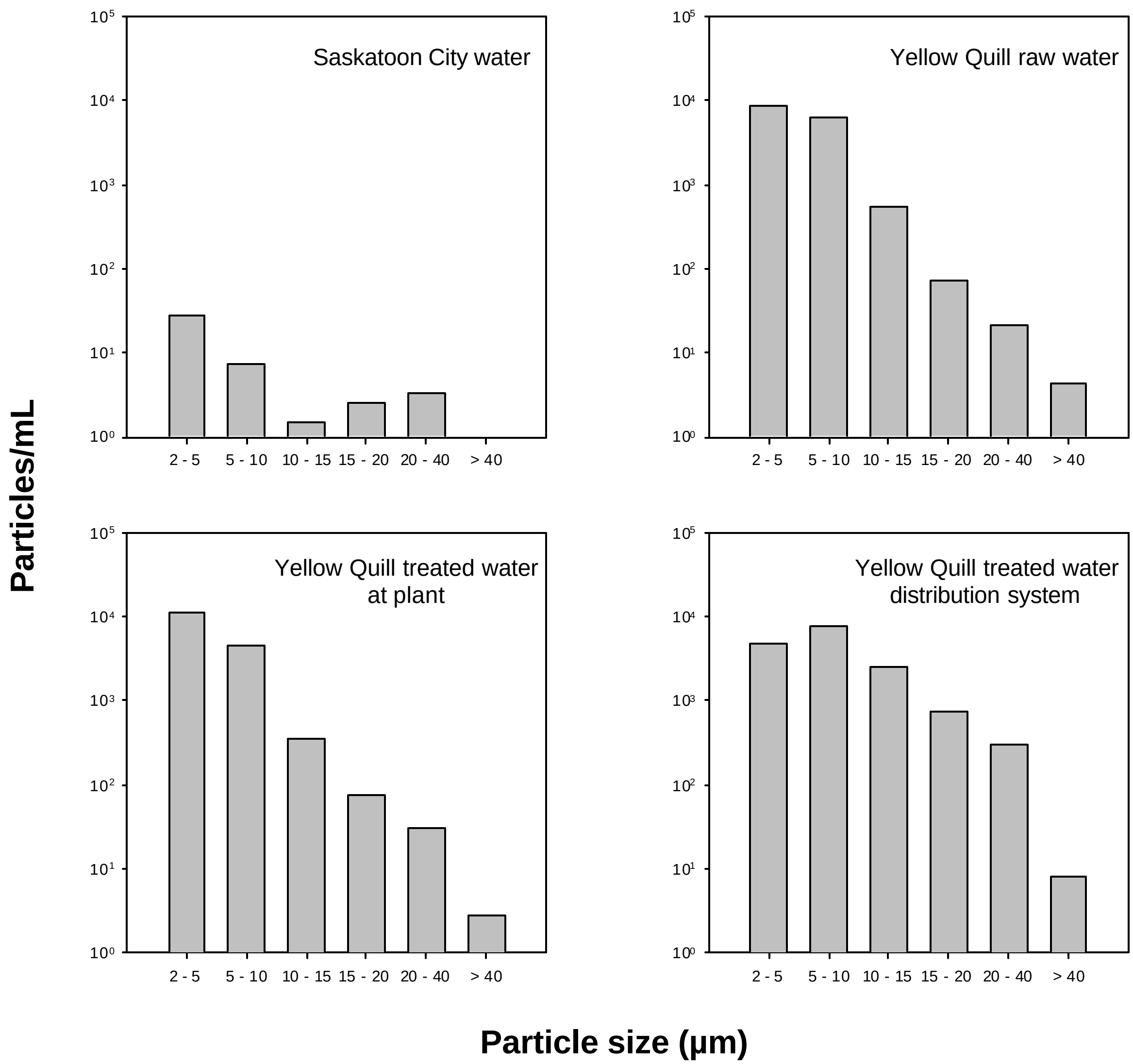

Figure 2: Particle size distribution comparing Saskatoon City water and water at Yellow Quill First Nations.Detecting waterborne illnesses:

The number of identified and reported outbreaks in the CDC database for surface and ground water likely represents a small percentage of actual waterborne disease outbreaks (NRC, 1999). There are several reasons for this, including, lack of active disease surveillance systems and difficulty in recognizing small outbreaks (USEPA, 2000). Most outbreaks may not be recognized until a sizable proportion of the population (1-2%) becomes ill (Craun and Calderon, 1996). The Milwaukee incidence of cryptosporidosis (403,000 illnesses) was not recognized by health authorities until it was near its peak (MacKenzie et al. 1994). Weaknesses in disease surveillance were evident as the outbreak was not identified until a pharmacist alerted the health authorities to unusually high sales of over-the-counter diarrheal medicines.

When estimating the actual cases of waterborne illnesses, the use of rather large multipliers is needed. A study from Ontario showed that the reported cases of giardiasis need to be multiplied by at least 10 to arrive at actual numbers of clinical infections (asymptomatic carriers were not included, Wallis et al. 1998). To estimate the total impact of a particular illness on a community, province, or a country therefore becomes quite a challenging proposition.

Implications of waterborne illnesses:

New information links "mainstream" diseases such as diabetes, myocarditis, congenital heart disease, meningitis, encephalitis, and eye infections to one enteric waterborne virus, the Coxsackie B virus (USEPA, 2000). There are more than another 140 types of pathogenic viruses in human sewage (Husman et al. in press) with unknown incidence rates in Canadian water sources. Typically, physicians will categorize clinical symptoms, but not the underlying causes. There is little known about the occurrence of viruses in water and diagnosing waterborne viral illnesses remain a great challenge for physicians. The emergence of water as a major concern in human illness prompted Physicians for Social Responsibility (PSR, 2000) to declare that we have only seen the very tip of the iceberg.

The lack of high quality water sources and poor treatment practices in rural Canada begs a question. What portion of human-ill health in rural Canada (including individual users, small communities, First Nations) can be attributed to waterborne illnesses? Differences in urban vs. rural health can be summed up as shorter life expectancy and higher death and infant mortality rates (Watanabe and Casebeer, 1999).

Here an examination is made of official Canadian health records for several diseases that are caused by microorganisms with potential waterborne transmission paths. The microbes were selected to be representative of viruses, bacteria and parasites. The illnesses associated with each microbe also needed to be reportable in Canada. The organisms selected include one parasite with both human and animal hosts (*Giardia*), two bacteria which have both animal and human hosts (*Campylobacter, Escherichia coli* O157:H7), one bacterium with primarily human hosts (*Shigella*) and one virus (hepatitis A) with exclusively human hosts. Because microbial illnesses affect the very young strongly, disease data was also compared with infant mortality data. The data was generated by provincial health departments and made available by Health Canada and Statistics Canada.

While there are different transmission routes for the above organisms the importance of water can be seen from the most recently reported U.S. health statistics (1997-98) which identified the most common waterborne illnesses as caused by *Cryptosporidium* (not reportable in all Canadian provinces), *Giardia*, *E. coli* O157:H7 and *Shigella* (PSR, 2000). For 1985-1992 the bacterial agents associated with waterborne outbreaks were mainly *Shigella* and *Campylobacter* (Moe, 1996). Recreational water outbreaks were mainly associated with *Pseudomonas*, *Shigella* and *Legionella* (Moe, 1996). All of the parasitic and bacterial pathogens selected are therefore important waterborne disease carriers in their own right in addition to serving as indicators for other parasitic and bacterial illnesses. Hepatitis A, while present in 7% of wells studied in the U.S. (NRC, 1999) and 3% of treated drinking water in Europe (Grabow et al. in press), the importance of this virus in waterborne transmissions has not been established. This is similar to most viruses for which little data exist. Yet viral illness, as a category, is assumed to cause five times more waterborne illnesses than bacteria (USEPA, 2000).

DISCUSSION OF CANADIAN DATA:

Waterborne illnesses in Canada:

Giardia, *E. coli* O157:H7 and *Campylobacter* have animal and human hosts, while *Shigella* mainly affects humans and hepatitis A exclusively affects humans. The effective dose for enteric viruses and protozoan parasites is typically low with as few as 1-10 infectious units or (oo)cysts (PSR, 2000). Enteric bacteria generally require higher doses ranging from 100-100 million colony forming units (PSR, 2000) although *E. coli* O157:H7 has an estimated infectious dose of less than 100 organisms (Griffin and Tauxe, 1991).

It should be recognized that when a province vaccinates a large proportion of the population against a specific illness, such as hepatitis A, its usefulness as an indicator organism is lost as it can be present in the water without eliciting that specific illness in the population. In addition to the microbes selected for scrutiny here, there are many other microbes that have been shown to be present in drinking water sources, but they are not reportable illnesses in Canada (see Tables 1-3). This is therefore only a limited survey of potentially waterborne illnesses. It is anticipated that a much larger number of illnesses will be reportable in the future. For example, a complication from the disease campylobacteriosis, Guillain Barre Paralysis, has only been made a reportable disease this year.

Giardiasis cases 1990-1998

The protozoan *Giardia* is approximately 5-10 µm in diameter. It is therefore not anticipated that this large organism will be present in ground water unless it is under the influence of surface water. The majority of the illnesses associated with waterborne *Giardia* are therefore expected to originate from consumption of water from surface water reservoirs, lakes, rivers, and creeks.

The occurrence of giardiasis in the different provinces did not follow any specific trend for several provinces, but Alberta, BC and Saskatchewan did register lower numbers of cases with time. In Quebec, however, there was an increase in case numbers. Giardiasis was not a reportable disease in Manitoba until 1997 when it reported low numbers. Typically when a province starts reporting an illness there are annual increases until physicians and health surveillance units have improved detection processes. Indeed, the giardiasis cases in Manitoba more than doubled from 1997 to 1998.

The two territories lead in terms of reported cases/1000 people. Due to the small number of people these numbers can fluctuate greatly making an interpretation of these rates difficult. For the provinces, British Columbia had the highest number of *Giardia* cases/1000 people with Saskatchewan a close second and then Alberta.

Table 5: Reported cases of giardiasis per province from 1990 -1998.

Province	Year									avg	Reported
	1990	1991	1992	1993	1994	1995	1996	1997	1998		
ALTA	1354	1453	1131	941	854	609	545	568	605	896	0.35
BC	2235	2023	1767	1468	1485	1496	1301	1181	1107	1563	0.48
MAN	nr	nr	nr	nr	nr	nr	nr	84	195	140	0.13
NB	134	130	141	138	112	99	111	133	76	119	0.16
NFLD	46	208	167	71	80	67	42	42	54	86	0.15
NWT	42	73	49	56	45	28	22	18	16	39	0.67
NS	119	174	116	108	113	107	138	92	96	118	0.13
ONT	3462	3754	2854	3054	2695	2695	2535	2393	2124	2841	0.28
PEI	18	3	13	11	13	4	9	5	9	9	0.07
QUE	688	641	676	748	701	794	934	899	983	785	0.11
SASK	649	661	523	446	397	359	400	241	236	435	0.44
YUK	39	48	49	22	28	37	22	21	18	32	1.14
Total	**8786**	**9168**	**7486**	**7063**	**6523**	**6295**	**6059**	**5677**	**5519**	**7061**	**0.26**

From Health Canada 2000

Campylobacteriosis cases 1990-98

The bacterium *Campylobacter* is associated with livestock, other animals and human waste. BC is the clear leader in reported cases for this bacterium with 0.76 cases/1,000 people. Ontario is number two and PEI number three.

The comparatively low rate in Saskatchewan and Manitoba is somewhat puzzling as both these provinces have large livestock industries and both provinces use drinking water sources potentially impacted by agriculture. Indeed, many rural water supplies have drainage basins that drain predominantly agricultural areas. This is again an illness that can have relatively mild clinical symptoms and a low proportion of reported to actual cases can be expected. It would be interesting to look at regional maps for each province and try to determine if there is a relationship between reported cases and specific areas.

Despite typically mild clinical symptoms, a small percentage of people that contract campylobacteriosis will be afflicted by paralysis (the Guillain-Barre Syndrome). Surveillance for Acute Flaccid Paralysis is carried out under the Canadian Paediatric Surveillance Program (Health Canada, 1999). This is part of the global polio eradication program. To establish if the polio virus is responsible for the paralysis, a stool sample needs to be taken within two weeks after the onset of paralysis. The number of cases where this has been done is increasing, but needs to reach 80% to meet WHO recommendations (Health Canada, 1999). The conclusions from one study are that the number of cases has increased by

40% from 1998 to 1999, which is seen as an improvement in reporting and not an increase in the disease (Health Canada, 1999). Eighty-three percent of the paralysis cases were diagnosed as the Guillain-Barre Syndrome. There is no regional distribution data available, but a comparison of the occurrence of this illness in rural as opposed to urban areas should be conducted. There have been no cases of paralysis caused by the wild polio virus in recent years in Canada (Health Canada, 1999).

Table 6: Reported cases of campylobacteriosis per province from 1990 - 1998.

Province	**Year**									**avg**	**Reported**
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**		
ALTA	842	925	1005	1101	1269	908	893	1183	1374	1056	0.41
BC	1916	2115	2112	2377	3157	2817	2621	2581	2789	2498	0.76
MAN	nr	nr	nr	nr	270	257	200	227	253	241	0.22
NB	382	427	297	321	348	241	258	249	345	319	0.44
NFLD	130	102	87	135	123	89	101	109	215	121	0.21
NWT	7	8	16	17	13	16	20	17	13	14	0.24
NS	223	283	328	339	312	234	212	213	214	262	0.29
ONT	5768	6081	6115	6804	7463	6370	5381	5253	5381	6068	0.60
PEI	90	65	79	90	104	50	43	49	45	68	0.53
QUE	2151	2478	2086	1989	2412	2461	2816	3447	3333	2575	0.37
SASK	298	248	262	256	242	239	249	207	266	252	0.25
YUK	10	9	5	8	10	4	9	9	8	8	0.29
Total	**11817**	**12741**	**12392**	**13437**	**15723**	**13686**	**12803**	**13544**	**14236**	**13483**	0.49

From Health Canada 2000

Verotoxigenic E. coli O157:H7 cases 1990-1998

It was not until 1993 that illness caused by this organism became reportable for all of Canada. An outbreak in the Northwest Territories in 1991 resulted in the highest average for the entire time period studied. The number of cases was, however, low in the Northwest Territories apart form in 1991. A more even distribution of cases was evident in the provinces with their much higher population base. PEI had the highest incidence (at 0.10 reported cases/1,000) closely followed by Alberta (0.08) and Manitoba (0.07). Alberta reached a low in 1994, but numbers have increased every year since that time.

In Ontario the average occurrence is only 0.05 cases/1,000 people. *[Editor's note: As a result of the Walkerton outbreak this figure will change dramatically for the year 2000.]* It is indeed likely that the number of cases will increase in every province and territory as physicians and the general public have been alerted to the symptoms of this particular disease.

Table 7: Reported clinically identified illness cased by *Escherichia coli* O157:H7 from 1990 - 1998.

Province	Year									avg	Reported
	1990	1991	1992	1993	1994	1995	1996	1997	1998		
ALTA	247	200	352	153	108	125	143	189	256	197	0.08
BC	Nr	nr	312	157	222	196	138	134	181	191	0.06
MAN	59	71	60	81	38	159	104	77	86	82	0.07
NB	Nr	nr	nr	24	3	4	19	23	51	21	0.03
NFLD	Nr	7	13	7	6	12	2	1	7	7	0.01
NWT	Nr	186	3	3	0	0	0	7	0	25	0.43
NS	Nr	nr	28	21	18	18	37	6	74	29	0.03
ONT	627	563	433	392	457	579	462	423	402	482	0.05
PEI	Nr	19	23	11	12	8	10	8	11	13	0.10
QUE	505	524	383	274	288	342	301	369	378	374	0.05
SASK	Nr	46	61	50	31	51	31	36	38	43	0.04
YUK	Nr	nr	4	0	0	0	0	0	0	0.5	0.02
Total	**1438**	**1616**	**1672**	**1173**	**1183**	**1494**	**1247**	**1273**	**1484**	**1463**	0.05

From Health Canada 2000

Shigellosis cases 1990-98

Shigellosis was most common on the prairies with Saskatchewan, Manitoba and Alberta having the highest rates of disease. Low rates were even reported for the territories. Saskatchewan's case load was greater than Quebec's and just below Ontario's during 1992 and 1993, but cases in Saskatchewan have since declined. Alberta reached a low of 60 cases in 1996, but the numbers steeply increased to 161 in 1997 and 274 in 1998. For Alberta and Saskatchewan 1992 and 1993 had high case numbers and for Manitoba the highest numbers were recorded in 1993 and 1998. For many of the provinces extremely low levels of shigellosis were recorded. New Brunswick, Nova Scotia, PEI's case loads/1,000 were 10% or less of Saskatchewan's.

Table 8: Reported cases of shigellosis from 1990 - 1998.

Province	Year										Reported
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**		
ALTA	117	100	371	424	132	91	60	161	274	192	0.08
BC	229	193	149	203	239	151	199	279	251	210	0.06
MAN	42	46	123	294	142	81	97	104	243	130	0.12
NB	62	13	7	2	7	9	4	12	12	14	0.02
NFLD	3	1	1	2	0	1	1	3	2	2	0.00
NWT	0	0	3	1	1	2	0	2	2	1	0.02
NS	12	8	9	8	7	9	6	10	8	9	0.01
ONT	530	479	576	371	483	427	318	370	410	440	0.04
PEI	3	0	2	4	0	2	2	7	0	2	0.02
QUE	418	325	261	309	290	330	284	474	283	330	0.05
SASK	233	99	482	324	128	111	115	85	107	187	0.19
YUK	3	3	2	1	0	3	0	2	1	2	0.06
Total	**1652**	**1267**	**1986**	**1943**	**1429**	**1217**	**1086**	**1509**	**1593**	**1520**	0.06

From Health Canada 2000

Hepatitis A cases 1990-98

Similar to the picture for shigellosis, hepatitis A was more common in Saskatchewan and Manitoba than any other Canadian province. Two outbreaks in the North West Territories in 1991 and 1992 gave this territory an even higher average. Overall, 19% of all hepatitis A cases were reported in Manitoba and Saskatchewan. In 1994 Manitoba accounted for 31% of all hepatitis A cases in Canada with only 4.0% of the population, and in 1996 Saskatchewan accounted for 17% of the cases and only 3.6% of the population. BC had the third highest ratio (0.15) with the remaining provinces being less than half of this rate.

Saskatchewan's rate dropped dramatically in 1998, which can probably be attributed to a large vaccination campaign. Once such a vaccination campaign has been carried out it is not possible to use this particular illness as an indicator of potential sanitary and unsafe drinking water conditions as the virus can still be prevalent in the environment without eliciting that particular illness in the population. It is, however, rare that a particular virus would occur in isolation and other potentially disease-causing microorganisms may still be of concern in communities that were previously affected by hepatitis A.

Table 9: Reported cases of hepatitis A per province from 1990 - 1998.

Province	Year									avg	Reported
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**		
ALTA	274	228	303	234	158	216	197	213	106	214	0.08
BC	556	425	1000	475	281	406	487	362	385	486	0.15
MAN	91	87	95	261	528	377	244	95	31	201	0.18
NB	5	5	1	1	4	2	8	7	5	4	0.01
NFLD	4	6	1	3	3	3	1	3	2	3	0.01
NWT	1	271	206	7	1	0	2	0	1	54	0.94
NS	4	3	3	3	35	12	11	15	9	11	0.01
ONT	412	1015	585	496	425	496	615	450	313	534	0.05
PEI	1	0	0	0	1	0	1	0	1	0	0.00
QUE	315	681	284	180	207	445	589	569	196	385	0.06
SASK	275	299	209	160	64	103	450	188	40	199	0.20
YUK	1	0	2	5	5	2	0	2	1	2	0.07
Total	**1939**	**3020**	**2689**	**1825**	**1712**	**2062**	**2605**	**1904**	**1090**	**2094**	0.08

From Health Canada 2000

Groups at risk for waterborne illnesses:

Illnesses caused by waterborne, pathogenic microbes are in part dependent on age and immune status. Infants and the fetus are especially vulnerable as their immune systems have not been extensively developed. People with a compromised immune system, such as those recovering from operations, people suffering from AIDS or other illnesses are also susceptible. Children and pregnant women are especially at risk (Gerba *et al.*, 1996). For example, rotavirus and enterovirus infections affect mainly children (USEPA, 1999), several having serious health consequences (see Table 3). Gerba, *et al.*, (1996) suggests that women may be at increased risk during pregnancy with potential transmission of Coxsackie and echoviruses from the mother to the child *in utero* resulting in severe illness in the newborn. Hepatitis and myocarditis can cause extremely high fatality rates (83%, Modlin, 1986).

Mortality rates for Type B viruses were estimated to be 0.92% for infants one month or less with much lower rates for the rest of the population (0.04%, USEPA, 2000). USEPA recognized that mortality rates for infants may be underestimated as rates of three percent have been reported (Jenista *et al.*, 1984; Modlin, 1986). The increased sensitivity for infants therefore ranges from 23-75 times. USEPA (2000) further assumes that for Type A viruses 88% of exposed children under two years of age become sick (Kapikian and Chanock, 1996) and for all other groups 10% was assumed (Wenman et al. 1979; Foster et al. 1980).

There are some pathogens that will affect adults more severely than children, such as hepatitis A and E, but they are exceptions. The bacterial pathogen *E. coli* O157:H7 affects children under 5 severely including the development of the Hemolytic Uremic Syndrome resulting in the most common cause of kidney failure in children (CDC, 2000). Children are also at much higher risks of exposure to waterborne pathogens, such as recreational exposures from wading pools which are frequently contaminated by enteric viruses (Keswick et al. 1981).

Although direct evidence is lacking, it is possible that infant mortality may be affected by exposure to waterborne pathogens. To see whether such a hypothesis has any merit infant mortality data for provinces and territories in Canada are included in Table 10. In contrast to most waterborne disease statistics, which are not very accurate, infant mortality is a statistic with a likely much smaller error margin.

The trend from 1990 to 1998 is for decreased infant mortality rates for all provinces except for Manitoba and Saskatchewan and two territories (Yukon and North West Territories). In contrast to most other provinces, Saskatchewan's infant mortality rate for the first four years (1990-1993), was actually lower than for the next four years (1994-1997). The rate increased by 13% while Alberta's decreased by 11%. Saskatchewan's infant mortality rate during 1994-1997 was 39% higher than Alberta's and 50% higher than the Canadian average. In 1997 Saskatchewan's rate was double that of PEI and Nova Scotia and almost double that of Alberta and B.C.

It is recognized that infant mortality is clinically identified as congenital abnormalities, perinatal conditions, injury, Sudden Infant Death Syndrome (SIDS), infectious diseases as well as children dying from causes that have not been clinically established. It should, however, be noted that microorganisms that can be waterborne can cause both perinatal complications, congenital anomalies and indeed myocarditis. One microorganism alone, the Coxsackie B virus, is capable of inducing all these conditions. Therefore, while it is possible to clinically categorize infant death data, the underlying causes of infant mortality data remains to be established. Determinations of several different viruses that are of high concern for infants and the fetus, such as Coxsackie B virus and echoviruses, should be carried out before water can be ruled out as a possible cause of death.

Table 10: Infant mortality rates 1990 - 1997 (calculated as number of deaths of children less than one year of age per 1,000 live births).

Province	**Year**								**avg**
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	
ALTA	8.0	6.7	7.2	6.7	7.4	7.0	6.2	4.8	6.8
BC	7.5	6.5	6.2	5.7	6.3	6.0	5.1	4.7	6.0
MAN	8.0	6.4	6.8	7.1	7.0	7.6	6.7	7.5	7.1
NB	7.2	6.1	6.3	7.2	5.4	4.8	4.9	5.7	6.0
NFLD	9.2	7.8	7.1	7.8	8.2	7.9	6.6	5.2	7.5
NWT	12.0	12.2	16.7	9.6	14.6	13.0	12.2	10.9	12.7
NS	6.3	5.7	6.0	7.1	6.0	4.9	5.6	4.4	5.8
ONT	6.3	6.3	5.9	6.2	6.0	6.0	5.7	5.5	6.0
PEI	6.0	6.9	1.6	9.1	6.4	4.6	4.7	4.4	5.5
QUE	6.2	5.9	5.4	5.7	5.6	5.5	4.7	5.6	5.6
SASK	7.6	8.2	7.3	8.1	8.9	9.1	8.4	8.9	8.3
YUK	7.2	10.6	3.8	7.9	2.3	12.8	0.0	8.4	6.6
CANADA	**6.8**	**6.4**	**6.1**	**6.3**	**6.3**	**6.1**	**5.6**	**5.5**	**6.1**

From Statistics Canada 2000

Waterborne disease occurrence - a summary:

For the five reportable diseases discussed here, giardiasis, campylobacteriosis, *E. coli* O157:H7, shigellosis, and hepatitis A, the three provinces with the highest reported cases/1,000 have been compiled together with the infant mortality data (Table 11). Manitoba could only be judged for four of the five diseases as it did not start to collect giardiasis data until 1997. *Cryptosporidium* is a prominent parasite with a potential waterborne transmission path, but it is not reportable in all provinces and could therefore not be used in this assessment. Other waterborne microbes that can cause a host of illnesses, such as the enteric virus *Coxsackie B*, are not reportable and could therefore neither be used in this assessment. The number of illnesses that can be potentially waterborne was therefore limited to five diseases. There are other modes of transmission for all of these illnesses, such as person to person and through contaminated food, but their relative importance is not known.

Table 11: Three provinces with the highest numbers of reported illness from 1990 to 1998 for giardiasis, campylobacteriosis, E. coli, shigellosis, hepatitis A and infant mortality (1990-1997)

Giardiasis		**Campylobacteriosis**		***E. coli* O157:H7**		**Shigellosis**		**Hepatitis A**		**Infant mortality**	
Reported cases/1000		Reported cases/1000		Reported cases/1000		Reported cases/1000		Reported cases/1000		Deaths/1000 live births	
BC	0.48	**BC**	0.76	**PEI**	0.1	**SASK**	0.19	**SASK**	0.2	**SASK**	8.3
SASK	0.44	**ONT**	0.6	**AB**	0.08	**MAN**	0.12	**MAN**	0.18	**NFLD**	7.5
AB	0.35	**PEI**	0.53	**MAN**	0.07	**ALTA**	0.08	**BC**	0.15	**MB**	7.1

Apart from campylobacteriosis, which is most prevalent in BC, Ontario and PEI, all other potentially waterborne illnesses reviewed are dominated by the three prairie provinces. Although definitive evidence is lacking, it is possible that drinking water is in part responsible for this. The prairie provinces are unique in Canada in that a large proportion of the rural population relies on water from dugouts and shallow aquifers that drain or are recharged from agricultural fields and areas with relatively high levels of livestock. The most populated parts of these three provinces are in a semi-arid climatic region with evaporation exceeding precipitation resulting in a high concentration of organic material in small surface water reservoirs (Sketchell et al. 1993) and in some aquifers.

This results in water that is difficult to disinfect as part of the disinfectant is consumed in reactions with the dissolved organic material rather then killing microbes. In addition, these reactions cause excessive formation of disinfection by-products that can be carcinogenic. Other forms of water supplies on the prairies include an extensive network of low-pressure water pipelines distributing “raw” water to rural users. This water may have received some form of treatment, but the “raw” designation simply means that no monitoring or regular maintenance is required. The quality of rural drinking water on the prairies is questionable and may be linked to the high levels of potentially waterborne illnesses and potentially to infant mortality as well.

Infant mortality in rural areas in Canada is around 40% higher than in urban areas (Watanabe and Casebeer, 1999) pointing to some generalized problems, one of which may be unsafe drinking water. The severity of specific waterborne illnesses in infants (and even in the fetus) due in part to undeveloped immune systems calls for a critical assessment of risks and cause of deaths for infants in rural Canada. Within urban areas correlations between income and infant mortality have been established with low income areas having higher rates (Wilkins et al., 1991). High infant mortalities have also been ascribed to First Nations (Health and Welfare Canada, 1988; Morrison et al.,1986). First Nations can, however, also be considered as part of the rural population facing similar limitations as other rural people (individual users and small communities) having difficulties in producing safe drinking water.

It is recognized that other causes of mortality, such as cancer, cardiovascular diseases, injuries *etc.* are higher in rural areas (Watanabe and Casebeer, 1999) and may be related to different determinants of health (education, income/poverty, unemployment, use of tobacco products, access to health services *etc.*). It is actually quite conclusive that several of these diseases including cancer and cardiovascular disease may also have waterborne causes. For example, it is not possible to chlorinate water from most surface water sources and many ground water sources on the Canadian prairies without the generation of cancer-causing trihalomethane levels well above Canadian Drinking Water Quality Guidelines (Peterson et al. 1993). Considering that other types of carcinogenic disinfection by-products, such as haloacetic acids, do not have guidelines in Canada, excess levels of several cancer-causing substances in rural drinking water is to be expected. Inflammation of the cardiac muscular tissue (myocarditis) has been associated with the Coxsackie B virus (Klingel et al., 1992). This is especially of concern considering 41% of all deaths in elderly people are associated with the heart (NRC, 1999).

Even in countries, such as the U.S., that have invested large resources to improve small community treatment systems, the facts are not encouraging. Ninety-six percent of systems violating the Total Coliform Rule serve communities of 10,000 or fewer people with the highest violations among systems serving 500 people or less (NRC, 1997).

Canada is alone in the developed world to have transferred the safety of the drinking water to a lower level of government. Drinking water is a provincial responsibility, but many provinces, lacking resources, have moved responsibility even further down the line to the municipal level. While this may be appropriate for resource-rich cities, it has left rural areas with few means to produce safe drinking water. This is, however, providing an excellent opportunity for health protection research and may be an important avenue to effectively reduce rural illness. Canada's average infant rate of mortality around 6.0/1000 would, if rural infant mortality was improved, come closer to countries that have been able to maintain infant mortalities around 4.0/1,000. Individual health districts in Saskatchewan reached infant mortality rates as high as 19.0-20.6/1,000 (Saskatchewan Health, 2000). Although, we don't know the exact proportion of illness that can be attributed to water as other modes of transmission are also possible. As we find out more about waterborne transmission of disease what we are able to determine as waterborne at the present time is only the very tip of the iceberg (PSR, 2000). Can we afford to ignore the possibility of a connection between poor rural water quality and higher infant mortality?

CONCLUSIONS:

Poor quality rural water sources, combined with ineffective water treatment, results in the consumption of unsafe drinking water by many rural citizens. Presently used methods to detect unsafe drinking water conditions (presence of coliform indicator bacteria) has only successfully detected around one-third of waterborne outbreaks emphasizing the need to implement treatment (removal of microbes) standards in addition to water analysis requirements. Presence of pathogenic viruses, bacteria and protozoan parasites in rural water is a consequence of the proximity to contamination sources whether on-farm or in a small rural community. People with under-developed or weakened immune systems are especially vulnerable to pathogen exposure with infants having risk factors that can be orders of magnitude greater than healthy adults. Diseases associated with the presence of one potentially waterborne virus (hepatitis A), three bacteria (*E. coli* O157:H7, *Campylobacter*, and *Shigella*) and one protozoan parasite (*Giardia*) were more common in Manitoba and Saskatchewan than in other Canadian provinces. Manitoba and Saskatchewan also had Canada's highest infant mortality rates over an eight-year period (1990-1997). It is possible that part of this high infant mortality may be explained by the use of especially poor quality water in rural areas of both of these provinces. Rural Canada as a whole has infant mortality rates that are 40% higher than urban Canada suggesting a generalized problem that may be connected to pathogenic viruses, bacteria and protozoan parasites that cannot be effectively removed with existing water treatment systems.

There is an urgent need to identify the presence of viruses, bacteria and protozoan parasites in rural water sources. Strategies for reducing those populations need to be developed. It will also require the development of water treatment technologies that can form effective barriers for these microbes. Removal rates in excess of 1,000-fold needs to be achieved. Other water quality concerns include the high levels of dissolved organic material in rural water supplies. This impairs the disinfection process as well as increasing the formation of carcinogenic disinfection by-products. Treatment techniques, that can remove dissolved organic material in a sustainable fashion, are therefore also required. Removal rates ranging from 2-10 mg DOC/L are required. Epidemiological studies should be carried out both as a tool to detect water quality concerns for specific communities and to establish the extent by which water is a risk factor in the development of human illness.

The Safe Drinking Water Foundation has started to develop and adopt methods to determine non-pathogenic and pathogenic microorganisms in rural water supplies. We expect to be able to assess different types of source waters with the intention of finding solutions that can be used in rural areas to produce safe drinking water in Canada and elsewhere. As stated by Watanabe and Casebeer (1999): "Research must be an agent of change, not just a report on a shelf. How can we translate research into action", they continued "Universities must look at becoming more relevant to communities". There is ample opportunity to extend this to government agencies at all levels. While water is a provincial mandate, solutions to rural water quality, is a national requirement and as such federal, provincial, and municipal agencies need to work together with scientists from Canada and around the world to make safe rural drinking water a reality.

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volunteer scientific support. The Safe Drinking Water Foundation is a regular contributor to national and provincial magazines dealing with rural issues and it is through combined efforts we hope that rural drinking water quality will, in the future, reach a quality similar to city water.

REFERENCES

Campbell I., A.S. Tzipori, and G. Hutchinson. 1982. Effect of disinfectants on survival of *Cryptospooridium* oocysts. *Veterinary Record* 111:414-15.

CCDR. 1997a. *Shigella* vaccine research and development. Canada Communicable Disease Report, Health Canada, April 1997.

CCDR. 1997b. Outbreaks of *Escherichia coli* O157:H7 infection and cryptosporidosis associated with drinking unpasteurized apple cider - Connecticut and New York, October 1996, Canada Communicable Disease Report, Health Canada, March 1997.

CCDR. 1998a. *Vibrio cholerae* non-O1 on blood culture, Saskatchewan. Canada Communicable Disease Report, Health Canada, November 1998.

CCDR. 1998b. Outbreak of echovirus 30 meningitis in southern Saskatchewan. Canada Communicable Disease Report, December 1998.

CCDR 1999a. An outbreak of *Escherichia coli* O157:H7 infection associated with unpasteurized non-commercial, custom-pressed apple cider - Ontario 1998. Canada Communicable Disease Report, July 1999.

CCDR 1999b. *Salmonella typhimurium* definitive Type 104 isolates in British Columbia, 1997-1998. Canada Communicable Disease Report, August 1999.

CCDR 1999c. Outbreak of cryptosporidiosis associated with a water sprinkler fountain - Minnesota, 1997. Canada Communicable Disease Report, January 1999.

CDC 2000. Escherichia coli O157:H7. Fact sheet prepared by Centre for Disease Control, Atlanta, http://www.cdc.gov/ncidod/dmb/diseaseinfo/escherichiacolit.htm.

Craun G.F. and R. Calderon. 1996. *Microbial riskes in groundwater systems, epidemiology of waterborne outbreaks.* in: Under the microscope, proceedings of the Ground Water Foundation's 12th Annual Fall Symposium 1996, Boston, MA. American Water Works Association, Denver, CO, pp.9-15.

Crowe L.W., L. Lau, McLeod et al. 1998. Outbreaks of *Shigella sonnei* infection associated with eating fresh parsley - Minnesota, Massachusetts, California, Florida, and Canada. MMWR, reported in CCDR, September 1999.

Degremont, 1991. *Water treatment handbook*, Sixth Edition, Lavoisier Publishing, Paris.

Ewan P. 1982. The species *Vibrio cholerae.* CDWR 8:68.

Foster S.O., E.L. Palmer, G.W. Gary Jr., M.L. Martin, K.L. Herrmann, P. Beasley and J. Sampson. 1980. Gastroenteritis due to rotavirus in an isolated Pacific Island group: and epidemic of 3,439 cases. *Journal of Infectious Diseases* 141:32-39.

Freeze F.A. and J.A. Cherry. 1979. *Groundwater*. Prentice Hall. Englewood Cliffs, New Jersey

Geldreich E.E. 1996 *Microbial quality of water supply in distribution systems.* Lewis Publishers, Boca Raton, Florida, pp. 504.

Gerba C.P., J.B. Rose, and C.N. Haas. 1996. Sensitive populations: who is at the greatest risk? *Int. Journal of Food Microbiology* 30:113-123.

Grabow W.O.K., M.B. Taylor, C.G. Clay, and J.C. de Villiers. In press. Molecular detection of viruses in drinking water: implications for safety and disinfection. In: *Second International Conference on "The Safety of water disinfection: balancing chemical and microbial risks*, November 15-17, 1999, International Life Sciences Institute, Washington D.C.

Griffin P.M., and R.V. Tauxe. 1991. The epidemiology of infections caused by *E. coli* O157:H7, other enterohemorrhagic *E. coli*, and the associated hemolytic uremic syndrome. *Epidemiologic Reviews* 13:60-98.

Health Canada 1999. Canadian Paediatric Surveillance Program. Surveillance studies undertaken in 1999: Acute flaccid paralysis. Canadian Paediatric Surveveillance Program 1999 Results, p. 11-15.

Health Canada 2000. Number of reportable cases of campylobacteriosis, *E. coli* O157:H7, Giardiasis, hepatitis A, and shigellosis, 1990-1998. (Carol Scott, Health Canada).

Health and Welfare Canada 1988. Health status of Canadian Indians and Inuit: update 1987. Ottawa: Indian and Northern Health Services, Medical Services Branch, 1988.

Husman de Roda A.M., W.J. Lodder, O.E.M. Nijst, J.F. Schijven and E.J.T.M. Leenen. in press. Removal of enteric viruses from wastewater and surface water: a study of two treatment plants in the Netherlands. In: *Second International Conference on "The Safety of water disinfection: balancing chemical and microbial risks*, November 15-17, 1999, International Life Sciences Institute, Washington D.C.

Jenista J.A., K.R. Powell, and M.A. Menegaus. 1984. Epidemiology of neonatal enterovirus infection. *Journal of Pediatrics* 104:685-690.

Kapikian A.Z. and R. M Chanock. 1996. Rotaviruses. In B.N. Fileds *et al*., eds. *Virology*, 3rd Ed., Volumes 2, New York : Raven Press, pp.1657-1708.

Keswick B.H., C.P. Gerba, and S.M. Goyal. 1981. Occurrence of enteroviruses in community swimming pools. *American Journal of Public Health* 71:1026-1030.

Klingel K., C. Hohenadl, A. Canu, M. Albrecht, M. Seemann, G. Mall and R. Kandolf. 1992. Ongoing enterovirus-induced myocarditis is associated with persistent heart muscle infection: Quantitative analysis of virus replication, tissue damage and inflammation. Proceedings of the National Academy of Sciences 89:314-318.

Lederberg J. (Editor) 1999. *Encyclopedia of microbiology*. Academic Press, pp. 2000.

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

Millard P.S., K.F. Gensheimer, and D.G. Addiss. 1994. An outbreak of cryptosporidosis from fresh-pressed apple cider. *Journal of the American Medical Association* 272:1592-96.

Modlin J.F. 1986. Perinatal Echovirus Infection: Insights from a Literature Review of 61 cases of serious infection and 16 outbreaks in nurseries. *Reviews of Infectious Diseases* 8:918-926.

Moe C. 1996. Waterborne transmission of infectious agents, p. 136-152. In: *Manual of Environmental Microbiology*, American Society of Microbiology Press, Washington DC

Morrison H.I., Semenciw R.M., Mao Y., Wigle D.T. 1986. Infant mortality on Canadian Indian reserves 1976–1983. *Canadian Journal of Public Health* 77:269–73.

NRC (National Research Council) 1997. *Safe drinking water from every tap. Improving water service to small communities*. National Academy Press, Washington D.C., 218 pp.

NRC (National Research Council) 1999. *Setting priorities for drinking water contaminants.* Committee on drinking water contaminants. National Academy Press, Washington D.C., pp. 128.

Paul J.H., J.B. Rose, S.C. Jiang, X. Zhou, P. Cochran, C. Kellogg, J.B. Kang, D. Griffin, S. Farrah, and J. Lukasik. 1997. Evidence for groundwater and surface marine water contamination by waste disposal wells in the Florida Keys. *Water Research* 31:1448-1454.

Peterson H.G. 2000. Biological filtration - a performance analysis. WateResearch Corp., Saskatoon. A report prepared for the Canada-Saskatchewan Agri-Food Innovation Fund.

Peterson H.G., J. Milos, D. Spink, S.E. Hrudey, and J. Sketchell. 1993. Trihalomethanes in finished drinking water in relation to dissolved organic carbon and treatment process for Alberta surface waters. *Environmental Technology* 14:877-884.

PSR. 2000. Physicians for social responsibility web site http://www.psr.org. The document quoted from was “Drinking water and Disease, what health care providers should know”.

Saskatchewan Health. 2000. The epidemiology of infant mortality in Saskatchewan 1982-1996. Saskatchewan Health, May 2000, 50 pp.

Sinton L.W., R.K. Finlay, L.Pang and D.M. Scott. 1997. Transport of bacteria and bacteriophages in irrigated effluent and trough an alluvial gravel aquifer. *Water, Air and Soil Pollution* 98:17-42.

Sketchell J., H.G. Peterson, N. Christofi, and G. Brandt. 1993. Dissolved organic carbon in surface drinking water reservoirs in Saskatchewan. In: *Disinfection Dilemma: Microbiological Control versus By-products*. Proceedings of the Fifth National Conference on Drinking Water, Winnipeg, Manitoba, Canada, Sept. 13-15, 1992. W. Robertson, R. Tobin and K. Kjartanson (eds), American Water Works Association, Denver, Co., pp. 365-382.

Statistics Canada 2000. Infant mortality for provinces and territories in Canada.

USEPA. 1997a. Response to congress in the use of decentralized wastewater treatment systems. April 1997. EPA 832-R-97-001b.

USEPA. 1997b. Guidelines for wellhead and springhead protection area in carbonate rocks. EPA 904-B-97-0003.

USEPA 1998. Announcement of the Drinking Water Contaminant Candidate List; Notice. Federal Register 63 (40):10274-10287.

USEPA 1999. *Drinking Water Criteria Document for Viruses: An Addendum.* EPA/822/R/98/042, January 15, 1999.

USEPA. 2000. National Primary Drinking Water Regulations: Ground Water Rule. Notice published on the Internet before publication in the Federal Register, 40 CFR Subpart S, Parts 141-142. (http:www.epa.gov), pp. 315.

Wallis P.M., B. Primrose and W.J. Robertson. 1998. Outbreak of waterborne Giardiasis caused by sewage contamination of drinking water. *Environmental Health Review* 42:44-51.

Watanabe M. and A. Casebeer. 1999. *Rural health research: The quest for equitable health status for all Canadians*. A report of The Rural Health Research Summit, Prince George, BC, 23-25 October, 1999, 47 pp.

Wenman W.M., D. Hinde, S. Felthan and M. Gurwith. 1979. Rotavirus in adults. Result of a prospective study. *New England Journal of Medicine* 301:303-306.

Wilkins R., Sherman G., and P.A.F. Best. 1991. Birth outcomes and infant mortality by income in urban Canada 1986. *Health Reports* 3:7–31.

Zhao T., M.P. Doyle and R.E. Besser 1993. Fate of enterohemorrhagic *Escherichia coli* O157:H7 in apple cider with and without preservatives. *Applied Environmental Microbiology* 59:2526-30.