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Cryptosporidium Outbreak (Water Treatment Failure): North Battleford, Saskatchewan, Spring 2001

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Cryptosporidium Outbreak (Water Treatment Failure): North Battleford, Saskatchewan, Spring 2001

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Abstract: An outbreak of cryptosporidiosis occurred in the town of North Battleford, Saskatchewan, Canada in the spring of 2001. The outbreak left thousands of people sick including about 50 people hospitalized. The source of the outbreak was from the city's surface water treatment plant. The Sedimentation Contact Unit did not satisfactorily remove suspended solids from the source water, resulting in filter breakthrough. Contaminated water was released into the distribution system causing the outbreak. Communication breakdown and confusion exacerbated the situation, extending the duration of the outbreak. The outbreak prompted the province to change the way it regulated municipal utilities of water and wastewater.

CE Database subject headings: Water treatment plants; Environmental issues; Case reports; Pathogens; Canada.

Introduction

This paper is a summary of an environmental failure case study that took place in Northwest Saskatchewan, Canada where a *Cryptosporidium* outbreak occurred in the spring of 2001. Many (5,800–7,100) people became ill due to the event (Stirling et al. 2001a, b). An inquiry (Laing 2002) was formed immediately after this event to "report on, and make findings and recommendations regarding the circumstances that led to contamination, adequacy and effectiveness of actions taken by officials, effects of regulations, bylaws, policies, guidelines, and procedures on this occurrence, and other matters relevant to assure safe drinking water in the future." The outbreak itself had some possible causes: inadequate facility planning, antiquated technology, ineffective management, and communication. These causes have been examined in detail, but it is important to note that the outbreak was entirely preventable. It is also important to understand that a combination of causes was required for this outbreak to occur.

Description of North Battleford

The City of North Battleford is located in Northwest Saskatchewan on the North Saskatchewan River. It is a small town with a population of 15,000. North Battleford is located north of the river while Battleford lies on the south side. The two towns have separate treatment systems for wastewater and water. The local economy is based mostly upon agriculture and has suffered with declining meat prices. The population is relatively static but the demographic is changing. The numbers of children and retired people are increasing while working age people are leaving (http://www.cityofnb.ca 2006). Likewise, the depressed economy has resulted in less local government revenue. Life on the high plains can be very tough due to extremes in weather and this takes a toll on a city's infrastructure. Maintenance of an aging city is always difficult, but it is even more difficult without a robust tax base.

The North Saskatchewan River is very important in this case study and deserves more detail. Its headwaters are in the Rocky Mountains of Alberta. The river flows east through the city of Edmonton and through the prairie into Saskatchewan. The Battleford's area is not far from the provincial border. Flow rates range from a low point in the winter of 100 m^3/s to 800 m^3/s for peak flows in late spring/summer when the river is swollen by snowmelt. Agriculture such as cattle farming occurs in the watershed, which has a significant impact on water quality (Laing 2002).

Cryptosporidiosis

The City of North Battleford experienced an outbreak of cryptosporidiosis during the spring of 2001. Cryptosporidiosis is caused by the protozoan parasite *Cryptosporidium parvum* and inflicts its host with symptoms of diarrhea, abdominal cramps, vomiting, and headaches. There is no known cure or treatment for this infection. Healthy or immunocompetent people will fight off the parasite in 10–14 days (Finch and Belosevic 2001; O'Donoghue 1995). However, cryptosporidiosis can be a chronic condition and sometimes deadly for people with weakened immune systems. The real danger to the host lies in dehydration that occurs with diarrhea. The most well known outbreak of cryptosporidiosis occurred in Milwaukee in 1993. In this catas-

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trophe, about 400,000 people became ill and 100 people died (Peterson 2004).

Cryptosporidium parvum is a gastrointestinal parasite and is spread through fecal material (Finch and Belosevic 2001; Hsu et al. 2001; O'Donoghue 1995). The parasite is transported by a robust environmental vehicle called an oocyst. The oocyst leaves the parent host with fecal material. Next, the oocyst is ingested by mouth and enters the digestive system of the new host. This typically is done through poor sanitation such as dirty hands and contaminated food and water. The oocyst breaks down in the digestive system of the new host and settles in the small intestine where growth, reproduction, and oocyst formation occur (O'Donoghue 1995). The time between infection and oocyst excretion can range from 2 to 14 days (O'Donoghue 1995). At this point, the host displays symptoms of cryptosporidiosis.

The oocyst stage of *cryptosporidium*'s lifecycle presents a challenge to water treatment (Hsu et al. 2001; Medema et al. 1998; Peeters et al. 1989; Searcy et al. 2005). Similar to *Giardia spp.*, this cyst is quite resistant to conventional water treatment. The oocyst consists of a matrix of glycoproteins and sugar molecules that are strongly resistant to conventional disinfectants such as chlorine (O'Donoghue 1995; Searcy et al. 2005). While disinfection with chlorine is very effective against bacteria, it is relatively ineffective for inactivating *Cryptosporidium*. Another characteristic and problem with the oocyst is its size. Oocysts are very small and average 5 μm but have been known to pass through filters of 1 μm (Finch and Belosevic 2001; Medema et al. 1998). However, oocysts are known to be attracted to particles and are removed by flocculation/sedimentation in conventional water treatment (Fewtrell et al. 2001; Searcy et al. 2005).

Cryptosporidium parvum affects many animals including fish, reptiles, birds, and mammals. There are two genotypes that infect humans. They are referred to as genotypes 1 and 2. Genotype 1 is human specific and can only be spread by humans to other humans. The most common example is drinking water contaminated with sewage. Genotype 2 is carried by and primarily effects mammals, but this genotype can infect people. It is associated with agricultural runoff, cattle, and sheep in particular (O'Donoghue 1995). In the cryptosporidiosis outbreak of North Battleford, 12 samples from ill people were tested for genotype. Eleven samples were confirmed to be the human-derived genotype 1 and the twelfth sample was unknown. These results helped in determining the contamination source of the outbreak (Laing 2002).

Description of Facilities

Water and wastewater treatment facilities of North Battleford include a sewage plant and two water treatment plants. The primary water treatment plant is a groundwater source plant while the second one, the surface water plant, uses the North Saskatchewan River as its source. The wastewater treatment plant is 3.5 km upstream of the intake for the surface water plant. Dye tests from 1992 have shown that the wastewater effluent plume runs close to the surface water intake (Laing 2002). It is reasonable to assume that the plume changes with river flow and a portion of this plume may enter the surface water plant intake.

A description of the wastewater treatment plant (WWTP) can be summarized from the North Battleford Water Inquiry, Commissioner Robert D. Laing (Laing 2002). The WWTP is a two stage activated sludge plant that was built in 1957 and has gone through several renovations and additions. First, the water passes through a bar screen to remove large objects followed by a grit chamber. Next, the water enters one of two primary settling tanks. Secondary treatment begins when the water is fed to an aero-accelerator followed by a secondary settling tank. Finally, treated water is passed into a chlorine contact chamber for disinfection before discharge to the river. The plant has a capacity to treat 5,455 to5,910 L/min while inflow rates range from 1,818 to 4,546 L/min. Plant capacity can become exceeded during periods of heavy precipitation when the storm sewers are overwhelmed. When this happens, excess sanitary sewage bypasses treatment and discharges into the river. This is said to occur about twice a year (Laing 2002).

The primary water treatment plant for North Battleford uses groundwater as its source. The groundwater plant was built in the 1940s and runs continuously. Wells provide the source water that is filtered, treated to remove iron and manganese, and finally, disinfected. The groundwater plant provides 55 to 75% of the city's drinking water, but this continually varies. The years prior to the outbreak had seen a decline in the amount of water coming from groundwater. When demand surpasses the groundwater plant capacity, the surface water treatment plant is run to supplement this need. The surface water plant does not run continuously and runs 8–16 hours a day when in use (Laing 2002).

The surface water treatment plant was built in 1950 and has undergone numerous additions and renovations. A schematic diagram of the surface water treatment plant can be seen in Fig. 1. The raw water source is the river, which is pumped through sand separators on its way to the solid contacts unit (SCU) or sedimentation tank. Between the sand separators and the SCU, coagulants are added to initiate the process of coagulation, flocculation, and sedimentation. These chemicals consist of aluminum sulfate (Alum), polyaluminum chloride (Aluminex 3), potassium permanganate, and chlorine. Potassium permanganate is used to oxidize organic material. Gaseous chlorine is added at this point to prevent growth in the SCU and to increase chlorine contact time. Lime and polymer are added directly to the SCU and agitation is introduced. Polymer is added to assist in flocculation while lime is added to increase pH. A pH around 7 is preferred to prevent corrosion of equipment and pipes. The SCU is arguably the most important section of the plant. The SCU holds nearly 700,000 L of water and agitation is provided by a turbine mixer with a variable speed drive. Coagulation, flocculation, and sedimentation processes are critical for removing suspended solids from raw water (Fewtrell et al. 2001; Hsu and Yeh 2003; Searcy et al., 2005). Settling rates for North Battleford's SCU are typically 10 to 20%. Water proceeds from the SCU to one of two banks of dual media (sand and anthracite) filters and then clearwells. Finally, treated water enters the distribution system from the clearwells (Laing 2002).

Government and Agencies Involved

While an engineering failure caused the outbreak, confusion and communication breakdown resulted in an extended exposure of the public to *Cryptosporidium* oocysts. At the local government level, it has been assessed that personnel instability, insufficient budget, and a lack of effective communication with the regulatory branch of Saskatchewan Environment and Resource Management (SERM) contributed to this incident (Laing 2002).

Two government agencies are critical for public health concerning public sanitation: SERM and the Battlefords Public Health District. SERM was the regulatory agency in charge of making sure that plants in the province performed according to

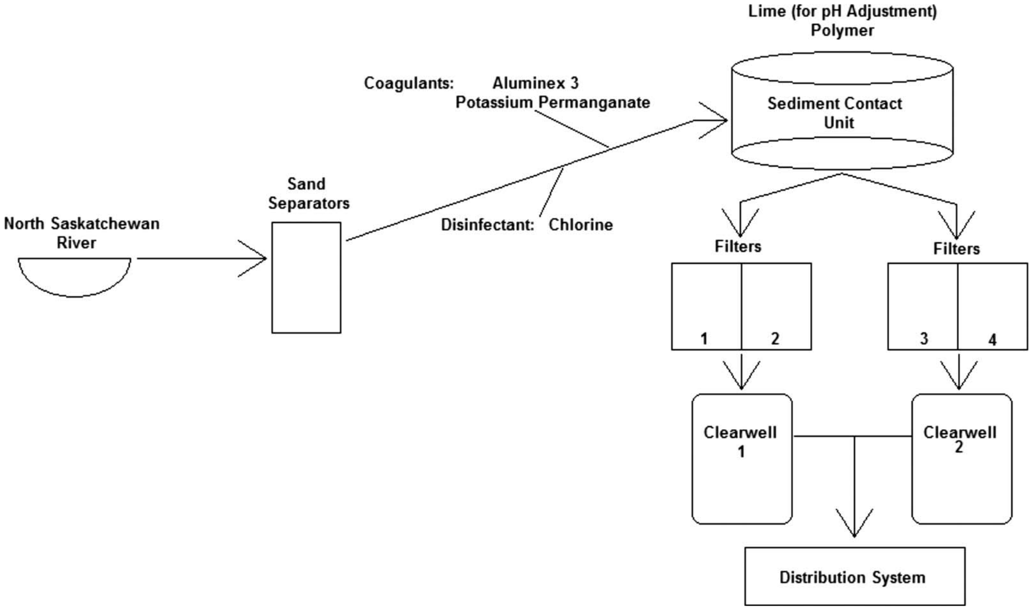

Fig. 1. Process diagram of North Battleford's surface water plant during *Cryptosporidium* outbreak

regulations. Similar to the town of North Battleford, SERM went through a restructuring plan to reduce bureaucratic costs in 1993 (Laing 2002). The critical change was that actual or physical inspections of wastewater and drinking water plants were discontinued. At the time of the outbreak, a physical inspection of the surface water plant had not taken place since 1991. In small municipalities, such as North Battleford, the burden of monitoring public works was left to the town. If conditions or an event occurred that could harm public safety, it was to the responsibility of the municipality to notify SERM.

The Battlefords Health District monitors public health and investigates possible illness outbreaks. It was the health district and associated medical community that discovered a possible outbreak of cryptosporidiosis was occurring. This was not an easy feat considering that cryptosporidiosis is largely under-reported. Confirmation of the illness requires a stool sample of the infected person as well as 5–7 days to acquire results. In addition, the medical community is not trained in the pathology of engineering and public works functions. Nevertheless, vigilant public health officials noticed a health problem and asked questions, which eventually led to the cause of the outbreak (Laing 2002).

Previous Problems

The outbreak of cryptosporidiosis that occurred in March and April 2001 was not the first time waterborne illness had been found in North Battleford. Isolated cases of cryptosporidiosis occurred in 1994 through 1998 and coliform bacteria were found in the distribution system in September 2000. The sources of these cases were never discovered. *Cryptosporidium parvum* is a difficult organism to test for and just because it was not found in tests does not mean oocysts were not present. The conventional testing method for cryptosporidiosis is known as the ICR method and requires very large sample volumes such as 100 L (Hsu et al. 2001). Obviously, source water from a large river with sewage effluent upstream is a source of concern. Madore et al. (1987) found average sewage effluent from activated sludge plants contain 1,400 to 40,000 oocysts per 100 L.

North Battleford's coliform contamination event in September 2000 in combination with a bacterial outbreak in Walkerton, Ontario in May 2000 that caused the death of seven people should have increased concern for public safety (Hrudley et al. 2003; O'Connor 2002). Coliform bacteria are easier to test for and treat than *Cryptosporidium* oocysts. North Battleford's coliform bacteria contamination event began with a positive sample found in a dead end section of the distribution system where flow was minimal. Further investigation found that chlorine residual levels were below regulatory levels of 0.5 mg/L and had been, at various intervals, for years due to residential complaints of stained laundry. Chlorine oxidizes manganese (Mn) and iron (Fe), which are commonly found in groundwater. Oxidized Mn and Fe turn treated water brown and can stain clothing. After this event, SERM requested a hydrology study of the distribution system, a quality assurance response plan, and an evaluation of the surface water plant. These were not done by the time the outbreak occurred (Laing 2002).

Contamination Event

The event responsible for the *cryptosporidium* outbreak occurred on March 20, 2001 when the surface water plant was shut down for planned maintenance. The SCU was completely drained, repaired, and cleaned. There was a crack in the floor of the SCU that needed patching and a complete cleaning of the SCU was performed. Shutdown procedures usually left residual amounts of the sludge blanket in the tank for restarting the sedimentation process (Laing 2002). After the work was completed, the plant was started up again late in the afternoon. The SCU was filled up again, necessary chemicals were added, and finished water was discarded or run to waste. The water was run to waste until a turbidity of 5 NTUs and a free chlorine concentration of 2 mg/L was observed. It was assumed that the filters could effectively remove suspended solids if finished water met this specification. This took about 3.5 hours and afterwards water was run to the two banks of dual media filters and ultimately to the clearwells. Data show that at this time turbidity was 2.29 NTU and free chlorine was 2.15 mg/L. It is important to note that shut downs in previous years ran finished SCU water to waste for 10 hours to 1.5 days (Laing 2002).

Evidence from the North Battleford water inquiry shows while turbidities were relatively low, sedimentation was not occurring. Coagulant and polymer levels were increased to no avail. In fact, finished water leaving the SCU sometimes had higher turbidities than the raw water source. Breakthrough of the filters occurred relatively quickly and the filters had to be backwashed. Water from backwashing and during the filter ripening stage should have been run to waste but was not. This represents a major problem because particulates and contaminants trapped in the filters were now being agitated free and released into the clearwells. Rapid filter breakthrough reduced the efficacy of sedimentation and filtration. Low sedimentation percentage was noted and bentonite was bought to help form a floc blanket (Laing 2002).

The surface water plant was run every day until April 25. April 25 was the day a health crisis was realized and a precautionary drinking water advisory (PDWA) was issued. Water was being fed to the distribution system even though settling percentages in the SCU were unacceptable and final turbidities in the clearwells were sometimes above 0.3 NTU. A very important point made later by investigators is that these final turbidities are a combination of water passing through two different banks of filters. It was not possible to see if water from filters 1 and 2 were performing worse than filters 3 and 4. However, a study from an engineering consultant years before showed that the filter bank consisting of filters 1 and 2 did not perform as well as filters 3 and 4.

Even though the city was having significant problems with their water treatment, SERM and the Battlefords Health District were not notified. The outbreak was discovered by health professionals who, like other residents, did not know there was a problem with the drinking water. Many of these health professionals and their families experienced cryptosporidiosis themselves. The first known case was identified and reported to the health district on April 4, 2001, with the second case being reported a day later. A family doctor discovered unusually high sales of diarrhea medications at a local pharmacy and informed the health district administrator. At this point, the administrator, who was also a practicing doctor at the Battlefords Union Hospital, ordered stool samples for all patients coming in because of diarrhea. On April 24, the administrator, realizing a possible outbreak was present, asked a public health inspector to ask the Director of Public Works and Engineering of North Battleford if there were any problems with water treatment. The director admitted there was a problem getting an effective floc blanket in the surface water plant, but that it was not a safety concern. However, the public health officer for the province concluded, due to recent problems with North Battleford's water supply, that a waterborne source was most likely the problem (Laing 2002). The following day, April 25, the local SERM official was notified of the problem. The local SERM official reviewed the information and advised a PDWA immediately. A day later, a boil water order was issued due to the lack of settling in the SCU (Laing 2002).

Health Canada extrapolated known results during their epidemiological investigation and estimated 5,800 to 7,100 people developed cryptosporidiosis. Fortunately, no one died but 50 people were hospitalized (Stirling et al. 2001a, b). In addition, the outbreak affected people not necessarily living in the Battlefords area. Many people simply traveling through and unlucky enough to have a drink of water became ill. The outbreak peaked on April 13, 2001 and quickly dropped once the PDWA was issued on April 25. Spatial regression also showed that residents living towards the southeast part of North Battleford's water distribution system were two to four times more likely to become ill than residents living on the northwest side of town (Stirling et al. 2001a, b). The southeast side of North Battleford is where water from the surface water plant enters the distribution system while the groundwater plant feeds the northwest section, even though the water from both plants mixes.

Remediation

The epidemiological investigation showed that the outbreak ended in May. However, the boil water order (BWO) remained in place until July 25, 2001. With the surface water plant's troubled history, the removal of the BWO was cautiously slow. A physical plant inspection was executed and a report generated. A procedure for removing the BWO was not approved until June 19, 2001. This procedure required the city to show the treatment process was working safely and required the city to design a plan to prevent the problem from reoccurring (Laing 2002).

North Battleford hired a consulting engineering firm to design and implement changes for safe drinking water. At the time this paper was written, the same consultant was still employed by the city (http://www.cityofnb.ca/noticefiles/2549_DRINKINGWATERReport2005.pdf 2006). The changes made are illustrated in Fig. 2. Possibly, the most important engineering change was adding new valves and pipes so water could be run to waste. These critical valves were added at the SCU and the filter banks. Sampling sites were added after the filter runs to allow for manual water collection and continuous monitoring of turbidity and particulates. Coagulant chemicals were added at the sand separators for better mixing. UV disinfection units were added after both filter banks. UV light has been shown to be more effective than chemicals for inactivating *Cryptosporidium* oocysts (Finch and Belosevic 2001). Chlorine disinfection was moved to the clearwells instead of before the SCU. Chlorination units would also be installed for the town's water supply reservoirs within the distribution system. Chlorine disinfection was increased at the sewage plant for the purpose of treating bypass sewage. Finally, standard operating procedures (SOPs) were added for the purposes of quality assurance. The new SOPs called for the surface water plant to shut down or run water to waste when the following occur:

1. Sewage bypass events;
2. Chlorination malfunction;
3. Malfunction in the SCU; and
4. Finished water with a turbidity greater than 0.3 NTU.

The remediation solution is a long-term plan concerning the groundwater plant, sewage plant, and the surface water plant. While all the plants are antiquated, the sewage plant and surface water plants should be abandoned for new plants. In 2005, there was only one positive sample for *Cryptosporidium* occurring in the raw source water and no oocysts were found in finished water (http://www.cityofnb.ca/noticefiles/2549_DRINKINGWATERReport2005.pdf 2006). However, common sense dictates that a water intake for drinking water should not occur immediately downstream from sewage effluent. In addition, raw source water should come from a protected watershed, not from a large turbid waterway downstream from cities and agricultural areas.

A multibarrier approach as presented by Finch and Belosevic (2001) is especially important for treating raw source water known for harboring *Cryptosporidium*. First, the watershed

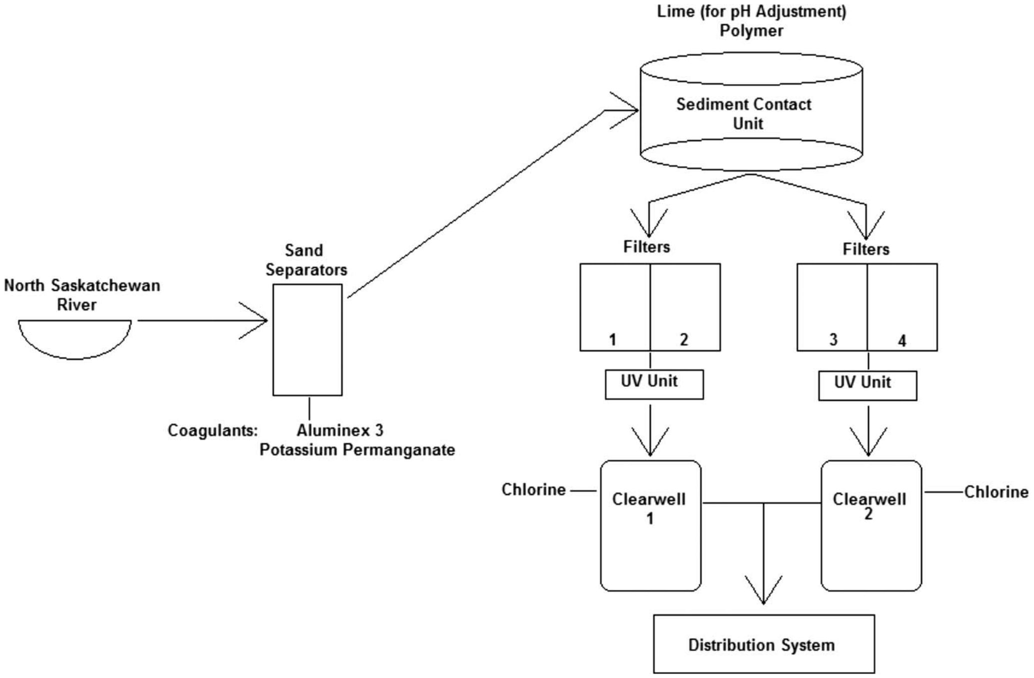

Fig. 2. Process diagram of North Battleford's surface water treatment plant postremediation

should be protected from intensive agriculture. Second, microorganisms such as *Cryptosporidium* and *Giardia* should be treated like particles, as they are best removed via flocculation and sedimentation. Evidence exists that *Cryptosporidium* oocysts have an affinity towards particulates and, thus, the sedimentation process is an effective method to remove them (Medema et al. 1998; Searcy et al. 2005). Finally, a good disinfection procedure incorporating both oxidation and UV light is needed. Chlorine is needed to kill bacteria and UV light is needed to inactivate oocysts. A point that SERM makes is that the multibarrier approach and finished water specifications should be customized for each plant as each plant design varies, just like raw source water.

The cryptosporidiosis outbreak of North Battleford had a dramatic effect upon SERM. In 2002, many recommendations of the North Battleford water inquiry were implemented. These are listed in a publication released by SERM (http://www.se.gob.sk.ca/environment/production/water/Drinking%20Water%20brochure.pdf 2006). Some of the changes include:

1. Increased funding for the regulatory branch of SERM as well as more personnel.
2. At least one inspection of drinking water and sewage plants per year.
3. Plant operators must be certified.
4. Plant owners must notify SERM when chlorine levels are low and when equipment breaks down.
5. Watershed planning will be used to protect source water from contamination.

Conclusions

The *Cryptosporidium* outbreak of North Battleford was preventable. Essentially, personnel and government policies manifested themselves in the engineering failure, which resulted in illness. The North Battleford water inquiry found both government bodies of North Battleford and SERM suffered from the same common problem, i.e., organizational restructuring and cost cutting, which went too far (Laing 2002).

In the 1990s, SERM went through restructuring and budget cuts, which reduced the number of auditors and physical inspections. A risk assessment model was used to determine where problems could arise. Effective use of this model favors larger municipalities and urban areas. Another point made in the North Battleford water inquiry is that there are many small communities like North Battleford all across North America that need closer attention by SERM or appropriate regulatory agencies. Naturally, this requires greater resources for regulatory agencies (http://www.se.gob.sk.ca/environment/production/water/Drinking%20Water%20brochure.pdf 2006).

Technically, the greatest issue appears to be a lack of communication when the SCU was malfunctioning. The local government, "faced with monetary constraints," was reluctant to spend money on improvements for public works unless forced to. The North Battleford water inquiry recommended a proactive approach for utility remediation using funding from increased water rates for customers and financial assistance from provincial as well as federal authorities (Laing 2002). The solutions to avoid such an incident lie in having management that emphasizes sound technical practices, optimum allocation of resources, and better communication among all government agencies. Budget constraints are always a major concern and smaller towns are becoming increasingly short of funds, as their economies are generally shrinking. The access to funds for small towns such as the Battlefords area is critical and requires support from the provincial and federal governments.

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