Springer Water

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Water Policy in Canada

Problems and Possible Solutions

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For my daughters and their partners:
Sophia and Andy; Roshan and Joe;
Naomi and Mark. May they and our
grandchildren do what they can
for a clean environment and clean water.

Foreword

On the Difference Between Promise and Practice: Water Policy in Canada

As the famous American water scholar Helen Ingram regularly pointed out, there is often a big difference between promise and practice in the delivery of water policy. Nowhere, it appears, is that more so than in Canada where we have managed to superimpose a myth of effective management over a myth of limitless abundance. While we often tell ourselves that we are world leaders in various aspects of water management, thorough, objective analysis such as that provided in this book reveals that except in rare cases we are not doing what we say we are doing or even meeting the standards that we ourselves set with respect to the protection of water quality.

Though not the first comprehensive analysis of water resource policy in Canada, this is clearly one of the best researched and most readable. It begins by examining the record of waterborne disease outbreaks in developed countries where cholera and typhoid have been eradicated but other preventable waterborne diseases continue to affect both urban and rural populations. Diseases such as cryptosporidiosis, giardiasis, toxoplasmosis, campylobacteriosis and Escherichia coli (E. coli) continue to be seen in the USA, Canada and parts of Europe. Why? This book tries to answer that question at least in the Canadian context. The answer to that question becomes a theme that pervades the rest of the book. Inadequate public investment in drinking water infrastructure and incomplete treatment of wastewater that ends up in lakes and rivers is threatening public health right across Canada.

The book also puts into relief the fact that others elsewhere have been where we are now in terms of population and economic growth and have faced similar challenges in the integrated management of water resources. This book demonstrates what we can learn from the example of places such as Europe with respect to careful husbanding of source waters, adequate attention to drinking water treatment technologies, and proper maintenance of water distribution networks. Countries like Denmark, the Netherlands and Germany offer real and practical lessons on water resource management, conservation and proper investment in drinking water treatment and distribution.

The book also clearly demonstrates that the threats to water quality in Canada are not just the obvious ones related to mining and resource extraction that we hear about in the media. Contamination from intensive cattle and livestock operations, and agricultural runoff laced with pesticides, herbicides and fertilizer residues are now seen as the most serious threat to water quality in this country. When these threats to water quality are added to contamination issues related to the exploitation of oil sands, the possible growth of fracking, and the future potential threats to water resources due to transportation of oil products to ports for export to distant markets, a different picture concerning the state of Canada's water resource than the one we expect begins to emerge. What we have created in Canada are hidden subsidies, in that each of these economic activities incurs social costs that are not included in the prices and taxes paid by the economic activity. In other words, there are 'externalities' which are not being priced into the products of the economic activity. In contrast, in Germany, for example, the cost of wastewater treatment is based explicitly on the 'polluter pays' principle.

Another important dimension that emerges from the comparative analysis is the emphasis placed in countries like Germany and Denmark on the priority given to whole *ecosystem health*, whereas in North America regulatory policy is focused entirely on the health of human populations. The book suggests that the social good should coincide with whole ecosystem health, and not just the health of humans.

The value of this book is much enhanced by the inclusion of several chapters that deal specifically with provincial water policies in Canada. It is not just serious readers who will find much of interest in these chapters. In light of the comparative lessons they provide they will be of great value to provincial government regulators who may wish to re-examine their regulatory policies in the light of lessons from other jurisdictions outlined in this book.

This is an important book that has appeared at a critical juncture in the history of water policy in Canada. It provides an opportunity to examine what worked and what has not worked elsewhere in the world so that we can avoid spending billions of dollars on public policy actions that appear to reform water resource management habits but in fact only perpetuate current circumstances while worsening scarcity in the future. This book provides a blueprint for making water management practice consistent with policy promise in Canada. It is a blueprint worth following.

October 2014

Robert Sandford
EPCOR Chair of the Canadian Partnership
Initiative in support of United Nations
"Water for Life" Decade
Forum for Leadership in Water, Toronto

Preface

This writing project began as a book on a number of issues affecting drinking water and governmental policy on water resource management. But the range and depth of the material on the subject necessitated that it be split into two companion books, each of which could be read and appreciated independently of the other. The title of the first is "Global Drinking Water Management And Conservation: Optimal Decision-Making." This book is now in print; its focus is on a number of theoretical principles that should guide water resource management and drinking water production, both in the developed and the developing countries. It makes sense to bring these theoretical principles under one cover, especially this year, as this is the United Nations "International Decade for Action, Water for Life, 2005–2015." This companion book includes a summary of the principles covered in the first book, but focuses on water policy in Canada. However, each book can be read independently of the other.

The two books add to a considerable body of research on water issues. In a series of books and reports, Dr. Peter Gleick, President of the Pacific Institute, has carried out painstaking research on a large number of issues relevant for the sustainable use of water resources. His last biannual report was released in January 2014. The near- to medium-term urgent impacts of climate change on water have also been researched by Canadian scientists. This technical work has been very ably summarized by Dr. Robert Sandford in his 2012 book entitled "Cold Matters: The State and Fate of Canada's Fresh waters," published by Rocky Mountain Books. A paragraph from that book is worth quoting:

> …Canada's hydrological systems…are on the move. The natural variability in rain and snowfall, river flows, lake levels…are all changing. In scientific terms Canada is experiencing a loss of hydrological stationarity. As a result, precipitation and river flows will be different from what we have come to expect. New ranges of variability will emerge. There will be more and more times when that variability will be outside the range for which our urban and rural infrastructure was designed to function. There will be more times when climate variability will be outside our current ability to adapt… The loss of hydrological stationarity will void traditional approaches to how we assess risk in the design of buildings, roads, storm sewers and water treatment systems (Sandford 2012, p. 230).

Dr. Sandford, who has kindly written the Foreword to this book, was summarizing research focused on northern Canada. But these same changes will have reverberations right across Canada. Climate change is already affecting all parts of Canada (Dore and Simcisko 2013) and its main impact is likely to be on public infrastructure as stated in the quotation given above. This means that water conservation and judicious water management is becoming ever more urgent.

The concern of this set of two books is the management of drinking water, although this cannot be divorced from sustainable water resource management for ecosystem health, the overarching philosophy for sustainable use that German and other European authorities have explicitly recognized. Maintenance and restoration of ecosystem functioning and health *within a context of climate change* ought now to be recognized as being synonymous with the "social good." In Chap. 8 on water policy in British Columbia we discuss the legislation of the 2014 *Water Sustainability Act*, in which the province of British Columbia moved partly in that direction, but there is still inadequate protection for watersheds and inadequate recognition of impending hydrological changes. However, there is recognition of the need to preserve ecosystem health, if only to protect jobs and incomes.

All over the globe environmental damage can be seen in stresses on land, air, oceans, and freshwater. It is clear that in much of the world the "social good" is being very narrowly defined. The stress on water resources is due not only to economic development of middle income and poorer countries but also to the loss of hydrological stationarity mentioned above. The emerging evidence on climate change indicates that the northern hemisphere is getting wetter, but some pockets of dry areas are likely to get even drier, such as the mid-southwest of the United States and drier areas of western Canada. On the other hand in Africa, desertification is advancing and flow rates in the existing rivers and lakes are becoming more variable. Areas in Southern Europe can also expect increasing water stress. Under these conditions, conservation of water has increased in importance. Some water-stressed areas are beginning to look for inter-basin water transfers, but these are unsound from the perspective of ecosystem health. There is also growing evidence of water conflicts becoming more prominent. A large trade in drinking water in the form of bottled water exists but there is also a search for bulk water exports. For example much of Canada's water flows north, but from time to time there are fears of the possibility of bulk water export or diversion of freshwater from the northern rivers and the Great Lakes into the Mississippi River though the Chicago Diversion for the growing population of the US "sunbelt" (Dore and Whorley 2006). Similarly Turkey has proposed bulk water exports to Israel. Some inter-basin transfers, such as those from the Great Lakes to the south of the US have the potential for future conflict.

Inter-basin water transfers and the potential for conflict can be avoided if there is in place a committed policy of water conservation in order to ensure that ecosystem health is ranked as a priority in water resource management all over the globe. This primary aim needs to be supplemented with systemic adaptation to the changing availability of fresh water due to climate change. However, rapid (though uneven) economic development is making water scarcity a major threat. As fresh and clean water supply comes under stress, most drinking water is no longer pristine and must be treated for pathogens and other contaminants. In North America, the treatment method relies largely on chlorine, primarily to kill bacteria and viruses. But the threats from protozoa remain, and these have led to a number of waterborne disease outbreaks, as chlorine is ineffective against a number of pathogens, as this books shows.

The production of drinking water requires adequate management, with appropriate pricing and management under risk, an idea that the World Health Organization has been promoting in order to reduce or eliminate waterborne disease outbreaks. In the first of the two books, the major theoretical issues in the management of drinking water are considered in some detail. These issues are: (1) watershed protection from harmful human industrial, mining and agricultural activity; (2) characteristics and efficacies of drinking water treatment technologies and their unit costs under conditions of economies of scale; (3) theory and practice of water pricing; (4) methods and processes of adopting risk assessment in drinking water management; (5) up-to-date water infrastructure management incorporating risk; (6) a serious commitment to overcoming risks to long-term health through reduced reliance on chlorine and chlorine derivatives for disinfection; (7) the need for an adequate response to the threat of lead in in drinking water; and (8) overcoming the current inadequate treatment of wastewater discharged into surface waters that become the source of drinking water, with the concomitant presence of micro-pollutants in the drinking water. All that is the subject of the first book. In this companion book, the focus is on conservation and on government-level policy on water in Canada and the extent to which cattle farming, mining, and oil and gas drilling, and possibilities of oil pipelines threaten both the land environment and freshwater resources. In other words, agriculture and industry are not bearing the full *social cost* of their activities. As water is a provincial responsibility, there are separate chapters on water policy in four provinces: Ontario, Alberta, British Columbia, and Newfoundland and Labrador.

Drinking water supply is organized in a number of ways in developed countries. Some large cities in Europe operate water supply as a private but regulated business. However, in much of the world water is almost exclusively provided by a local municipality, as a local ‘public’ good. Naturally in this case there is no profit motive, and no incentive to innovate, introduce more advanced technology, or to improve water quality. The European private companies and other pockets of privatized water companies seem well managed, but it is not clear that they are innovators in delivering higher water quality. What seems to lead to higher quality drinking water is government leadership through adequate regulation, as in Denmark, the Netherlands, and Germany. Public awareness of what is possible and what has been done in other jurisdictions may perhaps drive citizens and their utilities to improve water quality.

There are two long-term threats to health associated with the treatment and delivery of drinking water: one is the presence of lead in drinking water, which is a serious health hazard. It is therefore imperative that the lead content of drinking water is properly measured; there are two chapters that deal with lead in drinking water in the first book (Dore 2015, Chaps. 10 and 11). The other long-term threat is the use of chlorine and chlorine derivatives used in the disinfection of drinking water, which is also covered in the first book (Chap. 9). The use of chlorine results in a large number of "disinfection byproducts," some of which are regulated in the developed countries. But chlorine alone is ineffective against protozoa, and the byproducts carry some very long-term threats to human health. There are new treatment technologies that do not have these byproducts and are therefore safer. These newer technologies can be used to deliver a higher quality of water, but there appears to be a lack of knowledge of these possibilities, and possibly apathy among North American governments. Consumers might demand better water quality if they had more information on the new technologies and their costs.

Communities in Europe seem more cognizant of some of the long-term threats to health associated with the use of chlorine as a primary disinfectant, but other threats due to lead in the water remain a major concern, although there are some European countries (like Denmark) where this threat is taken very seriously and largely eliminated. But in the rest of the world the presence of lead in old pipes and even in the treatment systems continues to be a concern. For the threat of lead, what is required is a scientifically sound lead sampling protocol and an appropriate maximum contamination level (MCL) set as a regulation. It would also help if there were a systematic plan to eliminate all lead pipes and fixtures.

Most developed countries have strong regulations against the presence of pathogens and once lead is eliminated, the next frontier in water quality will be the elimination of chemical contaminants such as *pesticides* (e.g. *atrazine*), *herbicides*, *pharmaceuticals and personal care products*. This is a problem when the source water comes from multi-use watersheds like the Great (North American) Lakes. Europe (for example, Germany and the Netherlands) has made real progress in dealing with these problems; most European jurisdictions have moved away from surface water as a source and switched to groundwater, which by itself is a natural form of "treatment"; groundwater is often free of contaminants except where there are known contaminants, such as iron and manganese. The proper treatment of wastewater to the tertiary level is another urgent need and here again countries like Germany, Denmark, and the Netherlands have made remarkable progress.

It could be argued that smaller countries like Denmark and the Netherlands can afford to be aggressive in assuring better quality of water. But the comparative case study of Germany reported in this book shows what can be done to improve drinking water quality by avoiding some of the long-term risks. Germany offers some important lessons both for North America and for the developing world on how water supply could and should be managed.

I hope that the coverage of these important topics in the management and delivery of clean water will stimulate discussion on what can be learnt from Germany to help improve drinking water quality everywhere, including the developing countries. Thus the two books are oriented toward filling the knowledge gap and showing the potential for improvement. As such both books are likely to be of interest to water system owners, managers, water engineering consultants, and regulators all over the world. The comparative dimension may also appeal to some readers, to see how some jurisdictions manage their water supply as a public service producing a product essential to life.

I should like to record all the help that I have received in writing this and the companion book. First, the two books would not have been possible without the research grants that I have been fortunate enough to receive from the Social Sciences and Humanities Research Council of Canada (SSHRC), The National Science and Engineering Council of Canada (NSERC), the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS),[1] the US National Science Foundation (US-NSF), the Climate Change Action Fund of the Federal Government of Canada, and grants for teaching release from Brock University, which in turn were possible thanks to the Research Time Release Stipends included in my SSHRC grants over the last few years. The research grants enabled me to establish my Climate Change Lab at Brock University. In this lab I was fortunate in hiring many of my students as research assistants, and most of them wrote their graduate or undergraduate honors theses under my supervision in the lab. They have greatly influenced my thinking and many contributed important germs of new ideas, and new models as vehicles of inquiry; these dramatically altered my thinking, as teaching is a two-way enriching process. I want to record my debt to all my former students, who are now well established in their own careers. The names that I remember most (in alphabetical order) are: Abba Ansah, Katherine Ball, Geoff Black, Ryan Bruno, Hassan Chilmeran, Ridha Chilmeran, Eric Eastman, Ken Gilmour, Clay Greene, Indra Hardeen, Ryan Harder, Aaron Janzen (at the University of Calgary), Jamie Jiang, Mathew Chang Kit, Ryan Kwan, Soomin (Tomy) Lee, Tony Lipiec, Roelof Makken, Michael Patterson, Jeff Pelletier, Sasha Radulovich, Angela Ragoonath, Noureen Shah, Amar Shangavi, Peter Simcisko, Rajiv Singh, Harvey Stevens, Mireille Trent, and Klemen Zumer. They all cut their "research" teeth in my lab but gave much of their time and effort, and are now my friends. While some are completing Ph.Ds, others are well advanced in their professional careers; one of them (Roelof Makken) generously established the 'Mohammed Dore Graduate Research Scholarship' at Brock University and is now an adjunct Professor at Brock University, where he has taken over some of my teaching. Jamie Jiang in particular has taken on much of the econometric estimation work as well as the editorial work of these two books. Her work is meticulous and painstaking; she left my lab in the Fall of this year to start her Ph.D program. I think of all of my former students as my co-authors of these two books; I cannot imagine how I would have functioned without them.

I would like to thank two colleagues in the Department of Economics, Professors Tomson Ogwang, for teaching me nonparametric statistics and for being the Chair of the Department and being a friend, and Professor Robert Dimand, co-author on macroeconomic issues, and for being a friend for many years. I have valued their counsel and support on many issues over the years.

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[1] Now transformed by the Federal Government into the "Canadian Climate Forum," it is no longer a granting agency.

My thanks also go to the Deans of the Faculty of Social Sciences (Deans David Siegel and Thomas Dunk) and the Office of the Vice President, Research Services; their help has been invaluable. The research on Germany in the first book was read by two people in Germany: my good friend Dieter Jablonka and Mr. Michael Schneemann, water engineer at *Wasserbeschaffungsverband*, the water utility in Harburg, Germany. Mr. Schneemann's comments and suggestions were very helpful. I also received help and advice from Prof. Dr.-Ing. Helmut Grüning, at the IWARU Institute of Water in Münster, and from Dr. Christiane Markard, Head of Division II, "Environmental Health and Protection of Ecosystems," at *Umweltbundesamt,* which is the Environmental Protection Agency of the Federal Republic of Germany. In this book the comparative last chapter draws on that research on Germany.

Some chapters were read by anonymous referees chosen by my Editor at Springer and I would like to thank them for their constructive comments and suggestions. Robert Sandford read the whole book and he too offered constructive comments. Oliver Brandes read the chapter on British Columbia and Aaron Janzen read the chapter on Alberta; both offered constructive comments and corrected some out-of-date information. Colleen Beard and Sarah Holmes of the Brock University Map, Data, and GIS Library prepared the maps in this book and I wish to thank them too for their timely and expert assistance.

I wish to express my thanks to all of the people mentioned above for their help. But I alone am responsible for the contents of this book and for any remaining deficiencies.

I must thank Margaret Dore who over the years has read and edited *all* my books and many of my articles. She has read and improved many successive drafts of the two books being published by Springer. Finally I wish to record my thanks to my Editor, Dr. Tobias Wassermann, at Springer for constructive comments and constant encouragement; in many ways he is an ideal editor.

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Contents

Chapter 1
Introduction: Drinking Water Management

1.1 Introduction

This book and its companion volume ("Global Drinking Water Management and Conservation: Optimal Decision-Making," Springer, 2015) are motivated by the fact that within a span of 11 years, there were two major drinking waterborne disease outbreaks, one in the USA and the other in Canada, two of the world's most developed countries. The outbreaks were the worst in both the US and Canadian histories. Both represent a massive failure of public control and regulation. Both have now been studied well and their jurisdictions have introduced major regulatory changes after the outbreaks.

When we look at the record, these two outbreaks seem to be part of a pattern of waterborne diseases. They raise the whole question of how drinking water is managed and what should be the governing principles of sound management that will not only avoid waterborne disease outbreaks, but also produce the kind of higher quality water that some European countries deliver to their citizens. Perhaps these governing principles needed to be spelt out in detail, and this we have attempted to do in "Global Drinking Water Management and Conservation: Optimal Decision-Making." These principles are summarized in this book in Chap. 2.

In Canada water is a provincial responsibility, except where water crosses international boundaries. The present volume is a critical appraisal of water policy in four of Canada's provinces, with a focus on (a) demand management and the possibilities of water conservation, (b) potential for the adoption of better water treatment technologies, (c) lessons from risk assessment, on how a disaggregated examination of risks associated with different factors such as methods of disinfection, presence of organic matter in source water, turbidity, color, and so on might contribute to possible risks of failure, and (d) departures from the principles of good management practice. While the risk assessment findings have a micro, treatment at

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plant-level focus, the findings on the departures from good management practice offer the possibility of a higher level reform of water policy and regulation.

In this introductory chapter, we begin by outlining the recent course of waterborne disease outbreaks and assess what can be learned from them. By noting what went wrong and what caused the waterborne disease outbreaks, we hope to reinforce the importance of the principles of good management and show what could and should be done to manage drinking water.

The chapter on small water systems analyzes both the demand side of drinking water as well as the supply side, i.e., both demand for water and how conservation could be encouraged, as well as the costs and technology of drinking water production, where we aim to identify the dominant cost components in treatment trains, and estimate at what flow rate economies of scale set in.

The nature of the analysis of the book is partly determined by the availability of data; the survey of water systems by Environment Canada data made the chapter on small water systems possible. Similarly, the risk assessment of the different factors mentioned above was made possible because the government of Newfoundland and Labrador not only collects excellent data but also has a policy of making the data available to the public for analysis and use. The provincial case studies of water policy and respective threats to water were made possible because we were able to use Federal Government of Canada data, and reports and research papers from the provincial governments as well as peer-reviewed journals and other publications.

For the remainder of this chapter, we attempt to seek lessons from the recent record of waterborne diseases in developed countries.

1.2 Introduction to Waterborne Diseases Outbreaks

It would make sense to begin by putting the problem of waterborne diseases into a global context. According to the World Health Organization, waterborne diseases account for an estimated 4.1 % of the total DALY ("disability adjusted life years") global burden of disease, and cause about 1.8 million human deaths annually. The World Health Organization estimates that 88 % of that burden is attributable to unsafe water supply, sanitation, and hygiene (WHO 2004). A major health issue has been the emergence of HIV/AIDS in the latter half of the last century. But the waterborne disease called *schistosomiasis*, also called bilharzia, has been known for many years in the developing countries. The two are now linked: Schistosomiasis appears to be a cofactor in the spread and progression of HIV/AIDS in areas wherein both diseases are endemic, mainly in the developing countries. It has been found in South Africa that women who have been exposed to schistosomiasis are more prone to contract HIV/AIDS (Secor 2012). And of course developing countries still have to contend with outbreaks of typhoid and cholera.

While the developed countries have seen the end of cholera and typhoid as waterborne diseases, other preventable waterborne diseases have become prominent (Table 1.1), of which outbreak #6 was the largest in US history and #25 was the largest in Canada. The outbreak in the US was caused by *cryptosporidium* and the one in Canada was due to the *Escherichia coli* bacteria; both in theory could have been prevented with adequate treatment. Both outbreaks have been studied and the Canadian outbreak led to a major judicial inquiry that more or less revolutionized water regulation in Ontario. Justice O'Connor led the "Walkerton Inquiry" (O'Connor 2002), and made 28 recommendations in Chap. 15 of his report. All of his recommendations were accepted and adopted by the Government of Ontario; there is nothing like major political scandal and social trauma to focus a government.

There have of course been disease outbreaks caused by pathogens other than bacteria, and such outbreaks are listed in Table 1.1. The known or suspected causes are also listed in the table. What can we learn from these outbreaks? That is the subject of the next subsection.

1.3 Lessons from Disease Outbreaks

Drinking water disease outbreaks are the result of multiple failures within a water system. The most common failures that allow outbreaks to occur are improper or neglected treatment equipment and failure to maintain standard monitoring procedures and operations. Outbreaks indicate the need for continual vigilance and adequate monitoring in drinking water production and distribution, as well as continual testing of water quality to maintain adequate quality standards. Outbreaks can be used to gain knowledge and understanding of the techniques and methods that are most effective for providing safe drinking water. Lessons can be learned nationally within countries as well as internationally among countries, from outbreaks that have occurred in Canada, the United States, and Europe.

Steven and Elizabeth Hrudey are able to make conclusions in their book, Safe Drinking Water (2004), based on their summary of outbreaks from 1974 to 2002. They conclude that the multibarrier approach continues to be a requirement for a safe drinking water system. Barriers in place at each stage within the system for the source, treatment, distribution, monitoring, and response are all required to ensure safe drinking water. Both human and nonhuman elements can cause failures throughout the system. Continued emphasis on the multibarrier approach is necessary in order to detect and treat contamination at all stages before the water is distributed to the consumer. This approach is still the most effective method to provide safe drinking water.

The first barrier is watershed protection. The second barrier is the treatment stage. If the source water is contaminated, the goal of treatment is to inactivate and remove the pathogen before the water continues into the distribution system. Chlorine is the most commonly used chemical disinfectant because of its cost-effectiveness. It is of course well known that standard chlorine disinfection is effective against bacterial contaminations of campylobacter and *E. coli*, but ineffective against protozoan contaminations of cryptosporidium, giardia, and toxoplasma. Cryptosporidium is the most resistant, but all three protozoa are able

Table 1.1 A list of waterborne disease outbreaks

No.	Disease outbreak	Location	Dates	Impact	Known or suspected cause
1	Cryptosporidiosis	Braun Station, Texas	May to July of 1984	2,000 cases of illness out of 5,900 people	Sewage contamination; system failure with a lack of effective treatment
2	Cryptosporidiosis	Carrollton, Georgia	January to February of 1987	Over 13,000 cases of illness out of 27,000 people	Fecal runoff; sewage overflow; the failure of a flocculator; inadequate filtration and monitoring practices
3	Cryptosporidiosis	Jackson County, Oregon	January to June of 1992	3,000 cases of defined illness out of 15,000 people	Agricultural runoff; a lack of filtration and a sole reliance on chlorination
4	Cryptosporidiosis	North Cumbria in England	January to June of 1992	Undetermined number of cases of illness out of 160,000 people	Runoff from nearby livestock; a lack of filtration and a sole reliance on chlorination
5	Cryptosporidiosis	Warrington England	November 1992 to February 1993	1,840 people affected by the contaminated water that was supplied to 38,000 people	Agricultural runoff; heavy rainfall; livestock fecal matter; a lack of filtration and reliance on chlorine alone; a lack of monitoring of the water supply
6	Cryptosporidiosis	Milwaukee, Wisconsin	March to April of 1993	Over 403,000 cases of illness and 100 deaths out of approximately 840,000 people	Cattle runoff and human sewage; recycled backwash waters
7	Cryptosporidiosis	Kitchener and Waterloo, Ontario	March 1993	1,000 cases of cryptosporidiosis occurred in the region of 390,000 people	Change in a water system switched from a groundwater source to a surface source; recycled backwash waters
8	Cryptosporidiosis	Cranbrook, British Columbia	May 1996	2000 cases of illness out of 18,131 people	Runoff of cattle manure; a lack of filtration and reliance on chlorine alone
9	Cryptosporidiosis	Kelowna, British Columbia	May 1996	10,000–15,000 cases of illness out of 89,442 people	Runoff of cattle manure; a lack of filtration and reliance on chlorine alone

(continued)

Table 1.1 (continued)

No.	Disease outbreak	Location	Dates	Impact	Known or suspected cause
10	Cryptosporidiosis	Northern Ireland	May 2000, August 2000, and April 2001	Between 117 and 230 cases of illnesses out of approximately 400,000 people	Livestock runoff; human sewage from a septic tank; wastewater from a blocked drain
11	Cryptosporidiosis	North Battleford, Saskatchewan	April 2001	5,800–7,100 cases of illness out of 15,000 people	Sewage from a sewage treatment plant; calf feces runoff from the agricultural activity; inadequate coagulation
12	Cryptosporidiosis	Gwynedd and Anglesey, Wales	November 2005	231 cases of illness out of 70,000 households	Human sewage effluent; runoff of animal fecal matter; no specific treatment failure, but the treatment methods such as pressurized sand filtration and chlorination were not effective against cryptosporidium
13	Cryptosporidiosis	Galway, Ireland	February 2007	242 cases of illness out of 72,000 people	Human fecal matter; a lack of filtration in the older treatment plant
14	Giardiasis	Rome, New York	November 1974	4,800 to 5,300 cases of illness out of 50,148 people	Untreated human waste; only chloramine disinfection was used, with no filtration or sedimentation
15	Giardiasis	Bradford, Pennsylvania	September to December 1979	Affecting 3,500 people	Fecal matter from beavers; the failure of a chlorinator; a lack of filtration; inadequate treatment and monitoring (i.e., the failure to monitor chlorine residual levels)
16	Giardiasis	Pittsfield, Massachusetts	December 1985	3,800 cases of illness out of 50,265 people	Fecal matter from infected beavers or muskrats; water treatment changes at the treatment plant; the failure of a chlorinator and the new filtration had not yet been installed
17	Giardiasis	Penticton, British Columbia	1986	Over 3,000 cases of giardiasis	Animal fecal matter; chlorinated but unfiltered
18	Toxoplasmosis	Panama	1979	Unknown	Unknown

(continued)

Table 1.1 (continued)

No.	Disease outbreak	Location	Dates	Impact	Known or suspected cause
19	Toxoplasmosis	Victoria, British Columbia	October 1994 to April 1995	110 cases of illness and infecting over 2,900–7,700 people	Cat or cougar fecal matter; water system relied on chloramine disinfection without filtration
20	Toxoplasmosis	Brazil	2002	209 cases of illness	Unknown
21	Campylobacteriosis	Greenville, Florida	May 1983	865 cases of illness out of 1,096 people	Animal fecal matter such as infected bird droppings into open water towers; the failure of a pre-chlorinator; unlicensed operator and insufficient treatment
22	Campylobacteriosis	Orangeville, Ontario	March 1985	241 cases of illness	Surface drainage from animal farming activity that followed a heavy spring rainfall and runoff; a lack of chlorination disinfection
23	Campylobacteriosis	Haukipudas, Finland	1998	3,000 cases of illness out of 15,000 people	Bird droppings through holes in the water tower; a lack of chlorination disinfection
24	*Escherichia coli* (*E. coli*)	Cabool, Missouri	1989	243 cases of illness and 4 deaths out of 2,090 people	Fecal contamination from sewage; unseasonably cold weather caused the water mains to break; a lack of chlorination disinfection
25	*Escherichia coli* (*E. coli*)	Walkerton, Ontario	2000	Over 2,300 cases of illness and 7 deaths out of 4,800 people	Cattle manure; heavy rainfall causing the runoff into the water source; system deficiencies, including treatment and operational failures, including incompetence and fraud

to surpass simple chlorine treatment, as has been shown in numerous outbreaks. It is impossible to prevent contaminants from entering water sources, especially surface water, but the barriers of filtration and disinfection are critical in preventing the spread of contamination that leads to outbreaks.

Steven and Elizabeth Hrudey also conclude that microbial pathogens are the primary concern for drinking water safety. All the outbreaks stated in Table 1.1 are caused by pathogens, such as cryptosporidium, giardia, *E. coli*, and so on. Such pathogens originate from within human and animal fecal matter and sources deemed to be of high quality could become contaminated with such fecal matter, especially surface water sources. S. Hrudey and E. Hrudey emphasize the growing occurrence of cryptosporidium since the 1990s up to the Walkerton contamination in 2000. With its high resistance to chlorine, the most commonly used method of disinfection, the threat of cryptosporidium continues past the Walkerton outbreak to pose the highest risk to water systems. With the extent of research and the numerous outbreaks associated with this dominant pathogen, it is surprising that outbreaks continue to occur.

The Hrudeys also emphasize the effects of a change on a drinking water system. A system that is adaptable to change will be more capable of providing safe drinking water. Change can include changes in the weather, changes within the community, and changes within the water system. This is a contributing factor in many of the mentioned outbreaks. Change in the weather, either due to season changes or severe rainfalls due to climate change, prior to the occurrence of outbreaks is a common event, such as in the outbreak of Carrollton Georgia in 1987, Warrington England in 1992, Cranbrook B.C. in 1996, and Galway Ireland in 2007. Change in a community can occur from human activity, such as farming. Agricultural runoff from farming activity was the specified cause in outbreaks such as Jackson County Oregon in 1992, Warrington England in 1992, and in Galway Ireland in 2007. Change in a water system contributed to outbreaks such as Kitchener in 1993 when the water system switched from a groundwater source to a surface source, and also in Pittsfield Massachusetts in 1985 when a filtration plant was in the process of being installed. Change should act as a warning to system operators of possible contamination. Monitoring should be heightened during times of change, and precautions may be necessary.

The conclusions by Hrudey and Hrudey (2004), based on outbreaks prior to 2002, emphasize that the Walkerton outbreak should have been the defining example of the consequences of contamination. However, it does not seem that water authorities have absorbed this lesson, as outbreaks from other contaminants have continued to occur since then. The outbreak in Gwynedd and Anglesey Wales in 2005 and the outbreak in Galway Ireland in 2007 are the most recent outbreaks after the publication of the book by the Hrudeys. Considering the patterns that emerge from the outbreaks might help to prevent future outbreaks.

First, from the analysis of outbreaks reported here, we can conclude that there are no seasonal patterns to outbreaks. It can be argued that during spring runoff from winter thaws and with higher amounts of rainfall, contamination is more likely to enter water sources, especially surface sources. However, outbreaks can occur at any time during the year. This can be observed from the outbreaks reported here, as over half of the outbreaks surveyed here did not occur in the spring season. Spring runoff and rainfall are natural events, but human events such as improper practices by system operators can cause outbreaks as well. Frequent human failures that cause outbreaks include improper and ineffective treatment, insufficient monitoring, and inadequate training of operators. What is needed are fail-safe systems that minimize human error.

We can also conclude that outbreaks do not follow a pattern based on the size of a water system. In contrast to what may be common belief, outbreaks are not specific to only small rural communities. Although outbreaks may be more frequent in smaller towns because of lower maintenance and less efficient water systems, due to lack of finance, this does not mean that larger systems are immune from failure. This survey of waterborne disease outbreaks makes it clear that outbreaks can occur in both large and small communities. As mentioned above, Milwaukee with a large population of 840,000 served by the water system, and North Battleford with a smaller population of 15,000, have both experienced outbreaks. The major difference is that an outbreak among a larger population is likely to have a more significant impact, as more people are affected. The outbreaks that have occurred after Walkerton in 2000 also indicate that large communities are also susceptible to having contaminated water.

A common pattern within the waterborne disease outbreaks is the ineffective role of chlorine. Communities that rely heavily and especially those that rely solely on chlorine disinfection are vulnerable to contamination. This chapter suggests that the most dominant microbial contaminant of the outbreaks referred to here is a protozoan pathogen, namely cryptosporidium. The ability of protozoa to infiltrate and pass through many drinking water systems is because of their resistance to chlorine. Alternative treatments that are effective against protozoa are filtration, ozone treatment, and ultraviolet light (UV) treatment. Communities that have experienced problems of cryptosporidium contamination often rely heavily or solely on chlorination. Another disadvantage of chlorine is the by-products that can result from its use. Trihalomethanes (THMs) form through a reaction between chlorine and organic compounds. These are known as disinfection by-products (DBPs) and can have long-term health effects (Moghadam and Dore 2012; Dore 2015). Chlorine can also create a distinctive taste if high levels of disinfection are required, which is often strongly disliked by receiving communities. Alternative methods of disinfection should be considered to avoid the problem of ineffective disinfection and the occurrence of THMs.

Multiuse watersheds involve a variety of activities and operations that could potentially contribute to contamination. It was noted that farming operations often result in animal fecal matter contaminating watercourses. Sewage treatment plants are another common factor that can result in contamination. Animal and human fecal matter are the most common source of contamination in the drinking water outbreaks. The increase of human activity in a watershed also increases the possibility of contamination. For this reason, multiuse watersheds need to increase the scrutiny of their water quality.

Another factor to note is the issuing of boil water advisories. Boil water advisories (BWAs) are issued precisely to avert a disease outbreak. BWAs are issued at the local level by the water authority of a community often following the detection of contamination, as a precautionary measure. A BWA can be used to prevent the consumption of contaminated water, or as a precaution against the consumption of possibly contaminated water. A BWA requires all citizens of the specified community to boil their water prior to consumption in order to kill the possible pathogens within the water. A BWA is effective when the detection of a pathogen in a water system is confirmed. However, a BWA can be ineffective when uncertainty of the water quality results in a continuous use of BWAs. A BWA is also ineffective when it is used as an alternative to providing the necessary treatment equipment to supply safe drinking water. A BWA should not be issued to avoid the responsibility of proper treatment and maintenance, but continuous and long-standing advisories indicate that this occurs, particularly in small communities. Continuous BWAs are more common in smaller rural communities that are unable to maintain or upgrade their systems, often due to lack of finance.

Overall, the issue of drinking water quality will continue to remain a primary concern worldwide. Hrudey and Hrudey (2004) analyzed the lessons from their review of 69 outbreaks in the 1974–2002 period. When we include outbreaks after 2002, similar patterns emerge. Contamination and outbreaks can occur at any time and anywhere regardless of season or size of water system. The patterns among the outbreaks clearly show the ineffectiveness of chlorine against cryptosporidium, the vulnerability of multiuse watersheds, and the failures indicated by an overuse of BWAs. It becomes clear that proper treatment is essential to ensure the distribution of safe drinking water, as well as proper monitoring to be able to communicate a BWA if necessary to prevent the spread of an outbreak.

1.4 Overview of the Rest of the Book

Chapter 2 summarizes the key governing principles of sound water management. Chapter 3 is an analysis of two aspects of small water systems: (a) demand management, covering consumer behavior and supplementary conservation measures, and (b) a disaggregated examination of water treatment technologies and their costs. Chapter 4 is an analysis of water policy in Ontario; we show its strengths but also point out some weaknesses. Chapter 5 is an in-depth study of demand management in Ontario, and the possibilities of water conservation measures. Chapter 6 is about water policy in Newfoundland, including an analysis of risks of failures of water systems. Chapters 7 and 8 are analyses of water policies in Alberta and British Columbia and the threats to water due to industrial, agricultural, and mining activities in the respective provinces.

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Chapter 2
Principles for Sound Drinking Water Management: A Review

2.1 Introduction

As stated in the previous chapter, the whole of the companion book (Dore 2015) was devoted to the major principles and concepts of sound drinking water management. The objective of this chapter is to summarize these principles. The key principles may be stated as follows: source water protection; classification of drinking water technologies according to the contaminants they remove; risk assessment methods and the incorporation of risk in water management; well-formulated infrastructure asset management plans; and the reduction or elimination of long-term risks. These topics are summarized in separate sections, *brevatim et seriatim.*

2.2 Source Water Protection

What is the first step in preventing waterborne disease outbreaks? In the multi-barrier approach, the first component is the establishment of protection of source waters. This may require a watershed protection plan, including supporting legislation. Implementing watershed protection requires an understanding of the key principles of watershed management, which are now well known. Both the US and Ontario have sound legislation on watershed protection, which is lacking in the provinces of Alberta and British Columbia, as we show in Chaps. 7 and 8. For the legislation and approach to watershed protection in Ontario, see Chap. 4.

A simple way of summarizing the principles of source water protection is to focus on *point source pollution* and *nonpoint source pollution*.

M.H. Dore, *Water Policy in Canada*, Springer Water,
DOI 10.1007/978-3-319-15883-9_2

2.2.1 Point Source Pollution

Point source pollution can originate from sewage treatment plants, industrial plant effluents, and animal and crop farms. Point sources of water pollution are still a major problem in most developing countries due to lack of adequate administration, infrastructure, regulation or its enforcement. In Canada, the U.S., and most other developed countries, the quality of effluents discharged from sewage treatment plants and industrial facilities is highly regulated, and thus these effluents do not generally pose a significant threat to the quality of receiving surface waters, unless wastewater treatment is inadequate or faulty. But animal production and farms are an exception. Below is a discussion of farm animal production problems and water pollution control in the United States, where animal production farms still pose a major threat to water quality. In the U.S., there are about 450,000 farms with animal feeding operations. About 85 % of these facilities are small with less than 250 animals, but there are many animal feeding operations with more than 1,000 animals (USEPA 2002). These large farms are called "Concentrated Animal Feeding Operations," or CFAOs. In Canada, they are called "Combined Feeding Operations."

For CFAOs, farm owners/operators are required to have a permit that ensures safe disposal of all the manure, urine, and dead animal matter. The farms are subject to inspection and must have a comprehensive nutrient management plan that considers the safety of all nearby water bodies including groundwater. All CFAOs are required to keep records of the quantity of manure produced and how the manure was utilized, applied to land, sold to third parties for the manufacture of fertilizers, or used for methane generation as an energy source.

Apart from the regulatory requirements, there are additional voluntary guidelines from the U.S. Department of Agriculture (USDA) for best management practices (BMPs) on farms as well as tax incentives for demonstrating the implementation of BMPs. There are financial and technical assistance programs for implementing nutrient management plans as well as environmental education programs. And there are performance measures for the implementation of the "Unified National Animal Feeding Operations Strategy" (USEPA 2002).

Farm animals should be required to be fenced and not allowed to be within a specified distance of public watercourses. Many of the disease outbreaks listed in Table 1.1 occurred because animal fecal matter got into the public watercourses in Europe, the USA, and in Canada. The Walkerton outbreak was made worse due to the fact that there were torrential rains for more than 2 days, and it was this rain that carried the *E. coli* bacteria from surrounding cattle farms into the drinking water wells. But there were also failures of other mechanisms that led to the 7 deaths and kidney impairment of more than 200 people.

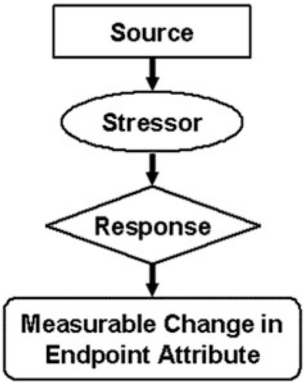
2.2.2 Nonpoint Source Pollution

Nonpoint sources of pollution, also called diffused pollution, mostly originate from unknown origins and locations; it is the pollution that shows up downstream; it may include pollution due to the death of wild animals in a water course at an unknown location, or even bird feces. Nonpoint sources of pollution associated with surface runoff include sediments, nutrients, pesticides, pathogens, metals, oils, and many chemical contaminants entering water bodies from roads and roofs and other unknown locations. Controlling nonpoint sources of pollution is rather difficult and complicated because of its diffused characteristics and difficulty in pinpointing the origin of contaminants flowing to surface waters. Watershed management and implementing BMPs are considered effective tools for nonpoint source pollution control.

To deal with nonpoint source pollution, the USEPA recommends the application of Ecological Risk Assessment (ERA) to watershed management (USEPA 1998). As defined by the USEPA, "ERA is a process to collect, organize, and analyze scientific information in order to evaluate the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors" (USEPA 1998). Watershed ERA can be summarized as follows. The conceptual models describe the various physical, chemical, and biological stressors, their sources, assessment endpoints, and the possible pathways, and also disclose how the assessment endpoints respond to the stressors via possible pathways, as shown in Fig. 2.1 (USEPA 2007).

As shown in Fig. 2.1, the source is some public water body such as a lake or river. The "stressor" could be wild animals or farm animals contaminating the source, but this stressor is unknown to the watershed authorities. A good knowledge of the human activity in the watershed and possibilities of contamination, based on past history, and a series of measurements of contaminants at specific locations can minimize the impacts on the "endpoint." Complete mapping of subwatersheds and the location of farms within each subwatershed can be useful in minimizing nonpoint source pollution and its possible impacts.

Fig. 2.1 Elementary model of ERA (USEPA 2007)



In May 1983, in Greenville Florida, the campylobacter pathogen entered the water source through infected bird droppings into open water towers. This was an example of "nonpoint" source water pollution, as this is a random act and although the "point" source was later identified, the problem was the *open water towers.*

2.3 Classification of Treatment Technologies

We begin by classifying some commonly used drinking water treatment technologies. The waterborne disease outbreak in Carollton Georgia in 1987 was in part due to failure of flocculators. There are also other examples of faulty equipment.

Most large water treatment plants use conventional water treatment which is: pre-sedimentation or screening, chemical coagulation and flocculation, settling, filtration (usually sand filtration), and disinfection, typically using chlorine or chlorine derivatives. Conventional treatment is used to reduce total suspended solids and turbidity. (For further discussion and classification of the conventional treatment train, see below). However, conventional treatment is not suitable for small water systems. We therefore focus here on treatment technologies that are suitable for small as well as large water systems.

Table 2.1 is a classification of treatment technologies on the basis of what contaminant(s) each technology can *remove*.

Table 2.1 Proposed water treatment classes

Class	Typical treatment technology	Contaminants removed
Class 1	Chlorination	Water disinfection; removal of most bacteria but not all pathogens
Class 2	High rate clarification and filtration	Disinfection plus suspended solid removal
Class 3	Ultra Violet	Class 2 plus inactivation of Protozoa and Viruses
Class 4	Ozonation	Class 3 plus removal of dissolved organic matter (no DPB[a] precursors)
Class 5a	Membrane filtration; includes activated carbon, granular or powdered	Class 3 plus removal of geosmin and other taste and odor compounds, DBPs, volatile organic Compounds; reduction of endocrine disruptors, micropollutants, pesticides, pharmaceuticals, and personal care products
Class 5b	Advanced oxidation processes (may be based on UV or ozonation)	Class 5a removal plus higher efficacy of the removal of chemicals and other micropollutants (e.g., pesticides, pharmaceuticals, personal care products, taste, and odor concerns)
Class 6	Reverse osmosis or distillation	Class 5 plus removal of salinity; but note that contaminants with molecules smaller than water (e.g., acetaminophen) will not be removed by RO alone

[a] DPB stands for "disinfection byproducts."

Class 1 represents the minimum level of treatment, which is disinfection by chlorination only. We consider chlorination the minimum disinfection treatment level since all water treatment plants are required to produce water that is free of pathogens. While most groundwater-based systems would rely on chlorine only (Class 1), many surface water small water systems will be Class 2, i.e., water that has suspended solids removed and is disinfected. In a Class 3 plant, protozoa as well as viruses will also be removed or inactivated, possibly with the aid of UV or ozonation. If, in addition, all dissolved organic matter is also removed before chlorination, then that would be water without disinfection by-products (DBP), and we classify such treatment technology as Class 4.

On the other hand Class 5 (i.e., Classes 5a and 5b) represents technologies that also reduce or remove chemicals, micropollutants, DBPs, protozoa, and suspended solids in addition to disinfection. In the scheme proposed above, each progressively higher treatment class indicates a greater removal of contaminants. However, this classification scheme is fairly broad in scope, an initial attempt, although other more finely graded classifications are possible. Note that we are classifying *treatment categories or classes, not final water quality.* What emerges from this classification is a way of comparing final water quality *indirectly*, on the basis of what treatment systems are used, and also assessing any possible long-term health threats.

In North America most drinking water comes from surface water, which needs to be treated adequately. According to the American Water Works Report (AWWA 2008), chlorine gas remained the predominant disinfectant in the US, used by 63 % of respondents to a survey whereas those who used chloramine accounted for 30 %; chlorine dioxide for 8 %; ozone for 9 %; and ultraviolet light (UV) for 2 %. (The figures do not add up to 100 as some may use more than one disinfection method.) In Canada, according to the Environment Canada survey of Municipal Water and Wastewater Plants (2004), some 93 % used chlorine as the only disinfectant. Those using UV or ozonation accounted for only 6 % of the total. This shows the dominant role played by chlorine and chlorine derivatives in North America, where this Class 1 technology is concerned almost exclusively with the removal of pathogens, although we know that chlorine is not effective against protozoa and other pathogens. However for most large cities and populations, the conventional water treatment method of coagulation, flocculation, clarification, and filtration, and is typically followed by disinfection by chlorine or chlorine derivative. But the failure of a flocculator led to an outbreak of *cryptosporidiosis* in Carrollton Georgia in 1987; the failure of a chlorinator led to an outbreak of *giardiasis* in Bradford Pennsylvania in 1979. Thus the conventional treatment train is best described as being Class 3 *if it removes all protozoa;* it cannot be classified as Class 4 as chlorination will leave DBP precursors in the water. For this reason, in Ontario and indeed in the whole of North America, the main DBPs, called Trihalomethanes (THMs), nitrosamines, and Haloacetic Acids (HAAs) are regulated with maximum contamination limits. But there are also many thousands of other DBPs, called Halides, that are not regulated at all.

The most significant drinking water outbreak of *cryptosporidiosis* was in Milwaukee Wisconsin from March to April of 1993, the worst waterborne disease outbreak in US history. Two water treatment plants supplying water to Milwaukee used water from Lake Michigan. Both plants used conventional treatment of coagulation, flocculation, sedimentation, rapid sand filtration, and chlorination treatment (Solo-Gabriele and Neumeister 1996, p. 81). Again the failure to remove a protozoon indicates that these plants functioned as no more than Class 2 treatment systems.

Based on the evidence and the above classification system, we are led to the conclusion that the conventional treatment plants in North America are at best Class 3, and no more than Class 2 when they fail to remove protozoa.[1] Note that this conclusion is based on treatment technologies and not on the quality of final drinking water, which may be quite good in some areas, depending on the characteristics of the source water; our focus here is on treatment.

It should also be noted that after a large fall in unit costs of ozonation, many water utilities are choosing ozonation as the primary treatment option (Class 4). In Europe the treatment of choice is granular activated carbon, which we classify as Class 5a. Granular activated carbon (GAC) has been used extensively for the removal of dissolved organics from drinking water. In the early 1970s, it was reported that bacteria, which proliferate in GAC filters, may be responsible for a fraction of the net removal of organics in the filter. Following this discovery, pre-ozonation was found to enhance significantly the biological activity on GAC. The combination of ozonation and GAC is commonly referred to as the biological activated carbon (BAC) process, or biologically enhanced activated carbon process. This was implemented in many large water treatment plants in Europe in the 1980s. The efficacy of activated carbon in removing all sorts of contaminants has been further confirmed by Rodriguez-Mozaz et al. (2004).

Advanced oxidation processes (with ozonation or UV-based) is essentially the same as Class 5a, but experiments show a greater efficacy of removal of the same contaminants as those in Class 5a; for evidence, see Chap. 4 in this book. We therefore classify Advanced Oxidation processes as Class 5b.

In Germany, roughly 74 % of drinking water is drawn from ground and spring water, and the remainder is drawn from surface water sources, such as lakes and rivers (Althoff 2007). By 2010, 63 % of the groundwater bodies in Germany had achieved a rating of "good chemical status" (BMU 2014). Of the total 1,000 groundwater bodies, only 4 % have not achieved a "good quantitative status," i.e., 4 % of the aquifers did not have enough water. The status of surface water is such

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[1] An anonymous referee of this book has suggested that the use of alum should be mentioned. Alum is used widely as a coagulant. Optimum coagulation to achieve maximum reductions of turbidity and microbes requires careful control of coagulant dose, pH, and consideration of the quality of the water being treated, as well as appropriate mixing conditions for optimum flocculation. Lack of attention to these details can result in poor coagulation-flocculation and inefficient removal of particles and microbes. Under optimum conditions, coagulation-flocculation and sedimentation with alum and iron can achieve microbial reductions of 1 or 2 log for all classes of waterborne pathogens. Thus by itself the coagulation-flocculation is never enough to meet regulatory requirements in North America.

that 88 % of water bodies achieved a "good" chemical status, while only 10 % of all surface water bodies had obtained at least a "good" ecological status (BMU 2014). Given the quality of groundwater, practically no disinfection is needed. The 2011 Profile of the German Water Sector (ATT 2011) states:

> The quality of drinking water is so good that the use of disinfectants in water treatment can even be forgone in many places without compromising the high hygienic drinking water standard.

Since there is no chlorine, there are no DBPs; in areas where the source is groundwater, there are no chemical residues in the water and of course no salinity. Thus for the groundwater sources we can conclude that German drinking water from the water treatment plants is equivalent to Class 5. In North Rhine-Westphalia, in the City of Cologne, they use groundwater as the source, which is then filtered through activated carbon, producing a very high quality of water. To quote from the City of Cologne[2] website:

> Some waterworks in Cologne used disinfectant to prevent an increase in the number of germs and thus hygienic deterioration of the drinking water quality on the way to the customer. Our water lab proved, however, that the perfect hygienic quality of drinking water can be guaranteed even without the use of chlorine dioxide or chlorine.

Where surface water is used in North Rhine-Westphalia, they detected perfluorooctanoate (PFOA) in drinking water at concentrations up to 0.64 μ/L in Arnsberg, Sauerland, Germany. In response, the German Drinking Water Commission (TWK) assessed perfluorinated compounds (PFCs) in drinking water and in June 2006 became the first in the world to set a health-based guideline value for safe lifelong exposure at 0.3 μ/L (sum of PFOA and perfluorooctanesulfonate, PFOS). PFOA and PFOS can be effectively removed from drinking water by percolation over granular activated carbon.

We should also note that for 90 % of the residents of Ontario, the source water is the Great Lakes, which also receive wastewater that is not always treated to remove chemicals, particularly pesticides, pharmaceuticals, and personal care products; this topic is deferred to the chapter dealing with wastewater and its impacts on drinking water (Chaps. 4 and 9).

We return to the classification of treatment classes given in Table 2.1. This classification scheme is fairly broad in scope, and other more finely graded classifications would be possible. Note that we are classifying *treatment categories or classes, not final water quality.* In this chapter we are interested in the main technologies for water systems and what contaminants can be removed from raw water. Table 2.2 is a description and minimum plant size for a number of treatment technologies.

The corresponding costs as a function of scale for these technologies are summarized in Fig. 2.2.

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[2] http://www.rheinenergie.com/media/portale/downloads_4/rheinenergie_1/broschueren_1/Colognes_Drinking_Water.pdf.

Table 2.2 Treatment technologies

Technology	Description	Treatment class
Chlorination	• Removal of bacteria only; but not protozoa or other pathogens resistant to chlorine	Class 1
HIGH rate treatment and clarification[a]	• Consists of a clarification system (Actiflo) and filtration system (Dusenflo mixed bed filters)	Class 2
	• Reduces turbidity, color, suspended solids, algae, taste and odor (T&O), metals and total organic carbon	
	• The resulting filtered water from the Dusenflo gravity filter can contain little or no Giardia and Cryptosporidium cysts	
	• Minimum plant size: 473 m^3/day	
UV system[b]	• Utilizes the ability of Ultra Violet rays to deactivate microorganisms	Class 3
	• This system on its own is chemical free and produces no disinfection by-products	
	• However, it can also be used in conjunction with other treatment processes forming a “multi-barrier” approach for treating water for drinking purposes	
	• UV will inactivate bacteria, viruses and protozoa, including Giardia and Cryptosporidium with a dose of 40 mJ/cm^2	
	• We assume some filtration system to remove sediments (e.g., sand filtration) would be required and is included in the cost	
	• Minimum plant size: 200 m^3/day	
MF-UF[c]	• Micro filtration and ultra filtration involve separating water from organic and inorganic matter contained in the water by forcing it through a micro porous membrane	Class 3
	• Pore sizes in microfiltration membranes are 0.1–10 μ thick while ultra filtration membranes are between 0.001 and 0.1 μ	
	• Microfiltration will remove Giardia and Cryptosporidium cysts, bacteria, and some viruses; however not all viruses can be removed via this process	
	• Microfiltration is also used in sterilization of beverages and pharmaceuticals, clearing of fruit juices, wine and beer, separation of oil–water emulsions and pretreatment of water for Nanofiltration and reverse osmosis	
	• Ultra filtration removes all viruses, bacteria, and suspended solids between 0.001 and 0.1 μm. Ultra filtration is used in paint treatment, oil–water emulsion separations, the food industry, and textile industry	
	• Minimum plant size: 379 m^3/day	

(continued)

Table 2.2 (continued)

Technology	Description	Treatment class
Ozonation[d]	• Ozonation systems utilize the ability of ozone to inactivate microorganisms through oxidation	Class 4
	• The system consists of an ozone pretreatment unit, a BioSand filter, and a BioCarbon filter	
	• The roughing filtration system removes suspended solids and coliforms as well as some Cryptosporidium	
	• The BioSand Filter is used to treat parasites, color, cysts, manganese, mercury, iron, and turbidity while the BioCarbon Filter treats dissolved organic carbon, tannins, pesticides, iron, bacteria, color, and odors	
	• Minimum plant size: 11.4 m^3/day	
Advanced oxidation (based on UV)	• A UV-oxidation process designed to provide disinfection and Taste and Odor treatment; it destroys Geosmin and 2-methylisoborneol	Class 5
	• Also oxidizes pharmaceuticals, personal care products, pesticides, and trace contaminants	
	• System consists of a UV reactor, H_2O_2 dosage, and storage system. We assume some filtration system to remove sediments (e.g., sand filtration) would be required and is included in the cost	
	• Minimum plant size: 818 m^3/day	
RO–NF[e]	• Removes all suspended solids, viruses, bacteria, pathogens, and all forms of biological contaminants	Class 6
	• Removes mono and multivalent ions, salts, and organics	
	• Essentially passes only pure water. Smallest pore size for membranes to date	
	• Minimum plant size: 1893 m^3/day	

[a] Produced by Veolia Water Solutions and Technologies in France under subsidiaries John Meunier and Kruger USA

[b] Produced by Trojan Technologies in Canada

[c] MF and UF information obtained from Koch Membrane Systems and Lenntech Water Treatment Solutions

[d] Information for ozonation obtained from Mainstream Water Solutions Inc.

[e] A thorough description can be obtained from Koch Membrane Systems

Table 2.2 and Fig. 2.2 show what treatment technologies are possible for consideration, depending on (a) source water characteristics, and (b) *target* water quality desired. Figure 2.2 indicates that ozone technology, a Class 4 water treatment, is more expensive than the Class 3 (UV and MF-UF) and Class 2 (HRC) treatment types. Class 3 treatments MF-UF and UV seem to be cheaper than HRC for plants which produce less than 100 m^3 of water per day and all the way up to 500 m^3/day, even though HRC is a Class 2 water treatment process. But in general Fig. 2.2

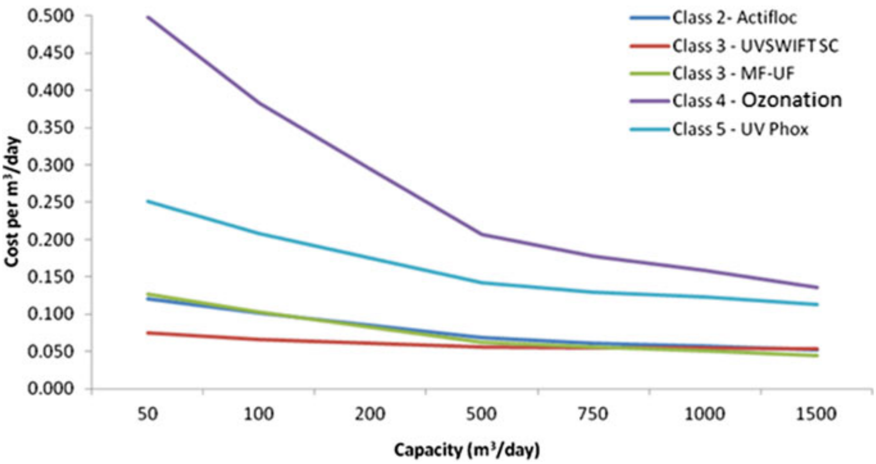

Fig. 2.2 Estimated cost curves: *Class 2* for HRC, *Class 3* for UV and MF-UF, *Class 4* for Ozonation, and *Class 5* for a UV-based AOP (Dore 2015)

suggests that the higher the Class of water treatment the higher the average costs per cubic meter. Notice how UV unit costs are lowest for almost all scales of operation.

It is possible that older small systems continue to use higher cost older technologies, as there is no incentive to modernize in the public sector. In other words, there are technologies currently available in the market that can provide higher contaminant removal at a much lower cost per cubic meter. Hence, we find that a technology which can provide Class 3 and 4 water treatment shows lower average cost per cubic meter than a small system, which is only providing Class 1 and 2 water treatments. Another possible reason is that there are site-specific costs that can contribute to the gap in the costs between technology and actual existing systems that are in the same class. For example, many of the small systems in British Columbia have higher transportation cost due to remoteness and the handling of hazardous materials such as chlorine. However, site-specific costs alone cannot account for this very large gap. We observe that some treatment classes at lower flow rates dominate in terms of cost-effectiveness. Class 3 MF-UF and UV provide water treatment at a much lower cost per cubic meter than some existing small systems in Classes 1 and 2 between output flow rates of 50–200 m^3 per day; but at higher flow rates this gap tends to decrease.

Of course we need to distinguish between systems that use groundwater as the source and systems that use surface water. Most of the above analysis is concerned with surface water as the source for water treatment plants. Our general conclusion is that while any specific water treatment facility will need to take account of raw source water quality, the *actual* target quality for small systems seems to be to meet only the *minimum regulatory requirements*. Our results show that for surface water, unless the raw water is high in color and in turbidity, a UV-based plant would be economical and cost effective even when the additional cost of sediment removal is added.

This conclusion is especially true for small plants producing less than 100 m^3 per day. Such a plant could obtain the same or better quality water with UV for less than 8 cents per cubic meter per day. Our finding of the cost-effectiveness of UV is in agreement with USEPA (1996), Gadgil (1998) and Parrotta and Bekdash (1998).

The cost curves in Fig. 2.2 take into account both average capital and operating cost, but of course not site-specific costs. Nevertheless, Table 2.2 and Fig. 2.2 offer a spectrum of treatment technologies, which could be deployed for a wide range of flow rates and population sizes. Unfortunately in North America, most small systems rely on chlorination alone. That simply invites a possible future waterborne disease outbreak, as shown in Chap. 1.

The major factor in the choice of chlorination as a primary disinfection seems to be the legal, regulatory requirement of a chlorine residual of between 0.5 mg/L in Newfoundland and Labrador to a maximum of 4 mg/L in Ontario. USEPA requirements are that the chlorine residual shall not be less than 0.2 mg/L for any period greater than 4 h at the entrance to the distribution system, and cannot be undetectable in more than 5 % of the samples taken each month in the distribution system (CWWA n.d.). This secondary chlorine requirement in practice means that most small systems in North America choose their primary disinfection system to be chlorine or a chlorine derivative.

Such a chlorine residual requirement does not exist in most of Europe, and so water utilities are free to choose their primary disinfection method. We have argued that UV disinfection is cheap and affordable for most small systems and yet it is not implemented. Many large systems in Canada (e.g., Victoria, Municipality of Durham in Ontario, and Edmonton) do use UV disinfection system, supplemented by the required chlorine residual for the distribution systems.

2.4 Risk Assessment in Water Treatment

Major approaches for risk management to produce potable water discussed below include (a) the HACCP protocol, (b) WHO Water Safety Plan and the Bonn charter, and (c) Quantitative Microbial Risk Assessment (QMRA). Here we summarize the HACCP protocol only; for detailed discussion of the other risk management protocols, (see Dore 2015, Chap. 6, Sect. 6.3).

2.4.1 Hazard Analysis and Critical Control Point (HACCP) Protocol

In the 1960s the U.S. National Aeronautics and Space Administration (NASA) asked the Pillsbury Corporation to design and manufacture food for space flights. For safety, a protocol was devised to make sure that prepared foods were safe. This protocol became known as the Hazard Analysis and Critical Control Point (HACCP) protocol, which incorporated the systematic checks of the *Codex Alimentarius Austriacus,* first used in the Austro-Hungarian Empire (Dore 2015, p. 123). The HACCP protocol has since then received global acceptance as a procedure for handling and preparing food that is free of pathogens and is safe to eat.

The HACCP protocol is based on seven principles (Canadian Food Inspection Agency 2012):

Principle 1: Conduct a hazard analysis—Plans determine the food safety hazards and identify the preventative measures the plan can apply to control these hazards. A food safety hazard is any biological, chemical, or physical property that may cause a food to be unsafe for human consumption.
Principle 2: Identify critical control points—A *critical control point* (CCP) is a point, step, or procedure in a food manufacturing process at which control can be applied and, as a result, a food safety hazard can be prevented, eliminated, or reduced to an acceptable level.
Principle 3: Establish critical limits for each critical control point—A critical limit is the maximum or minimum value to which a physical, biological, or chemical hazard must be controlled at a critical control point to prevent, eliminate, or reduce risk to an acceptable level.
Principle 4: Establish critical control point monitoring requirements—Monitoring activities are necessary to ensure that the process is under control at each critical control point.
Principle 5: Establish corrective actions—These are actions to be taken when monitoring indicates a deviation from an established critical limit. Corrective actions are intended to ensure that no product injurious to health or otherwise adulterated as a result of the deviation, enters commerce.
Principle 6: Establish procedures for ensuring the HACCP system is working as intended—Validation ensures that the plants do what they were designed to do; that is, they are successful in ensuring the production of a safe product. *Verification* ensures the HACCP plan is working as intended.
Principle 7: Establish record keeping procedures—The HACCP protocol requires that all plants maintain certain documents, including a hazard analysis and a written HACCP plan, and record the monitoring of critical control points, critical limits, verification activities, and the handling of processing deviations.

Any organization interested in risk minimization practice toward food and water can apply for certification for both the HACCP protocol and the International Organization for Standards (ISO) protocol, ISO 9001.[3] The latter certification

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[3] ISO (International Organization for Standardization) is a worldwide network of national standards bodies from over 160 countries, which was established in 1947. The mission of ISO is to develop International Standards (i.e., ISO 9001, ISO 14000, ISO 27000, ISO 22000), and to make sure that goods, services as well as processes are safe, reliable, and of good quality. As the management system standard, ISO 9001:2008 sets out the criteria for a quality management system implemented by over one million companies and organizations. To ensure that food is safe, ISO 22000:2005 contains the overall guidelines for food safety management, helping to identify

demonstrates that quality and customer satisfaction are priorities for the enterprise. The HACCP audits are conducted using auditor checklists as well as local statutory and regulatory requirements. Food processors can be certified for ISO 9001 simultaneously while an audit is conducted of their HACCP plans, resulting in certification for both. To provide food processors dual certification, it is possible to obtain a combined ISO/HACCP certification in preparation for the ISO 22000 standard for the food industry. ISO 22000 can be applied independently of other management system standards or integrated with existing management system requirements. The importance of ISO 22000 is that it integrates the principles of the Hazard Analysis and Critical Control Point (HACCP) system and application steps developed by the *Codex Alimentarius* Commission. Perhaps this is the standard to which water treatment plants will aspire in the future. For example, the water utilities of Halifax, Edmonton, and the Regional Municipality of Durham in Ontario are certified under the ISO 14001 protocol; it would be good if they and others went further and sought certification under ISO 22000.

2.5 Water Infrastructure Asset Management

One of the aspects of water management that the Walkerton Inquiry also identified was the issue of the management of water infrastructure assets. Each water utility must have a complete inventory of all the treatment equipment, reservoirs, pumps, pipes, etc. and their ages and when each component should be replaced before there is failure.

The Queensland government of Australia has published an online[4] manual entitled Strategic Asset Management in order to assist its departments in the management of infrastructure assets. It identifies a number of methods for managing infrastructure depending on the application. However, the basic concepts and foundation are consistent throughout the manual.

The objectives of the Australian approach are: structured and accountable corporate planning; establishment of a relationship between service delivery and resource planning; creation of plans for capital, maintenance, and disposal; diffusion of appropriate processes to manage new assets; more effective and innovative service delivery; private sector participation in financing, provision, management, and maintenance of infrastructure; and enhanced coordination of public assets from a “whole-of-government” perspective.

In this approach all infrastructure goes through a 5-stage cycle: “plan, create or acquire, operate and maintain, refurbish or enhance, and dispose” (Queensland

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(Footnote 3 continued)
and control food safety hazards. Detailed information can be found from http://www.iso.org/iso/home.html.

[4] http://www.build.qld.gov.au/sam/sam_web/frames/guidelin.htm.

government of Australia 2002). The plan recognizes the fact that decisions at any one point in the life cycle have cost and output implications at other stages.

The asset management plan identifies the following six principles:

- Assets exist only to support the delivery of services.
- Asset planning is a key corporate activity that must be undertaken along with planning for human resources, information, and finances.
- Nonasset solutions, full life cycle costs, risks, and existing alternatives must be considered before investing in built assets.
- Responsibility for assets should reside with the agencies that control them.
- Strategic Asset Management within agencies must reflect the whole-of-government asset policy framework.
- The full cost of providing, operating, and maintaining assets should be reflected in agency budgets.

Figure 2.3 shows the organization of the plan as a matrix for each stage of the life cycle. It has a 5-step approach to production: Planning, Investment, Operational management, Maintenance, and Disposal of assets.

In meeting service demands, the utility must manage demand, maintain value, and manage risk. Risk management entails identifying risk and methods by which to mitigate the size of the risk.

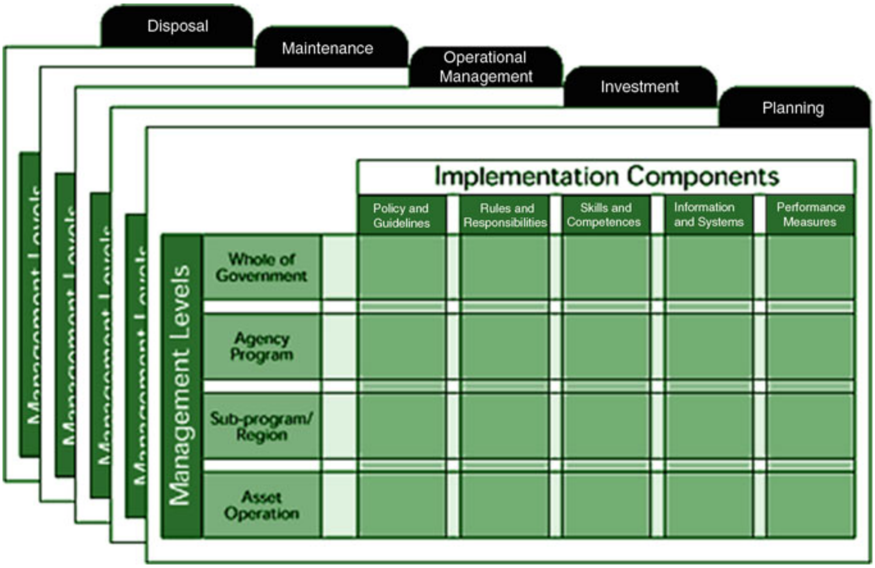

Fig. 2.3 The five matrices of the Australian strategic asset management

Upon implementation of an asset management plan a number of benefits should materialize. There should be a clear understanding of the purpose of the assets. Each asset should link to a specific service delivery objective. The capital should be in place to achieve the objective. Assets should be working properly and used in a way that extracts the highest level of service from them. The plan should lead to appropriate environmental and workplace health. Assets that are unused or not needed should be identified and decommissioned or sold. Information should be available as to the current value of assets at all times. Reserve funds should be utilized in a way that leads to optimum service. There should be an awareness of all opportunities and risks.

Since the objective of the utility is to serve the community, this service must be tracked. The best indicator of the performance of the utility and the asset management plan will be the level of service experienced by the community. Though individual assets and financial performance are important, the output level of service must remain the primary indicator of performance.

2.6 Planned Elimination of Long-Term Risks

In North America, over 90 % of the water systems use chlorine or chlorine derivatives to disinfect their water. In Dore (2015), (Chap. 9) we have outlined the long-term risks associated with the use of chlorine. Chlorine reacts with organic matter to form disinfection by-products (DBPs). Recently epidemiological studies have confirmed associations between human health effects and exposure to chlorinated DBPs. The evidence for carcinogenicity of DBPs is strongest for bladder cancer, while some but not all findings have reported positive associations between colon and rectal cancer and DBP exposure. In addition, some epidemiological studies also reported associations between consumption of chlorinated water and adverse reproductive outcomes, including preterm births and defects in the unborn child. The regulation of DBPs has played an important role for safe drinking water and public health; however, more than 50 % of the toxic halides formed during disinfection have not been defined. In some developed countries, particularly in EU countries, alternative methods of disinfection of drinking water such as Ozone and UV and cartridge filtration are being used to minimize the use of chlorine. But in the USA and Canada, chlorine remains the most widely used method of disinfection of drinking water. Therefore, it seems clear that (1) comprehensive toxicological evaluation of whole DBP mixtures are necessary, and (2) greater emphasis must be placed on continuing to reduce the allowable concentrations of all toxic halides in drinking water. As a long-term policy, it would be sensible to follow the example of the European countries that have completely eliminated the use of chlorine in drinking water.

In the past, the use of chlorine has been shown to have benefitted large populations all over the world. For example, typhoid fever had killed about 25 out of

100,000 people in the U.S. annually, a death rate close to that now associated with automobile accidents. Today, typhoid fever has been virtually eliminated. But the new evidence suggests grave long-term health risks associated with the use of chlorine. Section 2.2 contains a review of drinking water treatment technologies, which clearly shows that there are alternatives for disinfection that are cost effective. Therefore, we can conclude that chlorination of drinking water is now an obsolete technology and it is high time for North America to move away from chlorination and follow the example of the Netherlands, Denmark, and Germany.

2.7 Conclusion

In this chapter we have summarized the key principles of sound water management. These are source water or watershed protection; investment in treatment technologies other than chlorination, such as UV, ozonation, and membrane filtration; incorporation of some risk management protocol at the treatment plant, such as HACCP; systematic records of water infrastructure assets, through an asset management plan; and the planned reduction of long-term risks by moving away from chlorination as the primary disinfection method. In the chapters that follow we shall see which principles are typically violated. For example, in Chap. 3, which is about small water systems, while we will not use all the above principles as a "check list," we shall nevertheless assess some of the shortcomings of such systems.

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Chapter 3
Canadian Small Water Systems: Demand and Treatment Costs

3.1 Introduction

According to the USEPA (2012), 94 % of 156,000 public water systems in the US are small water systems, serving a population of fewer than 3,300 people. In Canada, the proportion of small systems in one survey was over 75 % (Environment Canada 2004). With a smaller tax base, all small water systems face special challenges, unless the government aggressively supports small water treatment systems. In Canada many continue to encounter boil water advisories and even disease outbreaks. With appropriate public funding, many of these problems can be reduced or eliminated. However, typically in North America, each small community or rural jurisdiction must cover the capital and operating costs of its drinking water supply, although some jurisdictions offer a subsidy for capital costs. Often a rural community has a small population, lower average income, and consequently a lower tax base. These financial constraints as well as other risk factors were highlighted at a 2004 conference on small water systems (Ford et al. 2005). These constraints are more severe in developing countries.

It is known that water is used wastefully, especially in small water systems, often because there is no connection between the fee charged for water and the volume of water consumption. Most resource analysts emphasize the need to foster conservation of all resources, including water. Is a price that reflects a volumetric charge an adequate tool to control water use and promote conservation? Are water consumers in small systems "different" from populations in larger cities? To what extent is their water demand sensitive to price? Is their consumer behavior conditioned by their special circumstances?

We can attempt to answer some of these questions by investigating at least two dimensions affecting small systems. One is the level of water consumption: we wish to see how it is affected by various pricing schemes, such as flat rate charges (FLATs), decreasing block rate (DBR) charges, and increasing block rate (IBR) charges. We can also see if metering and the level of income affects water

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consumption. The second dimension is the cost structure of small systems. We can try to find at what flow rate economies of scale begin to reduce costs. In addition, we can attempt to see which treatment train components are used by small systems and consider which tend to reduce costs and which tend to increase costs. The answers to these questions will help small systems to know which treatment train components they should consider in future upgrades and new treatment plants.

Section 3.2 introduces conservation and water demand management in small water systems in Canada. Section 3.3 considers behavioral questions on the sensitivity of water demand to pricing schemes and to metering; this information is relevant in designing a conservation strategy. Section 3.4 investigates the question of economies of scale and where these kick in. Section 3.5 pursues this investigation in greater detail to identify which particular treatment train components contribute to the economies of scale. Section 3.6 draws some conclusions.

3.2 Conservation and Water Demand Management

Figure 3.1 indicates minimum consumption estimates obtained from Health Canada. When we compare that with Fig. 3.2, it is clear that Canadian per capita water consumption is high. Next, consider Table 3.1, which shows alternative water conservation methods offered by Canadian municipalities with different population sizes. In more populated areas, it appears that there is a greater effort in implementing water conservation policies.

Note: According to the WHO (2013), the latest minimum water consumption requirements are 70 L/capita/day.

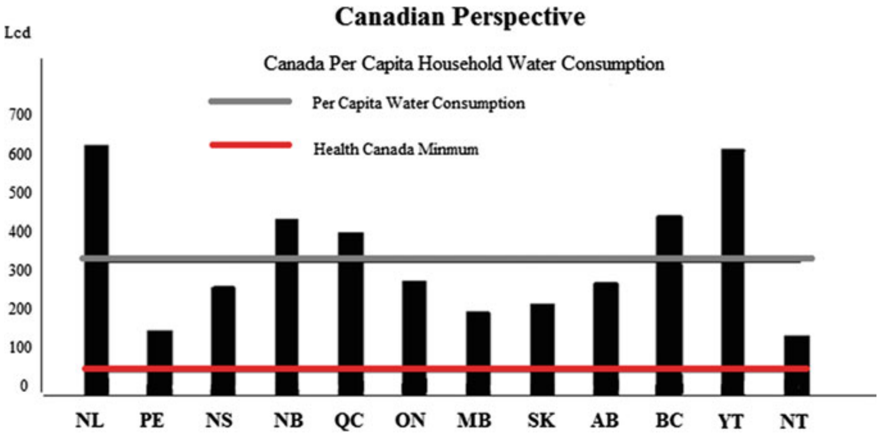


Fig. 3.1 The Canadian perspective and the minimum consumption requirements suggested by health Canada for the Year 2004 (World Conservation Union 2006)

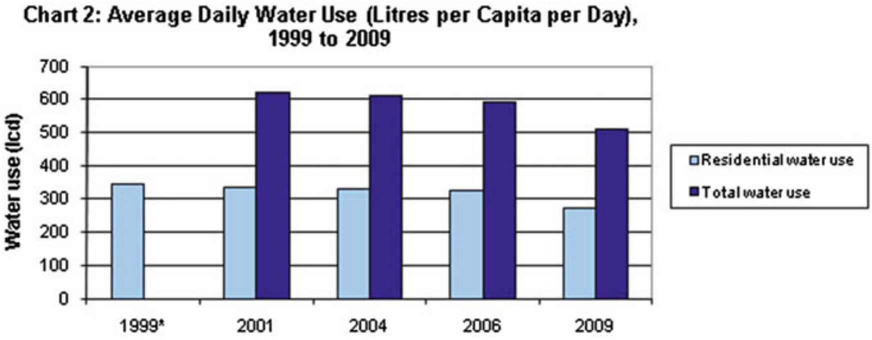


Fig. 3.2 Canada's average daily water use for residential sector (Environment Canada 2011)

The goal of water demand management is to influence household decisions on the amount of water consumed through a conservation strategy, which include pricing schemes and metering. There are four main price schemes that are used by water authorities to recover the cost of supplying water; these are flat rates, constant unit charges (CUCs), DBRs, and IBRs. A flat rate is a fixed fee charged to consumers periodically for the use of water services. Once a flat rate is paid, there is no limit to the amount the consumer can use. In other words, users are unaware of their consumption levels since the rate charged is unrelated to levels of consumption. Flat rates are the simplest structure to impose, and in the past have been the most common, but can clearly lead to wasteful water use.

In contrast to flat rates, a CUC of water is a volumetric charge. CUCs can cause a household bill to fluctuate as it depends on the amount of water consumed. There is also a DBR charge and an IBR charge. Both rate types involve a two-tier charging system. DBRs occur when the unit price for water decreases as the volume consumed increases. Normally, this structure consists of a series of "price blocks," which are set quantities of water sold at a given unit price. The unit price for each block decreases as the price block quantity increases (Western Resource Advocates 2005). DCRs are usually preferred in commercial sectors, but are also used in residential areas. DBRs provide no incentive to conserve and can actually promote wasteful water use.

When IBRs are imposed, the unit price for water increases as the volume increases. Under this scheme, the unit price for each block increases as the block volume increases. Thus, consumers who use low volumes of water will be charged a lower unit price, and consumers who use a larger amount of water will be charged higher unit price (Western Resource Advocates 2005).

When consumers pay a flat rate fee, there is no need for metering. But once a volumetric price is in effect, meters have to be introduced to determine the total volume of consumption. Other policies that can promote conservation are bylaws to restrict lawn watering and home audits, and encouragement to install efficiency-enhancing equipment, such as low-flow showerheads and toilets (Environment Canada 2004). Table 3.1 shows alternative water conservation methods offered by

Table 3.1 Water conservation measures[a] as a percentage of responding municipalities, by municipal population[b] (Values derived from the 2001 Municipal Water Use Data, Environment Canada)

Municipal population	Advising clients (Industrial and Commercial)	Advising residential clients	Installing more water meters	Installing efficiency equipment	Providing home audits	Providing home water efficiency kits	Instituting lawn watering by laws	Other measures
<2,000	7.2	4.1	2.5	1.6	19.8	3.5	21.1	10
2,000–5,000	9.5	9.9	4.5	3.3	34.7	7	28.1	19
5,000–50,000	14.2	12.1	6.6	8.5	46.5	9.4	42	29
50,000–5,00,000	23.9	28.4	13.4	20.9	47.8	17.9	59.7	32.8
>5,00,000	55.6	66.7	11.1	44.4	55.8	55.6	77.8	55.6

[a] Includes existing or planned measures

[b] Industrial/commercial/institutional

Canadian municipalities with different populations. In more populated areas, it appears that there is a greater effort in implementing water conservation policies.

The following section attempts to analyze the effectiveness of water demand management within municipalities of population size 3,000 and below. We attempt to determine if small populations exhibit “different” behavior, and what would be the constituents of an effective conservation strategy for small communities.

3.3 Analysis of Small Municipal Water Consumption: A Panel Data Analysis

3.3.1 Description of the Data

Data used in this study was collected by Environment Canada (Municipal Water Pricing Data and Municipal Water Use Data) and contains observations for the pricing, metering, and consumption of water for the years 2001 and 2004. The data also provides information on the size of the municipality, with respect to population. Statistics Canada provided 2001 and 2004 median household income data through the Canadian Census. Combined, the water survey, water pricing, and income data were used to analyze the response of per capita consumption of water as a result of a change in price, income, and degree of water metering. Furthermore, the price structures, which include flat rates, CUCs, IBRs, and DBRs, were also taken into account in order to determine if they influence per capita consumption of water.

The data made it possible to examine the average price of residential water for 2001 and 2004. While the data reported residential price for 25 m^3 of water, it allowed for calculating the average price for each year. In 2001, the average price of water was \$0.72 and this rate increased in 2004 to \$0.73.

Median household income has increased in small municipalities. In 2001, households were receiving on average \$19,537 a year. Median household income only increased slightly in 2004 to \$24,161. However, it should be noted that Statistics Canada reported Community Profile Household income for years 2000 and 2005; as a result, the observable data for estimation purposes used 2001 data for 2000, and 2005 data for 2004 (Statistics Canada 2013).

Along with price and income, metering was another important variable included in the Municipal Water Pricing database. Even though each year (i.e., 2001 and 2004) contained different sample sizes, the samples were still able to provide useful information on the general use of water meters. In 2001, approximately 54 % of small municipalities used, to some degree, water meters to measure the amount of water being consumed. The use of water meters decreased to 45 % in 2004, possibly due to amalgamation of municipalities.

The Municipal Water Pricing database also provided information on the size of the municipality. By separating the size of municipalities into three groups (i.e., small, medium, and large), it may be possible to distinguish consumption levels of municipalities based on their size. For the purpose of this study, small municipalities have a population between 1 and 2,999 people, medium municipalities have a population between 3,000 and 49,999 people, and large municipalities have a population over 50,000 people. Figures 3.3 and 3.4 show how the municipalities are distributed according to their size groups for 2001 and 2004, respectively. Medium municipalities accounted for 43 % of the municipalities in Canada in 2001 and 44 % in 2004. Large municipalities accounted for 4 % of the municipalities in Canada in 2001 and increased to 5 % in 2004. Finally, small municipalities accounted for 53 % of the municipalities in Canada in 2001, but decreased to 51 % in 2004. The reason for the significant changes in the small and large distributions can be explained by the number of municipal amalgamations that occurred in the late 1990s and early 2000s. As a result, small municipalities merged into medium and larger ones, which forced the number of medium and large municipalities to increase.

The database also made it possible to illustrate the distribution of pricing schemes for small municipalities (see Figs. 3.5 and 3.6). In 2001, 65 % of municipalities had a FLAT, 24 % had a CUC, 9 % implemented a DBR, and 2 %

Fig. 3.3 Distribution of municipalities for 2001

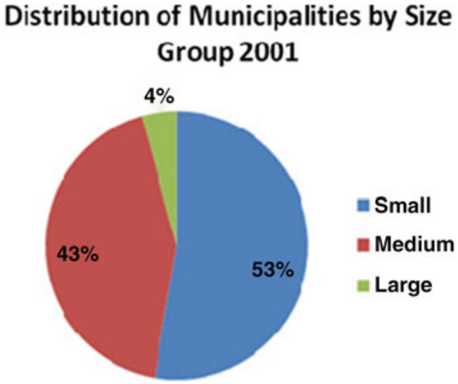


Fig. 3.4 Distribution of municipalities for 2004

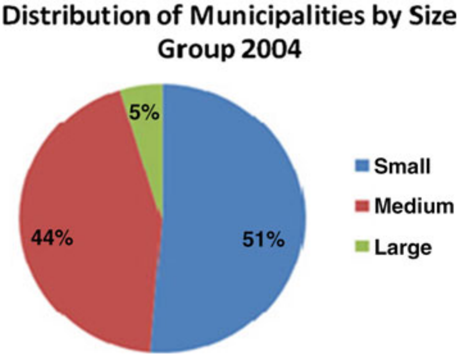


Fig. 3.5 Distribution of price schemes for residential water use 2001

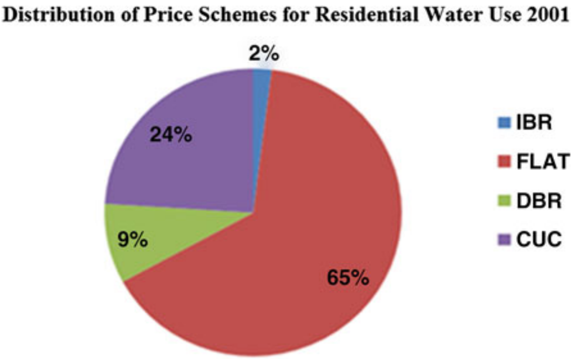
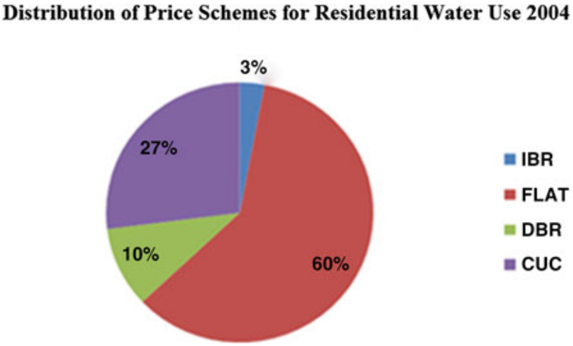


Fig. 3.6 Distribution of price schemes for residential water use 2004



implemented an IBR (see Fig. 3.5). These statistics were observed from a total of 270 usable observations (i.e., municipalities). It is clear that in 2001 flat rates were the most used pricing scheme among the municipalities, and this indicates that water conservation was not a major concern for municipal authorities at that time. Flat rates are easy to apply, but consumers have no incentive to avoid leaks and wasteful consumption.

In 2004, 60 % of municipalities had a FLAT, 27 % had a CUC, 10 % had a DBR, and 3 % had an IBR. There appears to have been a decrease in flat rates being charged to residents, while there has been an increase in CUCs and IBRs (see Fig. 3.6).

Figure 3.6 1 indicates that volumetric pricing, namely CUCs, was replacing the traditional FLATs in 2004 and becoming more common within municipalities. We see also that the mean per capita consumption rate in 2004 was 0.39 m^3/day. Overall, this signals a decline or a decreasing trend in per capita consumption of water between the years 2001 and 2004, which indicates that conservation measures may be affecting small municipalities. Figure 3.7 displays the decreasing trend in per capita consumption in small municipalities for 2001 and 2004. It is difficult at this point to determine what accounted for the changes in distribution of price schemes and per capita consumption; perhaps it was due to a slowly growing concern over municipal budgets.

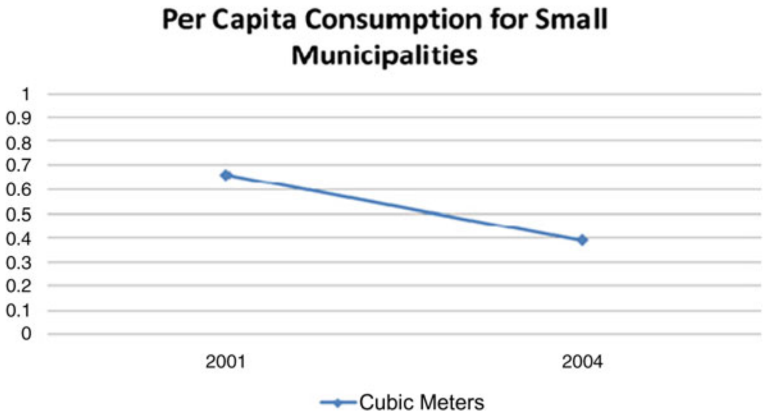


Fig. 3.7 Per capita consumption for 2001 and 2004

The database has observations for 114 municipalities for small water plants in 2001 and 138 municipalities in 2004. Overall, only 111 municipalities were observed in both years. Although the sample size is limited by attrition, the sample is still sufficient to represent the population and perform panel regressions in order to determine the effects of certain factors on per capita consumption of water.[1]

3.3.2 Panel Data Estimation

Using the panel regression framework, we consider two different models, namely the individual effect and the time random effect models Time random effects model, in the analysis of water consumption.

The regression model[2] for the panel data is specified in Eq. 3.1:

$$\log C_{it} = \beta_0 + \beta_1 \log P_{it} + \beta_2 \log I_{it} + \beta_3 M_{it} + \beta_4 \mathrm{CUC}_i + \beta_5 \mathrm{DBR}_i + \beta_6 \mathrm{IBR}_i + u_{it}, \quad (3.1)$$

where log C_{it} is the natural logarithm of the daily consumption (per cubic meter) per capita in the ith municipality in year t ($i = 1, 2, \ldots, 111$; $t = 1, \ldots, 2$). The first year $t = 1$ represents 2001; the second year $t = 2$ represents 2004. The variables log P_{it} and log I_{it} represent the price and income in logarithms (i.e., to estimate elasticities)

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[1] Despite the problem of attrition, the data that was collected for the purpose of this section is a balanced panel. More specifically, the dependent and independent variables are observed for each municipality and each time period (2001 and 2004). This is in contrast to an unbalanced panel, which has some missing data for at least one time period for at least one municipality.

[2] The definition of each variable is listed in Appendix 3.1.

in the *i*th municipality in year *t*, respectively. The variable M represents the percentage of water metering in the *i*th municipality in year *t*. The variables CUC, DBR and IBR are a set of dummy variables with 1 indicating the variety of pricing methods that are used to affect per capita consumption of water, 0 (zero) otherwise. The error terms, u_{it} are zero mean random variables that vary across the municipalities and over time.

3.3.3 Panel Data Estimates

The estimated parameters of the individual and time-fixed effects models are present in Appendix 3.2. Overall, the individual fixed effects model yields a higher R^2 value of 0.66 compared to an estimate of 0.29 for the time-fixed effects model, indicating that the independent variables stated in Eq. 3.1 explain approximately 66 % of the variance in per capita water consumption. This goodness of fit value suggests that the individual fixed effects model is reasonable at explaining the patterns of per capita consumption of water compared to the time-fixed effect model.

The coefficients of the individual and time effects models are relatively similar in their estimated signs. The continuous variables (log *P* and log *M*) are statistically significant at the 5 % level for both models. The coefficient estimate on price for the individual effects model is –0.41 compared to –0.37 for the time effects model. This indicates the price elasticity of water consumption (i.e., the sensitivity measure) is inelastic. That is, if price increases by 1 % then per capita water consumption would decrease by 0.41 % and by 0.37 % for the two regressions, respectively. The low-price elasticity indicates that the demand for water will not be affected by very much, if there is a change in price. Furthermore, the signs on the slope coefficient price are expected since water is considered to be a “necessity.” For the continuous variable M (Metering), the coefficient denotes that if the percentage of water metering increases within a municipality by 1 %, per capita consumption of water would decrease by 0.73 m^3, ceteris paribus. In other words, the use of water meters is an effective structural strategy in reducing the demand for water. The degree to which per capita consumption responds to metering as determined by the individual fixed effects model is fairly consistent with the results presented in the time fixed effects model (i.e., –0.72).

Although income did not appear to be significant in both models, the signs of the coefficients are useful in examining what effect income has on per capita consumption. If income were significant, it would have indicated that per capita consumption of water is responsive to changes in income.

In the individual fixed effects model, the dummy variables (CUC, DBR, and IBR) are not statistically significant, indicating that they do not influence the household’s consumption, i.e., the type of pricing scheme does not affect per capita consumption of water. That is, there are no significant differences in the rate structures compared to FLAT rates. On the other hand, the time fixed effects model only reported significance at the 5 % level on the pricing scheme DBR. It indicates that per capita consumption would increase, which is consistent with the definition of this type of rate. Therefore, if consumers are being charged a DBR, they will consume approximately 30 % more than those being charged with a flat rate.

To summarize the results: The individual fixed effects model indicates price and metering are significant and important factors that, to a certain extent, will lead to the decline of per capita consumption of water. However, volumetric pricing does not reduce the amount of water consumed. This model removes the influence of omitted variables such as water conservation measures, household habits, location, weather, and so on. On the other hand, the time-fixed effects model controls for unobserved variables that vary over time but are held constant over municipalities such as government regulations and water conservation policies.

This result does suggest that small populations below 5,000 are indeed a little "different" from larger populations. The results presented here indicate that while price and metering affect water consumption, the respective elasticities are very small. This suggests that in order to promote conservation and reduce per capita consumption of water, other policies will have to be enacted. A program of consumer education, such as the one used in Victoria, might help raise awareness. Victoria also has a policy of rationing, although Stage I rationing is very liberal—lawn watering is only permitted twice a week from May 1 to September 30 (Stage 2 and Stage 3 rationing are much more restrictive.). Perhaps small systems appear to be different because they are not yet used to volumetric pricing, and more data may be required before we can conclude that neither pricing not metering matters very much, and that utilities may simply be better off dispensing with pricing and metering, save the costs of metering and the additional administration, and simply charge a flat rate fee for water. For some very small communities, it would undoubtedly be the case that the additional costs of metering and administration would be higher than the cost savings of reduced consumption due to metering and volumetric pricing. It should also be noted that in very small communities, the "utility" does more that just treat and supply water—the public servant of the "utility" might also mend road potholes, take care of street lighting, and collect household waste. In such circumstances, it does not make sense to view treated water as a *separable* public service. A fixed charge for water and a charge for other services could be included in the property tax.

We conclude that the consumers of water in small systems are indeed different from those in large municipalities. Water conservation in small communities would require different policies, such as educational outreach programs expressing concern over the environment as a whole, and encouraging households to fix water leakages, and adopt rainwater harvesting for gardening.

The next section considers the "supply side" of small water systems. The key questions are: (1) Do small water systems show evidence of economies of scale, and if so at what point do the economies of scale begin? (2) What is the differential cost contribution of the components of water treatment trains? Answers to these questions would also help in the design of a conservation strategy.

3.4 Analysis of Small[3] Municipal Water Treatment Costs: A Nonparametric and Semiparametric Approach for the Evidence of Economies of Scale

3.4.1 Description of the Data

The cost data was obtained from Water Pricing and Finance Information 2006 (Municipal Water Pricing Data 2006). The costs are presented as percentages of total expenditures for the following categories: Repairs/upgrades, expansion, financing/borrowing costs, bulk water purchases, and others. The database has observations for 686 municipalities for small water plants in 2006. Overall, only 39 municipalities were included in the 2006 survey. Though the usable sample size was limited, it was still sufficient to perform regressions in order to determine and demonstrate economies of scale.

3.4.2 Introduction to Semiparametric Regression

Ogwang et al. (2011) provides a description of the kernel method of semiparametic regression function estimation, to obtain the kernel estimates. These are the Nadaraya-Watson kernel estimates (Nadaraya 1964; Watson 1964).

On the other hand, a semiparametric partially linear model is estimated and is specified as Eq. 3.2:

$$y_i = x_{1i}\beta + f(x_{2i}) + u_i \quad i = 1, 2, \ldots, n, \tag{3.2}$$

where y_i is the ith observation on the dependent variable; x_{1i} is the $1 \times k$ vector of the ith observation of each of the k independent variables that are incorporated in the parametric/linear part of the model; β is the $k \times 1$ vector of coefficients; x_{2i} is the $1 \times r$ vector of the ith observation of each of the r independent variables that appear in the nonparametric part of the model; and u_i is the error term such that its mean, conditional upon the independent variables, is zero. The exact functional form of $f(\cdot)$ is not specified in the nonparametric part of a semiparametric regression.

The parametric, linear model corresponding to Eq. 3.2 is $y_i = x_{1i}\beta_1 + x_{2i}\beta_2 + u_i$ and the pure nonparametric model corresponding to the same equation is $y_i = f(x_{1i}, x_{2i}) + u_i$ where the exact functional form of $f(\cdot)$ is not specified; the best functional form is determined by the kernel method.

Following Robinson (1988), Eq. 3.1 can be rewritten as Eq. 3.3

$$y_i - E(y_i/x_{2i}) = [x_{1i} - E(x_{1i}/x_{2i})]\beta + u_i, \tag{3.3}$$

where, $E(y/x)$ denotes the conditional mean of y given x.

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[3] In this study, small municipalities refer to a population between 1 and 4,999 people.

Robinson shows how Eq. 3.3 could be exploited to obtain consistent estimates of β using a "double residual" approach in two steps. In the first step, obtain the estimates of the relevant conditional means (i.e., $\hat{E}(y_i/x_{2i})$ and $\hat{E}(x_{1i}/x_{2i})$) using the kernel method of nonparametric regression estimation.[4] In the second step, obtain $\hat{\beta}$, the estimator of β in Eq. 3.4, by applying OLS (with the intercept suppressed) to the model

$$y_i - \hat{E}(y_i/x_{2i}) = [x_{1i} - \hat{E}(x_{1i}/x_{2i})]\beta + u_i \tag{3.4}$$

Note that $y_i - \hat{E}(y_i/x_{2i})$ on the left-hand side of Eq. 3.4 is the residual of the kernel nonparametric regression of y_i on x_{2i}. Likewise, $x_{1i} - \hat{E}(x_{1i}/x_{2i})$ on the right-hand side of the same equation is the residual of the kernel nonparametric regression of x_{1i} on x_{2i}. It follows from Eq. 3.5 that the predicted value of y is given by

$$\hat{y}_i = \hat{E}(y_i/x_{2i}) + [x_{1i} - \hat{E}(x_{1i}/x_{2i})]\hat{\beta} \tag{3.5}$$

3.4.3 Semiparametric Estimation

The regression model[5] for the semiparametric analysis is specified in Eq. 3.6:

$$\begin{aligned}\text{Log}(\text{costs}_i) = {} & \beta_1\text{MS}_i + \beta_2\text{FLOC}_i + \beta_3\text{SED}_i + \beta_4\text{SSF}_i + \beta_5\text{PH}_i + \beta_6\text{CC}_i \\ & + \beta_7\text{FL}_i + \beta_8\text{MF}_i + \beta_9\text{GF}_i + f(\log(\text{flow}_i)) + u_i\end{aligned} \tag{3.6}$$

The variable log(costs) is the natural logarithm of the treatment costs per cubic meter. $f(\cdot)$ is an unspecified function of the variables included on the right-hand side and u the error term. With respect to the right-hand side variables, log(flow), the logarithm of the water flow in cubic meters, is a continuous variable which measures quantity; microstraining (MS), flocculation (FLOC), sedimentation (SED), slow sand filtration (SSF), the level of pH control (PH), corrosion control (CC), fluoridation (FL), membrane filtration (MF), and granular filtration (GF) are a set of dummy variables with 1 indicating the water treatment component that is used to influence the costs per cubic meter, 0 (zero) otherwise. The variables on the right-hand side of Eq. 3.6 are either continuous variables (log(flow)) or dummy variables (MS, FLOC, SED, SSF, PH, CC, FL, MF, GF). In the semiparametric case, we adopt Robinson's (1988) partially linear specification using some combination of

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[4] In this study, the kernel estimation of nonparametric regressions was conducted using the Nadaraya-Watson (1964) approach.

[5] The definition of each variable is listed in Appendix 3.3.

log(flow), as the nonparametric component in Eq. 3.6 and all the dummy variables as the linear component. The “double residual” approach, as previously explained, is then used to obtain consistent estimates of the parameters of the parametric component.

3.4.4 Semiparametric Estimates

The results of the different models estimated are presented in Appendix 3.4. Overall, the semiparametric model yields a superior fit to its parametric counterpart. The R^2 is equal to 0.862, indicating that 86.2 % variations in the independent variables explain the variations in the dependant variable, and 13.8 % are explained by other factors. This goodness-of-fit value suggests that the model is a good fit at explaining the patterns of treatment costs per cubic meter in small municipalities.

The coefficients of the linear component of the semiparametric models are relatively similar in estimated signs to those of their parametric counterparts. The OLS double-log model suffers with nonconstant variances in the error term; in that case, the estimates are no longer best linear unbiased estimates (BLUE). However, it is still useful information to compare the slope coefficients to those with the semiparametric model. The coefficient of the quantity variable (i.e., the natural logarithm of the flow in cubic meters) is negative and significant for the parametric model in Appendix 3.4; suggesting that when greater quantities are supplied by the water plant, the costs are lowered. The parametric model yields sensitivity estimates with respect to supply of water flow in the municipality of –0.93, indicating that 1 % increase in the available flow results in approximately 0.93 % decrease in water treatment costs. This is a measure of the economies of scale in small systems.

3.4.5 Nonparametric Estimates

In order to perform the Nadaraya–Watson kernel method of nonparametric estimation, a nonparametric regression model was set up. In this particular case, the logarithm of costs (i.e., log(costs)) is the dependent variable and the logarithm of flow (i.e., log(flow)) is the independent variable. Equation 3.7 is the nonparametric model used to determine the general relation between these two variables.

$$\log(\mathrm{costs}_i) = f(\log(\mathrm{flow}_i)) + u_i \tag{3.7}$$

The regression function $f(\log(\mathrm{flow}_i))$ is not specified for nonparametric models, which assumes that the relationship between costs per cubic meter and flow in cubic

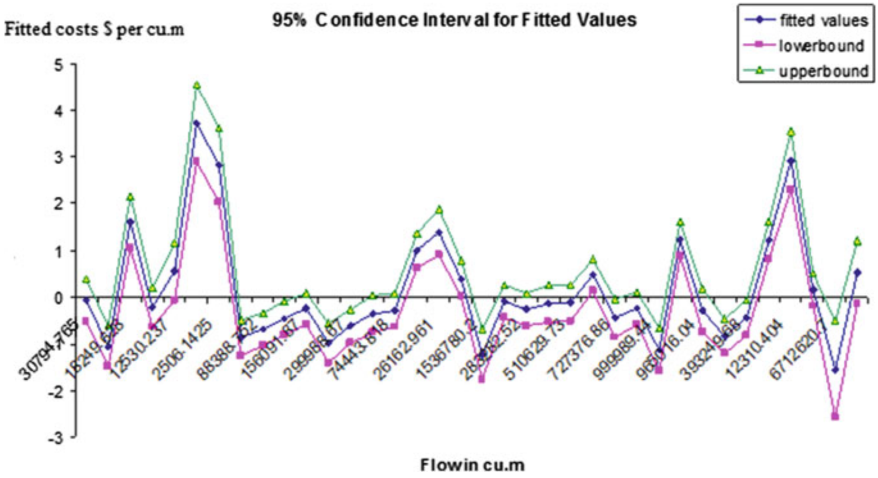

Fig. 3.8 Confidence Interval for fitted values generated by the nonparametric regression

meter is unknown. However, the Nadaraya–Watson nonparametric method calculates the predicted values of the logarithm of costs per cubic meter in logarithms, with respect to different levels of flow.[6]

The confidence interval indicates that 95 % of the time treatment costs per cubic meter for each municipality will be in between the upper and lower limits as illustrated in Fig. 3.8. While most municipalities face a narrow confidence interval, there are very few municipalities that appear to have a wide confidence interval. Wide confidence intervals imply poor results. On the other hand, our results illustrate that the confidence intervals are predicting *statistically* significant results in treatment costs.

Figure 3.9 illustrates the relationship between predicted values of costs per cubic meter and flow in cubic meters. We can conclude that the functional form of the regression model based on Eq. 3.7 is in fact nonlinear. In addition, economies of scale are present; this graph reinforces the conclusion that as the flow rate increases, the unit treatment costs per cubic meter decrease, indicating economies of scale. For the sake of clarity, Fig. 3.10 magnifies the presence of economies of scale for costs of $\$1.8/\text{m}^3$ and below.

Figure 3.11 is a plot of the absolute cost elasticities against the various levels of the flow in cubic meters (or logarithm of flow), indicating in general if water flows were to increase by 1 %, per cubic meter drinking water treatment costs will decrease depending on the initial level of flow. It is important to note that at very low-flow levels there are *diseconomies* of scale, that is, the cost elasticities *rise* until the annual quantity of water flow is up to roughly 1,800 m^3 (or the logarithm of flow is approximately 7.50 m^3). Once the flow exceeds this "threshold point," there

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[6] The estimated results for nonparametric model are summarized in Appendix 3.4.

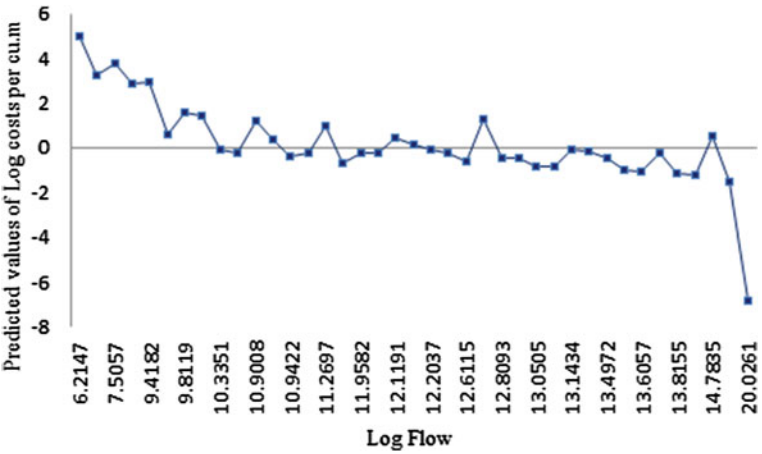

Fig. 3.9 Predicted values of Log treatment costs per cubic meter against Log flow in cubic meter

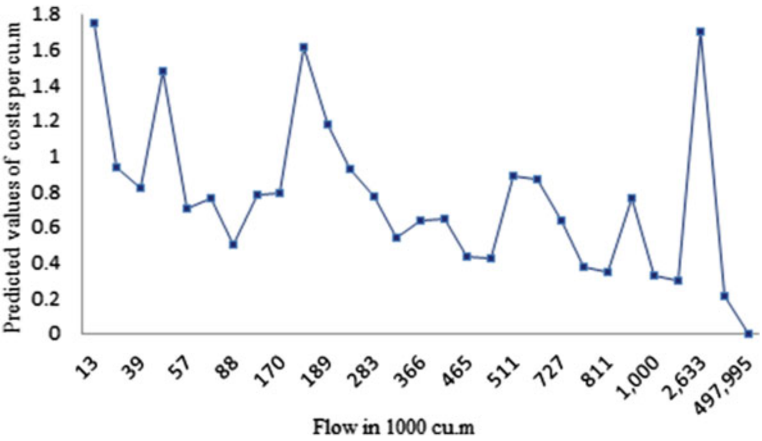

Fig. 3.10 Predicted values of treatment costs per cubic meter (<$1.8) against flow in thousand cubic meters

are *strong and variable* economies of scale. Yet, the parametric estimation hides this interesting feature associated with the drinking water treatment costs.

3.4.6 Summary of the Section

In this section, treatment costs of drinking water in Canadian municipalities with small water systems were examined; both parametric and semiparametric models were constructed to capture the relationship between cost and scale in water

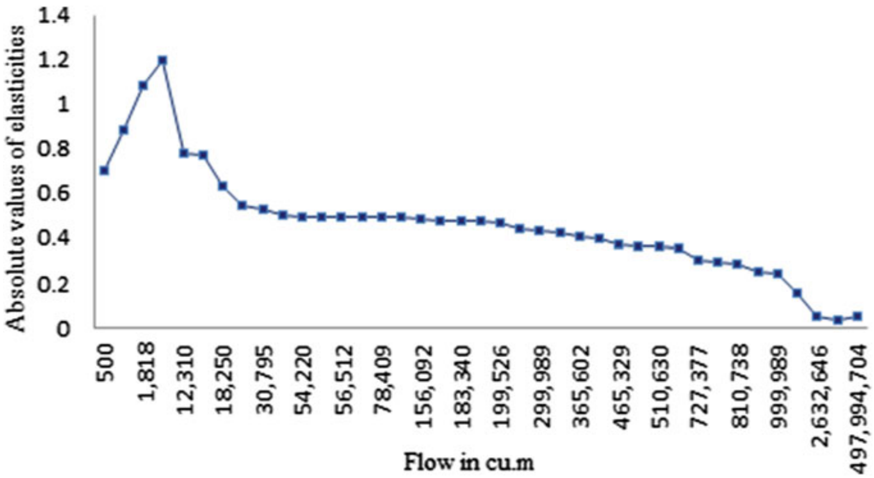

Fig. 3.11 Cost elasticities against flows in cubic meter per day

treatment. Overall, the regressions were based on the approach referred to as the Nadaraya–Watson kernel method. It was discovered that when the functional form is not specified, the regression was nonlinear. Also, the results demonstrated the presence of economies of scale in municipalities with small water plants, but the economies of scale do not begin at the lowest scale. In fact, there are *diseconomies* of scale until the “threshold point”. After that, there are strong economies of scale.

3.5 Estimating the Differential Costs of Treatment Train Components: A Semiparametric Approach with Clustered Data

Data used in this chapter were collected by Environment Canada (Municipal Water Use Data from Municipal Water and Wastewater Survey (MWWS)). The 2006 MWWS collected data on municipal water distribution system, sewer systems, wastewater treatment plants, and drinking water treatments such as MF, FL, SED pH control, etc., that serve at least 100 residents or 50 total connections for the 2006 calendar year. The survey was distributed to municipalities with populations greater than 1,000, and to a select sample of those under 1,000, omitting those on Federal Lands, including First Nations.

The database made it possible to illustrate the distribution of water treatments for small municipalities. In 2006, the most common treatments were: 24 % of municipalities used GF, 22 % used FLOC, and 14 % implemented pH control. It must be noted that these statistics were observed from a total of 305 usable

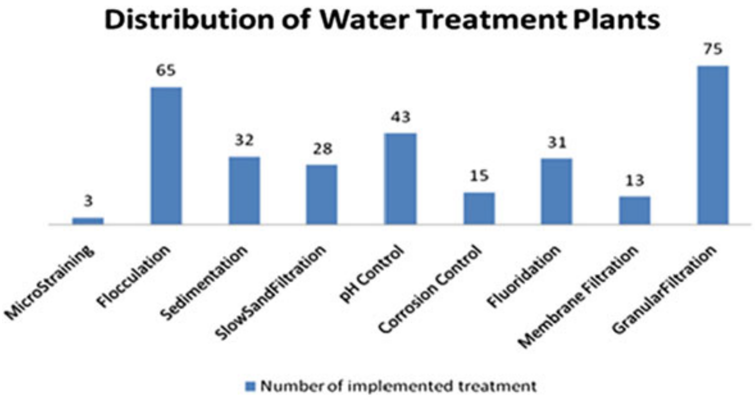

Fig. 3.12 Distribution of water treatment components in plants for 2006

observations (i.e., municipalities). Figure 3.12 shows the distribution of water treatment components in small municipalities; some may use multiple components.

In this section, we extend our econometric research to consider the impact of costs due to various components of the treatment train. We focus on MS, FLOC, SED, SSF, pH control CC, MF, and GF. We investigate whether each component decreases unit costs or increases them, for a range of population sizes. This is carried out using cluster analysis.[7] The results indicate the presence of economies of scale associated with some of the components, where we find decreases in costs (and in some cases increases in costs) in the small water treatment plants for the population range of 1–4,999. The regression models for the clustered semiparametric analysis are specified in Eqs. 3.8–3.12:

$$\begin{aligned}\text{costs}_i =& \beta_1\text{SMALL}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i + \beta_6\text{PH}_i \\ &+ \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + f(\text{flow}_i) + u_i\end{aligned} \tag{3.8}$$

$$\begin{aligned}\text{costs}_i =& \beta_1\text{SMALL2}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i + \beta_6\text{PH}_i \\ &+ \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + f(\text{flow}_i) + u_i\end{aligned} \tag{3.9}$$

$$\begin{aligned}\text{costs}_i =& \beta_1\text{MEDIUM}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i + \beta_6\text{PH}_i \\ &+ \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + f(\text{flow}_i) + u_i\end{aligned} \tag{3.10}$$

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[7] The definition of each variable is listed in Appendix 3.6.

$$\begin{aligned}\text{costs}_i = {} & \beta_1\text{MEDIUM2}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i \\ & + \beta_6\text{PH}_i + \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + f(\text{flow}_i) + u_i \end{aligned} \tag{3.11}$$

$$\begin{aligned}\text{costs}_i = {} & \beta_1\text{LARGE2}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i + \beta_6\text{PH}_i \\ & + \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + f(\text{flow}_i) + u_i \end{aligned} \tag{3.12}$$

The variable (costs) is defined as the treatment costs per cubic meter for Eqs. 3.8–3.12. $f(\cdot)$ is an unspecified function of the variables included on the right-hand side and u the error term. With respect to the right-hand side variables, the variables on the coefficient β_1 indicate population clusters. The variable flow, indicates water flow in cubic meters; it is a continuous variable which measures quantity; MS, FLOC, SED (SED), SSF, control of the pH level (PH), CC, FL, MF, and GF (GF) are a set of dummy variables with 1 indicating the components of the water treatment train that are used to influence the costs per cubic meter, 0 (zero) otherwise. Once again, the "double residual" approach, as previously explained, is then used to obtain consistent estimates of the parameters of the parametric component.

From the estimated results, in all five semiparametric models, the treatment components FLOC, SSF, MF, and GF were highly significant.[8] Specifically, the treatment components: FLOC, CC and MF were significant at the 5 % level while GF was only significant at the 10 % level.

We summarize the estimated coefficients of the water treatment components from the semiparametric models that are statistically significant in Table 3.2, which indicates what types of treatment components trigger costs to rise or decline. We find that, *ceteris paribus*, the component FLOC would lower drinking water treatment costs by approximately \$0.99 m^3 over the population ranges 1–1,999, while the other drinking water treatment components such as MF, SSF and GF would raise costs by approximately \$0.72, \$0.99 and \$1.00 m^3, respectively, for the population size of 0–1,999. The next population size (2,000–5,999) shows a larger decrease in cost in FLOC of \$1.11 m^3, and the other components increase costs, with GF having the highest marginal increase in costs of \$1.14 (see Table 3.2).

According to the estimated results[9] from the parametric models which take the following specifications:

$$\begin{aligned}\text{costs}_i = {} & \beta_0 + \beta_1\text{SMALL}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i \\ & + \beta_6\text{PH}_i + \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + u_i \end{aligned} \tag{3.13}$$

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[8] The estimated results from semiparametric models are summarized in Appendix 3.7.

[9] The estimated results from parametric models are summarized in Appendix 3.8.

Table 3.2 Summary table of the estimated treatment costs ($) in terms of treatment components

Population size	0–1,999	2,000–5,999	6,000–15,999	16,000–49,999	50,000+	Sum of treatment costs ($)
Flocculation ($)	–0.9929	–1.1136	–1.053	–1.044	–1.0594	–5.2629
Membrane Filtration ($)	0.7279	0.6765	0.7038	0.7002	0.6995	3.5079
Slow sand Filtration ($)	0.9966	1.0648	0.986	1.0037	0.988	5.0391
Granular Filtration ($)	1.005	1.1471	1.1064	1.111	1.1211	5.4906

$$\begin{aligned}\text{costs}_i = {} & \beta_0 + \beta_1\text{SMALL2}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i \\ & + \beta_6\text{PH}_i + \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + u_i\end{aligned} \tag{3.14}$$

$$\begin{aligned}\text{costs}_i = {} & \beta_0 + \beta_1\text{MEDIUM}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i \\ & + \beta_6\text{PH}_i + \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + u_i\end{aligned} \tag{3.15}$$

$$\begin{aligned}\text{costs}_i = {} & \beta_0 + \beta_1\text{MEDIUM2}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i \\ & + \beta_6\text{PH}_i + \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + u_i\end{aligned} \tag{3.16}$$

$$\begin{aligned}\text{costs}_i = {} & \beta_0 + \beta_1\text{LARGE}_i + \beta_2\text{MS}_i + \beta_3\text{FLOC}_i + \beta_4\text{SED}_i + \beta_5\text{SSF}_i \\ & + \beta_6\text{PH}_i + \beta_7\text{CC}_i + \beta_8\text{FL}_i + \beta_9\text{MF}_i + \beta_{10}\text{GF}_i + u_i\end{aligned} \tag{3.17}$$

Only FLOC and GF were significant in all five parametric models; MF was merely significant for Eq. 3.13. Hence, the clustered semiparametric models yield a superior fit and are better models than their parametric counterpart. Moreover, the coefficients of the treatment components of the parametric models are similar in estimated signs to those of their semiparametric counterparts. In particular, it was estimated that, *ceteris paribus*, FLOC as a treatment component would lower drinking water treatment costs by approximately \$4.44 m^3 for the full population range under consideration, while GF would raise costs by approximately \$5.18 m^3. We can conclude that there are significant economies of scale associated with MS and FLOC. On the other hand for small treatment plants, we find that SSF, CC, MF, and GF would raise costs of water treatment.

3.6 Conclusions

In this chapter on small water systems, we provide three kinds of empirical information: (a) Demand elasticities for pricing schemes (flat rate, increasing and DBRs), (b) the optimal scale of water production and where economies of scale become evident even in small systems, and (c) how treatment costs change with *different treatment train components*. We can come to some important conclusions, as listed below:

1. We found that for the small systems as a whole demand was price inelastic, confirming our view that water is a necessity and not a normal or "luxury" good. The individual fixed effects model and the time-fixed effects model showed that price and metering are both statistically significant, but the elasticities were very small. This indicates that raising prices alone is unlikely to affect water consumption by very much.
2. Perhaps, small systems appear to be different because they are not yet used to volumetric pricing. More data may be required before we can conclude that neither pricing nor metering matters very much, and utilities may simply be better off dispensing with pricing and metering, saving the costs of metering and the additional administration, and charging a flat rate fee for water. For some very small communities, it would undoubtedly be the case that the additional costs of metering and administration would be higher than the cost savings due to reduced consumption, attributable to pricing and metering. It should also be noted that in very small communities, the "utility" (usually one person) does more that just treat and supply water—the public servant of the "utility" might also mend road potholes, take care of street lighting, and collect household waste. In such circumstances, it does not make sense to view treated water as a *separable* public service. A fixed charge for water and a charge for other services could be included in the property tax.
3. In 2006, the most common treatment components were as follows: Some 24 % of municipalities used GF, 22 % used FLOC and 14 % implemented pH control.
4. The database has observations for 686 municipalities for small water plants in 2006. Overall, only 39 municipalities were included in the 2006 survey. Though the usable sample size may be limited, it is still adequate and sufficient to perform statistical analysis in order to determine and demonstrate economies of scale.
5. Overall, the semiparametric model yields a superior fit to its parametric counterpart. Its R^2 is 0.862. However, the coefficients of the linear component of the semiparametric models are relatively similar in estimated signs to those of their parametric counterparts.
6. While the semiparametric model is superior to the parametric model, the results from both models are consistent and agree on which treatment train component reduces costs and which increases costs. We were able to disaggregate the impacts of economies of scale into five population sizes: (a) 0–1,999; (b) 2,000–5,999; (c) 6,000–15,999; (d) 16,000–49,999; and (e) more than 50,000.
7. Using cluster analysis, we were able to demonstrate the presence of economies of scale even at the level of treatment components in small water plants. The greatest marginal decreases in costs due to economies of scale occur in the population range 2,000–5,999.

8. Components that *reduce costs* are: MS, FLOC, SED, pH control, and FL.
9. Components that *increase costs* are: SSF, CC, MF, and GF.

Wasteful consumption would place stress on the Canadian water and water supply infrastructure if it were to continue to grow. Canadian water consumption is high by international standards and there is a case for introducing a strategy of water conservation. Pricing of water and metering are important components of such a strategy, but by themselves they are not enough. The elasticities of price and metering are low, not only because water in Canada is "cheap," but also because the total household expenditure on water is a very small component of total consumption expenditure. Thus raising the price of water by itself is unlikely to lead to greater conservation; what is needed is first a large community outreach program to educate households on the need to conserve water. The Regional Municipality of Victoria does this, and has managed to reduce per capita water consumption to 300 L/person/day (Program on Water Governance 2013). Other methods include the free distribution of low-flow showerheads, low-flow toilets, and rain barrels to collect water for outdoor use in the summer. A rationing program of the sort introduced by the Regional Municipality of Victoria might be worth considering, although it is likely to be unpopular at first.

Appendix 3.1 Definitions of Variables for Eq. 3.1, Panel Data Analysis

Variable	Definition
C	Per capita consumption in cubic meters per day of the *i*th municipality
Log (C)	Logarithm of consumption
P	Average price for 1 m^3 of the *i*th municipality. Values based on an average consumption of 25 m^3/month
Log (P)	Logarithm of price
I	Median household income of the *i*th municipality
Log (I)	Logarithm of median household income
M	Degree of domestic water metering, as a fractional percentage of the population served of the *i*th municipality
CUC (1 = CUC; 0 = otherwise)	Dummy variable that takes the value 1 if the municipality implements CUC, FLAT rate is reference dummy
DBR (1 = DBR; 0 = otherwise)	Dummy variable that takes the value 1 if the municipality implements DBR, FLAT rate is reference dummy
CUC (1 = IBR; 0 = otherwise)	Dummy variable that takes the value 1 if the municipality implements IBR, FLAT rate is reference dummy

Appendix 3.2 Estimated Parameters of the Individual and Time-Fixed Effects Models When Log Costs is the Dependent Variable (n = 111)

Independent variable	Individual fixed effects	Time-fixed effects
Constant	–0.525 (1.819)	–1.172 (1.52)
log (P)	–0.411 (0.113)***	–0.377 (0.063)***
log (I)	0.152 (0.187)	0.198 (0.152)
M	–0.732 (0.222)***	–0.722 (0.185)***
CUC	0.023 (0.197)	0.118 (0.136)
DBR	0.299 (0.218)	0.337 (0.151)**
IBR	–0.149 (0.287)	0.089 (0.214)
R^2	0.685	0.285
P-value (F)	0.0019**	4.32e-13**

Note The standard errors are reported in parenthesis; */**/*** indicates significance at the 5/10/1 % level; *P*-value (F) pertains to overall significance of the regression

Appendix 3.3 Definitions of Variables for Eq. 3.6, Semiparametric Analysis

Variable	Definition
Costs	Annual water treatment costs in $ per cubic meter
Log (Costs)	Logarithm of costs
Flow	Annual quantity of water flow in cubic meter
Log (Flow)	Logarithm of flow
MS (1 = MS; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was microstraining
FLOC (1 = FLOC; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was flocculation
SED (1 = SED; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was sedimentation
SSF (1 = SSF; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was slow sand filtration
PH (1 = PH; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was pH control
CC (1 = CC; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was corrosion control
FL (1 = FL; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was Fluoridation
MF (1 = MF; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was membrane filtration
GF (1 = CC; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was granular filtration

Appendix 3.4 Estimated Parameters of the Parametric and Semiparametric Models When Log Costs is the Dependent Variable (n = 39)

Independent variable	OLS robust standard errors	Semiparametric
Constant	11.230 (1.296)***	n/a
log(flow)	–0.932 (0.11)***	n/a
MS	0.235 (0.345)	–0.245 (1.126)
FLOC	1.369 (0.469)***	1.555 (0.562)*
SED	–0.427 (0.393)	–0.490 (0.514)
SSF	–0.776 (0.595)	–0.750 (0.655)
PH	–0.421 (0.445)	0.54E-01 (0.447)
CC	2.221 (1.601)	2.619 (0.912)*
FL	–0.098 (0.827)	–0.267 (0.557)
MF	0.560 (0.8)	1.312 (0.658)*
GF	–0.515 (0.498)	–0.791 (0.47)**
R^2	0.809	0.862
F	21.35*	n/a
B-Pagan	15.447	n/a
White	15.322	n/a
RESET (2)	0.016	n/a
RESET (3)	6.47*	n/a

n/a indicates not applicable

Note The standard errors are reported in parenthesis; */**/*** indicates significance at the 5/10/1 level; F pertains to overall significance of the regression; B-Pagan is the Breusch-Pagan test for heteroscedasticity; Heteroscedasticity White is White's test for heteroscedasticity; RESET is the RESET test for model specification; and R^2 for the Semiparametric model is the square of the correlation coefficient between the actual value of the dependent variable and its predicted value

Appendix 3.5 Summary Statistics of the Predicted Values of Water Treatment Costs per Cubic Meter for Small Municipalities (Population <5,000) using Nonparametric Model

Municipality	Population	Actual costs per cubic meter	Predicted costs per cubic meter	Flow (cubic meter)	Elasticity
Stonewall	4,376	834.3892	143.8973	500	–0.7039
Argyle	1,073	57.639	26.0521	1,091	–0.8866
Norman's Cove-Long Cove	773	30.1836	42.1443	1,818	–1.0823

(continued)

(continued)

Municipality	Population	Actual costs per cubic meter	Predicted costs per cubic meter	Flow (cubic meter)	Elasticity
Semans	195	23.7694	16.9353	2,506	–1.198
Beaverlodge	2,264	62.5584	18.7239	12,310	–0.7819
Minburn County No. 27	3,319	3.9968	1.7444	12,530	–0.774
Northern Lights No. 22	3,772	2.0493	5.0168	18,250	–0.6332
Harrison	812	4.9175	4.0346	26,163	–0.5494
Drake	232	0.5761	0.9373	30,795	–0.5259
Vanguard	152	1.2441	0.8173	39,242	–0.5042
Claresholm	3,700	10.5708	3.3515	54,220	–0.4928
St. Louis	431	2.5279	1.4817	55,265	–0.4925
Victoria	1,149	2.0383	0.6994	56,512	–0.4923
Saint-Wenceslas	1,101	1.5672	0.7592	74,444	–0.4919
Standard	380	1.5252	2.7205	78,409	–0.4921
Rockglen	366	0.855	0.5056	88,389	–0.4925
Memramcook	4,638	0.5523	0.7848	156,092	–0.4836
Falher	941	2.1749	0.7906	170,008	–0.4797
Castor	931	1.7594	1.6122	183,340	–0.4757
Macklin	1,290	6.3617	1.1774	188,773	–0.4739
Eastend	471	0.9999	0.9273	199,526	–0.4703
Red Rock	1,063	0.989	0.7695	283,283	–0.4399
Coalhurst	1,523	0.3487	0.541	299,989	–0.4337
Carman	2,880	1.191	3.4837	337,021	–0.4201
Powerview-Pine Falls	1,294	0.2287	0.6383	365,602	–0.4098
Casselman	3,294	1.302	0.6502	393,250	–0.4001
Sundre	2,518	1.0804	0.4336	465,329	–0.376
Ville-Marie	2,696	0.1518	0.4222	493,955	–0.3669
Warfield	1,729	0.5751	0.8924	510,630	–0.3617
Black Diamond	1,900	0.5224	0.8677	545,523	–0.3511
Saint-Quentin	2,250	0.5038	0.641	727,377	–0.302
Burgeo	1,607	0.1298	0.3733	775,684	–0.2903
Bienfait	748	0.0297	0.3484	810,738	–0.2822
Enderby	2,828	0.4223	0.7596	965,016	–0.2493
Lake Cowichan	2,948	0.3913	0.3262	999,989	–0.2424
Elkford	2,463	0.1218	0.2938	1,536,780	–0.1568
Killaloe, Hagarty and Richards	2,550	3.9503	1.6979	2,632,646	–0.0529
Brackley	336	0.2788	0.2118	6,712,621	0.0338
Souris	1,772	0.0011	0.0011	497,994,704	–0.05

Appendix 3.6 Definitions of Variables for Eqs. 3.8–3.17, Semiparametric Analysis of Clustered Data and Parametric Analysis

Variable	Definition
Costs	Annual water treatment costs in $ per cubic meter
Flow	Annual quantity of water flow in cubic meter
MS (1 = MS; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was Microstraining
FLOC (1 = FLOC; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was flocculation
SED (1 = SED; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was sedimentation
SSF (1 = SSF; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was slow sand filtration
PH (1 = PH; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was pH control
CC (1 = CC; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was corrosion control
FL (1 = FL; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was fluoridation
MF (1 = MF; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was membrane filtration
GF (1 = CC; 0 = otherwise)	Dummy variable that takes the value 1 if the treatment implemented was granular filtration
SMALL (1 = SMALL; 0 = otherwise)	Dummy variable that takes the value 1 for population size 0–1,999
SMALL2 (1 = SMALL2; 0 = otherwise)	Dummy variable that takes the value 1 for population size 2,000–5,999
MEDIUM (1 = MEDIUM; 0 = otherwise)	Dummy variable that takes the value 1 for population size 6,000–15,999
MEDIUM2 (1 = MEDIUM2; 0 = otherwise)	Dummy variable that takes the value 1 for population size 16,000–49,999
LARGE (1 = LARGE; 0 = otherwise)	Dummy variable that takes the value 1 for population size 5,00,000+

Appendix 3.7 Summary Statistics of the Estimated Coefficients of the Treatment Components $ per Cubic Meter from Semiparametric Models (*n* = 102)

Treatments \population	§0–1,999 *n* = 22	2,000–5,999 *n* = 19	6,000–15,999 *n* = 19	16,000–49,999 *n* = 22	50,000 + *n* = 20
Constant	N/a	N/a	N/a	N/a	N/a
Microstraining	–0.0759	–0.0847	–0.2008	–0.1981	–0.1882
	–0.861	–0.849	–0.646	–0.65	–0.667
Flocculation	–0.9929	–1.1136	–1.053	–1.044	–1.0594
	(0.002)***	(0.001)***	(0.001)***	(0.002)***	(0.001)***
Sedimentation	–0.1748	–0.1588	–0.1863	–0.1865	–0.1837
	–0.49	–0.535	–0.469	–0.468	–0.474
Slow sand filtration	0.9966	1.0648	0.986	1.0037	0.988
	(0.003)***	(0.002)***	(0.005)***	(0.004)***	(0.004)***
pH control	–0.0577	–0.0204	–0.0167	–0.0315	–0.0138
	–0.799	–0.929	–0.942	–0.893	–0.952
Corrosion control	0.3663	0.2511	0.2502	0.2446	0.2615
	–0.248	–0.419	–0.425	–0.434	–0.421
Fluoridation	–0.1631	–0.1698	–0.1288	–0.1369	0.1358
	–0.497	–0.486	–0.598	–0.573	–0.576
Membrane filtration	0.7279	0.6765	0.7038	0.7002	0.6995
	(0.017)**	(0.027)**	(0.023)**	(0.023)**	(0.023)**
Granular filtration	1.005	1.1471	1.1064	1.111	1.1211
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
R^2	0.35	0.34	0.33	0.33	0.33
F	N/a	N/a	N/a	N/a	N/a
B-Bagan	N/a	N/a	N/a	N/a	N/a
White	N/a	N/a	N/a	N/a	N/a
RESET (2)	N/a	N/a	N/a	N/a	N/a
RESET (3)	N/a	N/a	N/a	N/a	N/a

Note The *p*-values are reported in parenthesis; */**/*** indicates significance at the 10/5/1 % level

Appendix 3.8 Summary Statistics of the Estimated Coefficients of the Treatment Components $ per Cubic Meter from Parametric Models (n = 102)

Treatments \population	0–1,999 n = 22	2,000–5,999 n = 19	6,000–15,999 n = 19	16,000–49,999 n = 22	50,000 + n = 20
Constant	0.8522 (0.000)***	0.9302 (0.000)***	0.9155 (0.000)***	0.9233 (0.000)***	0.9585 (0.000)***
Microstraining	–0.2104 (0.409)	–0.3103 (0.275)	–0.3186 (0.264)	–0.3237 (0.249)	–0.2620 (0.364)
Flocculation	–0.8342 (0.033)**	–0.9098 (0.023)**	–0.9054 (0.023)**	–0.9020 (0.020)**	–0.8871 (0.022)**
Sedimentation	–0.2699 (0.175)	–0.2856 (0.183)	–0.2860 (0.188)	–0.2881 (0.181)	–0.2425 (0.242)
Slow sand Filtration	0.7485 (0.142)	0.7686 (0.123)	0.7659 (0.135)	0.7591 (0.14)	0.7058 (0.167)
pH Control	–0.1135 (0.661)	–0.0849 (0.749)	–0.0859 (0.748)	–0.0846 (0.76)	–0.0566 (0.828)
Corrosion Control	0.5032 (0.110)	0.3941 (0.213)	0.3908 (0.214)	0.3939 (0.21)	0.4542 (0.137)
Fluoridation	–0.1104 (0.53)	–0.1078 (0.541)	–0.1049 (0.566)	–0.1021 (0.573)	–0.0706 (0.701)
Membrane Filtration	0.8489 (0.092)*	0.8170 (0.113)	0.8172 (0.118)	0.8203 (0.115)	0.8402 (0.102)
Granular Filtration	0.9066 (0.016)**	1.023 (0.01)**	1.0267 (0.009)***	1.0188 (0.009)***	1.002 (0.010)**
R^2	0.31	0.29	0.29	0.29	0.31
F	(0.214)	(0.267)	(0.243)	(0.241)	(0.162)
B-Bagan	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
White	(0.000)***	(0.000)***	(0.001)***	(0.000)***	(0.000)***
RESET (2)	(2.34e-007)	(1.25e-006)	(1.73e-006)	(2.15e-006)	(1.16e-006)
RESET (3)	(8.44e-009)	(1.05e-007)	(2.01e-007)	(2.63e-007)	(1.93e-007)

Note The p-values are reported in parenthesis; */**/*** indicates significance at the 10/5/1 % level; F pertains to overall significance of the regression; B-Pagan is the Breusch-Pagan test for heteroscedasticity; White is White's test for heteroscedasticity; RESET is the RESET test for model specification; and R^2 for the Semiparametric model is the square of the correlation coefficient between the actual value of the dependent variable and its predicted value

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Chapter 4
Water Policy in Ontario

4.1 Introduction

This chapter discusses Ontario's approach to safe drinking water through the Ontario Drinking Water Quality Standards (DWQS). Section 4.2 provides an introduction to drinking water systems in Ontario. The purpose of Sect. 4.3 is to review the principles of watershed management in Ontario. Steps that Ontario has taken to create and implement DWQS are introduced in Sect. 4.4. Ontario's progress report on the various legislations and regulations are then outlined. In Sect. 4.5, we assess Ontario's Drinking Water Quality Standards and their procedures for dealing with chemicals of emerging concern such as pesticides, pharmaceuticals, and personal care products (PPCPs).

After the Walkerton tragedy in 2000, Ontario revamped and improved water quality regulations. However, we show that there is room for improvement in regulating the chemicals of emerging concern (PPCPs), which could be greatly reduced by adding advanced oxidation to the drinking water treatment train, if they are not removed from the wastewater that is discharged into the lakes and rivers. But for that Ontario would need to enact new regulations. Enhanced wastewater treatment could also be part of the solution, but for that similar legislation in the US would also be required as Canada and the US share the waters in the Great Lakes. Accordingly, the Canada-US Great Lakes Water Quality Agreement (GLWQA) is discussed in Sect. 4.6. The last section has some concluding remarks.

4.2 Introduction to Drinking Water Systems in Ontario

Ontario's drinking water is drawn from surface water sources, such as lakes and rivers, and groundwater sources for public or private wells. Municipalities provide over 80 % of Ontario's drinking water and the remainder is provided by privately

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owned water systems, ranging from private wells to large-scale residential water supply systems. The privately owned water systems are also called "Small Drinking Water Systems," i.e., drinking water that is made available to the public and comes from a nonmunicipal drinking water system. The Municipal Drinking Water Systems are regulated by the Ontario Ministry of the Environment (MOE), while the Small Drinking Water Systems are regulated by the Ontario Ministry of Health and Long-Term care. These systems are defined in the Drinking Water Systems Regulation (O. Reg. 170/03) under the Safe Drinking Water Act.

Drinking water systems in Ontario supplied 1,670 million cubic meters of drinking water in 2011 (see Fig. 4.1). Surface water sources provided about 90 % of the total volume, while groundwater sources provided the remaining 10 %. In comparison with 2007, the total volume of drinking water produced decreased by 13 % from 1,924.8 million cubic meters in 2011, indicating a decline in water consumption over the last decade. The decline for surface water sources was more evident at 14 % than it was for groundwater sources, which declined by 10 %.

In 2011, drinking water systems provided water to over 11 million Ontarians (see Fig. 4.2). The majority of those (nearly 10 million people) received drinking

Fig. 4.1 Drinking water volumes by source water type, Ontario 2007 and 2011 (Statistics Canada 2013)

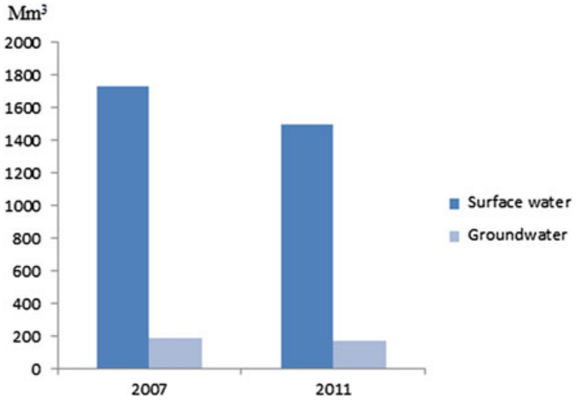
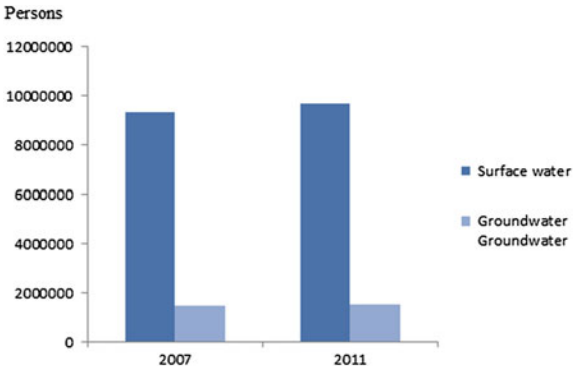


Fig. 4.2 Population served by drinking water plants, Ontario 2007 and 2011 (Statistics Canada 2013)



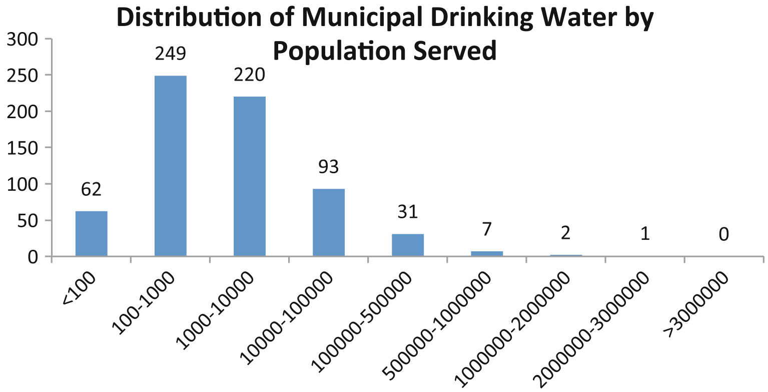


Fig. 4.3 Distribution of municipal drinking water by population served in Ontario (Statistics Canada 2013)

water drawn from surface water sources. Groundwater sources supplied close to one and a half million people. Between 2007 and 2011, the total population served by drinking water plants grew by 4 %, or nearly a half million people. Surface water sources accommodated all of this growth; groundwater experienced small declines in the number of people supplied.

As shown in Fig. 4.3, there were 665 public water systems registered with the Ministry of the Environment in Ontario. Of those, 62 serviced fewer than 100 people and were classified as “Small Municipal Residential Systems.” Furthermore, the public drinking water systems were largely located in small population areas with approximately 50 % of these systems serving fewer than 1,000 people and 80 % serving fewer than 10,000 people. Moreover, approximately 450 public water systems were located within the 19 source protection areas and regions (on which more below).

4.3 Watershed Protection in Ontario

With existing or potential watershed-related issues such as limited water quality and quantity, numerous competing water users, and various agencies with different mandates in Ontario, continuing to improve the effectiveness of watershed management has become increasingly important (Conservation Ontario 2010, p. 4). The objective of this section is to review the principles of watershed management in the province of Ontario. The 30 main watersheds in Ontario are shown in Fig. 4.4.

The 12 principles of watershed management are summarized below.

Principle 1: Characterizing the Water System. Characterizing the forms and functions of the water system as well as identifying the issues of water management are the preliminary steps in building a watershed management framework (Conservation

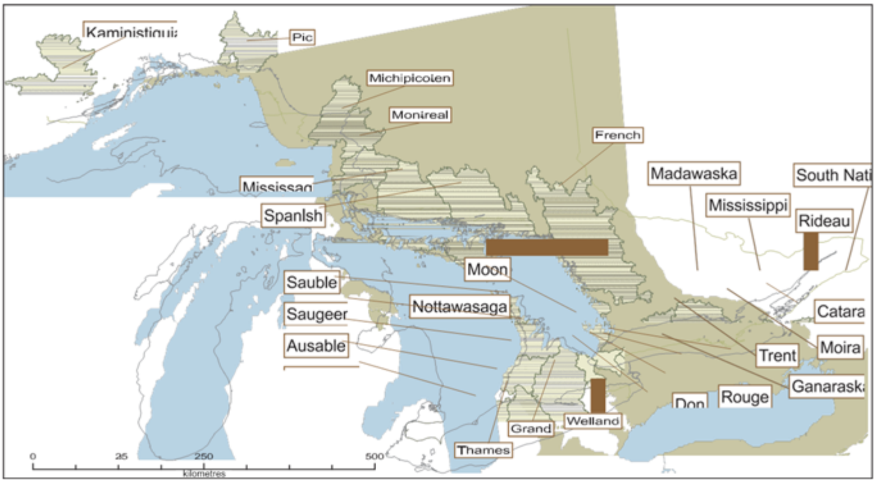


Fig. 4.4 Locations of the 30 watersheds of Ontario (Ontario Ministry of the Environment 2013a)

Ontario 2010, p. 5). One of the largest provinces in Canada, Ontario adjoins the world's largest freshwater body, the Great Lakes. Three primary watersheds are contained in Ontario, which are the Great Lakes, Nelson River, and Hudson Bay (Bone 2011, p. 180). Over 35 million people who live in the Great Lakes basin put enormous pressures and have caused serious problems within the watershed; the problems center on water supply, sewage disposal, and water pollution (Bone 2011, p. 186). For example, in May 2000, the drinking water was polluted by *Escherichia coli* in agricultural waste, which led to a tragedy with seven deaths and many illnesses at Walkerton in southwestern Ontario (Bone 2011, p. 185; see also Chap. 1). Furthermore, lack of an adequate understanding of the water system in watershed management can cause droughts, flooding, and other ecological problems.

Principle 2: Monitoring. The monitoring within the watershed management framework should cover water supply and water demand measurement as well as performance monitoring of the implemented water management plans (Conservation Ontario 2010, p. 5). Monitoring supply includes water quantity and quality measurement (i.e., groundwater and surface water quantities), and climatological measurements (i.e., climate variability in the mean values of climatic variables). Monitoring demand includes proper forecasting and the possible impacts of demand in each locality within the watershed.

Principle 3: Current and Future Use. Economic as well as institutional development within the watershed should be coordinated with an understanding of the impacts on the environment. Natural resources within the watershed should be protected to take into account the needs of the ecosystem. Efforts must be made so that the source water is safe now and in the future for human as well as other ecosystem users without contamination from farm animals. In trying to relieve the pressure on water supply due to population growth, plans should be made to satisfy the current and future use in a sustainable manner.

Principle 4: Assessments. Assessments determine the capacity of a water system, which includes (a) water demand, (b) current water supply, (c) water quality, and (d) availability of water quantity over the longer term (Conservation Ontario 2010, p. 20). In order to measure whether water demand is less than supply, the water budgets approach must be prepared to measure the quantities and rates of water movement through all watersheds based on plans for sustainable use, mentioned in Principle 3 above (Conservation Ontario 2010, p. 20).

Principle 5: Management Instruments. Multiple management instruments such as legislation, policies or programs, watershed plans, institutional roles, collaborative partnerships, and conflict resolution need to be developed to solve a series of watershed-related issues (Conservation Ontario 2010, p. 22).

Principle 6: Implementation Plans. Implementation plans or water management plans deal with one or more watershed issues, which can include (a) source protection plans, (b) water conservation plans, (c) water demand plans, (d) water efficiency plans, (e) storm water management plans, and (f) nutrient management plans (Conservation Ontario 2010, p. 23).

Principle 7: Source Protection Areas. As the first barrier in the drinking water system, source water protection helps to prevent contaminants entering the water sources including lakes, rivers, and aquifers (Ontario Ministry of the Environment 2014). In 2006, the Clean Water Act (CWA) was established to protect existing and potential sources of drinking water (Ontario Ministry of the Environment 2014). Geographical determination and definition of the source protection areas on a watershed basis should be a primary and essential component of source water protection. To improve the effectiveness of source water protection, the nature of all the unique components, living and nonliving, within the watershed zone boundaries should be recognized. Moreover, all the elements of the ecosystem within the source protection areas should be maintained and developed in a sustainable manner. According to the CWA, currently, 36 designated Source Protection Areas have been established all across southern Ontario, and new Source Protection Areas may be defined by the Minister of the Environment (Davids and Annis 2006, p. 1). The Conservation Authority is responsible for governing the "Conservation Authority Areas" (CAAs) that are also source protection areas (Davids and Annis 2006, p. 1).

Principle 8: Institutional Structure of Water Conservation Authorities. The responsibility of source water protection is to be shared among the lead source protection authority, municipalities, businesses, individuals, and communities across the province. As a supervisory authority, the Source Protection Authority is responsible for overseeing each Source Protection Area; it also sets up the Drinking Water Source Protection Committee (the "Committee"). The Committee consists of municipalities, the general public, First Nations, farmers, industry, public health bodies, and other nongovernmental organizations (Davids and Annis 2006, p. 1). As stakeholders, people in agriculture, real estate, and mining should be involved in the Committee (Davids and Annis 2006, p. 3) since they may suffer significant losses if their activities are considered a threat to drinking water sources, and therefore forbidden by legislation or regulations. With their participation, a cooperative solution and transition to appropriate activities can be worked out.

Principle 9: Source Protection Plan. The Committee is responsible for preparing the Assessment Report and Source Protection Plan. As the basis of the Source Protection Plan, the Assessment Report must define the following (Davids and Annis 2006, p. 2):

- All existing watersheds, groundwater aquifers, surface water intake protection zones
- Wellspring protection areas within the Source Protection Area
- The quality and quantity of water in each watershed
- The extent of threats to drinking water in the various water sources

The objective of the Source Protection Plan is to guide the activities of all participants, and all governmental agencies are required to abide by it. In addition, in order to avoid the conflicts that might occur in the assessment reports and source protection plans, the Source Protection Authority and Committees are required to cooperate with each other (Davids and Annis 2006, p. 2). In practice, a monitoring program is a necessary component of source water protection; it must be implemented by the Source Protection Authority to prevent hazardous events within the source protection areas, especially for "vulnerable areas" (Davids and Annis 2006, p. 2). Moreover, if the Source Protection Plan is inconsistent with other legislation and regulations such as the Niagara Escarpment Planning and Development Act, it should follow the principle of maximizing the efficiency of conservation to protect water quality and quantity.

Principle 10: Enforcement. Davids and Annis (2006) noted that "Part IV of the CWA [CWA] authorizes governmental organizations with authority over water production, treatment, and storage to enforce protective measures for drinking water sources via permits, inspection programs, by-laws, resolutions or regulations, and their associated fees." More specifically, when people engage in activities that might be considered a threat to drinking water in the areas that are defined in the Assessment Report, such people are required to submit a risk assessment report to a permits official (Davids and Annis 2006, p. 3). If the permits official judges that the activity could threaten drinking water sources, then the permit may be refused (Davids and Annis 2006, p. 3).

Principle 11: Estimate risks associated with various stressors. The identification of water pollution stressors and their sources is essential in ensuring the effectiveness of watershed management. The water pollution stressors can be categorized into point source pollution (e.g., cattle manure) and nonpoint source pollution (e.g., animals and birds dying in some streams at unknown locations).

Point source pollution includes the following:

- Municipal sewage lagoons discharging PPCPs, nutrients, pathogens, and hazardous chemicals
- Industrial discharges releasing hazardous chemicals
- Pipeline breakage releasing hydrocarbons or other chemicals

Nonpoint source pollution covers the following:

- Faulty septic systems
- Atmospheric deposition
- Accidental spills/releases

Point source pollution can be controlled by multiple legislation or regulations such as stipulating the quantity and usage of pesticide and fertilizers, while nonpoint source pollution problems cannot be corrected by existing regulations due to the limitations in recognizing both pollution sources and pathways. Inability to deal with nonpoint source pollution is a major weakness in Ontario. In contrast, in the USA, the EPA recommends an alternative approach, which is the application of Ecological Risk Assessment (ERA) to watershed management for both point sources and nonpoint sources (see Dore 2015, Chap. 6). This approach evaluates the probability of occurrence of pollution and its ecological effects due to one or more stressors through a specific process (i.e., risk characterization, problem formulation, risk communication, risk analysis, and risk management). For example, in the application of ERA, the Canaan Valley Task Force in West Virginia created an inventory of environmental stressors, focused on determining the effects of stressors, and developed solutions (USEPA 2007, p. 7).

Principle 12: Nutrient Management. To improve the protection of natural systems and develop agricultural operations as well as the rural economy in a sustainable manner, in 2002, the Nutrient Management Act was established to manage nutrients (i.e., manure and chemical fertilizers) and other materials that are applied to land by farmers and other people. The purpose of the Nutrient Management Act was to reduce the transport of nutrients into watersheds such as rivers, lakes, and groundwater (Ontario Ministry of the Environment 2014). For example, nitrates in fertilizers can flow into rivers and penetrate into groundwater due to the expansion of agrarian land. The drinking water is then polluted by nitrates, which can increase the risk of health problems such as cancer and heart disease. Furthermore, a series of nutrient management plans are designed to address animal waste and other contaminants under the Nutrient Management Act. But of course nutrient flow plans have to be enforced.

In theory, the above 12 principles are supposed to guide source water protection. And the instruments of protection are the Environmental Protection Act 1990, Nutrient Management Act 2002, the CWA, 2006, and Water Opportunities and Conservation Act, 2010. The MOE (now called the Ministry of Environment and Climate Change, after the June 2014 election) is responsible for implementing the nutrient management standards under the Nutrient Management Act (Ontario Ministry of the Environment 2009, p. 1). The Ministry's Environmental Officers have the authority to (a) supervise farm operations (b) help farm owner–operators achieve compliance (c) determine whether farm operations are fully in accord with the legal requirements, and (c) prevent activities that threaten natural systems and public health (Ontario Ministry of the Environment 2009, p. 2). In addition, the Ministry of Agriculture, Food and Rural Affairs is required to provide technical support and reports on progress in meeting the standards (Ontario Ministry of the Environment 2009, p. 1).

The purpose of the Nutrient Management Act, 2002 was to provide for the management of nutrients in ways that will enhance protection of the natural environment and provide a sustainable future for agricultural operations and rural development (Service Ontario 2002, Chap. 4). For example, there are specific rules that keep all farm animals at a certain distance from all watercourses and violators can be prosecuted. Even elected councilors and aldermen in regional and municipal councils can be held personally liable for failing to ensure that agricultural practices are in compliance with all legislation mentioned here. However, success depends on how extensively nutrient management plans and regulations are enforced.

The first barrier in the multibarrier approach to protect drinking water is of course source protection, and for Ontario a number of laws stated above have been enacted to enhance source protection. Is there an independent assessment of the *implementation* of the above-mentioned protection measures?

One independent source is the 2014 (released on December 9, 2014) report of the Office of the Auditor General of Ontario.[1] The assessment in this Report is quite damning. We begin with one summary quote from this report:

> Fourteen years after the crisis in Walkerton, the locally developed source water protection plans envisioned by the Walkerton Commission of Inquiry and legislated under Ontario's *Clean Water Act, 2006*, are not in place to ensure the first level of defence for the safety of drinking water for Ontarians. As well, situations of non-compliance with the *Nutrient Management Act, 2002* and its regulations, and the Ministry of the Environment and Climate Change's …weak enforcement activities, increase the risk that source water (water that flows into water treatment plants and wells) in Ontario is not being effectively protected.

The Report identifies a number of deficiencies in the *implementation and enforcement* of the legislation, which we can summarize as follows:

1. The water policy expert whom the Auditor General retained to assist in the audit noted that source water protection plans will over time meet the intent of the *Clean Water Act* provided they are approved and implemented as soon as possible and go through at least one further iteration of affirmation and improvement to address unforeseen weaknesses and challenges.
2. Although plans identify many threats, they may not include all potential threats such as threats to the Great Lakes. There is a high likelihood that spills from industrial and commercial facilities may also pose a significant danger in the near future.
3. The enforcement of the *Nutrient management Act* is wholly inadequate. Only a limited number of farms that produce and use manure are captured under the requirements of the *Nutrient Management Act* and its regulations. The farm that was the source of contamination in Walkerton would currently not be captured under the Act's regulations. The Ministry of the Environment and the Ministry

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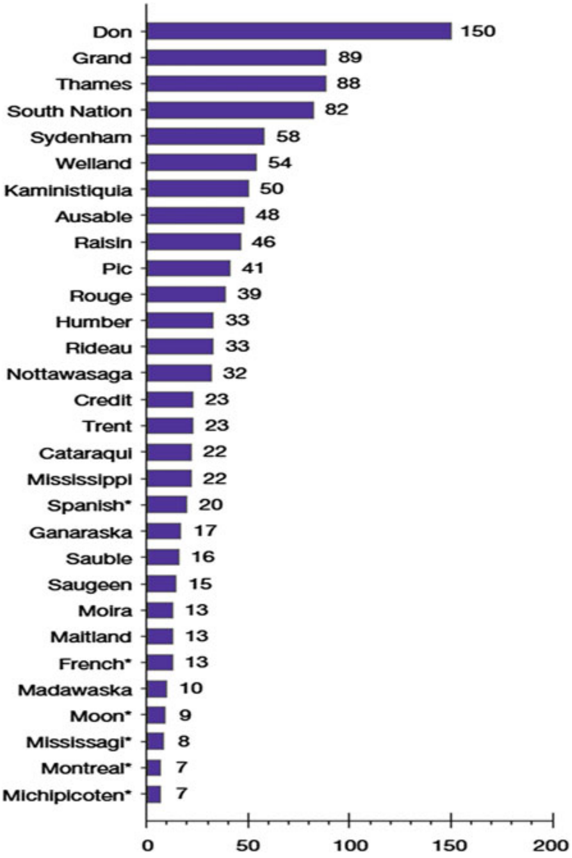
[1] Office of the Auditor General of Ontario, 2014 Report, Queen's Printer, Toronto. http://www.auditor.on.ca/en/reports_2014_en.htm. Accessed December 12, 2014.

of Agriculture, Food and Rural Affairs have acknowledged the need to phase in more farms to adhere to the regulations, but to date this has not been done.

4. Neither the Ministry of the Environment nor the Ministry of Agriculture, Food and Rural Affairs has information on the total number of farms that produce manure and need to manage it in accordance with the Act and regulations. In 2013/2014, the Ministry inspected only 3 % of the farms known to adhere to the Act's regulations for the proper storage and application of manure.
5. The Report notes that over the past 2 years, about 50 % of the farms that had been inspected were found to be noncompliant with the *Nutrient Management Act* and its regulations. Of these, the Ministry of the Environment found that about half of the noncompliance issues were likely to cause a risk or threat to the environment and/or human health.
6. The *Nutrient Management Act* was proclaimed in 2002, but the Report finds that since that time, phosphorous and nitrogen contamination in the province's agricultural watersheds is increasing. This finding is consistent with what is reported below (see Fig. 4.5).

Fig. 4.5 Median phosphorus concentration (μg/L) in 30 Ontario Rivers, 2007–2011 (data identified by an asterisk based on 2002–2006 data) (Ontario Ministry of the Environment 2013a)



7. Ontario's industrial and commercial users are continuing to be subsidized by the Ontario taxpayers. The Report found the Ministry was recovering about $200,000 of the $9.5 million direct annual program costs attributable to the taking of water by industrial and commercial users.
8. The water policy expert whom the Auditor General retained to examine the state of the ecology of the Great Lakes found that 3 of Ontario's 4 Great Lakes are now in a measurable state of ecological decline because of the pressures of population growth, development, and ecological threats including invasive species and climate change.
9. There is inadequate public investment in water treatment across rural Ontario. As of June 30, 2014, the Ministry of Health and Long-Term Care had nearly 300 advisories outstanding against treated drinking water in all parts of the province. Over 40 % of the advisories were in southern Ontario where population density is high. About two-thirds of the advisories had been outstanding for over a year. Over half were "boil water" advisories to reduce elevated levels of bacteria, while a number were "do not drink" due to elevated levels of chemicals in the water.

From the 2014 Report of the Auditor General of Ontario, it is clear that while Ontario has enacted legislation to protect source water, the government has not yet enforced the law to bring agriculture and industry into compliance. Fine laws on paper do not by themselves protect source water, just as laws against crime cannot protect citizens if there is inadequate or incomplete law enforcement.

4.4 Ontario Water Quality Standards

Although standards of drinking water may vary between communities, the ultimate safeguard of Ontario's drinking water depends on its comprehensive safety net. The most important component of Ontario's safety net is its legislative and regulatory framework. Strong legislative and regulatory measures are required to have a proper drinking water safety net. As noted earlier provincial legislation, intended to ensure drinking water safety, includes the legislative acts already mentioned above. In addition The Safe Drinking Water Act (SDWA) 2002, primarily governs the overall protection framework for drinking water while its Regulations address source protection through the CWA, agricultural issues through the Nutrient Management Act, and financing of water systems through the Water Opportunities and Conservation Act.

The SDWA contains a number of important features designed to protect drinking water for consumers. The Act creates, through the DWQS Regulation (O. Reg. 169/03), legally binding standards for contaminants in drinking water. These standards are intended to protect public health. The SDWA also creates, through the Drinking Water Systems Regulations (O. Reg. 170/03), requirements for the sampling and testing of drinking water and the installation and operation of treatment equipment.

More specifically, the Drinking Water Systems Regulations (O. Reg. 170/03) specify the frequency of sampling and testing for each drinking water system category. For municipal residential drinking water systems, continuous monitoring equipment is required for turbidity and chlorine residual. The Drinking Water Systems Regulations (O. Reg. 170/03) also establish specific requirements for the minimum levels of treatment that must be provided. The SDWA makes it mandatory to use licensed and accredited laboratories for drinking water testing through the Drinking Water Testing Services Regulation (O. Reg. 248/03). The SDWA requires, in conjunction with the Drinking Water Systems Regulations (O. Reg. 170/03), reporting of adverse test results where contaminants in drinking water do not meet drinking water quality standards. The Act imposes a duty to report adverse test results to the MOE and Climate Change and to the local Medical Officer of Health. Both the operator and owner of the laboratory must comply with this reporting requirement. All operators of municipal drinking water systems must be trained and certified according to the Certification of Drinking Water System Operators and Water Quality Analysts Regulation (O. Reg. 128/04). Drinking water system operators must hold a valid operator's certificate issued under the regulations.

The Safe Drinking Water Act also establishes a licensing regime for municipal drinking water systems under its Licensing of Municipal Drinking Water Systems Regulation (O. Reg. 188/07). Under the Act all owners of municipal drinking water systems must obtain a license from the Director of the MOE and Climate Change in order to operate their water systems. The SDWA's Financial Plans Regulation (O. Reg. 453/07) requires financial plans from municipal drinking water systems for an application for a license. Under the SDWA's Financial Plans Regulation (O. Reg. 453/07) all residential drinking water system owners applying for a drinking water license must have financial plans approved by the Municipal Council that satisfy the requirements prescribed in the Regulation. Financial plans must include full cost pricing and provision for the funding of the renewal of plant and infrastructure, including any funds required for past deferred maintenance. These requirements include a statement that the financial impacts of the drinking water system have been considered, and that the financial plans cover at least 6 years. The SDWA gives broad inspection powers to officers of the MOE and Climate Change, and creates a new position of Chief Inspector who oversees inspection and enforcement. Provincial officers may conduct inspections without a warrant or court order in order to determine compliance with the Act and other regulations. If a deficiency (such as a violation that poses a drinking water health hazard) is found during an inspection, the provincial officer must conduct a follow-up inspection within a year. The appointed Chief Inspector must submit annual reports on inspection and enforcement matters to the Legislature. The SDWA requires specific inspection under its Compliance and Enforcement Regulation (O. Reg. 242/05) and also imposes a statutory standard of care upon managers of municipal drinking water systems.

The SDWA contains very stringent regulations that go beyond a standard Water Safety Plan. The Director may impose administrative penalties with respect to contraventions of the SDWA, with a maximum of $10,000 fine for each day that the contravention occurs. For individuals convicted under the SDWA, the fines range between $20,000 and $7,000,000, depending on the offense. Convicted individuals may also be imprisoned for some offenses. For corporations convicted under the SDWA, the maximum fines payable range from $100,000 to $10,000,000, depending on the offense. The court may also impose on both individuals and corporations other orders and monetary penalties such as profit stripping, restitution orders, or orders to prevent damage.

Although the SDWA serves as the overall protection framework for Ontario's safety net, its Regulations also provide support to Ontario's drinking water standards. With Ontario's safety net encompassing water sources, the CWA, 2006 serves as legislation that protects existing and future sources of drinking water (Service Ontario 2006, Chap. 22). With the implementation of the multibarrier approach to Ontario's drinking water supplies, up-to-date methods are needed so that the highest quality of drinking water standards are met. The objectives of the Water Opportunities and Conservation Act 2010 are: to foster innovative water, wastewater and storm water technologies, services and practices in the private and public sectors; to create opportunities for economic development and clean technology jobs in Ontario; and to conserve and sustain water resources for present and future generations (Service Ontario 2010, Chap. 19).

Much earlier, in 1986, Ontario created a Drinking Water Surveillance Program which monitored the quality of Ontario's source water and treated drinking water. Although this program monitored emerging contaminants such as algal toxins and pharmaceuticals, Ontario has not successfully implemented any treatment procedures which can enforce the removal of these contaminants effectively (Ontario Ministry of the Environment 2012, p. 5). To increase the protection of source water and public health, the Ontario Ministry has introduced new regulations under the Environmental Protection Act, for the collection and management of post-consumer waste pharmaceuticals and sharp objects such as needles (Ontario Ministry of the Environment 2012, p. 11). The Environmental Protection Act prohibits the discharge into the environment of any contaminants which may cause or are likely to cause negative effects, and in the case of some approved contaminants, requires that they must not exceed approved and regulated limits. It further requires that any spills of pollutants be reported and cleaned up in a timely fashion, and that producers take responsibility for the collection and proper management of these wastes, thus reducing the amount of pollutants that potentially enter the source waters (Ontario Environmental Protection Act 1990).

4.5 Remaining Problems

From the constructive feedback given by the Canadian Institute for Environmental Law and Policy (CIELP), Drinking Water Advisory Council (ODWAC) and the MOE, many changes were made to Ontario's Drinking Water Quality Standards. In the Chief Drinking Water Inspector's Annual Report (2010–2011), it is clear that the Municipal Residential Drinking Water Systems, Nonmunicipal Residential Systems and the Systems Serving Designated Facilities have a 99 % compliance in meeting the DWQS for the parameters: *E. coli*, Total Coliform, Total Microbiological, Chemical and Radiological parameters (Ontario Ministry of the Environment 2013b). Although there is 99 % compliance for pathogens among the systems, for all *chemical parameters* there is no way of knowing if the MCLs meet the WHO guideline values. For example, when inspecting the compliance of the Municipal and Nonmunicipal Systems for lead, although there is above 95 % compliance with the DWQS (Ontario SDWA, 2002-O. Reg. 169/03), this may not be enough; as Ontario uses a weaker lead sampling protocol (Ontario Ministry of the Environment 2013b). The problem of lead is discussed in depth in Chaps. 10 and 11 of Dore (2015).

4.5.1 Low Standards for Chemical Parameters in Drinking Water Supplies

In 2003, the Canadian Institute for Environmental Law and Policy published a paper titled, "*Drinking Water Quality Standards in Ontario—Are They Tough?*" addressing concern over chemical parameters in drinking water supplies set by both Ontario and Canada in relation to the WHO's guideline values (Mohapatra and Mitchel 2003). In particular, the Canadian Institute for Environmental Law and Policy critiqued the Maximum Contamination Levels (MCLs) (also referred to as Maximum Acceptable Concentration (MACs)) of many of Ontario's chemical parameters and observed that they were higher than the MCLs of the WHO guideline values. The Canadian Institute for Environmental Law and Policy further found that there existed inorganic chemical parameters, such as: Beryllium, Molybdenum, Nickel, Thallium[2] and Chlorite, as well as organic chemical parameters, such as: 1, 2 Dichloroethylene, 1,2 Dichloropropane, Hexachlorobenzene and Endothall, which did not have any MCL standards set by Ontario as defined in the WHO guideline values. These chemicals, and many others, are very dangerous and should be taken into consideration, as their presence could compromise the population's health and can result in a number of health problems such as: stomach and intestinal problems, thyroid problems, and cardiovascular problems. Ontario has a tougher standard than the WHO guideline value for a few organic chemicals such as aldicarb and benzo (a) pyrine; however, the fact that higher MCL values are prescribed by Ontario for most of the pesticide residues and other persistent organic chemicals is of serious concern. Many of these chemical parameters with no established standards in Ontario are also well below their respective detection limits. Canadian Institute for Environmental Law and Policy

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[2] Thallium is currently included in the list of Chemical Standards under Safe Drinking Water Act, 2002 (O. Reg. 169/03) since December 1, 2008. For new proposals to reduce some of the MCLs in 2015, please see Chap. 9, Appendix 9.3. This will in the main bring Ontario in line the Canada Drinking Water Guidelines.

concluded that "…the Ontario standard limits as well as the Canadian guideline values for most of the carcinogenic organic chemicals are higher than the USEPA standard and/or WHO guideline value" (Mohapatra and Mitchel 2003, p. 2). Ontario's standard limits for several known or suspected carcinogenic organic chemicals (such as 1,1-Dichloroethylene, 2,4-Dichlorophenoxy acetic acid (2,4-D), Chlordane, DDT, Dichloromethane, Lindane, Metolachlor, Pentachlorophenol, Simazine, Trifluralin and Vinyl Chloride) are higher than the USEPA standard or WHO guideline values, which results in a higher risk to human health (see Chap. 9, Appendix 9.3).

With changes needed to the MCLs of many chemical parameters in Ontario's Drinking Water Quality Standards, recommendations were made to bring them to the attention of the federal-provincial agenda (O'Connor 2002). However, no new chemical having pronounced health effects has been considered for inclusion in the DWQS by the MOE in the SDWA. Furthermore, none of the existing organic chemicals have been revised for tougher standards. The Canadian Institute for Environmental Law and Policy also stated that monitoring programs for the detection of pesticide residues in treated drinking water were virtually nonexistent in Ontario, although metals and disinfection by-products can be measured very well (Ritter 2002). The only exception is that there are MCLs for Trihalomethanes (THMs) and Haloacetic acids (HAAs). For example, DWQS (Ontario Safe Drinking Water Act 2002-O. Reg. 169/03) has established a MCL of 0.1 mg/L for THMs, which is the same as the USEPA standard. But there is no systematic monitoring of organic contaminants in surface waters of Ontario (Molot et al. 2001).

The MOE stated that the Ministry had a significant database for the monitoring of pesticides and other parameters for which there were no established standards under the Drinking Water Surveillance Program (Mohapatra and Mitchel 2003). The Canadian Institute for Environmental Law and Policy, however, found that these established standard chemicals were well below their respective detection limits and that the people of Ontario should be aware of the concentration of these chemicals in water. According to the USEPA Office of Water, legally enforceable drinking water standards (called Primary Standards by the USEPA) are developed to protect drinking water quality by limiting the levels of specific contaminants that are known or anticipated to occur in water and can adversely affect public health. Taking this statement into consideration, the Canadian Institute for Environmental Law and Policy disagreed with the MOE that there is no requirement to monitor chemicals such as beryllium, molybdenum, nickel, 1, 2 dichloropropane, and hexachlorobenzene or to establish a standard for these chemicals, as average concentrations of these chemicals are below the respective detection limits. The MOE argued that the WHO did not consider the technological component within its guidelines; however, the argument was void as methods were already available for the chemical treatment and the MOE was already monitoring these chemicals in drinking water (Mohapatra and Mitchel 2003). While introducing the SDWA in the Ontario provincial parliament in October 2002, the Environment Minister announced that Ontario had the "best and toughest clean water policies in the world" (Ontario Ministry of the Environment 2002). The Canadian Institute for

Environmental Law and Policy, however, stated that it was too early to make such a claim since there was no adequate legislation regarding chemical parameter standards and moreover, no effective monitoring.

In January 2010 the MOE revised and published a report titled, "*Strategies for Minimizing the Disinfection Byproducts: Trihalomethanes and Haloacetic Acids*" in which they outline simple, affordable strategies to minimize the formation of trihalomethanes (THMs) and haloacetic acids (HAAs) when chlorinating drinking water. The MOE's report served as a guideline for utilities to ensure that they would achieve adequate disinfection and satisfy microbiological water quality standards. Strategies introduced were: eliminating prechlorination and moving the chlorination point; practicing enhanced coagulation; optimizing chlorine dosing through disinfection benchmarking; and switching to chloramines for secondary disinfection. The report also provided a brief section on newer treatment technologies for minimizing disinfection by-products. These alternatives are: Ultraviolet (UV) disinfection; Granular Activated Carbon (GAC); Membrane Filtration; and Magnetic Ion Exchange (MIEX). But the regulations do not require that these technologies be implemented in the water treatment plants. The adoption of new treatment technology is key to future drinking water safety, but the water utilities have no incentive to implement and invest in these new technologies; they are content to rely heavily on chlorination within their old conventional water treatment trains as these methods meet the minimal regulatory standards.

4.5.2 Nutrient and Algal Issues

The "Water Quality in Ontario 2012 Report" presented the results of water monitoring and investigation for nutrient content and algal blooms (Ontario Ministry of the Environment 2013a). Nutrients, especially phosphorus, have been a major concern for Great Lakes water quality. The findings presented in the report showed that phosphorus levels in Lake Simcoe, the Great Lakes and some streams and inland lakes in Ontario have decreased over time as observed through the weekly routine monitoring of nutrients and algal concentrations in raw water samples from drinking water treatment plants.

However, as shown in Fig. 4.5, 47 % of Ontario rivers exceed the interim Provincial Water Quality Objective of 30 μg/L of phosphorus. The highest concentrations of phosphorus are in southern Ontario rivers and streams (i.e., Don, Grand, Thames, South Nation, etc.). In addition, there is no decline in the amount of phosphorus inflowing into southwestern Ontario streams in agricultural areas, and in some streams phosphorus may even be increasing due to phosphorus loads from a wide range of sources. These sources include point sources (i.e., discharge from municipal and industrial wastewater facilities) and nonpoint sources (such as fertilizers, livestock and pet waste, and failing septic systems). The main sources of new phosphorus are nonpoint inputs from runoff from agricultural and urban lands (Ontario Ministry of the Environment 2013a). We can, in fact, see that amounts of phosphorus in southern Ontario rivers and streams are increasing, mainly due to the higher human population density and larger amount of agricultural and urban lands being developed. Ontario faces a significant challenge in ensuring that best management actions are carried out to control nonpoint sources of phosphorus in southern Ontario rivers and streams.

A high concentration of phosphorus leads to excessive growth of algae and the excessive algae growth can result in algal blooms. These blooms negatively affect drinking water and recreational activities such as swimming and fishing when they enter the shorelines and drinking water intakes. For example, in Lake Erie, blue-green algal blooms have been a key issue in the lake's western and central areas. Through the implementation of the Nutrient Management Act in 2004, the Ministry has been working with local partners such as health units to monitor the water quality of several streams in agricultural regions. However, the Act does not address some important sources of nutrients. For instance, the Act applies to livestock operations but not to crop farms, which can also be a source of nutrients to streams.

4.5.3 Chemicals of Emerging Concern in Water Sources

In 2006 the Canadian Institute for Environmental Law and Policy published a report titled, "*There is No* "*Away*"" which documented the detection of pharmaceuticals, personal care products, and endocrine disrupting substances as *emerging contaminants* in water sources (Holtz 2006). The Canadian Institute for Environmental Law and Policy encouraged the MOE to consider the need for appropriate wastewater management to address these emerging contaminants. The report outlined four major theoretical routes that could bring pharmaceuticals, personal care products, and some other emerging contaminants into water. They were: manufacturing facilities; user discharges into wastewater that is not treated to remove the emerging contaminants; excretions into treated wastewater; and discharges and excretions into runoff flowing to water bodies or groundwater. It was further stated that the clearest points of concentration were immediately downstream from the wastewater outfalls of manufacturing plants, wastewater treatment plants (WWTPs), livestock operations, and leachate from private septic systems. Thus, the primary question was whether the emerging contaminants were actually being documented from these possible sources. The report further stated that improper disposal of pharmaceuticals and personal care products (PPCPs) through municipal solid waste or sewage systems also occurs due to a lack of public awareness of their impacts. As a result there would be a high concentration of contaminants from PPCPs found in wastewater (Holtz 2006).

The Canadian Institute for Environmental Law and Policy also encouraged the MOE to address concerns over hazardous wastes discharged into water. The Canadian Institute for Environmental Law and Policy's 2007 report titled, "*Hazardous Waste in Ontario: Progress and Challenges*" made a number of recommendations to Ontario. These included the need to monitor and regulate PPCPs in wastewater treatment plants, document and report the quality of sewage discharge into water, and develop an improved storm water management plan, in addition to further recommendations to address hazardous waste discharges (Whitney 2007).

The "Water Quality in Ontario 2012" Report suggested that over the last 40 years, the legacy contaminants such as DDT and PCBs have declined significantly in fish in the Great Lakes and are no longer a concern. However, consumer use of chemicals, including "pharmaceuticals, personal care products, electronics, furniture and in plastics and building products" has increased, and these substances are found in increasing concentrations in the environment. Pharmaceuticals and other personal care products have been detected at selected sites in the areas of the Great Lakes (Servos et al. 2007).

Furthermore, the special monitoring equipment called "polar organic chemical integrative samplers (POCIS)" was applied to assess the average concentration of pharmaceuticals over the period. This technique was a collaborative study undertaken by the ministry staff and Trent University researchers. The results from studies in Lake Ontario (2006) and Lake Erie (2007) indicated that pharmaceutical concentrations were usually in the low nanogram per liter (ng/L), as shown in Fig. 4.6. However, there were higher concentrations near urban areas due to wastewater discharged by municipal wastewater treatment plants (e.g., near Hamilton and Toronto). This equipment could be used to identify compounds that cannot be detected using standard sampling techniques as they are at very low levels.

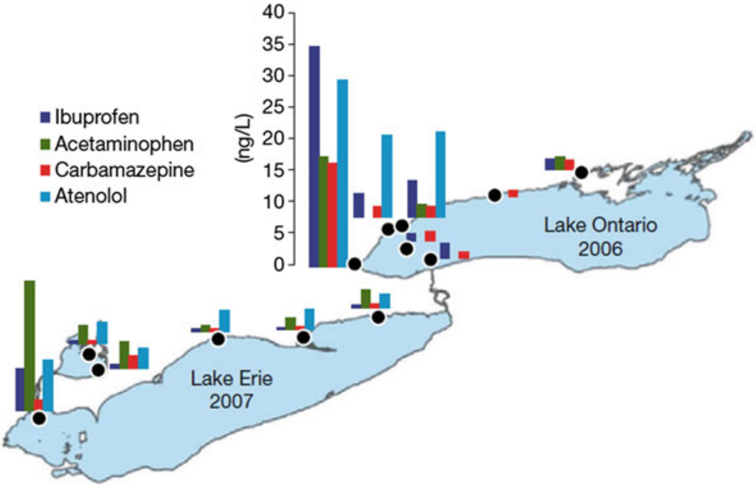


Fig. 4.6 Concentrations (nanograms/liter) of selected pharmaceuticals in near-shore waters of Lake St. Clair, Lake Erie, and Lake Ontario as estimated from POCIS passive samplers (Li et al. 2010)

Similarly, in 2007, the Great Lakes advisory groups established by the International Joint Commission (IJC) found that discharges from wastewater treatment plants have been a major source of contaminants to surface waters in the Great Lakes basin (International Joint Commission 2009). These results pointed out that it is necessary to assess and improve the treatment technologies as a lot of wastewater is discharged by wastewater treatment plants without removing chemicals of emerging concern. In 2011, the "Chemicals of Emerging Concern Work Group" charged by the International Joint Commission, developed an inventory of municipal wastewater treatment plants which discharge into the Great Lakes basin. The objective was to assess the performance of wastewater treatment plants for removal of chemicals of emerging concern (International Joint Commission 2011). The group found that a total of 1,448 municipal wastewater treatment plants discharged 18 billion liters per day of treated effluent into the Great Lakes basin.

As seen in Table 4.1, a total of 470 municipal wastewater treatment plants in Ontario discharge into the Great Lakes basin. Of these, 212 and 68 are secondary (activated sludge) and tertiary (advanced) treatment facilities, respectively. Smaller communities are served by 175 lagoon treatment systems, and only 8 facilities contain primary treatment. Hence, greater than 95 % of the wastewater discharged by municipal wastewater treatment plants into the basin receives either secondary (activated sludge) or tertiary (advanced) treatment. But of the total average daily flow of wastewater, only 8 % received tertiary treatment in 2011.

Based on the Clean Watershed Need Survey, for the US, 4 and 96 % are secondary (activated sludge) and tertiary (advanced) treatment facilities, respectively, out of all the 978 facilities (see Table 4.2). Thus the amount of tertiary treatment in the US is much higher than in Ontario.

Table 4.1 Distribution of Ontario wastewater treatment plants in the Great Lakes Basin (International Joint Commission 2011)

Facility type	Number of facilities	Percentage of total number of facilities (%)	Total average daily flow (MLD)	Percentage of total average daily flow (%)
Primary	8	1.7	96	1.7
Community septic (all types)	7	1.5	1	0.0
Lagoons (all types)	175	37.2	178	3.1
Secondary	212	45.2	5038.1	87.3
Tertiary	68	14.5	456.8	7.9
Totals	470	100.0	5769.1	100.0

MLD million liters per day

Table 4.2 Distribution of U.S. wastewater treatment plants in the Great Lakes Basin (International Joint Commission 2011)

Facility type	Number of facilities	Percentage of total number of facilities (%)	Total average daily flow (MLD)	Percentage of total average daily flow (%)
Secondary treatment	311	31.7	135.9	4.2
Advanced treatment	563	57.6	3111.8	95.8
Unknown[a]	104	10.6	n/a	n/a
Totals	978	100.0	3247.7	100.0

[a] Detailed information is not available

MLD million liters per day

4.5.4 Review of the Effectiveness of Wastewater Treatment (WWT) and Water Treatment (WT) Technologies

An investigation in the US published by the Water Environment Research Foundation, entitled “Fate of Pharmaceuticals and Personal Care Products in Wastewater Treatment” estimated the quantities of 20 compounds at 8 municipal wastewater treatment plants, which used a variation of the activated sludge process (Stephenson and Oppenheimer 2007). As seen in Table 4.3, Methy1-3-phenylproprionate was infrequently detected but showed a high likelihood of removal. Galaxolide was frequently detected but poorly removed. Some compounds such as Benzyl Salicylate, Butylbenzyl phthalate, and Caffeine occurred frequently and had a high probability of at least 75 % removal efficiency in advanced treatment of wastewater. The research team further detected that if the solids retention times were increased, the removal rates of observed PPCPs would also increase.

Table 4.3 Removal efficiencies of pharmaceuticals and PPCPs by Activated Sludge Systems (Stephenson and Oppenheimer 2007)

Frequency of occurrence in samples	Poor removal (<25 %)	Moderate removal (25–75 %)	Good removal (>75 %)
Infrequent (<25 %)	Trichloroethyl phosphate (TCEP) Triphenyl phosphate	Octylphenol	Methy1-3 Phenylproprionate
Intermediate (25–75 %)	Butylated hydroxyanisole (BHA) N,N-diethyl-toluamide (DEET) Musk Ketone	Ethy1-3-phenylproprionate	Benzyl salicylate Butylbenzyl phthalate Caffeine Chloroxylenol Methylparaben Ibuprofen Octylmethoxycinnamate Oxybenzone 3-Phenylproprionate
Frequent (>75 %)	Galaxolide	Benzophenone Triclosan	

In Washington State, Lubliner et al. (2010) studied the removal efficacy of 172 PPCPs. This study helped to demonstrate how different wastewater treatment processes affect removal of PPCPs. Of the 172 organic compounds monitored in this study, 56 % were detected in at least one sample. Every sample in this study had detectable concentrations of multiple PPCPs. The results of this study confirmed findings from published studies that (1) PPCPs are routinely found in municipal wastewater, (2) treatment of PPCPs varies by chemical and treatment process, and (3) PPCP concentrations are comparable to those found in the literature. Their overall conclusion was that PPCP concentrations were reduced most effectively by the advanced biological nutrient removal with tertiary treatment technologies. But three PPCP compounds stood out as relatively untreatable by the treatment technologies studied: *carbamazepine, fluoxetine, and thiabendazole.*

Another article was published in 2013 in the *Water Quality Research Journal of Canada* titled "Protecting Our Great Lakes: Assessing the Effectiveness of Wastewater Treatments for the Removal of Chemicals of Emerging Concern." The authors studied the removal efficiencies for chemicals of emerging concern based on available data for the period 2000–2010 and pointed out that of 42 substances commonly found in the Great Lakes, at least half are likely to be removed by activated sludge systems (Arvai et al. 2013), but the other half would remain. As seen in Table 4.4, some substances such as DEHA and DEET were infrequently detected but demonstrated a high probability of at least 75 % removal efficiency. Other substances such as carbamazepine and diclofenac were frequently detected but had low removal rates. Only acetaminophen, caffeine, and estriol occurred frequently and could be removed by advanced (tertiary) treatment. But in Ontario, as shown in Table 4.1, only 7.9 % of the average daily flow of wastewater receives tertiary treatment (based on the IJC 2011 data).

Therefore, we may conclude that while there is awareness of chemicals of emerging concern, there is a great deal of room for improvement in Ontario. Increasing tertiary treatment of wastewater in Ontario would bring Ontario closer in line with the objectives of the revised 2012 Canada-US GLWQA. This Agreement is discussed in Sect. 4.6. But, as shown above, the US already has a better record of treating wastewater through secondary and tertiary treatment.

Although municipal wastewater treatment systems were not designed to remove chemicals of emerging concern, the Water Environment Research Foundation Reports in the US suggest that wastewater treatment plants consisting of secondary and advanced treatment systems could reduce a variety of substances (International Joint Commission 2011). In order to remove chemicals of emerging concern from wastewater, the primary as well as lagoon treatment facilities would have to be upgraded to at least secondary treatment in Ontario. The secondary plants should add biological nutrient removal processes and optimizing processes in order to improve removal of biodegradable chemicals of emerging concern (International Joint Commission 2011). In addition, to improve the effectiveness of removal of chemicals of emerging concern, a list of standards for indicator compounds needs to be established in Ontario, so that the treatment process can be regulated.

Table 4.4 Summary of confidence level versus removal efficiency for 42 chemicals of emerging concern by activated sludge Systems (Arvai et al. 2013)

Confidence level (n = # of records)	Low removal efficiency (<25 % probability of 75 % + removal)	Medium removal efficiency (25–75 % probability of 75 % + removal)	High removal efficiency (>75 % probability of 75 % + removal)
Low (n < 9)	Atrazine Pyrene	Benzophenone Indomethacin Sulfamerazine	Musk Ketone Di (2-ethylhexyl) adipate (DEHA) N,N-diethyl-toluamide (DEET) Testosterone
Medium (9 ≤ n ≤ 15)	Gemfibrozil Perfluorooctanoic acid (PFOA) Perfluorooctyl sulfonale (PFOS)	Di (2-ethylhexyl) phthalate (DEHP) Norfloxacin Ranitidine Roxithromycin Tetracycline	
High (n > 15)	Carbamazepine Ciprofloxacin Clofibric acid Diclofenac Erythromycin Trimethoprim	Bezafibrate Bisphenol A Estrone (E1) 17α-Ethynyl etradiol (EE2) 17β-Estradiol (E2) Galaxolide Ibuprofen Ketoprofen Naproxen Nonylphenol Nonylphenol monoethoxylate (NPIEO) Nonylphenol diethoxylate (NP2EO) Octylphenol Sulfamethoxazole Tonalide Triclosan	Acctaminophen Caffeine Estriol (E3)

It should be noted that the Ministry of the Environment of Ontario, the University of Ottawa and the National University of Singapore have completed a collaborative study on nanofiber membranes, which can be applied to wastewater treatment plants. These membranes would act as excellent filters for reducing emerging contaminants such as PPCPs and other compounds found in water and wastewater. However, this procedure is in the experimental phases (Ontario Ministry of the Environment 2012). One obvious and simple solution is to have more tertiary wastewater treatment plants in Ontario.

Wastewater can also be treated by using advanced oxidation processes. The introduction of Advanced Oxidation Processes (AOPs) is an alternative technology that employs ozone, hydrogen peroxide and/or UV light. This chemical process has proven to be very successful in removing taste and odor, pesticides, pharmaceuticals and personal care products (PPCPs) and endocrine disrupting substances (EDSs) as demonstrated by the following case studies conducted by Trojan UV.

The first case study conducted by Trojan UV was at the Neshaminy Falls drinking water treatment plant, Pennsylvania, US. The primary goal at this plant was to determine the most efficient alternative in removing taste and odor (T&O). The two alternative approaches tested were powdered activated carbon (PAC) systems and UV-oxidation systems. Upon investigation of the removal of Geosmin, Trojan UV found that PAC only achieved a 55 % reduction in Geosmin concentration, whereas UV-oxidation provided 80 % reduction at peak flow and 90 % reduction at average flow (see Fig. 4.7). Furthermore, UV-oxidation also provided a 3-log inactivation of Cryptosporidium and Giardia. Thus Ontario could invest in UV-Advanced Oxidation processes at wastewater treatment plants to reduce significantly all the contaminants of emerging concern. There would be a further dividend to using UV-Advanced Oxidation: fighting climate change.

In collaboration with the University of Western Ontario, Trojan UV tested the climate change potential of both systems and they found that the UV-oxidation system released 74 % less CO_2 emissions when compared to PAC (see Fig. 4.8). This shows that there is also an environmental benefit when incorporating AOPs as opposed to other treatment technologies such as PAC.

The second location where Trojan UV conducted a case study was at the Aurora Reservoir Water Purification Facility. Trojan UV found that nitrosamines, particularly NDMAs, were only treatable by UV-oxidation. Moreover, through bench- and pilot scale UV-oxidation systems, significant reduction in NDMA, Geosmin, Microcystin, Atrazine (pesticide), and Chlorotetracycline (a pharmaceutical) was recorded (see Fig. 4.9).

What we can see from these case studies is that AOPs provide efficient and effective removal of PPCPs and EDSs. Furthermore, AOPs are the best alternative for removing PPCPs and EDSs when compared with other treatment technologies (as shown in Figs. 4.7 and 4.8). But investing in AOPs requires political will and legislative action. It is clear that the next frontier in Ontario in obtaining higher

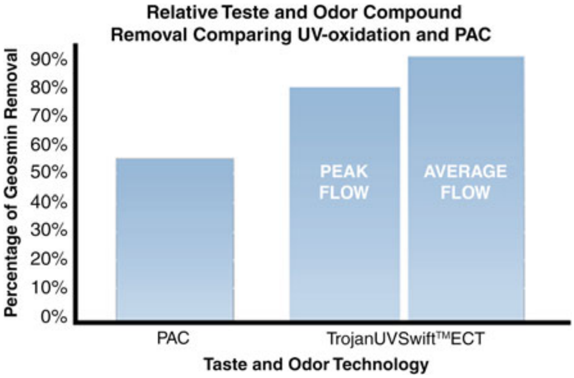


Fig. 4.7 Illustrating the Geosmin Removal of PAC and UV-oxidation (Trojan Technologies 2010)

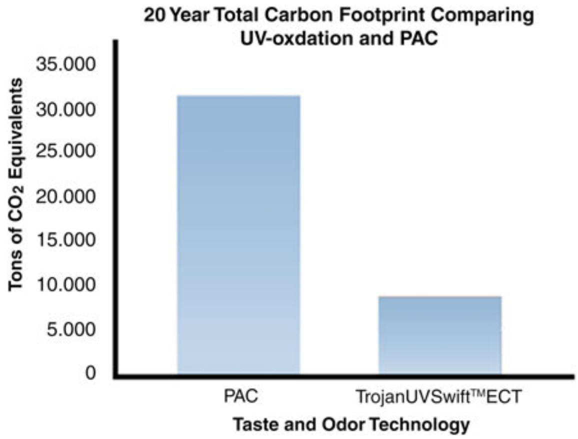


Fig. 4.8 Illustrating the Carbon Footprint of UV-oxidation and PAC (Trojan Technologies 2010)

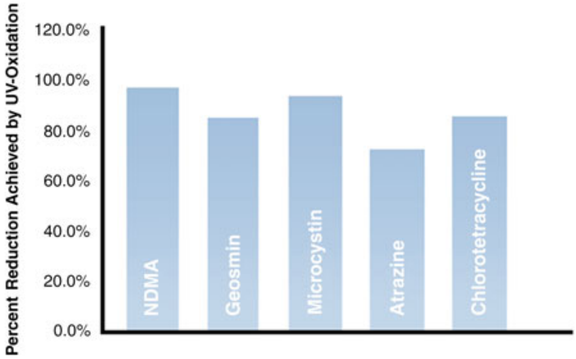


Fig. 4.9 Illustrating the Percentage Reduction of chemical parameters by AOPs (Trojan Technologies 2010)

quality drinking water is to remove PPCPs and EDSs; however, the problem is that at the moment the current regulations do not require their removal.

From the information we collected, it appears that AOP equipment has been incorporated into eight drinking water treatment plants in Ontario (see Table 4.5); however, they are only used to treat taste and odor during peak seasonal changes (Region of Peel 2012).

From Table 4.5, it is clear that not only were the targeted contaminants removed when applying AOPs at the treatment stage, but in some drinking water treatment plants (Six Nations and Region of Waterloo), additional removal of other chemicals (MIB and 1, 4-dioxane) and disinfection also took place. It seems clear that AOPs are effective alternatives for removing PPCPs and EDSs. Therefore, it would make good sense for all the drinking water treatment plants that already have the AOP technology in place to use it all year round rather that only when there is a concern for taste and odor.

When new alternatives are being introduced, cost is of course a concern. On conducting a cost-benefit analysis on alternative treatment technologies at the

Table 4.5 Illustrating the 8 drinking water treatment plants in Ontario that use advanced oxidation processes

Project name	Application	Chemicals treated	Target contaminants	Flow rate (measured in m^3/d)	Design log removal	Status	Type of reactor
Cornwall, ON water treatment plant	Drinking water	Taste and Odor (T&O)	MIB, Geosmin	99870.93	1 log removal of Geosmin	Operational since mid-2006 (currently experiencing quenching difficulties)	Trojan UV Swift 8L24
Region municipality of Waterloo, Greenbrook drinking water plant	Drinking water	TCE, 1, 4-dioxane and providing disinfection	TCE, 1,4-dioxane	12937.82	1.3-log removal of 1, 4-dioxane	Operational since May 2008	Trojan UV Phox D72AL75
Lorne Park water treatment plant, region of Peel	Drinking water	MIB, Geosmin	MIB, Geosmin	389278.64	1.0-log removal MIB; 1.25-log removal of Geosmin	Commissioning and testing to be completed by August 2012	Trojan UV Swift 16L30
West Elgin water treatment plant	Drinking water	MIB, Geosmin	MIB, Geosmin	14318.62	1.3 log removal of Geosmin	Operational since March 2010	Trojan UV Swift 8L24
Middleton Wellhead Site, region of Waterloo	Drinking water	TCE, 1, 4-dioxane and providing disinfection	TCE, 1,4-dioxane	9762.73	1 log removal of TCE	Operational since September 2009	Trojan UV Swift 16L30
Middleton water treatment plant, region of Waterloo	Drinking water	TCE, 1, 4-dioxane and providing disinfection	TCE, 1,4-dioxane	40299.96	1 log removal of TCE	Upgraded and in operation since 2010	Trojan UV Swift 16L30
Six nations	Drinking water	NDMA, 1, 4-dioxane	NDMA	4314.79	0.8 log removal of NDMA; 0.38 log removal of 1, 4-dioxane	Plant opened in January 2014; now in operation	Trojan UV Swift 8L24
Hanover ON	Taste and Odor	MIB, Geosmin	Geosmin	12870.40	0.65 log removal of Geosmin	30th August, 2012- System Operational (Peroxide Dosing an Issue) T&O treatment is generally good	Trojan UV Swift 8L24

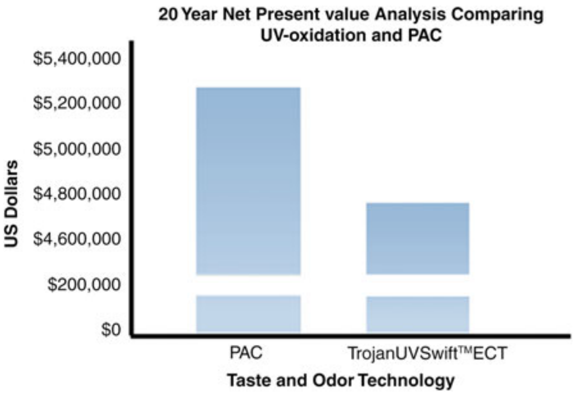


Fig. 4.10 Illustrating the cost over a 20-year period for implementing AOPs compared with Powdered Activated Carbon (PAC) System (Trojan Technologies 2010)

Neshaminy Falls drinking water treatment plant, Trojan UV found that UV-oxidation was a more economical solution than PAC (see Fig. 4.10). The net present value (NPV) analysis incorporated a number of different costs, including capital, construction, operation, and maintenance.

Figure 4.10 shows that utilizing AOPs year round would add little in the way of costs. Therefore, with minimal cost and high removal of PPCPs and EDSs, it would be economical for Ontario drinking water treatment plants to shift to utilizing AOPs year round to guarantee a higher quality of drinking water.

There is an obvious conclusion: drinking water treatment plants in Ontario that rely on chlorine for disinfection should consider buying AOP and adding it to their treatment trains not only for disinfection but also in order to remove PPCPs and EDSs.

4.6 Canada-US Great Lakes Water Quality Agreement

In the late 1960s the Great Lakes—and especially Lake Erie—were seriously polluted with algal blooms; the lakes were becoming oxygen-starved and became a public concern. In order to reduce the excess algae growth in Lake Erie and other areas in the Great Lakes, the GLWQA (GLWQA) was set up between Canada and U.S. in 1972 to address these and related issues cooperatively.

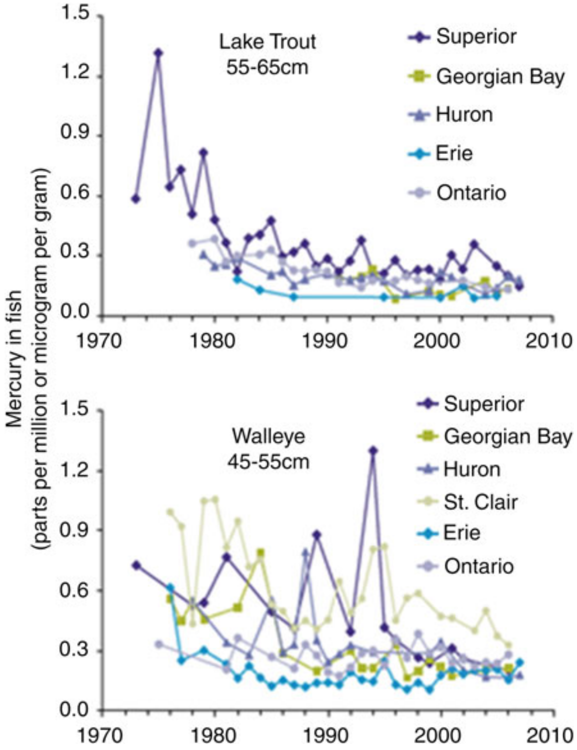
If the goal of the 1972 Agreement was mainly to reduce the algal blooms that were causing the eutrophication problems, the second generation of the GLWQA in 1978 was focused primarily on "restoring and maintaining the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem." The two key changes of 1978 GLWQA were (a) the "ecosystem approach:" that is, the identification and management of water quality issues as an integrated process for the whole ecosystem and (b) the "virtual elimination" of toxic pollution, which was described as "zero discharge" of toxic pollutants under Annex 12. The 1978 GLWQA required that "The discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated."

In 1987, the GLWQA was amended again and the idea of Area of Concern (AOC) was introduced for the first time. AOC is an environmentally degraded location within the Great Lakes Basin. Most of the AOCs are near large urban areas where pollution from industries, sewage treatment plants, landfills, and other sources enters nearby waterways. There were a total of 43 AOCs identified under Annex 1, 17 AOCs in Canada, 26 AOCs in U.S., with five shared by the two countries. Currently, of the 43 AOCs, 4 have been delisted: Collingwood Harbour, Severn Sound and Wheatley Harbour in Canada and Oswego River in U.S. The International Joint Commission is responsible for the monitoring process in all of the AOCs. In the same year, the governments of Canada and U.S. also established Lakewide Management Plans for each lake and Remedial Action Plans for each AOC to restore and protect the toxic "hot spots" (Environment Canada 2013a). It is obvious that the 1987 GLWQA continued to focus on dealing with toxic chemicals. Moreover, in 1994, the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA) was established to ensure implementation of the requirements of the 1987 GLWQA (Environment Canada 2013b).

The renegotiated GLWQA of 2012 further addressed protecting the water quality of the Great Lakes from current and emerging pollution. Through the GLWQA, the two governments plan to improve coordination and collaboration with "First Nations and Métis organizations, businesses, nongovernmental entities, and the public" to restore and protect water quality and ecosystem health in the Great Lakes. Moreover, the 2012 GLWQA provided a platform for new strategies to prevent aquatic invasive species as well as the protection of species and their habitat. Furthermore, climate change impact was introduced as a new factor into the 2012 GLWQA, which suggests that the agreement was to devote more attention to enhancing the long-term effectiveness of management strategies of the Great Lakes (Environment Canada 2013c).

However, there are some remaining challenges in the 2012 GLWQA. Firstly, although algal blooms are still a key issue in Lake Erie, the GLWQA merely requires "reducing phosphorous" but there are no specific targets. Secondly, the specific and numerical objectives for toxic chemical substances such as maximum concentrations of mercury, lead, and a number of pesticides were no longer included in the 2012 GLWQA. At present, although the levels of toxic substances within the Great Lakes ecosystem have significantly declined through concerted efforts from the two countries, the "zero discharge" target has not been achieved. In particular, due to chemical pollution of the Great Lakes coming primarily from wastewater treatment plants and industrial discharge as well as urban and agricultural runoff, at least 39 sites in the Great Lakes Basin were contaminated by persistent toxic chemicals which constitute a significant threat to water quality and human health. In addition, even though concentrations of mercury in fish from the Great Lakes declined significantly during the 1970s and 1980s, mercury levels have slightly increased recently (see Fig. 4.11). In fact, we can see that the toxic chemicals are still an unsolved ecological problem.

Fig. 4.11 Long-term trends of mercury levels in fish from the Canadian waters of the Great Lakes (Bhavsar et al. 2010)



Finally, while the Annex on "Toxins and Chemical Substances" was renamed to become "Chemicals of Mutual Concern,[3]" indicating that the emerging chemicals of concern like PPCPs are included in the GLWQA, it seems that there are no clear, specific, and measurable targets for these ecologically harmful chemical substances. For example, consider the binational finding on chemicals of emerging concern presented in the Great Lakes Binational Toxics Strategy 2008–2009 Biennial Progress Report. It demonstrated that detectable concentrations of pharmaceutical compounds existed in 34 % of the samples (Klecka et al. 2010). Yet, there are no standards, guidelines, or criteria with which to compare environmental concentrations and no targets to get to zero pollution.

The Canadian government has developed its own strategy to deal with chemical discharges into the Great Lakes through the Canadian Environment Protection Act, 1999. In Canada, thousands of chemical substances were reported but have not been fully assessed. These chemical substances must be identified to determine which need to be governed under the Canadian Environment Protection Act. However,

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[3] To prevent the release of chemical substances into the Great Lakes, Annex 3 of GLWQA, "Chemicals of Mutual Concern," outlines steps to reduce the anthropogenic release of chemicals of mutual concern to the waters of the Great Lakes by developing binational strategies.

only 326 chemical substances are included in the National Pollutant Release Inventory (NPRI) under the Canadian Environment Protection Act so far, and NPRI only requires pollutant releases to be reported if the total quantity released exceeds a set threshold that ranges from 10 tons to 5 kilograms depending on the pollutant. Thus these chemical substances can still enter the Great Lakes without being reported (Environment Canada 2013d). In consideration of the fact that a significant portion of the unassessed chemical substances may be toxic, a priority list based on factors such as degree of bioaccumulation is necessary and critical to be established under the GLWQA annex. Indeed there are a number of metrics of chronic toxicity that can be used to establish a priority ranking of contaminants that need to be removed urgently (see, for example, the web site of the US Center for Disease Control that has published online their "Priority List of Hazardous Substances").[4]

It cannot be emphasized too much that there is an urgent need to produce a list of standards, guidelines, or criteria for chemical substances that are being used and are being released into the Great Lakes Basin; such standards would strengthen the GLWQA. That is the only way to control chemical discharges into the Great Lakes.

4.7 Conclusion

As a result of the Walkerton Tragedy, Ontario has improved the regulations for providing safe water to its citizens. The SDWA enhances the level of drinking water protection across the province by creating a clear and comprehensive framework for drinking water treatment and distribution, but it also has some weaknesses. Firstly, while there is 99 % compliance for pathogens among the systems, Ontario's standard limits for several known or suspected carcinogenic organic chemicals are higher than the USEPA standard or WHO guideline values, which results in a higher risk to human health. Moreover, although the MOE monitors emerging contaminants such as algal toxins and pharmaceuticals, Ontario has not yet implemented regulations for the treatment and removal of these contaminants (Ontario Ministry of the Environment 2012, p. 5). Furthermore, as both Canada and the US communities discharge wastewater into the Great Lakes, only joint action by both countries will improve the quality of Great Lakes water. In particular, adequate treatment of wastewater that removes the chemicals of emerging concern, before discharging the wastewater into the Great Lakes, will be required. The US has a better record of tertiary wastewater treatment than Ontario. Advanced Oxidation Processes could, of course, be used at the drinking water treatment plants, but spending the money at the wastewater treatment plants would have the added advantage that it would benefit the entire ecosystem. Finally, it should be noted that although the Ontario Ministry of the Environment (2010) recommends UV Disinfection to reduce many contaminants, the majority of drinking water treatment

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[4] See, http://www.atsdr.cdc.gov/spl/. Accessed November 20, 2014.

plants have not yet spent any money to implement this recommendation, implicitly claiming that they do not *have* the money. The obvious reason why this investment has not occurred is because it is not a regulated requirement.

Clearly, the water that Ontario residents consume is not free of hormones and pharmaceuticals; these are reduced but not completely removed from the wastewater. And they are not removed at the drinking water treatment stage either. Therefore, the argument made by the Chief Drinking Water Inspector that Ontario's Drinking Water Quality Standards are "world class" cannot yet be substantiated. While major progress has been made through new and tighter regulations, the next frontier is (1) the enforcement of nutrient management laws and regulations to enhance source water protection, (2) the regulation and elimination of chemicals such as THMs, HAAs and other halides, and (3) tertiary treatment of all (or almost all) wastewater originating in Ontario. Tertiary treatment will reduce the concentration of a number of chemicals of emerging concern such as pharmaceuticals and PPCPs. (For a comparison of treated water quality in Ontario and Germany, see Chap. 9).

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Chapter 5
An In-Depth Study of Water Demand: An Ontario Case Study

5.1 Introduction

This chapter focuses on an econometric approach to investigate the effect that economic and structural water demand management strategies have had on Ontario's per capita consumption of water in 2001, 2006, and 2009. Such information would be a prelude to implementing water conservation measures. But the study of water demand should include not only linear methods. To this end, we also use nonparametric models that relax the assumptions of the specific functional form of the estimated equation. Linear models of demand analysis have their uses but there are also some disadvantages that can be overcome by including nonparametric estimation as well. This chapter is organized as follows.

Section 5.2 provides a description of Ontario municipal water consumption panel data for 2001, 2006, and 2009. The observed data is analyzed in order to determine the impacts of price, income, metering, type of price structure, and the size of the municipality on per capita consumption of water. The water demand equation is developed to capture the sensitivity to these variables, or what is usually called the elasticity of the independent variables and its effect on the dependent variable.

Section 5.3 extends the analysis of municipal water consumption in Ontario to a longitudinal analysis. The two-way effects panel data model is formulated and estimated in order to control for omitted variables that are constant across municipalities but vary over time. The model provides insights on the effects of price elasticity, income elasticity, metering, volumetric pricing, and size of the municipality on per capita consumption.

The purpose of Sect. 5.4 is to explore the variability among municipalities in Ontario, using a nonparametric regression to determine the effects of price, income, and metering as independent variables without a priori specification of the functional forms. Nonparametric regressions are a useful approach in determining the relationship between the dependent variable and the independent variables. More specifically, nonparametric regressions allow us to illustrate if the underlying data

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reflect linearity or whether a more general nonlinear model specification would yield better estimates. A nonlinear model consists of different price, income elasticities, and effects of metering that vary across municipalities. The resulting elasticities have implications for water demand management. The Nadaraya-Watson Kernel method of nonparametric regression is used in order to identify the functional form of econometric regression in the panel data for 2001, 2006, and 2009.

The final section is a summary of the major findings and the implications that they have for water policy in Ontario. There are some useful demand management tools that can be effective in promoting conservation if the right conditions are met, as the high per capita consumption of water in Canada as a whole suggests that water conservation has not been given priority. This final section provides some insights for water policy in Ontario.

5.2 Descriptions of Ontario Municipal Water Consumption Data

Ontario has a population of 13,537,994 people (Statistics Canada 2013a). This population is distributed among 444 municipalities, and each municipality is responsible for providing water services to its residents (Ontario Ministry of Municipal Affairs and Housing 2013). Ontario also has one of the largest freshwater surface areas of 158,654 Km^2 (Statistics Canada 2005). Contributing to this vast supply of freshwater are the Great Lakes. Shared between Ontario and the United States, the Great Lakes Basin is one of the world's largest freshwater lake systems (Environment Canada 2013). In addition, Ontario is a highly industrialized province, and is considered to be a leader in financing municipal water infrastructure. As a result, these characteristics make Ontario a key region of focus for water demand management practices. The rest of this section is a description of the available data used in this study.

5.2.1 The Data

Data used in this study was obtained from Environment Canada (Municipal Water Pricing Data) and contains observations for the pricing, metering, and consumption of water for the years 2001, 2006, and 2009. The data also provides information on the size and population of each municipality. In addition, Statistics Canada (2013b) provided median household income data through the Canadian Census for the years 2001, 2006, and 2009. Combined, the water pricing and income data were used to analyze the relationship of per capita consumption of water to price, income, degree of water metering, and size of municipality. Four types of price schemes were investigated. The four schemes are flat rates, constant unit charges, increasing block rates (IBRs), and decreasing block rates (DBRs).

First, the data made it possible to examine the average price of residential water for 2001, 2006, and 2009. We begin by showing that the average price for each year has increased throughout the time period. Figure 5.1 displays the average prices of water for the years 2001, 2006, and 2009. In 2001, the average price of water in Ontario was $1.26 and this rate increased in 2006 to $1.33. In 2009, the price of water increased further to $1.50. These average prices include minimum charges that are imposed on consumers, where applicable. Water prices can be expected to continue to increase in the future in order to finance and upgrade existing water infrastructure. According to Infrastructure Canada, "Water is the most capital-intensive of all utilities, yet in Canada water treatment and distribution are under-priced, and water infrastructure is under-funded" (Infrastructure Canada 2005). As a result, water prices will have to increase in order to reflect the true cost of its use.

Median household income has also increased in Ontario. In 2001, households were receiving on average $50,754 a year. Median household income increased slightly in 2006 to $57,821, but experienced a substantial increase in 2009, reaching an average of $63,518. Figure 5.2 illustrates the general increasing trend of income in Ontario for 2001, 2006, and 2009.

Along with price and income, metering was another important variable included in the Environment Canada, Municipal Water Pricing database. Even though each year (i.e., 2001, 2006, and 2009) contained different sample sizes, the data was still able to provide useful information on the general use of water meters. In 2001, 68 % of Ontario municipalities used, to some degree, water meters to measure the amount of water being consumed. The use of water meters increased to 75 % in 2006 and increased again to 81 % in 2009. Figure 5.3 shows the increase in water metering for the years 2001, 2006, and 2009. It should be noted that Fig. 5.3 only counts the municipalities that did not have any water metering and then began using water

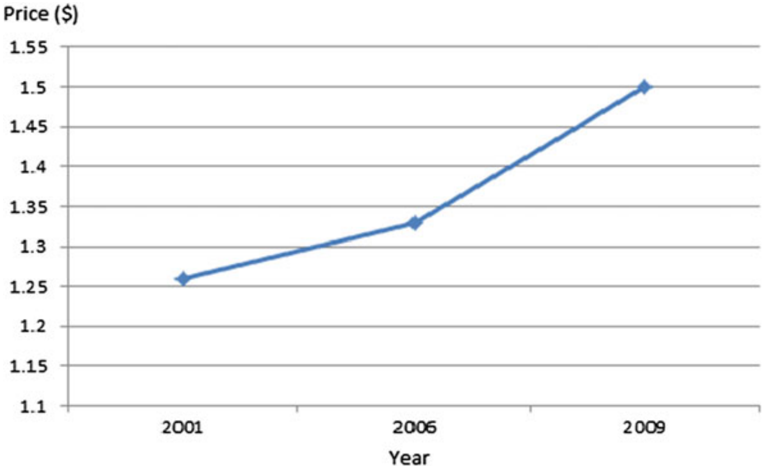


Fig. 5.1 The average price of water for municipalities in Ontario in 2001, 2006, and 2009

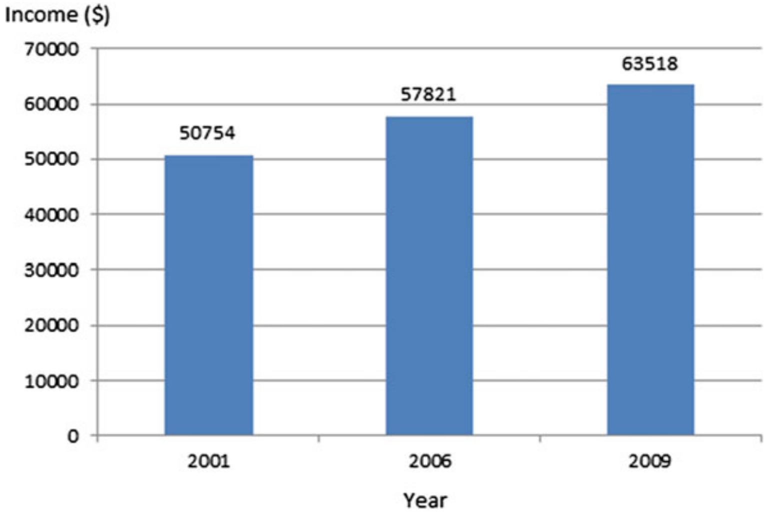
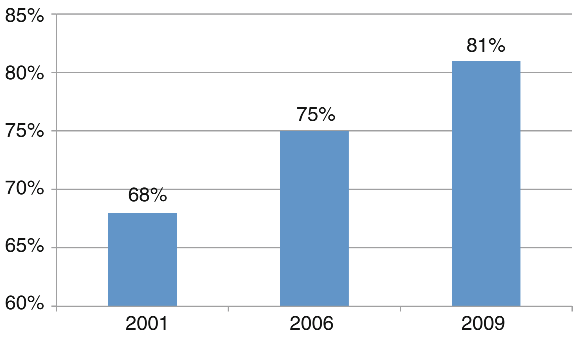


Fig. 5.2 The median household income in Ontario for 2001, 2006, and 2009

Fig. 5.3 Percentage of water metering in Ontario for 2001, 2006, and 2009



meters. It does not count municipalities that already had water metering, but increased the percentage of residents metered.

The Municipal Water Pricing database also provided information on the size of the municipality. By separating the size of municipalities into three groups (i.e., small, medium, and large), it may be possible to distinguish consumption levels of municipalities based on their size. For the purpose of this study, small municipalities have a population between 1 and 1,999 people, medium municipalities have a population between 2,000 and 49,999 people, and large municipalities have a population over 50,000 people. Figures 5.4, 5.5 and 5.6 display how the municipalities are distributed according to their size groups for 2001, 2006, and 2009. Medium municipalities accounted for 75 % of the municipalities in Ontario in 2001, 72 % in 2006, and 74 % in 2009. Large municipalities accounted for 14 % of the municipalities in Ontario in 1991 and 1996, but increased to 23 % in 2001.

Fig. 5.4 The distribution of Ontario municipalities by size in 2001

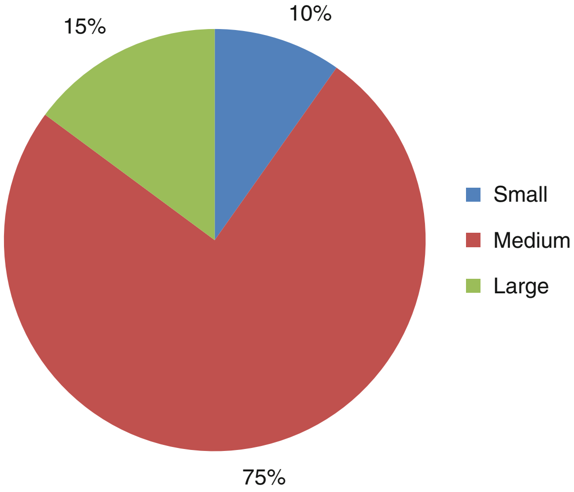
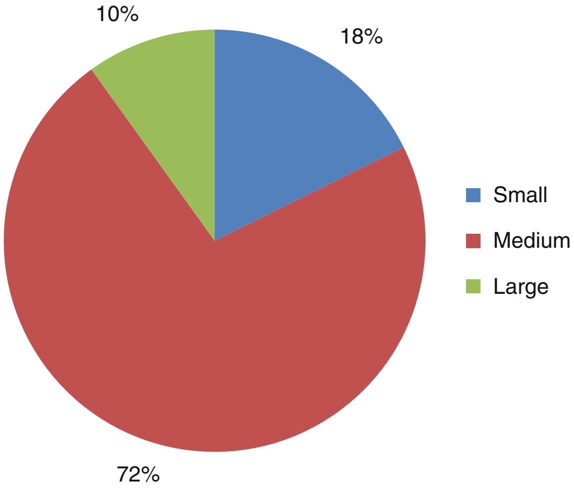


Fig. 5.5 The distribution of Ontario municipalities by size in 2006



Finally, small municipalities accounted for 15 % of the municipalities in Ontario in 2006 and 10 % in 1996, but decreased to 8 % in 2009. The reason for the significant changes in the small and large distributions can be explained by the number of municipal amalgamations that occurred in the late twentieth and early twenty-first centuries. The number of municipalities in Ontario decreased from 815 to 445 between 1996 and 2004 (Association of Municipalities of Ontario 2013), reflecting the merging of some small municipalities into larger ones, which increased the number of large municipalities.

The database also made it possible to illustrate the distribution of price structures throughout the municipalities of Ontario. In 2001, 46 % of municipalities had a flat

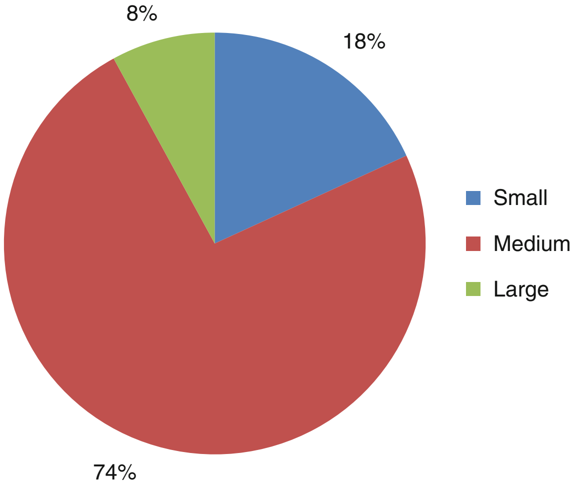


Fig. 5.6 The distribution of Ontario municipalities by size in 2009

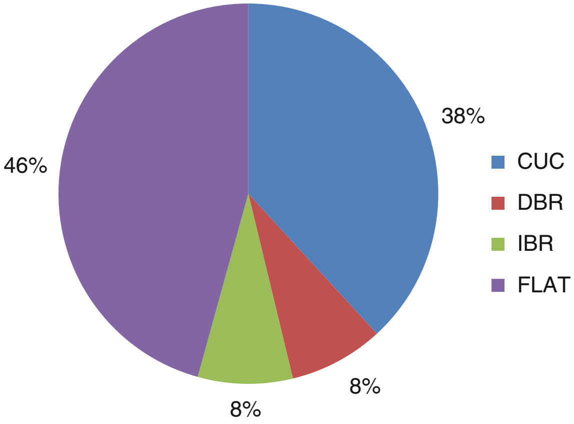


Fig. 5.7 The distribution of pricing schemes for residential water use in Ontario for 2001

rate charge (FLAT), 38 % had a constant unit charge (CUC), 8 % had a DBR, and 8 % had an IBR (see Fig. 5.7). These statistics were observed from a sample of 156 municipalities.

It is clear that in 2001 flat rates were the most used price structure among the municipalities, indicating that water conservation was not a major concern for municipal authorities.

In 2006, 36 % of municipalities had a FLAT, 45 % had a constant unit charge, 11 % had a DBR, and 7 % had an IBR (see Fig. 5.8). These statistics cover a total of 322 municipalities. There appears to have been a dramatic decrease in flat rates being charged to residents, while there has been an increase in constant unit charges.

In 2009, 21 % of municipalities had a FLAT, 61 % had a constant unit charge, 7 % had a DBR, and 10 % had an IBR (see Fig. 5.9).

Fig. 5.8 The distribution of pricing schemes for residential water use in Ontario for 2006

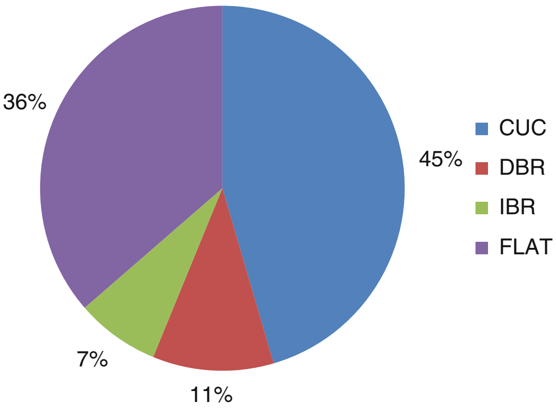
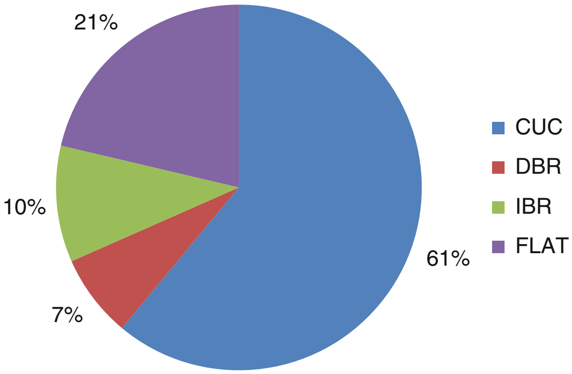


Fig. 5.9 The distribution of pricing schemes for residential water use in Ontario for 2009



Furthermore, Fig. 5.9 indicates that volumetric pricing, namely constant unit charges, were replacing the traditional FLAT by 2009 and becoming more common. These statistics are useful in seeing the general increase in the use of volumetric pricing, which Fig. 5.9 shows was constant unit charges. Furthermore, the statistics suggest that flat rates were being replaced by other pricing schemes and were no longer the dominant pricing policy for water.

The average residential water consumption per capita per day was 0.285 m^3 in 2001, 0.267 in 2006, and 0.225 in 2009 (see Fig. 5.10). There has been a dramatic decline in per capita consumption between 2006 and 2009. This decline was in part due to climatic factors. For Ontario overall, the temperatures in June and July 2009 were cold and average temperatures were 2–3 °C below the 2006 temperatures (Vintner's Quality Alliance (VQA 2013) Ontario 2009). Meanwhile, rainfall was higher than the 2006 level in July and August 2009. The lower temperatures and higher precipitation during the summer months could have contributed to the lower per capita water use in 2009 compared to 2006, as residential summer water consumption is usually much higher due to frequency of lawn watering, car washing, and other outdoor uses. In addition, the recent increase in the installation of

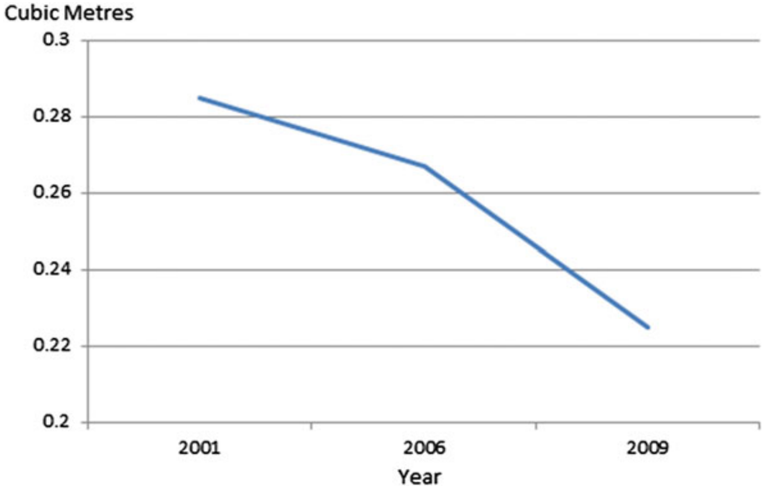


Fig. 5.10 The residential water consumption (Cubic Meters per capita per day) in Ontario for 2001, 2006, and 2009

residential water meters and volume-based pricing probably has affected municipal water consumption. Overall, there has been a general decreasing trend in per capita consumption of water, which may indicate some success of the conservation measures, or simply reflect climatic factors.

5.2.2 Water Demand Equation

The water demand equation is a double-log form that was chosen in order to analyze the percentage change reflected by the coefficients. In other words, this equation was structured to capture the sensitivity (i.e., elasticity) of the variables, or what is usually described as the effect of a percentage change in the independent variables and its effect on each dependent variable, treated separately. This type of percentage change can be measured since the double-log form indicates that the elasticities are constant, but the slopes are not. The water demand equation (Eq. 5.1) is given as follows:

$$\begin{aligned}\mathrm{LPCC} = {} & \beta_1 + \beta_2\mathrm{LPRICE} + \beta_3\mathrm{LINC} + \beta_4\mathrm{MET} + \beta_5\mathrm{PDMET} \\ & + \beta_6\mathrm{DIBR} + \beta_7\mathrm{DDBR} + \beta_8\mathrm{DCUC} + \beta_9\mathrm{PDIBR} + \beta_{10}\mathrm{PDDBR} \\ & + \beta_{11}\mathrm{PDCUC} + \beta_{12}\mathrm{DMEDIUM} + \beta_{13}\mathrm{DLARGE} + \beta_{14}\mathrm{PMED} \\ & + \beta_{15}\mathrm{PLARGE} + u \end{aligned} \tag{5.1}$$

The type and definition of each variable is listed in Appendix 5.1. There are three types of variables used in this econometric model and they are continuous variables, an intercept dummy, and a slope dummy. By including these three types of variables, it is possible to determine to what extent specific factors, both qualitative and quantitative, affect per capita consumption of water. It should be noted that the reference dummy variables are also included in the definition table in order to ensure a complete understanding of the role of each variable in the model. Naturally, the reference dummy variables were not included in the equation to avoid the dummy variable trap.[1]

5.3 Analysis of Ontario Municipal Water Consumption using Panel Data

5.3.1 Introduction to Panel Data

Panel data is the mixture of cross-section data and time series data that allows us to study the dynamic and cross-sectional aspects of per capita consumption in Ontario. Often referred to as longitudinal data, panel data is a collection of observations for multiple entities (i.e., municipalities) in which each entity is observed at two or more time periods (Stock and Watson 2011). This type of data allows us to study changes in the dependent variable over time and, as a result, eliminates the effect of omitted variables that differ across entities but are constant over time, or the effect of omitted variables that are constant across entities but vary through time. The panel data approach increases the reliability of the regression estimates.

Panel data estimation enables us to answer questions relating to the dynamics of change, which is not possible from either pure cross-section or pure time series data. Furthermore, one of the most important advantages of panel data is that it can avoid the problems that pure time series data can encounter, such as multicollinearity and simultaneity. All of these advantages help in obtaining more reliable results, and the panel data equation has a higher explanatory power.

But the biggest disadvantage of panel data is panel attrition. Panel attrition is the loss of panel members over time, which can result in a final panel that is unrepresentative of the population (Lohse et al. 2000). The Environment Canada (2011), Municipal Water Pricing data as well as Median Household Income data observations had 110 municipalities in 2001, 100 municipalities in 2006, and 93 municipalities in 2009. Overall, only 42 municipalities were observed in all 3 years. Although the size of the sample is limited by attrition, the sample is still sufficient to represent the population and to perform panel regressions in order to determine the effects of certain factors on per capita consumption of water.

Despite the disadvantages of panel data and the problem of attrition, the data that was collected for the purpose of this section is a balanced panel. More specifically, the dependent and independent variables are observed for each municipality and

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[1] That is, if reference dummy variables were included, it would lead to perfect multicollinearity.

each time period (2001, 2006 and 2009). This is in contrast to an unbalanced panel, which would have had some missing data for at least one time period for at least one municipality. But we were fortunate: we have a balanced panel.

There are various regression models that are designed to handle balanced panel data. We focus on two major techniques: the **fixed effects model** and the **random effects model**. The fixed effects model controls for all time-invariant differences between the individuals and it cannot be used to investigate time-invariant causes of the dependent variables, while the random effects model assumes that the entity's error term is not correlated with the regressors and is time-invariant and can be included to play a role as an explanatory variable. In order to decide between fixed or random effect, the Hausman test is usually applied to test whether the error term is correlated with the regressors. In a random effects model, the null hypothesis is that the error term is not correlated with the regressors. Our results of the Hausman test indicate that the null hypothesis is accepted when the p value is 0.409 which is not significant at 10 % level (see Appendix 5.2). The random effects model is therefore the best panel estimation method to use in order to determine the effects of price, income, metering, and type of price structure and size of municipality on per capita consumption of water in Ontario.

There are three types of random effects models. First, *the individual random effects model* controls for omitted variables in panel data when the omitted variables vary across municipalities but do not change over time. *The time random effects model* is the second panel estimation method that controls for variables that are constant across municipalities but evolve over time. Finally, the third *two-way random effects model* combines both time and individual effects. Since the two-way random effects model eliminates the effect of unobserved variables that vary across municipalities but are constant over time and for variables that vary over time but are constant across municipalities, it can be considered as the best approach to analyze the municipal panel data. Specifically, the model estimates a different intercept for each municipality at any given time and a different intercept over the years of 2001, 2006, and 2009. The slope coefficients are the same across the municipalities and over time within the two-way random effects model.

5.3.2 *Two-Way Random Effects Model Estimation*

The two-way random effects model is based on the baseline water demand equation. This panel consists of annual observations for 42 municipalities over the period of 2001 through 2009. Table 5.1 gives the estimated results of the two-way random effects model, using GLS. In order to calculate valid standard errors, we prefer to cluster standard errors and allow the errors to be correlated at the municipality level. The overall R^2 is equal to 0.47, indicating that the independent variables included in the two-way random effects model explain approximately

Table 5.1 Estimate of the parameters of the panel data using the two-way random effects model by GLS

Variable	Coefficient	Standard error	Z-stat	P-value
Continuous variables				
LPRICE	–0.4340	0.1416	–3.0600	0.0020
LINC	0.3014	0.2002	1.5100	0.1320
MET	0.0320	0.1720	0.1900	0.8520
Intercept dummies (Price)				
DCUC	–0.7378	0.1294	–5.7000	0.0000
DIBR	–1.1557	0.2043	–5.6600	0.0000
DDBR	–1.1374	0.3641	–3.1200	0.0020
Intercept dummies (Income)				
DMEDIUM	–0.5701	0.2373	–2.4000	0.0160
DLARGE	–0.9263	0.2978	–3.1100	0.0020
Slope dummies (Price)				
PDCUC	0.4514	0.0949	4.7400	0.0000
PDIBR	0.6056	0.1546	3.9200	0.0000
PDDBR	0.8314	0.1834	4.5300	0.0000
PMED	0.0262	0.1711	0.1500	0.8780
PLARGE	0.1260	0.2279	0.5500	0.5800
Slope dummies (Metering)				
PDMET	–0.1644	0.1076	–1.5300	0.1270

Number of observations = 126
Wald Chi-squared = 2551.95 P-value = 0
R-squared = 0.47

47 % of the variance in per capita water consumption. Table 5.2 reports the iterative maximum likelihood estimates (IMLE). The log likelihood-ratio test comparing the model with one-level ordinary linear regression indicates a highly significant model for the panel dataset. Furthermore, the Wald test shows that both Generalized Least Squares (GLS) and IMLE are significant.

5.3.3 Interpretation of the Continuous Variables and the Associated Slope Dummy Variables

Since the estimated results from the two-way effects model by GLS are very similar to the IMLE estimate, we only report the estimated results using GLS. Table 5.1 indicates that two of the estimated coefficients of continuous variables (income and metering) are not significant at the 5 % level. Price was significant at the 0.2 % level and had elasticity of –0.43. That is, if the price of water increased by 1 %, per capita consumption of water would only decrease by 0.43 %, holding everything else constant. This result indicates that demand for water is price inelastic. That is, residential consumers will respond to a very limited extent to changes in the price of

Table 5.2 Estimate of the parameters of the panel data using the two-way random effects model by IMLE (iterative maximum likelihood estimation)

Variable	Coefficient	Standard error	Z-stat	P-value
Continuous variables				
LPRICE	–0.4137	0.1768	–2.3400	0.0190
LINC	0.2660	0.1700	1.5600	0.1180
MET	0.0111	0.1734	0.0600	0.9490
Intercept dummies (Price)				
DCUC	–0.7456	0.2109	–3.5400	0.0000
DIBR	–1.1223	0.3838	–2.9200	0.0030
DDBR	–1.1767	0.3338	–3.5300	0.0000
Intercept dummies (Income)				
DMEDIUM	–0.5231	0.3246	–1.6100	0.1070
DLARGE	–0.8534	0.3897	–2.1900	0.0290
Slope dummies (Price)				
PDCUC	0.4443	0.1241	3.5800	0.0000
PDIBR	0.5689	0.3186	1.7900	0.0740
PDDBR	0.8602	0.2099	4.1000	0.0000
PMED	–0.0040	0.1713	–0.0200	0.9820
PLARGE	0.0827	0.2534	0.3300	0.7440
Slope dummies (Metering)				
PDMET	–0.1486	0.1081	–1.3800	0.1690

Number of observations = 126 Wald Chi-squared = 64.9 P-value = 0 Log likelihood = –43.348214 LR test versus linear regression: Chi-squared = 14.06 P-value = 0.0009

water. This confirms our earlier result on small water systems (Chap. 3) that the demand for water was not sensitive to price changes.

Income was significant at the 13 % level and had a coefficient of 0.3. This result suggested that a 1 % increase in income would increase per capita consumption of water by approximately 0.3 %, holding everything else constant. In addition, the positive income coefficient represents a positive and low-income elasticity, which implies that water is not a normal good but has the characteristics of a necessity. In addition, the insignificant results on metering indicated that water demand is unlikely to respond to metering.

The estimated results for the slope dummies related to the price structures (i.e., CUC, DBR, IBR, and FLAT) were positive and perfectly significant. That is, the effects of volumetric pricing (i.e., CUC, DDBR, and DIBR) were more significant on price elasticity than flat rates and the price elasticity of –0.43 cannot remain the same across the four rate structures. The slope dummy variables of PDCUC, PDIBR, and PDDBR had the estimated coefficients of 0.45, 0.61, and 0.83, which indicates that constant unit charges can be considered as being more elastic than flat rate, but less elastic than block rates.

The slope dummies, interacting price with the size of the municipality (PMED and PLARGE), were insignificant. As a result, the price elasticities do not vary between different sized municipalities. Similarly, the slope dummy, interacting metering with price (PDMET), was found to be statistically insignificant. Therefore, there is no difference in price elasticities between households that are metered and those that are not. Note that this result on metering is very different from the elasticity of metering in small communities, investigated in Chap. 3. Overall, the individual random effects model indicates that factors such as size of the municipality and metering do not influence the price elasticity of water demand, while the type of pricing scheme has significant effects on price elasticity of water demand.

5.3.4 Interpretation of the Intercept Dummy Variables

All the estimated coefficients of intercept dummy variables are negative and significant by GLS and ILME. The estimated coefficient of DCUC was perfectly significant and had the coefficient of –0.74, which indicates that residents facing a CUC will consume approximately 0.74 % less water than residents facing a flat rate, *ceteris paribus*. The dummy intercept variable DDBR is significant at the 0.2 % level and has a coefficient of –1.14. This estimate suggests that if a municipality implements a DBR, per capita consumption would be approximately 1.14 % lower than a municipality that imposes a FLAT, holding everything else constant. The estimated coefficient of DIBR was significant and had the coefficient of –1.16, which indicates that residents facing an IBR will consume approximately 1.16 % less water than residents facing a flat rate, *ceteris paribus*. Therefore, the estimated results from the two-way random effects model indicate that volumetric pricing can be an effective approach in decreasing the level of per capita consumption of water in Ontario.

In addition, large- and medium-sized municipalities were significantly different from small-sized municipalities. More specifically, if a municipality were considered to be medium or large, per capita consumption would be 57 or 93 % respectively, lower than a small-sized municipality in Ontario. This result comes as no surprise since small municipalities have lower densities of population and need more water to maintain lawns, gardens, and other outdoor uses. Larger municipalities have more multiple residential units (apartment buildings), which tend to reduce per capita water consumption.

5.4 A Nonparametric Regression Estimate for Ontario

The two-way random effects model in Sect. 5.3 was carried out under the assumption that the appropriate regression equation was linear in logarithms. The principal assumption of parametric regressions is that the functional form of the econometric model is known or is imposed a priori. Another assumption of parametric regressions is that the joint density of the dependent and independent variables is normally distributed (Ullah 1988, p. 626). However, making these assumptions can have serious consequences for the estimated parameters of the model. If the model is not specified correctly, it could lead to erroneous conclusions about the effects of the independent variables on the dependent variable. As a result, an alternative estimation method should be used that does not rely on parametric assumptions. One such alternative is a nonparametric regression, which estimates bivariate joint probability distributions using kernel methods for analyzing unknown regression relationships (Härdle 1991).

Nonparametric regression can be defined as "[a] collection of techniques for estimating a regression curve without making strong assumptions about the shape of the true regression function" (Altman 1992, p. 175). These techniques are useful for constructing and checking parametric models, as well as for describing the data. A nonparametric approach to estimate a regression is designed to provide a flexible means of exploring a general relationship between two variables. In addition, nonparametric regressions give predictions of observations yet to be made without reference to a fixed parametric model, and provide a tool for finding spurious observations by studying the influence of isolated points (Härdle 1991). Overall, a nonparametric analysis could assist in presenting basic parametric formulations of the regression relationship and identifying the optimal nonlinear form of the econometric model.

The Nadaraya-Watson kernel method is the nonparametric regression technique used in this section. The principal function of the Nadaraya-Watson kernel method is to calculate the predicted values of the independent variable by finding the ratio between the estimated joint density and the estimated marginal density. These predicted values can be plotted against the independent variables to determine if the function is linear or nonlinear. The Nadaraya-Watson kernel method is discussed in further detail throughout this section.

5.4.1 The Nadaraya-Watson Kernel Method of Nonparametric Regression

Ogwang (1994) provides a description of the kernel method of nonparametric regression function estimation, which fully explains how this method can be used to obtain the Nadaraya-Watson kernel estimates.

Consider the nonparametric regression model, Eq. 5.2

$$y_i = M(x_i) + u_i = E(y_i|x_i) + u_i, \quad i = 1, \ldots, n \tag{5.2}$$

where y_i is the observation for the ith municipality of the dependent variable; $x_i = [x_{i1}, \ldots, x_{in}]$ is the $1 \times n$ vector of observations on n independent variables in the ith municipality; and u_i is the disturbance term (independent of x) of each municipality.

The regression function $M(x_i)$ in Eq. 5.2 is the conditional mean of y_i given x_i. This function is treated as unknown in nonparametric models. In a parametric regression model, one would state the specific functional form of $M(x_i)$ For example, the previous section assumed that the functional form of the model was linear, i.e., $M(x_i) = a + bx_i$.

In order to estimate $M(x_i)$ using the kernel method, we assume that, (x_1, y_1), (x_2, y_2), …, (x_i, y_i) comprise a random sample of size n from a strictly continuous (n + 1) variate distribution whose density function, $f(x, y)$, is unknown. Note that is a scalar random variable and x is of order 1 × n. Since $M(x_i)$ is a conditional mean, it can be expressed in terms of a joint density and marginal density. These densities can be estimated nonparametrically using the Nadaraya-Watson kernel method. In this case, the kernel estimator of $M(x_i)$ can be derived by substituting the appropriate kernel estimators of the joint and marginal distributions into the formula for the conditional mean.

The conditional mean of y given x is given by Eq. 5.3.

$$E(y|x) = \int_{-\infty}^{\infty} y[f(y|x)]\mathrm{d}y = \int_{-\infty}^{\infty} y[f(x,y)/g(x)]\mathrm{d}y \tag{5.3}$$

where $f(y|x)$ is the conditional density of y given x; $f(x, y)$ is the joint density of x and y, and $g(x)$ is the marginal density of x.

The kernel estimator of the joint density is given by Eq. 5.4.

$$\hat{f}_I(x,y) = n^{-1}h^{-(n+1)}\sum_{i=1}^{n} K'(h^{-1}(y-y_i), h^{-1}(x-x_i)) \tag{5.4}$$

where $K'(\cdot)$ is a non-negative weighting function (e.g., the multivariate standard normal density) called the kernel function and the quantity h is called the smoothing parameter or bandwidth.

The kernel estimator of the marginal density of x is given by Eq. 5.5.

$$\hat{g}_I(x) = n^{-1}h^{-n}\sum_{i=1}^{n} K(h^{-1}(x-x_i)) \tag{5.5}$$

where $K(h^{-1}(x-x_i)) = \int_{-\infty}^{\infty} K'(h^{-1}(y-y_i), h^{-1}(x-x_i))\, d(h^{-1}(y-y_i))$

Substituting $f(x, y)$ and $g(x)$ in Eq. 5.3 with $\hat{f}_I(x, y)$ and $\hat{g}_I(x)$, respectively, and integrating the result, making use of certain properties of the kernel function, we acquire the following kernel estimator of the conditional mean shown in Eq. 5.6.

$$\hat{M}_n(x) = \hat{E}(y|x) = \sum_{i=1}^{n} y_i c_i \tag{5.6}$$

where $c_i = K(h^{-1}(x - x_i)) / \sum_{i=1}^{n} K(h^{-1}(x - x_i))$

Equation 5.6 is the Nadaraya-Watson type kernel estimator of the conditional mean. The kernel estimates of the conditional mean at any point x may be obtained by evaluating Eq. 5.6. The Nadaraya-Watson kernel estimates can also be interpreted as the predicted conditional mean values of the dependent variable given a specific value of the independent variable. These predicted values can then be plotted against the independent value in order to determine the functional form of the nonparametric regression (i.e., whether it is linear or nonlinear).

5.4.2 The Nadaraya-Watson Kernel Estimation

The nonparametric regressions are estimated using the 2001, 2006, and 2009 Ontario municipal water consumption data, respectively. In order to perform the Nadaraya-Watson kernel, a nonparametric regression model has to be specified. In this particular case, the logarithm of per capita consumption (LPCC) is the dependent variable and the logarithm of income (LINC), the logarithm of price (LPRICE), and the percentage of metering (MET) are considered the independent variables. Equation 5.7 is the nonparametric model used to determine the general relationships among these variables:

$$\mathrm{LPCC}_i = f(\mathrm{LINC}_i, \mathrm{LPRICE}_i, \mathrm{MET}_i) + u_i \tag{5.7}$$

The regression function $f(\mathrm{LINC}_i, \mathrm{LPRICE}_i, \mathrm{MET}_i)$ is not specified for nonparametric models, which means that the relationships among per capita consumption, income, price, and metering are unknown. However, the Nadaraya-Watson nonparametric method calculates the predicted values of the per capita consumption (in logarithms), with respect to the different levels of income, price, and metering.

The adjusted R^2 of the Nadaraya-Watson regressions for each year is around 0.2, indicating that the independent variables included in the nonparametric regression model explain approximately 20 % of the variance in per capita water consumption.[2]

5.4.3 Examining the Predicted Values of Per Capita Consumption

Generating the predicted values for LPCC is important in order to determine the functional form of an econometric model. It is even more important, however, to ensure that these predicted values are statistically appropriate. The width of the

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[2] Statistics from the Nadaraya-Watson nonparametric regression can be found in Appendix 5.3.

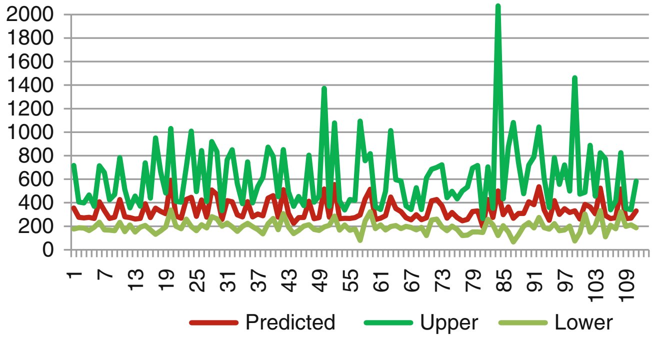


Fig. 5.11 Confidence intervals for the predicted values generated by the nonparametric regression in 2001

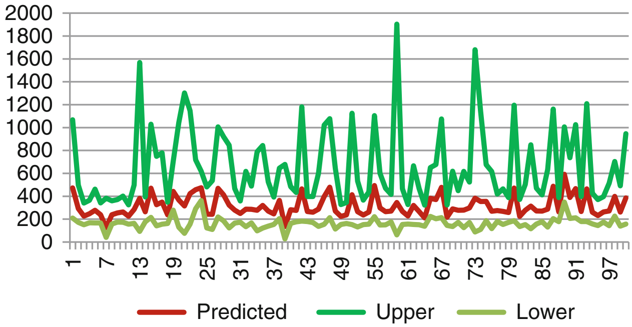


Fig. 5.12 Confidence intervals for the predicted values generated by the nonparametric regression in 2006

confidence interval will give us some idea about how certain we can be about each predicted value. A very wide interval may indicate that more data should be collected before anything definite can be said about the predicted values. Figures 5.11, 5.12 and 5.13 display the confidence intervals of the nonparametric predicted values for 2001, 2006, and 2009 respectively. In addition, Figs. 5.14, 5.15 and 5.16 show the predicted values and the actual values of per capita consumption for each municipality in Ontario in 2001, 2006, and 2009, respectively. The antilog of per capita consumption was also calculated in order to establish a more meaningful interpretation. Furthermore, the units of per capita consumption were converted into liters in an attempt to create a clearer depiction of the confidence intervals.

The confidence intervals indicate that we are 95 % confident that the per capita consumption of each municipality will be in between the upper and lower limits as illustrated in Figs. 5.11, 5.12 and 5.13, respectively. While most municipalities face a narrow confidence interval, there are some municipalities that appear to have a very wide confidence interval. The confidence intervals for Red Rock, Brockville,

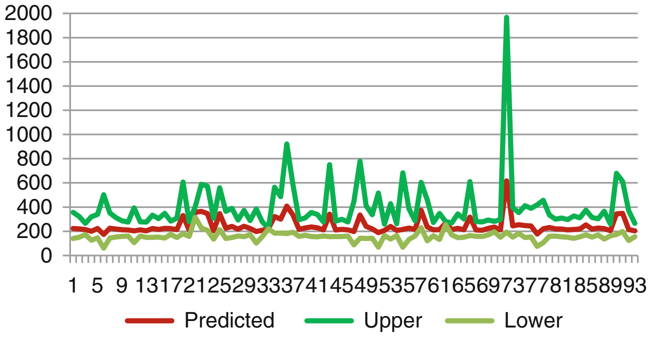


Fig. 5.13 Confidence intervals for the predicted values generated by the nonparametric regression in 2009

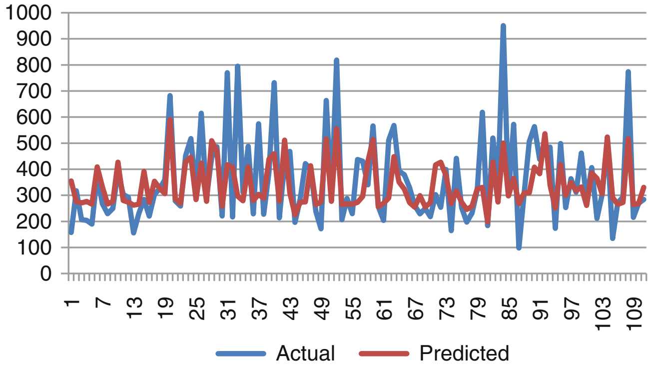


Fig. 5.14 Predicted values of per capita consumption and the actual values of per capita consumption in 2001

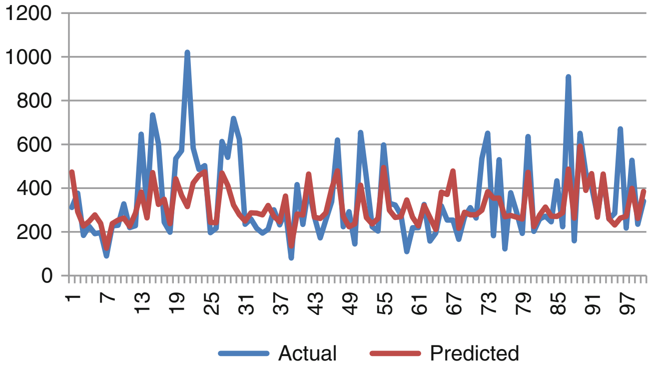


Fig. 5.15 Predicted values of per capita consumption and the actual values of per capita consumption in 2006

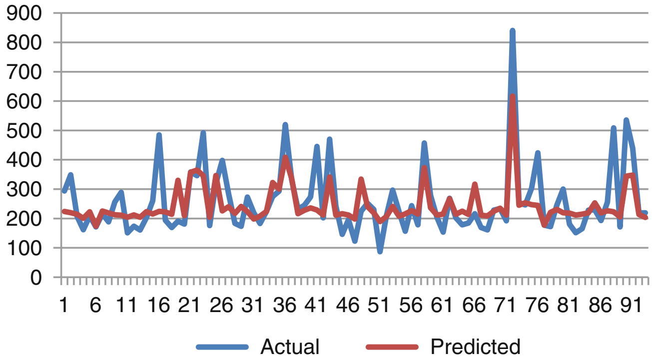


Fig. 5.16 Predicted values of per capita consumption and the actual values of per capita consumption in 2009

and Schreiber were the smallest in width in 2001, 2006, and 2009, respectively, and the confidence intervals for Sables-Spanish Rivers, Oliver Paipoonge and Highlands East were among the largest in width in 2001, 2006, and 2009 respectively. Wide confidence intervals imply poor results. That is, we can only identify possible values of per capita consumption to a broad and uninformative range. Nevertheless, none of the confidence intervals cross zero which indicates that the predicted values are in fact significant. Overall, since the confidence interval for predicted water consumption is smallest in 2009, this implies that the 2009 results are the best compared to other years. Therefore, we conduct a nonparametric regression analysis for 2009, as shown in the following section.

5.4.4 A Nonparametric Regression Analysis for 2009

Figures 5.17, 5.18 and 5.19 illustrate the relationship between predicted per capita consumption of water and different levels of price, income, and metering, respectively. Since the three scatterplots do not indicate there is at least something of a relationship (linear or nonlinear), the predicted values produced by the Nadaraya-Watson nonparametric method do not show a clear relationship with the three independent variables.

More specifically, as shown in Fig. 5.19, although the scatterplot does not indicate that the relationship between metering and per capita consumption is linear, it appears that the higher the percentage of water metering within a municipality the smaller the per capita water consumption. Furthermore, the correlation between logarithm of predicted consumption of water and percentage of metering was –0.78. That is, the linear relationship between the two variables is strongly negative. In fact we can see that in comparison with zero water metering, full water metering has a higher impact in reducing water consumption. Can we therefore conclude that full

Fig. 5.17 The nonparametric regression predicted values of LPCC against the different levels of price in 2009

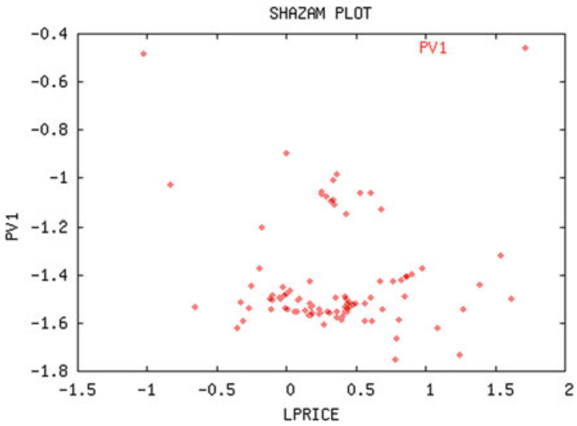


Fig. 5.18 The nonparametric regression predicted values of LPCC against the different levels of income in 2009

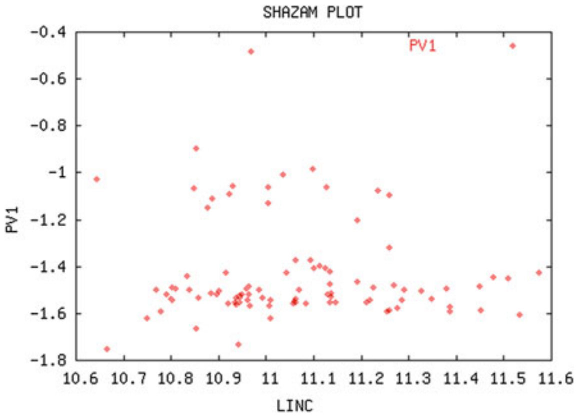


Fig. 5.19 The nonparametric regression predicted values of LPCC against the different levels of metering in Ontario municipalities in 2009

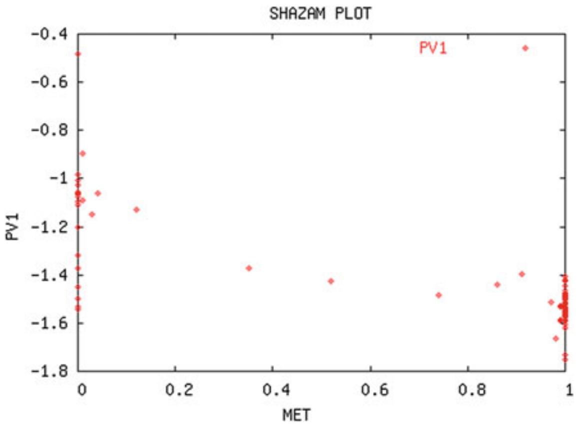


Fig. 5.20 The nonparametric regression coefficients that correspond to a given level of price in 2009

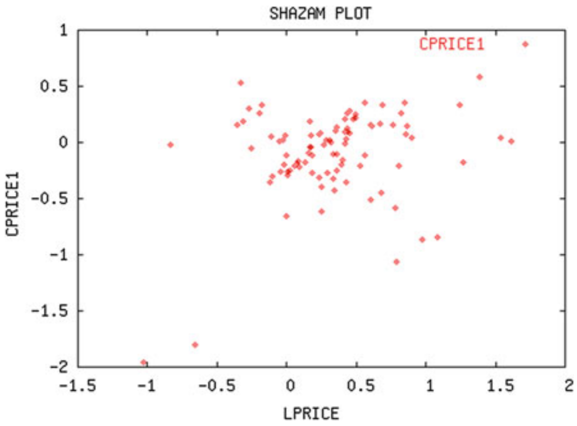
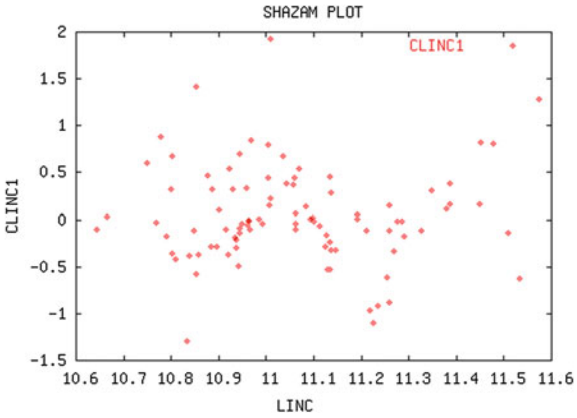


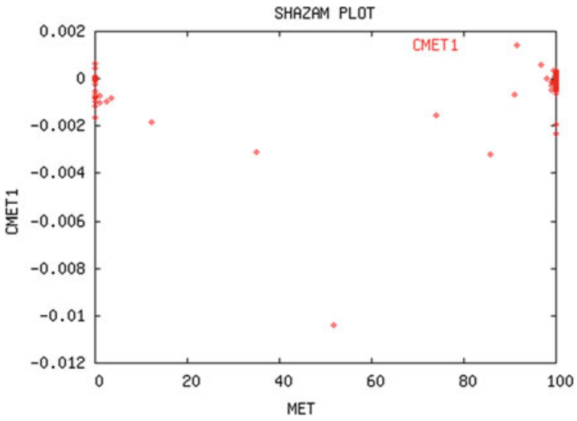
Fig. 5.21 The nonparametric regression coefficients that correspond to a given level of income in 2009



water metering is incentive-compatible? It is interesting to see that close to 88 % of the municipalities that had volumetric pricing had a high percentage of metering (greater than 90 %), while almost 90 % of municipalities in Ontario had a low percentage of metering (less than 5 %) when they provided flat rates in 2009 (see Appendix 5.3); this makes sense as with flat rates, no metering is necessary. Hence, a high percentage of metering is always supported by a volumetric pricing scheme.

Figures 5.20, 5.21 and 5.22 depict the coefficients that correspond to a given level of price, income, and percentage of metering, respectively. The three scatterplots show that the price elasticities, income elasticities, and effects of metering range from positive to negative values. That is, for example, if price were to increase by 1 %, per capita consumption of water will increase, decrease, or remain unchanged depending on the initial level of price, while price elasticity would be a *single* coefficient in a linear-based model. Since the functional form of the regression was established to be nonlinear, the price elasticity, income elasticity, and effect of metering are no longer constant across municipalities (Table 5.4).

Fig. 5.22 The nonparametric regression coefficients that correspond to a given level of metering in 2009



5.4.5 *Predicted Values for Specific Municipalities in 2009*

The Nadaraya-Watson kernel method of nonparametric regression estimates has provided us with a useful technique to evaluate the predicted values. Table 5.3 is a summary of the different predicted values of per capita consumption and other variables that can help explain the important role price has in contributing to an effective water demand management program. There are two municipalities included in this table and each was chosen based on the price of water in their municipality and the value of the predicted volume of per capita consumption. As a result, a clear pattern emerges showing that an appropriate price for water is needed to support the other elements of water demand management.

The predicted value for per capita consumption for Bancroft was the smallest at 174 L. In addition, out of all the municipalities observed in 2009, Bancroft faced the 15th lowest price of water and had the second lowest income. Moreover, the pricing structure during this year was a CUC and it was fully metered. The price elasticity suggests that a 1 % increase in price would decrease per capita consumption of water by 0.58 %, indicating the demand is price inelastic. Since income elasticity is low, household income has no significant effect on water consumption. Furthermore, the effect of metering was 0.36 L. That is, if the percentage of water metering increased within Bancroft by 1 % during 2009, per capita consumption of water would have increased merely by 0.36 L.[3] Although Bancroft was 100 % metered in 2009, the results indicate that the metering did not have a significant effect on per capita consumption of water in Bancroft. We can conclude that the CUC pricing scheme in Bancroft appears to play an important role in reducing per capita consumption of water. This result further demonstrates that metering is not an effective

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[3] The effects of water metering can be directly related to the actual amount being consumed. The interpretation is shown in Appendix 5.4.

Table 5.3 Summary statistics of two municipalities: Bancroft and Schreiber

Municipality	Rate structure	Metering (%)	Predicted value of PCC (L)	Price of water (m^{-3})	Income	Price elasticity	Income elasticity	Effects of metering (L)
Bancroft	CUC	100	174	$2.18	$42,825	–0.58	0.03	0.36
Schreiber	FLAT	0	617	$0.36	$58,043	–1.96	0.85	0.00

Table 5.4 Summary statistics for seven municipalities with high price elasticities or income elasticities in 2009

Municipality	Rate structure	Metering (%)	Predicted value of PCC (L)	Price of water (m^{-3})	Income	Price elasticity	Income Elasticity	Effects of metering (L)
Schreiber	FLAT	0	616.98	$0.36	$58,043	–1.96	0.85	0.00
North Bay	FLAT	0	215.64	$0.52	$56,609	–1.80	0.70	0.00
Minden Hills	CUC	98	189.23	$2.20	$51,693	–1.07	1.41	0.10
Malahide	CUC	100	198.02	$2.96	$60,343	–0.84	1.93	–1.90
Northern Bruce Peninsula	CUC	86	236.29	$4.00	$50,658	0.59	–1.30	–2.67
Brant	CUC	100	225.21	$2.34	$74,955	0.36	–1.10	0.10
Mono	IBR	100	240.9	$1.95	$106,273	0.17	1.28	–0.60

conservation tool unless it is supported by a volumetric pricing scheme. This makes intuitive sense.

In contrast, Schreiber had the highest predicted value for per capita consumption at 617 L, had the lowest price of water at \$0.36 m^{-3} and had the highest negative price elasticity of –1.96. The pricing structure that Schreiber implemented was a flat rate, but unlike Bancroft, Schreiber did not have any metering in their municipality and the estimated coefficient of metering was close to zero. The nonparametric regression estimated a price elasticity of –1.96 which suggests that a 1 % increase in price will cause per capita consumption in Schreiber to decrease by 1.96 %, or nearly 2 %, holding everything else constant.

These results show what linear models cannot show, namely the heterogeneity and different behaviors *among* municipalities. In Schreiber, increasing the flat rate price by 1 % would lower per capita consumption by 2 %. This is the case even when the price of water in Schreiber is so low. Moreover, as there was no metering, nothing can be said about its effect on water consumption.

5.4.6 High Price Elasticities or Income Elasticities of Demand for Specific Municipalities in 2009

The nonparametric regression provides the nonconstant price elasticities and income elasticities of demand to demonstrate *variability* across municipalities. Table 5.4 indicates that there are seven municipalities with high price elasticities or income elasticities out of all the observed municipalities. High elasticity of demand is defined as the value that is greater than one (in absolute value). That is, the changes in price or income have a relatively significant effect on per capita consumption of water.

Table 5.4 reports that price elasticity for Schreiber, North Bay, and Minden Hills was high and that household water demand was income elastic for Malahide, Minden Hills, Northern Bruce Peninsula, and Brant and Mono in 2009.

In contrast, although the municipality of North Bay faced the second highest price elasticity, the predicted value of per capita consumption was 215.64 L, which was below the average level of 225 L in Ontario. More specifically, the price elasticity for this municipality in 2009 was –1.8 and the actual price of water was \$0.52 m^{-3} which was ranked as the fourth lowest price. As a result, if the price increased by 1 %, per capita consumption of water in North Bay would decrease by 1.8 %. Furthermore, there is no effect of metering on per capita consumption and consumption was income inelastic, as seen in Table 5.4. But increasing the FLAT in North Bay would still lower per capita consumption of water. We find in fact that North Bay is a large-sized municipality with a population over 50,000 people. In large municipalities, the need for outdoor water use may be lower and the effort in implementing water conservation policies and practices would be greater, since larger municipalities also tend to offer incentives for reducing water consumption (Environment Canada 2004).

Income elasticity for the municipality of Malahide was 1.93 which is the highest income elasticity out of all the observed municipalities, and the average household income was $60,343. As a result, if the income increased by 1 %, per capita consumption of water in Malahide would increase 1.93 %. This positive income elasticity is an interesting anomaly; it suggests that in Malahide and Minden Hills water is a “normal” good; that is, as income increases more water would be consumed. But there are also two municipalities with negative income elasticities. These two (North Bruce Peninsula and Brant) indicate that for them water is an “inferior” good, indicating that with higher income, more would be spent on other goods. For these communities, it seems as if there are threshold effects: that is, they need water to some threshold level. This threshold volume of water that would be demanded (or “required”) would be independent of price and income.

5.5 General Conclusions of the Demand Analysis

The purpose of nonparametric regressions is to remove any assumptions about the functional form of the model and establish the general relationship between the variables. In turn, the nonparametric regressions can reduce the possibility of misspecification and increase the reliability of the results. The regressions were based on the approach referred to as the Nadaraya-Watson kernel method of nonparametric regression estimation. It was discovered that when the functional form is not specified, the regressions including income, price, and metering were nonlinear. That is, the predicted values of per capita consumption did not produce a linear relationship with any of the independent variables.

A major implication of having a nonlinear relationship between the dependent and independent variables is that the coefficients of the independent variables are not constant. More specifically, for every municipality reported for the independent variable, there is a corresponding coefficient. In the case of price and income, this meant that there were different price and income elasticities for each municipality. Therefore, the effect that price, income, and metering have on per capita consumption depends on the particular value given for that independent variable.

The nonparametric regression results cast doubt on standard neoclassical demand theory. For example, neoclassical demand theory assumes non-satiation and no habit formation. Perhaps one of the earliest studies to cast doubt on the static (linear) consumer demand was Houthakker and Taylor (1970) which showed that a number of standard assumptions about demand are false. Our nonparametric results indicate that standard consumer demand theory should incorporate a dynamic nonlinear counterpart that can account for the nonlinearities. However, since our nonparametric regression method is applied to cross-sectional data, an omitted variable bias could have occurred by not including all other determinants of water demand.

In comparison, the two-way random effects panel regression model eliminates omitted variable bias arising both from unobserved variables that are constant across municipalities and unobserved variables that are constant across time. The estimated relationship between per capita consumption and determinants of water demand is protected from omitted variable bias because of the ability of this model to control for these unobserved factors. But the cost is imposing a linear functional form a priori. Of course, the two-way random effects model was able to create a different intercept for each municipality at any given time and allow the intercepts to vary over the years of 2001, 2006, and 2009. Nevertheless, the two-way random effects regression model cannot account for the nonlinearities.

5.5.1 Effects of Price Elasticity for Water Demand

The results from the two-way random effects regression model suggest that the price elasticity was –0.43 and that being less than 1, it is considered inelastic. This makes sense because water is a necessity and will be consumed regardless of price. Therefore, the elasticity of water is generally expected to be low. In addition, pricing schemes to reduce per capita consumption of water have been greatly criticized by scholars (Nauges and Thomas 2003) as an ineffective policy tool that may not necessarily reduce per capita consumption. Similarly, our findings from the nonparametric regression model indicated that for almost all municipalities water demand was estimated to be price inelastic. There were only three municipalities that had high price elasticities that were above 1 (in absolute value). Although the demand for water is price inelastic, beyond a certain volumetric threshold, if prices are high enough, this could reduce water consumption when accompanied by a volumetric pricing strategy.

5.5.2 Effects of Income Elasticity for Water Demand

Economic theory classifies goods according to its income elasticity; an increase in income would increase the quantity demanded, if water were a normal good. In our panel data study, income elasticity demonstrated that income had a significantly positive but small impact on water consumption. This result is plausible because water is a necessity and consumed at a habitual rate irrespective of the level of income. Nevertheless, a positive income elasticity does make intuitive sense. For example, a family receiving a higher level of income may want to purchase dishwashers, jacuzzis, or even an outdoor pool. Although the results from the nonparametric regression model indicated that income elasticities *vary* across municipalities and range from positive to negative values, there are only three municipalities with high positive income elasticities and two municipalities with high negative income elasticities. Negative income elasticity indicates that if income were to increase, per capita consumption of water would decrease. This would make water an inferior good, according to economic theory. An interpretation of negative elasticity could be that as people receive higher incomes they are more willing to replace old household items including dishwashers, showerheads, and leaky faucets. For example, British Columbia Hydro offers water saving technologies such as Power Smart showerheads which save up to 15 % of a household's water use (BC Hydro 2006). BC Hydro also offers faucet aerators that can save up to 40 % of the water used for hand washing. They suggest that leaky faucets waste up to 130,000 L of water per year per household (BC Hydro 2006). However, these water saving technologies are not usually a priority for a low-income household, and may be purchased only if income is higher. Water is a necessary good, but higher income levels are needed to purchase the technologies available to reduce per capita consumption of water.

5.5.3 Effects of Water Metering and Pricing Structures

The results from the two-way random effects model and nonparametric regression model suggest that metering is not an effective conservation tool unless it is supported by a volumetric pricing scheme. The effects of volumetric pricing such as constant unit charges on reducing water consumption are more significant than non-volumetric pricing such as flat rates. We can conclude that if water demand management relies on economic strategies to implement demand-reducing policies, then it is important to determine if different pricing schemes actually help reduce water consumption.

5.5.4 Other Effects

We also found from the two-way random effects model and nonparametric regression model that medium and large-sized municipalities will consume lower amounts of water compared to small municipalities. A possible explanation for the different consumption levels may be given by investigating the density of housing in large municipalities. For example, the presence of large apartment buildings in major cities reduces the need for outdoor water use and therefore the amount of water consumed per household will be lower. However, in smaller cities and towns where more land is available to individual residents, outdoor water use may be more common and this may lead to higher consumption rates. Furthermore, in more populated municipalities it appears that there is a greater effort toward implementing water conservation policies and practices to reduce the rate of water consumption, since they have access to or implement alternative water demand management strategies, such as bylaws to restrict lawn watering at certain times, and encouraging home water audits (Environment Canada 2004).

A number of models were estimated for water demand in Ontario. Is there a general message that emerges for these empirical results? What light do these results throw on the conventional neoclassical treatment of water demand? The nonparametric estimations show how restrictive the assumptions of the general linear parametric models are. First, the nonparametric model demonstrates the variability of price and income elasticities among municipalities. When the functional form is not imposed, we see the variability emerge. Second, the nonparametric model results strongly suggest the possibility that for most people, at least in the medium and large municipalities, water is a "necessary good" (i.e., a necessity) and not a "normal good": the demand is largely insensitive to price and to income changes. The fact that water is a necessity suggests that at least for some threshold level, to be determined by medical evidence, water ought to be a free public good (for details, see Dore 2015, Chap. 5). Where the demand exceeds this threshold, a volumetric charge makes good economic and also public policy sense. Thus our empirical results show that the conventional treatment of water as a standard "normal" good that ought to be priced on the basis of elasticities may be a gross simplification; such a conventional view is largely driven by the a priori imposition of the linear functional form; once the linearity is dropped, a richer and more varied analysis emerges which has important policy implications.

The importance of nonparametric results shows what linear models hide, namely the heterogeneity among municipalities. In designing water conservation strategies, this heterogeneity should be taken into account. For water consumption, income is probably not a relevant factor, unless pricing policies explicitly take income redistribution or equity into account (see Dore 2015, Chap. 5). Metering is a prerequisite for any form of volumetric pricing, but when water consumption is a small part of the household budget, price elasticities are also likely to be small. For prices of water to have a serious conservation impact, the price of water would have to rise to European levels (see Chap. 9).

Appendix 5.1 The Type and Definition of Each Variable used in the Double-Log Model

Variable	Type	Definition
LPCC	Continuous	Per capita consumption (in cubic meters per day) of the *i*th municipality
LPRICE	Continuous	Average price for 1 m^{-3} (in Canadian dollars) of the *i*th municipality. Values based on an average consumption of 25 m^3/month and in log form
LINC	Continuous	Median household income of the *i*th municipality in log form
MET	Continuous	Degree of domestic water metering, as a fractional percentage of the population served of the *i*th municipality

(continued)

(continued)

Variable	Type	Definition
PDMET	Slope dummy	$D = 1$ if municipality has water metering; $D = 0$ otherwise. Captures the interaction effect of price and metering on per capita consumption
DIBR	Intercept dummy	$D = 1$ if municipality implements an IBR; $D = 0$ otherwise
DDBR	Intercept dummy	$D = 1$ if municipality implements a DBR; $D = 0$ otherwise
DCUC	Intercept dummy	$D = 1$ if municipality implements a CUC; $D = 0$ otherwise
DFLAT	Reference dummy	$D = 1$ if municipality implements a FLAT; $D = 0$ otherwise. If DCUC, DIBR or DDBR are significant then these price structures are significantly different from FLAT rates and will affect per capita consumption differently
PDIBR	Slope dummy	$D = 1$ if municipality implements an IBR; $D = 0$ otherwise. If significant DIBR will have a different price elasticity than flat rates
PDDBR	Slope dummy	$D = 1$ if municipality implements a DBR; $D = 0$ otherwise. If significant DDBR will have a different price elasticity than flat rates
PDCUC	Slope dummy	$D = 1$ if municipality implements a CUC; $D = 0$ otherwise. If significant CUC will have a different price elasticity than flat rates
SMALL	Reference dummy	$D = 1$ if municipality has a population between 1 and 1,999; $D = 0$ otherwise. If MEDIUM or LARGE are significant then per capita consumption is different from a SMALL size group
DMEDIUM	Intercept dummy	$D = 1$ if municipality has a population between 2000 and 49,999; $D = 0$ otherwise
DLARGE	Intercept dummy	$D = 1$ if municipality has a population of 50,000 plus; $D = 0$ otherwise
IMED	Slope dummy	$D = 1$ if municipality has a population between 2000 and 49,999; $D = 0$ otherwise. If significant MEDIUM size groups will have a different price elasticity than SMALL size groups
ILARGE	Slope dummy	$D = 1$ if municipality has a population of 50,000 plus; $D = 0$ otherwise. If significant LARGE size groups will have a different price elasticity than SMALL size groups

Appendix 5.2 Hausman Test for Fixed Effects Model and Random Effects Model

Variable	Coefficients			
	Fixed effects model (b)	Random effects model (B)	Difference (b–B)	Sqrt (diag (v_b-v_B)) S.E.
Continuous variables				
LPRICE	–0.4047	–0.3151	–0.8967	0.0777
LINC	–0.6379	0.0263	–0.6642	0.2787
MET	0.0088	–0.0899	0.9869	0.1090
Intercept dummies (Price)				
DCUC	–0.3722	–0.6513	0.2791	0.2674
DIBR	–0.6772	–0.8070	0.1298	0.3526
DDBR	–0.6032	–1.1496	0.5463	0.3468
Intercept dummies (Income)				
DMEDIUM	–	–	–	–
DLARGE	–	–	–	–
Slope dummies (Price)				
PDCUC	0.2882	0.3621	–0.0739	0.1174
PDIBR	0.3986	0.3178	0.0808	0.2622
PDDBR	0.4737	0.8347	–0.3610	0.1820
PMED	0.1304	–0.7836	0.2088	0.1440
PLARGE	0.0064	–0.1095	0.1159	0.1972
Slope dummies (Metering)				
PDMET	–0.1163	–0.8854	–0.0278	0.1082

Hausman Chi-squared = (b–B)′[(v_b–v_B)^(–1)](b–B) = 12.47
P-value = 0.409
Note DMEDIUM and DLARGE omitted because of collinearity in fixed effects model

Appendix 5.3 Summary Statistics of the Predicted Values of per capita Consumption in 2009 Using Nonparametric Regression Model

Municipality	Rate structure	Metering (%)	Actual value of PCC (L)	Predicted value of PCC (L)	Price ($)	Income	Price elasticity	Income elasticity	Effects of metering (L)
Alfred and Plantagenet	FLAT	100	293.54	223.72	0.89	59,020	–0.36	0	–0.22
Arnprior	DBR	100	172.29	220.04	1.57	53,250	0.09	–0.28	0.21
Arran-Elderslie	CUC	0	180.77	214.3	3.57	60,362	–0.17	0.22	0.00
Aurora	CUC	100	358.72	200.74	1.31	101,923	–0.02	–0.63	0.37
Aylmer	CUC	100	345.89	223.08	1.53	50,908	0.03	–0.38	0.29
Bancroft	CUC	100	492.13	173.76	2.18	42,825	–0.58	0.03	0.36
Brant	CUC	100	175.98	225.21	2.34	74,955	0.36	–1.1	0.06
Brantford	CUC	100	319.58	219.04	1.63	56,837	0.22	–0.05	0.02
Brighton	CUC	100	398.19	212.66	1.15	63,497	–0.18	0.45	–0.38
Brockton	CUC	100	284.91	211.18	1.36	65,065	0.02	0.14	–0.14
Brockville	DBR	99	245.79	204.1	0.73	47,903	0.19	0.89	–0.46
Cambridge	CUC	100	183.23	212.09	1.51	68,373	0.09	–0.24	0.07
Centre Wellington	CUC	100	173.1	203.88	1.85	77,246	0.15	–0.61	0.18
Champlain	CUC	100	273.19	223.43	0.96	64,182	–0.26	0.54	–0.38
Chatham-Kent	CUC	100	219.08	215.48	1.19	51,851	0.07	–0.37	0.10
Chatsworth	IBR	100	229.47	224.17	1.83	57,378	0.15	0.34	–0.13
Clarence-Rockland	CUC	100	182.83	222.58	1.08	82,898	–0.17	–0.12	0.10
Cobourg	IBR	100	193.15	214.36	1.01	57,611	–0.29	–0.05	–0.25
Cochrane	FLAT	0	348.75	330.36	1.4	53,398	–0.42	0.32	0.00
Collingwood	IBR	100	255.98	209.89	1.27	56,131	0.08	–0.3	0.01
Cornwall	FLAT	0	207.26	357.5	0.43	41,924	–0.02	–0.1	0.00
Cramahe	FLAT	0	161.77	365	1.4	62,027	–0.11	0.68	0.00
Dryden	FLAT	0	208.45	345.73	1.7	60,058	–0.2	0.8	0.00

(continued)

(continued)

Municipality	Rate structure	Metering (%)	Actual value of PCC (L)	Predicted value of PCC (L)	Price ($)	Income	Price elasticity	Income elasticity	Effects of metering (L)
East Gwillimbury	FLAT	99	171.37	204.26	2.24	94,038	–0.21	0.82	–0.30
Edwardsburgh/ Cardinal	FLAT	4	215.82	346.11	1.83	67,970	–0.51	–0.16	–0.03
Gananoque	CUC	100	224.09	226.08	1.52	49,111	–0.01	–0.36	0.31
Greater Sudbury/ Grand Sudbury	CUC	100	275.09	240.22	2.14	62,481	0.16	0.38	–0.49
Guelph	CUC	99	293.18	217.41	1.2	68,570	–0.27	0.28	–0.14
Haldimand County	DBR	100	300.34	241.32	2.27	68,510	0.26	–0.53	–0.24
Hamilton	CUC	100	520	223.24	1.1	79,962	–0.22	–0.18	0.16
Hanover	CUC	100	331.62	198.27	0.7	46,595	0.15	0.6	–0.23
Hearst	CUC	100	232.52	208.27	1.19	57,881	–0.04	–0.11	–0.15
Highlands East	FLAT	0	188.48	223.88	5	47,434	0.01	-0.02	0.00
Huron East	DBR	12	180.34	322.54	1.98	60,124	–0.44	0.45	–0.22
Huron-Kinloss	CUC	0	244.72	300.22	0.83	72,470	0.34	0.05	0.00
Ignace	CUC	1	273.6	408.46	1	51,601	–0.66	–0.58	–0.01
Iroquois Falls	FLAT	1	256.47	335.56	1.4	55,385	-0.33	0.54	–0.01
Kawartha Lakes	CUC	99	445.69	216.25	1.57	59,392	0.28	–0.04	–0.06
Kincardine	CUC	100	201.87	228	1	78,284	–0.11	–0.33	0.26
King	IBR	100	508.99	236.13	0.77	96,500	–0.05	0.81	–0.46
Kingsville	CUC	100	470.21	228.9	1	68,419	–0.26	0.46	–0.18
Kitchener	CUC	100	242.5	211.52	1.43	63,709	0.14	0.07	–0.12
Laurentian Valley	FLAT	0	289.3	341.18	1.33	75,782	0.02	–0.92	0.00
Leamington	CUC	100	145.98	211.1	1.27	55,192	0.09	–0.36	0.06

(continued)

(continued)

Municipality	Rate structure	Metering (%)	Actual value of PCC (L)	Predicted value of PCC (L)	Price ($)	Income	Price elasticity	Income elasticity	Effects of metering (L)
London	IBR	100	171.4	216.16	1.53	56,241	0.21	–0.21	0.08
Loyalist	CUC	100	196.19	211.61	1.54	69,324	0.09	–0.32	0.12
Malahide	CUC	100	122.59	198.02	2.96	60,343	–0.84	1.93	–1.94
Mapleton	FLAT	0	151.07	334.38	1.37	77,506	0	–0.89	0.00
Markstay-Warren	CUC	52	224.79	240.36	1.18	54,996	–0.04	–0.1	–5.31
Midland	CUC	100	251.57	219.37	1.18	48,496	0.19	–0.17	0.04
Minden Hills	CUC	98	231.04	189.23	2.2	51,693	–1.07	1.41	0.07
Mississippi Mills	CUC	100	86.71	206.75	1.43	78,953	–0.25	–0.01	0.04
Mono	IBR	100	535.76	240.9	1.95	106,273	0.17	1.28	–0.61
Newmarket	CUC	100	209.4	207.79	1.49	88,084	–0.16	0.16	–0.06
North Bay	FLAT	0	173.57	215.64	0.52	56,609	–1.8	0.7	0.00
North Huron	CUC	74	296.6	226.86	0.9	57,763	–0.3	–0.01	–1.17
North Perth	CUC	100	223.47	214.79	1.54	63,727	0.26	–0.04	–0.07
North Stormont	FLAT	0	160.73	373.23	1.43	66,072	–0.1	0.02	0.00
Northern Bruce Peninsula	CUC	86	156.75	236.29	4	50,658	0.59	–1.3	–2.69
Orangeville	CUC	100	243.78	211.62	1.34	73,953	–0.27	–0.12	0.11
Orillia	CUC	100	178.34	214.61	0.99	48,972	0.06	0.32	–0.26
Otonabee-South Monaghan	FLAT	0	203.02	267.28	4.65	77,512	0.04	0.15	0.00
Ottawa	CUC	100	457.13	214.39	1.26	79,634	–0.32	–0.02	0.06
Owen Sound	IBR	100	439.43	224.67	1.42	49,428	0.1	–0.42	0.26
Perth East	CUC	100	278.81	213.52	1.98	74,488	0.33	–0.96	0.21

(continued)

(continued)

Municipality	Rate structure	Metering (%)	Actual value of PCC (L)	Predicted value of PCC (L)	Price ($)	Income	Price elasticity	Income elasticity	Effects of metering (L)
Peterborough	DBR	3	151.44	317.09	1.53	52,883	–0.36	0.46	–0.03
Petrolia	CUC	100	204.25	211.05	1.2	63,396	–0.12	0.37	–0.33
Quinte West	CUC	100	153.32	208.65	1.17	60,310	–0.09	0.16	–0.29
Richmond Hill	CUC	100	269	224.15	0.95	87,388	0.01	0.11	–0.06
Russell	FLAT	0	260.31	234.98	0.97	99,646	0.02	–0.14	0.00
Sault Ste. Marie	IBR	100	218.71	211.77	1.07	56,051	–0.19	–0.19	–0.14
Schreiber	FLAT	0	485.06	616.98	0.36	58,043	–1.96	0.85	0.00
Severn	CUC	100	202.78	245.29	2.36	66,186	0.07	–0.02	–0.51
Shelburne	CUC	35	178.18	253.75	0.82	63,608	0.26	–0.11	–1.08
Sioux Lookout	CUC	91	184.29	247.02	2.46	67,034	0.04	–0.06	–0.59
South Glengarry	CUC	100	216.19	244.52	2.37	67,735	0.14	–0.29	–0.40
South Huron	CUC	100	168.97	177.1	3.46	56,447	0.33	–0.49	–2.31
South Stormont	CUC	97	161.31	220.6	0.72	68,547	0.54	–0.32	0.51
St. Clair	DBR	100	165.14	231.09	1.02	72,444	–0.25	0.01	0.12
St. Marys	DBR	100	228.29	219.53	1.75	68,175	0.35	–0.52	0.09
St. Thomas	CUC	100	228.51	218.37	1.61	56,599	0.21	–0.09	0.04
Stratford	CUC	100	233.93	211.91	1.06	56,641	–0.21	–0.14	–0.18
Tecumseh	CUC	100	192.14	214.79	0.76	84,771	0.3	0.31	–0.17
Thunder Bay	CUC	100	840.86	219.19	1.64	57,646	0.25	–0.01	–0.02
Tiny	FLAT	0	194.18	253.31	2.64	65,666	–0.87	0	0.00
Trent Hills	CUC	100	253.82	218.99	1.55	53,908	0.12	–0.28	0.18
Vaughan	CUC	100	246.12	226.48	0.98	93,816	–0.2	0.16	–0.07
Wasaga Beach	CUC	100	303.21	222.72	0.9	54,241	–0.3	0.1	–0.23

(continued)

(continued)

Municipality	Rate structure	Metering (%)	Actual value of PCC (L)	Predicted value of PCC (L)	Price ($)	Income	Price elasticity	Income elasticity	Effects of metering (L)
Waterloo	CUC	100	423.62	205.17	1.48	77,626	–0.2	–0.11	0.08
West Nipissing/ Nipissing Ou	FLAT	0	169.24	344.16	1.29	51,422	–0.61	–0.11	0.00
Whitewater Region	FLAT	0	190.9	348.02	1.28	55,794	–0.39	0.32	0.00
Windsor	IBR	100	219.41	213.83	0.89	49,113	0.05	0.68	–0.45
Woolwich	CUC	100	177.47	203.53	1.76	88,161	–0.11	0.39	–0.19

Number of Observations = 93
R-squared = 0.2125

Appendix 5.4 The Determination for the Effects of Water Metering on Water Consumption

Taking into account a simplified double-log model (Eq. 5.7), which is similar to that of Eq. 5.1, the following can be derived:

Simplified Model (Eq. 5.7[4]):

$$\ln y_i = a + bx_i$$

Since the continuous variable MET was already in percentage format, it was not necessary to take the logarithm of the metering variable. As a result, the interpretation of metering is different from the rest of the coefficients. Therefore, by finding $\frac{\mathrm{d}y_i}{\mathrm{d}x_i}$, it is possible to determine the exact effect of a 1 unit (i.e., 1 %) increase in the percentage of water metering on per capita consumption.

Derivation:

We know from Eq. 5.7 that $\frac{\mathrm{d}\ln y_i}{\mathrm{d}x_i} = b$

But $\frac{\mathrm{d}\ln y_i}{\mathrm{d}x_i} = \frac{\mathrm{d}\ln y_i}{\mathrm{d}y_i}\frac{\mathrm{d}y_i}{\mathrm{d}x_i} = \frac{1}{y_i}\frac{\mathrm{d}y_i}{\mathrm{d}x_i}$ since $\frac{\mathrm{d}\ln y_i}{\mathrm{d}y_i} = \frac{1}{y_i}$

It therefore follows that:

$$\frac{1}{y_i}\frac{\mathrm{d}y_i}{\mathrm{d}x_i} = b \text{Implying that} \frac{\mathrm{d}y_i}{\mathrm{d}x_i} = by_i$$

This derivation suggests that the derivative of per capita consumption with respect to the percentage of water metering in a municipality changes as the percentage of metering changes. In other words, the effect of water metering is directly related to the actual amount being consumed.

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[4] In Eq. 5.7 y = per capita consumption and x = the percentage of water metering within a municipality. X and Y variables were used in order to simplify the derivation.

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Chapter 6
Water Policy in Newfoundland and Labrador

6.1 Introduction

The province of Newfoundland and Labrador (NL) joined the Canadian Federation in 1948. For many years its economy was based on one single industry, namely fisheries. It was a poor province with a small population, until oil was discovered offshore and it became a major oil-producing province. Even so, its population in 2013 was only 526,702 (Statistics Canada 2013). There are only two major cities and much of the province is rural in nature. In the provision of drinking water, this province faces severe challenges of turbidity, color, and natural organic matter in the water, which makes water treatment difficult. In this chapter, we describe the water sector and then carry out a statistical analysis of the risks associated with turbidity, color, and natural organic matter and other factors, and show what the risks of failure are for each factor. For example, one major result of the statistical model is that moving from chloramines to chlorine gas reduces the probability of failure by 18 %. The statistical results have some lessons for the rest of Canada, as risk management becomes more important in the future.

This chapter is organized as follows. Section 6.2 is a detailed profile of the public water systems in NL. Section 6.3 covers government policy and regulations. Section 6.4 covers finance and pricing in NL. Section 6.5 is a description of the "potable water dispensing units" (PWDUs) that provide high-quality drinking water to remote areas. Section 6.6 is an introduction to the statistical analysis of risk for health. Section 6.7 specifies a statistical Probit Model, a probabilistic analysis of a system failure and lessons for water policy and priorities. The final section has some conclusions. An important conclusion is that the evidence shows the commitment the Government of NL has made to drinking water supply for its rural population.

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6.2 The Profile of Public Water Systems in Newfoundland and Labrador

As of 31 March 2009, there were 531 public water systems, among which 29 received their water from other municipalities, for a total of 502 separate public water sources in NL. Of that total, 362 were serving fewer than 500 people and were classified as "very small" according to the Atlantic Canada Waterworks Voluntary Certification Board. Furthermore, 317 of 502 public water sources were designated as Protected Public Water Supplies providing water for 91 % of the NL population. Among the protected public water supplies, 258 had surface water sources, which constitute 305 of 502 public water sources, while 59 had groundwater sources. Moreover, the protected public water supplies were largely located in small population areas with 65 % of them serving fewer than 500 people and 89 % serving fewer than 1,500 people, according to Conestoga-Rovers & Associates (CRA 2010). In the CRA study, 69 % of very small public water sources and 89 % of all public water sources serving fewer than 1,500 people were surface water sources.

The province of NL has an extensive online Water Resources Portal database open to the public, maintained by the Department of Environment and Conservation. This database provides regularly updated information regarding all public water systems in NL, including information such as population served, source of water (surface or groundwater), and sampling results for physical, chemical, and metallic parameters covered under the *Guidelines for Canadian Drinking Water Quality, 6th Edition* (GCDWQ). The number of public water systems in NL on April 29, 2011, are shown in Table 6.1[1] (NL Department of Environment and Conservation 2011).

It is clear from Table 6.1 that: (i) Of the 531 public water supplies, 215 were under Boil Water Advisories (BWAs) by the NL Department of Health and Community Services or the Department of Government Services based on the Water Resources Act SNL cW-4.01, representing approximately 45 % of the total public water supplies. A BWA is generally issued when there is reason to suspect pathogen contamination, defined as exceeding the concentration limit for the given pathogen provided in the Guidelines for Canadian Drinking Water Quality (GCDWQ); (ii) nonprotected public water systems are more likely to be under a BWA than those that are protected, while a larger proportion of groundwater systems have active BWAs compared to surface water systems; and (iii) approximately two-thirds of all public water systems in Newfoundland are surface water and a similar proportion is protected with nearly 90 % of surface water systems and about 45 % of groundwater systems being protected (NL Department of Environment and Conservation 2011). The relative lack of protection of groundwater systems may be explained by the fact that groundwater systems serve smaller populations and are in naturally sheltered aquifers.

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[1] Note that all non-public water sources are excluded in this analysis as no relevant data could be found.

Table 6.1 Public water systems in Newfoundland and Labrador (Total number of public water systems: 534) (Newfoundland and Labrador Department of Environment and Conservation 2011)[a]

	BWA	Non-BWA	Total
Surface Water	123	217	340
Groundwater	92	99	191
Total	215	316	531
Protected	116	261	377
Not Protected	99	54	153
Total	215	315	530

[a] *Notes* Discrepancies in Table 6.1 are due to the removal of: (i) Three observations that did not specify surface/groundwater or the protection status; and, (ii) one observation which was marked "partially protected" whose specific meaning could not be deciphered. Protected public water systems is a voluntary designation under *Water Resources Act SNL 2002 cW-4.01* which imposes limitations on human activity around the water systems in a willing community, including restrictions on depositing waste material and establishing camp sites (NL Department of Environment and Conservation Newfoundland and Labrador Department of Environment and Conservation 2009 and CRA 2010)

Among the 215 BWAs, 35.1 % were due to residual chlorination problems (excess chlorine present in the water distribution system), 23.7 % were due to having no disinfection system, and 14.7 % were due to broken disinfection system or a lack of chlorine, while operational problems in distribution systems, voluntarily offline disinfection systems, and microbiological contamination comprised 11.4, 10.4, and 4.7 % of BWAs, respectively.

The CRA report estimates that approximately 50 % of very small public water supplies (serving fewer than 500 people) were under BWA as of February 2009, while 16 % of those serving more than 500 people were under BWA. This result overlaps with a very high rate of BWA among Local Service Districts (LSDs), all but two of which had fewer than 500 residents, with 63 % under a BWA while 24 % of non-LSD municipalities were under BWA. As a consequence, though LSDs, which administer areas considered to have similar needs and consist of five to seven member elected LSD Committees—made up a third of the CRA survey respondents, they made up the majority of BWAs in the survey. LSDs are not incorporated as municipalities and their residents do not pay property taxes.

According to the CRA report, Labrador had the highest proportion of BWAs among public water supplies. This fact is further supported by the Annual Report 2009, which shows that Labrador public supplies had the highest proportion testing positive for coliforms and *Escherichia coli* in the whole province of NL. However, the CRA result may be due to the small number of observations (six of 93 survey results). In addition, the eastern and western regions of NL had higher rates of BWA, at 38 and 45 %, respectively, than the central region at 21 %. This may be due to the higher proportion of communities in the eastern and western regions that are administered by LSDs. The central region has a larger proportion of public water supplies serving fewer than 500 people than the eastern or western regions.

The number of BWAs and communities affected by BWAs has declined or remained constant every year between 2001 and 2007, increasing slightly in 2008 before reverting to the downward trend in 2009. The number of BWAs in 2001 was 322, with 223 communities affected, declining to 215 and 145, respectively, in 2007. Both figures increased in 2008, to 229 for the number of BWAs and 159 for the number of communities affected by BWAs, though the figures dropped below or matched the 2007 amounts in 2009, at 211 and 145, respectively. In 2011, the number of BWAs had again increased to 215.

6.2.1 Source Water Quality and Disinfection

A large majority of NL communities receive their water from protected public water supplies (approximately 65 % of public water supplies are protected, serving 91 % of the NL population). This provides some assurance of quality for NL water sources as protected public water supplies are regulated, and activities that may impair water quality are restricted. Disinfection treatment methods in NL were dominated by chlorine-based systems with 435 of 502 public water supplies (87 %) employing chlorine as of March 2009. The CRA survey in February 2009 found all but 5 of 93 respondents had chlorination and those 5 had no disinfection. Four of the five public supplies with no disinfection were in locations serving fewer than 500 people; as were 56 of 93 respondents (60 %). Meanwhile, all public supplies serving more than 1,500 people had chlorine-based disinfection systems. Further, three of five public supplies with no disinfection were in Western NL, where 26 of 93 respondents were located.

The NL Department of Environment and Conservation (referred to as the department) is responsible for monitoring the chemical and physical quality of public water supplies. The department classifies contaminants into three categories: Inorganic, including metals and other physical and aesthetic parameters; disinfection by-products (DBP), including trihalomethanes (THM) and haloacetic acids (HAA); and special parameters, which include radionuclides, carbon tetrachloride, benzene, and bromate as of March, 2009. In total, 16 water quality indicators (WQI) are measured for adherence (or lack thereof) to the GCDWQ, and these results are presented in the department's annual reports. GCDWQ, in contrast to this department, classifies WQI into DBP, aesthetic, and health indicators. Since GCDWQ is the guideline that the department has adopted, GCDWQ classification will be used in the following sections.

The Department of Government Services is responsible for bacteriological sampling, the frequency for a given public water supply being determined by population size. Specifically, very small systems serving fewer than 100 people are sampled once a month; those serving fewer than 5,000 people but more than 100 are sampled four times a month, while public water supplies that serve a population greater than 5,000 are sampled once every month. It is the department that collects other WQI data; DBPs in surface water public water supplies are sampled 4 times/ year and groundwater sampling for DBPs is usually limited to new public wells.

In the fiscal year ending in March 2009, the Department of Government Services collected a total of 18,836 bacteriological samples divided according to region. These showed significant differences between regions in NL. In particular, Avalon Region, covering the far southeastern part of NL, had the smallest percentage of positives for both coliforms and *E. coli* bacteria at 2.2 and 0.3 %, respectively. On the other hand, Labrador had coliform and *E. coli* positive rates of 6.6 and 1.5 %, well above the NL-wide average of 4.4 and 0.7 %, respectively. Likewise, Western NL exceeded the provincial average, sampling 5.6 % coliform positives and 1.0 % *E. coli* positives. Central NL had coliform and *E. coli* positive rates of 5.5 and 0.7 %, and Eastern NL had rates of 4.1 and 0.4 %, respectively. This distribution only partially correlates with the distribution of BWAs described in the section above, where Labrador was found to have the highest rate of BWAs, but the CRA study found the central region to have a smaller proportion of BWAs than the eastern or western regions (Avalon was included in the eastern region).

6.2.1.1 Bacteriological Indicators

Coliform bacteria are normally found in feces of warm-blooded animals, but they can also survive in external environments, including in aquatic and agricultural environments. There were approximately 10 % greater coliform positives in the 2008–2009 fiscal year than in the previous year, prompting the writers of the *Annual Report 2009* to call for an immediate investigation.

Escherichia coli bacteria naturally inhabit the lower intestines of humans and animals. The presence of *E. coli* in water indicates fecal contamination and suggests deficiency in water-treatment processes or post-treatment contamination. There were three fewer *E. coli* incidences in 2008–2009 than in the previous fiscal year, a decrease of less than 3 % in *E. coli* positives.

6.2.1.2 Physical and Chemical Indicators

The Department of Environment collects all non-bacteriological data for source and tap water in NL. In the 2008–2009 fiscal year, it collected 4,207 samples for chemical indicators. The annual report 2009 presents the number of samples exceeding the Government of Canada Drinking Water Quality guidelines (GCDWQ). Note that the number of samples scheduled by the department was 50 % greater than in the 2007–2008 fiscal period and included 489 source water samples and 3,802 tap water samples. Among the 4,207 actual collected samples, 483 were source water samples and 3,719 were tap water samples. In addition, March 2008 figures from the CRA report are mentioned below, as the report provides the information broken down into sources and communities.

6.2.1.3 Disinfection By-Products

Disinfection By-products (DBPs) are formed when chlorine used for disinfection purposes reacts with humic or fulvic acids in naturally occurring organic materials, such as leaves and tree branches, and bromide ions found in water sources. Therefore, DBPs are more prevalent among surface water sources than groundwater sources. DBPs are considered carcinogenic and the Department of Environment collects data on two types of DBPs regulated by GCDWQ, namely Trihalomethanes (THMs) and Haloacetic Acids (HAAs). A THM component, Bromodichoromethane (BDCM), was regulated separately under GCDWQ guidelines until the guideline for BDCM was rescinded in 2009.

GCDWQ allows maximum concentrations of 100 μg/L THMs in drinking water based on an annual average of quarterly samples. The GCDWQ technical documentation on THMs does not give definitive evidence on the carcinogenicity of THMs in humans. However, experiments on animals have shown that THMs containing bromine seem to induce a greater incidence of cancerous growth than THMs resulting from organic materials. On this basis, a concentration limit of a maximum of 16 μg/L for BDCM had been included in GCDWQ, but the GCDWQ no longer has a separate MCL for BDCM.

In fiscal year 2008–2009, the department observed 128 total THM exceedances comprising 3.4 % of all tap water samples, a 15 % increase from the previous fiscal year. Among the THM exceedances, 50 exhibited BDCM levels above 16 μg/L, a slight increase from the previous year. The CRA study states that 51.1 and 13.1 % of NL communities reported THM and BDCM exceedances in 2008, respectively. This is not surprising given the widespread use of chlorination.

GCDWQ limits total drinking water concentrations of HAAs to 60 μg/L. Yet, there are 5 HAAs commonly found in tap water: Monochloroacetic acid (MCA), dichloroacetic acid (DCA), trichloroacetic acid (TCA), monobromoacetic acid (MBA), and dibromoacetic acid (DBA). Each HAA has studies available, with DCA and TCA having been most extensively studied, while relatively little study seems to have been reported for other HAAs. In general, no conclusive evidence exists to demonstrate potential dangers of HAAs to humans.

In the fiscal year 2008–2009, there were 144 HAA exceedances in NL, including 3.9 % of all tap water samples collected by the department. The fiscal year 2008–2009 was the first year that HAAs were included with a guideline value in the GCDWQ. The CRA study indicates that 54 % of NL communities had exceedances of HAAs; again this is not surprising given the widespread use of chlorination.

6.2.2 Aesthetics

Aesthetic indicators collected by the department include color, pH levels, as well as iron, manganese, copper, chloride, sodium, sulfate, and Total Dissolved Solids (TDS). TDS are inorganic and organic substances that dissolve in water, which negatively affect the taste of water and may also cause hardness in water due to mineral deposits and corrosion. The pH value measures the acidity of water.

The color of drinking water is usually due to organic debris (e.g., soil runoff, leaf remnants, etc.) or metals present in the water. Both surface and groundwater can be colored, but surface water colors are mainly from natural sources, as well as industrial and agricultural runoffs, while groundwater colors primarily arise from dissolved metals. Although color is itself an aesthetic indicator, color can identify dissolved organic material that could increase the chances of DBP formation during the disinfection process. Color is measured in True Color Units (TCU), a measure of light in a solution with 1 mg/L of platinum. The GCDWQ recommends a maximum of 15 TCU in drinking water.

Excessive drinking water color is common in NL with 523 exceedances, or 14.0 % of tap water samples, in fiscal year 2008–2009, which was a 35 % increase from the previous year. The CRA study found 74 % of NL communities' drinking water exceeded 15 TCU, in part due to heavy exposure of NL surface water to organic substances carried in wetlands.

The pH value is the negative common logarithm of hydrogen ion activity that indicates the acidity of water. The acceptable range of pH in the GCDWQ is 6.5–8.5 pH. (The lower the pH, the greater the acidity of the water; with higher pH, the water is considered more "basic.") The effects of pH depend on the acidity of water; high pH decreases the efficiency of chlorine disinfection and creates scales in water distribution systems; meanwhile, low pH improves the efficiency of chlorination processes, but corrodes metals found in water distribution systems. NL water sources tend to have low pH as many surface public water supplies are located in watersheds that have large areas of bogs.

In the 2008–2009 fiscal year, the department found 283 samples below 6.5 pH and 21 samples above 8.5 pH, or 7.6 and 0.6 % of all tap water samples, respectively. PH exceedances increased 25 % from 2008, when the CRA study found that 72 % of NL communities had pH lower than 6.5, while only 3.5 % of the public water supplies in NL had pH higher than 8.5.

Among other aesthetic parameters, chloride, sodium, sulfate, and TDS levels in NL were negligible in the 2008–2009 fiscal year. However, iron and manganese were common in NL, where iron in drinking water is caused by the dissolution of iron piping and manganese is naturally occurring in both NL groundwater and surface water sources. Neither metal has harmful effects on humans, though taste is adversely affected and the metals in water may stain household items. The GCDWQ recommends maximum iron and manganese concentrations of 0.3 and 0.05 mg/L, respectively.

There were 121 iron and 81 manganese exceedances during the 2008–2009 fiscal year, comprising 3.2 and 2.2 % of total department tap water samples, respectively. The CRA study reports that, in 2008, 29 % of NL communities had iron concentrations greater than the GCDWQ guidelines and 24 % had manganese concentrations greater than the GCDWQ.

6.2.3 Health

The health parameters in the GCDWQ collected by the department include turbidity, arsenic, lead, fluoride, and barium, all of which have potentially severe harmful effects on human health. Turbidity denotes the “cloudiness” of water due to organic and inorganic matter as well as microscopic organisms. The incidence of turbidity remains a serious problem in all source waters in NL.

Turbidity is measured in nephelometric turbidity units (NTU) and the GCDWQ guidelines suggest a maximum of 0.1 NTU in drinking water at all times. The *Annual Report 2009* and the CRA study use a less stringent maximum of one NTU, the alternative recommendation in the GCDWQ for chemically assisted filtration systems. To provide some perspective, raw surface water and groundwater sources under the direct influence of surface water (GUDI) range between 1.0 and 1000 NTU. Some of these would be unprotected wells.

Turbidity is considered a health parameter, as suspended matter in water can include toxic substances, such as metals as well as microorganisms. Moreover, high turbidity often denotes the presence of biological matter in drinking water and raises the amount of DBPs formed through disinfection processes. High turbidity may also reduce the effectiveness of some disinfection processes; for example, the effectiveness of ultraviolet (UV) radiation for disinfection would be reduced. The nature of turbidity and its health implications differs based on the water source: surface water and GUDI sources—the large majority of small NL public water supplies—tend to contain industrial wastes and organic matter, and turbidity from these sources is often a serious health hazard. But turbidity from groundwater sources generally does not contain toxic or organic substances and may not be harmful. This will become known only after testing the water source.

Turbidity is a significant and growing concern in NL with 63 exceedances in the 2008–2009 fiscal year, or 1.7 % of all tap water samples, a growth of nearly 35 % from the previous fiscal year. The CRA study states that, in 2008, 47 % of NL communities had drinking water exceeding one NTU and only 11 of the 149 water systems with high turbidity results had the necessary filtration treatment to deal with the turbidity issue.

6.2.4 Relationship to Boil Water Advisories (BWAs)

The CRA report found the relative percentage of NL communities with high levels of the above health and aesthetic parameters to be not statistically different from communities with BWA—not a surprising result. PH levels are an exception, where 61 % of communities with BWA had low pH readings in 2008, compared to 80 % for communities without BWA (high pH exceedances were below 5 % in both groups of communities). This may be due to low pH water improving the effectiveness of water treatment processes.

The same report states that a correlation between BWA and DBP exceedances was found in 2008 with less than 30 % of communities under BWA having excess DBP, while over 60 % of non-BWA communities had excess DBP in their drinking water. This suggests insufficient chlorination in BWA-affected communities and over-chlorination in non-BWA communities in NL.

6.2.5 Disinfection Methods

Disinfection processes in NL are dominated by chlorine systems, which accounted for 87 % of all public water supplies in March 2009. Among the chlorine systems, 68 % were liquid chlorine systems, 30 % were chlorine gas systems, and the rest were chlorine powder systems. In addition, there were 31 UV, 4 ozonation, and 6 mixed oxidant systems. These non-chlorine disinfection treatment methods made up only 8 % of the 502 public water supply systems in NL.

What follows here is an outline of the nonfinancial aspects of different disinfection methods. See Sect. 6.3 for financial aspects of the disinfection processes.

6.2.5.1 Chlorination

The majority of disinfection systems in NL are either gas chlorination or hypochlorite (liquid or powder) chlorination type. In *Chlorination Equipment Selection Guidelines* (the chlorination report/study), published by the Department for the Environment and Conservation in 2005, typical gas equipment consists of 68–908 kg equipment sets and requires an airtight room for disinfection. Hypochlorination systems require less equipment, but sodium hypochlorite (for liquid chlorination) is only 12 % chloride, and powder chlorine is 65 % chloride (when mixed). This effectively limits the amount of chlorine solution available for disinfection at 12 % for liquid and 65 % for powder chlorination systems. On the other hand, gas chlorine is a pure chloride and provides 100 % available disinfection. All chlorination processes produce DBPs when chlorine solutions react with organic substances in source water. It should be noted that chlorination is generally effective in eliminating bacteria and viruses, but not protozoa.

Powdered chlorine is primarily used in very small and remote communities as there is no delivery during the winter season—powdered chlorine can retain potency until mixed, while liquid chloride has a shelf life of 3 months and gas systems are generally more expensive. The chlorination report counted 10 powder systems in NL in May 2005, serving 4,946 people; and one powder system was on BWA. This suggests a decrease of one powder system in March 2009, compared to 2005, which may be due to the overall number of public water systems decreasing from 533 to 502 during the same period.

Gas systems served a disproportionately large population in 2005 with 160 serving 348,846 people, or 35 % of all public water supply systems serving 85 % of the total NL population. Among those, 17 were on BWA affecting 10,998 people, a slightly larger proportion than with powdered chlorine, but still far smaller than for liquid chlorination systems. The 17 gas systems that were under BWA comprised 11 % of the 155 BWAs in NL (in May 2005).

Liquid systems suffered from disproportionate BWAs with 137 of 284 NL liquid systems under BWA in May 2005. The liquid systems served 57,421 people, and together with gas systems, these made up 65 % of the public water systems in NL. However, liquid systems were responsible for 89 % of BWAs in NL. This finding is largely in agreement with the CRA study's findings that showed public water supply systems serving fewer than 500 people were much more likely to be under BWA than those serving larger populations. The chlorination report notes that most of BWAs can be attributed to lack of expertise necessary to operate chlorination equipment properly in small communities.

6.2.5.2 Other Processes

UV irradiationused in UV systems is capable of inactivating surface water pathogens such as *Cryptosporidium* oocysts and *Giardia* cysts effectively without producing DBPs. In March 2009, there were 31 UV systems in NL. According to the February 2009 survey by CRA, all UV systems were located in public systems serving more than 500 people and were located in Western NL. As noted above, there were four ozonation systems and six mixed oxidant systems in NL as of March 2009.

6.2.6 Treatment Process Distribution

Treatment process distribution data have been entirely derived from the CRA study, which used a survey of 93 public systems in NL (22 % of total public systems) during February 2009. This study found no clear trends based on geography or governance, but a significant trend seemed evident based on population served.

In total, 20 of the 93 respondents had filtration and 14 had pH adjustment systems. Fewer than 10 respondents indicated the presence of the other treatment systems in the survey, with softening and arsenic removal systems having only one positive reply. Similarly, taste and odor amelioration, fluoridation, and UV systems were present in two public systems. In general, a high proportion of NL communities had exceedances in measures of pH, turbidity, color, and other GCDWQ indicators.

6.2.7 Geography and Governance

There were six public water supply systems in Labrador. All of these had chlorination systems and yet all were under a BWA as of February 2009. In addition, Labrador systems had the highest incidence of pH adjustment and filtration systems among the four regions in the CRA study (Labrador, west, central, and east regions). The only region in the survey sample to rival Labrador for filtration system prevalence—the most common solution for turbidity—among the public systems was Central NL (8 of 23), the region with the lowest proportion of systems under BWA in February 2009. The west region (29 of 93 respondents) had the largest proportion of systems with no disinfection systems.

Among the 30 LSDs responding to the survey, none had pH adjustment facilities and two had no disinfection systems (or 6.7 %). Of the 63 municipalities in the survey, 14 had pH adjustment facilities (22.2 %) and three had no disinfection systems (4.8 %). Municipalities had a large majority of filtration systems with 18 of 63 public water supply systems (28.6 %) compared to 2 of 30 LSD systems (6.7 %). These figures show an overwhelming concentration of BWAs in LSDs.

As stated earlier, a large majority of NL public water supply systems serve fewer than 500 people and small systems have a disproportionately large share of the total BWAs. This is clearly demonstrated in the CRA survey which had BWAs in four of 56 very small systems (fewer than 500 people served), one of 21 small systems (serving between 500 and 1,500 people), and none of 16 medium to large systems (more than 1,500 people served). Most had no disinfection system.

For treatment processes, one of 56 very small public water systems (1.8 %), five of 21 small public water systems (23.8 %), and 8 of 16 medium to large public water systems (50 %) had pH adjustment facilities in the CRA survey. Likewise, both systems with taste and odor control systems were medium to large size, and among the two systems with UV, one was a small system and the other was a medium to large system. Overall, medium to large systems were more likely to have sedimentation, flocculation and fluoridation capabilities than very small and small systems.

The above tendency of positive correlation between size and facility does not hold for all treatment processes in the CRA survey. The largest percentage incidence of filtration systems occurred in small systems (8 of 21 or 38 %), followed by medium to large systems (5 of 20 or 25 %) and very small systems (7 of 52, or 14 %). Moreover, there were no small systems respondents with fluoridation, while one very small system and two medium to large systems were equipped with fluoridation facilities—although, as mentioned above, fluoridation distribution is more likely in facilities in larger systems. Nevertheless, the CRA study concludes that a significant positive correlation exists in the survey data between population served and facilities available.

6.3 Government Policy and Regulations

6.3.1 Government Policy

The water policy of the Government of NL is based on the Multi-Barrier Strategic Action Plan (MBSAP) involving the Department of Environment and Conservation, Government Services, Health Services, and the Department of Municipal Affairs (MAF), with the Department of Environment and Conservation leading policy implementation. The multi-barrier approach to drinking water treatment has been adopted by policy makers for its success at enhancing water quality and averting disease outbreaks (NL Department of Environment and Conservation 2010; Cool et al. 2010; WHO 2011). The multi-barrier approach comprises three parts, including source water protection, water treatment, and distribution management, where the goal is to "block or control microbiological pathogens and chemical contaminants that may enter the water supply system, regardless of whether these substances have been identified as a concern" (CDW[2] and WQTG[3] 2004, p. 15). In the case of the MBSAP in NL, the component barriers are divided into three levels: The first deals with the standard requirements of the multi-barrier approach—source water protection, water treatment, and distribution system maintenance; the second level concerns monitoring, enforcement, and operator training; and the third level involves public relations, legal frameworks, and corrective measures (Department of Environment and Conservation 2009).

6.3.2 Multi-Barrier Strategic Action Plan (MBSAP) Level 1

Level 1 of the MBSAP covers source water protection, drinking water treatment, and drinking water distribution. The primary method of source water protection, the formation of protected public water supply systems, has already been discussed above. Therefore, the following sections will concentrate on specific procedures pertaining to these systems. Drinking water treatment in NL has been described above and this section will only report on water treatment plants. Finally, drinking water distribution in NL will be detailed in some depth.

The *Annual Report 2009* gives information about the "Protected Public Water Supply" systems which were established under the *Water Resources Act SNL 2002 cW-4.01*: The designation of "protected" is voluntary and a willing community must submit an application to the Department of Environment and Conservation to begin the "protected" designation process. Once an application has been submitted, the Water Resources Management Division at the department collects information about land ownership, drainage patterns, natural boundaries of the watershed area,

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[2] Federal-Provincial-Territorial Committee on Drinking Water.

[3] Canadian Council of Ministers of the Environment Water Quality Task Group.

nearby land-use activities, and surrounding topography. This information is used by the department to delineate watershed boundaries, which are then entered into its geographic information system (GIS) database. Then the map produced through the GIS database is submitted to government's Interdepartmental Land-Use Committee, which reviews the proposal for a new protected system for any land-use conflicts (recreational, commercial, or any other activities that may be forbidden once the protection comes into effect) and creates possible resolutions for the conflicts. Once the committee's review is complete, the government designates the water supply as either a "Protected Public Area" or a "Protected Wellhead" for surface and groundwater sources, respectively. Finally, a legal description of the protected public water supply system is posted in the *Newfoundland and Labrador Gazette*.

The Water Resources Act, *SNL 2002 cW-4.01* sets the basis for the protection policy and bans activities considered potentially harmful to drinking water quality. The *Act* also secures buffer zones around the area of a minimum 50 m for major tributaries, lakes or ponds, up to a minimum 150 m for intake ponds and lakes where the following restrictions hold.

Activities banned in a protected public water supply system include: Depositing sewage, chemicals, or industrial wastes; transporting logs or riding any motor vehicle when the area is ice-covered; construction and development; storage of chemicals; clear cutting of forests; establishing camp sites; establishing cemeteries, waste disposal facilities, or any other facilities that the NL Minister of Environment considers unacceptable.

Activities requiring prior ministerial approval in protected systems include: Expansion or upgrading of existing facilities; development of farm lands for non-animal food production (grains, fruits and vegetables, and forage); forest logging, resource road construction and use, tree farming, and other related forestry activities not considered harmful by the minister; mineral exploration; installation of pipelines; and any other activities which the minister considers to have potential for harm to drinking water.

It is the responsibility of municipalities and LSDs to ensure the provisions of the *Act* are fulfilled for their own protected water system, and are obligated to order a stop to, and report to the government any possible violations of the *Act*. Once a violation has been identified, the minister can order the violator to provide an alternate supply of drinking water until the existing water system has been restored, force the violator to rehabilitate the protected water quality, or remove any facilities deemed necessary by the minister to eliminate the risk of contamination.

The minister is granted extensive powers over protected water supply management by the *Act* as has already been described. In addition, the minister may revoke any approval he/she has already given if the proponent in the approval has failed to comply with the terms of the approval, if the approval is found to have been issued in error or with incomplete information, or if the minister concludes that the approved activity in question has the potential to cause impairment to water or environmental quality not anticipated at the time of the approval. Moreover, the minister has the authority to remake the boundaries of a protected water supply system if he/she decides it is necessary.

Thirteen NL water treatment plants were in operation—in general serving medium to large populations—in March 2009, and they are required to meet the GCDWQ guidelines. Of the 13 water treatment plants, 6 were full-scale conventional plants with coagulation, flocculation, sedimentation, and filtration capabilities designed to treat water. All 13 water treatment plants used chlorination as the primary disinfectant and 8 received upgrades to their chlorination systems during the 2008–2009 fiscal year.

Communities can obtain a water treatment plant by applying jointly to the Department of Municipal Affairs and the Department of Environment, when the latter has determined that there are water quality problems that require correction. Subsequently, the beneficiary municipality must engage an engineering consultant to recommend appropriate water treatment technologies by reviewing at least six technologies and then piloting three of them. The consultant is to review water quality data, operations of pilot plants, and economic viability of the given technology prior to offering a recommendation. The recommendation must be accompanied by a report that the Department and Municipal Affairs appraise before the plan is finalized.

The final components of MBSAP are the 531 public water distribution systems that encompass all pipes, valves, service lines, pumping stations, fire hydrants, and storage facilities required to deliver drinking water. As noted earlier, a large majority of the distribution systems (68 %) serve fewer than 500 people (in 2009). Only three distribution systems cater to more than 15,000 people, 0.6 % of all systems.

The very small distribution systems face significant challenges in meeting GCDWQ standards. In particular, some small communities lack the resources to uphold proper operation and maintenance (O&M), including attracting and retaining skilled and certified staff. Furthermore, many very small communities are spread over large geographic areas, seriously undermining possible economies of scale and adding to administrative costs. To mitigate these weaknesses, in 2008–2009 fiscal year, Municipal Affairs allocated approximately $16 million to help fund 33 water infrastructure programs. The details of O&M policy and practices in NL are discussed in the subsection below.

6.3.3 Multi-Barrier Strategic Action Plan Level 2

MBSAP Level 2 was designed to identify and resolve failures in MBSAP level 1, and contains monitoring, data management and reporting, inspection and enforcement, and operator training, as well as implementing the drinking water policy of the province.

In 2008–2009, the department was responsible for physical and chemical indicator sampling and collected 4,207 samples, approximately a 50 % increase from 2007–2008, primarily from new guidelines for HAA published in the GCDWQ. Among the 4,207 samples, 483 were source samples including 266 surface water source and 217 groundwater source samples. 3,719 tap samples were taken in the same period, including 3,015 surface water samples and 704 groundwater samples. All source water samples were inorganic testing samples, while 1,061 tap water samples were tested for inorganic. The rest of the tap water samples were for THMs and HAAs. For THMs, there were 1,130 samples, and for HAAs, 1,528 samples, comprising much of the increase in sampling between fiscal years 2008–2009 and 2007–2008.

Government Services is responsible for bacteriological sampling, and the department collected 18,836 samples in 2008–2009. Regionally, it collected 6,749 samples in Avalon, 1,557 in Eastern NL, 4,586 in Central NL, 3,537 in Western NL, and 2,407 in Labrador.

The maximum allowed concentrations (MACs) of physical and chemical parameters and other standards are prescribed in *Guidelines for Canadian Drinking Water Quality, 6th Edition* (GCDWQ), 1996. The department determines the parameters to be sampled for, based on the GCDWQ. The current chemical parameters monitored include: Aluminum, ammonia, antimony, arsenic, barium, boron, cadmium, calcium, chloride, chromium, copper, fluoride, HAAs, hardness, iron, lead, magnesium, nitrate, potassium, selenium, sodium, sulfate, Total Organic Carbon (TOC), THMs, uranium, and zinc, notably not including gasoline. Physical parameters monitored include: Color, conductivity, pH, TDS, and turbidity.

The Water Resources Act, *SNL 2002 cW-4.01* divides each fiscal year into four sampling windows, approximating the seasons of the year, which are different between the Island of Newfoundland and Labrador. The four sampling windows for the Island are: May 16–June 30, August 1–September 30, November 1–December 15, and January 15–March 15. For Labrador they are: May 1–June 30, July 1–August 30, October 1–November 15, and January 1–March 15. Note that approximately a month is excluded in both the Island and Labrador windows around December.

Source water is sampled every 2–3 years, and in the year where the given source water is sampled, the frequency is semi-annual. Tap water is sampled at least semi-annually for inorganic parameters, rising to a minimum of once per sampling window for public water systems serving more than 5,000 people. DBPs have a separate sampling schedule of minimum once per sampling window for surface water sources and at least annually for groundwater sources with a DBP concentration of less than 10 μg/L. Groundwater sources with DBP concentrations above 10 μg/L have the same schedule ordinance as surface water sources. Sampling rotations of 3 years are maintained, whereby groundwater sources are sampled during the summer and winter months while surface water sources are sampled during the spring and fall months. The sampling times are reversed for the next sampling rotation between surface and groundwater sources.

Source water samples are taken prior to any disinfection or other treatment, in as close proximity to the intake as possible. Tap water samples are typically taken from a single location per public water system about two-thirds of the way through the distribution system. The grab sample method is used for tap water samples, where the tap must be run for at least 5 min prior to sampling to ensure that all standing or stagnant water is flushed from the plumbing system. THMs are sampled in the same way as other tap water samples while HAAs are sampled in the same way except that the sampling location is toward the beginning of the distribution system. All samples must be received by the laboratory for testing in less than 5 days following sampling.

Bacteriological sampling parameters of interest are *E. coli* and total coliforms, and the maximum allowed concentration is zero. Separate bacteriological sample procedures exist for public systems and private wells. For public systems, at least one sample must be taken from the beginning and the end of the distribution system, and disinfection residuals must be confirmed for each sampling point, except for PWDUs, for which disinfection residuals need not be checked. (PWDUs are discussed in Sect. 6.5.)

If *E. coli* is discovered in a public system, then resampling of the collection point as well as up and downstream locations must be performed within 24 h. If the existence of *E. coli* is confirmed in the drinking water, a BWA is recommended for the system. A BWA is also recommended for distribution systems lacking disinfection residuals and for systems without continuous disinfection operations. If testing shows the presence of total coliforms but not *E. coli*, a BWA is only recommended if the system has no additional water treatment (e.g., coagulation, filtration, etc.) or no significant operational controls over the system. Any boil water advisory may only be rescinded upon two consecutive samples confirming the eradication of bacteria in the drinking water system.

Government Services offers bacteriological sample testing for private wells without charge. Private citizens may obtain authorized containers from government service centers located around NL and return the collected water samples to be tested. If neither total coliforms nor *E. coli* is detected, no further testing is ordered. If the bacteriological test reveals one–ten total coliforms without any *E. coli* in a 100 mL sample, the private well is considered adequate for private consumption and further routine testing is required. If total coliforms exceed ten in a 100 mL sample, then the water is considered substandard and disinfection is recommended, after which the well is retested. Lastly, if testing shows any *E. coli* bacteria, the water is considered unsatisfactory and immediate corrective action is recommended, followed by retesting.

6.3.4 Boil Water Advisories

Among the constituent stages in the MBSAP, BWA belong to Level two as a part of the monitoring component, and are separated into eight categories (NL Department of Environment and Conservation 2009; CRA 2010), as shown in Table 6.2.

Figure 6.1 shows that category E, which is insufficient chlorine residual, contributes the largest portion of BWAs in Newfoundland. The Canada Drinking Water Guidelines recommend chlorine residual equal to 0.2 mg/L for treated water to prevent recontamination as well as limit the growth of biofilm in water pipes, which causes unpleasant taste and odor (Health Canada 2009a). Categories A and C, both relating to a lack of proper disinfection system, are the most frequent after category

Table 6.2 Categories of BWAs in Newfoundland and Labrador

Category	Description of the drinking water system	Active Cases in NL[a]
A	No disinfection system	42
B	Disinfection system turned off by operator	23
C	Non-functional disinfection system or no chlorine	41
D	Operational problem in the distribution system	17
E	No or insufficient chlorine residual in the distribution system	79
F	Microbiological contaminants detected in treated/tap water	28
G	Water system compromised due to disaster (e.g., earthquake)	0
H	Waterborne disease outbreak ongoing	0
Z	No samples submitted for testing	3

NL Department of Environment and Conservation (2011)

[a] Sums to 233 due to water systems with multiple reasons for BWA

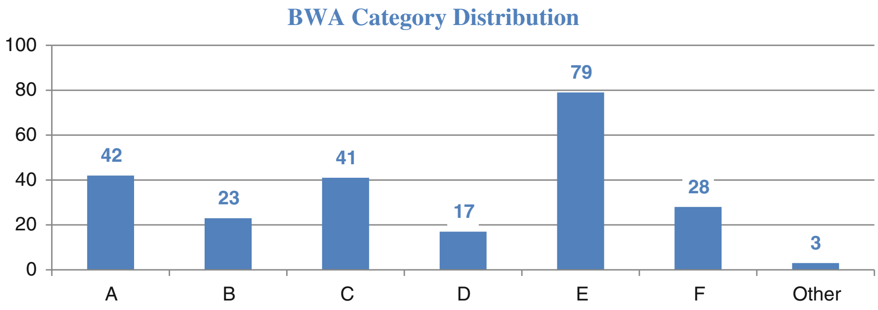

Fig. 6.1 Distribution of BWA categories

E, together suggesting that NL has inadequate infrastructure, increasing the risk of water system failure. However, Fig. 6.2 suggests that when population affected is considered instead of BWA frequency, then operational problems in the water system, category D, become more worrisome. Nevertheless, this does not change the finding that drinking water infrastructure is inadequate in Newfoundland, as operational problems in water systems are often caused by insufficient capital investment (CRA 2010). Comparably small numbers of category F—and no G or H—BWAs indicate that most BWAs in NL are precautionary.

The large incidence of insufficient chlorine as the reason for BWA in Table 6.2 reflects the fact that an overwhelming majority of water systems in NL are chlorine-based. To illustrate, only 6 out of 478 treated water systems in NL do not use chlorination, and only 158 systems have any other form of treatment installed (Department of Environment and Conservation 2011). Of the 158 public water systems with non-chlorine treatments, 65 use a non-chlorine primary disinfectant

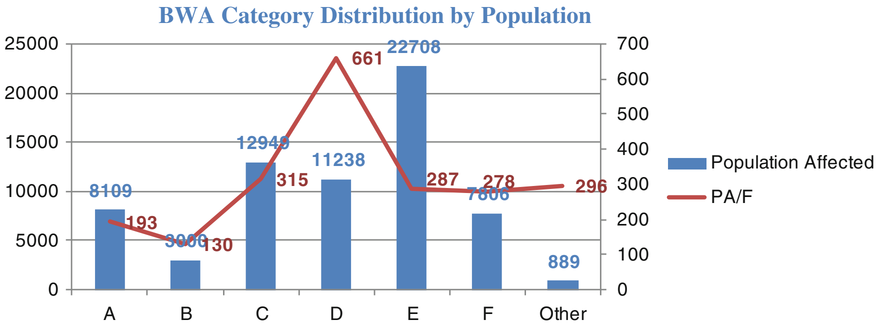

Fig. 6.2 Distribution of BWA categories by population affected (Reproduced from NL Department of Environment and Conservation 2011). *Note* PA/F = Population Affected ÷ Category Frequency (see Table 6.2)

including 28 ultraviolet radiation (UV) systems, 12 PWDUs, and 25 systems served by water treatment plants (Department of Environment and Conservation 2011). All 65 public water systems without chlorine-based primary disinfection still have chlorination facilities to meet chlorine residual requirements (CRA 2010 and NL Department of Environment and Conservation 2011).

The most commonly used chlorination processes in Newfoundland are liquid and gas chlorine, which are used by 293 and 163 public water systems, respectively. Powder and mixed oxidant chlorination is less frequent and is used by 15 water systems located in remote communities that benefit from the slow speed of degradation of powder chlorine (NL Department of Environment and Conservation 2011 and Health Canada 2009a). Between gas and liquid chlorine, gas is the more effective disinfectant, although the gas requires greater technical expertise than a liquid chlorine system (AWWA, Michigan Section 2006). Consequently, chlorine gas tends to be present in larger public water systems, averaging 2,176 people served per water system, while liquid chlorine systems serve just 188 people (NL Department of Environment and Conservation 2011). It is then no surprise that more populated communities are less exposed to BWA, as shown in Fig. 6.3.

Figure 6.3 shows that an overwhelming majority of BWA are in very small communities with fewer than 500 residents, based on the 2006 Census. This suggests many localities under a BWA are likely to lack the economies of scale needed to maintain advanced water treatment systems (Cool et al. 2010 and CRA 2010). In response, the Newfoundland provincial government funds 90 % of most capital costs incurred for water infrastructure if the community has fewer than 3,000 residents. Larger municipalities with a population of up to 7,000 people are eligible for 80 % of their capital costs, while a community that has more than 7,000 residents is funded up to 70 % of the capital costs (Department of Environment and Conservation 2009 and CRA 2010).

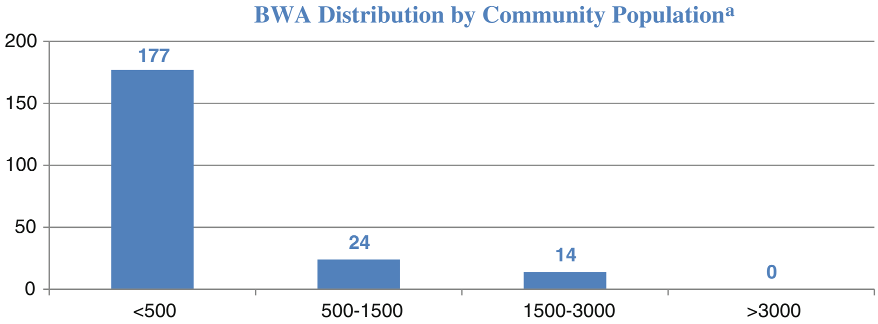

Fig. 6.3 BWA distribution by community population (NL Department of Environment and Conservation 2011). [a] "Community" refers to a legally defined municipality or a Local Service District

6.3.5 *Data Management and Reporting*

The Department of Environment and Conservation Drinking Water Monitoring Program partly funds the Water Resources Management Division, which is responsible for managing the drinking water quality database and the drinking water GIS application. The database contains the results of every drinking water sample collected in NL as well as other critical information for water quality monitoring, such as the region, source water type and population. Before being entered into the database, the results from the laboratory undergo a comprehensive Quality Assessment and Quality Control (QA/QC) procedure usually lasting approximately 6 weeks. In the 2008–2009 fiscal year, the Department of Environment and Conservation issued 1,344 Drinking Water Quality Reports as a part of the QA/QC process.

The QC element of QA/QC refers to technical activities employed to ensure that data collected is adequate for QA purposes. QC includes: Inspection of water quality monitoring stations; calibration of probe, its sensors, and other water quality monitoring equipment; taking grab samples at the time of and following the removal, calibration, and reinstallation of water quality monitoring equipment; as well as correcting and recording data if readings prior to calibration are deemed inaccurate.

After the completion of QC, QA commences, involving: Comparison of field results between samples taken prior to and following the calibration and reinstallation; evaluating whether different results are within acceptable ranges, and determining why results may be divergent (if they are); calculating long-term and monthly data based on corrected data; producing time series figures for each parameter; publishing daily updates on the Water Resources Management web page for review; preparing a monthly report for each monitoring station regarding problems with maintenance, calibration, QA/QC procedures, and any data issues; and creating annual reports for each monitoring station at the end of the calendar year. Once the QA/QC process has been fully completed, the sampling data is entered into the Department of Environment and Conservation drinking water quality database and the GIS application.

Water Resources Management uses the Drinking Water Quality Search Engine to review and analyze drinking water quality data. During the 2008–2009 fiscal year, this application was redesigned, changes including: Altered user interface; ability to view and export a community's drinking water data; addition of data sets for THM and HAA average; several improvements for flagging exceedances; enhanced data security; inclusion of detailed summary pages for the season, fiscal year, or water quality parameter; and the ability to view related samples.

Aside from the search engine, the Department of Environment and Conservation deployed a Drinking Water Quality GIS application for internal use in 2004, integrating spatial components of water supplies and watersheds into more conventional drinking water quality data. In the 2007–2008 fiscal year, the Department of Environment and Conservation, "GeoConnections" program provided funds to make the GIS application available to the public through the department website and to enable compatibility between the GIS application and other web applications.

Another comprehensive database, named the Municipal Affairs Management System (MIMS), was created in 2002 by Municipal Affairs to ease the sharing of water supply and water quality data between government departments. The MIMS stores basic information about NL's municipalities, such as their waste management facilities, capital works, financial details, municipal profiles, and water supplies. MIMS, the Drinking Water Quality Search Engine, and the GIS application are essential to the protected public water system designation process as the Department of Environment staff prepare much of the documentation from the databases, directly affecting a community's "protection" designation prospects.

Of the total 1,344 Drinking Water Quality Reports issued in fiscal 2008–2009 by the department, 71 were exceedances reports. Among the 71 exceedances reports, 51 were due to Bromodichoromethane (BDCM) exceedances. Seasonally, over 300 reports were produced for spring, summer, and fall, 2008, as well as winter, 2009. In terms of exceedances reports, about 10 reports were filed for each season as listed above, demonstrating an especially high proportion of exceedances reports during the summer season 2008. The increase in summer months may be expected as the prevalence of potential organic contaminants increases due to higher temperatures.

6.3.6 Inspection and Enforcement

The design and construction of all water and sewage infrastructure in NL require a permit from the Department of Environment and Conservation. As discussed earlier, the permit to construct may be issued once a licenced engineer submits a plan determined by the Minister to be in compliance with the *Water Resources Act SNL 2002 cW-4.01*. Permits to operate are granted to raise the awareness of municipal government leaders of the importance of proper water system maintenance and are awarded when the Minister decides that a municipal water infrastructure has the capabilities and the maintenance required to meet GCDWQ standards. Finally, permits for activities within protected water systems must be obtained prior to beginning construction or activity. In total, 163 permits to construct, 77 permits to operate, and 103 permits for activities within protected areas were issued in fiscal year 2008–2009.

6.3.7 Operator Training and Education

The Department of Environment and Conservation has developed the Operator Education, Training and Certification (OETC) program as the chief NL policy standard for water systems operators in the province. According to the *Annual Report 2009*, OETC was specifically intended to alleviate drinking water problems facing small NL communities. The OETC encompasses three aspects reflected in its name: Operator education, certification, and training.

To address the education component, the OETC funds free seminars located throughout NL to minimize travel costs. Seminar courses include: Water Distribution Basics, Water Distribution System Hydraulics, Water Quality Issues, and Water Treatment Levels I and II. Each seminar course is offered annually, and in fiscal 2008–2009, 52 operators attended three seminars covering the first three courses listed above and a further 29 attended a 3-day Water Treatment I and II session in Gander, NL.

In general, the level of operator education seems inadequate given that 30 operators retired, moved away, or took on other duties in 2008–2009, and that there are 502 public water supply systems in NL requiring operators to function properly. The CRA study mentions that, referring to OETC training records from February 2006 to February 2009, uninformed operators are more likely to turn off disinfection treatment from complaints of chlorine taste; they may not be adequately trained to understand the need to have chlorine residuals in the water to combat pathogens.

The OETC also provides on-site training to existing water systems operators using mobile training units who delivered 185 training sessions in fiscal 2008–2009 to 174 of 502 public systems, with a repeat rate of 6 %. In total, 345 operators attended on-site training in the fiscal year, categorized into: 128 operators received disinfection/chlorination training from 81 sessions, 50 received fire hydrant maintenance training from 22 sessions, 106 operators received training on pipe tapping in 44 sessions, and a further 61 operators received control valves, leak detection, or distribution system flushing training in 38 sessions. The CRA survey, taken in February 2009, seems to suggest relative success of the mobile training units with 52 of 93 survey respondents (56 %) indicating they have a trained operator on site. However, annual average training per operator was still less than 1.5 h/year among respondents.

As of March 2009, there were 275 certified water and wastewater operators in NL collectively holding 520 certificates. Of the 275 certified operators, 260 were employed by 116 of 364 municipalities (31.9 %), five were employed by two First Nations communities, and the rest employed by National Defense and the Canadian Forces, three national parks, and two industrial/commercial systems. This statistic is in agreement with the CRA survey which found 50 of 93 public systems survey respondents (54 %) indicating a lack of certified operator, including 28 of 34 survey respondents under a BWA (82 %) and 22 of 59 non-BWA respondents (37 %), implying significant positive correlation between the likelihood of a BWA and lack of a certified operator.

6.4 Finance and Pricing

The CRA study contains an extensive analysis of financing and pricing in NL based on 25 representative communities, which were chosen on the basis of population, water source, service issues, geographic location, and governance type. The analysis is based on on-site visits in February 2009. Since this report provides sufficient coverage and summarizes information from official reports and databases, the CRA study is the primary source for this part of the chapter.

6.4.1 Finance: Budget and Water Rates

This section summarizes some of the CRA study findings most relevant to small water systems in NL. Of particular note are the clear patterns emerging that suggest substantial differences between water systems in governance structures and population.

Eight LSD communities included in the CRA study all had fewer than 500 people served: Among them three had groundwater sources and five had surface water sources. 18 municipalities were included in communities studied, nine of them serving more than 500 people, and eight serving fewer than 500 people. All nine municipal water sources serving more than 500 people were surface water sources, and seven sources serving fewer than 500 people were surface water sources; only one municipal water source was from groundwater.

Community budgets for drinking water provision were strongly correlated with both governance and population. Although six of eight very small municipalities had budgets between $100,000–$500,000, seven out of eight Local Service Districts had budgets below $50,000. Municipalities serving more than 500 people had five of nine among them with budgets over $1 million. Overall, eight of 25 communities studied had less than $100,000 budgeted for drinking water services, seven—all Local Service Districts—had less than $50,000 budgeted, five—all municipalities serving more than 500 people—had over $1 million budgeted, and two and three communities, respectively, had $50,000–$100, 000 and $500,000–$1 million budgeted.

As suggested by the generally smaller water service budgets in Local Service Districts (LSDs) compared to municipalities, water rates to consumers in Local Service Districts were significantly lower than those of municipalities of comparable populations. Of the eight LSDs, five had water rates of between $100–200 year^{-1} (63 %), two LSDs had water rates of between $200–300 (25 %), and one had water rates of below $100 annually (13 %). Conversely, in the large majority of municipalities serving fewer than 500 people, six out of seven (86 %), had water rates of between $200–300 with one having a water rate between $100–200 (14 %). Larger population communities seem to have somewhat lower water rates (perhaps due to economies of scale) with four of nine public systems serving more than 500 people (44 %) having water rates between $100–200, and five with water rates between $200–300 (56 %).

6.4.2 Operator Wages and Employment

LSDs offered lower wages and were more dependent on volunteers than municipalities; water sources serving larger populations had a greater proportion of full-time operators employed and provided higher operator wages; and the choice of water source seems to have negligible effect on operator wages and employment.

Of the nine LSDs the CRA visited, seven (78 %) had only volunteer operators and, of the remaining two, one LSD had a part-time operator and the other a full-time operator (11 % each). Operators in very small municipalities (serving fewer than 500 people) were much more likely to be full-time (six of eight or 75 %), and were much less likely to depend on volunteer operators with one very small municipality (12 %) maintaining a wholly volunteer operation. Of the very small municipalities and the nine municipal systems serving more than 500 people, the larger municipalities were more likely to have full-time operators.

Operator wages also differed based on population size. Municipalities serving more than 500 people were primarily compensating their operators at $10–15 h^{-1} (four of nine or 44 %), but three of the nine relatively large municipalities (33 %) had operator wages of more than $15 h^{-1}. In comparison, seven of the eight (88 %) very small municipalities had operator wages of between $10 and $15, with the last being a volunteer operation. The only non-volunteer LSD water system paid its operator between $1 and $10 h^{-1}. Thus, water systems serving larger populations had somewhat higher wages for their operators than smaller systems.

A community's water source does not seem to affect operator wages and employment with the one non-volunteer LSD water system receiving water from a groundwater source and paying $1–$10 h^{-1}. Meanwhile, the only municipal groundwater source employed a full-time operator but paid an average $10–$15 h^{-1}. In summary, two of four groundwater sources (all serving fewer than 500 people) had non-volunteer operations, and 6 of 12 very small surface water sources had paid operators. Thus there is no evidence to suggest the water source makes a difference to operator wages and employment.

As discussed in earlier sections, water systems budgets and water rates in LSDs are lower than those of municipalities, and this trend holds for operator wages and employment. Among the municipalities, those serving larger populations had larger water system budgets and lower annual water rates possibly due to economies of scale.

In general the larger the population served in a public water supply system, the less likely that it will be under a BWA. The earlier data presented above also indicate that LSDs are disproportionately represented among BWAs, comprising the majority of BWAs in effect as of March 2009, and yet LSDs represent a minority of public water supply systems in NL. The distribution of operator wages and employment, together with the distribution of BWAs display a negative correlation between wages of water system operators in a community, as well as with the level of employment (voluntary, part-time, or full-time), and the likelihood of the public system being under BWA.

6.4.3 Capital Funding for Water Systems

Primary funding for water infrastructure construction in NL is from Municipal Affairs and its Municipal Capital Works (MCW) program. MCW provides 90 % of the total water infrastructure project costs for the 258 municipalities in NL with fewer than 3,000 people serviced (31 % of NL population), 80 % of total costs for the 16 municipalities serving between 3,000 and 7,000 people (14 % of provincial population), and 70 % for the nine municipalities serving over 7,000 people (43 % of NL population). Remaining costs are borne by the municipalities. LSDs may receive full (100 %) funding for eligible drinking water projects. No project is eligible for financial assistance without a drinking water permit obtained for construction from the Department of Environment and Conservation and no project is funded if the locality has a debt-to-service ratio (principal and interest divided as a % of local government revenue) in excess of 30 %.

Aspects of water infrastructure covered by the Municipal Capital Works program include: Engineering consulting and other fees; road construction, alteration, or expansion but not sidewalks; paving or upgrading municipal parking lots; storm drainage systems; relocation of public utilities due to the approved water infrastructure, such as hydro poles and sewer lines; reinstatement of property damaged by Department of Environment and Conservation approved construction; all water and wastewater disinfection and treatment facilities and equipment recommended by a certified engineer and approved by the department; and re-establishing recreational facilities rendered unusable due to approved water infrastructure.

Each year all localities in NL are invited to apply for capital funding from Municipal Affairs. When a locality notifies Municipal Affairs of its intention to apply, the locality has 21 days to submit a full legal agreement to Municipal Affairs specifying, among others, the consultant certified engineer obtained by the locality. The engineer hired is to create a detailed plan for the water project including timetables, and has 90 days to submit the engineering documents to a regional office. Lastly, once the locality receives the tender offer for assistance from the department, the locality has 45 days to finalize the contract. If any of the above time lines is exceeded, then the project is canceled unless a previous extension has been granted.

The CRA survey found 75 % of LSDs had a debt-to-service ratio less than 30 %, while the remaining 25 % had debt-to-service ratio of more than 50 %. Some 87 % of the municipalities reported less than 30 % debt-service ratio. No significant differences emerged between the debt-service ratios of very small public systems and those serving more than 500 people.

6.5 Policy for Potable Water Dispensing Units (PWDUs)

It was stated that the Government of NL water policy is based on the MBSAP involving the Department of Environment and Conservation, Government Services, Health Services, and the Department of Municipal Affairs, with Environment leading policy implementation. Of note for small water systems in NL is the Rural Drinking Water Safety Initiative, a voluntary program initiated in May 2008, whose objective is to improve drinking water quality in very small rural communities with fewer than 500 residents. The government had initially allocated $20.9 million for this initiative and $18 million was allocated by Municipal Affairs in fiscal years 2008 through 2011. A significant portion of the funds spent under Municipal Affairs contributed to the installation of PWDUs in very small communities serving fewer than 500 people (NL Department of Environment and Conservation 2011). A PWDU is a stand-alone drinking water station, close to the small community. The unit delivers very high quality drinking water to the consumer at very low cost.

The studies funded by Municipal Affairs included "Evaluation of Existing PWDUs and Recommendations for Design and Operational Guidelines" (2010), which examined the seven existing PWDUs for 1 year from April, 2009, to evaluate the strengths and weaknesses of divergent PWDU configurations. The overall influence of this study on the proposed designs of 23 PWDUs thus far to be installed in NL with Rural Drinking Water Safety Initiative funding is unclear. Some of the findings are summarized below.

6.5.1 Summary Statistics

Contrary to the stated focus of the Drinking Water Safety Initiative on very small communities, only three of seven PWDUs (43 %) were in very small public systems and two among them were installed prior to the start of the Initiative. All other PWDUs were serving populations greater than 500, specifically three of seven (43 %) serving between 500 and 1,000 people, and one PWDU serving between 1,000 and 1,500 people (14 %). The first PWDU was installed in year 2000, and the latest, in March 2010.

6.5.2 PWDU Characteristics

Three companies supplied the seven PWDUs: Durpro installed three PWDUs, Atlantic Purification Systems (APS) also provided three, and Flotech Enterprises delivered one PWDU. Three of seven PWDUs had official approval by the Department of Environment and Conservation, including two Durpro and one APS installations, as well as the one PWDU created under the Drinking Water Initiative.

One PWDU had a capacity greater than 10,000 L/day, while all others had a capacity below 5,000 L/day, with a range of 2,000–15,000 L/day. In general, average water use was much lower than PWDU capacity, with a range between 250–3,000 L/day. Two PWDUs experienced average flows of more than 1,000 L/day and one had an average flow to capacity ratio of 50 % or higher, while four PWDUs had less than 25 % average flow to capacity ratios.

The seven PWDUs studied can be technologically categorized into two groups: PWDUs that employ reverse osmosis (RO) as the primary disinfection method, and those that use ozonation for the same purpose. Among the PWDUs, four had RO, and three had ozonation disinfection systems. Note that UV disinfection was the last step of disinfection for each PWDU except one that had an RO system. Furthermore, a granular activated carbon (GAC) filter was an important part of pre-treatment for all PWDUs except for an ozonation system whose raw water quality was deemed high enough not to require pre-treatment.

Prices of water from PWDUs varied widely with the mean of \$0.32 L^{-1} dispensed and a standard deviation \$0.315 L^{-1}. The very high standard deviation is largely due to two outliers with prices of \$0.94 and \$0.55 each, which use RO and ozonation, respectively. By contrast, the median cost is \$0.18 L^{-1} where the lowest cost is observed for an RO PWDU. Of the seven PWDUs, only the one with a price of \$0.94 L^{-1} was taken offline due to a lack of funds—in December 2009—though the PWDU resumed operations soon thereafter, after receiving financial assistance worth \$20,000 from Municipal Affairs.

6.6 Statistical Analysis: Risk and Health

6.6.1 Introduction

In recent decades, major episodes of drinking water systems failure, such as those that occurred in Walkerton (in 2000) and Temagami (in 1994) in Ontario, have highlighted the potential for dangerous gaps in the management, treatment, and distribution of drinking water. Even following the highly publicized case from Walkerton, some public water systems in Canada have yet to achieve standards established by Government of Canada Drinking Water Quality (GCDWQ) guidelines or their respective provincial regulations (CRA 2010). Continuing vulnerabilities among Canadian water systems are indicated by the prevalence of active BWAs, numbering over 1,700 in 2008 (Eggertson 2008). Given that water systems in Canada remain exposed to the potential of failure, an urgent research task is trying to find what factors are associated with the risk of water system failure.

The risk of drinking water system failure may arise from a number of the components of water services. To begin with, source water may be vulnerable to contamination, depending on its chemical and biological composition, and whether it is protected or not (Cool et al. 2010; Rizak and Hrudey 2008; Gagnon et al. 2005). Rizak and Hrudey (2008) have found rapid changes in environmental conditions and source water quality to be especially damaging to drinking water safety. The variability of source water quality may be limited by watershed protection involving limits on access to and activity within a designated area around a protected water source (Cool et al. 2010 and Islam et al. 2011). Where such protection is in place, episodes of source water contamination decrease in frequency and severity, thereby reducing the costs associated with drinking water treatment and distribution (Conboy and Goss 2000; Islam et al. 2011). This renders source water protection a highly cost-effective means to assure drinking water safety (Islam et al. 2011).

The effects of source water characteristics on the risk of water system failure can also be substantially mitigated by the treatment system. Treatments that sustain sufficiently high concentrations of disinfectant residuals, for example, are only minimally affected by source water quality (Gagnon et al. 2005; Health Canada 2009a and Zhang et al. 2010). In the case of Canada, free chlorine and chloramine have been adopted as the most common disinfection residuals for their effectiveness against bacteriological contaminants (Health Canada 2009a). On the other hand, a major factor that amplifies the negative effects of low-quality source water is the water residence time in the distribution system (Westrell et al. 2003). Stagnant pipelines or extended stays of treated water in reservoirs allow bacterial growth and may increase organic concentration, raising the risk of microbial contamination (Westrell et al. 2003; Gagnon et al. 2005). Furthermore, aged and deteriorated pipes may induce recontamination of the treated water via leakages, whose conventional methods for detection remain costly and labor-intensive despite recent studies offering more efficient statistical methods (Xu et al. 2011).

One response to the risk of water system failure is the adoption of a water safety plan by water utilities, as the World Health Organization (WHO) began recommending in 2004 (Bartram et al. 2009). Water safety plans involve systematic identification of potential hazards and their corresponding controls such that a risk is efficiently discovered and resolved, in contrast to the ad hoc reactions to a failure in common practice (Jayaratne 2008; Bartram et al. 2009 and Gunnarsdottir et al. 2012). A particularly widespread type of water safety plan is the HACCP (Hazard Analysis Critical Control Points) method, which is distinguished from other plans in its specification of critical control points and the creation of critical limits—maximum turbidity, acceptable pH range, and so on—for each critical point

(Bartram et al. 2009). Most important critical control points, locations where the water system is at risk, include cross-connections to untreated water and pipes carrying treated water from the disinfection plant (Jayaratne 2008; Medema and Ashbolt 2006). In general, water safety plans and HACCPs have been successful in improving water quality while gaining the support of local stakeholders and operators, although concerns regarding a lack of adequate record keeping and oversight exist in some HACCP implementations (Damikouka et al. 2007; Jayaratne 2008; Bartram et al. 2009 and Gunnarsdottir et al. 2012).

Despite the attention given to HACCP, complications arise from the process of identifying critical control points and assigning critical limits for them (Medema and Ashbolt 2006; Smeets et al. 2010). Without statistical or other objective methods, the identification of critical points and the setting of critical limits have been based on operator experience and industry log credits which may be insufficient or inappropriate (Smeets et al. 2010). To address this problem, quantitative HACCP approaches that incorporate QMRA (Quantitative Microbial Risk Assessment) have been proposed (Damikouka et al. 2007 and Smeets et al. 2010). This method combines information regarding health effects of pathogens with the exposure of a population and its water system to provide objective critical control points and critical limits based on risk estimates and confidence intervals (Medema and Ashbolt 2006). Crucially, QMRA allows the ranking of facilities and hazards based on vulnerability and expected harm, thus improving efficiency through priority setting (Medema and Ashbolt 2006; Smeets et al. 2010).

6.6.2 Water Systems Failure and Boil Water Advisories in Canada

BWAs are generally issued to prevent illness through pathogens in tap water when there is some evidence of vulnerability due to harmful microbes, such as *E. coli*, being identified in the water infrastructure (Wallis et al. 1998; Hrudey et al. 2003; Department of Environment and Conservation 2009; Cool et al. 2010). In Canada, BWAs have typically been issued by governmental authorities as both precautionary measures to prevent the consequences of waterborne pathogens, and to ameliorate the effects of an already unfolding tap water-related bacteriological crisis (Wallis et al. 1998; Hrudey et al. 2003; Jameson et al. 2008). To illustrate, in Ontario, Fort William at Thunder Bay was issued a BWA in 1997 after Giardia cysts were detected from treated water sampling, while Temagami was placed under BWA once an outbreak of waterborne giardiasis emerged in early 1994 (Wallis et al. 1998), exemplifying precautionary and ameliorating issuances of BWAs, respectively. It is nonetheless important to note that political and other exogenous factors could play a role in the decision to issue a BWA (Snider 2004).

The Walkerton crisis in 2000 was caused by waterborne *E. coli* in the town's water system (Snider 2004). The crisis led to awareness of the vulnerability of small water systems and, all over Canada, the number of BWAs increased as a precautionary measure. In Newfoundland, some 41 out of 217 active BWAs as of May 2011, were issued between June 13 and June 23, 2000, approximately 1 month after the Walkerton crisis. This major crisis eventually led to drinking water reregulation (Snider 2004). The crisis had a significant influence on the number of BWAs, which suggests that many BWAs are issued due to potential threats to health rather than a confirmed system failure. Thus in the immediate aftermath of Walkerton, a BWA might be a weaker proxy of water treatment failure.

There is, however, evidence that suggests that the number of BWAs issued after Walkerton remains a reasonable proxy for water systems failure. If the active BWAs declared in June 2000, were merely precautionary, there can be little incentive to keep the 41 water systems under BWA for over a decade. Moreover, there exists literature that maintains that BWAs are reasonable indicators for water treatment failure (Cool et al. 2010). Lastly, international, national, and provincial authorities all have adopted cautious policies toward issuing BWAs only where the threat to public health is significant and likely to coincide with water systems failure (WHO 2011; Health Canada 2009b; NL Department of Environment and Conservation 2009 and Nolan 2011).

The World Health Organization advises caution in issuing BWAs, citing serious health and compliance costs associated with frequent or extended periods under BWAs. Once the public has become desensitized to BWAs, some may no longer take the advisories seriously (WHO 2011). The WHO guideline on BWAs is that an advisory should be issued only when the risk to public health from water systems failure outweighs any increased risk of burns and scalding as a result of boiling water (WHO 2011). Health Canada seems to agree, with its own guidelines on boil advisories listing confirmed presence of *E. coli* or other coliforms, inadequate or malfunctioning water treatment facilities, and water quality conditions—especially high turbidity and other particle counts—that signal significant exposure to potentially harmful microbes as necessary reasons for a BWA (Health Canada 2009b, p. 3). Finally, the NL provincial government has standards for BWAs based on the Government of Canada Drinking Water Quality guidelines published by Health Canada (NL Department of Environment and Conservation 2009). Furthermore, Nolan (2011) suggests that BWAs are not issued without significant public health risk.

In 2008, there were 1,766 BWAs in Canada excluding the 118 advisories, as of June 2011, in First Nations reserves (Eggertson 2008; Health Canada 2011). The BWA distribution is shown in Table 6.3.

Table 6.3 Boil water advisory distribution in Canada, 2008 (2011 for First Nations)

Province/first nations	Total BWAs	BWAs/population (2006 Census, per 10,000)[†]
Alberta	13	0.04
British Columbia	530	1.29
Manitoba	59	0.51
New Brunswick	2	0.03
Newfoundland and Labrador	228	4.51
Northwest Territories	1	0.24
Nova Scotia	67	0.73
Nunavut	0	0
Ontario	679	0.56
Prince Edward Island	0	0
Quebec	61	0.08
Saskatchewan	126	1.30
Yukon	0	0
First Nations	118[‡]	3.17[a]
Canada	1884	0.60

Provincial and territorial BWA data from Eggertson (2008)

[†] Calculated using 2006 census data from Statistics Canada; all provincial and territorial figures excluding aboriginal populations. Provincial and territorial figures calculated using only non-aboriginal population

[‡] From Health Canada (2011)

[a] Calculated using total aboriginal population in 2006 census

6.7 The Statistical Model and Methodology

6.7.1 The Statistical Model

A standard Probit model was used for estimation with explanatory variables listed in Table 6.4. The Probit model specifies the form of $P_i \equiv \Phi(x)$ such that $\Phi(x)$ follows the cumulative standard normal distribution (SND):

$$\Phi(x) = \int_{-\infty}^{x} (2\pi)^{-\frac{1}{2}} \exp\left(-\frac{1}{2}t^2\right) \mathrm{d}t \tag{6.1}$$

where x denotes the regression variable to be estimated. Note that Eq. (6.1) does not have a closed-form expression and it has been estimated iteratively using the maximum likelihood method.

The general model includes all independent variables from Table 6.4, and is defined as per Eq. (6.2):

Table 6.4 Variables used

Name	Description	Source
LPop	Natural Logarithm of population served by the public water system	ENVC[a]
Prot	PROT = 1 means public water system is designated a Protected Public Water Source, PROT = 0 if not protected	ENVC
ChlLiquid	Chlliquid = 1 indicates the use of liquid chlorine in the PUBLIC WATER SYSTEM	ENVC
OtherChl	Otherchl = 1 indicates the use of powder/mixed oxidant chlorination in the public water system	ENVC
NoTreat	Notreat = 1 indicates the absence of any drinking water treatment system in the public water system	ENVC
GAN	GAN = 1 indicates public water system is located in the Gander Region	ENVC, calculated[b]
E	E = 1 indicates the public water system is located in Eastern Newfoundland	ENVC, calculated
W	W = 1 indicates public water system located in Western NL	ENVC, calculated
L	L = 1 indicates public water system located in Labrador	ENVC, calculated
ThrTurb	ThrTurb = 1 indicates that the public water system samples exceeded NTU of greater than 1.0 at least three times of the latest five samples taken	ENVC
ThrCol	ThrCol = 1 indicates that the public water system samples exceeded TCU of greater than 1.0 at least three times of the latest five samples taken	ENVC
ThrAcid	ThrAcid = 1 indicates that the public water system samples exceeded pH of less than 6.5 at least three times of the latest five samples taken	ENVC
DOC	The median reading of DOC, in mg/L, among the latest five samples	ENVC
BWA	BWA = 1 indicates boil water advisory in effect (dependent variable)	ENVC

[a] ENVC (2011), stands for NL Department of Environment and Conservation

[b] Calculated refers to manipulations and/or other data compilation done by the author

$$\begin{aligned} P(BWA = 1|X) \\ &= \Phi(\alpha_0 + \alpha_1 \mathrm{POP}_i + \alpha_2 \mathrm{PROT}_i + \alpha_3 \mathrm{CHL}_i + \alpha_4 \mathrm{REG}_i + \alpha_5 \mathrm{PHY}_i + \epsilon_i) \end{aligned} \tag{6.2}$$

where X is the vector of all independent variables listed in Table 6.4, and *POP* denotes LPop, $(\mathrm{LPop})^2$, and $(\mathrm{LPop})^3$ variables, *CHL*and *REG* represent the chlorination type and region binary variables, respectively, and *PHY* includes all physical parameters shown in Table 6.4: ThrTurb, ThrCol, ThrAcid, DOC, and DOC^2. ϵ is the error term, while i indicates the cross-sectional form of the data and

Table 6.5 Summary statistics[a]

Variable	Mean	Std. Dev.	Min	Max
BWA	0.4098361	0.492308	0	1
Pop	836.8279	4102.448	3	81517
LPop	5.329	1.490	1.10	11.31
Prot	0.7151639	0.4518	0	1
Chlgas	0.3053279	0.4610188	0	1
Chlliquid	0.5860656	0.493042	0	1
Otherchl	0.0266393	0.161192	0	1
Notreat	0.0819672	0.274596	0	1
GAN	0.2213115	0.4155557	0	1
SJ	0.1639344	0.370596	0	1
E	0.2704918	0.44467	0	1
W	0.2930328	0.45562	0	1
L	0.0512295	0.220692	0	1
ThrTurb	0.0860656	0.280749	0	1
ThrCol	0.5901639	0.492308	0	1
ThrAcid	0.3155738	0.465221	0	1
DOC	4.603893	3.498678	0	22

[a] The sample includes 534 public water sources in NL less 39 public water systems without population data or with reported population served of zero

α is the vector of the corresponding coefficients. The benchmark variables for *CHL* and *REG* groups are, respectively, liquid chlorination and the St. John's region.

6.7.2 Data Analysis

The model (2) covers 488 public water systems which have the required data,[4] described in Table 6.5:

Table 6.5 presents substantial diversity among public water systems in NL. Specifically, populations served by a public water system range from just three to 81,517 people, and dissolved organiccarbon concentrations are as low as zero, but are as high as 22 mg/L. Elsewhere, close to 60 % of the public water systems use liquid chlorine, while less than 3 % have powder or mixed oxidant chlorination and a mere 5 % are in Labrador. Table 6.5 indicates that approximately 30 % of the public water systems use gas chlorination, and one-fifth of them are located in the

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[4] Six observations found to have no chlorination, but equipped with arsenic removal facilities, were excluded in addition to those lacking population data to simplify the interpretation of *CHL* marginal effects. Another data point was removed due to its designation as 'partially protected' in the NL Department of Environment and Conservation (2011) database, whose precise definition could not be located.

Gander Region. Additionally, 59 and 32 % of the public water systems had consistent color and acidity exceedances, respectively.

Turbidity, color and the acidity characteristics of public water systems are included as explanatory variables due to their importance in the efficiency of disinfection (Health Canada 2003, 2006). Turbidity refers to the concentration of suspended particles in water, and turbid source water can be difficult to treat as suspended material protects microorganisms from disinfection (Health Canada 2003). Acidity similarly reduces the efficiency of chlorination, and can result in the corrosion of pipes over time (Health Canada 2006). Color listed in Table 6.5 is measured in TCU and indicates true color of the source water following the filtration of organic substances. Therefore, a higher TCU indicates greater inorganic mineral and metallic presence in water (Chapman and Kimstach 1996). The color itself may also interfere with the chemical analysis of water (Health Canada 1995).

Dissolved organic carbon (DOC) is another physical parameter and arises from living material in freshwater, either directly from plant photosynthesis or from surface exposure (Chapman and Kimstach 1996). Rather than crudely differentiating source water types between surface and groundwater, the DOC and DOC^2 variables are used as proxies for the exposure of the source water to terrestrial matter and contaminants from human activity. The DOC levels are increased by the presence of industrial and agricultural runoffs, as well as wastewater and other organic materials (Chapman and Kimstach 1996). High levels of DOC would signify surface water or groundwater under the influence of surface water (GUDI), while groundwater and pristine surface water would be characterized by low concentrations of DOC. The DOC^2 variable is included in the model for the possibility that the increase in water system risk is marginally decreasing as DOC rises due to the relationship between DOC and industrialization. Since dissolved organic carbon is often caused by heavy economic activity, a high DOC reading may indicate a relatively advanced industrial development, resulting in superior capability to manage public water systems. This capability may help counteract the increase in the risk of system failure from greater source water contamination at very high DOC levels.

6.7.3 Methodological Issues

ThrTurb variable was generated such that ThrTurb = 1 if at least three of the last five samples, as of May, 2011, had readings above GDCWQ recommended levels for turbidity, and ThrTurb = 0 otherwise. The same procedure was used to create ThrCol and ThrAcid variables for color and acidity, respectively. For the public water systems with fewer than five recorded sample results, ThrTurb, ThrCol, and ThrAcid values were set to one if at least two-thirds of recorded results exceeded GDCWQ limits as stated in Table 6.4. For example, if three sample results were available for a public water system, ThrTurb = 1 if at least two readings exceeded 1.0 NTU, and ThrTurb = 0 otherwise. A similar process was performed for the

Table 6.6 Correlation coefficient and collinearity statistics between ThrTurb and DOC

	ThrTurb	VIF	R-squared
DOC	0.2092 (0.000)	2.49	0.5989

Parentheses indicate *p*-values

Variance Inflation factor (VIF) and R-Squared calculated using ThrTurb and DOC only

DOC variables, where the median DOC readings from the five latest samples were used as the variable values. These methodologies ensure that the physical parameters in the model identify consistent exceedances or degree of surface exposure, rather than outlier results, which may have been affected by faulty equipment or analysis.

Multicollinearity may be present among the *PHY* variables as both ThrTurb and DOC measure organic substances in water. Table 6.6 summarizes correlation and collinearity statistics between ThrTurb and DOC:

Table 6.6 does not present acute multicollinearity, though statistical significance of correlations involving DOC suggests any inference from statistical analysis would be conservative.

The LPop variables proxy the economies of scale and the availability of human resources, which may change as the population served by a public water system rises. Note that the degree of the LPop polynomial was set to three as chosen by both Akaike's and Bayesian information criteria, as well as the log-likelihood ratio test. Meanwhile, the Prot variable captures the effectiveness of source water protection in the multi-barrier drinking water strategy, and the variables for chlorination type help evaluate the relative efficacy of the major chlorine-based disinfection technologies. Lastly, binary variables denoting each Department of Environment region are included to control for any possible region-related influences on water system risk. However, region designation for some public water systems could not be located, and those systems were assigned to the same region as the closest public water system with an official designation.

6.7.4 Estimated Statistical Results

Table 6.7 summarizes the probit regression result.

Results in Table 6.7 are not surprising. The model estimates that source water protection reduces water system risk of failure while a lack of treatment, as well as consistently turbid or acidic source water, increases the risk. Further, gas chlorination compares favorably to liquid systems, but no statistically significant difference is observed between liquid and powder chlorine. DOC estimates suggest that surface exposure of source water has negative effects on drinking water quality, while the negative DOC^2 coefficient may indicate the income effects from economic development as discussed. Other estimates in Table 6.7 are more usefully presented as average partial effects (APE). Table 6.8 summarizes the estimated APE from our model:

Table 6.7 Model results

Variable	Estimate	Std. error	Z-stat	P-value
LPop	–3.597943	1.867729	–1.93	0.054
$(LPop)^2$	0.8116786	0.3924766	2.07	0.039
$(LPop)^3$	–0.0597541	0.0266251	–2.24	0.025
Prot	–0.709247	0.1678731	–4.22	0.000
Chlgas	–0.855478	0.2094123	–4.09	0.000
Otherchl	–0.2762653	0.4326251	–0.64	0.523
Notreat	1.431998	0.3672242	3.90	0.000
GAN	–0.4031798	0.2460148	–1.64	0.101
E	–0.8641187	0.2266871	–3.81	0.000
W	–0.1233076	0.2156421	–0.57	0.567
L	–0.4700047	0.3743834	–1.26	0.209
ThrTurb	0.5893154	0.2426757	2.43	0.015
ThrCol	–0.270671	0.2755481	–0.98	0.326
ThrAcid	0.356339	0.1740624	2.05	0.041
DOC	0.2249874	0.0765495	2.94	0.003
DOC^2	–0.0097494	0.0042034	–2.32	0.020
McFadden Pseudo-R^2		0.2947		
χ^2		194.65		
AIC		499.90		
BIC		571.14		
Sensitivity		66.50 %		
Specificity		83.68 %		
Correctly classified		76.64 %		

The APE for LPop indicate that the probability of BWA decreases, on average, by about 4.9 % points for each % increase in the population served by a public water system. This result suggests that the reduction in the risk of water system failure due to economies of scale is significant. Table 6.8 also shows a negative average partial effect for Prot, which implies that a public water system with source water protection is expected to face a lower risk of BWA, by approximately 19 % points, compared to an unprotected system. Conversely, the APE of ThrTurb and ThrAcid are positive, where the estimated average partial effect coefficients of those variables signify that consistently turbid or acidic source water increases the risk of BWA by approximately 15.9 and 9.6 % points, respectively. Likewise, the DOC average partial effect is positive, and states that the probability of BWA increases by nearly 3.9 % for 1 mg/L rise in the source water concentration of DOC. Thus, although the DOC^2 coefficient estimate is negative, our model suggests that higher concentrations of dissolved organic carbon would generally indicate greater risk of water system failure. Results of Table 6.8 show that true color of a source water has no statistically significant effect on the probability of BWA.

With regard to treatment types, chlorine gas treatment has been found to reduce the risk of boil water advisory for a public water system by approximately 23 %

Table 6.8 Average partial effects[a]

Variable	Estimate	Std. error	Z-stat	P-value
LPop	–0.0494987	0.0184767	–2.68	0.007
Prot	−0.1913848	0.0425498	–4.50	0.000
Chlgas	–0.230844	0.0533774	–4.32	0.000
Otherchl	–0.074548	0.1166247	–0.64	0.523
Notreat	0.3864134	0.0946744	4.08	0.000
GAN	–0.1087949	0.0658923	–1.65	0.099
E	–0.2331757	0.0583719	–3.99	0.000
W	–0.0332736	0.058144	–0.57	0.567
L	–0.1268271	0.1004654	–1.26	0.207
ThrTurb	0.1590222	0.0641113	2.48	0.013
ThrCol	–0.0730385	0.0741141	–0.99	0.324
ThrAcid	0.0961553	0.0462988	2.08	0.038
DOC	0.036914	0.0117032	3.15	0.002

[a] Average percentage change computed from the derivative of each variable, for continuous variables, and as variable value increases by one unit, for binary variables, across all observations (see Wooldridge 2009)

points compared to a water system using liquid or powder chlorine. Nevertheless, any chlorination system is considerably preferable to no treatment, as a system without disinfection is estimated to have a probability of BWA approximately 38.6 % points higher, on average, than systems with liquid or powder chlorination, and over 60 % points greater than those equipped with gas chlorine treatment. The APE of the *REG* variables are more puzzling, as Eastern Newfoundland region seems to have a significantly lower probability of BWA than elsewhere in the province, while the St. John's Region encompassing the Avalon Peninsula has a significantly increased BWA risk, all else held constant. The reasons for these results could not be identified.

Heteroscedasticity is a common problem for models using cross-sectional data and may be present in the probit regression estimates. To address this issue, log-likelihood tests for heteroscedasticity with respect to both the water source type, surface versus groundwater, and the level of DOC were conducted, and their results suggest a presence of heteroscedasticity. In contrast, the Hausman tests for heteroscedasticity consistently rejected the hypothesis of heteroscedasticity. Moreover, both log-likelihood and Hausman tests for heteroscedasticity were performed with respect to population served, where the results found no evidence of heteroscedasticity. Therefore, it seemed reasonable to reject heteroscedasticity-adjusted models (not shown) based on the inconclusive test results and the mostly trivial dissimilarities in estimate results relative to the standard probit model regression.

The chosen proxies in the probit models create further complications, this time regarding data limitations. In particular, budgetary and operator certification data would have been superior measures for human resource availability than the LPop variables, notwithstanding the considerable difficulties involved in collecting such data. However, CRA (2010) presents a summary of budgetary and operator training data for select communities. We also carried out the link test for biases from model misspecification. We found insufficient evidence to suggest a model misspecification, indicating no serious reason to think that any important variable has been excluded in the model.

6.7.5 Model Fit for Probit Analysis: Sensitivity versus Specificity

Evaluating regression models with binary dependent variables involves *sensitivity* and *specificity* analysis. *Sensitivity* refers to the percentage of true positives identified as such by a given model, while *specificity* is the percentage of actual negatives correctly identified. In the case of our probit model, an observation is classified as a true positive if the model predicts a 50 % or greater probability of boil water advisory. Since 96 out of 488 samples have predicted probability of BWA between 40 and 60 %, one would not expect high sensitivity and specificity. This is because observations with probabilities near 50 % have close to the same likelihood of being true positives as being true negatives. Nevertheless, Table 6.7 shows that the sensitivity of our model equals 66.5 % and its specificity is 83.68 %, providing an overall correctly classified percentage of 76.64 %. This analysis reveals that our model has reasonably strong predictive power, although the sensitivity of the model is significantly lower than its specificity.

For the purposes of public health, the sensitivity statistic is more important than specificity, as correctly identifying a potential incidence of system failure is the goal. Further, the 50 % true positive classification cut-off may not be sufficiently risk averse for water system safety. These factors suggest a lower true positive cutoff, which would raise the sensitivity of the model and decrease its specificity, is warranted. To illustrate, see Fig. 6.4 and Table 6.9:

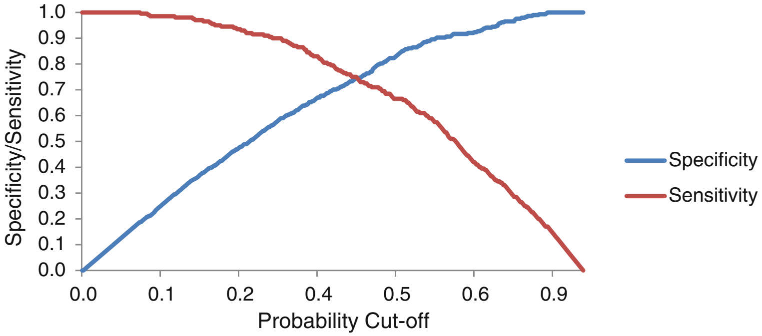

Fig. 6.4 Sensitivity-specificity cut-off curve for model (2)

Table 6.9 Select cut-off percentages and corresponding model (2) sensitivity and specificity

Cut-off %		Sensitivity (%)	Specificity (%)	YI (× 100)[a]
50		66.5	76.6	50.2
40		76.0	72.9	48.9
30		89.0	59.4	48.0
20		94.5	43.8	37.9
10		98.5	29.5	28.0
Optimum cut-off				
Youden max	51.0	66.0	85.8	51.8
Prioritized sensitivity	32.4	86.5	63.9	50.4

[a] Youden Index multiplied by one hundred

Figure 6.4 shows how sensitivity and specificity of our model change as the probability cut-off varies, while Table 6.9 presents select cut-off percentages and their corresponding sensitivity and specificity statistics. Table 6.9 also provides the cut-off where the Youden Index—sum of specificity and sensitivity minus one—is maximized (called "Youden Max"), which is often considered the optimal probability cut-off when no preference between sensitivity and specificity exists (Leeflang et al. 2008). In the public health literature, false negative results, where true positives are not identified as such, have been given particular attention—failing to diagnose properly those with illnesses as ill, for example, often comes with high costs (Babin et al. 2011). Thus, sensitivity has often been more heavily emphasized than specificity in the health literature (Marei et al. 2011 and Hamza et al. 2011).

For that reason, the "Prioritized Sensitivity" cut-off is presented in Table 6.9. The Prioritized Sensitivity cut-off corresponds to

$$\max\{\text{Sensitivity} + \text{Specificity} - 1\}\ \text{s.t. Sensitivity} > \text{Specificity} \tag{6.3}$$

Therefore, the Prioritized Sensitivity cut-off is where the Youden Index is maximized subject to the constraint that sensitivity must be greater than specificity. Equation (6.3) allows for sensitivity to be given precedence without requiring further assertions on risk averseness and the relative costs of false positives versus false negatives, topics outside the scope of this work. From this we arrive at the Prioritized Sensitivity cut-off of 32.4 %, which has sensitivity equal to 86.5 % and specificity at 63.9 %. Moreover, the lower cut-off does not underestimate the proportion of public water systems in the sample that have a boil water advisory, the proxy for water system failure. The true proportion is approximately 41 %, but the Youden Max cut-off predicts 35.5 % of the sample systems to have an active advisory, whereas the Prioritised Sensitivity cut-off estimates 56.8 % of the systems to be under a BWA.

Both the high sensitivity and still acceptable specificity obtained at 32.4 % cut-off as well as the reasonable sensitivity and specificity figures from conventional Youden Index maximization suggest our probit model has a decent fit. Another popular measure of model fit for probit, McFadden pseudo-R^2, also indicates a good model fit at 0.2947 as reported in Table 6.7 (Veall and Zimmermann 1994; Hagle and Mitchell 1992). The pseudo-R^2 index tends to be considerably lower than comparable R^2 metric applied to linear models, and the McFadden pseudo-R^2 value between 0.2 and 0.4 is considered a good fit (McFadden 1979, p. 307).

6.7.6 Ranking of Factors Based on Associated Risk of Water System Failure

The purpose of this section is to rank the factors related to water systems failure by their effects on risk using statistical analysis. Doing so requires tests comparing the magnitudes of the risk associated with select sets of variables from the estimates of our model. Specifically, the absolute values of pairs of variable coefficient estimates are tested, using standard linear hypothesis testing, to determine whether they are statistically different from each other at 10 % significance. If not, the two variables are considered to have statistically equivalent influence on the risk of water system failure. Conversely, the rejection of the null hypothesis indicates that the two variables have statistically different magnitudes of effect on risk. Therefore, one factor may be prioritized over the other. The results of the tests are shown in Table 6.10

Table 6.10 states whether a particular variable listed along the left column has a statistically equivalent magnitude of effect on water system risk compared to the corresponding variable across the top row. If the magnitudes are statistically different, then Table 6.10 shows whether the variable on the column has an effect with greater or smaller magnitude than that of the corresponding row variable. As the tests of coefficients used above are symmetric, entries in Table 6.10 above and below the diagonal have identical meaning. Interpreting Table 6.10, one observes that the effects of persistent turbidity, persistent acidity, and source water protection

Table 6.10 Relevant model (2) coefficient test results

Variables	Having estimated coefficients with equal magnitude to (p-values)				
	Notreat	Thrturb	Thracid	Prot	Chlgas
Notreat		No—greater (0.0525)	No—greater (0.0079)	No—greater (0.0772)	Yes (0.1941)
Thrturb	No—smaller (0.0525)		Yes (0.4299)	Yes (0.6764)	Yes (0.3786)
Thracid	No—smaller (0.0079)	Yes (0.4299)		Yes (0.1418)	No—smaller (0.0623)
Prot	No—smaller (0.0772)	Yes (0.6764)	Yes (0.1418)		Yes (0.5942)
Chlgas	Yes (0.1941)	Yes (0.3786)	No—greater (0.0623)	Yes (0.5942)	

on water system risk have statistically equivalent magnitudes. The test results also demonstrate the large difference in risk between a utility without treatment and one with liquid chlorination, whose magnitude is statistically greater, at 10 %, than those of persistent turbidity, acidity, and source water protection. Although the risk differential between no treatment and liquid chlorine is not statistically larger than between gas and liquid chlorine, the significance level is not large at below 20 %. This implies the importance of having a functioning treatment system—whether liquid or powder chlorine—for reducing water system risk. Figure 6.5 presents the 90 % confidence intervals of the coefficient magnitudes of variables in Table 6.10

Figure 6.5 clearly indicates the relatively large influence of a change from no treatment to liquid chlorine, or the reverse, on water system risk compared to other factors. We can summarize the effects as follows:

1. The change from no treatment to liquid chlorination (or the reverse) has the greatest magnitude of effect such that ensuring each utility has a functioning liquid or powder[5] chlorination system ought to be the foremost concern. To illustrate, the effect on water system risk due to a change from liquid chlorination to no treatment is statistically equivalent to the effects of persistent turbidity and acidity combined (p-value: 0.2999).
2. The change from liquid to gas chlorination (or the reverse) has the magnitude of effect similar to implementing source water protection and dealing with persistent turbidity. This suggests that the primary issue when deciding between installing a gas chlorination system or replacing it with source water protection, is not its corresponding effectiveness in reducing risk; rather, other factors such as cost, operator friendliness, robustness and so on should be the factors that should be taken into account. Nevertheless, Fig. 6.5 shows that after treatment, the most important factor in reducing risk is source protection. Source protection is more important than dealing with persistent turbidity or dealing with persistent acidity.
3. Persistent acidity has the smallest magnitude of effect on water system risk. This is in agreement with Table 6.10, where the change from liquid to gas chlorine is shown to have a statistically larger effect on risk than persistent acidity, but not statistically different from source water protection or persistent turbidity.
4. In summary the order of magnitude of the importance of policy actions is as follows: (a) First make sure there is treatment; this is the ***best*** policy to reduce risk; (b) if there is liquid chlorine treatment, a switch to gas chlorine will reduce risk; if there is no treatment, then the next best policy is to implement source water protection. Reducing turbidity and acidity are of a lower order of importance.

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[5] Otherchl coefficient is not significantly different from zero as shown in Table 6.9. Since liquid chlorination is the base case, this result means that the effect of ‘other chlorine’ (mostly powder chlorine in NL) is statistically equivalent to the effects of liquid chlorine.

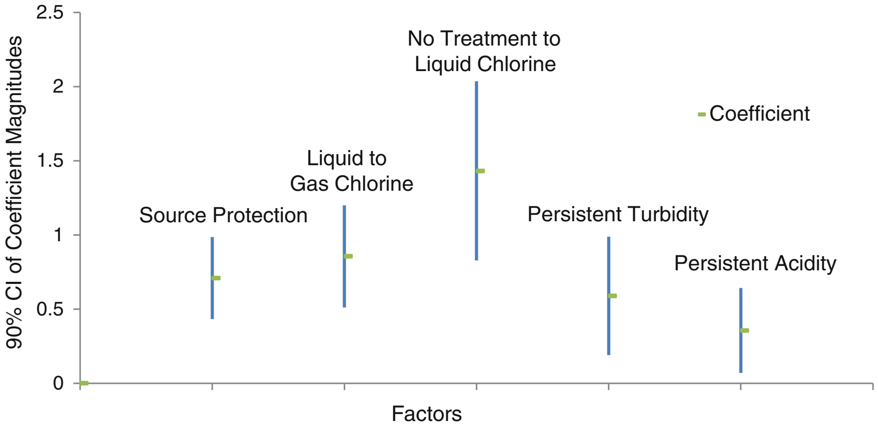

Fig. 6.5 90 % confidence intervals for select variable coefficient magnitudes

6.8 Conclusion

We used data on public water systems in NL to estimate a probit model. The probit model contributed to the ranking in importance of various factors influencing the risk of water system failure, using the probability of BWAs as proxy. First, our model estimates suggest that installing liquid or powder chlorination in water systems lacking treatment would be sufficient to overcome the risk from either persistent turbidity or acidity of source water by a substantial margin. Equivalently, the model estimates that a lack of functioning treatment is more strongly correlated to water system failure than persistently turbid or acidic source water. Liquid or powder chlorination is also significantly more effective than source water protection in reducing the risk of water system failure, and protection alone cannot sufficiently counteract existing source water turbidity and acidity. However, the true color of the source water does not seem to have any statistically significant impact on water system risk.

This chapter surveys and summarizes the very active role played by all NL government agencies: The Department of Environment and Conservation, Government Services, and Municipal Affairs all play an active role in trying to overcome the tremendous challenges that NL water sources pose to the public. NL source water is characterized by high turbidity, color and the prevalence of bogs that render much of the surface water expensive to treat for drinking water. The government devotes a lot of resources to capital equipment, especially for very small communities, and operator training. Their capital assistance follows the "textbook" economic theory of public utilities, whereas other governments like Ontario have left lower jurisdictions (small villages and towns) to find their own capital for water treatment, except for the small program in which the capital costs can be shared one-third by the Federal government and one-third by the province.

In contrast, the government of NL has a scaled program of capital assistance, based on population size. Finally the government of NL follows a policy of very professional data collection, management and public disclosure of data. All data and consultants' reports on the water sector are posted onto the government's water portal. All this makes the government of NL a leader in water and water health; it is a leader worth emulating.

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Chapter 7
Water Policy in Alberta

7.1 Introduction

This chapter focuses on the impacts of agricultural and industrial activity on water resources in the province of Alberta, and how these activities could compromise drinking water quality. In Sect. 7.2, we provide a profile of the water and water policy sector in Alberta. Section 7.3 discusses the modification and implementation of the World Health Organization's guideline titled, "Water Safety Plan" in the province of Alberta, and we assess to what extent Water Safety Plans are likely to be able to enhance safe drinking water. A risk matrix from the Drinking Water Safety Plan is constructed to assess the severity of any existing or emerging chemical, microbiological, physical, or radiological parameters. However, the major problem is that there is no empirical data used to quantify risk parameters when defining the various types of likelihoods. Section 7.4 considers threats that the cattle industry in Alberta poses to drinking water systems in Southern Alberta. In Sect. 7.5, we focus on the North Saskatchewan River Watershed, and assess the problems posed there by the cattle industry. In Sect. 7.6, the impacts of oil sands operations in the Mackenzie River Basin are considered. Alternative approaches to enhancing water safety, such as implementing the Hazard Analysis Critical Control Points (HACCP) and incorporating UV disinfection in the treatment trains are introduced in Sect. 7.7. Finally, in Sect. 7.8 we draw some conclusions.

7.2 A Profile of the Water Sector and Water Policy in Alberta

In 2003, the Government of Alberta launched an "action plan" called "Water for Life," to promote the wise and sustainable use of water in Alberta. The Water for Life Action Plan was supported by an advisory group called "The Water Council of

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Alberta," which became a not-for-profit society in 2007, designed to champion the implementation of a renewed "Water for Life Strategy." While the renewal of Water for Life is mentioned in the Government of Alberta 2013–2016 Strategic Action Plan (Government of Alberta 2013), there appears to be no legislation in existence to give the Water for Life Strategy "legal status." It is one among a *number* of government "action plans" and "strategies," such as the government's "Climate Change Strategy," "Energy Strategy," "International Strategy," "Greening Strategy," and so on. Nevertheless, water conservation is one of the objectives of the Water Act and Water for Life is consistent with the Water Act, although it is not mentioned specifically either in the Water Act or in the Environmental Protection and Enhancement Act.

In the Water for Life Strategy, drinking water is one of the priorities. In December 2010, a revised edition of a publication entitled: *Water for Life*: *Facts and Information on Water in Alberta 2002* was published by the Government of Alberta detailing the drinking water systems in Alberta before the implementation of Drinking Water Safety Plans. Over 80 % of Albertans obtain their drinking water from municipal systems approved by Alberta (Alberta Environment and Sustainable Resource Development 2014a). The remaining residents, including First Nations and rural communities, obtain water from private systems such as wells, water co-ops, or by haulage in trucks. Municipal water systems, operator certification, water source protection, and compliance are covered in the Environmental Protection and Enhancement Act, 1993 as well as in various related regulations.

Alberta Environment and Conservation (the Ministry) also regulates public water systems in the province in accordance with Alberta's Environmental Protection and Enhancement Act, working in conjunction with Alberta Health and Wellness, and Alberta Health Services. Alberta's treatment facilities must meet standards based on Health Canada's Guidelines for Canadian Drinking Water Quality.

After public input, the Water Act 2000 was passed. This Act supports and promotes the conservation and management of water, including the "wise" allocation and use of water. It also recognizes the need for planning and enforcement to achieve outcomes desired by residents. The Water Act also allows a fair mechanism of protecting traditional agricultural water uses, while at the same time minimizing the impact on existing licensed users.

Thus, the legislation regulates all developments and activities that may impact rivers, lakes, wetlands, and groundwater. The Water Act is used to manage and protect the quantity and quality of water. The Environmental Protection and Enhancement Act protects the aquatic environment by regulating point source pollution from places like water treatment plants, refineries, and regulated water distribution systems. The 2010 published review concluded that Alberta has a well-established system for allocating and managing water, through the Water Act and the Environmental Protection and Enhancement Act (Alberta Environment and Sustainable Resource Development 2010a).

The Environmental Protection and Enhancement Act governs all approved public systems, which are the water systems that are required to treat raw water in accordance with the Canadian Drinking Water Quality guidelines. The approved public water systems (10 % of all water systems) in Alberta serve approximately 80 % of Alberta's population. Unapproved public water systems, which face less stringent standards, make up close to 90 % of Alberta's water systems, and yet serve only about 20 % of the population (Government of Alberta 2009).

7.2.1 *Water for Life Strategy*

As stated above, the Water for Life Strategy is being implemented by the Alberta Water Council, in conjunction with Watershed Planning and Advisory Councils (WPACs), and Watershed Stewardship Groups whose descriptions as well as directories are provided in the Alberta Water Portal. The Alberta Water Council comprises both private and public experts in water systems, and is responsible for producing a review of the Water for Life strategy every 2 or 3 years. Four implementation reviews of the Water for Life Strategy have been completed by the Alberta Water Council and the most recent review was released in 2012, while the next review is scheduled to be released in late 2015.

Watershed Planning and Advisory Councils are mainly responsible for creating, implementing, and evaluating watershed management plans in concert with local authorities. There are currently 11 WPACs covering much of Alberta (see Fig. 7.1). Alberta Water Council *Review of Implementation Progress 2009–2011* (2012) has reported good progress on the creation of watershed management plans by WPACs. With the establishment of WPACs for the Athabasca and Peace watersheds, there are now in existence WPACs for all major watersheds.

Watershed Stewardship Groups play a key role in taking community-level action to safeguard Alberta's water resources. There are currently over 140 Watershed Stewardship Groups in existence in all major watersheds and their task is to promote best management practices among Albertan landholders to help improve source water quality and the ecological health of water bodies (Alberta Environment and Sustainable Resource Development 2013a). In 2011, a total of $135,000 was funded to 23 Watershed Stewardship Groups across 10 of Alberta's 11 major watersheds. 19 of these groups were able to complete their projects, which included (a) invasive plant species removal, (b) water and wildlife monitoring, (c) monitoring of riparian areas damaged by livestock and human activity, (d) surface water and groundwater quality assessment, and (e) native tree and shrub plantings. In some cases, Watershed Stewardship Groups have developed technical reports on the state of the watersheds.

The Water for Life strategy sought to achieve three goals by 2014: safe and secure drinking water supplies; healthy aquatic ecosystems; and sustainable water supplies. To those ends, Water for Life was renewed in 2008 and extended to 2019. The specific actions planned were (a) to expand public access to information regarding Alberta's water systems and watersheds, (b) to form local partnerships with private counterparts to encourage stewardship of watersheds, and (c) to foster

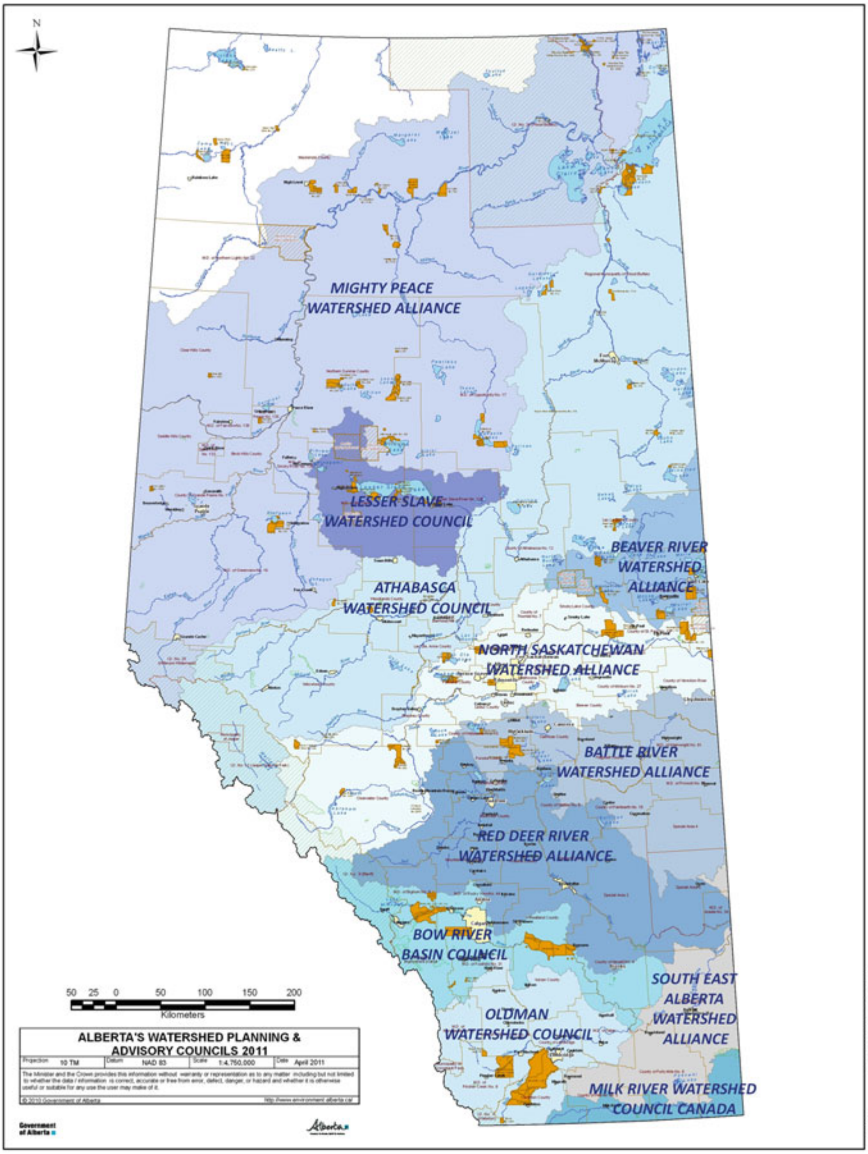

Fig. 7.1 Eleven watershed planning and advisory councils (WPACs) in Alberta (Alberta Environment and Sustainable Resource Development 2014b)

an ethic of water conservation in the province (Alberta Environment and Sustainable Resource Development 2012a).

The analysis of "Water for Life" comes from two documents produced by the Alberta Water Council: (1) "Water for Life: Recommendations for Renewal" (2008) and (2) Alberta Water Council's regular "Review of Implementation

Progress." The Recommendations (2008) report was produced in response to the decision of the Alberta provincial government to renew and review Water for Life in 2006. This (2008) document is often vague, but suggests that Water for Life goals of retaining healthy aquatic ecosystems and conserving water have fallen behind schedule. It notes that, through 2007, little emphasis was placed on protecting aquatic ecosystems, while problems in persuading the Alberta general public that water is a limited resource (not an abundant one) have hampered water conservation (Alberta Water Council 2008). Alberta Water Council's Review of Implementation Progress of Water for Life, 2005–2006 (2007) is more specific, and suggests that there has been progress on the goals of safe and secure drinking water, as well as expanding knowledge and research regarding water. However, like the Recommendations (2008), the Review (2007) finds that efforts toward the Water for Life goals of healthy aquatic ecosystems and water conservation have fallen behind schedule. In particular, even though the development of policy for and the assessment of Alberta's wetlands are on schedule and progress has been made, the systems for monitoring aquatic ecosystem health have yet to be created (Alberta Water Council 2007). In addition, three reports on the use of economic instruments (see Sect. 7.2.1.1) to improve water use productivity have been completed, but no economic instruments have been implemented.

Water for Life: Recommendations for Renewal (2008) presented two key themes: safeguarding water and accelerating action. The themes break down as follows (Alberta Water Council 2008):

Safeguarding water: This aims to (a) halt ecological degradation by adopting the precautionary principle, which states that a lack of knowledge or understanding should not deter intervention in cases where irreversible or severe harm to the environment is imminent, (b) integrate water and land management, such that downstream effects of water systems are minimized and comprehensive watershed protection schemes exist, and (c) create innovative tools and best practices to adapt to new challenges, such as climate change and the rapid growth of the economy and population in Alberta.

Accelerate action: Its purpose is to (a) clarify roles, responsibilities, and accountabilities between the provincial government and its partners in water system management, (b) enhance data collection, analysis, and reporting, to allow Alberta's public and research community a more complete picture of water systems in Alberta, and (c) expand and integrate various public awareness and education programs regarding water, thereby reducing fragmentation among programs and ensuring that the Alberta public understands the shared responsibilities in watershed management.

In 2012, Alberta Water Council's Review of Implementation Progress of Water for Life, 2009–2011 (2012) focused on the implementation of renewed Water for Life action plans (Alberta Water Council 2009). The action plans and their achievements are summarized as follows (Government of Alberta 2009; Alberta Water Council 2012):

Assure safe drinking water

(a) The *short-term plan* (by 2012) focused on (1) expanding water education programs and information resources (online and in print) for private well owners and (2) developing operating standards for conducting an initial audit on small public water systems (which are not governed under the Environmental Protection and Enhancement Act).
(b) The *medium-term plan* (by 2015) was developed to (1) assist First Nations and Metis communities by providing ongoing operator training and water system assessments, (2) conduct household well surveys on contaminants in areas identified with risk, and (3) undertake research on priority water contaminants.
(c) The *long-term plan* (by 2019) was to (1) work with WPACs to incorporate source water protection into watershed planning and (2) develop a management framework to allow for the safe household use of reclaimed water.

Progress so far[1] (in January 2012): The short-term action plans were completed, while there was uncertainty whether a number of the medium to long-term plans would be completed on schedule. Information resources and water education programs like Working Well Program were available to private well owners. Moreover, operating standards and several initiatives such as a new voluntary operator training program and initial audit of small public water systems have been carried out by Alberta Health. Furthermore, 28 new water supply systems and four new wastewater systems were established in 2007 and 2011. Some Stewardship groups like Moose Lake and Elbow River were dealing with source protection by conducting water quality testing.

Healthy aquatic ecosystems

(a) The *short-term plan* (by 2012) intended to (1) complete wetland inventory and develop indicators of wetland health, (2) identify endangered aquatic ecosystems to be prioritized, and (3) establish Bow Habitat Station as a center for public aquatic ecosystem learning.
(b) The *medium-term plan* (by 2015) is designed to (1) set objectives for water conservation on all major water basins and (2) introduce legislation and management plans to improve endangered aquatic water systems.
(c) The *long-term plan* (by 2019) focuses on monitoring and adjusting policy as necessary to ensure the health of aquatic life.

Progress so far (as reported in January 2012): The short-term plan to establish the Bow Habitat Station was completed. The medium to long-term action plan for the South Saskatchewan River basin is expected to be completed by 2015. However, although wetland inventories and indicators have been developed, there seems to be no regulatory mechanism to protect the wetlands.

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[1] Based on Alberta Water Council's "Review of Implementation Progress of Water for Life, 2009–2011" (2012). The next Review is scheduled for release in late 2015. All progress made in fulfilling the plans reported here is based on official Government of Alberta documents; no independent verification was possible.

Reliable water supplies

(a) The *short-term plan* to 2012 aimed to (1) review Alberta's water allocation system, (2) develop automated systems for temporary water diversion licenses, and (3) model future climate change-related effects on major watersheds.
(b) The *medium-term plan* to 2015 was established to (1) implement water allocation transfer systems province-wide, (2) develop a Climate Change Adaptation Strategy for water systems, and (3) make public water use reporting mandatory for all water license holders.

Progress so far (as reported in January 2012): Some short-term goals were achieved by 2012, while several medium-term actions could not be initiated until the remaining short-term goals were achieved. A series of reports on Alberta's water allocation system have been developed, but it seems that the Government of Alberta has not completed this review. Although a number of research initiatives such as hydroclimate modeling have been done, it was difficult to assess their significance and their value. However, mandatory water use reporting has been implemented for water licenses, which was ahead of schedule.

Knowledge and research

(a) The *short-term plan* to 2012 focused on (1) developing online and printed teacher-material for water education (2) assisting Alberta Water Research Institute (AWRI) to identify and support Alberta's water research specialties (mainly hydrogeology).
(b) The *long-term plan* to 2019 aims to (1) complete flood risk maps and warning systems for all communities with flood risk, (2) map and model Alberta's groundwater, and (3) implement a water quality and supply monitoring and evaluation system.

Progress so far (as reported in January 2012): Several short-term action plans have not been completed. For example, while the Government of Alberta made an effort to construct a comprehensive educational framework, the implementation has been halted since users' needs cannot be identified. Thus, this action needs to be re-evaluated by defining the users and their needs. Some long-term actions have begun to be implemented. Initiatives such as new provincial environmental monitoring programs are in the process of being developed.

Partnerships for watershed management

(a) The *short-term plan* to 2012 was established to (1) create sustainable operational funding for watershed management partners to enhance their capabilities over time, (2) establish cross-ministry watershed planning teams, (3) develop indicators for watershed and regional water system planning, (4) establish WPACs for Athabasca and Peace watersheds, and (5) complete transboundary agreements for sustainable water use with neighboring jurisdictions (Montana, British Columbia, Saskatchewan, and Northwest Territories).
(b) The *medium-term plan* to the end of 2015 was to focus on completing watershed management plans by WPACs for their respective regions.

(c) The *long-term plan* was to implement watershed management plans created by WPACs.

Progress so far (as reported in January 2012): Some of the short-term action plans were achieved and some were underway in 2012. In particular, the Government of Alberta funded around $9 million to watershed management partners to enhance their capabilities during 2009 and 2011, but a sustainable operational funding strategy has yet to be completed. Furthermore, indicators for watershed management were established, while regional water system planning has not been accomplished. In addition, to improve sustainable water use with neighboring jurisdictions, Alberta completed transboundary agreements with British Columbia and the Northwest Territories, but the remaining plans have yet to be achieved. Moreover, the two new WPACs for Athabasca and Peace watersheds were established. The medium-term actions were ongoing and the watershed management plans for major watersheds will have been established by 2015. Finally, the long-term goals will not be initiated until medium-term goals are achieved.

Water conservation

(a) The *short-term plan* (by 2012) aimed to (1) develop and implement an intensive education program for water conservation and (2) develop Conservation, Efficiency and Productivity (CEP) plans for key water sectors.
(b) The *medium-term plan* (by 2015) was meant to (1) develop tools to integrate environmental and socioeconomic values into water management decision-making and (2) implement the CEP plans for key water sectors.

The *long-term plan* (by 2019) was to focus on establishing an ongoing monitoring system to ensure water use efficiency; conservation and productivity objectives were to be met by all major water using sectors.

Progress so far (as reported in October 2012): Several short to medium-term action plans were completed by June 2012. Specifically, all the major water using sectors had developed and implemented the CEP plans, but a long-term monitoring system has yet to be established to ensure water use efficiency. Moreover, an enhanced education program was being evaluated by the Government of Alberta, but this has not yet been completed. In addition, two pilot projects including an ecosystem approach to integrate environmental, economic, and social values into wetland management decision-making, as well as a rapid assessment tool to assess wetland function were completed, but no other projects have been initiated.

7.2.1.1 The Proposed Use of Economic Instruments in the Water for Life Strategy

The following four tools are listed as being the Government of Alberta's approach for water management (Alberta Environment and Sustainable Resource Development 2010b).

1. *Economic instruments*: these are referred to as market-based instruments that provide financial incentives and disincentives to guide behavior to help meet desired policy or management objectives.
2. *Cooperative management agreements*: parties agreed to undertake specific actions in a cooperative manner to address an issue.
3. *Information disclosure*: the plan was to inform the public of risks or benefits to human health or natural resources, and the environmental consequences of undertaking an activity (for example, pollution release, upgrading a water treatment process, etc.).
4. *Voluntary stewardship*: the plan was to encourage self-motivated and self-directed actions of private parties toward meeting an objective.

In this section, we report and comment only on the "market-based economic instruments" and how Alberta plans to use them to achieve conservation objectives. The stated objectives in the Water for Life Strategy are (1) water use reporting; (2) meeting water conservation objectives in different basins; (3) reduction or elimination of nonpoint source pollution; (4) water conservation in basins without caps; (5) protection of riparian areas; and (6) protection of wetlands. For each of the above objectives, there is a proposed set of "economic, market based instruments," designed to serve as an incentive to achieve the six objectives.

(1) *Water Use Reporting*

The economic instrument proposed is a refundable annual administration fee. Fees may be used to provide an incentive to licensees to report water use.

Comment: refundable fees will simply mean that the burden of water use reporting will fall on the taxpayer; this is hardly a market-based solution.

(2) *Meeting Water Conservation Objectives In Different Basins*

There are three possible options for meeting the conservation objective:

(a) Government purchases of licenses to restore stream flow to meet water conservation objectives, (b) third party purchases of licenses, (c) return of unused allocation to the government.

Comment: at the moment, the rule in water use is "*first in time, first in right*." This rule is unlikely to help with conservation unless the government buys back all the existing water rights that are being exercised contrary to the conservation objectives.

Alberta has several "closed basins" where all available water has been allocated. For any new withdrawals of water in these basins, people have to buy a license from individuals or corporate entities who hold current water allocation rights. The price paid for a water license is *regulated*, and the transfer process ensures that the proper procedure is followed. While various policies apply to the transfer process: e.g., Is the license in "good standing?" Is the withdrawal point on the same reach of the river? Should in-stream flow needs be applied to the transferred license? In a water shortage (drought), the oldest license holder has the ability to withdraw water before more junior or later licensees. The decision as to who is allowed to withdraw water in a shortage is called "water mastering." Thus the price of a water license depends on a number of factors including seniority, "good standing," location and dependence on in-stream flow needs. The key question is how is the price going to be regulated, and whether, when water is scarce, existing license holders could refuse to transfer water at the regulated price. As with any price below market equilibrium, there will emerge other "non-market" allocation mechanisms. Thus, for example, an applicant for a new license may make a hidden "side payment," to reflect the market price of a scarce good. If Schindler and Donahue (2006), and other scientists are right, there are going to be lower water flows due to climate change. Hence any historical holder of a license could suddenly discover that his/her "water rights" are extremely valuable. If the government were to succeed in buying the license, the holder would make a huge windfall gain. At a time of declining tax revenues, either the proposed "government purchase" is likely to be very costly, or some future legislation will have to determine what the "price" would be for the government purchase. If the government ends up imposing the price, the whole idea of market-based instruments will have been violated and there will be no faith in the so-called "market based solution."

(3) *Reduce or Eliminate Nonpoint Source Pollution*
The plan is to introduce "Cap-and-trade for nutrient trading in watersheds", and introduce an "Offset program," whereby polluters may be asked to fund improvement in nutrient management to offset their loadings to the watershed. Comment: Cap-and-trade works when the "point source" is known, as with sulfur emission from known power plants. But the defining characteristic of a "nonpoint source" is that the point of origin is not known, unless all farmers are asked to submit invoices for the amount of fertilizers they plan to buy and use on the farms. This turns a market-based instrument into "command and control," i.e., the amount of fertilizer used will have to become *regulated.* Thus cap-and-trade for nonpoint source pollution is unlikely to work. That leaves the so-called "Offset Programs."

In the offset program, all farmers, as "polluters" would have to accept collective responsibility for their share of the nutrient loadings. This is a classic "public bad" problem, which is likely to be contested; the government would have to find a way of "attributing" nonsource pollution to specific farms, for specific amounts. This is not going to be easy; in fact it would be nearly impossible. The objective is that farmers would themselves take responsibility for their "share" of the pollution, a share that is nearly impossible to determine. The simplest thing to do is to put a value-added tax on the amount of fertilizer sold. This comes close to a market-based solution. It is the same sort of solution that is advocated for carbon emissions, namely a carbon tax. (There is in fact a tax that Alberta levies on carbon emissions.)

(4) *Water Conservation In Basins Without Caps*
In basins where there are no caps to water withdrawal, a volumetric price would have to be introduced; but this volume would have to be monitored by some regulatory agency. Of course a municipality can do this. But for rights

already allocated, a "cap-and-trade" regime is envisaged. All cap-and-trade regimes are costly to implement and costly to run. Those holding existing water rights may have no incentive to participate, unless they stand to make a huge windfall gain.

(5) *Protection of Riparian Areas*

It is expected that there would be subsidies and or tax credits for developers who protect riparian areas.

Comment: This again means a burden on the taxpayer. This is not a market-based solution.

(6) *Protection of Wetlands*

Wetland restoration will be compensated through municipal taxation policies that exempt wetlands from taxation. In addition, there will be a "hunters' access fee" to provide an incentive to landowners to protect wetlands in exchange for allowing hunters access to their property.

Comment: If wetland restoration is compensated by reduced municipal taxation, then this effectively means a shortfall that municipalities will have to offset by raising property taxes; an alternative would be that the provincial government would compensate municipalities for the loss of tax revenue. One way or the other, this shifts the burden to the taxpayer and so cannot be called a "market-based solution." On the other hand, if hunters pay landowners a fee, then this is truly a market-based solution. This is creating a market in hunting animals. But the owners will have to install electronic monitoring devices and fences so that unauthorized hunting is quickly discovered. The fee will have to be set by landowners, determined by what the market will bear. The cost of monitoring may be more than the total fee revenue, and this may be what is called a "thin" market. Thin markets, in which by definition demand is low, do not survive. Much of wildlife meat (deer, elk, bison, wild boar, etc.) is now farmed in Alberta and elsewhere so that hunting is mostly a "sport." Also, First Nations hunters may have to be exempt from paying a fee. A more likely source of revenue might be access for snowmobile tracks on private land in the winter.

In summary, it looks extremely unlikely that market-based instruments will work to enhance water conservation in the Water For Life Strategy. The proposed commitment to market-based instruments is more likely to confuse all the people who are likely to be the major actors in the conservation effort.

7.2.2 Approaches to Drinking Water

Alberta has adopted a multibarrier approach to drinking water, which it calls the "Source to Tap, Multi-Barrier Approach." The multibarrier approach to drinking water seeks to minimize the risk of water system failure by placing safeguards at each step of the drinking water cycle—from source water intake to the tap. The Alberta Environment's Drinking Water Program: "Source-to-tap Approach" (2009a) document provides details of its source to tap, multibarrier approach, whose main components are legislation, drinking water systems, knowledge and awareness, performance assurance, and source water protection. The legislative portion of the source-to-tap, multibarrier approach includes the Environmental Protection and Enhancement Act, the Public Health Act, and regulations under these acts. In particular, the Environmental Protection and Enhancement Act requires all approved public water systems to adhere to the Guidelines for Canadian Drinking Water Quality recommendations.

The drinking water system portion of the source to tap, multibarrier approach refers to the funding and design aspects of water treatment. The Alberta Municipal Water/Wastewater Partnership is the principal policy instrument for water system financing in Alberta (detailed in the Sect. 7.2.4). The source to tap, multibarrier approach's knowledge and awareness component includes the monitoring and evaluation of water systems, and also the development and implementation of full cost accounting initiatives among water systems.

The performance assurance portion of the source to tap, multibarrier approach consists of approvals and registrations, compliance assistance, and enforcement. These areas are discussed below (Alberta Environment and Sustainable Resource Development 2009a):

Approvals and registrations—approved waterworks systems must receive approvals for the construction and maintenance of treatment facilities and procedures, where the specific approvals provide explicit monitoring, reporting, and other water quality-related objectives.

Compliance assistance—compliance inspectors audit waterworks on the province's behalf to ensure relevant regulations are being followed.

Enforcement—if water system operators and/or owners have failed to meet regulatory requirements, then Alberta Environment and Sustainable Resource Development may pursue legal action, including issuing Boil Water Advisories (BWA) and criminal prosecution of the water system operator/owner on the basis of the Environmental Protection and Enhancement Act, Public Health Act, or other legislation.

Abatement—Alberta's provincial government employs Drinking Water Operations Specialists who help water system operators with technical advice, emergency decision-making, and onsite training.

Source water protection is the first barrier in the source to tap, multibarrier approach. The Water for Life strategy assigns all watersheds in Alberta to the eleven Water Protection Advisory Committees which devise specific water management plans for individual water basins. WPACs have yet to complete their respective water management plans, and the full implementation of WPACs plans is due by 2019. Once a plan has been completed, each stakeholder (i.e., affected municipalities, government ministries, etc.) is responsible for implementing the relevant parts of the final plan within its own legal framework. For example, local agricultural organizations may act upon the sections of the completed plan which affect farmers. The Bow River Basin Council is an example of WPACs and it focuses on conditions affecting the Bow River Basin specifically when creating its management plan. However, Bow River Basin Council and other WPACs are not yet at a stage where their recommendations can be implemented.

The protection element of the source to tap, multibarrier approach also includes water sampling/testing. Approved public water systems have individual sampling frequencies that are stated in the community or regional water system approval or code of practice. In general, the approvals and codes of practice follow Guidelines for Canadian Drinking Water Quality in their sampling and other monitoring requirements. The Communication and Action Protocol for Failed Bacteriological Results in Drinking Water (2009b) provides a framework for water quality monitoring and emergency response. Some of its key points and procedures are listed below (Alberta Environment and Sustainable Resource Development 2009b):

- Bacteriological sampling frequency is determined by Guidelines for Canadian Drinking Water Quality, community approval, or the code of practice.
- Following a repair of water treatment or distribution facility/equipment, the operator must flush the line and sample for total coliforms or *Escherichia coli*, chlorine residual, and turbidity.
- All samples are to be tested using Defined Substrate Technology for coliforms and *E. coli*. These have to be submitted to the Provincial Laboratory. The City of Calgary and EPCOR[2] are allowed to process 50 % of their samples in their own laboratories.
- Maximum Allowable Concentrations (MAC): (a) *E. coli* should not be detected per 100 mL water sample, i.e., concentrations should be zero and (b) total coliforms should not be detected per 100 mL water sample; however, systems collecting more than 10 samples per month are exempt from this total coliform rule. Instead, no consecutive samples and no more than 10 % of all samples may show total coliforms.
- If MAC set in the Protocol or the community code of practice are breached, the lab must contact Alberta Environment and Sustainable Resource Development or Health Canada (if a First Nations community is involved). The corrective actions aim to (a) repair the water system, (b) optimize the treatment system if turbidity is exceeded, (c) increase disinfectant dosage and monitoring for chlorine residual, and (d) flush water mains until the chlorine residual minimum concentration is met.
- If a maximum allowable concentration is breached in a sample, resampling must be completed by the operator. First, three resamples must be completed for each sample found to contain total coliforms or *E. coli*, at the site where it was first detected as well as points up- and down-stream from that site. Second, resamples must be completed within 24 h of notification to the water system owner or operator. Finally, for each resample with positive total coliforms or *E. coli*, the municipality must submit another three sample sets.

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[2] EPCOR is the major water utility for Edmonton.

7.2.3 Boil Water Advisories

Boil Water Advisories in Alberta are governed under the Environmental Protection and Enhancement Act, and are regulated by the Communication and Action Protocol for Failed Bacteriological Results in Drinking Water (August 2009). A Boil Water Advisory in Alberta may be issued by Alberta Health Services, Alberta's integrated public health system, in consultation with Alberta Environment and Sustainable Development as well as the owner or operator of the water facility in question. If a First Nations community is involved, Health Canada may issue a Boil Water Advisory instead. Alberta Environment and Sustainable Resource Development and Health Canada reserve the authority to designate either the entire community which the offending water system serves or just those areas directly affected. Alberta Health Services and Health Canada may limit a Boil Water Advisory to a specific building if water quality problems are specific to that facility. The Alberta Environment and Sustainable Resource Development or Health Canada (for cases involving First Nations) may issue a Boil Water Advisory where: (a) test results exceeded the bacteriological limits set in the Guidelines for Canadian Drinking Water Quality; (b) equipment or facility malfunction or deactivation causes concerns regarding the effectiveness of the water plant or distribution system; (c) an officer of the Alberta Health Services or Health Canada (for First Nations cases) believes that the results of analysis reveal a public health concern; (d) turbidity limits or disinfection residual levels set in the approval documents of the water system in question have been breached; (e) an increase in waterborne illness is detected in a community; (f) the presence of *E. coli* is confirmed via three resamplings of treated water; and (g) total coliform concentration in water, with the absence of *E. coli*, exceeds 10 organisms per 100 mL. Water systems with water safety plans approved by Alberta Environment and Sustainable Resource Development, Alberta Health Services, and Health Canada may follow the instructions in the water safety plans (on which more below), rather than issue a Boil Water Advisory.

The owner or operator of the water system with a Boil Water Advisory and the local district offices of Alberta Health Services are responsible for informing consumers of the Boil Water Advisory. In general, Alberta Health Services and Health Canada have broad authority in issuing and revoking BWA, insofar as Alberta Health Services and Health Canada have significant authority to determine what constitutes danger to public health.

Alberta keeps data regarding BWA for 5 years from the revocation of the Boil Water Advisory. Between January 2006 and May 2012, there were 95 BWA in Alberta, which usually remained active for less than a month. The most frequent cases of Boil Water Advisory issuance were precautionary advisories in response to water distribution or pumping system failure (39 out of 95 BWA), followed by precautionary BWA due to a breach of turbidity or free chlorine residual standards (32 out of 95 BWA). To resolve the problem that first led to the boil water advisory, 46 out of 95 Boil Water Advisory designated water systems received assistance from the officials of Alberta Environment and Sustainable Resource Development. All other BWA were resolved by local operators.

7.2.4 Water Facilities and Capital Funding

Financing for water system infrastructure in Alberta is provided by both local and provincial governments. Alberta Municipal Water/Wastewater Partnership, operated by the Alberta Ministry of Transport, is the program through which the provincial government assists in the funding of individual municipal and, under the Alberta Municipal Water/Wastewater Partnership's Regional Systems initiative, regional capital projects. Alberta Municipal Water/Wastewater Partnership dates from 1991 and is governed under the Environmental Protection and Enhancement Act and the Water Act, as well as specific legislation concerning the program.

The *Water Act* places household use of water as the most important purpose for water in Alberta. Accordingly, the prioritization of funds dispensed to water-related capital works projects is (1) health-related improvements benefitting household users, (2) environmental protection, and (3) safety, fire protection, and operational improvements for water system facilities.

No database containing source water characteristics and treated water sampling results for Alberta's water systems exists. An online query system listing separate *E. coli*, total coliforms and free chlorine residual sample readings is functional, though it provides only limited information, and is difficult to use for the purposes of surveying all water systems in Alberta. However, the Water for Life initiative led to the publication of a *Waterworks Facility Assessment Report* in 2004, which provides an overview of Alberta's water systems. The report indicates that there are 665 public water systems registered with the Ministry (Alberta Environment and Sustainable Resource Development 2004). Of these, 192 (36 %) had surface water sources, 26 (5 %) had groundwater under direct influence of surface water (GUDI) as water source, and 116 (22 %) had high-quality groundwater sources.[3]

The Alberta Municipal Water/Wastewater Partnership applies to any single municipality, which includes cities, towns, villages, Metis settlements, and hamlets, with an official population below 45,000. Regional water or wastewater commissions—institutions that manage water/wastewater systems across multiple localities—whose individual municipal members have populations smaller than 45,000 are also eligible for the Alberta Municipal Water/Wastewater Partnership. Applicant municipalities must complete a feasibility study for the proposed project. Communities with larger populations receive a progressively smaller proportion of capital costs funded by the provincial government. The funding formulas are shown in Table 7.1.

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[3] The Report's other findings and recommendations are out-dated, and thus are excluded.

Table 7.1 Water/wastewater funding based on population

Population	Provincial portion (%)	Example
≤1,000	75	Provincial portion = 75 %
1,001–3,000	$\frac{(0.5 \times \text{Pop}) + 250}{\text{Pop}} \times 100$	Population: 1,500 provincial portion $= \frac{(0.5 \times 1{,}500) + 250}{1{,}500} \times 100$ $= 67\ \%$
3,001–10,000	$\frac{(0.25 \times \text{Pop}) + 1{,}000}{\text{Pop}} \times 100$	Population: 4,000 provincial portion $= \frac{(0.25 \times 4{,}000) + 1{,}000}{4{,}000} \times 100$ $= 50\ \%$
10,001–45,000	$35 - 0.001\,(\text{Pop} - 10{,}000)$	Population: 20,000 provincial portion $= 35 - 0.001\,(20{,}000 - 10{,}000)$ $= 25\ \%$
>45,000	None	Provincial portion = 0 %

Pop = population of municipality

Not all costs relating to drinking water-related capital projects are eligible for funding as presented above. Eligible expenses include such components as wells and all raw-water intakes, municipal labor and equipment costs, supply lines and water storage, water treatment facilities, and connection from treatment plant to the first point on the distribution system. Costs for operating, routine maintenance, the purchase of small capital assets, general municipal administration, Goods and Services Tax, depreciation or amortization as well as loan fees are not eligible for funding (Municipal Affairs 2013).

A regional commission, group of municipalities, or public–private partnership may be eligible for funding under the Alberta Municipal Water/Wastewater Partnership Regional Systems program if it can show that a regional project connecting multiple localities is more cost effective than separate municipal projects. This program started in 2006 as a part of the Water for Life (2003) strategy implemented by the Alberta government to encourage the creation of water systems integrating multiple localities. The Regional Systems program applies to both new regional water systems as well as existing ones, if the localities involved individually have populations below 45,000 and are eligible for the Alberta Municipal Water/Wastewater Partnership. Parts of the project costs assigned to private commercial or industrial partners are not covered under the Regional Systems program (or the Alberta Municipal Water/Wastewater Partnership).

For existing regional systems, both the funding formula and the list of eligible costs covered are the same as for the Regional Systems program and Alberta Municipal Water/Wastewater Partnership. The only differences between Regional Systems and Alberta Municipal Water/Wastewater Partnership programs are the need to separate funding payouts to different municipalities and the separation of costs incurred to noneligible partners (such as private firms) from all other costs in the Regional Systems program. The proportion of the total payout from the

Regional Systems program that will be given to a partner community is equal to the proportion of total population that will be served by the regional capital water project:

$$\textit{Payout for Community A} = \frac{\textit{Pop of A}}{\textit{Total Pop of all Communities}} \times \textit{Funding from WL}$$

The funding for new regional systems needs to be reviewed by the Departments of Municipal Affairs, Environment, and Health before approval under the Regional Systems program. This review will consider cost effectiveness and cost-benefit of the project, as well as the provincial government's budgetary concerns. Funding will be provided only if the primary purpose of the new connections is for household use. A feasibility study must be completed by the applicants as a part of the review.

The Alberta Municipal Water/Wastewater Partnership includes a water conservation policy that affects municipalities found to have (a) no water metering in place and an average per capita water consumption higher than the average of the area and (b) water meters in place, but without a water price schedule based on consumption. Water systems affected by the water conservation policy have their provincial capital funding portion under the Alberta Municipal Water/Wastewater Partnership reduced by 10 % points. For example, if a municipality is otherwise eligible for 60 % of capital costs to be paid by the province, only 50 % of these costs will be covered.

As a part of the Water for Life strategy, Alberta's provincial government has a policy of encouraging the use of full cost accounting among drinking water systems. Full cost accounting allows system owners and the provincial government to have an accurate understanding of the costs associated with a given water system, such that proper management and capital funding plans may be devised. Moreover, full cost accounting assists the public in understanding the relationship between water rates and the costs of providing drinking water. *A Guide to Alberta Environment's Full Cost Accounting Program* provides a good overview of the program, which is not mandatory; but the 2009 Alberta Water Council Water for Life implementation report states that the program has been successful in leading water systems to adopt the accounting principle. However this is not quite correct; research underway by a Masters student at the University of Calgary has found many small systems have not implemented full cost accounting.

There are two types of cost accounting: the *utility approach*, which is preferred, and the *cash needs* approach, used only in instances where the utility approach has been tried. Both approaches were first recognized by the American Water and Wastewater Association. The utility approach is true full cost accounting as it includes all operation and maintenance costs, as well as depreciation and return on capital, while the cash needs approach contains operation and maintenance costs, debt service, and nondebt capital expenditures; it comes close to what economists would call marginal cost pricing.

Table 7.2 Water rates of private utilities in Alberta for residential users

Utility	Special note	Fixed monthly charge ($)	Metered charge ($ per m^3)
Corix Group	None	44.85	1.580
CU Water Ltd	Urban (rural)	16.24 (40.80)	3.559 (3.559)
Langdon Waterworks	None	37.00	1.539
Regional Water Services Ltd	(Above 20 m^3)	46.00	1.500 (4.100)
Westridge Utility Inc.	(Above 30 m^3)	63.69	0.760 (1.010)

There exists no systematic water pricing pattern or province-wide water pricing regulation in Alberta. Further, water rate schedules of different water systems are not compiled in a database, although some public water systems' rates are posted on their respective municipality websites. The rates charged by private water utilities are also available, on the Alberta Utility Commission website.[4] The Alberta Utility Commission regulates investor-owned electric, gas, and water utilities in Alberta. Water pricing schedules used by the private utilities in 2014 are given in Table 7.2.

Private utility water rate schedules, as well as a preliminary online search on select municipal websites (including Calgary), suggest that the typical water rates in Alberta include both a fixed monthly charge and a variable metered charge. Occasionally, other prices may be charged as in CU Water Ltd[5] above, which has different fixed charges for urban and rural customers. Regional Water Services Ltd and Westridge Utility Inc. charge greater metered prices above a certain threshold of use in a month (20 and 30 m^3 per month, respectively).

7.2.5 Operator Training and Certification

Alberta has a robust operator certification and certificate renewal program, where operators are required to engage in continuous training to retain their certification. The Alberta operator training and certification program is detailed in the *Alberta Environment and Sustainable Resource Development Water and Wastewater Operators' Certification Guidelines*, and is governed by the Environmental Protection and Enhancement Act. Note that First Nations water systems are not under

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[4] http://www.auc.ab.ca/utility-sector/rates-and-tariffs/Pages/WaterRatesandTermsandConditionsofService.aspx.

[5] In 2010, CU Water Ltd was acquired by the "Highway 14 Water Services Commission" which supplies drinking water to many small communities such as Beaver County, Strathcona County, the Town of Tofield, the Village of Holden, the Village of Ryley and the Town of Viking.

Table 7.3 Certification requirements for management positions in water utilities in Alberta

Certification level	Maximum level of facility the operator may be in charge of
Small systems	None
I	I
II	II
III	III
IV	IV

Reproduced from Alberta Environment and Sustainable Resource Development (2013b)

the authority of Alberta's provincial government and are regulated by Health Canada and other federal agencies.

All water system operators in Alberta are required to be certified. The lowest certification, small system operator, may not be in charge of day-to-day operations of any facilities. Those with level I, II, III, or IV certification may be in charge of, at most, level I, II, III, or IV facilities, respectively (Alberta Environment and Sustainable Resource Development 2013b). See Table 7.3 for certification requirements.

All drinking water systems typically have water distribution systems, and a water treatment plant component. Water distribution systems include systems of pipes as well as all other means by which treated water is stored or conveyed to a service connection—for example, pumping stations and post-treatment reservoirs. The water treatment plants are the portions of waterworks where the physical, chemical, or bacteriological characteristics of the source water are improved, but facilities which only chlorinate groundwater without influence from surface water are not considered water treatment plants (Alberta Environment and Sustainable Resource Development 2013b). The water facility levels are given in Table 7.4.

Water distribution systems are categorized by the population served, whereas water treatment plants levels are determined by the Alberta Water and Wastewater Operator Certification based on the difficulty of operating a given plant as indicated by factors such as source water quality and technologies involved in the operation of the plant. Specific facility staffing levels are summarized in Table 7.5.

As shown above, staffing requirements of water distribution systems vary only by population served (the way the systems' levels are determined), whereas the requirements for water treatment plants differ by both the plant level and the population served.

Table 7.4 Water facility classifications. (Reproduced from Alberta Environment and Sustainable Resource Development 2013b)

Type	I	II	III	IV
Water distribution	Serves 1,500 or fewer people	Serves 1,501–15,000	Serves 15,001–50,000	Serves 50,001 or more
Water treatment	Determined by AEWWOCC[a] based on operation difficulty			

[a] Alberta Environment Water and Wastewater Operator Certification Committee

Table 7.5 Facility staffing requirements. (Reproduced from Alberta Environment and Sustainable Resource Development 2013b)

Facility level	Minimum certification for operator in charge	Other operator minimum certification
I	Level I	Small systems
II	Level II	Small systems
III	Level III	Depends on population served
		<1,500—*small systems*
		1,500–15,000—*at least one operator with Level I or higher certification; others need small systems certification or better*
		15,000–50,000—*at least one operator with Level II or higher, others need small systems*
		>50,000—*at least one operator with Level II or higher plus another with Level I or higher, others need small systems*
IV	Level IV	Depends on population served
		<200,000—*at least two Level III or higher plus one Level II or better operator per each shift, others need small systems or better*
		>200,000—*same as above except need one operator with Level IV and another with Level III or IV rather than two Level III or higher operators*

Level IV Water distribution systems always have requirements as if they have <200,000 population

An aspiring operator may obtain certification by obtaining at least a 70 % score on certification exams. To qualify for the exams, one must meet the requirements set out in Table 7.6.

Table 7.6 Requirements for each exam level. (Reproduced from Alberta Environment and Sustainable Resource Development 2013b)

Exam level	Minimum training/education	Minimum experience
Small systems	6 h of applicable training	6 months in small system
I	12 h; high school diploma or equivalent	One year in Level I or higher facility
II	High school diploma or equivalent	3 years in Level II or higher facility
III	2 years post-secondary education in relevant field, or 900 h of applicable training; high school diploma or equivalent	4 years in Level II or higher facility, including 2 years of DRC experience
IV	4 years post-secondary education in relevant field, or 1,800 h of applicable training; high school diploma or equivalent	4 years total, including 2 years of DRC experience in Level III or IV facility

Table 7.7 Alberta water and wastewater plant operator pay and employment

Average hours worked (weekly)	39.7	5th percentile wage (hourly)	$12.00
Average wage (hourly)	$25.28	95th percentile wage (hourly)	$36.11
Average pay (annual)	$53,147	Vacant positions	3 %

Direct Responsible Charge (DRC) refers to any positions in water systems where one supervises day-to-day operations of the facility, and may only be gained after the operator attains Level II or higher certification. The Alberta Environment and Sustainable Resource Development approves courses and training modules that could be counted toward the hours of applicable training for water system operator certification exams.

Experience may be used to substitute up to 50 % of education or training requirements for the certification exam requirements at higher than Level I. One year of approved post-secondary education can substitute a year of non-DRC experience toward Level II or higher exams. The years of education put forward as a substitute for experience are not counted as a part of applicable training hours.

Conversely, DRC experience may substitute for education requirements. For a Level 3 exam, up to 1 year of DRC experience at a Class II or higher facility can be substituted for 1 year of post-secondary education. For Level 4, a maximum of 2 years of DRC experience may be substituted for an equivalent period of post-secondary education. Substitutions for education and experience do not remove the minimum requirement of high school diploma or equivalent.

A certified water system operator must renew his or her certification every 3 years. To do so, one must obtain a minimum of 12 months of experience in the 3 year period and complete 36 h of applicable approved education and training. If this is not possible, 72 h of applicable approved education/training or rewriting the certification exam during the 3-year period may be used to renew certification through up to two 3-year renewal periods. A small system certified operator is exempt from the above renewal conditions, and must obtain only 6 h of approved training every 3 years to retain his or her certification.

Water and wastewater plant operator pay and employment data can be accessed through the WAGE*info* database maintained by the Alberta Human Services, Government of Alberta (Alberta Human Services 2013). The database was accessed in July 2012, and data from 2011 is given in Table 7.7.

7.2.6 New Initiatives and Other Water Issues

The two new Alberta government initiatives on drinking water are both tied to the division in water use pattern between northern and central-southern Alberta (which has over 80 % of all Alberta residents). In particular, the water basins of the Athabasca and South Saskatchewan Rivers see elevated water use as well as high levels of groundwater well penetration. The provincial government is, under the

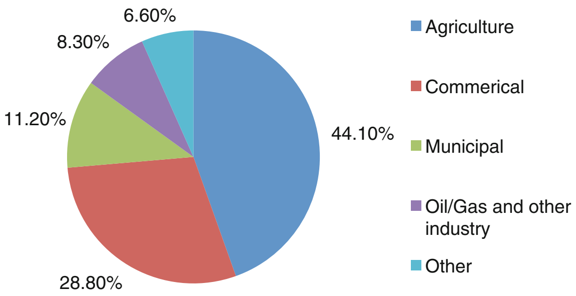

Fig. 7.2 The distribution of water allocations among different economic sectors in Alberta in 2010 (Alberta Environment and Sustainable Resource Development 2014c)

Water for Life strategy, implementing a series of groundwater and water allocation transfer programs.

Water allocations refer to the amount of water a holder of the allocation may draw each year. The different economic sectors in Alberta are: agriculture, commercial, municipal, oil/gas, and other industry. Their respective shares are 44.1, 28.8, 11.2, and 8.3 % in 2010 (see Fig. 7.2).

The distribution of water allocations is drastically different depending on geographical location within Alberta. Northern Alberta tends to have a much higher proportion of water allocations provided to the oil and gas industry, whereas Southern Alberta's water is overwhelmingly assigned to agriculture. For example, southern water basins around the Milk, South Saskatchewan, and North Saskatchewan Rivers have approximately 80 % of their water allocated toward agricultural uses. On the other hand, central Alberta's Athabasca River Basin and the northern Hay River Basin have over 60 % of their water allocated to the oil and gas industries.

Southern and Central Alberta have much higher rates of water allocation as a proportion of total natural flows than Northern Alberta. All water basins with more than 10 % of natural flows allocated are in Southern Alberta, while all northern basins have less than 10 % allocated. In particular, there are more than 70 % of natural flows allocated in Sounding Creek, South Saskatchewan River, and Pakowki Lake basins, while less than 10 % is allocated in the North Saskatchewan River Basin.

All of Northern Canada's water sources, including Alberta, will face enormous strains due to climate change; all established hydrological patterns are likely to change, due to loss of "hydrologic stationarity" (Sandford 2012). Furthermore, the rivers of Alberta and British Columbia depend on flows from glacial melt and snowpack melt. The detailed coverage of technical findings of scientists of the impacts of climate change on Northern Canada are brilliantly summarized by Dr. Robert Sandford in his 2012 book referenced above. For a survey of future climate change scenarios affecting Canada as a whole, see Dore and Simcisko (2013).

Facing very high rates of diversion from natural water flows in Southern Alberta, the Alberta government passed revisions to the Water Act, in part to ease the pressures on natural water flows in Southern Alberta. The Alberta government closed several basins to new allocations. The Water Act allows, uniquely in Canada, holders of rights to certain amounts of water per year to transfer, permanently or temporarily, those rights to others at a price. The provincial government can refuse requests for new allocations and not allocate portions of natural flows to new users. Instead, newcomers may purchase rights to allocations from existing license holders.

The transfer of a water allocation right must be approved by the Director of Alberta Environment and Sustainable Resource Development before coming into effect. In addition, household and residential water licenses cannot be transferred. Among those that have been approved and may be transferred, the current license holder may transfer a part or the whole of his or her allocation, and the transfer may be permanent or temporary.

There are no restrictions on the terms and conditions by which the license holder and the license buyer can transfer the water allocation. However, Alberta Environment and Sustainable Resource Development may withhold up to 10 % of the water allocation from being transferred for aquatic ecosystem preservation or water conservation purposes.

New water allocation transfers are allowed only in the South Saskatchewan River Basin area, where new allocations (since 2006) have been made to First Nations communities, and for water conservation and storage projects. Otherwise, there are to be no new water allocations; this means that most new residents and businesses in the basin must access the water license market and purchase water allocations from existing users.

Groundwater in Alberta is accessed by wells, which are overwhelmingly located in Southern Alberta. The Athabasca River Basin in central Alberta has the largest allocation of groundwater at 39 % of all allocations, but the majority of groundwater allocations are in Southern Alberta, including North Saskatchewan River Basin (16 %), South Saskatchewan River Basin (32 %) and other smaller basins.

Groundwater is most heavily allocated to the oil and gas industries, which hold 41 % of the allocations, followed by the agricultural sector at 23 %. Of particular note is a method now known as fracturing or “fracking,” the use of groundwater for oilfield injection. This involves pumping steam underground to induce oil flow. The resulting used water is then unsuitable for other uses.

To help preserve Alberta’s groundwater, the Provincial Groundwater Inventory Program was launched in 2008. The Program seeks to map completely groundwater sources in Alberta and provide information on risk to those sources. Initially, the area in and between Calgary and Edmonton was chosen to be completed first due to heavy build up in the area in the past decade. Most of the groundwater in this area had been mapped by 2011. Since then, the Provincial Groundwater Inventory Program has also created groundwater vulnerability maps in the South and North Saskatchewan River Basins as well as in the Red Deer River Basin. The Provincial Groundwater Inventory Program uses aerial photography, groundwater sampling, and the analysis of water, oil, and gas well drilling records for this purpose (Alberta Environment and Sustainable Resource Development 2013c).

In 2010, another groundwater initiative was launched which sought to achieve a 4-log virus inactivation in drinking water systems that use groundwater wells as their source, presumably because the groundwater is contaminated. This program has brought to light the complexity of chlorination of groundwater that has naturally occurring ammonia, because the ammonia absorbs much of the chlorine. The simplest solution in many cases is to maintain free chlorine residual after achieving chlorine breakpoint. Even though the breakpoint is achieved by dosing higher concentrations of chlorine, the resulting free chlorine residual is lower than the dosage since the ammonia absorbs much of the chlorine. In some cases, chlorine breakpoint is not feasible and other techniques such as ammonia removal or UV disinfection are being recommended. Since breakpoint chlorine can be achieved without major capital upgrades, it is used more frequently than ammonia removal, UV disinfection, and new chlorine contact chambers which all have higher capital costs. The chlorine dosing would of course create disinfection byproducts, if there is natural organic material in the groundwater or in the distribution pipes.

7.3 Drinking Water Safety Plans

Water Safety Plans are defined by the World Health Organization as a 'comprehensive risk assessment and management approach' to water system risk. Drinking Water Safety Plans are designed to move operators from being reactive to proactive in managing risk. The WHO first endorsed Water Safety Plans for water system risk management in 2004, and has reiterated its support for Water Safety Plans in each year since.

In Alberta, Water Safety Plans are adapted to drinking water and are termed "Drinking Water Safety Plans." They receive their regulatory basis from the Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems (2012b). This measure requires drinking water utilities to complete a "source-to-tap" risk assessment of the utilities' facilities authorized by Alberta Environment and Sustainable Resource Development. The current Drinking Water Safety Plan framework devised by the Government of Alberta aims to (a) gather information on plant manuals and records, water quality, and customer contact records, (b) complete the Drinking Water Safety Plan template (i.e., fill out basic information like details on water source and treatment type, assess generic risks and review and verify all parts of the Drinking Water Safety Plan at least once each year), (c) implement the Action Plan (i.e., evaluate the effectiveness of control measures in the Plan and create a management plan), and (d) maintain the Action Plan (i.e., update Risk Scores following any control measure implementation or change to reevaluate whether a risk remains problematic, and to review priorities) (Alberta Environment and Sustainable Resource Development 2014d).

Drinking Water Safety Plans are being implemented across Alberta as outlined in *Implementation of Alberta's Drinking Water Safety Plans* (Reid et al. 2013). The primary responsibility to produce and submit Drinking Water Safety Plans lies with municipal and regional water systems. Alberta Environment and Sustainable Resource Development gave the water systems until December 31, 2013, to complete a Drinking Water Safety Plan.

7.3.1 The Risk Matrix in the Drinking Water Safety Plan

Why did Alberta embark on creating Drinking Water Safety Plans, when they could have imposed the implementation of HACCP or other safety protocol? It would make sense only if the legislation for watershed protection is not working properly, or there is a perceived risk due to other human activity that needs to be overcome by implementing a policy of requiring each water treatment unit to implement a Drinking Water Safety Plan.

The main component of the Drinking Water Safety Plan is a risk matrix designed to assess the severity of any existing or emerging chemical, microbiological, physical, or radiological parameters. Risk, as defined by the WHO, is the product of the probability that an event will occur (p) and the expected consequences of any hazardous event (E). That is, $\text{risk} = p \times E$. There are, however, a number of concerns that must be addressed in the construction of these values for risk calculation.

One major problem is the quantitative estimation of the various types of possible likelihoods or probabilities. These probabilities are unknown and their estimation by the operator is purely subjective. Moreover, from the definition of probability, empirical data is fundamental in order to create a quantifiable value that would be used in order to calculate risk. Unfortunately, no empirical data is used to create quantifiable values when defining the various types of likelihoods, and thus Alberta's likelihood values will be arbitrary. This leads into another major flaw in the risk calculation, namely the operator's experience. Although the WHO guidelines state that operators must go through the specified training, their experience may very well vary, from being new to the Water Safety Plan system to having an extensive experience of operation for a number of years. It is possible that if the operator is new to the Water Safety Plan system, then he or she will have to rely on someone else providing the particular probability.

Similar arguments can also be made regarding the determination of the expected consequences. The method for assessing the severity of the consequence is ambiguous; for example, what are the consequences of a change in quality of treated water? The change in water quality may be due to microbiological, chemical, or radiological parameters. But how will the severity of the consequences of each of these changes be estimated? Regrettably there is the danger that they will remain undifferentiated. To pursue this further, *Cryptosporidium*, for example, is a more severe risk as opposed to say, *Salmonella*, and should be classified as having a different consequence. However, due to the ambiguity of the method, both microbiological parameters would be classified under the same type of consequence, as they both create a change in the quality of the water. This is a huge

Table 7.8 Illustrating the Alberta drinking water safety plan risk matrix

			Consequence descriptor				
	Score	Not applicable	Insignificant	Minor	Moderate	Severe	Catastrophic
Likelihood descriptor	Not applicable	0	1	2	4	8	16
	Most unlikely	1	1	2	4	8	16
	Unlikely	2	2	4	8	16	32
	Medium	4	4	8	16	32	64
	Probable	8	8	16	32	64	128
	Almost certain	16	16	32	64	128	256

problem, since incorrect handling and poor classification of the consequences could lead to a weakening of the readiness to be proactive in risk assessment and thus endanger the drinking water supply. All this could expose the population to a severe health risk.

Another problem with the Drinking Water Safety Plan definition of a "consequence" is that only two types of consequences seem to be recognized. But there can be many types of consequences. For example, within the "change in water quality" criterion, it may make sense to differentiate between the consequences of radiological and of chemical changes.

When examining the risk matrix from Alberta's Drinking Water Safety Plan it can be seen that both variables, that is, likelihood and consequence, are given an index, although the ranking is purely ordinal (see Table 7.8). This would mean that each category of each parameter is represented by an index which corresponds to a probability. Since there are five categories displayed in the risk matrix above, each category has a probability that increases by 0.2. The problem with this matrix assignment is that none of these probabilities is based on empirical data or derived from a Probit Model. A risk-averse operator might therefore overstate the probability of most hazards. (An example of the estimation of probabilities using a Probit model is given in Chap. 6.)

Next consider the "consequences descriptor" in the risk matrix. Again we have the same ordinal ranking of the consequences. The possible consequences are (1) supply interruption, or (2) change in quality of pretreated water. What is unclear about the first consequence (supply interruption) is that there is no indication as to how an index is assigned to a parameter violating this criterion. Furthermore, given that an index is assigned, there is no indication that the assigned index increases with the duration of the interruption.

Now coming to the second consequence (quality of pretreated water), there is no specification as to how this consequence (change in quality of pretreated water) is mapped to the specified indices 2, 4, 6.... Suppose an *E. coli* outbreak occurs. It is obvious that it should and would be treated as "catastrophic" and so would merit the highest number, but if some outbreak is considered "rare," then the probability index attached to it would be low. This will make the product (Probability × Consequence) smaller than would be desirable. Indeed if there is an *E. coli* outbreak detected in the distribution system, it might be better to shut the water supply down and clear the water of the pathogen rather than issue a Boil Water Advisory, since there is a danger that some people might ignore the Boil Water Advisory. There is no way of telling whether the existence of a Drinking Water Safety Plan will ameliorate the situation. Shutting down the water supply until the problem is identified and corrected might be a better "intervention." For safety what is needed is *action* or an intervention at some *critical control point*.

Another problem with the assignment of the indices to the consequences is that the estimate would not be able to differentiate between the different types of contaminants; for example, it is unclear how operators will treat a *Salmonella* outbreak compared to a *Cryptosporidium* or *Giardia* outbreak based on the ambiguous assignment to the consequence. A risk-averse operator may classify all pathogenic outbreaks as of equal seriousness and assign the *same highest index* to all such consequences. In that case the matrix becomes useless, and the probability calculation becomes meaningless. The operator would have been better off knowing just a comprehensive list of possible consequences, and when to shut down the plant.

The risk matrix is the fundamental tool, which governs Alberta's Drinking Water Safety Plan; however, the above criticism shows that the matrix is unlikely to increase water safety. The Drinking Water Safety Plan is unlikely to enhance safety. It would be more cost effective to add a UV disinfection component with a fail-safe device, whereby if the UV unit fails, the water supply can be shut off until action is taken. UV disinfection units are quite inexpensive and available for varying water flow rates. It is interesting that this is exactly what EPCOR has done, i.e., install UV equipment, although EPCOR as an Alberta water utility has also prepared a Drinking Water Safety Plan, as required by law (on EPCOR, see Sect. 7.5.2).

7.4 Potential Hazards to Drinking Water in Southern Alberta

In this section, we assess the effectiveness of watershed protection efforts in Alberta, where there is a large cattle industry. Cattle are known to be a source of pathogens like *Cryptosporidium* and *Giardia*. Therefore, cattle husbandry and manure management practices can impact the concentration of these microbiological contaminants in ground and surface water (Budo-Amoako et al. 2012). Other possible microbiological contaminants that can emerge from cattle and by extension, their feces, are *E. coli* O157 and Verocytotoxigenic *E. coli* O157 (VTEC O157). The strain known as VTEC O157 can potentially be as dangerous to humans as *E. coli* O157 since it can cause a range of diseases in people, from mild diarrhea to life-threatening hemolytic uremic syndrome, which causes the destruction of red blood cells and leads to kidney injuries (Smith et al. 2009). Chemical contaminants, such as phosphorous and nitrogen, can also enter surface waters through cattle bedding and grazing (Olson et al. 2011). Although phosphorus in water treatment plants is not life threatening to human health, it can interfere with coagulation in humans. The existence of phosphorous can in turn lead to microbiological contaminants not being completely removed before distribution. Similarly, nitrogen is not life threatening to humans in small amounts; however, prolonged exposure to nitrogen ingestion can lead to methemoglobinemia or blue baby syndrome, which causes gastric problems due to the formation of nitrosamines. Severe methemoglobinemia can further result in brain damage and death.

In some farm industries, hormones are applied to cattle food supplies for breeding purposes. This is because the hormones can significantly shorten the time it takes for cattle to reach ideal size and weight; however, hormones have negative effects on human health. Estrogenic hormones, for example, are used for breeding purposes. These hormones can be released into groundwater supplies from cattle feedlots, and can lead to women developing breast cancer and men experiencing abnormal sexual development (Soto et al. 2004).

7.4.1 The Failures of Watershed Protection in Southern Saskatchewan River Basin in Alberta

Alberta has just over 40 % of Canada's cattle population (see Fig. 7.3); specifically this means 5,585,000 cattle (Statistics Canada 2013). A large concentration of this number of cattle is in Southern Alberta (see Fig. 7.4). With such large-scale cattle production, some cattle are kept in feedlots (around Lethbridge and Calgary in Fig. 7.4) while others graze in open fields and are only kept in feedlots during the

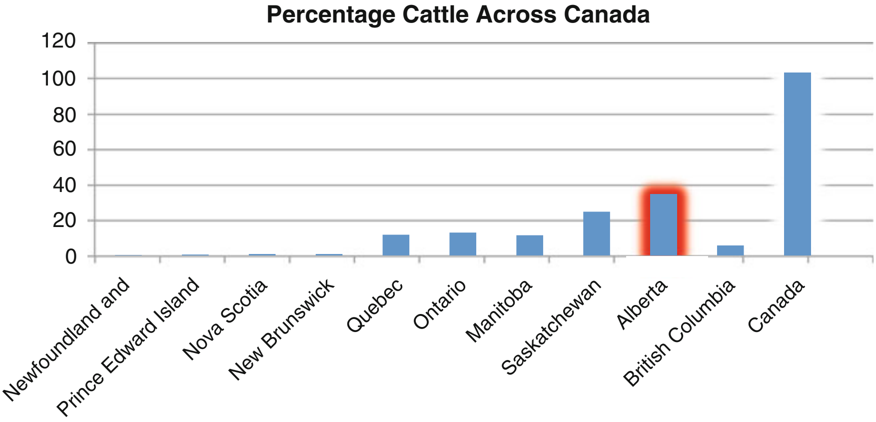

Fig. 7.3 Distribution of Cattle (percent) across Canada (Statistics Canada 2013)

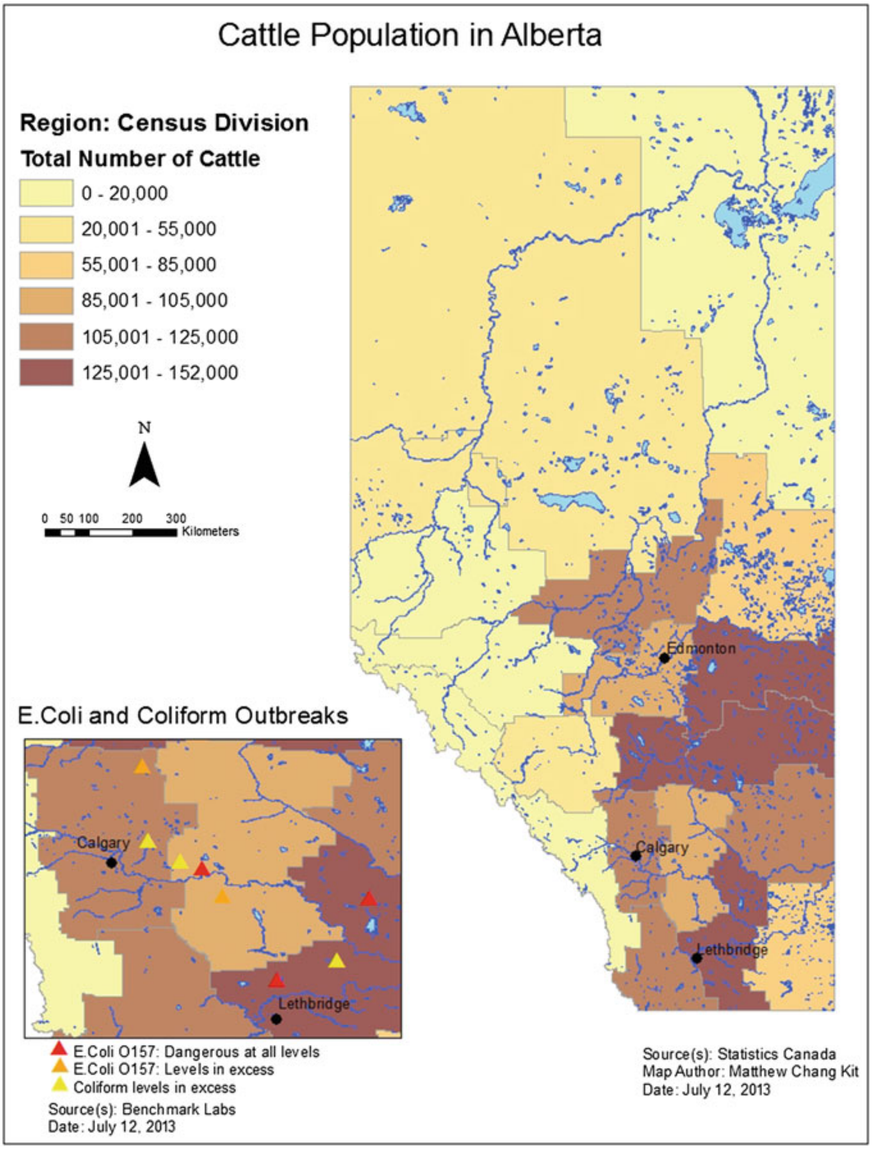

Fig. 7.4 The Density of the total number of cattle in Alberta and the detection of *Escherichia coli* outbreaks

winter (as in Northern Alberta, see Fig. 7.4). With feedlots producing approximately one ton of manure per head per year and the large density of feedlots existing near a vast number of water bodies in Southern Alberta, there is a high probability that cattle feces will enter surface and groundwater. Additionally, this pool of potentially infective material may contaminate the cattle's hide with pathogens such as VTEC O157 and *E. coli*, which can be transferred by cross-contamination. If the cattle die while in a river or stream, pathogens from the hide will leak into the watersheds (Smith et al. 2009). Coupling the continuous grazing done in Alberta with the large amounts of fecal matter from the cattle, a lot of sediment, nutrients, and *E. coli* can be flushed into nearby surface waters (Kalischuk et al. 2009). Hence the cattle industry can have a major impact on pollution of both ground and surface water.

Confined Feeding Operations (CFOs) are "fenced or enclosed land or buildings where livestock are confined for the purpose of growing, sustaining, finishing or breeding" (Alberta Agriculture and Rural Development 2014). There are about 2000 CFOs in Alberta (Auditor General of Alberta 2011). The CFOs are regulated by the Natural Resources Conservation Board (NRCB) through the Agricultural Operation Practices Act (AOPA). A most recent letter to the Minister, Alberta Agriculture and Rural Development from the Sage Environment (Southern Alberta Group for the Environment) (2014) suggests that the CFOs have been an issue of concern for water quality and human health in Southern Alberta.

According to the Oldman River State of the Watershed Report (2010), there are over 500 CFOs in the Oldman Watershed and the majority are located in the prairie subbasins in the vicinity of Lethbridge (see Fig. 7.5). Other livestock operations like cow–calf facilities and range cattle are widely dispersed over this area. The increasing numbers of CFOs and other livestock operations contribute high concentrations of nutrients, phosphorus, suspended solids, *E. coli*, and fecal coliforms into nearby waters.

Gannon et al. (2004) studied water samples from the Little Bow River and Lethbridge Northern Irrigation District during 2000 and 2001, and found *E. coli* O157:H7 and *Salmonella* spp. in the Oldman River Basin. They further found that the highest number of *E. coli* O157:H7 and *Salmonella* spp. were in the raw water during the summer months (see Table 7.9). As noted earlier, large cattle feedlots exist in Southern Alberta's watersheds. During the summer, increased livestock near the rivers contributes to the increased rate of these bacteria in the Oldman River Basin.

The above result is consistent with the findings of Turnbull and Ryan (2012), who showed that the occurrences of *E. coli* O157 and fecal coliforms in southern Alberta rivers, as well as the number of *E. coli* O157 and fecal coliforms, peaked during summer months. Their water quality data, over the period 1970 to 2008, was collected from two sites upstream and downstream of urban locations in Calgary and Lethbridge, and three points downstream of agricultural sites (see Table 7.10). Both concentrations of *E. coli* and fecal coliforms in the rivers upstream of urban areas were relatively low (<2 mL^{-1}).[6] All of the downstream sites including two urban locations and three agricultural sites demonstrated a variation of the *E. coli* and fecal coliforms concentrations, ranging from less than 1 to more than 1,000 colony forming units (CFU) per 100 mL over time, but most of the concentrations

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[6] Data is not shown in the article.

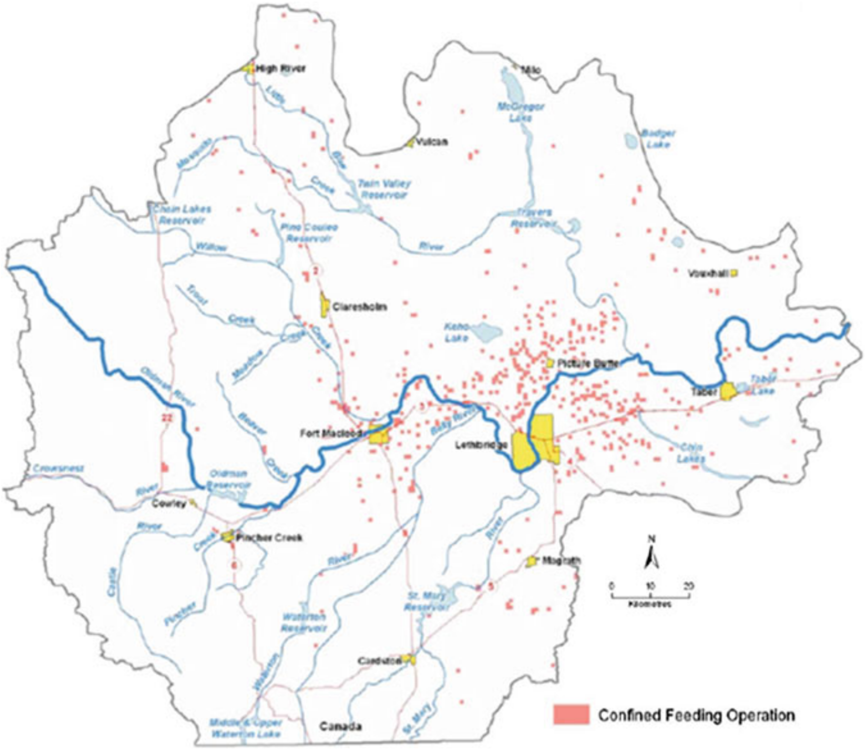

Fig. 7.5 Confined feeding operations in the Oldman Watershed (Oldman Watershed Council 2010)

of *E. coli* and fecal coliforms were between 10 and 100 CFU per 100 mL. Moreover, they found that the highest concentrations of *E. coli* O157 and fecal coliforms were detected in the three agricultural sites during May and July, while there is some evidence to support the view that the sites in urban areas have a seasonal water quality problem. The results further demonstrate that feeding operations and other livestock operations are major contributors to high concentrations of bacterial pathogens in the Southern Alberta Rivers.

The 2013 Auditor General's Report highlights some critical issues that the NRCB has failed to address for the protection of ground and surface water from pathogens that escape from CFOs. Some of these critical issues are failure to monitor internal compliance with: (a) policy for risk-based compliance, (b) directive for leak detection, (c) water well reporting, and (d) failure to respond to complaints about groundwater. Although the NRCB developed a risk-based approach to monitoring conditions at CFOs in 2002, the Board has no documented internal guidelines or procedures for leak detection and water well monitoring. Furthermore, the Auditor General of Alberta (2013) found that some CFOs were not able to meet the groundwater monitoring and reporting conditions specified in

Table 7.9 *Escherichia coli* O157:H7 and *Salmonella* spp. isolated from water samples from the little Bow River and the Lethbridge Northern Irrigation District (LNID) during 2000 and 2001 (Gannon et al. 2004)

Date	*E. coli* O157:H7			*Salmonella* spp.		
	Little Bow River (%)	LNID (%)	Total (%)	Little Bow River (%)	LNID (%)	Total (%)
2000						
May	0	0	0	1.5	2.6	2
June	3.2	0	1.4	4.7	1.3	2.9
July	0	5.3	3.1	17.2	15.8	16.4
August	2.5	0	1.3	16.3	6.6	11.5
September	0	2.6	1.4	0	3.9	2
October	0	0	0	0	0	0
Year total	0.8	1.7	1.4	4.7	6.2	5.5
2001						
May	0	ND	0	6.7	ND	6.7
June	2.4	1.3	2	4	1.3	3
July	6	1.1	3.4	41.7	20	30.2
August	2.9	2.6	2.8	31.4	22.4	27.6
September	1.2	0	0.6	4.8	1.3	3.1
October	2.5	1.2	2	16.7	11.8	14.9
Year total	1.8	1.6	1.7	11.5	8.6	10.3

Table 7.10 Summary table of the location of the five sites (Turnbull and Ryan 2012)

Site	Location	Major land use	Sampling location names
1U	Bow River	Urban	Upstream (Cochrane); downstream (Siter's Ranch[a]/ Policeman's Flats[b]) of calgary
2A	Bow River	Agricultural	Near Ronalane[a]
3U	Oldman River	Urban	Discharge upstream of Lethbridge[a]
			Water quality at Town of picture Rutte[a]
4A	Oldman River	Agricultural	Near Taber[a]
5A	Crowfoot Creek	Agricultural	Near Cluny[a]

[a] Alberta Environment and Sustainable Resource Development historic water quality sampling location

[b] City of Calgary historic water quality sampling location (2004–2007 data only)

their permits since the NRCB's inspectors did not document their follow-up actions or decisions. Thus, the NRCB's monitoring activities are not effective due to a lack of documentation on key actions and decisions. Moreover, while the NRCB intended to reinspect all the sites assessed as high risk to groundwater, 20 % of these were not reinspected and data used to track inspection results was not up to date. The Auditor General of Alberta (2013) further states that the NRCB did not have a defined process to ensure it would appropriately assess risks at all CFOs identified as potentially high risk to groundwater quality. As a result, these CFOs might not undergo the risk assessment that the NRCB designed for these sites (Alberta Environment and Sustainable Resource Development 2013a). In addition, in an earlier report, the Auditor General of Alberta (2011) pointed out that the NRCB's risk-based compliance program was focused only on groundwater. The risk assessment of CFOs had not been completed for surface water even by the year 2011. The Auditor General also indicated that the NRCB had not developed adequate procedures for assessing surface water risks; this could be done for example by introducing a checklist to document surface water observations at CFOs. The Auditor General of Alberta (2013) also stated that where the checklist existed, it was not consistently applied to surface water monitoring. The Board also failed to implement a process to monitor effectively internal compliance with its data collection requirements in their surface water plan. Because the NRCB's management failed to document their work, the Auditor General could not verify the existence or operating effectiveness of the monitoring mechanisms.

From the Auditor General's Report it is very clear that the NRCB has failed to do its job in monitoring and protecting the watersheds from microbiological and chemical pathogens arising from CFOs. For the few sites that may have been monitored, the NRCB's management has failed in documenting their findings and therefore do not have any valid proof that they are doing their job in keeping ground and surface water protected from pathogens. Perhaps the new legislation and the new requirement to have Drinking Water Safety Plans at all water utilities were a response to this finding.

In an interview with CBC news on June 25, 2012, the CEO of Benchmark Labs, Chris Bolton (2012), reported that he had found *E. coli* O157 in several spots across Southern Alberta (see inset in Fig. 7.4). He stated that too many cattle operations were doing too little to keep their manure runoff out of waterways. It was apparent to Bolton that there was no containment between open livestock pens, dairy barns, and other facilities in the specified areas. Furthermore, these facilities, pens, and barns all sloped directly down toward canals. Of the 60 sites he visited, two or three canals flow into small creeks that then lead to larger water ways.

Over the past 2 years, Bolton has not only found *E. coli* O157 but also high coliform counts and *Salmonella* in irrigation canals. From the 60 samples that he took, 85 % tested positive for total coliforms, 51 % tested positive for *E. coli*, 3 % tested positive for *E. coli* O157, and 45 % tested positive for *Salmonella*. Bolton stated that although irrigation ditches are not expected to be sterile, the *E. coli* bacteria strain can be lethal at any level as it produces toxins which can cause gastroenteritis and hemolytic Uremic Syndrome-which can cause permanent vascular and kidney damage and can be fatal to children. The Canadian Food Inspection Agency reinforces the point that *E. coli* O157 can be deadly at any level. With the consumption of food or water contaminated with this bacterium, serious and potentially life-threatening illnesses can emerge. Symptoms include severe abdominal pain and bloody diarrhea, and, depending on the individual, the bacterium may even cause seizures or strokes. Others may have to live with permanent kidney damage. One major challenge that Bolton faced was the lack of governmental authority. He stated that he was unable to find a single government agency that would take ownership for the emerging issue. The Government of Alberta specifies that the NRCB is responsible for monitoring and rectifying problems associated with waste discharge. However, Bolton states that the NRCB understood their directives on this subject matter to be purely voluntary. The Auditor General's Report states that part of the NRCB's responsibility is to monitor and enforce compliance with the AOPA so as to ensure that Alberta's CFOs operate in an environmentally sustainable way. The AOPA sets out mandatory standards that address risks to the environment and impacts on communities. The major risk is contamination of groundwater and surface water. CFOs can also cause unpleasant odors in their vicinity. The Auditor General states that recommendations were made to the NRCB in 2004, and repeated in 2007, to cover both groundwater and surface water risks: however, the NRCB interpreted the Auditor's recommendation as being solely for groundwater risks. The Auditor General further states that the NRCB's approach will be unable to detect significant surface water risks before contamination occurs (Report of the Auditor General of Alberta 2011, April). Therefore, the Auditor General reiterated that it is part of the NRCB's duty that they test these facilities. However, they incorrectly assumed that it was not part of their job to monitor and enforce compliance for surface water supplies.

When pinpointing the geographical location of the *E. coli* and total coliform occurrences near the CFOs (see Fig. 7.4), we see that the densest areas (Lethbridge and Calgary) are where large cattle feedlots exist. This raises concerns that cattle fecal runoff could be a major source of *E. coli* and coliforms entering the water supply. From the evidence reported here, coupled with the findings of Chris Bolton from Benchmark Labs, it is clear that Alberta's legislation to protect its watersheds is ineffective. To reduce risks, stronger and more stringent protocols must be implemented.

7.5 Potential Hazards to Drinking Water in North Saskatchewan River Basin in Alberta

Escherichia coli and total coliforms are not the only pathogens that Albertans have to worry about, but also protozoa, such as *Cryptosporidium* and *Giardia*. The North Saskatchewan River (NSR) is a large water basin located southwest of Edmonton, which has a population of approximately 76,000 people, not counting the residents of Edmonton itself. The communities of the basin primarily use surface water as their water supply (Partners for the Saskatchewan River Basin 2009). The city of Edmonton itself has a population of 817,498; it is the largest city in Alberta, and has two water treatment plants owned and operated by EPCOR, a corporation that is in turn owned by the City of Edmonton.

Most of the North Saskatchewan River watershed is rural, although there are 18 hamlets, eight summer villages, four villages and five towns that are scattered throughout the area. Only about 23,000 people are serviced by wastewater treatment plants and the remainder use private septic systems. These smaller communities, along with farmsteads, tend to use only groundwater (Partners for the Saskatchewan River Basin 2009). The North Saskatchewan River basin is filled with a multitude of land-use activities, such as crop farms and livestock ranches, such as cattle, hogs, ranched elk and bison, as well as wildlife. As a result of the livestock, the rivers and streams in the subwatersheds show evidence of waterborne parasites. These parasites are transported from specific sources on the land to the river by runoff, which gathers in-streams and finally enters the main rivers that eventually flow into the North Saskatchewan River. These specific land sources are predominantly fecal matter that originate from livestock in CFOs.

In the North Saskatchewan River basin, cattle make up about 68 % of all the livestock. Moreover, the cattle in the North Saskatchewan River basin constitute about 5 % (approximately 300,000 cattle) of the total number of cattle in Alberta. This area is, in fact, the third most intensive area for beef cattle production in Alberta. Most of these livestock are concentrated in the southern areas of the North Saskatchewan River watershed, specifically: Mishow, Tomahawk, Weed, Wabamun, Conjuring, Modeste, and Strawberry Creek, which is located southwest of Edmonton (see Fig. 7.6). The concentration of fecal matter that this livestock produce amounts to approximately 100,000 tonnes/year of manure (EPCOR Water Services Inc. 2012) within these specific creeks (see Fig. 7.7). Since there is a large

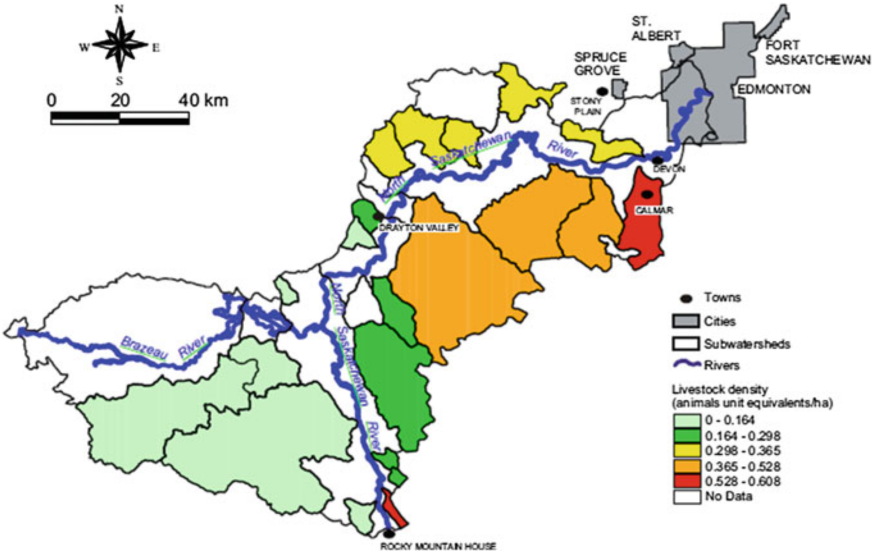

Fig. 7.6 Density of total livestock in each study watershed in the North Saskatchewan River basin (Mitchell 2002)

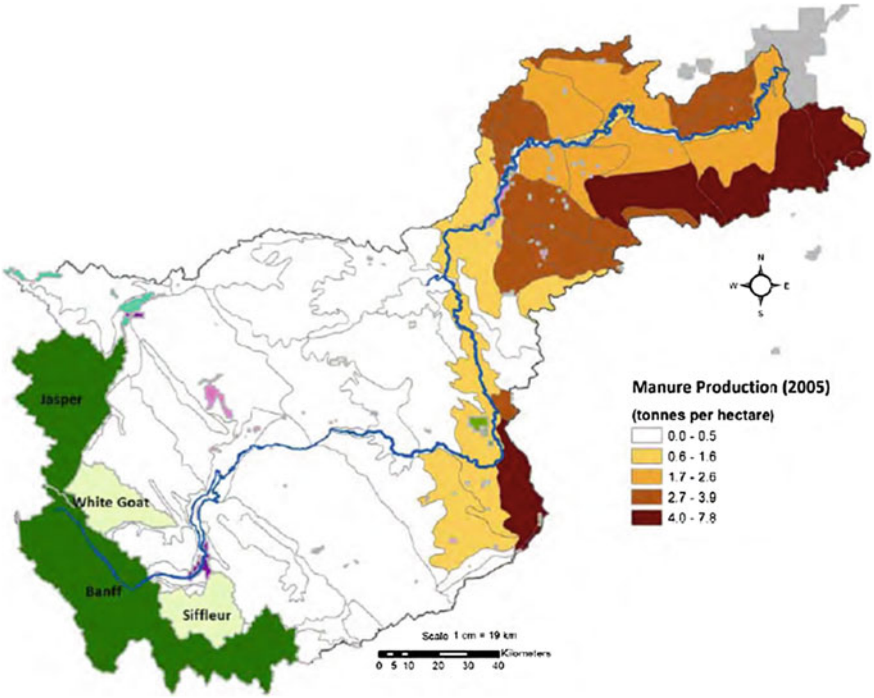

Fig. 7.7 Manure production from all livestock in the North Saskatchewan River watershed (EPCOR 2012)

percentage of livestock which are cattle, and cattle are the main contributors of fecal runoff into the rivers, they must also be the main contributors to the high levels of *Cryptosporidium* and *Giardia*, as shown in Table 7.11 (Mitchell 2002).

Table 7.11 Prevalence and average concentration of Giardia cysts and Cryptosporidium oocysts in fecal samples from livestock, specifically cattle (Mitchell 2002)

Livestock	Sample size	Giardia		Cryptosporidium	
		Prevalence (%)	Avg. Conc.	Prevalence (%)	Avg. Conc.
Beef Cattle	1,561	29	5,801	3	267
Dairy Cattle	92	18	16	18	254
Hogs	40	17	16	0	0
Elk	38	16	1,665	21	3,742
Bison	41	15	2,649	5	2,369
Horse	1	0	0	0	0

7.5.1 The Failures of Watershed Protection in North Saskatchewan River Basin in Alberta

In 1998, a study was undertaken to assess the relative contributions of contaminants from three potential sources in the North Saskatchewan River (Heitman et al. 2002; Mitchell 2002). The sources were agriculture, municipal sewage effluent and wildlife, and the primary objectives were (a) to discover if cattle contributed significant amounts of *Cryptosporidium* and *Giardia* to surface water compared to wildlife and municipal sewage and (b) to discover if watersheds with high densities of cattle and other livestock contributed greater quantities of contaminants to the North Saskatchewan River than nonagricultural watersheds.

Within the study, two types of pollution were identified and studied: *non-point source pollution*—from diffuse or undefined sources mainly carried from the land in runoff, and *point source pollution*—such as from a pipe discharging from sewage treatment plants or drainage from confined livestock feeding operations. Runoff that is due to seasonal change can pick up parasites, organic matter, fecal bacteria, and other contaminants that eventually reach the North Saskatchewan River after gathering in streams. Protozoan parasites such as cysts and oocysts are able to attach onto soil particles or organic matter as runoff occurs, and can then be picked up by water in the streams and carried along until it reaches the North Saskatchewan River.

A number of procedures were included in the study. First, a longitudinal survey was conducted where 20 streams were sampled (see Fig. 7.8) (Mitchell 2002). Samples were collected during peak seasonal periods (spring runoff and summer

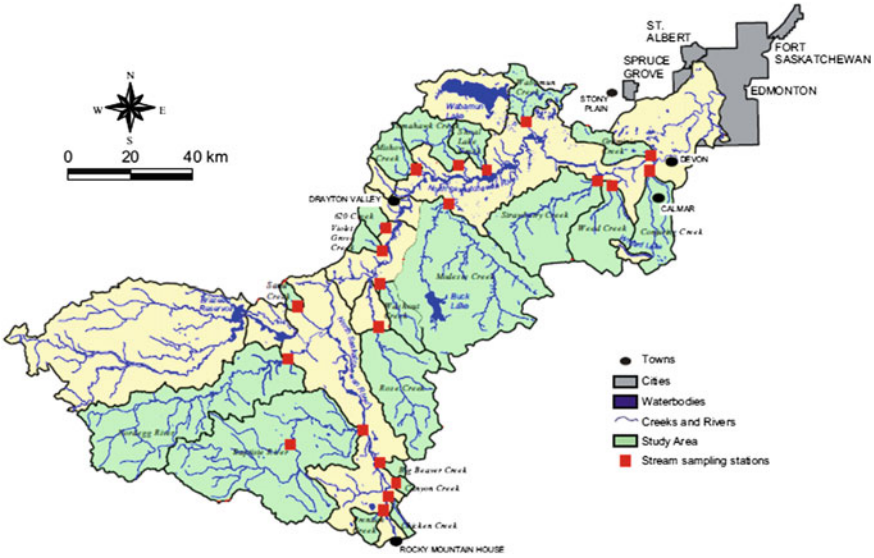

Fig. 7.8 Stream sampling stations along North Saskatchewan River basin (Mitchell 2002)

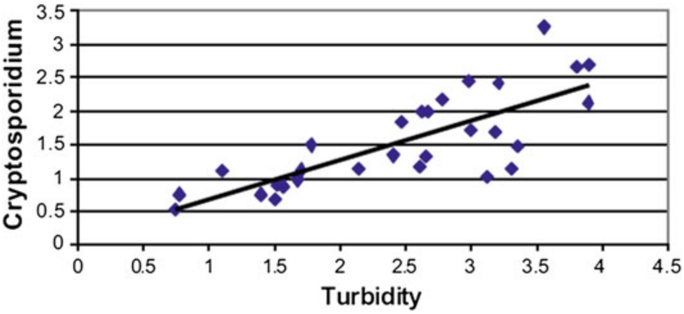

Fig. 7.9 Strong positive correlation between *Cryptosporidium* and turbidity (Mitchell 2002)

rainfall) for 3 years. Mass loads were then calculated for a 1-week period during each runoff. The results of this survey showed that the greatest proportion of the total cysts and oocysts entering the North Saskatchewan River was from agricultural streams, except for *Cryptosporidium* in the summer of 1998. The overall average percentage of the total load entering the river from agricultural streams was 56 % for *Cryptosporidium* and approximately 80 % for *Giardia*. The longitudinal survey concluded from the data that agricultural streams were the major contributors to the number of parasites in the river during runoff periods.

For a thorough study, an intensive watershed survey was also conducted (Mitchell 2002). Six streams were chosen out of the 20 longitudinal survey streams. They were: Baptiste and Nordegg Rivers (nonagricultural), Mishow and Tomahawk creeks (mainly cow-calf production), and Strawberry and Weed creeks (with all types of livestock). 145 samples were collected from the streams during 1999 and 2000. The streams were sampled twice a week during peak runoff periods. The results showed that parasite concentrations increased when flow increased in the streams. Also, a strong positive correlation among *Cryptosporidium*, *Giardia*, turbidity, and total phosphorous was found. They concluded that when streams have increased turbidity, there is a probability that many parasites are also present in the water (see Fig. 7.9). Furthermore, they found that during seasonal changes, such as spring, *Giardia* levels were strongly positively correlated with beef cattle, while in summer, *Cryptosporidium* levels were positively correlated with dairy cattle.

During a synoptic survey, 11 sampling sites were constructed along Strawberry Creek, since it was found to be contributing large parasite loads to the North Saskatchewan River. Seven additional sites were set up along Tomahawk Creek. At each site, one sample was taken during runoff for the months May, June, and July. Loads were then calculated for each site. From the data collected, they found that the upstream load was higher than the downstream load, resulting from a difference in stream flow between sampling sites. Although the upstream was higher than the downstream between sampling sites, some areas of Tomahawk Creek watershed had produced more parasites than other areas.

In this particular study, there were five drinking water treatment plants that used the North Saskatchewan River as a water source. These were: Rocky Mountain

House, Drayton Valley, Thorsby, Devon and Edmonton (E.L. Smith water treatment plant). Other municipalities in the upper basin which used groundwater or other surface water sources for their water supply were excluded. Raw and treated water samples were collected from each of the major water treatment plants upstream of Edmonton and were analyzed for parasites. Simultaneously, samples were collected from Thorsby and E.L. Smith water treatment plants to analyze water for parasites, turbidity, fecal coliform, and color. From the data it was found that on average, parasites in the raw water at Devon and E.L. Smith were approximately twice that of two plants further upstream. Overall, *Giardia* concentrations were higher than *Cryptosporidium* in all plants; however, during peak seasonal changes, such as heavy rainfall leading to high runoff, *Cryptosporidium* levels were equal to or higher than *Giardia* levels. Most of the time, treated water was parasite free. On four occasions, at the Devon treatment plant, *Giardia* was present and exceeded the 0.1 cysts/100 L detection limits with a maximum observed level of 0.5 cysts/100 L. *Cryptosporidium* levels detected also exceeded their detection limits at 0.5 oocysts/100 L. The critical limits were set to 5 organisms/100 L in treated water, and if the number of organisms exceeded this level, the utility would increase monitoring, and possibly have a boil water advisory issued.

Cryptosporidium and *Giardia* can also be found in municipal sewage effluents from sewage treatment facilities. From Fig. 7.10, within the subwatersheds, especially Mishow, Tomahawk, Weed, Conjuring, Wabamun, Modeste, and Strawberry Creek, there are multiple sewage treatment facilities, and we note that these sewage treatment facilities are very close in proximity to multiple streams that lead into the North Saskatchewan River. Sewage treatment plants can easily discharge sewage

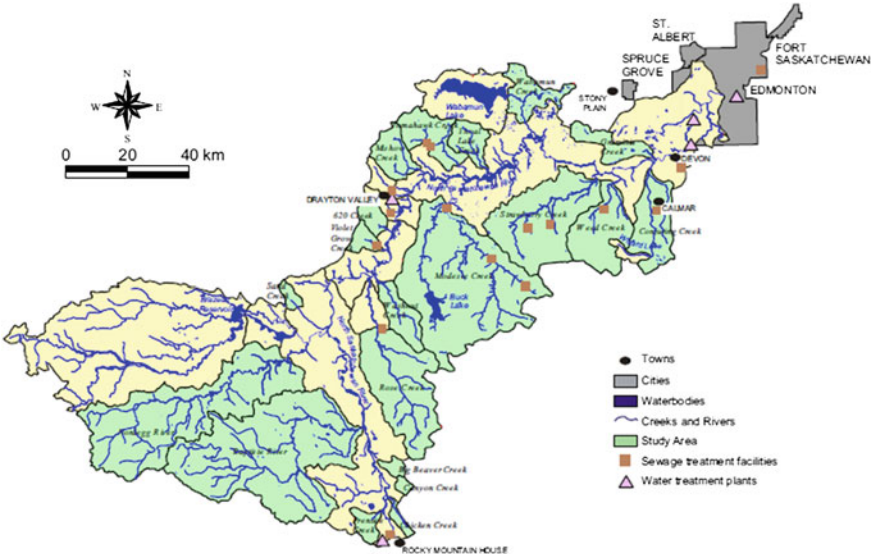

Fig. 7.10 Sewage treatment facilities in North Saskatchewan River basin (Mitchell 2002)

effluents continuously, and can contribute to a year-round base load of *Giardia* and *Cryptosporidium* to the North Saskatchewan River (Mitchell 2002).

There are additional possible point source and nonpoint source contamination hazards that could affect the North Saskatchewan River raw water, and thus affect the drinking water supply systems. The point source hazards are: small urban continuous waste (Rocky Mountain House, Drayton Valley, and Devon) discharging pharmaceuticals and personal care products (PPCPs), nutrients, pathogens, and hazardous chemicals; municipal sewage lagoons discharging PPCPs, nutrients, pathogens, and hazardous chemicals; industrial discharges releasing hazardous chemicals; and pipeline breakage releasing hydrocarbons or other chemicals. The nonpoint source hazards are: fertilizers and pesticides from crop cultivation, sediment from improperly managed construction sites, crop and forest land and eroding stream banks; faulty septic systems; atmospheric deposition; and accidental spills/releases (EPCOR Water Services Inc. 2012).

The main result emerging from these studies is that protozoan parasites, *Cryptosporidium* and *Giardia*, thrive in fecal matter from livestock, specifically cattle, and municipal sewage effluents. Moreover, the fecal runoffs from CFOs and municipal sewage effluents from sewage treatment facilities are in close proximity to water bodies and are the major sources of these microbiological pathogens escaping into the water supply systems. *Cryptosporidium* and *Giardia* in surface water pose great risk to human health when the water is used as a raw water source for drinking. Although the risk can be low if treatment plants are operating effectively, the water treatment process can still be compromised during peak runoff periods such as spring runoff and following heavy rainfall, when contaminant loads in the river are high, as seen from the recent flooding of the North Saskatchewan River reported by Global Toronto television (Kornik 2013, June 26). It should be noted that under Alberta law, small treatment facilities are not required to monitor parasites in raw or treated drinking water and therefore they typically do not include monitoring costs in their budgets. This poses a great threat to the quality of water that the small communities rely on in the North Saskatchewan River watershed.

7.5.2 EPCOR

EPCOR Water Services Inc. (EPCOR) provides Edmonton customers with water. EPCOR is unique in that it is set up as a private corporation that pays corporate taxes, but all the shares in this corporation are owned by the City of Edmonton.

EPCOR is required to meet performance standards in the areas of system reliability, customer service, environment safety and water quality. EPCOR is committed to maintaining a “Source-to-Tap Multi-barrier Approach.” This involves source water protection, treatment, distribution and storage, and monitoring. EPCOR maintains a source water protection and monitoring program that identifies risks in the raw water supply in the North Saskatchewan River. EPCOR’s Source Water Protection Plan, developed in 2008, helps communities and other stakeholders to mitigate potential risks to source water supplies through understanding the pressures on the watershed. Its Watershed Protection Program has two primary goals. These are: to provide a safe, secure drinking water supply through source water protection principles; and to ensure minimal effects from their operations on water quality and aquatic ecosystem health.

EPCOR has two water treatment plants in Edmonton. The two plants are Rossdale and E.L. Smith. Both use conventional treatment that consists of coagulation with alum and flocculation and dual-media filtration to remove particulate and colloidal material from North Saskatchewan River water (EPCOR Water Services Inc. 2012). Both plants also have UV as part of the treatment train. The combined effect is that the treatments neutralize any bacteria, viruses, *Giardia* cysts and *Cryptosporidium* oocysts that might be present in untreated river water. Primary disinfection techniques are provided by free chlorine which is an additional barrier against bacteria and viruses, and a partial barrier against *Giardia* cysts. UV light disinfection provides an additional three log removal of *Giardia* cysts and *Cryptosporidium* oocysts. Ammonia is added to the water to form monochloramine which provides a lasting disinfectant residual through reservoir storage and the distribution system within the Edmonton and regional waterworks systems.

EPCOR's distribution system includes ongoing maintenance programs that safeguard distribution system integrity and water quality. These maintenance programs include: distribution system pipe and appurtenance replacement; main break repair; unidirectional flushing and hydrant servicing; distribution system leak detection; and distribution system pressure monitoring. An additional public health protection barrier is provided through a Cross Connection Control (CCC) Program maintained by EPCOR. This program minimizes the potential for unintended backflow into the distribution system from high risk residential, commercial, and industrial customers. This is done by ensuring backflow prevention devices are in place and tested as required by the City of Edmonton Waterworks bylaw #12585. A Lead Response Program is also applied at the distribution stage. This program reduces the potential for exposure to lead in tap water in approximately 5,000 homes in the older part of the city that are supplied through lead service lines.

To ensure the safety of drinking water up to customers' taps, EPCOR monitors raw water entering Rossdale and E.L. Smith water treatment plants, and treated drinking water entering the distribution system. In addition, a routine monitoring program ensures water quality throughout the reservoirs and the distribution system. EPCOR performs monitoring and testing well above the minimum required by regulation. For example, Health Canada recommends 155 samples be collected from the distribution system each month for bacteriological testing for a city the size of Edmonton. However, on average, 234 samples are collected monthly. In 2011, the EPCOR Water Laboratory carried out more than 113,000 tests on 100 parameters (47 inorganic/physical, 47 organic and 5 microbiological) for Edmonton water. Another 5,000 tests were done on 222 additional parameters (211 trace organics and eight radionuclides) by external commercial laboratories. In addition to the laboratory testing, EPCOR also uses numerous online analyzers to monitor continuously critical treatment performance and water quality variables in the treatment plants such as chlorine concentration and filtered water turbidity. Backups are provided for critical analyzers. There are over 75 online analyzers in each treatment plant. A quality assurance program is in place to confirm these online analyzers are reliable.

In 2011, EPCOR's treated drinking water met the Health Canada Guidelines for Canadian Drinking Water Quality for all chemical, physical, and radiological parameters. A total of two water quality violations were reported to Sustainable Resource Development for the year; both were detection of total coliform bacteria that occurred in the distribution system in September. One event was caused by the use of incorrect sampling procedures when water samples were collected from hydrants. The other event was caused by stagnant water in a water main after a valve was left in the wrong position. Both events were resolved within 72 h and there was no risk to public health. One isolated incident of very low levels of *Giardia* and *Cryptosporidium* in the finished water occurred at the Rossdale plant on Nov 21, 2011 (*Giardia* at 0.1 cysts/100 L and *Cryptosporidium* at 0.1 oocysts/100 L). Follow-up samples were negative. The treated water was disinfected with ultraviolet light (an additional barrier) so there was no risk to public health.

In 2011, 271 out of a total of 50,252 applicable tests on the treated water did not pass EPCOR's internal quality standards. However, the cumulative Water Quality Index at the end of 2011 was 99.71 %, which surpassed the City of Edmonton's Waterworks By-Law Performance Based Regulation target of 99.6 %. In addition to the Water Quality Index, EPCOR strives to meet other requirements set by the City of Edmonton Performance Based Regulation. These performance measures ensure EPCOR maintains performance in a number of areas, while aiming for improvements in efficiency (EPCOR Water Services Inc. 2011).

It should be noted that although there is no legislation or regulation in place to protect source water around Edmonton, EPCOR has a Drinking Water Safety Plan that could in principle introduce risk management for its two water treatment plants (see Table 7.12). As part of its risk management approach, EPCOR has a list of potential risks by which the operator can classify the type and assess how severe the risk is. In its risk matrix, EPCOR distinguishes two types of risk: inherent risk—without any controls applied, i.e., in watershed management; and residual risks—all remaining risk aside from the inherent risk (EPCOR Water Services Inc. 2012).

However, there are some shortcomings in EPCOR's risk management which is based on its Drinking Water Safety Plans. The first is the interpretation behind the risk matrix. Is this classification of risk into inherent and residual enough to describe fully all types of risk? And if it is, how does the operator know how to classify potential contaminants as low, medium or high risk if there is no quantifiable data available (see Table 7.12)? This is similar to the argument that we made previously against Alberta's Drinking Water Safety Plan's risk matrix. There is no quantifiable data, and the risk calculation is defined in exactly the same way as Alberta's Drinking Water Safety Plan. Classification of the severity of potential contaminants is left to the operator's discretion, which is totally subjective;

Table 7.12 EPCOR's risk matrix detailing all possible risks and their corresponding threat level (EPCOR 2012)

Source	Land-uses/potential contaminant source/activity	Inherent risk	Residual risk
Point	Small urban waste discharges from wastewater treatment plant	H	L
	Municipal sewage lagoon discharges	H	L
	Pipeline break	M–H	M–L
	Industrial discharges	H	L
Nonpoint	Livestock waste excretion	H	L
	Livestock physical alteration of watershed	M–H	L
	Agricultural cropping activities	M–H	L
	Agricultural land cover and use	M–H	L
	Wildlife activity in watershed	M–H	L
	Rural septic fields	M–H	L
	Small urban storm water runoff	M–H	L
	Forest harvesting activities	M–H	L
	Pine beetle infestation	M–H	L
	Forest fires	M–H	L
	Waste disposal sites	M–L	L
	Alteration in climate (natural and anthropogenic)	M–H	L
	City of Edmonton storm water runoff	H	L
	Contamination of pet fecal matter in urban areas	M–H	L
	Proximity to transportation corridor	M–H	L
	Spill on a bridge	M–H	M–L
	Recreational actives	M–L	L
	Groundwater contamination from airport	M–L	L
	Gravel extraction activities	M–L	L
	Coal surface mining	L	L
	Disposal of animal remains within watershed	M–L	L
	Dam operation and management	M–L	L
	Industrial contamination of shallow aquifers	M–H	M–L
	Industrial land spillage	M–H	M–L
Other	Intentional contamination at critical source intakes	M–H	M–L
	Insufficient raw water quantity	M–L	L
	Catastrophic failure of dams	M–H	L
	Contamination of raw water due to intentional dumping or release of chemicals from industries	M–H	M–L

however, EPCOR has treatment trains at both plants that include UV. This probably makes the legally required risk matrix redundant.

Furthermore, EPCOR specifically states that it does not have a warning station to warn the water treatment plants and wastewater treatment plants of possible contaminants moving down the North Saskatchewan River, and that it relies on communications from the Alberta Environment and Sustainable Resource Development, the City of Edmonton's Drainage Service and/or the Fire Rescue Services in the event of possible spills/releases that may affect the water treatment plants. As a result, what we gather from this information is that there is no authority that manages the quality of raw water entering the drinking water systems, and furthermore, there are no stringent procedures in place to detect microbiological or chemical contaminants in raw water supplies. It seems that the only possible point of intervention is at the treatment stage, and, depending on the water treatment plant's water technology, it may not even be efficient in removing all the contaminants that have entered the water supply systems. But, of course, at the two Edmonton treatment plants, they have UV disinfection, which is probably more important in guaranteeing safe water than the Drinking Water Safety Plan that the law requires EPCOR to have.

Although the two water treatment plants for Edmonton (Rossdale and E.L. Smith) are well equipped to deal with these protozoan parasites, as they contain UV disinfection technology to inactivate protozoan parasites from treated water, the wastewater treatment plants in surrounding subwatersheds do not have UV disinfection plants and are susceptible to microbiological parasites escaping into their water supplies (The exception is the wastewater treatment plant in the Drayton Valley which installed the UV treatment in 2011 (ISL Engineering and Land Services 2014)). Moreover, subwatersheds do not have any treatment mechanisms in place to safeguard raw water supplies from runoffs that contain microbiological parasites.

7.6 Potential Hazards in the Mackenzie River Basin

7.6.1 *Inefficient and Wasteful Use of Fresh Water in the Oil Sands Industry*

Alberta is well known for its oil production. The province's remaining proven oil reserves are about 168 billion barrels (or 26.7 billion cubic meters) in the oil sands, amounting to 13 % of total global oil reserves. About 1.9 million barrels of crude were produced every day from the oil sands in 2012, which made up over 22 % of Alberta's GDP (Government of Alberta 2014). At the time of writing (February 2014), there are 114 active oil sands projects in Alberta (Government of Alberta 2014). Of these, six are open-pit mining operations and the remaining projects are in situ operations. Since oil sands mining operations are based on a necessary process that uses hot water to extract the bitumen[7] from the oil sands, water plays a

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[7] Bitumen is a viscous mixture of hydrocarbons, including about 83 % carbon, 10 % hydrogen, 5 % sulfur, 1 % oxygen, 0.4 % nitrogen, and trace quantities of methane, hydrogen sulfide, and metals (Timoney and Lee 2009).

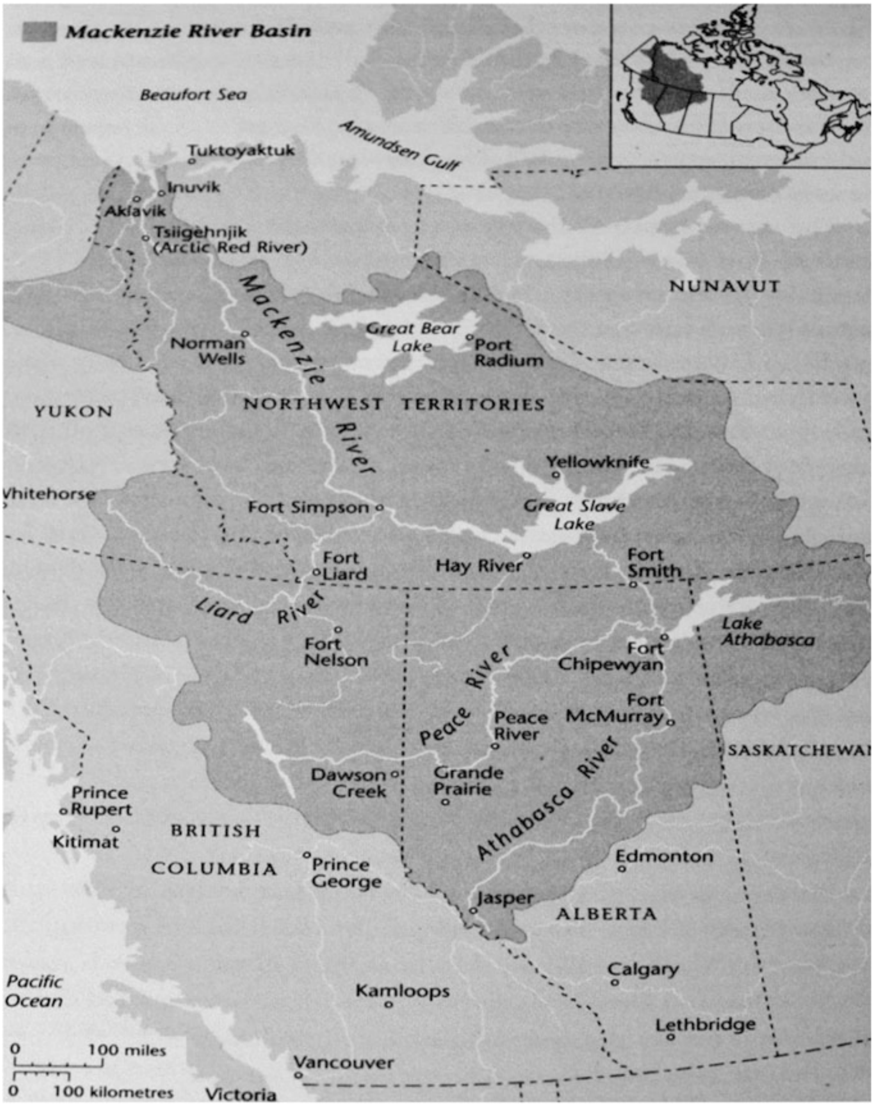

Fig. 7.11 A map of the Mackenzie River basin (Nikiforuk 2010)

significant role in the oil sands industry. On average, a barrel of oil sands production requires around three barrels of fresh or potable water, while in situ operations primarily rely on groundwater for their water needs, with an increasing amount being saline water.

Alberta's oil sands deposits are found mainly under the forest and wetlands of the Mackenzie River basin (see Fig. 7.11). These oil sands projects, especially those which use open-pit mining operations, not only destroy water-conserving forest and wetlands, but also use large amounts of water from the Athabasca and Peace Rivers. For example, Shell's Albian sands project, in addition to destroying 31,000 acres of forest and wetlands, withdraws 53.8 million cubic meters of water a year from the Athabasca River (Nikiforuk 2010). Moreover, the Kearl oil sands project, one of Canada's largest open-pit mining operations, damaged 320 acres of fish habitat along the Muskeg and Firebag Rivers, as well as using 104 million cubic meters of water from the Athabasca River which accounts for 2.3 % of the river's annual flow (Nikiforuk 2010). In 2010, freshwater use for oil sands production was approximately 170 million cubic meters, which could supply the needs of 43 % of the residents of Toronto (Canadian Association of Petroleum Producers 2010). Currently, total annual water allocation for the oil industry in Alberta is 9.9 billion cubic meters per year. Of this, the oil sands industry accounts for 7 % (or 693 million cubic meters), which is enough to supply two cities the size of Calgary.

Oil sands mining already accounts for the largest consumption of water in the Mackenzie River Basin. In fact, the oil sands industry makes up more than 76 % of water allocations on the Athabasca River. Oil sands water use is therefore a major concern. In 2006, the "Oil Sands Ministerial Strategy Committee" prepared a report for the Alberta cabinet entitled "Investing in Our Future: Responding to the Rapid Growth of Oil Sands Development" (Alberta Environment and Sustainable Resource Development 2006), which suggested that "over the long term the Athabasca River may not have sufficient flows to meet the needs of all the planned mining operations and maintain adequate stream flows." The report also concluded that Alberta Environment and Sustainable Resource Development had failed "to provide timely advice and direction" on water use and that the province's ability to enforce environmental regulations was "inadequate". Moreover, Nikiforuk (2010) noted that "in the wintertime, water levels drop so low that by 2015, industry will be withdrawing more than 12 % of the river's flow." Approximately "90 % of the fresh water" withdrawn from the Athabasca River "ends up in the tailing ponds."

In 2007, Professor David Schindler, one of the world's foremost water ecologists, worked with two other researchers, Donahue and Thompson (Schindler et al. 2007). They found that summer (May–August) flows in the Athabasca River had declined by 29 % from 1970 to 2005 (see Fig. 7.12). In addition, net water runoff in the winter months had decreased by 50 % in the Athabasca Basin and could drop further by 2050 (Fig. 7.13). They concluded that the decline in summer and winter flows in the Athabasca River is caused not only by climate change but by increased oil sands projects along the Athabasca River basin. Schindler finally pointed out that the "projected bitumen extraction in the oil sands will require too much water to sustain the river and the Athabasca Delta, especially with the effects of predicted climate warming" (Schindler et al. 2007).

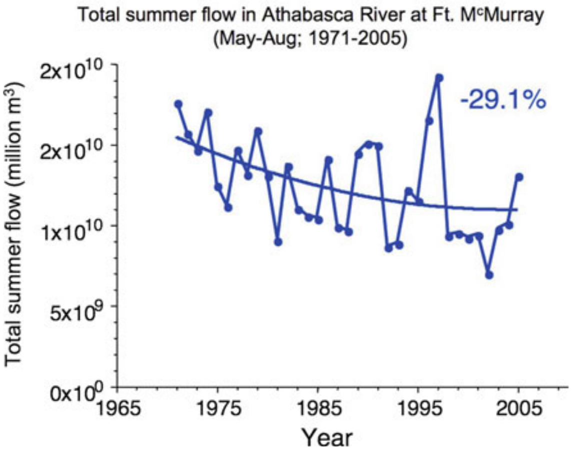

Fig. 7.12 The decline in average summer flow in the Athabasca River (1970–2005) (Schindler et al. 2007)

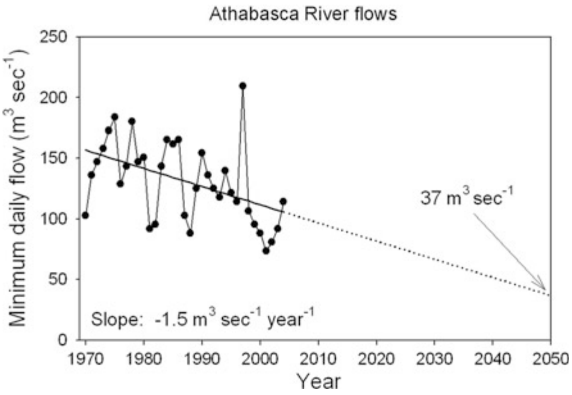

Fig. 7.13 The trend over time in lowest winter flows in the Athabasca River note: the dotted line is the regression through measured data points (Schindler et al. 2007)

7.6.2 Influence of Tailing Ponds on Groundwater Quality

The tailing ponds contain "the residue or tails left after bitumen is extracted from the sand, which consists of process water, sand, fines (silts and clays), residual bitumen (1–5 %), and associated chemicals" (Timoney and Lee 2009). Nikiforuk (2010) described the tailing ponds as the "world's fantastic concentration of toxic waste." Tailing ponds are common to all types of surface mining, which produces 400 million gallons of toxic sludge every day, enough to fill 720 Olympic pools (Nikiforuk 2010).

In 2008, 1600 ducks died after landing on Syncrude's Aurora tailings pond in Northern Alberta. More recently, a 2010 investigation by CBC News revealed that a tailing pond owned by Canadian Natural Resources Ltd appeared to have "toxic sludge flowing into the muskeg from an uncontained western edge" (Dick and Hees 2010, November 15). "Some of those chemicals have to be seeping into groundwater," Schindler said as he watched the video. Schindler also said, "I do not

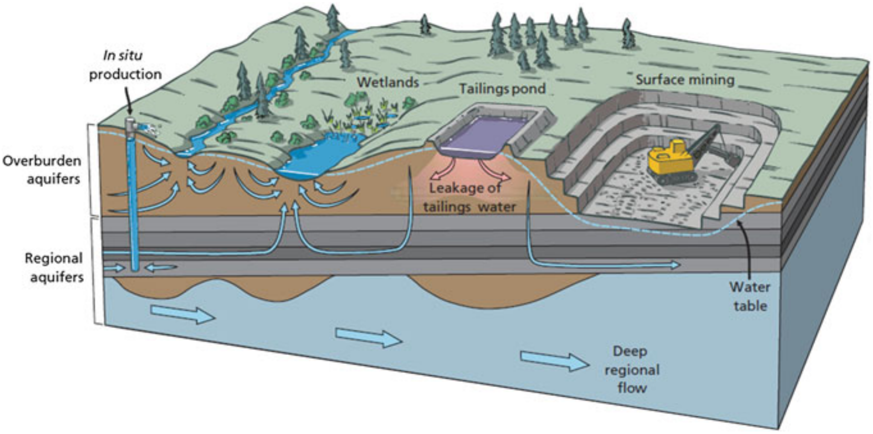

Fig. 7.14 Schematic diagram of key groundwater issues in the Athabasca oil sands region (Council of Canadian Academies 2009)

believe that regulators would approve this type of tailings pond" (Dick and Hees 2010, November 15).

Leakage of tailings water from the tailing ponds into groundwater is a key groundwater issue in the Athabasca oil sands region (see Fig. 7.14). For example, seepage of tailings water from Suncor's Tar Island Pond One[8] into groundwater hydraulically connected to the Athabasca River has been quantified at 5.6 million L per day (Timoney and Lee 2009). If the clay layer underlying the tailing pond is not low permeable silt, the leakage rates will be higher.

The major toxicants contained in tailings water are naphthenic acids (NAs). Other identified chemicals of concern are arsenic, ammonia, barium, chromium, bismuth, iron, lithium, manganese, selenium, strontium, tin, vanadium, zinc, methylnaphthalene, and C2 naphthalene. Seepage of heavily contaminated tailings water into groundwater causes serious impacts on both human and aquatic ecosystem health. Unfortunately, Canadian Environmental Quality Guidelines for the protection of aquatic life are not directly applied to the tailings ponds.

7.6.3 Impact on Water Quality Downstream

In order to explore the significant deterioration of water quality associated with pollutants from the oil sands industry, a study was undertaken by Timoney and Lee (2009). The primary objectives of the study were (a) to discover the levels of contaminants in the lower Athabasca River system, (b) to determine if there is

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[8] Suncor's Tar Island Pond One is located in the Athabasca River basin and it occupies 1.45 million square meters.

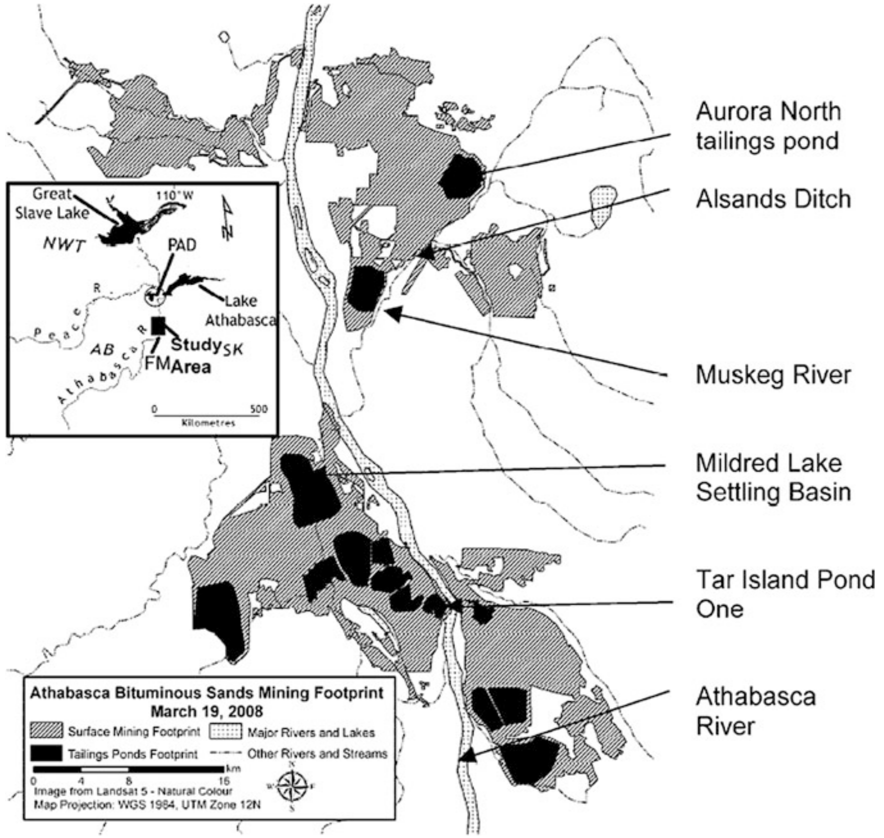
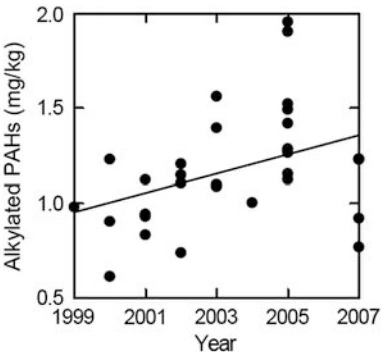


Fig. 7.15 Athabasca oil sands industrial footprint as of March 2008 (Timoney and Lee 2009) (*Note* AB = alberta, FM = fort mcmurray, NWT = northwest territories, PAD = peace-Athabasca delta and Fort Chipewyan, SK = Saskatchewan.)

evidence of increased levels of contaminants through the comparisons of sites downstream of industry and upstream of industry, and (c) to present documented incidents of industrial pollution or degradation. The study area was located in northeastern Alberta's Boreal Forest Natural Region. As we can see from Fig. 7.15, an open-pit mine spans the Athabasca River and extends from northern Ft. McMurray to the Firebug River.

In order to explore the relationship between oil sands development and concentrations of polycyclic aromatic hydrocarbons (PAHs) in the Muskeg River, two sites were set up. The site called MUR-6 was located upstream of oil sands industrial development, while the site named MUR-5 was located downstream of oil sands industrial development. Semipermeable membrane devices were deployed in the two sites to detect the concentration of PAHs during the summer of 2006. The datasets for 28 species of PAHs from the two sites were analyzed, and the results indicated that most of the concentrations of PAHs in MUR-5 were higher

Fig. 7.16 Trends in alkylated PAH concentrations from Athabasca River delta sediment (1999–2007) (Timoney and Lee 2009)



than in MUR-6. Of these, the concentrations of C2 and C3 Dibenzothiophenes, C2 and C3 Fluorenes, and C2 henanthrenes/Anthracenes in MUR-5 were at least 10 times higher than in MUR-6. Furthermore, the relationship between oil sands development and all PAH concentrations was strong and significant, which indicated that the oil sands development increased the concentrations of PAHs in the Muskeg River. Hence, Timoney and Lee pointed out that "withdrawal of Muskeg River water by oil sands operations between sites MUR-6 and MUR-5 was considered as a possible explanation for increased PAH concentrations."

A 2005 Technical Report from the Regional Aquatics Monitoring Program[9] found that sediments from the lower Athabasca River and its delta were "toxic to several species of invertebrates" and contained "high levels of PAHs and metals." However, there are currently "no Canadian guidelines for total PAHs in sediment." The US National Oceanic and Atmospheric Administration (NOAA) recommends a standard of "1 mg/kg dry weight of total PAHs in marine sediment" (Timoney and Lee 2009). If the level of total PAHs in sediment is above 1 mg/kg, the risk of liver disease will be higher. The estimated results from the least-squares linear regression model indicated that the concentrations of alkylated PAH increased from 1 to 1.3 mg/kg in Athabasca River Delta sediment between 1999 and 2007 (see Fig. 7.16). Furthermore, above 1 mg/kg of alkylated PAH concentrations were found in over a half of observed samples. In addition, Parajulee and Wania (2014) applied a georeferenced Grid-Catchment Integrated Environmental Modeling System to simulate the transport and pathways for three representative PAHs in the Athabasca oil sands region. Their results indicate that environmental impact assessment models typically underestimate the amount of PAHs. This means that the negative environmental impacts are underestimated and hence the potential adverse human and ecosystem health impacts in the Athabasca oil sands region have also been underestimated. Hence, the standards of PAH emissions from oil sands operations should either be brought in line with the NOAA standard or a

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[9] Regional Aquatics Monitoring Program is an industry-funded multistakeholder group, which was established in 1997. Its objective was to integrate aquatic monitoring activities in the Athabasca oil sands region (Regional Aquatics Monitoring Program 2014).

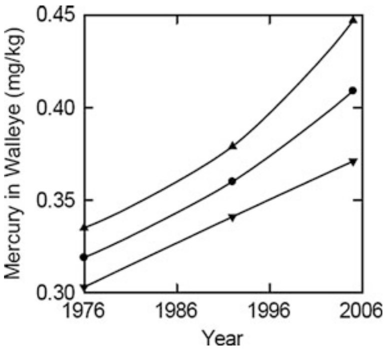

Fig. 7.17 Trend in mean mercury concentration (±1 SE) in muscle of mature walleye of the lower Athabasca River (1976–2005) (Regional Aquatics Monitoring Program 2006)

Canadian Federal Government standard needs to be developed. As the tar sands projects are approved on the basis of environmental impacts assessments, this suggests that with a higher standard fewer projects would have been approved. The Parajulee and Wania (2014) results are more recent and have important policy implications, on which see more below.

Furthermore, mercury was found in the lower Athabasca River. Figure 7.17 shows that the mean mercury concentrations in Lower Athabasca River walleye increased from 1976 to 2005. According to Health Canada's subsistence fisher guideline, the maximum allowable concentration of mercury is 0.2 mg/kg. Yet virtually all the observed samples of mature walleye contained more than 0.2 mg/kg of mercury and the highest mercury concentration reached 0.765 mg/kg.

In order to discover the impact of Tar Island Pond One seepage on Athabasca River sediments, data on the concentration of dissolved analytes (i.e., arsenic, iron, silver, and zinc) were collected from pore water in the sediment of the Athabasca River upstream (Site 1) and downstream (Site 6) of Tar Island Pond One. The results suggested that the downstream concentrations for primary analytes were 2–5.1 times higher than upstream concentrations (see Table 7.13). Virtually, all the concentrations of analytes exceeded the Canadian Water Quality Guidelines for the protection of aquatic life. In addition, the iron concentration at Site 6 was eight times higher than the guidelines.

Table 7.13 Porewater dissolved analyte concentrations at depth of 0.3 m in the sediment of the Athabasca River at Site 1 (Upstream) and Site 6 (Downstream) of Tar Island pond one (Timoney and Lee 2009)

Analyte	Site 1 (mg/L)	Site 6 (mg/L)	Site 6–Site 1 (mg/L)	Effect (Site 6/ Site 1)	CCME guideline[a] (mg/L)
Arsenic	0.0029	0.0147	0.0118	5.1	0.005
Iron	10.6	24.5	13.9	2.3	0.3
Silver	<0.0002	0.0002	0.0001	2.0	0.0001
Zinc	0.02	0.088	0.068	4.4	0.03

[a] Canadian Water Quality Guidelines for the Protection of Aquatic Life

Timoney and Lee further pointed out that “contaminant discharges to the Athabasca River are common.” For example, on September 7, 2007, Suncor Energy Inc. spilled about 9.8 million L of wastewater into the Athabasca River, but the impact and extent of the chemical contamination of the discharge incident was not reported. Furthermore, in March 2011, Suncor Energy Inc. spilled wastewater into the Athabasca River for 3 days, but the discharge incident was not reported until Alberta’s Environment and Sustainable Resource Development found out the source of the toxic elements in the water. Moreover, on March 25, 2013, Suncor Energy Inc. spilled about 350,000 L of industrial wastewater into the Athabasca River over 10 h (Tait 2013a, April 12). The company said this discharge incident caused “a short term, negligible impact on the river”. However, according to Alberta’s Department of Environment and Sustainable Resource Development, test results showed that the sample of Suncor’s undiluted wastewater was toxic.

7.6.4 Policy and Regulation

The Alberta Ministry of Environment and Sustainable Development is supposed to regulate oil sands activities, in principle. Before June 2013, the oil sands were regulated by the Energy Resources Conservation Board (ERCB) (Blake et al. 2010). The ERCB was responsible for oil sands and gas project approvals and compliance as well as “ensuring that the public interest is protected and oil sands development is environmentally responsible” (Energy Resources Conservation Board 2011). The Alberta Energy Regulator (AER) has succeeded and replaced the ERCB from June 17, 2013.

The mission of the Alberta Ministry of Environment and Sustainable Development is to protect Alberta’s environment and manage Alberta’s natural resources as well as deal with climate change issues and waste management (Blake et al. 2010). The project permits issued by the ERCB must contain “appropriate conditions and limits on water use, air and water emissions, disturbances to water bodies and reclamation activities” under the provincial Water Act, the Environmental Protection and Enhancement Act, and the Public Lands Act (Energy Resources Conservation Board 2011).

However, like the failures of the NRCB reported in Sect. 7.4.1, some actions of the ERCB have been questioned. For example, in 2006, the ERCB approved an oil sands project proposed by Suncor Energy Inc. and stated that… “expansion would not be permitted if Suncor Energy Inc. did not improve the performance of its tailings management” (Energy Resources Conservation Board 2011). However, after Suncor’s wastewater discharge incidents occurred in 2007 and 2011, respectively, a Suncor’s oil sand project was permitted to expand and other projects were still allowed to proceed (Energy Resources Conservation Board 2011). It seems that the Directive 074 titled “Tailings Performance Criteria and Requirements for Oil Sands Mining Schemes” exists in name only. Dr. Schindler has pointed out, “Although the ERCB has added conditions and amendments to oil sands proposals, it has never yet rejected a project” (Schindler 2010).

In addition, the ERCB was accused of “poor transparency and foot-dragging” (Tait 2013b, May 13). For instance, on April 29 2011, about 28,000 barrels of oil were spilled in the Rainbow pipeline rupture, which is the largest spill in Alberta in 36 years. In 2013, Greenpeace Canada suggested a public investigation into the Rainbow Pipeline spill, but the chief operating officer of the ERCB rejected the request (Tait 2013b, May 13). As indicated above, there have been a number of incidents of widespread water pollution from the tar sands, and it seems that the ERCB has been very accommodating for a regulatory agency. Its lack of action in curbing acts of pollution suggests that the ERCB has violated the objectives of “Water for Life,” and therefore also the Alberta Water Act. Perhaps because of the level of criticism that the Board faced, in June 2013 it was abolished and replaced with a single “Energy Regulator” (Alberta Energy Regulator 2014). This body has a board of directors drawn mainly from industry. The AER is 100 % funded by the oil and gas industry, according to its website. It therefore seems that the business of *regulation* of the oil and gas sector has in effect been privatized, although in theory the AER is an “arms-length” agency, and in principle the Alberta Ministry of Environment and Sustainable Development is the overall regulator responsible for implementing the Water Act.

As oil and gas is internationally traded and the operations of the oil and gas sector affect the environment as a whole, the Federal government also has a role. For this reason, Environment Canada, the Department of Fisheries and Oceans (Canada), and the Alberta Environment and Sustainable Resource Development jointly monitor water quality in the oil sands, but it seems there is no single government agency monitoring the Athabasca River and its tributaries (Schindler 2010). According to Dr. Schindler: “Much of the water monitoring has ended up with the Regional Aquatics Monitoring Program—a body with some serious shortcomings….” [and that water quality has]…. “not been monitored frequently enough and for a long enough period to detect trends” (Standing Committee on Environment and Sustainable Development 2010). He further pointed out that “any future Environment Canada monitoring program requires strict oversight by a committee of independent scientists as well as frequent expert reviews and public updates” (Standing Committee on Environment and Sustainable Development 2010).

The oil sands industry and Alberta government have repudiated the claim that the toxins in the Athabasca River and its tributaries are attributable to the oil sands mining; instead, they argue that the toxins are from natural seepage from bitumen deposits. In order to test this claim of natural seepage, in 2008 Dr. Schindler conducted two field studies to test if the toxins such as PAHs in the river arose from natural sources. He found “a wide variety of toxic contaminants deposited in the snowpack, some detectable as far as 50 km from the main pollutant sources” (Schindler 2010). On the basis of his findings, in 2009, Dr. Schindler told the Parliament of Canada, House of Commons, Standing Committee on Environment and Sustainable Development, that “the toxins present in the Athabasca River just below Fort McMurrary, confirmed that there are indeed natural sources of PAH in the river. However, there are large increases in the region of oil sands mining. Also, dissolved PAH in some of the impacted tributaries showed strongly increasing concentrations downstream of mining activity" (Standing Committee on Environment and Sustainable Development 2010). But, findings from the Regional Aquatics Monitoring Program and provincial monitoring programs did not agree with this claim.

In an attempt to resolve this dispute, in 2010, the Royal Society of Canada appointed an Expert Panel of Canadian Scientists to review and assess the relevant evidence. The main conclusion of the expert panel was that:

> Current evidence on water quality impacts on the Athabasca River system suggests that oil sands development activities are not a current threat to aquatic ecosystem viability. However there are valid concerns about the current Regional Aquatics Monitoring Program (RAMP) that must be addressed. The regional cumulative impact on groundwater quality and quantity has not been assessed. (The Royal Society of Canada Expert Panel 2010, p. 2).
> The Report also added:

> The environmental regulatory capacity of the Alberta and Canadian Governments does not appear to have kept pace with the rapid expansion of the oil sands industry over the past decade. The environmental impacts assessment process relied upon by decision-makers to determine whether proposed projects are in the public interest has serious deficiencies in relation to international best practice. Environmental data access for cumulative impact assessment needs to improve. (The Royal Society of Canada Expert Panel 2010, p. 2)

It seemed that as far as the Premier of Alberta at that time (Ed Stelmach) was concerned, there still remained doubts as Dr. Schindler and his group maintained that their finding of increasing seepage of contaminants was based on sound science. Their two articles (Kelly et al. 2009, 2010) stated that the oil sands development is a greater source of contaminants than was previously recognized. Many of the pollutants that they found in snow pack and river samples are toxic at low concentrations (trace metals), while others, such as Polycyclic Aromatic Compounds (PAC), could harm fish embryos in the rivers. They also indicated that current monitoring programs throughout the oil sands region are inadequate to determine impacts of these chemicals. So in September 2010, the Premier appointed yet another expert panel (Dillon et al. 2011), whose report disagreed with the research reports in Kelly et al. (2009, 2010). Some members of this panel, who had been funded by the oil industry in the past, might have had a conflict of interest. The links to the oil industry are not disclosed in the biography of authors given in this document, which is surprising. However, the report by this second panel resolved nothing when it was presented in 2011. Therefore it is important to consider the results of a later study by *two independent authors* to which reference has already been made, namely Parajulee and Wania (2014), and for this article Dr. John Giesy was the Guest Editor of the issue of the Proceedings of the National Academy. Dr. Giesy was one of the authors of the Stelmach Expert Panel referenced above as Dillon et al. (2011). To quote from Parajulee and Wania (2014):

> The results of the TP [Tailing Ponds] simulations reaffirm that emissions estimates for the AOSR [Athabasca Oils Sands Region] that take into account only direct emissions to air do not appear to be adequate representations of actual emissions in the region. Furthermore, indirect emissions of PAHs [polycyclic aromatic hydrocarbons] from secondary sources, such as tailings ponds, to the atmosphere may be a more significant contributor of oil sands PAHs to the AOSR atmosphere relative to direct emissions to air. The results also suggest that these

> alternative emissions sources (e.g., blowing dust from mine faces or waste coke disposal) require better quantification for low K_{AW} PAHs in particular. The relatively low modeled concentrations of BaP [benzo (a)pyrene] in air, foliage, soil and, to a lesser degree, freshwater may also be indicative of longer half-lives in these media than those that were used in this study. In the case of the soil, the estimated initial contamination may also have been too low.

One more passage from the same paper is worth quoting:

> The impact of oil sands development on PAH cycling through the AOSR remains unclear, in part because of monitoring programs that have been deemed inadequate by various review panels…[references numbers omitted], and the difficulty in ascribing observed environmental residue levels to natural sources versus anthropogenic activity. However, a recent assessment of PAHs in lake sediment cores provides compelling evidence that oil sands development has led to a significant increase in PAH levels in the AOSR environment….

This later study, which is by researchers at the University of Toronto, who are independent of the contesting two groups, seems to come down clearly on the side of Drs. Kelly and Schindler.

In order to enhance water monitoring, in February 2012, the Government of Canada and the Government of Alberta worked together to release the Joint Canada-Alberta Implementation Plan for Oil Sands Monitoring. The monitoring plan in the oil sands region increased the number of sampling locations, parameters, and frequency, introducing new air, surface water, and groundwater monitoring stations as well as new sampling areas such as river ice and snow. The 3-year plan (2012–2015) will be fully implemented in 2015 (see Fig. 7.18). Moreover, a new Oil Sands Data Management Network (OS-DMN) will provide "credible, comprehensive oil sands environmental monitoring data and supporting information" and make them available online (Alberta Environment and Sustainable Resource Development 2014a).

It remains to be seen how this joint federal-provincial monitoring agreement will work with the new (oil sand industry dominated) AER. But at last now there is a check-and-balance institutional mechanism in place.

This brief review of the impact of tar sands production in the Mackenzie River basin indicates that the Government of Alberta has given high priority to the production of bitumen from the oil sands in Northern Alberta, at the expense of water quality and local ecosystem health. The actions allowed in this basin *completely contradict* the objectives of the Water for Life Strategy. It is as if the "Water for Life Strategy" is for the *rest* of the province and that the oil sands industry is exempt from the provisions of the Water Act. However, with the Joint Federal—Provincial agreement, there is an arms-length mechanism in place that might act as a counter balance to the AER; there appears a possibility that pollution from the oils sands industry will receive greater scrutiny and that there will be greater transparency in data collection, which will also be made public.[10]

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[10] Both the Federal and the Alberta governments have set up websites reporting on new data and two annual reports have been published to date (Feb 23, 2015). See for example: http://www.jointoilsandsmonitoring.ca/; it is too early to determine if this joint monitoring exercise is effective in curbing pollutants.

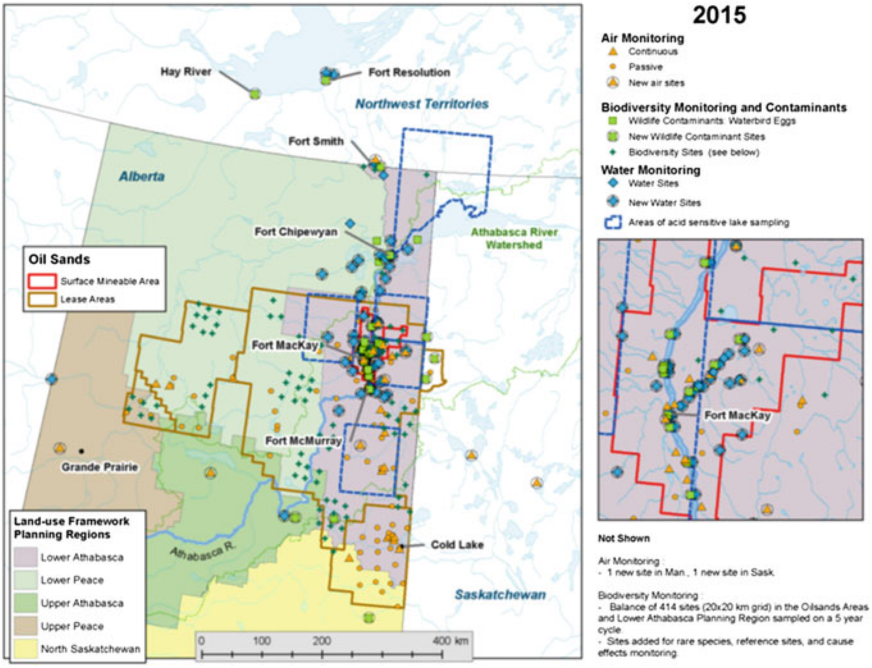

Fig. 7.18 Proposed monitoring by 2015 (Alberta Environment and Sustainable Resource Development 2012c)

7.7 Long-Term Approaches to Water Safety

It should be noted that the focus of Alberta's Drinking Water Safety Plan is not only source water protection but also detection of contaminants at the treatment, distribution, and consumer stages. Despite the implementation of the Drinking Water Safety Plan, operators can only intervene at the treatment stage. This poses a large problem if and when any type of contaminant (chemical, microbiological, physical, or radiological) emerges in either the catchment, distribution, or consumer areas. Although Alberta claims that its Drinking Water Safety Plan is a proactive approach, if any contaminants are found in the distribution or consumer areas, operators cannot intervene and deal with these potential problems; and past the water treatment stage, the detection risk system becomes a reactive approach, not a proactive one. The fact that operators can act only *at the treatment stage* is a serious limitation of the Drinking Water Safety Plan.

An alternative approach to the Drinking Water Safety Plan would be implementing the HACCP coupled with a comprehensive list of the possible risks for each parameter (chemical, microbiological, physical, and radiological). In Ontario, the Municipality of Peel has fully implemented HACCP and indeed has gone further in becoming fully certified by ISO 9000 (Region of Peel 2014).

The combination of HACCP and the comprehensive list of risk parameters serves as a better approach to maintaining safe drinking water. Consider the fact that in the long term there can be changes to watershed features such as geology, changes in human activity, vegetation and precipitation events; all these changes can lead to increases in raw water turbidity. Since operators can only intervene at the treatment level, there is no obvious possibility to remediate at any other stage other than at the treatment plant. Therefore, implementing HACCP is a more proactive and preventative approach than the Drinking Water Safety Plan.

With the new methods used for detecting chemicals in the environment, trace levels of pharmaceuticals have been found in waterways. In 2005, due to a large number of concerns about the potential impacts on humans, livestock, aquatic organisms, and wildlife, Alberta Environment and Sustainable Resource Development sampled treated wastewater treatment plants effluents from the cities of Calgary, Edmonton, Red Deer, Lethbridge, and Medicine Hat for a broad range of organic wastewater contaminants. These compounds were also taken from receiving waters from the Bow, North Saskatchewan, Red Deer, Oldman, and South Saskatchewan Rivers. From the results of the preliminary study, the Ministry found that a broad range of pharmaceuticals, endocrine disruptors, and other organic wastewater contaminants were present in wastewater treatment plant effluents and receiving rivers in Alberta. Although Sosiak and Hebben report that it was a “one-time” survey, recommendations were made that long-term monitoring was a necessary step in order to detect these emerging contaminants (Sosiak and Hebben 2005, September). Currently, Alberta has a province-wide program for the disposal of household pharmaceutical waste; however, it is not regulated (Health Canada, Environmental Impact Initiative 2009). Therefore, it appears that Alberta has no effective policies in place to monitor pharmaceuticals, pesticides, and personal care products (PPPCPs); and PPPCPs can be found in both untreated and treated water.

Another possible approach to implementing the Drinking Water Safety Plan would be investing in new treatment technology called Advanced Oxidation Processes in which ultraviolet (UV) light, hydrogen peroxide, and/or ozone are employed in the removal of organic and inorganic materials present in water and waste water.[11] Recognized treatment processes manufactured by companies such as Trojan UV are safe, more cost effective, and are an environmentally responsible alternative to Drinking Water Safety Plans. UV systems such as Trojan UV Swift ECT employ sophisticated controls to optimize the treatment of environmental contaminants, and also safeguard against many harmful microorganisms, including *Cryptosporidium* and *Giardia*. As a result, UV systems have become the preferred choice in many US cities and locations.

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[11] In Canada, there are several municipalities that use Advanced Oxidation Processes, but mainly for taste and odor concerns. See Chap. 4 “Water Policy in Ontario” for further details.

7.8 Conclusion

Since Alberta has the largest beef industry in Canada it should be a leader in applying measures to reduce their impact on the environment. Alberta Urban Municipalities Association's 2012 Municipal Water Policy states that harmonized regulations relating to wastewater effluent must be developed through collaboration and coordination of the federal, provincial, and municipal governments in order to ensure the protection of human and environmental health (Alberta Urban Municipalities Association 2012). Environment Canada recently released its new Wastewater Systems Effluent Regulations (November 2012) which ensure that point source effluents from wastewater treatment plants are managed effectively to protect water quality; however, this regulation is inadequate for watershed protection as it does not include measures that will protect source water from microbiological and chemical contaminants.

The large and extensive cattle industry (beef and dairy) in Alberta has large "externalities"—side effects or consequences of an industrial or commercial activity that affect other parties. These are costs which are not incorporated in their products but are passed on to society in the form of polluted waters. The potential hazards are due to pathogens such as *E. coli* O157, *Cryptosporidium*, and *Giardia*. The Drinking Water Safety Plan that the Alberta Government has put in place at all water treatment plants is unlikely to meet the challenges of *E. coli*, *Cryptosporidium,* and *Giardia*. The North Saskatchewan River faces the same problems of *Cryptosporidium* and *Giardia* in its subwatersheds. Although the City of Edmonton has already taken the necessary steps in treating drinking water at the treatment stage, the underlying issue, however, is that the North Saskatchewan River water sources are highly exposed to pathogens, and farms in the manure producing areas that produce manure greater than 0.6 tonnes per hectare could be at risk. Furthermore, Charrois et al. (2007) studied the samples collected from a total of 20 public utilities during July and September 2004 and demonstrated the presence of *N*-nitrosodimethylamine (NDMA) and two other *N*-nitrosamines (*N*-nitrosopyrrolidine (NMor) and *N*-nitrosomorpholine (NPyr)) in Alberta municipal drinking water distribution systems. As a highly toxic chemical substance, *N*-nitrosodimethylamine (NDMA) may cause an increase in liver tumors and other types of tumors. The chemical standard of N-nitrosamines in Ontario is now regulated at a maximum of 9 ng/L (Ontario Safe Drinking Water Act, 2002-O. Reg. 169/03), while the maximum allowable concentration set in the Guidelines for Canadian Drinking Water Quality is 40 ng/L. In Alberta, water from regulated waterworks systems must meet Health Canada's Guidelines for Canadian Drinking Water Quality under Potable Water Regulations (Alberta Environment and Sustainable Resource Development 2013d). However, Charrois et al. found that concentrations of N-nitrosodimethylamine (NDMA) were up to 100 ng/L, which far exceeded the Guidelines for Canadian Drinking Water Quality as well as the Ontario Drinking Water Quality Standards.

Finally in Sect. 7.6, the impacts of oil sands operations in the Mackenzie River basin were considered. There is controversy as to whether oil sands production is adding contaminants such as PAC into the Athabasca River and its tributaries. Two expert panels have said that there is no danger of degrading the waters of these rivers. Dr. Schindler and coresearchers continue to maintain that the oil sands are indeed an additional source, a position that has now been confirmed by a study from two independent researchers from the University of Toronto. It is also possible that the environmental impacts assessments have been underreporting these contaminants, thus increasing the number of tar sand projects that are approved. It also seems that the Water for Life Strategy that is applied elsewhere in Alberta is either *not applicable* to the Mackenzie River Basin, or that the oil sands producers have some special exemption that allows them to violate Alberta's Water Act.

We can assume that communities in the Mackenzie Basin will also have to produce a Drinking Water Safety Plan, but that Plan is mainly about avoiding pathogens, not trace metals and harmful chemicals. The Water Safety Plans are unlikely to do anything for these long-term threats to health. But in this region the threat is mainly to First Nations communities, which happen to be a Federal government responsibility.

Let us consider an alternative to implementing a Drinking Water Safety Plan. Instead of spending money on a Drinking Water Safety Plan, it might be better to begin a program that encourages all cattle ranches to aim to follow the best management practices guide. Of course in an ideal world, it would be best if the cattle farms themselves were HACCP certified. Then they would deal with the contamination of the source water at the "control point." In this way, waste is decontaminated at the source, before the waste from the ranch is discharged into streams and rivers. This approach may be expensive and may be initially politically unpopular, but the Alberta cattle industry is probably not going to grow, as global beef consumption has continued to decline. With fewer cattle ranches, it may not be as difficult a task. However, to be realistic, it seems unlikely that the cattle farms would be receptive to the idea of HAACP certification. The Alberta meat packing industry is in general HAACP certified, although they too have had problems with *E. coli* outbreaks.

Instead of a Drinking Water Safety Plan, is there an "intervention" at the plant that would definitely enhance water safety? The answer is yes there is: for most water systems (small or large), the addition of a UV unit to the treatment train would make a huge difference in enhancing safety. This can be done very easily in the short term.

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Chapter 8
Water Policy in British Columbia

8.1 Introduction

British Columbia is Canada's third-largest province, with most people located in the lower mainland and the city of Greater Victoria. British Columbia has abundant natural resources and good water quality in some areas that rank among the highest in the world. However, the current laws and regulations could be strengthened to promote resource conservation without discouraging business growth. The water allocation principle of "*first in time, first in right* (FITFIR)" results in an over-allocation of water rights regardless of changing water inventories, and changing inflows and recharge rates for aquifers. The government of British Columbia has now passed the Water Sustainability Act (WSA) of 2014, which will come into force in 2015.

The purpose of this chapter is to assess the progress that British Columbia has made in water management. In the second section, we provide a profile of the water systems and drinking water policy in British Columbia. Since many small water systems in British Columbia are under long-term boil water advisories, in Sect. 8.3, we explore the issues affecting small water systems and two useful measures that might solve these issues. Section 8.4 shows that cattle farming, mining, oil and gas, as well as the forestry and logging industry pose potential hazards to water quality in British Columbia. In Sect. 8.5 we show how wastewater is managed, treated, and discharged into the ocean. In Sect. 8.6, we examine laws affecting watersheds. Section 8.7 is a description of the new WSA, its strengths, and its weaknesses. As this Act does not enhance watershed protection, we state some proposals to reform watersheds in Sect. 8.8. Finally Sect. 8.9 contains some conclusions.

M.H. Dore, *Water Policy in Canada*, Springer Water,
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8.2 A Profile of Water Systems and Drinking Water Policy in British Columbia

8.2.1 A Profile of British Columbia's Water Systems

In British Columbia, roughly 90 % of water systems serve about 10 % of the province's population, while approximately 10 % of drinking water suppliers provide drinking water to around 90 % of British Columbians who live in urban centers (Office of the Ombudsman 2008). As of March 2009, the six health authority districts of BC had identified 4,550 public drinking water systems in British Columbia: 478 in the Fraser Health Authority, 746 in the Vancouver Island Health Authority, 1,114 in the Northern Health Authority, 361 in the Vancouver Coastal Health Authority, and 1,851 in the Interior Health Authority (see Figs. 8.1 and 8.2) (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012). Of those 4,550 systems, 3,328 or 73 % of water systems were serving fewer than 15 connections; 997 or 22 % of water systems served between 15 and 300 connections, and 225 or 5 % of water systems served more than 300 individual

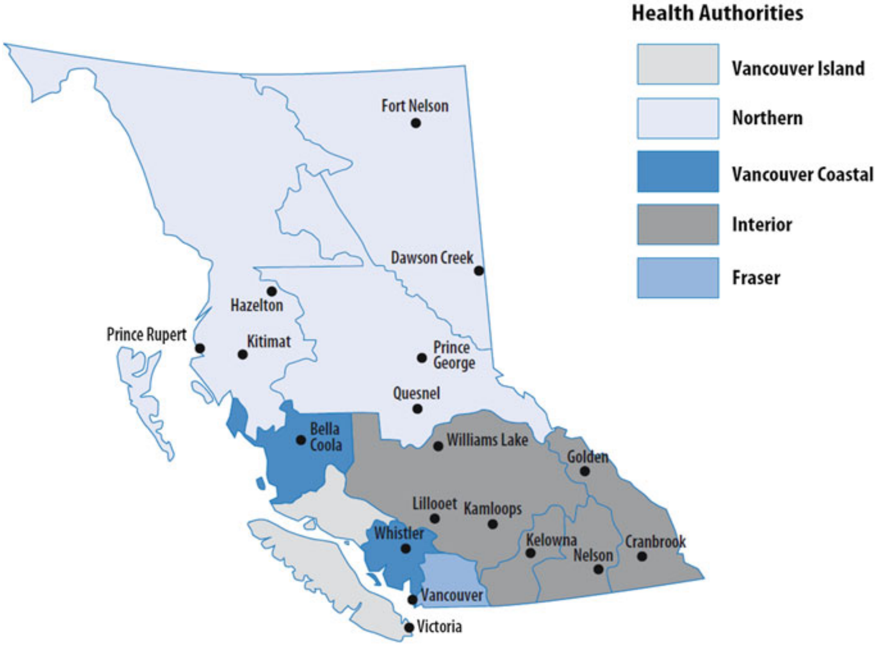

Fig. 8.1 The five health districts that regulate drinking water in BC (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012)

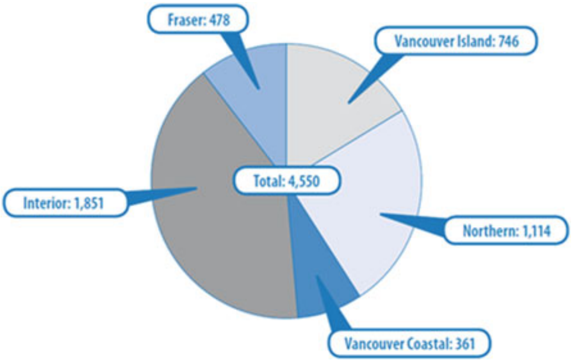

Fig. 8.2 Number of recorded drinking water systems in British Columbia by health authority (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012)

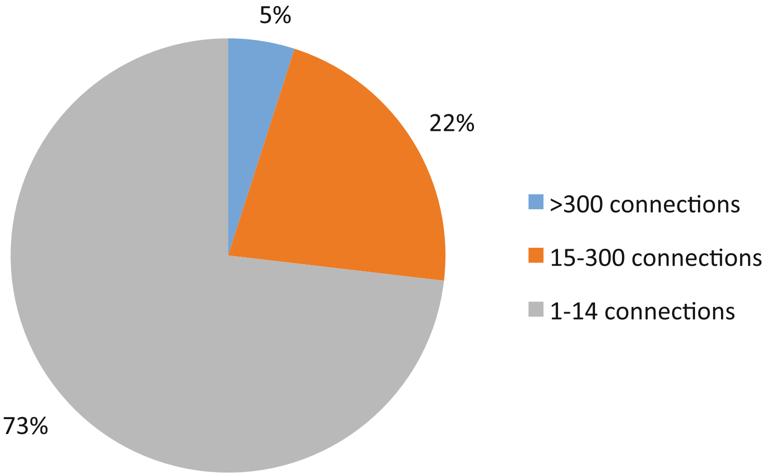

Fig. 8.3 The distribution of public water systems serviced by connections in 2009 (reproduced from the British Columbia Ministry of Health, Office of the Provincial Health Officer 2012)

connections (see Fig. 8.3). Although there is no absolute correlation between the number of connections and the population served, it is usually supposed that systems serving fewer than 15 connections will serve fewer than 500 people/day, and will thus be classified as small water systems according to the British Columbia Ministry of Health (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012). Furthermore, among the public water systems, 90 % relied on surface water sources, which constitute 4,095 of 4,550 water systems, while 10 % relied on groundwater sources (Environment Canada 2011).

The Health Authorities[1] are responsible for surveillance and monitoring of the community water systems to assure the water quality complies with the Drinking Water Protection Act (DWPA) and Drinking Water Protection Regulation (DWPR). Monitoring is carried out by Drinking Water Officers (DWO). Water systems on Federal lands and First Nations reserves are mainly inspected by Environmental Health Officers who are employed by Health Canada (Vancouver Island Health Authority 2014). Furthermore, Health Canada's First Nations and Inuit Health Environmental Health Services program has established a routine process of undertaking assessments of all water supply systems on reserves in First Nations communities (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012).

Each district health authority appoints a Drinking Water Officer and each officer can advise on what treatment technology to adopt, decide if testing for physical and chemical parameters is required and establish the frequency of testing. DWO are also in charge of the enforcement of the so-called "4-3-2-1-0" rule (as explained below). Since the majority of waters systems are supplied by surface water and the main health risks related to surface water in British Columbia are from bacteria, viruses, or parasites, the Guidelines for Canadian Drinking Water Quality (GCDWQ) recommends that most surface water must be filtered in addition to adequate disinfection (Vancouver Island Health Authority 2012). The "4-3-2-1-0" regulatory rule was developed as a simple way to explain the basic GCDWQ to ensure the treatment effectively safeguards against pathogens. The regulatory rule, requires (a) *4*-log (99.99 %) inactivation of viruses and bacteria, (b) *3*-log (99.9 %) removal or inactivation of Giardia and Cryptosporidium, (c) *2* treatment processes—filtration and disinfection—for all surface water or a groundwater under the influence of surface water, (d) less than or equal to *1* Nephelometric turbidity unit (NTU) of turbidity, and (e) *0* total and fecal coliforms and *Escherichia coli* (Vancouver Island Health Authority 2012). Although all the district health authorities have the objective of compliance with the "4-3-2-1-0" rule, their enforcement is uneven, according to a reliable source.

According to the 2011 report, *Progress on the Action Plan for Safe Drinking Water in British Columbia*, a total number of 4,836 inspections of drinking water systems were conducted over two fiscal years (see Fig. 8.4). Based on the results of the inspections, the number of water systems with a hazard rating was 4,077 (see Fig. 8.5). Of these, 2,373 water systems were under low hazard rating, 1,301 water systems were under medium hazard rating, and 403 water systems were under high-hazard rating. In particular, over 60 % of high-hazard ratings for drinking water systems were reported from the Interior Region; this was likely due to inadequate treatment of their source water.

Under the "4-3-2-1-0" rule, water supplies from surface water or a groundwater under the influence of surface water must have two treatment processes, while most

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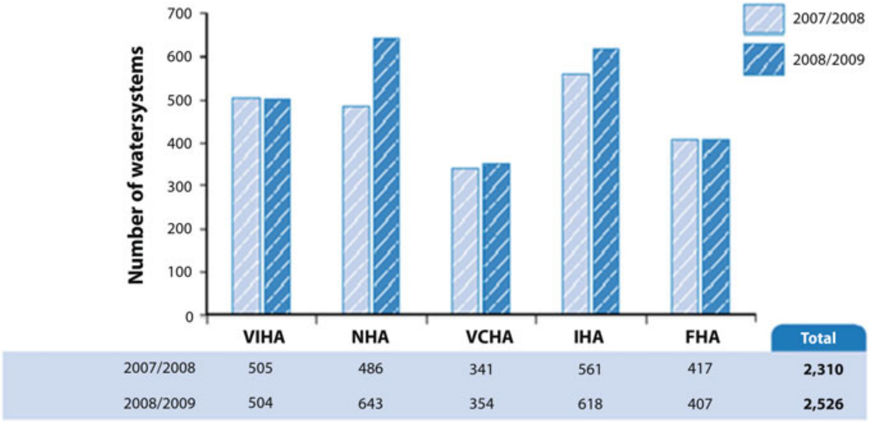
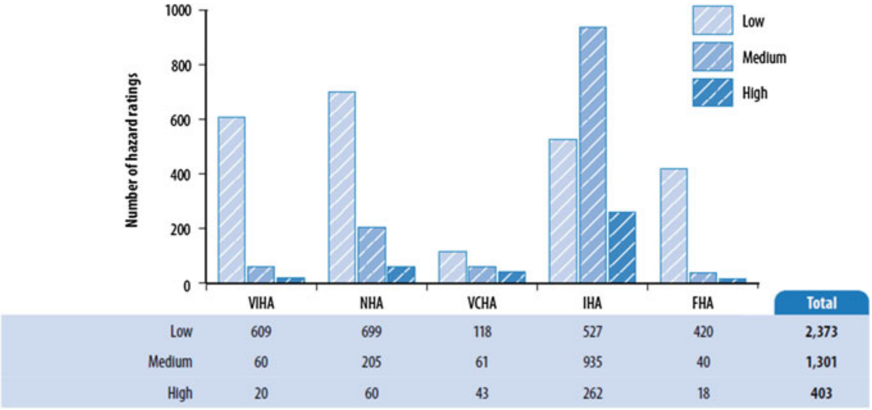
[1] Health Authorities in British Columbia are composed of the Provincial Health Services Authority and the other five district health authorities: Fraser Health, Interior Health, Vancouver Island Health, Northern Health, and Vancouver Costal Health. The Provincial Health Services Authority coordinates the functioning of the other five health authorities.



	VIHA	NHA	VCHA	IHA	FHA	Total
2007/2008	505	486	341	561	417	**2,310**
2008/2009	504	643	354	618	407	**2,526**

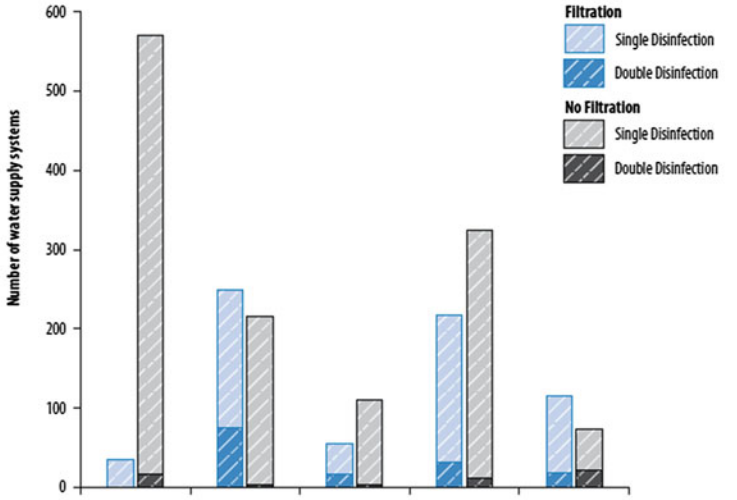
Fig. 8.4 Number of drinking water systems inspected, by health authority (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012)



	VIHA	NHA	VCHA	IHA	FHA	Total
Low	609	699	118	527	420	**2,373**
Medium	60	205	61	935	40	**1,301**
High	20	60	43	262	18	**403**

Fig. 8.5 Hazard ratings for drinking water systems, by health authority as of March 2009 (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012)

water systems supplied by groundwater have no treatment requirement. Filtration is required (a) to remove pathogens, (b) to ensure that disinfection is effective, and (c) to minimize the formation of disinfection byproducts (DBPs) from the use of chlorine or chlorine derivatives. However, as shown in Fig. 8.6, in total, some 1,236 drinking water systems that serve 3,076,743 residents, or approximately 70 % of British Columbia's population of 4,410,000, had only disinfection as of 2009. Moreover, 675 systems that serve 359,118 residents or around 8 % of population in the province had two treatment processes of filtration and disinfection (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012). While some water systems in British Columbia are able to conduct a treatment process



	VIHA	NHA	VCHA	IHA	FHA	Total
Filtration						
Single Disinfection	35	175	39	186	97	**532**
Population	5,065	48,647	23,008	–	160,569	**237,289**
Double Disinfection	–	75	17	32	19	**143**
Population	–	26,394	56,805	–	38,630	**121,829**
No Filtration						
Single Disinfection	554	211	106	313	52	**1,236**
Population	361,218	117,989	1,073,612	–	12,563	**1,565,382**
Double Disinfection	16	4	4	12	21	**57**
Population	447,425	760	1,086	–	1,062,090	**1,511,361**

Fig. 8.6 Number of water supply systems and population served using different levels of treatment, by health authority, as of March 2009 (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012)

with a combination of ultraviolet irradiation and chlorination, filtration is still required for most of them (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012).

8.2.2 *Overview of British Columbia's Drinking Water Policy*

In 2002, the Government of British Columbia released the *Action Plan for Safe Drinking Water in British Columbia*. The *Action Plan* includes "comprehensive legislation and measures to protect drinking water from source to tap by improving standards for monitoring, treatment, reporting and accountability to the public" (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012). The key principles of the *Action Plan* were as follows: (a) the safety of drinking water is a public health issue; (b) source protection is a critical part of drinking water protection; (c) providing safe drinking water requires an integrated approach; (d) all water systems need to be thoroughly assessed to determine risks; (e) proper treatment and water distribution system integrity are important to protect human health; (f) tap water must meet acceptable safety standards and be monitored; (g) small systems require flexibility and safeguards; and (h) safe drinking water should be affordable, with users paying appropriate costs (British Columbia Ministry of Health Planning 2002).

In May 2003, the *DWPA along with the DWPR* came into force, complementing the provincial government's overarching Action Plan for Safe Drinking Water in British Columbia (British Columbia Ministry of Health, Office of the Provincial Health Officer 2007). The Act designated the Ministry of Health as the lead agency for drinking water issues in the province, and the Provincial Health Officer is required to report to the Minister of Health on activities conducted under the Act under Sect. 8.4.1 of the Act (British Columbia Ministry of Health 2014). As of March 2014, three such reports have been released by the Ministry of Health in 2007, 2009, and 2012. In the 2007 report, *Progress on the Action Plan for Safe Drinking Water in British Columbia,* it was stated that (British Columbia Ministry of Health, Office of the Provincial Health Officer 2007):

> The Act and regulation brought a multi-barrier approach to water safety. This approach recognizes that drinking water supplies need to be protected in their entirety: from the source water in the watershed or aquifer, through the treatment and distribution systems, all the way to the consumer's tap. Under this "source-to-tap" approach, protection is achieved as a multi-step process. This process includes gathering information about the system through inspections, assessments, and water monitoring, and then puts barriers in place to stop contaminants from entering the drinking water supply.

The DWPR sets out "requirements for drinking water quality—including treatment, construction and operation of water systems, monitoring, reporting, and public notification in the event that water becomes undrinkable" (British Columbia Ministry of Health 2014). To meet the needs of small water systems in British Columbia, the DWPR was amended in December 2005. It included the following: (a) A small system was redefined as those serving up to 500 people in a 24-h period; (b) the installation of "point-of-use" treatment devices was permitted; (c) discretionary authority is given to DWO to determine certification requirements for small system operators and no requirement for construction permits; (d) small systems that do not provide water for consumption or food preparation were not required to meet the potability requirements; and (e) allowance was made for "flexible" application of the regulation by treating small water systems differently from other systems (British Columbia Ministry of Health 2014). The *Action Plan* and the legislation put in place comprehensive measures, regulations, and accountability structures designed to protect drinking water in British Columbia (British Columbia Ministry of Health 2014).

The GCDWQ set maximum acceptable levels for hundreds of physical, chemical, microbiological, and radiological contaminants; while in British Columbia, the DWPR does not require these maximum acceptable limits except for *E. coli*, total coliform, and fecal coliform bacteria (Office of Ombudsman 2008). As far as

Table 8.1 Comparisons of drinking water regulations between British Columbia, Ontario, Canada, and the World Health Organization (Government of British Columbia 2013; "Ontario Regulation 169/03" 2008; Health Canada 2012 and WHO 2011)

Criterion		British Columbia regulations in force	Ontario regulations (MCL levels where applicable)	Canada guidelines	WHO guidelines
Microbiological	*E. coli* O157	Yes	Yes	Yes	Yes
	Fecal Coliform	Yes	Yes	Yes	Yes
	Giardia	Yes	Yes	0 is desirable	Yes
	Cryptosporidium	Yes	Yes	0 is desirable	Yes
Chemical	Turbidity	Yes: less than 1.0 NTU	Yes: less than 1.0 NTU	Yes: 0.1 NTU	Yes: less than 1.0 NTU
	Specific chemical targets	No official enforceable legislation	Yes: various MCLs for numerous chemicals	Yes: various MCLs for numerous chemicals	Yes: various MCLs for numerous chemicals
	Disinfection by-products	No official enforceable legislation	Yes: various MCLs for numerous chemicals	Yes: various MCLs for numerous chemicals	Yes: various MCLs for numerous chemicals
Algal exudates	Microcystin	No	Yes	Yes	Yes
Taste and odor		No	No	Suggested, no standard	Suggested, no standard
Pharmaceuticals and personal care products		No	No		
Endocrine disrupting substances		No	Yes		
Source water protection	Legislated	Not legally enforceable; guidelines only	Yes: Clean Water Act, 2006	Yes	Some countries use and enforce WHO guidelines
	Enforceable	Not directly	Yes	Only in federal jurisdictions, often indirect	
	Focus on multi-barrier protection	No	Yes	No	

drinking water is concerned British Columbia remains behind Ontario in Canada in controlling the maximum contamination levels (MCLs) as Table 8.1 shows. In other provinces, the GCDWQ typically become legal requirements.

There is no regulation or maximum contaminant level for chemical contaminants such as phosphorous, nitrogen, and lead. However, British Columbia has recommended, but nonenforceable, guidelines which are comparable to the Canada Guidelines. From Table 8.1 it is very clear that British Columbia has no regulations on physical, chemical, Algal Exudates, taste and odor controls, pharmaceuticals and personal care products (PPCPs), and endocrine disrupting substances.

Table 8.2 Waterborne disease reported cases in British Columbia (2001–2012) (British Columbia Centre for Disease control 2010 and 2012)

Year	Total number of reported cases in British Columbia				
	Campylobacter	Cryptosporidium	Shiga toxigenic *E. coli*	Giardia	Salmonella
2001	2,193	173	137	860	763
2002	2,052	130	138	710	789
2003	1,708	161	123	742	659
2004	1,471	100	193	738	747
2005	1,569	124	114	691	739
2006	1,583	129	151	672	704
2007	1,640	88	184	648	792
2008	1,645	115	114	634	922
2009	1,755	86	160	614	952
2010	1,558	55	109	623	1,078
2011	1,722	53	112	617	1,104
2012	1,853	74	136	613	930
Total	20,749	1,288	1,671	8,162	10,179

Microbiological parameters such as *E. coli* O157 can be deadly to human health, as we have seen from the Walkerton Tragedy in May 2000. As a result, many provinces, such as Ontario, have taken strong measures to protect both source waters and their drinking water from *E. coli* which is a bacterium. *Giardia* and *Cryptosporidium* are protozoan parasites that can escape into waterbodies through a multiplicity of ways, including runoffs, municipal sewage effluents, and fecal matter from cattle grazing. In British Columbia, although "zero *E. coli*" has been regulated under the "4-3-2-1-0" rule, the enforcement of this rule is uneven across the distinct health authorities, and so there have been a number of waterborne disease outbreaks. From 2001 to 2012, there were 20,749 reported cases and the number of reported *Giardia* and Shiga toxigenic *E. coli* cases were 8162 and 1671, respectively (see Table 8.2) (British Columbia Centre for Disease control 2010 and 2012). In addition to Cryptosporidium, all the waterborne disease infection rates shown in Fig. 8.7 far exceed the Canadian infection rates in recent years. It should be noted that British Columbia's Salmonella infection rate has significantly increased since 2006, while it declined slightly in 2012.

The fact that groundwater is not regulated may cause a potential problem unless it is well-known that a particular groundwater source is of high quality. But in general, the DWO have wide discretion on which groundwater sources pose a potential threat.[2] Testing for physical and chemical parameters is not mandatory,

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[2] The groundwater is not required to be treated if it is well known that the groundwater is of high quality.

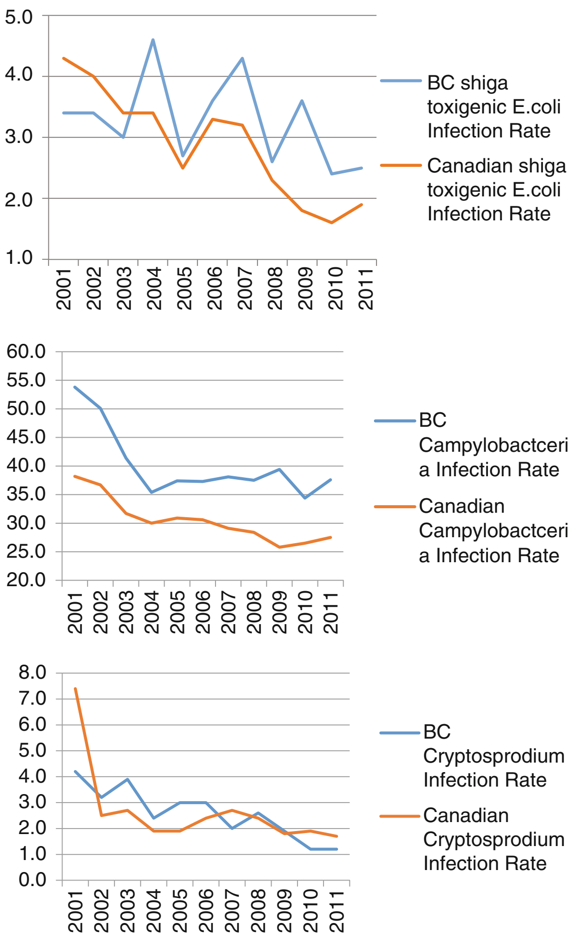
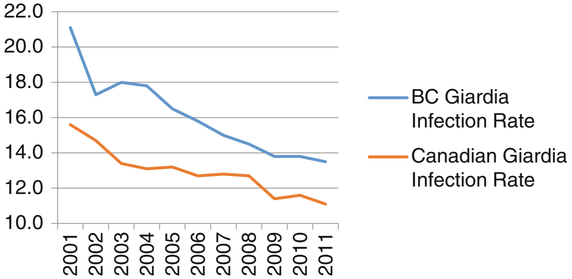


Fig. 8.7 Waterborne disease infection rates by year, 2001–2011 (rate per 100,000 population) (British Columbia Centre for Disease control 2010 and 2012)

and groundwater drawn from private wells or a common aquifer is not regulated, although under the new WSA of 2014, large-scale groundwater withdrawals will require permits. Not regulating the quality of groundwater could compromise the effectiveness of the DWPA, as groundwater could become contaminated if agricultural fertilizers, nitrates, or cattle fecal material with Giardia entered into the aquifers.



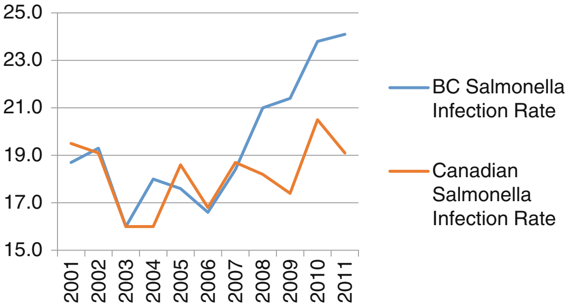


Fig. 8.7 (continued)

8.3 Small Water Systems

8.3.1 Issues Affecting Small Water Systems

The Province of British Columbia is divided into 28 “Regional districts” (KnowBC 2014). Regional districts provide rural residents with a form of local government, while also representing municipal residents on regional issues. Regional districts enable municipalities and electoral areas to work together to provide local services with the exception of roads and policing. Unlike municipalities, regional districts are required to match the benefits and costs of its services to the people who benefit from the services. Costs are recovered by taxing those who benefit from the services —in other words, residents pay for what they get. Rural regional districts are home to approximately 12 % of British Columbia’s population.

There are some 5,000 small water systems but only about 150 of them are owned and operated by regional districts. Typically, the bigger municipalities within the regional districts run and operate water systems. But the vast majority of small water systems are run by their respective communities outside the control and influence of the regional district, and are thus unable to obtain finance and grants for their water systems. A regional district will take over a water system only if it considers it financially viable, and reasonably well maintained; but a water system run by the regional municipality would obtain control over water rates, something that many communities do not wish to allow; they prefer low water rates even it means inferior water quality, as long as it meets the bare minimum of the provincial water regulations; they may even agree to be on a boil water advisory.[3]

In the interior of British Columbia, there are many residents who claim that they cannot afford to pay $14,000 per household to cover the cost of a new central drinking water treatment plant for their community. Their argument is that if the province wishes to "impose" the rather expensive 4-3-2-1-0 regulatory rule, then the province should cover the capital cost of the new plant. Otherwise, they are content to go on using untreated surface water even under a long-term BWA. In other words, they will take their chances with that raw untreated surface water. But there is potential danger here: If one day there is a major Guardia or a Cryptosporidium outbreak, it is the province that will get the blame.

Thus it is clear that there is significant opposition to the government's attempt to bring properly treated drinking water to small rural communities as it would involve a one-time capital cost that some households (both rich and poor) find unacceptable. This is a classic "free-rider" problem, well-known in public sector economics. Is there a solution for the small water systems in BC?

It is instructive to report on how the City of Guelph in Ontario approached a similar problem. The problem was the additional cost of replacing old pipes with new lead-free pipes. The citizens were unwilling to pay for new lead-free pipes, and so the City of Guelph replaced the pipes anyway and added an amortized cost to the property taxes.

It is clear that the Government of British Columbia cannot afford a possible scandal for disease outbreaks. Sooner or later they will have to impose a solution, mostly probably not with any outright grant to so many small systems but by law: the regional districts could be compelled to start a program of installing proper treatment and pass on the cost in the form of some increase in property taxes, suitably amortized. It is possible that such a move would be criticized as being "undemocratic"; but the ultimate guarantor of health is the provincial government. If the people can afford to own their own homes, *and* also pay property taxes, they will just have to pay a bit more, sometime in the near future.

In Ontario, after Walkerton, each community must pay the full cost for water. When a community cannot afford a water system or is in trouble, the province of Ontario sends in the Ontario Clean Water Agency (OCWA, a provincial crown corporation) to take over and manage the system. OCWA will then upgrade the water system, and charge for managing it for a fixed time period. At the end of that period, the community has the opportunity to either rehire OCWA or get some other agency to manage it. But the law is that the community *must pay the full cost of water*, including the planning cost of some future upgrades. This is exactly what happened in Walkerton. In Ontario, no community has the option to remain on an indefinite boil water advisory.

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[3] The source is from personal email communication with a director of Small Water Users Association of British Columbia.

A large number of long-term (greater than 1 year) boil water advisories in British Columbia are mainly due to inadequate treatment. Ensuring that people in small communities have access to high-quality drinking water has been a challenge in British Columbia for a long time. Apart from lack of finance, the other major problems are:

Reliability—government legislation does not require operators of small water systems (serving up to 500 people) to take any training courses or be certified. Most small water systems operators are very poorly paid and there is a high turnover.

Sustainability—very few small water systems do any long-range financial or other planning. Many have poor or inadequate governance structures, characterized by high turnover and shoddy recordkeeping.

Insurability—most small water systems cannot afford the cost of liability insurance. Users of systems that are user-owned and that have untreated surface water may be personally liable in a lawsuit arising from the illness or death of a visitor due to waterborne pathogens, and yet most do not realize this and/or do not think there is any risk.

Enforceability—DWO have the dual role of offering helpful advice to small water systems and also of enforcing regulations—these dual roles are incompatible.

8.3.2 Boil Water Advisories

A boil water advisory is generally issued when there is a reason to suspect pathogen contamination, such as (a) unacceptable levels of microbiological contamination detected in drinking water supply, (b) inadequate disinfection or disinfectant residual, (c) untreated surface water, and (d) unacceptable levels of *E. coli*, fecal coliform, or total coliform bacteria counts under the DWPR.

As of February 2014, there were a total of 569 boil water advisories affecting approximately 13 % of water supply systems in the province, and the majority of the BWAs were in small water systems (see Table 8.3). Of these advisories, 150 were in effect for more than a decade, and nearly half of these long-term boil water advisories were reported by the Interior Health Authority. Many boil water advisories are of long standing, indicating zero or inadequate water treatment. For example, in the Interior Region a small water system at Silver Creek has been under boil water advisory for 24 years as of 2014 due to inadequate treatment. One reason these advisories last for a number of years is because "the regional health authorities have not taken sufficient steps to bring systems on long-standing advisories into compliance with the DWPA and its Regulation" according to the Ombudsman's special report (Office of the Ombudsperson 2008). The Health Authorities made a commitment to the Ombudsman to reduce the advisories by 10 % by the end of 2011–2012 fiscal year. We collected the data on boil water advisories from the websites of each district health authority in August 2013 and in February 2014, respectively. As shown in Fig. 8.8, the number of boil water advisories has increased since 2001, while it declined by 13 % in 2013 compared to 2009. In 2014, the number of boil water advisories was on the rise again.

Table 8.3 Boil water advisories in British Columbia health districts as of February 2014

	Northern health	Interior health	Vancouver Island health authority	Vancouver coastal health	Fraser health	Total
0–1 year	7	65	6	0	1	79
>1–5 year	22	132	8	20	1	183
>5–10 year	8	114	10	24	1	157
>10–20 year	6	102	5	7	2	122
>20	2	20	0	4	2	28
Total	45	433	29	55	7	569

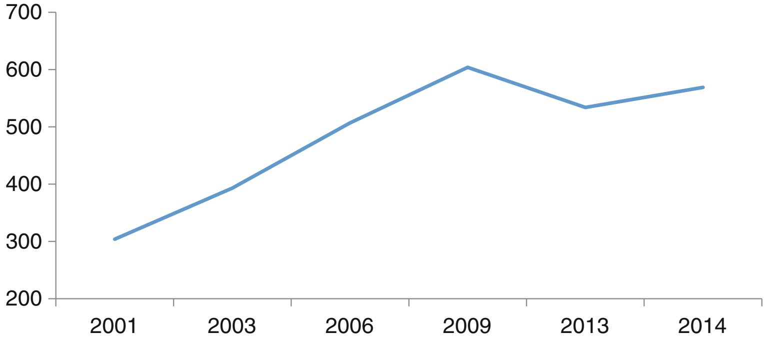


Fig. 8.8 The number of boil water advisories in British Columbia (2001–2014)

British Columbia has a considerably greater incidence of boil water advisories per population than elsewhere in Canada except for First Nations and Newfoundland and Labrador jurisdictions (Statistics Canada 2014). Boil water advisories are supposed to be temporary fixes, but in cases where a quality or safety problem is not resolved, it may last for weeks, months, or even years. In general, small water systems are subject to long-term boil water advisories, while the short-term boil water advisories are always on larger water systems. In 2006, only one large water system (defined as those serving more than 500 people) was under a boil water advisory (British Columbia Ministry of Health, Office of the Provincial Health Officer 2007).

In the 2011 report, *Progress on the Action Plan for Safe Drinking Water in British Columbia*, the provincial health officer stated (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012):

> After the Drinking Water Protection Act was promulgated in May 2003, DWO began re-evaluating programs that encourage public awareness of water quality problems. As public notification procedures have changed, the value of tracking the number of boil water advisories as a way of assessing the overall performance of drinking water programs has become questionable.
>
> The proportion of systems under advisories does not reflect the proportion of the population affected. Most of the long-term advisories in the province are on small public water supply systems with 1–300 connections. These systems are estimated to serve less than 1 % of the

> total population in British Columbia. Care needs to be taken to ensure that the focus on reducing the number of boil water advisories does not undermine the fundamental purpose of an advisory, which is to inform specific communities about concerns related to the quality of their drinking water. Further, one of the primary reasons that the number of advisories and notices increases over time is the discovery of existing, but previously unpermitted, small water systems with inadequate treatment. The people served by these systems have not experienced a decrease in water quality, but are now being formally notified of the risk to their health from drinking their water.

Although “less than 1 % of the total population in British Columbia [is] served by small water systems”, this population can still be affected by poor quality of drinking water which may be harmful to their health. According to the data from Boettger (2005), a Provincial Drinking Water Officer, most of the waterborne disease outbreaks occurred in small communities of the Interior Region during the period 1980–2004 (see Table 8.4). While “the number of boil water advisories as a way of assessing the overall performance of drinking water programs has become questionable since the public notification procedures have changed,” the boil water advisories still serve as a signal of unsafe drinking water to warn the public. The government needs to demonstrate that it is taking effective measures to improve the treatment technology of the small water systems and bring systems on long-standing advisories into compliance with the DWPA and its Regulation. There are two measures which may be effective: one is to reduce the number of these small water systems through amalgamation and another is to increase the application of point of entry and point of use (POE/POU) water treatment technology, especially for remote households.

Table 8.4 Waterborne disease outbreaks in British Columbia communities (1980–2004) (Boettger 2005)

Year	Community	Health authority	Year	Community	Health authority
1980	Nakusp	Interior	1991	Barriere	Interior
1981	100 Mile House	Interior	1991[a]	Granisle	Northern
1982	Kimberley	Interior	1991[a]	Fort Fraser	Northern
1984	Chilliwack	Fraser	1992	Kaslo	Interior
1985	Creston	Interior	1993	Ski hill near Fernie	Interior
1986	Penticton	Interior	1995	Victoria	Vancouver Island
1986	Penticton	Interior	1995	Revelstoke	Interior
1987	Black Mountain	Interior	1996	Cranbrook	Interior
1987	Kamloops	Interior	1996	Kelowna	Interior
1998	Near Lytton	Interior	1996	Valemount	Northern
1990	Kitimat	Northern	1997	Princeton	Interior
1990	Creston	Interior	1998	Camp Malibu	Interior
1990	Fernie	Interior	1998	Chilliwack	Fraser
1990	West Trail/Rossland	Interior	2004	Hagensborg	Vancouver Island
1990	Matsqui	Fraser			

[a] Suspected outbreaks

8.3.3 Application of Point of Entry and Point of Use (POE/POU) Water Treatment Technology

The point of entry and point of use (POE/POU) water treatment Technology is primarily aimed at small water systems, especially for those having less than 100 connections. Many treatment technologies used in POE/POU treatment devices are the same as the treatment technologies that are applied in centralized treatment plants. The difference is that the central treatment plants treat all water distributed to the consumer, while POE/POU devices are designed to treat only a portion of the total flow delivered by the water supply system (British Columbia Ministry of Health 2007). The POE and POU either treats all the water before entering the house (POE) or treats the water where needed such as kitchens (POU) (see Fig. 8.9). Since POE/POU treatment systems are able to meet treatment requirements at an affordable cost, they become an alternative to conventional centralized water treatment systems (British Columbia Ministry of Health 2007 and British Columbia Ministry of Health, Health Protection Branch 2013). In addition, amendments to the DWPR in 2005 provided the opportunity for small water systems to choose POE and POU treatment devices to treat drinking water in very small communities (British Columbia Ministry of Health, Office of the Provincial Health Officer 2012). That is, if a household in a small community has a point of entry (POE) or point of use (POU) treatment system that makes the water potable, it is then exempt from any other requirements that apply to the rest of the community that relies on a communal treatment plant with a distribution system.

The great advantage of POE/POU is that it can relieve the funding shortage of small community water systems. To compare the cost of POE/POU with centralized treatment, an approach has been created to determine the "cross-over" point at which the unit cost of water treated by POE/POU would be the same as the unit cost of water treated by a centralized treatment approach. As illustrated in Fig. 8.10, for example, if the number of households is below 73, the unit cost of water treated by using the POU reverse osmosis (RO) device is less than the unit cost of water treated by a centralized treatment. If the number of households is between 73 and 97, it is more economical to

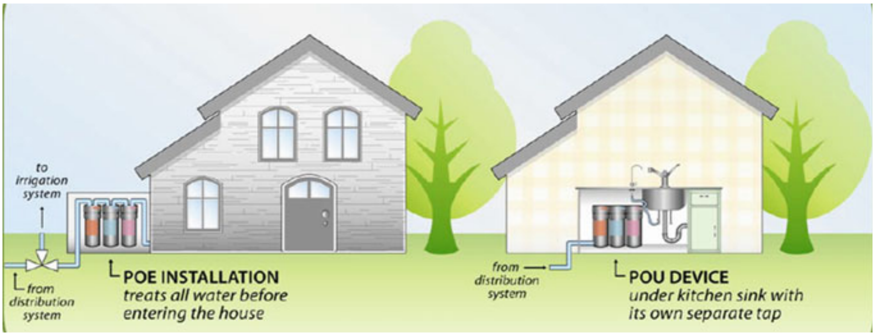


Fig. 8.9 POE and POU devices (British Columbia Ministry of Health, Health Protection Branch 2013)

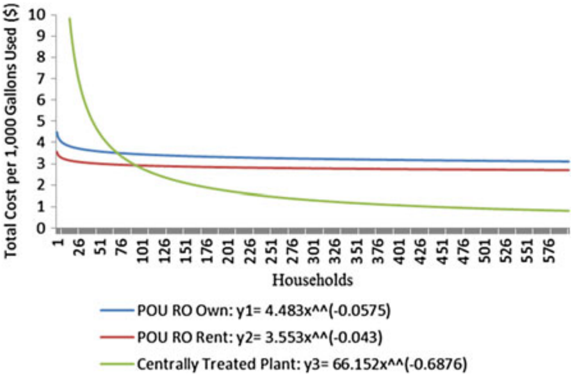


Fig. 8.10 A cost analysis of POU treatment using RO compared with Centralized Treatment (Kempic and Khera 2003, as cited in British Columbia Ministry of Health 2007)

rent a POU RO treatment device. When the number of households exceeds 97, the cost of water treated by using POU RO (buy or rent) would be higher than the unit cost of water treated by a centralized treatment approach.

In British Columbia, several small communities have relied and are continuing to rely on POU/POE systems. There are two case studies on the use of POE/POU treatment technology in these small communities. The first case study is a small water community of 14 houses on the east shore of Kootenay Lake. The community installed POE treatment devices on each house in place of central treatment with the approval of the Interior Health Authority in 2002. Each POE treatment device consisted of: (a) A back-washable sediment (turbidity) filter (about 30 μ) plus a storage tank, (b) 10 and 5 μ cartridge filters, (c) a Trojan Ultraviolet (UV) lamp with automatic shutoff and alarm in the event of malfunction. The total cost was about $2,800 per household. The Drinking Water Officer tests the water sample at regular times and the results indicate that there has never been a sample test failure (British Columbia Ministry of Health 2007).

Another case study is a small water system of 36 connections located on the east Shore of Harrison Lake near Harrison Hot Springs. Due to being under a boil water advisory, the small water system asked each household to install its own POE treatment device. Eventually, 26 of 36 houses have installed treatment devices that include a 5 μ cartridge filter followed by a Trojan UV unit. The total cost was approximately $1300 per household. Although the entire water system is still under a boil advisory from Fraser Health Authority, only the 10 users who did not choose the POE treatment are required to boil their water (British Columbia Ministry of Health 2007).

8.4 Potential Hazards to Drinking Water in British Columbia

In British Columbia, the major threats to water quality are: Cattle farming, mining, oil and gas, as well as the forestry and logging industry. We consider each in turn.

8.4.1 Cattle Farming

British Columbia has 540,000 cattle, just over 4 % of Canada's cattle population (Statistics Canada 2014). A large concentration of them is located in southern and central British Columbia (See Fig. 8.11). Cattle are known to be a source of pathogens like *Cryptosporidium* and *Giardia*. An important zoonotic disease, *Giardiasis*, is caused by Giardia, which is one of the most commonly identified intestinal pathogens in humans and animals in the world (Olson et al. 1997).

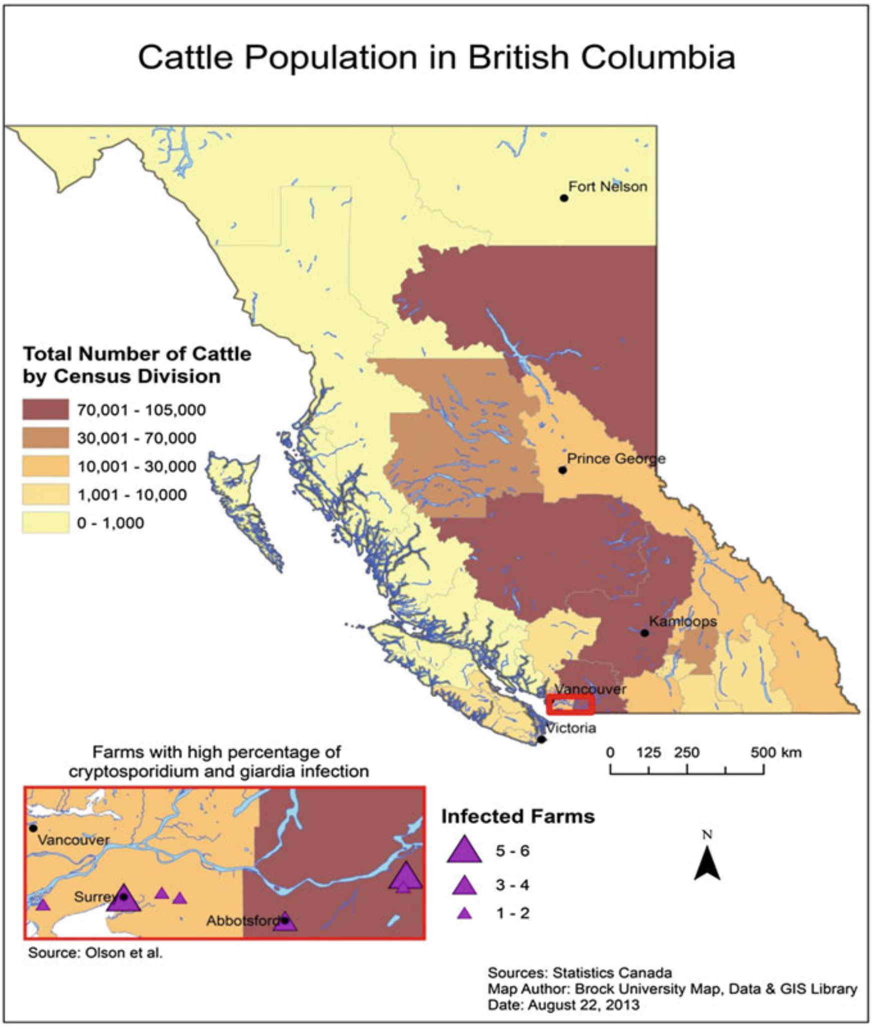


Fig. 8.11 The density of cattle in British Columbia and the farms with a high percentage of *Cryptosporidium* and *Giardia* infection

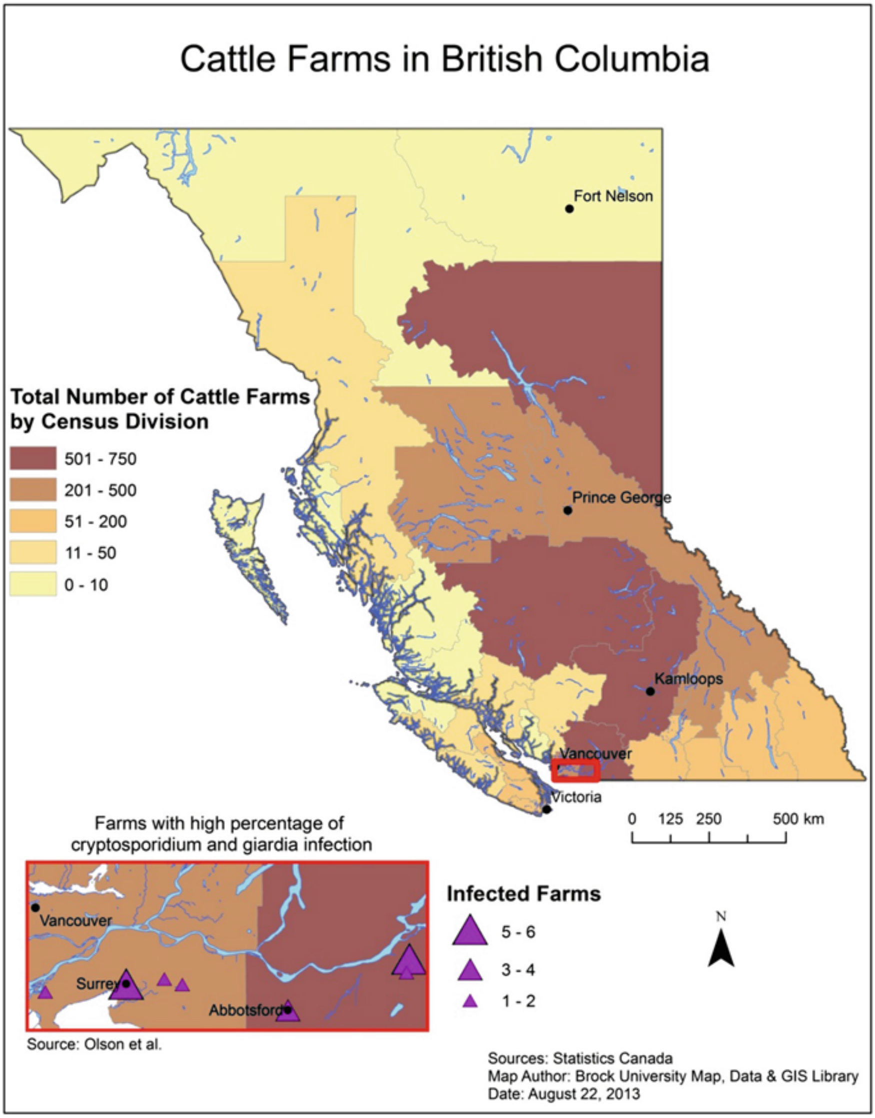


Fig. 8.12 The total number of cattle farms in British Columbia and the farms with a high percentage of Cryptosporidium and Giardia infection

In addition, *Cryptosporidium parvum* has been an important cause of diarrhea among dairy calves (Xiao 1994). Whether cattle are in feedlots or whether they are grazing in the fields, the chances are that the pathogens the cattle carry eventually end up in groundwater supplies.

In 1996, a study was undertaken to assess the prevalence of Giardia and Cryptosporidium infections in dairy calves. Olson et al. 1997 examined fresh fecal samples collected from 386 calves in 20 farms located in the lower Fraser river valley (see Figs. 8.11 and 8.12) and found the presence of Giardia *intestinalis* in all 20 farms, with site prevalence varying from 50 to 100 % and an overall prevalence of 73 %. They further found that *Cryptosporidium parvum* was identified in 16 of 20 farms with an overall prevalence of 15 % and Cryptosporidium *muris* was demonstrated to exist in 5 of 20 farms with an overall prevalence of 2 %.

In 1998, another study was conducted to determine the prevalence of Giardia and Cryptosporidium spp. in beef calves (McAllister et al. 2005). A total of 193 fecal samples were collected from 10 farms representing the 4 watersheds in southeastern British Columbia (see Fig. 8.13). McAllister et al. found the overall prevalence of Giardia and Cryptosporidium spp. in beef calves was 36 and 13 %, respectively.

In British Columbia, there were 1,288 reported Cryptosporidium cases and 8,162 reported Giardia cases in recent years. Contamination of water by dairy operations or livestock operations could be a potential source of human infection. It is clear that enhancement of cattle husbandry and manure management practices could reduce the concentration of these microbiological contaminants in ground and surface water (Budu-Amoako et. al. 2012). Olson et al. pointed out that *fenbendazole* is highly effective in the treatment of giardiasis in dairy calves. In addition, McAllister et al. found that keeping cattle away from surface water during periods of high rate of fecal shedding of *Cryptosporidium parvum* oocysts in the cattle herds may reduce watershed contamination.

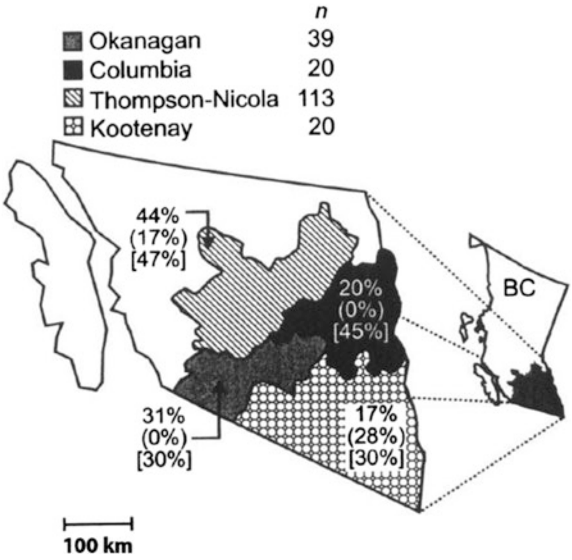


Fig. 8.13 Prevalence of Giardia and Cryptosporidium spp. infections among beef calves in Southeastern British Columbia

8.4.2 Oil and Gas Industry

8.4.2.1 Fracking: Inefficient and Wasteful Use of Freshwater in the Oil and Gas Industry

In British Columbia, the oil and gas industry is regulated by British Columbia Oil and Gas CommissionBritish Columbia Oil and Gas Commission (the "Commission") and its activity has been increasing for the past decade with new drilling techniques known as fracking in which large quantities of water along with chemicals and grained sand are injected at high pressure into the ground to shatter the rock containing oil and gas and force it out of the ground (British Columbia Oil and Gas Commission 2010 and Gage 2010, August 18). Currently, fracking has been one of the main uses for water, especially for the natural gas industry in British Columbia.

Shale gas is natural gas stored in very fine-grained sedimentary rocks such as shale (Canadian Association of Petroleum Producers (CAPP), n.d.). The fracking technology is commonly applied to shale gas extraction, which requires large volumes of water; once used, this water cannot be returned to freshwater systems (Campbell and Horne 2011). The shift to develop shale gas began recently in British Columbia since it is abundant and relatively inexpensive to produce (Campbell and Horne 2011). The development of shale gas extraction in British Columbia has exacerbated concerns of environmental impacts, especially for water. Yet, to date there has been no comprehensive investment in research and monitoring of environmental impacts, and data is limited or not available to the public (Council of Canadian Academies 2014). A new report released in May 2014 focusing on potential environmental impacts of shale gas development in Canada was prepared by an expert panel from the Council of Canadian Academies commissioned by Environment Canada. This report examined several issues of concern regarding potential impacts on surface water and groundwater. The report acknowledges that "…impacts on water raise the greatest environmental concern by shale gas development" (Council of Canadian Academies 2014). According to the expert panel:

> The greatest threat to groundwater is gas leakage from wells. While an area's natural assimilation capacity may limit the impacts of such leakage, this capacity varies. The potential impacts of leaking wells are not being systematically monitored, and predictions remain unreliable. Potable groundwater can also be at risk if pathways for the migration of gases, and possibly saline fluids and fracturing chemicals, exist deep underground.

The Panel further noted that "shale gas promises significant economic benefits, but these must be weighed against possible adverse impacts on people and ecosystems" and in the future, "well-targeted science is required to ensure a better understanding of the environmental impacts of shale gas development. This requires ongoing research and monitoring to gather and evaluate data, and draft effective regulations" (Council of Canadian Academies 2014).

According to the 2010 report of the British Columbia Oil and Gas Commission titled “Oil and Gas Water Use in British Columbia,” oil and gas operations made up only 1 % of the total water licensed in British Columbia by the end of 2009. The report further stated that “a preliminary look at actual volumes drawn and maximum approved shows use rates of less than 5 %.” However, only 4 % of water license holders reported usage for this purpose. The actual use of water in the oil and gas industry is likely to be far in excess of the reported number, since water overuse has been a common phenomenon in the industries. In a 2010 article posted by West Coast Environmental Laws, *Oil and Gas Commission gets a failing grade for water regulation*, Gage (2010, August 18), a West Coast Environmental Law Staff Lawyer, argued that “while 99 % of the oil and gas industry’s water use occurs in Peace River Country, the [Commission’s] 2010 report merely compares the industry’s water use against province-wide usage.” Hence, we do not know how badly water use in the oil and gas industry impacts water in the Peace River.

What is the Peace River status regarding water flows? In the Ministry of Environment’s 2010 information bulletin, *Stream flow and Water Supply Conditions*, the Minister Barry Penner stated:

> In Northern B.C., river levels are well below normal. The Peace region is classified as Drought Level 3 (very dry conditions) and is expected to reach Drought Level 4 (extremely dry conditions). The Skeena and Nass region is expected to remain at Drought Level 3 throughout the summer … Potential for serious effects on fish and aquatic organisms due to low stream flows, and water supply shortages (including groundwater aquifers) are highly probable. Water conservation is urged. Water restrictions at the local level should be considered where appropriate, and drought management plans should be reviewed and implemented.

However, in the summer of 2011, British Columbia Oil and Gas Commission issued 20-year-term water licenses to Talisman Energy and Cambrian Energy without any public consultation process, and they were the first of dozens of such licenses to be approved (Parfitt and Quirk 2012). Each company was permitted to withdraw 7.3 million m^3 of water per year which is equivalent to 2,920 Olympic swimming pools. Recently, three environmental groups filed a lawsuit against the British Columbia Oil and Gas CommissionBritish Columbia Oil and Gas Commission and the natural gas company Encana over the use of water from British Columbia’s lakes and rivers. They pointed out that “Encana proceeded with the fracking process to extract natural gas from underground reserves; it drew 880 Olympic swimming pools worth of water over 3 years from the Kiskatinaw River, which supplies drinking water to the city of Dawson Creek” (“B.C. Oil and Gas Commission accused of violating Water Act” 2013, November 13).

Fracking does not only use large quantities of water, but it also contaminates the drinking water sources. It should be noted that fracking results in a large quantity of return wastewater which includes potentially toxic substances such as diesel fuel (which contains benzene, ethylbenzene, toluene, xylene, and napththalene), 2-butoxyethanol, polycyclic aromatic hydrocarbons, methanol, formaldehyde, ethylene, glycol, glycol ethers, hydrocholoric acid, and sodium hydroxide, and is typically contaminated with the various minerals and other materials it has come into contact with below ground, along with traces of the chemicals used in the fracking process as well as some of the fracking sand (Parfitt and Quirk 2012). All fracking return water is used for further fracking, or is disposed of by injection into deep subsurface formations, since in British Columbia, produced water and fracking return water cannot be discharged into surface waters and near surface aquifers that are used for potable water supply. Contamination of water tables and groundwater aquifers due to fracking has been a concern, and the full impact of fracking on water contamination is unknown. “People who live near gas drilling and fracking are worried about their water. They fear contamination, potential shortages, and what further gas development will do to the environment,” Eoin Madden with the Wilderness Committee said. “The bottom line is that we need to ensure that B.C.’s water is protected for people and the environment” (The Canadian Press and the CBC: “B.C. Oil and Gas Commission accused of violating Water Act” 2013, November 13, 2013). Some jurisdictions in Canada have established moratoria on the fracking technique until the full impacts on water contamination becomes known and the government is able to ensure that water is adequately protected. However, in British Columbia, currently much of the water used by the fracking industry is obtained by getting free permits authorized by the Oil and Gas Commission under Sect. 8.8, Water Act (Parfitt and Quirk 2012). So far, fracking has not been regulated in British Columbia.

There is a further danger that extensive fracking could trigger earthquakes, as the experience of Oklahoma and Arkansas show. A seismologist working in Arkansas reported recent research showing that 98 % of the recent earthquakes occurred within 6 km of one of three waste disposal wells after the start of injection of wastewater at those gas wells. This close spatial and temporal correlation supports the hypothesis that the recent increase in earthquake activity is caused by fluid injection at the waste disposal wells (Horton 2012). This link between earthquakes and injection of wastewater from fracking operations has been confirmed in Oklahoma in a recent issue of the journal “Science” (Keranen et al. 2014).

8.4.2.2 Oil Pipelines Carrying Alberta Oil: Potential Threats to Water in British Columbia

According to information obtained by CBC News (2013, October 28), British Columbia had the highest number of reported pipeline safety incidents for the past decade in Canada. A total number of 279 incidents involving federally-regulated pipelines such as small leaks, large oil spills, and gas ruptures took place in British Columbia between 2000 and 2012 based on the data provided by the National Energy Board (The CBC: “B.C. home of most pipeline safety incidents since 2000” 2013, October 28). This shows that Federal and provincial regulations and laws have failed to prevent pipeline spills and leaks.

These pipeline safety incidents, oil spills, and leaks have significant negative impacts on water. For example, in August 2000, the Taylor-to-Kamloops pipeline spilled 6,200 barrels of crude oil into the Pine River, which flows into the Peace River in Northeastern British Columbia (Peace River Block Daily News and the

Canadian Press: “Oil spilled from a burst pipeline into the Pine River may reach Chetwynd today” 2000, August 2). The spill, reported to be 21 km long, moved toward Chetwynd. While the spill occurred about 65 km upstream of the town of Chetwynd, the town’s water supply was contaminated. Charlie Lasser, the Mayor of Chetwynd said “the town’s long-term water supply could be threatened.” The river used to be the only source of drinking water in Chetwynd. In addition, many groundwater wells near the river were contaminated and people had to stop using them for a number of years. Although the Pembina Pipeline Corporation spent over $30 million to clean up the spill, only 20 % of the spilled crude oil was removed. In 2001, the Pine River was considered to be “dead.”

By 2018, a new oil Pipeline known as Enbridge Northern Gateway Pipeline project could be in operation, which includes two 1,170 km long pipelines from the tar sands in Alberta to the coast at Kitimat (West Coast Environmental Law 2009). The pipeline will cross over 1,000 streams and rivers, including the headwaters of the Fraser River (crossing the Stuart, Endako and Salmon Rivers) and the headwaters of the Skeena River (crossing the Morice and Bulkley watersheds) (see Fig. 8.14). The project poses a potential threat to these streams and rivers as well as the First Nations community living downstream. Once the pipeline is operational, communities downstream of the pipeline crossings will be at risk of spills. Since the toxic effects of oil spills and leaks can be devastating for rivers and streams and ecosystems, we can expect death or disease of fish, aquatic insects, birds, and other wildlife, and contamination of water supplies (West Coast Environmental Law 2009). The toxicity can linger in the environment for many years. For example,

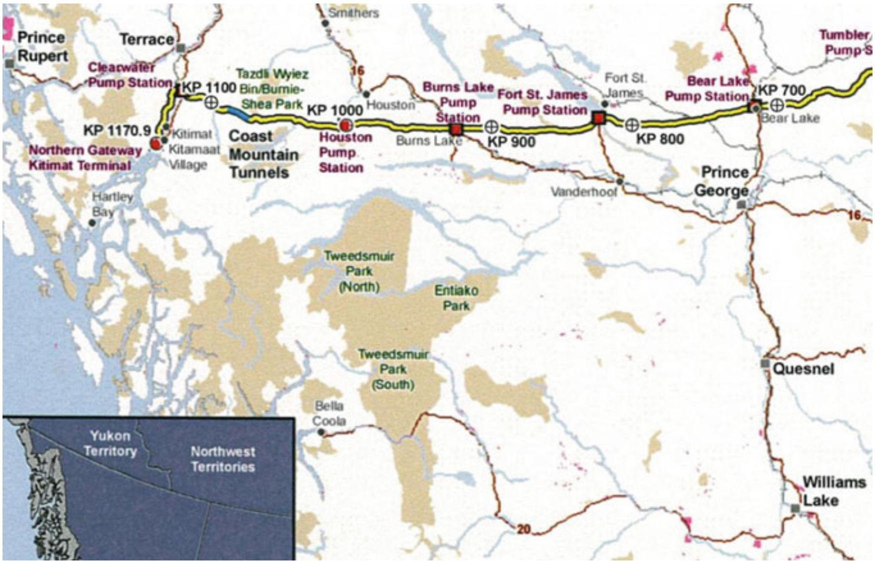


Fig. 8.14 Map of the Enbridge Northern Gateway Pipeline Project (West Coast Environmental Law 2009)

although 25 years have passed, the Alaska coast still has high concentrations of oil on the beaches and in the ground due to the massive oil spill that occurred with the Exxon-Valdez disaster in 1989. Furthermore, river water is likely to take the toxins and contaminants into the ground, mixing with groundwater contained in aquifers (Stanford et al. 2005). In addition, the construction phase of the project will probably release huge amounts of sediment into streams and rivers.

If and when it is built, the proposed pipeline will transport 525,000 barrels of oil per day to the ocean for export, and import 193,000 barrels of condensate, which contains a number of chemicals known to cause cancer. So after a moratorium of 48 years, crude oil tanker traffic in British Columbia's fragile inland waters could restart (West Coast Environmental Law 2009). But with the growth of domestic petroleum production in the US, demand conditions could change worldwide.

According to Enbridge's Corporate Social Responsibility Report (2008), its pipelines had an average of 67 oil spills each year between 2003 and 2007. Moreover, in 2010, an Enbridge pipeline spilled 3.3 million liters of oil into Michigan's Kalamazoo River, which is the largest on-land spill in the US (Max Paris Environmental Unit 2013, September 6). It is not surprising that US Regulators rejected Enbridge's initial proposal to restart the pipeline as they felt the company had not taken adequate steps to evaluate the threats due to the spill. The company was still cleaning up in 2013 and learning lessons about the way diluted bitumen behaves in freshwater (Max Paris Environmental Unit 2013, September 6). Based on the above facts, it seems doubtful if the company has the capacity to take responsibility for the safety of the proposed oil pipeline project.

In June 2014, the Federal government approved the construction of the pipeline, subject to many conditions. However, a major decision of the Supreme Court of Canada has re-affirmed the rights of First Nations to their traditional lands, and many First Nations communities have started legal proceedings to stop this project from going ahead. It could take years before this pipeline project goes ahead, if at all.

8.4.3 Mining

Until recently, groundwater was unregulated in British Columbia and when it is used for drinking water, it does not have to be treated, subject to the approval of the Drinking Water Officer of the district. Groundwater is an important source of drinking water in BC. Groundwater supplies provided 750,000 British Columbians or approximately 25 % of the total municipal drinking water in the province, excluding Vancouver Island. However, industries, including manufacturing, mining, and aquaculture, are the largest users of groundwater in British Columbia, making up approximately 55 % of total water use. This is followed by agriculture and municipalities which both had approximately 20 % of total water use. According to the 2007 report from the British Columbia Ministry of Environment titled "Environmental Trends in British Columbia: 2007," the percentage of wells

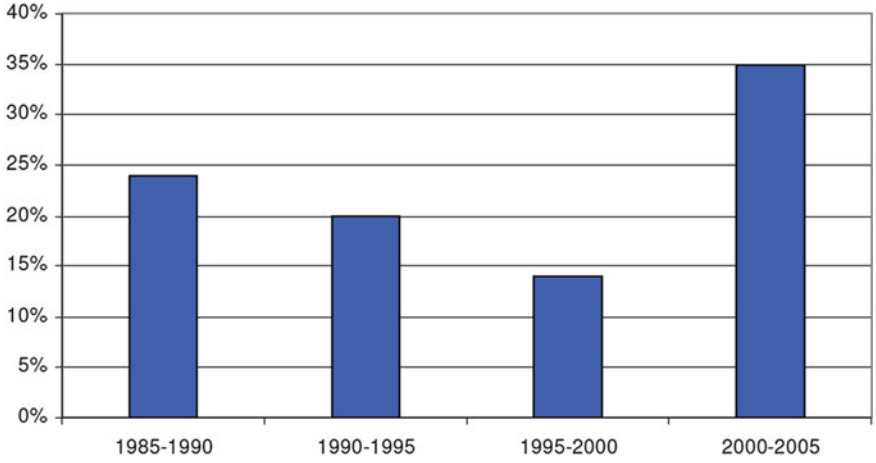
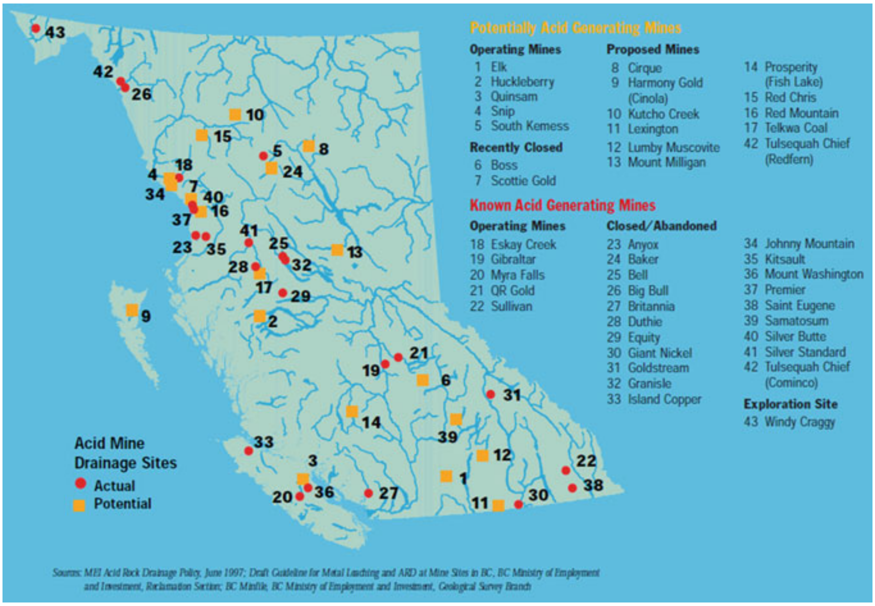


Fig. 8.15 Percentage of observation wells that show declining water levels due to human activities in British Columbia (2000–2005) (British Columbia Ministry of Environment 2007)

with declining water levels due primarily to human activity was 35 % in 2000–2005 (see Fig. 8.15). As the largest user of groundwater, mining could be responsible for the declining water levels.

Moreover, mine drainage is one of the main sources of chemical threats to groundwater quality in British Columbia (British Columbia Ministry of Environment 2007). Mine tailings ponds also pose a threat, but this time to surface water. In Canada, the average grade of mined copper is under 1 %, meaning that for every ton of copper extracted, 99 tons of waste material (i.e., waste rock, tailings) must be removed. The amount of gold extracted per ton of material disturbed is even less (Dobb 1996). The waste rock, and tailings consisting of acid-generating sulfides, heavy metals, and other contaminants, are usually stored above ground in large free-draining piles after the waste material is removed (Environmental Mining Council of British Columbia 2006). This waste rock and the tailings may present a major source of heavy metals contamination of waterways in British Columbia. By 1994, according to British Columbia State of the Environment Report, there were an estimated 240 million tons of acid-generating waste rock and 72 million tons of acid-generating mine tailings in British Columbia (Government of British Columbia 1994 as cited in Environmental Mining Council of British Columbia 2006). Moreover, the tailings and waste rock from mining grow by 25 million tons each year (Government of British Columbia 1994).

The types of water pollution from mining are: (a) Acid mine drainage (i.e., sulfuric acid), (b) heavy metal contamination and leaching (i.e., arsenic, cobalt, copper, cadmium, lead, silver, and zinc), (c) processing chemicals pollution (i.e., cyanide, sulfuric acid), and (d) erosion and sedimentation (i.e., sediment). Of these, acid mine drainage is the biggest threat to water in British Columbia. British Columbia is prominent on maps identifying Canada's pollution sites of acid mine



Sources: MEI Acid Rock Drainage Policy, June 1997; Draft Guideline for Metal Leaching and ARD at Mine Sites in BC, BC Ministry of Employment and Investment, Reclamation Section; BC Minfile, BC Ministry of Employment and Investment, Geological Survey Branch

Fig. 8.16 Map of acid mine drainage sites (Environmental Mining Council of British Columbia 2006)

drainage (Environmental Mining Council of British Columbia 2006). By the end of 1997, 25 mines were closed and abandoned; these became known as acid pollution sites. At least 17 other mines were identified as potential acid pollution sites (see Fig. 8.16).

The negative impacts of an acid-generating mine on rivers, streams, and aquatic life can last for many years. For example, the Mount Washington Copper mine, one of the 25 acid-generating mines, operated from 1964 through 1966, mining copper on Vancouver Island. After the mine closed, it left 940,000 tons of waste rock as a toxic legacy (Hume 2011, March 6). The sulfuric acid, copper, and other heavy metals went into Pyrrhotite and Murex Creeks, and then entered into the Tsolum River watershed, where the contaminants killed a lot of fish. After 40 years, fish have returned to the Tsolum River.

On August 4, 2014, there was a serious ecological disaster, one that one newspaper[4] regarded as the worst in BC history. Imperial Metals owns a gold and copper mine at Mount Polley, which has a large tailings pond of mine waste, including toxic metals such as arsenic, mercury, and sulfur. This tailings pond was contained in a dam, which gave way, allowing millions of cubic meters of contaminated mine waste to flow into Hazeltine Creek, which in turn affected Quesnel Lake, Polley Lake, and Cariboo Creek. The spill affected the entire Quesnel and

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[4] The Globe and Mail, August 7, 2014.

Cariboo river systems right up to the salmon-bearing Fraser River. The community of the town called Likely was asked not to drink the water or even bathe in it. Although the spill was contained, serious concern has been expressed about the total environmental impact on fish and wildlife. The aboriginal communities in the area are worried that the salmon stocks could be affected. It will be months before the full extent of the environmental damage can be assessed, and lessons drawn from this environmental disaster.

There are of course other mines in British Columbia. There are a large number of coalmines, which can release selenium into watercourses. McDonald and Strosher (1998) found selenium downstream from coalmines in the Elk River Basin at levels far exceeding the guidelines of the Council of Canadian Ministers of the Environment (CCME).

The Ministry of Energy and Mines, as well as the Ministry of the Environment regulate mining activity. The laws and regulations for preventing and managing mine waste include the federal Fisheries Act, the BC Waste Management Act, the BC Mines Act, and both the BC and Canadian Environmental Assessment Acts. A number of potential acid-generating mines have been approved, including Huckleberry and South Kemess mines. There have been a number of preventable accidents including massive sediment loading into fish-bearing streams, the building of roads with acid generating waste rock, noncompliance with waste handling plans, and repeated violations of water quality standards. Acid mine drainage guidelines for mine sites were developed by the British Columbia Reclamation Advisory Committee, but are not enforced.

8.4.4 Forestry and Logging Industry

The major industries, and historically the largest employers in British Columbia, are forestry (logging, lumber manufacturing, pulp and paper), mining and smelting, and fishing (and fish canning). All of them depend on the plentiful resources of the land and sea. Other important industries such as agriculture (and food processing) and oil and gas also depend on the natural resources of the land.

8.4.4.1 History of Forestry in British Columbia

Before the nineteenth century, First Nations people used the forests for building houses, boats and canoes, and for their art. By the 1930s, federal and provincial governments began to use forestry to provide employment during the great depression, when unemployment in Canada approached 25 % (Taylor 1999). In 1935 and 1937, the government of British Columbia developed the Young Men's Forestry Training Plan and the Forest Development Project, respectively, to support the forest industry. During the 1950s and 1960s, the federal government provided funding for road development, forest inventory, and forest protection measures under cooperative agreements with the government of British Columbia to mitigate the effects of the great depression (Taylor 1999). After World War II, the expansion of the forest industry proceeded with great speed in British Columbia.

In the early nineteenth century, hundreds of the drinking water watersheds in British Columbia were protected through the Land Act Watershed Reserves on which no commercial logging was permitted. The provincial Royal Commission on Forest Resources and the provincial Task Force created over 300 Watershed Reserves to protect permanently these drinking water sources under the Land Act in the 1940s and 1970s, respectively. However, the forest service in the Okanagan Valley appeared to be ignoring legislation that protected the Watershed Reserves. In addition, although the Nelson community's drinking watershed, Five Mile Creek, had been a Watershed Reserve since 1939, the Ministry of Forests did not prevent forest harvesting activities in the region's watershed. As a result, drinking water sources were jeopardized throughout the Nelson Forest Region.

Furthermore, with the agreement of the government of British Columbia, a number of primarily government foresters and forest advisors proposed to "allow industrial resource users to operate at a profit in areas that were protected as Watershed Reserves" (Koop 2006). In 1946, a US Forest Service forester, George A. Duthie, proposed that the protected watersheds become "multiple use" watersheds, and thousands of the protected community watersheds in the US were "opened up" for the "common good of the forest industry." Then this "multiple use" or "integrated resource management" approach was introduced to British Columbia to replace the "single use" policy on the protected watersheds" (Koop 2006). At a 1952 British Columbia Natural Resources conference, a resolution on forest harvesting in British Columbia's protected drinking water watersheds was passed by professional foresters and engineers. A sustained yield logging of Victoria's watershed forests during the 1950s was the first case of "multiple use" approach to watersheds in Canada (Koop 2006). In 1960, the BC Forest Act was amended to allow forest harvesting activities in drinking water watersheds within their permit boundaries. In 1967, a government forester recommended a change in the department's policy for the protection of forests in Watershed Reserves. In 1976, the Ministry of Lands, Forests and Water Resources was split up, creating the Ministry of Forests and the Ministry of Environment. The Ministry of Forests began to ignore the policies that were designed to protect the drinking water watersheds. In 1978, the Ministry of Forests approved a recommendation from a provincial Task Force to create about 150 Watershed Reserves under the Land Act (Koop 2006). Eventually, all these reserves were included in the timber harvesting land base. In 1984, the Ministry of Forests and the Ministry of Environment initiated an Integrated Watershed Management Plan to force provincial water users to accept the "multiple use" policy on the protected watersheds, but the plan failed due to a collective boycott by water users. After 1986, the Ministry of Forests downgraded a large number of drinking water watersheds from Reserves to "Notations of Interest," a nonprotective designation. From 1993 to 1995, an internal government committee on drinking water watersheds reclassified hundreds of Watershed

Reserves as Community Watersheds under the Forest Practices Code Act. As a result of the forestry activity, water sources became polluted and community water users were required to pay for expensive water treatments (Koop 2006).

8.4.4.2 Economic State of the Forest Industry in British Columbia

Growth in the forest industry has made a significant contribution to British Columbia's economic development in the 1800s and 1900s (Ministry of Forests, Lands and Natural Resource Operations 2010). Currently, the forest industry is one of the largest goods-producing industries in British Columbia. On average, the forest industry accounted for approximately 26 % of GDP by goods-producing industries during the last decade (see Fig. 8.17).

During the period 1992–1996, British Columbia's forest industry harvested an average of 76.1 million m^3/year (see Fig. 8.18). Over 2000–2011, the average harvest volume decreased by roughly 9 % compared to the period 1992–1996, primarily because the US housing market collapsed in the global economic downturn of 2007–2008 (Forestry Innovation Investment (FII) 2014 and Ministry of Forests, Lands and Natural Resource Operations 2010) (see Fig. 8.19). In particular, the average timber harvest volume declined to 69 million m^3/year during this period.

On average, the forest industry provided approximately 75,400 direct jobs per year during 2000–2011, accounting for about 4.6 % of British Columbia's employment (see Fig. 8.20). Overall, employment in the forest industry has slowly declined, while for many rural communities, household incomes are still highly dependent on timber-based industry. Many of these communities are in the Central Interior (Ministry of Forests, Lands and Natural Resource Operations 2010).

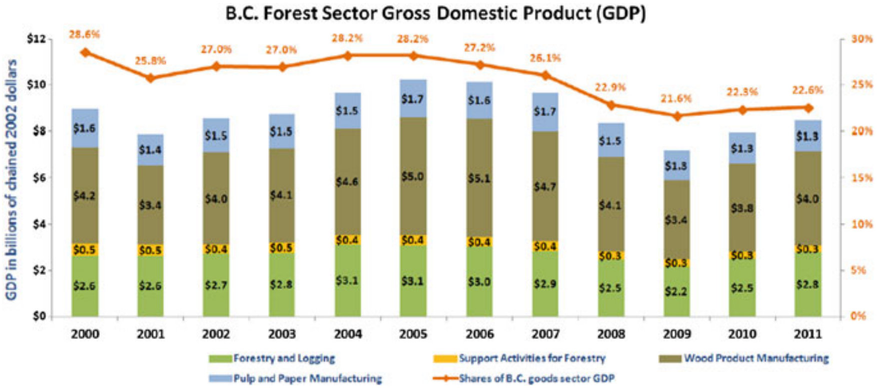

Fig. 8.17 Forest sector GDP and shares of goods sector GDP in British Columbia (Forestry Innovation Investment (FII) 2014)

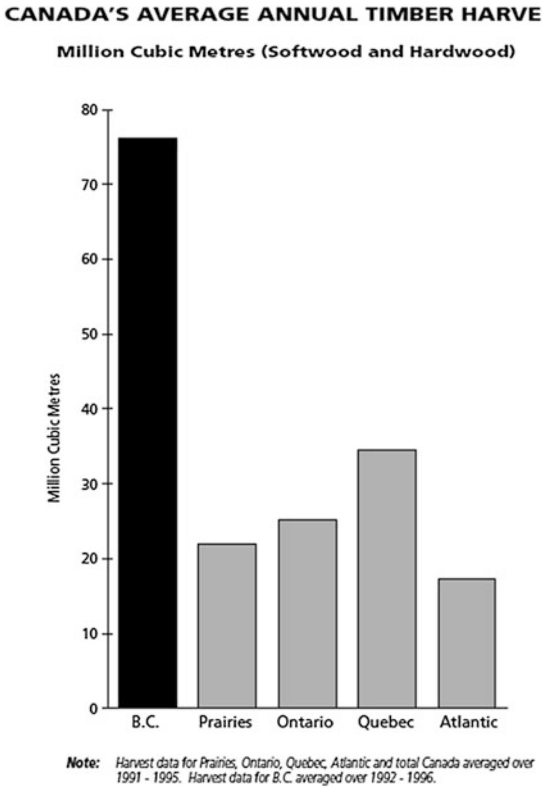

Fig. 8.18 Average annual timber harvest across Canada (Council of Forest Industries 1997)

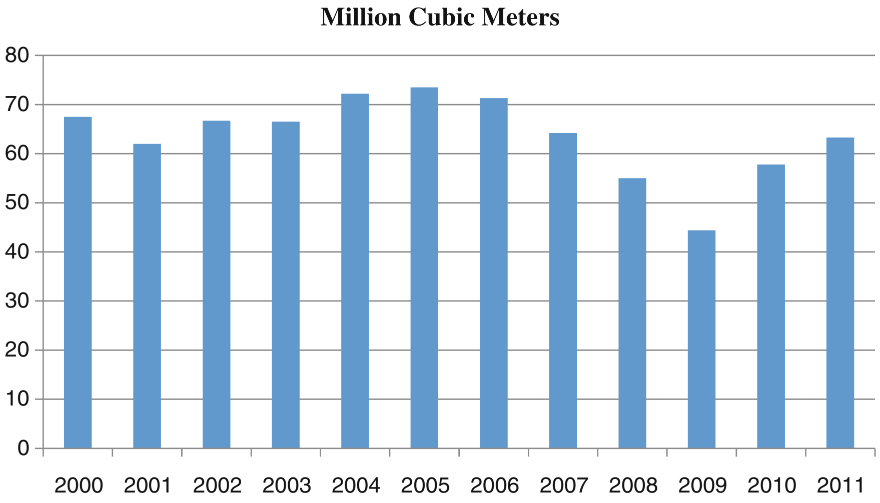

Fig. 8.19 Total harvest volume in British Columbia (Forestry Innovation Investment (FII) 2014)

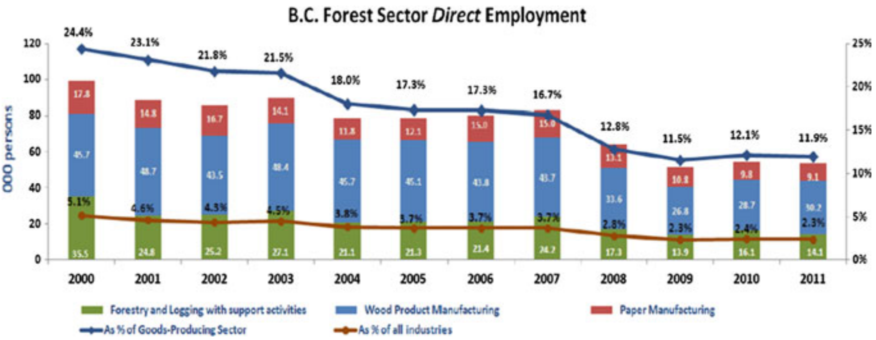

Fig. 8.20 Total harvest volume in British Columbia (2000–2011) (FII 2014)

8.4.4.3 Watershed Degradation Due to Forestry in British Columbia

Although British Columbia's forests provide economic and social benefits, forest development over the last century has resulted in a number of forestry-related disturbances. Some significant historic disturbances include (a) logging of floodplains, fans, and riparian forests; (b) cross-stream yarding and removal of wood from within stream channels; (c) harvesting terrain features that were susceptible to instability or erosion, such as gullied slopes, escarpments, and steep, unstable, or marginally stable slopes; and (d) poor road construction practices (Polster et al. 2010).

In British Columbia, about 83 % of forests are dominated by conifers such as Lodgepole pine, and huge tracts of mature trees making up the forest have been killed by a massive outbreak of the mountain pine beetle (*Dendroctonus ponderosae*) (Ministry of Forests, Lands and Natural Resource Operations 2010). In 2007, over 10 million hectares were under attack and roughly 50 % of the mature pines were killed. This has posed both directly and indirectly potential risks to watersheds. In particular, the high tree mortality can directly increase the risk of windthrow[5] into the water body, with possibly decreased bank strength and increased sediment loss. The government's response has been to allow clear-cutting of the forests, although as David Suzuki and Faisal Moola[6] have argued, this is not a good solution, as clear-cutting destroys younger healthier trees that have not been infected. To date no long-lasting solution has been found to deal with the infestation of mountain pine beetle.

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[5] Windthrow is a natural phenomenon and it refers to the trees that are broken by the force of wind, the mutual action of soil and the base as well as the biological and mechanical attributes of trees. Riparian reserve zones are prone to windthrow (British Columbia Ministry of Forests, Lands and Natural Resource Operations 2014).

[6] See http://www.straight.com/news/david-suzuki-how-mountain-pine-beetle-devastated-bcs-forests. Accessed November 30, 2014.

8.4.4.4 Ecological Impacts of Clear-Cutting

The most serious effects of clear-cutting on water quality include: (a) Increased sedimentation and nutrient loading; (b) increased stream temperature; (c) injury to fish, amphibian and other wildlife population; and (d) water yield changes, such as increased high flows from storms and spring run-off, and decreased low flows in summer. All these factors have a negative impact on riparian and aquatic habitat (Battle Creek Alliance n.d.). For a photograph of the devastating impact of clear-cutting in British Columbia, see Fig. 8.21.

Bates and Henry (1928) undertook a 15-year study on the effects of clear-cutting in Colorado snow-zone watersheds. Their results indicated that clear-cutting increases peak flows and sedimentation in watersheds. According to the findings from Foster Wheeler Environmental Corporation (2000), "logging and related activities such as road building, skidding, slash burning, and others have the potential to produce erosion that can deliver sediment and nutrients to streams." Moreover, Euphrat (1992) pointed out that "bare ground is a potential source area for stream sedimentation, because machine-operated ground creates surfaces of relatively lower permeability over which overland flow is more likely to carry sediment." He further conducted an analysis of residuals from the rainfall-runoff resulting from large storms in the Middle and South Forks of the Mokelumne in northern California in USA; he found that "runoff is getting greater over time, with a significance at the 99 % level or higher…These data indicate that, over time, these streams are increasing their total flows per storm by many percent…Timber harvesting affects runoff by its reduction of vegetation cover and subsequent impacts on the snow pack. It may be fair to say that more recent timber harvesting, affecting annually and cumulatively greater and greater areas, combined with roads, skid trails, and tree removal, is creating progressively greater runoffs from large storms, with the largest storms displaying the greatest increase of runoff."

Furthermore, "[t]he lowering of the lowest weekly flows, significant on Forest Creek at the 95 % level, and on the South Fork at the 99.99 % level, is important in terms of the riparian and aquatic habitats available in the streams of the lower Mokelumne watersheds. For fish and other aquatic species, decreased low-flows reduce available living area and increase temperatures through lack of dilution. For riparian species, low-flows change habitat close to stream channels and allow more species that cannot tolerate perennial flooding to live adjacent to the stream. For people and animals, it restricts the amount of water available for consumption and lowers its quality, through heat and associated eutrophication" (Euphrat 1992).

8.4.4.5 Potential Hazards of Logging, Pulp and Paper Industry on Water Quality and Quantity

The forestry and logging industry has had a major impact on water quality and quantity, because along with forestry there developed a pulp and paper industry that required large quantities of water, and many chemicals used in the manufacture of pulp and paper ended up in the rivers and lakes.

Fig. 8.21 Forest products timber tenure clear-cutting in British Columbia (McAllister 2008)

Pulp and paper operations are highly reliant on water use. Water is used in all major process stages, which include: (a) Raw materials preparation (i.e., wood chip washing), (b) pulp washing and screening, and (c) paper machines (i.e., pulp slurry dilution and fabric showers). Water is also used for other processes such as process cooling, materials transport and equipment cleaning, as well as generating steam for use in processes and on-site power generation (see Fig. 8.22) (Sappi Fine Paper North America 2012). The pulp and paper industry is the largest industrial user of water in Canada and a major source of pollution (Report of the Auditor General of Canada 1993). For example, in British Columbia, about 17 craft pulp mills discharged around 641 billion liters of effluent containing toxic by-products of pulp manufacturing into rivers and marine waters every year (Broten and Ritchlin 2012). The findings from

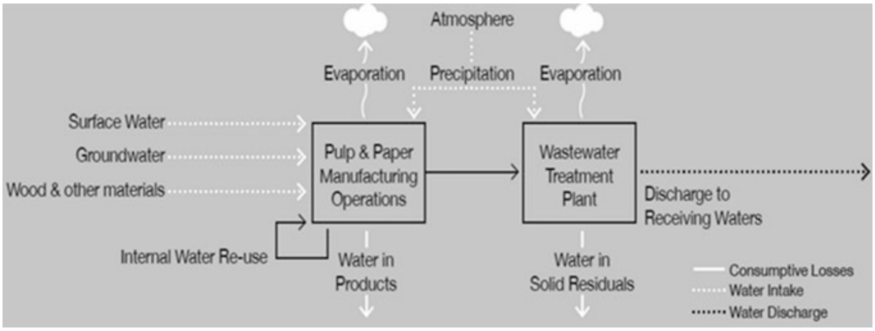

Fig. 8.22 Water use and treatment in the pulp and paper Industry (Sappi Fine Paper North America 2012)

Easton et al. (1997) indicated that mill effluent causes reproductive impairment in zooplankton, invertebrates, and shellfish, and genetic damage and immune system reactions in fish. Moreover, Broten and Ritchlin (1999) pointed out: "even after the pollution control investments of the mid-1990s by the forest industry, the Fraser River, BC's largest watershed and one of the best wild salmon rivers in the world, is still 1 % pulp mill effluent for 600 km during winter low water."

In addition, there is a long history of log transportation in rivers, which was used extensively in the Western USA and Eastern British Columbia. These logs are chemically treated and then they are floated in rivers. This is a cheap means of transporting the logs down the river and up to a paper mill. The primary chemical effects of log handling on the marine and estuarine aquatic environments are: (a) Increased biochemical oxygen demand (BOD), (b) production of hydrogen sulfide (H2S) and ammonia (NH3) during the decomposition of bark and woody debris, and (c) release of soluble organic compounds (leachates) from logs (Sedell et al. 1991).

8.4.4.6 Watershed Restoration Projects in British Columbia

In the early 1990s, as a result of the unsound forestry practices that were harmful to the environment, there were many and frequent landslides in British Columbia. The government of BC started a number of major programs of forest rehabilitation to address the impacts from forest exploitation.

In 1993, the British Columbia Ministry of Forests initiated the Watershed Restoration Program (WRP). In 1994, Forest Renewal BC was established to provide a funding mechanism for watershed restoration activities such as the Terrestrial Ecosystem Restoration Program as well as other activities related to forest management, such as research. Moreover, a series of standards and guidelines for assessments and restoration activities have been developed for the WRP as well as Forest Renewal BC and its programs. In 1995, the Forest Practices Code Act of British Columbia was passed. The purpose of the Act was to change forest practices to reduce the need for restoration. The significant changes affecting watershed conditions now include: (a) The establishment of specified riparian management zones and reserves; (b) the identification of unstable or potentially unstable terrain for both roads and cut blocks, and avoidance of harvesting or road construction that would lead to a higher hazard of landslides; (c) higher standards for road construction and maintenance; and (d) specific guidelines for stream crossings and fish passage to minimize sediment introduction to streams (Polster et al. 2010).

Through setting clear goals for the project and specific objectives for individual remedial measures, considerable experience has been gained from a number of successful restoration projects since 1993, such as understanding the ecological processes at work in the watershed and working with these processes in designing and implementing restoration measures (Polster et al. 2010). But restoring forests and ecosystem health will require strong restrictions on the forestry and pulp and paper industry.

8.4.4.7 Summary of the Section

In British Columbia, there used to be many drinking water watersheds that were protected from logging and foresting activity in the last century. The protection that was enshrined in the British Columbia Land Act was repealed in the 1960s by the government that was in power to "open up" BC for extensive exploitation of their rich forest reserves, and a major forestry industry grew. This led at first to massive clear-cutting of forests, and vast areas of forests were devastated. The clear-cutting and forestry practices led to many and frequent landslides. In the 1990s, the government was forced to bring in legislation to enforce better forestry management practices and a program to rehabilitate forests was begun.

Currently, there are only three watersheds in Vancouver and one in Victoria that still remain designated as "protected drinking water watersheds." The three watersheds of the Greater Vancouver Regional District municipalities are Coquitlam (20,461 ha), Seymour (12,375 ha), and Capilano (19,535 ha). In addition, illegal logging ended in the Sooke watershed in April 1994 (British Columbia Tap Water Alliance 2013). Now as a unique "single use" watershed in Greater Victoria, it provides high quality fresh drinking water. In fact almost all of the surface water supply watersheds in British Columbia are forested, and therefore there is need of special protection and legislation (British Columbia Tap Water Alliance 2013).

8.5 Wastewater Treatment in British Columbia

8.5.1 Level of Wastewater Treatment

In British Columbia, wastewater treatment plants are regulated through operational certificates issued by the Provincial Ministry of Environment (Greater Vancouver Regional District 2014). The operating certificate sets maximum limits on (a) the amount of treated wastewater that can be released into the water bodies, and (b) the amount of biological oxygen demand (BOD) and total suspended solids (TSS) that can be present in treated wastewater (Greater Vancouver Regional District 2014). The regional district regularly monitors wastewater to ensure it meets Provincial standards under the Municipal Wastewater Regulation of the Environmental Management Act. Moreover, all municipalities are required to have a Liquid Waste Management Plan which allows municipalities to develop community-specific solutions for wastewater management that meet or exceed existing regulations (British Columbia Ministry of Environment 2010). The discharges are illegal if the municipality does not have an approved plan.

The main sources of wastewater are households, industrial operations, commercial operations, and stormwater runoff (British Columbia Ministry of Environment 2007). The wastewater may contain agricultural nutrients, PPCPs, heavy metals, and other pollutants. The release of untreated or inadequately treated wastewater could lead to human health risk if drinking water is contaminated with

Table 8.5 Population of British Columbia served by each level of waste treatment plants (1983–2009) (*Source* British Columbia Ministry of Environment 2007 and Environment Canada 2011)

Year	Municipal population with treatment	Proportion of municipal population with			
		No wastewater treatment or preliminary-only treatment (%)	Primary treatment (%)	Secondary treatment (%)	Tertiary treatment (%)
1983	1,990,863	7.0	64.0	23.0	6.0
1986	2,007,356	7.0	65.0	23.0	5.0
1989	2,264,064	7.0	63.0	25.0	5.0
1991	2,422,783	6.0	63.0	24.0	7.0
1994	2,626,018	6.0	62.0	24.0	8.0
1996	2,865,142	8.0	62.0	23.0	8.0
1999	2,986,973	7.0	29.0	56.0	8.0
2004	3,059,509	1.1	35.0	56.4	7.5
2009	2,775,340	8.2	13.8	64.4	13.6

toxic substances. But the target of wastewater treatment is primarily to remove biological nutrients and to reduce the BOD and TSS before treated sewage is discharged into the source water. This still leaves many contaminants in the wastewater that end up in lakes, rivers, and oceans.

In British Columbia, most wastewater treatment plants use primary and secondary levels of treatment, and some also use tertiary treatments (see Table 8.5). According to the data from Environment Canada, there were no major treatment plant upgrades or construction of new plants from 1983 to 1996, while the proportion of municipal population with secondary treatment increased to 33 % in 1999, when the largest wastewater treatment plant in Greater Vancouver Regional District called Annacis Island Sewage wastewater treatment plant was upgraded from primary to secondary treatment (see Table 8.5). The differences between 2004 and 2009 for secondary and primary treatment were significant, because a number of primary treatments were upgraded to secondary treatments such as the Northwest Langley wastewater treatment plant. But still the proportion of wastewater that received tertiary treatment (in 2011) was very small as shown in Table 8.5.

8.5.1.1 Wastewater Discharge in Metro Vancouver

Metro Vancouver operates five wastewater treatment plants that treat about 440 billion liters of wastewater every year (see Fig. 8.23) (Greater Vancouver Regional District 2014). In 2012, more than half of this volume received primary treatment at the Iona Island wastewater treatment plant and Lion's Gate wastewater treatment plant; this wastewater is then discharged into the Strait of Georgia (Greater Vancouver Regional District 2014). In early 2013, the Lion's Gate wastewater treatment plant was to be upgraded and a new secondary treatment plant will be completed by

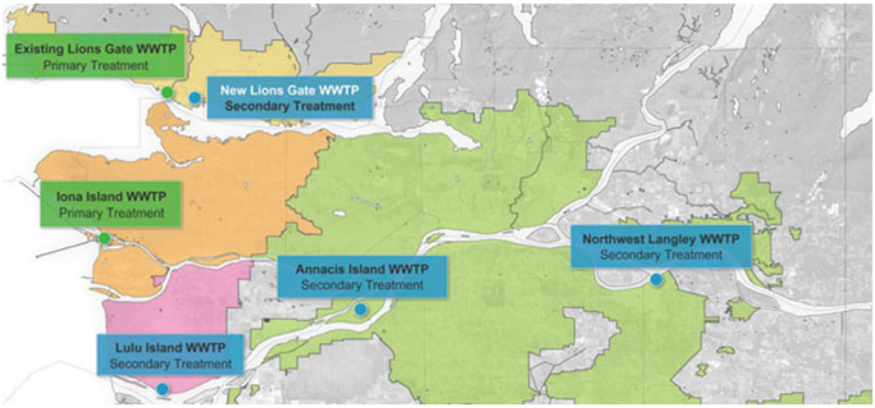

Fig. 8.23 Map of five wastewater treatment plants in Metro Vancouver (Greater Vancouver Regional District 2014)

2020. The remaining three plants (Annacis, Lulu, and Langley) provide secondary treatment and discharge into the Fraser River. Secondary plants can reduce BOD and TSS by 90 %, while reductions for primary plants are expected to be 30 % for BOD and 60 % for TSS.

8.5.1.2 Wastewater Discharge in Greater Victoria

Victoria used to discharge up to 130 million liters of raw sewage per day into the Juan de Fuca Strait via two large outflow pipes—one at Clover Point in Victoria, the other at McLoughlin Point in Esquimalt ("New treatment plant to stop dumping of raw sewage into Pacific" August 25, 2010). Although Greater Victoria is currently served by six treatment plants that provide secondary treatment across the region, including Saanich Peninsula, Port Renfrew, Cannon Crescent (North Pender Island), Schooner Way (North Pender Island), Ganges Harbour (Salt Spring Island), and Maliview (Salt Spring Island), wastewater in the core area receives merely preliminary treatment (screening) prior to being discharged at outfalls at Clover Point and Mcloughlin Point (Capital Regional District 2014). In February 2012, $783 million was approved for funding by the province to develop the Seaterra Program which provides secondary wastewater treatment for the core area and Greater Victoria (Capital Regional District 2014). The Capital Regional District is committed to a policy that Greater Victoria will not release untreated wastewater into the Juan de Fuca Strait by 2018.

8.5.1.3 Reducing Phosphorus Loadings in Okanagan Lake

Okanagan Valley is one of the most important agricultural regions in British Columbia and agricultural irrigation accounts for approximately 55 % of total water use (Okanagan Basin Water Board 2011). Blooms of algae occurred in Vernon, Penticton, and Kelowna in the late 1960s (Okanagan Basin Water Board 2014). Okanagan Lake has been facing the problem of phosphorus loadings over decades. Agricultural phosphorus loadings in Okanagan Lake are primarily caused by movement of phosphorus through soil from fertilized cropland or direct runoff of animal waste (Kennedy and Oldham 1972). Agricultural control efforts were conducted during the last four decades to reduce agricultural phosphorus loadings in Okanagan Lake, including (a) new winter manure storage facilities on dairy farms, (b) relocation of feedlot pens and cattle wintering further from water courses, (c) waste runoff control facilities at feedlots, and (d) changes to cattle management (Jensen and Epp 2002). Furthermore, most municipal wastewater has been treated by secondary treatment processes since 1970 to remove the phosphorus concentrations from the wastewater. In 1983, Kelowna built the first tertiary treatment plant in the Okanagan, which contained advanced nutrient and carbonaceous removal systems. The improvements in nutrient removal capability resulted in a decrease in phosphorus loading into the Okanagan Lake from 60,000 kg in 1970 to less than 2,000 kg in 2006 (see Fig. 8.24). As shown in Fig. 8.25, Okanagan Lake total phosphorus in the spring has declined to approximately 3 μg/L in 2007, and has also met the water quality objective since 2001. In addition, Fig. 8.26 shows a decrease in total phosphorus concentrations in Lake Osoyoos and Skaha lakes.

There have been significant improvements in nutrient removal from wastewater, but increases in emerging chemical contaminants such as PPCPs in wastewater

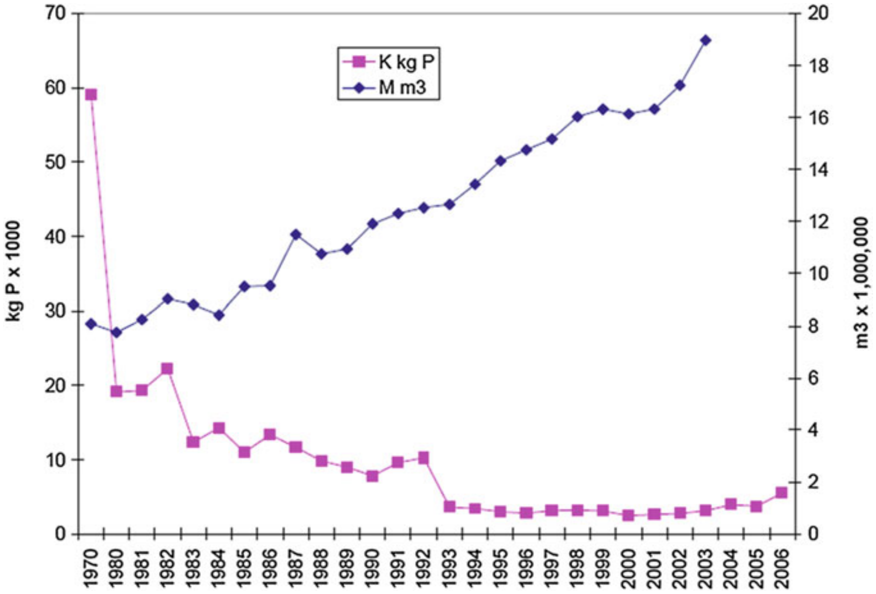

Fig. 8.24 Municipal effluent volume (M m^3/year) and phosphorus loading (K kg/year), to surface waters of Okanagan Basin 1970–2006 (Jensen 2010)

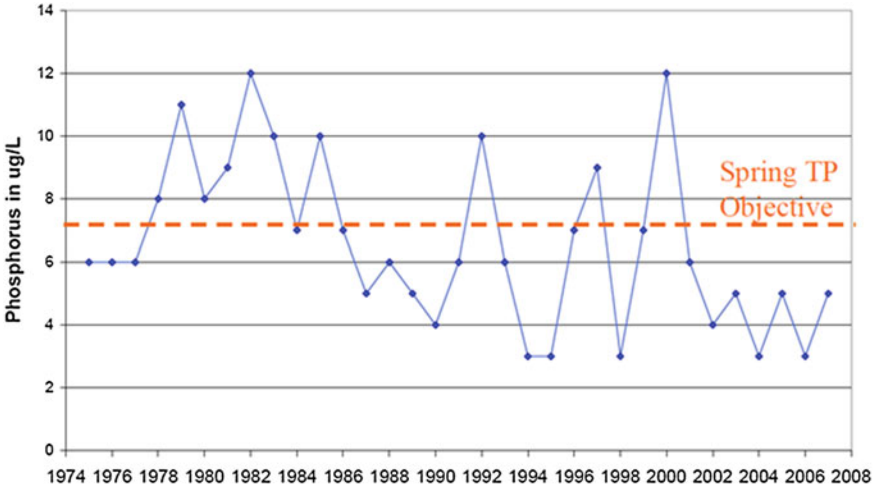

Fig. 8.25 Spring total phosphorus (µg/L) in the south end of Okanagan Lake (1975–2007) (Jensen 2010)

streams have been a concern. In order to control emerging contaminants, in 1996, a Medications Return Program was developed to conduct safe disposal of expired and used medicines including all nonprescription and prescription drugs, all nonprescription medicines, herbal products, mineral supplements, vitamin supplements, and throat lozenges in British Columbia (Okanagan Water Stewardship Council 2008). In addition to the program, adequate wastewater treatment is also essential to clean water in the Okanagan Basin.

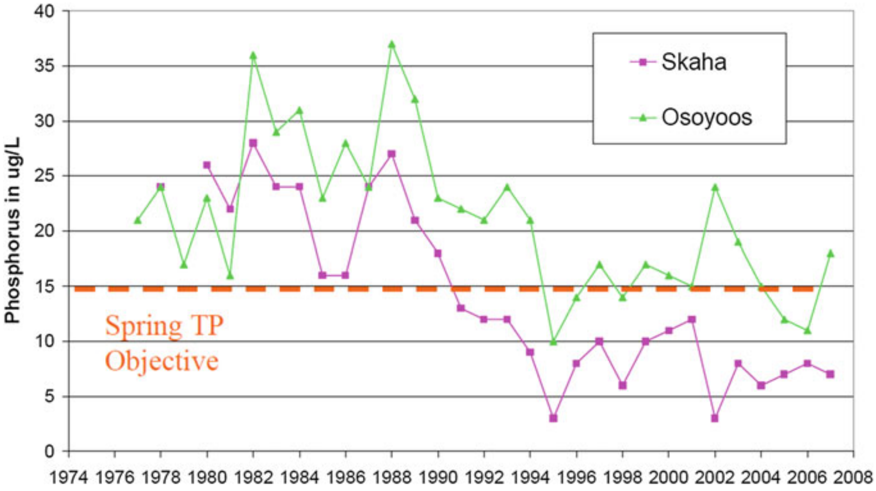

Fig. 8.26 Spring total phosphorus (µg/L) in Skaha and Osoyoos lakes (1975–2007) (Jensen 2010)

8.6 Laws Affecting Watersheds

In British Columbia, there are more than 291,000 sub-watersheds. By volume, the largest river is the Columbia River, which has the largest flow of 2,780 m^3/s and runs approximately 2,000 km from the Rockies to the Pacific Ocean. The vast majority of community water supply systems rely on surface water. For example, a number of the communities in the Regional District of Central Kootenay draw their water from Lake Kootenay and other lakes and rivers in the region (Regional District of Central Kootenay 2014). The first barrier that should be in place to protect the quality of the drinking water supply is protection of the watershed to ensure the best quality source water. The *Constitution Act*, 1867 divides responsibility and distributes power between provincial and federal governments, and gives provincial governments primary responsibility for making decisions about water and watersheds (Brandes and O'Riordan 2014). In 1987, the *Federal Water Policy* assigned leadership to the federal government. However, this *Policy* has not been fully implemented and the federal role in watershed management has diminished (Pentland and Wood 2013).

One of the prime issues for watershed governance in British Columbia is how the responsibility for managing land and water is divided between four levels of government. In 2014 the POLIS project issued a paper entitled "*A Blueprint for Watershed Governance in British Columbia*." The authors Oliver Brandes and Jon O'Riordan pointed out that "in British Columbia, the current governance approach is focused primarily on resource extraction—not resource stewardship. This approach is driven by decisions made by government regulators and an environmental assessment process with the primary function of approving development proposals that are subject to minimal conditions to address environmental, community, and First Nation's interest."

In British Columbia, the principal water legislation was the Water Act, 1909. The focus of this 100-year old Act was British Columbia's surface water allocation rights, based on the principle, "*FITFIR*." This principle led to an over-allocation of water rights regardless of changing water inventories, and changing inflows and recharge rates for aquifers. Oliver Brandes, Co-Director of the *Polis Project on Ecological Governance* at the University of Victoria, pointed out that "the problem with the current Act is that it's focused on handing out water-use licenses to industry, not on protecting water supplies" (Severinson 2011). In fact, of the roughly 44,000 water licenses in British Columbia, currently only 4 % are reporting usage (British Columbia Waste and Water Association 2012). The vast majority of water licensed in the province for nonconsumptive uses such as power production carries no requirement to report usage (BCWWA 2012). Moreover, the use of groundwater in British Columbia is currently unregulated and uncontrolled, while most Canadian jurisdictions have passed laws on groundwater use (British Columbia Ministry of Health 2014). In British Columbia, anyone is free to drill a well on their land and draw water from a common aquifer. For example, Nestlé, the world's biggest bottled water seller, is not required to report the amount of water it draws, nor is it required to pay a fee. In fact it does not require a permit for the water it draws from British Columbia wells (Fumano 2013).

As we discussed in Sect. 8.2.2, the DWPA, 2003 and its regulations bring a “source-to-tap” approach to protect drinking water and require source protection planning. However, such plans have yet to be implemented.

Although the Water Act paid more attention to resource extraction and economic benefits, more recent legislation developed in 1990s has focused on stewardship and the restoration of fish-bearing streams impacted by forestry. In 1994, the *Water Protection Act* was established as a comprehensive framework to protect British Columbia’s water resources from pollution and overuse; it is administered by the Ministry of Environment. The *Act* aims to (a) re-confirm the ownership of surface water and groundwater, (b) maintain existing bulk water removal rights, within clearly defined limits, (c) prohibit bulk removal of British Columbia’s water to locations outside the province, and (d) prohibit large-scale diversion between major watersheds of the province (British Columbia Ministry of Environment, Water Stewardship Division n.d.). More especially, the *Act* prohibits dams on the Fraser River.

In 1997, to protect fish flows, the *Fish Protection Act* was passed; it identified and designated some sensitive streams and provided some options for future water allocation. In 2004, the *Riparian Assessment Regulation* was released to define Streamside Protection and Enhancement Areas where new development was prohibited or restricted.

Moreover, there are two resource framework laws, which provide some provisions for water management. One is the *Forest and Range Practices Act*, 2004 which aims to prevent erosion in riparian areas, and protects wildlife and fishery in watersheds outside urban development areas. Another important piece of legislation is the *Oil and Gas Activities Act*, 2008 and its regulations, which define oil and gas development in northern British Columbia.

In 2008, the provincial water strategy, *Living Water Smart,* shifted away from resource extraction and development to water stewardship. Yet, to date, many aspects of the policy have not been initiated.

8.6.1 A Brief History of the Formal Watershed-Scale Governance Institutions in British Columbia

Like the whole of Sect. 8.6, this subsection draws heavily on Brandes and O’Riordan (2014). In 1970, the Okanagan Basin Water Board was established under the Municipalities Enabling and Validating Act, consisting of representatives from the Regional Districts, the Water Supply Association, and the Okanagan First Nation. The Water Board has tax powers to deal with water problems that crossed the jurisdictional boundaries of the Okanagan Regional Districts, such as grants for sewage treatment infrastructure, and is in partnership with the province to clean up effluent discharge. In 1997, Fraser Basin Council, a nonprofit organization with a small board of governors selected by federal, provincial, local, and First Nations governments, was established by the province and the federal government. The Council has a province-wide mandate to address the water problems in the Fraser Basin area through project-based funding, combined with a portion of "fee-for-service."

Another form of watershed stewardship is to develop the "trust model." In 1974, to relieve the development pressures in the Gulf Islands, the Islands Trust was established to preserve the unique environment in the Gulf Islands: The Trust is essentially a form of local government. Moreover, in 1996, the Columbia Basin Trust was established to undertake individual projects, largely to mitigate losses caused by the flooding of several valleys due to the four hydroelectric projects that were built under the Columbia River Treaty.

8.7 The Water Sustainability Act (WSA) of 2014

After many years of discussion, the government of British Columbia released its proposal for new water legislation for public comment. The new Act was passed in 2014, and is called the WSA. It is to come into force in 2016.[7] It has seven key elements. They are:

Protect stream health and aquatic environments. (a) Guidelines will be used to determine the in stream flow, and decision makers will be required to consider these in new water allocation decisions for both ground and surface water. This approach will provide protection of in stream flows with enforceable terms and conditions in water licenses. (b) Activities that may cause damage to aquatic environments will be regulated.

Consider water in land-use decisions. (a) Provincial Water Objectives will be established for British Columbia. Provincial Water Objectives will guide decisions made by statutory decision makers under the WSA and other laws affecting resource use on crown and private land. Provincial Water Objectives can focus on: (1) Ensuring secure access to healthy water; (2) addressing conflicts among users, and pressures and trends in water supply and demand; (3) protecting naturally flow-sensitive streams and ecosystem health; and (4) addressing cumulative impacts. (b) Provincial Water Objectives will improve consistency in decision-making across all regions of BC to protect water quality, quantity, and flow. (c) In some areas, Provincial Water Objectives may determine how and where land and resources are developed.

Regulate groundwater use. (a) Groundwater extraction and use will be regulated in problem areas and for all large groundwater withdrawals across BC. All existing

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[7] Personal correspondence with Oliver Brandes, Co-Director of POLIS (Center for Global Studies) and Adjunct professor of law, and of public administration, University of Victoria.

and new large groundwater users throughout the province will be required to obtain a license. (b) Licenses will specify the maximum quantity of groundwater that can be extracted and used, and will set out other terms and conditions of pumping and use. (c) There will be new costs for development of groundwater, requirements for monitoring and reporting of use, and potentially costs to implement water use efficiency measures such as metering and volumetric pricing.

Regulate during times of scarcity. (a) A staged approach will be taken (over time or as conditions dictate) to manage water in times of scarcity. This will promote water conservation and efficiency. (b) The approach will maintain licensees' certainty of access during times of scarcity, other than in exceptional circumstances. (c) The approach may reduce the frequency of restrictions on usage, improving access and fairness for junior licensees. However, the principle of "*FITFIR*" will be retained, so that older license holders retain their priority of access and use. The Act also extends that approach to groundwater use, retroactively giving licenses to use water to well owners based on the date that they first used their well. But the FITFIR principle does not seem to apply to First Nations, a curious paradox, as noted by Curran[8] (2014, March 14), a professor of law at the University of Victoria.

Improve security, water use efficiency, and conservation. (a) A range of economic instruments will serve as incentives for improving water use efficiency. Measures include: fee-based measures; rebates; liability, and assurance regimes; and tradable permits. (b) Water use efficiency will be incorporated into the definition of beneficial use. Water users will be required to demonstrate efficiency of use. (c) Agricultural water reserves, which expand the current powers to reserve water for an irrigation system or project, will be enabled. Transfers, extension of rights or other forms of collaborative sharing within an agricultural water reserve amongst users will be considered.

Measure and report. (a) Licensed ground and surface water users will be required to report actual water use, and in some cases stream flow, groundwater levels, well performance, and water quality will be taken into account. (b) Requirements to report will begin with large surface and groundwater users province- wide. (c) Additional or more stringent requirements for monitoring and reporting in problem areas will be enabled.

Enable a range of governance approaches. (a) A range of approaches to support increased collaboration and participation in activities and decision processes will be enabled. (b) Through the area-based approach, the Provincial Government will continue to establish and coordinate laws, rules, agreements, and financial arrangements, including setting provincial objectives and outcomes. (c) The province will also determine the compliance and enforcement framework.

The WSA will be important to fisheries, a major industry in British Columbia; the fishery industry provides economic benefits to the British Columbian and Canadian governments as a whole. It is the fourth largest primary industry within

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[8] http://wcel.org/resources/environmental-law-alert/strengths-and-weaknesses-new-water-sustainability-act. Accessed November 30, 2014.

British Columbia (British Columbia Ministry of Agriculture and Lands n.d.). According to BC Stats, aquaculture is the largest sector within the provincial fishery industry. It is followed by sport fishing, seafood processing, and commercial fishing, respectively (BC Stats 2007). Aquaculture is the largest sector due to technological advancements that allow it to be more efficiently operated by the cultivators, and such advancements also have a positive impact on the seafood-processing sector (BC Stats 2007). On the other hand, the commercial fishing sector has suffered a drop because of government limits on the number of fishing licenses, and because of the decline of certain fish stocks in the wild (BC Stats 2007).

The WSA could lead to legal challenges to current land-use practices. For example, the serious impacts of forestry outlined above could be considered illegal under the new Act. Taking ecosystem health into account could potentially limit adverse environmental impacts of mining, oil and gas, including fracking, where harm can be demonstrated. However, the government has the right to issue repeat short-term licenses for water use to the same person, for existing purposes, and for the same place. This could limit the effectiveness of the WSA, as it can be used to facilitate hydraulic water licenses for fracking, an existing use.

8.8 Proposals to Reform Watershed Protection in British Columbia

The WSA does not contain any direct measures that could specifically protect watersheds. But the provision to protect water for ecosystem health could perhaps be interpreted as going some way toward offering watersheds some possible protection. But if all we have are “guides” for watershed protection and no enforceable legislation that mandates how cattle are to be farmed away from watercourses; how forestry and pulp and paper industries are to be practiced without polluting rivers; how crop farming is to limit its nutrient flows; and how mining activity is compelled to manage its contaminants in the form of tailings ponds, source water protection will receive little or no priority.

A research and ecological governance, law and policy think tank based at the University of Victoria, called *POLIS*, has made 9 recommendations that could serve as a blueprint for watershed governance. These are:

(1) Enabling powers in Legislation for Watershed Entities: The watershed organizations need to work with some form of legislated authority, such as the Columbia Basin Trust which cooperated with Okanagan Basin Water Board;
(2) Co-Governance with First Nations: A working relationship with local First Nations that would ensure the local First Nations participate and share a formal role in decisions in their watersheds;
(3) Support and form partnerships with local government: The local government to play an important role in seeking to improve watershed sustainability;

(4) Sustainable long-term funding: An ongoing funding mechanism for watershed organizations to support innovative local activities, such as improving the treatment technology of small water systems. At a minimum, the province and local government must enable access to local taxation and resource royalties that can be used to leverage further funds from other sources;

(5) A functional legal framework for sustainable water and watershed management: There must be enabling legislation so that resource decisions are made for watershed stewardship;

(6) Public availability of data on watershed monitoring: It is important that the province work with watershed organizations to build a comprehensive province-wide water-use database, and make data available to the public;

(7) Independent oversight and public reporting: An independent oversight body is effective and efficient for conducting investigations, handling citizen complaints, and monitoring compliance with key legislation, in cooperation with independent bodies that already exist in British Columbia, such as the Ombudsmen, the Forest Practices Board, and Auditor General;

(8) Assessing cumulative impact: The objective of cumulative impact assessments is to make science-based decisions and prohibit development in cases where watershed functions are threatened; and

(9) Continuous peer-to-peer learning and capacity building: It is important not only to learn new practices or lessons from other watershed groups, but also to undertake pilots to test new tools, data systems, and interactions between watershed groups (Brandes and Riordan 2014).

Perhaps future amendments to the WSA could incorporate provisions for adequate protection of watersheds along the lines suggested by *Polis*, outlined above.

8.9 Conclusion

In British Columbia, legislation gives wide regulatory powers to the regional health authorities to protect drinking water by enforcing the “4-3-2-1-0” treatment rule, but the enforcements are uneven across the health authorities. However, this rule leaves out a whole lot of other contaminants as shown in Table 8.1. Moreover, the small systems have poor or no treatment and many of these small water systems have been under long-term boil water advisories. Furthermore, there are a number of potential hazards to watersheds such as cattle farming, mining, oil, and gas as well as the forestry and logging industry. For example, fracking techniques result in inefficient and wasteful use of freshwater in the gas and oil industry, but this has not been regulated. Legislation to protect the water source in watersheds should be enhanced, since British Columbia has large quantities of water in small creeks or streams flowing off mountain slopes, which lead to a great challenge to watershed management.

Water policy is in transition in British Columbia. The WSA will come into force in 2016. The Act fails to reverse the inequalities of current water system rights, based on "FITFIR," as that system has been retained in the new Act. There was a proposal to enshrine the Public Trust Doctrine applicable to water, which would have ensured ecosystem sustainability and equity between current and future generations. But the new Act does not include the Public Trust Doctrine.

Nevertheless there are a few good provisions that could help protect the environment. Court challenges based on the new Act could reduce the most egregious effects of forestry, mining, and oil and gas. But there is no watershed protection in this Act, and so cattle farming is unlikely to be modified based on this Act alone. Although drinking water has a priority in water allocations, this Act is also unlikely to benefit the vast areas of small drinking water systems, many of which remain under boil water advisories. Perhaps legal challenges made by environmental advocacy groups and First Nations might succeed in curbing some of the worst excesses of agricultural and industrial activity, as the polluters do not bear the full social cost of their activity. Any form of "dumping" or environmental damage for which industrial activity does not bear the full social cost is in fact a form of subsidy.

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Chapter 9
Water Policy in Ontario and Europe: A Study in Contrasts

9.1 Introduction

In 2004, Canadians were ranked among the largest users of water in the world, using 343 L per person per day (Ministry of Natural Resources and Forestry 2008). In April 2010, the Ontario Ministry of the Environment (Ontario Ministry of the Environment 2010) reported that Ontarians use about 260 L of water per capita per day, nearly twice as much as other countries with similar standards of living such as Germany, the United Kingdom and the Netherlands.

The level of per capita consumption is further confirmed if we look at the average residential water use in the City of Windsor, which is approximately 320 L/day (City of Windsor Water Department 2014). In contrast, in Germany, per capita consumption has decreased steadily, as shown in Fig. 9.1, to 122 L per capita.

Another fact worth noting is that in Ontario, the source water for drinking is surface water, mainly the Great Lakes. In contrast Germany, like the rest of Europe, has moved away from surface water in order to increase water safety: more than 70 % of drinking water is from groundwater sources.[1] The remainder, such as in North Rhine-Westphalia, comes from surface water. Where possible, the surface water is drawn from bank filtration (Mertsch 2013).

This chapter is organized as follows. In Sect. 9.2, we compare the German regulatory requirements such as Maximum Concentration Levels (MCLs) for drinking water with those of Ontario. For a full comparison of the MCLs in Ontario, WHO, USA, EU, Germany, and Canada, see Appendices 9.3 and 9.4. In Sect. 9.3, we classify water treatment into six classes and compare the current status of drinking water treatment in North America and Germany. In Sect. 9.4, we compare consumer satisfaction (i.e., quality of drinking water) in the US, Ontario, and Germany. Section 9.5 covers the state of water infrastructure in EU countries as well as in Ontario. In Sect. 9.6, we consider the

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[1] Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) in Hannover (Federal Institute for Geosciences and Natural Resources). See http://www.bgr.bund.de/EN/Themen/Wasser/wasser_node_en.html Retrieved December 4, 2014.

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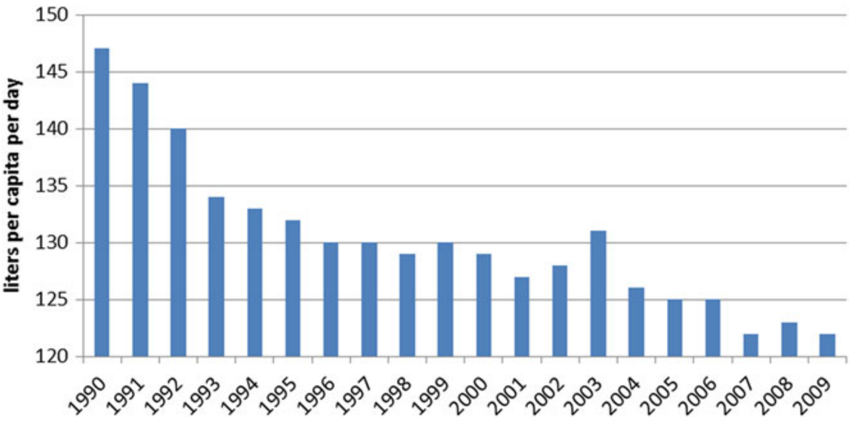

Fig. 9.1 Water consumption in Germany (1990–2009) (Reproduced from ATT et al. (2011))

current status of wastewater treatment in Ontario and Germany. Section 9.7 examines how the problems of micropollutants are handled in Ontario and Germany. Section 9.8 focuses on exploring the long-term health effects of using chlorine in untreated water and shows the dominant role of chlorine in North America and the diminishing use of chlorine in EU countries. Section 9.9 draws some conclusions.

9.2 Regulatory Requirements: Comparing Ontario and Germany

Like most developed countries, Germany has set MCLs for drinking water (see Appendices 9.1 and 9.2). These cover chemical and other indicator parameters, while MCLs on water quality in Ontario are divided into three categories: microbiological, chemical, and radiological parameters. All MCLs for microbiological parameters are zero in Germany and Ontario. That is, *Escherichia coli* (*E. coli*) and total coliforms should not be detectable in a drinking water sample. Although Germany does not set MCLs for radiological parameters, in comparison with Ontario a number of MCLs for chemical parameters are considerably lower, including 1, 2-dichloroethane, antimony, boron, cadmium, nitrite, tetrachloroethane, trichloroethane, trihalomethanes (THMs), uranium, and vinyl chloride. The German MCL for nitrate is 50 mg/L, which when converted to nitrate-nitrogen (NO_3–N) is 11.29 mg/L, which is essentially the same as the MCL in Ontario, of 10 mg/L.[2] However, as shown in Dore (2015), wastewater treatment achieves a

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[2] I am grateful to an anonymous referee of this book who pointed out that I should convert the European MCL, which is a nitrate measure to nitrate-nitrogen. I am also grateful to Professor Andrew Laursen and Dr Sophia Dore for confirming my conversion and for teaching me some basic chemistry.

significant reduction of nitrate in Germany, and since 2010, nitrate concentrations comply with the limit value of 50 mg/L (=11.29 mg/L of NO_3–N). Some chemicals such as N-nitrosodimethylamine (NDMA), polychlorinated biphenyls (PCB), dichlorodiphenyltrichloroethane (DDT) + metabolites, and pentachlorophenol have no required MCLs in Germany, but are regulated in Ontario, while acrylamide, copper, epichlorohydrin, nickel, and polycyclic aromatic hydrocarbons have stated MCLs in Germany, but are not regulated in Ontario. We expect that NDMA and PCBs are not regulated in Germany because wastewater treatment is of a sufficiently high standard that these contaminants are removed at the wastewater treatment stage, on which more later. However, unlike Ontario, there are unregulated guidelines called "Health-Related Indicator Values" for all micropollutants in Germany (Sect. 9.3). This is a significant advancement in the quest for contaminant-free drinking water.

9.3 Drinking Water Treatment

While it is difficult to classify the quality of drinking water, one way may be to classify drinking water *treatment* technologies on the basis of what contaminants are removed, an approach taken in Chap. 2. In Table 9.1[3] Class 1 represents the minimum level of treatment, which is disinfection by chlorination only. We consider chlorination as the minimum disinfection treatment level since all water treatment plants are required to produce water that is free of pathogens. Depending on source water quality, most groundwater-based systems may need little or no treatment; however, if there were a distribution system, it would require chlorine only in some jurisdictions (Class 1). Many surface water small water systems will be Class 2, i.e., water that has suspended solids removed and is disinfected. In a Class 3 plant, protozoa will also be removed or inactivated, possibly with the aid of UV or ozonation. If, in addition, all dissolved organic matter is also removed before chlorination, then that water will be without disinfection by-products (DBP), and we classify such treatment technology as Class 4.

On the other hand, Class 5 represents a technology that also removes chemicals, micropollutants, DBPs, protozoa, and suspended solids in addition to disinfection. In the scheme proposed above, each progressively higher treatment class indicates a greater removal of contaminants. However, this classification scheme is fairly broad in scope, an initial attempt, although other more finely graded classifications are possible. Note that we are classifying *treatment categories or classes, not final water quality.* What emerges from this classification is a way of comparing final water quality *indirectly*, on the basis of what treatment systems are used, and also assessing any possible long-term health threats.

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[3] This is the same table as Table 2.1 in Chap. 2; it is reproduced here in order to make this chapter readable without having to read Chap. 2.

Table 9.1 Proposed water treatment classes

Class	Typical treatment technology	Contaminants removed
Class 1	Chlorination	Water disinfection; removal of most pathogens
Class 2	High rate clarification and filtration; or sand filtration	Disinfection plus suspended solid removal
Class 3	Ultra violet	Class 2 plus removal of protozoa
Class 4	Ozonation	Class 3 plus removal of dissolved organic matter (no DBP[a] precursors)
Class 5a	Granular Activated Carbon	Class 3 plus removal of geosmin and other taste and odor compounds, DBPs, Volatile organic Compounds, Endocrine Disruptors, micropollutants, pesticides, pharmaceuticals, and personal care products
Class 5b	Advanced oxidation process	Class 4 plus higher efficacy of the removal of chemicals and other micropollutants (e.g., pesticides, pharmaceuticals, taste, and odor concerns)
Class 6	Reverse osmosis or distillation	Class 5 plus removal of salinity

[a] DBP stands for "disinfection byproducts." Ozonation will have no DBPs if there is no bromide in the source water

In North America most drinking water comes from surface water, which needs to be treated adequately. According to the American Water Works Report (AWWA, Water Quality Division Disinfection 2008), chlorine gas remained the predominant disinfectant in the US, used by 63 % of respondents to a survey, whereas those who used chloramine accounted for 30 %; chlorine dioxide for 8 %; ozone for 9 %; and ultraviolet light (UV) for 2 %. (The figures do not add up to 100 as some may use more than one disinfection method.) In Canada, according to the Environment Canada survey of Municipal Water and Wastewater Plants (2004), some 93 % used chlorine as the only disinfectant. Those using UV or ozonation accounted for only 6 % of the total. This shows the dominant role played by chlorine and chlorine derivatives in North America, where this Class 1 technology is concerned almost exclusively with the removal of pathogens, although we know that chlorine is not effective against protozoa and other pathogens. However, for most large cities and populations, the conventional water treatment is coagulation, flocculation, clarification, and filtration, and is typically followed by disinfection by chlorine or chlorine derivative. But the failure of a flocculator led to an outbreak of *cryptosporidiosis* in Carrollton Georgia in 1987; and the failure of a chlorinator led to an outbreak of *giardiasis* in Bradford Pennsylvania in 1979. Thus the conventional treatment train is best described as being Class 3 *if it removes all protozoa;* it cannot be classified as Class 4, as chlorination will leave DBP precursors in the water if there is any organic matter in the source water. For this reason, in Ontario and indeed in the whole of North America, the main DBPs, called THMs, nitrosamines and haloacetic acids (HAAs) are regulated with maximum contamination limits.

But there are also many other DBPs, called halides, that are not regulated at all. If a conventional treatment plant receives "credits" for 3 log removal of protozoa (i.e., 99.9 % removal), it is best classified as Class 3.

The most significant drinking water outbreak of *cryptosporidiosis* was in Milwaukee Wisconsin from March to April of 1993, the worst waterborne disease outbreak in the US history (see Chap. 1). Two water treatment plants supplying water to Milwaukee used water from Lake Michigan. Both plants used conventional treatment of coagulation, flocculation, sedimentation, rapid sand filtration, and chlorination treatment (Solo-Gabriele and Neumeister 1996, p. 81). The failure to remove a protozoon indicates that these plants functioned as no more than Class 2 treatment systems.

Based on the evidence and the above classification system, we are led to the conclusion that conventional treatment plants in North America are at best Class 3, and no more than Class 2 when they fail to remove protozoa. Note that this conclusion is based on treatment technologies and not on the quality of final drinking water, which may be quite good in some areas, depending on the characteristics of the source water; our focus here is on treatment.

It should also be noted that after a large fall in unit costs of ozonation, many water utilities are choosing ozonation as the primary treatment option (Class 4). In Europe the treatment of choice is granular activated carbon, which we classify as Class 5a. Advanced oxidation processes (AOPs) (with ozonation or UV-based) are essentially the same as Class 5a, but experiments show a greater efficacy of removal of the same contaminants as those in Class 5a; we therefore classify AOPs as Class 5b. (For evidence on the higher efficiency of AOPs, see Chap. 4, Sect. 4.5.4).

We should also note that for 90 % of the residents of Ontario, the source water is the Great Lakes, which also receive wastewater that is not always treated to remove chemicals, particularly pesticides, pharmaceuticals, and personal care products; this topic is deferred to the section below dealing with wastewater and its impacts on drinking water.

In contrast, as noted above, in Germany more than 70 % of drinking water is drawn from ground and spring water, and the remainder is drawn from surface water sources, such as lakes and rivers (Althoff 2007). By 2010, 63 % of groundwater bodies in Germany had achieved a rating of "good chemical status" (BMU 2014). Of the total 1,000 groundwater bodies, only 4 % have not achieved a "good quantitative status," i.e., 4 % of the aquifers did not have enough water. The status of surface water is such that 88 % of water bodies achieved a "good" chemical status, while only 10 % of all surface water bodies had obtained at least a "good" ecological status (BMU 2014). Given the quality of groundwater, practically no disinfection is needed. The 2011 Profile of the German Water Sector states: "The quality of drinking water is so good that the use of disinfectants in water treatment can even be forgone in many places without [compromising] the high hygienic drinking water standard." Since there is no chlorine, there are no DBPs; in areas where the source is groundwater, there is no chlorine residual in the water and of course no salinity. Thus for the groundwater sources we can conclude that German drinking water from the water treatment plants is equivalent to Class 6. In

North Rhine-Westphalia, in the City of Cologne, they use groundwater as the source, which is then filtered through activated carbon, producing a very high quality of water. To quote from the City of Cologne website (RheinEnergie AG n.d.):

> Some waterworks in Cologne used disinfectant to prevent an increase in the number of germs and thus hygienic deterioration of the drinking water quality on the way to the customer. Our water lab proved, however, that the perfect hygienic quality of drinking water can be guaranteed even without the use of chlorine dioxide or chlorine.

Where surface water is used in North Rhine-Westphalia, they detected perfluorooctanoate (PFOA) in drinking water at concentrations up to 0.64 mμ/L in Arnsberg, Sauerland, Germany (Wilhelm et al. 2010). In response, the German Drinking Water Commission (TWK) assessed perfluorinated compounds (PFCs) in drinking water and in June 2006 became the first in the world to set a health-based guideline value for safe lifelong exposure at 0.3 mμ/L (sum of PFOA and perfluorooctanesulfonate, PFOS). PFOA and PFOS can be effectively removed from drinking water by percolation over granular activated carbon.

The German Echthausen Water Works is one of the eight water works of Wasserwerke Westfalen GmbH, located in Dortmund, Germany. It is the largest producer of drinking water in the German state of North Rhine-Westphalia, delivering 105 million cubic meters of drinking water per year (76 million gallons per day). Echthausen Water Works supplies 20 communities with some 20 million cubic meters (706.3 million cubic feet) of drinking water, 20 % of the whole delivery rate. This facility uses activated carbon filter, and has replaced the chlorine dioxide disinfection system with UV disinfection.

9.4 Consumer Satisfaction

According to a 2009 national survey in Germany for the business association BDEW (BDEW customer barometer), 91.1 % of customers were satisfied or very satisfied with the quality of their drinking water. More than 80 % were satisfied or very satisfied with the service provided by their drinking water provider. 77.4 % were satisfied or very satisfied with the service provided by their wastewater utility (ATT et al. 2011).

In Canada, Ipsos Reid conducted a survey from February 5–12, 2009, sampling 2,165 adults across Canada. The 2009 Canadian Water Attitudes Study found that 84 % of respondents were concerned about the availability and quality of water in the long term as reported in the National Post, March 18, 2009. However, 74 % of Canadians were confident or very confident in the safety of Canada's water supply. 68 % of Canadians drank the tap water in their home, indicating that two-thirds of Canadians were satisfied with the quality of their drinking water (RBC and Unilever Canada 2009). Furthermore, in 2011, Health Canada, in collaboration with Indian and Northern Affairs Canada, conducted another survey to study the perceptions of drinking water quality in First Nations communities and in the general population (Ekos Research Associates Inc. 2011). The survey involved 700 individuals with First Nations communities and 200 in other small communities. The results indicated that 65 % of residents of other small communities were satisfied with the quality of their drinking water, but fewer than 50 % of First Nations residents had confidence in the quality of their drinking water. 88 % of residents of other small communities felt their tap water supply to be safe, while 78 % of First Nations residents stated that they rely on water that is piped. However, 20 % of First Nations residents preferred bottled water because they did not trust the tap water, while most residents of other small communities used bottled water instead of tap water because they preferred the taste or smell of bottled water. 18 % of First Nations residents considered that their water treatment facilities or infrastructure had worsened, while only 4 % of residents of other small communities blamed their water treatment facilities or infrastructure. In addition, First Nations residents were more likely to complain of outdated or unsafe treatment procedures, facilities, and utilities.

In the US, the EPA commissioned a Gallup poll survey in August 2003 to determine if consumers had confidence in their tap water. The results were (USEPA, Office of Groundwater and Drinking Water (OGWDW) 2003):

- 82 % (which equates to 231 million people nationally) drank tap water.
- 56 % (157 million) drank water straight from the tap.
- 37 % (104 million) reported using a filtering or treatment device.
- 74 % (208 million) purchased and drank bottled water.
- 20 %[4] (56 million) drank bottled water exclusively.

The percentage of people using some form of filtering or treatment device at home is very indicative of their level of confidence in their tap water (see Fig. 9.2).

9.5 State of Water Infrastructure

In Ontario and much of Canada and the US, water infrastructure is in a perilous state due to lack of public funding and budget cuts. This is the result of what is called "deferred maintenance."

In contrast, water infrastructure in Germany is in excellent shape through continual renewal and systematic investment. Althoff (2007) pointed out that "a major factor for long-term security is continuous investment in maintenance and renewal of the infrastructure."

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[4] *Note* Percentages total do not add up. The Gallup survey asked specific questions regarding water use. Percentages may overlap. For example people who drink tap water at home, may buy bottled water when they are out, or they may filter tap water at the office but not at home. The percentages in this case overlap.

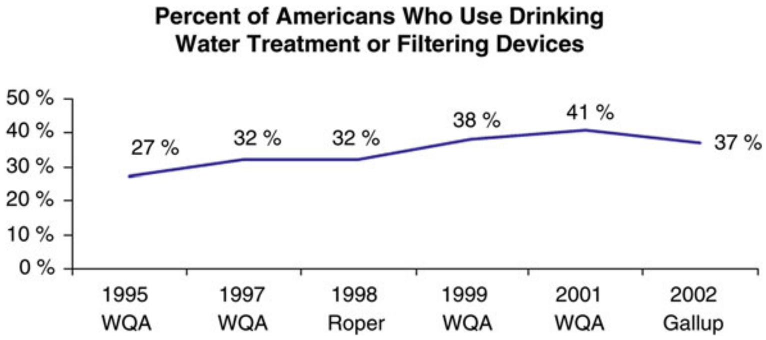

Fig. 9.2 Percent of Americans who use drinking water treatment or filtering devices (USEPA, Office of Groundwater and Drinking Water OGWDW (2003)

According to the most recent statistics available from Environment Canada, approximately 13 % of water on average is lost from distribution systems before reaching consumers across Canada. El-Diraby et al. (2009) provide data showing a great variation in this figure across cities in Ontario with a low of 3.2 % and a high of 30 % (Table 9.2). These figures represent water lost due to leaks, system flushing, maintenance, and other factors. They are based on estimated losses reported by municipal water suppliers across Canada, but these estimates have not been independently verified. Water loss is a most important indicator of network quality and security of supply.

Germany has high technical standards of treatment and distribution as well as a well-maintained distribution network of pipes. The water losses caused by burst pipes and leakage have reduced considerably from 600 to 495 millions of cubic meters during the 1990–2004 period. As a result, German citizens have not experienced a long-term interruption of water supply. Compared to other European

Table 9.2 Unaccounted water losses by city in Ontario (El-Diraby et al. 2009)

City	Water losses in percent	Year
Toronto	26	2007
Ottawa	22–28	
London	8	2008
Guelph	13	2008
Vaughan	10	2006
Windsor	25	2008
Kingston	38	2002
Barrie	3	2006
Port Colborne	30	2006
Niagara Falls	28	2006
Thorold	25	2006
Chatham Kent	17	2006

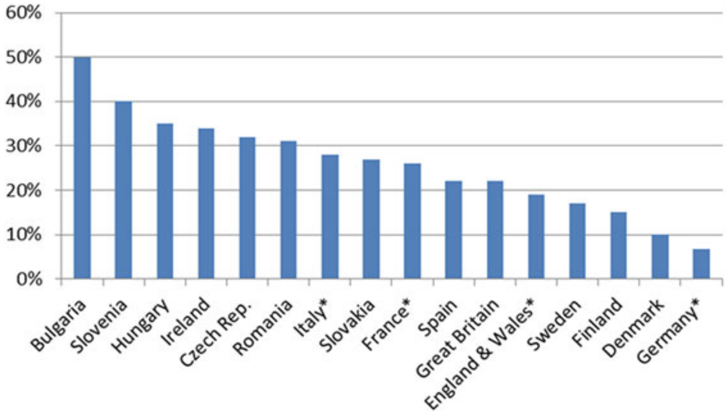

Fig. 9.3 Water losses in the public drinking water networks in EU countries (VEWA-Studie 2006, as cited in Althoff 2007). *Note* *Extractions for operational purposes and fire control are rated as losses

countries, water losses in Germany are 6.8 %, which is the lowest rate of loss in Europe, followed by Denmark with 9 %. The low water losses in Germany are due to investments into maintenance and renewal of infrastructure. In Italy and France, as well as England and Wales, water losses amount to 28, 26 and 19 %, respectively (see Fig. 9.3).

On average, the rates of damages to water supply lines are less than 10 damages per 100 km per year. Moreover, the total investment in drinking water supply amounts to more than 2 billion euros per year. The investments are financed through higher prices and charges that also cover facility maintenance. Due to a stable population, there appears to be no need for an extension of the water network. Furthermore, Germany has the highest average investments in the drinking water sector. In the period from 1995 to 2003, Germany invested 0.54 euros per cubic meter, while England and Wales invested 0.53 euros per cubic meter, France 0.33 euros per cubic meter, and Italy 0.15 euros per cubic meter in the same period (VEWA-Studie 2006, as cited in Althoff 2007).

9.6 Wastewater Treatment in Ontario and Germany

In Germany, the average investment per cubic meter of wastewater was 1.27 euros, followed by England/Wales with 0.91 euros, France with 0.72 euros, and Italy with 0.11 euros from 1995 to 2003 (VEWA-Studie 2006, as cited in Althoff 2007). In 2005, the water and wastewater utilities in Germany invested about 8 billion euros in sewage networks. It should be noted that all investment costs are financed through prices and charges, while in other countries investments are financed partially by the municipalities. Germany passed legislation for the requirement of tertiary wastewater treatment. The amendment of the First General Regulations Concerning the Discharge of Municipal Wastewater issued target values for nitrogen and phosphorus in 1989.

A total of 10 billion cubic meters of wastewater (i.e., sewage water, rainwater, and infiltration water) was treated in the public sewage plants in 2010 (Umweltbundesamt, German Federal Environment Agency 2014). Of this, only 0.03 % was not treated by a biological wastewater treatment process (see Fig. 9.4). With the implementation of Appendix 9.1 of the *Waste Water Ordinance* and *EU Urban Waste Water Treatment Directive,* as well as investments in wastewater treatment over the last decade in Germany, by 2010, 98.1 % of municipal mechanical-biological plants have the capacity to remove nitrogen and phosphate, bringing a significant improvement in biological water quality.

Furthermore, from 2002 to 2011, the share of wastewater treated in biological sewage plants with selective removal of nutrients increased to 82 %. As a consequence, in 2011, on average, the municipal wastewater treatment plants achieved a reduction in nutrient loads of 91 % for phosphorus and 81 % for nitrogen, which clearly exceeded the requirements of the EU Urban Waste Water Treatment Directive (Directive 91/271/EEC) (Umweltbundesamt, German Federal Environment Agency 2014). This is a reduction of 75 % for both substances taken together. The 98 % biological treatment is a high standard, and one would expect that most of the contaminants, including pharmaceuticals, pesticides, and personal care products (PPCPs), would be removed or oxidized.

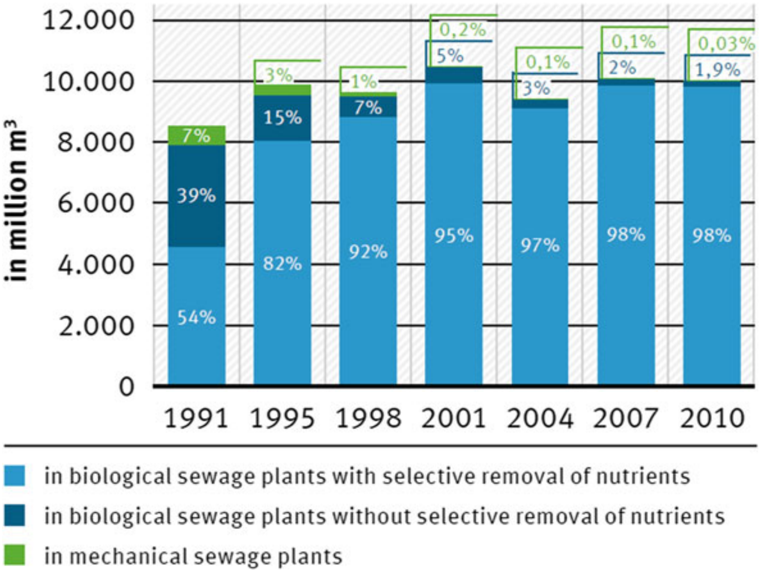

Fig. 9.4 Wastewater volumes treated in public sewage plants (Umweltbundesamt, German Federal Environment Agency 2014)

Table 9.3 Distribution of Ontario wastewater treatment plants in the Great Lakes Basin (International Joint Commission 2011)

Facility type	Number of facilities	Percentage of total number of facilities (%)	Total average daily flow (MLD)	Percentage of total average daily flow (%)
Primary	8	1.7	96	1.7
Community septic (all types)	7	1.5	1	0.0
Lagoons (all types)	175	37.2	178	3.1
Secondary	212	45.2	5038.1	87.3
Tertiary	68	14.5	456.8	7.9
Totals	470	100.0	5769.1	100.0

MLD = million liters per day

On the other hand in Ontario, as stated above, there is a problem of deferred maintenance. Furthermore, only about 15 % of wastewater treatment plants provide tertiary treatment in Ontario (see Table 9.3). Thus the “zero discharge goal” of the Great Lakes Water Quality Agreement with the US has not yet been met.

As shown in Table 9.3, a total of 470 municipal wastewater treatment plants in Ontario discharge into the Great Lakes basin. Of these, 212 and 68 are secondary (activated sludge) and tertiary (advanced) treatment facilities, respectively. Moreover, smaller communities are served by 175 lagoon treatment systems, and only 8 facilities carry out primary treatment. Hence, 82 % of the wastewater discharged by municipal wastewater treatment plants into the basin receives either primary or secondary (activated sludge) treatment. Tertiary (advanced) treatments are only about 15 % of the facilities; this means that only 8 % of average daily flow of wastewater receives tertiary treatment (in 2011).

For the US, based on the Clean Watershed Need Survey, 32 and 58 % are secondary (activated sludge) and tertiary (advanced) treatment facilities, respectively, out of all the 978 facilities (see Table 9.4). Thus the US is doing a lot better than Canada, as 96 % of the average daily flow receives tertiary treatment.

Table 9.4 Distribution of the U.S. wastewater treatment plants in the Great Lakes Basin (International Joint Commission 2011)

Facility type	Number of facilities	Percentage of total number of facilities (%)	Total average daily flow (MLD)	Percentage of total average daily flow (%)
Secondary Treatment	311	31.7	135.9	4.2
Advanced treatment	563	57.6	3,111.8	95.8
Unknown[a]	104	10.6	n/a	n/a
Totals	978	100.0	3,247.7	100.0

MLD = million liters per day

[a] Detailed information is not available

9.7 Micropollutants

9.7.1 Micropollutants in Ontario

In 2006 the Canadian Institute for Environmental Law and Policy published a report titled, *“There is No “Away””* which documented the detection of pharmaceuticals, personal care products, and endocrine disrupting substances as *emerging contaminants* in Canadian water sources (Holtz 2006). The Canadian Institute for Environmental Law and Policy encouraged the Ontario Ministry of the Environment to consider the need for appropriate wastewater management to address these emerging contaminants. The report outlined four major theoretical routes that could bring pharmaceuticals, personal care products, and some other emerging contaminants into water. They were: manufacturing facilities; user discharges into wastewater that is not treated to remove the emerging contaminants; excretions into treated wastewater; and discharges and excretions into runoff flowing to water bodies or groundwater. It was further stated that the clearest points of concentration were immediately downstream from the wastewater outfalls of manufacturing plants, wastewater treatment plants (WWTPs), livestock operations, and leachate from private septic systems. Thus, the primary question was whether the emerging contaminants were actually being documented from these possible sources. The report further stated that improper disposal of pharmaceuticals and personal care products (PPCPs) through municipal solid waste or sewage systems also occurs due to a lack of public awareness of their impacts. As a result there would be a high concentration of contaminants from PPCPs found in wastewater (Holtz 2006).

The “Water Quality in Ontario 2012” report suggests that over the last 40 years, the legacy contaminants such as DDT and PCBs have declined significantly in fish in the Great Lakes and are no longer a concern. However, consumer use of chemicals, including “pharmaceuticals, personal care products, electronics, furniture and in plastics and building products” has led to these emerging contaminants being found in increasing concentrations in the environment. Pharmaceuticals and other personal care products have been detected at selected sites in the area of the Great Lakes (Servos et al. 2007).

Another recent article was published in 2013 in the *Water Quality Research Journal of Canada* titled “Protecting Our Great Lakes: Assessing the Effectiveness of Wastewater Treatments for the Removal of Chemicals of Emerging Concern”. The authors studied the removal efficiencies for chemicals of emerging concern based on available data for the period 2000–2010 and pointed out that of 42 substances commonly found in the Great Lakes, at least half could be removed by activated sludge systems (Arvai et al. 2013). Some substances such as DEHA and DEET were infrequently detected but demonstrated a high probability of at least 75 % removal efficiency. Other substances such as carbamazepine and diclofenac were frequently detected but had low removal rates. Only acetaminophen, caffeine, and estriol occurred frequently; these are also difficult to remove.

Although municipal wastewater treatment systems were not designed to remove chemicals of emerging concern, the Water Environment Research Foundation Reports suggest that if the wastewater treatment plants consist of secondary and tertiary treatment systems, they have the capability of reducing a variety of substances (International Joint Commission 2011). In order to remove chemicals of emerging concern from wastewater, the primary as well as lagoon treatment facilities should be upgraded to at least secondary treatment. The secondary plants could add biological nutrient removal processes and optimizing processes in order to improve removal of biodegradable chemicals of emerging concern (International Joint Commission 2011). In addition, to improve the effectiveness of removal of chemicals of emerging concern, a list of standards for indicator compounds needs to be established, so that the treatment process can be regulated.

Therefore, we can conclude that while there is awareness of chemicals of emerging concern, there is a great deal of room for improvement in Ontario; what is needed is to upgrade wastewater treatment plants to tertiary levels for almost all of the wastewater flows. Proper wastewater treatment will also benefit drinking water, as most of the sources for drinking water are surface water sources such as the Great Lakes.

It is clear that the next frontier in Ontario in obtaining higher quality drinking water is to remove PPCPs and EDSs from the drinking water. The adoption of disinfection technologies other than chlorination would also reduce the regulated and unregulated halides. However, the problem is that at the moment the current regulations do not require the removal of PPCPs, EDSs, and halides. Nor are there any guidelines for what would be desirable or acceptable concentrations without a threat to health.

9.7.2 Micropollutants in Germany

The German Federal Environment Agency (Umweltbundesamt) has developed recommendations for those micropollutants, which are more or less equivalent to “thresholds of toxicological concern” although the micropollutants are not regulated so far in Germany. Instead, depending on the amount of toxicological information available for specific substances, Germany has set guidelines that are called “Health-Related Indicator Values (HRIV)”, which range from 0.01 to 3.0 mg/L. A Health-Related Indicator Value of 0.1 mg/L has been set as a precautionary value, which should allow lifelong consumption of the drinking water for 70 years (Umweltbundesamt 2003). The value of 0.1 mg/L applies to both nongenotoxic compounds and the majority of genotoxic compounds, while highly genotoxic compounds cannot be used for lifetime exposure, but are safe for short periods only (Umweltbundesamt 2003). Table 9.5 shows maximum values for lifelong exposure to unregulated contaminants in drinking water in Germany, in which the Health-Related Indicator Values (HRIV) can be up to, or even over 3 mg/L, depending on the quality of the available information.

Table 9.5 Maximum values for lifelong exposure to unregulated contaminants in drinking water in Germany (Umweltbundesamt 2003, as cited in Mons et al. 2013)

HRIV (mg/L)	Explanation
0.1	No toxicological data available
0.3	Only genotoxicity data available, indicating the substance to be nongenotoxic
–	No other toxicological data available
1	Substance proven nongenotoxic (see above). Data on neurotoxicity and germ cell damaging potential available, indicating a value <0.3 mg/L
3	Substance neither genotoxic nor germ cell damaging nor neurotoxic
–	In vivo data on subchronic oral toxicity available, indicating a value lower <1 mg/L
>3	At least one chronic oral study is available enabling (almost) complete toxicological data
–	Information not indicating a value <3 mg/L

As a matter of fact, higher Health-Related Indicator Values can be applied for chemicals if toxicological data shows sufficient safety (Mons et al. 2013). It should be noted that the Health-Related Indicator Values… "only consider the prevention of adverse health effects," and "not the principle that anthropogenic contaminants do not belong in drinking water." The shortcoming of the German approach is that the sum of values of chemical compounds from *mixtures of contaminants* in drinking water has not been used. In other words, something comparable to the Dutch concern for "concentration action" of mixtures of compounds should be adopted in Germany. Mons et al. (2013) pointed out that the "presence of a range of [individual] contaminants at concentrations just below their individual target value is undesirable [by itself], because it demonstrates that a variety of [mixtures of] contaminants can pass drinking water treatment." Hence the total mixture should also be a serious concern, as it is in the Netherlands.

Although the drinking water treatment plants in Germany are not able to remove all micropollutants in the main cites, "drinking water conditioning in Germany aims at removing pollutants (also micropollutants) from water to such a degree, that there is no risk for human health [even if there is] … lifelong consumption of the drinking water (2 L daily for a period of 70 years)" (Markard 2014). As Germany is highly industrialized and densely populated, it is not surprising if micropollutants are detected in drinking water samples. Thus, the German government attempts to "keep [a] hazardous substance which can influence drinking water quality, as low as achievable according to the generally acknowledged technical standard of treatment within [reasonable] expenditure [limits]" according to the "minimization rule" of the German Drinking Water Ordinance (Markard 2014).

At this point it is worth recalling what was noted above on the high quality of wastewater treatment in Germany. Biological degradation of wastewater is practised on a vast scale, with only 0.03 % of wastewater not subjected to biological treatment (Fig. 9.4). If we assume that the wastewater treatment plants use the scientifically required time for biological degradation, then we can expect that in Germany, PPCPs will be well below the Health-Related Indicator Values (HRIV) stated in Table 9.5, which are themselves quite stringent. Although the HRIV are above the targets set in the Netherlands (see Table 9.6), they are still below the I_{70} limits, which are quantities *ingested after 70 years of consumption of 2 L of drinking water per day, with the maximum concentration of pharmaceuticals observed in drinking water.*

Note that the PPCPs being well below the Health-Related Indicator Values are only relevant for the portion of the population that relies on surface water, which may have been subject to wastewater discharges.

As noted above, only about 30 % of drinking water comes from surface water in Germany, and the rest is from groundwater, which is presumably free or mostly free of micropollutants. Therefore, we can conclude that in Germany, *treated* drinking water quality is of high quality, probably Class 5, in terms of the classification scheme given in Table 9.1.

Table 9.6 Concentrations of some of the pharmaceuticals detected in treated water in the Netherlands in comparison with safe drinking water levels (SDWL) and I_{70} values (Mons et al. 2013)

Compound	MCLs observed in treated drinking water (ng/L)	DWL[a] (ng/L)	DWL Daily drinking water consumption needed to reach DWL (L)	I_{70} value (mg)[b]	Therapeutic dose (mg/day)	I_{70}/therapeutic dose (%)
Acetylsalicylic acid	122	25×10^3	205	6.2	20	30
Diclofenac	18	7,500[c]	417	0.9	15	6
Carbamazepine	90	50×10^{3}[c]	556	4.6	100	5
Prozac (fluoxetine)	10	10,000[c]	1,000	0.5	20	2.5
Bezafibrate	20	35,000[c]	1,750	1	67	1.5
Metoprolol	26	50,000[c]	1,923	1.3	100	1.3
Fenofibrate	21	50,000[c]	2,381	1.1	100	1.1
Clofibric acid	136	30,000[c]	221	6.9	1,200	0.6
Phenazone	29	125,000[c]	4,310	1.5	250	0.6
Ibuprofen	28	150×10^{3}[c]	5,357	1.4	300	0.5
Paracetamol	33	150,000	4,545	1.7	1,200	0.15
Lincomycine	21	30×10^3	1,429	1.1	1,200	0.1
Sulfamethoxazole	40	75×10^3	1,875	2	2,000	0.1
Amidotrizoic acid	83	250×10^{6}[d]	3×10^6	4.2	50,000[d]	0.008
Iopamidol	68	415×10^{6}[d]	6×10^6	3.5	83,000[d]	0.004
Iopromide	36	250×10^{6}[d]	7×10^6	1.8	50,000[d]	0.004
Iohexol	57	375×10^{6}[d]	7×10^6	2.9	75,000[d]	0.004

9.8 Long-Term Health Threats Due to the Use of Chlorine

9.8.1 The Use of Chlorine in North America and EU Countries

Although chlorine is not the only disinfecting agent available to the water supply industry, it is the most widely used disinfectant in North America. It is currently employed by over 98 % of all the U.S. water utilities that disinfect drinking water (Calomiris and Christman 1998). However, it is ineffective against parasitic protozoans *Cryptosporidium parvum* and *Giardia lamblia*. The use of chlorine as a disinfectant has one major drawback. Disinfection by-products (DBPs) are formed through chemical reaction between natural organic matters (NOMs) and the disinfectant (i.e., chlorine, chloramine, and chlorine dioxide) in the treatment of drinking water. Chlorinated DBPs have been recognized as a potential public health concern in drinking water since they were first reported in the1970s and identified as a carcinogen in 1976 (National Cancer Institute 1976). In 1974, Rook (1974) first discovered DBPs in the Netherlands. Since then, more than 700 chemical compounds associated with DBPs such as THMs and haloacetic acids (HAAs) have been identified, together making up approximately 50 % of the total organic halides (TOX) formed by chlorination (Villanueva et al. 2014). As the main DBPs, THMs make up around 20–30 % of TOX and they are the most commonly regulated (Itoh et al. 2011). In particular, the maximum acceptable concentration of total THMs in the European Union (EU), Canada, and Ontario is 100 μg/L, but in Ontario a further reduction to 80 μg/L was under active consideration (in 2008–2009), to bring it in line with the USEPA, which also has a maximum acceptable concentration (MAC) of 80 μg/L. However, as of May 2014, the MAC in Ontario and Canada is still 100 μg/L.

The results from studies on risks to human health by the use of chlorine reviewed in Dore (2015) seem to suggest that the Health Canada guideline for total THMs of 100 μg/L (Health Canada 2006) and of 80 μg/L (Health Canada 2008) for HAAs is out of date. Even the reduction of MAC for THMs to 80 μg/L in Ontario may be unsafe. For some Ontario municipalities, the total THMs far exceed the regulatory limit, with the average of the 90th percentile being 93.8. The 95th and 99th percentile values for Ontario are 106.02 and 152.88, respectively.

In 2009, Health Canada issued a national consultation document on chlorine in drinking water (Health Canada 2009). Its primary concern was with disinfection, and while Health Canada brought in a limit for BDCM of a maximum of 16 μg/L (Health Canada 2006), the maximum limit of THMs remained unchanged (at 100 μg/L). But BDCM was delisted in 2009, although the maximum limit of THMs and HAAs remains unchanged.

Health Canada (2009) states that: “Disinfection is essential to safeguard drinking water; the health risks from disinfection by-products are much less than the risks from consuming water that has not been disinfected” (Health Canada 2009, p. 1) This is largely a “benefit-cost” conclusion rather than a serious assessment of risks.

In fact the document states that the Guideline… “does not review the benefits or the processes of chlorination, nor does it assess the health risks related to exposure to by-products formed as a result of the chlorination process.” How can a “Health Canada” guideline fail to assess the health risks…of exposure to disinfection by-products? The document goes on to state: “Health Canada has classified chlorine as unlikely to be carcinogenic to humans. Studies in laboratory animals and humans indicate that chlorine exhibits low toxicity, regardless of the route of exposure (i.e., ingestion, inhalation, dermal). Studies in animals have not been able to identify a concentration of chlorine associated with adverse health effects, in part because of aversion to its taste and odor. No adverse health effects have been observed in humans from consuming water with high chlorine levels (up to 50 mg/L) over a short period of time.” It supports a free chlorine residual of 200 μg/L in the distribution system to prevent regrowth of bacteria. It concludes boldly that: “Because chlorine is not stable under environmental conditions, exposure is not expected to be significant, and there are few data available” (Health Canada 2009, p. 16). It contains the following statement: “[T]here have not been any epidemiological studies that have specifically examined free chlorine concentrations in water and long-term health effects in the human population.” This assertion is completely out of date, as shown above; the study by Hwang et al. (2008) raises important questions and suggests that any level greater that 4 μg/L carries serious risk for nursing mothers.[5]

In Germany, chlorine or chlorine dioxide are rarely used, and only when required. An engineer from a drinking water treatment company in Hamburg, Germany said that they have not used chlorine to disinfect their distribution system since the beginning of the 1950s and there is no chlorine residual at all in their 10 waterworks and their distribution system.[6]

In Denmark there has been a policy of gradual elimination of *all* chlorine from their water treatment plants. In fact, according to the online edition of Copenhagen Post (2009, June 3), Copenhagen became the last municipality to rely completely on underground aquifers and completely stopped using all chlorine after using it for the past 37 years. They have no need to worry about THMs, as there are none in their drinking water.

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[5] WHO also considers potential health effects caused by exposure to the four compounds simultaneously. In addition to the individual guidelines, there is an additional guideline that states the following: the sum of each individual THM concentration divided by its guideline value should not be greater than one. This is depicted in the following equation, where GV stands for Guideline value:

$$\frac{bromoform}{bromoform\ GV} + \frac{BDCM}{BDCM\ GV} + \frac{DBCM}{DBCM\ GV} + \frac{Bromoform}{Bromoform\ GV} < 1$$

[6] Personal communication by E-mail, from Dr. M. Schneemann, Hamburg.

In the Netherlands, they have gone considerably further in that as of 2005, *no chlorine is used at all* (Smeets et al. 2009). From 1976 onwards, the use of chlorine has been steadily reduced until 2005, when the last use of chlorine was replaced by UV. Moreover, according to Smeets et al. (2009, p. 3), "UV inactivates a wider spectrum of pathogens than chemical disinfection, and microbial safety is easily warranted by process monitoring and control." Note also that no chlorine is used in the distribution system; the approach is to "starve" regrowth of pathogens rather than rely on disinfection. To quote again:

"There was no more need for a disinfectant residual during distribution to prevent regrowth. The level of post-disinfection at surface water treatment plants was lowered to such an extent that, in 2008, no chlorine is being applied at all, and at the few locations where chemical disinfection is applied (chlorine dioxide) no residual disinfectant can be measured in the distributed water." Thus the Netherlands has more or less completely eliminated THMs and HAAs.

9.8.2 Long-term Health Effects of Using Chlorine

In the past, the use of chlorine has been shown to benefit large populations all over the world. For example, typhoid fever had killed about 25 out of 100,000 people in the U.S. annually, a death rate close to that now associated with automobile accidents. Today, typhoid fever has been virtually eliminated. But the new evidence suggests grave long-term health risks associated with the use of chlorine. Recently, epidemiological studies have confirmed associations between human health effects and exposure to chlorinated DBPs. The evidence for carcinogenicity of DBPs is strongest for bladder cancer, while some but not all findings have reported positive associations between colon and rectal cancer and DBP exposure. In addition, some epidemiological studies also reported associations between consumption of chlorinated water and adverse reproductive outcomes, including preterm births and defects in the unborn child. The regulation of DBPs has played an important role for safe drinking water and public health; however, more than 50 % of the toxic halides formed during disinfection have not been defined.

In some developed countries, particularly in EU countries, alternative methods of disinfection of drinking water such as ozone and UV and cartridge filtration are being used to minimize the use of chlorine. But in the USA and Canada, chlorine remains the most widely used method of disinfection of drinking water. Therefore, it seems clear that (1) comprehensive toxicological evaluation of whole DBP mixtures are necessary, and (2) greater emphasis must be placed on continuing to reduce the allowable concentrations of all toxic halides in drinking water. As a long-term policy, it would be sensible to follow the example of the European countries that have completely eliminated the use of chlorine in drinking water.

9.9 Conclusion

As there is no profit motive, there is no competition in the publicly owned and controlled water sector in Ontario. There is also no incentive to improve drinking water quality. Knowledge of higher drinking water quality in one jurisdiction might spur consumers to demand higher quality elsewhere. Hence a comparative analysis of water treatment and water quality in different jurisdictions might be of some value; households in North America could demand better quality of treated water that we see is possible in Germany and other European countries.

In North America chlorine disinfection dominates although there are well-known and well-documented long-term health risks due to the use of chlorine. There are cost competitive alternative treatment technologies, as shown in Chap. 3 of Dore (2015). We have classified the main treatment technologies into six classes, in which we find Class 5a and 5b to be comparable, with AOPs having higher efficacy and a lower energy use and a lower carbon footprint. European water treatment plants seem to use granular activated carbon filtration (in our Class 5a) that effectively removes almost all contaminants including micropollutants. We view this to be a higher treatment class than the conventional treatment made up of coagulation, flocculation, sedimentation, and disinfection by some chlorine derivative, which is the main treatment train used in North America. In North America there is the further requirement of residual chlorine of 0.04–2 mg/L in the distribution system. This legal requirement also predisposes water treatment plants to use chlorine also as a primary disinfection. But the use of chlorine results in DBPs in the treated water, not to mention the other long-term health risks. As a consequence, Ontario has to regulate the resulting DBPs as well. But only the well known THMs and HAAs are regulated; all other DBPs are ignored.

Consumers in Germany show high confidence in their tap water. In North America, consumers spend additional money on in-home further filtration equipment, or they buy bottled water. The sales of bottled water are highest in Canada and the US.

In Ontario (and other North American jurisdictions) the state of the water infrastructure is also poor. This is evidenced by the high water losses due to leakages. In Germany there continues to be appropriate investment in maintaining the integrity of their water infrastructure.

We have not relied on actual water quality samples from Germany and Ontario. Instead we have focused on treatment technologies and what contaminants these treatment technologies can *remove*. This is an indirect but possibly better way of comparing treated water quality. We come to the conclusion that in Germany, treated water quality is at least of Class 5b, i.e., mostly free of pathogens and free of chemicals, pharmaceuticals, and personal care products (called "micro-pollutants"), or at least under the HRIV guidelines. In contrast, in North America, where the source water is surface water, the quality of drinking water is much lower as it is likely to contain micropollutants.

The lessons for North America seem clear: emulate what Germany does. That is, invest in granular activated carbon filtration or invest in advanced oxidation. At the very least reduce and eventually move away from chlorination for primary disinfection. Also begin to treat all wastewater to the same extent as the plants in North Rhine-Westphalia. For Ontario, it means fulfilling the objective of "zero pollution" stated in the Canada–US Great Lakes Water Quality Agreement.

Appendix 9.1 German Drinking Water Maximum Concentration Level for Chemical Parameters (Bundesgesetzblatt 2011)

Chemical parameters			
Parameter	MCL (mg/L)	Parameter	MCL (mg/L)
Acrylamide	0.0001	Antimony	0,005
Benzene	0.001	Arsenic	0.01
Boron	1	Benzo [a] pyrene	0.00001
Bromate	0.01	Lead	0.01
Chrome	0.05	Cadmium	0.003
Cyanide	0.05	Epichlorohydrin	0.0001
1,2-dichloroethane	0.003	Copper	2
Fluoride	1.5	Nickel	0.02
Nitrate	50	Nitrite	0.5
Plant protection products and biocidal products	0.0001	Polycyclic aromatic hydrocarbons	0.0001
Plant protection products and biocidal total	0.0005	THMs	0.05
Mercury	0.001	Vinyl chloride	0.0005
Selenium	0.01	Uranium	0.01
Tetrachloroethene Trichloroethene	0.01 0.01		

Note Measured quantities are based on a representative for the weekly average value ingested by consumers; this is provided in Article 7, Para 4 of the Drinking Water Directive, which calls for the establishment of a harmonized procedure. The competent authorities shall ensure that all appropriate measures are taken to reduce the concentration of lead in water intended for human consumption within the period that is necessary to achieve the limit as far as possible. Measures to achieve this value progressively give priority to the store where the lead concentration in water for human consumption is high

Appendix 9.2 German Drinking Water Maximum Concentration Level for Indicator Parameters (Bundesgesetzblatt 2011)

Indicator parameters		
Parameter	Unit	MCL (mg/L)
Aluminum	mg/L	0.2
Ammonium	mg/L	0.5
Chloride	mg/L	250
Clostridium perfringens (including spores)	Number/100 mL	0
Coliform bacteria	Number/100 mL	0
Iron	mg/L	0.2
Staining (Spectral absorption coefficient at 436 nm)	1/m	0.5
Odor	Ton	3 at 23° C.
Taste		Acceptable to consumers and no abnormal change
Colony count at 22° C		No abnormal change
Colony count at 36° C		No abnormal change
Electrical conductivity	µS/cm at 25° C	2,790
Manganese	mg/L	0.05
Sodium	mg/L	200
Organic carbon	mg/L	No abnormal change
Oxidizability	mg/L O_2 demand	5
Sulfate	mg/L	250
Cloudiness	Nephelometric turbidity units (NTU)	1
Hydrogen ion concentration	pH units	6.5–9.5
Calcite	mg/L $CaCO_3$	5
Tritium	Bq/L	100
Total indicative dose	mSv/year	0.1

Appendix 9.3 Regulatory MCLs (μG/L) for Chemicals in Drinking Water (Ontario Regulation 169/03** 2008, WHO 2011, USEPA 2009, EU Council 1998, Bundesgesetzblatt 2011, and Health Canada 2012)

Chemical parameters	Ontario	WHO	USEPA	EU	Germany	Canada	Chemical group
1,1,1-Trichloroethane	N/S	N/S	200	N/S	N/S	N/S	Organic
1,1,2-Trichloroethane	N/S	N/S	5	N/S	N/S	N/S	Organic
1,1-Dichloroethylene (vinylidene chloride)	14	N/S	7	N/S	N/S	14	Organic
1,2,4-Trichlorobenzene	N/S	N/S	70	N/S	N/S	N/S	Organic
1,2-Dibromo-3_chloropropane (DBCP)	N/S	1	0.2	N/S	N/S	N/S	Organic
1,2-Dibromoethane	N/S	0.4	N/S	N/S	N/S	N/S	Organic
1,2-Dichlorobenzene	200	1,000	600	N/S	N/S	200	Organic
1,2-Dichloroethane	5	50	5	3	3	5	Organic
1,2-Dichloropropane	N/S	40	5	N/S	N/S	N/S	Organic
1,3-Dichloropropane	N/S	20	N/S	N/S	N/S	N/S	Organic
1,4-Dichlorobenzene	5	300	75	N/S	N/S	5	Organic
1,4-Dioxane	N/S	50	N/S	N/S	N/S	N/S	Organic
2,3,4,6-Tetrachlorophenol	100	N/S	N/S	N/S	N/S	100	Organic
2,4,5-Trichlorophenoxy acetic acid (2,4,5-T)	280	9	N/S	N/S	N/S	N/S	Organic
2,4,6-Trichlorophenol	5	200	N/S	N/S	N/S	5	Organic
2,4-Dichlorofenoxy butyric acid	N/S	90	N/S	N/S	N/S	N/S	Organic
2,4-Dichlorophenol	900	N/S	N/S	N/S	N/S	900	Organic
2,4-Dichlorophenoxy acetic acid (2,4-D)	100	30	70	N/S	N/S	100	Pesticide
4-(2-Methyl-4-chlorophenoxy)acetic acid (MCPA)	N/S	2	N/S	N/S	N/S	100	Pesticide
Acrylamide	N/S	0.5	[a]	0.1	0.1	N/S	Organic
Alachlor	5	20	2	N/S	N/S	N/S	Organic
Aldicarb	9	10	N/S	N/S	N/S	N/S	Organic
Aldrin + Dieldrin	0.7	0.03	N/S	N/S	N/S	N/S	Organic

(continued)

(continued)

Chemical parameters	Ontario	WHO	USEPA	EU	Germany	Canada	Chemical group
Aluminum	N/S	N/S	N/S	200	200	N/S	Inorganic
Ammonium	N/S	N/S	N/S	500	500	N/S	
Antimony	6	20	6	5	5	6	Inorganic
Arsenic	25	10	10	10	10	10	Inorganic
Asbestos (million fibers > 10 μg/L)	N/S	N/S	7	N/S	N/S	N/S	Inorganic
Atazine	N/S	100[b]	3	N/S	N/S	5	Pesticide
Atrazine + N-dealkylated metabolites	5	N/S	N/S	N/S	N/S	N/S	Organic
Azinphos-methyl	20	N/S	N/S	N/S	N/S	20	Pesticide
Barium	1,000	700	2,000	N/S	N/S	1,000	Inorganic
Bendiocarb	40	N/S	N/S	N/S	N/S		Inorganic
Benzene	5	10	5	1	1	5	Organic
Benzo(a)pyrene	0.01	0.7	0.2	0.01	0.01	0.01	Organic
Boron	5,000	2,400	N/S	1,000	1,000	5,000	Inorganic
Bromate	10	10	10	10	10	10	DBP
Bromodichloromethane (BDCM)	N/S	60	N/S	N/S	N/S	N/S	DBP
Bromoform	N/S	100	N/S	N/S	N/S	N/S	DBP
Bromoxynil	5	N/S	N/S	N/S	N/S	5	Pesticide
Cadmium	5	3	5	5	5	5	Inorganic
Calcite	N/S	N/S	N/S	N/S	5,000	N/S	Inorganic
Carbaryl	90	N/S	N/S	N/S	N/S	90	Pesticide
Carbofuran	90	7	40	N/S	N/S	90	Pesticide
Carbon Tetrachloride	5	4	5	N/S	N/S	2	Organic
Chlopyifos	N/S	30	N/S	N/S	N/S	N/S	Organic
Chloramines	3,000	N/S	4,000	N/S	N/S	3,000	Disinfectant
Chlorate	N/S	700	N/S	N/S	N/S	1,000	DBP
Chlordane (Total)	7	0.2	2	N/S	N/S	N/S	Organic

(continued)

(continued)

Chemical parameters	Ontario	WHO	USEPA	EU	Germany	Canada	Chemical group
Chloride	N/S	N/S	N/S	250,000	250,000	N/S	Inorganic
Chlorine dioxide	N/S	N/S	800	N/S	N/S	N/S	Disinfectant
Chlorine	4,000	5,000	4,000	N/S	N/S	N/S	Disinfectant
Chlorite	N/S	700	1,000	N/S	N/S	1,000	DBP
Chlorobenzene	N/S	N/S	100	N/S	N/S	N/S	Organic
Chloroform	N/S	300	N/S	N/S	N/S	N/S	DBP
Chlorotoluron	N/S	30	N/S	N/S	N/S	N/S	Organic
Chlorpyrifos	90	N/S	N/S	N/S	N/S	90	Pesticide
Chromium (Total)	50	50	100	50	50	50	Inorganic
cis-1,2-Dichloroethylene	N/S	N/S	70	N/S	N/S	N/S	Organic
Copper	N/S	2,000	13,000	2,000	2,000	N/S	Inorganic
Cyanazine	10	0.6	N/S	N/S	N/S	N/S	Organic
Cyanide	200	N/S	200	50	50	200	Inorganic
Cyanobacterial toxins-Microcystin-LR	N/S	N/S	N/S	N/S	N/S	1.5	Organic
Dalapon	N/S	N/S	200	N/S	N/S	N/S	Organic
Di(2-ethylhexyl) adipate	N/S	N/S	400	N/S	N/S	N/S	Organic
Di(2-ethylhexyl) phtalate	N/S	8	6	N/S	N/S	N/S	Organic
Diazinon	20	N/S	N/S	N/S	N/S	20	Pesticide
Dibromochloromethane	N/S	100	N/S	N/S	N/S	N/S	Organic
Dicamba	120	N/S	N/S	N/S	N/S	120	Pesticide
Dichloroacetate	N/S	50	N/S	N/S	N/S	N/S	DBP
Dichloroacetonitrile	N/S	20	N/S	N/S	N/S	N/S	DBP
Dichlorodiphenyltrichloroethane (DDT) + metabolites	30	1	N/S	N/S	N/S	N/S	Organic
Dichloroisocyanurate (as cyanuric acid)	N/S	40,000	N/S	N/S	N/S	N/S	Disinfectant

(continued)

(continued)

Chemical parameters	Ontario	WHO	USEPA	EU	Germany	Canada	Chemical group
Dichloromethane	50	20	5	N/S	N/S	50	Organic
Dichlorprop	N/S	100	N/S	N/S	N/S	N/S	Organic
Diclofop-methyl	9	N/S	N/S	N/S	N/S	9	Pesticide
Dimethoate	20	6	N/S	N/S	N/S	20	Pesticide
Dinoseb	10	N/S	7	N/S	N/S	N/S	Organic
Dioxin (2,3,7,8-TCDD) and Furan	0.000015	N/S	0.00003	N/S	N/S	N/S	Organic
Diquat	70	N/S	20	N/S	N/S	70	Pesticide
Diuron	150	N/S	N/S	N/S	N/S	150	Pesticide
Edetic acid	N/S	600	N/S	N/S	N/S	N/S	Organic
Endothall	N/S	N/S	100	N/S	N/S	N/S	Organic
Endrin	N/S	0.6	2	N/S	N/S	N/S	Organic
Epichlorohydrin	N/S	0.4	[a]	0.1	0.1	N/S	Organic
Ethylbenzene	N/S	300	700	N/S	N/S	N/S	Organic
Ethylene dibromide	N/S		0.05	N/S	N/S	N/S	Organic
Fluoride	1,500	1,500	4,000	1,500	1,500	1,500	Inorganic
Glyphosate	280	N/S	700	N/S	N/S	280	Pesticide
Haloacetic acids (HAAs)	N/S	N/S	60	N/S	N/S	80	DBP
Heptachlor	N/S	N/S	0.4	N/S	N/S	N/S	Organic
Heptachlor + Heptachlor Epoxide	3	N/S		N/S	N/S	N/S	Organic
Heptachlor Epoxide	N/S	N/S	0.2	N/S	N/S	N/S	Organic
Hexachlorobenzene	N/S	N/S	1	N/S	N/S	N/S	Organic
Hexachlorobutadiene	N/S	0.6	N/S	N/S	N/S	N/S	Organic
Hexachlorocyclopentadiene	N/S	N/S	50	N/S	N/S	N/S	Organic
Hydroxyatrazine	N/S	200	N/S	N/S	N/S	N/S	Organic
Iron	N/S	N/S	N/S	200	200	N/S	Inorganic
Isoproturon	N/S	9		N/S	N/S	N/S	Organic

(continued)

(continued)

Chemical parameters	Ontario	WHO	USEPA	EU	Germany	Canada	Chemical group
Lead	10	10	15	10	10	10	Inorganic
Lindane (Total)	4	2	0.2	N/S	N/S	N/S	Organic
Malathion	190	N/S	N/S	N/S	N/S	190	Pesticide
Manganese	N/S	N/S	N/S	50	50	N/S	Inorganic
Mecoprop	N/S	10	N/S	N/S	N/S	N/S	Organic
Mercury	1	6	2	1	1	1	Inorganic
Methoxychlor	900	20	40	N/S	N/S	N/S	Organic
Metolachlor	50	10	N/S	N/S	N/S	50	Pesticide
Metribuzin	80	N/S	N/S	N/S	N/S	80	Pesticide
Microcystin LR	1.5	1	N/S	N/S	N/S	N/S	Algal toxin
Molinate	N/S	6	N/S	N/S	N/S	N/S	Organic
Monochloramine	N/S	3,000	N/S	N/S	N/S	N/S	Disinfectant
Monochloroacetate	N/S	20	N/S	N/S	N/S	N/S	DBP
Monochlorobenzene	80	N/S	N/S	N/S	N/S	80	Organic
Nickel	N/S	70	N/S	20	20	N/S	Inorganic
Nitrate (as nitrate)	N/S	50,000	N/S	50,000	50,000	45,000	Inorganic
Nitrate (as nitrogen)	10,000	11,000	10,000	N/S	N/S	10,000	Inorganic
Nitrate + Nitrite (as nitrogen)	10,000	N/S	N/S	N/S	N/S	N/S	Inorganic
Nitrilotriacetic Acid (NTA)	400	200	N/S	N/S	N/S	400	Organic
Nitrite (as nitrogen)	1,000	3,000	1,000	500	500	1,000	Inorganic
N-Nitrosodimethylamine (NDMA)	0.009	0.1	N/S	N/S	N/S	0.04	DBP
Organic carbon	N/S	N/S	N/S	N/S	No abnormal change	N/S	Organic
Oxamyl (Vydate)	N/S	N/S	200	N/S	N/S	N/S	Organic
Paraquat	10	N/S	N/S	N/S	N/S	N/S	Pesticide

(continued)

(continued)

Chemical parameters	Ontario	WHO	USEPA	EU	Germany	Canada	Chemical group
Paraquat (as paraquat dichloride)	N/S	N/S	N/S	N/S	N/S	10	Pesticide
Paraquat (as paraquation)	N/S	N/S	N/S	N/S	N/S	7	Pesticide
Parathion	50	N/S	N/S	N/S	N/S	N/S	Pesticide
Pendimethalin	N/S	20	N/S	N/S	N/S	N/S	Organic
Pentachlorophenol	60	9	1	N/S	N/S	60	Organic
Pesticides	N/S	N/S	N/S	0.1	N/S	N/S	Organic
Pesticides (Total)	N/S	N/S	N/S	0.5	N/S	N/S	Organic
Phorate	2	N/S	N/S	N/S	N/S	2	Pesticide
Picloram	190		500	N/S	N/S	190	Pesticide
Plant protection products and biocidal products	N/S	N/S	N/S	N/S	0.1	N/S	Organic
Plant protection products and biocidal total	N/S	N/S	N/S	N/S	0.5	N/S	Organic
Polychlorinated Biphenyls (PCBs)	3	N/S	0.5	N/S	N/S	N/S	Organic
Polycyclic aromatic hydrocarbons	N/S	N/S	N/S	0.1	0.1	N/S	Organic
Prometryne	1	N/S	N/S	N/S	N/S	N/S	Organic
Selenium	10	40	50	10	10	10	Inorganic
Simazine	10	2	4	N/S	N/S	10	Pesticide
Sodium (as sodium dichloroisocyanurate)	N/S	50,000	N/S	200,000	200,000	N/S	Disinfectant
Styrene	N/S	20	100	N/S	N/S	N/S	Organic
Sulfate	N/S	N/S	N/S	200,000	200,000	N/S	Inorganic
Sulfate	N/S	N/S	N/S	250,000		N/S	Inorganic
Temephos	280	N/S	N/S	N/S	N/S	N/S	Pesticide
Terbufos	1	N/S	N/S	N/S	N/S	1	Pesticide
Tertbutylazine	N/S	7		N/S	N/S	N/S	Organic
Tetrachloroethylene (perchloroethylene)	30	40	5	10	10	30	Organic
Thallium	N/S		2	N/S	N/S	N/S	Inorganic

(continued)

(continued)

Chemical parameters	Ontario	WHO	USEPA	EU	Germany	Canada	Chemical group
Toluene	N/S	700	1,000	N/S	N/S	N/S	Organic
Toxaphene	N/S	N/S	3	N/S	N/S	N/S	Organic
trans-1,2-Dichloroethylene	N/S	N/S	100	N/S	N/S	N/S	Organic
Triallate	230	N/S	N/S	N/S	N/S	N/S	Pesticide
Trichloroacetate	N/S	200	N/S	N/S	N/S	N/S	DBP
Trichloroethylene/Trichloroethene	5	20	5	N/S	N/S	5	Organic
Trifluralin	45	20	N/S	N/S	N/S	45	Pesticide
Trihalomethanes (THMs)	100	N/S	80	100	100	100	DBP
Uranium	20	N/S	N/S	N/S	10	20	Inorganic
Vinyl Chloride	2	0.3	2	0.2	0.2	2	Organic
Xylenes	N/S	500	10,000	N/S	N/S	N/S	Organic

Note N/S refers to Not Specified

** On December 18, 2015, the Ontario government proposed tightening the permissible levels of some contaminants in piped drinking water by amending *Ontario Regulation 169/03—Drinking Water Standards*, under the Safe Drinking Water Act. This proposal was open for public comment until February 16, 2015. The proposal is to lower the MCLs of the following contaminants:

- Lower the MCL for Arsenic from 25 to 10 μg/L;
- Lower the MCL for Carbon Tetrachloride from 5 to 2 μg/L;
- Lower the MCL for Benzene from 5 to 1 μg/L;
- Lower the MCL for Vinyl Chloride from 2 to 1 μg/L;

In addition, *new* standards will be brought in for:

- New MCL for Chlorite of 1000 μg/L;
- New MCL for Chlorate of 1000 μg/L;
- New 100 μg/L MCL for 2-Methyl-4-chlorophenoxyacetic acid (MCPA); and
- New 80 μg/L MCL for Haloacetic Acids (HAAs) as an annual average of quarterly samples.

In the main, these new MCLs will bring Ontario in line with the Canada Drinking Water Guidelines, once passed into law. This could happen later this year with a grace period before they become binding on all water systems.

[a] Each water system must certify annually that when it uses acrylamide and/or epichlorohydrin to treat water, the combination of dose and monomer level does not exceed the levels specified, as follows: acrylamide = 0.05 % dosed at 1 mg/L (or equivalent); epichlorohydrin = 0.01 % dosed at 20 mg/L (or equivalent)

[b] Includes its chloro-s-triazine metabolites

Appendix 9.4 Regulatory MCLs (in Terms of Log Removal) for Microbials in Drinking Water (Ontario Regulation 169/03 2008, WHO 2011, USEPA 2009, EU Council 1998, Bundesgesetzblatt 2011 and Health Canada 2012)

Microbiological Parameter	Ontario	WHO	USEPA	EU	Germany	Canada
Escherichia coli (*E. coli*)	4	4	4[d]	4	4	4
Cryptosporidium	4	4	4[a]	4	4	3
Giardia lamblia	4	4	3	4	4	3
Heterotrophic Plate Count (HPC)	3	3	3[c]	3	3	3
Legionella	2	2	[d]	N/S	3.8	2
Total coliforms	4	4	[e]	4	4	4
Viruses (enteric)	4	N/S	4	4	4	4

Note N/S refers to Not Specified

Turbidity: For systems that use conventional or direct filtration, at no time can turbidity (cloudiness of water) go higher than 1 Nephelometric Turbidity Unit (NTU), and samples for turbidity must be less than or equal to 0.3 NTUs in at least 95 % of the samples in any month. Systems that use filtration other than the conventional or direct filtration must follow state limits, which must include turbidity at no time exceeding 5 NTUs (USEPA 2009). Guideline Treated water <0.1 NTU at all times (Health Canada 2012)

[a] Cryptosporidium: Unfiltered systems are required to include Cryptosporidium in their existing watershed control provisions

[b] Heterotrophic Plate Count (HPC): No more than 500 bacterial colonies per milliliter

[c] Legionella: No limit, but EPA believes that if Giardia and viruses are removed/inactivated, according to the treatment techniques in the Surface Water Treatment Rule, Legionella will also be controlled

[d] No more than 5.0 % samples total coliform-positive (TC-positive) in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli*; if there are two consecutive total coliform-positive samples, and one is also positive for *E. coli* fecal coliforms, then the system is in serious violation of the required MCL

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